A Pilot’s Guide to Aircraft And Their Systems

The more you know about your aircraft systems, the better you fly

Dale Crane
A Pilot's Guide to Aircraft and Their Systems
by Dale Crane

Aviation Supplies & Academics, Inc.
7005 132nd Place SE
Newcastle, Washington 98059-3153
www.asa2fly.com

© 2002 Aviation Supplies & Academics, Inc.
All rights reserved. No part of this book may be reproduced, stored in any
retrieval system, or transmitted by any means electronic, mechanical,
xerographic, audio/visual, or otherwise, without written permission from
the publisher. While every precaution has been taken in the preparation of
this book, the publisher and Dale Crane assume no responsibility for errors
or omissions. Neither is any liability assumed for damages resulting from
the use of the information contained herein.
None of the material in this manual supersedes any documents,
procedures, or regulations issued by the Federal Aviation Administration,
or aircraft and avionics manufacturers.

Published 2002 by Aviation Supplies & Academics, Inc.

Printed in the United States of America
05 04 03 02 9 8 7 6 5 4 3 2 1

ASA-ACFT-SYS
ISBN 1-56027-461-1

Photo credits: p.52, Cessna Aircraft; p.57 and cover, Lancair;
p.283, TEC Aviation Division.

Library of Congress Cataloging-in-Publication Data:
Crane, Dale.
A pilot's guide to aircraft and their systems : the more you know
about your aircraft systems, the better you fly / by Dale Crane.
 p. cm. — (Focus series book)
Includes index.
ISBN 1-56027-461-1
1. Airplanes. 2. Aeronautical instruments. 3. Aeronautics—Systems
engineering. 4. Private flying. I. Title. II. Series.
TL670 .C74 2002
629.133'34—dc21 2002153716
Contents

Preface

Section 1
Principles of Flight

Chapter 1  Forces Acting on an Airplane in Flight ......................................................... 3
How Does a Heaver-Than-Air Flying Machine Defy the Law of Gravity? 1
Five Forces

Chapter 2  Axes of an Airplane .................................................................................. 6
Control of an Airplane

Chapter 3  Stability ........................................................................................................ 9
Static Stability 1 Dynamic Stability

Chapter 4  Secondary Controls and Devices ................................................................. 11
Flaps 1 Slots and Slats 1 Stall Strips 1 Trim Devices 1 Spoilers

Chapter 5  Phases of Flight .......................................................................................... 17
Takeoff 1 Climb 1 Cruise 1 Turning Flight 1 Stalls 1 Descent 1
Approach 1 Touchdown 1 Ground Effect

Chapter 6  Basic Rotary-Wing Aerodynamics .............................................................. 21
Aerodynamic Principles 1 Lift, or Rotor Thrust 1 Dissymmetry of Lift 1
Retreating Blade Stall 1 Torque 1 Autorotation 1 Ground Effect 1
Gyroscopic Precession

Chapter 7  Rotor Systems ............................................................................................ 29

Chapter 8  Helicopter Flight Controls ........................................................................ 30
Collective Pitch Control 1 Cyclic Pitch Control 1 Horizontal Stabilizer 1
Antitorque Pedals

Chapter 9  Stabilization Systems ............................................................................... 33
Stabilizer Bar 1 Offset Flapping Hinge
Section 2
Aircraft Weight and Balance

Chapter 10  Determining the Loaded Weight and Center of Gravity ............................................. 37
The Computational Method  I  The Electronic Flight Computer Method  I
The Loading Graph Method

Section 3
Aircraft Structures

Chapter 11  Types of Structures ........................................................................................................ 47
Truss Structures  I  Monocoque Structure

Chapter 12  Structural Loads .............................................................................................................. 49
Tension  I  Compression  I  Torsion  I  Bending  I  Shear

Chapter 13  Structural Materials ...................................................................................................... 51
Metallic Materials  I  Nonmetallic Materials

Section 4
Aircraft Hydraulic and Landing Gear Systems

Chapter 14  Hydraulic Principles ..................................................................................................... 63

Chapter 15  Hydraulic Fluid .............................................................................................................. 64
Vegetable Base Fluid  I  Mineral Base Fluid  I  Phosphate Ester Fluid

Chapter 16  Aircraft Hydraulic Systems .......................................................................................... 65

Chapter 17  Hydraulic Brakes ........................................................................................................... 68
Brake Master Cylinder  I  Brake Wheel Units  I  Brake Servicing

Chapter 18  Landing Gear .................................................................................................................. 71
Oleo Strut  I  Shimmy Dampers  I  Nose Wheel Centering Mechanism

Chapter 19  Aircraft Wheels .............................................................................................................. 74

Chapter 20  Aircraft Tires .................................................................................................................... 75
Tire Maintenance
Section 5
Aircraft Fuel Systems

Chapter 21  Aircraft Fuel ................................................................. 79
The Correct Fuel is Essential  I  Clean Fuel is Vital

Chapter 22  Refueling Safety .............................................................. 82
Aircraft Fuel Systems  I  Fuel Quantity Measuring Systems

