Appendix A

Timeline for Control of Automotive Emissions in the United States

<table>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1946</td>
<td>South Coast Air Quality Management District</td>
<td>Formed by California legislation to control pollution in Los Angeles basin.</td>
</tr>
<tr>
<td>1947</td>
<td>Los Angeles County Air Pollution District</td>
<td>Formed by California legislation.</td>
</tr>
<tr>
<td>1961</td>
<td>PCV California</td>
<td>Provided by auto companies, prior to legislation.</td>
</tr>
<tr>
<td>1963</td>
<td>PCV USA</td>
<td>Provided by auto companies, prior to legislation.</td>
</tr>
<tr>
<td>1963</td>
<td>Clean Air Act for USA</td>
<td>Congress passed first legislation controlling environmental pollution.</td>
</tr>
<tr>
<td>1965</td>
<td>Amended Clean Air Act</td>
<td>Auto emissions added to controls.</td>
</tr>
<tr>
<td>1966</td>
<td>First year for emission controls in California</td>
<td>Response to Clean Air Act.</td>
</tr>
<tr>
<td>1967</td>
<td>Amended Clean Air Act</td>
<td>Air Quality Act by U.S. Congress.</td>
</tr>
<tr>
<td>1967</td>
<td>Inter-Industry Emission Control Program (IIEC1)</td>
<td>Formed to develop an emission-free automotive powerplant.</td>
</tr>
</tbody>
</table>
**Cleaner Cars**

<table>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1968</td>
<td>California Air Resources Board (CARB)</td>
<td>Established by California legislation.</td>
</tr>
<tr>
<td>1968</td>
<td>First year for emission controls in USA</td>
<td>Response to Clean Air Act.</td>
</tr>
<tr>
<td>1968</td>
<td>CARB empowered to establish emission standards for diesel-powered vehicles</td>
<td>Established by California legislation.</td>
</tr>
<tr>
<td>1968</td>
<td>7-Mode Driving Test cycle</td>
<td>Established by CARB, emission test.</td>
</tr>
<tr>
<td>1969</td>
<td>End-of-line audit procedure</td>
<td>Established by CARB.</td>
</tr>
<tr>
<td>1969</td>
<td>Smog Case antitrust suit against GM, Ford, Chrysler, and American Motors</td>
<td>United States Department of Justice under the Sherman Act.</td>
</tr>
<tr>
<td>1970</td>
<td>Environmental Protection Agency (EPA) established</td>
<td>Established by U.S. Congress, William Ruckelshaus appointed administrator.</td>
</tr>
<tr>
<td>1970</td>
<td>National Ambient Air Quality Standards (NAAQS)</td>
<td>EPA established first air quality standards.</td>
</tr>
<tr>
<td>1972</td>
<td>Lead removal from gasoline established by EPA</td>
<td>0.05 g/gal, upper limit by 1975, no leaded fuel after January 1, 1997.</td>
</tr>
<tr>
<td>1972</td>
<td>Original Federal Test Procedure (FTP), cold start only</td>
<td>Established by EPA in 1970, Driving Test Procedure, replaced the 7-Mode Test.</td>
</tr>
</tbody>
</table>
## Appendix A

