CASPER RET 2013 – Modifying the Model Drop Capsule for Optimal Microgravity

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Abstract— **Creating a microgravity environment is desirable for many fields of research including biotechnology, combustion science and fluid physics. One way to create microgravity is a drop tower in which the falling object experiences a period of freefall and is not effected by forces due to gravity. The Baylor Research and Collaborative (BRIC) plans to add a 2 second drop tower to their new facility in Waco, Texas. A visiting German student, Kirk Boehm, fabricated a scaled down model of a freefall capsule for the drop tower. This investigation explores modifications to improve the quality and measurement of microgravity achieved.**

Index Terms—**Drop Tower, Microgravity**

I. Introduction

THERE are many areas of research driven by various lucrative commercial applications where it is desirable to eliminate the effects of gravity in scientific investigations. Forces caused by gravity often mask other science principles at work. In the biotechnology fields using reduced gravity environments could produce great strides with improvements in health, agriculture, and environmental protection. For example, without convection and sedimentation (which are both caused by gravity) better and larger protein crystals can be grown allowing more understanding of their structure and function leading to improved pharmaceutical drug design. Without the effects of buoyancy and convection it is much easier to apply mathematical models in combustion science because the phenomena are more spherical and symmetric. Increased understanding of soot formation and dust clouds can improve coalmine and grain elevator safety. Similarly fluid physics research would benefit from the elimination of convection. Better knowledge of fluid behavior could advance earthquake safety (soil with fluid-like behavior), power plant stability (vapor-liquid mixtures), and heating and air conditioning efficiency (multiphase flow). [1] Reduced gravity can also further the study of nanomaterials. In microgravity larger samples of xerogels can form allowing for better insight for applications involving films in hydrogen fuel cells. [2]

Reduced gravity experimentation can take place on the ground, in flight, or in space. Drop towers and tubes on the ground have a release mechanism, an area of freefall, and stopping apparatus. A plane flying in a parabolic trajectory, such as the modified Boeing 727-200, *G-FORCE ONE*, or a sounding rocket can produce a longer period of reduced gravity, but at a much greater cost. The space shuttle in orbit and the International Space Station (ISS) allow for much longer microgravity conditions, but opportunities are very limited and expensive. In addition to the trade off of duration and expense, the quality of microgravity must be considered. Table 1 provides a qualitative comparison of the factors to consider with different facilities.

Table I.
Main factors that differ with reduced gravity facilities [2]

	duration	cost	quality
drop tower	short	low	very good
plane	medium	medium	low
sounding rocket	medium	high	low
space shuttle	long	very high	good
ISS	very long	very high	good

II. BRIC Drop Tower

There are plans to add a 20 meter drop tower to the

Manuscript received August 6, 2013. This work was supported in part by the National Science Foundation through the Research Experience for Teachers program. This work is also supported by the Baylor Department of Physics.

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BRIC facility. It will be used to test apparatus bound for space and made available to other groups for their own research. A standardized dropping protocol and protective encasement must be created to ensure high quality reproducible low gravity conditions. Rather than creating a vacuum in the drop shaft, the design of the drop vessel will minimize air resistance during freefall.

Visiting student, Kirk Boehm, designed a drop capsule based on the cylindrical one used at the Queensland University of Technology (QUT) because they have a similar height tower and are able to achieve a very low gravity. It has an inner capsule to house the research apparatus and an outer capsule to act as a drag shield and protection for landing. The dimensions of the inner capsule were determined by the space and mass allowed on a sounding rocket. It would have a diameter of 9.1 cm and a height of 95.0 cm. The outer capsule would have a diameter of 113 cm and a height of 135 cm. The inner capsule has flexible space to allow experimenters to attach whatever apparatus and data collection devices they desire. Multiple inner capsules could be available for users to outfit at their own facility before scheduling tower time at the BRIC facility.

III. MODEL CAPSULE

Boehm built a small approximately one third scale drop capsule with commercial off-the-shelf materials. The lid of a small round charcoal grill was used for the bottom of the outer capsule. Pressed particle board was used for the base of each cylinder. Wooden vertical beams were connected to the frame and each other with right angle fasteners. Lightweight plastic wrap covered the outer capsule to eliminate air drag for the inner capsule. [3]

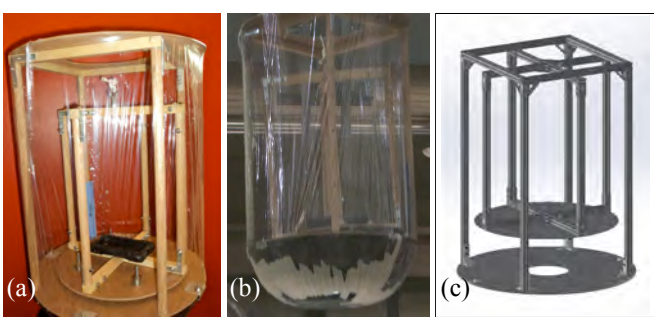

Fig 1 (a) shows the inner capsule, (b) shows the base of the falling capsule, and (c) is Boehm's technical drawing of the plans.