Section 6
Aircraft Electrical Systems

Chapter 23  Electricity and the Aircraft ............................................. 93
Electrical Principles

Chapter 24  DC Generation Systems ............................................... 95

Chapter 25  Aircraft Electrical Systems ........................................... 97
The Alternator Circuit  I  The Battery Circuit  I  The Electronic Bus  I
The Starter Circuit  I  Ground Service Power Circuit  I  The Primary Bus

Chapter 26  Electrical System Troubleshooting .................................. 102
Alternator Failure in Flight

Chapter 27  Aircraft Batteries ............................................................ 105
Battery Terms  I  Lead-Acid Batteries  I  Nickel-Cadmium Batteries  I
Battery Care

Section 7
Aircraft Instrument Systems

Chapter 28  Flight Instruments .......................................................... 111
Magnetic Compass  I  Pitot-Static System  I  Altimeter  I  Airspeed Indicator  I
Vertical-Speed Indicators

Chapter 29  Gyroscopic Instruments .................................................. 131
Attitude Indicator  I  Heading Indicator  I  Rate Instruments  I  Gyroscopic
Instrument Power Sources  I  Automatic Flight Control Systems  I
Flight Director Indicator  I  Horizontal Situation Indicator

Chapter 30  Powerplant Instruments .................................................. 145
Pressure Measuring Instruments  I  Temperature Measuring Instruments  I
Mechanical Movement Measuring Instruments

Chapter 31  Instrument Marking .......................................................... 150
Section 8
Avionics Systems

Chapter 32  Communications ................................................................. 155
    Introduction  1  Basic Radio Theory

Chapter 33  Navigation ................................................................. 158
    Early Electronic Navigation  1  Automatic Direction Finder (ADF)  1
    Four-Course Low-Frequency Radio Range  1  Very-High-Frequency
    Omnidirectional Range (VOR)  1  Distance Measuring Equipment (DME)  1
    Area Navigation (RNAV)  1  Instrument Landing System (ILS)  1  LORAN  1
    Global Positioning System (GPS)  1  Emergency Locator Transmitter (ELT)

Section 9
Aircraft Environmental Control Systems

Chapter 34  Heating Systems ................................................................. 171
    Introduction  1  Cabin Heat

Chapter 35  Cooling Systems ............................................................... 173
    Refrigerant

Chapter 36  Oxygen Systems ............................................................... 175
    Physical Effects

Chapter 37  Pressurization Systems ....................................................... 176
    Cabin Environment  1  Things to Watch For

Section 10
Aircraft Ice and Rain Control Systems

Chapter 38  Ice Control Systems ......................................................... 181
    Dangers of Inflight Icing  1  Types of Ice Control Systems  1
    Rain Removal Systems

Section 11
Aircraft Fire Extinguishing Systems

Chapter 39  Ingredients for Detection and Protection ................................ 195
    How a Fire Happens  1  Fire-Extinguishing Agents  1
    Hand-Held Fire Extinguishers
Section 12
Aircraft Piston Engines

Chapter 40  Theory of Operation ................................................................. 201
             Internal Combustion  I  The Otto Cycle

Chapter 41  Piston Engine Construction .................................................. 205
             Crankcase  I  Crankshaft  I  Connecting Rods  I  Cylinders  I  Pistons  I
             Camshaft  I  Valves  I  Gears

Section 13
Aircraft Turbine Engines

Chapter 42  Types of Turbine Engines ...................................................... 215
             Introduction  I  Turbojet Engines  I  Turbofan Engines  I
             Turboprop Engines  I  Turboshaft Engines

Chapter 43  Theory of Operation .............................................................. 217

Chapter 44  Turbine Engine Construction ............................................... 219
             Inlet Air Ducts  I  Compressors

Chapter 45  Turbine Engine Systems ....................................................... 223
             Ignition System  I  Fuel Metering System  I  Lubrication System  I
             Cooling System  I  Starting System

Section 14
Aircraft Piston Engine Induction and Fuel Metering Systems

Chapter 46  Induction Systems ............................................................... 229
             Unsupercharged Engines  I  Altitude Engines

Chapter 47  Fuel Metering Systems ......................................................... 232
             Float Carburetors  I  Fuel Injection Systems

Section 15
Aircraft Piston Engine Ignition and Starting Systems

Chapter 48  Aircraft Magneto ................................................................. 243
             Operating Principles  I  Auxiliary Systems for Starting

Chapter 49  Ignition Leads ................................................................. 247

Chapter 50  Aircraft Spark Plugs ............................................................ 248
             Types of Spark Plugs  I  Spark Plug Servicing

Chapter 51  Piston Engine Starting Systems ............................................ 251
             Starters With a Bendix Drive  I  Starters With a Helical Spring Drive
Section 16
Aircraft Piston Engine Lubrication and Cooling Systems

Chapter 52  Aircraft Engine Lubricating Oil ................................................................. 257
             Types of Oil

Chapter 53  Lubrication System Servicing ................................................................. 259
             Engine Oil Change

