Investigation of Artificial Gravity Habitat Dynamics

Oklahoma State University Space Cowboys Research Team

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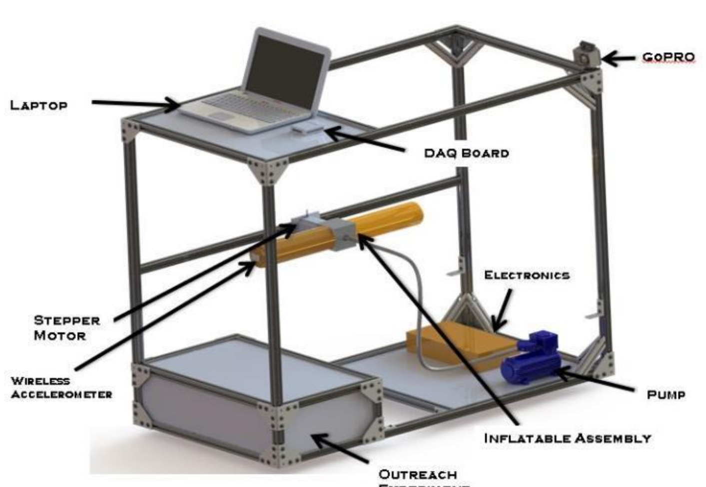
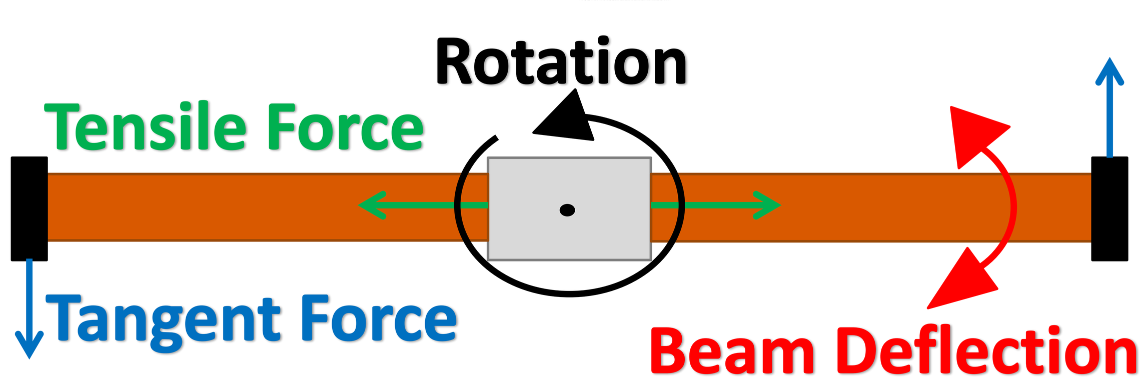
Background

Future envisioned missions to deep space elicit problems and challenges not fully investigated by the world's spaceflight organizations. One of the most prominent issues is prolonged exposure to weightlessness. The human body functions day-to-day with the resistance and force of gravity; in the absence of this phenomenon, bones/muscles swiftly atrophy. Another alarming effect, which has been acknowledged in recent years, is loss of vision due to prolonged spaceflight.

Abstract

Using inflatable structures to generate artificial gravity through rotation could solve many of the issues with prolonged exposer to zero gravity environments. For a small-scale investigation of this concept, the OSU team has designed an inflatable beam rotating experiment. The effects of various internal pressures on the beam's stiffness and rotational stability will be examined. The concept developed by the Oklahoma State University Space Cowboys team consists of rotating air beams within an aluminum frame. The end-caps on each inflatable beam simulate crew quarters or a similar structure where a continuous gravity force is desirable. The experiment is designed to allow the deployment pressure to be altered between test runs (parabolas). This will allow the team to examine the effect of varied pressure, hence beam stiffness, on the stability of the structure under various rotation rates in a reduced gravity environment. Demonstrating the feasibility of this concept will provide an additional solution path for long-duration space missions, providing NASA with data and design concepts to help justify further development.





Hypothesis

The Oklahoma State University Space Cowboys hypothesize there is a correlation between internal beam pressure and beam stiffness that in turn produces stable rotation. Each test will fix a defined internal pressure. A near constant acceleration criteria, along with advanced motion tracking methods, will be used to quantify the optimal inflation pressure that produces inflatable beams that resist wrinkling when rotating. The team expects that there will be a measurable difference between the pressure required to induce wrinkling during ground tests and in 0g. Ground tests in 1g will be performed with the same pressures to be examined during actual flight testing so that the differences between the two environments can be compared.

