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AN OVERVIEW OF THE PENN STATE PROPULSION ENGINEERING RESEARCH CENTER

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I. Research Objectives and Long Term Perspective of the Center

Penn State's Propulsion Engineering Research Center was established in August, 1988 under a grant from NASA's University Space Engineering Research Centers (USERC) Program. The Center includes participation from the Colleges of Engineering and Science at Penn State, and a cooperative program with Lincoln University. The Center's primary focus is to conduct research and educate students in the broad areas of space propulsion, but it also includes auxiliary efforts in gas turbine propulsion, internal combustion engines, and some topics in marine propulsion. There are currently fourteen faculty participating in the Center. In addition, some twenty-seven graduate students and sixteen undergraduate students are supported by the Center. The Center's research program is focussed around five concentrations: Combustion, Fluid Mechanics and Heat Transfer, Materials Compatibility, Turbomachinery, and Advanced Propulsion Concepts. Downstream plans include broadening the effort in turbomachinery and adding efforts on electric and nuclear propulsion.

The objectives of the Propulsion Center are to provide a focussed research effort in space propulsion that will attract students to space engineering opportunities and will provide a continuing supply of graduates at all degree levels with interest and expertise in space propulsion. A parallel objective is to enhance participation in engineering by women and under-represented minorities. As space exploration and development mature, space activities will have a larger and larger impact on world economics. The United States needs to ensure an adequate supply of engineers and scientists with expertise in these areas if we are to compete in this emerging world market. The Center's goal is to provide graduates for this expanding field, as well as to provide research advances that will lead to improved technologies.

The organizational structure of the center includes a Director, an external Policy Advisory Board, and an internal Faculty Advisory Board. The Director has responsibility for day-to-day operation of the Center and for ensuring that it works in an integrated fashion toward a common goal. The external Policy Advisory Board assists him in matters of policy and research emphasis, while the internal Faculty Review Board assists in decision-making. The Policy Advisory Board is composed of leaders from government, industry, and academia and is charged with guiding the long range development of the Center. The Policy Board has one formal and one informal meeting each year to evaluate Center progress, and to advise as to appropriate technical direction. The Faculty Review Board reviews internal proposals for research projects, including in their deliberations evaluations from members of the Policy Advisory Board. The Faculty Review Board is composed of senior faculty plus the Senior Vice-President for Research and Graduate Studies.

The responsibilities for directing individual research projects are delegated to individual faculty in a mix of three categories of research programs: Core Research Projects, Matching Funds Projects and Exploratory Projects. The first two of these provide for multi-year, research programs. Core Projects are funded by the Center; Matching Projects receive shared funds from the Center and outside agencies. Exploratory projects are small, short-term efforts to establish feasibility of new ideas. The individual PI's work in close fashion with each other and the Director to provide the cross-fertilization that ensures that the whole of the Center's output is more than the sum of its parts.

In our first two years of operation, the Center has, indeed, had a major impact on graduate student enrollment and has enabled us to start a small, but highly successful, minority program. Graduate student involvement in the Center is through two paths. We offer NASA Traineeships which are funded through the Center itself, and Research Assistantships which are funded through the individual projects that comprise the Center. Of the 31 graduate students currently supported by the Center, 28 are U. S. citizens. Undergraduate involvement is fostered by a summer research program that is focused on minority students from both Lincoln University and Penn State University. This program included three minority students in our first year, and is supporting five students this summer. We also have Penn State undergraduates involved at the Center during the school year. During the recently completed academic year, we had two graduate and two undergraduate minority students working in the Center.

II. Current Status and Operational Philosophy

At the outset of the Center, we deliberately chose a start-up philosophy that focused attention toward a narrow facet of space propulsion. This allowed us to begin in an orderly fashion with a truly integrated "Center" concept while laying the foundation for later expansion into a more broadly based program. The choice for our initial focus was liquid rocket propulsion systems. This choice was made because of the dominance of liquid rocket engines in present and future space transportation programs of the United States, and because it was an area which had seen but little research emphasis in the previous ten or fifteen years.

