Unit T19: Aircraft Structural Analysis

Unit code:	M/503/9993
QCF level:	6
Credit value:	15

Aim

The aim of this unit is to develop learner ability to determine the operational loads imposed on airframe structures and to assess the effects of those loads on airframe life and airworthiness. It will develop their understanding of structural fatigue, damage prediction and design against failure and their ability to analyse aircraft structures.

Unit abstract

The continual improvements that have been made to the specific weight, strength, toughness and sustainability of airframe structures have resulted not only in improvements to materials technology but also in design engineers having a better understanding of the loads imposed on aircraft structures and structural components and the effects of these loads on aircraft operation. In particular, the use of computer simulation modelling has led to a much deeper understanding of the nature and effects of fatigue and hence to subsequent design improvements which mitigate the damaging effects that may develop as a result of fatigue loads.

This unit initially considers the structural aspects of airworthiness, in particular the determination of inertia and manoeuvre loads imposed on the aircraft as a result of flight operation. The safety factors associated with these loads are summarised for each aircraft type within its flight and gust envelopes. Specific attention is given to the important subject of fatigue loading, its effect on airframe integrity, the design against these effects and the estimation of fatigue crack growth damage and airframe fatigue life. The elementary theory of bending, shear and torsion for open and closed, thin-walled beams is then analysed as a prelude to the final part of the unit, where the analysis of aircraft fuselage and wing structures subject to loads is covered.

Learning outcomes

On successful completion of this unit a learner will:

1 be able to determine airframe operational loads and their impact on aircraft airworthiness

2 understand aircraft structural fatigue, damage prediction and design against failure

3 be able to use beam theory to analyse thin walled structures

4 be able to analyse aircraft wing and fuselage structures.

Unit content

1 Be able to determine airframe operational loads and their impact on aircraft airworthiness

Airframe operational load determination: inertia loads (generated from take-off, landing and ground taxying operations); manoeuvre loads (for level flight, symmetric manoeuvres, diving flight and turning flight)

Airframe loading: flight envelope safety factors (limit load, proof load, ultimate load, stall limits, significance of flight speed)

Airworthiness: specific airworthiness requirements and codes for aircraft structural loads and load limits, as contained in, eg JAR21, JAR/CS 22, 23, 25, 27, 29; safety significance of aircraft gust envelope eg sharp edged gusts, graded gusts, stall curve, diving speed, cruising speed

2 Understand aircraft structural fatigue, damage prediction and design against failure

Fatigue: sources and nature, eg cyclic, corrosion, fretting, thermal and acoustic; cyclic stresses, alternating, fluctuating, repeating; S-N curves, fatigue strength, fatigue limit, endurance limit; fatigue behaviour in both metal alloy and composite aircraft structures

Fatigue damage prediction: fatigue life prediction methods, eg structural fatigue testing, empirical stress relationships (such as Goodman equation, Gerber parabolic equation, Soderberg equation), Miner's law of cumulative damage, ground-air-ground and gust load cycles; use of Linear Elastic Fracture Mechanics (LEFM) to predict fatigue crack behaviour, eg modes and cyclic stress concentration factors, crack tip plasticity and stress intensity factors, crack propagation rates and time to failure predictions

Airframe design against fatigue failure: methods, eg materials selection, use of jointing compounds, surface finish, avoidance of sudden changes in cross-section, use of doublers and butt straps; strategies, eg aircraft structural categorisation for failure (primary, secondary, tertiary structures), structurally significant items, failsafe design, damage tolerant design, safe life design

3 Be able to use beam theory to analyse thin walled structures

Bending of open and closed thin walled beams: analysis using bending theory of stresses due to symmetrical and unsymmetrical bending, eg assumptions, notation, direct stress distributions, position of neutral axis, deflections due to direct bending, temperature effects, section properties, approximations for thin-walled beams

Shear in thin-walled beams: analysis using bending theory of general shear stress, strain and displacement relationships for, eg open section beams, closed section beams, shear centre, twisting and warping

Torsion in beams: analysis using torsional bending theory of torsion in open and closed section beams, eg Bredt-Batho shear flow, condition for zero warping and finite warping in closed and open section beams

4 **Be able to analyse aircraft wing and fuselage structures**

Idealisation of airframe complex structural sections: idealisation, eg principles, effects on bending shear and torsional analysis of open and closed section beams

Wing spars and box beams: analysis of, eg tapered wing spar, open and closed section tapered beams, box sections, beams with variable stringers

