

# Advanced Earth-to-Orbit Propulsion Technology 1992

N93-28680

Unclas

G3/20 0169398

(NASA-CR-192561) ADVANCED  
EARTH-TO-ORBIT PROPULSION  
TECHNOLOGY INFORMATION,  
DISSEMINATION AND RESEARCH Final  
Report, 13 Jul. 1989 - 31 May 1993  
(Alabama Univ.) 45 p

*Edited by*  
R. J. Richmond  
*George C. Marshall Space Flight Center*  
*Marshall Space Flight Center, Alabama*

S. T. Wu  
*The University of Alabama in Huntsville*  
*Huntsville, Alabama*

Proceedings of a conference held at  
NASA George C. Marshall Space Flight Center  
Marshall Space Flight Center, Alabama  
May 19-21, 1992

**NASA**

National Aeronautics and  
Space Administration

Office of Management

Scientific and Technical  
Information Program

1992

FINAL REPORT

NAS8-36955 D.O. 32

ADVANCED EARTH-TO-ORBIT PROPULSION TECHNOLOGY  
INFORMATION, DISSEMINATION AND RESEARCH

Submitted to:

Attn.: Mr. James Moses  
Research and Technology Office, ER 01  
Marshall Space Flight Center  
National Aeronautics and Space Administration  
Marshall Space Flight Center, Alabama 35812

Prepared by:

Dr. S. T. Wu  
Department of Mechanical Engineering and  
Center for Space Plasma and Aeronomic Research  
The University of Alabama in Huntsville  
Huntsville, Alabama 35899  
(205) 895-6413

## BACKGROUND

In the development of the Space Shuttle Main Engine (SSME) and the Space Transportation Main Engine (STME) it was felt by NASA that upgrading the capabilities of this engine concept was necessary in order to meet the challenge of the space transportation system needs for the future. The Marshall Space Flight Center (MSFC) was given the lead role to identify technology opportunities, develop multi-year plans and to oversee the implementation of these plans with the assistance and involvement of the Lewis Research Center. The overall objective of this program is the establishment of basic discipline technology necessary for an orderly evolution of high pressure oxygen-hydrogen stage combustion rocket engines to meet the needs of the earth-to-orbit space transportation for the next twenty-thirty years. It is expected that the accomplishments of these objectives have contributed to the nation's space program through providing a sound technological foundation for improvement in the technical specialties of rotor dynamics, structural dynamics, fluid and gasdynamics, fatigue/fracture mechanics/life, turbomachinery fluid mechanics, ignition/combustion processes, NDT/NDE inspection method, manufacturing/producibility, materials development/evaluation, cryogenic bearings, and instrumentation.

Since 1984 a series of conferences describing the research achievements on the NASA-wide research and technology programs dealing with advanced oxygen/hydrogen and oxygen/hydrocarbon earth-to-orbit propulsion has been held at Marshall Space Flight Center. The purpose of these conferences was to provide a forum for the timely dissemination to the propulsion community of the results emerging from this program with particular emphasis on the transfer of information from the scientific/research to the designer.

The first conference on the oxygen/hydrogen program was held at MSFC, on June 27-29, 1984. Proceedings of that conference entitled "Advanced High Pressure O<sub>2</sub>/H<sub>2</sub> Technology" were published as NASA Conference Publication 2372. Subsequently, NASA's separate research and technology programs dealing with oxygen/hydrogen and oxygen/hydrocarbon propulsion were combined into one program entitled "Advanced Earth-to-Orbit Propulsion Technology". The second conference proceedings entitled "Advanced Earth-to-Orbit Propulsion Technology, Volumes I and II" were published as NASA Conference Publications 2436 and 2437. That conference was held on May 13-15, 1986. The third conference on these subjects was held on May 10-12, 1988. The third conference proceedings entitled "Advanced Earth-to-Orbit Propulsion Technology" were published as in two volumes as NASA Conference Publication 3012. The fourth conference on these subjects was held on May 12 - 15, 1990. The fourth conference proceedings entitled "Advanced Earth-to-Orbit Propulsion Technology - 1990" were published in three volumes as NASA Conference Publication 3092. In this contract, we are responsible for organizing and executing the fifth conference which was held May 19-21, 1992. This fifth conference proceedings entitled "Advanced Earth-to-Orbit Propulsion Technology 1992" were published in two volumes as NASA Conference Publication 3174. A copy of the table of contents and participants list is included in Appendix I. In addition a proceedings entitled Hydrogen Effects on Materials in Propulsion Systems was assembled and submitted to NASA/MSFC in July 1992 for publication. A copy

of the table of contents and participants list is included in Appendix II.

The program grew significantly from nine sessions, with forty-three papers in the first conference to eighteen sessions, three special sessions and two workshops. A total of 129 papers was presented in the 18 regular sessions which were included in the proceedings. An additional 38 presentations were made in the special sessions and workshops and are being published separately. The attendance has approximately doubled from just over 200 in 1984 to about 400 in 1992. The contents of the conference was originally organized into ten topics and has grown to eleven topics which include: Materials Development, Manufacturing, Instrumentation, Turbomachinery, Fluid and Gas Dynamics, Ignition and Combustion, Fatigue and Fracture, Bearing Materials, Bearings, Structural Dynamics, and Controls. Additionally, a Hydrogen Environment Embrittlement in Advanced Propulsion Systems Workshop was conducted concurrently with the 1986 conference, during the 1988 conference a workshop on the Status Review of Hydrocarbon-Fuels/Copper Materials Compatibility was held and during the 1990 conference two workshops (Hydrogen Standardization Workshop and Efficient Engine Workshop) were conducted. The presentations at the 1986 workshop were published in the conference proceedings, the 1988 workshop was composed of informal discussions and manuscripts were not prepared, and the 1990 workshop presentations were published in the conference proceedings. In 1992, three special sessions concentrating on Fluid/Structure Interaction, Robust Turbopump, Turbomachinery Seals and two workshops entitled Propulsion System Avionics and Hydrogen Effects on Materials in Propulsion Systems were conducted concurrently with the conference.

The Marshall Space Flight Center Advanced Earth-to-Orbit Propulsion Technology program is a long standing program. Proper interaction between industry/university and government communities are necessary. It has been demonstrated by each of these conferences that we were able to fill this need to provide a forum for these agencies.

#### SPECIFIC TASKS ACCOMPLISHED:

In order to implement the program the following specific tasks were performed:

1. Together with the designated MSFC personnel, the P.I. coordinated the activities involve in an Advanced Earth-to-Orbit Propulsion Technology Conference held in May 1992.
2. The P.I. with the approval of the designated MSFC personnel was responsible in selecting members to serve on the technical committee for the conferences (Session Chairpersons).
3. The P.I. with the approval of the designated MSFC personnel and Session Chairpersons were responsible for selecting scientists and engineers to participate in the conference.

4. The P.I. with the approval of the designated MSFC personnel and Session Chairpersons selected papers for presentations for at the conference.
5. The P.I. provided all the necessary logistic and technical support for the preparation and duration of the conference.

#### CONCLUDING REMARKS

In these series of conferences, we have achieved our goal to facilitate the quick exchange of up-to-date information and documented them for limited dissemination to the scientific, engineering, and technical communities which include universities, government and industry within the United States. This program has enhanced the research and development activities.

APPENDIX I

"Advanced Earth-to-Orbit Propulsion Technology 1992 Volume I and II"  
NASA Conference Publications 3174

Table of Contents and Participant List

**VOLUME I**  
**TABLE OF CONTENTS**

Foreword	
Welcome, J. Wayne Littles, NASA/MSFC .....	1
OAST Overview, R. L. Kline, NASA Headquarters .....	3
Transportation Thrust and E-T-O Program Overview, E. E. VanLandingham, NASA Headquarters ....	7
Earth-to-Orbit Propulsion Technology Program at MSFC, James L. Moses, NASA/MSFC .....	10
Earth-to-Orbit Propulsion Technology Program Comments, Anita D. Liang, NASA/LeRC .....	12
Space Shuttle Main Engine Technology Test Bed Overview, H. V. McConnaughey, NASA/MSFC .....	13

**MATERIALS DEVELOPMENT AND EVALUATION**

Chairpersons: S. J. Gentz, NASA/MSFC and R. L. Dreshfield, NASA/LeRC

Preliminary Evaluation of a Powder Metal Copper-8 Cr-4 Nb Alloy, D. L. Ellis and R. L. Dreshfield, NASA/LeRC .....	18
Observations on W-24Re-Hf-C Wire Reinforced High Temperature Alloy Composites, F. J. Ritzert and R. L. Dreshfield, NASA/LeRC .....	28
Evaluation of Fiber Reinforced Superalloy Airfoil Root Attachment Techniques, L. G. Fritzemeier and J. R. Wooten, Rocketdyne Division, Rockwell International .....	38
A High Pressure DTA/TGA System For Materials Oxidation Studies, J. W. Bransford and B. J. Filla, National Institute of Standards and Technology .....	48
DTA Analysis of Several Iron and Nickel Based Alloys, J. W. Bransford and B. J. Filla, National Institute of Standards and Technology .....	57
Thermomechanical Processing and Microstructure Relationships in INCO 909, F. P. Cone, UTC- Pratt & Whitney .....	68
Dual Property Super A-286 for National Launch System (NLS) Space Transportation Main Engine (STME) Oxygen Turbopump, F. P. Cone, UTC-Pratt & Whitney .....	77

**MANUFACTURING/PRODUCIBILITY/INSPECTION**

Chairpersons: C. S. Jones, NASA/MSFC and T. P. Herbell, NASA/LeRC

Ceramic Matrix Composites for Rocket Engine Turbine Applications, T. P. Herbell and A. J. Eckel, NASA/LeRC .....	87
Ceramic Matrix Composite Turbopump Development, J. W. Brockmeyer, Rocketdyne Division, Rockwell International .....	97
Vacuum Plasma Spray Forming of NARLOY-Z, F. R. Zimmerman, R. M. Poorman, NASA/MSFC, T. M. McKechnie, and Y. K. Liaw, Rocketdyne Division, Rockwell International .....	107
Advanced Welding Process Control Technology, C. S. Jones, A. C. Nunes, K. G. Lawless, NASA/MSFC and K. N. Andersen, Mid-South Engineering .....	115

Non-Destructive Examination of Rocket Motor Components, R. D. Beshears, NASA/MSFC, J. A. Gilbert, Univ. of Alabama in Huntsville, D. R. Matthys, Marquette University .....	121
--	-----

