The Hong Kong University of Science and Technology
UG Course Syllabus

Course Title: Aerodynamics
Course Code: MECH-3640
Number of Credits: 3
Pre-requisites: CENG-2220 or CIVL-2510 or MECH-1907 or MECH-1910 or MECH-2210
Instructor: Prof. Larry Li
Email: larryli@ust.hk

Course Description

This course introduces the fundamental aerodynamic principles governing the motion and performance of aerospace vehicles, from low-speed incompressible flight to high-speed compressible regimes. Building on prior knowledge of fluid mechanics, students will learn how aerodynamic forces arise from fluid motion around airfoils and wings, and how these forces may be estimated using simplified analytical models, numerical simulations, and wind tunnel experiments.

The course begins with a review of basic concepts, including conservation laws, streamlines, vorticity, velocity potential, circulation, the Kutta condition, and the Kutta–Joukowski theorem. These concepts are then applied to incompressible inviscid flow around two-dimensional airfoils, leading to thin airfoil theory and vortex panel methods. The course then extends the analysis to three-dimensional finite-span wings, where students examine trailing vortices, downwash, induced drag, lifting line theory, and vortex lattice methods. Viscous effects are introduced via boundary layer theory and discussions of laminar and turbulent flows. The final part of the course addresses compressible aerodynamics, including normal and oblique shock waves, Prandtl–Meyer expansion fans, and transonic flow phenomena.

The course is delivered via lectures, tutorials and laboratories that combine mathematical derivation, physical interpretation, and real-world practice. Students will complete homework assignments to develop analytical problem-solving skills and will undertake an integrative project involving numerical simulations and wind tunnel experiments. Through this combination of theory, computation, and experiment, students will develop the ability to explain aerodynamic phenomena, estimate lift and drag in simplified scenarios, interpret aerodynamic data, and appreciate the assumptions and limitations of different modeling approaches.

Intended Learning Outcomes (ILOs)

By the end of this course, students should be able to:

1. Apply the basic tools of incompressible inviscid aerodynamic analysis to estimate lift for an airfoil.
2. Explain and quantify the effects of viscosity on airfoil performance.
3. Explain the differences in aerodynamic performance between an infinite-span, two-dimensional airfoil and a finite-span, three-dimensional wing.
4. Account for the effects of compressibility in aerodynamics.

Assessment and Grading

This course will be assessed using criterion-referencing. Grades will not be assigned using a curve. Student performance will be evaluated according to their demonstrated achievement of the intended learning outcomes (ILOs) via homework assignments, an integrative project, and a final examination. Rubrics and grade descriptors are provided below to clarify the criteria used for evaluation.

Assessment Task	Contribution to Overall Course Grade (%)	Due Date
Homework assignments	20%	Throughout the term
Project: wind tunnel experiments and numerical simulations	40%	Around week 10–11
Final examination	40%	Final examination period

Mapping of Course ILOs to Assessment Tasks

Assessed Task	Mapped ILOs	Explanation
Homework assignments	ILO 1, ILO 2, ILO 3, ILO 4	Homework assignments assess students' ability to apply the theoretical and analytical tools introduced in lectures and tutorials. Through structured problem sets, students estimate lift and moments for airfoils using incompressible inviscid aerodynamic analysis (ILO 1), calculate and interpret viscous boundary-layer quantities and airfoil performance effects (ILO 2), analyze finite-wing effects such as downwash, induced angle of attack, and induced drag (ILO 3), and solve problems involving compressible-flow phenomena such as nozzle flow, shock waves, expansion fans, and compressibility corrections (ILO 4).
Project: wind tunnel experiments and numerical simulations	ILO 1, ILO 2, ILO 3	The project assesses students' ability to integrate analytical, experimental, and numerical approaches in aerodynamic analysis. Students apply thin airfoil theory and numerical airfoil tools to estimate lift and moments, and compare results with wind tunnel data (ILO 1), examine viscous effects on lift, drag, stall behavior, and airfoil performance using experiments and simulations (ILO 2), and compare two-dimensional airfoil behavior with finite-span wing performance using lifting line theory, vortex lattice methods, and numerical simulations (ILO 3).
Final examination	ILO 1, ILO 2, ILO 3, ILO 4	The final examination is cumulative and assesses individual achievement of the core conceptual and analytical learning outcomes of the course. Students are required to apply incompressible inviscid aerodynamic analysis to airfoil problems (ILO 1), explain and quantify viscous effects such as boundary-layer behavior, skin friction, flow separation, and stall (ILO 2), distinguish between two-dimensional airfoil and three-dimensional finite-wing aerodynamic performance including induced drag and downwash (ILO 3), and account for compressibility effects in subsonic, transonic, and supersonic flow regimes (ILO 4).

