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A Numerical Study of a Rotary Valve Internal Combustion Engine

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Contents

Certificate of Authorship and Originality xix

Acknowledgements xx

Abstract xxi

1 Introduction **1**
- 1.1 Fundamental Principles 1
  - 1.1.1 Terminology 3
- 1.2 The Modern High Performance Poppet Valve Engine 5
- 1.3 Rotary Valve Engine Fundamentals 7
- 1.4 History of the Rotary Valve Engine 9
  - 1.4.1 Early History 9
  - 1.4.2 Modern Developments in Rotary Valve Engines 21
  - 1.4.3 The Bishop Rotary Valve Engine 25
- 1.5 Outline of The Current Work 27

2 Mathematical Models **28**
- 2.1 Notation 28
- 2.2 Conservation Equations 29
  - 2.2.1 Continuity 29
  - 2.2.2 Momentum 29
  - 2.2.3 Energy 30
  - 2.2.4 Equation of State 30
  - 2.2.5 Passive Scalars 31
- 2.3 Turbulence 31
  - 2.3.1 Direct Numerical Simulation 33
  - 2.3.2 Reynolds Averaged Equations 33
  - 2.3.3 Reynolds Stress Models 37
  - 2.3.4 The k-ϵ Turbulence Model 39
  - 2.3.5 Large Eddy Simulation 42

3 Numerical Methods **45**
- 3.1 SIMPLEC Algorithm 46
  - 3.1.1 Body Fitted Coordinates 46

3.2 Discretisation . . . 48
  3.2.1 Temporal Terms . . . 49
  3.2.2 Diffusion Terms . . . 50
  3.2.3 Advection Terms . . . 50
  3.2.4 Source Terms . . . 52
  3.2.5 Numerical Considerations . . . 52
  3.2.6 Application to the SIMPLEC Algorithm . . . 54
3.3 Boundary Conditions . . . 57
  3.3.1 Wall Boundary Conditions . . . 57
  3.3.2 Wall Functions Limitations . . . 61
  3.3.3 Pressure Boundaries . . . 62

4 Literature Review 63
4.1 Combustion . . . 63
4.2 In-Cylinder Flow . . . 68
  4.2.1 Definitions . . . 68
  4.2.2 Parameterisation . . . 73
  4.2.3 Turbulence Enhancement Mechanisms . . . 75
4.3 Manifold Flows . . . 82
4.4 Engine Flows Modelling . . . 84
  4.4.1 One-Dimensional Models . . . 84
  4.4.2 Two-Dimensional Models . . . 97
  4.4.3 Three-Dimensional Models . . . 100
4.5 Turbulence in In-Cylinder Flows . . . 119
  4.5.1 Reynolds Averaging . . . 119
  4.5.2 Limitations of Reynolds Averaging . . . 120
  4.5.3 Cycle to Cycle Variations . . . 120
  4.5.4 Large Eddy Simulation . . . 123

5 Validation of Numerical Simulation Code 126
5.1 Summary of Existing Validations . . . 128
  5.1.1 Laminar Flow Over a Backstep . . . 128
  5.1.2 Turbulent Flow Over a Backstep . . . 130
  5.1.3 Differencing Schemes . . . 132
  5.1.4 Moving Grids . . . 134
  5.1.5 General Benchmarks . . . 138
  5.1.6 Aerofoil Modelling . . . 139
  5.1.7 Turbulent Boundary Layer . . . 140
  5.1.8 Simulation of Complex External Flows . . . 142
5.2 One-Dimensional Shock Tube . . . 145
  5.2.1 Description . . . 146
  5.2.2 Exact Solution . . . 147
  5.2.3 Numerical Modelling . . . 150
  5.2.4 Overshoots and Shock Resolution . . . 152
  5.2.5 Inviscid and Non-Conductive Assumptions . . . 154

5.2.6 Time Step Size 154
5.2.7 Other Numerical Schemes 155
5.3 Discussion 157

6 Compression Stroke Tumble Vortex Breakdown 159
6.1 Previous Works 159
6.1.1 Experimental Studies 159
6.1.2 Numerical Studies 162
6.2 Description 169
6.2.1 Geometry 169
6.2.2 Dimensionality 171
6.2.3 Other Numerical Factors 172
6.2.4 Initial Conditions 173
6.3 Mesh Independence 174
6.4 Initial Conditions Independence 182
6.5 Two- and Three-Dimensions 184
6.6 $CR = 4$ Model 185
6.7 $CR = 10$ Model 190
6.7.1 Intake Stroke 190
6.7.2 Bottom Dead Centre 192
6.7.3 Compression Stroke 206
6.7.4 Averaged Parameters 233
6.7.5 Conditions at Various Points 237
6.8 Discussion 246
6.9 LES Model 249
6.9.1 Model Description 249
6.9.2 Turbulent Length Scales 251
6.9.3 Computation Time 252
6.9.4 $CR = 4$ Results 253
6.9.5 $CR = 10$ Results 255
6.9.6 Velocity Decomposition 271
6.9.7 Discussion 279

