Unit T20: Aircraft Conceptual Design

Unit code:	A/504/0127
QCF level:	6
Credit value:	15

Aim

The aim of this unit is to provide learners with an understanding of the procedures and practices needed to produce an initial (baseline) concept design configuration for a fixed wing aircraft, from a preliminary written requirement.

Unit abstract

Aircraft design requires an interdisciplinary approach to be adopted, where numerous specialist disciplines combine to produce an optimum aircraft configuration that meets a given requirement. As is always the case with engineering design, compromises need to be made between the various specialist disciplines to produce the best solution from a number of conflicting requirements, therefore many process iterations may be necessary before the optimum conceptual design solution is achieved. This unit considers the initial stages in the design process leading to an optimised aircraft conceptual design configuration that meets the general design specification and is capable of being passed on with confidence to the detail design and production planning stages.

The unit starts with an overview of the whole aircraft design process, including details on the design requirements/airworthiness, regulations, environmental issues, specification and the baseline design synthesis process that must be considered. Next follows the first of three learning outcomes dedicated to the synthesis of the baseline concept design where suitable overall aircraft configurations, powerplant, fuselage layout and wing configurations are established for further consideration. In the second of these learning outcomes, basic lift, drag and mass estimates together with performance estimates for the various phases of flight are determined. In the third learning outcome, learners will carry out parametric analysis and optimisation procedures for the baseline design are undertaken. In the final part of the unit the concept design as a whole is analysed and the design characteristics refined to meet requirements.

Learning outcomes

On successful completion of this unit a learner will:

1 understand the aircraft design process

2 be able to select suitable overall aircraft and major component design configurations

3 be able to determine basic lift, drag, mass and performance estimates

4 be able to carry out parametric analysis and optimisation procedures

5 be able to analyse aircraft conceptual designs.

Unit content

1 Understand the aircraft design process

Design requirements for airworthiness: EASA part 23/25 documentation; Def-Stan 00-970, eg requirements for performance, flight, structural design, powerplant; acceptable levels of safety for design of aircraft structures and systems

*Environmental is*sues: noise pollution, eg noise control limits, noise reduction measures, engine type, engine design; emissions – pollutants, eg NOx, CO, HC, S2O; pollutant reduction methods, eg engine design, airframe design, reduced fuel consumption, operational procedures, use of different fuels

Design specification content: performance, eg range, payload, maximum operating speed, normal operating speed, take-off and landing field length limitations, climb performance, operating altitude; operational considerations , eg size limitations, mass limitations, crew compliment, occupant environment, payload variations, maintainability targets, availability targets, geographical operating environment; general, eg market, growth potential, cost targets, airframe life, airworthiness requirements

Costs: predictions; direct operating costs, eg insurance, fuel, expendables, maintenance, replacement parts; indirect operating costs; life-cycle costs, eg design, development, aircraft procurement, operating, disposal

Design synthesis: process sequential and concurrent activities (requirement, specification, configuration, fuselage layout, wing layout, estimates for lift, drag and mass, performance estimates, parametric analysis, design optimisation, configuration comparisons); concept design analysis; detail design

2 Be able to select suitable overall aircraft and major component design configurations

Overall aircraft configuration: conventional layout (cantilever monoplane wing, separate vertical and horizontal tail surfaces, discrete fuselage, retractable tricycle undercarriage); general component layout, eg power plant location (such as nose, fuselage, wing mounted, pod mounted), empennage (variable incidence tailplane, all moving tailplane), undercarriage arrangement (bogie type, number of l, egs, tailwheel, nosewheel), wing (backward/forward sweep, variable sweep, winglets); variations, eg short/vertical take-off, landing (STOL/VTOL), military use, waterborne aircraft

Powerplant: available types and characteristics, eg piston, prop, gas turbine (such as turbojet, turbofan, turboprop/turboshaft), selection and performance characteristics (thrust, efficiency, noise, fuel consumption, mass, power)

Fuselage: primary layout considerations (payload, pressurisation, powerplant location; overall layout (aerodynamics, external shape, junctions, structure); local layout considerations (vertical location of wing, control and stabilising surfaces, landing gear, systems, fuel, equipment); crew and payload (crew compartment, military, passenger cabin, freight)

