HAROLD J. SCHOCK, JR.
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EMPLOYMENT:

August 2007 - Present Michigan State University East Lansing, Michigan	Professor, Mechanical Engineering Director, Energy and Automotive Research Laboratory
Nov. 2004 – 2016 Beijing Institute of Technology Beijing, China	Visiting Professor
Dec. 2011 – 2016 Zhejiang Automotive Engineering Institute,	Honorary Professor (Participate in Lecture series)
November 1996 - 2007 Michigan State University East Lansing, Michigan	Professor, Mechanical Engineering Director, Automotive Research Experiment Station
January 1994 - November 1996 Michigan State University East Lansing, Michigan	Professor, Mechanical Engineering Director, Engine Research Laboratory
September 1987 - December 1993 Michigan State University East Lansing, Michigan	Associate Professor, Mechanical Engineering Director, MSU Engine Research Laboratory
May 1986 - August 1987 NASA Lewis Research Center Cleveland, Ohio	Deputy Chief, Turbine and Rotary Engine Technology Branch
May 1985 - May 1986 NASA Lewis Research Center Cleveland, Ohio	Head, Intermittent Combustion Engine Technology Section
May 1979 - May 1985 NASA Lewis Research Center Cleveland, Ohio	Research Engineer, Small Engine Propulsion Branch

EDUCATION:

Ph.D. Mechanical Engineering
Michigan Technological University
Houghton, Michigan 1979

"Simulation and Measurement of Dispersing Gaseous Exhaust Emissions from Diesel Engines in a Mine Environment"

M.S. Mechanical Engineering
University of Michigan
Ann Arbor, Michigan 1975

B.S. Mechanical Engineering (cum laude)
Michigan Technological University
Houghton, Michigan 1973

NASA LEWIS RESEARCH CENTER:

In Dr. Schock's position as Head, IC Engine Technology Section/Deputy Chief, Turbine and Rotary Engine Technology Branch, he supervised the research work of up to eight full-time NASA researchers and up to an additional eight summer faculty, co-op and summer students. The thrust of this work was to develop the technology for an advanced low heat rejection stratified-charge rotary engine for aircraft applications. As section advocate to upper management and general consultant, Dr. Schock primarily worked with stress analysis and materials. Dr. Schock was the Technical Leader over several research projects (see descriptions below).

Dr. Schock, using a Laser Doppler Velocimetry (LDV) system, developed and implemented experimental activity to obtain the first, simultaneous 3D velocity and turbulence measurements in a piston-cylinder configuration. This involved build-up of an LDV system and motored engine with optical access. Using laser speckle photography, a flow visualization was conducted to analyze the persistence of the vortical structures, which are formed during intake.

He coordinated the development of and participated in the implementation of operational codes, which simulate the multi-dimensional turbulent flow in internal combustion engines. These codes were developed on grants, with final implementation and extensive testing being carried out on the IBM-3033 or Cray at Lewis Research Center. A portion of this work includes displaying the first computer generated color movies of this type of experimental result.

Dr. Schock directed the build-up of a Wankel style Rotary Combustion Engine (RCE), fitting it with sapphire windows for optical access to the combustion chamber for airflow determination during the four-stroke cycle. The technique for performing this flow visualization was Holographic Interferometry. He was the co-developer of the first system to measure IMEP (cyclic work) in a rotary IC engine, a technique later adopted in every engine laboratory, worldwide.

He directed the build-up of a Holography Laboratory to produce custom holographic optical elements for aberration correction in Laser Doppler Velocimetry and for flow visualizations. These dichromated gelatin holograms had a high transmission efficiency permitting the use of power dense laser beams.

Dr. Schock was the NASA Technical Officer for several grants (see the list below). This duty included evaluation of solicited and unsolicited proposals; making recommendations to management; setting the direction and general approach for the work to be performed; and coordinating experimental and non-experimental activity. After grant award, the Technical Officer is responsible for ensuring timely progress and reporting of the results, giving technical assistance where appropriate, report editing, as well as lobbying with management for future support as needed.

- "The Two-Stroke Diesel Engine: A Numerical Simulation of the Flow Field, Flame Propagation and Emissions," Ramos, J. I., Principal Investigator, Carnegie-Mellon University, Pittsburgh, PA (5)*.

- "Study of Jet Ignition Using Liquid Fuels," Oppenheim, A. K., Principal Investigator, UC, Berkeley, CA (3).

- "Generalized Internal Combustion Engine Cycle Simulations: Direct Injection Stratified-Change Rotary Engine for Aircraft Applications," Heywood, J. B., Principal Investigator, MIT, Cambridge, MA (2).

- "A Dynamic Analysis of Rotary Combustion Engine Seals," Vilmann, C. R., Michigan Technological University, Houghton, MI (1).
- "Numerical Studies of the Fluid Flow, Heat Transfer and Combustion Processes Inside the Combustion Chamber of a Direct-Injected Stratified-Charge Rotary Engine," Shih, T. I-P., Principal Investigator, University of Florida, Gainesville, FL (3).

- "Study of Computer Graphic Display of Fluid Flow and Combustion in an Axisymmetric Piston Cylinder," White, P. R., Principal Investigator, University of Toledo, Toledo, OH (2).

*Number in parentheses indicates the number of years Dr. Schock was responsible for this activity.

PARTICIPATION IN GRADUATE EDUCATION OF OTHERS WHILE AT NASA LEWIS:

Carolyn Regan Mercer, M.S. Applied Optics, Cleveland State University, Co-Advisor with Professor Jim Lock. Thesis: "Flow Visualization within a Piston Engine," completed June 1986.

Jim Stegeman, M.S. Mechanical Engineering, University of Toledo (with his academic advisor Professor Phil White, providing technical supervision on thesis while at LeRC). Thesis: "IDDS - A Computer Graphics Package for Combustion and Flow Visualization," completed June 1986.

Mark Carpenter, Ph.D., Mechanical Engineering, Carnegie-Mellon University. (Served on thesis committee with his academic advisor, Professor J. I. Ramos, providing technical supervision on thesis while at LeRC). Thesis: "Numerical Simulation of a Two-Stroke Diesel Engine," completed June 1986.

DIRECTOR, MICHIGAN STATE UNIVERSITY (MSU), AUTOMOTIVE RESEARCH EXPERIMENT STATION (ARES) AND FOUNDER OF THE ENERGY AND AUTOMOTIVE RESEARCH LABORATORY(EARL):

The MSU Engine Research Laboratory (ERL) was launched in the fall of 1987 by Dr. Harold Schock. At that time there were no physical facilities or equipment for engine studies at MSU. Dr. Schock started out in a 500 square foot area with internal flow measurements in rotary engines, the work being sponsored by NASA. In 1992, the MSUERL group moved into a 5,000 square foot facility dedicated to the engine research activities. These activities are described in publications by Dr. Schock and his colleagues. Dr.

Schock located this building and lobbied the University Administration to purchase it, using money provided by Ford, General Motors, and Chrysler.

In the fall of 1997, the Provost authorized the establishment of the Automotive Research Experiment Station (ARES) to serve the University as a broad based organization with a primary, but not exclusive, focus on research. At this time, Dr. Schock was named Director of ARES. The organization enabled Michigan State University to continue to develop their leadership position for specific research activities within the auto industry. It has provided a model training ground for future leaders of the industry.

ARES represented an expansion of ERL related engine research and includes other energy related projects. The responsibility of the ARES Director includes supervision of the work of full time professionals, graduate and post-doctoral students. Graduate students and paid undergraduate assistants also participate in the ARES activities. Major equipment included dynamometers; a gamma ray spectrometer; one 45-watt Cu-vapor laser used for high speed film imaging for mass air flow sensors/motion studies and fuel spray studies; a high speed rotating prism camera; a rotating drum camera; a three-component LDV system; several single cylinder research engines; a rotary engine rig assembly; an electronic high pressure fuel injection system; emission measurement equipment; four modern workstations; and twenty personal computers. ARES acquired a laser-induced fluorescence system consisting of two Excimer lasers (one is tunable), ICCD camera, spectrophotometer and liquid vapor calibration hardware. Direct current and universal dynamometers have been installed and are at operational status at the Lab. Several water brake dynamometers are used for various projects. Hydraulic dynamometers are also available for use with small engines.

Unique experimental facilities have been brought into operational status using a MSU-developed laser diagnostic technique to map in-cylinder flows. This method, called Molecular Tagging Velocimetry, allows us to measure in-cylinder planar flows on a cycle-by-cycle basis. Currently, we are using these facilities to quantify the effects that charge motion control valves and active flow control devices have on in-cylinder motion. We believe that the capability to routinely measure in-cylinder planar flows (3D), without particles as tracers, can only be found at the MSU Automotive Research Experiment Station.

In the winter of 2007, Michigan State University opened the Engineering Research Center (ERC), South. The Energy and Automotive Research Laboratory (EARL) located in a new wing at ERC-South was established to expand the concept outlined in the Partnership for a New Generation of Vehicles (collaboration between the Federal Government and the Industry Leaders) and the Freedom Vehicle Program, to identify and stimulate expansion of current research, education, and outreach activities. In the fundraising effort led by Dr. Schock, nearly five million external dollars raised for the ERC-South facility construction. The architects were chosen by Professor Schock and approved by the MSU facilities and planning group through their normal processes. This effort included interactions at the senior level of management at Ford, GM, and DaimlerChrysler, as well as obtaining Alumna solicitations. Dr. Schock has a working relationship with the Michigan U.S. Congressional Delegation, the State of Michigan Representatives, and members of Congress. Activity in the $12 million facility focuses on improving engine efficiency, reducing vehicle emissions, investigating the new powertrain concepts including hybrids and evaluating alternative energy sources. This facility includes a powertrain laboratory capable of conducting experiments with a six-wheel drive vehicle. There are currently 8 operational dynamometers in the new ERC-South facility. Five ME faculty, six staff and about 25 graduate students currently occupy this facility, supported by dozens externally funded projects. A 2010 EARL addition increased the capacity of this facility to over 50 graduate students with 2 ChE/MS Faculty and their students conducting thermoelectrics and battery research, sharing thermoelectric material processing facilities with Professor Schock's group. In March, 2013, EARL was formally established as a College of Engineering Center with Professor Schock as the first Director. Since the EARL Center opened in 2007, over $40M in sponsored research has been conducted in this facility.

SUPERVISION OF GRADUATE STUDENTS AT MSU AS MAJOR PROFESSOR:

1. Tom Stuecken, M.S. Agricultural Engineering Technology, Co-Advisor with Professor T. Burkhardt, "Design and Development of a Two-Stroke Overhead Valve Piston Engine," completed 6/1989.
2. Emil Chouinard, M.S.M.E., "Internal Flow Studies in a Rotary Combustion Engine," completed 6/1990.
3. Yooseok Chung, M.S.M.E., "Ion Implantation for Wear Analysis," completed 8/1989.
4. Todd Rachel, M.S.M.E., "Ion Implantation for Wear Studies," completed 3/1991.
5. Lorna Clowater, M.S.M.E., "Flow Visualization Using a Fiber Optic-Based System," completed 8/1991.
6. Craig Olbrich, M.S.M.E., "Development of SURFMAP, a Surface Mapping System," completed 12/1991.
7. Mike DeFilippis, M.S.M.E., "Internal Flow Studies in a Rotary Combustion Engine," completed 6/1992.
8. Dick Barkman, M.S.M.E., "Evaluation of the Parameters Involved in Wear Studies Using Surface Layer Activation," completed 8/1992.
9. Yooseok Chung, Ph.D., "Development of a Fire Ring Wear Model for a Piston Engine," completed 8/1992.
10. Roy Schafer, M.S.M.E., "The Development of an Improved Quantitative Calibration for an Exciplex Liquid/Vapor Fuel Visualization System," completed 8/1993.
11. Dan McCarrick, M.S.M.E., "Flow Studies in an Automotive Torque Converter Using Laser Doppler Velocimetry," completed 4/1994.
12. S.C. Yoo, Ph.D., "An In-Cylinder Air Flow Study in a Four-Valve SI Engine by Three-Dimensional LDV Measurements and High Speed Flow Visualization," completed 4/1994.
13. Ajit Venkataraman, M.S.M.E., "Image Tiling for Profiling Large Objects," completed 9/1994.
14. Hans G. Hascher, M.S.M.E., "Design of a Telemetry System between the Piston and the Crank Case of a Combustion Engine," completed 9/1994.
15. K.S. Hwang, M.S.M.E., "Flow Studies in a Catalytic Converter Assembly under Transient Conditions," completed 12/1994.
16. John Mueller, M.S.M.E., "Three Dimensional Analysis of Tumble and Swirl in a Piston Cylinder Assembly," completed 5/1995.
17. Yolanda Hicks, Ph.D., "Multi-Dimensional Measurements in Flame Tube and Sector Gas Turbine Combustions," completed 5/1996.
18. Kasser Jaffri, M.S.M.E., "A Volumetric Quantification of In-Cylinder Flow Motion Inside a Four-Valve SI Engine Using Three-Dimensional Laser Doppler Velocimetry," completed 8/1996.
19. Jong Uk Kim, Ph.D. (co-advised with B. Golding, Physics), "Visualization of Two-Phase Fluid Distributions Using Laser-Induced Exciplex Fluorescence," completed 8/1997.
20. Lawrence Dalimonte, M.S.M.E., "Measurements of Flows in the Impeller and Turbine Side of an Automotive Torque Converter at 0.4 and 0.8 Speed Ratios," completed 5/1998.
21. Jon Darrow, M.S.M.E., "Development of an Optical Accessible Engine and Premixing System for Analysis of a Direct Injected Engine Using Laser Induced Fluorescence," completed 5/1998.
22. Matthew Foster, M.S.M.E., "A Quantitative Study of Primary Flow Fields within an Automotive Torque Converter Using Laser Doppler Velocimetry," completed 8/1998.
23. Mikhail Ejakov, Ph.D., "Ring Pack Behavior and Oil Consumption Modeling in IC Engines," completed 8/1998.

24. Hans G. Hascher, Ph.D., “The Influence of Speed, Stroke and Load Variations on the Major In-Cylinder Flow Patterns of a Four-Valve SI-Engine,” completed 11/1999.
25. Steven George, M.S.M.E., “Design of a High Compression, Direct-Injection, Spark-Ignition Methanol Fueled Research Engine with an Integral Injector-Ignition Source Insert,” completed 8/2000.
26. Xin Zhang, M.S.M.E., “Dynamic Flow Study in a Flow Oscillating System Using Laser Doppler Velocimetry and Numerical Simulation,” completed 8/2000.
27. Stephen Yen, M.S.M.E., “Establishment of Cylinder Kit Design Guidelines for Four-Stroke Internal Combustion Engines Using Numerical Simulations,” completed 12/2000.
28. Boon Keat Chui, M.S.M.E., “Computational Analysis of Piston Ring Wear and Oil Consumption for an Internal Combustion Engine,” completed 6/2001.
29. Anthony Christie, M.S.M.E., “Computational Analysis of a 4-Stroke Engine using Kiva-3V,” 2002.
30. Andrew Fedewa, M.S.M.E., “The Effect of Active Flow Control on In-Cylinder Flow and Engine Performance,” completed 2002.
31. Yuan Shen, Ph.D., “Development of a Basis for Control of Combustion in an Internal Combustion Engine,” completed 2003.
32. Joshua Bedford, M.S.M.E., “Instantaneous Measurements of Cycle-to-Cycle Variability in Fuel Injectors," completed 2004.
33. Boon Keat Chui, PhD., “Elastohydrodynamic Modeling and Measurement of Cylinder-Kit Assembly -Tribological Performance,” completed 6/2005.
34. Andreas Panayi, M.S.M.E., “Piston Design and Analysis: Parameterized and Complete Finite Element Analysis Approach for the Assessment of Piston Performance,” completed 5/2006.
35. Kimberly Sarbo, M.S.M.E., “Design of Experiments for Thermoelectric Materials,” 8/2006.
36. Yuxin Zhang, M.S.M.E., “A Numerical Study of the Mixture Preparation Process in a GDI Engine,” completed 2007.
37. Jia Ma, Ph.D., “Development of the Infinity Variable Valve Timing and Lift in an IC Engine,” completed 2007.
38. Andrew Hartsig, M.S.M.E., “Thermoelectric Conversion of Waste Heat to Electricity in an IC Engine
39. Powered Vehicle: An Engine Modeling Approach,” completed 5/2008.
40. Mayank Mittal, Ph.D., “The Development of Stereoscopic Molecular Tagging Velocimetry (MTV) for In-Cylinder Flow Field Measurements,” 12/2009.
41. Andreas Panayi, Ph.D., “On the Evaluation of Piston Secondary Dynamics,” completed 5/2009
42. Andrew Huisjen, M.S.M.E., “Application of an Electronically Controlled Pneumatic Valve Actuator Strategy on an Ethanol Engine,” completed 5/2010.
43. Cody Squibb, M.S.M.E., “Infrared Analysis of Fuel Spray and Combustion in Diesel Engines,” completed May, 2009
44. Matthew Lyle, M.S.M.E., “Advanced Thermoelectrics for Energy Recovery,” completed 5/ 2011.
45. Cody Squibb, M.S.M.E., “Experimental Measurements and Analysis of In-Cylinder Fuel-Air Mixing and Combustion Using an Optical DI Diesel Engine Under Realistic Operating Conditions” completed May, 2009, Ph.D., 2012
46. Andrew Huisjen, PhD., “Homogeneous Charge Compression Ignition Steady State Operation and Mode Switch with Two-Step Cam and Phasing System in Metal and Optical Engines,” completed, Dec. 2013
47. Chao Chang, PhD., “Cylinder Wall Tribology Under Cold Starting Conditions,” expected completion, 2013
48. Charles Maines, MSME, “Advanced Combustion System Design Strategy,” expected completion in 2014
49. Ravi Vendula, PhD, “Development of Molecular Tagging Velocimetry for Engine Flows with Air as the Working Fluid,” expected completion in 2015
50. Vasya Ivanov, MSME, “Development of a Bismuth Telluride Thermoelectric Generator for a