7 Modelling of the BRV Engine 281
7.1 BRV Engine Layout 281
7.2 Method of Creating the CFD Model 281
7.2.1 Mesh Motion 292
7.2.2 Valve Sliding Grid 294
7.3 Parameters Used in BRV Simulation 301
7.3.1 “Two Cycle” Simulation 301
7.3.2 Fluid Parameters 303
7.3.3 Exhaust Gas Scalar 303
7.3.4 Wall Boundary Conditions 303
7.3.5 Convergence Parameters 304
7.4 Validation of BRV CFD Model 305

7.4.1 Description of Dynamometer Facility 305
7.4.2 Time Step Size 306
7.4.3 Inlet Manifold Pressure 308
7.4.4 Mesh Refinement Study 309
7.4.5 Effect of Gas Initial and Boundary Temperature 312
7.5 Mark I Combustion Chamber 319
7.6 Mark II and III Combustion Chamber 321
7.6.1 Previous Work on Dual Tumble 326
7.7 Analysis of Dual Cross Tumble 332
7.7.1 Breakdown to Turbulence Mechanism 334
7.7.2 Dual Cross Tumble Generation 334
7.7.3 Dual Cross Tumble Parameterisation 335
7.8 Behaviour of Dual Cross Tumble 336

8 Analysis of the BRV Engine 347
8.1 Prediction of Volumetric Efficiency 347
8.2 Effect of the Inlet Manifold Wave 352
8.3 Effect of Constrictions in the Valve 357
8.4 Effect of Different Valve Sizes 366
8.5 Effect of Manifold Wall Heat Transfer 376
8.6 Effect of Bore to Stroke Ratio 378
8.6.1 Introduction 378
8.6.2 Results 382
8.6.3 Discussion 394
8.7 Turbulence Scaling 396
8.8 Discussion 402

9 Conclusion 404

Bibliography 409

A Fortran Subroutines 436
A.1 pointinquad 436
A.2 manreblock 437

B Publications 439
B.1 "Tumble Vortex Breakdown During the Compression Stroke of a Model Internal Combustion Engine", 2000 440

List of Figures

1.1 Diagrammatic representation of a four stroke, spark ignition, reciprocating, internal combustion engine 2
1.2 Schematic diagram of a four valve pentroof combustion chamber . . 6
1.3 Sections of the four cylinder, in-line Rover K series engine 7
1.4 Schematic diagram of the Cross Rotary Valve engine 10
1.5 The lubrication system used in the Cross Rotary Valve engine . . . 11
1.6 The 1.6 L, radial four cylinder Cross Rotary Valve engine 13
1.7 Comparison of the Cross 350 Single Cylinder Rotary Valve engine and a Rover 2000 poppet valve engine 13
1.8 The Aspin rotary valve engine 14
1.9 The Aspin rotary valve combustion chamber 15
1.10 The Aspin rotary valve engine from the late 1940s 16
1.11 The Itala Rotary valve and engine layout 17
1.12 Cross section of the Junkers JUMO KM8 disk valve torpedo engine 20
1.13 Operating principle of the MGN rotary valve engine 22
1.14 The Coates Spherical Rotary Valve engine head 23

2.1 Typical energy spectrum for a turbulent flow 32

3.1 Grid structure in computational space and physical space 47
3.2 Control volume notation 48
3.3 Block diagram of the time stepping loop of the CFX code 55
3.4 Block diagram of the SIMPLEC algorithm 55
3.5 Block diagram of a linear solver 56
3.6 Typical velocity profile for a turbulent boundary layer 58

4.1 Comparison between laminar and turbulent flame fronts during combustion 66
4.2 The relationship between turbulence intensity and burning velocity 68
4.3 Microshadowgraphs of the flame propagation in an internal combustion engine from Arcoumanis and Whitelaw 69
4.4 Example of an induced squish flow 70
4.5 A typical piston used for high squish engines 70
4.6 An engine configuration to generate a large squish flow 71
4.7 A swirl vortex, depicted on the direct-injection 2.5 L Ford Diesel engine 72
4.8 A tumble vortex 73

