Chemical Propulsion Information Analysis Center

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In-Flight Performance of the MESSENGER Propulsion System

by Michael D. Trela
The Johns Hopkins University Applied Physics Laboratory

On 14 January 2008, the MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft became the first probe to pass by the planet Mercury in nearly 33 years (Fig. 1). The mission to become the first manmade satellite to orbit the innermost planet is the seventh in a series of successful NASA Discovery Program missions. Designed, built, and operated for NASA by The Johns Hopkins University Applied Physics Laboratory (APL), the MESSENGER spacecraft was launched from Cape Canaveral Air Force Station on 3 August 2004, on a Delta II 7925H-9.5 launch vehicle. MESSENGER will enter into orbit about Mercury in March 2011 and will begin acquiring scientific data that will be used to understand the formation of the planet and the inner solar system. The demanding 6.6-year orbital trajectory is designed to align the spacecraft's heliocentric orbit with Mercury's just before Mercury Orbit Insertion (MOI).

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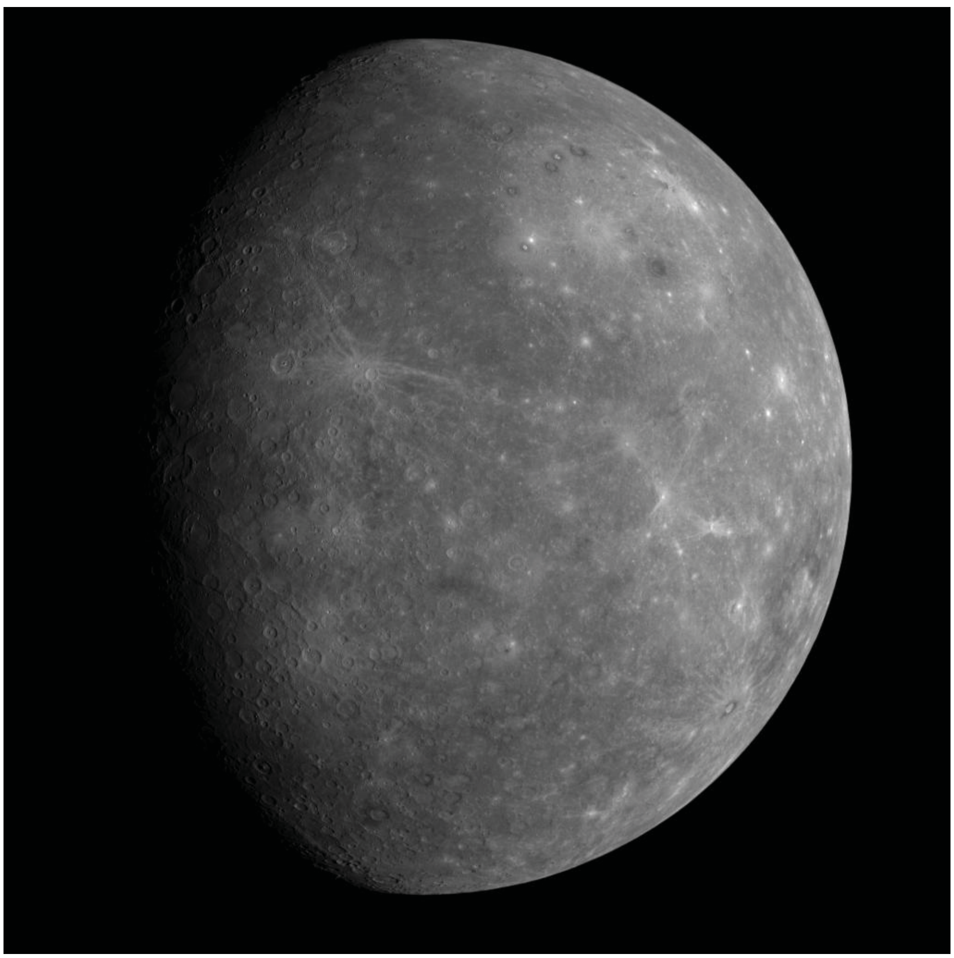

Courtesy NASA/Johns Hopkins University Applied Physics Laboratory/Carnegie Institution of Washington

Figure 1. This image from MESSENGER's Mercury Dual Imaging System (MDIS) provides the first detailed look at the hemisphere of Mercury not viewed by Mariner 10.

JANNAF to Convene in Boston May 12-16, 2008

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Inside This Issue

CPIAC's Technical/Bibliographic Inquiry Service

CPIAC offers a variety of services to its subscribers, including responses to technical/bibliographic inquiries. Answers are usually provided within three working days and take the form of telephoned, telefaxed, electronic or written technical summaries. Customers are provided with copies of JANNAF papers, excerpts from technical reports, bibliographies of pertinent literature, names of recognized experts, propellant/ingredient data sheets, computer program tapes and instructions, and/or theoretical performance calculations. The CPIAC staff responds to nearly 800 inquiries per year from over 180 customer organizations. CPIAC invites inquiries via telephone, fax, e-mail, or letter. For further information, please contact Ron Fry by e-mail to rs_fry@jhu.edu. Representative recent inquiries include:

TECHNICAL INQUIRIES

- Low energy sputter yield of xenon on Aluminum (Req. 25733)
- Concerns with catocene or butacene loaded propellants (Req. 25762)
- Impact sensitivity problems with Minuteman Stage 1 and 2 (Req. 25768)
- Russian SAM SRM and propellant information (Req. 25814)
- Historical basis of para-hydrogen heat of formation (Req. 25806)
- N_2 and Air solubility in JP-10 (Req. 25815)

BIBLIOGRAPHIC INQUIRIES

- Efficiency of fluorine-containing propellants (Req. 25966)
- MMH/NTO reaction kinetics (Req. 25951)

Recent CPIAC Products and Publications

JSC CD-49, ***JANNAF 5th Modeling and Simulation, 3rd Liquid Propulsion, 2nd Spacecraft Propulsion Joint Subcommittee Meeting,*** May 2007.

Do you have news about a propulsion-related event or activity you'd like to share with our subscribers? Send it to bulletin@cpiac.jhu.edu.

The Chemical Propulsion Information Analysis Center (CPIAC), a DoD Information Analysis Center, is sponsored and administratively managed by the Defense Technical Information Center (DTIC). CPIAC is responsible for the acquisition, compilation, analysis, and dissemination of information and data relevant to chemical, electric, and nuclear propulsion technology. In addition, CPIAC provides technical and administrative support to the Joint Army-Navy-NASA-Air Force (JANNAF) Interagency Propulsion Committee. The purpose of JANNAF is to solve propulsion problems, affect coordination of technical programs, and promote an exchange of technical information in the areas of missile, space, and gun propulsion technology. A fee commensurate with CPIAC products and services is charged to subscribers, who must meet security and need-to-know requirements.

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Meeting Reminders

JANNAF 6th Modeling and Simulation Subcommittee (MSS)/4th Liquid Propulsion Subcommittee (LPS)/ 3rd Spacecraft Propulsion Subcommittee (SPS) Joint Meeting

Date: December 8-12, 2008
Abstract Deadline:
June 16, 2008
Hilton Walt Disney World
Orlando, FL

For more information on the above meetings, contact CPIAC Meeting Planners Pat Szybist or Krystle Jones at 410-992-7302, ext. 215, or 410-992-7301, ext. 201, respectively, or by e-mail to pats@jhu.edu or kjones@jhu.edu.

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The *Bulletin* Board

Various meetings and events of interest are listed below. We welcome all such announcements, so that the propulsion community can be better served with timely information. For information on additional industry meetings, visit the CPIAC calendar of ***Meetings & Symposia*** available at http://www.cpia.jhu.edu/templates/cpiacTemplate/meetings/. The JANNAF Calendar appears on the back page.