Fuselage: analysis of fuselage with circular cross-section in bending, shear and torsion, effects of cut outs in fuselage

Wings: analysis of complete three-boom wing in bending, shear and torsion; effects of cut outs in wing

Learning outcomes and assessment criteria

Learning outcomes On successful completion of this unit a learner will:	**Assessment criteria for pass** The learner can:
LO1 Be able to determine airframe operational loads and their impact on aircraft airworthiness	1.1 Determine mathematically the inertia loads and manoeuvre loads that act on an airframe structure during aircraft operations 1.2 Determine the flight envelope load limits for large jet aircraft 1.3 Critically assess the significance of flight envelope load limits for the continuing airworthiness of a large jet aircraft airframe 1.4 Assess the impact of 'sharp-edged' and 'graded' gust loads on airworthiness
LO2 Understand aircraft structural fatigue, damage prediction and design against failure	2.1 Compare the differences in the sources, nature and behaviour of fatigue, between metal alloy and carbon composite airframe structures 2.2 Compare and contrast the cyclic strength values for two different specimen materials, subject to varying cyclic load regimes 2.3 Determine quantitative estimates for the fatigue life of light alloy metallic airframe structures subject to specified cyclic stress regimes 2.4 Determine quantitative estimates for crack propagation rates and times to failure of aircraft structural materials subject to specified cyclic stress regimes 2.5 Develop an argument justifying and contrasting the use of failsafe, safe life and damage tolerant design strategies for the continued airworthiness of a structurally significant item of airframe structure
LO3 Be able to use beam theory to analyse thin walled structures	3.1 Analyse open and closed section thin-walled beams subject to loads causing symmetric and non-symmetric bending, determining the required direct stress and deflection parameters 3.2 Analyse open and closed section thin-walled beams, subject to external axial and off-axis loading, determining required shear stress parameters 3.3 Analyse open and closed section thin-walled beams subject to constant torque loading, determining required parameters

Learning outcomes On successful completion of this unit a learner will:	**Assessment criteria for pass** The learner can:
LO4 Be able to analyse aircraft wing and fuselage structures	4.1 Use idealisation theory to show how a complex airframe component is simplified to aid its quantitative analysis 4.2 Analyse an open and closed wing box section and tapered wing section subject to loads, and determine the required bending, shear and torsional parameters 4.3 Analyse an idealised multi-sectioned tapered wing, subject to loads and determine the required parameters 4.4 Analyse a circular fuselage section with cut outs subject to loads, determining the required bending, shear and torsional 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 4: Mechanical Principles	*Unit T18: Aircraft Aerodynamics*
Unit 35: Further Analytical Methods for Engineers	*Unit T20: Aircraft Conceptual Design*
Unit 89: Aircraft Structural Integrity	

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 Edexcel BTEC Level 6 Diploma units to IEng programmes.

Essential requirements

Learners will need access to some form of laboratory fatigue test machine, equipped with at least two different types of material specimens, capable of being subjected to differing cyclic loads. Access to aircraft specialist airworthiness publications such as JAR/CS 21, 22 23, 25, 27 or their military AP101 series equivalents, is also required to meet the unit outcomes. Finally, sight of representative aircraft structures and/or structural components, similar to those being analysed is considered highly desirable, if not essential, to aid learning.

Delivery

The learning outcomes should be delivered in the order in which they are presented using a variety of teaching techniques and facilities appropriate to the unit content. Formal tutor input is likely to be through lectures, tutorials and laboratory work. Structured visits to establishments where aircraft structures and/or structural components are being manufactured or assembled will prove particularly useful as a method of enhancing learning. The whole programme should be designed to give learners sufficient time for self-study and for the completion of their unit assignments.

Assessment

The unit may best be assessed through a combination of summative assignments and laboratory exercises, together with a final written assessment, sufficient to meet external examiner requirements and centre quality standards.

Resources

Books

Baker A – *Composite materials for Aircraft Structures*, Second Edition (AIAA, 2004) ISBN 978-1563475405

Janssen M, Zuidema J and Wanhill R – *Fracture Mechanics*, Second Edition (Taylor and Francis, 2004) ISBN 978-0415346221

Megson T H G – *Introduction to Aircraft Structural Analysis* (Butterworth-Heinemann, 2010) ISBN 978-1856179324

Megson T H G – *Aircraft Structures for Engineering Students* (Butterworth-Heineman, 2012) ISBN 978-0750668170

