Unit T24: Aircraft Gas Turbine Thermo-fluid Dynamics, Design and Performance

Unit code:	K/504/0205
QCF level:	6
Credit value:	15

Aim

The aim of this unit is to give learners an understanding of the fluid dynamic and thermodynamic theory that underpins the design of aircraft gas turbine engines. Learners will apply this theory to the analysis of engine and engine components, design and performance.

Unit abstract

The practical development of aircraft gas turbine engines has enabled them to become the most widespread and effective means of aircraft propulsion. They have almost totally displaced the reciprocating piston engines that dominated the early years of aviation.

With the production of ever larger and more sophisticated aircraft, a need for continuous improvement has developed in gas turbine engine design, performance and technology.This is to keep pace with the quest for more power and better performance. These improvements to the design of aircraft powerplant must also take account of the ever more important environmental imperatives for 'greener' aircraft propulsion.

This unit considers the thermo-fluid dynamics associated with gas flow behaviour through ducts, in particular, compressible flows through constant and variable area ducts (that model the behaviour of the gas as it flows through aircraft turbine engines). Then the thermodynamic theory of gas cycles is applied to the performance analysis of real gas turbine cycles for turbojet, turboshaft and turboprop engines. Next, gas turbine engine component design point and off-design performance is looked at in some detail, with particular emphasis on the compressor, combustor and turbine that go to make-up the 'gas generator' core of aircraft turbine engines. The environmental aspects of design including emissions and noise pollution are also considered. In the final part of the unit, the performance prediction of aircraft gas turbine powerplant as a whole is considered, where equilibrium design running points and off-design performance is analysed under differing operating conditions.

Learning outcomes

On successful completion of this unit a learner will:

1 understand gas flow dynamics

2 be able to analyse aircraft gas turbine engine cycles

3 be able to analyse the design and performance of aircraft gas turbine engine components

4 be able to determine off-design operational performance of aircraft gas turbine engines.

Unit content

1 Understand gas flow dynamics

Idealised incompressible gas flow: gas stream through ducts and nozzles; equations (energy, continuity, momentum); parameters (static enthalpy, stagnation enthalpy, temperature, pressure)

One-dimensional compressible flow: high speed gas flow compressibility effects (adiabatic and isentropic pressure, temperature and density changes, sonic velocity and shock wave formation); basic equations and properties for idealised isentropic one-dimensional flow in ducts and nozzles (equations of state, conservation of mass, energy and momentum); properties (static and stagnation ratios for temperature, pressure and Mach number)

Raleigh and Fanno flow: Raleigh (equations and relationships for frictionless constant area flow, with heat transfer, in ducts, use of tables); Fanno (equations and relationships for adiabatic flow in constant area ducts with friction, use of tables)

Normal and oblique shocks: adiabatic normal shocks (equations and relationships for adiabatic frictionless flows, use of shock tables); oblique shocks (equations and relationships for quasi isentropic two-dimensional flows, use of normal shock tables); intake geometry design for high speed gas flows

2 Be able to analyse aircraft gas turbine engine cycles

Propulsion fundamentals: propulsive thrust relationships (gross thrust, net thrust, pressure thrust, thrust power); propulsive efficiencies (thermal, propulsive, overall)

The ideal gas turbine cycle: cycle processes (isentropic compression, constant pressure heat addition, adiabatic frictionless flow); process parameters (pressure-volume, temperature-entropy relationships)

The real turbojet cycle and component efficiencies: real cycle losses (such as due to friction, heat transfer, use of non-ideal gases, combustion, flame stability, turbulence); component efficiencies and gas cycle analysis (intake, compressor, combustor, turbine, jetpipe, propelling nozzle); overall generalised turbojet performance

The turboprop and turbofan cycles: turboprop, turbofan cycle analysis; generalised performance for (turboprop, turboshaft and turbofan engines)

3 Be able to analyse the design and performance of aircraft gas turbine engine components

Centrifugal compressors: construction, basic operation and design features; design and performance parameters (work done, pressure rise, flow through diffusers, compressibility and its effects); non-dimensional compressor characteristics

Axial flow compressors: construction, basic operation and design features; design analysis and parameter estimates (stage velocity triangles, factor affecting stage pressure ratio, degree of reaction, three-dimensional flow, rotational speed, annulus dimensions, stage number estimates, blade design profiles); performance behaviour predictions (stage performance, compressibility effects, off-design performance, characteristics curves)

Combustion systems: operational requirements; design features (types, combustion process determination and methods, combustor design); combustion-chamber performance prediction (pressure loss, combustion efficiency, stability limits)

Gas turbine emissions: operational considerations; pollutant formation; emissions reduction methods; noise pollution and reduction methods; future design developments

Axial flow turbines: blade and stage design (axial flow through turbine stage, velocity triangles, stage efficiencies, loss coefficients, free vortex design, blade profile, pitch and chord determination, blade cooling design methods); blade, stage and overall turbine performance

