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APPLYING INSIGHTS OF GAME THEORY TO THE MICROGRAVITY UTILIZATION MARKET

Author: Ms. Sirisha Bandla
Commercial Spaceflight Federation, United States, ssbandla@gmail.com

Mr. Bradley Cheetham
University of Colorado Boulder, bradley.cheetham@colorado.edu
Ms. Rachel Hakeem
United States, rachel.hakeem@gmail.com
Mr. Luis Zea
University of Colorado Boulder, luiszea@gmail.com

It is commonly assumed that microgravity environments are utilized only for space-based applications. However, microgravity platforms have been used for science and industrial applications long before a national space program was conceived. This paper will discuss microgravity platforms and their utilization as they are available now, explore technology that will grant access to longer durations of weightlessness, and further identify the community of users of these technologies in order to better understand the overall microgravity utilization market.

The Emerging Space Industry Leaders (ESIL) workshop series is an ongoing effort supported by the Federal Aviation Administration (FAA) Center of Excellence for Commercial Space Transportation established to foster ongoing discussion and analysis of various segments of the commercial space industry. This paper is the result of the fourth workshop held in Louisville, Colorado June 1st and 2nd 2013 which set out to accomplish the following objectives:

1. Develop an understanding of the current microgravity utilization industry and identify any trends in users and applications.
2. Evaluate the microgravity utilization market through the application of Game Theory and the PARTS market model.
3. Identify favorable applications of microgravity platforms and outline key areas for beneficial partnerships in industry.

To accomplish these objectives, this paper will provide an overview of the multiple platforms currently available for research and development to the scientific and industrial communities. Each platform varies in many factors that affect the research that can be done, such as quality of microgravity, cost of the platform, and others that must be taken into consideration when analyzing the utilization market. The paper will discuss currently available platforms such as drop towers, parabolic aircraft and orbital platforms, in addition to suborbital platforms that will come online in the coming years.

Characterization of the microgravity utilization industry was done using a realization of game theory, the PARTS model, developed by Brandenburger and Nalebuff. While not analyzed mathematically, the PARTS model of game theory was used to identify the major factors governing the development and utilization of the microgravity market. From this analysis, two strategies were recommended. The first is to address existing misperceptions of the industry, which are inhibiting the market from growing. This strategy requires cooperation by the current suppliers, payload integrators and funding agencies. The second strategy focuses on creating new perceptions to stimulate market growth and does not require cooperation between entities. These strategies and implementation recommendations are discussed further in the paper.

FAA COE + ESIL Background

The Emerging Space Industry Leaders (ESIL) workshop series is an ongoing effort supported by the Federal Aviation Administration (FAA) Center of Excellence for Commercial Space Transportation, established to foster ongoing discussion and analysis of various segments of the commercial space industry. Participants in these workshops are exposed to a myriad of background information on specific industry sectors and then proceed to perform structured analyses which are subsequently presented at industry conferences. This paper is the result of the fourth ESIL workshop (ESIL-04) which applies the Game Theory PARTS Model (Players, Added Value, Rules, Tactics and Scope) to the microgravity utilization market.

INTRODUCTION (*industry status and trends)*

It is commonly assumed that microgravity environments are utilized only for space-based applications. Any industrial applications that come from research in a low-gravity environment is usually written off as a byproduct of 'space research.' However, microgravity platforms have been used for science and industrial applications long before a national space program was conceived. From tales of Galileo's use of the Leaning Tower of Pisa to observe objects in freefall to the construction of shot towers in the 1700s to create perfectly round lead shots for use in firearms (Minchinton, 1992), microgravity environments have been utilized throughout history and continue to be used today for research and commercial applications. Even though free fall is still used to achieve weightlessness, additional platforms now exist that allow access to micro-g environments. This paper will discuss microgravity platforms and their utilization as they are available now, explore technology currently in development that will grant access to longer durations of weightlessness, and further explore the community of users of these technologies in order to better understand the overall microgravity utilization market. The word microgravity is used throughout this paper not in its scientific definition (1×10^{-6} g) but in its commonly used meaning, *i.e.* reduced gravity.

OBJECTIVES

The ESIL-04 workshop held in Louisville/Broomfield, Colorado preceded the Next-Generation Suborbital Researchers Conference, and set out to accomplish the following objectives:

1. Develop an understanding of the current microgravity utilization industry and identify any trends in users and applications.
2. Evaluate the microgravity utilization market through the application of Game Theory and the PARTS market model.
3. Identify favorable applications of microgravity platforms and outline key areas for beneficial partnerships in industry.

