

**MULTI-DIMENSIONAL NUMERICAL SIMULATION OF SCAVENGE FLOW
IN A SMALL TWO-STROKE ENGINE**

Sameera Devsritha Wijeyakulasuriya



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations

This thesis is submitted to the Department of Mechanical Engineering

of the University of Moratuwa

in partial fulfillment of the requirements for the Degree of

Master of Science

Department of Mechanical Engineering

University of Moratuwa, Sri Lanka

October 2007

ACKNOWLEDGMENT

I'm grateful to the National Science Foundation of Sri Lanka, which funded me for this research. The Guidance and help rendered at every stage of this research by my supervisors Prof. Razi Nalim, Associate Professor, School of Mechanical Engineering, IUPUI, USA and Dr. A.G.T. Sugathapala, Head of Department, Mechanical Engineering, University of Moratuwa are appreciated with heart felt gratitude.

The assistance of, Mr. Indika Perera, Lecturer, Department of Mechanical Engineering, University of Moratuwa and the staff of the CAD Centre at the University of Moratuwa, and the assistance of Dr. S. A. Khalid and the staff of the Computer Networking Centre at IUPUI, USA are also acknowledged.

The support received from es-ice support team of CD-adapco towards resolving moving grid issues are also appreciated. Computing resources from Indiana University's AVIDD supercomputing cluster, VLSI supercomputer and academic licensing of STAR-CD were valuable in this work.

Visits to vehicle manufacturers and dealers were also helpful, and the insights of David Peries Motor Company, Sri Lanka, LML Industries, India, and Mr. Narayan Iyer (formerly of Bajaj Auto, India) are particularly appreciated.

Finally I'd like to thank my family for all the support and understanding throughout this research.

ABSTRACT

Computational study of scavenging flow in a typical small vehicle engine is accomplished using multi-dimensional moving-mesh unsteady and quasi-steady models. A representative two-stroke 5 port engine was selected and sectioned to measure the geometrical features of the transfer ports. The commercial codes Auto CAD and Pro-Engineer was used to model the cylinder and ports. The commercial code Star-CD was used to analyze the unsteady gas exchange process within the engine combustion chamber soon after combustion. Pressure boundary conditions were used to represent crankcase conditions and exhaust tail pipe conditions at the scavenge port inlets and the exhaust port exit respectively. The simulation was stated at top-dead-centre (TDC) after combustion, assuming no exhaust gas remained in the engine from the previous cycle. For moving-mesh calculation, a cycle simulation is performed in two stages, separated by a theoretical constant-volume combustion calculation. The TDC calculation was initialized using a preliminary simulation starting at the bottom-dead-centre (BDC) assuming no exhaust gas remained in the cylinder at the start of simulation at Parallel computing was used to run the simulation.

Both quasi-steady and transient simulations indicate that typical multi-port inlet placement and timing allow significant short-circuiting of mixture, consistent with emissions observations. Residual gas is well scavenged from the hemi-spherical head cylinder. Backflow of combustion gasses into the transfer ports were observed upon opening of the transfer ports which indicate an inadequate blow down period. The inlet angles of the mixture from transfer ports are oriented upwards towards the dome of the cylinder and are satisfactory. The relative positioning and orientation of the scavenge ports promote good mixing and helps to reduce the inflow velocities, though considerable short-circuiting is still present in the engine.