4.9 Definition of squish areas 74
4.10 Schematic interpretation of the “triple-vortex” from Kuwuhara et al 82
4.11 Pressure in the inlet manifold of the engine studied by Takeyama et al 87
4.12 The Formula One engine inlet geometry modelled by Ferlet 91
4.13 The inlet geometry dimensions used by Ferlet to model a Formula One inlet manifold 92
4.14 Comparison of measured and calculated pressure in the inlet manifold of a Formula One engine at 13000 rpm by Ferlet 93
4.15 Comparison of measured and calculated pressure in the exhaust manifold of a Formula One engine at 13000 rpm by Ferlet 93
4.16 Cross section of the 1997 BRV geometry from Horrocks 95
4.17 Pressures in the 1997 BRV engine inlet manifold from Horrocks . . 96
4.18 The flow field predicted in a four cylinder engine intake mainfold at 224 °CA by Chapman 98
4.19 Streamlines predicted in an axisymmetric inlet valve by Naser and Gosman 99
4.20 The exhaust manifold junction modelled by Leschziner and Dimitriadis 101
4.21 The inlet geometry and results from Taylor et al 104
4.22 The mesh used in the water analog steady flow geometry modelled by O’Connor and McKinley 107
4.23 Simulation of Ferrari Formula One engine by Bianchi et al 109
4.24 The direct injection spark ignition engine simulated by Han et al . . 110
4.25 Flow fields predicted by Han et al in a direct injection spark ignition engine 111
4.26 Simulation of Mercedes-Benz M111 four valve spark ignition engine, reproduced from Gosman 112
4.27 Cylinder pressure predicted for the Mercedes-Benz M111 engine, from Gosman 113
4.28 The cylinder mesh used by Das and Dent 114
4.29 Simulation of the exhaust stroke of a spark ignition engine from Lisbona 117
4.30 Comparison of averaged and instantaneous velocity fields at TDC of a square piston engine from Maurel et al 121

5.1 Model of a Tecumseh small utility engine from Foster 127
5.2 Comparison of predictions using various turbulence models for flow over a backstep at Re = 51615 from Clarke and Wilkes 131
5.3 Backwards facing step and pipe with a splitter plate simulations from Alderton and Wilkes 133
5.4 The grid used and velocity vectors predicted in the model of an axisymmetric Diesel engine cylinder at TDC from Hawkins and Wilkes 135
5.5 Turbulent kinetic energy predicted for piston bowl compression stroke simulation at various points from Hawkins and Wilkes 136
5.6 Simulation of moving valve poppet valve by Hawkins and Wilkes . . 137
5.7 Instantaneous streamlines of a 4% Gurney flap aerofoil at zero angle of attack, from Date and Turnock 140

5.8 Time averaged C_L and C_D versus angle of attack for a NACA 0012 aerofoil with a 4% Gurney flap from Date and Turnock 141
5.9 Skin friction coefficient versus Reynolds Number for various numerical models and experimental results from Date and Turnock 143
5.10 Simulations of a simplified vehicle geometry modelled by Shaw and Simcox 144
5.11 Geometry used for one-dimensional shock tube 146
5.12 Diagram indicating the various gas states in the shock tube after a period of time has passed 147
5.13 Representation of shock tube after time has elapsed 148
5.14 Density, pressure and velocity predictions from one-dimensional shock tube simulation 151
5.15 Detail of pressure near the shock from the one-dimensional shock tube simulation 153
5.16 Results of the one-dimensional shock tube simulation using various time step sizes 156
5.17 Detail of pressure near the shock for various temporal differencing schemes and solution algorithms 157

6.1 PIV ensemble averaged velocity fields in a pentroof combustion chamber at 2000 rpm, from Rouland 160
6.2 Flow field structures during the compression stroke of a pentroof combustion chamber engine, reproduced from Kuwahara and Ando 161
6.3 Development of in-cylinder flow during the compression stroke, reproduced from Khaligh 162
6.4 Normalised turbulence, TR and CR during the compression stroke, from Khalighi 163
6.5 Velocity field predicted by k-ϵ and Reynolds stress turbulence models during the compression stroke, from Lebrère and Dillies 164
6.6 Streamlines modelled during the compression stroke of an axisymmetric flat piston engine from Naitoh et al 166
6.7 Experimental and simulated density contours in the intake stroke of rectangular piston engine, from Naitoh and Kuwahara 167
6.8 Experimental and simulated density contours in the compression stroke of rectangular piston engine, from Naitoh and Kuwahara . . 168
6.9 Geometry used by IMFT researchers, from Borée et al 170
6.10 Dimensions of the geometry in the Z mid plane from Marc et al . . 170
6.11 Velocity vectors in YZ plane at BDC from Marc et al 171
6.12 Velocity vectors in YZ plane at 61 °CA, from Marc 172
6.13 Detail of mesh used around inlet manifold/cylinder junction 175
6.14 Grid convergence of cylinder averaged parameters in the square piston engine 177
6.15 Grid convergence at the central point of the square piston engine . . 178
6.16 Effect of grid density on flow field predicted at TDC by the RSM model180
6.17 Effect of initial turbulence conditions on $CR = 5$ simulation 183