## INSTRUMENTATION

Chairpersons: W. T. Powers, NASA/MSFC and W. C. Nieberding, NASA/LeRC

Fiber Optic Pressure Sensor for Combustion Chamber Monitoring, K. A. James, N. Shrestha, California State Univ. at Long Beach and W. H. Quick, OPCOA Inc. ....	128
Implementation of the Nonintrusive Speed Sensor for the SSME High Pressure Oxidizer Turbopump, J. Reinert, Rocketdyne Division, Rockwell International .....	134
A Brushless Torquemeter and Derivative Measurements, A. Schwartzbart, S. Balcer, Rocketdyne Division, Rockwell International .....	138
Progress in Thin Film Heat Flux Sensors, H. A. Will, NASA/LeRC .....	148
Thin Film Thermocouples for High Temperature Applications, L. C. Martin, NASA/LeRC .....	154
Raman Based Leak Detection Technology, T. W. Duryea, Rocketdyne Division, Rockwell International .....	162
Optical Leak Imaging of Rocket Engine Systems, A. Steffens, R. Delcher, and S. Barkhoudarian, Rocketdyne Division, Rockwell International ....	173
Leak Detection from the SSME Using Sequential Image Processing, J. A. Malone, BL. M. Smith, and R. A. Crawford, Univ. of Tennessee Space Institute .....	180
Hydrogen Sensor Technology at NASA Lewis Research Center, G. W. Hunter, G. C. Madzsar, P. G. Neudeck, NASA/LeRC, C. C. Liu and Q. H. Wu, Case Western Reserve Univ. ....	190
Correlation of Hydrogen and Air Flow in Critical Flow Nozzles Part 1: Primary Calibration Facility, T. M. Kegel, Colorado Engineering Experiment Station, Inc. ....	200
Small-Inertia Clamp-On Cryogenic Flowmeter Transducer, L. C. Lynnworth, J. E. Matson, T. H. Nguyen, Panametrics Inc. and W. T. Powers, NASA/MSFC .....	207
Vortex Shedding Flowmeters for SSME Ducts, J. D. Siegwarth, and M. A. Lewis National Inst. of Standards and Technology .....	217
A Cryogenic Pressure Sensor For Rocket Engine Applications, S. K. Kahng, NASA/Langley, Q. A. Shams, Analytical Services and Materials Inc., and V. B. Cruz, NASA/Langley .....	226
Progress in Laser Diagnostics for SSME Gas Phase Measurements, J. A. Shirley, United Technologies Research Center .....	238
Application of Laser Induced Fluorescence to Rocket Motor Exhausts, C. W. Brasier, Sverdrup Technology, Inc. ....	248



A Laser Raman Polychromator for Rotational Temperature Measurements of H <sub>2</sub> in Sub-Scale Combustors, C. C. Dobson, R. H. Eskridge, and M. Lee, NASA/MSFC .....	258
Optical Detection of SSME Preburner Faceplate Degradation, A. E. Cooper, W. T. Powers, NASA/MSFC and T. L. Wallace, Air Force Arnold Engr. Dev. Center/SvT .....	264
Status of Spectrometric Evaluation Support for SSME Plumes, L. M. Wyett, Rocketdyne Division, Rockwell International .....	271
Plume Diagnostics Instrumentation for Flight Rocket Engines, G. C. Madzsar, NASA/LeRC, R. L. Bickford, Aerojet Propulsion Division, and D. B. Duncan, Duncan Technologies .....	281
An Application of the Laser Speckle Shift Measurement Technique for Measuring Strain in Small Diameter Wires and Fibers, L. C. Greer and L. G. Oberle, NASA/LeRC .....	296
General Procedure for Using Artificial Neural Networks to Automate the Alignment of Optical Components in Harsh Environments, A. J. Decker and M. J. Krasowski, NASA/LeRC .....	303
SSME Plume Spectral Data Obtained During Ground Testing at SSC: Analysis and Correlation with Engine Operating Characteristics, D. B. Van Dyke, G. D. Tejwani, F. E. Bircher Sverdrup Technology Inc. and T. J. Cobb Rocketdyne Division, Rockwell International .....	313
SSME (TTB) and DTFT Spectral Data Quantitative Analysis, G. D. Tejwani, Sverdrup Technology, Inc. ....	327
Real Time Identification and Quantification of SSME Alloys in the DTF Exhaust Plume, F. E. Bircher and G. D. Tejwani, Sverdrup Technology .....	339

## TURBOMACHINERY

Chairpersons: P. K. McConnaughey, NASA/MSFC and J. W. Gauntner, NASA/LeRC

Development of an Oxidizer Turbine for Advanced Gas Generator Rocket Engines, F. W. Huber, P. D. Johnson, X. A. Montesdeoca, Pratt & Whitney .....	352
Navier-Stokes Verification of Advanced Gas Generator Oxidizer Turbine Stages, C. Hah, NASA/LeRC .....	362
Unsteady Flow Calculation in a Single Stage of an Advanced Gas Generator Turbine, A. A. Rangwalla, Sterling Software, NASA/ARC .....	371
Simulation of Unsteady Flow for an Advanced Gas Generator Turbine at High and Low Subsonic Mach Numbers, O. P. Sharma, K. A. Belford, C. R. Soderberg, J. B. Gertz, J. B. Staubach, Pratt & Whitney and L. W. Griffin, NASA/MSFC .....	384
CFD Benchmark Data for Pump Flows, A. H. Eastland, W. Hsu, L. Brozowski, D. Chan, T. Ferguson and L. Rojas, Rocketdyne Division, Rockwell International .....	396

Incompressible Navier-Stokes Computations in Pump Flows, C. Kiris, MCAT Institute, D. Kwak and S. Rogers, NASA/ARC.....	406
Inducer Analysis and Pump Model Development, Y. S. Chen, Engineering Sciences, Inc., G. C. Cheng, SECA, Inc., and R. Garcia, NASA/MSFC.	417
Hydrodynamic Design of Generic Pump Components, G. H. Prueger, W.-C. Chen, D. C. Chan and A. H. Eastland, Rocketdyne Division, Rockwell International .....	426
Static Brush Seals for Propulsion System Interfaces, R. C. Hendricks, J. A. Carlile and A. D. Liang, B. M. Steinetz, NASA/LeRC, B. T. Easter, J. W. Onstott, Rocketdyne Division, Rockwell International, and H. Howe, Technetics, Inc.....	432
Development of a Knowledge Based System for Turbopump Seals, A. D. Liang, R. C. Hendricks, NASA/LeRC, W. Shapiro, and B. Aggarwal, Mechanical Technology Inc.....	440
Development of a CFD Code for Accurate 3D Analysis of Cylindrical Seals, A. J. Przekwas, M. M. Athavale, CFD Research Corporation, R. C. Hendricks and A. Liang, NASA/LeRC .....	447
Turbulence Measurements of High Shear Flow Fields in a Turbomachine Seal Configuration, G. L. Morrison, R. E. DeOtte, Jr., and H. D. Thames, III, Texas A & M Univ.....	457
Thermohydrodynamic Analysis of Cryogenic Liquid Annular Seals, L. San Andres, Z. Yang, and D. W. Childs, Texas A & M University .....	468
Theory Versus Experiment for Short ( $L/D = 1/6$ ) Honeycomb and Smooth Annular Pressure Seals, D. W. Childs and G. F. Kleynhans, Texas A & M Univ.....	488
Computational Analysis of Bearings, Seals and Material Tester Cavity Flows, R. K. Avva, M. L. Ratcliff, CFD Research Corp., R. W. Williams and P. K. McConnaughey, NASA/MSFC .....	498
Probabilistic Rotor Instability Analysis, Y.-T. Wu, T. Y. Torng, and O. H. Burnside, Southwest Research Institute.....	508
NDE of PWA 1480 Single Crystal Turbine Blade Material, S. J. Klima, T. W. Orange and R. L. Dreshfield, NASA/LeRC .....	522
Cryogenic Damper-Test Facility and Curved Plate Damper Results, A. B. Palazzolo, Texas A & M Univ., A. F. Kascak, U. S. Army, R. Gadangi, J. Moore, Texas A & M Univ. and E. Olan, E. I. DuPont.....	533
Numerical Analysis of the Three-Dimensional Viscous Flow in the Pratt & Whitney SSME HPFTP Two-Stage Turbine, K. R. Kirtley, W. A. Maul, III, and T. A. Beach, Sverdrup Technologies .....	544
The Unsteady Aerodynamic Analysis: LINFLO, J. M. Verdon, United Technologies Research Center .....	557
Forced Response Prediction System (Current Status), D. V. Murthy, Univ. of Toledo and G. L. Stefko, NASA/LeRC .....	569

Analysis of Flexibility Enhancements to Rolling Element Bearing Mechanics,  
L. M. Greenhill, D. H. Merchant, C. S. Vallance, Gencorp Aerojet Propulsion Division, and S. G. Ryan,  
NASA/MSFC ..... 578

Table of Contents of Volume II ..... 588

List of Participants ..... 593

Author Index ..... 614

*NASA Conference Publication 3174, Vol. II*

# Advanced Earth-to-Orbit Propulsion Technology 1992

*Edited by*  
R. J. Richmond  
*George C. Marshall Space Flight Center*  
*Marshall Space Flight Center, Alabama*

S. T. Wu  
*The University of Alabama in Huntsville*  
*Huntsville, Alabama*

Proceedings of a conference held at  
NASA George C. Marshall Space Flight Center  
Marshall Space Flight Center, Alabama  
May 19-21, 1992

**NASA**

National Aeronautics and  
Space Administration  
Office of Management  
Scientific and Technical  
Information Program

**1992**

**VOLUME II**  
**TABLE OF CONTENTS**

Foreword

**FLUID AND GAS DYNAMICS**

Chairpersons: H. G. Struck, NASA/MSFC and R. E. Gaugler, NASA/LeRC

Experimental and Computational Results from a Large, Low-Speed Centrifugal Impeller, M. D. Hathaway, U.S. Army Propulsion Directorate, R. M. Chriss, J. R. Wood, and A. J. Strazisar, NASA/LeRC .....	1
Flow Field at the Nozzle Exit of the Penn State Axial Flow Turbine Facility, B. Lakshminarayana and M. Zaccaria, Penn State Univ.....	11
Time Averaged Heat Transfer and Pressure Measurements for Comparison with Prediction for a Two- Stage Turbine, M. Dunn, J. Kim, Calspan/UB Research Center, K. Civinskas and R. Boyle, NASA/LeRC.....	25
Flow Study in Supersonic Turbine Stages for Rocket Engines, C. Hah, NASA/LeRC.....	41
Comparison of Three-Dimensional Viscous SSME Heat Transfer Computations with Experiment, R. J. Boyle, NASA/LeRC and P. W. Giel, Sverdrup Technology Inc.....	49
Two Fluid Mixing, Y. Hardalupas, H. McDonald and J. H. Whitelaw, Imperial College of Science, Technology and Medicine, United Kingdom.....	63
SSME Turbine Heat Transfer Prediction Using Advanced Turbulence Modeling, A. A. Ameri, NASA/LeRC.....	73
Applications of Two Layer Modeling to Complex Flows, C. P. Chen, K. L. Guo and P. Huang, Univ. of Alabama in Huntsville .....	85
Adaptive Grid Solutions for Internal Flow, Y.-M. Kim and B. Gatlin, Mississippi State Univ.....	95
Calculation of Internal Flow in a Hot-Gas Manifold Pilot Model, S. K. Choi, R.C. Buggeln, Scientific Research Associates, Inc. ....	104
Reliability Enhancement of Navier-Stokes Codes Through Convergence Enhancement, C. L. Merkle, G. Dulikravich, S. Venkateswaran, K. Choi, and P. E. O. Buelow, Penn State University .....	114
Propulsion Applications in Numerical Grid Generation, B. K. Soni, Mississippi State Univ.....	124
Comparative Study of Advanced Turbulence Models for Turbomachinery, A. H. Hadid and M. M. Sindir, Rocketdyne Division, Rockwell International.....	134
Treating Convection in Sequential Solvers, W. Shyy, S. Thakur, Univ. of Florida and P. K. Tucker, NASA/MSFC.....	144

Development of Evaluation Criteria and a Procedure for Assessing Predictive Capability and Code Performance, S. J. Lin, S. L. Barson and M. M. Sindir, Rocketdyne Division, Rockwell International.....	154
--	-----

