Proposal for a New Course

Title: Computational Aeromechanics and Control of UAVs

Pre-requisites (desirable): Aeromechanics of Unmanned Aerial Systems

Per Week: Lectures: 2, Practical :1 Lab (3 hours)

Credits: 9

Duration of Course: 1 Semester (39hrs)

Proposing Department: AE (PG elective: DE/OE)

Proposing Instructor(s): Dr. C. S. Upadhyay, Dr. Navrose, Dr. M. Damodaran

Course Description: This course covers key topics related to modelling and simulation of Unmanned Aerial Vehicles (UAV). Different aspects of modelling and simulation, ranging from flight dynamics, structural mechanics and aerodynamic modelling, will be covered. The focus is on understanding the application of various popular tools for detailed design and development of UAV.

Objective: The objective of the course is to enable students of Aerospace Engineering to get a comprehensive overview of modelling methods for structural, aerodynamic and flight dynamic analysis of UAVs, and a detailed exposure to their application. The course will culminate with a project wherein the knowledge of the aforementioned methods will be employed in the design of a UAV. Use of computational structural mechanics and computational fluid dynamics tools would be emphasized. It is expected of the students to write their own flight dynamic tools using Aerospace Blockset in MATLAB and Simulink (and/or other available software) for their project.

Contents:

S. No.	Broad Title	Topics	Hours
1.	Introduction to modelling and simulation	1. Engineering modelling, idealizations, and fidelity of models; Fixed Wing and Rotary Wing UAS	2L
2.	Structural Modelling	1. Introduction of finite element method for structural analysis 2. Static analysis (strength-based design) 3. Modal analysis (natural frequency and mode shapes) 4. Impact modelling and analysis	6L 3Lab
3.	Aerodynamic Flow Modelling	1. Introduction of Computational Fluid Dynamics (CFD) 2. Problem setup, computational domain, initial and boundary conditions 3. Mesh generation 4. Overview of turbulence modelling 5. 2D and 3D RANS calculations 6. Convergence and Accuracy of Computed	10L 5Lab

		Flows 7. Numerical Flow Visualisation 8. Introduction to CFD modelling of propellers and rotor blades	
4.	Flight Dynamics and Control Modelling	1. Solving Newton-Euler equations 2. Realtime simulation 3. Hardware-in-the-loop simulation (HILS) / Software-in-the-loop simulation (SILS) 4. Flight Control Models: PID, LQR	6L 3Lab
5.	Computational Aeromechanical Model of the UAV	Integrating all Flight Dynamics, Control, Aerodynamics and Structural Models to form the complete Computational Aeromechanical Model to simulate various problems in aeromechanics.	2L 2Lab

Total -- Lectures:26; Lab sessions: 13

Short Summary for including in course of study booklet: This course provides an elaborate introduction and exposure to the usage of various methods and tools in aeromechanical application of Unmanned Aerial Vehicles.

References:

Books -

1. Beard, R., and McLain, T., Small Unmanned Aircraft: Theory and Practice, Princeton University Press, 2012.

2. Witt Robert D. Cook, David S. Malkus, Michael Plesha, Robert J Witt, Concepts and Applications of Finite Elements Analysis, Wiley; Fourth edition 2007.

3. S. C. Gupta, Applied Computational Fluid Dynamics, Wiley.

4. Matko Orsag, Christopher Korpela, Paul Oh, Stjepan Bogdan, Aerial Manipulation, Springer 2018.

5. Pascual Marqués and Andrea Da Ronch, Advanced UAV Aerodynamics, Flight Stability and Control: Novel Concepts, Theory and Applications; Wiley, 2017.

6. Yasmina Bestaoui Sebbane, Smart Autonomous Aircraft: Flight Control and Planning for UAV, CRC 2016.

Tools/Softwares -

The following list of -software is proposed for the Lab assignment and projects. These are based on the current state-of-the-art tools that are openly available. The list may be revised on a yearly basis.

1. SHARPY: https://www.imperial.ac.uk/news/195013/new-open-source-software-sharpy-launched/ Open Source code available on GitHub and Description available at *Journal of Open Source Software* (JOSS) link - https://joss.theoj.org/papers/10.21105/joss.01885

2. ASWING https://web.mit.edu/drela/Public/web/aswing/ (From Mark Drela (MIT):) https://web.mit.edu/drela/Public/web/aswing/asw_aiaa.pdf (Paper AIAA 99-1394, "Integrated Simulation Model for Preliminary Aerodynamic, Structural, and Control-Law Design of Aircraft.") (Free for Academic Users)

3. QPROP: Propeller-Windmill Analysis Program https://web.mit.edu/drela/Public/web/qprop/
   Aso from Mark Drela (MIT); Free Open Source.

4. FEniCS: https://fenicsproject.org/ is an open-source computing platform for solving partial differential equations (PDEs) with the finite element method (FEM). FEniCS enables users to quickly translate scientific models into efficient finite element codes.

5. FEMCOD: Code accompanying Reference 4. This is also coupled with VisualFEA.

6. CALCULIX: https://www.calculix.de/ is a free open-source Finite Element software which can also be coupled with the open source flow solver OpenFOAM https://www.openfoam.com/

7. OPENFOAM: https://www.openfoam.com/ (open-source toolkit for Multiphysics CFD/CSD) https://www.openfoam.com/documentation/guides/v2206/api/classFoam_1_1fv_1_1rotorDiskSource.html#details

8. SU2: https://su2code.github.io/ (Open-source toolkit for Multiphysics CFD/CSD) https://doi.org/10.1016/j.cam.2020.113340- M.C. Morelli, T. Bellosta, A. Guardone Development and Preliminary Assessment of the Open-Source CFD Toolkit SU2 for Rotorcraft Flows, *Journal of Computational and Applied Mathematics*, Vol. 389, 2021, 113340.

9. MATLAB/Simulink Resources and Aerospace Blockset.

10. Behdad Davoudi, Ehsan Taheri, Karthik Duraisamy, Balaji Jayaraman and Ilya Kolmanovsky, “Quad-Rotor Flight Simulation in Realistic Atmospheric Conditions” *AIAA J.*, 58(5) May 2020 https://doi.org/10.2514/1.J058327; Codes at https://github.com/behdad2018/FlightSim_QR_AIAA

Software Tools for Use in Module 2: Tools 1,4,5,6
Software Tools for Use in Module 3: Tools 1,2,3,7,8,9
Software Tools for Use in Module 4: Tools 9,10
Software Tools for Use in Module 5: Tools 2,9,10