IAC-04-Q.6/T.5.06

TRANSITIONING A FUNDAMENTAL RESEARCH PROGRAM TO ALIGN WITH THE NASA EXPLORATION INITIATIVE – PERSPECTIVES FROM MICROGRAVITY COMBUSTION SCIENCE AND FLUID PHYSICS

Thomas J. Sutliff
Fred J. Kohl
Exploration Systems Division
NASA Glenn Research Center
21000 Brookpark Road
Cleveland, Ohio 44135 USA

Abstract

A new Vision for Space Exploration was announced earlier this year by U.S. President George W. Bush. NASA has evaluated on-going programs for strategic alignment with this vision. The evaluation proceeded at a rapid pace and is resulting in changes to the scope and focus of experimental research that will be conducted in support of the new vision. The existing network of researchers in the physical sciences – a highly capable, independent, and loosely knitted community – typically have shared conclusions derived from their work within appropriate discipline-specific peer reviewed journals and publications. The initial result of introducing this Vision for Space Exploration has been to shift research focus from a broad coverage of numerous, widely varying topics into a research program focused on a nearly-singular set of supporting research objectives to enable advances in space exploration.

Two of these traditional physical science research disciplines, Combustion Science and Fluid Physics, are implementing a course adjustment from a portfolio dominated by "Fundamental Science Research" to one focused nearly exclusively on supporting the Exploration Vision. Underlying scientific and engineering competencies and infrastructure of the Microgravity Combustion Science and Fluid Physics disciplines do provide essential research capabilities to support the contemporary thrusts of human life support, radiation countermeasures, human health, low gravity research for propulsion and materials and, ultimately, research conducted on the Moon and Mars.

A perspective on how these two research disciplines responded to the course change will be presented. The relevance to the new NASA direction is provided, while demonstrating through two examples how the prior investment in fundamental research is being brought to bear on solving the issues confronting the successful implementation of the exploration goals.

Introduction

On January 14, 2004, the President of the United States announced a new Vision for Space Exploration - one that is likely to invigorate the worldwide aerospace community as well. The newly defined program begins by finishing the International Space Station, and using it for enabling research. Furthermore, the vision outlines development of a Crew Exploration Vehicle, with continued plans to execute a Mars-via-Moon exploration effort using its capability.[1] NASA is currently reevaluating all on-going programs within the

Agency for strategic alignment with these new space exploration goals. This reevaluation is proceeding at a rapid pace, and is resulting in changes to research facility capabilities planned for the International Space Station as well as changes to the scope and focus of experimental research that will be conducted in those facilities and on the ground.

The Microgravity Combustion Science and Fluid Physics disciplines have been two of the cornerstones within the NASA Physical Sciences Microgravity Research Program since the early 1980's. In the mid-1990's, each discipline had begun a reassessment of the content of its research portfolio and, in fact, had begun selecting peer reviewed research topics via the NASA Research Announcement (NRA) process based on their relevance to an anticipated Exploration-type vision.[2,3,4,5] The initial result of introducing the Exploration Vision has been to alter course from a broad, widely divergent coverage of numerous research topics into one focused on a nearly-singular set of research objectives.

The shift from curiosity-driven research ideas to goal-based research for the specific intended purpose of supporting the Vision for Space Exploration has been of no surprise for researchers familiar with a model providing a continuous progression from exploratory- to directed- to applied-research maturation as is employed by the U.S. Department of Defense and many industry research organizations.[6] This progression is illustrated in figure 1. After all, the university-based researchers conducting low-gravity research also have been the same individuals investigating fundamental and applications-based physical phenomena for terrestrial purposes. When the focus on specific applications of combustion and fluid physics research was introduced, a review of the existing research portfolios was conducted. The outcome of the review provides insight into how far the programs had progressed in preparing for an announcement defining the next steps in exploration.

