



**P. J. Swatton**

# **Principles of Flight** **for Pilots**

**Aerospace Series**

Editors **Peter Belobaba, Jonathan Cooper,**  
**Roy Langton and Allan Seabridge**

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# **The Principles of Flight for Pilots**

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**P. J. Swatton**



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## Series Preface

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The field of aerospace is wide ranging and covers a variety of products, disciplines and domains, not merely in engineering but in many supporting activities. These combine to enable the aerospace industry to produce exciting and technologically challenging products. A wealth of knowledge is contained by practitioners and professionals in the industry in the aerospace fields that is of benefit to other practitioners in the industry, and to those entering the industry from University or other fields.

The Aerospace Series aims to be a practical and topical series of books aimed at engineering professionals, operators and users and allied professions such as commercial and legal executives in the aerospace industry. The range of topics spans design and development, manufacture, operation and support of the aircraft as well as infrastructure operations, and developments in research and technology. The intention is to provide a source of relevant information that will be of interest and benefit to all those people working in aerospace.

The other books in the Aerospace Series concentrate very much on the technical aspects of Airframe, Structure and Systems - providing technical descriptions that are of use to engineers and designers. In most of these books the Human Machine interface is described, especially in Aircraft Display Systems.

Aircraft Performance, Theory and Practice for Pilots by P. J. Swatton extended the Series from the Design phase of the life-cycle into the operate phase by introducing aspects of the aircraft that are essential to the pilot.

In this book, Principles of Flight for Pilots, the author takes this a step further by introducing principles of flight in a comprehensive and easy to use compendium of knowledge complemented by self-assessment exercises. The book is packed with information from basic aerodynamics and stability through aerodynamic principles for level flight, manoeuvre and high speed flight. Even though this book is aimed squarely at pilots wishing to study for the EASA ATPL and CPL examinations, it should also be considered as essential reading for students wishing to enter the field of aero engineering and for practitioners in systems engineering, design, aerodynamics and testing.

Allan Seabridge

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# Preface

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Since the Wright brothers' triumphant production of a flying machine in 1903, followed by Bleriot's successful navigation of the Channel in 1909, the mysteries of how an aeroplane flies have fascinated almost everyone. Although aerodynamics is a complicated subject it is essential that all aviators have a basic understanding of the principles of flight for the safety of themselves and those on the ground, without the prerequisite of comprehending all of the mathematics involved. This is the prime objective of the syllabus formulated by the JAA and now adopted by EASA. Although the knowledge and manipulation of some formulae is required, the syllabus limits it to those necessary to safely execute the duties of a pilot.

The aim of this book is to provide a trustworthy work of reference for pilots. It is collated and presented in such a manner that it will not only help student pilots to pass the examination but will also enable experienced personnel to gain a deeper understanding of the Principles of Flight and related subjects. **It is not intended to be a comprehensive study of aerodynamics.**

An examination in Principles of Flight is set by the Flight Crew Licensing Department of the Civil Aviation Authority (CAA) acting as an agent for EASA. To validate a licence, together with other requirements, a candidate must attain a mark of at least 75% in the examination.

## Principles of Flight for Pilots

*The Complete Manual.* This manual has been written in a manner for easy learning primarily for trainee pilots wishing to study for the EASA ATPL and CPL licence examinations. It is also a useful reference book for qualified transport aeroplane pilots and has been comprehensively indexed for easy use.

The manual is divided into seven parts. Each part contains the necessary number of chapters to explain the appropriate topic in detail. After each chapter is a set of self-assessed questions that have been gleaned from the feedback of previous candidates in the Principles of Flight examination over the past nine years. The calculations and explanations to the correct solutions are those of the author are given in Chapter 19.

*Part 1 – The Preliminaries.* This part of the manual is devoted to an introduction to that area of basic physics applicable to the principles of flight and to the definitions that are used in the subsequent chapters.

*Part 2 – Basic Aerodynamics.* Theoretical aspects of aeroplane control and lift generation are confined to this part of the manual.

*Part 3 – Level Flight Aerodynamics.* This part is devoted to lift analysis, lift augmentation, drag, stalling and the thrust and power essential to maintain level flight.

*Part 4 – Stability.* This part examines in detail the complex topics of aeroplane static and dynamic stability.

*Part 5 – Manoeuvre Aerodynamics.* Level-flight manoeuvres such as turns and dives together with the aerodynamics of climbs and descents are the main topics of this part of the manual.

