Index

Absolute pressure 21 Absolute streamlines 42 Absolute system of units 7 Acoustic intensity method 278, 290 Adiabatic change 18 Aerofoil 162 section 162 Air bubble method 281 Allievi's equation, valve closure 246	Bernoulli 60 equation 56-70 applications 62-70 Blade 162 Body force 85 Borda-Carnot, head loss 74 Boundary element method 269-73 Green's formula 269 panel method 269
Anemometer hot-wire 184-5 interference fringe 186 laser Doppler 185-6 reference beam 185, 186 single-beam 186 Angle of attack, wing 163	Boundary layer 101-6, 148 development 102-4 displacement thickness 103 equation of motion 104-5 main flow 101 momentum thickness 103, 104 separation 105-6
Angular momentum conservation 76–8 equation of 76–7 Animation method 278	thickness 103 transition zone 104 Boundary-fitted grid, finite volume method 262
Applications Bernoulli's equation 62–70 dimensional analysis 172–4 equation of momentum 72–6 Appolonius circles 208 Archimedes 34	Bourdon gauge 28-9 tube 28 pressure gauges 28-9 Boyle's-Charles' law 17 Branch pipes 127, 128
principle 34 Area colouring manifestation method 278 Area flowmeter 189–90 float-type 189–90 Aspect ratio, wing 163 Atmospheric pressure 20, 21 standard 20 Attachment amplifier 193	Buckingham's π Theorem 172 Bulk modulus 16, 223 Buoyancy 33–5 Archimedes' principle 34 Bursting phenomenon, Kline 274 process 98 Butterfly valves 129–30
Backward difference 250 Ball valve, loss factor 131 Bars 20 Base units 6–7 Bazin equation, open channel 138 Beam-Warming method 257 Bellows, pressure gauges 28–9 Bend, pipes 125–7	Camber line 163 Capillarity 14–15 correction 15 and liquid surface 15 Cascade 166, 167 Cauchy–Riemann equations 202 Cavitation 167–9 number 169

CCD camera 287	Contact angle 14
Central difference 251	Continuity equation 55–6, 88
Centre of pressure 31	viscous fluid 82–3
CGS system, units 7	Contour
Change in flow quantity, pipe line 242–3	manifestation method 278
Characteristic curve, pumping 133	presentation 288
Chattock tilting manometer 28	Contraction, coefficient of 67
Chemical reaction tracer method 276,	Control volume 71, 262, 263
283	Convective accelerations 87
Chezy's formula, open channel 137	Convergent
Choke 121	nozzle 228–9
number 121	pipes 125
Choked flow 229	Convergent-divergent nozzle 229-30
Chord length 162	Conversion of units, pressure 21
Circular	Correction
pipes, flow 91–4	capillarity 15
water channel 139-40	Pitot tube 225–6
Circulating flume, model testing 178	Correlation 95
Circulation 50–1	Couette flow, viscosity 9
Cocks 130-1	Couette-Poiseuille flow 91
loss factor 130	Critical
Coefficient	density 229
of contraction 67	depth 142
of diffusion 88	pressure 229
	-
of discharge 64, 67	Reynolds number 46, 154
drag 163	temperature 229
friction drag 158	velocity 44, 46, 143, 229
interference 167	Curl 49
lift 163	Cylinder
moment 163	drag 150–1
Pitot tube 182	coefficient 151
of velocity 66, 67	flow around 152, 153
of viscosity 9	pressure distribution 152
Colour streak method 279–83	Cylinder-type, Pitot tube 182–4
Complex	Cylindrical coordinates 87
potential 201–3	rotational motion 36
velocity 202	
Compressibility 6, 16–17	d'Alembert's paradox 152
	d'Alembert's paradox 152
Compressible fluids 6, 46–7, 218–37	Darcy-Weisbach equation 115
finite difference 257–9	De Laval nozzle 229–30
Compression wave, propagation 234	Density 8
Computational fluid mechanics, 249–73	correlation method 277
Computer tomography 278, 287	critical 229
Computer-aided	Depth, critical 142
flow visualisation (CAFV) 274	Depth tuft method 275
visualisation 277, 286–90	Derived units 7
Cone	Development
drag coefficient 151	boundary layer 102-4
supersonic velocity 231	lift 161–2
Conformal mapping 212–16	Diaphragm, pressure gauges 28-9
Conjugate complex, velocity 202	Differential manometer 27–8
Conservation	Dimension 8
of angular momentum 76-8	Dimensional analysis 171–4
of energy 56–70	applications 172–4
of mass, principle of 56	Direct simulation, turbulence 261-2
Constant	Disc valve 131
discharge, water channels 142–3	Discharge
<i>U</i> ,	
gas 17	coefficient of 67
pressure, specific heat 18	pumping 133
specific energy 143, 144	Discrete vortex
volume, specific heat 18	element 271
water depth 143–4	method 272
nator deput 145-4	111001100 412

