Unit T23: Flight Dynamics

Unit code: J/504/0132
QCF level: 6
Credit value: 15

Aim

The aim of this unit is to develop learners understanding of aircraft flight dynamic principles by considering and analysing the relationships between aircraft flight dynamic motion, aircraft stability and airframe aerodynamics and control.

Unit abstract

The unit has been designed as an introduction to linear flight dynamics, stability and control required for the satisfactory dynamic performance of a conventional piloted aircraft.

The unit starts with some underpinning aircraft dynamics fundamentals considering the system of airframe axes and notation, static stability, trim and aircraft steady manoeuvres. Next, the fundamental equations of motion for a rigid aircraft are derived and solved. The longitudinal, lateral and direction dynamic behaviour of the aircraft are then analysed. Finally, automatic flight control and stability augmentation systems are considered, in particular, the closed loop control analysis of stability augmentation systems.

Learning outcomes

On successful completion of this unit a learner will:

1 understand aircraft dynamics

2 be able to use equations for aircraft motion

3 be able to analyse flight dynamic motion

4 be able to analyse automatic flight control and stability augmentation systems.

Unit content

1 Understand aircraft dynamics

Aircraft axes and reference geometry: body axes, wind axes (notation, analytical function, transformation); aircraft reference geometry (nature, use in mathematical modelling)

Aircraft trim: external conditions and trim, symmetric trimmed flight; pitching moment equation development

Static stability: static stability (longitudinal, lateral, directional), conditions (controls fixed and controls free)

Manoeuvres: steady symmetric manoeuvres (steady pull-up, steady banked turn, longitudinal and lateral manoeuvre stability margins)

2 Be able to use equations for aircraft motion

Derivation of motion equations: equations for rigid symmetric aircraft (inertial components, generalised form of equations); linearized form of equations (gravitational terms, aerodynamic terms, control terms, small perturbations); alternative form of equations (dimensionless, state space, normalised)

Solution of motion equations: methods of solution (Cramer's rule, Laplace transforms, response transfer function approach to solution of small perturbation equations, state space method)

3 Be able to analyse flight dynamic motion

Longitudinal flight dynamics: motion response to controls eg longitudinal response equation of motion, response transfer functions (TF) to elevator controls, the characteristic equation; dynamic stability modes, eg phugoid, short period pitching oscillation, mode approximations; frequency response eg natural and damped oscillation frequencies, damping index, damping ratio, use, interpretation of Bode plots of frequency responses

Lateral-directional flight dynamics: motion response to controls, eg TF solutions to lateral-directional equations of motion for aileron, rudder; dynamic stability modes (roll, spiral, Dutch roll, approximations); frequency response (interpretation of Bode plots for frequency response)

4 Be able to analyse automatic flight control and stability augmentation systems

Automatic flight control and stability fundamentals: scope, applications, architecture of automatic flight control system (autopilot outer loop control, attitude control, flight path control, primary control surfaces); natural frequency and damping ratio requirements from handling qualities diagrams; stability augmentation inner loop architecture (for longitudinal, lateral and directional stability augmentation control)

Stability augmentation closed loop control design analysis: closed loop transfer functions and root locus plots for (longitudinal stability augmentation, lateral - directional stability augmentation); sideslip, roll and yaw feedback analysis (Transfer Function, root locus, pole placement methods)

Learning outcomes and assessment criteria

Learning outcomes On successful completion of this unit a learner will:	**Assessment criteria for pass** The learner can:
LO1 Understand aircraft dynamics	1.1 Analyse the body axes and wind axes systems determining their function and method of transformation 1.2 Assess the significance of aircraft reference geometry in the mathematical modelling process 1.3 Determine an aircraft's trim condition for steady symmetric trimmed flight, under varying external conditions 1.4 Develop a simplified version of the pitching moment equation when only normal forces act on the aircraft 1.5 Analyse longitudinal, lateral and directional, static stability behaviour under varying conditions 1.6 Analyse the effects of steady state manoeuvres on aircraft lateral and longitudinal stability
LO2 Be able to use equations for aircraft motion	2.1 Derive a set of linear equations of motion from the generalised equations of motion, for given motion variables 2.2 Derive the linear equations for small perturbations from the linearised expressions for aerodynamic, control, gravitational and thrust terms 2.3 Assess the merits of the equations of motion in their dimensionless, state space and normalised forms 2.4 Solve motion equations, for required response variables, using a variety of methods