*Part 6 – Other Aerodynamic Considerations.* High-speed flight, including supersonic flight, is explained in detail because of the EASA syllabus requirements; despite the fact that there are no supersonic transport aeroplanes any longer. CPL examination candidates should ignore Chapter 15 – High Speed Flight.

*Part 7 – Conclusion.* This part includes a summary of the major components of the Principles of Flight syllabus and the solutions to all of the self-assessed exercises

The author would like to stress that, although *The Principles of Flight for Pilots* is directed towards explaining basic theory of flight, the explanations, advice and interpretations given are his alone, and not necessarily shared by EASA or any other legislative body. It does not seek to replace any of the works mentioned in the bibliography, but should be used in conjunction with them. References quoted in the text of the manual were current in May 2010.

Every effort has been made to ensure that the information contained in *The Principles of Flight for Pilots* was up-to-date at the time of publication; but readers are reminded that every document listed in the bibliography on which this book is based is subject to amendment. It is true that major changes of policy are not implemented without adequate warning and publicity; but minor alterations could escape notice and every reader is advised to pay careful attention to any amendment list issued by the CAA and EASA. No responsibility is accepted for any errors or discrepancy.

*P. J. Swatton*



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# Acknowledgements

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My grateful thanks once again go to David Webb who has willingly given his expert advice and contributed in no small part by drawing all of the illustrations using his computer.

## The Principles of Flight Examination

This manual contains the information required to cover the ATPL (A) and CPL (A) Learning Objectives for the EASA subject 081 - Principles of Flight. The examination in this subject is from 0930 to 1030 on the first day of the examinations for ATPL candidates and contains 40 questions. For CPL candidates the examination is from 0900 to 0945 on the first day of the examinations and contains 34 questions.

The main reference documents for the Principles of Flight examination are:

- (1) EU-OPS1
- (2) AMC Definitions
- (3) CS-23 Normal and Commuter Aeroplanes
- (4) CS-25 Large Aeroplanes
- (5) Civil Aviation Aeronautical Information Circulars

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# List of Abbreviations

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<b>a</b>	Acceleration
<b>A</b>	Cross-Sectional Area
<b>A/F</b>	Airfield
<b>A and AEE</b>	The Aeroplane and Armament Experimental Establishment
<b>aal</b>	above aerodrome level
<b>AC</b>	Aerodynamic Centre
<b>AFM</b>	Aeroplane Flight Manual
<b>agl</b>	above ground level
<b>AIC</b>	Aeronautical Information Circular
<b>AIP</b>	Aeronautical Information Package
<b>amsl</b>	above mean sea level
<b>AoA</b>	Angle of Attack
<b>AR</b>	Aspect Ratio
<b>ASD</b>	Accelerate/Stop Distance
<b>ASDR</b>	Accelerate/Stop Distance Required
<b>ASIR</b>	Airspeed Indicator Reading
<b>ATM</b>	Aerodynamic Twisting Moment
<b>AUM</b>	All-Up Mass
<b>AUW</b>	All-Up Weight
<b>BHP</b>	Brake Horsepower
<b>BRP</b>	Brake Release Point
<b>C of A</b>	Certificate of Airworthiness
<b>CP</b>	Centre of Pressure
<b>CAA</b>	Civil Aviation Authority
<b>CAP</b>	Civil Aviation Publication
<b>CAS</b>	Calibrated Airspeed
<b>C<sub>d</sub></b>	Coefficient of Drag
<b>C<sub>DI</sub></b>	Coefficient of induced drag
<b>C<sub>DP</sub></b>	Coefficient of parasite drag
<b>C<sub>DA</sub></b>	Mean Coefficient of drag in the air
<b>C<sub>DG</sub></b>	Mean Coefficient of drag on the ground
<b>CF</b>	Centrifugal Force
<b>CG</b>	Centre of Gravity
<b>CL</b>	Coefficient of Lift
<b>C<sub>Lmax</sub></b>	Maximum Coefficient of Lift
<b>C<sub>n</sub></b>	Yawing Moment Coefficient
<b>C<sub>M</sub></b>	Pitching Moment
<b>C<sub>M0</sub></b>	Pitching Moment at the Zero Lift value