## IGNITION AND COMBUSTION PROCESSES

Chairpersons: C. S. Cornelius NASA/MSFC and M. D. Klem NASA/LeRC

Combustion-Wave Ignition for Rocket Engines, L. C. Liou, NASA/LeRC .....	165
Experimental Results of High-Aspect-Ratio Cooling Passages, J. A. Carlile, NASA/LeRC and R. J. Quentmeyer, Sverdrup Technology, Inc.....	181
Formed Platelet Technology for Low Cost, Long Life Combustion Chambers, W. M. Burkhardt and W. A. Hayes, Aerojet Propulsion Division .....	190
Rocket Combustor Interactive Design (ROCCID) Methodology Development and Test Program, J. L. Pieper, T. V. Nguyen, and R. E. Walker, Aerojet Propulsion Division .....	199
3-D Combustor Acoustic Analysis, R. J. Priem, Priem Consultants and K. J. Breisacher, NASA/LeRC .....	209
Liquid-Propellant Combustion Instabilities in F-1 Engines: A Comprehensive Review, J. C. Oefelein and V. Yang, Penn State Univ.....	219
Space Transportation Engine Combustion Chamber Design and Fabrication, J. D. Brady and J. C. Vega, Rocketdyne Div., Rockwell International.....	230

## FATIGUE/FRACTURE/LIFE

Chairpersons: G. C. Faile, NASA/MSFC and M. A. McGaw, NASA/LeRC

Surface Crack Behavior in Inconel 718 During Elastic-Plastic Cycling, R. C. McClung and S. J. Hudak, Jr., Southwest Research Institute .....	240
NASCRCAC Fracture Mechanics Computer Code Verification, J. Favnesi, J. Lambert, Nichols Research Corp., A. R. Ingraffea, Cornell Univ., R. Stallworth and C. Wilson, NASA/MFSC .....	250
Improvement in the Database for Crack Growth Properties of Materials, J. A. Henkener, V. B. Lawrence, L. C. Williams, Lockheed Engr. and Sci. Co. and R. G. Forman, NASA/JSC.....	258
Cumulative Damage Concepts in Thermomechanical Fatigue, M. A. McGaw, NASA/LeRC.....	267
Application of a Life Prediction Model for High Temperature Multiaxial Fatigue, P. J. Bonacuse, U. S. Army AVSCOM Propulsion Directorate NASA/LeRC, and S. Kalluri, Sverdrup Technology, Inc.....	279

## BEARING MATERIALS DEVELOPMENT AND NON-DESTRUCTIVE EVALUATION

Chairpersons: S. J. Gentz, NASA/MSFC and R. L. Thom, NASA/MSFC

Analysis of Rolling Contact Spall Life in 440C Bearing Steel, P. C. Bastias, G. T. Hahn, V. Gupta, C. A. Rubin Vanderbilt University and X. Leng, TRW Safety Systems .....	289
Systems Design of Advanced Bearing Steels, T. A. Stephenson C. E. Campbell and G. B. Olson, Northwestern Univ. ....	299
Selection of Materials for Bearing Applications in Oxygen, J. Dees, J. Peterson, Lockheed-ESC and J. M. Stoltzfus, NASA/JSC .....	308
Measurement of the Mechanical Properties of Thin, Hard Coatings at Ambient and Low Temperatures, K. B. Yoder, D. S. Stone, Univ. of Wisconsin-Madison, W. D. Sproul and P. J. Rudnik, Northwestern Univ. ....	317
Concerning High Eddy Current Indications in Localized Region of Raceway for ATD 440C Ball Bearing Outer Race PWA 4750349 #89566-8, H. A. Chin, D. A. Haluck, J. A. Umbach and J. T. Sinski, UTC-Pratt & Whitney .....	327
Eddy Current Inspection of Space Shuttle Main Engine/Alternate Turbopump (SSME/AT) Bearings at Pratt & Whitney, R. R. Stephan, Pratt & Whitney/Government Engines and Space Propulsion .....	336
Lubrication/Corrosion Protection Bimetal Coating for Cryogenic Bearing Steel AISI 9310, H. A. Chin, D. A. Haluck, R. W. Bursey, Jr. and H. M. Privett III, UTC-Pratt & Whitney .....	343
Cryogenic Turbopump Bearing Material Development Program, R. F. Spitzer, MRC Bearing, H. A. Chin, and D. A. Haluck, Pratt & Whitney .....	353

## BEARINGS

Chairpersons: R. L. Thom, NASA/MSFC and J. F. Walker, NASA/LeRC

Tribometer Testing of Turbopump Bearing Materials, Y. Naerheim S. E. McVey and E. J. Kreig, Rocketdyne Division, Rockwell International .....	361
High Performance Cryogenic Traction Test Facility, P. B. Hall, NASA/MSFC and J. L. Tevaarwerk, Battelle Memorial Institute .....	369
Improvements to the BASIC Retainer, J. B. Gleeson and J. Kannel, Battelle .....	381
Development of Rub Tolerant Cryogenic Ball Bearing Cage for High DN Applications, R. W. Bursey, Jr, Pratt & Whitney .....	391
Tribological Behavior of 440C/Diamond-Like-Carbon Film Couples, A. J. Slifka, R. Compos, National Inst. of Standards and Technology, R. Wei, P. Wilbur, Colorado State Univ., and D. K. Chaudhuri, Tennessee State Univ. ....	398

Development of Transient Thermo/Mechanical Bearing Analysis Methodology and Subsequent Software Implementation on a Personal Computer, D. E. Marty, J. D. Moore, and J. C. Cody, SRS Technologies.....	404
Pratt & Whitney Design and Test of Space Shuttle Main Engine (SSME) Alternate Turbopump Development (ATD) Bearings, D. A. Haluck, R. W. Bursey, Jr., and W. L. Gamble, Pratt & Whitney.....	408
Bearing Test Performed in Liquid Oxygen, H. G. Gibson and S. D. Fears, NASA/MSFC.....	417
Application of Compliant Fluid-Film Bearings to the High-Pressure Oxygen Turbopump of the SSME, H. Heshmat, W. Shapiro and A. Artiles, Mechanical Technology Inc.....	429
Bearing Coolant Flow Optimization, M. R. Subbaraman, J. E. Keba and A. H. Hadid, Rocketdyne Division, Rockwell International, and T. R. Tyler, Micro Craft, Inc.....	439
Lewis Research Center Cryogenic Bearing Tester Results, J. F. Walker, NASA/LeRC and F. Schuller, Sverdrup/LeRC.....	450
Analysis of Cryogenic Turbopump Bearings by XPS and SEM/EDS, S. V. Pepper, J. Walker, D. Jayne, A. Korenyi-Both, F. Honey, and C. DellaCorte, NASA/LeRC.....	461
Operating Characteristics of an 85-MM Ball Bearing in RP-1 to 1.7 Million DN, H. E. Addy, Jr., NASA/LeRC and F. T. Schuller, Sverdrup Technology.....	471
Overview of Foil Bearing Investigations at Penn State, M. Carpino, Penn State Univ.....	483
Tests of a Cryogenic Magnetic Bearing with Permanent Magnet Bias, E. DiRusso and G. V. Brown, NASA/LeRC.....	491
<b>STRUCTURAL DYNAMICS</b>	
Chairpersons: L. A. Kiefling, NASA/MSFC and C. C. Chamis, NASA/LeRC	
Reliability/Risk Methods for Engine Structures, C. C. Chamis, NASA/LeRC.....	501
Structural Reliability Assessment (SRA) Capability in NESSUS, H. Millwater, and Y.-T. Wu, Southwest Research Institute.....	511
Probabilistic Boundary Element Structural Analysis, Q. Huang and T. A. Cruse, Vanderbilt Univ.....	522
Probabilistic Space Shuttle Main Engine Load Simulation: Enhanced Capability, J. F. Newell, and H. Ho, Rocketdyne Division, Rockwell International.....	532
Blade Tip Rubbing Test Experience, G. A. Davis and R. C. Clough, Rocketdyne Division, Rockwell International.....	542
An Interactive Fluid/Structure Interaction Analysis Computer Program, B. L. Liu, J. M. O'Farrell, K. S. Ray, Rockwell International, T. E. Nesman, and D. K. Reed, NASA/MSFC.....	552



Acoustic Characteristics of Turbomachinery Cavities, M. J. Lucas and K. J. Plotkin, Wyle Laboratories .....	562
Exploring How Shroud Constraints Can Affect Vibratory Response in Turbomachinery, J. H. Griffin and M.-T. Yang, Carnegie Mellon Univ. ....	569
Detection of Degradation in Turbomachinery Bearings, W. D. Dorland, T. Coffin, and J. Cockburn, Wyle Laboratories. ....	579
Some Recent Developments in Turbomachinery Diagnostic Monitoring, J. Y. Jong, T. Coffin, W. L. Swanson, Wyle Laboratories, J. E. McBride, J. H. Jones, and P. C. Jones, T. F. Zoladz, NASA/MSFC. ....	586

## CONTROLS

Chairpersons: D. P. Valley, NASA/MSFC and W. C. Merrill, NASA/LeRC

An Advanced Framework for Control of Reusable Rocket Engines, E. Nemeth, R. R. Anderson, J. Maram, A. Norman, Rocketdyne Division, Rockwell International, and W. Merrill, NASA/LeRC .....	595
A Demonstration of an Intelligent Control System for a Reusable Rocket Engine, J. L. Musgrave, D. E. Paxson, NASA/LeRC, J. S. Litt, U. S. Army, and W. C. Merrill, NASA/LeRC .....	613
Real-Time Diagnostics for a Reusable Rocket Engine, T. H. Guo, W. Merrill, NASA/LeRC and A. Duyar, Florida Atlantic Univ. ....	622
Implementation of an Intelligent Control System, D. L. Simon, U.S. Army, E. Wong, and J. L. Musgrave, NASA/LeRC .....	634
Life Extending Control for Rocket Engines, C. F. Lorenzo, J. R. Saus, NASA/LeRC, A. Ray, M. Carpino, M.-K. Wu, Penn State Univ. ....	644
Procedural Automation of Space Shuttle Main Engine (SSME) Fault Diagnostics, J. Pooley and W. Thompson, SPARTA, J. McBride, J. Jones and T. Zoladz, NASA/MSFC .....	661
Accommodation of Repressurization and Venting Effects in the SSME Real-Time Failure Control Algorithm, H. Panossian and V. Kemp, Rockwell International. ....	684
Table of Contents of Volume I .....	691
List of Participants .....	696
Author Index .....	717

LIST OF PARTICIPANTS

Gene Addy  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

Bharat Aggarwal  
Mechanical Technology, Inc.  
968 Albany-Shaker Rd.  
Latham, NY 12110

Pravin K. Aggarwal  
NASA/MSFC  
ED 25  
MSFC, AL 35812

David B. Allen  
Carnegie Mellon University  
Mat. Sci. & Engr. Dept.  
5000 Forbes Avenue  
Pittsburgh, PA 15213

Ali A. Ameri  
Lewis Research Center  
5-11  
21000 Brookpark Rd.  
Cleveland, OH 44135

Brenda L. Lindley-Anderson  
MSFC NASA  
EP55  
Huntsville, AL 35812

Ram K. Avva  
CFD Research Corporation  
3325-D Triana Blvd.  
Huntsville, AL 35805

Markus A. Baker  
NASA/MSFC  
EH 14  
MSFC, AL 35812

Ron Baldwin  
Martin Marietta Energy Systems  
Oak Ridge National Laboratory  
Bldg. 6155  
P.O. Box 2008  
Oak Ridge, TN 37831

Rick Ballard  
Sverdrup Technology/MSFC Group  
MP53  
620 Discovery Dr.  
Huntsville, AL 35801

