

Unit 71: Theory of Flight

NQF Level 3: BTEC National

Guided learning hours: 60

Unit abstract

Large modern passenger aircraft can weigh in excess of six hundred thousand kilogrammes when they fly with a full fuel and passenger load, yet this combined mass is lifted into the air with apparent ease. Modern jet fighter aircraft can exceed the speed of sound and are very manoeuvrable. This unit will help learners understand how such aircraft fly and how they are controlled and stabilised.

This unit has been designed to provide learners with a basic understanding of aircraft flight principles, including the means by which aircraft are controlled, manoeuvred and stabilised. In addition, the particular problems associated with aircraft that fly close to the speed of sound (transonic range) will also be investigated.

Learners will develop an understanding of the forces that act on an aircraft during flight and use simple equations to calculate such forces. Experimental work using wind tunnels or wind generators will form an essential part of the unit and will aid learners' understanding of the forces and airflows that act on an aircraft during flight. How aircraft are controlled and stabilised is looked at in some depth. A range of flight controls and life augmentation devices are considered and the way in which they affect control about the aircraft axes is also covered.

A brief look at high-speed flight and the effects created by the air flowing over the aircraft at high subsonic, transonic and supersonic speeds is also undertaken. A qualitative treatment of static and dynamic stability, together with a brief look at the design features that enhance stability, will provide learners with a suitable introduction to the fundamental concepts associated with aircraft stability.

This unit will be of benefit not only to those studying at BTEC National level but also to those following an apprenticeship in aircraft manufacture or maintenance, as well as those currently undergoing aircraft engineering training with the armed forces. It also covers some of the underpinning knowledge required for those taking the European Aviation Safety Agency (EASA) Part 66 examinations.

Learning outcomes

On completion of this unit a learner should:

- 1 Be able to explain the generation of lift and drag forces and determine the values of basic flight forces and manoeuvre forces
- 2 Know the purpose and operation of control surfaces and lift augmentation devices
- 3 Understand, the nature of airflow over aerodynamic surfaces and the factors that affect airflow when at subsonic, transonic and supersonic velocities
- 4 Understand the nature of aircraft response and the methods used for improving stability.

Unit content

1 Be able to explain the generation of lift and drag forces and determine the values of basic flight forces and manoeuvre forces

Lift and drag force generation: Bernoulli and Venturi principles and their relationship to lift force generation; the aerofoil shape and lift; aerofoil terminology; angle of attack; airspeed and lift; drag types eg drag, total drag, induced drag, profile drag (such as skin friction, form, interference); drag factors eg shape, streamlining, drag coefficient, airspeed; significance of atmospheric parameters on lift and drag generation eg barometric pressure, buoyancy, density, relative density, airflow velocity, temperature, altitude, standard sea level values, the international standard atmosphere (ISA)

Basic flight forces: lift, weight, thrust, drag; force couples (lift/weight, thrust/drag); action of forces and force couples in straight and level flight

Determination of flight and manoeuvre forces: calculate lift and drag forces using the basic equations, $L = C_L \frac{1}{2} \rho V^2 S$, $D = C_D \frac{1}{2} \rho V^2 S$; experimentally determine basic flight force parameters eg lift and drag plots, lift to drag ratio (L/D), coefficients of lift and drag, minimum drag, pitching moment; manoeuvre axes (longitudinal, lateral and normal) eg roll, pitch, yaw; manoeuvre force diagrams, load factor, manoeuvre envelopes, flight forces and other parameters (such as velocity, centripetal acceleration, centripetal force, manoeuvre angles); manoeuvres eg climb, cruise, dive, level steady turn, stall, pullout from a dive

2 Know the purpose and operation of control surfaces and lift augmentation devices

Purpose and operation of control surfaces: primary controls (ailerons, elevators, rudder); secondary controls eg spoilers (lift/dump and roll), airbrakes, canards, stabilisers, elevons, tailerons, flaperons

Purpose and operation of lift augmentation devices: eg plain, split, slotted, double slotted, fowler, multi-slotted fowler, Krueger, slots, slats, vortex generators, wing fences, winglets

3 Understand, the nature of airflow over aerodynamic surfaces and the factors that affect airflow when at subsonic, transonic and supersonic velocities