OBJECTIVE 1: REVIEW INDUSTRY STATUS AND TRENDS

There are multiple platforms currently available for research and development to the scientific community and industry. Each platform varies when it comes to cost, time spent in and the quality of the microgravity environment, and each has unique restrictions on the payloads it can accommodate. While there is some overlap, these differences result in distinctive research being performed on each platform through the scientific community and industry, and allow for organizations to prototype their research on lower cost platforms before moving to more expensive payloads and platforms. The following section focuses on currently available platforms such as drop towers, parabolic aircraft, sounding rockets, and orbital platforms. Platforms under development will be discussed in detail at the end of this section.

The following table illustrates some of the important differentiating factors of these platforms that organizations take into consideration when looking for a microgravity environment for their payload. Micro-g time can vary from a few seconds with a drop tower, to months in an on-orbit environment. Later in the analysis, we discuss which science and industry sectors require higher amounts of micro-g time for their research to be feasible and why. The importance of the level of reduced gravity (*e.g.* 1×10^{-2} *g* vs. 1×10^{-6} *g*) depends on the purpose of the user's payload. For example, a payload collecting data on the behavior of fluids in micro-g would need a very low gravity environment to obtain an accurate model, whereas a payload that is just testing flight software that will collect data during the experiment or other technology operation could pay a lower price for a platform with a not-as-low gravitational environment and still perform a successful test. The table below lists each platform's gravitational environment in orders of magnitude. The max G-load, the highest acceleration experienced by the payload during the flight, is an important factor for users to consider when developing their payload. A payload designed to withstand stronger accelerations is built to be more robust and will thus cost more. Payload costs are further inflated if it requires the intact recovery of payload components, particularly for drop towers and sounding rockets. Flight frequency combined with cost is important for organizations to consider if they are looking to test often. Although clinostats, an apparatus made up of a slowly revolving disk, and rotating wall vessels (RWV) can simulate the reduced-gravity environment around a small particle (*e.g.* cell), the gravity vector remains at a 1 *g* magnitude and is therefore not listed here. Nevertheless, these devices are ideal for gravitational microbiology research (Briegleb, 2007; Brown et al., 2002; Klaus et al., 1998).

Platform	Reduced-gravity Time	Gravitational Environment (*g*)	Max G-load	Max Apogee (km)	Flight Frequency	Cost
Drop Tower	2-10 sec	1.0E-05	65	n/a	Daily	Low
Parabolic Aircraft	~20 sec/parabola	1.0E-02	2	10	~50 per year	Low
Sounding Rocket	5-20 min	1.0E-04	21	1500	~20 per year	High
Suborbital	3-4 min	1.0E-2 - 1.0E-4	~3-5	110	Daily	Medium
Orbital	Months +	1.0E-06	~4-5	Varies	~4 per year	High

Table 1: Summary of microgravity platforms

Drop Towers

A drop tower is a long vertical shaft where payloads are dropped and experience microgravity while in free fall. These platforms can be above ground (tower) or below ground (shaft). They provide short durations of microgravity, anywhere from a couple of seconds up to as much as 10.5 seconds at the drop tower at the Japanese Microgravity Center (JAMIC) in Kamisunagawa, Japan (DeLombard). The figure below shows the general profile of a typical drop tower where a payload is hoisted up to the release point, released, and captured at the bottom. The capture can vary across drop towers but are typically magnetic deceleration, high load airbag deployment or polystyrene pellets.

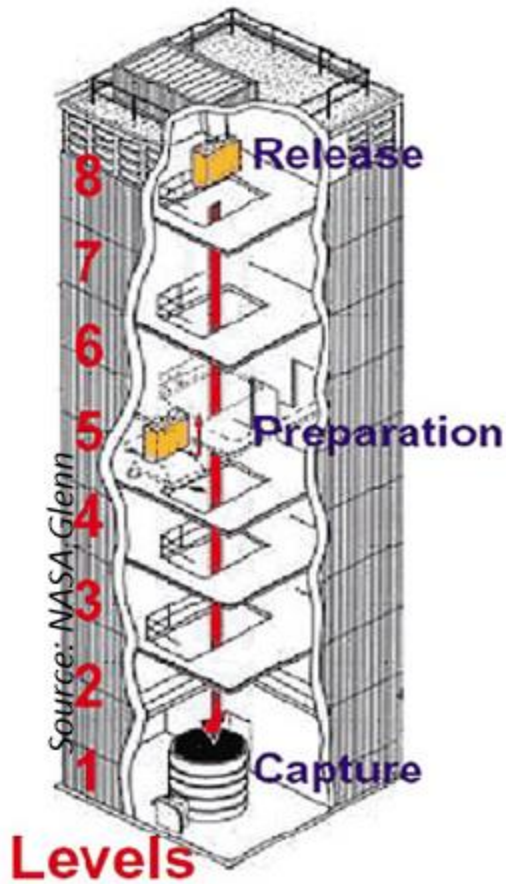

Figure 1: General Drop Tower Construction (http://facilities.grc.nasa.gov/drop/capabilities.html)

