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Introduction

Chairman Nelson, Ranking Member Cruz, and Members of the Subcommittee: Thank you for the opportunity to provide testimony to this subcommittee on the important role that commercial space, particularly commercial reusable suborbital vehicles, are beginning to play in my research, the research of my colleagues across the country in numerous fields, and the development of new technologies at NASA and elsewhere.

I believe that we are beginning an era of low-cost, routine space access that will offer incredible new opportunities for the research community. Reusable commercial suborbital vehicles will allow researchers to fly payloads often, conduct more experiments and collect more data, for the price of one traditional launch vehicle. Payloads will have a gentler ride to space, resulting in reduced payload development cost and the opportunity to fly experiments that were prohibitively difficult to fly before. With short lead times, there will be opportunities to launch coincident with terrestrial and astronomical phenomena, providing astronomers and earth scientists telescope observation prospects from the edge of space. Some of the platforms will also fly researchers alongside their payloads, an exciting new addition to space-based research that will provide flexibility that can only come from having an investigator in the loop, and reduce the need for expensive and error-prone automation. Like researchers on ocean-going vessels, in Antarctica, and on research aircraft, space-based researchers will be able to more effectively conduct their experiments when they fly with them to adapt to discovery and to acquire *in-situ* data.

The availability of reusable suborbital vehicles with other existing platforms, like parabolic flights and the International Space Station (ISS), will allow researchers to benefit from a full suite of micro-gravity and space environments. I am tremendously excited about these upcoming opportunities for my own research. I have performed microgravity fluids experiments at drop towers, led my students on more than thirty parabolic aircraft experiments, and designed two of the six tests performed in the successful Capillary Flow Experiment onboard the International Space Station. I have also flown research on several test flights of new suborbital vehicles, serve as a member of the Suborbital Applications Researcher's Group, and am now a member of the Scientific Advisory Board for the Center for the Advancement of Science in Space (CASIS). The full ladder of microgravity platforms is important for a broad swath of researchers, as it allows us to test equipment, improve experimental design, and gather data at one rung before moving up to the next rung in microgravity duration and expense.

Industry Progress

The suborbital industry has reached many milestones recently, and I expect multiple providers will be flying participants and payloads within the next few years. In the last eight months alone:

> Blue Origin successfully tested their suborbital crew capsule escape system, which in the event of a pad abort will rocket the crew away from the launch pad, demonstrating one of the key safety systems being developed for their vehicle.
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> Armadillo Aerospace launched two flight tests of their liquid-engine reusable sounding rocket, STIG-B, marking the first FAA licensed launch out of Spaceport America's vertical launch facility. Both of these flights carried payloads developed by my students at Purdue University.

XCOR Aerospace performed the first firing of a full piston-pump-powered rocket engine, which will allow their vehicle to fly inexpensively multiple times a day, with aircraft-like operations.

Masten Space Systems achieved a record altitude with Xombie, their precision vertical take-off, vertical landing vehicle. In March, Xombie reached an altitude of nearly 500 meters, testing guidance, navigation, and control systems that could be used on future missions to Mars or other destinations.

Virgin Galactic and Scaled Composites completed the 24th glide test of SpaceShipTwo and a week thereafter conducted the first powered flight test. After being released at an altitude of 47,000ft by WhiteKnightTwo, SpaceShipTwo ignited its hybrid rocket motor to achieve an altitude of 55,000ft and a velocity of Mach 1.2 before gliding to a landing at the Mojave Air & Space Port.

With this kind of progress by suborbital companies, the first wave of licensed flights carrying participants and payloads are expected to begin soon. In addition, research payload development takes several years, and to fully exploit the new capabilities that these vehicles will provide, we must put in place programs now to create a pipeline of science and research payloads. NASA has taken steps to begin to benefit from commercial, reusable suborbital vehicles, but there is still much more that can be done in and out of NASA to take full advantage of all the opportunities these vehicles create.