46th Robert H. Goddard Memorial Symposium
Exploration to Commercialization: Going to Work in Space
4-6 March 2008
Greenbelt, MD
POC: http://www.astronautical.org/index.php?

24th National Space Symposium
7-9 April 2008
Colorado Springs, CO
POC: www.nationalspacesymposium.org/

24th Aerospace Testing Seminar
8-10 April 2008
Manhattan Beach, CA
POC: www.aero.org/conferences/ats/

NDIA Gun and Missile Systems Conference and Exhibition
21-24 April 2008
New Orleans, LA
POC: www.ndia.org

3rd International Symposium on Energetic Materials and their Applications
24-25 April 2008
Tokyo, Japan
POC: www.jes.or.jp/eng/

Small Business Industry Day
29 April 2008
Washington, D.C.
POC: Heather Gatta, 410-306-8651 or e-mail to SBID2008@batelle.org

Composite Materials for Aerospace
29 April-1 May 2008
Beltsville, MD
POC: www. ATIcourses.com

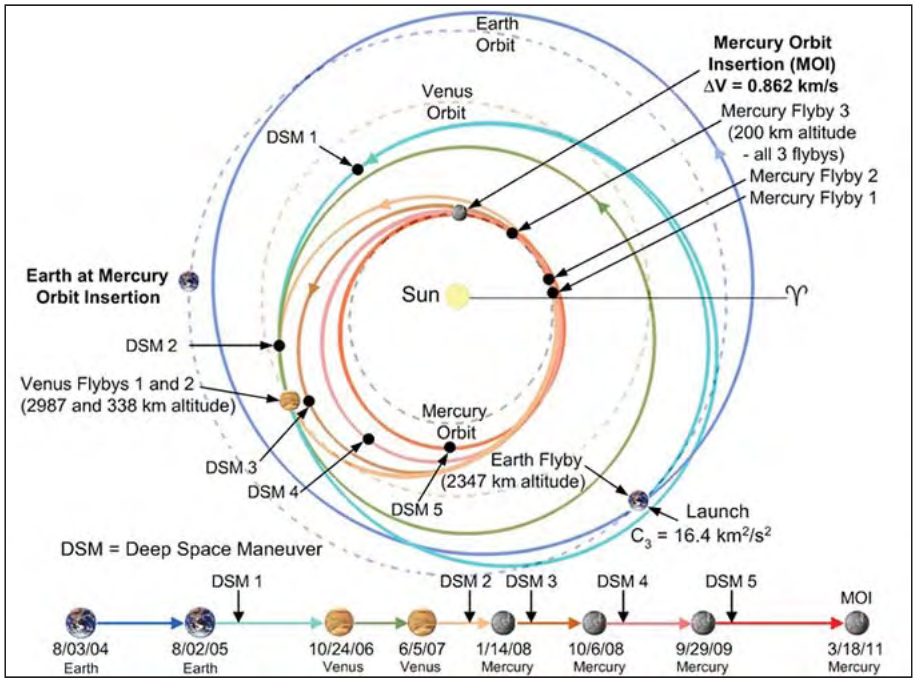
Space Propulsion 2008 - 5th International Spacecraft Propulsion Conference AND 2nd International Symposium on Propulsion for Space Transportation
5-9 May 2008
HERAKLION, Crete, Greece
POC: www.propulsion2008.com/index.html

Fundamentals of Explosives - Short Course on Chemical and Physical Principles including Blast Effects and Forensics
6-8 May 2008
Kingston, RI
POC: Dr. Jimmie Oxley, 401-874-2103 or e-mail to joxley@chm.uri.edu

26th International Symposium on Space Technology and Science (ISTS)
1-8 June 2008
Hanamatsu City, Shizuoka Prefecture, Japan
POC: www.ists.or.jp

Gordon Research Conference on Energetic Materials
15-20 June 2008
Tilton, NH
POC: www.grc.org/programs.aspx

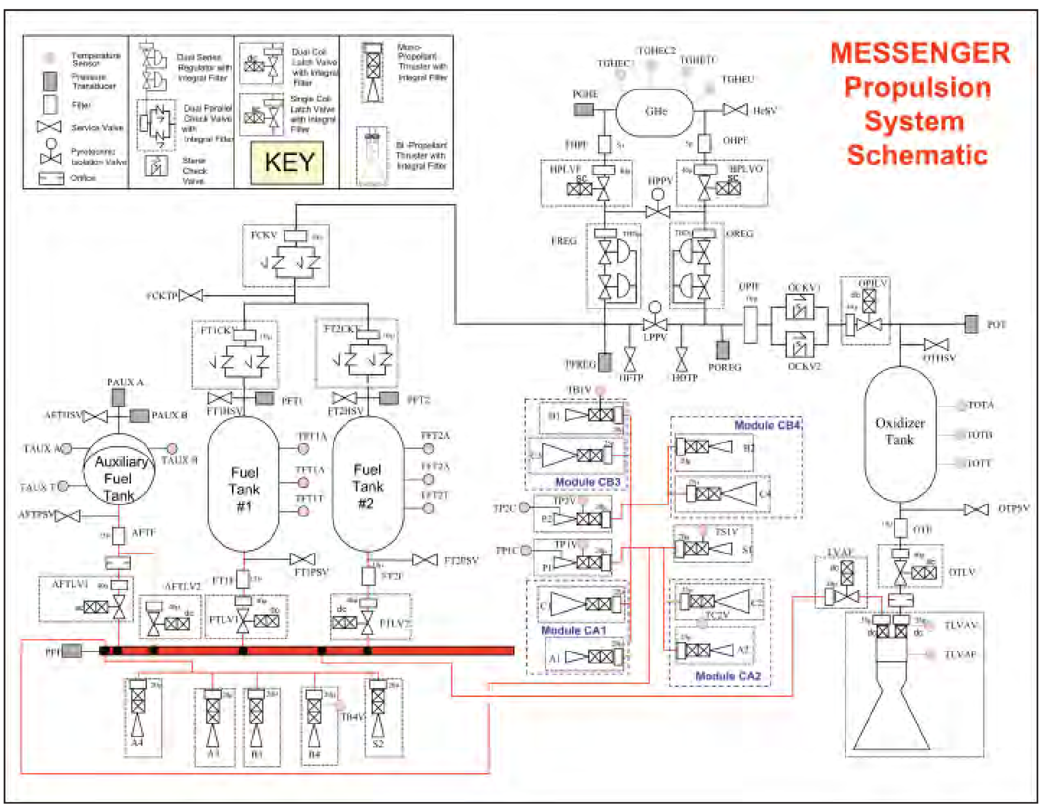
This requires that MESSENGER use planetary gravity assists from the Earth once, Venus twice, and Mercury three times, as well as execute several large deep-space maneuvers (DSMs) (Fig. 2). To achieve this challenging mission profile, APL, together with Aerojet, designed, developed, and qualified a new lightweight, dual-mode propulsion system capable of delivering approximately 2250 m/s spacecraft velocity change (ΔV).[1]



Courtesy NASA/Johns Hopkins University Applied Physics Laboratory/ Carnegie Institution of Washington

Figure 2. MESSENGER spacecraft trajectory and timeline.