D' ' ' ' ' ' ' '	- C 4'
Discretisation 265	of motion
Displacement thickness, boundary layer	boundary layer 104-5
103	Euler's 59
Divergence 83	of Nikuradse 116
Divergent pipes 123–5	Equi-value area
Division of elements, finite element method	manifestation method 278
264	presentation 289
Doppler effect 224	Equiaccelerated straight-line motion,
Doublet 208	relatively stationary state 35-6
Drag	Euler 5, 59
of a body 149–61	equation of motion 59, 197–8
coefficient 149–50, 163	Eulerian method, flow 41
cone 151	
	Examples, potential flow 203–12
cylinder 151	Experimental visualisation methods 274 Exterior flows 148–70
hemisphere 151	Exterior flows 148–70
oblong board 151	D 005 (
passenger car 151	Fanno flow 235–6
cylinder 150–1	Fanno line 236
flat plate 156–60	Finite difference
form 149	compressible fluid 257–9
friction 149, 150	indication 249–51
ideal fluid 150–3	method 249-62
pressure 149, 150	turbulence 259-62
sphere 156	Finite element method 264-9
turbulent boundary layer 158–60	division of elements 264
twin vortices 153	equation-overlapping elements 267
viscous fluid 153–6	Galerkin method 266
Dynamic pressure 60	interpolating function 266-7
Dynamic temperature 225	weighted residuals 265–6
Dynamic viscosity 9	Finite volume method 262–4
Dynamic viscosity 9	
Eddwing water assessed 50	boundary-fitted grid 262
Eddying water currents 50	control volume 262, 263
Efficiency, propeller 75–6	preservative form 262
Ekman 46	structured grid 262
Elastic-type pressure gauges 28–9	unstructured grid 262, 264
Elbow pipes 126, 127	Five-hole spherical Pitot tube 183, 184
Electric-type pressure gauges 29–30	Flat plate
Electrically controlled tracer method 276,	drag 156–60
283	laminar boundary layer 157–8
Electrolytic colouring method 276	Float-type, area flowmeter 189-90
Electrolytic corrosion method 275	Floating sawdust method 282
Electrolytic precipitation method 282	Floating tracer method 276, 281
Energy	Flow
conservation of 56–70	around cylinder 152, 153
internal 219	choked 229
kinetic 56	circular pipes 91–4
law of conservation 56	contraction, losses 120–1
line 62	Couette-Poiseuille 91
potential 56	curved pipe 72
_ ^	
Enthalpy 219	discharge, measurement 186–95
Entrance length, pipes 112	Eulerian method 41
Entrance region, pipes 112	expansion, losses 119–20
Entropy 220	Fanno 235–6
Equation-overlapping elements, finite	forced vortex 50
element method 267	free vortex 50
Equations	irrotational 49, 199
of angular momentum 76-7	Lagrangiam method 41
of Blasius 116	laminar 44-6
of Itaya 116	one-dimensional 43-4, 55-81
of Kármán-Nikuradse 116	parallel plates 9, 88-91
of momentum 70-1	in pipes 110–35
application 72–6	potential 199