To release the model capsule, an L-shaped wooden support was taped to the rail of the second floor overlook at the BRIC facility. One end of a small braided rope was tied to an eye-hook on the inside capsule. The rope was guided into a wide groove at the end of the wooden support with the other end tied to a screw sticking out of the wood. When the hanging capsule was steady, the rope was cut with scissors.

Fig 2 Wooden support with hanging capsule

The falling capsule landed 6 meters below the initial position into a cardboard cylinder containing a plastic bag of Styrofoam packing peanuts.

Fig 3 Model capsule prepared to drop from the second to first floor of the BRIC facility in Waco, Texas

Fig 4 Packing peanuts used to decelerate the model capsule

IV. INITIAL FINDINGS

An iPhone with an accelerometer application was inserted into a case attached to the inner capsule. A high speed camera was also used to analyze the acceleration achieved. Cutting and even burning of the thin braided rope did not produce a clean release and caused the capsule to tilt while falling. Drops were completed with and without the outer plastic wrap determining that the wrap provided a better reduced gravity. A measured microgravity between 3.46×10^{-2} and 1.83×10^{-4} g was reported. [3]

V. MODIFICATIONS AND RESULTS

In the summer of 2013 two modifications were made to the dropping technique to improve the pursuit of reduced gravity. The braided this fiber rope was replaced by a monofilament fishing line. The same wooden support structure was used and the line was burned with a lighter to release the capsule. This modification was successful. The hanging capsule stabilized much more quickly and fell without tilting. The plastic bag of Styrofoam packing peanuts was replaced with loose peanuts in the cardboard cylinder loosely covered with plastic from a garbage bag for containment. It was easier to fluff the peanuts prior to dropping the capsule and less peanuts scattered on the floor than had previously through holes in the plastic bag.

A free iPhone application from *Mobile Science* was used to measure the acceleration with the *calibrate* toggle switched off. It recorded 100 readings per second for the acceleration in the x, y, and z directions and output the data as an emailed .csv file. The system was problematic in that the counter seemed to reset if the capsule hung too long waiting to stabilize before release. Because of this, only about half of our drops yielded usable data.

The initial drop during the modification process only produced a .45 s period of freefall instead of the full second that was expected. It is believed that the inner capsule contacted the outer capsule long before it reached the packing peanut landing.

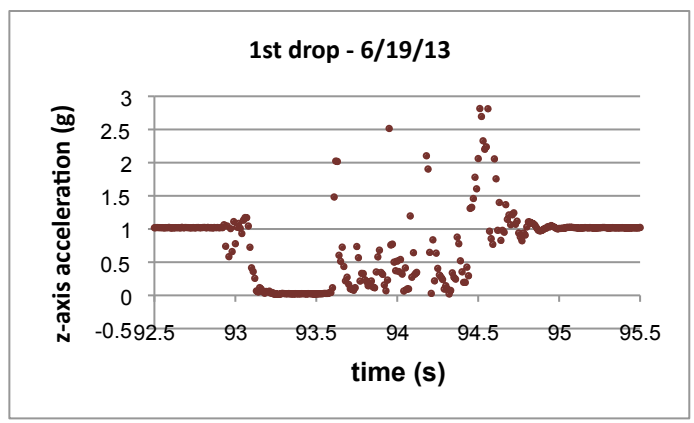

Fig 5 At time 93.2 s a period of .45 s of freefall is recorded

A small mirror was mounted under the iPhone to utilize the video camera feature to record a scale mounted on the outer capsule in order to determine how and why there was not a longer period of freefall. The video quality during freefall was poor and not of use.

Fig 6 Mirror mounted to utilize video camera

To eliminate the problem of the inner capsule hitting the bottom of the outer capsule before landing, the inner capsule was altered by replacing the vertical wooded pieces with shorter ones. Video from an outside vantage point confirmed that with the modification the small capsule was in freefall until it reached the landing point.

