

Overview of Rocket Propulsion Testing at NASA Stennis Space Center

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ABSTRACT

The recent nationwide thrust towards development of low-cost space transportation has precipitated a sharp increase in demand for subscale and full-scale propulsion test services. This paper highlights the unique capabilities of Stennis Space Center (SSC) to meet these demands, and summarizes several major propulsion test activities and other related milestone achievements during the 1999 calendar year. The current and projected list of SSC test projects heralds an even more vigorous, interesting, and challenging future in propulsion test.

BACKGROUND

On October 25, 1961, an area of 13,800 acres in Hancock County of Southern Mississippi was commissioned to be the propulsion test site for full-scale rocket engine and vehicle stage testing of the Saturn vehicles. This area, along with the surrounding 125,000 acre buffer zone, was chosen by a NASA committee of experts after evaluation of several potential sites and subsequently named the Mississippi Test Facility (MTF).¹ Several large test stands were built at MTF between 1961 and 1969 and utilized to do the majority of the testing for the Apollo and Space Shuttle programs.

More recently, on August 3, 1988, the south Mississippi facility was dedicated the John C. Stennis Space Center (SSC) in honor of Senator Stennis by an executive order from President Reagan. As reported in Ref. 1, the very same evening "the Space Shuttle test team static-fired the SSME 2206 on the newly modified B-1 test position for 2,017 seconds, a record run for an SSME." Shortly thereafter, as America's Center of Excellence for Propulsion Testing, SSC began construction of a major new facility known as the Component Test Facility (CTF) in order to support the development of the joint Air Force-NASA Advanced Launch System.

On May 29, 1996, Center Director Roy Estess received an official letter from Mr. Trafton, the Associate Administrator for the Office of Space Flight, designating Stennis as NASA's Lead Center for Rocket Propulsion Testing. This brought to SSC complete oversight responsibility of all NASA's rocket propulsion test assets including those at Alabama's NASA Marshall Space Flight Center, Ohio's NASA Lewis Research Center (now Glenn Research Center) and New Mexico's NASA White Sands Test Facility. In addition, this meant also coordinating with the DOD and industry as appropriate in order to make best use of available national testing assets.

Stennis Space Center today is engaged in three lines of business: Propulsion Testing, Commercial Remote Sensing, and Earth Systems Science. Also, NASA SSC serves as a federal manager and host to multiple resident government agencies on-site. Approximately 4000

persons are employed at the SSC site working for 30 federal or state agencies (e.g. Navy Oceanography Office, Naval Research Lab, Coast Guard, NOAA, USGS), as well as multiple contractor organizations (e.g. Lockheed-Martin, Boeing, Pratt and Whitney, CSC). The direct economic impact in 1998 to the surrounding area (southern Mississippi and North east New Orleans) was estimated to be \$143M from NASA alone, and \$366M from SSC as a whole.²

CURRENT PROPULSION TEST CAPABILITIES

During the last four decades, NASA SSC has evolved into a national asset for large-scale rocket testing largely due to continuing investments in site capabilities and infrastructure in order to meet propulsion test needs as they arose. The test facilities at SSC are often mentioned in terms of two test areas known as the A/B-complex and the E-complex; together they make up the many test positions that are now called A1, A2, B1, B2, E1, E2 and E3. The three E-stands actually have multiple test cells totaling six test positions. Some of the particulars of the test stands are summarized below, followed by descriptions of other important supporting capabilities.

A/B Test Complex

The largest test stands at SSC are the A1, A2 and B stands. As depicted in Figure 1 (top), the two "A" stands A1 and A2 are nearly identical single-position stands whereas the B stand consists of two test positions B1 and B2. Both are configured for vertical stage or engine firings and feature water-cooled "J"-deflectors to dilute and redirect rocket engine exhaust products. A state-of-the-art remote test control center (A-TCC) is shared by the A1 and A2 stands, and a similar B-TCC building is dedicated to the B test stand. Detailed information on the large test stands is available in Ref. 3 and 4. Recent activity on these stands includes the Aerospike engine, the SSME engine, and the Fastrac engine/stage (cf. Ref. 5).

E Test Complex

During the 1990s, several additional test capabilities were implemented at SSC to respond to growing needs for development testing. Currently, the E-complex test stands, E1, E2 and E3, provide engine-component testing capability at large, medium, and small scale, with very high-pressure blowdown capability for liquid and gaseous propellants (~8500 psi) propellant tank feed pressure. The largest component test facility, E1 stand, consists of 3 test cells where the assets are configured to focus on either pressure-fed thrust chambers (Cell 1), or turbopump testing (either Cell 2 or Cell 3). An example of a full-scale, pressure-fed, 650 Klbf thrust chamber test configuration in Cell 1 is illustrated in Figure 1 (middle). The E2 test stand currently provides pressure-fed propellant capability but is limited to thrust levels of approximately 75 Klbf steady-state. A current test project at E2 is an oxygen-rich LOX/RP preburner. Finally, the E3 facility features two test cells which are now engaged in testing of LOX-fed hybrid motors (Cell 1) and Hydrogen Peroxide propellant thrust chambers and engines (Cell 2).^{6,7} E1 and E2 have independent state-of-the-art remote control rooms, and implementation of a modern control room for E3 is in progress. Originally introduced in Ref. 4, the current features and capabilities of the E-complex are thoroughly documented in the SSC Test Facilities Capability Handbook (Ref. 3).

