Aircraft Flight Mechanics and Flight Control Systems

Introduction

Aircraft is an important class of air vehicle that requires a high degree of reliability in order to ensure safe and efficient operation under a range of conditions, which are prescribed during its design through the mission flight envelope. In this context, it is to be noted that as the design can generally address requirements pertaining to only a few of the operating conditions of the mission, and that there is a need to ensure safe and optimal operations for many more requirements arising throughout its flight envelope, we need to include concepts of flight control to ensure this requirement. However, in order to design suitable control schemes to achieve a desirable behaviour under different conditions, we first need to understand its mechanics.

The discipline of flight mechanics is the formal study of the way in which the aircraft responds to various inputs and is closely coupled to its overall performance expected under various flight conditions. In view of this, the discipline of flight mechanics involves modelling the various forces that act on the aircraft under different conditions and generating the resulting motion parameters. On the other hand, the discipline of flight control involves developing control schemes for ensuring the desired behaviour of the aircraft under different operating environments.

Motivation for the Course

Aircraft, by virtue of the fact that it is expected to execute a wide variety of motion scenarios, is typically acted upon by a complex system of forces that arise from aerodynamic, propulsive and gravitational sources. These forces, in most cases, are not only non-linear but also are uncertain. In addition, aircraft configuration itself makes it a non-linear, time varying and uncertain system. In view of these complexities, there is a need for systematic methodology that helps us to model and predict the behaviour as well as enables us to synthesize control schemes and structures, which result in acceptable behaviour of aircraft over its entire flight envelope. The present course aims to describe some of the important techniques, tools and procedures, which are part of flight mechanics and flight control discipline. The contents are particularly useful to those planning to design fixed-wing unmanned aircraft that are capable of executing missions in an autonomous manner.

Course Objectives

To establish basic concepts of equilibrium, static stability and steady-state control.
To study aircraft motion in terms of component modes of the aircraft flight dynamics.
To provide exposure to flight dynamics under various manoeuvres.
To discuss some of the flight control schemes required for ensuring the performance.

Course Contents

Module-1: Basic Definitions - Concept of aircraft flight, axes, sign conventions for forces, moments and motion variables. Lift & pitching moment models, concept of aerodynamic centre. (**4 Hours**).

Module-2: Steady-state Longitudinal Analysis – Concept of longitudinal trim and stability of flight, 2-d model and correction for 3-d effects. Role of horizontal tail and effects of power plants and fuselage. Concept of neutral point and its importance in design. Elevator as longitudinal control, stick-free stability concept, concept of control power and stick forces. Steady longitudinal manoeuvres. (**8 Hours**).

Module-3: Steady-state Lateral-Directional Analysis – Definitions of sideslip, rolling and yawing motions, contributions of vertical fin, dihedral angle and wing position to lateral-directional stability. Rudder as directional and ailerons as lateral control. Steady turn manoeuvre. (**6 Hours**).

Module-4: Basics of Flight Dynamic Modelling - Frames of references and basic flight dynamic formulation, inertial attitude and velocity, complete flight dynamic equations, description of applicable forces and moments. (**6 Hours**).

Module-5: Longitudinal and Lateral-Directional Modes - Linearized longitudinal and lateral dynamic models, Phugoid and short period approximations. Roll, Spiral and Dutch roll approximations, open loop response to control actuation. (**6 Hours**).

Module-6: Basics of Flight Control Modelling - Flight envelope as a mission statement, flying & handling quality requirements and design objectives for the flight control systems. (**4 Hours**).

Module-7: Basic Flight Control Systems - Longitudinal and lateral stability augmentation systems (SAS) and standard autopilots e.g. speed hold, altitude hold etc. Basic control augmentation systems (CAS). Effects of flight conditions, high angles of attack & high roll rates, inertia cross-coupling, structural flexibility and human pilot modelling, actuator saturation. (**8 Hours**).

Pre-requisites

Participants should be familiar with basic aircraft features e.g. wing, tail, fuselage and terms e.g. lift, drag, pitching moment etc. In addition, familiarity with aircraft performance attributes e.g. take-off, cruise, climb, landing, turn etc. are expected. Further, familiarity with ordinary differential equations and their solution, including numerical techniques, will be useful. Lastly, an exposure to basic control concepts e.g. single as well as multi-loop feedback control structures, applicable control elements and their design would be quite helpful.

Text/References

McLean, 'Automatic Flight Control Systems', Prentice Hall, 1990.
Blakelock, 'Automatic Control of Aircraft and Missiles', Wiley-Interscience, 1991.
Stevens and Lewis, 'Aircraft Control and Simulation', John Wiley, 1992.
Etkin and Reid, 'Dynamics of Flight – Stability and Control', Wiley India, 1996.
Nelson 'Flight Stability and Automatic Control', 2nd Ed., McGraw Hill, 1998.
Anderson, 'Introduction to Flight', McGraw-Hill, 2005.
Stengel 'Flight Dynamics', Princeton Univ. Press, 2004; Overseas Press, 2009.

Mode of Conduct and Delivery

The course is planned to be conducted fully in the on-line format, with two hours per week engagement. Further, it will be run in a module-wise sequence.