The MESSENGER propulsion system includes twelve Aerojet 4.4-N (1-lb$_f$) MR-111C hydrazine thrusters, four Aerojet 22-N (5-lb$_f$) MR-106E hydrazine thrusters, and one 667-N (150-lb$_f$) AMPAC-ISP LEROS-1b bi-propellant hydrazine/nitrogen tetroxide engine (Fig. 3). To provide propellant to each of the thrusters, the system includes three main propellant tanks that are pressurized by a single gaseous helium tank, a diaphragm auxiliary fuel tank, and the necessary propellant and pressurant flow control components (Fig. 4). At launch, the total propellant and pressurant mass was 599.24 kg – 54% of the total spacecraft mass. The dry mass of the propulsion system was 81.74 kg. The propulsion system operates in one of four modes: a passive thermal management mode or three distinct active thruster modes. In the passive thermal management mode, thermostatically- and computer-controlled heater elements are used to keep the propellant and system components within the appropriate operating limits. The mode-1 maneuver uses the diaphragm auxiliary fuel tank in a blow-down configuration to feed a combination of the twelve 4.4-N thrusters. A mode-2 maneuver draws propellant from one of the two main hydrazine tanks to feed the 22-N primary-burn thrusters and smaller 4.4-N attitude control thrusters. A mode-3 maneuver draws propellant from one pressurized main fuel tank at a time and the oxidizer tank, and fires the 667-N Large Velocity Adjust (LVA) engine for most of the ΔV, while using the 22-N and 4.4-N thrusters for attitude control. Because the main propellant tanks do not contain a means for controlling the location of the propellant within them, four 4.4-N thrusters, fed by the diaphragm auxiliary tank, are fired for a short duration at the start of mode-2 and mode-3 maneuvers to settle the propellant over the liquid outlet in the main tanks before



Courtesy S. Wiley and K. Dommer[1]

Figure 3. Schematic drawing of the MESSENGER propulsion system.

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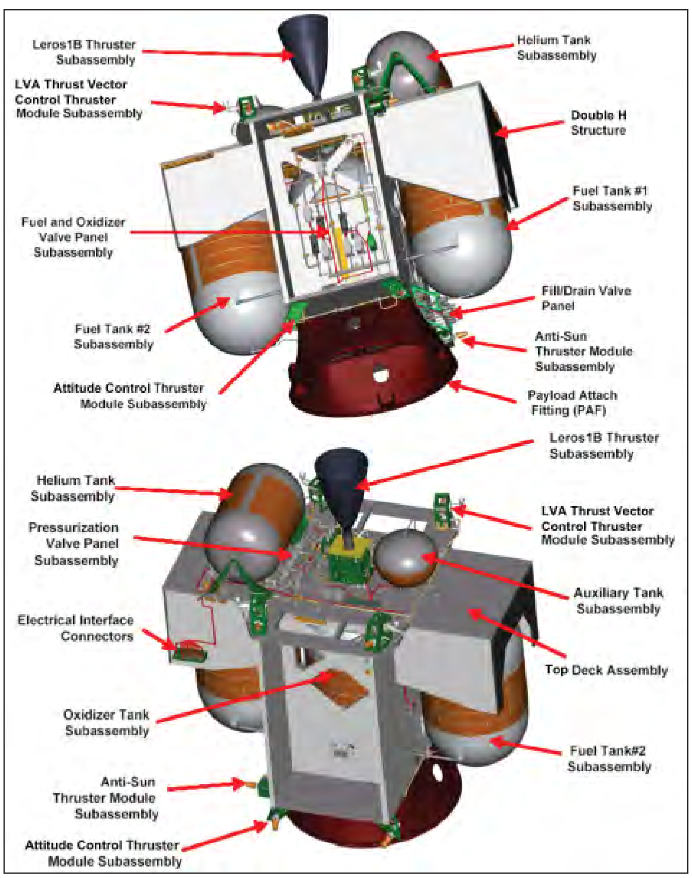
the tank latch valves are opened. Also, for both mode-2 and mode-3 maneuvers, the flight software provides an option for one of the main hydrazine tank latch valves to open and refill the auxiliary fuel tank before the main burn commences.

In all, the MESSENGER propulsion system will execute five DSMs (ΔV 40–315 m/s), a large MOI maneuver (ΔV approximately 862 m/s), several orbital-correction maneuvers (OCMs) (ΔV 4–26 m/s), numerous smaller trajectory-correction maneuvers (TCMs), and momentum dumps to unload angular momentum from the four reaction wheels. As of this writing, MESSENGER has executed twelve TCMs, two DSMs, and three momentum dumps. TCM-1, TCM-2, and TCM-3 were all executed using the mode-2 configuration and corrected the launch vehicle dispersion errors associated with the heliocentric orbit insertion. TCM-5 and TCM-6 (mode-1 maneuvers) oriented the spacecraft trajectory to pass through an optimal closest approach Earth flyby altitude of 2347 km on 2 August 2005. Following the first planetary flyby, the first mode-3 maneuver, DSM-1, was executed on 12 December 2005. As a result of a shift in the propellant location within the main propellant tanks due to the forces associated with DSM-1, the first commanded momentum dump (CMD-1) was performed shortly thereafter. TCM-10 was executed as a mode-1 maneuver to clean up nominal performance errors associated with DSM-1. Several months later, a second commanded momentum dump (CMD-2) was executed. TCM-11 was executed as the first multiple-component burn (a mode-2 followed by a mode-1 burn). With TCM-11 and TCM-12 (a mode-1 burn), the spacecraft trajectory was adjusted for the first Venus flyby, which occurred on 24 October 2006, with a closest approach altitude of 2987 km. Just after the first Venus flyby, a superior solar conjunction prevented communication with the spacecraft and, as a result, the spacecraft successfully executed a required momentum dump autonomously (AMD-1). To clean up trajectory errors associated with Venus flyby 1, a large (>35 m/s) spacecraft maneuver was required at TCM-13; however, given thermal restrictions on the spacecraft attitude, the TCM-13 burn could not have been executed entirely on the main LVA engine. As a result, a three-component maneuver (mode-1, mode-3, mode-1) was executed, with a refill of the auxiliary fuel tank occurring during the mode-3 component. TCM-15 and TCM-16 (mode-1 burns) resulted in a very successful Venus flyby 2 on 5 June 2007, with a closest approach altitude of 338 km. The second DSM (mode-3 maneuver) was executed just prior to a 45-day superior solar conjunction and placed the spacecraft on a trajectory to fly by the planet Mercury for the first time. TCM-19 (mode-1 maneuver) was executed to finely tune the spacecraft trajectory and, as a result, set up a historic pass by the planet Mercury on 14 January 2008, at an altitude of approximately 200 km.



Courtesy S. Wiley and K. Dommer[1]

Figure 4. A diagram highlighting key features of the integrated MESSENGER propulsion system.

In 2008, the MESSENGER team will be extremely busy with two deep-space maneuvers, two planetary flybys, and the associated trajectory correction maneuvers. As a result, the propulsion system will continually be utilized nearly four years after launch. In little over three years, MESSENGER will become the first man-made object to orbit the planet Mercury and will unravel many of the mysteries surrounding the planet closest to the Sun. Further information about the MESSENGER mission can be found online at http://messenger.jhuapl.edu.

Reference:

[1]S. Wiley and K. Dommer, Design and Development of the MESSENGER Propulsion System, *39th American Institute of Aeronautics and Astronautics/American Society of Mechanical Engineers/Society of Automotive Engineers/American Society for Engineering Education Joint Propulsion Conference and Exhibit*, paper AIAA-2003-5078, pp.17, Huntsville, AL, July 20-23, 2003.

About the Author

Michael D. Trela is a Systems Engineer in the Space Department of The Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland. He is currently the primary Propulsion Analyst and a Fault Protection Engineer for the MESSENGER mission and the Lead Fault Protection Engineer for the twin STEREO spacecraft.

PSHS Panels Cover Many Safety and Hazards Issues

JANNAF subcommittees promote many of their objectives through the activities of various panels composed of scientists and engineers in the propulsion community. The Propulsion Systems Hazards Subcommittee (PSHS) has four such panels, engaged in a variety of tasks and actions.