Wing: control/high lift devices , eg trailing edge flaps, leading edge flaps/slats, flying control surfaces, spoilers, airbrakes; wing configuration, eg planform/geometry (such as aspect ratio, span, taper, sweep, dihedral, winglets), structural mass/volume, wing area/loading

3 **Be able to determine basic lift, drag, mass and performance estimates**

Lift: initial data (aspect ratio, sweep, Mach number, type of high lift system); lift coefficient equations/estimates for low and high aspect ratio wing configurations at, eg take-off, cruise, maximum altitude, approach/landing

Drag: drag components (profile, skin friction, vortex, total zero lift, total lift induced, total), design parameters (such as flight speed, lift coefficient, wing area, aspect ratio, thickness/chord ratio, wing sweep, Reynolds number, aircraft length, fuselage cross-section); drag estimates for aircraft when in take-off/climb out/cruise configurations

Mass: initial estimates – fixed (fuselage, payload, operational items); variable (all lifting surfaces, powerplant, systems/equipment, fuel, secondary lifting devices); total (fixed plus variable)

Performance estimates: required design data (mass data for different phases of flight, lift/drag/ powerplant characteristics); fundamental parameters (thrust/weight ratio, wing loading); flight phase performance estimates for, eg take-off, climb to operating altitude, cruise/operating flight, maximum speed, descent, approach/landing

4 **Be able to carry out parametric analysis and optimisation procedures**

First stage parametric analysis: procedure – select overall aircraft concept(s) for investigation, identify most probable power plant type, prepare preliminary fuselage layout, select appropriate wing geometric configurations, evaluate lift characteristics for selected wing/high lift devices, determine appropriate drag coefficients, select range of wing loadings for further investigation, select and use relevant performance equations to establish thrust/weight ratios as a function of wing loading, establish design point values for each set of parameters

Second stage parametric analysis and optimisation; procedure – use of mass prediction data/output data from first stage, determine fixed masses (payload, fuselage, operational items), determine variable masses (lifting surface, powerplant, systems, fuel), optimise mass solutions; additional data acquisition, eg assumptions, wing location, centre of gravity, control surface/stabiliser characteristics

5 **Be able to analyse aircraft conceptual designs**

Data sources and analytical tools: sources, eg journals, year books, technical books (such as on aircraft flight, aerodynamics, performance, powerplant, structures, aircraft design); airworthiness requirements; tables of properties; manufacturers' data: analytical tools, eg spread sheets, wind-tunnels, graphs/charts, AutoCAD, MathCAD, matlab

Analysis: powerplant, eg engine mass/performance data, selection, location, acoustic considerations; structure, eg lifting surfaces (function, configuration), fuselage (function, layout, configuration, operating mass), landing gear (geometry, size, location); aerodynamic (performance, stability, control); results of analysis (iterative refinement); costs

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 the aircraft design process	1.1 Discuss the impact of current airworthiness requirements on initial aircraft conceptual design 1.2 Appraise the developments made in aircraft design to help reduce environmentally polluting noise and emissions 1.3 Discuss the relationship between design specification development and the establishment of critical performance design parameters 1.4 Evaluate the major cost drivers of a selected aircraft design 1.5 Detail the necessary order of events for the design synthesis process
LO2 Be able to select suitable overall aircraft and major component design configurations	2.1 Select alternative aircraft component layouts, to meet a set of basic written requirements 2.2 Discuss the variations in powerplant location and wing geometry for short take-off and landing and vertical take-off and landing aircraft 2.3 Select alternative powerplant configurations that meet a set of basic written requirements 2.4 Select alternative fuselage layouts that take into account both primary and local layout considerations 2.5 Assess the relevance of differing control and high lift device configurations for both subsonic and supersonic flight r, egimes 2.6 Select alternative wing configurations that meet a set of basic written requirements
LO3 Be able to determine basic lift, drag, mass and performance estimates	3.1 Determine the lift coefficient equations for a low aspect ratio wing configuration aircraft at take-off and cruise 3.2 Determine lift coefficient estimates for a high aspect ratio wing configuration aircraft during take-off and approach for landing 3.3 Explain the dependency between drag components, design parameters and aircraft configuration, when determining relationships for drag estimates