Bart Barisa  
NASA/MSFC  
625 Eplanade # 39  
Redondo Beach, CA 90277

Sarkis Barkhoudarian  
Rockwell Int'l Rocketdyne Div.  
JB21  
6633 Canoga Avenue  
Canoga Park, CA 91303

Brian B. Barrontine  
Calspan-Marshall Oper.  
Stennis Space Center  
B-1 Complex  
SSC, MS 39529

Mark Battison  
Williams International  
MS 5-18  
2280 W. Maple Rd.  
P.O. Box 200  
Walled Lake, MI 48390

Ernest R. Bedegrew  
Lockheed Missiles & Space Company Inc.  
ORGN 81-90, Bldg. 157  
1111 Lockheed Way  
Sunnyvale, CA 94089-3504

Theodore A. Benjamin  
NASA/MSFC  
ED 32  
MSFC, AL 35812

Raymond C. Benn  
Textron Lycoming  
Engineering Dept. LSD7  
550 Main St.  
Stratford, Ct 06497

Ron Beshears  
NASA/MSFC  
EH 13  
MSFC, AL 35812

Biliyar N. Bhat  
NASA/MSFC  
EH 23  
MSFC, AL 35812

Larry Van Bibber  
Westinghouse Electric Corp.  
Advanced Programs  
ED Building  
P.O. Box 158  
Madison, PA 15663-0158

Randy Bickford  
Aerojet Propulsion Division  
B/2019A,D/5154  
P.O.Box 13222  
Sacramento, CA 95813

Felix E. Bircher  
Sverdrup Technology, Inc.  
Bldg. 2109  
SSC, MS 39529

Ron Biroscak  
FAG Bearings Corp.  
35 Corporate Drive  
Trumbull, CT 06611

William P. Blankenship  
Westinghouse Electric Corp.  
P.O. Box 10864  
Pittsburgh, PA 15236

Robert W. Bond  
IIT Research Institute  
Metallurgy Research Facility  
Building 4618  
MSFC, AL 35812

Frank G. Borgardt  
Lockheed Missiles and Space Co.Inc.  
81-50/157  
1111 Lockheed Way  
Sunnyvale, CA 94089-3504

R.J. Boyle  
NASA/LeRC  
MS 5-11  
21000 Brookpark Rd.  
Cleveland, OH 44135

Fred Braam  
NASA/MSFC  
EP 52  
MSFC, AL 35812

Walter W. Brandon, Jr.  
NASA/MSFC  
PD 13  
MSFC, AL 35812

James W. Bransford  
Nat'l Inst. of Stand.&Tech.  
853.07  
325 Broadway  
Boulder, CO 80303

Carl W. Brasier  
Sverdrup Technology, Inc.  
Group EL5, Mail Stop 900  
Arnold AFB, TN 37389

Barry Breindel  
Gencorp-Aerojet  
700 Boulevard South STE 301  
Huntsville, AL 35802

Kevin Breisacher  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

Jerry W. Brockmeyer  
Rockwell International  
MS IB33  
6633 Canoga Ave.  
Canoga Park, CA 91303

Gerald V. Brown  
NASA/LeRC  
23-3  
21000 Brookpark Rd.  
Cleveland, OH 44135

Richard C. Buggeln  
Scientific Research Assoc., Inc.  
P.O.Box 1058  
Glastonbury, CT 06033

Wendel M. Burkhardt  
Aerojet Propulsion Division  
Dept. 5154/ BLDG. 2019  
P.O.Box 13222  
Sacramento, CA 95813-6000

R. W. Bursey  
Pratt & Whitney  
P.O. Box 109600  
W Palm Bch, FL 33410-9600

Dr. Barry L. Butler  
Science Applications  
International Corp. (SAIC)  
C2J  
10260 Campus Point Drive  
San Diego, CA 92121

Julie A. Carlile  
NASA/LeRC  
SPTD-2  
21000 Brookpark Rd.  
Cleveland, OH 44135

Marc Carpino  
Penn State University  
203 A Mechanical Engr.  
University Park, PA 16802

Christos C. Chamis  
NASA-LeRC  
49-8  
21000 Brookpark RD.  
Cleveland, OH 44135

Robert H. Champion  
NASA/MSFC  
PD 13  
MSFC, AL 35812

J.K. Chang  
Rockwell Int'l/Rocketyne DV  
AC37  
6633 Canoga Avenue  
Canoga Park, CA 91303

Jack M. Chapman, II  
NASA/MSFC  
PD 13  
MSFC, AL 35812

Dilip K. Chauduri  
Tennessee State University  
3500 John A. Merritt Blvd.  
Nashville, TN 37209

C.P. Chen  
U of Alabama in Huntsville  
Dept. of Chemical Engr.  
Huntsville, AL 35899

Po-Shou Chen  
IIT Research Institute  
Bldg 4618  
MSFC, AL 35812

Yen-Sen Chen  
Engineering Sciences, Inc.  
4920 Corporate Dr., STE K  
Huntsville, AL 35805

Don chenevert  
NASA  
Stennis space Center  
Bldg. 1100  
SSC, MS 39529

Dr. Dara Childs  
Texas A&M University  
3123  
Turbomach. Lab/Mech. Eng.  
Col. Sta., TX 77843-3123

Herbert A. Chin  
Pratt & Whitney  
MS 706-38  
P.O. Box 109600  
W Palm Bch, FL 33410-9600

Alan Chow  
NASA/MSFC  
EP 55  
MSFC, AL 35812

Dr. Hui-Huang Chyou  
United Technologies - USBI  
C-6000 Technology Drive  
Box 1900  
Huntsville, AL 35807

James E. Clark  
NASA/MSFC  
ER 21  
MSFC, AL 35812

Joe C. Cody  
SRS Technologies  
990 Explorer Blvd NW  
Huntsville, AL 35806

Thomas Coffin  
Wyle Laboratories  
EB7c  
P.O.Box 1008  
Huntsville, AL 35807

David G. Coggin  
Sverdrup Technology, Inc.  
620 Discovery Drive  
Huntsville, AL 35806

John E. Cole III  
Cambridge Acoust. Assoc., Inc.  
80 Sherman St.  
Cambridge, MA 02173

Fred Cone  
Pratt & Whitney  
MS 706-38  
P.O. Box 109600  
W Palm Bch, CA 33410-9600

R. Congo  
NASA/MSFC  
EH 32  
MSFC, AL 35812

Charles Cornelius  
NASA/MSFC  
EP 61  
MSFC, AL 35812

Dr. Thomas L. Cost  
U of Alabama in Huntsville  
Dept. of Mechanical Eng.  
Huntsville, AL 35899

Brad Cowles  
Pratt & Whitney  
714-70  
P.O.Box 109600  
W Palm Bch, FL 33410-9600

George B. Cox, Jr.  
Pratt & Whitney  
MS 715-89  
P. O. Box 109600  
W Palm Bch, CA 33410-9600

Kenneth J. Cox  
NASA/Johnson Space Center  
EG  
NASA Road 1  
Houston, TX 77058

William K. Crain  
United Technologies-USBI  
C600  
9037 Craigmont Rd.  
Huntsville, AL. 35802

Dr. T. A. Cruse  
Dept. of Mech. Engr.  
Vanderbilt University  
Box 1597 Station B  
Nashville, TN 37235

Leslie Curtis  
NASA/MSFC  
ER 21  
MSFC, AL 35812

Jonathan Mark Darden  
NASA/MSFC  
ED 14  
MSFC, Al 35812

David P. Davidson  
Rotadata, Inc.  
11584 Goldcoast Dr.  
Cincinnati, OH 45249

Laurence M. Davies  
United Technologies USBI  
C-6000  
Box 1900  
Huntsville, AL 35807

G. Davis  
Rocketdyne Division  
Rockwell Int'l  
6633 Canoga Ave.  
Canoga Park, CA 91303

Joe D. Davis  
NASA/MSFC  
EH 53  
MSFC, AL 35812

Arthur J. Decker  
NASA/LeRC  
77-1  
21000 Brookpark Rd.  
Cleveland, OH 44135

Jesse Dees  
Lockheed-ESC  
Bldg. 200  
P.O. Drawer MM  
Las Cruces, NM 88001

Daniel P. DeLuca  
Pratt & Whitney  
MS 707-20  
P.O. Box 109600  
W Palm Bch, FL 33410-9600

Charles S. Denniston  
NASA/MSFC  
ED 25  
MSFC, AL 35812

Forin Dimofte  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 441

Dr. Ravinder M. Diwan  
Southern University  
Mechanical Engineering Dept.  
Baton Rouge, LA 70813

Chris Dobson  
NASA/MSFC EP 55  
MSFC, AL 35812

Glenn R. Dodd  
NASA/MSFC  
PP 03  
MSFC, AL 35812

Wade Dorland  
Wyle Laboratories  
EB7c  
P.O. Box 35807  
Huntsville, AL 35807

Karen C. Doyle  
NASA-Stennis Space Ctr.  
BLDG. 1100  
SSC.MS 39529

Robert Dreshfield  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

David Duncan  
Duncan Technologies  
P.O. Box 1150  
Newcastle, CA 95658

Michael Dunn  
Calspan Corporation  
P.O. Box 400  
Buffalo, NY 14225

T. W. Duryea  
Rocketdyne Div.  
Rockwell Int'l  
6633 Canoga Ave.  
Canoga Park, CA 91303

A.H.J. Eastland  
Rockwell Int'l-IA34  
6633 Canoga Ave.  
Canoga Park, CA 91303

David L. Ellis  
NASA/LeRC 106-5  
21000 Brookpark Rd.  
Cleveland, OH 44135

David Elrod  
Sverdrup Technology, Inc.  
620 Discovery Drive  
Huntsville, AL 35806

William J. Emrich, Jr.  
NASA/MSFC  
PD 13  
MSFC, AL 35812

Michael Epstein  
Allied-Signal Aerospace Co.  
2/13  
Williams Ave.  
Teterboro, NJ 07608

William J.D. Escher  
NASA-HQ  
RST  
600 Independence Ave. SW  
Washington, D.C. 20546

Richard Eskridge  
NASA/MSFC  
EP 55  
MSFC, AL 35812

Gwyn C. Faile  
NASA/MSFC  
ED 25  
MSFC, AL 35812

John E. Farmer  
NASA  
ED14  
501 Greendale Dr.  
Huntsville, AL 35806

Tracy Farris  
Rockwell International  
ZA06  
555 Discovery Dr.  
Huntsville, AL 35806

Jim Favenesi  
Nichols Research Corp.  
MS4-2-OOB  
4040 South Memorial Pkwy.  
Huntsville, AL 35802

Shawn Fears  
NASA/MSFC  
EP 62  
MSFC, AL 35812

Steven C. Fisher  
Rockwell International  
MS IA06  
6633 Canoga Ave.  
Canoga Park, CA 91303

Valery Paige Fortner  
Tennessee Tech. University  
Center for Electric Power  
Box 5032  
Cookeville, TN 38505

Tom Fox  
NASA/MSFC  
ED 14  
MSFC, AL 35812

Ron Franz  
SECA, Inc.  
3313 Bob Wallace Ave  
Suite 202  
Huntsville, AL 35805

James V. French  
Pratt & Whitney  
740-16  
P.O.Box 1900  
Huntsville, AL 35807

Leslie G. Fritzeimer  
Rockwell International  
IB33  
6633 Canoga Avenue  
Canoga Park, CA 91303

Kerry M. Funston  
NASA/MSFC ED 14  
MSFC, AL 35812

Wayne R. Gamwell  
NASA/MSFC EH 23  
MSFC, AL 35812

Lt. J'Anthony Gandy  
Space Systems Division  
Advanced Dev. Program  
Norton AFB, CA 92409