<table>
<thead>
<tr>
<th>Year</th>
<th>Title</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>Exhaust gas recirculation (EGR) introduced</td>
<td>Required to meet EPA NO\textsubscript{X} standards.</td>
</tr>
<tr>
<td>1973</td>
<td>Regulations for diesel-powered light duty vehicles</td>
<td>Established by CARB, dynamometer test.</td>
</tr>
<tr>
<td>1974</td>
<td>IIEC2 formed</td>
<td>Inter-Industry Emission Control Program extended.</td>
</tr>
<tr>
<td>1975</td>
<td>Oxidizing catalysts introduced</td>
<td>Required to meet EPA standards.</td>
</tr>
<tr>
<td>1975</td>
<td>75FTP, Revised Federal Test Procedure</td>
<td>EPA revised test procedure to include cold start and hot start.</td>
</tr>
<tr>
<td>1977</td>
<td>IIEC2 terminated</td>
<td></td>
</tr>
<tr>
<td>1981</td>
<td>Three-way catalysts and electronic controls introduced</td>
<td>Required to meet EPA standards.</td>
</tr>
<tr>
<td>1986</td>
<td>Particulate standard introduced</td>
<td>Established by EPA.</td>
</tr>
<tr>
<td>1987</td>
<td>Chrysler purchased American Motors</td>
<td></td>
</tr>
<tr>
<td>1989</td>
<td>Auto/Oil Air Quality Improvement Program (AQIRP)</td>
<td>Established by 14 oil companies and 3 U.S. automakers.</td>
</tr>
<tr>
<td>1990</td>
<td>Revised Clean Air Act</td>
<td>U.S. Congress, sweeping of 1990 changes to requirements for emission controls.</td>
</tr>
<tr>
<td>Year</td>
<td>Title</td>
<td>Comment</td>
</tr>
<tr>
<td>------</td>
<td>-----------------------------------------------------------------------</td>
<td>------------------------------------------------------------</td>
</tr>
<tr>
<td>1993</td>
<td>Formaldehyde standard introduced</td>
<td>Established by EPA.</td>
</tr>
<tr>
<td>1997</td>
<td>Auto/Oil Air Quality Final Report</td>
<td>Report covering all three original phases.</td>
</tr>
<tr>
<td>1998</td>
<td>Daimler Benz and Chrysler merge</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B

People and Places

Many, many individuals have contributed to this book. The first group consists of the many outstanding individuals whom I have had the opportunity to work with and for during my automotive career. Obviously, my contacts have primarily been with individuals within General Motors, where I worked for 43 years. The second group consists of individuals from the Ford and Chrysler organizations some of whom I have not had the opportunity to meet. To honor their contributions to the development of automotive emission controls, I have asked a colleague from each organization to comment on significant events in the development of automotive emission controls in their “shop” and the individuals involved. The third group consists of members of the supplier community, especially catalyst companies. I would like to acknowledge them for their contributions to advancing the state of the art in emission control systems.

General Motors

Beginning in the late 1960s, General Motors mounted a monumental effort to develop systems and components to control emissions from automobiles. This effort was a logical extension of GM’s ongoing research and development activities, and ultimately involved all of GM’s operations.

In 1969, at GM Research, a team of chemists, physical chemists, and physicists was assembled in the Physical Chemistry Department to focus on the possible use of catalytic converters to control automotive emissions. Preliminary studies were encouraging, but available catalysts were sparse and existing converters were much too large. Thus, a team consisting of members of the Research Laboratories, Engineering Staff, Buick Division, and AC Spark Plug Division was assembled to pursue advanced systems and technologies to lower tailpipe emissions.
**Cleaner Cars**

General Motor’s management designated the AC Spark Plug Division to serve as the focal point for all catalysts supplied to General Motors. This eliminated the confusion and duplication of effort that would have delayed the development of emission control technologies; the various catalyst suppliers no longer had to coordinate programs with many different GM car divisions. AC Spark Plug Division also developed screening tests to expedite sorting and rating performance of alternative catalyst materials from suppliers.

A staff of catalyst experts was assembled at the Research Laboratories. John Larson, head of the Physical Chemistry Department, served as leader of this staff, which included Richard Klimish, Kathy Taylor, Louis Hegedus, Jerry Summers, James Schlatter, and others.

The Fuels and Lubricants Department was led by Charles Tuesday, and staff included William Agnew, Joseph Colucci, Norman Brinkman, James Spearot, Fred Bowditch, Jack Benson, and many others. The smog chamber was developed in the Fuels and Lubricants Department through the efforts of Joe Wentworth, Charles Begeman, Joe Collucci, Chuck Tuesday, and John Kaplan.

The Emissions Research and Engine Research Departments focused their efforts on studying engine controls and alternative engine designs. William Agnew, Charles Amann, Nick Gallopoulos, and James Mattavi, with the support of many colleagues, contributed toward developing the technology necessary to control emissions from automobiles.