Learning outcomes On successful completion of this unit a learner will:	**Assessment criteria for pass** The learner can:
LO3 Be able to analyse flight dynamic motion	3.1 Explain in detail, how the response Transfer Function solutions to the longitudinal equations of motion, model the linear dynamic response to a control input in the plane of symmetry 3.2 Analyse phugoid and short period longitudinal dynamic stability modes determining a reduced order approximation for the short period pitching mode 3.3 Assess the use of frequency domain analysis for determining aircraft flight dynamic response behaviour 3.4 Analyse the lateral-directional stability modes determining reduced order approximations for spiral and dutch-roll modes 3.5 Analyse Bode plots interpreting the longitudinal, lateral and directional frequency response modes to disturbances 3.6 Solve problems on the characterisation of longitudinal aircraft short period motion 3.7 Solve problems on the characterisation of lateral-directional aircraft short period motion
LO4 Be able to analyse automatic flight control and stability augmentation systems	4.1 Analyse modern automatic flight control system architecture, determining the signal interactions between the motion variables, the autopilot control system components and the control surface actuators 4.2 Analyse modern Command and Stability Augmentation System (CSAS) architecture determining the methods used for inner loop stability control 4.3 Determine required longitudinal, lateral and directional stability augmentation parameters, from Transfer Functions and root locus plots 4.4 Analyse roll, sideslip and yaw closed loop stability feedback, determining required design parameters

Guidance

Links to National Occupational Standards, other BTEC units, other BTEC qualifications and other relevant units and qualifications

The learning outcomes associated with this unit are closely linked with:

Level 5	Level 6
Unit 35: Further Analytical Methods for Engineers	*Unit T7: Modelling and Simulation for Engineers*
Unit 59: Advanced Mathematics for Engineering	*Unit T9: Control Engineering Design*
Unit 84: Aerodynamic Principles and Aircraft Stability and Performance	*Unit T18: Aircraft Aerodynamics*
	Unit T22: Avionic Systems Engineering

The content of this unit has been designed and mapped against the Engineering Council's current learning outcomes for IEng accreditation. The completion of the learning outcomes for this unit will contribute knowledge, understanding and skills towards the evidence requirements for IEng registration.

See *Annexe B* for mapping of the Edexcel Level 6 units to IEng programmes.

Essential requirements

Learner will need access to MathCAD software and *Flight Dynamic Principles* by M V Cook. Although not essential, access to a Merlin flight simulator (or similar simulation hardware) and/or MATLAB/Simulink software, would significantly enhance the delivery of this unit.

Delivery

The learning outcomes may best be taught in the order in which they are presented. Although the learning outcomes present the subject matter in a discrete manner, learning will be enhanced if an *integrated approach is adopted* when designing assessment material. Structured visits to establishments that possess flight simulators or airborne laboratory facilities would significantly enhance learner understanding of the subject matter and the delivery of assignment work.

In view of the academic rigour posed by this unit, it is suggested that it is delivered towards the end of the programme after learners have acquired a working knowledge of advanced engineering mathematics and control engineering. The unit *T9: Control Engineering Design* could usefully be delivered in tandem with this unit, consolidating learner understanding of engineering control as applied to aircraft flight dynamics and automatic flight control systems.

Assessment

The unit may best be assessed through a combination of investigative integrative assignments and a final written assessment, sufficient to meet external examiner requirements and centre quality standards.

Resources

Textbooks

Attaway S – *MATLAB A Practical Introduction to Programming and Problem Solving* (Butterworth-Heinemann, 2009) ISBN 978-0750687621

Cook M V – *Flight Dynamic Principles*, Second Edition (Butterworth Heinemann, 2007) ISBN 978-0750669276

Dorf R C and Bishop R H – *Modern Control Engineering* (Pearson International, 2008) ISBN 978-0132270283

Etter D M – *Introduction to MATLAB* (Prentice Hall, 2011) ISBN 978-0132170659

Nise N S – *Control Systems Engineering*, Sixth Edition (John Wiley, 2011) ISBN 978-0470646120

Pratt R W – *Flight Control Systems – Practical Issues in Design and Implementation* (Co-published by IEE and AIAA, 2000) ISBN 978-1563474040

Pritchard P – *Mathcad: a Tool for Engineers and Scientists*, Second Edition (B.E.S.T., 2007) ISBN 978-00772311569

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