6.18 Comparison of turbulent kinetic energy from experimental results and numerical simulation for model with $CR = 4$ at 86 °CA 186
6.19 Comparison of velocity vectors from experimental results and numerical simulation for model with $CR = 4$ at 86 °CA 188
6.20 Comparison of turbulent kinetic energy from experimental results and numerical simulation for model with $CR = 4$ at BDC 189
6.21 Comparison of velocity vectors from experimental results and numerical simulation for model with $CR = 4$ at BDC 191
6.22 Comparison of velocity predictions in the $Z = 50$ mm plane for $CR = 10$, at 87 °CA 193
6.23 Comparison of turbulent energy predictions in the $Z = 50$ mm plane for $CR = 10$, at 87 °CA 194
6.24 Comparison of velocity predictions in the $X = 93$ mm plane for $CR = 10$, at 64 °CA 195
6.25 Comparison of turbulent energy predictions in the $X = 93$ mm plane for $CR = 10$, at 64 °CA 196
6.26 Comparison of velocity predictions in the $Z = 50$ mm plane for $CR = 10$, at BDC 197
6.27 Comparison of velocity predictions in the $X = 93$ mm plane for $CR = 10$, at BDC 198
6.28 Vortex centre positions for $CR = 10$ model at BDC 199
6.29 Comparison of velocity profiles from $CR = 10$ model at BDC for $Y = 50$ mm, $Z = 50$ mm 200
6.30 Turbulence profile at BDC along line $X = 93$ mm, $Z = 50$ mm . . . 202
6.31 Comparison of turbulent energy predictions in the $Z = 50$ mm plane for $CR = 10$, at BDC 203
6.32 Comparison of $\overline{uu}$ predictions in the $Z = 50$ mm plane for $CR = 10$, at BDC 204
6.33 Comparison of $\overline{vv}$ predictions in the $Z = 50$ mm plane for $CR = 10$, at BDC 204
6.34 Comparison of $\overline{ww}$ predictions in the $Z = 50$ mm plane for $CR = 10$, at BDC 205
6.35 Comparison of $\overline{uv}$ predictions in the $Z = 50$ mm plane for $CR = 10$, at BDC 205
6.36 Velocity vectors in $Z = 50$ mm plane at 276 °CA 207
6.37 Position of the centre of the vortex at 276 °CA 208
6.38 Turbulent kinetic energy in $Z = 50$ mm plane at 276 °CA 209
6.39 Velocity vectors in $X = 93$ mm plane at 276 °CA 210
6.40 Turbulent kinetic energy in $X = 93$ mm plane at 276 °CA 211
6.41 Velocity vectors in $Z = 50$ mm plane at 299 °CA 212
6.42 Position of the centre of the vortex at 299 °CA 213
6.43 Turbulent kinetic energy in $Z = 50$ mm plane at 299 °CA 214
6.44 Velocity vectors in $X = 93$ mm plane at 299 °CA 215
6.45 Turbulent kinetic energy in $X = 93$ mm plane at 299 °CA 216
6.46 Velocity vectors in $Z = 50$ mm plane at 312 °CA 217