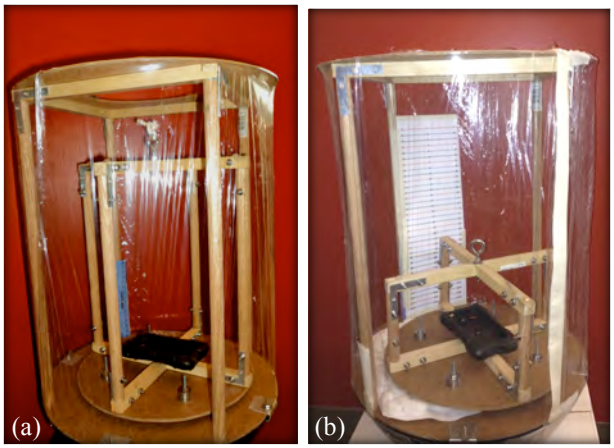

Fig 7 (a) original and (b) shortened inner capsule

The shape of an item determines the amount of air drag it experiences. Fig 8 suggests that a rounded top would produce less eddy currents and therefore better microgravity than a flat top. The lid of the small round charcoal grill that was used on the bottom of the capsule had a base that was added to the top of the capsule as shown in Fig 9. Three small spring clips held the rounded *hat* in place.

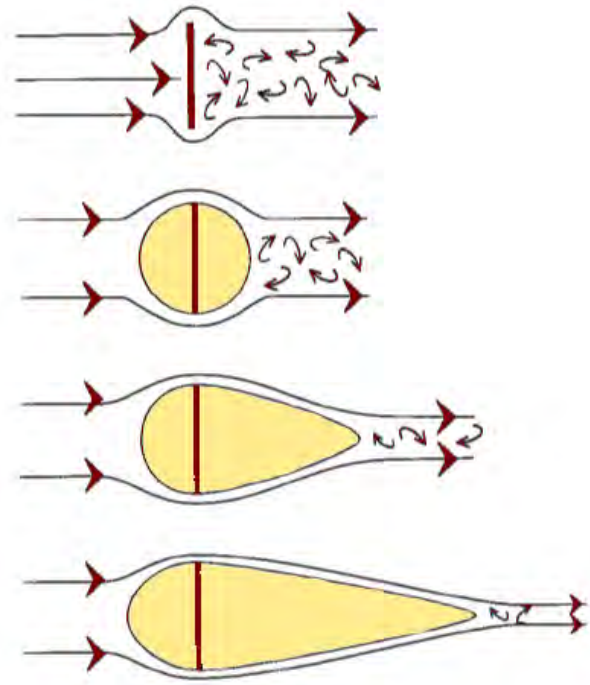

Fig 9 Form drag depends on shape

Fig 9 Rounded *hat* added to model drop capsule

Adding the rounded top did improve the quality of microgravity experience by the falling capsule. The average value of acceleration in the z direction was reduced by 16%.

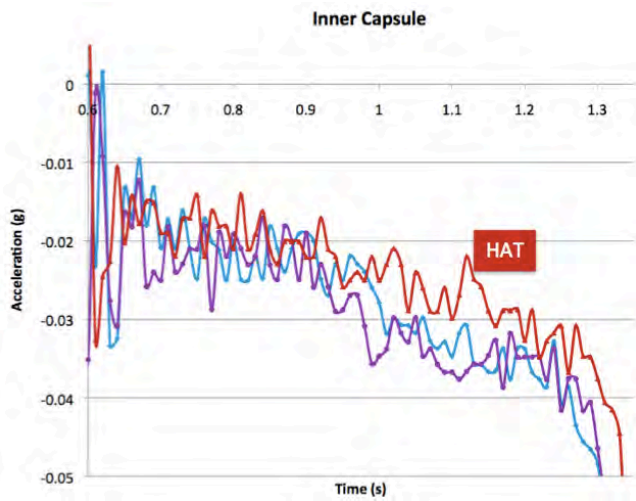

Fig 11 The acceleration of the capsule with the rounded top (red) compared to two drops without the *hat* (blue and purple)

Because little was known about the iPhone acceleration application, a simple adjustment was done to compensate for the accuracy. Data was recorded while the phone sat motionlessly face up on a desk for 6 seconds and then flipped face down to sit 6 additional seconds. As shown in Fig 12, the average of the two values was considered to be zero. With the calculated *flip calibration* of -.015757 g applied, the smallest inner capsule z acceleration recorded was -.007111 g. This value falls short of the 10^{-4} range that is desired.