Grading Rubrics

The following rubrics describe the general criteria used to assess the major assessment components in this course. More detailed task-specific marking schemes may be provided for individual homework assignments, project elements, and examination questions.

Rubric for Homework Assignments

Criteria	**Excellent**	**Good**	**Satisfactory**	**Marginal**	**Fail**	**Map to Course ILOs**
Conceptual understanding	Demonstrates clear and accurate understanding of the relevant aerodynamic concepts and physical mechanisms. Correctly explains the assumptions and limitations of the models used.	Shows good understanding of the main concepts, with only minor omissions or imprecision.	Shows adequate understanding of basic concepts but may lack depth or contain some conceptual gaps.	Shows limited understanding; explanations are incomplete or partially incorrect.	Shows little or no understanding of the relevant aerodynamic concepts.	ILO 1, ILO 2, ILO 3, ILO 4
Application of aerodynamic theory	Selects and applies appropriate aerodynamic theories and equations correctly and efficiently, including potential-flow tools, thin airfoil theory, lifting line theory, boundary-layer relations, and compressible-flow relations where relevant.	Applies appropriate methods with mostly correct reasoning and only minor errors.	Applies standard methods to familiar problems but may require clearer justification or contain some procedural errors.	Attempts to apply relevant methods but with significant errors or weak justification.	Fails to apply appropriate aerodynamic methods or uses irrelevant approaches.	ILO 1, ILO 2, ILO 3, ILO 4
Mathematical accuracy and problem solving	Solutions are mathematically sound, logically organized, and lead to correct results with appropriate units and notation.	Solutions are generally correct, with minor algebraic, numerical, or unit errors.	Solutions show reasonable effort and partial correctness but include some significant errors.	Solutions are incomplete or contain major mathematical errors.	Solutions are largely absent, incorrect, or not submitted.	ILO 1, ILO 2, ILO 3, ILO 4
Physical interpretation of results	Provides clear interpretation of results, including aerodynamic trends, limiting cases, model assumptions, and engineering significance.	Provides reasonable interpretation, though some details may be missing.	Provides basic interpretation but may not fully connect results to physical aerodynamic behavior.	Provides limited or superficial interpretation.	Provides no meaningful interpretation of results.	ILO 1, ILO 2, ILO 3, ILO 4
Clarity of presentation	Work is clear, well structured, legible, and easy to follow, with appropriate equations, diagrams, and explanations.	Work is mostly clear and organized.	Work is understandable but may be disorganized or difficult to follow in places.	Work is poorly organized or hard to follow.	Work is illegible, incoherent, or missing.	ILO 1, ILO 2, ILO 3, ILO 4