Vehicle with 3.5 L Ford Ecoboost Internal Combustion Engine," completed December, 2013
51. James Holly, MSME, "Engine Modeling: Valve Timing Lift Profiles," completed, May 2014
52. Nariman Mansouriboroujeni, PhD, "Design Considerations and Estimated On-Vehicle Performance for a Compression-Couple Based Thermoelectric Generator," completed November, 2015.
53. Sedigheh Tolou, PhD, "Lean Burn Engines for a Low CO2 World," completed, Feb. 2019.
54. Joshua Myers, MSME, "Energy Flow of a Direct Injection SI Engine," completed, May 2017.
55. Ali Kharazmi, PhD, "Piston Assembly Study Using CASE Program," completed, December 2017
56. Cyrus Ashok Arupratan Atis, PhD, "Development of Advanced Combustion Systems for Modern Lean Burn Engines," completed, January, 2021.
57. Sabah Chowdhury, "3D Modeling and Validation of Cylinder-kit Processes ….," PhD completed, 6/2021
58. Yidnekachew Messele Ayele, "Experimental Analysis and Model Development of Dual Mode, Turbulent Jet Ignition (DM-TJI) Engine Operating with Gasoline and Alternative Fuels," PhD completed June, 2022
59. Daniel Nicklowitz, "Application of Abrasive Coatings to an IC Engine Cylinder," PhD in progress, expected completion 2025
60. Fawaz Imtiaz, PhD in progress, expected completion 2025

SUPERVISION OF MSUERL STAFF AT MICHIGAN STATE UNIVERSITY:

1. Dr. Fakhri Hamady, 1989 - 1992, Research Scientist, MSUERL
2. Mr. Tom Stuecken, 1989 - present, Manager of the MSUARES
3. Dr. Keunchul Lee, 1992 - 1999, Research Scientist, MSUERL
4. Mr. Mark Novak, 1994 - 2003, Software Development Engineer, MSUERL
5. Dr. Bassem Ramadan, 1994 - 1998, Research Scientist, MSUERL
6. Dr. Yu Liang Lin, 1998 - 2001, Post Doctorial, Research Scientist, MSUERL
7. Mr. Edward Timm, 1999 - 2015, Research Specialist, MSUARES
8. Dr. Kyle Judd, 1999 - 2001, Post Doctorial, Research Scientist, MSUERL
9. Dr. Yuan Shen, 2001 - 2005, Post Doctorial, Research Scientist, MSUERL
10. Dr. Murad Ismailov, 2002 - 2006, Research Scientist, MSUERL/Combustion Dynamics Corp.
11. Ms. Melissa Flegel, 2005 - present, Secretary II, MSUARES
12. Ms. Jan Chappell, 1999 - 2004 & 2008 - 2012, Research Assistant I, MSUARES
13. Mr. Dustin Baker, 2008 Research Assistant I, MSUARES
14. Mr. Trevor Ruckle, 2008 - 2015, Research Assistant I, MSUARES
15. Dr. Elisa Toulson, 2009 - 2011, Research Associate, MSUARES
16. Ms. Terri Wing, 2009 - 2010, 2012-present, Technical Assistant, MSUARES
17. Mr. Kevin Moran 2009 - present, Research Specialist, MSUARES
18. Mr. Jeff Higel, 2009 - present, Machinist, MSUARES
19. Mr. Gary Keeney, 2009 - 2015, Machinist, MSUARES
20. Dr. Andreas Panayi, May 2010 - 2011, Research Associate, MSUARES
21. Ms. Jennifer Higel, 2010 – 2018, Technical Assistant, MSU EARL
22. Mr. Brian Rowley, 2012 – present, Machinist, MSU EARL
23. Ms. Kathy Chomas, 2013 – 2017, Research Administrator I, MSU EARL
24. Mr. John Przybyl, 2015 – present, Machinist, MSU EARL
25. Mr. Brian Deimling, 2016 – 2020, Machinist, MSU EARL

PROFESSIONAL SOCIETIES/AWARDS/SERVICE:

Named First Gardener Professor of Mechanical Engineering, July 1, 2020. Distinguished Faculty Award, Michigan State University, 2/8/2011; Withrow Distinguished Scholar-Senior Award, Michigan State University, March 2009; The 2009 National Academies, Board on Environmental Studies and Toxicology, Certificate of Appreciation for Outstanding Service; (2004) SAE International Member Service Award - in recognition of 25 years active member; Michigan Economic Development, Lansing Regional Chamber, (2006) 21st Century Jobs Fund Recipient; National Research Council, Committee on State Practices in Setting Mobile Source Emissions Standards, (2004 - 2006); nominated Robert Hubbard (retired MSU Professor) as an SAE Fellow, awarded 2007. Adjunct Professor, Beijing Institute of Technology, April 2006, Michigan Technological University, Academy of Mechanical Engineering and Engineering Mechanics Award, in the "Recognition of Significant Contributions to the Engineering Profession," (Sept. 21, 2002); Fellow - Society of Automotive Engineers, (March 4, 2002); SAE "Service Recognition Award"; Mid Michigan, SAE, Earl R. Wilson, Sr., "Engineer of the Year Award," 2002; Board Member of Central States Section of the Combustion Institute (1998 - 2002); participant in the SAE Advanced Power Plant Committee (1988 - present); Michigan State University, Supervisor SAE Student Group Formula Car Project (2/88 - 9/1995); member of the National Research Council Mobile Electric Power Plant Committee (1987 - 1989). Consultant to: Meyer Company (1987 - 2000); Department of Energy (1986 - 1987), Cleveland Clinic (1986 - 987). MSU ME Department Activity: University Automotive Advisory Committee (1996 - 2004); Graduate Studies Committee (1995 - 1997); Minority Recruitment Committee (1991 - 2005); elected to Promotion Committee (1989, 1992); elected to the ME Long Range Planning Committee (1989 - 1991); elected to the ME Faculty Advisory Committee (8/1988 - 8/1990), served on Seminar Committee (Spring, 1988). Appointed Supervisory Aerospace Engineer, NASA Lewis Research Center, by competitive placement, Cleveland, Ohio, March 1985; "Window Aberration Correction in Laser Velocimetry Using Multifaceted Holographic Optical Elements," Schock, H. J., Case, S. K., and Konicek, L. Nominated for the LERC, Research Center Best Paper of the Year Award, Propulsion Systems Division, NASA Lewis Research Center, Cleveland, Ohio, (1984).

ADVISOR OF SAE FORMULA CAR, STUDENT GROUP - AWARDS RECEIVED:

Exhibit and Display Professionalism, 3rd Place, SAE Congress and Exposition, Detroit, Michigan, (1990); Exhibit and Display Professionalism, 2nd Place, SAE Congress and Exposition, Detroit, Michigan, (1991); Team Sportsmanship Award, SAE Formula Car Competition, Warren, Michigan, (1991); Exhibit and Display Professionalism, 2nd Place, SAE Congress and Exposition, Detroit, Michigan, (1992); Safety and Crashworthiness Award, 1st Place, SAE Formula Car Competition, Pontiac, Michigan, (1994).

CURRENT/RECENT CONTRACT/GRANT ACTIVITY:

Aramco Services, Novi, Michigan, "Demonstration of a Prototype IV Jetfire Engine," $150,000, PI Harold Schock, August 1, 2022 to Dec 30, 2022.

MTRAC and MSU matching funds, Jetfire Ignition for High-Efficiency Gasoline Engines, Harold Schock PI, $100,000 August 1, 2019 to October 31, 2020

US Army Phase I, Mid Michigan Research, Sole Member, Harold Schock, JP-8 Conversion Kit for Small Spark Ignition Engines Using Jetfire Technology, May 2019-March 30,2020, $108,000

- Subcontract to Professor Carl Lira: Fuel Fractionation for Jetfire Ignition Engines
- Subcontract overseen by Professor George Zhu, Testing of JP-8 Fuel in a Jetfire Engine

(Note: All subcontracts from MMR to MSU went through the MSU contracts and grant system with appropriate approvals including Board of Trustee Approval for working with an employee owned company)

State of Michigan Funding, SBDC – Emerging Technology Fund, Mid Michigan Research April 24, 2020 – Dec. 31, 2020, Amount: $25,000 Matching Funds for Phase I SBIR Award "JP-8 Conversion Kit for Small Spark Ignition Engines Using Jetfire Technology."

US Army Phase I Option, Mid Michigan Research, Jetfire Ignition for Low-Compression-Ratio Gasoline Engines, Awarded November, 2021, $54,000, Supports continuation of Phase I work until Phase II contract finalized. Phase I Options awarded after a project has been chosen for Phase II.

US Army Phase II, Mid Michigan Research, "Design and Demonstration of a JP-8 fueled Piston Jetfire Engine," award selection September 21, 2020, period of performance January 1, 2021- June, 2023, Award Amount: $1,100,000

Engines," Used by Cummins and others since about 2007, developed on an Army SBIR Phase I and Phase II program which ended about 2003. This code has influenced the design of millions of Cummins engines, Detroit Diesel engines, Ford engines and others.

Note: Current MMR Employees include: Dr. Lawrence Brombolich, Ms. Jennifer Higel, Mr. Scott Baeder, Dr. Andreas Panayi, Mr. Gary Hunter, Mr. Brian Fedewa and Mr. Scott Leonard. No MMR employees have an affiliation with MSU. MMR subcontracts work to MSU and others within government regulations and those of participating organizations.

PAST GRANTS & AWARDS WHILE AT MICHIGAN STATE UNIVERSITY:

Aramco FFS Contract, PI: Harold Schock, "Testing Strategy of Aramco Directed Metal Engine Components," April 15, 2020 extended to Dec. 31, 2020. $50,000,

Fiat Chrysler Automobiles US LLC, Single Cylinder Engine Testing Support for 3D Combustion Model Validation, Harold Schock PI. extension to project below due to FCA requested testing changes

Fiat Chrysler Automobiles US LLC, Single Cylinder Engine Testing Support for 3D Combustion Model Validation, Harold Schock PI, Gouming Zhu, Co-PI, $475,600, 4/13/17 to 6/30/19

Hanon Industries, Harold Schock (PI), 3 Dimensional Simulation of PPS-GS40 Centrifugal Pump, Modeling Tesla Mosdel S Cooling, $90,000, 6/30/18-1/31/19

Environmental Protection Agency, Harold Schock (PI), Christopher Saffron, Thomas Voice, Giles Brereton, Guoming Zhu "Engineering and Environmental Policy Research to Reduce Greenhouse Gases (GHG) from Terrestrial Transportation while Providing the Scientific Basis and Required Experience for Future Global Policymakers," $1,000,000, 12/18/15-6/30/19

Michigan Economic Development Corporation, Harold Schock (PI), "Engineering and Environmental Policy Research to Reduce Greenhouse Gases (GHG) from Terrestrial Transportation while Providing the Scientific Basis and Required Experience for Future Global Policymakers," $200,000, 4/15/16-6/30/19

Tenneco Automotive Operating Company, Harold Schock (PI), "Engineering and Environmental Policy Research to Reduce Greenhouse Gases (GHG) from Terrestrial Transportation while Providing the Scientific Basis and Required Experience for Future Global Policymakers, "$400,000, 6/15/16-6/30/19

Ford Motor Company, Harold Schock (PI), "Particulate Formation and Control in Direct Injected Engines," $196,386, 9/8/16-12/31/16

US Department of Energy, "High Efficiency Clean Combustion Flex Fuel Optimized SI and HCCI Engine," 01-01-2010 09-30-2013, $694,172; Harold J Schock and Guoming G Zhu, (PI).

Environmental Protection Agency, "Engine Research and Development for Future Advanced Vehicle Technologies That Will Improve Fuel Efficiency and Reduce Emissions," 06-30-2010 - 2014, $800,000: Harold J Schock, (PI).

Defense Logistics Agency, "Advanced Biofuels as JP-8 Replacements for Aviation and Ground Applications," 04-01-2011- 03-30-2014 $4.6M; Harold Schock,(PI) Kris A Berglund, Giles J Brereton, Farhad Ansari Jaberi, Carl Thomas Lira, Dennis John Miller.

Science Applications International Corporation, "Advanced Hybrid Electric Powertrain Program," 03-01-2011-04-30-2013, $1,827,276; Harold J Schock, (PI). Elias G Strangas and Bingsen Wang, Guoming G Zhu.

US Department of Energy, Energy Frontier Research Centers, PI: Donald T. Morelli, Co-PIs: Harold Schock (18 co-PIs), "Revolutionary Materials for Solid State Energy Conversion," $10,625,000, 8/1/2009 - 7/31/2014.

Benteler Automotive, PI Harold Schock, Development of High Efficiency EGR Coolers, $200,000, 12/30/12 – 12/30/13

Aramco Services. Harold Schock (PI), Guoming Zhu, "Consortium on Applications of Thermoelectrics to Convert Waste Heat to Electricity", $450,000, 4/12/13 – 11/30/15

Tenneco. Harold Schock(PI), Guoming Zhu, "Consortium on Applications of Thermoelectrics to Convert Waste Heat to Electricity", $450,000, 9/13/13 – 11/30/15, verbal approval pending final contract details

Chrysler Corporation, Harold Schock (PI), Guoming Zhu "Characterizing Fuel-Air Mixing, Fuel Influences and Combustion Events Over a Wide Range of Speeds and Loads for FCA Engines," 6/17/15-2/29/16, $546,753

National Science Foundation, Elisa Toulson (PI), Harold Schock, Guoming Zhu, Indrek Wichman, Farhad Jaberi, Giles Brereton "NSF/DOE Partnership on Advanced Combustion Engines- Modeling and Experimental Studies of Controllable Cavity Turbulent Jet Ignition Systems," 9/11/15-8/31/16 $1,300,000

- US Department of Energy, "Novel Biofuel Formulations for Enhanced Vehicle Performance," 10-01-2007 09-30-2012, $1,715,506; Kris A Berglund, Farhad Ansari Jaberi, Tonghun Lee, Carl Thomas Lira, Dennis John Miller (PI), Ramani Narayan, Harold J Schock.
- US Department of Energy, "Thermoelectric Conversion of Waste Heat to Electricity in an IC Engine Powered Vehicle" 01-01-2005 03-30-2011, $4,423,322; Harold Schock (PI), Eldon D Case, Tim Hogan, M G Kanatzidis, Fang Zheng Peng, Jeff S Sakamoto.