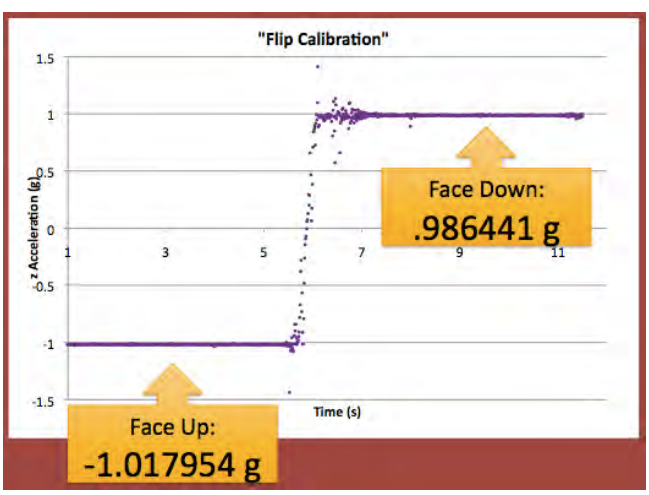

Fig 12 Determined the adjustment for acceleration data

Another modification to the model capsule involved the outer wrapping. There was a concern that the thin plastic Saran Wrap flapped enough to adversely affect the aerodynamics of the capsule. A desire to view the inner capsule during freefall limited the wrap options to transparent materials. A heavyweight clear shower curtain was stretched taunt and secured with duct tape at the top and bottom of the outer capsule. A closable flap remained to access the iPhone accelerometer. Data was successfully obtained for only one drop with the shower curtain wrap, but the results were inconclusive. More testing must be conducted to determine if the microgravity benefited by the adaptation. The experimenters did feel more comfortable handling the capsule and the hat securing clips did not tear the wrap with the stronger material.

To numerically confirm that the inner capsule's relative acceleration was in fact less than the outer capsule's, the inner capsule holding the iPhone accelerometer was secured in the top starting position with duck tape to prevent it from falling. Fig 13 shows that the g values for the inner capsule are much less than the outer capsule.

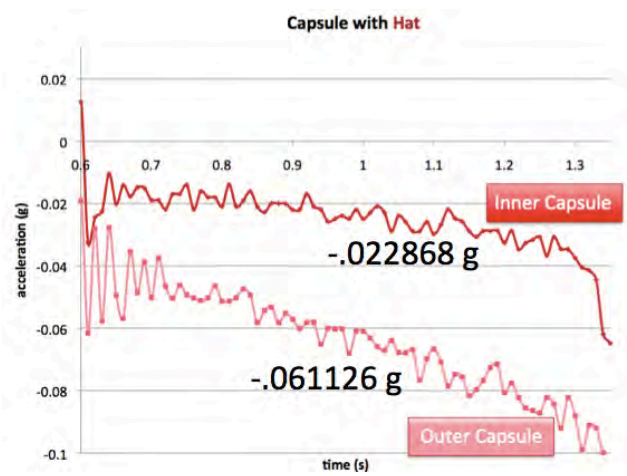

Fig 13 Comparing inner to outer capsule acceleration without *flip calibration*

The final modification made to the model drop capsule was a change in shape for the top. A cone shaped hat was constructed with poster board and attached with duck tape. According to Fig 9, the aerodynamics of the capsule should be improved. A hole at the point of the cone allowed the fishing line to pass through so that the same dropping mechanism could be used. The capsule was dropped twice with the pointed hat, but the accelerometer only recorded usable data for one drop. The cone-shaped hat seemed to reduce the relative gravity slightly, but more data must be obtained for confirmation.

Fig 14 Model drop capsule with cone shaped hat

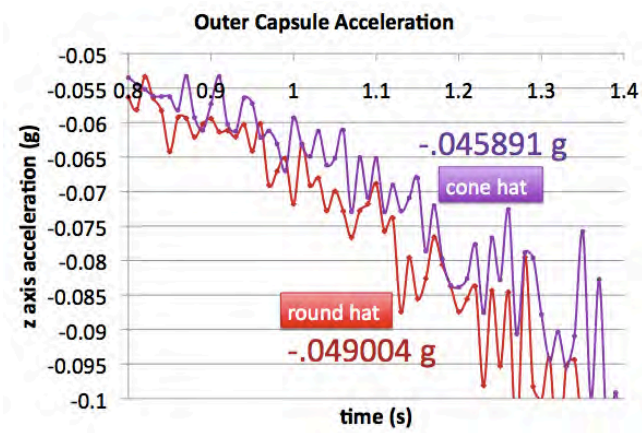

Fig 15 Data from a single drop indicates that cone shaped hat improves microgravity

ACKNOWLEDGMENT

The author thanks Michael Dropmann for guidance and assistance in capsule drops, Dr. Truell Hyde and Dr. Lorin Matthews for being accessible, approachable, and creating a high caliber program for science teachers, and the National Science Foundation for funding the adventure.

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