Rubric for Project

Criteria	Excellent	Good	Satisfactory	Marginal	Fail	Map to Course ILOs
Airfoil aerodynamic analysis	Accurately applies incompressible inviscid aerodynamic analysis, including thin airfoil theory and related airfoil models, to estimate lift, moment, zero-lift angle of attack, center of pressure, and aerodynamic center. Results are clearly interpreted and compared with numerical and experimental data.	Performs airfoil analysis correctly with minor errors or omissions. Comparisons with numerical and experimental results are mostly clear.	Performs basic airfoil analysis but with limited depth, some technical errors, or incomplete comparison across methods.	Provides incomplete or weak airfoil analysis with significant errors in theory, calculation, or interpretation.	Fails to conduct meaningful airfoil aerodynamic analysis.	ILO 1
Viscous effects on airfoil performance	Clearly explains and quantifies the effects of viscosity on airfoil performance, including drag, boundary-layer behavior, transition, separation, stall, and Reynolds-number-related effects. Uses wind tunnel data, flow visualization, and numerical results effectively.	Provides good discussion of viscous effects with mostly correct interpretation of experimental and numerical results.	Provides basic discussion of viscous effects but may lack depth or contain some inaccuracies.	Provides limited or superficial treatment of viscous effects, with weak connection to data or physical mechanisms.	Fails to explain or quantify viscous effects on airfoil performance.	ILO 2
Comparison of 2D airfoil and 3D wing performance	Clearly explains the differences between infinite-span airfoil and finite-span wing performance, including downwash, induced angle of attack, induced drag, aspect ratio, taper, twist, and span efficiency. Applies lifting line theory and numerical wing analysis appropriately.	Provides good comparison of 2D and 3D aerodynamic performance with minor omissions.	Provides an adequate comparison but may omit some important finite-wing effects or contain errors.	Provides limited comparison with weak understanding of finite-wing aerodynamic effects.	Fails to distinguish meaningfully between 2D airfoil and 3D wing performance.	ILO 3
Integration of analytical, experimental, and numerical methods	Insightfully compares analytical, wind tunnel, and numerical results; explains similarities and discrepancies using aerodynamic principles and model assumptions.	Compares different methods clearly and identifies major similarities and differences.	Provides some comparison across methods, but discussion is mainly descriptive rather than analytical.	Provides limited comparison with weak explanation of discrepancies.	Provides no meaningful comparison or integration of different analysis methods.	ILO 1, ILO 2, ILO 3
Quality of figures, tables, and data presentation	Figures, tables, equations, and plots are accurate, clearly labelled, well formatted, and used effectively to support technical arguments.	Most figures, tables, and plots are clear and accurate, with minor formatting or labeling issues.	Presentation is adequate but may include unclear plots, missing labels, or limited use of supporting data.	Presentation is difficult to follow, with poorly prepared or incomplete figures and tables.	Presentation is absent, unclear, or technically unusable.	ILO 1, ILO 2, ILO 3

Criteria	Excellent	Good	Satisfactory	Marginal	Fail	Map to Course ILOs
Physical reasoning and engineering judgement	Demonstrates strong physical insight, explains trends using aerodynamic principles, recognizes limitations of methods, and makes sound engineering judgements about aerodynamic design implications.	Provides good physical explanations and reasonable engineering judgement.	Provides basic explanations but may lack depth or miss some important implications.	Provides limited or superficial physical reasoning.	Provides no meaningful physical reasoning or engineering judgement.	ILO 1, ILO 2, ILO 3

Rubric for Final Examination

Criteria	Excellent	Good	Satisfactory	Marginal	Fail	Map to Course ILOs
Incompressible inviscid airfoil analysis	Correctly and independently applies potential-flow concepts, the Kutta–Joukowski theorem, thin airfoil theory, and related analytical tools to estimate airfoil lift and associated aerodynamic quantities.	Applies incompressible inviscid airfoil methods mostly correctly with minor errors.	Applies airfoil analysis methods to familiar problems but with some errors or incomplete reasoning.	Shows limited ability to apply airfoil analysis methods.	Fails to apply basic tools for estimating airfoil lift.	ILO 1
Viscous effects	Clearly explains and quantifies viscous effects on airfoil performance, including boundary-layer development, skin friction, laminar and turbulent behavior, separation, and stall.	Demonstrates good understanding of viscous effects with minor omissions.	Demonstrates adequate understanding of basic viscous effects but with limited depth.	Demonstrates limited or fragmented understanding of viscous effects.	Demonstrates insufficient understanding of viscosity and its effect on airfoil performance.	ILO 2
2D airfoil versus 3D finite-wing performance	Clearly explains and analyzes the aerodynamic differences between infinite-span airfoils and finite-span wings, including downwash, induced angle of attack, induced drag, aspect ratio effects, and lifting line theory.	Provides good analysis of finite-wing effects with minor errors or omissions.	Provides adequate discussion or calculation of finite-wing effects but may lack depth.	Shows limited understanding of the distinction between 2D and 3D aerodynamic performance.	Fails to explain meaningful differences between 2D airfoils and 3D wings.	ILO 3
Compressibility effects	Correctly accounts for compressibility effects in aerodynamic analysis, including Mach number effects, isentropic flow, choking, shock waves, expansion fans, Prandtl–Glauert correction, wave drag, and transonic phenomena where relevant.	Applies compressible-flow concepts mostly correctly with minor errors.	Demonstrates adequate understanding of basic compressibility effects but may struggle with more complex problems.	Shows limited or fragmented understanding of compressible aerodynamics.	Fails to account for compressibility effects at an acceptable level.	ILO 4