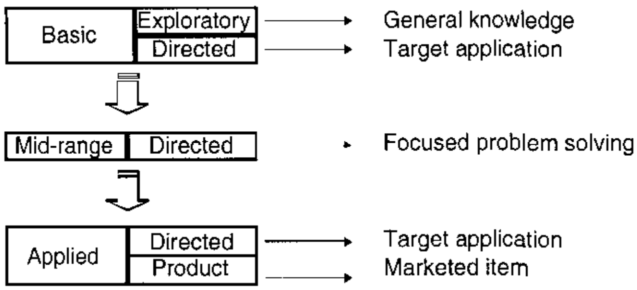

Figure 1: Research Progression and Outcomes

Two examples of the breadth and depth of research with application to the Vision for Space Exploration are the areas of spacecraft fire safety and two-phase flow technologies. When the assessment was conducted, we found that we are well positioned to bridge from the basic research model previously employed to the more focused, applications-driven model required to enable exploration. The combustion research portfolio has 25 ground-based and 7 flight-based investigations addressing problems in materials flammability, fire suppression and fire/smoke detection in non-Earth conditions. The fluid physics research portfolio contains 10 ground-based and 5 flight-based investigations considering issues associated with phase change, nucleate boiling, and two-phase flow technologies. It is this research base that provides the foundation for applied-research productivity.

Focused basic research initiates the steps necessary to bring new technologies and capabilities to a flight readiness status for inclusion in a mission. NASA uses a progression of research maturation called Technology Readiness Levels (see figure 2).

Within the new Vision for Space Exploration, research and technology (R&T) development activities supporting Life Support and Habitation systems remain at a critical level of

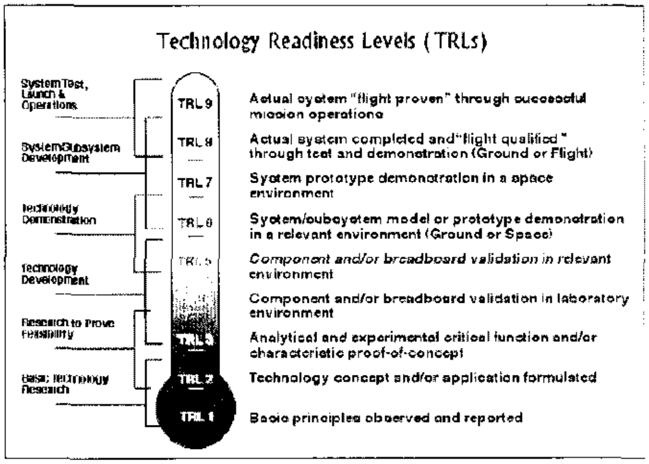

Figure 2: NASA's Technology Readiness Level definitions for flight systems

importance. Investment in human system R&T recognizes the human as a critical system within the "system-of-systems" development approach, and the need for optimal integration of people and systems. Payoffs from these investments enable long-duration human exploration reaching beyond low Earth orbit and brief Moon visits by overcoming life support technological issues.

Historical Knowledge Gathered

Both the Combustion Science and Fluid Physics disciplines are already providing exploration-based research results. Two examples are provided: fire safety and two-phase flows will be used to illustrate the influence of current capabilities on the exploration initiative.

Combustion:

Fire is a particularly serious danger due to the closed nature of the system in which the astronauts reside. While on Earth, escape by leaving the area of a fire is an option; in space it is not. Accordingly, we are conducting numerous studies in the area of fire prevention. None-the-less, if we choose to continue to explore, the probability of a fire event during future space missions is unity. So appropriate means to detect and suppress the fire, or pre-fire condition is needed. There are many potential fire sources in a spacecraft system.

- Electrical Failures -- Short Circuits, Overloads
- Heater, Electrolysis Unit, or Thermostat Failures
- Spills or Line Breaks Creating Flammable Aerosols
- Experiment Failures -- Chemical Reactions
- Crew or Ground Errors -- Poor Housekeeping
- Spontaneous Ignition in Trash or Waste

Similarly, previous knowledge has resulted in a number of design "rules" being developed and used.

- Materials and configurations are tested to pass a stated criteria of fire resistance
- Electrical wiring is sized according to derated current capacity with appropriate fusing
- Pressure vessels are reduced for high safety factors
- Propagation barriers are provided through boxes and enclosures
- Non-fire-resistant articles (paper, fabrics) are identified and isolated by limits on quantity, spacing, and containment

Numerous studies continue in the area of fire prevention through development of criteria for optimum choice of materials, improvement in fire detection systems optimized for detection in reduced or microgravity environments (with emphasis on detection of incipient fires), and fire suppression techniques suitable for use in a microgravity environment. To intelligently engineer solutions, researchers must provide a deeper understanding of the mechanisms of ignition, flame spread, and extinguishment of fires in reduced or microgravity environments.