The GM Proving Grounds was an invaluable resource, testing hundreds of vehicles thousands of miles, to provide emission control data. R. Johnson, M. Homfeld, and W. Kolbe were early contributors to vehicle test procedures and test schedules. Al Robinson consistently advocated common sense approaches to vehicle emission testing and correlation of data. Harold Haskew contributed his knowledge of fuels and evaporative emissions, as well as his skills in negotiating with government agencies for logical solutions to emission controls.

During the 1960s, technical experts and administrators from the various GM staffs, primarily Research, had to spend a great deal of their time testifying in Washington, D.C., responding to requests from the U.S. Government for information on progress in research and development toward meeting emission standards. This heightened federal interest in industry procedures prompted GM in 1971 to organize a new staff to deal with environmental regulations.
Appendix B

The Environmental Activities staff was responsible for interactions with all government agencies issuing any type of environmental regulations that concerned GM; this included not only motor vehicles regulations, but also plant emissions regulations. One of the primary responsibilities of the Environmental Activities staff was to improve GM’s technical image with the public and the government, particularly with regard to environmental issues. The new vice president lured to head up this staff was Dr. Ernest Starkman, a member of the faculty of the University of California, whose specialty was combustion processes and associated chemistry.

Ford Motor Company

(Courtesy of Bob McCabe, Principal Staff Engineer, Chemical Engineering Department, Ford Research Laboratory)

The Ford Motor Company, under the leadership of Henry Ford II, also relied on its Research Laboratories to guide development of emission control systems. Starting out with fewer resources than General Motors, Ford entered into cooperative efforts with other industry supporters and suppliers, including oil companies and catalyst companies. An outgrowth of these joint efforts was the IIEC Program.

Inter-Industry Emission Control (IIEC) Program

Robert Campau, Executive Engineer, emerged as the spokesman for the IIEC effort, which involved eleven separate companies. Started in 1967, the three-year program, estimated to spend $7.0 million, ultimately spent $21.0 million over a six-year period.

Catalytic Converter Development

A team of chemists, physical chemists, engineers, and supporting staff was organized at the Ford Scientific Research Laboratories (SRL) to investigate catalysts and catalytic converter systems. J.T. Kummer, M. Shelef, and Klaus Otto contributed to the technology, and H.S.Gandhi established himself as a worldwide authority on catalyst systems for automobiles. Much of the work at the Ford Scientific Research Laboratories was carried out under the direction of Serge Gratch.
**Cleaner Cars**

In addition to the work at SRL, notable contributions were made by Eugene Weaver and Jim Gagliardi in Powertrain Operations. These two individuals, together with Joe Kummer, are generally credited with Ford's decision to proceed with the development and application of monolithic catalytic converters, which are now the industry standard. The issue of monoliths vs. pellets for substrates, and which was the better choice, will probably never be satisfactorily answered; each had both advantages and disadvantages.

**Chrysler Corporation**

(Courtesy of Michael Brady, Engineering Specialist, Supervisor, Catalyst Development, Advanced Engine System Development, Chrysler Corporation.)

During the 1970s, Chrysler Corporation endured some very difficult times. Many industry observers did not believe the company would survive. The story of Lee Iaccoca's leadership and the company's return to financial health is a legend in the auto industry. During the trying times, Chrysler was in no position to mount a large effort to study emission controls. Nevertheless, a number of dedicated individuals, including Maxwell Teague, Floyd Allen, Richard Goodwillie, and Bernard Robertson, managed to ensure that technology to control emissions was incorporated into vehicles. Much of the technology was a product of joint projects between Chrysler and its supplier network, which historically has provided Chrysler with more of its emission control technology than that provided to General Motors and Ford.

In 1970, various parts of Chrysler were assigned the joint task of meeting the dictates of the Clean Air Act of 1970. In the research office, the Chemical Research Department was directed to develop a catalyst, and Power Plant Research, headed by James Franceschina, was assigned the task of integrating catalytic converters into vehicles. In 1970, the Chief Research Scientist for Basic Sciences was Clayton Lewis. Lewis was succeeded by D. Maxwell Teague, who headed the catalyst research effort through most of the formative years.