- Defense Logistics Agency, "Advanced Biofuels as JP-8 Replacements for Aviation and Ground Applications," 05-16-2009 05-15-2010, $2,790,000; Harold Schock,(PI) Kris A Berglund, Giles J Brereton, Ling-Shun Hung, Farhad Ansari Jaberi, Carl Thomas Lira, Dennis John Miller.
- Michigan Economic Development Corporation, Lansing Regional Chamber, - 21ST Century Jobs Fund, PI: Elias Strangas, Co-PI's: Harold Schock, Fang Peng, and Ronald Averill, "Development and Demonstration of a Low Cost Hybrid Drive Train for Medium and Heavy Duty Vehicles," $2,425,851, January 18, 2007 – December 31, 2010.
- Michigan Economic Development Corporation - 21ST Century Jobs Fund, PI: Harold Schock, Co-PI's: Farhad Jaberi, and Giles Brereton, "Advanced Ethanol Tolerant Engines," $1,443,689, December 21, 2006 - December 31, 2010.
- Environmental Protection Agency, PI: Harold J. Schock, Co-PI: B. Ramadan,
"Experimental and Numerical Investigations of Advanced Clean Diesel Combustion Systems," $800,000, September 1, 2005 - March 30, 2010.
- US Department of Energy, MAHLE Powertrain, Harold J. Schock, "Optimally Controlled Flexible Fuel Powertrain System," 7/1/08 - 6/30/09, $115,897
- Science Applications International Corporation, PI: Harold Schock, Co-PI: Guoming Zhu, "Preparation of Test Cell and Testing of Autonomous Platform Demonstration (APD)," 3/28/09 - 02/02/2010, $1,254,534.
- Office of Naval Research - Northwestern University, PI: Timothy Hogan, Co-PI's: Eldon Case, and Harold Schock, (M. Kanatzidis, Northwestern University) "Nanostructured Chalcogenide-Based Thermoelectric Materials for High Efficiency Energy Conversion: Design and Application," 7/1/2008 - 6/30/2011, $666,750. (7/1/08-6/30/09 = $235,610; 7/1/09 - 6/30/2010 = $212,265; 7/1/2010 - 6/30/2011 = $218,875).
- Office of Naval Research, Tim Hogan, Eldon D. Case, Harold J. Schock, "DURIP: Powder Processing Instrumentation for Thermoelectrics Research," $263,545, March 9, 2007 – June 30, 2008.
- Multi-University Research Initiative, Office of Naval Research, PI: Mercouri Kanatzidis, Co-PI's: John, L. McCracken, Harold Schock Timothy Hogan, Eldon Case, and S. D. Mahanti, "Development and Application of High Efficiency Thermoelectric Materials for Power Generation," Five Year Proposal, $5,455,311, Plus MSU Cost Share 100k Per Year, 3 Years. Dr. Schock Co PI., May 1, 2003 - June 30, 2008.
- US Department of Defense, Tim Hogan, Eldon D. Case, Harold J. Schock, "Advanced Soldier Thermoelectric Power System for Power Generation from Battlefield Heat Sources," $278,464, May 9, 2008 – April 30, 2009.
- Department of Energy, "High-Compression-Ratio; Atkinson-Cycle Engine Using Low-Pressure Direct Injection and Pneumatic-Electronic Valve Actuation Enabled by Ionization Current and Forward-Backward Mass Air Flow Sensor Feedback," PI: Harold J. Schock, Co-PI's: Giles Brereton, Farhad Jaberi, George Zhu, $675,647, July 1, 2005 - June 30, 2007.
- General Motors Powertrain, General Research Gift, Unrestricted Grant For ARES Research Projects, "General Motors Powertrain & Michigan State University, Satellite Laboratory for Powertrain Research, Engineering, Design, and Testing," $100,000 per year for 5 years, total $500,000. 2001 – 2006.PI:Harold Schock
- Mid Michigan Research, "Diesel Test Engine Setup," $15,000, December 1, 2007 – December 31, 2007. PI:Harold Schock
- Mid Michigan Research, "Diesel Common Rail Injector Driver," $15,000, November 1, 2006 - November 30, 2006. PI: Harold Schock
- Mid Michigan Research, "Direct Injector Test Bench Assembly/Demonstration," $15,000, August 1, 2006 - August 30, 2006. PI: Harold Schock
- Mid Michigan Research, "Diesel Injector Signal/Spray Testing," $15,000, June 1, 2006 - June 30, 2006. PI: Harold Schock
- Mid Michigan Research, "Direct Injector Test Bench Assembly/Demonstration," $15,000, May 1, 2006 May 31, 2006. PI: Harold Schock

- Visteon Corporation, Testing, "Single Cylinder Engine Tests," $10,000, February 14, 2005 - February 25, 2005. PI: Harold Schock
- Visteon Corporation, Testing, "Dynamic Testing of Mass Air Flow Meter," $2,500, February 14, 2005 - February 18, 2005. PI: Harold Schock
- Mid Michigan Research, "Development of a Diesel Engine Management System - Part 1," $15,000, December 1, 2005 - December 31, 2005. PI: Harold Schock
- Environmental Protection Agency, "Numerical and Experimental Studies on New Engine Concepts to Improve Fuel Efficiency and Reduce Engine Emissions - Development of Advanced Internal Combustion Concepts for the 21st Century," $420.000, March 28, 2003, 6/1/2003 - 5/31/2005. PI:Harold Schock
- Mid Michigan Research, "Measurement of Cylinder Wall Oil Film Thickness Using Fluorescence Imaging Part VIII," $10,000, April 25, 2005 - May 6, 2005. PI: Harold Schock
- Center for Sensor Materials, National Science Foundation, Materials Science Research and Engineering Center, (with 12 PI's) also sponsored by State of Michigan, Research Excellence Fund, "Flow Visualization," $5,200,000, 2002 – 2006 (PI: M. Kanatzidis, Co-PI's: Harold J. Schock, others).
- Nantomics, Inc., "Evaluation of the Nantomics Meter, A Dynamic Fuel Measurement System," $33,000, June 2002. PI: Harold Schock
- Midwest Custom Services, "Evaluation of the Effect that Subject Fire Extinguishment had on a Hatz Diesel Engine," $7,000, 2/8/2002. PI: Harold Schock
- Center for Sensor Materials, National Science Foundation, Materials Science Research and Engineering Center, $75,000, 1/31/2002 - 1/4/2003.
- CFMR Block Grant Proposal, "Fuel Cell Science and Technology," Project Leader: Greg Swain; Team Members: Harold Schock, Greg Baker, Gary Blanchard, Merlin Bruning, Simon Garrett, Jes Asmusson, and Tom Grotjohn, Michigan State University; Andrzej Wieckowski, University of Illinios; Terry Hu and Jim McIntyre, Dow Chemical, $285,000, 2 years, 2002 - 2004.
- Environmental Protection Agency, "Experimental and Numerical Evaluation of the Effect of Exhaust-Gas-Recirculation, Swirl, Piston-Bowl and Fuel-Injection on Fuel-Air Mixing, Combustion and Emissions in an Advanced DI Alternative Fueled Engine," $861,673, 3/1/2001 - 12/31/2002, PI: Harold J. Schock, Co-PI's: B. Ramadan.
- The Eberhard Foundation, Unrestricted Grant – General Research Gift, "Improve the Performance of Internal Combustion Engines," $7,000, February 22, 2002. PI: Harold Schock
- Halo Spark Plug, Inc., Research and Development, "Flame and Combustion Analysis for Spark Ignited Engines," $4,500, 2001. PI: Harold Schock
- The Eberhart Foundation, General Research Gift, "Improve the Performance of Internal Combustion Engines," $8,000, Oct. 18, 2001. PI: Harold Schock
- Ford Motor Company, "3D In-Cylinder Flow Characterization Using Laser Diagnostic Techniques," $122,500, 1/01/2000 - 12/31/2000. PI: Harold Schock
- Ford Motor Company, "Research on Generating Reproducible Flows in Internal Combustion Engines," Open dates, $100,000. PI: Harold Schock
- Department of Energy and Ford Motor Company, "Active Flow Control for Maximizing Performance of Spark-Ignited Stratified Charge Engines," $998,635.00. PI: Harold J. Schock, Co-PI's: Giles Brereton, Tom Shih, Manoochehr M. Koochesfahani, Ford cost share $200,000, 5/16/1999 - 7/31/2002.
- DaimlerChrysler Corporation, "Three Dimensional In-Cylinder Flow Characterization of 3.5L 4-V Direct Injection SI Engine Using Laser Diagnostic Techniques," $204,226, 5/1/1999 - 4/30/2001. PI: Harold Schock
- Environmental Protection Agency, "Experimental and Numerical Evaluation of Fuel-Air Mixing and Performance of Alcohol-Fueled Two and Four Stroke Direct Injection Stratified Charge Engines," $780,000, 1/01/1999 - 12/31/2000. PI: Harold Schock
- Delphi Automotive, "Measurement and Visualization of Flows in a Mass Airflow Sensor Assembly," $29,900, 5/1/1999 - 8/30/1999. PI: Harold Schock

- Center for Sensor Materials, National Science Foundation, Materials Research Science and Engineering Center, PI: B. Golding, Co-PI's: Harold J. Schock(in obtaining 5 year renewal)and 12 others, also sponsored by State of Michigan, Research Excellence Fund, $5,200,000, 9/1/1998 - 8/31/2002.
- Chrysler Corporation, "Flow Studies in a Chrysler Head Assembly," $60,000, 3/1/98 - 2/28/99. PI: Harold Schock
- MSU Manufacturing Research Consortium, "Studies of Fuel Distribution in an IC Engine," $55,000, 7/1/1997 - 8/30/1998. PI: Harold Schock
- Ford Motor Company, "Detailed Measurements for In-Cylinder Flow Velocities and Tumble Intensities for 4.6L SI Tumble Engines," $125,000, 1/1/1997 - 12/31/1997. PI:Harold Schock
- Ford Motor Company, "Three-Dimensional Measurement of Flows in the Impeller and Turbine Side of an Automotive Torque Converter at .4 and .8 Speed Ratios," $50,000, 12/30/1996 - 6/1/1997. PI: Harold Schock
- Ford Motor Company, "Measurement of Flows in 50 and 60mm MAFS Housings," $57,500, 1/1/1996 - 6/30/1996. PI: Harold Schock
- Environmental Protection Agency, "Numerical and Experimental Investigation of Combustion Chamber Design, Fuel-Air Mixing and Combustion in Directly Injected Engines," $500,000, 9/1/1996 - 8/31/1998. PI: Harold Schock
- Ford Motor Company, "Measurement of Flows in the Impeller and Turbine Side of an Automotive Torque Converter at .4 and .8 Speed Ratios," $30,000, 5/22/1996 - 11/30/1996. PI: Harold Schock
- General Motors Corporation, "Numerical and Experimental Study of Closed-Coupled Catalytic Converter Assemblies," $55,000, 1/31/1996 - 9/30/1996. PI: Harold Schock
- General Motors Corporation, "An Experimental Study of Close-Coupled Catalytic Converter Assemblies," $35,000, 1/31/1996 - 9/30/1996. PI: Harold Schock
- Ford Motor Company, "Flow Studies in an Automotive Torque Converter," 9/1995 - 6/1996, $50,000. PI: Harold Schock
- Chrysler Corporation, "Determination of Fuel/Air Mixture Distribution in the Combustion Chamber Using a Laser Induced Fluorescence Technique," $144,964, 1/31/1995. PI: Harold Schock
- Chrysler Corporation, "Flow Studies in a 3.5L Piston Cylinder," $45,000, 1/1995 - 12/1995. PI: Harold Schock
- MSU Foundation, "Automotive Initiative Research Excellence Funds," $100,000, 1995. PI: Harold Schock
- Chrysler Corporation, "Flow Studies in a 2.0L Piston Cylinder Assembly," $50,000, 1/95 - 12/95. PI: Harold Schock
- Chrysler Corporation, "Flow Studies in a Catalytic Converter Assembly," $30,000, 1/1995 - 12/1995. PI: Harold Schock
- Ford Motor Company, "Design and Construction of an Automated System for Torque Converter Analysis," $100,000, 1995. PI: Harold Schock
- Ford Motor Company, "Performance Analysis of a New MAFS Design," $160,000, 1994. PI:Harold Schock
- Ford Motor Company, "Thin Component Velocity Measurement in an Automotive Torque Converter," $50,000, 9/1994 - 12/1994. PI: Harold Schock
- Hyundai, "Flow Measurement in a Catalytic Converter Assembly," $30,000, 4/1994 - 8/1994. PI: Harold Schock
- Environmental Protection Agency, "Simulation and Measurement of Flows in a Direct Injected Engine," $109,000, 1994. PI: Harold Schock
- Chrysler Corporation, "Evaluation of Tumble and Swirl in a 4-Valve SI Engine," $90,000, 1994. PI: Harold Schock
- Center for Sensor Materials, National Science Foundation, Materials Research Science and Engineering Center, and the State of Michigan, Research Excellence Fund (matching from State), (PI: Brage Golding, with 12 Co-PI's) $5,500,000, 1994 - 1999.

- NASA Lewis Research Center, "Image Tiling for Profiling Large Objects," $50,000, 1994. PI: Harold Schock
- Ford Motor Company, "Torque Converter Project (Phase II)," $40,000, 6/1993 - 12/1993. PI: Harold Schock
- Ford Motor Company, "Piston Ring Land Pressure Measurements," $68,000, 4/1993 - 12/1993. PI: Harold Schock
- NASA Lewis Research Center, "Solid Image Construction of Free Form Surfaces," $41,575, 4/1993 - 12/1993. PI: Harold Schock
- Chrysler Corporation, "Quantification of In-Cylinder Air Flow in a 3.5L Four-Valve SI Engine," $109,522, 1/1993 - 12/1993. PI: Harold Schock
- Chrysler Corporation, "In-Cylinder Airflow 3.5L Engine," $125,000, 1/1993 - 12/1993. PI: Harold Schock
- Ford Motor Company, "Performance Analysis of the MAFS Under Normal Flow Conditions," $232,000, 1992 - 1994. PI: Harold Schock
- Ford Motor Company, "Internal Flow Studies in an Automotive Torque Converter," $163,000, 1992 - 1994. PI: Harold Schock
- Environmental Protection Agency, "Flow Studies in a Methanol Fueled Engine," $125,000, 10/1992 - 12/1993. PI: Harold Schock
- Chrysler Corporation, "Air Flow Visualization and LDV Measurements in a Four-Valve SI Engine," $109,000, 1/1991 - 2/1992. PI: Harold Schock
- NASA Lewis Research Center, "Investigation on the Use of Digital Control of a Fiber-Based Phase Stepping Interferometer," $30,000, 1/1991 - 9/1991. PI: Harold Schock
- Battelle, "Effect of Ion Implantation on the Wear Properties of Si_3N_4," $8,000, 1991. PI: Harold Schock
- Detroit Diesel Company, Formula Car Design and Construction, $10,000, 1990 - 1992. PI: Harold Schock
- Ford Motor Company, "Flow Studies in an Aerostar Induction System," $27,000, 1990 - 1991. PI: Harold Schock
- Ford Motor Company, SAE Formula Car Design and Construction, $37,500, 1989 - 1992. PI: Harold Schock
- Ford Motor Company, "Flow Studies in a 3.8L SC Induction Assembly," (with J. Foss) $120,000 (MSUERL share $50,000), 1989. PI: Harold Schock
- State of Michigan, Research Excellence Fund, "Implantation of ^{7}Be and ^{22}Na for Tribology Studies Using a High Energy Cyclotron," (with Burkhardt, Grummon, Lloyd, McHarris and Ronningen), This award was based on work completed by PI's Mallory and Schock and on work proposed to NSF by Mallory, Schock, Grummon, Ronningen, Lloyd and Burkhardt. Amount funded $250,000 (MSUERL share $83,500), 1988 - 1990.
- Chrysler Corporation, "Flow Studies in a Chrysler Cylinder Head," $50,000, 1988 - 1989.
- Michigan State University, Research Excellence Fund, "Wear Quantification of Ceramic Parts," $50,000, 1988. PI: Harold Schock
- NASA Lewis Research Center, (PI: Harold Schock, Co-PI Somerton, C.) "Flow Studies in a Stratified Charge Rotary Combustion Engine," $1,045,000, 1987 - 1994.

PATENT ACTIVITY:

- Patent Disclosure to USPTO: "Actuation System for Jetfire Cartridge Air Valve on an Internal Combustion Engine," Harold Schock*, Tom Stuecken**, Jennifer Higel* and Gary Hunter*, *Mid Michigan Research, ** Michigan State University, July 16, 2021, pending
- Schock, H., Internal Combustion Engine Including Multiple Fuel Injections External to the Pre-Chamber, Submitted to USPTO May 20, 2020, patent pending,

- Schock, H. and Stuecken, T., Engine Turbulent Jet Ignition System, submitted USPTO, Dec. 19, 2019, patent granted, Engine Turbulent Jet Ignition System, Patent No. US 11,408,329B2 Aug 9, 2022
- Schock, H and Zhu, G.. Diesel Engine with Turbulent Jet Ignition, submitted USPTO July 26, 2018., patent granted, Diesel Engine with Turbulent Jet Ignition System, Patent No. US 11,187,142 B2 Nov. 30, 2021 (not reported in 2021)
- Schock, H., Zhu, G., Toulson, E., Stuecken, T.R. (December 25, 2018). *U.S. Patent No. US 10,161,296 B2.* East Lansing, MI: U.S. Patent and Trademark Office.
- US Provisional Patent No. 61/500,667, "High Temperature, High Pressure Window Assembly for Optical Access to Combustion Chambers and Other Vessels," Schock, H., filed 6/2011
- US Patent Disclosure, "A Waste Heat Recovery Method using a CVT A Turbo-Compound System," Zhu, G., Schock, H. and Winkelman, J. filed 2010
- US Patent Disclosure, "Functionally Graded Materials for Thermoelectrics," Timm, E., Schock, H., Ruckle, T., Sakamoto, J., and Lyle, M. filed 2010
- US Patent Disclosure, "A Couple Bypass System for Series Configured Thermoelectric Generators," H. Schock, G. Zhu, K. Moran, T. Ruckle, Timm, E., Sakamoto, J. and Lyle, M., filed 2010.
- US Patent No. 7,555,945 B2, "Mass Air Flow Sensor," Ahmed M. Naguib, A. Aditjandra, B. Trosin, Harold J. Schock, Tom R. Stuecken, and Edward Timm, Jul. 7, 2009.
- US Patent, "Method and Apparatus for Enhancing the Performance of a Camless Valve Actuator," Jia Ma, George Zhu, Harold Schock and Tom Stuecken, Application: November 1, 2007. pending.
- US Patent No. 6,408,698, "Sensors and Method for Measurement of Flow Rates and Cumulative Flows in Ducts," Giles J. Brereton, Harold J. Schock, Ruby N. Ghosh, and Fathi M. Salam, June 25, 2002.
- US Patent No. 6,065,454, "Method and Apparatus for Active Control of the Combustion Processes in an Internal Combustion Engine," Harold J. Schock, Manoochehr Koochesfahani, Daniel G. Nocera, May 23, 2000.
- U.S. Patent No. 5,762,988, June 9, 1998, "Method for Removing Hulls from a Nut Mixture," H. J. Schock and T. R. Stuecken.
- U.S. Patent No. 5,720,395, February 24, 1998, "Method and Apparatus for Removing Hulls from a Nut Mixture," H. J. Schock and T. R. Stuecken.

