

FLIGHTWISE

PRINCIPLES OF
AIRCRAFT FLIGHT



CHRIS CARPENTER

Contents

Foreword	iii
Preface	xi
Author's Introduction	xv
Chapter 1 – The Requirements of a Flying Machine	
Introduction	1
What is an Aeroplane?	2
What Makes a Better Aeroplane?	5
Speed	5
Manoeuvrability	6
Range and Payload	7
Economy	9
Height	10
Endurance	10
Short Take-off and Landing (STOL)	11
Good Handling Qualities	12
Stealth	13
Chapter 2 – Forces and Aeroplanes	
Introduction	15
Newton's Laws of Motion	16
Newton's Third Law	16
Newton's Second and First Laws	17
A Brief Historical Diversion	18
Returning to Newton's First and Second Laws	20
Units	23
Broadening the Discussion	26
Vectors	26
Diagrammatic Representation of Vectors	27
Resolution of Vectors	28
Combining Vectors	30
The Forces Acting on an Aircraft	33
Aircraft in Straight and Level Flight	33
Aircraft in Steady Climbing or Descending Flight	36
Forces in Curved Motion	38
Transitional Flight	44
Chapter 3 – Aerodynamic Force	
Introduction	46
The Force Agent	46
Normal Force Distribution	48

Tangential Force Distribution	49
What Aerodynamic Force is Not	50
Lift and Drag	50
The Aerofoil	53
Aerodynamic Coefficients	55
Coefficient of Lift	56
Coefficient of Drag	67

Chapter 4 – Pressure and Energy

Introduction	68
Energy	68
Principle of Conservation of Energy	71
Kinetic Energy	72
Atmospheric Pressure	73
Buoyancy	78
Static Pressure and Dynamic Pressure	81
Flow Around Objects and Bernoulli’s Principle	86

Chapter 5 – Working Out Aerodynamic Force

Introduction	90
The Two-Dimensional Circular Cylinder	91
Uniform, Inviscid Airflow	93
Taking Stock	98
The Continuity Principle	99
The Incompressible Assumption	101
Reflections on the Continuity Equation	104
Continuity and Bernoulli Combined	109
Application to the Circular Cylinder	111
Simplifying Aerodynamic Coefficients	113
Circular Cylinder Pressure Coefficients	115
Conclusion and d’Alembert’s Paradox	117

Chapter 6 – The Boundary Layer and Drag

Introduction	119
Viscosity	120
The Boundary Layer	128
Laminar and Turbulent Boundary Layers	131
Rates of Change	134
Returning to Boundary Layers	136
Skin Friction	137
Form Drag	139
One Effect of the Boundary Layer – Kinetic Heating	140
Boundary Layer Separation	144
Reduction of Form Drag by Prevention of Separation	148

Chapter 7 – Discovering the Aerofoil Shape

Introduction and Caution	151
Refining the Inviscid Model	154
Lift in Inviscid Flow	161
Cylinder Lift in Real Flow	164
The Need for Viscosity	170
Circulation	175
Kutta Condition	177

Chapter 8 – Physical Modelling and the Effect of Scale

Introduction	181
The Problem	183
Boundary Layer Transition	184
Dynamic Similarity	186
Reynolds Number	188
Scaled Forces	196
The Modelling Problem	201
Transition Fixing	206
Critical Reynolds Number	208
Balls	211

Chapter 9 – Practical Aerofoils in Real Flow

Introduction	213
Aerofoil Terminology	213
A Caution	218
Aerofoil Characteristics	219
Camber	221
Lift Curve Slope	222
Thickness	222
Leading Edge Stall	223
Trailing Edge Stall	224
C_D/α and C_L/C_D Curves	225
Stalling	229
Effects	229
Recovery	229
Deep stall	231
Spinning	232
Modification for Flight – Lift Augmentation	235
Boundary Layer Control	240
Camber-increasing Devices	245
Flap System Drag – Pro's and Con's	248

Chapter 10 – Supersonic Aerofoils

Introduction	252
Why the Speed of Sound?	254
Mach Lines, Zones of Influence and Zones of Silence	257
The Speed of Sound	261
Shock Waves	262
Expansion Fans	267
The Flat Plate Aerofoil	269
Wave Drag Due to Lift	270
The Double Wedge Aerofoil	271
Low Speed/High Speed Design Considerations	273
Seeing Shock Waves	277

Chapter 11 – Aerofoils in Transonic Flow

Introduction	281
The Problem	282
So What?	289
Transonic Flight Features	294
Drag Increase	294
Longitudinal Trim Changes	298
Control Heaviness and Loss of Effectiveness	306
Roll Control Problems	309
Living With Compressibility	311
Overcoming the Sound Barrier	311
Raising the Critical Mach Number	314
Supercritical Aerofoils	316
Overcoming Control Problems	319

Chapter 12 – Introduction to Three-Dimensional Effects

Introduction	321
Horse-shoe Vortex System	322
Wake Vortices	324
Downwash	325
Induced Drag	328
Aspect Ratio	331
Speed Stability	334
Winglets and Wing-tip Sails	337
Three-Dimensional Considerations for Supersonic Wings	339
Induced Drag in Nature	341

Chapter 13 – Wing Planform Considerations

Introduction	342
Extending the Horse-shoe Vortex Model	343
Biot-Savart's Law	347

Looking at Planforms	350
Elliptical Wing	351
Rectangular Wing	355
Highly Tapered Wing	357
Swept-back Wing	359
Swept-back and Tapered Wing	361
Solutions to Tip-stalling Problem	365
Leading Edge Vortices – the Plus Side	370
Forward-swept Wings	372
Chapter 14 – Gust Response	380
Modelling a Gust	384
Factors Affecting Ride Hardness	388