Cookoff Hazards Technology Panel

One of the tasks of the Cookoff Hazards Technology Panel is to develop and validate a credible subscale fast cookoff (or bonfire) test protocol that can be used for hazard classification of large rocket motors. The task will assist in development of modeling techniques for predicting all aspects of rocket motor cookoff and will coordinate experimental efforts to define appropriate phenomenology, provide material properties, and establish data necessary for validation. The Air Force, Department of Defense Explosives Safety Board (DDESB), Army Aviation and Missile Research Development and Engineering Center (AMRDEC), and the Navy funded a Solid Propellant Rocket Motor Hazards Project in support of a subscale alternate test protocol. The panel established a task group that reviewed the large motor fast cookoff (FCO) testing of PAC3. Subscale FCO experimental designs have been developed and are being validated. Another panel task is to provide a current review of the state of the art of cookoff hazards prediction capabilities and assess critical needs, in order to focus appropriate research and development. Emphasis on hazards mitigation to meet insensitive munitions needs may point out gaps in experimentation or modeling that need to be addressed promptly. They are also working to preserve historical data. Also being considered is a broad survey of cookoff investigators to provide written input for a document that will be updated as needed. Contact Dr. Arthur Ratzel, acratze@sandia.gov, or Dr. Anita Renlund, amrenlu@sandia.gov, for further information.

Safety and Hazard Classification Panel

The Safety and Hazard Classification Panel has a task to review "DoD Ammunition and Explosives Hazard Classification Procedures," Technical Bulletin (TB) 700-2. Recommendations regarding appropriate revisions to TB 700-2 will be developed and submitted to DDESB for consideration. This is an ongoing task, in response to periodic requests from DDESB for review and comment on proposed modifications of TB 700-2. Recent discussions between the Panel Chair, other Service personnel, and DDESB have focused on several major issues affecting hazard classification of propulsion systems, propellants, and explosives. The combined expertise of the Service Safety Offices and the materials hazard behavior and testing experts on the Panel provide a uniquely qualified group to address these issues. The panel completed formulating recommendations to the DDESB regarding the Super Large Scale Gap Test (SLSGT) and critical diameter test requirements, as defined in the Alternate Test Series in TB 700-2. The Service hazard classifiers subsequently met and accepted these recommendations with only slight changes. DDESB has accepted the new protocol. Contact Dr. Josephine Covino, josephine.covino@ddesb.osd.mil, or Patricia Vittitow, patricia.vittitow@us.army.mil, for further information.

Impact/Shock-induced Reactions Panel

One of the tasks of the Impact/Shock-induced Reactions Panel is to conduct a round-robin testing program comparing Naval Ordnance Laboratory (NOL) Large Scale Gap Test (LSGT) results obtained by participating organizations, using propellant test samples prepared from the same 5-gallon mix for each type of propellant. Since each organization has its own test methods, debate sometimes occurs regarding interpretation and comparison of results. The intent of the round robin is twofold: (1) To gauge the propulsion community regarding the reliability, accuracy and precision of each organization's test setup and methodology, and (2) To rekindle a discussion about the importance of the test and its consequences for continued propellant development. Four Government facilities and five contractor facilities have agreed to participate in the program by conducting gap tests on propellants produced at AMRDEC. Another panel task is to develop approaches needed for quantitative assessment of the hazards associated with propellant system response when exposed to unintended impact stimuli. The panel will attempt to assist in the development of modeling techniques for predicting all aspects of energetic material impact response, including the level of reaction violence necessary for a positive threat/hazard assessment, and to coordinate experimental efforts to define appropriate phenomenology (including threat hazard boundary conditions), provide material properties, and establish data necessary for validation. The physical and chemical processes involved in impact response are complex and coupled. The modeling methodologies for each process will be validated with advanced diagnostic experiments. The panel distributed an initial questionnaire in an effort to have people identify the technical gaps that need to be addressed to solve this problem. Contact Dr. Patrick Baker, pbaker@arl.army.mil, for further information.

Insensitive Munitions (IM) Technology Panel

The IM Technology Panel has a task to document previous IM technology development efforts in a summary form that

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PSHS Panels....*continued from page 6*

scientists and engineers can then reference and use in the planning and execution of current and future work. Currently no single source of this information exists. Within the last few years, there has been a renewed emphasis on the development and integration of IM technology. Within some organizations, this renewed interest has followed a period of little or no funded IM programs. Consequently, the technical personnel now actively working in various areas of IM technology development may not have been involved in or knowledgeable of earlier technology programs. Even individuals who were involved in previous efforts may not be familiar with work from other organizations. By preparing concise summaries of IM technology development efforts and consolidating them in a JANNAF document, information on these prior efforts will become readily available to technologists and program planners. Individuals from DoD and industry volunteered to initiate the collection of information from within their organizations. CPIAC will assist in reviewing the collected historical information and establishing a standard format for documentation. Contact Jamie Fisher, jamie.fisher@us.army.mil, or Stephen Struck, stephen.struck@eglin.af.mil, for further information.

JANNAF to Convene in Boston May 12-16, 2008

Join us for the 55th JANNAF Propulsion Meeting and Joint Meeting of the 42nd Combustion Subcommittee, 30th Airbreathing Propulsion Subcommittee, 30th Exhaust Plume Technology Subcommittee, 24th Propulsion Systems Hazards Subcommittee, and 12th SPIRITS User Group

The 55th Joint Army-Navy-NASA-Air Force (JANNAF) Propulsion Meeting (JPM), 42nd Combustion Subcommittee (CS), 30th Airbreathing Propulsion Subcommittee (APS), 30th Exhaust Plume Technology Subcommittee (EPTS), 24th Propulsion Systems Hazards Subcommittee (PSHS), and 12th SPIRITS User Group Joint Meeting will be held May 12-16, 2008, at the Boston Marriott Newton, in Newton, Massachusetts, and at Hanscom AFB, Massachusetts.

Boston Marriott Newton overlooking the Charles River.

Mr. John B. Moore is Program Chair of this meeting. Mr. Moore is currently assigned to the Solid Propulsion Branch of the Naval Air Warfare Center Weapons Division (NAWCWD) and is the propulsion monitor for the GQM-163A (Coyote) and co-investigator of an effort to improve the NAWCWD airbreathing engine cycle analysis tools. He is the principal investigator of an effort to super-plastically form and diffusion bond tubular structures with an emphasis on inlets and transfer ducts. Mr. Moore has also served as principal investigator on several ramjet inlet technology programs, most notably the Low Drag Ramjet (LDRJ) and Fasthawk.

Mr. Moore is a recipient of the Dr. Manuel A. Garcia Memorial Award, which recognizes a civilian employee of NAWCWD who has made significant contributions to the methodology and/or validity of the processes for Test and Evaluation of weapon systems through innovation and/or application of sound engineering principles.

Mr. John B. Moore
Program Chair

Technical Program

This year's technical program consists of fifty-seven technical sessions, workshops and numerous panel and town meetings.

The JPM will host eleven sessions, three of which are joint sessions with CS; CS will host a total of twenty sessions, including three sessions combined with JPM; APS will host thirteen sessions; EPTS will host seven sessions while SPIRITS will host two; and, PSHS will host seven technical sessions and a workshop on scaling hazard testing. An MSS workshop, "JANNAF Guide to Simulation Credibility in Propulsion Modeling" is also being planned for this venue. JANNAF Executive Committee and Subcommittee Technical Achievement Awards will be presented and recipients recognized.

Meeting Keynote Address

Steven H. Walker, Deputy Director of the Tactical Technology Office (TTO) at the Defense Advanced Research Projects Agency (DARPA) will deliver the keynote address entitled, "Air-Breathing Hypersonic Flight - Closer Than We Have Ever Been."

DARPA is the principal Agency within the Department of Defense (DoD) for research, development, and demonstration of concepts, devices, and systems that provide highly advanced military capabilities. TTO addresses the critical mission areas of Air/Space/Land/Sea platforms, Precision Strike, Laser Systems, Unmanned Systems, and Space

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JANNAF to Convene in Boston.... *continued from* *page 8*

Dr. Steven H. Walker
Keynote Speaker

Operations. Dr. Walker is a member of the Senior Executive Service.