Data Acquisition and Control Systems (DACs)

It was reported in Ref. 4 that among the most highly-valued customer needs for propulsion testing is a reliable and high-performance test control and data acquisition capability. As

discussed extensively in Ref. 8 and Ref. 9, SSC has invested in implementing the state-of-the-art, Commercial Off The Shelf (COTS) hardware and software in order to meet this need. Computerized test control via Programmable Logic Controllers (PLC), utilized for instance in process control industries, have proven to be effective for aerospace propulsion testing on test stands A1, B2, and E-complex; they are now the norm rather than the exception. Additionally, high-channel count, and high-speed data acquisition/processing (e.g. 100,000 data samples/sec) using the appropriate instrumentation with RACAL recorders has been thoroughly verified and utilized at SSC.⁹ The value of such modern capability becomes evident when potentially catastrophic engine failures are prevented by pre-programmed safe-shutdown via automated control.

Critical Support Infrastructure

There exist numerous supporting infrastructure elements that enable large-scale propulsion testing. These include (1) specialized cryogenic operations equipment to handle/transfer LOX and LH2, (2) High-Pressure Gas Facility (~4000 psi) to provide pressurization gases site-wide (N2, O2, H2, He) in large quantity, (3) the High-Pressure Industrial Water Plant to provide large amounts of cooling water for plume deflectors, and (4) instrument calibration and checkout laboratory, to name a few (cf. Ref. 3 and 4). It is also important to note that the use of high-energy propellants and other hazardous chemicals requires special expertise in piping component design/materials (e.g. high-flow valves and flowmeters) as well as cleaning and cleanliness verification. SSC personnel participate heavily in local and national forums (such as the ASME G-4 Oxygen Safety Committee) in order to obtain or develop the technology and procedures for proper usage of materials with combustible propellants.^{10,11}

PROPULSION TEST ACTIVITY 1999

The latter part of this decade has brought an exponential increase in launch vehicle development activity and future technology development activity. Thus, the need for subscale and full-scale propulsion test services has also increased dramatically. This section summarizes some noteworthy examples of Stennis Space Center contributions to the national effort towards low-cost space transportation.

Full-Scale Propulsion Testing

A very active year in propulsion testing is summarized in Figure 2. A series of development engine tests were completed on the 60 Klbf Fastrac engine at the B2 test position between January and November 1999. This engine will power the reusable X-34 technology demonstrator vehicle. Testing of the engine alone, as well as the engine mounted to the stage (Propulsion Test Article, Figure 2 - top) was accomplished for both short and long duration, and included tests with densified propellants. The 266 Klbf Aerospike engine for the X-33 flight vehicle has undergone a series of "powerpack" integrated turbomachinery tests, and a series of full-engine testing has begun on the A1 stand. Additionally, the AR2-3 engine⁷ developed first in the 1960s is currently undergoing a series of monopropellant and bipropellant testing at E3 stand with Hydrogen Peroxide, a "clean" propellant that is touted for a variety of applications. The AR2-3 engine is slated for the X-37 flight vehicle.

Two additional test activities include the continuing SSME engine flight certification tests at A2 stand, and the newly developed RS-68 testing at B1 test position (cf. Figure 3). These particular projects are now operated by the engine developer (Boeing-Rocketdyne), however, they still rely substantially on various NASA-managed infrastructure elements.

Propulsion Development Testing

Both small-scale and large-scale development testing is underway at the E-complex. The most notable event was the E1 Cell 1 test firing of the 250K Hybrid rocket motor (Figure 2 bottom) developed by the hybrid development "consortium" known as the Hybrid Propulsion Demonstration Program. Two tests of up to approximately 40 secs duration demonstrated high-pressure blowdown testing of a full-scale hybrid thrust chamber. Several smaller scale hybrid rocket motors were also tested this year at the E3 test stand.

Notably, several major milestones were achieved at NASA SSC in 1999.

- Jan.-Apr. First test series with Hydrogen Peroxide propellant (mono-prop and bi-prop)
- Feb. 14 ISO 9000 Certification at SSC
- January First fully-automated DACS system usage on B2 stand (Fastrac engine)
- Mar. 2 First mainstage test (5 sec duration) on the Fastrac engine
- May-Jun Activation/first use of the LOX high-pressure blowdown capability of E1 facility
- July 9 First successful 250 KlbF hybrid motor firing; and first major test at E1 Cell 1
- Aug. 2 First "stage" test (3 sec duration) on reactivated B2 stand (Fastrac PTA)
- General- Significant use of CAD modeling/analysis to manage facility-to-engine interfaces
- General- First extensive use of the new state-of-the-art RACAL high-speed data system
- General- First use of fiber-optic communications for high data-throughput from engine-stand to test control center (B2 testing on Fastrac)
- General- First use of internet technology for immediate data transmittal to test customers

