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Motion of Air Bubbles in Water Subjected to Microgravity Accelerations

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The International Space Station (ISS) serves as a platform for microgravity research for the foreseeable future. A microgravity environment is one in which the effects of gravity are drastically reduced which then allows physical experiments to be conducted without the overpowering effects of gravity. During his six month stay on the ISS, astronaut Donald R. Pettit performed many informal / impromptu science experiments with available equipment. One such experiment focused on the motion of air bubbles in a rectangular container nearly filled with de-ionized water. Bubbles were introduced by shaking and then the container was secured in place for several hours while motion of the bubbles were recorded using time-lapse photography. This paper shows correlation between bubble motion and quasi-steady acceleration levels during one such experiment operation. The quasi-steady acceleration vectors were measured by the Microgravity Acceleration Measurement System. Essentially linear motion was observed in the condition considered here. Dr. Pettit also created other conditions which produced linear and circulating motion, which are the subjects of further study. Initial observations of this bubble motion agree with calculations from many microgravity physical science experiments conducted on Shuttle microgravity science missions. Many crystal-growth furnaces involve heavy metals and high temperatures in which undesired acceleration-driven convection during solidification can adversely affect the crystal. Presented in this paper will be results showing correlation between bubble motion and the quasi-steady acceleration vector.

Nomenclature

AADSF	=	Advanced Automated Directional Solidification Furnace
CGF	=	Crystal Growth Furnace
g	=	nominal gravitational acceleration at the Earth's surface (~ 9.8 m/s^2)
GMT	=	Greenwich Mean Time
ISS	=	International Space Station
MAMS	=	Microgravity Acceleration Measurement System
OSS	=	Orbital Acceleration Research Experiment Sensor System
P_x, P_y, P_z	=	Orthogonal position variables
PAS	=	Passive Accelerometer System
PIMS	=	Principal Investigator Microgravity Services
STS	=	Space Transportation System
US Lab	=	United States laboratory module
USML	=	United States Microgravity Laboratory
USMP	=	United States Microgravity Payload
X_A, Y_A, Z_A	=	ISS Analysis coordinate system
XPOP	=	X-axis perpendicular to orbital plane

I. Background & Related Work

A. ISS quasi-steady microgravity environment

The microgravity environment of an orbiting spacecraft such as the International Space Station (ISS) is not simply "zero G" as is popularly assumed. Although not ideal, the closest to "zero G" on the ISS would be experienced by an article floating in mid-air at the center of mass of the ISS. Any other article attached to the vehicle will experience vibrations (accelerations) from a variety of sources, such as pumps, fans, ISS attitude control, atmospheric drag, gravity gradient, and others. These disturbances are transmitted mechanically through the vehicle structure and acoustically through the air in the habitable modules. The spectrum of vibrations is comprised of a variety of frequencies from steady to 300 Hz across the range which can disturb physical science experiments. The magnitude of these vibrations varies with frequency ranging from 1x10^{-5} m/s^2 at low-frequencies to 1x10^{-1} m/s^2 at higher frequencies. Since the lower acceleration levels are approximately one-millionth of Earth's 1-g (~ 9.8 m/s^2), this environment is referred to as "microgravity."

The ISS quasi-steady microgravity environment is comprised of those accelerations at or below a frequency of 0.01 Hz or with a period greater than 100 seconds. These accelerations are caused primarily by atmospheric drag, gravity gradient forces, vehicle motions, and venting.[1, 2, 3, 4] The magnitudes of accelerations in this low-frequency regime generally do not exceed 2x10^{-5} m/s^2 under normal operations during which physical science experiments are conducted.[3] These quasi-steady accelerations are, in general, unique for different locations on a vehicle since the quasi-steady acceleration levels depend on the direction and distance from the vehicle's center of mass.

B. ISS attitude and orientation affect on the acceleration environment

The quasi-steady acceleration experienced at a particular location on an orbital vehicle is dependent on many factors including atmospheric drag (and its myriad of subordinate factors, such as atmospheric density and vehicle altitude), the vehicle attitude relative to its flight path, and the distance of that location from the center of mass of the vehicle. For a treatment of this topic relative to quasi-steady (and other) accelerations, see reference 4.