NASA Programs – Flight Opportunities, and Payload Development

In 2011, NASA created the Flight Opportunities Program (FOP) within its Space Technology Mission Directorate to use commercial suborbital rockets, balloons, and parabolic aircraft for technology development. By serving as an anchor customer for research flights to space, FOP is enabling companies to raise private investment, fostering the development of reusable suborbital vehicles, with the goal of creating routine, cost-effective and enduring space flight research platforms. The program only pays for flights flown, placing development expenses on the vehicle providers and their investors. Through FOP solicitations, researchers are able to fly technology payloads to space, raising the Technology Readiness Level (TRL) of technology needed by NASA, demonstrating an application in a relevant environment, or testing instruments and experiments in microgravity before they take a costly trip to orbit.

Earlier this year, Near Space Corporation, a company that provides high-altitude balloon systems, flew a payload for the New Mexico Institute of Mining and Technology (NMT) through the Flight Opportunities Program. NMT was testing a monitoring system to determine structural integrity for space vehicles, which is important for reusable spacecraft re-entering the atmosphere. NASA will be able to use tested technologies like these in future orbital and suborbital missions. Next month, Near Space is scheduled to fly the first upper-stratospheric low-gravity aircraft flights with their balloon-launched glider in a flight test program that I am involved in through NASA’s FOP.

By flying payloads like these, FOP can rapidly refresh NASA’s technology base and promote investment by the private sector by supporting the early adopters of new technology. We researchers who fly early will provide the proofs of concept that pave the way for those who fly later. However, currently the pool of researchers that can get NASA funding for reusable suborbital flights is limited, as FOP solicits only technology payloads. For researchers such as myself, and many of my colleagues creating science payloads, the solicitations through NASA to fund our payload development and fly on these vehicles are few and far between. I encourage the use of broader science-oriented solicitations for suborbital vehicles, so that NASA will reap the full benefits from both the science and technology areas, and to encourage early adopters from a broader range of disciplines. Additionally, along with drop towers and parabolic flights, these vehicles allow researchers to gather the data necessary at a lower rung before moving up the ladder to experiments on orbit. Gathering initial data on readily available platforms will allow more researchers to confidently send their experiments to an extended micro-gravity environment, reducing risk and increasing utilization of valuable on-orbit tools such as the International Space Station.

The Principal Investigator for the very successful German Capillary Channel Flow experiment in ISS tells me that drop tower experiments and traditional ESA sounding-rocket flights were critical steps for his team to be able to design the experiment to operate so well in orbit. My Purdue colleague who is Principal Investigator for the Critical Heat Flux Experiment being built for the ISS tells me that his parabolic aircraft flight research history in flow boiling is why he was able to conceive and design the experiment, propose it in a NASA competition, and win.

Furthermore, the new era of affordable and frequent access to space is accessible to any federal agency with research, technology, or testing needs. Spaceflight research need not be a NASA-only endeavor when this uniquely American industry hits its stride.

Scientific Applications of Suborbital Flights

Though there are limited funding opportunities for suborbital scientists, exciting research is already in development. In many cases, payloads are funded by a patchwork of internal funds and small grants, so the current research is just skimming the surface of the pool of interested researchers. If more science payloads are funded, scientists will be able to dive deeper into their respective subjects, and produce results that are broadly applicable on Earth and in space.

I specialize in two-phase fluid dynamics research, and micro-gravity is a powerful tool for exploring Earth-bound applications and is obviously vital for spaceflight topics. My research involves the observation of fluid behavior free of gravity-induced effects such as sedimentation and buoyancy-induced convection. For example, in 2014 I will be launching to ISS the "Fluids Education Experiment" on the existence and stability of equilibrium capillary states. This research grows from computational research I did with researchers at a Centers for Disease Control laboratory a decade ago, where we investigated how minute water droplets can obstruct lung passages. Some of my other efforts seek to advance the ability of engineers to control and gauge the liquid rocket fuel in commercial communication satellites. A Purdue colleague's research into boiling and condensation processes, as used in refrigeration, is important to both expanding our spaceflight capabilities and to improving such systems on Earth.