6.47 Turbulent kinetic energy in $Z = 50\,\text{mm}$ plane at 312 °CA 218
6.48 Instantaneous streamlines from the three-dimensional RSM simulation at 312 °CA 220
6.49 Velocity vectors in $X = 93\,\text{mm}$ plane at 312 °CA 221
6.50 Turbulent kinetic energy in $X = 93\,\text{mm}$ plane at 312 °CA 221
6.51 Velocity vectors in $Z = 50\,\text{mm}$ plane at 321 °CA 222
6.52 Turbulent kinetic energy in $Z = 50\,\text{mm}$ plane at 321 °CA 224
6.53 Velocity vectors in $X = 93\,\text{mm}$ plane at 321 °CA 225
6.54 Turbulent kinetic energy in $X = 93\,\text{mm}$ plane at 321 °CA 225
6.55 Velocity vectors in $Z = 50\,\text{mm}$ plane at 328 °CA 226
6.56 Turbulent kinetic energy in $Z = 50\,\text{mm}$ plane at 328 °CA 228
6.57 Velocity vectors in $Z = 50\,\text{mm}$ plane at 335 °CA 229
6.58 Turbulent kinetic energy in $Z = 50\,\text{mm}$ plane at 335 °CA 230
6.59 Velocity vectors in $Z = 50\,\text{mm}$ plane at TDC 231
6.60 Turbulent kinetic energy in $Z = 50\,\text{mm}$ plane at TDC 232
6.61 Instantaneous streamlines from the three-dimensional RSM simulation at TDC 233
6.62 Mass averaged turbulence for two- and three-dimensional $CR = 10$ CFD models 235
6.63 Mass averaged velocity squared for two- and three-dimensional $CR = 10$ CFD models 236
6.64 Tumble ratio for two- and three-dimensional $CR = 10$ CFD models in the square piston engine 238
6.65 The definition of the LDA points analysed, from Marc 239
6.66 Comparison of LDA and CFD results at point 15 240
6.67 Comparison of LDA and CFD results at point 55 241
6.68 Comparison of LDA and CFD results at point 12 242
6.69 Comparison of LDA and CFD results at point 13 243
6.70 Comparison of LDA and CFD results at point 17 244
6.71 Comparison of LDA and CFD results at point 18 245
6.72 Integral length scale at TDC 252
6.73 Comparison of velocity vectors from experimental results and numerical simulation for model with $CR = 4$ at 86 °CA 253
6.74 Comparison of velocity vectors. Experimental results and numerical simulation for model with $CR = 4$ at BDC 254
6.75 Comparison of LES velocity predictions in the $Z = 50\,\text{mm}$ plane for $CR = 10$, at 87 °CA 255
6.76 Comparison of LES velocity predictions in the $X = 93\,\text{mm}$ plane for $CR = 10$, at 64 °CA 256
6.77 Comparison of LES velocity predictions in the $Z = 50\,\text{mm}$ plane for $CR = 10$, at BDC 257
6.78 Vortex centre positions for $CR = 10$ LES model at BDC 258
6.79 Comparison of LES velocity predictions in the $X = 93\,\text{mm}$ plane for $CR = 10$, at BDC 259

6.80 Comparison of LES simulation velocity profiles from $CR = 10$ model at BDC for $Y = 50$ mm, $Z = 50$ mm 260
6.81 Instantaneous streamlines for the LES model at BDC 260
6.82 Velocity vectors in $Z = 50$ mm plane from the LES simulation at 276 °CA 261
6.83 Velocity vectors in $Z = 50$ mm plane from the LES simulation at 299 °CA 262
6.84 Velocity vectors in $Z = 50$ mm plane from the LES simulation at 312 °CA 262
6.85 Velocity vectors in $Z = 50$ mm plane from the LES simulation at 321 °CA 263
6.86 Velocity vectors in $Z = 50$ mm plane from the LES simulation at 328 °CA 263
6.87 Velocity vectors in $Z = 50$ mm plane from the LES simulation at 335 °CA 264
6.88 Position of the centre of the vortex predicted by the LES simulation at 276 °CA 265
6.89 Position of the centre of the vortex predicted by the LES simulation at 299 °CA 266
6.90 Velocity vectors in $X = 93$ mm plane from the LES simulation at 276 °CA 266
6.91 Velocity vectors in $X = 93$ mm plane from the LES simulation at 299 °CA 267
6.92 Velocity vectors in $X = 93$ mm plane from the LES simulation at 312 °CA 267
6.93 Velocity vectors in $X = 93$ mm plane from the LES simulation at 321 °CA 268
6.94 Velocity vectors from the LES simulation in the $Z = 50$ mm plane at TDC 268
6.95 Instantaneous streamlines for the LES model at TDC 269
6.96 Mass averaged velocity squared and tumble ratio for the LES model 270
6.97 v_{mean} and v_{raw} velocity at point 15 from the $CR = 10$ LES model . . 272
6.98 Comparison of LDA and LES results at point 12 273
6.99 Comparison of LDA and LES results at point 13 274
6.100 Comparison of LDA and LES results at point 15 275
6.101 Comparison of LDA and LES results at point 17 276
6.102 Comparison of LDA and LES results at point 18 277
6.103 Comparison of LDA and LES results at point 55 278

7.1 Diagram of the overall layout of the BRV engine valve and cylinder head 282
7.2 Diagram of the overall layout of the BRV engine valve drive system 282
7.3 Various isometric views of the valve geometry, as originally imported 284
7.4 Isometric view of the imported BRV engine geometry 284
7.5 Cylinder head geometry meshing operations 286