The head of Catalyst Development was Leo B. Clougherty, and the early group leaders were Jack Engel and Philip J. Willson, followed in the mid-'70s by Edward J. Lesniak, Philip J. Willson, and Michael J. Brady. Willson
Appendix B

did much of the early substrate development and selection for Chrysler, while Engel and Brady were responsible for formulation development; Lesniak was responsible for process development.

Chrysler worked with Universal Oil Products (UOP) to jointly develop catalyst formulation and design and build the manufacturing plant in Tulsa, Oklahoma. During the time period 1972–1973, the 1975 production oxidation catalyst systems were developed. Richard E. Goodwillie was the manager of the department, which included both the certification group and the early engine and emission system development group. At that time, Richard Geiss and Roger Ortega were the senior engineers for the development groups that were most actively involved with catalysts. They both reported to William Hoffmeier, who, in turn, reported to Goodwillie. Douglas Teague and Richard Geiss were involved with supplier interactions and selections.

By 1975, Floyd Allen and Bernard Robertson had assumed supervision of the development of the three-way catalyst system with feedback control, which was introduced in production in 1980 in California. Advanced Engine Systems Development was formed, with Floyd Allen, Richard O. Schaum, and Richard Geiss leading the efforts of Clinton L. Syverson, Dewane D. Cogswell, Galen Kerns, and David C. VanRaaphorst. The Engine Performance Development Department, headed by Howard Padgham, was responsible for carburetor development and dynamometer testing, of catalyst performance.

In 1980, Gordon Rinschler became manager of Advanced Engine Systems Development, with both groups reporting to James Franceschina. In recent years, suppliers have become more involved than in the 1970s; however, emission control system have always been calibrated within Chrysler.
### Appendix C

## Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A/F</td>
<td>air to fuel ratio</td>
</tr>
<tr>
<td>AAMA</td>
<td>American Association of Automobile Manufacturers</td>
</tr>
<tr>
<td>ADP</td>
<td>alternative durability procedure</td>
</tr>
<tr>
<td>AIR</td>
<td>air injection reactor</td>
</tr>
<tr>
<td>AMA</td>
<td>Automobile Manufacturers Association</td>
</tr>
<tr>
<td>AQIRP</td>
<td>Air Quality Improvement Research Program</td>
</tr>
<tr>
<td>BSFC</td>
<td>brake specific fuel consumption</td>
</tr>
<tr>
<td>BSNO\textsubscript{X}</td>
<td>brake specific oxides of nitrogen</td>
</tr>
<tr>
<td>CAFE</td>
<td>Corporate Average Fuel Economy</td>
</tr>
<tr>
<td>CARB</td>
<td>California Air Resources Board</td>
</tr>
<tr>
<td>CFC</td>
<td>chlorofluorocarbon</td>
</tr>
<tr>
<td>CLA</td>
<td>chemiluminescence analyzer</td>
</tr>
<tr>
<td>CNG</td>
<td>compressed natural gas</td>
</tr>
<tr>
<td>CRADA</td>
<td>Cooperative Research and Development Activity</td>
</tr>
<tr>
<td>CRC</td>
<td>Coordinating Research Council</td>
</tr>
<tr>
<td>CVS</td>
<td>constant volume sampler</td>
</tr>
<tr>
<td>CVT</td>
<td>continuously variable transmission</td>
</tr>
<tr>
<td>DF</td>
<td>deterioration factor</td>
</tr>
<tr>
<td>DME</td>
<td>dimethyl ether</td>
</tr>
<tr>
<td>DOT</td>
<td>Department of Transportation</td>
</tr>
<tr>
<td>DS-VDV</td>
<td>distributor-spark vacuum delay valve</td>
</tr>
<tr>
<td>DS-VMV</td>
<td>distributor-spark vacuum modulator valve</td>
</tr>
<tr>
<td>ECE</td>
<td>Economic Commission for Europe</td>
</tr>
<tr>
<td>ECM</td>
<td>electronic control module</td>
</tr>
<tr>
<td>ECS</td>
<td>evaporation control system</td>
</tr>
<tr>
<td>EEC</td>
<td>European Economic Community</td>
</tr>
<tr>
<td>EFE</td>
<td>early fuel evaporation</td>
</tr>
</tbody>
</table>