LEAD CENTER ROLE FOR ROCKET PROPULSION TEST

Coordination of such an extensive suite of test projects and test stands is a major management task by itself. As mentioned earlier, the agency authorized SSC to be the Lead Center for Rocket Propulsion Test on 29 May 1996. This kicked off a number of efforts including databasing, scheduling, budgeting and overall advocacy and prioritization of SSC and other agency testing assets, in coordination with the DOD, within the organizational and operational framework of the National Rocket Propulsion Test Alliance (NRPTA).¹²

Once a test project is assigned to a test center, and then within the center to a specific test stand, the process of implementing the test project begins. At SSC, the process is initiated by the assignment of a project manager and project team. The group will first work towards documenting a firm set of test requirements, costs, timelines, and then proceed to perform the necessary designs, analyses, safety reviews, procurements, construction mods, activation of new systems, software development, documentation, and test readiness review in order to establish the confidence to begin testing. While project budgets and scopes can vary greatly, some level of all the above activities must be performed. The composite test stand schedule for SSC illustrates that each test position is currently either in testing or occupied by construction work for an upcoming project.

TEST FACILITY	CALENDAR YEARS																			
	99				00				01				02				03			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
A1	[Solid black bar]																			
A2	[Solid black bar]																			
B1	[Solid black bar]																			
B2	[Solid black bar]																			
E1	[Solid black bar with small white rectangles indicating activity]																			
E2	[Solid black bar]																			
E3	[Solid black bar]																			
H1	Mothballed																			

FUTURE TESTING AT NASA STENNIS

A significant amount of development testing is anticipated over the next two years. The composite schedule indicates continued testing of the SSME and RS-68 engines with a new test project at B2 to test the RS-68 engine on its vehicle stage (the EELV's Common Booster Core or CBC). The three test cells of the E1 stand will be utilized for testing components (chambers, preburners, and turbopumps) associated with the Integrated Powerhead Demonstrator (IPD) and the TRW Ultra-Low-Cost-Engine (ULCE). E2 will continue its testing of the oxygen-rich preburner (for RS-76 engine). Finally, the E3 test assignments will include further Hydrogen Peroxide/JP test articles with new activity arriving from the recent NRA 8-21(cycle 2) awards. With the renewed focus on airbreathing engine development at NASA and industry, a potential new testing assignment for SSC is likely to follow. Planning is underway for longer-term facility needs for development and acceptance testing of the coming generation of rocket-based combined-cycle propulsion as this advanced technology matures. Clearly, the upcoming needs of the rocket development industry are quite diverse and will require prudent planning and resources to be effectively served.

ACKNOWLEDGMENTS

The authors would like to recognize the entire NASA and contractor team that makes safe and cost-effective propulsion testing a reality. This includes personnel from several NASA organizations (Propulsion Test Directorate, Center Operations Directorate, Safety and Mission Assurance, Human Resources) as well as our direct support organizations (Lockheed-Martin Stennis Operations, Boeing-Rocketdyne, Mississippi Space Services), and a multitude of off-site partners providing on-demand services.

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11. Yentzen, M., Powell, B., and Jordan, S., "Relative Performance of Elastomeric Materials in the Seal Configuration Test Apparatus," in *Flammability and Sensitivity of Materials in Oxygen*, pp. 411-418.
12. Co-chairs M. Dawson and D. Bradley, "Briefing: Annual Report of National Rocket Propulsion Test Alliance (NRPTA)," dated May 17, 1999.

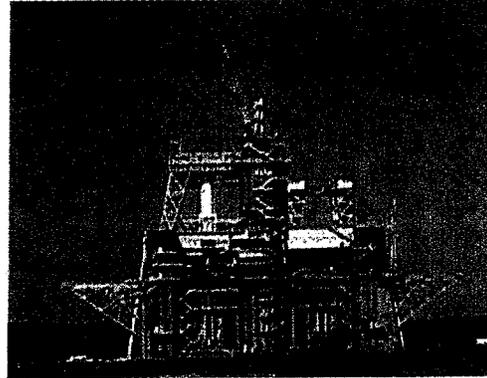
A1, A2 Test Stands

160 ft. high
1.5 Mlbf Thrust (single position)
LOX/LH2 Propellant Supply
Diffuser (A2)