Flow (contd)	Frictional loss, pipes 118-19
Rayleigh 235–6	Froude 146
resistance, sphere 172-4	number 145
restrictions 187–8	law of similarity 176–7
nozzle 187, 188	Function mapping 213
orifice 187	
Venturi tube 187, 188–9	Galerkin method, finite element method
rotational 50	266
steady 43	Ganguillet-Kutter equation, open channel
synthesising 206–12	137–8
three-dimensional 43	Gas
turbulent 44-6	constant 17, 219
two-dimensional 43	ideal 17
unsteady 43	perfect 17–18
velocity	Gases 6
coefficient, open channel 137	Gate valves 128, 129
measurement 182–6	Gauge pressure 21
visualisation 274–90	Gauss-Seidel sequential iteration method
computer-aided (CAFV) 274	253
Flowmeter	Geometrical moment of inertia 31
area 189-90	Globe valves 128, 129
fluidic 193–4	Göttingen University 163
magnetic 191-2	Göttingen-type manometer 28
positive displacement 190	Green's formula, boundary element method
turbine 190–1	269
ultrasonic 192-3	Gyrostatics, rotational motion 36
vortex-shedding 193	
Fluctuating velocities, velocity distribution	Hagen 93
95	Hagen-Poiseuille formula 93
Fluidic	Head loss, Borda-Carnot 74
flowmeter 193–4	Head pumping 133
oscillator 193	Height of liquid surface 14–15
Fluids	Helmholtz 5
at rest, pressure 23–6	vortex theory 88
compressible 6, 46–7	Hemisphere, drag coefficient 151
ideal 6	Henry's Law 168
incompressible 6, 46–7, 251–7	Higher critical Reynolds number 46
Newtonian 13	Holographic Particle Imaging Velocimetry
non-Newtonian 13	(HPIV) 277
perfect 6	Hot-wire anemometer 184–5
Fluorescent mini-tuft method 280	Hurricanes 50
Force	Hydraulic
body 85	grade line 62
inertial 85	jump 144–6
jet 72–4	mean depth
pressure 85	open channel 137
restoring 35	pipes 118
viscous 85–6	press 23
Forced vortex, flow 50	Hydraulics 1
Forces acting on a body 149	Hydrodynamics 1
Form drag 149	Hydrogen bubble method 276, 283
Forward difference 250	
Free vortex	Ideal fluids 6, 197–217
flow 50	Ideal drag 150-3
potential flow 205–6	Ideal gas 6, 17–18
Friction	Image
coefficient, pipes 115	presentation 274
drag 149, 150	processing 274
coefficient 158	Implicit Approximate Factorisation (IAF)
pipes 114–18	method 257
torque, revolving disc 160–1	Inclined manometer 28
velocity 98	Incompressible fluids 6, 46–7, 251–7

Indication, finite difference 249-51	Laser Doppler
Inertia term 87	anemometer 185–6
Inertial force 85	velocimeter, three-dimensional 290
Injected tracer method 276	Laser holographic interferometer method
Injection	277, 285, 287
path line method 276	Laser light sheet method 277
streak line method 276	Laser Speckle Method (LSM) 277
Inlet	Law of conservation of energy 56
length, pipes 112	Law of similarity 175–80
loss factor 121	Froude number 176–7
region, pipes 112	Mach number 177
Instantaneous valve closure 245-6	non-dimensional groups 175–7
Interference	Weber number 177
coefficient 167	Law of viscosity, Newton 10
fringes 284	Leading edge 162
anemometer 186	Length, chord 162
Internal energy 219	Leonardo da Vinci 3–4
Interpolating function, finite element	Lift 161–7
method 266–7	coefficient 163
Irrotational flow 49, 199	development 161–2
	stall 164
Isaac Newton 10	
Isentropic	stalling angle 164
flow 226–30	wing 162–7
index 18, 219	Lift-drag
Isobaric change 18	polar, wing 165
Isochoric change 18	ratio 165
Isothermal change 18	Liquids 6
	column, U-tube 238–40
Jet and a second	rotation and spinning 47–50
force of 72–4	surface
plane 231	and capillarity 15
pump 75	height of 14–15
Joukowski's hypothesis 166	Logarithmic velocity distribution 100-1
Journal bearing, theory of lubrication	Loss factor
108	ball valve 131
Junction pipes 127, 128	cocks 130
	disc valve 131
k - ε model 260	needle valve 131
Kármán 101	relief valves 131
vortex 153	spool valve 131
Kinematic	Loss of head 62, 112
viscosity 11	Losses
turbulent flow 96	flow contraction 120-1
Kinetic energy 56	flow expansion 119-20
Kline, bursting phenomenon 274	inlet loss factor 121
Kutta condition 166	in pipe lines 119–32
Kutta-Joukowski equation 162	Lower critical Reynolds number 46
Kutta condition 215	Lubrication, theory of 106–9
	Luminescent mini-tuft method 275
La Système International d'Unités, see SI	
units	MacCormack method 257
Lagrangian method, flow 41	Mach 178
Laminar	angle 224
boundary layer, flat plate 157–8	cone 224
flow 44–6	number 223–4
pipes 115	law of similarity 177
velocity distribution 88–94	sonic flow 177
frictional resistance 239-40	subsonic flow 177
	subsonic flow 177 supersonic flow 177
sublayer 98 Laplace's equation 199	transonic flow 177
Large Eddy Simulation (LES), turbulence	wave 224
261	MachZehnder interferometer method 27