Dr. Walker also serves as Program Manager for the Falcon Program, which supports the development and validation of in-flight technologies that will enable a prompt global reach capability while at the same time demonstrating affordable and responsive space lift. The Falcon Program will demonstrate long duration, reusable hypersonic flight through a series of critical flight demonstrations. Dr. Walker also manages the Hypersonic Cooperative Australian/U.S. Experiment or Hycause Program and is the Deputy Program Manager of the Air Force/DARPA Scramjet Engine and High Speed Turbine Engine demonstration programs.

Prior to his assignment as a Program Manager at DARPA, Dr. Walker was the Special Assistant to the Director, Defense Research and Engineering from July 2001 to July 2002. In this role, he developed a national technology development framework for airbreathing hypersonics, reusable access to space and space technology programs known as the National Aerospace Initiative. He also conducted the first DoD technical readiness assessment of a major ACAT I acquisition program, the Joint Strike Fighter (JSF), prior to a System Design and Development (SDD) decision.

Block Diagram and Administrative Information

The tentative block diagram for the meeting is given in Tables 1 and 2 (See Insert), but please remember that date and time assignments are subject to change between the preliminary and final programs. Authors and attendees should contact CPIAC for updates as necessary. For more information on the Technical Subcommittees, the Subcommittee Panels, or the Workshops, please contact Ronald S. Fry at rs_fry@jhu.edu. The preliminary program and registration materials for the meeting will be available in March from CPIAC; please contact Patricia Szybist at pats@jhu.edu or 410-992-7302, ext. 215, if you do not receive a copy.

Attendance at this JANNAF meeting is restricted to U.S. citizens whose organizations are registered with an appropriately classified contract with the Defense Technical Information Center and certified for receipt of export-controlled technical data with the Defense Logistics Information Service.

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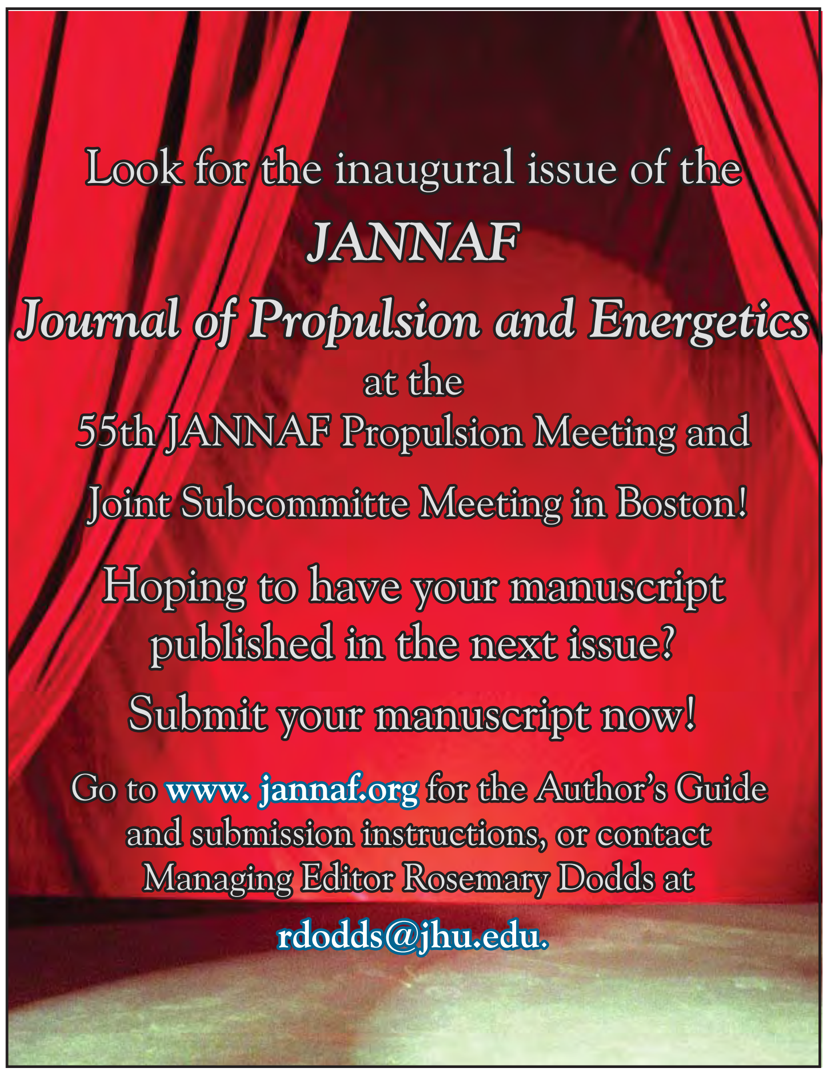


Table 1. May 2008 JPM PRELIMINARY BLOCK DIAGRAM, Part I.

Boston Marriott Newton/ Hanscom AFB	Grand Ballroom A	Grand Ballroom B	Grand Ballroom F	Grand Ballroom G	Grand Ballroom H
Monday PM May 12, 2008	JPM Ares I-X Flight Testing	EPTS Code Development and Enhancements - I		APS Conventional Ramjet Propulsion	CS Reactive Materials - I
Tuesday AM May 13, 2008	JPM Space Access Propulsion & Technology, Session - I	EPTS Code Development and Enhancements - II	JPM Propulsion & Energetics Test Facilities - I	APS Hypersonic Technology Overviews	PSHS Gun Propellant Vulnerability
Tuesday PM	JPM Space Access Propulsion & Technology, Session - II	EPTS Flowfield Data and Modeling	JPM Propulsion & Energetics Test Facilities - II	APS Scramjet Propulsion	JPM / CS Interior Ballistics & Propellant Combustion Modeling
Wednesday AM May 14, 2008	JPM Tactical Propulsion Session - I	CS / PSHS Ambient Atmosphere Solid Propellant Combustion Session - I	JPM Ares I Aerodynamics	APS RBCC & PDE Technology	CS Analysis and Modeling of Gun Propellant & Igniter Ingredients
Wednesday PM	JPM Tactical Propulsion Session - II	CS / PSHS Ambient Atmosphere Solid Propellant Combustion Session - II		APS TBCC & Inlet Technology	JPM / CS Development of Gun Propellants, and Propellant Ingredients
Thursday AM May 15, 2008	JPM Missile Defense/Strategic Propulsion	CS Solid Combustion Modeling and Combustion Instability			CS Ballistics Studies of Small & Medium Caliber Rounds
Thursday PM		EPTS Plume Effects and Signatures - I			JPM / CS Gun Systems & Charge Design
Friday AM May 16, 2008		EPTS Plume Effects and Signatures - II			

Table 2. May 2008 JPM PRELIMINARY BLOCK DIAGRAM, Part II.

Boston Marriott Newton/ Hanscom AFB	Charles River Room East	Charles River Room West	Lexington	**Hanscom AFB** Lexington Amphitheatre	**Hanscom AFB** Concord Auditorium
Monday PM May 12, 2008	APS Scramjet Component Engine Testing - I	CS Ignition and Solid Propellant Combustion	PSHS Thermal Decomposition and Cookoff - I		
Tuesday AM May 13, 2008	CS Reactive Materials - II	CS Novel Liquid Rocket Propellants & Combustion	PSHS Thermal Decomposition and Cookoff - II		
Tuesday PM	APS Scramjet Propulsion/ Structures APS Component Modeling & Simulation	CS Modeling Engine Flowfields in Test Facilities	PSHS Sympathetic Denotation Modeling Demonstration		
Wednesday AM May 14, 2008	Scramjet Combustion Engine Testing - II	CS Modeling & Data For Combustion Simulation) - I	CS Enhanced Blast - I		EPTS Plume Signatures
Wednesday PM	CS Solid Propellant Burn Rate Augmentation and Combustion Efficiency	CS Modeling & Data For Combustion Simulation - II	CS Enhanced Blast - II		EPTS Plume Signatures and Applications and Validation - I
Thursday AM May 15, 2008	CS Reactive Materials - III	CS Combustion Diagnostics	PSHS Insensitive Munitions Technology - I	EPTS Plume Signatures and Applications and Validation - II SPIRITS SPIRITS - I	APS Ground Test of X-51A SED Flight Development Engine SJX61-1
Thursday PM	CS Aluminum Combustion and Combustion Efficiency	CS Enhanced Blast - III	PSHS Insensitive Munitions Technology - II	SPIRITS SPIRITS - II	
Friday AM May 16, 2008	APS Scramjet Test Facilities & Flight Tests		PSHS Propulsion System Safety/Hazard Classification		

In Memoriam

Dr. James R. Kliegel

Dr. James R. Kliegel

Dr. James R. Kliegel died January 10, 2008, at Hoag Hospital in Newport Beach, California, after an extended illness.