Criteria	Excellent	Good	Satisfactory	Marginal	Fail	Map to Course ILOs
Mathematical accuracy, organization, and clarity	Work is accurate, logically structured, clearly presented, and uses appropriate equations, units, notation, and physical reasoning under examination conditions.	Work is generally clear and accurate, with minor errors.	Work is understandable but may contain errors, omissions, or lack organization.	Work is poorly organized or contains major errors.	Work is incoherent, largely incorrect, or missing.	ILO 1, ILO 2, ILO 3, ILO 4

Final Grade Descriptors

Grade	Short Description	Elaboration on Subject Grading Description
A	Excellent Performance	Demonstrates an excellent command of the fundamental principles of aerodynamics. Applies incompressible inviscid analysis accurately and insightfully to estimate airfoil lift. Clearly explains and quantifies viscous effects on airfoil performance, including boundary-layer behavior, drag, separation, and stall. Provides a strong and physically grounded comparison between infinite-span airfoils and finite-span wings, including induced drag and downwash. Accounts for compressibility effects with confidence across subsonic, transonic, and supersonic regimes. Work is accurate, well organized, and shows strong physical insight and engineering judgement.
B	Good Performance	Demonstrates good understanding of the main concepts in aerodynamics. Applies most incompressible inviscid methods correctly to airfoil problems and shows good ability to explain viscous effects, finite-wing effects, and compressibility effects. Solves standard and moderately challenging problems with generally sound reasoning. Project and homework submissions are clear and technically competent, with only minor weaknesses in depth, precision, or completeness.
C	Satisfactory Performance	Demonstrates adequate understanding of core aerodynamic concepts and can apply standard methods to familiar problems. Shows satisfactory ability to estimate airfoil lift, describe viscous effects, distinguish between 2D airfoil and 3D wing behavior, and account for basic compressibility effects. Some errors or gaps in reasoning may be present, and physical interpretation may lack depth, but the main learning outcomes are achieved at an acceptable level.
D	Marginal Pass	Demonstrates threshold understanding of basic aerodynamic concepts but has difficulty applying theories consistently or accurately. Can attempt standard calculations involving airfoil lift, viscous effects, finite-wing performance, and compressibility, but work may contain significant errors, incomplete reasoning, or weak physical interpretation. There is sufficient evidence of partial achievement of the course learning outcomes, but performance is limited.
F	Fail	Demonstrates insufficient understanding of fundamental aerodynamic concepts. Is unable to apply basic incompressible inviscid tools to estimate airfoil lift, does not adequately explain viscous effects, fails to distinguish between 2D airfoil and 3D wing performance, or cannot account for compressibility effects at an acceptable level. Work contains major conceptual and mathematical errors, is incomplete, or does not demonstrate achievement of the intended learning outcomes.

Course AI Policy

The use of artificial intelligence (AI) tools is permitted in this course for learning support, brainstorming, checking understanding, improving writing clarity, and assisting with coding or software-related tasks. However, students remain fully responsible for the accuracy, originality, and integrity of all submitted work.

For homework and project submissions, students may use AI tools to support their learning, but they must ensure that the final submitted work reflects their own understanding and reasoning. Students should not submit AI-generated solutions without verification, explanation, and independent judgement. Any use of AI that contributes substantively to submitted work should be acknowledged where appropriate.

During the final examination, the use of AI tools is not permitted.

Communication and Feedback

Assessment marks for individual assessed tasks will normally be communicated via Canvas within two weeks of submission. Feedback may include written comments, annotated solutions, marking rubrics, sample solutions, in-class or tutorial discussion, or verbal feedback during project-related activities.