Drop towers are relatively easy to access, and many universities maintain drop towers in house for students and faculty. NASA's Glenn Research Center also maintains a 132-meter shaft providing approximately 5.2 seconds of high quality microgravity ("Creating Microgravity"). However, the short micro-g durations of towers, the size restrictions, and the loads endured during capture can be limiting on the research that can be conducted on these platforms.

Drop towers are popular for modeling droplet combustion experiments, providing the ideal short amount of time in a micro-g environment needed ("Why Study Liquid Fuel Combusion"). These experiments are conducted for a variety of reasons from creating accurate computational models of fluids to discovering new insights in fire hazard mitigation. Without natural convection in a space, studies must be conducted to better sense and mitigate unwanted fires in this environment. This research could provide insights for not only a space-based environment, but could develop a database for fire hazard mitigation both on the ground and in the air here on Earth.

Parabolic Aircraft

Aircraft are capable of providing a microgravity environment by flying parabolic flight profiles as shown in the figure below. Each nose low maneuver provides approximately 20 seconds of microgravity, followed by a 2-g pullout. The number of parabolas vary on the operator of the aircraft and the needs of the researchers onboard but typically average around 30 parabolas. Parabolic flights are available commercially in the U.S. through providers like the ZERO Gravity Corporation in addition to NASA sponsored flights for researchers. ZERO-G Corporation also offers 'Adventure Flights' to people who just want to experience weightlessness.

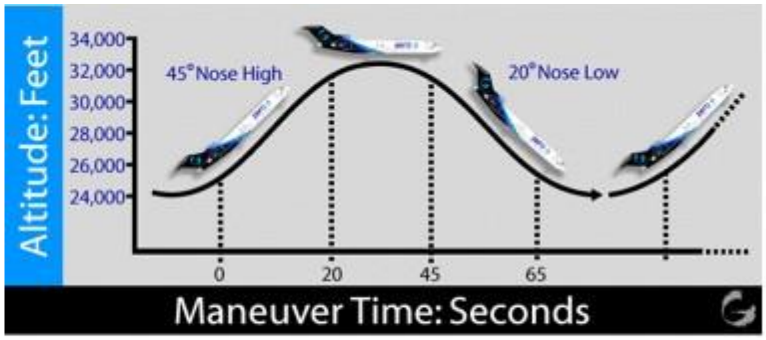

Figure 2: ZERO Gravity Corporation Parabolic Flight Profile (http://www.gozerog.com/)

Parabolic flights are low-cost compared to other platforms and can be booked through a commercial carrier. A parabolic flight can also accommodate human tended payloads which can lower the cost of the experiment by reducing the expense of fully automating a payload. The restrictions on the dimensions and weight of the payload are less limiting when compared to other platforms, and can range from an experiment bolted to the aircraft floor to 'free float' experiments that are released during the nose low phase of the flight. The gravitational environment on a parabolic flight is approximately .01g, and the quality of the microgravity can also be lacking due to g-gitter; the lab's interaction with the aircraft structure and atmosphere.

The ease of access, quick turn-around times, and low cost has resulted in parabolic flights emerging as a top platform for education, the scientific community, and industry. The research being done on parabolic aircraft spans almost every field of science. For example, a Purdue University team devised an experiment to model the behavior of flexible diaphragms in a micro-g lab environment that could apply to future on-orbit depot development ("NASA Reduced Gravity Student Flight Opportunities Program"). Another company, Made In Space, used the parabolic platform to test and debug their 3-D printing machine before its costly trip to the International Space Station (Made In Space).

Sounding Rockets

Sounding rockets are expendable rockets that take payloads on a parabolic suborbital trajectory that results in anywhere from 5-20 minutes of reduced gravity. Since these rockets are expendable, they come with a price tag in the millions (Jurist) and consequently have potentially a long lead time. A researcher could potentially wait anywhere from 3 months to a year for a ride on a sounding rocket. However, these vehicles currently provide the longest duration of microgravity of any platforms without paying the even higher price tag to orbit and is a popular platform within the science community. Sounding rockets launch from licensed facilities carrying payloads to predetermined altitudes ranging from 40km to some as high as 1500km, and provide a high quality microgravity environment (Eberspeaker). The payload will usually return via parachute and can be recovered and reused. The launch and recovery operations of a sounding rocket places a high load, comparable to that of drop towers, on the payload. This typically results in a higher cost to develop and build the payload.