Airflow over aerodynamic surfaces: effects eg subsonic (boundary layer thickening, centre of pressure forward, turbulence (effects of ice, snow and frost build up), reduction in velocity rear of surface, normal stall), transonic (formation of shockwave, shock stall), supersonic (increase in velocity, reduction in pressure at rear of surface, centre of pressure movement, trim change); aerodynamic cross-sections eg high camber, low camber, high speed; flow parameters eg streamlines, laminar flow, turbulent flow, boundary layer, incompressible, compressible, separation, transition point, stagnation; speed ranges eg subsonic, transonic, supersonic; speed of sound; Mach number

Factors affecting airflow: normal shockwave formation eg density and pressure rise, velocity fall, pitching, buffeting, shock stall, loss of control effectiveness, design factors (washout, wash-in, area ruling, vortex generators, blown air, sweepback, wing fences)

4 Understand the nature of aircraft response and the methods used for improving stability

Nature of aircraft response to a disturbance: condition eg stable, unstable, neutrally stable; aircraft static and dynamic response motion; static stability (lateral, longitudinal and directional); aircraft dynamic stability eg lateral (directional divergence, spiral divergence, Dutch roll), longitudinal (phugoid motion, porpoising), directional (aerodynamic coupling)

Methods of improving stability: lateral stability eg wing dihedral, sweepback, high wing position, keel surface, yaw dampers; longitudinal stability eg tailplane (horizontal stabiliser) size and position, elevator movement; directional stability eg fin, keel surface aft of centre of gravity

Grading grid

In order to pass this unit, the evidence that the learner presents for assessment needs to demonstrate that they can meet all of the learning outcomes for the unit. The criteria for a pass grade describes the level of achievement required to pass this unit.

Grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
<p>P1 explain how lift force is generated over aerofoil surfaces and how atmospheric parameters affect lift and drag force generation as an aircraft gains altitude</p> <p>P2 describe the four basic forces and two force couples that act on an aircraft during straight and level flight and apply basic equations to determine lift and drag forces</p> <p>P3 carry out a wind tunnel or wind generator experiment and produce lift and drag plots for a given aerofoil section or aircraft model for varying angle of attack and air velocity</p> <p>P4 sketch the force diagrams and calculate force and velocity parameters for an aircraft involved in two different manoeuvres</p>	<p>M1 use experimentally obtained data, plot appropriate lift and drag curves against velocity and use them to determine the maximum L/D and minimum total drag</p> <p>M2 explain how area ruling, sweepback and wing fence designs help to alleviate some of the undesirable factors associated with flight through the transonic range.</p>	<p>D1 produce force diagrams for an aircraft subject to four different types of aircraft manoeuvre and calculate the required acceleration, force and velocity parameters for each, using appropriate formulae</p> <p>D2 explain the dynamic stability phenomena; directional divergence, spiral divergence and porpoising and for each explain how these undesirable effects may be reduced.</p>

Grading criteria		
To achieve a pass grade the evidence must show that the learner is able to:	To achieve a merit grade the evidence must show that, in addition to the pass criteria, the learner is able to:	To achieve a distinction grade the evidence must show that, in addition to the pass and merit criteria, the learner is able to:
<p>P5 state the purpose and describe the operation of all primary controls, three secondary controls and four lift augmentation devices</p> <p>P6 explain the effects on the air flowing over aerodynamic surfaces when travelling at subsonic and supersonic speeds</p> <p>P7 define the subsonic, transonic and supersonic speed ranges, speed of sound and Mach number</p> <p>P8 describe how a normal shock wave is first formed and the result on the airflow and subsequently the aircraft, as the airflow passes through a shockwave</p> <p>P9 sketch the response motions of an aircraft to a disturbance when the aircraft is statically stable and dynamically stable and when statically stable and dynamically unstable</p> <p>P10 explain how lateral static stability is improved using wing dihedral and sweepback and how longitudinal and directional static stability improvements are achieved using horizontal stabilisers and fin/keel surface respectively.</p>		

Essential guidance for tutors

Delivery

This unit has been designed to cover the elementary flight theory necessary for all those wishing to enter the aerospace industry at technician level, irrespective of their chosen field of specialisation. As such, it is expected that this unit should be delivered as part of most, if not all, BTEC Aerospace Engineering programmes. Elements of the content of this unit will act as a crucial foundation for further study of both mechanical and avionic units.

Centres could deliver this unit early in the first year of the programme, providing an aeronautical flavour at an early stage. Learners will need to have been introduced to the concepts of force, pressure and density. They should also have sufficient mathematical ability to manipulate formulae associated with flight and manoeuvre loads, and have an idea of vector quantities and their representation.

