P. J. Swatton

Principles of Flight for Pilots

Aerospace Series

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

WILEY

The Principles of Flight for Pilots

P. J. Swatton

WILEY
A John Wiley and Sons, Ltd., Publication

This edition first published 2011

Registered office
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

Library of Congress Cataloging-in-Publication Data

Swatton, P. J. (Peter J.)
The principles of flight for pilots / P. J. Swatton.
p. cm.
Includes index.
ISBN 978-0-470-71073-9 (pbk.)
1. Airplanes–Piloting. 2. Aerodynamics. 3. Flight. I. Title.
TL710.S774 2010
629.132–dc22 2010014529

A catalogue record for this book is available from the British Library.

Print ISBN: 9780470710739
ePDF ISBN: 9780470710937
oBook ISBN: 9780470710944

Set in 9/11 Times by Aptara Inc., New Delhi, India.
Printed and bound in Singapore by Markono Print Media Pte Ltd

The Principles of Flight for Pilots

Aerospace Series List

Cooperative Path Planning of Unmanned Aerial Vehicles	Tsourdos et al	November 2010
Principles of Flight for Pilots	Swatton	October 2010
Air Travel and Health: A Systems Perspective	Seabridge et al	September 2010
Design and Analysis of Composite Structures: With Applications to Aerospace Structures	Kassapoglou	September 2010
Unmanned Aircraft Systems: UAVS Design, Development and Deployment	Austin	April 2010
Introduction to Antenna Placement & Installations	Macnamara	April 2010
Principles of Flight Simulation	Allerton	October 2009
Aircraft Fuel Systems	Langton et al	May 2009
The Global Airline Industry	Belobaba	April 2009
Computational Modelling and Simulation of Aircraft and the Environment: Volume 1 – Platform Kinematics and Synthetic Environment	Diston	April 2009
Handbook of Space Technology	Ley, Wittmann Hallmann	April 2009
Aircraft Performance Theory and Practice for Pilots	Swatton	August 2008
Surrogate Modelling in Engineering Design: A Practical Guide	Forrester, Sobester, Keane	August 2008
Aircraft Systems, 3rd Edition	Moir & Seabridge	March 2008
Introduction to Aircraft Aeroelasticity And Loads	Wright & Cooper	December 2007
Stability and Control of Aircraft Systems	Langton	September 2006
Military Avionics Systems	Moir & Seabridge	February 2006
Design and Development of Aircraft Systems	Moir & Seabridge	June 2004
Aircraft Loading and Structural Layout	Howe	May 2004
Aircraft Display Systems	Jukes	December 2003
Civil Avionics Systems	Moir & Seabridge	December 2002

Series Preface

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

Preface

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

Acknowledgements

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

List of Abbreviations

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

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

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

V_S	Stalling speed CAS
V_{S0}	The stalling speed CAS with the flaps at the landing setting
V_{S1}	The stalling speed CAS for the configuration under consideration
V_{S1g}	Stalling speed CAS at 1g
V_{SR}	Reference stalling speed CAS
V_{SR0}	Reference stalling speed CAS in the landing configuration
V_{SR1}	Reference stalling speed CAS for the configuration under consideration
V_{SW}	The speed at which the onset of the natural or artificial stall warning activates
V_X	The speed at which the maximum gradient of climb will be achieved
V_Y	The speed at which the maximum rate of climb will be achieved
WC	Wind Component
WED	Water-Equivalent Depth

Weight and Mass

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. Weight = mass in kg × 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 mass × acceleration.

1 Newton = 1 kg × 1 m/s^2. At the surface of the Earth the acceleration due to gravity equals 9.81 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 m/s^2 therefore 1 kg is equal to 10 Newtons.

Contents