Research done on sounding rockets consists of in-situ measurements of the upper atmosphere (aeronomy), astronomy, and research that depends on extended periods of microgravity. Using a Starfire rocket built by EER Systems Corporation, a NASA funded launch carried experiments from two universities to study the effects of microgravity on various materials and biomedical samples. These experiments were possible because a microgravity environment was needed for an extended period of time, a condition that was not fulfilled through drop towers or parabolic aircraft. This particular mission provided 7-8 minutes in a micro-g environment (NASA).

Orbital platforms

The International Space Station (ISS) is currently used as the primary orbital platform for research and development in micro-g that requires long duration access. Orbital platforms can provide days to months of access to the micro-g environment. Astronauts aboard ISS can also tend to a payload while on orbit. However, because of the cost and frequency of current launches to the ISS, the pipeline for payloads is incredibly long. With more orbital platforms in development, this lead time has the potential to diminish. The cost of an orbital launch is incredibly high compared to all other platforms and will be a significant factor for utilization of this platform for microgravity. With more vehicles under development, this price has the potential to decrease but will still be much higher than other existing platforms. However the quality of micro-g and the long duration of access is unparalleled, making this platform invaluable for microgravity utilization.

Currently, all science and research conducted on the ISS is through NASA astronauts. This can be a major constraint for organizations and can also increase the risk of a non-successful experiment. However, this has not stopped many organizations from conducting research and technology development aboard Station. Amgen, a pharmaceutical company partnered with BioServe Space Technologies conducted bone and muscle loss studies aboard the ISS. The research collected from this experiment is applicable for long term human exploration missions and for fighting bone and muscle loss via aging on Earth (NASA, International Space Station Program Science Office). Even more recently, the advertising firm Dentsu, the University of Tokyo, robot developer Robo Garage and Toyota teamed up to develop and send a robot to Station to act as a companion for ISS commander Wakata from the Japanese Aerospace Exploration Agency. Along with advertising for the companies involved, the robot is part of a broader study of robot companionship for long periods of isolation and is testing its navigation systems in microgravity environments (Kibo Robot Project).

Reusable Suborbital Launch Vehicles (rSLVs)

New reusable vehicles under development will provide another platform of access to the microgravity environment. Reusable suborbital launch vehicles (RSLVs) will take payloads to about 100km and will provide approximately 4-5 minutes of high quality microgravity. Depending on the vehicle, human tended payloads can also be accommodated, lowering the cost of development and opening up the possibility of what kinds of research can be conducted. In addition, because of advances in engine capabilities these vehicles have low turnaround times and are proposed to be flown daily. Vehicles that will be flying tourists and payloads in the coming years vary from vertical take-off, horizontal take-off and even release from an aircraft. The cost of these platforms are much higher than drop towers and parabolic flights but are a fraction of the cost of a sounding rocket, although they cannot deliver the same duration of micro-g time as some sounding rocket vehicles. These vehicles have created much hype in various industries for their uses, from space tourism and concerts in 'space' to scientific research.

Virgin Galactic's SpaceShipTwo and XCOR Aerospace's Lynx are two rSLVs that are in development and projected to be flying with passengers and research in the coming years. NASA's Flight Opportunities program already has multiple payloads in the pipeline for these vehicles. Researchers have proposed a variety of experiments for these vehicles. One team will be testing cryogenic chill down processes in microgravity to create an efficient system for a reliable cryogenic supply for future in space exploration operations ("Near-Zero Gravity Cryogenic Line Chilldown Experiment in a SRLV"). Another will be looking at particle dispersions in microgravity to create a predictable model of behavior for these particulate materials to better understand nebulae clouds in space and even volcanic ash plumes here on Earth (“Particle Dispersion System for Microgravity Environments”).

OBJECTIVE 2: APPLY THE PARTS MODEL TO THE MICRO-G UTILIZATION MARKET

Introduction to Game Theory

Characterization of the microgravity utilization industry was done using a realization of game theory, the PARTS model, developed by Brandenburger and Nalebuff. Game theory refers to "the study of mathematical models of conflict and cooperation between intelligent rational decision-makers." (Myerson) While not analyzed mathematically, the PARTS model of game theory was used to identify the major factors governing the development and utilization of the microgravity market. PARTS stands for Players, Added Value, Rules, Tactics and Scope. These elements will be presented and expanded upon in the analysis that follows.

