Unit T18: Aircraft Aerodynamics

Unit code: K/503/9992

QCF level: 6

Credit value: 15

Aim

The aim of this unit is to enable learners to develop and apply aspects of aerodynamic theory and practical testing to determine, their aerofoil and wing, aerodynamic characteristics. It will also develop an understanding of compressible airflow behaviour and its influence on aircraft wing design.

Unit abstract

This unit will give learners the ability to analyse aspects of fundamental incompressible and compressible airflows, using practical wind tunnel testing and aerodynamic theory. The results of the theoretical and practical analysis will then be used to establish aerofoil and wing characteristics, such as aerofoil section aerodynamic coefficients and features of wing geometry, to meet particular aircraft flight requirements.

The unit starts with the consolidation of basic aerodynamic principles including a review of some fundamental aerodynamic properties, the analysis of aerodynamic force and moment, an introduction to dimensional analysis and a qualitative introduction to airflow fundamentals and the circulation theory of lift.

The ideas and concepts of thin aerofoil theory are then introduced and, together with experimental wind tunnel modelling, applied to the characterisation of aerofoil sections. Incompressible flow over finite wings is then considered, where the vortex system theoretical model for lift is developed and together with the results from aerofoil theory used to determine the aerodynamic characteristics of finite aircraft wings.

Finally, quasi-one dimensional compressible flows and shockwaves are analysed, to assess the effects their behaviour has on subsequent wing design needed to overcome the problems associated with transonic flight.

Learning outcomes

On successful completion of this unit a learner will:

1 understand aerodynamic principles

2 be able to determine aerofoil characteristics

3 be able to determine aircraft wing characteristics

4 understand compressible airflow behaviour and its influence on wing design.

Unit content

1 Understand aerodynamic principles

Fundamental properties and relationships: eg fluid temperature, pressure, density, viscosity, steady and unsteady flow, wing and aerofoil (geometry, nomenclature, identification methods), Bernoulli's equation for (incompressible flow, compressible flow), speed of sound, bulk elasticity, Mach number

Dimensional analysis: principles and common aerodynamic relationships, eg Buckingham pi method, Rayleigh's formula, aerodynamic force, scale effect, dynamic similarity, non-dimensional coefficients, Reynolds number, sonic velocity, Mach number

Aerodynamic force, pressure and moment: lift and drag force, pitching, rolling and yawing moments, lift, drag and pitching moment coefficients; types of drag, eg total drag, induced/vortex drag, profile drag (form drag, skin friction drag), wave drag; aerofoil pressure distribution, centre of pressure, aerodynamic centre

Fundamentals of airflow: qualitative explanation for circulation theory of lift, eg assumptions, inviscid flow past circular cylinder without circulation, definition of air circulation, circular cylinder with circulation, Magnus effect, airflow past a two-dimensional aerofoil, the Kutta effect, the wake; the boundary layer and drag, laminar and turbulent boundary layers, transition, relationship between Reynolds number and the nature of boundary layer

2 Be able to determine aerofoil design characteristics

Fundamentals of inviscid, incompressible flow: Bernoulli, Laplace governing equations for non-rotational incompressible flow, elementary flows (such as uniform flow, source flow, doublet flow, vortex flow); inviscid flow over a cylinder, eg non-lifting, lifting, source panel method for non-lifting flow over bodies of arbitrary shape, Kutta-Zhukovsky theorem for generation of lift

Thin aerofoil theory: theoretical background, eg vortex sheets, Kutta condition, Kelvins circulation theorem; quantitative development of thin aerofoil theory equations for symmetric aerofoils, cambered aerofoils; viscous flow aerofoil drag, eg skin friction drag estimates for laminar flow, turbulent flow, flow separation

Practical application of theory: experimental determination of modern low speed aerofoil characteristics, eg pressure distribution, centre of pressure, aerodynamic coefficients, lift, drag, pitching moment

3 **Be able to determine aircraft wing design characteristics**

Incompressible flow analysis for finite wings: additional characteristics (downwash, effective angle of attack, induced drag), additional analytical tools (curved vortex filament, Helmholtz theorem, Biot-Savart law)

Methods for predicting aerodynamic characteristics of a finite wing: Prandtl's lift line method, eg Prandtl's fundamental integral equation, elliptical lift distribution analysis, general lift distribution analysis; other methods, eg numerical non-linear lifting line method, lifting surface method, vortex lattice numerical method, application to delta wings