Homework feedback will focus on the correctness of methods, mathematical execution, physical interpretation, and clarity of presentation. Project feedback will address the quality of aerodynamic analysis, use of analytical, numerical, and experimental methods, interpretation of results, and technical communication.

Students who have questions about feedback or marks should contact the instructor or teaching team within two weeks after the feedback is released.

Late Submission Policy

To ensure fairness to students who submit work on time, late submissions for homework and project components will be subject to a penalty of **10% of the attained mark per day**, unless prior approval has been granted by the instructor or valid supporting documentation is provided.

Required Texts and Materials

The main textbook for this course is:

- *Fundamentals of Aerodynamics* (5th, 6th, or 7th edition) by J.D. Anderson.

The textbook is available online via the HKUST Library. Students may use any of the listed editions, as the core material is broadly consistent across these editions.

Additional recommended (optional) references include:

- *Aerodynamics for Engineering Students* by E.L. Houghton, P.W. Carpenter, S.H. Collicott, and D.T. Valentine.
- *Aerodynamics for Engineers* by J.J. Bertin and R.M. Cummings.

Other materials, including lecture slides, tutorial handouts, homework assignments, project instructions, datasets, and software-related guidance, will be provided via Canvas.

Academic Integrity

Students are expected to uphold HKUST's Academic Honor Code and maintain the highest standards of academic integrity. The University has zero tolerance for academic misconduct, including plagiarism, cheating, fabrication of data, and misrepresentation of work.

Students may discuss course concepts, homework strategies, and project ideas with classmates, the instructor, and teaching assistants. However, submitted work must be the student's own unless a task is explicitly designated as group work. For project work, students must ensure that all data processing, analysis, interpretation, and writing are conducted honestly and that any external assistance, including the use of AI tools, is acknowledged where appropriate.

Students should refer to the HKUST Academic Registry for the University's definitions of academic misconduct and guidance on academic integrity.

Course Outline

1. Introduction and Basic Concepts in Fluid Dynamics [Weeks 1–2]

- A brief history of flight
- Conservation laws for mass and momentum
- Streamlines, vorticity, stream function, velocity potential, and Laplace's equation
- Circulation, irrotationality, and linear superposition of potential flows
- Bernoulli's equation and the Kutta–Joukowski theorem for lift prediction

2. Incompressible Flow around Airfoils (2D) [Weeks 3–4]

- Vortex strength distribution, streamline condition, and Kutta condition
- Thin airfoil theory (TAT): lift and moment coefficients
- Effects of angle of attack, camber, and thickness
- Lift curves, drag polars, stall characteristics, and high-lift devices
- Limitations of TAT and introduction to the vortex panel method

3. Incompressible Flow around Wings (3D) [Weeks 5–6]

- Effects of finite wingspan: trailing vortices, downwash velocity, and induced drag
- Flow physics near the wingtip: 2D airfoils versus 3D wings
- Lifting line theory (LLT): lift and induced drag for elliptical and generic wings
- Design considerations: aspect ratio, wing taper, twist, and wingtip devices
- Limitations of LLT and introduction to the vortex lattice method

4. Viscous Effects in Incompressible Flow [Week 7]

- Blasius theory for a laminar boundary layer over a flat plate
- Basic characteristics of turbulent flows
- Effects of viscosity on airfoil performance, drag, separation, and stall

5. Basic Concepts in Compressible Flow [Week 8]

- Speed of sound, Mach number, and Mach cones
- Isentropic flow in a duct
- Choking and supersonic flow in a converging–diverging nozzle

6. Shock Waves and Expansion Fans [Weeks 9–10]

- Normal and oblique shock waves
- Shock detachment and wedge flows
- Prandtl–Meyer expansion fans

7. Airfoils in Compressible Flow [Weeks 11–12]

- Derivation of the full potential equation
- Linearized potential equation for small disturbances
- Subsonic regime: Prandtl–Glauert similarity transformation
- Supersonic regime: wave equation, and lift and wave-drag calculation
- Comparison with shock–expansion theory

8. Airfoils in Transonic Flow [Week 13]

- Critical Mach number
- Transonic drag rise and drag-divergence Mach number
- Shock-induced effects and high-speed airfoil performance
- Design considerations: sweep-back, supercritical airfoils, and area rule