Earth Based Gravity Machines

Phase 1, Feasibility Study Report

Mike Conroy – Florida Space Institute with the Center for Microgravity Research – 12/12/2019

Opportunity

Studies indicate a relatively small number of microgravity drop towers in the world today. Microgravity duration up to 2 seconds is rare and drop towers providing over 3 seconds are limited to a small number of national institutes in the US, China, Japan and Germany; with the longest microgravity duration under 10 seconds. Any testing involves travel or remote testing, dramatically limiting educational involvement other than sub-second experiments in room sized facilities.

Vision

A Gravity Machine will dramatically increase the availability and quality of microgravity sources in the State of Florida. The approach is twofold. The first effort will focus on microgravity opportunity awareness and science. It will create a set of easily reproducible, portable, microgravity stations, providing from 3 to 4 seconds of microgravity, for CubeSat 1U and 2U sized payloads and suitable for simple Research and STEAM (Science, Technology, Engineering, Art and Math) Education. The Center for Microgravity Research team will create a set of reproducible microgravity research components, experiments and challenges suitable for middle and high school educational experiences specifically for targeted educational opportunities (STEAM, At Risk, Under Served). The second focus will create a financially self-sufficient, Florida based, research quality microgravity source suitable for undergraduate and graduate level research, providing 4 to 12 seconds of microgravity as well as support services and expertise necessary for continued STEAM education activities. Design work for both areas will be performed through the Florida Space Institute by Florida University Senior Design teams and design competitions. The overall activity will be managed by the Florida Space Institute (FSI).

Phases

Complex efforts are often best broken into segments. Ideally, the segments can stand alone, will provide usable value at the end of the phase and provide a window (between segments) to enable modification of the effort, the inclusion of new systems / information or assessment of work to date for continuation or termination. This project is no different. The project is broken into 4 phases:

Phase 1 – Feasibility Study
- A look at the physics, technologies, state of the art and operational concepts.
- Test goal is 3 seconds of Microgravity
- Will determine if project continues to Phase 2

Phase 2 – Mark 1 Vehicle
A basic vehicle suitable for STEM/STEAM outreach
Goal is 3 to 4 seconds of Microgravity
Will include a series of basic student microgravity experiments
Will determine if project continues to Phase 3

Phase 3 – Mark 2 Vehicle
A more advanced vehicle, longer duration and higher quality Microgravity
Goal is 4 to 8 seconds of Microgravity
Will determine if project continues to Phase 4

Phase 4 – Mark 3 Vehicle Study
Significantly more advanced vehicle and lift system
Goal is 8 to 12 seconds of Microgravity
Study only, no development

Phase 1 – Feasibility Study

Content

The Feasibility Study will focus on assessing the suitability of a drop vehicle (3 concepts), weighing up to 16 pounds (4-pound reserve for payload), to provide adequate (~10-2 G) microgravity to support education and research. The Study will include a series of instrumented drops to quantify vehicle performance and the provided microgravity environment. The vehicles will be developed by UCF MAE Senior Design Teams. Lifting services will be provided by a commercial drone operator and commercial instrumentation will measure and record the vehicle dynamic environment as well as wind speed and direction. It is expected that the vehicle will also include a payload mass simulator with an easily removable instrumentation package. A payload integration system (rails, clamps, access) is not required for the Study, just installation and removal of the instrumentation package. It is envisioned that the Carrier will release the Drop Vehicle and that short tether will inform the vehicle it has been released.

Data will be collected across 3 intervals and conforming concepts will be ranked as follows:

1. Segment 1, 25% - 0.25 seconds to 2 seconds (disregard release), sum of average acceleration in each axis plus max value for each axis
2. Segment 2, 50% - 2 seconds to 3 seconds, sum of average acceleration in each axis plus max value for each axis
3. Segment 4, 25% - 3 seconds to stopped on ground, sum of 3 largest acceleration values minus 3 (approx. necessary deceleration)

Expected Results

The Feasibility Study is expected to provide knowledge on the concept, the operational implications, design limitations and the viability and feasibility of the project. Specific knowledge areas include:

1. Feasibility of the Drone and Drop concept for Microgravity Research as well as initial characterization of the provided environment
2. Recommendations for Phase 2
3. Feasibility of Student Design Teams for further development of the concept
4. An understanding of the operational cadence associated with the Drone Drop concept.