OTHER ACTIVITIES:

Pilot, Single Engine Land, Instrument Rated - IFR, 9/1997 - present.
Expert witness on behalf of Mitsubishi Orbital Engine Company & Mahle, 2003.
Expert Witness, Metal Levy, South America, 2003 - 2004.
Expert Witness, Numerous patent issues. Baker and McKenzie, on behalf of
Volkswagen Group of America, 2018-2019
Expert Witness, Numerous patent issues, Stern and Kessler, , on behalf of
Volkswagen Group of America, 2019-present
Expert Witness, On behalf of unnamed person and OEM, Violation of Clean Air Act
2019-present

ADDITIONAL INFORMATION:

During the past several years Dr. Schock has given formal presentations at the following annual conferences or at meetings sponsored by these organizations: Society of Mining Engineers; Society of Automotive Engineers; American Institute of Aeronautics and Astronautics; Sandia National Laboratory; Ford Motor Scientific Laboratory; General Motors Research Laboratory; DaimlerChrysler Corporation; Argonne National Laboratory; Oak Ridge National Laboratory; Experimental Aircraft Association meetings; and Kernforschungszentrum Karlsruhe (West Germany). Dr. Schock has evaluated over 100 research proposals

for NASA, DOE, and the U.S. Army. He is a regular reviewer for SAE and has also reviewed papers for ASME Journals and Applied Optics. Dr. Schock has organized and chaired several SAE Technical Sessions. Dr. Schock is an internationally recognized expert in IC engines related to tribology, combustion pressure/optical diagnostics and turbulent jet ignition systems.

PUBLICATION LIST

Book Chapters/Other:

1. Ramos, J. I., T. I-P Shih, and H. J. Schock, (October 1987). "Wankel Engine Modeling," Heat and Mass Transfer in Gasoline and Diesel Engines, Hemisphere Publishing Corporation, pp. 524-538, D. B. Spalding, ed.
2. Koochesfahani, M. M., Goh, A. C., and Schock, H. J. [2004] "Molecular Tagging Velocimetry (MTV) and Its Automotive Applications," The Aerodynamics of Heavy Vehicles: Trucks, Buses, and Trains, *Lecture Notes in Applied and Computational Mechanics*, Vol. 19, 143-155, Eds. McCallen, R., Browand, F., and Ross, J., Springer-Verlag, 2004.
3. Scientific American, Ask the Experts, Why is the fuel economy of a vehicle poorer in the winter than in the summer? April 19, 2004
4. Schock, Harold, "A Brief History of Positive Displacement Aviation Engines," Encyclopedia of Aerospace Engineering, 2010.
5. Schock, Harold, "Energy and Automotive Research Laboratory," Research Compendium, Michigan State University, December, 2012

Articles:

1. Ayele, Yidnekachew, Stuecken, T., and Schock, H., " A Study of the Influence of Orifice Diameter on a Dual Mode, Turbulent Jet Ignition Engine Through Variable Engine Speed," International J of Engine Research, I-10, IMechE 2022, DOI: 10.1177/14680874221097745
2. Atis, Cyrus, Ayele, Y., Stuecken, T. and Schock, H., "Effect of pre-chamber scavenging strategy on EGR tolerance and thermal efficiency of pre-chamber turbulent jet ignition systems," International J of Engine Research, I-23, IMECHE 2022, DOI: 10.1177/14680874221105162
3. Atis, C. and Schock, H., "Comparison of Excess Air (Lean) vs EGR Diluted Operation in a Pre-Chamber Air/Fuel Scavenged Dual Mode, Turbulent Jet Ignition Engine at High Dilution Rate (~40%)," *SAE Int. J. Adv. & Curr. Prac. in Mobility* 3(4):1569-1584, 2021, https://doi.org/10.4271/2021-01-0455.
4. Tolou, Sedigheh, Vedula, R., Schock, H., et al. "Combustion Model for a Homogeneous TurbochargedGasoline Direct-Injection Engine," Journal of Engineering for Gas Turbines and Power, Vol. 141, Issue 1, November 2019
5. Bisht, Ashish, Gupta, S.K., Mittal, M and Schock, "Analysis of spray variations and macroscopic spray characteristics in a gasoline direct-injection engine at different injection timings," Journal of Visualization, August 22, 2019, Vol. 22, Issue 4, PP 761-771

6. Tolou, Sedegah and Harold Schock, “Experiments and Modeling of a Dual-Mode Turbulent Jet Ignition Engine,” International Journal of Engines, 1-21 IMechE 2019, DOI: 10.1177/146
7. Vedula Tavi Teja, Gentz Gerald Raymond, Stuecken, Thomas R., Toulson Elisa, Schock, Harold, “Lean Burn Combustion in a Rapid Compression Machine Using Dual Mode Turbulent Jet Ignition System,” SAE International Journal of Engines, Vol. 11, pp95-107, (2018).
8. Song Ruitao , Vedula Ravi Teja , Zhu Guoming G , , "A control-oriented combustion model for a turbulent jet ignition engine using liquid fuel" ". International Journal of Engine Research. Vol. 19. No. 8. pp. 813-826. Other Information: DOI: 10.1177/1468087417731698. (August 2018).
9. Vedula Ravi Teja , Men Yifan , Atis Cyrus , Stuecken Thomas , Zhu Guoming G , , Wooldridge Steven, "Soot Observations and Exhaust Soot Comparisons from Ethanol-blended and Methanol blended Gasoline Combustion in a Direct-Injected Engine ". SAE International Journal of Fuels and Lubricants. Vol. 11. No. 2. Other Information: DOI: 10.4271/04-11-02-0008. (May 2018).
10. Tolou Sedigheh , Vedula Ravi Teja ,Schock, H. , Zhu Guoming G , Yong Sun , Kotrba Adam, "Combustion model for a homogeneous turbocharged gasoline direct-injection engine ". ASME Journal of Engineering for Gas Turbines and Power. Vol. 140. No. 10. pp. 102804. (October 2018).
11. Vedula, R.T., Stuecken, T., Schock, H., Squibb, C. and Hardman, K., 2017. Optical Engine Operation to Attain Piston Temperatures Representative of Metal Engine Conditions. *SAE International Journal of Engines*, 10(3):767-777.
12. Vedula, R.T., Song, R., Stuecken, T., Zhu, G.G. and Schock, H., 2017. Thermal efficiency of a dual-mode turbulent jet ignition engine under lean and near-stoichiometric operation. *International Journal of Engine Research*, 18(10):1055 - 1066.
13. Vedula, R.T., Mittal, M. and Schock, H., 2017. Parametric Study to Improve Subpixel Accuracy of Nitric Oxide Tagging Velocimetry with Image Preprocessing. *Journal of Combustion*, *2017*.
14. Validi, AbdoulAhad, Harold Schock, Farhad Jaberi, Turbulent jet ignition assisted combustion in a rapid compression machine, Combustion and Flame 186 (2017) 65-82
15. Song, R., Vedula, R.T., Zhu, G. and Schock, H., 2017. A control-oriented combustion model for a turbulent jet ignition engine using liquid fuel. *International Journal of Engine Research*, p.1468087417731698.
16. Zhung, Shupeng, Huisjen, Andrew, Zhu, Guoming, Schock, Harold, “Improvement in the Combustion Mode Transition for an HCCI Capable SI Engine*.” IMechE Journal of Automobile Engineering*. Vol. 239. No. 2. Pp. 215-228. (2016).

17. Song, Ruitao, Zhu, Guoming, Attard, Elisa Toulson, Schock, Harold, “A Control-Oriented Model of Turbulent Jet Ignition Combustion in a Rapid Compression Machine.” Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering. (November 2016).

18. Zhang, Shupeng, Huisjen, Andrew, Zhu, Guoming, Schock, Harold, “Improvement in the Combustion Mode Transition for a Spark Ignition Engine Capable of Homogeneous Charge Compression Ignition.” *Proceedings of the Institution of Mechanical Engineers, PartD: Journal of Automobile Engineering*. Vol. 230. No. 2. Pp. 215-228. (February 2016).

19. Mansouri, Nariman, Timm, Edward, Schock, Harold, Sahoo, Dipankar, Kotrba, Adam, "Development of a Circular Thermoelectric Skutterudite Couple Using Compression Technology." *Journal of Energy Resources Technology, Transactions of the ASME*. Vol. 138. No. 5. (September 2016).

20. Cheng, Chao, Schock, Harold, Richardson, Dan, "The Dynamics of Second Ring Flutter and Collapse in Modern Diesel Engines." *Journal of Engineering for Gas Turbines and Power*. Vol. 137. No. 11. (November 2015).

21. Cheng, Chao, Kharazmi, Ali, Schock, Harold, Winland, Richard, Brombolich, Larry, "Three-Dimensional Piston Ring-Cylinder Bore Contact Modeling." *Journal of Engineering for Gas Turbines and Power.* Vol. 137, No. 11. (November 2015).

22. Poort, Mulyanto, Cheng, Chao, Richardson, Dan, Schock, Harold, "Piston Ring and Groove Side Wear Analysis for Diesel Engines." *Journal of Engineering for Gas Turbines and Power*. Vol. 137. No. 11. (November 2015).

23. Cheng, Chao, Kharazmi, Ali, Schock, Harold. "Modeling of Piston Ring-Cylinder Bore-Piston Groove Contact." *SAE International.* 2015-01-1724.

24. Mittal, Mayank, Schock, Harold, "The Effect of Fuel Injection Pressure on Spray and Combustion Characteristics in a Gasoline Direct-Injection Engine." SAE International, Paper No. 2014-01-2604, October 2014.

25. Vedula, Ravi, Mittal, Mayank, Schock, Harold, "Molecular Tagging Velocimetry and Its Application to In-cylinder Flow Measurements." *ASME Journal of Fluids Engineering*. Vol. 135, December 2013.

26. Allen, Casey M., Toulsen, Elisa, Tepe, Daniel, Schock, Harold J., Miller, Dennis John, Lee, Tonghun. "Characterization of the Effect of Fatty Ester Composition on the Ignition Behavior of Fuel Sprays". *Fuels*. Vol. III. Pp. 659-669 (Sept. 2013).

27. Banaeizadeh, Araz, Afshari, Asghar, Schock, Harold J., Jaberi, Farhad. "Large-Eddy Simulations of Turbulent Flows in Internal Combustion Engines". *International Journal of Heat and Mass Transfer*. Vol. 60. Pp. 781-796 (2013).

28. Banaeizadeh, A., Afshari, A., Schock, H.J., Jaberi, F., "Large-Eddy Simulations of Turbulent Flows in Internal Combustion Engines, Combustion and Flame," *International Journal of Heat and Mass Transfer*. Vol. 60, May 2013, pp 781-796 .

29. Schock, Harold J., Brereton, Giles J., Case, Eldon D., D'Angelo, J., Hogan, Tim, Lyle, M., Maloney, R., Moran, Kevin, Novak, Jim, Nelson, Chris, Panayi, A., Ruckle, T., Sakamoto, Jeff, Shih, Tom, Timm, Ed, Zhang, L., Zhu, Guoming. "Prospects for Implementation of Thermoelectric Generators as Waste Heat Recovery System in Class 8 Truck Applications". *ASME J. Energy Resour. Technology*. Vol. 135. No. 2. Pp 022001 (Jan. 2013).

30. Toulson, E., Huisjen, A., Chen, X., Squibb, C., Zhu, G., Schock, H., Attard, W.P., "Visualization of Propane and Natural Gas Spark Ignition and Turbulent Jet Ignition Combustion". *SAE International Journal*. Vol. 5 No. 4. Pp. 1821-1835. (December 2012).

31. Lee, T., Allen, C., Toulson, E., Tepe, D., Schock, H., Miller, D., "Ignition Behavior and Surrogate Modeling of JP-8 and of Camelina and Tallow Hydrotreated Renewable Jet Fuels at Low Temperature, Combustion and Flame". *Combustion and Flame*. Vol. 160. No. 2. Pp. 232-239. (2012).

32. Schock, Harold, et al. "Prospects for Implementation of Thermoelectric Generators as Waste Heat Recovery Systems in Class 8 Truck Applications," Journal of Energy Resources Technology, JERT-11-1087, submitted 7/2011.

33. Rahi, M., Shih, T., Schock, H.J., "Heat Transfer Enhancement Using Protrusions for Thermoelectric Power Generators," *Journal of Enhanced Heat Transfer*. Vol. 18. No. 6. Pp. 465-480. (2011).

34. Mittal, M., Hung, D.L.S., Zhu, G., Schock, H.J., "Fuel Spray Visualization and it's Impingement Analysis on In-Cylinder Surfaces in a Direct Injection Spark-Ignition Engine," *Journal of Visualization*. Vol. 14. Pp. 149-160. (2011).

35. Ma, J., Zhu, G., Schock, H.J., "Adaptive Control of Pneumatic Valve Actuator for an Internal Combustion Engine*". IEEE Transactions on Control Systems Technology*. Vol. 19. No. 4. Pp. 730-743. (July 2011).

36. Allen, C. M., Toulson, E., Tepe, D., Schock, H.J., Miller, D., Lee, T., "Characterization of the Effect of Fatty Ester Composition on the Ignition Behavior of Biodiesel Fuel Sprays," Submitted to *Biomass & Bioenergy*, May 2011.

37. Allen, C. M., Toulson, E., Hung, D.L.S., Schock, H.J., Miller, D., Lee, T., "Ignition Characteristics of Diesel and Canola Biodiesel Sprays in the Low Temperature Combustion Regime," *Energy Fuels.* 25(7), 2896-2908. (2011).

38. Toulson, E., C. M. Allen, D. Miller, J. McFarlane, H. J. Schock, T. Lee, "Modeling the Auto-Ignition of Biodiesel Blends with a Multi-Step Model," *Energy Fuels.* 25(2), 632-639. (2011).

39. Toulson, E., C. M. Allen, D. Miller, H. J. Schock, T. Lee, "Optimization of a Multi-Step Model for the Auto-Ignition of Dimethyl Ether in a Rapid Compression Machine, Energy and Fuels," 2010. *24* (6), 3510-3516.

40. Ma, Jia, Guoming, Zhu, Schock, Harold, (March, 2010). "A Dynamic Model of an Electropneumatic Valve Actuator for Internal Combustion Engines," *ASME Journal of Dynamic Systems, Measurement and Control*, Vol. 132, March, 2010 (DOI: 10.1115/1.4000816).

41. Mittal, M., Schock, H. J. (July 2010). "A Study of Cycle-to-Cycle Variations and the Influence of Charge Motion Control on In-Cylinder Flow in an IC Engine," Journal of Fluids Engineering, Vol 132.

42. J. Ma, G. Zhu, and H. Schock, (March, 2010) "A dynamic model of an electro-pneumatic valve actuator for internal combustion engines," ASME Journal of Dynamic Systems, Measurement and Control, Vol. 132, (DOI: 10.1115/1.4000816).

43. G. Zhu, D Hung, and H. Schock, (2010) "Combustion characteristics of a single-cylinder gasoline and ethanol dual-fuel engine," Proceedings of the Institution of Mechanical Engineers, Part D, Journal of Automobile Engineering, 224(D3), 387-403 (DOI: 10.1243/09544070JAUTO1236).

44. Mittal, M., Sadr, R., Schock, H. J., Fedewa, A.., and Naqwi, A., (2009). "In-cylinder Engine Flow Measurement using Stereoscopic Molecular Tagging Velocimetry (SMTV)," *Exp. Fluids,* 46 (2), 277-284.

45. Mittal, M., Zhu, G., and Schock, H. J. (2009). "Fast Mass Fraction Burned Calculation Using Net Pressure Method for Real-Time Applications," *Proc. IMechE, Part D, Journal of Automobile Engineering*. Vol. 223, pp389-394.

46. Panayi, A. P. and Schock, H. J., (2008). "On the Approximation of the Integral of the Asperity Height Distribution for the Greenwood-Tripp Asperity Contact Model," Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, Professional Engineering Publishing, ISSN No. 1350-6501, v.222, Number 2 /2008, pp. 165-169.

47. Liu, Xing-hua, Liu Fu-shui, Zhou, Lei and Schock, Harold, "Backfire Prediction in a Manifold Injection Hydrogen Internal Combustion Engine," International Journal of Hydrogen Energy, Vol 33, Issue 14, July 2008, Pages 3847-3855

48. Panayi, A. P., Diaz, A. R. and Schock, H. J., (2008). "On the Optimization of Piston Skirt Profiles using a Pseudo-Adaptive Response Surface Method," Journal of Structural and Multidisciplinary Optimization, DOI: 10.1007/s00158-008-0295-7.

49. Pilchak, A. L., Ren, F., Case, E. D., Timm, E. J., and Schock, H. J., (2007). "The Effect of Milling Time and Grinding Media Upon the Particle Size Distribution for LAST (Lead, Antimony, Silver, Tellurium) Powders," Philos. Mag. A.

