**Decadal Survey on Biological and Physical Sciences Research in Space 2023-2032**

# GROUND-BASED INCUBATOR PROGRAM

**Topical White Papers**

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## Abstract

This white paper recommends a robust ground-based incubator program for the next decade to enhance access and engage researchers for disciplinary research progress and development of new ideas for flight investigations. With the authors' decades of service for NASA, this BPS2023 describes how the drop-tower facilities were established, and how they enable talents to merge. There are three recommendations: (1) welcome more micro-g experiment design ideas from the public, (2) increase the number of students in higher education, and (3) maximize utilization of existing facilities.

## Background

***Overview:*** During the 1990s and extending until 2004, the microgravity physical sciences had robust ground programs. While the flight experiments (deservedly) received much of the attention with dedicated missions such as the United States Microgravity Laboratory (USML-1, & 2) and the Microgravity Science Laboratory-1 (MSL-1) [1–3], the foundation and the efficacy of the program relied on the ground-based investigations for a range of research topics, specifically, in areas such as, materials science, fluid dynamics, biotechnology, and combustion science. For instance, the MSL-1 mission addressed two combustion experiments, the Laminar Soot Processes (LSP) and the Structure of Flame Balls at Low-Lewis Number (SOFBALL). The bulk of the investigations [4,5] were led by universities with tenure-track faculty serving as the Principal Investigators (PI) and guiding the work. The hands-on research, however, was performed by undergraduate and graduate students and post-doctoral fellows under the tutelage of the PI, which added a critical human resource infrastructure training component to the work.

***What were the major facilities for ground-based investigations?*** During the course of the ground-based investigations, researchers conducted their work in laboratories at their institutions supported by NASA funding, but a significant number also conducted their work at purpose-built and maintained NASA reduced-gravity facilities. These facilities included the 2.2 and 5.2 second drop towers at the NASA Glenn Research Center, the reduced gravity aircraft and sounding rockets. Moreover along this history, the experimental and numerical work by PI Dryer [6–13] at Princeton University led to experiments aboard the space shuttle, the Fiber Supported Droplet Combustion (FSDC) and the Droplet Combustion Experiment (DCE) [14,15]. These NASA-operated micro-g drop towers offered students and researchers from diverse institutions a unique opportunity to work in state-of-the-art facilities and share experiences with NASA scientists, engineers and affiliated associates. In contrast to the sometimes competitive nature of research, these facilities created a unifying environment for research professionals to cooperate and collaborate.

***Who are the people benefiting from these ground-based studies?*** In combustion alone, hundreds of undergraduate, graduate and post-doctoral researchers relied on access to NASA ground-based facilities for their senior projects, theses and journal publications. Today, many of these students have taken leadership roles at NASA, in government labs, educational institutions and industry. Their accomplishments were greatly enabled by the opportunities provided by the ground-based microgravity science research program. While the research innovations associated with the Physical Sciences research programs understandably garner the most attention, the most lasting impact of the program is the lifelong contributions from the researchers who honed their creativity and innovation skills through their participation in the microgravity program as part of their education.

***Why ground-based facilities?*** A major reason for this lasting and dominant training impact was that NASA ground-based facilities were ***the*** state-of-the-art during the 1990s. Despite being designed and built in the 1960s, the NASA GRC Zero-Gravity facility led the world as a hotbed of NASA innovation. The smaller 2.2 second drop tower underwent continuous changes to improve the research environment and throughput. For decades, this was the ONLY 2+ second microgravity facility openly available in the country [6–12,16–27]. Over the years NASA scientists and engineers developed innovations in drop towers and reduced gravity aircraft [28–35] that helped make NASA a world leader in Physical Sciences research. Furthermore, those drop-tower discoveries and innovations made any subsequent flight experiments much more refined, focused, and cost-effective. While it is not possible to accomplish a detailed cost-benefit analysis (CBA) of the combined drop-tower/flight experiment model for microgravity science, an empirical basis estimate from years of microgravity project experience and observation indicates that drop tower tests are easily on the order of 1% the cost of any flight tests. Even more, a 50/50 split between flight and ground-based study means that the science would benefit even if it took 100 drop tests to help identify and downselect the optimal conditions for a future single target flight test.