Fred Garcia  
Rockwell Int'l, Rocketdyne Div.  
950 Explorer Blvd. Suite 3B  
Huntsville, AL 35806

Donald Gardner  
Sverdrup Technology, Inc.  
Bldg. T-2109  
Stennis Space Center  
SSC, MS 39529

B. Gatlin  
Mississippi State Univ.  
Engineering Research Ctr.  
P.O. Box 6176  
Mississippi State, MS 39762

Ray Gaugler  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

Jim Gauntner  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

Dr. Raymond L. Gause  
Science Applications  
Int'l Corp. (SAIC)  
6725 Odyssey Drive  
Huntsville, AL 35806

Gary Genge  
NASA/MSFC  
EP 62  
MSFC, AL 35812

Steven J. Gentz  
NASA/MSFC  
EH 22  
MSFC, AL 35812

Dr. William W. Gerberich  
Chem. Engr. & Mat. Sci.  
151 Amundson Hall  
University of Minnesota  
Minneapolis, MN 55455

George F. Gessler  
Honeywell, Inc.  
479-5  
13350 U.S. Hwy. 19 N.  
Clearwater, FL 34624

Howard G. Gibson  
NASA/MSFC  
EH 14  
MSFC, AL 35812

Valerie Gibson  
Aerojet Propulsion Div.  
BLDG 2019 RM. 2542  
P.O.Box 13222  
Sacramento, CA 95813

Richard L. Gilbrech  
NASA-SSC  
Bldg. 1100  
SSC, MS 39529

Jim Gleeson  
Battelle  
505 King Ave.  
Columbus, OH 43201

Fredrick Gluszek  
Pratt & Whitney  
MS 740-16  
P.O. Box 109600  
W Palm Bch, FL 33410-9600

Sol Gorland  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

Stephen M. Graham  
Materials Engr. Assc., Inc.  
9700-B M. L. King, Jr. Hwy  
Lanham, Maryland 20706-1837



Larry Greer  
NASA/LeRC 77-1  
21000 Brookpark Rd.  
Cleveland, OH 44135

Jerry H. Griffin  
Carnegie Mellon Univ.  
Mechanical Engr. Dept.  
Pittsburgh, PA 15213

Lisa W. Griffin  
NASA/MSFC  
ED 32  
MSFC, AL 35812

Clark Grove  
Edwards AFB  
6500 sw/MSCT  
Edwards AFB, CA

T.H. Guo  
NASA/LeRC  
77-1  
21000 Brookpark Rd.  
Cleveland, OH 44135

V. Gupta  
Vanderbilt Univ.  
Mat. Sci.& Engr. Dept.  
Knoxville, TN 37235

Chunill Hah  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

Keith Hale  
Texas A&M University  
MS 3123  
Turbomachinery Lab/ME  
Coll. Sta., TX 77843-3123

P. B. Hall  
NASA/MSFC  
EH 14  
MSFC, AL 35812

David A. Haluck  
Pratt & Whitney  
715-91  
P.O.Box 109600  
West Palm Beach, FL 33410-9600

Dr. Walter E. Hammond  
Sverdrup Technology, Inc.  
Sys. Anal.& Integr. Dept.  
620 Discovery Drive, NW  
Huntsville, AL 35806

J. Harbison  
NASA/MSFC  
EP 64  
MSFC, AL 35812

Y. Hardalupas  
Imperial College  
Mechanical Engr. Dept.  
London SW7 2BX, England

Dr. Dallis A. Hardwick  
Rockwell International  
MS A25  
1049 Camino Dos Rios  
Thousand Oaks, CA 91360

Michael D. Hathaway  
U.S. Army Propulsion Dir.  
MS 5-11  
21000 Brookpark Rd.  
Cleveland, OH 44135

Thomas Haykin  
USBI Company  
USB-HV-AE-2  
188 Sparkman Dr.  
P.O.Box 1900  
Huntsville, AL 35807

J. Heaman  
NASA/MSFC  
ED 35  
MSFC, AL 35812

Bob Hendricks  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

Julie Henkener  
Lockheed Engr.& Sci. Co.  
B22  
2400 NASA Rd. 1  
Houston, Texas 77058

Tom Herbell  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

David Hissam  
NASA/MSFC  
ER 64  
MSFC, AL 35812

Ronald Horn  
Aerojet Propulsion Div.  
2019A2 Dept. 5268  
P.O.Box 13222  
Sacramento, CA

F.W. Huber  
Pratt & Whitney GESP  
715-92  
P.O.Box 109600  
W. Palm Bch, FL 33410-9600

Don Hull  
NASA/MSFC  
CP 11  
MSFC, AL 35812

Gary Hunter  
NASA/LeRC  
77-1  
21000 Brookpark Rd.  
Cleveland, OH 44135

John Hutt  
NASA/MSFC  
EP 55  
MSFC, AL 35812

Mike Ise  
NASA/MSFC  
EP 52  
MSFC, AL 35812

Matthew A. Isham  
NASA/MSFC  
EH 34  
MSFC, AL 35812

Bob J. Jackson  
Sunstrand Aerospace  
Mechanical Systems/MS 430E6  
4747 Harrison Ave.  
P.O. Box 7002  
Rockford, IL 61125-7002

E. D. Jackson  
Rockwell International  
JB15  
6633 Caonga Ave  
Canoga Park, CA 91303

Maria-Christina Jackson  
Univ. of Wisconsin at Madison  
225 W. Gilman #3  
Madison, WI 53703

Tamara-Corina Jackson  
Univ. of Wisconsin at Madison  
225 W. Gilman #3  
Madison, WI 53703

Bob Jacobs  
IITRI/MRF  
Building 4618 MSFC  
MSFC, AL 35812

Kenneth A. James  
CSU at Long Beach  
12881 Knott St., STE 109  
Garden Grove, CA 92641

Timothy R. Jett  
NASA/MSFC  
EH 14  
MSFC, AL 35812

Robert P. Jewett  
Rocketdyne IB 17  
6633 Canoga Ave.  
Canoga Park, CA 91303

C.W. Johnson  
Dynamics Research Corp.  
3077 Leeman Ferry Rd.  
Huntsville, AL 35802

Lawrence M. Johnston  
NASA/MSFC  
ED 25  
MSFC, AL 35812

Harry M. Johnstone  
Sverdrup  
ALOO  
SSC, MS 39529

Scott Johnstone  
NASA/MSFC EP 75  
MSFC, AL 35812

C. S. Jones EH 42  
NASA/MSFC  
MSFC, AL 35812

Steve Jones  
Martin Marietta  
MS 4320  
P.O.Box 29304  
New Orleans, LA 70189

William G. Jones  
NASA/MSFC  
EL 56  
MSFC, AL 35812

Jen-Yi-Jong  
Wyle Laboratories  
EB7c  
P.O.Box 35807  
Huntsville, AL 35807

John L. Jordan  
Sverdrup Technology, Inc.  
Bldg. T-2109  
Stennis Space Center  
SSC, MS 39529

Selin K. Kahng  
NASA-LaRC  
235  
Hampton, VA 23665

S. Kalluri  
Sverdrup Tech., Inc.  
NASA/LeRC Group  
21000 Brookpark Rd./ MS 49-7  
Cleveland, OH 44135

Gerald R. Karr  
Univ. of Alabama in Huntsville  
EB113  
Mechanical Engineering Dept.  
Huntsville, AL 35899

William Kaukler  
MSB C 203  
UAH  
Huntsville, AL 35899

Thomas Kegel  
Colorado Engineering Experiment  
Station, Inc.  
54043 WCR 37  
Nunn, CO 80648

Matti Kert  
Honeywell, Inc.  
922-5  
13350 US Hwy 19 N  
Clearwater, FL 34624

Larry A. Kiefling  
NASA/MSFC  
ED 23  
MSFC, AL 35812

Jonathan H. Kim  
NASA/MSFC  
PD 14  
MSFC, AL 35812

Jungho Kim  
Calspan Corporation  
P.O.Box 400  
Buffalo, NY 14225 5

Cetin Kiris  
MCAT Inst/NASA-Ames Res. Ctr.  
258-1  
NASA Ames Res. Ctr. MS 258-1  
Moffet Field, CA 94035

Dr. Kevin R. Kirtley  
Sverdrup/LeRC Group  
2001 Aerospace Parkway  
Brookpark, OH 44132-1099

Mark Klem  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

Stanley J. Klima  
NASA LeRC  
6-1  
21000 Brookpark Rd.  
Cleveland, OH 44135

Dick Kline  
NASA-HQ  
MS Code R  
NASA Headquarters  
Washington, D.C. 20546

Karl C. Knight  
Sverdrup Technology/MSFC  
620 Discovery Drive  
Huntsville, AL 35758

Michael P. Kovach  
Pratt & Whitney  
MS 707-22  
P.O. Box 109600  
W. Palm Beach, FL 33410-9600

Ganesh N. Kumar  
Sverdrup Technology, Inc.  
MD3  
620 Discovery Dr.  
Huntsville, AL 35805

Fred Y. Kuo  
NASA/MSFC  
ED 14  
MSFC, AL 35812

A.K. Kuruvilla  
IIT Research Institute  
Bldg.4618  
MSFC, AL 35812

Budugur Lakshminarayana  
Pennsylvania State University  
153 Hammond Bldg.  
University Park, PA 16802

Jay Lambert  
Nichols Research Corporation  
MS4-2-OOB  
4040 South Memorial Parkway  
Huntsville, AL 35802

Richard P. Leclair  
SPARTA  
43210 Gingham Ave  
Suite 6  
Lancaster, CA 93535

Jonathan A. Lee  
NASA/MSFC  
EH 23  
MSFC, AL 35812

James Lee  
NASA/MSFC  
EE 83  
MSFC, AL 35812

Dr. Kon Leung  
United Technologies-USBI  
C-6000 Technology Drive  
Box 1900  
Huntsville, AL 35807

Anita Liang  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

Yoon K. Liaw  
Rocketdyne Division  
Ste. 3B  
950 Explorer Blvd.  
Huntsville, AL 35806

Larry Liou  
NASA/LeRC  
SPTD-2  
21000 Brookpark Rd.  
Cleveland, OH 44135

J. Wayne Littles  
NASA/MSFC  
DD 01  
MSFC, AL 35812

Baw-Lin Liu  
Rockwell International  
MS ZA06  
555 Discovery Drive  
Huntsville, AL 35806

Tai-Sheng (Jeffrey) Liu  
USBI  
MS: USB-HV-EN-EA  
P.O. Box 1900  
Huntsville, AL 35807

Bill Loden  
CALSPAN  
BLDG. 4708; Room 220C  
MSFC, AL. 35812

Joe Lopez  
Pratt & Whitney  
MS 711-67  
P.O.Box 109600  
W. Palm Beach, FL 33410-9600

Carl Lorenzo  
NASA/LeRC  
77-1  
21000 Brookpark Rd.  
Cleveland, OH 44135

Terry Lorier  
Rockwell International  
IB15  
6633 Canoga Ave.  
Canoga Park, CA 91303

Sam Lowry  
CFD Research Corporation  
3325-D Triana Blvd.  
Huntsville, AL 35805

Michael J. Lucas  
Wyle Laboratories  
2001 Jefferson Davis Hwy, Suite 701  
Arlington, Virginia 22202

Randal W. Lycans  
United Technologies-USBI  
C6000  
P.O. Box 1900  
Huntsville, AL 35758

Garry Lyles  
NASA/MSFC  
EP 51  
MSFC, AL 35812

Lawrence C. Lynnworth  
Panometrics INC.  
221 Crescent Street  
Waltham, MA 02154-3497