50. Ren, F., Case, E. D., Hall, B. D., Timm, E. J., and Schock, H. J., (2007), "Young's Modulus of N-Type Last Thermoelectric Material Determined from Knoop Indention," Chemistry of Physics and Materials.

51. Pilchak, A. L., Ren, F., Case, E. D., Timm, E. J., Schock, H. J., Wu, C. -I., Hogan, T. P., (October 2007). "Characterization of Dry Milled Powders of LAST (lead-antimony-silver-tellurium) Thermoelectric Material," Philosophical Magazine, v.http://www.informaworld.com/smpp/title~content=t713695589~db=all~tab=issueslist~branches=87 - v8787, Issue 29, pp. 4567-4591.

52. Ren, F., Case, E. D., Timm, E. J., Schock, H. J., (2007). "Young's Modulus as a Function of Composition for an N-Type Lead-Antimony-Silver-Telluride (LAST) Thermoelectric Material," Philosophical Magazine, v.87, Issue 31, pp. 4907-4934.

53. Ren, F., Case, E. D., Timm, E. J., and Schock, H. J., (2007). "Hardness as a Function of Composition for N-Type Last Thermoelectric Material," Applied Physics Letters.

54. Case, E. J., Ren, F., Schock, H. J., and Timm, E. J., (2006). "Weibull Analysis of Biaxial Fracture Strength of Cast P-Type LAST-T Thermoelectric Material," Philos. Mag. Lett. 86 [10]: pp. 673-682.

55. Ismailov, Murad M., Schock, Harold J., and Fedewa, Andrew, (2006). "Gaseous Flow Measurements in an Internal Combustion Engine Assembly Using Molecular Tagging Velocimetry," Experiments in Fluids 41: pp. 57-65.

56. Chui, Boon-Keat and Schock, Harold J., (2003). "An Analysis of the Influence of Piston Assembly Wear on the Performance of an Internal Combustion Engine," ASME, ICEF2002-529, ICE-Vol. 39, Journal of Tribology.

57. Ramadan, B., Hamady, F., Gray, C., Hellman, K., and Schock, H. J., (October 21, 2002). "Numerical Evaluation of a Methanol-Fueled Directly Injected Engine," SAE Paper No. 2002-01-2702, SAE Transactions, Journal of Fuels and Lubricants, V111-4, SAE Powertrain and Fluid Systems Conference and Exhibition, San Diego, CA.

58. Hascher, H. G., Novak, M., Stuecken, T., Schock, H. J., and Novak, J., (October 19, 2000). "The 3-D In-Cylinder Charge Motion of a Four-Valve SI Engine Under Stroke, Speed, and Load Variation," SAE Paper No. 2000-01-2798, SAE International Fall Fuels and Lubricants Meeting, Exhibition, Baltimore, Maryland. Also appears in SAE Transactions, Journal of Engines, v.109-3.

59. Ejakov, M., Schock, H. and Brombolich, L., (1998). "Modeling of Ring Twist for an IC Engine," SAE Paper No. 982693. Also appears in SAE Transactions, Journal of Engines, 1998, v.107-3.

60. Kasser, J., Hascher, H., Novak, M., Lee, K., Schock, H. J., Bonne, M. and Keller, P., (1997). "Tumble and Swirl Quantification within a Motored Four-Valve SI Engine Cylinder Based on 3-D LDV Measurements," SAE Paper No. 970792. Also appears in SAE Transactions, Journal of Engines, v.106.

61. Hascher, H., Jaffri, K., Novak, M., Lee, K., Schock, H. J., Bonne, M. and Keller, P., (1997). "An Evaluation of Turbulent Kinetic Energy for the In-Cylinder Flow of a Four-Valve 3.5L SI Engine Using 3-D LDV Measurements," SAE Paper No. 970793. Also appears in SAE Transactions, Journal of Engines, v.106.

62. Kim, J.U., Hartman, W., Schock, H. J., Golding, B. and Nocera, D., (1997). "The Electron Donor-Acceptor Exciplex of N, N-Diamethylaniline and 1, 4, 6-Trimethylnapthalene," Chemical Physics Letters, 267, pp. 323-328.

63. Kim, J.U., Schock, H. J., Nocera, D., Golding, B. and Keller, P., (1996). "Exciplex Fluorescence Visualization Systems for Two Phase Visualization," Bull., American Physical Society, 41, pp. 380.

64. Yoo, S-C., Lee, K., Novak, M., Schock, H. and Keller, P., (1995). "3-D LDV Measurement of In-Cylinder Air Flow in a 3.5L Four-Valve SI Engine," SAE Paper No. 950648. Also appears in SAE Transactions, Journal of Engines, v.104.

65. McHarris, W. C., Ronningen, R. M., Schock, H. J., Schalek, R. and Grummon, D. S., (1994). "Radioactive Ion Implantation for Wear Studies," Nuclear Instruments and Methods in Physics Research, A353, pp. 583-587.

66. DeFilippis, M., Hamady, F., Novak, M. and Schock, H. J., (1992). "Effects of Pocket Configuration of the Flow Field in a Rotary Engine Assembly," SAE Paper No. 920300. Also appears in SAE Transactions, Journal of Engines, v.101.

67. Schock, H. J., Hamady, F., DeFilippis, M., Stuecken, T., Gendrich, C. and LaPointe, L., (1991). "High Frame Rate Flow Visualization and LDV Measurements in Steady Flow Cylinder Head

Assembly," SAE Paper No. 910473, February 25 - March 1, 1991. Also appears in SAE Transactions, Journal of Engines, v.100, Section 3, pp. 666-704.

68. Hamady, F., DeFilippis, M., Stuecken, T. and Schock, H. J., (1991). "Experimental Analysis of Blowby and Flow Field Interaction in a Motored Rotary Engine," SAE Paper No. 910893. Also appears in SAE Transactions, Journal of Engines, v.100, Section 3, pp. 1416-1442.

69. Morita, T., Hamady, F., Stuecken, T., Somerton, C. and Schock, H. J., (1991). "Fuel-Air Mixing Visualization in a Motored Rotary Engine Assembly," SAE Paper No. 910704, February 25 - March 1,1991. Also appears in SAE Transactions, Journal of Engines, v.100, Section 3, pp. 1185-1205.

70. Rachel, T., Schock, H. J. and Bartrand, T., (1991). "Analysis of Frictional Power Losses Associated with the Side and Apex Seals of a Wankel Rotary Engine," SAE Paper No. 910626, February 25 - March 1, 1991. Also appears in SAE Transactions, Journal of Engines, v.100, Sect. 3, pp. 923-932.

71. E: McHarris, W. C., Mallory, M.C ., Ronningen, R. M, Dardenne, Y. X. and Schock, H. J., (May 21 - 24, 1990). "Gamma-Ray Spectroscopy of Implanted ^{7}Be and ^{22}Na for Tribology Studies," 7th Symposium on Radiation Measurements and Applications, University of Michigan, Ann Arbor, MI, Nuclear Instruments and Methods A299, pp. 593-596.

72. Hamady, F., Stuecken, T. and Schock, H. J., (March 1990). "Airflow Visualization and LDV Measurements in a Motored Rotary Engine Assembly - Part I, Flow Visualization," SAE Paper No. 900030, Also appears in SAE Transactions, Journal of Engines, v.99, Section 3, Part I, pp. 163-183. Presented at the SAE International Congress and Exposition, Detroit, MI, February 26 - March 2, 1990.

73. Chouinard, E., Hamady, F. and Schock, H. J>, (March 1990). "Airflow Visualization and LDV Measurements in a Motored Rotary Engine Assembly, Part II, LDV Measurements," SAE Paper No. 900031, Also appears in SAE Transactions, Journal of Engines, v.99, Section 3, Part I, pp. 184-207. Presented at the SAE International Congress and Exposition, Detroit, MI, February 26 - March 2, 1990.

74. Mallory, M. L., Ronningen, R. M., McHarris, W. C., Sherrill, B., Dardenne, Y. X. and Schock, H. J., (1989). "Tribology Studies: ^{7}Be Implantation in a Ceramic Sample by Means of a Fragmented High Energy Nitrogen Beam," Nuclear Instruments and Methods, B40/41, pp. 579.

75. Hamady, F., Kosterman, J., Chouinard, E., Somerton, C., Schock, H. J., Chun, K. and Hicks, Y., (1989). "Stratified Charge Rotary Engine Internal Flow Studies at the Engine Research Laboratory," SAE Paper No. 890331, SP.768. Also appears in SAE Transactions, Journal of Engines, v.98, Section 31, pp. 527-542. Presented at the SAE International Congress and Exposition, Detroit, MI, February 27 - March 3, 1989.

76. Steinthorsson, E., Shih, T. I-P., Schock, H. J. and Stegeman, J., (1988). "Calculations of the Unsteady Three-Dimensional Flow Field Inside a Motored Wankel Engine," SAE Paper No. 880625. Also appears in SAE Transactions, Journal of Engines, v.97, Section 6, pp. 1060-1108. Presented at the SAE International Congress and Exposition, Detroit, MI.

77. Lee, C. M. and Schock, H. J., (1989). "Regressed Relations for Forced Convection Heat Transfer in a Direct Injection Stratified Charge Rotary Engine," SAE Paper No. 880626. Also appears in SAE Transactions, Journal of Engines, v.97, Section 6, pp. 1189-1198. Presented at the SAE International Congress and Exposition, Detroit, MI, February 29 - March 4, 1988.

78. Shih, T. I-P, Schock, H. J., Nguyen, H. L. and Stegeman, J. D., (1987). "Numerical Simulation of the Flowfield in a Motored, Two-Dimensional Wankel Engine," AIAA Journal of Propulsion and Power, v.3, pp. 269-276.

79. Lock, J. A. and Schock, H. J., (July 1, 1985). "Incident Beam Polarizations for Laser Doppler Velocimetry Employing a Sapphire Cylindrical Window," Applied Optics, v.24, pp. 1987.

80. Schock, H. J., (1985). "Internal Combustion Engine Combustion Chamber Process Studies at NASA Lewis Research Center," AIAA Journal of Propulsion and Power, v.1, No. 5, September - October 1985.

81. Kim, R. Cl, Case, S. K. and Schock, H. J., (1985). "Holographic Optical System for Aberration Correction in Laser Doppler Velocimetry," Engineering, v.24, No. 5, September - October 1985.

82. Schock, H. J., D. J. Sosoka, and J. L. Ramos, (July 1984). "Formation and Destruction of Vortices in a Motored Four-Stroke Piston-Cylinder Configuration," Paper No. 83-0497, AIAA Journal, v.22, No. 7.

83. Schock, H. J., Case, S. K. and Konicek, L., (March 1984). "Window Aberration Correction in Laser Velocimetry using Multifaceted Holographic Optical Elements," Applied Optics, v.23, No. 5, pp. 752-756.

84. Schock, H. J. and Johnson, J. J., (1984). "A Methodology for Determining Pollutant Concentration from a Diesel Powered Vehicle in a Dead-Ended Drift," AIME Transactions, American Institute of Mining, Metallurgical and Petroleum Engineers, Volume 274, 1983 Journal of Engines, Chapter: Underground Mining, ISBN No. 0-89520-428-2.

85. M: Schock, H. J., Regan, C. A., Rice, W. J. and Chlebecek, R., (1983). "Multicomponent Velocity Measurement in a Piston-Cylinder Configuration," TSI Quarterly, v.IX, Issue 4.

86. Schock, H. J., Johnson, J. J. and Bunting, B., (May 1982). "A Comparison of Pollutant Concentrations for Three Ventilation Configurations in a Dead-Ended Drift," AIME Transactions, American Institute of Mining, Metallurgical and Petroleum Engineers Journal of Engines.

87. Schock, H. J., Johnson, J. H. and Bunting, B. G. (1981). "Summary of Experimental Work Comparing Three Ventilation Configurations in a Downsloping Dead-Ended Drift," AIME, American Institute of Mining, Metallurgical and Petroleum Engineers, Transactions Volume 270, Chapter: Underground Mining, ISBN No. 0-89520-296-X, Published January 1, 1982.

PAPERS PUBLISHED IN CONFERENCE PROCEEDINGS/OTHER:

1. Nicklowitz,, Daniel, Schock, H., Suman, A., Lowe, J., and Wood, A.I., "A Modeling Methodology for Analysis of Abradable Powder Piston Skirt Coatings, ", 2022 NDIA Michigan

Chapter, Ground Vehicle Systems Engineering and Technical Symposium, Modeling Technical Session, August 16-18, 2022, Novi, Michigan

2. Atis, C. and Schock, H., Comparison of excess air (lean) vs EGR diluted operation in a pre-chamber scavenged Dual Mode, Turbulent Jet Ignition engine at high dilution rate (~40%), SAE Technical Paper 2021-01-0563, pending publication in SAE WXC 2021.

3. Atis, C., Huisjen, A. ,Hardman, K. and Schock, H., Experimental Investigation on the Effects of Design and Control Factors on the Performance and Emissions Characteristics of a Boosted GDI Engine Using Taguchi method, SAE Technical Paper 2021-01-0691, pending publication in SAE WCX 2021.

4. Sadiyah Sabah Chowdhury, Harold Schock, Ali Kharazmi, " Effect of Ring-Groove Geometry on Engine Cylinder-kit Assembly Using Three-Dimensional Multiphase Physics-Based Modeling Methodology" No. 2021-01-0200, SAE Technical Paper, 2021.

5. Sadiyah Sabah Chowdhury, Brian Fedewa, Harold Schock, Andrew Suman,"Tribological Performance Assessment of Abradable Powder Coated Pistons Considering Piston Skirt Geometry and Surface Topography", No. 2021-01-0065, SAE Technical Paper, 2021.

6. Atis, C., Chowdhury, S., Ayele, Y., Stuecken, T. et al., "Ultra-Lean and High EGR Operation of Dual Mode, Turbulent Jet Ignition (DM-TJI) Engine with Active Pre-chamber Scavenging," SAE Technical Paper 2020-01-1117, 2020, https://doi.org/10.4271/2020-01-1117.
7. Sadiyah Sabah Chowdhury, Ali Kharazmi, Cyrus Atis, Harold Schock, "Three-Dimensional Multiphase Physics-Based Modeling Methodology to Study Engine Cylinder-kit Assembly Tribology and Design Considerations- Part I" No. 2020-01-2230, SAE Technical Paper, 2020.

8. Tolou, S., Vedula, R.T., Schock, H., Zhu, G., Sun, Y. and Kotrba, A., 2017, October. Combustion Model for a Homogeneous Turbocharged Gasoline Direct-Injection Engine. In *ASME 2017 Internal Combustion Engine Division Fall Technical Conference* (pp. V002T06A021-V002T06A021). American Society of Mechanical Engineers

9. Squibb, Cody W., Schock, Harold, Vedula, Ravi, Stuecken, Thomas, "Analysis of Variations in Fuel Spray, Combustion, and Soot Production in an Optical Diesel Engine Operating under High Simulated Exhaust Gas Recirculation Operating Conditions." *2016 SAE Technical Papers*. SAE International. Vol. 2016-April. (April 2016).

10. Cheng, Chao, Kharazmi, Ali, Schock, Harold, "Modeling of Piston Ring-Cylinder Bore-Piston Groove Contact." SAE 2015 World Congress and Exhibition, SAE International. (2015).

11. Song, Ruitao, Gentz, Gerald Raymond, Zhu, Guoming, Toulson, Elisa, Schock, Harold, "A Control-Oriented Jet Ignition Combustion Model for an SI Engine." Proceedings of 2015 Dynamics Systems and Control Conference, ASME, DSCC2015-9687. (October 2015)

12. Validi, Abdoulahad, Schock, Harold, Toulson, Elisa, Jaberi, Farhad, "LES/FMDF of Turbulent Jet Ignition in a Rapid Compression Machine." Bulletin of the American Physical Society. American Physical Society. Vol. 60. (November 2015).

13. Cheng, Chao, Kharazmi, Ali, Schock, Harold, Wineland, Richard, Brombolich, Larry, "Three Dimensional Piston Ring-Cylinder Bore Contact Modeling," ASME 2014 Internal Combustion Engine Division Fall Technical Conference, Columbus, IN, October 2014, Paper No. ICEF2014-5672.

14. Cheng, Chao, Schock, Harold, Richardson, Dan, "The Dynamics of Second Ring Flutter and Collapse in Modern Diesel Engines," ASME 2014 Internal Combustion Engine Division Fall Technical Conference, Columbus, IN, October 2014, Paper No. ICEF2014-5671.

15. Poort, Mulyanto, Cheng, Chao, Richardson, Dan, Schock, Harold, "Piston Ring and Groove Side Wear Analysis for Diesel Engines," ASME 2014 Internal Combustion Engine Division Fall Technical Conference, Columbus, IN, October 2014, Paper No. ICEF2014-5670.

16. Srivastava, Shalabh, Schock, Harold J., Jaberi, Farhad. "Numerical Simulations of Turbulent Sprays with a Multicomponent Evaporation Model". SAE World Congress, SAE International, Paper No. 2013-01-1603.