4 **Understand compressible airflow behaviour and its influence on wing design**

One-dimensional compressible flow: isentropic quasi-one-dimensional compressible flow, eg limitations, relationships (pressure, density, temperature ratios, velocity change), flow relationships through ducts, nozzles, high speed wind tunnels; effects of compressible airflow at subsonic, transonic, supersonic speeds

Airflows across normal shocks waves: one-dimensional properties of normal shock waves; calculations for airflow relationship changes across normal shocks, eg static pressure and density jumps, temperature rise, entropy change, Mach number change, velocity change, total pressure change

Airflows across oblique shock waves: behaviour (Mach waves, Prandtl-Meyer expansions); determining changes across oblique shocks, eg use of shock tables, Ackeret approximation method, supersonic wind tunnel testing

Aspects of transonic wing design: eg transonic flow, critical Mach number, transonic variation in drag, use of thin wings, supercritical aerofoil concepts, area rule and wing sweep, transonic variations in lift and pitching moment, trim problems and solutions

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 aerodynamic principles	1.1 Solve problems using fundamental properties and relationships 1.2 Determine the correct dimensionality of common aerodynamic relationships 1.3 Solve problems involving aerodynamic force, pressure and moment 1.4 Determine mathematically lift and drag parameters for differing flight speeds 1.5 Critically evaluate the relationship between induced drag, profile drag and lift for differing flight speeds 1.5 Give a detailed account of the circulatory nature of inviscid and viscous airflows, as they pass over immersed solid bodies and aerofoil sections
LO2 Be able to determine aerofoil characteristics	2.1 Determine non-rotational, incompressible flow parameters, using the governing equations 2.2 Analyse inviscid flows over cylinders and bodies of arbitrary shape to determine lift parameters 2.3 Critically evaluate vortex sheet concepts for modelling, inviscid, incompressible flow over aerofoils 2.4 Quantitatively develop equations for the determination of aerofoil lift characteristics 2.5 Determine skin friction drag estimates for laminar and turbulent flow using mathematical techniques 2.6 Determine from experiments, the aerodynamic characteristics of low speed aerofoils
LO3 Be able to determine aircraft finite wing characteristics	3.1 Compare the differences in the aerodynamic characteristics of a finite wing and its own aerofoil sections 3.2 Assess the applicability of the additional aerodynamic tools needed for the further development of finite wing theory 3.3 Use Prandtl's lift-line method to determine finite wing aerodynamic characteristics 3.4 Explain how aerodynamic characteristics for low aspect ratio wings may be determined using the vortex lattice numerical method

Learning outcomes On successful completion of this unit a learner will:	**Assessment criteria for pass** The learner can:
LO4 Understand compressible airflow behaviour and its influence on wing design	4.1 Analyse isentropic quasi-one dimensional compressible flow relationships through ducts and nozzles 4.2 Explain the behaviour of compressible airflows at subsonic, transonic and supersonic speeds 4.3 Analyse the behaviour of compressible airflows across normal shocks, mathematically determining the changes 4.4 Analyse the behaviour of compressible airflows across oblique shocks, mathematically determining the changes 4.5 Critically evaluate the relationship between transonic airflow behaviour and aircraft wing design

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 4	Level 5	Level 6
Unit 83: Aerodynamic principles and Aircraft Design	*Unit 59: Advanced Mathematics for Engineering*	*Unit T20: Aircraft Conceptual Design*
	Unit 84: Aerodynamic Principles and Aircraft Stability and Performance	*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 mapping of the Edexcel Level 6 units to IEng programmes.

Essential requirements

Learner will need access to low speed wind tunnel facilities, equipped with suitable aerofoil test sections and whole aircraft scale models. Also, in order to fully meet the assessment criteria for analysing the behaviour of high speed compressible airflows, learners will need access to some form of supersonic wind tunnel experimental set up, if possible.

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, with emphasis being placed on both theoretical and practical aspects of the subject matter, as appropriate. Structured visits to establishments which have the necessary wind tunnel facilities may be beneficial to enhance learning, where centres lack these facilities on-site. 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 theoretical and practical assignments, together with a final written assessment. Any assessment strategy should be sufficient to meets external examiner requirements and centre quality standards.

Resources

Books

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

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

Yahya S M – *Fundamentals of Compressible Flow with Aircraft and Rocket Propulsion*, Third Edition (New Age International, 2006) ISBN 978-8122414684