Stuart G. MacDonald  
SNR Bearings USA, Inc.  
329 Veterans Blvd.  
Carlstadt, NJ 07072

George Madzsar  
NASA Lewis Research Center  
SPTD-2  
21000 Brookpark Rd.  
Cleveland, OH 44135

Darby Makel  
Aerojet Propulsion Division  
B/2019A-D/5154  
P.O. Box 13222  
Sacramento, CA. 95813-6000

Ronald A. Marmol  
Sverdrup Technology  
620 Discovery Drive  
Huntsville, AL 35806

Larry A. Marshall  
Pratt & Whitney-GESP  
731-14  
109600  
West Palm Beach, FL 33410-9600

Lisa Martin  
NASA/LeRC  
77-1  
21000 Brookpark Rd.  
Cleveland, OH 44135

David E. Marty  
SRS Technologies  
990 Explorer Blvd NW  
Huntsville, AL 35806

Louis C. Maus  
NASA/MSFC  
PD 14  
MSFC, AL 35812

R. Craig McClung  
Southwest Research Institute  
6220 Culebra/P.O. Drawer 28510  
San Antonio, TX 78228-0510

Helen McConnaughey  
NASA/MSFC  
EP 01  
MSFC, AL 35812

Paul McConnaughey  
NASA/MSFC  
ED 32  
MSFC, AL 35812

David M. McDaniels  
NASA/MSFC ED 35  
MSFC, AL 35812

M. A. McGaw  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

Preston B. McGill  
NASA/MSFC  
EH 23  
MSFC, AL 35812

David P. McGraw  
Honeywell-Huntsville  
Engineering Center  
4801 University Square, Suite 29A  
Huntsville, AL 35816

Melvin C. McIlwain  
Aerojet Propulsion Division  
Dept. 5154/ BLDG. 2019  
P.O.Box 13222  
Sacramento, CA 95813

Timothy N. McKechnie  
Rocketdyne Division  
Ste. 3B  
950 Explorer Blvd.  
Huntsville, AL 35806

William B. Mc Pherson  
NASA/MSFC  
EH 23  
MSFC, AL 35812

Jay A. Medly  
NASA/MSFC  
EH 53  
MSFC, AL 35812

David H. Merchant  
Aerojet Propulsion Division  
Dept. 5242 Bldg. 2019-A2  
P.O.Box 13222  
Sacramento, CA 95813-6000

Dr. Charles L. Merkle  
Pennsylvania State University  
Department of Mechanical Engr.  
104 Research Building East  
University Park, PA 16802

Walt Merrill  
NASA/LeRC 77-1  
21000 Brookpark Rd.  
Cleveland, OH 44135

Harry Millwater  
Southwest Research Institute  
Bldg. 128  
P.O. Box 28510  
San Antonio, TX 78228-0510

James B. Min  
NASA/MSFCE ED 25  
MSFC, AL 35812

Neville R. Moody  
Sandia National Laboratories  
Division 8712  
P.O.Box 969  
Livermore, CA 94551-0969

James D. Moore  
SRS Technologies  
990 Explorer Blvd NW  
Huntsville, AL 35806

Gerald L. Morrison  
Texas A&M University  
MS3123  
Mechanical Engineering Dept.  
College Station, TX 77843-3123

James Moses  
ER 21  
NASA/MSFC  
MSFC, AL 35812

Shaman Mullick  
Harris Space Sys. Corp.  
Rock 1/201  
295 Barnes Blvd.  
P.O.Box 5000  
Rockledge, FL 32955

Durbha V. Murthy  
University of Toledo  
NASA/LeRC  
MS 23-3  
21000 Brookpark Road  
Cleveland, OH 44135

Jeff Musgrave  
NASA/LeRC 77-1  
21000 Brookpark Rd.  
Cleveland, OH 44135

Dr. Yngve Naerheim  
Rockwell Int'l Science Ctr.  
A12  
1049 Camino dos Rios  
Thousand Oaks, CA 91360 A

Mark Neely  
NASA/MSFC EP 52  
MSFC, AL 35812

Howard G. Nelson  
NASA-Ames RC 213-3  
Moffettfield, CA 94035-1000

Robert W. Neuschaefer  
NASA/MSFC CQ 11  
MSFC, AL 35812

Jim F. Newell  
Rocketdyne Division  
MS DD/545-126, JB11  
6633 Canoga Ave.  
Canoga Park, CA 91303

Bill Nieberding  
NASA/LeRC 77-1  
21000 Brookpark Rd.  
Cleveland, OH 44135

Ravi K. Nigam  
USBI  
MS: USB-HV-EN-EA  
P.O. Box 1900  
Huntsville, AL 35807

Robert F. Nixon  
NASA/MSFC  
PT 31  
MSFC, AL 35812

Arnold Norman  
Rocketdyne Div.  
Rockwell Int'l-IB03  
6633 Canoga Ave.  
Canoga Park, CA 90303

Larry O'berle  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

Joseph Oefelein  
Penn State University  
223 Research Building East  
Bigler Road  
University Park, PA 16802

John Michael O'Farrell  
Rockwell International  
ZA06  
555 Discovery Drive  
Huntsville, AL 35806

Dr. Alan B. Palazzolo  
Texas A&M University  
Mechanical Engineering Dept.  
College Station, TX 77843-3123

Binayak Panda  
IIT Research Institute  
Bldg 4618  
Marshall Space Flight Center  
MSFC, AL 35812

Robert Pangborn  
Penn State University  
227 Hammond Bldg.  
University Park, PA 16802

H.V. Panossian  
Rockwell International-Rocketdyne Div.  
JB11  
6633 Canoga Avenue  
Canoga Park, CA 91303

Joe R. Parker  
United Technologies USBI Co.  
USB-HV-AE-1  
P.O. Box 1900  
Huntsville, AL 35807

Larry D. Paul  
Babcock & Wilcox  
Materials Performance Section  
1562 Beeson St.  
Alliance, OH 44601

Alvin M. Payne  
NASA-SSC-Sverdrup Technology, Inc.  
HA 20  
Bldg 1100  
Stennis Space Center, MS 39529

Steve Pepper  
NASA/LeRC 23-2  
21000 Brookpark Rd.  
Cleveland, OH 44135

Jerry L. Pieper  
Aerojet Propulsion  
Bldg. 2019 Dept. 5246  
P.O. Box 13222  
Sacramento, CA 95813-6000

Frank Pizzano  
NASA/MSFC  
CT 11  
MSFC, AL 35812

J. Pooley  
SPARTA, Inc.  
4901 Corporate Dr. NW  
Huntsville, AL 35806

Doris J. Porter  
NASA/MSFC  
ER 21  
MSFC, AL 35812

Richard J. Priem  
Priem Consultants  
13533 Mohawk Tr.  
Cleveland, OH 44130

George H. Prueger  
Rocketdyne Division  
MS IA34  
6633 Canoga Ave.  
Canoga Park, CA 91303

W. T. Powers  
NASA/MSFC  
EB 22  
MSFC, AL 35812

Ned C. Pruitt  
Materials Engineering Associates, Inc.  
9700-B Martin L. King, Jr. Hwy  
Lanham, Maryland 20706-1837

Andrzej Przekwas  
CFD Research Corporation  
3325-D Triana Blvd.  
Huntsville, AL 35805



Richard J. Quentmeyer  
Sverdrup Technology, Inc.  
SPTD-2  
2001 Aerospace Parkway  
Brookpark, OH 44135

William H. Quick  
OPCOA  
12881 Knott St. #109  
Garden Grove, CA 92641

Paul E. Ramsey  
NASA/MSFC ED 35  
MSFC, AL 35812

Akil Abbas Rangwalla  
Sterling Software  
MS 258-2  
NASA-ARC  
Moffett Field, CA 94035

Professor Asok Ray  
Penn State University  
Mechanical Engineering Dept.  
University Park, PA 16803

J. Reinert  
Rocketdyne Div.  
Rockwell Int'l  
6633 Canoga Ave.  
Canoga Park, CA 91303

Jim Rhodes  
NASA/MSFC EP 75  
MSFC, AL 35812

Robert Richmond  
NASA/MSFC ER 21  
MSFC, AL 35812

Frank Ritzert  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

Max Roler  
Sverdrup Technology, Inc.  
AEDC group 980  
Arnold AFB, TN 37389-9998

Eric D. Roll  
Penn State University  
227 Hammond Building  
University Park, PA 16802

D.A. Russell  
Rockwell International Rocketdyne Div.  
JB11  
6633 Canoga Avenue  
Canoga Park, CA 91303

Stephen G. Ryan  
NASA/MSFC ED 14  
Huntsville, AL 35812

Jeffrey Sanders  
IIT Research Institute  
Bldg. 4618  
MSFC, AL 35812

Luis San Andres  
Texas A&M University  
Mechanical Engineering Dept.  
College Station, TX 77843

Joseph R. Saus  
NASA/LeRC 77-1  
21000 Brookpark Rd.  
Cleveland, OH 44135

Marshall Saville  
Allied Signal Aerospace, ALAD  
T 42  
2525 W. 190th St.  
P.O. Box 2960  
Torrance, CA 90509-2960

Charles Schafer  
NASA/MSFC EP 55  
MSFC, AL 35812

Michael A. Schwartz  
Technical Analysis Inc.  
4910 A Corporate Dr.  
Huntsville, AL 35805

A. Schwartzbart  
Rocketdyne /Rockwell Int'l  
6633 Canoga Ave.  
Canoga Park, CA 91303

R. J. Schwinghamer  
NASA/MSFC  
EA 01  
MSFC, AL 35812

Marie L. Semmel  
NASA/MSFC EH 23  
MSFC, AL 35812

Stephen F. Seufert  
Honeywell Inc.  
749-4  
13350 U.S. Highway 19 North  
Clearwater, FL 34624-7290

Dr. Steven J. Shamroth, President  
Scientific Research Associates, Inc.  
50 Nye Road  
P.O. Box 1058  
Glastonbury, CT 06033

Mickey R. Shanabarger  
Quantum Institute  
Univ. of California, Santa Barbara  
c/o NASA/Ames Research Center  
MS 213-3  
Moffett Field, CA 94035

Wilbur Shapiro  
Mechanical Technology, Inc.  
968 Albany-Shaker Rd.  
Latham, NY 12110

Nancy R. Shimp  
Aerojet Propulsion Division  
Bldg. 2019-A2. Dept. 5240  
P.O. Box 13222  
Sacramento, CA 95813-6000

John A. Shirley  
United Technologies Research Center  
129-90  
Silver Lane  
East Hartford, CT 06108

James D. Siegwarth  
NIST  
MS 832 03  
325 Broadway  
Boulder, CO 80303

Don Simon  
NASA/LeRC 77-1  
21000 Brookpark Rd.  
Cleveland, OH 44135

Dr. Munir M. Sindir  
Rocketdyne D/545-129, IB39  
6633 Canoga Ave.  
Canoga Park, CA 91303

Ashok K. Singhal  
CFD Research Corporation  
3325-D Triana Blvd.  
Huntsville, AL 35805

Andrew Slifka  
National Institute of Standards and Technology  
MS 853.07  
325 Broadway  
Boulder, CO 80303

Donald P. Sloteman  
Ingersoll-Rand Company  
942 Memorial Pkwy  
Phillipsburg, NJ 08865

Andrew W. Smith  
NASA/MSFCE ED 35  
MSFC, AL 35812

Dr. L. Montgomery Smith  
University of Tennessee Space Institute  
14 B.H. Goethert Parkway  
Tullahoma, TN 37388-8897