Chapter 54  Cold Weather Operation ........................................................................... 261

Chapter 55  Piston Engine Cooling Systems ................................................................ 262
             Pressure Cooling for Air-Cooled Engines

Section 17
Propellers

Chapter 56  Propeller Aerodynamics .......................................................................... 267
             Angle of Attack  I  Forces Acting on a Propeller

Chapter 57  Types of Propellers .................................................................................. 269

Chapter 58  Propeller Construction ............................................................................. 271
             Pitch Change Mechanism

Chapter 59  Feathering Propellers .............................................................................. 275
             Hartzell Constant-Speed Feathering Propeller  I  McCauley Constant-Speed
             Feathering Propeller

Chapter 60  Turboprop Propellers .............................................................................. 279

Chapter 61  Propeller Servicing .................................................................................. 281
             Propeller Vibration  I  Propeller Synchronizing  I  Propeller Deicing System

Glossary ....................................................................................................................... 285

Index ......................................................................................................................... 295
Chapter 1  Forces Acting on an Airplane in Flight

**How Does a Heavier-Than-Air Flying Machine Defy the Law of Gravity?**

A heavier-than-air craft flies by obeying a different law; Newton's third law of motion. An airplane flies by creating a downward force on a mass of air that is equal to its own weight. In return, this mass of air produces an upward force on the airplane and supports it.

---

Newton's third law of motion states that every action (or force) gives rise to a reaction (or opposing force) of equal strength but of opposite direction.

---

The wing of an airplane has a very special cross sectional shape called an airfoil section. When this airfoil moves through the air the relative wind strikes it at an angle called the angle of attack.

The air in the relative wind strikes the leading edge of the airfoil and some flows over the top and some across the bottom. The air flowing over the top finds the surface dropping away from it, and, in the same way you speed up as you run down a hill, the air speeds up. According to Bernoulli's principle, when the air speeds up, its pressure drops and the low pressure above the wing pulls the air down to the surface and as it leaves the wing it is deflected downward.

*Bernoulli's principle.* When the total energy in a column of moving fluid remains constant, any increase in the kinetic energy of the fluid (its velocity) results in a corresponding decrease in its potential energy (its pressure).

---

![Diagram](image)

**Figure 1.** The angle of attack is the acute angle between the chord line of an airfoil and the relative wind.
The air flowing below the wing finds the surface rising into its path. This slows down the air and its pressure increases. As the air leaves the airfoil it is deflected downward.

When the weight of the air deflected downward equals the weight of the airplane, the air supports the airplane.

Five things affect the amount of air deflected downward:

1. Shape of the airfoil
2. Angle of attack
3. Area of the airfoil
4. Density of the air
5. Speed of the air

The shape and area of the airfoil are physical characteristics of the airplane. The density of the air is determined by the outside air temperature. The altitude, the speed of the air, and the angle of attack are controlled by the pilot.

**Five Forces**

In straight and level flight at a constant airspeed and altitude five forces are in balance on an airplane:

1. Thrust, acting forward, is caused by the propeller moving air rearward.
2. Lift, acting perpendicular to the relative wind, is caused by the wing deflecting air downward.
3. Weight of the aircraft, caused by gravity, acts toward the center of the Earth.
4. Drag, acting in the direction opposite to thrust, is caused by the resistance of the air as the aircraft moves through it.
5. Tail load is a downward aerodynamic force produced by the horizontal tail deflecting air upward. The amount of tail load is determined by the airspeed and it is used for longitudinal stability.
**Figure 2.** The shape of the airfoil causes the air through which it is passing to be deflected downward.

**Figure 3.** In straight and level, unaccelerated flight, the five forces are balanced.
A Pilot’s Guide to Aircraft and Their Systems

The more you know about your aircraft systems, the better you fly

by Dale Crane

Early aviators had to be both mechanic and pilot...early airplanes and engines were less than completely dependable. In a forced landing situation, they had to find and fix the problem themselves in order to get the airplane back into the air—fortunately their airplanes were not complex in their systems, nor complicated to fix. In the more than half a century since World War II, aircraft have become a vital component of our transportation system, developed and finely tuned to become the fast, efficient, dependable, and safe machines they are today. But technological advances have brought additional complexities that demand the aircraft be operated in exactly the way the designer intended. To do this, pilots must understand what each handle or knob controls and what he or she can expect from each system.

A Pilot’s Guide to Aircraft and Their Systems furnishes pilots and armchair aviators with explanation and insight into what the aircraft, powerplant, and each of the systems do, and does so in language they can identify with. Understanding their aircrafts’ systems will help pilots enjoy their flying more, and make them safer and more efficient aviators.

Other books by Dale Crane, published by ASA:
- Aviation Maintenance Technician Series: General/Airframe/Powerplant
- Dictionary of Aeronautical Terms
- Fast-Track Series Test Guides for General, Airframe, and Powerplant FAA Knowledge Tests
- Aviation Maintenance Technician Oral & Practical Exam Guide
- Inspection Authorization Test Prep
- Aviation Mechanics Handbook