The learning outcomes could be delivered in order. Learning outcome 1 is the largest and is likely to take up a considerable part of the delivery time. Learners' understanding of the concepts associated with the generation of lift and drag forces will be enhanced by appropriate experimental work and such experiments are considered an essential part of the delivery of this learning outcome. Simple calculations using the lift and drag equations will also help strengthen the principles that underpin the generation of these forces. The relationship between Bernoulli's principle, the Venturi tube and aerofoil cross-sections should be emphasised, particularly when explaining the generation of lift.

The effect that atmospheric parameters have on the generation of lift and drag with rising altitude should also be explained and learners should know the standard sea-level values for temperature, pressure and air density in the ISA. The classifications for the various parts of an aerofoil cross-section should also be emphasised and the concept of angle of attack clearly explained. These will prove particularly useful in aiding understanding when learners are engaged in wind-tunnel work.

Learning outcome 2 is concerned with the identification and function of control surfaces and lift augmentation devices and should take a relatively short amount of time to deliver. Learners should have a clear knowledge of control about the three aircraft axes and should be aware of the advantages/disadvantages of a selection of leading edge and trailing edge lift augmentation devices. The range and depth of treatment of these devices will clearly depend on the learners' specialisation. Only the purpose and operation of the control and lift augmentation surface need be emphasised, rather than the systems that operate them.

Learning outcome 3 is essentially about high-speed flight. The key to the delivery of this subject lies in learners' understanding of the formation and effects of the shockwave. All the problems associated with flight in the transonic range are dependent on the first appearance of the shock wave. Learners need to be aware of this fact and understand how the design features inherent in high-speed aircraft are primarily there to minimise the adverse effects and time spent flying in the transonic range. The changes in airflow behaviour over aerofoil sections when flowing at subsonic and truly supersonic velocities also need to be explained in detail.

When delivering the content relating to aircraft response and stability (learning outcome 4), a clear differentiation should be made between static and dynamic stability, and the resulting response motions after a disturbance should be known. The difficult dynamic concepts concerning directional divergence, spiral divergence, Dutch roll, dynamic phugoid motion, porpoising and aerodynamic coupling should be carefully explained, as these concepts are needed at distinction level.

Note that the use of 'eg' in the content is to give an indication and illustration of the breadth and depth of the area or topic. As such, not all content that follows an 'eg' needs to be taught or assessed.

Assessment

It is expected that a range of assessment methods will be used for this unit. Evidence may be gathered from written responses to assignments and formal timed assessments. Evidence from laboratory reports and observation records will be appropriate and necessary, particularly when addressing the assessment criteria for learning outcome 1.

To achieve a pass grade learners must understand the significance of the aerodynamic parameters (pressure, temperature, density), how they change with altitude and their subsequent effect on lift and drag forces. They must describe the four basic forces that act on the aircraft and be able to perform calculations using the lift and drag equations and a range of the aircraft manoeuvre equations. An understanding of the relationship between lift, drag, velocity and angle of attack is also needed. Assessment evidence from a laboratory experiment write-up could be used as evidence of learners' competence. Witness statements would be a good way to record their performance during the practical element of P3. The ability to state the purpose and describe the operation of a variety of control surfaces and lift augmentation devices may be assessed through a written assignment, where sketches and written responses can be gathered.

Learners are also required to be able to explain the effects of airflow over an aerofoil section when the air is travelling from subsonic up to supersonic speed. Evidence for this could be gathered using smoke tunnel and supersonic wind tunnel experiments, if this equipment is available.

Finally, a rudimentary understanding of the static and dynamic behaviour of an aircraft after being subject to a disturbance is required. This requires learners to provide a basic definition for static stability and dynamic stability and demonstrate through the production of sketches, knowledge of an aircraft's motion after a disturbance, based on whether or not the aircraft is dynamically stable or dynamically unstable. In the latter case learners need just show this situation as a diverging sinusoidal wave motion. A full understanding of the complex dynamic stability phenomena is not required for the pass criteria.

To achieve a merit grade learners need to build on their understanding of flight forces and other parameters (P1, P2, P4) and experimental plotting (P3). They will need to convert experimental data into plots capable of determining L/D ratios and minimum total drag. Learners' understanding of the significance of the L/D ratio and minimum drag (at the crossover point of induced drag and profile drag) also needs to be assessed. Learners will need to provide a clear explanation of some of the design features that have been produced to alleviate the problems associated with flying through the transonic range. For example how sweepback helps to delay the onset of the shock stall and thus reduce the time that the aircraft spends in the transonic range. Written responses would provide appropriate assessment evidence.