17. Mittal, M., Schock, H.J., Ravi, V., and Naguib, A. (2013) "Establishment of a database by conducting intake manifold and in-cylinder flow measurements in an internal combustion engine assembly," SAE World Congress, Detroit, MI, Paper No. 2013-01-0565.

18. Optical Diagnostic Combustion Comparisons of Pump Diesel with Bio-derived Diesel Blends in an Optical DI Diesel Engine, Cody Squibb, Harold Schock, Casey Allen, Tonghun Lee, Mulyanto Poort, Kyle Crayne, 2012 SAE World Congress, Paper No. 2012-01-0868, April 25th, 2012

19. William P. Attard, Elisa Toulson, Andrew Huisjen, Xuefei Chen, Guoming Zhu, Harold Schock, Spark Ignition and Pre-Chamber Turbulent Jet Ignition Combustion Visualization, SAE Paper 2012-01-0823, 2012 SAE World Congress, Detroit MI, April. 2012.

20. Mittal, M., Zhu, G., and Schock, H.J. (2012) "In-cylinder combustion visualization of a direct-injection spark ignition engine with different operating conditions and fuels," SAE 2012 Powertrains, Fuels & Lubricants Meeting, Malmo, Sweden, Paper No. 2012-01-1644.

21. M. Mittal, D. Hung, G. Zhu, and H. Schock, "A Study of Fuel Spray Visualization in a Direct-Injection Spark-Ignition Engine with Gasoline and Ethanol-Gasoline Blended Fuels," SAE Powertrain and Fluids Conference (SAE 2010-01-2153), San Diego, CA, Oct. 2010.

22. Mittal, M., Zhu, G., Hung, D., and Schock, H., (2010) "High-Speed Flow and Combustion Visualization to Study the Effects of Charge Motion Control on Fuel Spray Development and Combustion in a Direct-Injection Spark-Ignition Engine," SAE Paper No. 2011-11PFL-0230.

23. Toulson, E., Attard, W. P. and Schock, H., (2010) "A Review of Pre-Chamber Initiated Jet Ignition Combustion Systems," SAE Paper No. 2010-01-2263.

24. Mittal, M., Zhu, G., Stuecken, T. and Schock, H. J., (November, 2009). "Effects of Pre-injection on Combustion Characteristics of a Single-cylinder Diesel Engine," ASME 2009 International Mechanical Engineering Congress & Exposition, Lake Buena Vista, Florida.

25. Kenny S-Y Hu[i], X. Chi, and Tom Shih, Iowa State University and Harold J. Schock, (2009) Michigan State University, "Heat-Transfer Enhancement in Thermoelectric-Power Generation," AIAA 2009-1210.

26. Srivastava, Shalabh, Jaberi, Farhad A., Schock, Harold J. and Hung, David L.S. (July 2009). "Experimental and Computational Analysis of Fuel Mixing in a Low Pressure Direct Injection Gasoline Engine," ICLASS 2009, 11th Triennial International Conference on Liquid Atomization and Spray Systems, Vail, Colorado, USA.

27. Zhu, G. G., Ma, J. and Schock, H. J., (June 2009). "An Iterative Algorithm for Model-Based Predictive Control of an Electro-Pneumatic Valve Actuator," 2009 American Control Conference, St. Louis, Missouri.

28. Srivastava, Shalabh, Schock, Harold J., Jaberi, Farhad A. and Hung, David L.S., (2009). "Numerical Simulation of a Direct Injection Spark Ignition Engine with Alternative Fuels," SAE Paper No. 2009-01-0325, 2009 SAE Congress.

29. Hu, K., Chi, X., Shih, T.I-P. and Schock, H. J., (January 2009). "Heat Transfer Issues in Thermoelectric Power Generation," AIAA 2009-1210

30. Banaeizadeh, A., H. Schock, and F.A. Jaberi, "LES/FMDF of Spray Combustion in Internal Combustion Engines." National Combustion Meeting, The Combustion Institute, Ann Arbor, Michigan, May 2009.

31. Mittal, M., Schock, H. J., Sadr, R., (2008). "Evaluating the Influence of Charge Motion Control on In-Cylinder Flow Using MTV," ASME International Mechanical Engineering Congress and Exposition, IMECE2008-66490.

32. Sadr, R., Mittal, M., and Schock, H. J. (2008). "In-Cylinder IC Engine Velocity Measurements using Stereoscopic Molecular Tagging Velocimetry," Presented in Conference 61st Annual Meeting of American Physical Society, Division of Fluid Dynamics, San Antonio, Texas, November 23-25, DOI10.1007/s00348-008-0557-65.

33. Mittal, M., Zhu, G., Schock, H. J., Stuecken, T. and Hung, D. L. S., (2008). "Burn Rate Analysis of an Ethanol-Gasoline, Dual Fueled, Spark Ignition Engine," ASME International Mechanical Engineering Congress and Exposition 2008, IMECE2008-66139.

34. Zhu, Guoming, Stuecken, T., Schock, H. J., Xiaojian, Y., Hung, D. L. S. and Fedewa, A., (June 2008). "Combustion Characteristics of a Single-Cylinder Engine Equipped with Gasoline and Ethanol Dual-Fuel Systems," SAE Paper No. 2008-01-1767, To be presented at the SAE International Powertrains, Fuels and Lubricants Congress, Shanghai, CHINA, Session: SI Performance and Fuel Effects.

35. Ma, Jia, Zhu, Guoming and Schock, Harold, J., (June 2008). "Model-Based Predictive Control of an Electro-Pneumatic Exhaust Valve for Internal Combustion Engines," Proceedings of American Control Conference, Seattle, Washington.

36. Panayi, Andreas and Schock, H. J., (April 2008). "Avenues for Predicting Piston Wear: Employing 2D and 3D Numerical Piston Dynamics Models," SAE Paper No. 2008-01-1044, Presented at the

[i] Graduate Student.

SAE World Congress & Exhibition, Session: CI and SI Power Cylinder Systems (Part 2 of 2) Detroit, MI.

37. Ma, J., Zhu, G., Hartsig, A. and Schock, H. J., (April 2008). "Electro-Pneumatic Exhaust Valve Modeling and Control for an Internal Combustion Engine," ICES 2008-1653, Proceedings of ICES Spring Technical Conference, Chicago, IL, April 27 - 30, 2008.

38. Banaeizadeh, A., A. Afshari, H. Schock, F.A. Jaberi, "Large Eddy Simulations of Turbulent Flows in IC Engines," ASME paper # DETC2008-49788, ASME IDETC/CIE meeting, NY, NY, 2008.

39. Ma, Jia, Stuecken, T. and Schock, H. J., (April 2007). "Model Reference Adaptive Control of a Pneumatic Valve Actuator for Infinitely Variable Valve Timing and Lift," SAE Paper No. 2007-01-1297, SP2135, SAE World Congress & Exhibition, Detroit, MI, Session: Variable Valve Actuation (Part 2 of 3).

40. Hung, David L. S., Zhu, Guoming G., Winkelman, James R., Stuecken, Tom, Schock, Harold, J., and Fedewa, Andrew, (April 2007). "A High Speed Flow Visualization Study of Fuel Spray Pattern Effect on Mixture Formation in a Low Pressure Direct Injection Gasoline Engine," SAE Paper No. 2007-01-1411, SP2084, PFL-662, 2006, SAE World Congress & Exhibition, Detroit, MI, Session: Direct Injection SI Engine Technology (Part 2 of 3).

41. Ma., J., Schock, H. J., Carlson, U., Hoglund, A., and Hedman, M., (2006). "Analysis and Modeling of an Electronically Controlled Pneumatic Hydraulic Valve for an Automotive Engine," Cargine Engr. AB, SAE Paper No. 2006-01-0042, SP2007. Presented at the SAE World Congress and Exhibition.

42. Harris, R., Schock, H. J., Hogan, T. and Shih, T., (January 2006). "Heat Transfer and Electric Current Flow in a Thermoelectric Couple," AIAA Paper No. 2006-0575, Aerospace Sciences Meeting, Reno, Nevada.

43. Zhu, B., Schock, H. J., Hogan, T. and Shih, T., (January 2006). "Natural Convection and Radiation Heat Transfer in High Temperature Thermoelectric Couples," AIAA Paper No. 2006-0574, Aerospace Sciences Meeting, Reno, Nevada.

44. Bedford, Joshua C., Schock, Harold J. and Brereton, G., (Oct 2006). "Measurements of Cycle to Cycle Variability of the Inlet Flow of Fuel Injectors Using LDA," SAE Paper No. 2006-01-3314, Powertrain & Fluid Systems Conference and Exhibition, Toronto, ON, CANAD, Session: Combustion Diagnostics.

45. Bitar, Eilyan Y., Schock, Harold J. and Oppenheim, Antoni K., (April 2006). "Model for Control of Combustion in a Piston Engine," SAE Paper No. 2006-01-0401, SP2003, SAE World Congress & Exhibition, Detroit, MI, Session: Electronic Engine Controls (Part 1 of 9) - Controls I.

46. Panayi, Andreas P., Schock, Harold J., Chui, Boon-Keat and Ejakov, Mikhail A., (April 2006). "Parameterization and FEA Approach for the Assessment of Piston Characteristics," SAE Paper No. 2006-01-0429, SP2013, SAE World Congress & Exhibition, Detroit, MI, Session: CI and SI Power Cylinder Systems: Piston, Pins and Liners (Part 1 of 2).

47. Panayi, Andreas P. and Schock, Harold J., (2006)."Piston Finite Element Modeling for the Estimation of Hydrodynamic and Contact forces and Moments," ASME Proceedings of ICEF2006, 1587.

48. Schock, Harold, Case, Eldon, Downey, Adam, Hogan, Tim, Kanatzidis, Mercouri, Novak, James, Miller, John, Peng, Fang, Ren, Fei, Timm, Ed, Sakamoto, Jeff, Shih, Tom, Sheridan, Todd and Cauchy, Charles. (2006). "Thermoelectric Conversion of Waste Heat to Electricity in an IC Engine Powered Vehicle," Advanced Combustion Engine Technologies, IV.4, Progress Report.

49. Schock, Harold, Jaberi, Farhad, Gravel, Roland, Taylor, Sam, Winkelman, James, Zhu, George and Hung, David, (2006). "High-Compression-Ratio Atkinson-Cycle Engine Using Low-Pressure Direct Injection and Pneumatic-Electronic Valve Actuation Enabled by Ionization Current and Forward-Backward Mass Air Flow Sensor Feedback," Advanced Combustion Engine Technologies VII.7, Progress Report.

50. Zhu, B., Schock, H. J., Hogan, T. and Shih, T. I-P., (2006). "A Numerical Study of Convection and Radiative Heat Transfer between Parallel Plates Connected by an Array of Rods" AIAA 2006-0574.

51. Chui. B. K. and Schock, H. J., (2005). "Coupled Model of Partially Flooded Lubrication and Oil Vaporization in an Internal Combustion Engine," Proceedings of ICES2005, ASME Internal Combustion Engine Division, Spring Technical Conference, Chicago, IL, April 5 - 7, 2005.

52. Brereton, G. J., Schock, H. J. and Rahi, M. A. A., (2005). "An Indirect Pressure-Gradient Technique for Measuring Instantaneous Flow and Flow Rates in Unsteady Duct Flows," Bulletin of the American Physical Society, 50, 9.

53. Biter, E. I., Schock, H. J. and Oppenheim, A. K., (August 31, 2005). "Dynamic Model of Combustion in a Piston Engine," 20th ICDERS Proceedings, International Colloquium on the Dynamics of Explosions and Reactive Systems, Montreal, Canada.

54. Schock, H. J., (June 7, 2005). "Michigan State University, ONR - MURI Annual Report."

55. Schock, H. J., Case, E., Hogan, T., Kanatzidis, M., Miller, J., Novak, J., Peng, F., Timm, E., Shih, T.I-P, Zhu, B., Caillat, T., Sakamoto, J., Eckerle, W., Sheridan, T. and Cauchy, C., (October 3, 2005). "Thermoelectric Conversion of Waste Heat to Electricity in an IC Engine Powered Vehicle," Michigan State University, East Lansing, MI, Progress Report.

56. Schock, H. J., (June 14, 2005). "High Speed Photography and Infrared Imaging of Fuel Spray with Combustion in a Single Cylinder EPA Clean Diesel Engine," Environmental Protection Agency Final Report, East Lansing, MI.

57. Schock, H. J., (March 14, 2005). A04-233 "MEMs Based Micro Technology Engine Management/Health Monitoring," Submitted to Mr. David Yee, US Army TARDEC, Warren, MI.

58. Schock, H. J., (April 30, 2005). SBIR Activity: A04-233 Phase 1 - Report Number 2 "MEMs Based Micro Technology Engine Management/Health Monitoring System," Schock, H. J. Submitted to Mr. David Yee, US Army TARDEC, Warren, MI.

59. Schock, H. J., (June 21, 2005). SBIR Activity: A04-233 Phase 1 - Report Number 3 "MEMs Based Micro Technology Engine Management/Health Monitoring System," Schock, H. J. Submitted to Mr. David Yee, US Army TARDEC, Warren, MI.

60. Schock, H. J., (June 24, 2005). SBIR Activity: A04-233 Phase 1 - Final Report "MEMs Based Micro Technology Engine Management/Health Monitoring System," Schock, H. J. Submitted to Mr. David Yee, US Army TARDEC, Warren, MI.

61. Ismailov, Murad M., Combustion Dynamics Corp., and Schock, Harold J., MSU. (March 2004). "Quantification of Instantaneous of Diesel Flow Rate in Flow Generated by a Stable and Controllable Multi-Injection System (Rosa)," SAE Paper No. 2004-01-0028, SP1824. Presented at SAE World Congress Detroit.

62. Oppenheim, Antoni, K., University of California, Berkeley, and Schock, Harold, J., (March 2004). "Raison d'Etre of Fuel Cells and Hydrogen Fuel for Automotive Powerplants," SAE Paper No. 2004-01-0788, PT-96. Presented at World Congress, Detroit, MI. ISBN Number: 978-0-7680-1502-7 Date Published: September 2004.

63. Ismailov, Murad M., Combustion Dynamics Corp. and Schock, Harold J., (March 2004). "Performance Evaluation of a Multi-Burst Rapidly Operating Secondary Actuator Applied to Diesel Injection System," SAE Paper No. 2004-01-0022, SP-1824. Presented at SAE World Congress Detroit, MI.

64. Ramadan, B., Kettering University, Gray, C., Hamady, F. and Hellman, K., EPA, Ann Arbor, and Schock, H. J., MSU. (October 2003). "Multidimensional Predictions of Methanol Combustion in a High-Compression DI Engine," SAE Paper No. 2003-01-3133, SP-1803, Powertrain & Fluid Systems Conference & Exhibition, Pittsburgh, PA, Session: Spark Ignition Engine Modeling (Part B & C).

65. Ramadan, B., Kettering University, Gray, C., Hamady, F., and Hellman, K., EPA, Ann Arbor, and Schock, H. J., MSU. (October 2003). "Numerical Simulations in a High Swirl Methanol-Fueled Directly-Injected Engine," SAE Paper No. 2003-01-3132, SP-1803, Powertrain & Fluid Systems Conference & Exhibition, Pittsburgh, PA, Session: Spark Ignition Engine Modeling (Part B & C).

66. Schock, Harold J., Shen, Y., Timm, E., Stuecken, T. and Fedewa, A., (March 3 - 6, 2003). Michigan State University, Keller, P., DaimlerChrysler, (March 2003). "The Measurement and Control of Cyclic Variations of Flow in a Piston Cylinder Assembly," SAE Paper No. 2003-01-1357, SP1743, World Congress, Detroit, MI,

67. Shen, Yuan, Schock, H. J., MSU, and Oppenheim, A. K., UCB. (March 2003). "Pressure Diagnostics of Closed System in an SI Engine," SAE Paper No. 2003-01-0723, SP1745, World Congress, Detroit, MI, March 3 - 6, 2003.

68. Ramadan, B., Schock, H. J., Gray, C. L., Hamady, F. J. and Hellman, K. H., (2002). "Numerical Study to Achieve Stratified EGR in Engines," ASME, ICEF2002-533, ICE, v.39, Design, Application Performance and Emissions of Model Internal Combustion Engine Systems and Components.

69. Ramadan, B., Schock, H. J., Gray, C. L., Hamady, F. J. and Hellman, K. H., (2002). "Design of Engine Intake Systems Using Computer Simulations," ASME, ICEF2002-523, ICE, v.39, Design, Application Performance and Emissions of Modern Internal Combustion Engine Systems and Components.

70. Gu, X., Wu, H.-W., Schock, H. J. and Shih, T. I-P., (June 2002). "Two-Equation Versus Reynolds-Stress Modeling in Predicting Flow and Heat Transfer in a Smooth U-Duct with and without Rotation," ASME GT-2002-30616, IGTI Conference, Amsterdam.

71. Shih, T. I-P., Benard, A., Zhuang, M. and Schock, H. J., (December 2002). "CFD Analysis of IC Engine In-Cylinder Flows: Grid Quality and Resolution Issues," Final Report for Ford and DaimlerChrysler, Period - September 1, 1999 - August 31, 2002.