Dr. Kliegel was a senior member of the U.S. solid rocket community and had a long and successful career as a scientist, inventor, executive, founder of several businesses, and consultant.

Jim received a bachelor's degree in Applied Chemistry from the California Institute of Technology in 1953. He received a master's degree in Chemical Engineering in 1956 and his doctorate in Mechanical Engineering in 1959, both from the University of California at Berkeley.

Jim's career began in 1958 when he joined Space Technology Laboratories (later TRW) as a new Ph.D. graduate working on the original Minuteman development program. Jim worked at TRW until 1967 directing major staff support for technical direction of all propulsion contractors supporting the U.S. Air Force Ballistic Missile Development Programs. He was principal analyst and program manager leading development of the first successful coupled two phase flow solid rocket nozzle analysis and performance prediction computer program, and he had major design responsibility for performance of Apollo lunar landing engines. As program manager, he was responsible for development of the JANNAF-sponsored One Dimensional Kinetic (ODK) and Two Dimensional Kinetic (TDK) liquid rocket nozzle performance analysis computer programs. While there, he developed nationally-adopted rocket engine performance analysis computer programs, still in use today, and was the recipient of four NASA awards for excellence.

Dr. Kliegel was President of Dynamic Science, a small combustion research company, and later founded KVB, Inc., where he served as President and Board Chairman. While at KVB, Dr. Kliegel served on President-elect Reagan's Environmental Transition Task Force, and also served as Chairman of the National Academy of Sciences panel, investigating the technical feasibility of the newly proposed vehicular CO emission standard.

After KVB was sold, Jim rejoined TRW, where he managed and directed a number of advanced research and development efforts for the military, including for the Strategic Defense Initiative and the Minuteman, Peacekeeper and small ICBM missile programs. In recent years, Jim served as Chief Technical Officer for Global Energy Systems, LLC, (a Kelly Space and Technology Energy Subsidiary). Most recently, he was a senior consultant on solid rocket motor performance and advanced ballistic missiles for the Air Force Research Laboratory Propulsion Directorate (West) at Edwards AFB, California, and Aerojet, a GenCorp Inc. company.

He is survived by his wife Shirley of Santa Ana, California, and his children.

In Memoriam

Charles Albert Sinclair

Charles Albert Sinclair, a retired aeronautical engineer, died February 13, 2008, in San Jose, California. He was 73. Mr. Sinclair was born in Salida, Colorado, but lived in San Jose for 48 years.

During his 40-year career, he was Vice President of United Technologies and General Manager of Pratt & Whitney Chemical Systems Division.

He is survived by his wife of 52 years, Carolyn Sinclair; his daughters, Marian Wolf (Wesley Viets) and Kersten (Nicholas) Buck; his sister, Patricia Crose; his brother, James Sinclair; and five grandchildren. He was preceded in death by his daughter, Evelyn Sinclair; his sister, Gwendolyn Isola; and his brother, George Sinclair.

Excerpted from the San Jose Mercury News, 2/20/2008.

Workshop Puts Reactive Materials in Perspective

A workshop on reactive materials was held February 5-6, 2008, at the Crowne Plaza Atlanta Airport Hotel in Atlanta, Georgia, under the joint auspices of the JANNAF Combustion Subcommittee and Propellant and Explosives Development and Characterization Subcommittee. Reactive materials (RM), in this context, are materials that are not explosive themselves but are able to enhance blast and/or incendiary effects when utilized in conjunction with explosives. They are especially advantageous if they can be used as structural materials to replace non-reactive materials – for bomb cases, for example.

The 47 workshop participants came from a variety of backgrounds, including the three services, industry, and academia. Presentations and discussions included viewpoints from people with diverse backgrounds and perspectives, ranging from technical to programmatic. Dr. Barrie Homan of the Army Research Laboratory at Aberdeen Proving Ground, Maryland, and Dr. Richard Ames of the Naval Surface Warfare Center at Dahlgren, Virginia, co-chaired the workshop.

Advantages of RM that were discussed included the ability to vary output energy to match target characteristics, insensitivity that greatly facilitates storage and transportation, and ability to achieve prolonged burning. RMs also have the potential to direct their energy more selectively than conventional explosives.

A variety of RM fabrication methods were described. Presentations emphasized the need to understand the requirements of the specific application and the characteristics of the target in order to properly design an RM munition. Other subjects of presentations and discussions included screening test methods for material selection, the relative importance of thermal energy versus energy from expansion of gases under high pressure, the dependence of performance on atmospheric oxygen, the importance of material density, and the need for more consistent and more comprehensive performance modeling.

Although the technology's state of the art was discussed, the main goals of the workshop were to determine currently planned efforts, work that is needed to fully maximize the utility of RM, possible collaborations between the organizations, and procedures for facilitating the exchange of information. Dr. Homan will report on the workshop, including the presentations, a summary of the discussions and recommendations, at the JANNAF May 2008 meeting.

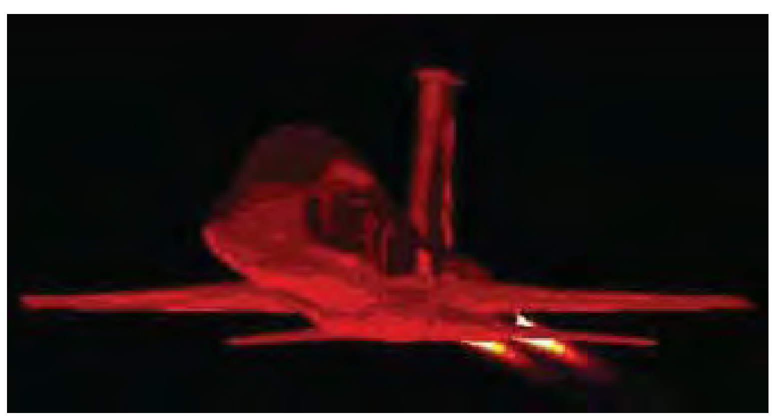
Attention SPIRITS Users and Interested Parties

CPIAC and Aerodyne Inc. will host a SPIRITS training course in conjunction with the JANNAF Meeting to be held May 12-16, 2008, at the Boston Marriott Newton.

The SPIRITS Training Course provides a complete, intensive introduction to SPIRITS-AC2, both for new users and for users of previous versions. The course length is four days, with a 50/50 mix of lectures and hands-on practice sessions. The course is led by Mr. John Conant, who has been Project Manager and lead designer for SPIRITS since its development in 1984.

Course registration is $2500 for the full four-day course and is on a first come first served basis; the deadline for registration is April 18, 2008. Registration includes admittance to the JANNAF meeting, course materials, use of laptops running either Linux or Windows XP, snacks and refreshments.

SPIRITS is the JANNAF-approved system of computer codes that is designed to predict the electro-optical (UltraViolet, VISible and InfraRed) signatures of complete hardbody/plume aircraft configurations in the 0.2 to 25 µm spectral region (hardbody signature without plume from 0.2 to 0.7 µm). It produces spectral and in-band intensities, and in-band images of vehicles and plumes both at the source and at the observer.