Many other researchers with different areas of interest are excited to use suborbital capabilities as well:

> *Aeronomy and Mesospheric Science:* Suborbital vehicles will be able to reach an area of the atmosphere that was only previously attainable through non-reusable and costly sounding rockets. This portion of the atmosphere, too high for balloons and too low for orbiting satellites, is sometimes called the "ignorosphere," and will now be accessible for *in-situ* high-altitude atmospheric research and to observe radiation from solar or astronomical sources that is blocked by the lower atmosphere.
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> *Human Physiology:* The three to five minutes of microgravity provided by suborbital vehicles, including transitions to and from high-g's, could provide new insight for some kinds of physiology research. In-situ monitoring may be available for numerous parameters such as heart rate, cardiac stroke volume, arterial blood pressure, oxygen saturation, regional blood volume, brain activity, eye movements, and spacecraft reference data. While enabling as much of the public as possible to have a chance to fly to space, this research may also produce insights on how to better research human conditions on the ground.

Fundamental Molecular Biology: One basic read-out of an organism's response to environmental stimulus is the changes in gene expression that the stimulus evokes. This response can be very rapid, and the signal transduction and initiation of gene expression can occur within minutes of perception. This type of response at the molecular level has been characterized in the stable, sustained microgravity environment of the space station and space shuttle, but the gene expression profiles associated with the transition from an environment with gravity to one without has yet to be examined. Thus, molecular biology experiments (which can be configured for rapid fixation by crew or citizen scientist) conducted on suborbital vehicles represents true, unexplored territory that can provide insight into the fundamental processes that underlie the initiation of novel stress responses.

Fundamental Physics of Particle Interactions: Suborbital flights offer sufficient time in microgravity to obtain physically important results on the interactions of regolith, dust and other small particles. The flexibility, re-flight possibility and cost of reusable suborbital flights will allow scientists to investigate the basic forces affecting a wide array of granular materials in a host of environments with applications to mining, pharmaceutical powders, food processing, and the ceramics-bricks-cement industries.

Pharmaceuticals: Through the study of protein structure and function in the human body, scientists can better develop drugs to interact with them, and create effective treatments. Typically longer term exposure to micro-gravity is ideal for protein crystal growth, but results have been obtained in sounding rockets with an exposure of just 30 seconds to micro-gravity. Mitsubishi Heavy Industries is planning to use XCOR's Lynx vehicle to perform drug discovery research on mice that have already gone through multiple parabolic flights.

Large Population Medical Research: The large population of spaceflight participants with varying medical histories offers new avenues for research. They will help scientists build a database to compare the response to spaceflight of people of varying levels of fitness, including smoking, alcohol use, stress & behavior, BMI, high cholesterol, low cholesterol, and physical inactivity. The effect of various medicines in microgravity can also be studied among the broad population and in specific subgroups.

With the research that can be conducted on these platforms comes an equally large potential for discoveries, products, and markets. For example, I have worked with my University to organize funding that will allow Indiana companies access to a suborbital flight for industrial research.

Of course, as with any scientific technique, much of the value of reusable suborbital flights may lie in areas that we do not anticipate. By opening up a new regime of research, we set the stage for discoveries that we cannot yet contemplate. Some scientists and policy-makers portray reusable suborbital vehicles as less useful because they offer flights that are shorter than orbital flights, more expensive than parabolic aircraft, and that reach lower altitudes than traditional expendable sounding rockets. These are similar to the objections many had to the first desktop computers, which were slower and less powerful than mainframes of that era. Yet, a new way of operation allowed our desktop computers to become vital to everyday life, even as they shrunk over time to become the mobile device you carry today. Similarly, judging reusable suborbital by the standards of the current orbital, sounding rocket and aircraft paradigm is beside the point.