To ensure a common thread of continuity in our initial research projects, we specialized even further in the first year by concentrating on combustion-related issues of liquid rockets including fluid dynamics, heat transfer and materials compatibility issues. Combustion and combustion devices represent an important subset of problems in liquid rocket propulsion, and, in addition, represent an area of strength at Penn State. At present this portion of the Center constitutes a fairly mature area; the projects are all well established and are providing significant research results. Downstream projections for the combustion area are to maintain it at about the present level augmenting in part the Center funds by auxiliary funds from other sources.

In the second year, we initiated an effort in the turbomachinery aspects of liquid propulsion engines as a first major step in broadening the focus of the Center. This second major thrust is just currently becoming established and is still growing in scope. Additional efforts in turbomachinery-related areas are planned for the immediate future.

In addition to this major emphasis on liquid rocket propulsion, we have also maintained modest efforts on advanced propulsion concepts. The Center is currently providing some support for a research effort on antimatter propulsion which is primarily supported by JPL and AFAL. There are also auxiliary efforts on microwave propulsion and advanced electric concepts. We expect additional growth in these non-chemical propulsion programs in the coming years.

An important part of our Center is the development and use of a major new cryogenic laboratory with ultimate capability for liquid oxygen and liquid hydrogen or liquid hydrocarbon propellants. Detail design and construction of this laboratory was begun shortly after Center start-up and our first hot firing was made with gaseous propellants in December 1989. This unique laboratory is currently the only one of its kind in U. S. universities. Similar systems used in the Sixties have been mothballed or dismantled. Now that the facility is operational for gaseous propellants, we are beginning testing and diagnostics at appropriate conditions of interest. Evolution of the propellant capabilities to cryogenic liquids is continuing, with a target of demonstrating LOX capability in calendar year 1990. The Cryogenic Laboratory enables us to do small scale tests (generally with uni-element injectors) with actual propellants under realistic conditions. The laboratory also enables us to give students experience in handling the cryogenic fluids that are generally used in space propulsion applications. The construction of this laboratory would have been totally impossible without the Center.

In all the areas described above, there is an integrated treatment of experimental and analytical efforts with close interaction among both faculty and students. This interaction is facilitated by the co-location of all faculty and students in the Center and through the shared use of the new Cryogenic Laboratory which is just being brought on line. The Cryogenic Laboratory is to be used for both combustion and materials testing by several Center projects.

In January of 1989, the Center became the first occupants of the newly constructed Research Building . The space originally allocated to the Center was the first floor of this building, but as the Center became established, it first expanded to include one quarter of the second floor, and is now occupying the recently completed basement floor bringing our total assigned area to about 16,000 square feet. This building offers excellent laboratory space with adjacent offices and provides a common working area for Center personnel. At present, the Research Building houses 12 faculty members,11 staff and approximately 50 graduate students along with 9 laboratories. The Center is also assigned 1,000 square feet of space in the High Pressure Laboratory for our Cryogenic Combustion Laboratory. Safety precautions prevent housing this facility in the main Center location.

In addition to research and student support, the Center has also had an impact on our instruction program. Penn State already had a rich offering of courses in propulsion when the Center began, but in conjunction with the Center, we have developed two new graduate offerings in propulsion and a third is tentatively planned for the 1990-91 academic year. The course instructors are Prof. Micci of Aerospace Engineering and Profs. Yang and Carpino of Mechanical Engineering.

III. Brief Description of Center Projects

The projects supported in the Center are divided into five concentrated areas. Each of these is outlined briefly below. More detail on the individual projects is given in the following papers in this volume.