Scope

The scope of the game defines its boundaries and allows for a more focused analysis of its dynamics. Industry boundaries are largely artificial, however, drawing a boundary around what is and is not a part of the game is necessary to draw clear conclusions. It is important to note that while this paper is concerned only with the microgravity utilization market other industries and players can and do have important impacts on it. Examples of activities beyond the direct scope of this analysis including commercial space tourism, remote sensing of the Earth, and other activities that may occur in the same domains but are not built upon the microgravity experienced.

For the purposes of this analysis, the scope has been limited to microgravity utilization for the purposes of research and development. Specifically, how government, academia, and industry utilize this market. Other uses for reduced gravity are in existence, and are called out below in the players section under complementors, but this analysis is primarily focused on research and development.

Players

The players consist of four main groups: suppliers, customers, competitors, and complementors. The suppliers are the specific entities that provide the industrial products, capabilities, and services required to expose payloads to a microgravity environment and have been reviewed in Objective 1. The customers are those utilizing and financially supporting the direct or indirect utilization of microgravity offered by the industry in consideration. Complementors can come into play on the demand and supply side of the industry. On the demand side, a player is a complementor if customers value your product more when they have the other player’s product than when they have your product alone. On the supply side, a player is a complementor if it’s more attractive for a supplier to provide resources to you when it’s also supplying the other player than when it’s supplying you alone (Davidian). Finally, competitors are the players who are supplying a competing product or service that reduces the demand for the industry’s offerings. The relationship between each of these is graphically displayed in the value net below.

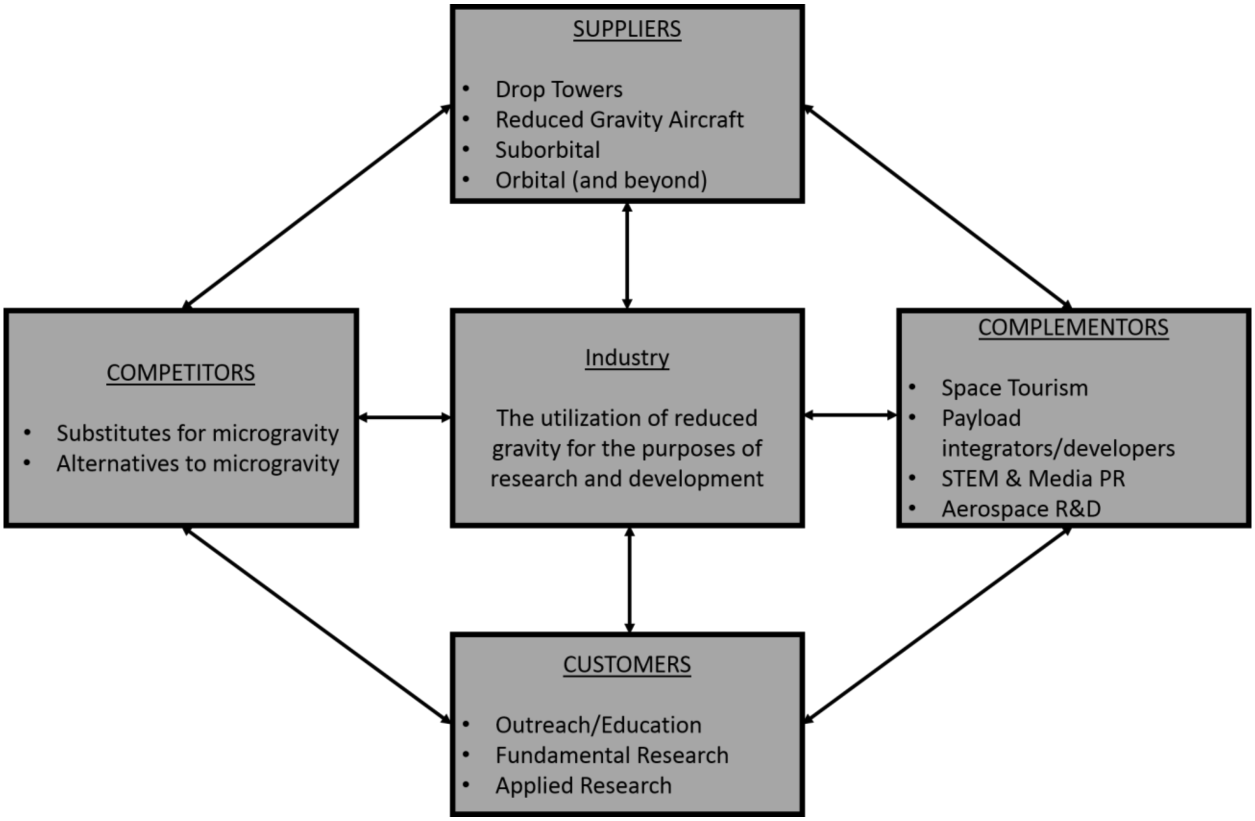

Figure 3: Players and their interactions around the industry.