Feasibility Study Results

Event

The Feasibility Study Drop test was held December 4, 2019 at Fort Christmas Park. The large field across from the park was used. Andy Modejo Steady Cam was contracted to provide the lifting service, pilot and safety officer. They also provided the release mechanism.

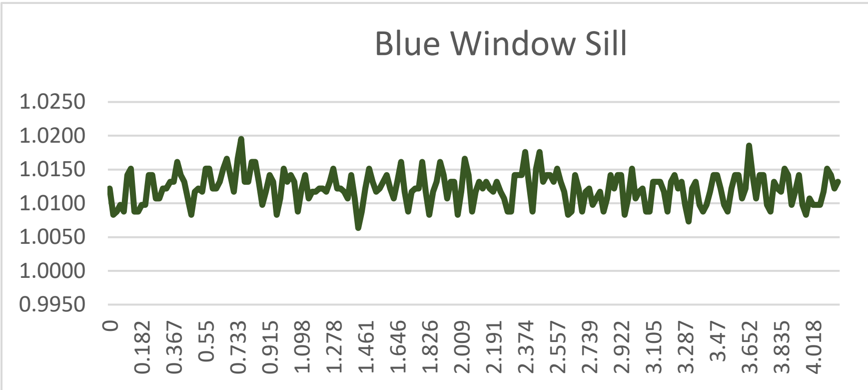
The event day was both cold and windy. It is believed that the cold created issues for the release mechanism, and some of the vehicles and the wind impacted the initial release by both spinning the vehicle as well as imparting a lateral acceleration.

All 3 concepts were tested at least one time. One concepts completed a second attempt. All 3 vehicles succumbed to parachute failures in one manner or another. In 2 of the 3 cases it is likely that, even though the parachute failed, the payload would have survived. In the third case, the tail mounted propulsion system tore loose on impact, traveled the entire center of the vehicle, and exited the nose to bury itself further in the ground than the rest of the vehicle. None of the electronics survived with data (primary or backup). Video footage did show the craft rapidly stabilize upon release and come down cleanly.

Data

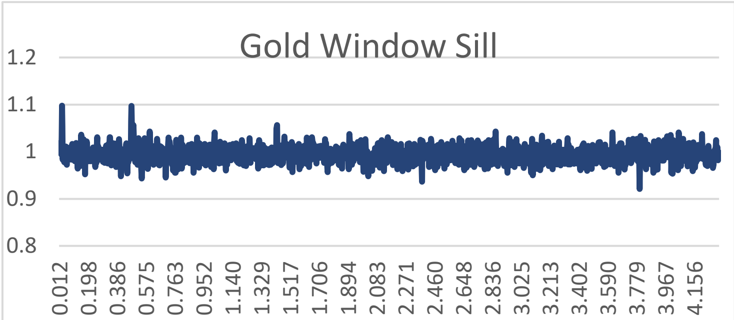
The goal for the Feasibility Study was 10^{-2} G, or Centi-G, with sufficient stability for useful microgravity research. The charts below show accelerometer runs from each of the 2 surviving data recorders as well as a single run of the structure of the Partnership 1 Building, second floor, room 210 window sill. The building run was used to better understand the noise inherent in the accelerometer package as well as establish an offset to use for analysis. Multiple process improvements have been identified based on the post event analysis. Foremost is to preclude students from altering the standard data capture parameters.

Window Sill Blue



The Window Sill was chosen for a close coupling with Partnership 1 structure and ease of access. The accelerometer was placed on the sill. The Accelerometer used by the Blue team was configured to meet their operational needs, specifically the sample rate was changed from the default 400 Hz to 50 Hz. This effected the noise level rather dramatically. The resulting Blue noise swing is 0.0176 G with an average value of 1.0123G. It is difficult to remove this senor noise after the fact. A lesson forward is to adjust the dead band parameters on the sensor package to reduce the noise to a reasonable level. This will be extended to defining a locked configuration for the data recorders. Feasibility Study recorders were purchased and configured by the teams.