TABLE OF CONTENTS

| | Page |
|---|------------|
| LIST OF TABLES | vi |
| LIST OF FIGURES | vii |
| ABSTRACT..... | x |
| 1. INTRODUCTION | 1 |
| 1.1 Background..... | 1 |
| 1.2 Problem Identification | 2 |
| 1.3 Objectives | 4 |
| 1.4 Scope..... | 4 |
| 2. LITERATURE SURVEY..... | 5 |
| 2.1 Two-Stroke Engine Transportation Application..... | 5 |
| 2.2 The Role of Two- and Three-Wheel Vehicles in South Asia | 5 |
| 2.3 Vehicle Fleet Data in Asia Countries..... | 6 |
| 2.3.1 Vehicle Population in Sri Lanka..... | 7 |
| 2.4 Emissions from Internal Combustion Engines | 8 |
| 2.4.1 Carbon Monoxide | 9 |
| 2.4.2 Nitrogen Oxides..... | 9 |
| 2.4.3 Particulate Matter..... | 9 |
| 2.4.4 Sulfur Dioxide..... | 9 |
| 2.5 Pollutant Formation in Internal Combustion Engines | 10 |
| 2.5.1 Carbon Monoxide Formation..... | 10 |
| 2.5.2 Unburnt Hydro Carbon Emission Formtion | 10 |
| 2.5.3 Nitrogen Oxide Emission Formation | 13 |
| 2.5.4 Particulate Matter Emission Formation | 13 |
| 2.6 Economic Costs of Air Pollution in South East Asia | 14 |
| 2.6.1 Nepal..... | 15 |
| 2.6.2 Bangladesh..... | 16 |
| 2.6.3 Phillipines | 16 |
| 2.7 Sri Lankan Scenario..... | 17 |
| 2.8 Emission Standards..... | 19 |
| 2.9 Two-Stroke Engines..... | 21 |
| 2.10 Strengths and Weaknesses of Two-Stroke Engines..... | 25 |

| | Page |
|--|-----------|
| 2.11 Two-Stroke Engine Design Features | 27 |
| 2.12 Two-Stroke Scavenging Performance Parameters..... | 30 |
| 3. REDUCING EMISSIONS FROM TWO-STROKE ENGINES | 32 |
| 3.1 Introduction..... | 32 |
| 3.2 Reducing Emissions from Tw-Stroke Engines | 33 |
| 3.3 Reducing Scavenging Losses in Two-Stroke Engines..... | 33 |
| 3.4 Gasoline Direct Injection | 35 |
| 3.5 Gas Dynamic Considerations in Exhaust Manifolds of Two-Stroke Engines | 39 |
| 3.6 Computer Simulation of Two-Stroke Engines..... | 46 |
| 4. GOVERNING TRANSPORT EQUATIONS..... | 48 |
| 4.1 Conservation of Mass | 48 |
| 4.2 Conservation of Linear Momentum..... | 49 |
| 4.3 Conservation of Energy | 49 |
| 4.4 Constitutive Relations..... | 50 |
| 5. COMPUTATIONAL FLUID DYNAMICS..... | 51 |
| 5.1 Numerical Solvers..... | 51 |
| 5.1.1 Fully Implicit Scheme..... | 53 |
| 5.1.2 Crank-Nicolson Scheme | 54 |
| 5.1.3 Solution Algorithm | 55 |
| 5.1.4 The Algebraic Multi-Grid (AMG) Method..... | 58 |
| 5.2 Turbulent Modeling | 58 |
| 5.2.1 Specifying Turbulent Parameters..... | 60 |
| 5.2.1.1 Turbulent Intensity..... | 60 |
| 5.2.1.2 Turbulent Kinetic Energy | 61 |
| 5.2.1.3 Turbulent Length Scale..... | 61 |
| 5.2.1.4 Turbulent Dissipation Rate | 62 |
| 5.2.1.5 Specific Dissipation Rate | 62 |
| 5.2.2 Algebraic Turbulence Models..... | 63 |
| 5.2.3 One Equation Models | 63 |
| 5.2.4 Two Equation Models..... | 64 |
| 5.2.4.1 Standard k-epsilon Model | 66 |
| 5.2.5 Reynolds Stress Models..... | 67 |
| 5.2.6 Large Eddy Simulation | 68 |
| 5.2.7 Direct Numerical Simulation | 68 |
| 5.3 Boundary and Initial Conditions..... | 68 |
| 5.3.1 Wall Boundary Conditions | 68 |
| 5.3.2 Static Pressure Boundary Condition | 70 |
| 5.3.3 Attachment Boundary Condition | 71 |
| 5.3.4 Thermo-Physical Properties..... | 72 |

| | Page |
|---|------------|
| 6. METHODOLOGY OF THE STUDY..... | 74 |
| 7. MODELING AND SIMULATION OF SCAVENGE FLOW OF A TWO-STROKE ENGINE | 78 |
| 7.1 Introduction..... | 78 |
| 7.2 Sectioning of Engine..... | 78 |
| 7.3 Measuring | 79 |
| 7.4 Solid Modeling..... | 80 |
| 7.5 Mesh Generation..... | 81 |
| 7.6 Boundary and Initial Conditions used in the present work..... | 84 |
| 8. ANALYSIS OF RESULTS | 86 |
| 8.1 Quasi-Steady Simulation | 86 |
| 8.2 Transient Simulation..... | 90 |
| 8.3 Direct Fuel Injection | 98 |
| 9. CONCLUTIONS AND RECOMMENDATIONS..... | 100 |
| LIST OF REFERENCES..... | 102 |