## Experience and Current Status

Today, there are a number of high-profile flight experiments, but very few if any are focused/established as a ground-based program comprising comprehensive experiments. Most of the former ground-based investigations were allowed to run their course with no further NASA Research Announcements (NRAs) to replenish the program and many were outright cancelled as funds were diverted elsewhere at NASA (those cancellations were decidedly not because of any performance issue). This decline in purposeful ground-based study has been to the overall detriment of the physical sciences programs.

Many of NASA's reduced-gravity facilities are relying on decades-old technology and are no longer the state-of-the-art facilities they once were. There are few flight opportunities available on reduced gravity aircraft, as NASA no longer directly supports their own aircraft. The 2.2 second drop tower at the NASA GRC is essentially shut down with only a handful of tests per year. This facility also has not seen any significant hardware or facility upgrade of note in over a decade. The same is true of the 5.2 second drop tower at the NASA GRC. The facility relies on the same 1960s technology with only modest infusion of funding to incrementally improve the facilities capabilities. This happens as other countries, recognizing the need for technological improvements to ground-based testing capabilities, have invested in new facilities and upgrades to old facilities to improve experiment throughput (multiple drops per day as opposed to one per day at the NASA 5.2 second drop tower), increase payload size and reduce the severity of the deceleration environment. This allows researchers to greatly improve the number, quality and significance of the experiments they perform in the facilities.

A related white paper and upgrade effort (High Throughput Ground-Based Reduced Gravity Testing) is underway for an advanced drop tower that further highlights and demonstrates the need and value for state-of-the-art and accessible NASA facilities. That document describes the development of a keystone world-class high-throughput 10-second, variable gravity drop facility to provide NASA the capability for important fundamental research opportunities, in both physical sciences and life sciences, and in partial and microgravity. Such a facility, combined with a robust ground-based research program mechanism, can reinstate the remarkable success profile of NASA's broad-based research initiation.

***What we learned and observed from the past ground-based studies.*** The past ground-based programs served as significant incubators and refinement tools for the flight program. In combustion, virtually all of the space flight experiments performed significant ground-based work prior to being accepted or promoted to a flight investigation [6–12,16–27,30,36]. The ground-based work allowed engineers and researchers to test hardware and diagnostic techniques, and to refine test matrices that greatly increased the success and reduced the risk of wasted flight investigations. There is no lack of impressive design concepts for these microgravity experiments. Just one example is the spherical electric field diffusion flames that were tested at the 2.2 second drop tower [25,26]. The idea was to symmetrically influence a spherical gaseous flame and control the flame size homogenously with electric field forces. The science learned after the free fall tests in the early 2000s is that the fuel tube of the spherical burner situated in a spherical shaped electrode mesh would influence enough of the electric field force to create nonsymmetric flames. This shared knowledge in the community contributed to the early E-FIELD Flames experiment using a converging coflow burner in the 2.2 second drop tower that demonstrated how the flame can be manipulated by an electric field force. It also showed that the test matrix required a relatively long settling time and longer test period [27] before sending it for flight test aboard the ISS

[37–41]. This pathway from ground-based experiments to efficient flight studies is repeated in all domains of the physical science program, particularly in microgravity combustion.