As stated previously, suppliers of microgravity for the purposes of R&D have been covered in the preceding section. The entities comprising the other three categories will be reviewed below. It is important to note the role of the government in each of the player categories. The government offers services that supply microgravity for R&D purposes, helps to promote the use of microgravity through commercial companies, utilizes microgravity solutions offered by industry, and helps fund competing technologies. The importance of government in each of these categories is acknowledged but its role will not be a central focus of this paper.

Customers

Primary customers for microgravity utilization are those seeking to do applied research and development (R&D). Applied R&D specifically means technology and product development, and simulation validation. Other customers include those conducting fundamental research, such as those wishing to test and validate a scientific hypothesis. These customers can be independent research organizations, universities, corporations, and educational institutions. Examples of research done with currently available microgravity platforms can be found under Objective 1 of this paper.

Complementors

One of the most important complementors identified is space tourism. The rise of this industry has spurred growth in space based microgravity platforms and has promoted public awareness of the benefits of microgravity research. This can best be seen by the investments in Virgin Galactic's SpaceShipTwo and XCOR Aerospace's Lynx vehicles. While primarily intended to provide access to space for tourism, both companies have announced plans to fly scientific missions as well. The development of these platforms would not have occurred without the space tourism industry as a high profile motivator for investors and platform developers.

While not as substantial as the tourism industry, the unique positioning of rSLVs for in-situ measurements of the atmosphere that too high for aircraft and too low for satellites have also spurred interest from the research community. Dubbed the 'ignorosphere,' the potential of extensive data collection in this area has captured another area of researchers. In addition, the onset of new microgravity platforms, both suborbital and orbital have created a renewed need for payload integration companies that work with customers and vehicle providers to arrange the flights while reducing the complexity for the customers.

Another important complementor to the microgravity R&D industry is the aerospace industry in general. Innovations in hardware and/or processes can help improve the overall availability and reliability of current microgravity providers. Additionally, as the commercial space industry continues to grow, new microgravity R&D platforms may be developed.

While not all microgravity providers are space based, important synergies can be leveraged by space based providers. Like the synergy that exists between the microgravity R&D industry and the space tourism industry, space based microgravity providers can use the unique properties of space to improve their overall market position.

Competitors

The primary competition to the microgravity R&D field are those research methods that can replicate the effects of microgravity without reducing gravity; examples of which are diamagnetic levitation, neutral buoyancy labs, and computer simulations. A common trait of any microgravity alternative is that they can only replicate certain aspects of microgravity; not the full effects of microgravity.

Rules

The rules that govern the provision of microgravity utilization services and capabilities are governed by general corporate common laws as any other transactions would be. Furthermore, this sector is heavily impacted by involvement of government regulators, national space agencies, and supplier specific requirements and limitations.

In terms of government regulations, the provision of microgravity via parabolic flight, suborbital flight, and orbital flight are regulated to various degrees by the Federal Aviation Administration in the United States. Parabolic flight is governed by regulations on safe aviation practices by the Federal Aviation Administration (FAA) in the U.S. and equivalent regulatory agencies abroad. Suborbital and orbital launch and re-entries are governed by the FAA Office of Commercial Space Transportation (FAA AST). For on-orbit platforms there is currently no legal regime in place to regulate activities in general. The International Space Station, however, is regulated by national space agencies and via international agreements.

Beyond these regulatory rules there exist certain restrictions and uncertainties posed by government involvement that must be considered. The application of intellectual property law is ambiguous in space, particularly on the International Space Station. Further confounding the complexity of performing research using space related platforms is the existence of export controls both in the United States and in other countries. Restrictions on the exchange of technical data and flight hardware present challenges to users of microgravity platforms that leverage space and/or rocket technologies in the process of delivering the desired environment.