Window Sill Gold

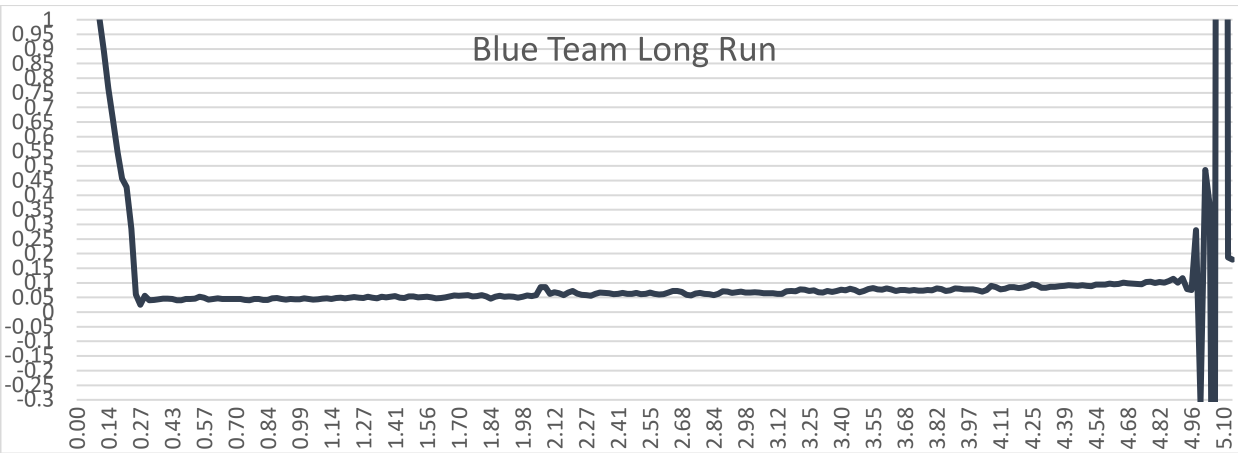


The Window Sill was chosen for a close coupling with Partnership 1 structure and ease of access. The accelerometer was placed on the sill. The Accelerometer used by the Gold team was left in the default configuration, as intended. The sample rate was the default 400 Hz. This effected the noise level rather dramatically. The resulting swing is 0.041 G (twice the Blue rate) with an average value of 0.9943G. It is difficult to remove this senor noise after the fact. A lesson forward is to adjust the dead band parameters on the sensor package to reduce the noise to a reasonable level. This will be extended to defining a locked configuration for the data recorders. Feasibility Study recorders were purchased and configured by the teams.

Blue Team

The Blue Team provided 2 sets of data. One for a premature tether release (0.5 seconds) and the run below. The Blue Team vehicle was the unpowered, highly aerodynamic option. They experienced the first parachute failure of the day with no chute deployment. The vehicle penetrated about 16 inches into the ground and stayed vertical in the field. The oscillation post impact is the avionics section ripping free from the internal mounts and traveling through the nose of the vehicle. The maximum impact was 11.5G. A lesson learned is to pre-define the accelerometer configuration prior to the test. Blue Team data is based on a 50 Hz sample rate, the default was 400 Hz. The lower sample rate was driven by a need to support a significant delay between payload insertion and vehicle delivery.

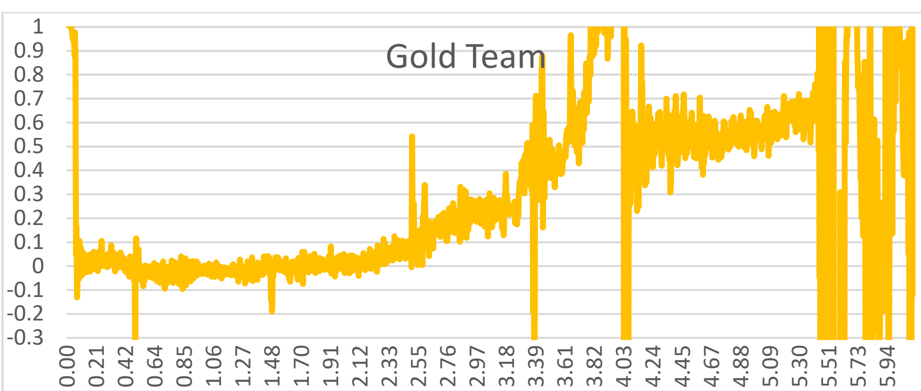
Blue Team data indicates a quick transition to freefall, a noise level of +- 0.005 G during the first 2 seconds of flight centered on a 0.05 G line. Noise rose a bit as velocity increased as did aerodynamic drag. The bias from the Window Sill data indicates that the true number would be closer to 0.0377 G. The line climbs slowly as aerodynamic drag builds. The defined end of the test was at 3.0 seconds. At that time, the Blue Team Vehicle has increased to about 0.065G and the noise is close to +-0.01G. Adjusting for the Window Sill data, the true value would be close to 0.0527 G with buffeting in the +-0.01G range. This noise level is very close to the baseline noise reading taken on the window sill of Partnership 1.