72. Chui, Boon-Keat and Schock, H. J., (2002). "Computational Analysis of Piston-Ring Wear and Oil Consumption for an Internal Combustion Engine," ICE, v.39, Design, Application, Performance and Emissions Modern Internal Combustion Engine Systems and Components, ASME, ICEF 2002-529.

73. Ramadan, B., Hamady, F., Gray, C., Hellman, K. and Schock, H. J., (October 2002). "Numerical Evaluation of a Methanol-Fueled Directly Injected Engine," SAE Paper No. 2002-01-2702, SP1720, SAE Transactions, Journal of Fuels and Lubricants, V111-4, SAE Powertrain and Fluid Systems Conference and Exhibition, San Diego, CA.

74. Shen, Y. and Schock, H. J., Michigan State University, T. H. J Sum and A. K. Oppenheim, University of California, (March 2002). "Dynamic State of Combustion in a Direct Injection Methanol Fueled Engine," SAE Paper No. 2002-01-0998. Presented at the SAE International Congress and Exposition, Detroit, MI.

75. George, Steven R., Schock, H. J., Gray, C. L., Hamady, F. J. and Hellman, K. H., (September 2001). "Design of a High Compression, Direct-Injection, Spark-Ignition, Methanol Fueled Research Engine with an Integral Injector-Ignition Source Insert," SAE Paper No. 2001-01-3651, International Fall Fuels and Lubricants Meeting and Exposition, San Antonio, Texas, September 24 - 27, 2001.

76. Gu, X., Schock, H. J. and Shih, T. I-P. from MSU; Hernandez, E.C. and Chu, D. from Ford Motor Company; and Keller, P. S. and Sun, R. L. from DaimlerChrysler Corporation, (January 2001). "Grid-Quality Measures for Structured and Unstructured Meshes," AAIA 2001-0652, 39th Aerospace Sciences Meeting and Exhibition, Reno, Nevada, January 8 - 11, 2001.

77. Lee, Keunchul C., Yoo, Seoung-Chool and Schock, H. J., (June 12, 2000). "Quantification of Volumetric In-Cylinder Flow of SI Engine Using 3D Laser Doppler Velocimetry," SAE Paper No. 2000-05-0035.

78. Lee, Keunchel, C., Yoo, Seoung-Chool and Schock, Harold J., (June 12, 2000). "Quantification of Primary Flows of a Torque Converter Using Laser Doppler Velocimetry," SAE Paper No. 2000-05-0106.

79. Hascher, H. G., Schock, H. J., Avanessian, O. and Novak, J., (Oct 2000). "A Comparison of Modeled and Measured 3-D In-Cylinder Charge Motion Throughout the Displacement of a Four-Valve SI Engine," SAE Paper No. 2000-01-2799, International Fall Fuels and Lubricants Meeting and Exposition, Baltimore, MD, October 16 - 19, 2000.

80. Hascher, H. Novak, G., M., Stuecken, T., Schock, H. J., and Novak, J., (October 2000). "The 3-D In-Cylinder Charge Motion of a Four-Valve SI Engine Under Stroke, Speed, and Load Variation," SAE Paper No. 2000-01-2798, SAE Transactions, International Fall Fuels and Lubricants Meeting and Exposition, Baltimore, MD, October 16 - 19, 2000.

81. Pint, S. and Schock, H. J., (March 2000). "Design and Development of a Software Module for Analysis of Three-Dimensional Piston Ring Wear," SAE Paper No. 2000-01-0920, SP-1495, SAE International Congress and Exposition, Detroit, MI, March 6 - 9, 2000.

82. Yen, S. R., Lee, K. and Schock, H. J., (1999). "Ring Pack Simulation, Analysis and Optimization of Cylinder 2 in a DaimlerChrysler 3.3 L V6 Spark-Injection Engine," DaimlerChrysler Tech Center Report.

83. Ejakov, M. A, Diaz, A. R. and Schock, H. J., (May 1999). "Numerical Optimization of Ring-Pack Behavior," SAE Paper No. 1999-01-1521, SP-1463, SAE International, International Spring Fuels and Lubricants Meeting & Exposition, Dearborn, MI, May 3 - 6, 1999.

84. Ejakov, M., Schock, H. J. and Brombolich, L., (October 1998). "Modeling of Ring Twist for an IC Engine," SAE Paper No. 982693, SAE Technical Paper Series, SAE Transactions, Journal of Engines, SAE International Fall Fuels and Lubricants Meeting and Exposition, San Francisco, CA, October 19 - 22, 1998.

85. Hascher, H. Novak, G., M., Lee, K. and Schock, H. J., (July 1998). "An Evaluation of IC-Engine Flows with the Use of Modern In-Cylinder Measuring Techniques," AIAA-98-3455, 34th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit, Cleveland, OH, July 13 - 15, 1998.

86. Ejakov, M., Schock, H. J., Brombolich, L., Carlstrom, C. and Williams, R., (1997). "Simulation Analysis of Inter-Ring Gas Pressure and Ring Dynamics and Their Effect on Blow-By," ICE, v.29-2, ASME, Fall Tech. Conference.

87. Hascher, H., Jaffri, K., Novak, M., Lee, K., Schock, H J., Bonne, M. and Keller, P., (February 1997). "An Evaluation of Turbulent Kinetic Energy for the In-Cylinder Flow of a Four-Valve 3.5L SI Engine Using 3-D LDV Measurements," SAE Paper No. 970793, SAE Transactions, Journal of Engines, 97, v.106, SAE International Congress and Exposition, Detroit, MI, February 24 - 27, 1997.

88. Jaffri, K, Hascher, H., Novak, M., Lee, K., Schock, H. J., Bonne, M. and Keller, P., (February 1997). "Tumble and Swirl Quantification within a Motored Four-Valve SI Engine Cylinder Based on 3-D LDV Measurements," SAE Paper No. 970792, SAE Transactions, Journal of Engines 97, v.106, International Congress and Exposition, Detroit, MI, February 24 - 27, 1997.

89. Lock, R., Hicks, Y., Anderson, R., Ockuneec, K. and Schock, H. J., (1996). "Imaging of Combustion Species in a Radially-Staged Gas Turbine Combustor," 33rd Joint Combustion and Propulsion Systems Hazards Subcommittee Meeting, Joint Army-Navy-NASA-Air Force Interagency Propulsion Committee, NASA Tech. Memorandum 107373.

90. Kim, J. U., Golding, B., Schock, H. J., Keller, P. and Nocera, D., (February 1996). "Exciplex Fluorescence Visualization Systems for Pre-Combustion Diagnosis of an Automotive Gasoline Engine," SAE International Congress and Exposition, SAE Paper No. 960826, SP-1157, February 26 - 29, 1996.

91. Hicks, Y., Locke, R., Anderson, R., Ockuneec, K. and Schock, H. J., (1996). "Planar Imaging of OH and NO in a High Temperature and Pressure Combustion Sector Rig," Optical Society of American Annual Meeting, NASA Technical Memorandum 107344.

92. Ejakov, M. A., Hasher, H. G., Schock, H. J., Brombolich, L. J., Trinker, F. H. and LoRusso, J. A., (1996). "Simulation Analysis of Ring Pack Behavior in a Deactivated Cylinder," ASME Fall Technical Conference, ICE, v.27-2.

93. Kim, J. U., Golding, B., Schock, H. J. and Nocera, D., (1995). "Determination of Fuel/Air Mixture Distribution in the Combustion Chamber Using a Laser Induced Fluorescence Technique," 9th Annual CFMR University/Industrial Symposium at Michigan State University.

94. Yoo, S-C., Lee, K., Novak, M., Schock, H. J. and Keller, P., (March 1995). "3-D LDV Measurements of In-Cylinder Air Flow in a 3.5L Four-Valve SI Engine," SAE Paper No. 950648, SAE Transactions, Journal of Engines, 95, v104. Presented at the SAE International Congress and Exposition, Detroit, MI, February 27 - March 2, 1995.

95. Hwang, K., Lee, K., Mueller, J., Stuecken, T., Schock, H. J. and Lee, J-C., (March 1995). "Dynamic Flow Study in a Catalytic Converter Using Laser Doppler Velocimetry and High Speed Flow Visualization," SAE Paper No. 950786, SP-1094. Presented at the International Congress and Exposition, Detroit, MI, February 27 - March 2, 1995.

96. Ejakov, M., Schock, H. J., Brombolich, L. and Williams, R., (1996). "Comparison Between Predicted and Measured Inner Ring Gas Pressures and Analysis of Factors Affecting Them," Ford Analytical Report No. 96-00858, Ford Motor Company, 1996. (M)

97. Rimlinger, M. J., Novak, M., Shih, T. I-P., and Schock, H. J., (November 1995). "Computation of Unsteady, Three-Dimensional Flow in a Mass Flow Sensor," Mid Michigan Research Report No. 95-2.

98. Rimlinger, M. J., Novak, M., Shih, T. I-P. and Schock, H. J., (November 1995). "Computation of Steady, Three-Dimensional Flow in a Mass Flow Sensor," Submitted to Ford Motor Company, Mid Michigan Research, Report No. 95-1.

99. Novak, M., Schock, H. J., Stuecken, T., Clowater, L. and Zurek, L., (November 1995). "Performance Analysis of the Prototype U-Flow MAFS Housing and Comparison to the 60mm Production MAFS Housing Under Normal Engine Operating Conditions," MSUERL Technical Report No. 95-1. Submitted to Ford Motor Company, November 1995.

100. Ramadan, B. and Schock, H. J., (August 1995). "Prediction of an Automotive Catalytic Converter, Internal Flow and Oxygen Sensor Location Using CFD," MSUERL No. 95-2.

101. M: Kim, J. U., Golding, B., Schock, H. J., Keller, P. and Nocera, D., (November 1995). "Exciplex Fluorescence Visualization Systems for Pre-Combustion Diagnosis of an Automotive Gasoline Engine," Submitted to Chrysler Corporation.

102. Ejakov, M., Hascher, H. and Schock, H. J., (August 1995). "Simulation and Analysis of Ring Pack Behavior in a Variable Displacement Engine," Submitted to Ford Motor Company.

103. Lee, K., Mueller, J., Hwang, K., Novak, M., Stuecken, T. and Schock, H. J., (March 1995). "Dynamic Flow Studies in a Catalytic Converter Using Laser Doppler Velocimetry and High-Speed Flow Visualization," Submitted to Hyundai, MSUERL No. 95-13.

104. Schock, H. J. (Februry 1995). "Measurement of Flows Through Catalytic Converter Assemblies with Different Inlet Configurations Using Laser Doppler Velocimetry," Submitted to Walker Manufacturing Company, MSUERL Technical Report 95-11.

105. Schafer, R., Schock, H. J. and Stuecken, T., (January 1994). "The Development of an Improved Quantitative Calibration for an Exciplex Liquid/Vapor Fuel Visualization System," Reprint from SPIE (Society of Photo-Optical Instrumentation Engineers) Conference Paper 25, Laser Applications in Combustion and Combustion Diagnostics II, v.2122/61.

106. Venkataraman, A. and Schock, H. J., (May 17, 1994). "Image Tiling for Profiling Large Objects," Presented at 1994 Conference on Advanced Earth-to-Orbit Propulsion Technology.

107. Lee, K. Mueller, J., Hwang, K., Novak, M., Ramadan, B., Stuecken, T and Schock, H. J., (May 1994). "Fuel Air Mixing in a Direct Injected Methanol Fueled Engine," Technical Report MSUERL, 94-3, Environmental Protection Agency.

108. Lee, K., Mueller, J., Hwang, K., Stuecken, T., Hascher, H., Sober, S., Turnbull, R., Stuecken, T. and Schock, H. J., (June 1994). "Design of a Wireless Telemetry System Between the Piston and the Crank Case of a Combustion Engine," Technical Report MSUERL, 94-1, Ford Motor Company.

109. Chung, Y., Schock, H. J. and Brombolich, L. J., (March 1993). "Fire Ring Wear Analysis for a Piston Engine," SAE Paper No. 930797, SP-959, SAE International Congress and Exposition," Detroit, MI, March 1 - 5, 1993.

110. Lee, K., Yoo, S-C., Stuecken, T., McCarrick, D., Schock, H. J., Hamady, F., LaPointe, L. A., Keller, P. and Hartman, P., (March 1993). "An Experimental Study of In-Cylinder Air Flow in a 3.5L Four-Valve S.I. Engine by High Speed Flow Visualization and Two-Component LDV Measurement," SAE Paper No. 930478. Presented at the SAE International Congress and Exposition, Detroit, MI, March 1 - 5, 1993.

111. DeFillipps, M., Hamady, F., Novak, M. and Schock, H. J., (February 1992). "Effects of Pocket Configuration on the Flow Field in a Rotary Engine," SAE Paper No. 920300, SAE Transactions, Journal of Engines, 92, v.101. Presented at the SAE International Congress and Exposition, Detroit, MI, February 24 - 28, 1992.

112. Schafer, R. S. and Schock, H. S., (September 1993). "The Development of an Improved Quantitative Calibration for an Exciplex Liquid/Vapor Fuel Visualization System," Technical Report MSUERL, 93-4, NASA Lewis Research Center.

113. McCarrick, D., Schock, H. J., and Lee, K., (Auust 1993). "An Experimental Investigation of the Flow Field in an Automotive Torque Converter Using Laser Doppler Velocimetry," Technical Report MSUERL, 93-3, Ford Motor Company.

114. Lee, K., Yoo, S.-C., Weber, M. and Schock, H. J., (August 1993). "Flow Characterization Through a Catalytic Converter Using Laser Doppler Velocimetry," Technical Report MSUERL, 93-2, Ford Motor Company.

115. Lee, K., Schock, H. J., Yoo, S.-C. and Stuecken, T., (May 10, 1993). "Performance Analysis of 60 mm Hitachi and Pre-Prototype Mass Air Flow Meters under Normal Engine Operating Conditions," Technical Report MSUERL, 93-1, Ford Motor Company.

116. Clowater, L., Hamady, F., and Schock, H. J., (February 1992). "Fiber Optic Imaging System for Remote Location Flow Visualization Studies," SAE Paper No. 920305, International Congress and Exposition, Detroit, MI, February 24 - 28, 1992.

117. Hamady, F. J., Stuecken, T., Ambrose, G. and Schock, H. J., (March 17, 1992). "Air Flow Visualization Studies in a 3.5L Four-Valve SI Engine," Technical Report MSUERL, R-92-1.

118. Schock, H. J., Hamady, F., DeFilippis, M., Stuecken, T., Gendrich, C. and LaPointe, L.A., (March 1991). "High Frame Rate Flow Visualization and LDV Measurements in a Steady Flow Cylinder Head Assembly," SAE Paper No. 910473, SAE Transactions, Journal of Engines, 91, v.100. Presented at the SAE International Congress and Exposition, Detroit, MI, February 25 - March 1, 1991.

119. Hamady, F. J., Stuecken, T., Defilippis, M. and Schock, H. J., (March 1991). "Experimental Analysis of Blowby and Flow Field Interaction in a Motored Rotary Engine," SAE Paper No. 910893, SAE Transactions, Journal of Engines, 91, v100. Presented at the SAE International Congress and Exposition, Detroit, MI, February 25 - March 1, 1991.

120. Morita, T. B., Hamady, F. J., Stuecken, T., Somerton, C. and Schock, H. J., (March 1991). "Fuel-Air Mixing Visualization in a Motored Rotary Engine Assembly," SAE Paper No. 910704, SAE Transactions, Journal of Engines, 91, v100. Presented at the SAE International Congress and Exposition, Detroit, MI, February 25 - March 1, 1991.

121. Rachel, T., Schock, H. J. and Bartrand, T., (March 1991). "Analysis of Frictional Power Losses Associated with the Side and Apex Seals of a Wankel Rotary Engine," SAE Paper No. 910626, SAE Transactions, Journal of Engines, 91, v.100. Presented at the SAE International Congress and Exposition, Detroit, MI, February 25 - March 1, 1991.

122. Li, Z., Shih, T. I-P., Schock, H. J. and Willis, E. A., (March 1991). "A Numerical Study on the Effects of Apex Seal Leakage on Wankel Engine Flow Fields," SAE Paper No. 910703. Presented at the SAE International Congress and Exposition, Detroit, MI, February 25 - March 1, 1991.

123. Schock, H. J., (October 1990). "Developments in High Energy Ion Implantation for Wear Analysis," MSUERL Status Report.

124. McHarris, W. C., Mallory, M. L., Ronningen, R. M., Dardenne, Y. X. and Schock, H. J., (May 1990). "Gamma-Ray Spectroscopy of Implanted ^{7}Be and ^{22}Na for Tribology Studies," 7th Symposium on Radiation Measurements and Applications, University of Michigan, Ann Arbor, MI. May 21 - 24, 1990.

125. Hamady, F., Stuecken, T. and Schock, H. J., (March 1990). "Airflow Visualization and LDV Measurements in a Motored Rotary Engine Assembly - Part I, Flow Visualization," SAE Paper No. 900030, Also appears in SAE Transactions, Journal of Engines, v.99, Section 3, Part I, pp. 163-183. Presented at the SAE International Congress and Exposition, Detroit, MI, February 26 - March 2, 1990.