Outside of the government, suppliers also impose rules primarily through constraints on the payload for safety and mission assurance. Through payload users guides, suppliers can place restrictions on the payload such as its contents and dimensions. Vehicle providers will often impose rules to protect the safety of the crew and the participant which may also affect the primary payload being tested. Additionally, suppliers also impose rules that protect sensitive technologies of their vehicle and may restrict access to parts of their platforms or impose other internal measures for security.

Finally, the customer also enforces rules on the supplier that directly affect their business such as accountability for mission success and assurance for required test parameters (such as expected micro-g quality and time).

OBJECTIVE 3: IDENTIFY POTENTIAL GROWTH STRATEGIES FOR MICRO-G UTILIZATION MARKET

The strategies and tactics identified to grow the microgravity utilization market are based on the misperceptions that are currently hindering its expansion and on new perceptions that may galvanize it.

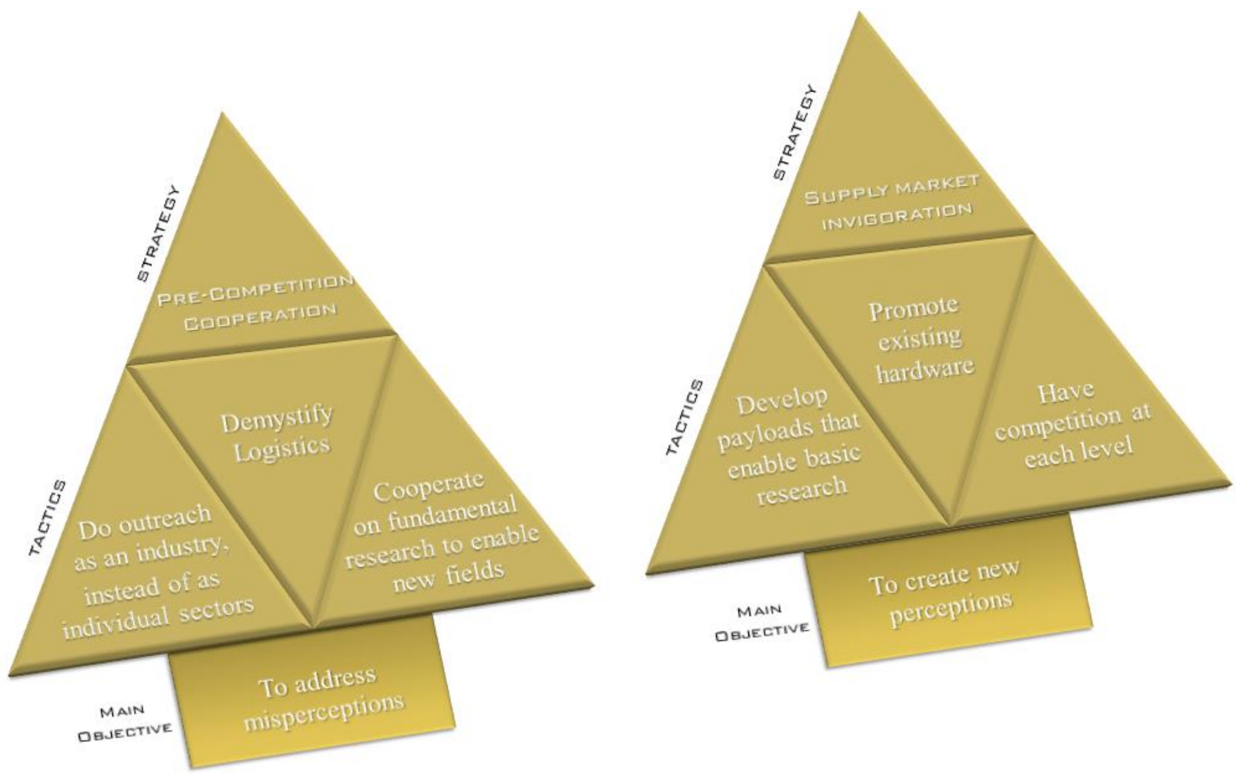

Figure 4: The two recommended strategies can be implemented in parallel and are driven by two different main objectives.

In this approach two strategies are recommended. The first strategy is focused on addressing the currently existing misperceptions, which are inhibiting the market from growing. This strategy requires cooperation by the current suppliers, payload integrators and funding agencies.