These vehicles will create routine, cost-effective space access, an improvement over our current space transportation capabilities in a unique direction. Research, after all, is not a linear path from discovery to discovery, or about building an ideal high-precision experimental setup and measuring the results once. It is rather about exploring ideas, some likely to be fruitful and some improbable, and learning about and testing a wide array of phenomena. History teaches us of numerous accidental discoveries that led to great things. By accelerating the design, build, test, fly cycle that is at the center of space research, we allow researchers to explore far more intellectual space than they could otherwise approach.

STEM Opportunities

Reusable suborbital vehicles offer exciting new opportunities for Science, Technology, Engineering, and Mathematics (STEM) education and public outreach. The American space program has been an inspiration to the generations that are building these vehicles and conducting research. Suborbital reusable vehicles have the capability to do the same for a new generation, by allowing orders of magnitude more students access to space. These vehicles, and the research and technology that will be conducted on them, will inspire the next-generation of scientists and engineers and provide hands-on experience in the entire design-build-test process.

At Purdue University, I created and teach today a hands-on team-based project course for undergraduate students, "*Zero-Gravity Flight Experiments.*" In this course, student-led teams design and propose an experiment to fly on a parabolic aircraft flight campaign, run by NASA. Students experience the entire process from proposal through building, testing, and flying, to data analysis and reporting. In the past few years, through a partnership with Armadillo Aerospace, I was able to expand the scope of this class to reusable suborbital vehicles, and more recently, the International Space Station. Student teams are now learning to design and build, and then work with suborbital vehicle providers to integrate their payload. With new suborbital vehicles arriving soon, I see endless possibilities for students to get the kind of hands-on experience highly valued by employers and academics.

Currently, space research is often limited by the dilatory cycle of launches—when one experiment finds a new phenomenon, the follow-up might take years to fly. The period from idea generation through grant application, experiment design, assembly and flight, can take more time than a graduate student spends in school. Because of this, many students only work on a small part of a larger project, a practice that does not lead smoothly to creating the next generation of principal investigators. Removing the wait to get on a space flight manifest allows students to conduct entire research projects and complete theses in space-based research within the timeframe of a degree. A surprisingly large number of the leaders in planetary science, astrophysics and other areas of NASA science, including the current Science Mission Directorate Associate Administrator John Grunsfeld, began their careers by leading small investigations on balloons and sounding rockets. Suborbital reusable flights offer a way to accelerate that process and give even more students the leadership experience that can be vital for further scientific success.

However, university research and education is just the beginning—a much younger generation will be able reap the benefits of these vehicles as well. From flying class-built payloads to flying teachers themselves, a new curriculum to inspire kids to pursue jobs in STEM fields can be built around flights that take place during a semester or a school year. In a study done by Change the Equation last year, the number of STEM job openings outnumbered unemployed people by almost two to one in certain STEM areas. Senior alums in the aerospace industry speak to me of their aging work force. Last weekend Purdue graduated 108 students with aerospace engineering Bachelor of Science degrees, and about 90% are already placed into jobs, graduate school, or military service. Our graduates are in demand. We all must utilize tools that can provide hands-on training and keep students interested in STEM topics and research if we are to keep our workforce competitive.

Conclusion

As I look around the country, I see a new and uniquely American industry, featuring many of my best former students, making progress toward routine flights of participants and payloads. The rocket science they are doing does not always perform on schedule, for it is both novel and challenging, but the trend is clear. New vehicles are entering the market as operational research platforms soon and this will mark a new chapter for U.S. innovation, science, and exploration.

I am honored to have had the opportunity to provide testimony for this hearing, and I look forward to answering any questions you have. The suborbital research community is excited about the possibilities reusable suborbital capabilities will bring to the table, and we believe that excitement will spread quickly to a broader community as we embark on this journey of discovery.