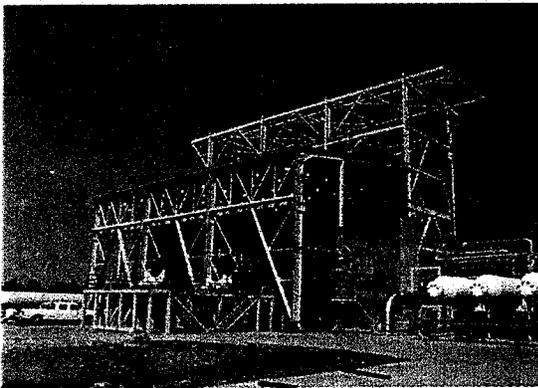


B Test Stand

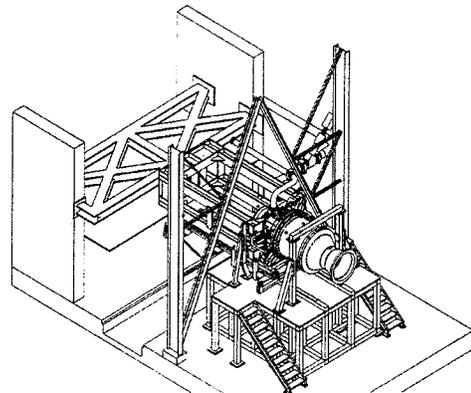
260 ft. high
10 Mlbf Thrust (Dual-position B1, B2)
LOX/LH2 Propellant Supply



Test Stand E1 (3 test cells)

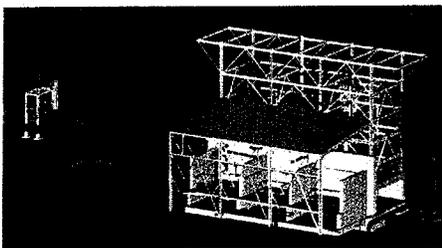


Pro/E Model: E1 Cell 1 with TRW 650K TCA

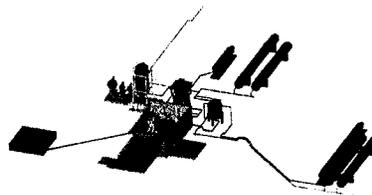


Pro/Engineer CAD Models of E-Complex Test Stands

E1 Stand
(Cell 1, 2, 3)
750 Klbf Thrust
90 ft. high



E2 Stand
(Cell 1)
100 Klbf Thrust



E3 Stand
(Cell 1, 2)
60Klbf/10Klbf Thrust
30 ft. high

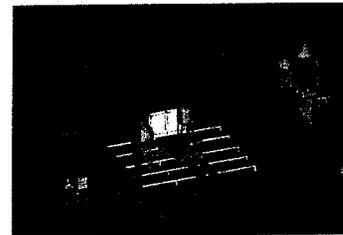
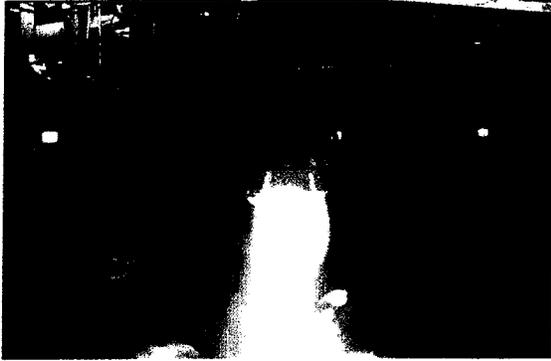
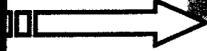


Figure 1. NASA SSC Propulsion Test Stands -- A/B-Complex and E-Complex.

NASA PTA/Fastrac 60 Klbf Engine (LOX/RP1)



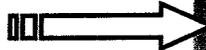
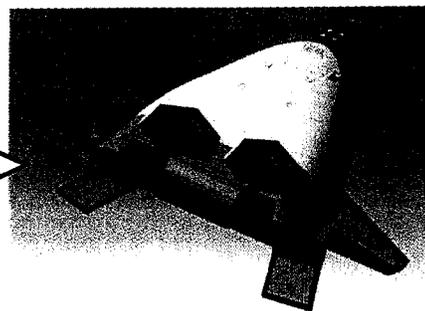
Orbital Sciences X-34 Vehicle



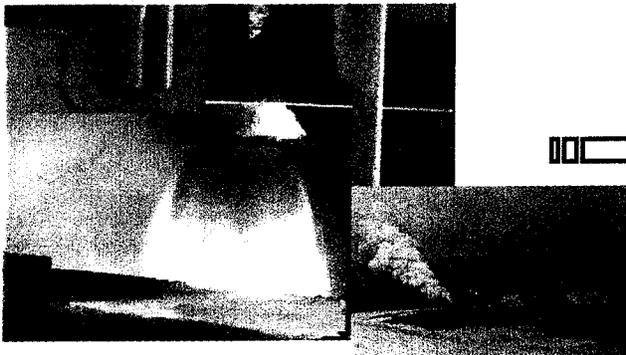
Boeing Aerospike 266 Klbf Engine (LOX/LH2)



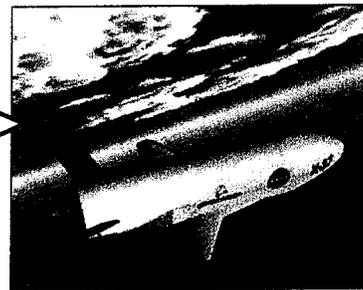
Lockheed-Martin X-33 Vehicle



Boeing AR2-3 6,000 lbf Engine (H2-Peroxide/JP)