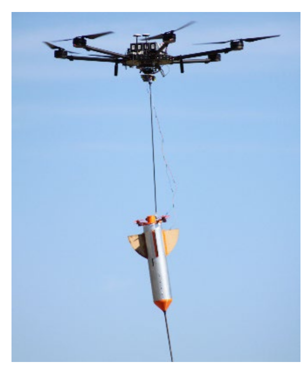


Gold Team

The Gold Team is the only team to fly twice. The initial drop was a short duration system test to validate parachute operation. The second flight was for the full 3 seconds. The Gold Team vehicle combined pusher propellers with a landing lance protruding from the nose. The Gold Team ran the accelerometer as the standard 400 Hz rate. The landing lance was designed to pierce the ground and reduce speed over the length of the lance. The parachute system was designed to reduce velocity to what was considered a reasonable level and ensure a vertical strike for the lance. One shortcoming of the Gold vehicle is that the parachute mechanism precluded a clean attach point. The vehicle was lifted slightly off center, resulting in a short period of oscillation upon release. During the short term test, the parachute did not provide a stability function and the vehicle swung in a wide arc that resulted in the lance striking the ground at a significant angle. However, the entire system was recovered without damage. During the long run the parachute ripped free. The lance pierced the ground at the correct angle, but at a rather high velocity. The lance was bent, but the vehicle was recovered.

The Gold Team data indicates the initial period of release instability, engine start and the point where aerodynamic drag overcame the ability of the motors to compensate. Visible is the parachute deployment around 3.5 seconds as well as the parachute failure around 4 seconds. Ground impact is visible around 5.45 seconds. The nature of the lance is such that the vehicle bounced on the lance for some time. The Gold Team vehicle was able to approximate 0.0G, but with a noise band of 0.05 to 0.09G. It is of note that this noise band extends throughout most of the powered phase of the flight, growing slightly as velocity increased. The gold team vehicle was significantly lighter than expected, weighing only about 14 pounds. It was also significantly less aerodynamic than either of the other concepts. Adjusting for the Window Sill data, the true value would be close to 0.04 G with buffeting in the +- 0.01G range. This noise level is very close to the baseline noise reading taken on the window sill of Partnership 1.





Black Team

The Black Team only flew one time. Their concept was to overcome aerodynamic drag with cold gas propulsion instead of propellers. They too suffered a parachute failure, however upon impact the gas bottle, valves and control system dislodged and moved from the rear of the vehicle, through the vehicle, and out the font of the vehicle. This destroyed the vehicle avionics as well as dislodged elements of the accelerometer, including the start switch and battery. This corrupted the data being written to the memory card. The destruction of the avionics also corrupted the data on the back up accelerometer.

Conclusions:

Parachute Design Needs Work

All of the teams experienced Parachute related issues. Two were related to complete non-deployment, one to a materials problem during the high speed deployment. Future teams will need to further develop Parachute options and sufficiently test them prior to the flight tests.

Free Fall is Viable for Short Duration Flights

The Blue Team vehicle was the Free Fall concept. It was highly aerodynamic and provided a stable platform. Aerodynamic drag did not begin to appreciably influence the data until after the 2 seconds into the drop.

Powered Flight Can Control Microgravity

The Gold Team vehicle demonstrated the ability of a powered descent to overcome aerodynamic drag. The Gold vehicle was significantly less aerodynamic than either of the others but held a constant G for just over 2 seconds. At this time aerodynamic drag overcame the power of the engines used.

Low Cost Options Exist

The Gold Team vehicle, during flight and testing, demonstrated the ability to perform microgravity experiments with a low cost vehicle. A combination of a more aerodynamic vehicle coupled with the Gold Team Recovery Lance and a multi-story building with a none paved surface should provide up to 1.25 seconds of test environment for under $100. The fact that this would be an unpowered implementation dramatically reduces complexity while the Lance design has demonstrated durability with a 400 foot, un-arrested drop.

Next Steps:

1. Consultation with the Center for Microgravity Research about any changes to the Phase 1 requirements, suggestions, goals and needs.
2. Discussion with Florida Space Grant on suitable options for STEM education.
3. Develop planning for Phase 1 implementation in Fall of 2020.
4. Specification development for the Phase 1 competition.