Learning outcomes On successful completion of this unit a learner will:	**Assessment criteria for pass** The learner can:
	3.4 Determine drag component and total drag estimates for subsonic high aspect ratio winged aircraft, during cruise and climb-out configurations 3.5 Determine initial fixed and variable mass estimates for a given set of design parameters 3.6 Explain how to obtain the required design data necessary to determine performance estimates, in varying phases of flight 3.7 Explain the significance of the fundamental design parameters in determining first phase performance estimates 3.8 Determine performance parameter estimates for aircraft in specified flight phases, given the appropriate aircraft mass and powerplant design data
LO4 Be able to carry out parametric analysis and optimisation procedures	4.1 Produce a route map of a complete parametric analysis and optimisation procedure, detailing the order of events and design data flow paths 4.2 Carry out a first stage parametric analysis on alternative design concepts 4.3 Carry out a second stage parametric analysis on alternative design concepts, determining variable and fixed mass estimates 4.4 Optimise a mass solution, from mass estimates and relevant additional data
LO5 Be able to analyse aircraft conceptual designs	5.1 Analyse alternative data sources, selecting required data for chosen concept design 5.2 Assess the benefits of use of analytical tools in aircraft conceptual designs 5.3 Analyse the powerplant, structure and aerodynamics of a chosen concept design, determining design parameters 5.4 Refine the results of the analysis to better meet design requirements 5.5 Analyse the costs associated with the chosen initial concept design, determining an overall cost estimate

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 T18 Aircraft Aerodynamics*
Unit 84: Aerodynamic Principles and Aircraft Stability and Performance	*Unit T19: Aircraft Structural Analysis*
	Unit T22: Avionic Systems Engineering
	Unit T23: Flight Dynamics

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 a mapping of the Edexcel BTEC Level 6 Diploma units to IEng programmes.

Essential requirements

Learners need access to aircraft specialist airworthiness publications (such as FAA/JAR/CS 23, 25 and/or Def. Stan. 00-970), together with access to aircraft design data (as contained in many of the listed textbooks). Access to spreadsheet software will also be necessary for learners to meet the learning outcomes.

Delivery

This unit will benefit from a mixed mode delivery, ideally including lectures, tutorials, investigative assignments, group work and set case studies. Emphasis should initially be placed on the synthesis of the process stages needed to deliver a baseline concept design configuration, after which the analysis of particular design elements and data parameters, needed for the optimised design solution, should be considered. In view of the unit subject matter, it may best be delivered towards the end of the programme when learners have acquired an understanding of aircraft aerodynamics, structures and systems that will help them understand the aircraft design process.

Assessment

This unit may be best assessed through use of carefully constructed case studies/assignments and/or a major small-group project. If a group project is used as the major assessment instrument, additional phased coursework/assignments could be employed, as necessary, to ensure learners meet all the assessment criteria.

Resources

Textbooks

Anderson J D – *Fundamentals of Aerodynamics*, Fifth Edition (McGraw-Hill, 2011) ISBN 978-0071289085

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

Houghton E and Carpenter P – *Aerodynamics for Engineering Students*, Fifth Edition (Butterworth-Heinemann, 2003) ISBN 978-0750651110

Howe D – *Aircraft Conceptual Design Synthesis* (Professional Engineering Publishing, 2005) ISBN 978-1860583018

Jenkinson L R, Simpkin P and Rhodes D – *Civil Jet Aircraft Design*, (Arnold, 1999) ISBN 978-0340741528

Mair W A and Birdsall D L – *Aircraft Performance* (Cambridge University Press, 2003) ISBN 978-0521568364

Mattingly J D, Heiser W H and Pratt D T – *Aircraft Engine Design*, Second Edition (AIAA, 2002) ISBN 978-1563475382

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

Niu M C Y – *Airframe Structural Design: Practical Design Information and Data on Aircraft Structures*, Second Edition (Adaso Adastra Engineering Center, 2006) ISBN 978-962728090

Raymer D P – *Aircraft Design: A Conceptual Approach*, Fourth Edition (AIAA, 2006) ISBN 978-1563478291

Spitzer C R – *Avionics: Development and Implementation (Avionics Handbook)*, Second Edition (CRC Press, 2006) ISBN 978-0849384417

Walsh P P and Fletcher P – *Gas Turbine Performance*, Second Edition (Blackwell, 2004) ISBN 978-0632064342