For more information on the SPIRITS training course or to register, contact Krystle Jones at 410-992-7301, ext. 201, or by e-mail to kjones@jhu.edu.

Spotlight on SBIRs

A Brief View of ATK and XCOR Aerospace's Liquid Oxygen and Methane Engine Development

Dan DeLong, Chief Engineer, XCOR Aerospace

Over the past nine years, XCOR Aerospace, Inc. has developed ten rocket engines, all using "green propellants" and all using augmented spark ignition.

XCOR began development of engines with the liquid oxygen (LOX) and methane (CH_4) propellant combination for numerous reasons. The advantages of LOX/CH_4 over current systems include high specific impulse, long term storability necessary for manned Moon or Mars missions, and a non-toxic nature that significantly lowers operations costs, enhances crew safety and is better for the environment. Methane is the highest performing stable hydrocarbon available, and it is far denser and more storable than liquid hydrogen. Its excellent cooling properties and lack of coking or fouling in the cooling passages hold great promise for its use in long-life, reusable, regeneratively cooled engines. Also, LOX with CH_4 is the highest performing non-toxic, space-storable propellant combination available.

The first LOX/CH_4 engine that XCOR developed was designed to be a reaction control thruster. XCOR used private investment money to build and test a self-pressurized 220 N (50 lbf) thrust rocket engine with regenerative cooling and specially designed injector that would demonstrate reliable ignition. The goal was to examine the possibilities of an engine with cryogenic fuels and regenerative cooling.

A subsequent Small Business Innovation Research (SBIR) Phase I contract enabled further testing of this engine, designated XR-3M9, to quantify performance characteristics and validate design models. The purpose of this Program was to examine the XR-3M9 for a relatively high specific impulse with safe, environmentally friendly propellants, and reliable, responsive operations. The test results enabled XCOR to predict performance of larger engines that will form the basis of low cost launch vehicles, satellite maneuvering stages, and commercial sounding rockets.

Soon after finishing this contract, Alliant Techsystems Inc. (ATK), with XCOR as a major subcontractor, was awarded a NASA contract to design, build, and test a 33 kN (7,500 lbf) LOX/CH_4 pressure-fed engine. The development work was funded by NASA's Exploration Technology Development Program at Langley, which is a part of the Propulsion and Cryogenics Advanced Development Project based at Glenn Research Center.

This engine was designated the XR-5M15, and demonstrated a series of thirty-eight hot fire tests at XCOR's Mojave, California facilities.

The XR-5M15 engine development uses several features from the XR-3M9, including the same augmented torch electrical ignition system and the propellant combination. Two rocket engines were designed, built, and tested in this program over the course of eleven months. The first, called the Trombone Engine (TE), had a water-cooled combustion chamber and movable heat-sink throat for adjustable chamber length (L') (Fig. 1). The second version was named the Workhorse Engine (WE), which was regeneratively cooled with methane and had a conical nozzle extension for sea level test designed to thermally simulate a parabolic vacuum nozzle (Fig. 2).

Courtesy Mike Massee, XCOR Aerospace

Figure 1. Test fire of the XR-5M15 Trombone Engine on the 40K test stand.

To handle tests of these engines, XCOR developed a 40,000 pound thrust mobile stand with a structural safety margin of four (Fig.1). It was built with private investment funding, and follows company practice of a mobile stand that travels to the remote test site only on the day of the test. The mobile stand is structurally mounted to a commercial trailer with all valves, fluid lines, controls, electrical power, and data acquisition system included. Pressurization gasses are supplied from a separate tube trailer.

The initial workhorse version of this engine is a major step along the path towards the ultimate goal of developing flight-weight hardware that could help return America to the Moon and

continued on page 13

Liquid Oxygen and Methane Engine Development.... *continued from page 12*

Figure 2. A test fire of the XR-5M15 Workhorse Engine at XCOR's Mojave test facilities.

Courtesy Mike Massee, XCOR Aerospace

allow astronauts to tap extraterrestrial sources of fuel. Specific applications of this engine include in-space maneuvering and Lunar Ascent Stage main propulsion.

The Trombone Engine was added to the program to determine minimum L' for good combustion efficiency, for use in the follow-on versions, and because the Workhorse L' was already set due to a tight schedule. The TE was intended only to measure run-to-run relative combustion efficiency (C*) to allow optimum L' evaluation. Test results demonstrated little or no C* efficiency loss at the minimum TE chamber length.

The initial test requirements were for precise relative mass-flow measurements, so small differences in mass-flow could be tracked accurately. The test setup was modified mid-program to improve absolute mass-flow measurement accuracy. Balanced Orifice Flow Meters were added to the system to provide backup for the existing cavitating venturis, and precision weighed-coldflow calibrations were conducted for both sets of instruments, to provide sufficient absolute accuracy for initial C* efficiency measurements.

A total of fifteen hot-fire runs of the Trombone Engine tested:

- Initial round of injector pressure-drop evaluation and modifications
- Initial thermal characteristics evaluation
- Gas-pressure "Pulser" preliminary tests for possible use in stability evaluation

The Workhorse Engine was the primary hot-fire test article for this program. It was 33 kN (7,500 lbf) nominal vacuum thrust at 17 MPa (250 psi) chamber pressure, with 3.3:1 Oxidizer/Fuel (O/F) ratio. The non-flightweight design was biased for operability and serviceability under test. Some of the components used were experimental pathfinders for possible flight-hardware fabrication methods. The preliminary WE test phase refined engine operating procedures, such as chills, control sequences, and feed pressures. Additional injector pressure drop data were gathered and tuning performed. These results demonstrated an injector fuel annuli diameter increase and an injector fuel gallery height increase.

Twenty-three hot fire tests of the Workhorse Engine accomplished:

- Initial steady state tests of 8 sec at nominal conditions with 80 L (20 gal) propellant tanks
- Significantly higher C* efficiency, which was observed in test runs 20, 22, and 23 conducted at increased fuel flow and less fuel heating
- Successful fast shutdown tests, where <1% thrust was accomplished within 1 sec of OFF command
- Engine run to LOX depletion with no damage

The Workhorse Engine fulfilled several NASA requirements. It validated the key engine design elements, including the regeneratively cooled chamber and throat assembly, the stability and performance of the injector, and the reliability of ignition. It also incorporated a number of design features for safety and reliability.

A qualified LOX/CH$_4$ engine will fit President Bush's U.S. Space Exploration Policy. In NASA's Exploration Systems Architecture Study, the Initial Reference Architecture baselined pressure-fed LOX/CH$_4$ engines "on the CEV Service Module and the lander ascent and descent stages to maximize commonality." (Exploration Systems Architecture Study, Final Report [Nov 2005], NASA-TM-2005-214062, www.sti.nasa.gov, Sec. 1, p. 16.) However, currently the United States lacks high performance, long-life, reusable liquid oxygen/hydrocarbon rocket engines. The development of such engines will enable U.S. government and commercial launch vehicles to employ higher performance upper stages than the current nitrogen tetroxide/hydrazine (N_2O_4/N_2H_4) upper stages. Plus, the long-life reusable feature of LOX/CH$_4$ engines makes them attractive for partially or fully reusable launch vehicle architectures for DoD, NASA, and commercial payload applications. Several recent U.S. reusable launch vehicle efforts (such as the X-33 and X-34) have encountered difficulties caused by the lack of suitable reusable long-life hydrocarbon engines.

While this program alone cannot put such engines in the U.S. inventory, it has reduced some of the technology risks associated with developing a LOX/CH$_4$ engine by generally enhancing the United States' experience base with LOX/CH$_4$ engines.