To date, results from combustion research continue to have an influence on spacecraft designs and operations. Previous research findings leading to NASA's spacecraft fire practices and policies include:

- Shutting off ventilation flow upon detection/start of fire event is more effective than only discharging a fire extinguisher.
- A recognition that margins of safety presupposed for material flammability in microgravity is, in fact, absent.

- A recognition that smoke particles in microgravity are different, changing the needed sensitivity in smoke detectors onboard spacecraft.
- Assisting in redesign of protection from fires similar to that which occurred on Mir due to the Solid Fuel Oxygen Generator mishap.

Three flight combustion research campaigns in spacecraft fire safety are planned for the ISS. Two are targeting questions regarding flame spread and extinguishment mechanisms, and a third assesses the changes in smoke and fire-precursors to enable design of an optimized spacecraft fire detector.

Fluids:

It is well known that most devices that operate with liquids and/or gasses as working fluids will behave differently in low gravity environments. In many cases, systems that perform adequately in normal gravity are not suitable for use in reduced or low gravity. To understand the performance of systems in low gravity, it is necessary to understand the underlying fluid physics phenomena responsible for the performance of the device. The Microgravity Fluid Physics discipline has a long history of conducting studies to understand the underlying physics that can explain the observed behavior to aid the development of design guidelines for advanced space worthy systems.

One specific example of a traditional research theme is the studies of boiling and condensation in static systems and the extension of these to various multiphase flow and fluid stability phenomena related primarily to power, propulsion, fluid and thermal management and advanced life support technologies. The heritage Microgravity Science Program emphasized the basic science aspects of the processes while the current and future Exploration Systems work will concentrate on advancing the technology readiness levels of actual systems for use in the exploration missions systems.

The influences of gravity on fluid dynamics are apparent. As the gravity level is reduced, a new balance comes into play between inertial and interfacial forces, so that the mechanics of the flow are drastically altered. This is manifested not only in a change in the shape and symmetry of the gas-liquid interface, but also the fluid flows in the vicinity of that interface. Boiling and condensation systems (i.e., two-phase systems) are widely used on Earth because of their ability to minimize the temperature difference between the heat sink and source as well as the ability to achieve higher power levels at reduced system size and mass, when compared to single-phase systems. They offer significant gains in efficiency when compared with single-phase systems. Reluctance to use these systems in low gravity environments originates with uncertainty about their performance. Historically, answers were unavailable for such simple performance requirements such as whether steady state boiling was achievable, whether or not dryout would occur and lead to a destructively high temperature at the heater surface, and whether stable operation was achievable over a sufficiently wide range of conditions. Beginning in 1992, Glenn Research Center, along with the Principal Investigator from the University of Michigan, conducted a series of Pool Boiling Experiments on the Space Shuttle.[7] Several new low gravity phenomena were discovered, and the wealth of data obtained is directly applicable for the inclusion of the boiling process in spacecraft thermal management systems. This earlier work, along with numerous complementary ground-based studies, has led to the contemporary development of the Boiling Experiment Facility that will conduct the Microarray Boiling Experiment and the Nucleate Pool Boiling Experiment on the International Space Station. The next generation of experiments are now being planned to study flow boiling, condensation, phase separation and system stability and other aspects of two-phase flows that relate to heat transfer and thermal management systems in a wide range of low gravity applications applicable to exploration systems.

The ultimate objectives in both these examples are to bring the Vision for Space Exploration to reality by providing key enabling technologies required to perform crewed expeditions of greater duration, with more flexibility, and therefore at a significantly improved level of mission success. This will be achieved via increased life support system performance and decreased maintenance complexity, and a higher likelihood of prevention and recovery in the event of a fire. For example, a more robust spacecraft may be designed through the use of closed-cycle environmental controls, life support applications, thermal management designs, and advanced space power and propulsion systems utilizing two-phase flow systems. And, by understanding materials performance, including flammability, a new family of lighter weight and spacecraft-specific materials may be used with confidence.