7.6 Cylinder head top surface mesh projected onto the piston crown . . 287
7.7 Mesh in valve window 287
7.8 Isometric views of the valve surface geometry 288
7.9 Isometric view of valve and inlet manifold blocks 289
7.10 Example of mesh used in the valve 289
7.11 Meshing of the throttle and trumpet sections 290
7.12 Various isometric views of the inlet manifold and valve mesh 291
7.13 Definition of piston location against crank angle 293
7.14 Definition of terms to determine if a point is in a quadrilateral . . . 296
7.15 Example mesh after node state has been determined 298
7.16 The first step in reblocking the window, extending the block in the i direction 299
7.17 The second step in reblocking the window, extending the block in the j direction 300
7.18 The window section completely reblocked 300
7.19 The region after both window and wall reblocking 301
7.20 Diagram of engine strokes for the BRV engine simulation 302
7.21 The effect of time step size on simulation results 307
7.22 Cross sections through the coarse and fine mesh used to model the BRV engine 310
7.23 Comparison of inlet manifold pressure, experimental results versus coarse and fine mesh results 311
7.24 Comparison of various cylinder parameters for coarse and fine meshes 313
7.25 Comparison of coarse and fine mesh results in the cross tumble plane at 238 °CA 314
7.26 Comparison of coarse and fine mesh results in the tumble plane at 238 °CA 315
7.27 Isometric views of BRV engine showing location of port pressure sensors 316
7.28 Comparison of inlet manifold and cylinder pressure during overlap . 318
7.29 Various isometric views of the Mark I combustion chamber 320
7.30 Comparison of the tumble generated by the short and long stroke Mark I combustion chamber BRV engines 322
7.31 Tumble ratio versus crank angle for long and short stroke BRV engine configurations 323
7.32 Various isometric views of the Mark II combustion chamber 324
7.33 Various isometric views of the Mark III combustion chamber 325
7.34 Cross sections of Mark I, II and III head geometries 325
7.35 Visualisations of the flow in the Mark I cylinder head at BDC . . . 327
7.36 Visualisations of the flow in the Mark II cylinder head at BDC . . . 328
7.37 Visualisations of the flow in the Mark III cylinder head at BDC . . 329
7.38 CFD model of mean velocity at 1500 rpm for a rotary valve engine by Muroki et al 331
7.39 Schematic representation of rotary valve engine flow simulated by Muroki et al 332

7.40 Effects of fuel injection on the velocity field predicted by Han et al, in a direct injection spark ignition engine 333
7.41 Flow field in tumble and cross tumble planes during the early intake stroke 338
7.42 Flow field in tumble and cross tumble planes during the late intake and compression strokes 339
7.43 Flow field in tumble and cross tumble planes at TDC of the compression stroke 340
7.44 Turbulence field in tumble and cross tumble planes during the early intake stroke 341
7.45 Turbulence field in tumble and cross tumble planes during the late intake and compression strokes 342
7.46 Turbulence field in tumble and cross tumble planes at TDC of the compression stroke 343
7.47 Various views of instantaneous streamlines at 79 °CA for BRV Mark III engine 344
7.48 Various views of instantaneous streamlines at 178 °CA for BRV Mark III engine 345
7.49 Various views of instantaneous streamlines at 247 °CA for BRV Mark III engine 346

8.1 Comparison of first and second cycle results for run 851, at 15000 rpm 353
8.2 Comparison of first and second cycle simulation flow fields for run 851 at 222 °CA 355
8.3 Comparison of first and second cycle results for run 852, at 18000 rpm 356
8.4 Valve cross sections for the open valve used in run 844 358
8.5 Valve cross sections for the constricted valve used in run 845 359
8.6 Comparison of tumble plane fluid speed for constricted and open valves at 218 °CA 361
8.7 Comparison of tumble plane flow field for constricted and open valves at 218 °CA 362
8.8 Comparison of cross tumble plane fluid speed for constricted and open valves at 218 °CA 363
8.9 Comparison of cross tumble plane flow field for constricted and open valves at 218 °CA 364
8.10 Comparison of in-cylinder parameters, open valve versus constricted valve 365
8.11 Comparison of maximum flow rates simulated during the inlet stroke in the 63 mm and 68 mm valve engines 367
8.12 Comparison of mass of gas trapped in the cylinder during the intake stroke of 63 mm and 68 mm valve BRV engines 368
8.13 Comparison of the mass averaged velocity squared and turbulent energy for the 63 mm and 68 mm valve BRV engines 370
8.14 Comparison of velocity field of 63 mm and 68 mm valve simulations at 252 °CA on the first cycle of the simulation 371