126. Chouinard, E., Hamady, F. and Schock, H. J., (March 1990). "Airflow Visualization and LDV Measurements in a Motored Rotary Engine Assembly, Part II, LDV Measurements," SAE Paper No. 900031, Also appears in SAE Transactions, Journal of Engines, v.99, Section 3, Part I, pp. 184-

207. Presented at the SAE International Congress and Exposition, Detroit, MI, February 26 - March 2, 1990.

127. Hamady, F. J., Stuecken, T. and Schock, H. J., (May 1990). "Flow Visualization and LDV Measurements Within an Air Filter Cover and Entry Region of a Mass Air Flow Sensor," Technical Report 90-3, Ford Motor Company.

128. Hamady, F. J., Stuecken, T. and Schock, H. J., (January 15, 1990). "Flow Characteristics in the Entry Region of a Mass Air Flow Sensor," Technical Report 90-2, Ford Motor Company.

129. Hamady, F. J., Somerton, C. and Schock, H. J., (January 1990). "Stratified Charge Rotary Engine Combustion Studies," Technical Report 90-1 to NASA Lewis Research Center.

130. Schock, H. J., Hamady, F. J. and Stuecken, T., (September 25, 1989). "Air Flow Visualization and LDV Measurements Around an Intake Valve in a Chrysler 2.2L Cylinder Head," Tech. Report 89-2, Chrysler Motors. Corporation.

131. Schock, H. J., Hamady, F. J. and Somerton, C., (July 6, 1989). "Stratified Charge Rotary Engine Combustion Studies," Tech. Report 89-3, NASA Lewis Research Center.

132. Schock, H. J., Hamady, F. J. and Stuecken, T., (May 25, 1989). "Visualization and Measurements of Air Flow Around an Intake Valve in a Chrysler 2.2L Cylinder Head," Technical Report 89-1, Chrysler Motors Corporation.

133. Hamady, F., Kosterman, J., Chouinard, E., Somerton, C., Schock, H.J., Chun, K. and Hicks, Y., (March 1989). "Stratified Charge Rotary Engine Internal Flow Studies at the Engine Research Laboratory," SAE Paper No. 890331, SP.768, Also appears in SAE Transactions, Journal of Engines, v.98, Section 31, pp. 527-542. Presented at the SAE International Congress and Exposition, Detroit, MI, February 27 - March 3, 1989.

134. Schock, H. J., (December 6, 1988). "Production and Implantation of ^{7}Be for Wear Analysis," Research Brief, NSCL and MSUERL.

135. Mallory, J. L., Ronningen, R. M., McHarris, W. C., Sherrill, B., Dardenne, Y. Y. and. Schock, H. J., (1988). "Tribology Studies: ^{7}Be Implantation in a Ceramic Sample by Means of a Fragmented High-Energy ^{14}N Beam," Invited Paper for Tenth Conference on the Application of Accelerators in Research and Industry, Denton, TX, November 7 - 9, 1988.

136. Hamady, F., Olbrich, C., Kurtz, M., Weller, K., Cummings, F. and Schock, H. J., (June 1988). "Stratified Charge Rotary Combustion Engine Studies," Progress Report of the MSU Engine Laboratory.

137. Schock, H. J., (April 1988). "Use of a Heavy Ion Cyclotron to Implant ^{7}Be in Ceramics, Polymers, Composites and Metals for Wear Studies," Research Brief, NSCL and MSUERL.

138. Mallory, M.L., Ronningen, R., Schock, H. J., Sherrill, B. and McHarris, W.C., (April 1988). "^{7}Be Studies for Wear Research," NSCL Annual Report.

139. Schock, H. J., with others (1988). "Mobile Electric Power Technologies for the Army of the Future," Committee on Mobile Electric Power Plant Technologies, Energy Engineering Board,

Commission on Engineering and Tech. Systems, National Research Council, National Academy Press, Washington, D.C.

140. 140. Steinthorsson, E., Shih, T. I-P., Stegeman, J. and Schock, H. J., (March 1988). "Calculations of the Unsteady, Three-Dimensional Flowfield Inside a Motored Wankel Engine," SAE Paper No. 880625, SAE Transactions, Journal of Engines, 88, v.97. Presented at the SAE International Congress and Exposition, Detroit, MI, February 29 - March 4, 1988.

141. 141. Lee, C. M. and Schock, H. J., (March 1988). "Regressed Relations for Forced Convection Heat Transfer in a Direct Injection Stratified Charge Rotary Engine," SAE Paper No. 880626, SAE Transactions, Journal of Engines, 88, v.97. Presented at the SAE International Congress and Exposition, February 28 - March 4, 1988.

142. 142. Shih, T. I-P., Yang, S. L. and Schock, H. J., (1987). "A Two-Dimensional Numerical Study of the Flow Inside the Combustion Chamber of a Motored Rotary Engine," NASA TM No. 87212, NASA Lewis Research Center, Cleveland, OH.

143. Lock, J. A. and Schock, H. J., (1987). "Incident Beam Polarizations for Laser Doppler Velocimetry Employing a Sapphire Cylindrical Window," NASA TM No. 87064, NASA Lewis Research Center, Cleveland, OH.

144. Schock, H. J., Willis, E. A. and Lee, C. M., (February 1987). "Stratified Charge Rotary Engine Program at NASA Lewis Research Center," SAE Paper No. 870407. Presented at the SAE International Congress and Exposition, Detroit, MI, February 23 - 27, 1987.

145. Nguyen, H. L., Schock, H. J., Carpenter, M. H., Ramos, J. I. and Stegeman, J.D., (February 1987). "Numerical Simulation of the Flow Field and Fuel Sprays in an I.C.Engine," SAE Paper No. 870599. Presented at the SAE International Congress and Exposition, Detroit, MI, February 23 - 27, 1987.

146. Shih, T. I.P., Schock, H. J. and Ramos, J. I., (February 1987). "Fuel-Air Mixing and Combustion in a Two-Dimensional Wankel Engine," SAE Paper No. 870408. Presented at the SAE International Congress and Exposition, Detroit, MI, February 23 - 27, 1987.

147. Regan, C. A., Chun, K. S. and Schock, H. J., (January 1987). "Engine Flow Visualization Using a Copper-Vapor Laser," Proceedings of the SPIE, v.737, Los Angeles, CA.

148. Nguyen, H. L., Schock, H. J. and Carpenter, M. H., et al., (October 1986). "Numerical Simulation of the Flow Field and Fuel Sprays in an Intermittent Combustion Engine," AIAA General Aviation Technology Conference, Anaheim, CA, September 29 - October 1, 1986.

149. Shih, T. I-P., Yang, S. L. and Schock, H. J., (July 1986). "A Two-Dimensional Numerical Study of the Flow Inside the Combustion Chamber of a Motored Rotary Engine," SAE Paper No. 860615. Presented at the SAE International Congress and Exposition, Detroit, MI, July 24 - 28, 1986.

150. Lock, J. A., Schock, H. J. and Regan, C. A., (July 1986). "The Determination of the Direction of the Optic Axis of Sapphire Windows," NASA TM No. 86892, NASA Lewis Research Center, Cleveland.

151. Hicks, Y. R., Schock, H. J., et al., (June 1986). "Visualizations of Flows in a Motored Rotary Combustion Engine Using Holographic Interferometry," AIAA No. 86-1557. Presented at the 22nd Joint Propulsion Conference, AAIA/ASME/SAE/ASEE, Huntsville, AL, June 16 - 18, 1986.

152. Kim, R. C., Case, S. K. and Schock, H. J., (January 1985). "Holographic Optical System for Aberration Correction in Laser Doppler Velocimetry," Presented at the SPIE Symposium on Optical and Electro-Optical Engineering, Los Angeles, CA, January 20 - 25, 1985.

153. Schock, H. J., (June 1984). "A Review of Internal Combustion Engine Combustion Chamber Process Studies at NASA Lewis Research Center," Presented at the AIAA/ASME/SAE 20th Joint Propulsion Specialists Conference, Cincinnati, OH, AIAA No. 84-1316, June 11 - 13, 1984.

154. Knoll, J., Vilmann, C. R., Schock, H. J. and Stumpf, R. P., (March 1984). "A Dynamic Analysis of Rotary Combustion Engine Seals," SAE Paper No. 840035. Presented at the SAE International Congress and Exposition, Detroit, MI, February 27 - March 2, 1984.

155. Schock, H. J., Sosoka, D .J. and Ramos, J. I., (January 1983). "Numerical Studies of the Formation and Destruction of Vortices in a Motored Four-Stroke Piston-Cylinder Configuration," Paper No. 83-0497. Presented at the AIAA Annual Meeting, Reno, NV.

156. Schock, H. J., (1983). "A Review of Internal Combustion Engine Combustion Chamber Process Studies at NASA Lewis Research Center," NASA TM No. 83666, NASA Lewis Research Center, Cleveland, OH.

157. Lock, J. A., Schock, H. J. and Regan, C. A., (1983). "Dynamic Behavior of Seals in a Rotary Combustion Engine," Knoll, J., C. R. Vilmann, H. Schock, and R. P. Stumpf, NASA TM No. 83536, NASA Lewis Research Center, Cleveland, OH.

158. Schock, H. J., Regan, C. A., Rice, W. J. and Chlebecek, R., (1983). "Multi-Component Velocity Measurement in a Piston-Cylinder Configuration," NASA TM No. 83534, NASA Lewis Research Center, Cleveland, OH.

159. Meng, P. R., Rice, W. J., Schock, H. J. and Pringle, D. P., (February 1982). "Preliminary Results on Performance Testing of a Turbocharged Rotary Combustion Engine," SAE Paper No. 820354. Presented at the SAE International Congress and Exposition, Detroit, MI, February 22 - 26, 1982.

160. Schock, H. J., Rice, W. J. and Meng, P. R., (February 1981). "Experimental Analysis of IMEP in a Rotary Combustion Engine," SAE Paper No. 810150. Presented at the SAE International Congress and Exposition, Detroit, MI, February 23 - 27, 1981.

161. Schock, H. J., and Johnson, J. J., (1981). "Simulation and Measurement of Space and Time Varying Pollutant Concentrations from a Diesel-Powered Vehicle in a Dead-Ended Drift," SME No. 81-64. Presented at the AIME Annual Meeting, Chicago, IL.

162. Schock, H. J., Johnson, J. J. and Bunting, B. G., (November 1980). "An Experimental Comparison of Pollutant Concentrations for Three Ventilation Configurations in a Down Sloping Dead-Ended Drift," SME No. 80-342. Presented at the SME Fall Meeting, Minneapolis, MN.

163. Schock, H. J., Ph.D. Dissertation, (May 9, 1979). "Measurement of Pollutant Dispersion from a Moving Variable-Speed, Variable-Strength Source in a Dead-Ended Tunnel."

SUMMARY OF PUBLICATIONS / OTHER WORKS WHICH INFLUENCE THE DESIGN OF IC ENGINES:

Conference #144 – First real time demonstration of IMEP measurement in a 4-stroke cycle engine published in the open literature (A Wankel Rotary is a 4-stroke cycle engine):
Schock, H. J., Rice, W. J. and Meng, P. R., (February 1981). "Experimental Analysis of IMEP in a Rotary Combustion Engine," SAE Paper No. 810150. Presented at the SAE International Congress and Exposition, Detroit, MI, February 23 - 27, 1981. This was the referred publication of how one could electronically and in real time measure the indicated mean effective pressure in a 4-stroke cycle engine. The measurement algorithm was designed to be complete and available for comparison after the cycle was complete and as such was suitable for control purposes. Schock developed the mathematical algorithm for the rotary engine configuration and conducted the experimental work on the engine. Rice implemented the algorithms developed by Schock in machine language used by microprocessor that he built. Meng had overall test cell responsibility. In future years, IMEP systems were built and used all over the world and the basic concepts demonstrated in this device are still in use today.

Conference – numerous, Articles 31,33 and 34 – Most extensive mapping of 3D in-cylinder flows ever conducted, two examples given below:
Hascher, H., Jaffri, K., Novak, M., Lee, K., Schock, H J., Bonne, M. and Keller, P., (February 1997). "An Evaluation of Turbulent Kinetic Energy for the In-Cylinder Flow of a Four-Valve 3.5L SI Engine Using 3-D LDV Measurements," SAE Paper No. 970793, SAE Transactions, Journal of Engines, 97, v.106, SAE International Congress and Exposition, Detroit, MI, February 24 - 27, 1997. Jaffri, K, Hascher, H., Novak, M., Lee, K., Schock, H. J., Bonne, M. and Keller, P., (February 1997). "Tumble and Swirl Quantification within a Motored Four-Valve SI Engine Cylinder Based on 3-D LDV Measurements," SAE Paper No. 970792, SAE Transactions, Journal of Engines 97, v.106, International Congress and Exposition, Detroit, MI, February 24 - 27, 1997. Schock was the leader of this activity and this mapping represented the culmination of a nearly 15 year effort to describe airflow motion in a piston-cylinder assembly. It is to date the most complete mapping ever conducted in a piston cylinder assembly. This work was conducted from 1981-1996. Hascher and Jaffri were my students.

Articles #14, 17 and 28 – First to experimentally quantify the cycle-to-cycle variability of planar flows in a four-stroke cycle piston cylinder assembly, two examples shown below:
Two examples: Mittal, M., Schock, H. J. (July 2010). "A Study of Cycle-to-Cycle Variations and the Influence of Charge Motion Control on In-Cylinder Flow in an IC Engine," Journal of Fluids Engineering, Vol 132. and Mittal, M., Sadr, R., Schock, H. J., Fedewa, A.., and Naqwi, A., (2009). "In-cylinder Engine Flow Measurement using Stereoscopic Molecular Tagging Velocimetry (SMTV)," *Exp. Fluids,* 46 (2), 277-284. Continuation of the flow measurement work described above in Hascher et al. and Jaffri et al. The MTV technique that was pioneered at MSU with Dr. Koochesfahani and Dr. Nocera. See US Patent No. 6,065,454 described above. Schock and his students (Mittal) were responsible for developing the Molecular Tagging Velocimetry technique for IC engines. Schock and Mittal extended this technique to 3D. It removes the need for particles following the flow as in particle image velocimetry and provides planar 3D measurements. It is the only reliable technique that can be used for this flow quantification during intake and compression strokes of a 4-stroke cycle engine. This experimental work elucidates the difficulty in using Reynolds Averaged Navier Stokes simulations (like Star-CD, Fire and KIVA) for modeling in cylinder flow processes. Also, this experimental work provided the impetus for the development of new simulations for IC engines called large eddy simulations. This LES simulation work was led by a colleague at MSU, F. Jaberi (see publications Article 1, Conference papers 13 and 21) and is considered the future in multidimensional engine simulation.

Articles #19, 20 and 29, Conference Papers #31, 36, 57, 66, 67, 68, 69, 71 and others – Developed blowby, friction and wear models of cylinder kits for a piston engine, two examples shown:
Panayi, A. P. and Schock, H. J., (2008). "On the Approximation of the Integral of the Asperity Height Distribution for the Greenwood-Tripp Asperity Contact Model," Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, Professional Engineering Publishing, ISSN No. 1350-6501, v.222, Number 2 /2008, pp. 165-169. And Ejakov, M., Schock, H. and Brombolich, L., (1998). "Modeling of Ring Twist for an IC Engine," SAE Paper No. 982693. Also appears in SAE Transactions, Journal of Engines, 1998, v.107-3. These papers describe the development technology implemented in a software system called CASE, Cylinder-kit Analysis System for Engines. It is currently in use by the Cummins Engine Company and has been used in the past by Ford and Detroit Diesel. Application of this code has influenced the design of millions of internal combustion engines for cars and trucks.

Comments on US Provisional Patent No. 61/500,667, "High Temperature, High Pressure Window Assembly for Optical Access to Combustion Chambers and Other Vessels," Schock, H., filed 6/2011

This invention addresses a problem of obtaining optical access within a piston-cylinder assembly while the system is operated under the high-pressure and high-temperature combustion conditions typical of an internal combustion engine. Currently, small windows are placed in a cylinder liner and sometimes in a radial location in the piston. They are typically a few mm^2 in area allow for very limited optical access to the combustion chamber. These small windows are used as they can be fabricated in a geometrical configuration that will mitigate stresses that occur within the windows. The subject invention permits one to use a complete cylindrical window of the diameter of the piston bore, offering tens of cm^2s of viewing area or as an area to deliver planar laser beams for laser induced fluorescence or other optical based experiments. Although this is not new for a non-firing or low-temperature, low-pressure configurations, it is new when one is attempting to provide optical access normal to the piston assembly at high-temperatures and high-pressures representative of actual engine operation.

The invention works by using a high strength steel cage to impart a compressive stress on the cylindrical window of interest. Optical window materials have a high compressive strength but their tensile strength is often low. In addition, if the window is constructed to be thick enough to withstand the tensile stresses of combustion, local stresses caused by thermal stress gradients can exceed optical material limits. By placing the optical cylinder in compression within a steel cage, the thermal stresses are managed in the material as it is not too thick to build up large temperature gradients while the pressure stresses are managed by the system which includes the compressive steel cage and the cylindrical window.

The invention was brought to practice in July, 2011 with a heated diesel engine and operated for about 100 consecutive cycles of firing at 150 bar peak cylinder pressure.