Resources (facilities)

A robust research program requires a certain element of infrastructure and research capability. The Fluid Physics and Combustion research activities continue to take advantage of significant ground-based resources within NASA, particularly at the Glenn Research Center, in Cleveland, Ohio. Beyond use of typical laboratories and computational capabilities, two unique drop towers provide 2.2 and 5.18 seconds of free-fall, eliminating the effects of gravity for short, repeatable tests. These facilities provide researchers an ability, for example, to study the ignition phenomena of materials in a controlled, and precise manner. Also available to the researchers is the NASA Zero-g Aircraft. This aircraft, currently a KC-135, flies a parabolic arc trajectory and thereby provides approximately 15-20 seconds of milli-g environment for experimentation.

In many cases five seconds of free-fall, or 20 seconds of a milli-g environment is insufficient to provide insight to the physical phenomena being investigated. The NASA Shuttle and International Space Station programs have provided access to space for the needed extended testing capabilities in a high-quality environment. Flight systems deployed or planned for the ISS include the Microgravity Science Glovebox, EXPRESS Racks and the two-rack Fluids and Combustion Facility. More information on each of these systems is available in references 8 and 9. [8,9]

The Transition

A series of directed, focused workshops have been conducted over the past 20 years to help the community identify the critical systems and technologies that require the most attention to enable NASA's proposed exploration missions. Many of the ideas from these workshops have already found their way into the 'common' way spacecraft systems are designed. Many more of the ideas for research which has not yet matured sufficiently for inclusion in flight system designs are poised to be of significant benefit in the future of space exploration. Recent workshops have redoubled the interest in external review of research plans, with more vehicle developers and designers in attendance, providing much needed feedback on research direction and information transfer of state-of-the-art research results.

A number of useful guiding documents have been created within NASA to aid in focusing basic research toward needs of human health, life support and habitation technologies. The Bioastronautics Critical Path Roadmap[10] as well as the CRAI (Capability Requirements, Analysis, and Integration) and ASTRA (Advanced Systems, Technologies, Research, and Analysis) work definition activities provide insights useful to the research community in charting a focused research course, and are serving as guidance to the research planning currently underway at NASA. The ultimate responsibility for the acquisition of research, technology, and systems in support of the vision belongs to the NASA Exploration Systems Mission Directorate.[11]

Future Possibilities

The research in Two-Phase Flow and in Fire Prevention, Detection, and Suppression are only two topical areas where current performance limitations can be overcome through leveraging the knowledge available within the research community and applying it to solve specific technological needs. Other areas scoped within the human systems technologies include reduction in dependence on transported resources through use of in-situ resources, improvements in power conversion and communication tools for extravehicular activity suits, sensors and environmental controls development for dusty environments, and improvements in crew-machine interfaces.

Conclusions

The Microgravity Combustion Science and Fluid Physics disciplines have successfully initiated the transition from idea/curiosity-driven independent research to focused basic and applied research programs delivering state-of-the-art products in support of a specific application – the Vision for Space Exploration.

References

1. The Vision for Space Exploration, NASA, NP-2004-01-334-HQ, February, 2004.
2. Workshop on Research for Space Exploration: Physical Sciences and Process Technology, NASA CP-1998-207431, 1998.
3. Workshop on Research Needs in Fire Safety for the Human Exploration and Utilization of Space, Cleveland, Ohio USA, *http://www.ncmr.org/events/firesafety/*, June, 2001.
4. Multiphase Flow in Space Power and Propulsion Workshop and Fluid Stability and Dynamics Workshop, Cleveland, Ohio, *http://www.ncmr.org/events/multiphase/*, May, 2003.
5. Conference-Workshop on Strategic Research to Enable NASA's Exploration Missions, *http://www.ncmr.org/events/fluids2004/proceedings.html*, June, 2004.
6. 1997 R&D Magazine Basic Research White Paper, 1997.
7. *http://microgravity.grc.nasa.gov/expr/pbeinfo.htm*
8. Kohl, F. J., et al., The NASA Microgravity Fluids Physics Program-Knowledge for Use on Earth and Future Space Missions, IAC-02-T.4.02 (TM-2002-212009), 2002.
9. Sutliff, T. J., et al., Combustion Research Aboard the ISS Utilizing the Combustion Integrated Rack and Microgravity Science Glovebox, IAC-02-T.4.05 (TM-2002-211998), 2002.
10. Bioastronautics Critical Path Roadmap, JSC 62577, *http://research.hq.nasa.gov/code_u/bcpr/index.cfm*, April, 2004.
11. *http://exploration.nasa.gov*