8.15 Comparison of turbulence field of 63 mm and 68 mm valve simulations at 252 °CA on the first cycle of the simulation 373
8.16 Speed simulated at 200 °CA in the cross tumble plane for 63 mm and 68 mm valve engines 374
8.17 Comparison of dynamometer results for 63 mm and 68 mm valve BRV engines 375
8.18 Comparison of isothermal and adiabatic wall heat transfer boundary conditions on the BRV engine simulation 377
8.19 Visualisations of the temperature field in the inlet manifold of the BRV engine 379
8.20 Comparison of various BSR BRV engine parameters 384
8.21 Comparison of mass averaged turbulence and velocity squared for various BSR BRV engines. 385
8.22 Visualisations of flow in the cross tumble plane at 181 °CA 386
8.23 Visualisations of flow in the tumble plane at 181 °CA 387
8.24 Visualisations of flow in the swirl plane at 181 °CA 388
8.25 Visualisations of flow in the cross tumble plane at 271 °CA 389
8.26 Visualisations of flow in the tumble plane 271 °CA 390
8.27 Visualisations of flow in the swirl plane 271 °CA 391
8.28 Visualisations of turbulence in the cross tumble plane at 271 °CA . 392
8.29 Visualisations of turbulence in the tumble plane at 271 °CA 393
8.30 Visualisations of turbulence in the cross tumble plane at 331 °CA . 394
8.31 Visualisations of turbulence in the tumble plane at 331 °CA 395
8.32 Turbulence at 331 °CA versus bore size 395
8.33 Normalised turbulence during the first compression stroke of the BRV engine 398
8.34 Normalised turbulence during the second compression stroke of the BRV engine 399
8.35 Spark advance of the experimental engine for various configurations 401

List of Tables

2.1 Constants used in the Reynolds Stress turbulence model 38
2.2 Constants used in the k-ϵ turbulence model 41

4.1 Tumble ratio versus engine output parameters from Miyachi 80
4.2 Optimised C_D and SR for an intake port design from Trigui et al . 103

5.1 Grids tested by Moore and Wilkes 129
5.2 Length of primary recirculation bubble from Moore and Wilkes . . . 129
5.3 Length of secondary recirculation bubble from Moore and Wilkes . 130
5.4 Experimental and predicted drag coefficients from Shaw and Simcox 145
5.5 Position of the shock wave, contact surface and rarefaction wave for various mesh densities, in comparison to analytical solution 153
5.6 Combinations of viscosity and thermal conductivity tested in the one-dimensional shock tube 154

6.1 y^+ for various meshes at BDC and TDC 176
6.2 Computation time for various mesh densities 181
6.3 Turbulence initial conditions tested 183
6.4 CPU time for two- and three-dimensional simulations 184
6.5 Vortex centre location for $CR = 4$ model at 87 °CA 187
6.6 Vortex centre location for $CR = 4$ model at BDC 190
6.7 Comparison of intake vortex centre location 192
6.8 Comparison of mass averaged turbulence for various simulations at the end of the compression stroke 248
6.9 CPU time for LES simulations 252
6.10 Vortex centre location for $CR = 4$ LES model at 86 °CA 254
6.11 Vortex centre location for $CR = 4$ LES model at BDC 254
6.12 Intake stroke vortex centre location for the LES model 256

7.1 Surface temperatures used for various engine components 304
7.2 Convergence parameters used for BRV engine simulations 304

8.1 Simulations performed on the BRV engine geometry and variations, part one 348
8.2 Simulations performed on the BRV engine geometry and variations, part two 348

8.3 Comparison of CFD simulated trapped air mass and experimentally measured air consumption for 63 mm valve BRV engine at 15000 rpm 351
8.4 Comparison of CFD simulated trapped air mass and experimentally measured air consumption for 68 mm valve BRV engine at 15000 rpm 351
8.5 Reference conditions for the CFD trapped air mass calculations of tables 8.3 and 8.4 351
8.6 Reference conditions for the experimental volumetric efficiency calculations of tables 8.3 and 8.4 351
8.7 Mass of air trapped at IVC for various configurations 369
8.8 Range of BSR simulations tested 382
8.9 Comparison of normalised turbulence during the compression stroke of the first engine cycle for engine configuration 1 397
8.10 Comparison of normalised turbulence during the compression stroke of the first engine cycle for engine configuration 2 397
8.11 Comparison of normalised turbulence during the compression stroke of the second engine cycle for engine configuration 1 400
8.12 Comparison of normalised turbulence during the compression stroke of the second engine cycle for engine configuration 2 400