4 Be able to determine off-design operational performance of aircraft gas turbine engines

Design point operation of single-shaft gas turbine engine: gas generator component characteristics (mass flow, pressure and efficiency variations with compressor and turbine rotational speeds); operational procedure for obtaining equilibrium running points and plots

Equilibrium running of gas generator: operational parameters (rotational speed and flow compatibility, pressure ratio determination, turbine inlet temperature prediction)

Off-design operation of free turbine engine: matching (gas generator and turbine, two turbines in series); key operating parameters (variation of power output and specific fuel consumption with rotational speed)

Off-design operation of turbojet engine: propelling nozzle characteristics (non-dimensional flow, pressure ratio); key off-design parameters (gas generator matching, variations of thrust and specific fuel consumption with rotational speed, forward speed and altitude, methods of displacing the equilibrium running line, minimisation of pressure losses within ducts and exhausts)

PD031360 – Edexcel BTEC Level 6 Diploma specification in Engineering – Issue 1 – May 2012

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 gas flow dynamics	1.1 Analyse incompressible gas flow through ducts and nozzles, determining required parameters 1.2 Explain in detail the changes that occur to the high speed gas stream as it approaches and reaches sonic velocity 1.3 Derive the basic equations for one-dimensional isentropic compressible flow, through ducts and nozzles, determining required properties 1.4 Analyse Raleigh and Fanno flow through ducts, determining relationship parameters 1.5 Analyse gas flow through normal and oblique shocks, determining relationship parameters 1.6 Determine the effects of intake design geometry on the passage of high subsonic, sonic and supersonic gas flows
LO2 Be able to analyse aircraft gas turbine engine cycles	2.1 Analyse propulsive thrust and efficiency relationships, determining how efficiencies affect thrust performance 2.2 Analyse the ideal gas turbine cycle, determining required process parameters 2.3 Compare and contrast ideal and real gas turbine cycles, determining the effect of real cycle losses on gas turbine performance 2.4 Analyse real turbojet gas cycle component efficiencies, determining required performance parameters 2.5 Determine estimates of overall turbojet performance, using given component efficiencies 2.6 Analyse turboprop and turbofan cycles determining generalised performance parameters

Learning outcomes On successful completion of this unit a learner will:	**Assessment criteria for pass** The learner can:
LO3 Be able to analyse the design and performance of aircraft gas turbine engine components	3.1 Compare and contrast the construction, operation and design of centrifugal and axial flow compressors 3.2 Determine centrifugal compressor performance parameters and non-dimensional characteristics 3.3 Analyse axial flow compressors, determining required design estimates and performance behaviour predictions 3.4 Assess the impact of combustion system operational requirements on subsequent combustion chamber design and performance 3.5 Investigate current design initiatives and those being considered to mitigate the effects of aircraft gas turbine emissions on the environment, reporting on findings 3.6 Analyse the design of gas turbine blades and stages, determining required parameters 3.7 Analyse turbine blade, stage and overall performance, making predictions
LO4 Be able to determine off-design operational performance of aircraft gas turbine engines	4.1 Determine gas generator component characteristics and single-shaft engine equilibrium running points 4.2 Determine gas generator operational running parameters 4.3 Assess the effects on free gas turbine performance of matching 4.4 Determine free gas turbine engine key off-design operational performance parameters 4.5 Determine turbojet engine propelling nozzle characteristics 4.6 Determine key off-design operational performance parameters for turbojet engines

Guidance

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

The learning outcomes in this unit are linked closely with the following units:

Level 4	Level 5	Level 6
Unit 21: Materials Engineering	*Unit 35: Further Analytical Methods for Engineers*	*Unit T18: Aircraft Aerodynamics*
Unit 90: Aircraft Propulsion Technology	*Unit 92: Aircraft Gas Turbine Science*	*Unit T18: Aircraft Aerodynamics*

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

Learners need access to spreadsheet software and *Gas Turbine Theory* (sixth edition) and *Gas Turbine Performance* (second edition) (see *Resources*).

Delivery

The learning outcomes should be delivered using a variety of teaching techniques appropriate to the syllabus content, for example lectures, tutorials and seminars. Structured visits to establishments that design, manufacture or test aircraft gas turbine engine assemblies or their major components are useful to enhance the learning experience.

Assessment

This unit may be best assessed through a combination of investigative assignments, computer software spreadsheet exercises and formal written assessments. These need to be sufficient to meet the unit outcomes, external examiner requirements and centre quality standards.

Resources

Textbooks

Cumpsty N – *Jet Propulsion – A Simple Guide to the Aerodynamic and Thermodynamic Design and Performance of Jet Engines* (Cambridge University Press, 1997) ISBN 978-0521596749

Rolls Royce – *The Jet Engine* (Rolls Royce Technical Publications, 2005) ISBN 0902121235

Saravanamuttoo H, Rogers G, Cohen H and Straznicky P – *Gas Turbine Theory Sixth Edition* (Pearson Prentice Hall, 2008) ISBN 978-0132224376

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

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