Dr. Bharat K. Soni  
Mississippi State University  
Engineering Research Ctr.  
P.O. Box 6176  
Mississippi State, MS 39762

Larry L. Sparks  
NIST - 853  
325 Broadway  
Boulder, CO 80303

William J. Sprow  
Aerojet  
P.O. Box 13222  
Sacramento, CA 95813-6000

Steven Ross Standley  
Mississippi State University  
Engineering Research Center  
P.O.Box 6176  
Mississippi State, MS 39762

George L. Stefko  
NASA LeRC  
23-3  
21000 Brookpark Rd.  
Cleveland, OH 44135

R. Robert Stephan II  
Pratt & Whitney  
MS 707-20  
P.O. Box 109600  
West Palm Beach, FL 33410-9600

Frank W. Stephenson  
W.J. Schafer Assoc.(NASA-HQ)  
Code RST  
600 Independence Ave.  
Washington D.C. 20546

Tim Stephenson  
BIRL  
1801 Maple Avenue  
Evanston, IL 60201-3135

Joel Stoltzfus  
NASA JSC White Sands Test Facility  
RF  
P.O. Drawer NM  
Las Cruces, NM 88004

Donald S. Stone  
University of Wisconsin at Madison  
M161 MSAE 1509 University Ave.  
Madison, WI 53706

Joseph P. Strizak  
Martin Marietta Energy Systems  
Oak Ridge National Laboratory  
Bldg.4508, MS 6088  
P.O. Box 2008  
Oak Ridge, TN 37831-6088

Heinrich G. Struck  
NASA/MSFC ED 31  
MSFC, AL 35812

Maria Subbaraman  
Rockwell International, Rocketdyne Division  
IA34  
6633 Canoga Ave.  
Canoga Park, CA 91304

Wayne Swanson  
Wyle Labs EB7c  
P.O.Box 1008  
Huntsville, AL 35807

Dr. Gopal Tejwani  
Sverdrup Technology Inc.  
Bldg. 2108  
Stennis Space Center, MS 39529

J. Telesman  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

James E. Thayer  
IITRI-MRF-(NASA)Bldg. 4618  
Bldg 4618 (EH23)  
2500 Redstone Rd. #64  
Huntsville, AL 35803

Robert L. Thom  
NASA/MSFC EH 14  
MSFC, AL 35812

Anthony W. Thompson  
Carnegie Mellon University  
Dept. Mater. Sci. & Eng.  
220 Daytona Drive  
Santa Barbara, CA 93117

James F. Thompson  
NASA/MSFC PD 13  
MSFC, AL 35812

Jerry Thompson  
Aerojet Propulsion. Division  
Bldg. 2019  
Sacramento, CA 95813

John D. Thompson, Jr.  
CALSPAN  
BLDG. 4708; Room 239  
MSFC, AL 35812

R. G. Thompson  
U of Alabama at Birmingham  
Material Sci. & Engr. Dept.  
School of Engineering  
Birmingham, AL 35294

Paul K. Tucker  
NASA/MSFC  
ED 32  
MSFC, AL 35812

Kathy Tygielshiy  
NASA/MSFC  
EP 62  
MSFC, AL 35812

Kearicia J. Valiant  
CALSPAN  
BLDG. 4708; Room 239  
MSFC, AL 35812

D. P. Vallely  
NASA/MSFC ED 14  
MSFC, AL 35812

David B. Van Dyke  
Sverdrup Technology Inc.  
Stennis Space Ctr - Bldg. 2109  
SSC, MS 39529

Peter A. Van Hoff, Jr.  
Allied Signal Aerospace Co., BGCS  
1525 Perimeter Parkway STE 150  
Huntsville, AL 35806

E. E. VanLandingham  
NASA HQS - RS  
600 Independence Ave., SW  
Washington, DC 20546

Robert H. Van Stone  
GE Aircraft Engines  
A333  
1 Newman Way  
Cincinnati, OH 45241

Russell Vaughn  
Vesco, Inc.  
1369  
Huntsville, AL 35807

John C. Vega, III  
Rocketdyne Division  
MS IA06  
6633 Canoga Ave.  
Canoga Park, CA 91304

Joseph M. Verdon  
United Technologies Research Center  
MS 129-20  
411 Silver Lane  
East Hartford, CT 06066

Michael Verrilli  
NASA/LeRC 49-7  
21000 Brookpark Rd.  
Cleveland, OH 44135

Edward J. Veseley  
IIT Research Institute  
Building 4618  
MSFC, AL 35812

Bruce K. Walker  
University of Cincinnati  
MS 343  
Cincinnati, OH 45221-0343

Jim Walker  
NASA/LeRC  
SPTD-2  
21000 Brookpark Rd.  
Cleveland, OH 44135

W. Glenn Walker  
USBI  
HV-EN-EA  
6000 C Technology Drive  
P.O. Box 1900  
Huntsville, AL 35807

William K. Ward  
NASA/MSFC EH 53  
MSFC, AL 35812

John Warren  
Pratt & Whitney  
MS 707-20  
P.O. Box 109600  
West Palm Beach, FL 33410-9600

Mike Watwood  
IIT Research Institute  
Building 4618  
MSFC, AL 35812

C. L. Horton Webb  
Aerojet Propulsion Division  
700 Boulevard South, Suite 301  
Huntsville, AL 35802

Rae Ann Weir  
NASA/MSFC  
EP 64  
MSFC, AL 35812

Dr. Francis C. Wessling  
University of Alabama in Huntsville  
Dept. Mechanical Engin.  
Engineering Bldg.  
Huntsville, Al 35899

Charles White  
NASA/MSFC  
EP 52  
MSFC, AL 35812

Tim White  
CALSPAN  
BLDG. 4708; Room 223  
MSFC, AL 35812

R. Barry Whitsett  
NASA/MSFC  
ED 14  
MSFC, AL 35812

Herb Will  
NASA/LeRC  
77-1  
21000 Brookpark Rd.  
Cleveland, OH 44135

Robert Williams  
NASA/MSFC ED 32  
MSFC, AL 35812

Christopher D. Wilson  
NASA/MSFC  
ED 25  
MSFC, AL 35812

James N. Wiser  
NASA/MSFC  
PD 14  
MSFC, AL 35812

Steven J. Wofford  
CALSPAN  
BLDG. 4708; Room 226  
MSFC, AL 35812

Gary L. Workman  
UAH  
RI A-6  
Huntsville. AL 35899

Charley Chengzhi Wu  
United Technologies, USBI  
Engineering 6000C  
188 Sparkman/P.O.Box 1900. 35807  
Huntsville, AL 35805

Shi Tsan Wu  
EB 157e  
University of Alabama, Huntsville  
Huntsville, AL 35899

Yih Tsuen Wu  
Southwest Research Institute  
6220 Culebra Rd.  
San Antonio, TX 78228-0510

Lynn M. Wyett  
Rocketdyne /Rockwell Int'l  
JB21 6633 Canoga Ave.  
Canoga Park, CA 91303

H. Q. Yang  
CFD Research Corperation  
3325-D Triana Blvd.  
Huntsville, AL 35805

Karl B. Yoder  
University of Wisconsin at Madison  
605 West Main #2  
Madison, WI 53703

George Young  
NASA/MSFC EP 62  
MSFC, AL 35812

Anthony T. Zachary  
The Aerospace Corporation  
MS M3/570  
P.O. Box 92957  
Los Angeles, CA 90009-2957

James L. Zachary  
Rosemount Inc.  
1395 S. Marietta Pkwy.  
Bldg. 700, suite 702  
Marietta, Georgia 30067

June Zakrajsek  
NASA/LeRC  
21000 Brookpark Rd.  
Cleveland, OH 44135

F. Zimmerman  
NASA/MSFC  
EH 42  
MSFC, AL 35812

APPENDIX II

"Hydrogen Effects on Materials in Propulsion Systems"  
In Press  
Table of Contents and Participant List

# WORKSHOP ON HYDROGEN EFFECTS ON MATERIALS IN PROPULSION SYSTEMS

Chairpersons: B. N. Bhat, NASA/MSFC, R. M. Horn, A. W. Thompson

Opening Remarks: R. J. Schwinghamer, NASA/MSFC .....	1
Hydrogen Effects in Advanced Aerospace Materials, H. G. Nelson, NASA/ARC .....	2
Facilities for Mechanical Property Testing in Gaseous Hydrogen, M. R. Shanabarger, Univ. of California, Santa Barbara .....	12
Hydrogen Test Standardization Tensile Tests, W. B. McPherson NASA/MSFC .....	23
Hydrogen Test Standardization Status of the Low Cycle Fatigue Tests, B. McPherson, NASA/MSFC .....	35
NLS Hydrogen Standardization Activities, R. P. Jewett, Rocketdyne Division, Rockwell International .....	45
Hydrogen Trapping in Superalloys, R. Jacobs and E. J. Vesely, Jr., IITRI/MRF .....	54
High Pressure Hydrogen Permeation of Composite Protective Coatings, E. D. Roll and R. N. Pangborn, The Pennsylvania State University .....	67
Application of Expert System Technology to Hydrogen Environment Embrittlement of SSME Alloys, W. F. Kaukler and G. L. Workman, University of Alabama in Huntsville .....	76
Assessment of Candidate Rocket Propulsion Materials in Gaseous Hydrogen Environment, V. A. Gibson, D. P. Dennies, and R. M. Horn, Aerojet .....	85
Hydrogen Evaluation of Incoloy 909 for the NLS Liquid Hydrogen TPA Turbine, D. P. Dennies, V. A. Gibson, and R. M. Horn, Aerojet Propulsion Division .....	95
Subcritical Crack Growth of Alloy 718 in Ni/H <sub>2</sub> Power Cell Environments, W. Cullen, G. Grewal, N. Pruitt, Materials Engineering Associates, S. Lenhart, C. Halbach, Space Systems/Loral, K. Garr, Rocketdyne Division, Rockwell International .....	101
The Effect of Machining Techniques, Notch Design and Strain Rate on the Notched Tensile Strength of Inconel 718 in High Pressure Hydrogen, R. Bond, M. Watwood, and E. J. Vesely, Jr. IITRI/MRF .....	111
Influence of Hydrogen on Fatigue Crack Growth of a Single Crystal Alloy, J. Telesman NASA/LeRC and L. J. Ghosn, Sverdrup Technology Inc. ....	121
The Low Cycle Fatigue and Tensile Behaviors of Ni-Base Superalloys PWA 1480 and PWA 1489 in Hydrogen, P. S. Chen, E. Vesely, B. Panda, IITRI/MRF W. D. Hamilton and R. A. Parr, NASA/MSFC ..	133
Development of JBK-75 for Service in High Pressure Hydrogen Environments: The Role of Microstruc- ture, N. R. Moody, J. A. Brooks, Sandia National Laboratories and A. W. Thompson, Carnegie Mellon Univ.....	145