<b>CP</b>	Critical Point
<b>CS</b>	Certification Standards Document
<b>CSU</b>	Constant Speed Unit
<b>CTM</b>	Centrifugal Twisting Moment
<b>DA</b>	Density Altitude
<b>EAS</b>	Equivalent Airspeed
<b>EASA</b>	European Aviation Safety Agency
<b>F</b>	Force
<b>FAA</b>	Federal Aviation Administration
<b>FAR</b>	Federal Aviation Regulations
<b>FLL</b>	Field-length-limited
<b>g</b>	Acceleration due to gravity
<b>GE</b>	Ground Effect
<b>G/S</b>	Groundspeed
<b>IAS</b>	Indicated Airspeed
<b>IAT</b>	Indicated Air Temperature
<b>ICAO</b>	International Civil Aviation Organisation
<b>ISA</b>	International Standard Atmosphere
<b>JAA</b>	Joint Aviation Authority
<b>JAR</b>	Joint Aviation Requirements
<b>JSA</b>	Jet Standard Atmosphere
<b>kg</b>	kilogram(s)
<b>km</b>	kilometre(s)
<b>kt</b>	nautical miles per hour (knots)
<b>KE</b>	Kinetic Energy
<b>L</b>	Rolling moment
<b>LD</b>	Landing Distance
<b>LE</b>	Leading Edge
<b>LER</b>	Leading Edge Radius
<b>LSS</b>	Local Speed of Sound
<b>m</b>	Mass
<b>M</b>	Mach Number
<b>M/S</b>	Mass per unit area of a wing (wing loading)
<b>MAC</b>	Mean Aerodynamic Chord
<b>MCDR</b>	Critical Drag Rise Mach Number
<b>MCRIT</b>	Critical Mach Number
<b>MDET</b>	Detachment Mach Number
<b>MFS</b>	The True Mach Number of an aeroplane
<b>ML</b>	The Local Mach Number
<b>MMO</b>	Maximum Operating Mach Number
<b>n</b>	Load Factor
<b>N</b>	Newton
<b>NP</b>	Neutral Point
<b>OAT</b>	Outside Air Temperature
<b>PCU</b>	Propeller Control Unit
<b>PIO</b>	Pilot-Induced Oscillation
<b>ps</b>	Static Pressure
<b>pt</b>	Total Pressure
<b>q</b>	Dynamic Pressure
<b>RAF</b>	Relative Airflow
<b>RAS</b>	Rectified Airspeed
<b>Re</b>	Reynold's Number

## **LIST OF ABBREVIATIONS**

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<b>ROC</b>	Rate of Climb
<b>ROD</b>	Rate of Descent
<b>RPM</b>	Revolutions per Minute
<b>S</b>	Wing Area
<b>SG</b>	Specific Gravity
<b>SM</b>	Static Margin
<b>SP</b>	Stagnation Point
<b>STOL</b>	Short-field take-off and landing
<b>TAS</b>	True Airspeed
<b>TAT</b>	Total Air Temperature
<b>TE</b>	Trailing Edge
<b>THS</b>	Trimmable Horizontal Stabilizer
<b>TOD</b>	Take-off Distance
<b>TOM</b>	Take-Off Mass
<b>TOR</b>	Take-off Run
<b>TOW</b>	Take-Off Weight
<b>TP</b>	Trim Point
<b>V<sub>A</sub></b>	Design Manoeuvring Speed
<b>V<sub>b</sub></b>	Basic Stalling Speed
<b>V<sub>B</sub></b>	Design Speed for maximum gust intensity
<b>V<sub>C</sub></b>	Design Cruising Speed
<b>V<sub>CLmax</sub></b>	CAS of the maximum CL.
<b>V<sub>D</sub></b>	Design Diving Speed
<b>V<sub>DD</sub></b>	Design Drag Devices speed
<b>V<sub>EF</sub></b>	The assumed speed of engine failure during the take-off ground run
<b>V<sub>F</sub></b>	Design Flap Speed
<b>V<sub>FE</sub></b>	Maximum speed for flying with flaps extended
<b>V<sub>FO</sub></b>	Maximum speed for operating the flaps
<b>V<sub>IMD</sub></b>	The velocity of minimum drag
<b>V<sub>IMP</sub></b>	The velocity of minimum power
<b>V<sub>LE</sub></b>	The maximum speed with the undercarriage (landing gear) extended
<b>V<sub>LO</sub></b>	The maximum speed at which the undercarriage (landing gear) may be operated
<b>V<sub>M</sub></b>	Manoeuvre Stalling Speed.
<b>V<sub>MC</sub></b>	The minimum control speed with the critical power unit inoperative
<b>V<sub>MCG</sub></b>	The minimum control speed on the ground with the critical power unit inoperative
<b>V<sub>MCL</sub></b>	The minimum control speed on the approach to land
<b>V<sub>MCL(1out)</sub></b>	The minimum control speed on the approach to land with one engine inoperative
<b>V<sub>MCL-2</sub></b>	The minimum control speed on the approach to land with two engines inoperative
<b>V<sub>IMD</sub></b>	Velocity of minimum drag IAS
<b>V<sub>IMP</sub></b>	Velocity of minimum power IAS
<b>V<sub>MD</sub></b>	Velocity of minimum drag TAS
<b>V<sub>MO</sub></b>	The maximum operating speed
<b>V<sub>MP</sub></b>	Velocity of minimum power TAS
<b>V<sub>MS</sub></b>	The minimum stalling speed
<b>V<sub>MS0</sub></b>	The minimum stalling speed with the flaps in the landing setting
<b>V<sub>MS1</sub></b>	The minimum stalling speed for the case under consideration
<b>V<sub>MU</sub></b>	The minimum unstick speed
<b>V<sub>NE</sub></b>	Never exceed speed
<b>V<sub>NO</sub></b>	Maximum normal operating speed.
<b>V<sub>O</sub></b>	The speed of the freestream airflow over an aerofoil surface
<b>V<sub>RA</sub></b>	The rough-air or turbulence speed
<b>V<sub>REF</sub></b>	The reference landing speed

