Contents

1 Introduction **1**

2 Physics of Fluid Dynamics **5**
2.1 Fundamental Equations of Fluid Dynamics 5
2.1.1 Equation of state 8
2.1.2 Fuel/Oxidizer Mixtures 9
2.2 Statistics of turbulent flows 10
2.2.1 Conventional and Favre averaging 10
2.2.2 The scales of turbulent motion 11
2.3 Mean principal conservation equations 14
2.4 RANS turbulence model equations 15

3 Premixed Combustion **19**
3.1 Physics of laminar flame propagation 20
3.1.1 The laminar Flamelet Equations 21
3.1.2 The Structure of Premixed Flames 24
3.1.3 Influences of strain and curvature 27
3.2 A Model for laminar flame propagation 30
3.3 Physics of turbulent flame propagation 32
3.3.1 The turbulent burning velocity 32
3.3.2 Regimes in premixed combustion 33
3.3.3 Approaches to modeling the turbulent burning velocity 35
3.4 Progress variable approaches 37
3.4.1 The Eddy-Breakup-Model 38
3.4.2 The Bray-Moss-Libby Model 39
3.4.3 Flame Surface Models 40
3.5 The Level Set approach 41
3.5.1 Unclosed mean flame front position equation 42
3.5.2 Unclosed equation for the flame brush thickness 45
3.5.3 Modeling closure 47
3.5.4 A dynamical equation for the flame surface area ratio 52

3.5.5 Behavior close to the wall . . . 54
3.5.6 Combining the presumed pdf shape approach with the flamelet equations . . . 57
3.5.7 Stratified mixtures . . . 58
3.6 Spark Ignition Modeling . . . 61
3.6.1 A Brief Literature Review . . . 61
3.6.2 A Spark Ignition Model Derived from the $\widetilde{G}$-equation . . . 62

4 Numerical Implementation **67**
4.1 General integration of the model into the CFD code . . . 67
4.2 Solving of model equations . . . 69
4.2.1 $\widetilde{G}$ equation . . . 69
4.2.2 $\widetilde{G''^2}$ equation . . . 72
4.2.3 $\widetilde{\sigma}_t$ equation . . . 72
4.3 Coupling of G-equation and heat release . . . 72
4.3.1 Determination of $\widetilde{P}_b$ . . . 73
4.3.2 Determination of a premixed volumetric reaction rate . . . 74
4.3.3 Model for thermodynamical states . . . 75

5 Validations **79**
5.1 Cylindrical Vessel experiment . . . 79
5.1.1 Experimental setup . . . 79
5.1.2 Cold Swirl Flow . . . 82
5.1.3 Validity of Flamelet/Heat release coupling . . . 83
5.1.4 Evaluation of different approaches for turbulent flame surface and turbulent curvature terms . . . 84
5.1.5 Discussion of results with swirl variation . . . 88
5.2 Homogeneous charge SI engine . . . 91
5.2.1 Setup for homogeneous charge . . . 91
5.2.2 Setup of numerical calculation . . . 92
5.2.3 Results . . . 92
5.3 Stratified charge SIDI engine . . . 100
5.3.1 Fuel injection . . . 102
5.3.2 Optically accessible engine . . . 102
5.3.3 Variation of engine speed and injected fuel mass . . . 108
5.4 Discussion . . . 115

6 Conclusions **119**

A The premixed turbulent reaction rate **121**

B Level Sets methods on unstructured grids **123**
B.1 Level Set Numerics 123
B.1.1 Introduction 123
B.1.2 Characteristics of the G-equation 124
B.2 Defining an Extension Velocity 125
B.3 The Fast Marching Method 127
B.4 Discretisation on an unstructured grid 128
B.5 Temporal integration 129

C Laminar Burning Velocity approximation **133**

D Turbulence prediction in the engine squish **141**

Bibliography **147**

Author's Index **157**

Nomenclature **161**