Properties of Cast and Wrought NASA-23 Alloy, B. Panda, ITTRI/MRF and B. N. Bhat NASA/MSFC .....	156
Effect of Chromium on the Hydrogen HEE Resistance of IN-903 Type Alloys, A. K. Kuruvilla, B. Panda ITTRI/MRF and B. N. Bhat, NASA/MSFC .....	166
Improved Crack Growth in Hydrogen with Modified Precipitate Morphology Single Crystal Nickel, D. P. DeLuca, H. B. Jones, B. A. Cowles, and F. D. Cobia, Pratt & Whitney .....	173
Material Structural Characterization of Inconel-718, K. J. Chang, D. A. Russell, Rocketdyne Division, Rockwell International and M. J. Verrilli, NASA/LeRC .....	184
Macroscopic and Microscopic Modeling of Hydrogen Embrittlement Thresholds, W. W. Gerberich, H. Huang, P. G. March, Univ. of Minnesota .....	196
The Cumulative Fatigue Damage Behavior of MAR-M-247 in Air and High Pressure Hydrogen, M. A. McGaw, NASA/LeRC, S. Kalluri, Sverdrup Technology Inc., D. Moore, NASA/MSFC, and J. Heine, Pratt & Whitney .....	205
Grain Boundary and Interface Cohesion in the Presence of a Steep Hydrogen Gradient, (A Preliminary Auger-Fracture Study) R. G. Thompson, B. H. King, M. C. Koopman and D. W. Davis, Univ. of Alabama at Birmingham .....	216
Effect of Hydrogen Exposure on the Microstructure and Mechanical Properties of the Titanium Alloy, Beta 21S, D. A. Hardwick, Rockwell International Science Center and D. G. Ulmer, Rocketdyne Division, Rockwell International .....	228
Hydrogen Effects in Titanium Aluminide Alloys, A. W. Thompson, Carnegie Mellon Univ. ....	236
Hydrides in Ti3Al Alloys, D. B. Allen and A. W. Thompson, Carnegie Mellon Univ. ....	244
Temperature-Pressure Effects of Hydrogen on Room Temperature Flexural Strength of SiC and Si3N4, M. A. Isham, NASA/MSFC .....	253
Closing Remarks B. Bhat, NASA/MSFC .....	261
List of Participants .....	262
Author Index .....	265

WORKSHOP ON HYDROGEN EFFECTS ON  
MATERIALS IN PROPULSION SYSTEMS

Allen, David B.  
Carnegie-Mellon University  
Department Of Materials Science  
5000 Forbes Avenue  
Pittsburgh, PA 15213  
(412) 268-2699

Bond, Robert  
IIT Research Institute  
Building 4618  
MSFC, AL 35812  
(205) 544-8277

Baldwin, Ron  
ORNL  
P.O. Box 2008  
Building 4500s MS6155  
Oak Ridge, TN 37831  
(615) 574-4929

Benn, Ray  
Textron-Lycoming  
Engineering Department LSD7  
550 Main Street  
Stratford, CT 06497-7593  
(203) 385-3840

Bhat, Biliyar  
NASA-MSFC - EH23  
Building 4612  
MSFC, AL 35812  
(205) 544-2596

Blankenship, Bill  
Westinghouse Electric Corporation  
Advanced Programs Department  
P.O. Box 10864  
Pittsburgh, PA 15236  
(412) 382-7150

Bonacuse, Pete  
NASA-LeRC  
(216) 433-3309

Bransford, James W.  
National Institute for Standards  
of Technology  
Mail Code 853.03  
325 Broadway  
Boulder, CO  
(303) 497-5144

Chang, Kuang Jain  
Rocketdyne Division, AC37  
Rockwell International  
6633 Canoga Avenue  
Canoga Park, CA 91303  
(818) 710-4079

Chen, Po-Shou  
IIT Research Institute  
Building 4618  
MSFC, AL 35812  
(205) 544-4171

Cone, Fred P.  
Pratt Whitney/Materials Engineering  
United Technologies  
P.O. Box 2691  
West Palm Beach, FL 33402  
(407) 796-6572

DeLuca, Daniel P.  
Mailstop 707-20  
United Technologies  
Pratt & Whitney  
P.O. Box 109600  
West Palm Beach, FL 33410  
(407) 796-6508

Diwan, Ravinder  
Mechanical Engineering/Southern University  
c/o NAMS-Ames Research Center  
(504) 771-4701

Dreshfield, Bob  
NASA-LeRC (49-3)  
(216) 433-3337

Ellis, David  
NASA-LeRC  
(216) 433-8736

Fisher, Dean  
HERCULES  
MSFC, AL 35812  
(205) 574-4929

Gamwell, Wayne R.  
NASA-MSFC - EH23  
MSFC, AL 38812  
(205) 544-3098

Gerberich, William  
Department of Chemical Engineering  
and Materials Science  
University of Minnesota  
421 Washington Avenue SE  
Minneapolis, MN 55455  
(612) 625-8548

Gibson, Valerie A.  
Aerojet - Building 2019H2  
Department 5270  
Propulsion Division  
P.O. Box 13222  
Sacramento, CA 95813-6000  
(916) 355-3131

WORKSHOP ON HYDROGEN EFFECTS ON  
MATERIALS IN PROPULSION SYSTEMS

Gluszek, Fred  
Pratt & Whitney  
United Technologies  
MSFC, AL 35812  
(205) 544-2124

Graham, Stephen  
Materials Engineering Associates, Inc.  
9700B M.L. King, Jr. Highway  
Lanham, MD 20706-1873  
(301) 577-9490

Hardwick, Dallas A.  
Rockwell International-Rocketdyne  
6633 Canoga Avenue MS WC79  
Canoga Park, CA 91303-2790  
(805) 373-4431

Henkener, Julie  
Lockheed, JSC  
2400 NASA Road 1  
Mail Code C62  
Houston, TX 77058  
(713) 483-6459

Horn, Ron M.  
Aerojet - Building 2019H2  
Department 5270  
Propulsion Division  
P.O. Box 13222  
Sacramento, CA 95813-6000  
(916) 355-2703

Isham, Matthew A.  
NASA-MSFC - EH34  
Mail Code EH34  
MSFC, AL 35812  
(205) 544-1782

Jacobs, Bob  
IIT Research Institute  
Building 4818  
MSFC, AL 35812  
(205) 544-9539

Jewett, Bob  
Rockwell International-Rocketdyne  
6633 Canoga Avenue MS WC79  
Canoga Park, CA 91303-2790  
(818) 718-4647

Kaukler, Prof. William F.  
Department of Chemistry  
UAH  
Mailstop - MSB C 203  
Huntsville, AL 35899  
(205) 895-6910

Kovach, Michael P.  
Pratt & Whitney  
United Technologies  
MSFC, AL 35812  
(205) 544-8685

Kuruville, A.K.  
IIT Research Institute  
Building 4618  
MSFC, AL 35812  
(205) 544-5134

Lee, Jimmy  
NASA-MSFC - EH83  
MSFC, AL 35812  
(205) 544-4951

Lee, Jonathan  
NASA-MSFC - EH23  
MSFC, AL 35812  
(205) 544-9290

Lowry, Sam  
CFD Research Corporation  
3325-D Triana Blvd.  
Huntsville, AL 35805  
(205) 536-6576

Liaw, Yoon K.  
Rocketdyne  
MSFC-NASA  
Suite 3B 950 Explorer Blvd.  
Huntsville, AL 35806-2823  
(205) 544-4320

McClung, R. Craig  
Southwest Research Institute  
P.O. Drawer 26510  
San Antonio, TX 78228  
(512) 522-2422

McGaw, Mike  
NASA-LeRC (49-7)  
(205) 433-3308

McPherson, W. Bryan  
NASA-MSFC - EH23  
MSFC, AL 35812  
(205) 544-2601

Moody, Neville R.  
Sandia National Laboratories  
P.O. Box 969  
Livermore, CA 94551-0969  
(510) 294-2622

WORKSHOP ON HYDROGEN EFFECTS ON  
MATERIALS IN PROPULSION SYSTEMS

Nelson, Howard G.  
Ames Research Center  
NASA Ames N230-4  
Moffett Field, CA 94035  
(415) 605-6700

Panda, Binayak  
IIT Research Institute  
Building 4618  
MSFC, AL 35812  
(205) 544-6349

Pangborn, Rob  
Department of Engineering, Science,  
and Mechanics  
227 Howard Building  
Pennsylvania State University  
University Park, PA 16802  
(814) 865-4523

Pruitt, Ned C.  
Materials Engineering Associates, Inc.  
(and Loral Corp.)  
9700B M.L. King, Jr. Highway  
Lanham, MD 20706-1837  
(301) 577-9490

Ritzert, Frank  
NASA-LeRC  
(216) 433-8199

Roll, Eric  
Penn State University  
227 Hammond Building  
University Park, PA 16802  
(814) 867-4513

Sanders, Jeffrey  
IIT Research Institute  
Building 4618  
MSFC, AL 35812  
(205) 544-8685

Schmidt, Diane  
NASA-MSFC - EH23  
MSFC, AL 35812  
(205) 544-4943

Shanabarger, Mickey R.  
UCSB/Quantum Institute  
c/o NASA Ames Research Center MS 213-3  
Moffett Field, CA 94035  
(415) 604-6377

Stephenson, Timothy A.  
BIRL  
1801 Maple Avenue  
Evanston, IL 60201-3135  
(708) 491-2747

Stone, Bob V.  
GE Aircraft Engines  
1 Neumann WAT/A333  
Cincinnati, OH 45215  
(513) 774-5093

Strizak, Joe  
Oak Ridge National Lab  
P.O. Box 2008, MS 6088  
Oak Ridge, TN 37831  
(615) 574-5117

Telesman, Jack  
NASA-LeRC  
Cleveland, OH 44135  
(216) 433-3310

Thayer, James  
IIT Research Institute  
MSFC, AL 35812  
(205) 544-6946

Verrilli, Mike  
NASA-LeRC (49-3)  
(216) 433-3337

Verma, Suresh  
IIT Research Institute  
10 West 35<sup>th</sup> Street  
Chicago, IL 60616  
(312) 567-4178

Warren, John  
Pratt & Whitney  
United Technologies  
P.O. Box 2691  
West Palm Beach, FL 33402  
(407) 796-6512

Watwood, Mike  
IIT Research Institute  
Building 4618  
MSFC, AL 35812  
(205) 544-4410

Workman, Dr. G.L.  
Center for Automation and Robotics  
UAH  
Mailstop RI A6  
Huntsville, AL 35899  
(205) 895-6578

**Report Document Page**

1. Report No. 5-32210FNL		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle "Advanced Earth-To-Orbit Propulsion Technology Information, Dissemination and Research"				5. Report Due May 31, 1993	
				6. Performing Organization Code University of Alabama in Huntsville	
7. Author(s) Dr. S.T. Wu				8. Performing Organization Report No. 5-32210FNL	
				10. Work Unit No.	
9. Performing Organization Name and Address University of Alabama in Huntsville Huntsville, Alabama 35899				11. Contract or Grant No. NAS8-36955 D.O. 32	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-001 Marshall Space Flight Center, AL 35812				13. Type of report and Period covered Final Report for 7/13/89 - 5/31/93	
				14. Sponsoring Agency Code	
15. Supplementary Notes					
16. Abstract A conference was held May 1992 describing the reserach achievements on the NASA-wide research and technology programs dealing with advanced oxygen/hydrogen and oxygen/hydrocarbon earth-to-orbit propulsion was held at MSFC. The purpose of this conference was to provide a forum for the timely disseminatin to the propulsion community of the results emerging from this program with particular emphasis on the transfer of information from the scientific/research to the designer.					
17. Key Words (Suggested by Author(s)) Earth-to-Orbit, Propulsion, Conference			18. Distribution Statement CN-22D,3; AT-01, 1; CN-01/Wofford, 1; EM-13/L. Smith, 1; ONRRR, 1; ERO21/J. Moses, 2+repor; NASA Sci & Tech Info. Fac., 1+reprt; Vaughn/UAH, 1.		
19. Security Class. (of this report) Unclassified		20. Security Class. (of this page) Unclassified		21. No. of pages 44	22. Price