<b>V<sub>s</sub></b>	Stalling speed CAS
<b>V<sub>s0</sub></b>	The stalling speed CAS with the flaps at the landing setting
<b>V<sub>s1</sub></b>	The stalling speed CAS for the configuration under consideration
<b>V<sub>s1g</sub></b>	Stalling speed CAS at 1g
<b>V<sub>SR</sub></b>	Reference stalling speed CAS
<b>V<sub>SR0</sub></b>	Reference stalling speed CAS in the landing configuration
<b>V<sub>SR1</sub></b>	Reference stalling speed CAS for the configuration under consideration
<b>V<sub>sw</sub></b>	The speed at which the onset of the natural or artificial stall warning activates
<b>V<sub>x</sub></b>	The speed at which the maximum gradient of climb will be achieved
<b>V<sub>y</sub></b>	The speed at which the maximum rate of climb will be achieved
<b>WC</b>	Wind Component
<b>WED</b>	Water-Equivalent Depth

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# Weight and Mass

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Before starting any calculations it is necessary to explain the difference between a Newton (N), which is a unit of force, a kilogram (kg), which is a unit of mass and weight, which is the force acting on a body by gravity. Most of us know what we mean when we use the term weight and become confused when the term mass is used in its place. In all of its documents the JAA consistently use the term mass whereas the majority of aviation documents produced by the manufacturers use the term weight. The following are the definitions of each of the terms and should help clarify the situation:

**Mass** The quantity of matter in a body as measured by its inertia is referred to as its mass. It determines the force exerted on that body by gravity, which is directly proportional to the mass. Gravity varies from place to place and also decreases with increased altitude above mean sea level.

**Weight** The force exerted on a body by gravity is known as its weight and is dependent on the mass of the body and the strength of the gravitational force for its value.  $\text{Weight} = \text{mass in kg} \times \text{gravity in Newtons}$ . Thus, the weight of a body varies with its location and elevation above mean sea level but the mass does not change for the same body.

The change of weight of an object due to its changed location is extremely small, even at 50 000 ft above mean sea level, however, it is technically incorrect and the term mass should be used. ***For the purposes of this manual the terms weight and mass are interchangeable.*** In the questions asked in the JAA examinations the word mass is used most of the time. *IEM OPS 1.605.*

**The Newton** A Newton is a unit of force, which equals  $\text{mass} \times \text{acceleration}$ .

$1 \text{ Newton} = 1 \text{ kg} \times 1 \text{ m/s}^2$ . At the surface of the Earth the acceleration due to gravity equals  $9.81 \text{ m/s}^2$ . Thus, the force acting on 1 kg at the Earth's surface is 9.81 Newtons. To simplify calculations in the examination the acceleration due to gravity is given as  $10 \text{ m/s}^2$  therefore 1 kg is equal to 10 Newtons.

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