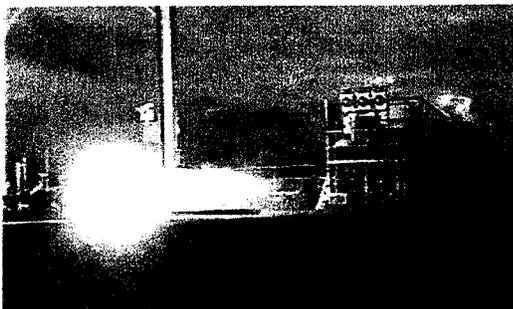


Boeing X-37 Vehicle



Development Test Projects

Lockheed-Martin 10 Klbf Hybrid Motor (E3)



Hybrid Consortium 250 Klbf Motor (E1)

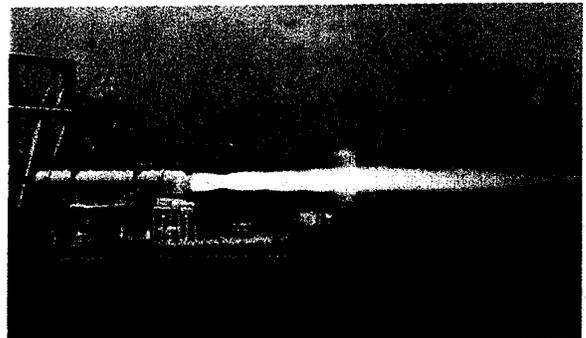
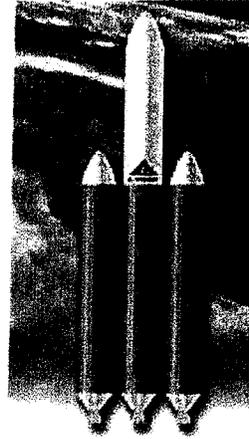


Figure 2. NASA Stennis Space Center 1999 Propulsion Test Highlights

Boeing RS-68 745 Klb Engine (LOX/LH2)



Boeing Delta IV EELV



Boeing SSME 500 Klb Engine (LOX/LH2)



Space Shuttle Orbiter

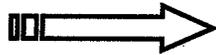


Figure 3. Further NASA Stennis Space Center 1999 Propulsion Test Highlights

**Propulsion
Engineering
Research Center
11th Annual
Symposium
on
Propulsion**

**November 18-19, 1999
The Atherton Hotel
(Adjacent to Penn State University)
State College, Pennsylvania 16801**

PENNSTATE



OBJECTIVE AND SCOPE

Each year since 1989, the Propulsion Engineering Research Center (PERC) at Penn State University has hosted the Annual Symposium on Propulsion as a forum for bringing together a select group of engineers and scientists to present research results, status of on-going programs and future trends in propulsion. Based on the success of the past ten Annual Symposiums, PERC is pleased to announce that the PERC 11th Annual Symposium on Propulsion will be held November 18-19, 1999 at The Atherton Hotel, State College, Pennsylvania, adjacent to Penn State University.

This year, the Symposium is comprised of eight sessions covering various aspects of propulsion. Four distinguished individuals from NASA, AFOSR, ONR and DLR have accepted invitations to present their agencies' perspective on future propulsion in the keynote session, *Propulsion Research and Development Beyond Y2K*. The remaining seven sessions cover a broad range of scientific and engineering issues related to Rocket Based Combined Cycle Propulsion, Pulse Detonation Engine Propulsion, Rocket Propulsion, Advanced Propulsion, Combustion Analysis, Combustion Measurements and Combustion Dynamics. Each paper will be presented by an invited speaker.

TOUR OF PERC FACILITIES

An optional tour of the experimental facilities at Penn State's Propulsion Engineering Research Center is provided as part of the Symposium. The tour scheduled for the afternoon of November 19 will include visits to the Cryogenic Combustion Laboratory (CCL) where laboratory scale RBCC and rocket propulsion research is conducted, the High Pressure Combustion Laboratory (HPCL) where solid and hybrid propulsion research is conducted, and various other experimental facilities within the Center.