Methodology

The team held constant the beam length, angular velocity, and the mass at each end of the beam throughout the experiment. The independent variable was the internal pressure of the beams. Varying the internal pressure allowed our team to monitor beam stability and acceleration at the end caps as a function of internal pressure. The following formula describes the relationship between angular velocity, radius, and force produced.

$$g = r\omega^2$$

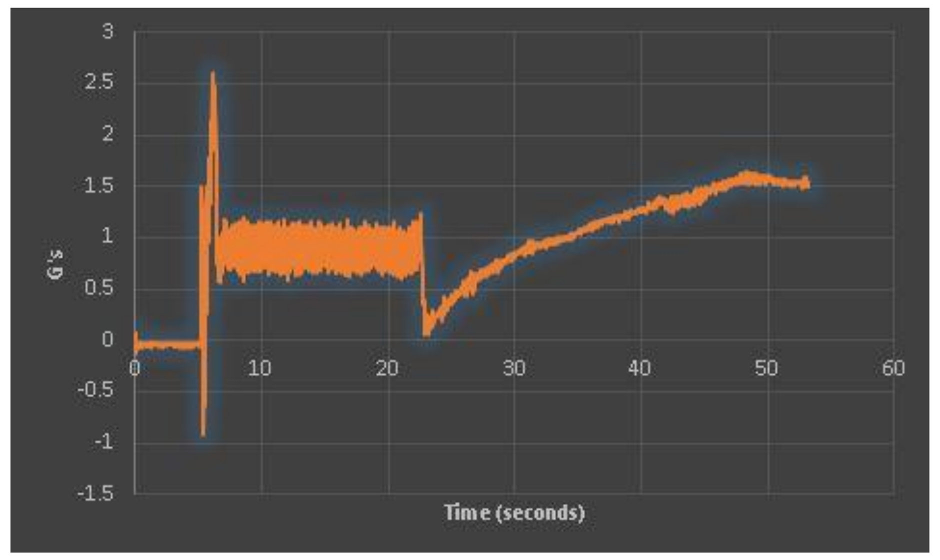
Our team selected a beam length of 16 inches, and an RPM of 47 based on size limitations and capabilities of our inflation, monitoring, and motor systems.

$$32.2\frac{ft}{s^2} = 16in\left(\frac{1ft}{12in}\right) * \left(47RPM\left(\frac{2\pi}{1R}\right)\left(\frac{1M}{60s}\right)\right)^2$$

The experiment consisted of an inflatable, rotating beam structure which is intended to generate artificial gravity by means of rotation. The rotating beam assembly consists of two 16 inch beams, made of heat sealable polyurethane-coated nylon, that are connected to a hub joint which is mounted onto a Applied Motion HT23-399D high torque step motor. The aluminum hub joint is connected to the pressurization system via a quick-connect valve. Under this design, both air beams will share a common inflation pressure of 1-3Psi. The experiment will be monitored and triggered by a separate accelerometer mounted on the test frame. Once inflated, the DC stepper motor will begin spinning at 47 RPM, and the video cameras will monitor the condition of the beams throughout the experiment.