Combustion Concentration: The combustion concentration was the first area established and remains the largest. Research thrusts in combustion include both experimental and analytical efforts and extend rather broadly across several propulsion areas. Much of the effort is directed towards the understanding of spray combustion phenomena. Specific experimental research includes studies of liquid jet break-up and atomization under both dense and dilute spray conditions. Non-obtrusive diagnostic procedures include optical techniques in the dilute spray regions and non-optical techniques in the dense spray regions. Particular optical diagnostics being used include laser doppler velocimetry, phase doppler particle anemometry, laser speckle velocimetry, advanced flame imaging techniques and planar laser-induced fluorescence. In non-optical diagnostics we are focusing on high intensity x-ray radiography.

Other aspects of spray combustion phenomena being studied include measurements of droplet-turbulence interactions and fundamental studies of the burning mechanisms of slurry fuel droplets. These experimental studies are corroborated by supporting theoretical research in multicomponent droplet vaporization in the supercritical and near-supercritical regimes as well as theoretical and numerical analyses of combustion instability phenomena.

A current focus of the combustion area is upon the construction of a major new Cryogenic Facility which will enable experimental studies of the combustion of hydrogen or liquid hydrocarbon fuels with cryogenic liquid oxygen. This facility provides us with an invaluable tool for studying the combustion processes in liquid rocket engines. The initial phase of this project was completed in calendar year 1989 and we are presently conducting initial tests with gaseous oxygen . The cryogenic (liquid) capability is expected to be completed in 1990.

Fluid Mechanics and Heat Transfer Concentration: The fluid mechanics and heat transfer concentration is directed towards experimental and computational studies of a broad range of propulsion applications. In the area of space propulsion, we are conducting experimental surveys of the boundary layers in low Reynolds number nozzles using emission spectroscopy. These efforts are complemented by computational fluid dynamic (CFD) studies of viscous supersonic flows as well as by studies of turbulent combustion modeling in the subsonic region of the combustor. Additional studies include the investigation of the stability characteristics of nozzle wall boundary in an attempt to identify methods for controlling transition to turbulence in low Reynolds number nozzles for the purpose of controlling heat transfer and performance losses. These CFD analyses are also being used for design trade-off studies between radiative and regenerative cooling.

Materials Compatibility Concentration: Our emphasis in materials is directed toward assessing the compatibility of new and existing materials with the harsh environments encountered in propulsion systems. Current emphasis is focused on hydrogen management considerations in conventional and composite materials through the use of multi-layered laminates to control diffusion at high temperatures and pressures and to provide increased materials durability in hydrogen environments. The approaches being considered include the deposition of thin films to provide surface protection and the experimental and theoretical evaluation of the manner in which these films perform in a combustor environment.

Turbomachinery Concentration: The field of turbomachinery represents the newest concentration area of the Center. Our emphasis in this area is on cryogenic bearings, seals and rotor dynamics. Current projects include the development and implementation of an analytical model for predicting the behavior of foil bearings in a cryogenic environment, and a combined experimental/analytical study of magnetic bearings. The foil bearing analysis is concerned with developing and implementing a model for the dynamics and mechanics of the coupled fluid-foil system. The magnetic bearing project includes the experimental set-up of a magnetic bearing facility and emphasizes the design and implementation of advanced closed loop algorithms for controlling the bearing. An advanced non-linear algorithm is being developed to control the dynamics of the magnetic bearing under simulated rocket engine turbopump conditions. An additional turbomachinery project is planned in the area of the hydrodynamic design of cryogenic pumps for liquid rocket engines.

Advanced Propulsion Concepts: The fifth and final research concentration in the Center is on advanced space propulsion concepts and includes research in antiproton annihilation propulsion, microwave propulsion and advanced electric propulsion concepts. The antiproton work includes studies of the feasibility of using antiproton-induced fission fragments to ignite DT pellets for eventual propulsion by inertial confinement fusion. Efforts in microwave and advanced electric propulsion include a vacuum facility for simulated altitude testing and a microwave-plasma facility for propulsion research.