PROGRAM

Thursday, November 18, 1999

- 7:30-8:00 AM REGISTRATION AND CONTINENTAL BREAKFAST (LOBBY)
- 8:00-8:15 AM Welcome and Opening Remarks (Regency A)
Robert Santoro, PERC Director, PSU
Robert McGrath, Assoc. Vice-President for Research, PSU
- 8:15-10:15 AM Session I (Regency A). Propulsion Research and Development Beyond Y2K
Chair: *Robert Santoro, PSU*
- The following distinguished speakers will present their agencies' views on future propulsion goals and directions
- 8:15-8:45 AM Dr. John Rogacki, *NASA MSFC*
- 8:45-9:15 AM Dr. Mitat Birkan, *AFOSR*
- 9:15-9:45 AM Dr. Gabriel Roy, *ONR* (Dr. Dave Netzer from *NPS* will give Dr. Roy's presentation)
- 9:45-10:15 AM Dr. Oskar Haidn, *DLR, Germany*
- 10:15-10:30 AM BREAK (LOBBY)
- 10:30-12:10 PM Session II (Regency A). Combustion Measurements
Chair: *Jean-Christophe Broda, PSU*
- 10:30-10:55 AM Study of Equivalence Ratio Fluctuations During Unstable Lean Premixed Combustion.
⇒ S. Berksoy, R. Bandaru, J. G. Lee and D. A. Santavicca, *PSU*
- 10:55-11:20 AM Development of a Chemiluminescence-Based Equivalence Ratio Probe for Pattern Factor Control in Lean Premixed Combustors.
⇒ R. Bandaru, S. A. Miller, K. Kim, J. G. Lee, R. L. Steinberger and D. A. Santavicca, *PSU*
- 11:20-11:45 AM Effects of Tube Diameter on OXSOL Regression Rate.
⇒ J. W. Mordosky, G. Harting, B. Zhang, T. T. Cook, and K. K. Kuo, *PSU*.
- 11:45-12:10 PM An Experimental Estimation of Mean Reaction Rate in a Lean-Premixed Gas Turbine Combustor.
⇒ S.-Y. Lee, S. Seo, J.-C. Broda, S. Pal and R. J. Santoro, *PSU*
- 10:30-12:10 PM Session III (Vanderbilt). Rocket Propulsion
Chair: *George Cox Jr., Pratt & Whitney (retired)*
- 10:30-10:55 AM Vehicle Engineering Development Activities at the Marshall Space Flight Center.
⇒ M. F. Fisher and R. H. Champion, *NASA MSFC*
- 10:55-11:20 AM Overview of Rocket Propulsion Testing at Stennis Space Center.
⇒ S. Rahman et al., *NASA Stennis*
- 11:20-11:45 AM Transient Operation of an Integrated Rocket Ramjet Engine: From Booster to Sustainer.
⇒ H.-G. Sung, H. Y. Hsieh, and V. Yang, *PSU*

- 11:45-12:10 PM Role of Coatings in Advanced Propulsion Systems.
⇒ J. Singh, *PSU Applied Research Laboratory*
- 12:10-1:50 PM Luncheon at the Atherton Hotel
Invited Keynote Speaker:
Robert Sackheim,
Assistant Director for Space Propulsion Systems,
NASA MSFC
- 1:50-3:05 PM Session III (Vanderbilt). Rocket Propulsion (*continued*)
Chair: **George Cox Jr., Pratt & Whitney (retired)**
- 1:50-2:15 PM Hot-Fire Studies of LOX Primary Atomization from Rocket Engine Coaxial Injectors.
⇒ Boniface, Y., Reeb, A., Woodward, R. and Santoro, R. J., *PSU*
- 2:15-2:40 PM Combustion Characteristics of HAN-based Liquid Propellants.
⇒ Y. P. Chang, J. E. Boyer, and K. K. Kuo, *PSU*
- 2:40-3:05 PM Liquid Methane/Oxygen Injector Study for Mars Ascent Engines.
⇒ H. P. Trinh, *NASA MSFC*
- 1:50-3:05 PM Session IV (Regency A). Rocket Based Combined Cycle Propulsion
Chair: **Uwe Hueter, NASA MSFC**
- 1:50-2:15 PM Retaining the Experience -- Prospects for the NASA Combined-Cycle Propulsion Database (CCPD) Project.
⇒ E. H. Hyde, *NASA MSFC*, and D.W. Escher and J.E. Roddy, SAIC-Huntsville
- 2:15-2:40 PM Recycling a Cold War Surveillance Drone to Flight Test NASA's Rocket Based Combined Cycle Engine.
⇒ N. Smith and T. Brown, *NASA MSFC*
- 2:40-3:05 PM RBCC Project Summary: Experimental Investigation of Ejector Mode.
⇒ M. Lehman, S. Pal and R. J. Santoro, *PSU*
- 3:05-3:20 PM BREAK (LOBBY)
- 3:20-5:00 PM (+) Session IV (Regency A). Rocket Based Combined Cycle Propulsion (*continued*)
Chair: **Uwe Hueter, NASA MSFC**
- 3:20-3:45 PM FDNS CFD Code Benchmark for RBCC Ejector Mode Operation.
⇒ J. B. Holt, *NASA MSFC*
- 3:45-4:10 PM Some RBCC ER/SJ Design Approach Alternatives and Potential Payload Performance Effects.
⇒ R. Foster, *Teknos*
- 4:10-4:35 PM Microwave Plasma Enhanced Supersonic Hydrocarbon Combustion.
⇒ S. G. Chianese and M. M. Micci, *PSU*
- 4:35-5:00 PM **TBD**
- Note: Additional Papers will be added to this session.**