Propulsion News Highlights

NASA Unveils $17.6 Billion Budget
Source: NASA, 4 Feb. 2008

NASA announced a $17.6 billion budget for fiscal year 2009 to continue exploring the solar system, building the International Space Station, studying Earth from space and conducting aeronautics research. NASA Deputy Administrator Shana Dale said the increase for NASA's 2009 budget demonstrates President Bush's commitment to the agency's missions. With the increase, NASA still accounts for less than 1 percent of the federal budget. The NASA budget includes $5.78 billion for the space shuttle and space station programs, $4.44 billion for science, $3.5 billion for development of new manned spacecraft systems and $447 million for aeronautics research. Dale noted steady progress with NASA's missions, with three successful space shuttle launches last year and up to six planned for this year, including a flight to service the Hubble Space Telescope. The agency also is making progress in developing the Orion spacecraft and Ares launch vehicles to replace the aging shuttle fleet and prepare for journeys to the moon and destinations beyond. Full press release: http://www.nasa.gov/home/hqnews/2008/feb/HQ_08034_FY2009_budget.html.

U.S. Navy Demonstrates World's Most Powerful Electromagnetic Railgun at 10 MJ
Source: Military Embedded Systems, 1 Feb. 2008

The Navy's Office of Naval Research successfully conducted a record-setting firing of an electromagnetic railgun at Naval Surface Warfare Center, Dahlgren, VA. An invited audience, including the Chief of Naval Operations, ADM Gary Roughead, witnessed this revolutionary technology in action. The technology uses high power electromagnetic energy instead of explosive chemical propellants (energetics) to propel a projectile farther and faster than any preceding gun. At full capability, the rail gun will be able to fire a projectile more than 200 nautical miles at a muzzle velocity of mach seven and impacting its target at mach five. In contrast, the current Navy gun, MK 45 five-inch gun, has a range of nearly 20 miles. The high velocity projectile will destroy its targets due to its kinetic energy rather than with conventional explosives. Full press release: http://www.mil-embedded.com/news/db/?10210.

Courtesy U.S. Navy

Firing of electromagnetic railgun at Naval Surface Warfare Center, Dahlgren, VA.

SpaceX Conducts First Multi-engine Firing of Falcon 9 Rocket
Source: SpaceRef.com, 28 Jan. 2008

On Jan. 18, Space Exploration Technologies Corp. (SpaceX) conducted the first multi-engine firing of its Falcon 9 medium to heavy lift rocket at its Texas Test Facility outside McGregor. The engines operated at full power, generating over 180,000 pounds of force, equivalent to a Boeing 777 at full power, and consuming 700 lbs per second of fuel and liquid oxygen during the run. "This is a major hardware milestone for our company," said Elon Musk, CEO and CTO of SpaceX. "It marks the first time that we have simultaneously fired two engines on the same stage. No significant problems were encountered transitioning from single-engine testing in November, which suggests that we will be able to ramp up rapidly to a full complement of nine Merlin engines. Our propulsion and test team has done a remarkable job." This two-engine test was the largest to date on the BFTS (Big Falcon Test Stand). The next run, scheduled for February, will use three engines operating for a full first stage mission duty cycle of three minutes. When operating in flight, the first stage will accelerate the 180-ft-long Falcon 9 vehicle to more than ten times the speed of sound in that short period of time. Following stage separation, the Falcon 9 second stage continues accelerating the payload to a final change in velocity that may be in excess of Mach 30 for missions beyond low Earth orbit. Full press release: http://www.spaceref.com/news/viewpr.html?pid=24627.

These excerpts have been taken from press releases that have been approved for public release.

People in Propulsion

George Sieg

George Sieg Retires from China Lake

by Stuart Blashill, NAWCWD

George Sieg, one of the top engineers in the country with an understanding of propellant and explosives processing and rocket motor and warhead production, recently retired from the Naval Air Warfare Center Weapons Division (NAWCWD), China Lake, California, after a 41-year career. The most telling feature of George may be conveyed by what he cited in a resume back in 2002 as his first entry under Work History Highlights – "36 years of fun". He still must be having fun, as he's planning to come back to work as a contractor in the near future.

George graduated from Washington State University in February 1966 with a Bachelor of Science degree in Chemical Engineering and immediately went to work for the Union Oil Company in Rodeo, California. He began his career at China Lake in August 1967 looking at CTPB propellants to improve their aging characteristics with a study on the effects of various antioxidants and to improve their low temperature. He soon moved on to be the project engineer for the high performance propellant program, which concentrated on high density zirconium propellant systems. During this same era, he was the project engineer for the installation and use of the SWECO vibro-energy mill where he developed China Lake's capability for producing ultra-fine ammonium perchlorate, including a drying system which enabled the recovery of 80-90% of the Freon used in the grinding process. George also had early involvement in the development of HTPB binder propellants, where he was in charge of development and scale-up work on high burning rate propellants.

During his long career, George spent 28 years in propellant formulation and processing and rocket motor processing, 2 years on Tomahawk warhead production, 7 years in rocket motor production and design, 9 years in program management and 3 years as the supervisor of 40 ordnancemen, technicians, chemists and engineers. Some of the highlights of his career, besides having fun, were building a spherical motor for the first controllable ejection seat to be tested in an upside-down cockpit, being the lead process engineer for the design and qualification of the Vertical Launch ASROC motor, helping to develop a new fuze for the Tomahawk warhead and running a live-fire test at the China Lake supersonic test track (SNORT) demonstrating the fuze capability. This latter effort was done in 90 days to support Operation Desert Storm.

George also served some time in the Solid Propulsion Branch working on Sidewinder and HARM production and the AMRAAM+5 program. He also initiated the technology work on high pressure, high burn-rate propellants in an end-burning configuration in a composite motor case and was instrumental in changing the emphasis in service life studies from *Does the motor work?* to *Has the motor changed?*

Most recently, George has been serving as the senior engineer in the processing branch. He has assisted with the training of many new employees fresh out of school and helped them find out just how much fun can be had working in propellant processing.

Propellant and Explosive Ingredients Database

CORRECTION

In the November 2007 issue, the article on the improved Propellant and Explosive Ingredients Database (PEID) stated that implementation and enhancement of the online database were funded jointly by the Naval Surface Warfare Center at Indian Head, MD and the Air Force Research Laboratory at Edward AFB, CA. In fact, the Army Research, Development and Engineering Command at Redstone Arsenal, Alabama, also contributed funds to implement and enhance the database. CPIAC regrets this inadvertent omission.

2008 Calendar of JANNAF Meetings and Events

55th JANNAF Propulsion Meeting/42nd Combustion Subcommittee/30th Airbreathing Propulsion Subcommittee/30th Exhaust Plume Technology Subcommittee/ 24th Propulsion Systems Hazards Subcommittee/12th SPIRITS Users Group

Date: May 12-16, 2008
Abstract Deadline: Still accepting abstracts.
Paper/Presentation/ Paper Clearance Deadline: April 7, 2008
Boston Marriott Newton, Newton, MA and Hanscom AFB
Ph. 617-969-1000/800-228-9290 (Refer to JANNAF Meeting)
Hotel Reservation Deadline: April 21, 2008
Reg. Forms due at CPIAC by: April 28, 2008

JANNAF 6th Modeling and Simulation Subcommittee (MSS)/4th Liquid Propulsion Subcommittee (LPS)/3rd Spacecraft Propulsion Subcommittee (SPS) Joint Meeting

Date: December 8-12, 2008
Abstract Deadline: June 16, 2008
Paper/Presentation/ Paper Clearance Deadline: November 3, 2008
Hilton Walt Disney World; Orlando, FL
Ph. 407-827-4000/800-782-4414 (Refer to JANNAF Meeting)
Hotel Reservation Deadline: November 17, 2008
Reg. Forms due at CPIAC by: November 24, 2008

For additional information on the above JANNAF meetings, contact CPIAC Meeting Planners Pat Szybist or Krystle Jones at 410-992-7302, ext. 215, or 410-992-7301, ext. 201, respectively, or by e-mail to pats@jhu.edu or kjones@jhu.edu.

Visit the JANNAF Web site at www.jannaf.org for meeting updates.