Magnetic flowmeter 191-2	Reynolds number 175-6
Main flow, boundary layer 101	Non-electrolytic reaction method 276
Manning equation, open channel 138	Non-Newtonian fluids 13
Manometer 26–8	Normal shock wave 234
Chattock tilting 28	Nozzle, flow restrictions 187, 188
differential 27-8	Numerical
Göttingen-type 28	data visualisation method 278, 287-9
inclined 28	viscosity 262
U-tube 26	Numerical fluid mechanics 249–73
Mapping	21,5 7,5
conformal 212–16	Oblique shock wave 234
function 213	Oblong board, drag coefficient 151
Marker and Cell (MAC) method 254	Oil-dots method 275
Mass	Oil-film method 275
flow rate 56	One-dimensional flow 43-4, 55-81
transfer method 275	compressible flow 224–6
Maximum thickness, wing 163	One-equation model 260
Mean free path 6	Open channel 136–8
Measured data visualisation 289-90	Bazin equation 138
method 278	Chezy's formula 137
Measurement	flow velocity coefficient 137
flow discharge 186-95	Ganguillet-Kutter equation 137-8
flow velocity 182-6	hydraulic mean depth 137
pressure 26–30	Manning equation 138
Mercury, surface tension 13	shape of 138, 141
Metacentre 35	specific energy 141–2
Metacentric height 35	wetted perimeter 137
Method of characteristics 257-9	Optical
Methyl alcohol, surface tension 13	method 276
Metres of water column, pressure 20	visualisation method 284-5
Micromanometers 28	Orifice 66
Mixing length	flow restrictions 187
Prandtl's hypothesis 97	plate 187
turbulent flow 97	Oval gear type, positive displacement
MKS system, units 7	flowmeter 190
Model testing 177–9	
circulating flume 178	Panel method, boundary element method
towing tank 178	269
wind tunnel 178, 179	Parallel
Moiré method 284	flow 203–4
Moment	plates, flow 9, 88–91
coefficient 163	Particle Imaging Velocimetry (PIV) 277, 286
of inertia 40	Particle Tracking Velocimetry (PTV) 286
geometrical 31	Pascal 20, 23
Momentum 70. 1	law 23
equations 70–1	Passenger car, drag coefficient 151
law of conservation 70–6	Path line 41, 42
thickness, boundary layer 103, 104	Perfect fluids 6, 197–217
Moody diagram 117	Perfect gas 6, 17–18
Noble 40	Pipe lines
Nabla 49 National Advisory Committee for	change in flow quantity 242–3 losses in 119–32
Aeronautics (NACA) 163	pressure propagation 240–1
National Aeronautics and Space	pressure wave velocity 243–4
Administration (NASA) 163	total loss 131–2
Navier 5, 87	Pipes 110–35
Navier-Stokes equation, viscous fluid 83–8	bend 125-7
Needle valve, loss factor 131	branch 127, 128
Newton, law of viscosity 10	convergent 125
Newtonian fluids 13	divergent 123–5
Non-dimensional groups	elbow 126, 127
law of similarity 175–7	entrance length 112

electric-type 29-30

head 60

Roots type, positive displacement flowmeter

Rotational flow 50	Standard atmospheric pressure 20
Rotational motion	Starting vortex 166, 167
cylindrical coordinates 36	Static pressure 60
gyrostatics 36	Static temperature 225
relatively stationary state 36–7	Steady flow 43
Rough circular pipe, turbulent flow 116-18	Stereophotography method 284
Royal Aircraft Establishment 163	Stokes 5
respersive Establishment 105	theorem 51
Schiller 46	Streak line 41, 42
Schlieren	Stream
method 284, 285	function 200–1
photograph method 277	and vorticity 251–4
Section, aerofoil 162	
	Stream tube 42, 43 Streamlines 41–2
Semiconductor strain gauge 29–30	
Separation	absolute 42
boundary layer 105–6	relative 42
point 105, 153	shape 3, 155
Shadowgraph method 276	Strength
Shaft horsepower, pumping 133	of sink 205
Shape	of source 205
open channel 138, 141	vortex 206
streamline 3	Strouhal number 155
Shear flow 10	Structured grid, finite volume method
Shock waves 230–5	262
normal 234	Sublayer
oblique 234	laminar 98
SI units 7	viscous 98
Single-beam anemometer 186	Subsonic flow 227
Sink	Mach number 177
and source 207–9	Successive over-relaxation (SOR) method
strength of 205	253
Smoke method 281	Sudden expansion 251
Smoke wire method 276, 283, 284	pipe 74
Smooth circular pipes, turbulent flow	Supercavitation 168
115–16	Supersonic
Sommerfeld 108	flow 227, 230
Sonic flow, Mach number 177	Mach number 177
Sonic velocity 221–3	velocity
Source	cone 231
potential flow 205-6	jet plane 231
and sink 207-9	Surface floating tracer method 276, 281
strength of 205	Surface tension 13–15
Spark tracing method 276, 283, 284	mercury 13
Specific energy	methyl alcohol 13
constant 143, 144	water 13
open channel 141–2	Surface tuft method 280
Specific gravity 8	Suspension method 276
Specific heat	Synthesising flows 206–12
constant pressure 18, 219	Synthesising news 200 12
constant volume 18, 219	Temperature
	critical 229
ratio 18, 219	
Specific volume 8	dynamic 225 static 225
Speckle method 277	
Sphere	total 225
drag 156	Temperature-sensitive-film method 275
flow resistance 172–4	Theory of lubrication 106–9
Spool valve, loss factor 131	journal bearing 108
Spread of aqua 37	thrust bearing 107
Stagnation point 64, 148	Thermodynamics, second law 221
Stagnation pressure 60	Thermographical method 278
Stall, lift 164	Thickness, boundary layer 103
Stalling angle, lift 164	Three-dimensional flow 43