- 3:20-5:25 PM** **Session V (Vanderbilt). Combustion Dynamics**
Chair: Jeff Lovett, Pratt & Whitney
- 3:20-3:45 PM** Effects of Swirl Injector Design and Other Important Parameters on Gas Turbine Combustion Instabilities.
⇒ C. Brossard, S. Y. Lee, C. Mordaunt, J. C. Broda and R. J. Santoro, *PSU*
- 3:45-4:10 PM** Combustion Dynamic Analysis: From Model Anchoring to Validation.
⇒ G. Hsiao and H. Mongia, *GE Aircraft Engines*
- 4:10-4:35 PM** Modeling of Combustion Dynamics in Lean-Premixed Gas Turbine Engines.
⇒ H. G. Sung, S. Y. Hsieh, D. N. You and V. Yang, *PSU*
- 4:35-5:00 PM** On Testing a Model for Heat Release Fluctuation During Unstable Combustion.
⇒ K. K. Venkataraman, J. G. Lee and D. A. Santavicca, *PSU*
- 5:00-5:25 PM** Active Control of Combustion Instability in a Model Gas Turbine Combustor.
⇒ K. Kim, J. G. Lee, and D. A. Santavicca, *PSU*

Friday, November 19, 1999

- 7:30-8:00 AM** **CONTINENTAL BREAKFAST (LOBBY)**
- 8:00-10:05 AM** **Session VI (Regency A). Pulse Detonation Propulsion**
Chair: Gabriel Roy, Office of Naval Research
- 8:00-8:25 AM** Some Results on the Constant Volume Limit of Pulsed Propulsion.
⇒ D. Talley, *AFRL, Edwards AFB*
- 8:25-8:50 AM** Establishing the Case for Pulse Detonation Wave Engines.
⇒ E. D. Lynch and R. B. Edelman, *Boeing, Rocketdyne*
- 8:50-9:15 AM** Experimental Results on Air Breathing Pulse Detonation Studies.
⇒ J. C. Broda, C. Conrad, S. Pal, R. Woodward and R. Santoro, *PSU*
- 9:15-9:40 AM** AFRL's In-House Research Pulse Detonation Engine.
⇒ F. Schauer, J. Stutrud, and R. Bradley, *AFRL, Wright-Patterson AFB*
- 9:40-10:05 AM** Recent ASI Progress in Pulse Detonation Rocket Engine (PDRE) Hardware Development.
⇒ D.C. Mueller, T. E. Bratkovich, K. Lupkes, S. Henderson, J. T. Williams, J. D. Williams and T. R. A. Bussing, *Adroit Systems Inc.*
- 8:00-10:05 AM** **Session VII (Vanderbilt). Combustion Analysis**
Chair: Kevin Tucker, NASA MSFC
- 8:00-8:25 AM** Numerical Simulation of Turbulent Combustion of Homogeneous Solid Propellant in a Rocket Motor.
⇒ S. V. Apte and V. Yang, *PSU*
- 8:25-8:50 AM** Progress on LES of Gas Turbine Spray Combustion Processes.
⇒ J. C. Oefelein, *Stanford University*

- 8:50-9:15 AM Optimization of a GO_2/GH_2 Swirl Coaxial Injector Element.
 ⇒ P. K. Tucker, *NASA MSFC*, and W. S. and R. Vaidyanathan, *University of Florida*
- 9:15-9:40 AM New Models for Droplet Vaporisation and Break-Up for High Pressure Spray Combustion Applications.
 ⇒ I. Gokalp, C. Chauveau, B. Vieille and B. Gelfand, *CNRS, France*.
- 9:40-10:05 AM *TBD*
- 10:05-10:20 PM **BREAK (LOBBY)**
- 10:20-12:00 AM **Session VI (Regency A). Pulse Detonation Propulsion (*continued*)**
Chair: Gabriel Roy, Office of Naval Research
- 10:20-10:45 AM Pulse Detonation Engine Performance Modeling.
 ⇒ D. Tew, *United Technologies Research Center*
- 10:45-11:10 AM Supersonic Inlet Aerodynamics of Air-Breathing Pulse Detonation Engines.
 ⇒ S. Y. Hsieh and V. Yang, *PSU*
- 11:10-11:35 AM *TBD*
- 11:35-12:00 AM *TBD*
- 10:20-12:25 AM **Session VIII (Vanderbilt). Advanced Propulsion**
Chair: George Schmidt, NASA MSFC
- 10:20-10:45 AM Low-Power Microwave Arcjet Spectroscopic Diagnostics and Performance Evaluation.
 ⇒ F. J. Souliez and M. M. Micci, *PSU*
- 10:45-11:10 AM Research on Ion Plasma Thrusters for Satellites in the French Facility PIVOINE.
 ⇒ S. Béchu+, P. Lasgorceix+, C. Pérot+, N. Gascon+, M. Dudeck+, D. Pagnon*, F. Darnon#, S. Roche*, L. Magne*, A. Bouchoule# and M. Touzeau*. +*CNRS, Orléans*, **CNRS and Université de Paris Sud, Orsay*, #*CNRS and Univesirté d'Orléans, Orléans*
- 11:10-11:35 AM Nuclear Pulse Propulsion.
 ⇒ G. Schmidt, *NASA MSFC*
- 11:35-12:00 AM Solid Hydrogen Testing and Analyses for Atomic Rocket Propulsion.
 ⇒ B. Palaszewski, *NASA GRC*
- 12:00-12:25 AM AIMStar: Antimatter Initiated Microfusion for Pre-cursor Interstellar Missions.
 ⇒ K. Kramer, R. A. Lewis, K. Meyer, G. A. Smith, and S. D. Howe, *PSU*
- 1:00-4:00 PM **TOUR OF PERC FACILITIES**

SYMPOSIUM VENUE

The Propulsion Engineering Research Center 11th Annual Symposium on Propulsion will be hosted at The Atherton Hotel located adjacent to Penn State University in State College, Pennsylvania.