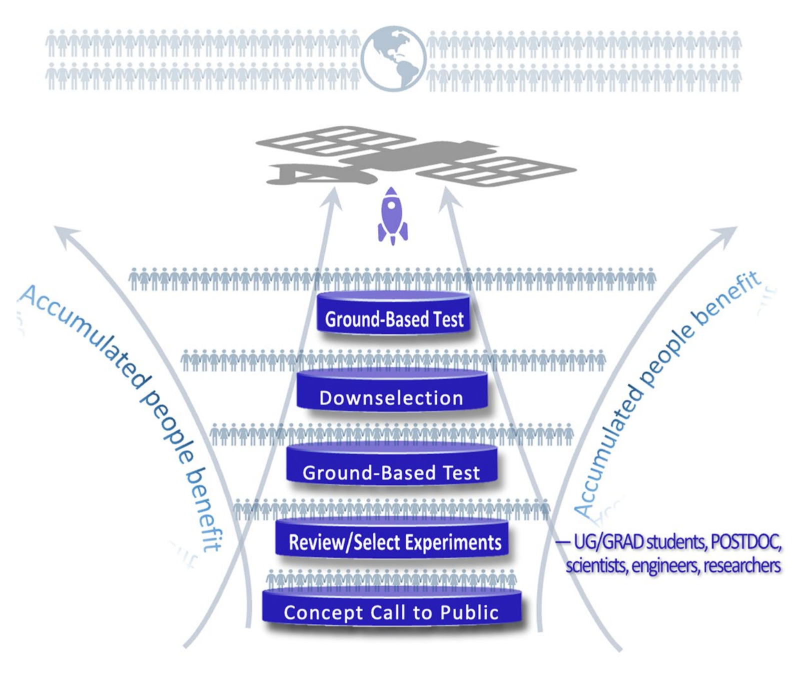
***The benefits of experiment design and cost with ground-based facilities.*** A robust ground program also provided NASA a means to fund high risk, high reward research concepts at significantly decreased cost. Innovative, but unproven ideas and technologies could be tested and vetted at very low cost to NASA and the taxpayer. This allows NASA to carefully select and develop the best and worthy ideas for flight.

The reduced ground program has also had a severely detrimental effect on NASA's ability to train the next generation of scientists and engineers. There are, and can be, only a handful of flight experiments in any given Physical Sciences discipline. This fact alone has greatly reduced the number of students supported by the Physical Sciences program. This is exacerbated when one considers that the typical tenure for an undergraduate student on a research project is approximately 2 years, and is the same for a master's student and post-doctoral fellow. Doctoral students likely have the longest tenure of between 4 and 5 years. Compare this with the typical duration of a flight experiment on the ISS, which is generally a minimum of 10 years or more when one considers the time from submitting the proposal to being accepted into the flight program, successfully passing the various reviews and building and flying the experiment. While there can and should be a priority placed on reducing this time, it is unlikely that it will ever be reduced to the point where PhD students, let alone masters students, can routinely begin work on a research topic coincident with the start of a flight project and then use the results of that experiment as the basis for their thesis.

***Broader Educational and Societal Impacts:*** Robust ground-based facilities and programs provide the opportunities for students to perform research from concept to reporting in a time commensurate with their education tenure. While students can and do perform testing at their host institutions, NASA, with a few notable exceptions, is the only institution that can provide effective and ready access to high quality reduced-gravity facilities.

## Specific Recommendations

1. Greatly increase the number of ground-based investigations in the Physical Sciences through the periodic release of NRAs, in addition to other innovative programs such as the Established Program to Stimulate Competitive Research (EPSCoR). These investigations will serve as incubators for future space flight experiments, but many will also stand on their own, able to achieve or exceed research expectations with only ground-based facilities.



**GROUND-BASED INCUBATOR**

2. Greatly improve student access to NASA research facilities. One of NASA's core missions is to inspire and educate the next generation of scientists and engineers. Providing students with access to state-of-the-art NASA facilities provides a remarkable educational opportunity, as they work side-by-side with NASA scientists and engineers, and students from other institutions.
3. Maximize utilization and upgrade NASA's reduced gravity facilities. The Physical Sciences research programs are much more mature than they were 30 years ago. In those early years, unique and innovative research could be accomplished with simple experiments with relatively rudimentary diagnostics (cameras). This is no longer the case, NASA must recognize that as the Physical Sciences program has matured so has the demand for the capabilities of the facilities. This should include investments to increase the throughput (number of tests per day, week, year), the size of the payload, the capabilities of the payload (e.g., advanced laser diagnostic techniques) and duration and quality of the reduced gravity time. This should also include the capability for partial gravity research to facilitate research to enable NASA's exploration efforts.

## Conclusion

Establishing the ground-based incubator initiative (combining improved accessible facilities with a robust and broad-based research training portfolio of projects) will collect and embrace more ideas from the public. This initiative requires a strong scientific committee for reviewing with an understanding of the underlying constraints. The program will conduct each project with a relatively short turn-around time, well-designed workflow and clear condition downselection process. The most important of all, is to allow a broader and enhanced educational value for undergraduate students, graduate students, postdocs, and researchers, particularly for microgravity and partial gravity experiments.

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