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**Cleaner Cars**

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EGR</td>
<td>exhaust gas recirculation</td>
</tr>
<tr>
<td>EGR-TVS</td>
<td>exhaust gas recirculation-thermal vacuum switch</td>
</tr>
<tr>
<td>EHC</td>
<td>electrically heated converter</td>
</tr>
<tr>
<td>EOS</td>
<td>exhaust oxygen sensor</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
</tr>
<tr>
<td>EPCA</td>
<td>Energy Policy and Conservation Act</td>
</tr>
<tr>
<td>EUDC</td>
<td>Extra Urban Driving Procedure</td>
</tr>
<tr>
<td>EVAP</td>
<td>evaporation control</td>
</tr>
<tr>
<td>FID</td>
<td>flame ionization detector</td>
</tr>
<tr>
<td>FTP</td>
<td>Federal Test Procedure</td>
</tr>
<tr>
<td>GVW</td>
<td>gross vehicle weight</td>
</tr>
<tr>
<td>H/C</td>
<td>hydrogen to carbon ratio</td>
</tr>
<tr>
<td>H₂S</td>
<td>hydrogen sulfide</td>
</tr>
<tr>
<td>HC</td>
<td>hydrocarbons</td>
</tr>
<tr>
<td>HEW</td>
<td>Health Education and Welfare</td>
</tr>
<tr>
<td>IIIEC</td>
<td>Inter-Industry Emission Control</td>
</tr>
<tr>
<td>LEV</td>
<td>low emission vehicle</td>
</tr>
<tr>
<td>LPG</td>
<td>liquid petroleum gas</td>
</tr>
<tr>
<td>LTR</td>
<td>lean thermal reactor</td>
</tr>
<tr>
<td>MBT</td>
<td>minimum spark advance for best torque</td>
</tr>
<tr>
<td>MIL</td>
<td>malfunction indicator light</td>
</tr>
<tr>
<td>MPI</td>
<td>multiport fuel injection</td>
</tr>
<tr>
<td>MTBE</td>
<td>methyl tertiary butyl ether</td>
</tr>
<tr>
<td>MVPCB</td>
<td>California Motor Vehicle Control Board</td>
</tr>
<tr>
<td>NAAQS</td>
<td>National Ambient Air Quality Standards</td>
</tr>
<tr>
<td>NDIR</td>
<td>non-dispersive infrared</td>
</tr>
<tr>
<td>NLEV</td>
<td>National Low Emission Vehicle</td>
</tr>
<tr>
<td>NMOG</td>
<td>non-methane organic gases</td>
</tr>
<tr>
<td>NOₓ</td>
<td>oxides of nitrogen (NO + NO₂)</td>
</tr>
<tr>
<td>OBD</td>
<td>on-board diagnostic</td>
</tr>
<tr>
<td>OEM</td>
<td>original equipment manufacturer</td>
</tr>
<tr>
<td>OTC</td>
<td>Ozone Transport Commission</td>
</tr>
<tr>
<td>PCV</td>
<td>positive crankcase ventilation</td>
</tr>
<tr>
<td>PM</td>
<td>particulate matter</td>
</tr>
<tr>
<td>PNGV</td>
<td>Program for New Generation Vehicle</td>
</tr>
<tr>
<td>PULSAIR</td>
<td>pulse air injection reactor</td>
</tr>
</tbody>
</table>
## Appendix C