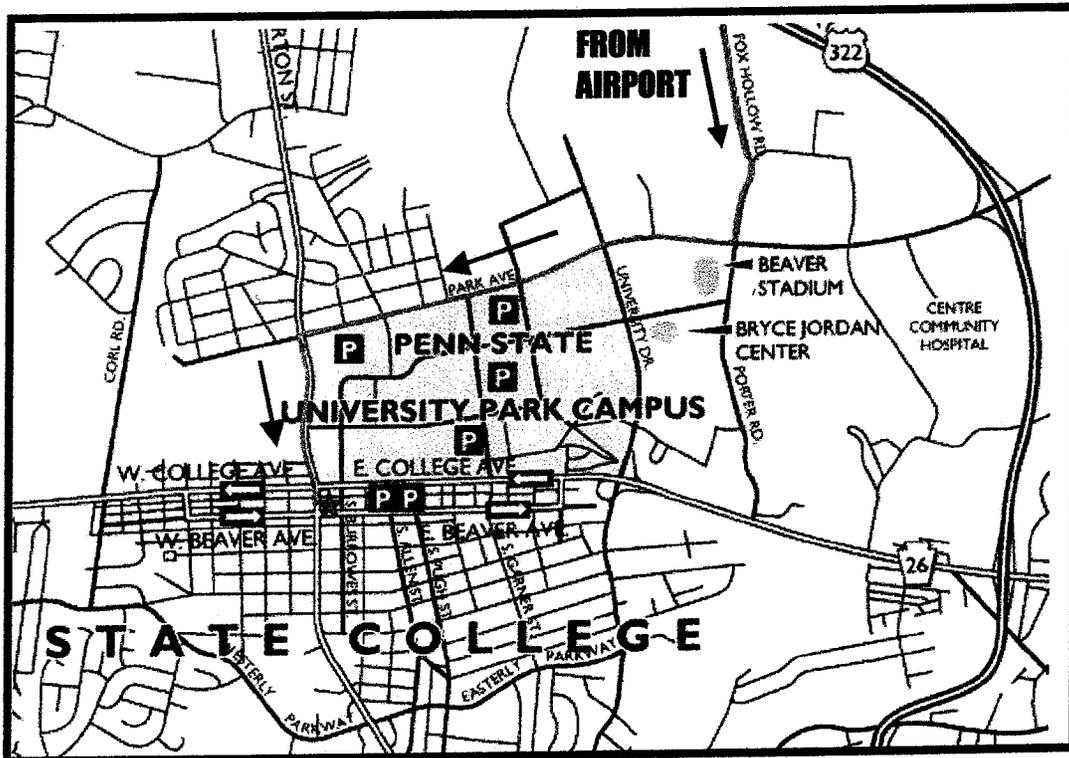
Address

125 South Atherton Street
State College, PA 16801

Location

Downtown, one block from Penn State campus on U.S. Route 322 (Atherton Street) between PA 26 (College and Beaver Avenues) North and South.

Map



Directions from Airport

Exit airport. Turn left onto Fox Hollow Road. Follow road for about 3 miles to a traffic light at Park Avenue. Turn right onto Park Avenue. At 5th traffic light, turn left onto Atherton St. (Business Rt. 322 East). At the fourth traffic light, after passing in front of the hotel on your left, turn left onto Beaver Avenue (Rt. 26 North). Stay in left lane. Make first left onto alley. At stop sign, turn left. Alley dead ends with hotel garage on the left.

ACCOMMODATIONS

A block of rooms has been reserved for November 17 and 18, 1999 at the Symposium venue, The Atherton Hotel, 125 South Atherton Street, State College, PA 16801, (Toll-free No. 800-832-0132) until October 28, 1999 at a special Symposium rate of \$53.00 plus tax. To obtain the special rate, please reference PERC Symposium when reserving. Attendees are encouraged to utilize this special rate. Please note that the hotel requires a 3-day notice for any cancellations.

Alternate accommodations in the State College area are listed in the following website: <http://www.psu.edu/lslr/hotels.htm>

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REGISTRATION

Please use the enclosed form, or e-mail the requested information to register for the Symposium and related activities. A response via mail, e-mail, or fax by November 1, 1999 is requested. Please note that the Registration Fee of \$70.00 is payable by check/cash (no credit cards, please). The fee covers all Symposium activities, including refreshments during the Thursday and Friday sessions, lunch at the The Atherton Hotel on Thursday, the Tour of PERC facilities on Friday afternoon, and a CD-ROM of the Symposium Proceedings.

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