mt C. Constitues Density	closure 246-7
Three-dimensional laser Doppler	
velocimeter 290	Allievi's equation 246
Throttle 121	instantaneous 2456
Thrust 75-6	gate 128, 129
Thrust bearing, theory of lubrication	globe 128, 129
107	Variational principle 265
Time line method 276	Vector manifestation method 278
Tornadoes 50	Vector presentation 289
Torricelli's theorem 67	Velocity
	absolute 78
Total head 60	
pumping 132	coefficient of 67
Total loss, pipe line 131–2	complex 202
Total pressure 60	conjugate complex 202
Pitot tube 184	critical 44, 46, 143, 229
Total temperature 225	distribution
Towing tank, model testing 178	fluctuating velocities 95
Trailing edge 162	laminar flow 88–94
Transition zone, boundary layer 104	logarithmic 100-1
Transonic flow, Mach number 177	turbulent flow 94-101
Transport equation, vorticity 88	friction 98
	head 60
Tuft grid method 280	
Tuft method 275	peripheral 78
Tuft stick method 275	potential 198-200
Turbine flowmeter 190–1	and pressure 254
Turbulence 44–6	relative 78
direct simulation 261–2	Vena contracta 67
finite difference 259-62	Venturi 63
large eddy simulation 261	tube 62, 63-4
model 259-60	flow restrictions 187, 188-9
Turbulent boundary layer, drag	Viscosity 6, 9–13
158-60	coefficient of 9
Turbulent flow	Couette flow 9
kinematic viscosity 96	dynamic 9
mixing length 97	index 13
	kinematic 11
pipes 115–18	
rough circular pipes 116-18	Newton's law of 10
smooth circular pipes 115-16	Viscous
velocity distribution 94-101	fluid 82–110
Twin vortices, drag 153	continuity equation 82–3
Two-dimensional flow 43	drag 153-6
Two-equation model 260	Navier-Stokes equation 83-8
	force 85-6
U-tube	sublayer 98
liquid column 238–40	Visualisation methods 274-86
manometer 26	Visualised image analysis 277,
Ultrasonic flowmeter 192–3	286–7
Units 6–8	Volume rendering method 278
absolute system 7	Volumetric flow rate 56
base 6–7	Vortex
	free 205-6
CGS system 7	
derived 7	Kármán 153
MKS system 7	point 206
of pressure 20–1	starting 166, 167
SI 7	strength of 206
Universal gas constant 219	theory, Helmholtz 88
Unsteady flow 43, 238–48	wing-bound 166
Unstructured grid, finite volume method	Vortex-shedding flowmeter 193
262, 264	Vorticity 49
Upwind difference method 254	and stream function 251-4
	transport equation 88
Valves 128-30	
butterfly 129-30	Wake 102, 148

Wall attachment phenomenon 123 effect, see wall attachment phenomenon Wall-tracing method 274, 275, 279 Water channels 136-47 constant discharge 142-3 depth, constant 143-4 horsepower, pumping 133 surface tension 13 Water clock 69 Water hammer 244-7 Water wheel, power 78 Wave resistance 176 Weber number, law of similarity 177 Weighted residuals, finite element method 265-6

Weighting function 265
Weirs 69-70, 194-5
Wetted perimeter
open channel 137
pipes 118
Whirl, and rotation 47-50
Wind tunnel, model testing 178, 179
Wing
angle of attack 163
aspect ratio 163
lift 162-7
lift-drag polar 165
maximum thickness 163
Wing-bound vortex 166
Wire strain gauge 29-30

Zero-equation model 259-60