Nomenclature

$\bar{R}$	Universal gas constant, see equation (2.6)
$\mathbf{B}$	Fluid body force, see equation (2.2)
$\mathbf{U}$	Local fluid velocity, see equation (2.1)
ϵ	Turbulent dissipation, see equation (2.35)
Γ	Scalar diffusion coefficient, see equation (2.8)
γ	Gas constant, or the ratio of specific heats, ($\gamma = C_p/C_v$), see equation (4.6)
λ	Fluid thermal conductivity, see equation (2.5)
$\mathbb{T}$	Fluid stress tensor, see equation (2.3)
$\mathbb{T}_t$	Turbulent stress tensor, see equation (2.23)
μ	Fluid molecular viscosity, see equation (2.3)
μ_t	Turbulent viscosity, see equation (2.37)
Φ	Scalar, see equation (2.8)
ρ	Fluid density, see equation (2.1)
°CA	Degrees crank angle. 0 °CA is defined as TDC at the start of the intake stroke, page 3
ζ	Fluid bulk viscosity, see equation (2.3)
A_e	Valve effective area, see equation (4.17)
C_D	Valve discharge coefficient, see equation (4.16)
C_p	Specific heat of gas at constant pressure, see equation (2.7)
H	Fluid total enthalpy, see equation (2.4)
h	Fluid static enthalpy, see equation (2.5)
H^+	Non-dimensional enthalpy near a wall, see equation (3.32)

H_t	Turbulent mean total enthaply, see equation (2.24)
k	Turbulent kinetic energy, see equation (2.25)
p	Fluid pressure, see equation (2.3)
S	Scalar source term, see equation (2.8)
T	Fluid temperature, see equation (2.5)
t	Time, see equation (2.1)
u^+	Non-dimensional velocity parallel to a wall, see equation (3.24)
W	Molecular mass, see equation (2.6)
y^+	Non-dimensional distance to the wall in a turbulent boundary layer, see equation (3.25)
$BMEP$	Brake mean effective pressure, see equation (1.3)
CFL	Courant-Friedrichs-Lewy stability criterion, see equation (5.10)
CR	Cross tumble ratio, see equation (4.4)
$IMEP$	Indicated mean effective pressure, see equation (1.1)
MPV	Mean piston velocity, see equation (8.3)
SQ	Squish ratio, see equation (4.2)
SR	Swirl ratio, see equation (4.5)
TR	Tumble ratio, see equation (4.3)
BDC	Bottom Dead Centre, that is the crank location which gives the maximum cylinder volume, page 3
BRV	Bishop Rotary Valve, page 25
BSR	Bore to stroke ratio, page 378
CFD	Computational fluid dynamics, page 28
DNS	Direct numerical simulation, page 33
EVC	Exhaust valve close point. Usually expressed in °CA after TDC, page 4
EVO	Exhaust valve open point. Usually expressed in °CA before BDC, page 4
IVC	Inlet valve close point. Usually expressed in °CA after BDC, page 4
IVO	Inlet valve open point. Usually expressed in °CA before TDC, page 4

LES	Large eddy simulation, page 42
MOC	Method of characteristics, page 84
RSM	Reynolds stress turbulence model, page 37
TDC	Top Dead Centre. Defined as the crank location which gives the minimum cylinder volume, page 3

Certificate of Authorship and Originality

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

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Abstract

A Computational Fluid Dynamics (CFD) simulation of the Bishop Rotary Valve (BRV) engine is developed. The simulation used an existing commercial CFD code, CFX 4.3, with a number of new routines written to allow it to simulate the conditions and motions involved in an internal combustion engine. The code is extensively validated using results from other researchers, and several new validations are performed to directly validate the code for simulating internal combustion engine flows.

Firstly, tumble vortex breakdown during the compression stroke of a square piston model engine is modelled. The results of the simulation are validated against published high quality experimental data. Both two- and three-dimensional models are tested, using the k-ϵ and Reynolds stress turbulence models. The Reynolds stress turbulence model simulations successfully predicted the tumble break down process during the compression stroke. A simple three-dimensional Large Eddy Simulation model is also presented.

The numerical simulation is then applied to the BRV engine. An in-cylinder flow field not previously described is discovered, created by the unique combustion chamber shape of the BRV engine. The flow field is not adequately described by the traditional descriptions of engine flows, being squish, swirl and tumble. The new flow structure is named “dual cross tumble”, and is characterised by two counter-rotating vortices in the cross tumble plane on either side of the inlet air jet.

Analysis of the dual tumble structure indicates that it is most beneficial in high bore to stroke ratio engines. This flow structure has been predicted or visualised by a small number of previous researchers, however no published research has recognised its significance or potential benefits. The validated code is then used to predict the effect of modifying the valve cross sectional area, the effect of the inlet manifold wave, the effect of heat transfer from the inlet manifold walls, the effect of bore to stroke ratio, and the effect of engine speed.

This work presents a numerical simulation of a new rotary valve engine technology. This opens up a whole new area of engine aerodynamics research as no detailed examination of the flows in a rotary valve engine have been presented previously. In the process, it discovers a new compression stroke turbulence generation mechanism, “dual cross tumble”, which offers the potential of performance levels not possible using poppet valve engines.