Results

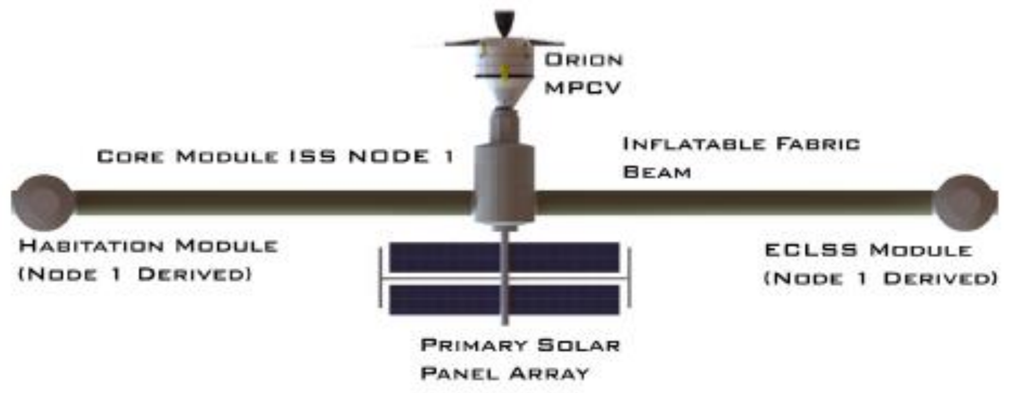
The team experimented with pressures from 1 to 3 psi. The flight footage revealed no visible buckling, along with nothing unexpected from the onboard accelerometers. At the lowest pressure the team expected for some form of buckling to occur. However, there was no sign of wrinkling or buckling even at the absolute minimum pressure, sometimes dipping below 1 psi. This is remarkable considering that the inflatable sometimes experienced the maximum impulse of acceleration possible, 2.6g, during spin-up before reaching the 1g level of artificial gravity; as seen below.



For the brief instant during spin-up, the .02 pound inflatable resisted buckling against an equivalent force of .92 pounds during the maximum impulse. Resisting buckling against 42 times the inflatable's own mass is quite impressive.

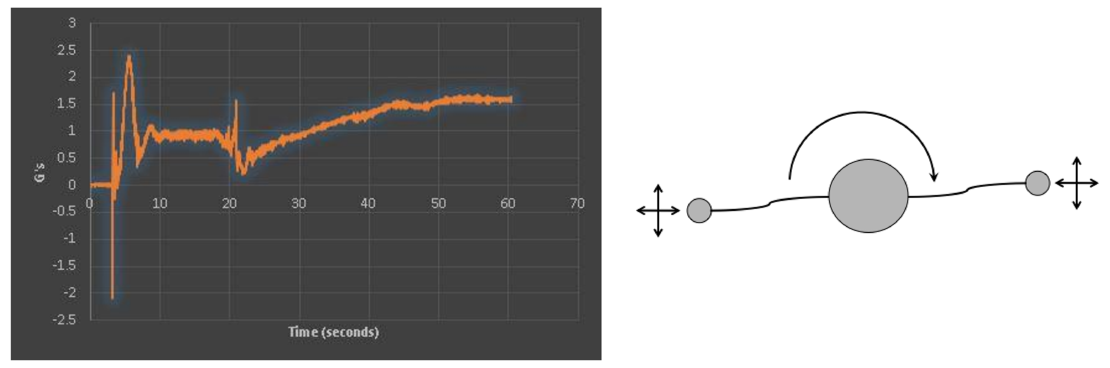
Conclusion

The team gathered even more information about inflatable technology and its benefits to add to Oklahoma State's growing portfolio of inflatable research and development, most notably, that an inflatable beam model can resist buckling during an artificial gravity spin-up procedure up to 42 times its own weight in force. This promotes further research and development of inflatable spacecraft. Our concept vehicle, as seen below, has a radius of 30m and a rotation rate of 5.45 RPM which will produce an artificial gravity level of 1-g. The design configuration shown here uses current ISS hardware, such as Node 1 modules and the MPCV, to keep costs low.



Discussion

Our experiment had one unexpected outcome during a pressure system failure, which caused the beams not to inflate during the test. However, despite the loss of internal pressure the 1g environment was maintained; as seen below.



In the event of a pressure source malfunction where the correct internal pressure could not be reached, the concept spacecraft could still generate artificial gravity. If there was an adequate supply of reserve propellant to correct for deviations in trajectory due to the increased duration of instability before the 1g equilibrium is reached, the inflatable beams act as a tether. This result is not surprising, but perhaps overlooked during the experiment planning.

Further Study

Additionally, the Coriolis effect is one aspect that our team was unable to account for in our scaled experiment, which would be a serious constraint in a prototype. As rotational speed is increased, a significant Coriolis effect is produced when a subject attempts to move within the rotating reference frame. A Coriolis force that is too high can lead to disorientation and motion sickness. To reduce the rotation and rate, but retain the necessary level of artificial gravity, a larger rotational radius is needed. The Figure below shows the known relationship between angular velocity, or rotation rate, and rotational radius while overlaying artificial gravity ranges. Note that the perceived amount of "comfort" is related to the Coriolis force and is not dependent on radius, but rotation rate.