LIST OF TABLES

| Table | | Page |
|-----------|---|------|
| Table 2.1 | Vehicle data by type and by country..... | 7 |
| Table 2.2 | Annual death tolls and estimated economic cost in US dollars in various cities or countries in Asia..... | 15 |
| Table 5.1 | Control parameter settings used for iterative SIMPLE calculation | 56 |
| Table 7.1 | Specifications of the engine | 78 |



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

LIST OF FIGURES

| Figure | Page |
|---|------|
| Figure 1.1 Two-stroke engine scavenging loss | 3 |
| Figure 2.1 Total registered population of each class of vehicle since 1990 | 7 |
| Figure 2.2 Yearly registration of vehicles since 1990..... | 8 |
| Figure 2.3 Sources of HC emissions | 11 |
| Figure 2.4 Mechanisms of pollutant formation | 14 |
| Figure 2.5 Pollutant data collected at Colombo fort in the month of January, 2006..... | 17 |
| Figure 2.6 Emission standards used in Asian countries | 21 |
| Figure 2.7 Different processes in a two-stroke engine | 22 |
| Figure 2.8 Loop scavenge engines | 24 |
| Figure 2.9 Cross scavenge engines | 25 |
| Figure 2.10 Through scavenge engines..... | 25 |
| Figure 2.11 Short-circuiting from a carbureted two-stroke engine | 27 |
| Figure 3.1 Emissions from different two-stroke technologies | 35 |
| Figure 3.2 Side injection vs. central injection..... | 37 |
| Figure 3.3 Direct injected two-stroke engine | 38 |
| Figure 3.4 Pressure variations at exhaust tail pipe in a two-stroke engine..... | 41 |
| Figure 3.5 Pressure pulse exiting the port | 42 |

| Figure | Page |
|-------------|---|
| Figure 3.6 | Expansion fan being reflected from the diffuser.....42 |
| Figure 3.7 | Reflected wave sucks in the exhaust and a compression wave is reflected 42 |
| Figure 3.8 | Reflected compression wave blocks the gas from escaping in to exhaust port..... 42 |
| Figure 3.9 | Exhaust port pressure vs. crank angle and port length..... 44 |
| Figure 3.10 | Velocity vectors at different crank angle showing blocking pulse and subsequent flow reversal..... 45 |
| Figure 5.1 | Attachment boundaries in cylinder and ports 72 |
| Figure 6.1 | Processes in transient flow simulation..... 76 |
| Figure 7.1 | Sectioning of the engine..... 79 |
| Figure 7.2 | Measuring of cylinder head 79 |
| Figure 7.3 | Booster port..... 80 |
| Figure 7.4 | Exhaust port..... 80 |
| Figure 7.5 | Assembled engine 80 |
| Figure 7.6 | Engine chamber modeled as one part 81 |
| Figure 7.7 | Surface mesh upon importing into Pro-Am 82 |
| Figure 7.8 | Mesh density made finer in ports..... 83 |
| Figure 7.9 | Volumetric mesh: piston at BDC..... 83 |
| Figure 7.10 | Mesh from es-ice..... 84 |
| Figure 7.11 | Boundary and initial conditions 85 |
| Figure 8.1 | Pressure contours at the central cross section 86 |
| Figure 8.2 | Velocity plots at central cross section 87 |
| Figure 8.3 | Particle tracks at average velocity fields showing short-circuiting..... 89 |

| Figure | Page |
|---|------|
| Figure 8.4 Blow down flow..... | 91 |
| Figure 8.5 Back flow..... | 91 |
| Figure 8.6 Static pressure at scavenge open..... | 92 |
| Figure 8.7 Flow across ports at BDC | 92 |
| Figure 8.8 Temperature Contours | 93 |
| Figure 8.9 Static Pressure Contours | 95 |
| Figure 8.10 Comparison of static pressure and velocity at BDC | 97 |
| Figure 8.11 Injector location | 98 |