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAF</td>
<td>reactivity adjustment factor</td>
</tr>
<tr>
<td>RTR</td>
<td>rich thermal reactor</td>
</tr>
<tr>
<td>RVP</td>
<td>Reid vapor pressure</td>
</tr>
<tr>
<td>SEA</td>
<td>Selective Enforcement Audit</td>
</tr>
<tr>
<td>SFTP</td>
<td>Supplemental Federal Test Procedure</td>
</tr>
<tr>
<td>SIP</td>
<td>State Implementation Plan</td>
</tr>
<tr>
<td>SO₂</td>
<td>sulfur dioxide</td>
</tr>
<tr>
<td>SOF</td>
<td>soluble organic fraction</td>
</tr>
<tr>
<td>SPI</td>
<td>sequential port fuel injection</td>
</tr>
<tr>
<td>SULEV</td>
<td>super ultra-low emission vehicle</td>
</tr>
<tr>
<td>TBI</td>
<td>throttle body injection</td>
</tr>
<tr>
<td>TCS</td>
<td>transmission control spark</td>
</tr>
<tr>
<td>THERMAC</td>
<td>thermal air cleaner</td>
</tr>
<tr>
<td>TLEV</td>
<td>transition low emission vehicle</td>
</tr>
<tr>
<td>TVS</td>
<td>thermovacuum switch</td>
</tr>
<tr>
<td>TWC</td>
<td>three-way catalyst</td>
</tr>
<tr>
<td>ULEV</td>
<td>ultra-low emission vehicle</td>
</tr>
<tr>
<td>USCAR</td>
<td>United States Council for Automotive Research</td>
</tr>
<tr>
<td>ZEV</td>
<td>zero emission vehicle</td>
</tr>
</tbody>
</table>
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About the Author

J. Robert Mondt is a retired GM engineer with 43 years in the industry and 28 years experience designing, building, and testing exhaust systems for spark-ignition engines. He is recognized as an international authority on systems and hardware for controlling automobile exhaust emissions.

From 1988–1991, Mondt worked in the AC Rochester Division developing the metal-monolith catalytic converter. In 1990, he was awarded the Charles McCuen Special Achievement Award at the GM Research Laboratories for inventing and developing for production the “herringbone” corrugated geometry for heat exchangers and catalytic converters. From 1991–1996, he served as Staff Engineer, supervisor for the Exhaust Systems Technology and Consortia Management Group, Exhaust Subsystems Engineering, for Delphi Energy and Engine Management. He also was Exhaust Subsystems Coordinator for USCAR LEP Cold Start Emissions Team and Lean NOX CRADA.

From 1969–1976, Mondt was a member of the original “GM Catalyst Team,” joint with AC Spark Plug Division, and charged with developing a catalytic converter system to control emissions from spark-ignited piston engines. Prior to that he worked at GM Research, focusing on the application of thermodynamics, heat transfer, and fluid mechanics to research on advanced automotive powerplants including gas turbine, free pistons, hybrids, steam, and advanced gasoline and diesel. He was responsible for much basic research on gas turbine regenerator heat exchangers, and for the design and development of the steam generator for the GM Steam Car, circa 1970.

Mondt holds 15 patents, and has authored 20 publications, mostly through ASME, SAE, and AIChE, on heat transfer, heat exchangers, and emission control. He has made presentations throughout the world, including in
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Brazil, Italy, England, Germany, Luxembourg, and India, and has lectured at various universities, including Stanford, Michigan State, Colorado State, University of Wisconsin, and Rensselaer Polytechnic Institute.

Mondt is a member of ASME, SAE, the Combustion Institute, the Michigan Catalysis Society, and Sigma Xi. He has served on the ASME Gas Turbine Heat Transfer Committee, and is currently a member of the ASME ad hoc Committee on Heat Transfer Education. In 1967, ASME recognized the “Mondt number” as a new dimensionless parameter for correlating conduction loss in high-performance heat exchangers, especially gas turbine regenerators and Stirling engine regenerators.

Mondt is a member of the SAE Vehicular Heat Transfer Activity, and initiated the Vehicle Thermal Management Systems Conferences, a joint effort between SAE and IMechE, and chaired the technical program committee for the first meeting, VTMS1, in 1993. Mondt has also served as chairman or co-chair for VTMS2, VTMS3, and VTMS4. He also serves as chairman of the SAE Transactions Selection Committee for all SAE papers on exhaust emissions.

Mondt was born and raised on a ranch in Colorado. He graduated from the University of Denver in 1953 with a BSME and immediately began employment at General Motors Research Laboratories. From 1954–1956, he was on military leave from GM, serving as 1st Lt., Ordnance Corps. Mondt earned a GM Fellowship to Stanford University, and graduated with an MSME in 1957. Following this, he returned to GM Research.