The misperceptions of highest impact can be grouped in two categories. First, it is commonly believed that microgravity is a research platform only for those who work in close relationship with NASA and/or on space exploration. Just as this misperception needs to be weakened among scientists and commercial sectors, the exact opposite needs to be created as a new impression: space-based research is not only for space-related applications but non-traditional fields can also benefit from it. This can be done through outreach such as educating the non-space community on microgravity experiments that have already flown and on potential applications. For example, it is not well known even by the space community, that the lumber and paper industry can take advantage of the microgravity environment (Campbell) (Cowles) or that non-space related companies, such as Coca Cola, have flown R&D experiments to space (Gupta) (Rudick). The outreach effort, where stories such as these would be broadcasted, should be conducted in a cooperative fashion where the entire industry takes part. Current customers in cooperation with suppliers need to showcase the work being performed in a microgravity environment such that it will incite new ideas and ventures in the microgravity market. Additionally, those experienced with conducting research in the microgravity market should partner with 'untraditional' sectors to perform fundamental research that will enable new fields to emerge for the micro-g environment.

Strategy I: Pre-Competition Cooperation
Current misperceptions being addressed
Microgravity platform doesn't provide any benefits
Schedules and performance are unreliable
Microgravity experiments are too complicated
Risks involved are too high
Perceptions being created
Space-based research is not only for space-related applications
Payload integrators take care of all the bureaucracy/documentation
Tactics
Do outreach as an industry
Cooperate on fundamental research to enable new fields
Demystify logistics

Table 2: The first strategy aims to address current misperceptions. It does so through three tactics, which also create new, positive perceptions.

The second category of misconceptions speaks to how microgravity research is "rocket science", *i.e.* believing that experiment planning and execution is extremely complicated, schedules are unreliable and the programmatic risk is too high. To counteract this misperception, payload integrators and suppliers need to demystify the logistics behind microgravity experiments by informing potential customers what testing a payload entails. Having a payload user's guide is not enough for someone who is not familiar with research in this field. Similarly, current funding providers, *e.g.* NASA and CASIS, do not have a "one opportunity to fly" mentality when it comes to microgravity research. For example, the U.S. National Lab part of the ISS is intended to be used as a laboratory, where if an experiment does not perform as intended the first time, it can be re-flown and lessons can still be learned from the first flight.

Strategy II: Supply Market Invigoration
Perceptions being created
Ready-to-fly hardware is available for a myriad of research fields
Funding is available from governmental sources
Tactics
Promote existing hardware
Develop payloads that enable basic research
Have competition at each level

Table 3: The second strategy aims to create new perceptions. It does so through three tactics, which should be implemented by each individual organization.

The second strategy focuses in creating new perceptions to stimulate market growth and does not require cooperation between entities. As a matter of fact, the implementation of this strategy through the recommended tactics would permit for supplier and payload integrator differentiation and competition. This strategy aims to create two new perceptions:

1. There is ready-to-fly hardware for a myriad of research fields.
2. Funding is currently available from governmental sources.

The first recommended tactic to achieve this is to identify non-traditional uses for currently existing hardware and promote it to non-space related entities. This would allow payload integrators to reduce engineering costs and maximize return on investment on their existing hardware. Another recommended tactic is for payload integrators and suppliers to develop new payload technologies that enable basic reduced gravity research. These new technologies should keep in mind standardization and modularization to galvanize horizontal translation of research programs and knowledge.

The final tactic for market invigoration is one that has long been held true for growth in the marketplace: competition. With multiple suppliers vying for a piece of the market, technologies will continue to evolve for the benefit of the customer and prices will stay at a reasonable price for the service being offered.

CONCLUSION

The FAA COE ESIL-04 workshop held in Louisville/Broomfield, Colorado set out with three objectives in mind: To develop an understanding of the current microgravity utilization industry, evaluate the microgravity utilization market through the application of Game Theory and the PARTS market model, and identify favorable applications of microgravity platforms and key areas for beneficial partnerships in industry.

Through presentations and discussions with industry, the participants of the workshop gained insight to current and future platforms for access to a microgravity environment as well as research utilizing these environments. With this understanding and the use of Game Theory and the PARTS market model, the microgravity utilization industry was further defined through its scope, players, and the rules that it is governed by. By evaluating an industry through its individual components, strategies were outlined to further grow the microgravity utilization market and invigorate the current market.

The recommendations from the ESIL-04 workshop was grouped into two categories. The first of which was to address common misperceptions of the microgravity utilization market and create new positive perceptions through outreach as industry, cooperation on fundamental research, and through transparent logistics. The second recommendation can be executed by individual suppliers and is aimed at invigorating the current market through the promotion of existing hardware, developing template payloads that enable basic research, and encouraging competition at every level.

These strategies are aimed to create sustainable growth in the microgravity utilization market to advance science, research, and technologies to enhance our lives in space and here on Earth.

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