To achieve a distinction grade learners will need to produce force diagrams for a range of aircraft manoeuvre situations. They will then need to solve problems by finding the required unknown parameters. Learners will also need to explain the dynamic stability phenomena, directional and spiral divergence, and porpoising. This will require learners to first have knowledge of directional, longitudinal and lateral dynamic stability and their interrelationships and how these affect the response behaviour of the aircraft. Evidence for both distinction criteria may best be obtained through the use of assignment questions that are designed to test learners' understanding of the underlying principles, not just to test recall.

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

This unit covers the knowledge and understanding associated with the European Aerospace Safety Agency (EASA) aircraft maintenance licence Part 66 examination for Module 8 Basic Aerodynamics. It also covers part of the requirements for Aeroplane Aerodynamics contained in Modules 11 and 13.

In addition, the unit provides some of the underpinning knowledge and understanding associated with the SEMTA Level 3 National Occupational Standards in Aeronautical Engineering, particularly:

- Unit 46: Installing Flying Control Surfaces and Systems
- Unit 59: Testing Aircraft Flying Control Surfaces and Systems.

This unit has strong links with *Unit 72: Principles and Applications of Aerospace Mechanical Science*.

Essential resources

Access to laboratory equipment, particularly wind tunnels, will be needed, especially for learning outcome 1. For those centres with limited resources, wind generators, aerofoil sections and appropriate lift and drag balances would be the absolute minimum requirement to meet the learning outcomes. Easy access to the following equipment would provide a more appropriate learning environment:

- open or closed section wind tunnel/s, aerofoil cross-sections and aircraft scale models
- smoke generation visualisation equipment
- high-speed wind tunnel and associated apparatus
- training aids, aircraft airframe components, flying control rigs.

Note that learning is enhanced when the wind tunnel measuring equipment is simple, such as the use of manometers, manual lift and drag balances etc. Interpreting sophisticated digital read outs and converting them to force measurements tends to have little meaning for learners at this stage.

Indicative reading for learners

Textbooks

Barnard R and Philpott D – *Aircraft Flight: A Description of the Physical Principles of Aircraft Flight* (Prentice Hall, 2003) ISBN 0131200437

Dingle L and Tooley M – *Aircraft Engineering Principles* (Butterworth-Heinemann, 2004) ISBN 075065015X

Kermode A, Barnard R and Philpott D – *Mechanics of Flight, 11th Edition* (Prentice Hall, 2006) ISBN 1405823593

Key skills

Achievement of key skills is not a requirement of this qualification but it is encouraged. Suggestions of opportunities for the generation of Level 3 key skill evidence are given here. Tutors should check that learners have produced all the evidence required by part B of the key skills specifications when assessing this evidence. Learners may need to develop additional evidence elsewhere to fully meet the requirements of the key skills specifications.

Application of number Level 3	
When learners are:	They should be able to develop the following key skills evidence:
<ul style="list-style-type: none"> determining lift and drag and preparing to carry out wind-tunnel testing modifying and plotting data and drawing force diagrams. 	<p>N3.1 Plan an activity and get relevant information from relevant sources.</p> <p>N3.2 Use this information to carry out multi-stage calculations to do with:</p> <ul style="list-style-type: none"> a amounts or sizes b scales or proportion c handling statistics d using formulae. <p>N3.3 Interpret the results of your calculations, present your findings and justify your methods.</p>

Communication Level 3	
When learners are:	They should be able to develop the following key skills evidence:
<ul style="list-style-type: none"> • explaining how lift force is generated over aerofoil surfaces and how atmospheric parameters affect lift and drag force generation • describing the basic forces and force couples that act on an aircraft during straight and level flight • describing the operation of primary controls, secondary controls and lift augmentation devices • explaining the effects on the air flowing over aerodynamic surfaces when travelling at subsonic and supersonic speeds • describing how a normal shock wave is first formed and the result on the airflow and subsequently the aircraft • explaining how lateral static stability is improved using wing dihedral and sweepback and how longitudinal and directional static stability improvements are achieved using horizontal stabilisers and fin/keel surface. 	<p>C3.3 Write two different types of documents, each one giving different information about complex subjects.</p> <p>One document must be at least 1000 words long.</p>