The ISS flight attitude is defined according to the attitude control reference system. While the subject bubble motion experiments were conducted, the ISS vehicle was oriented with its X axis perpendicular to the orbital plane (XPOP) with the Z-axis aligned at orbital noon.[3] This attitude develops a nearly sinusoidal time-varying acceleration signature in the quasi-steady frequency regime illustrated in Figure 1. These time-varying accelerations arise from the vehicle's rotation and the variable atmospheric drag through the day/night cycle of the orbit. The rotation of the vehicle relative to its orbital path causes centripetal acceleration and varies the gravity gradient acceleration levels. The sinusoidal signals of the Y-axis and Z-axis accelerations are approximately 90 degrees apart which, with the relatively constant X-axis acceleration, creates a spiral pattern of three-dimensional acceleration. Plotting the measured acceleration levels as three two-dimensional histograms, Figure 2, illustrates the circular nature of the acceleration.[5]

C. Related past investigations

Companion projects for measuring the microgravity environment and analyzing the resultant data have been operating in the NASA physical science program for over fifteen years. The Space Acceleration Measurement System, the Microgravity Acceleration Measurement System (MAMS), and the Principal Investigator Microgravity Services (PIMS) and their antecedent projects have been providing principal investigators with information about the microgravity environment before, during, and after the principal investigators' experiment operations.

The direction of the quasi-steady acceleration and its dependence on vehicle attitude have been utilized for materials science experiments on several Space Transportation System (STS) missions. Several of the samples processed in the Crystal Growth Furnace (CGF) for investigations on the first United States Microgravity Laboratory (USML-1) on the STS-50 mission in 1992 required the Orbiter to maintain a specific attitude to maximize the alignment of the quasi-steady acceleration vector with the cylindrical-sample orientation.[6] The mission planning incorporated three time intervals with the Orbiter in specific orientations while the samples were processed in the CGF to minimize disturbances by the quasi-steady acceleration levels.

On the STS-50 mission, a Passive Accelerometer System (PAS) measured the quasi-steady acceleration levels on the Orbiter.[7] The PAS hardware consisted of a cylinder filled with water and a single steel ball. Using initial trials, the crew members were able to align the cylinder with the average quasi-steady acceleration so the steel ball would traverse the cylinder. Measurement of the steel ball's position over time gave a measure of the g-level at that location and Orbital attitude. Unfortunately, the acceleration vector does not have a constant direction for long and the steel ball was observed to 'run into the wall.' This adversely affected the ball's speed along the cylinder and therefore the measurement of the acceleration magnitude.

The acceleration direction dependence on Orbiter attitude was also utilized in 1996 during the STS–75 mission with a materials science investigation within the third United States Microgravity Payload (USMP-3). The investigation *Compound Semiconductor Growth in a Low-g Environment* was conducted in the Advanced Automated Directional Solidification Furnace (AADSF), a multi-zone directional solidification furnace.[8] The investigation's purpose was to "determine how gravity-driven convection affects the composition of alloys where convection is driven by both thermal and compositional gradients." This investigation included three experiment samples in order to grow three separate crystals under differing microgravity acceleration environment conditions. One sample would be processed with the quasi-steady acceleration vector aligned with the direction of growth along the length of the sample, one sample would be processed with the quasi-steady acceleration vector aligned opposite to the direction of growth, and one would be processed with the quasi-steady acceleration vector aligned perpendicular to the direction of growth. Extensive modeling calculations[9] were done before and after the mission to ensure the Orbiter attitude was properly defined to result in the desired acceleration vector direction.

Since these investigators were primarily interested in the direction of the quasi-steady acceleration vector as opposed to the specific magnitude, a novel acceleration direction indicator was proposed.[10] This indicator utilizes a bubble or particle (or both) suspended in a liquid to visually indicate the direction of the quasi-steady acceleration vector. This device was envisioned to provide a simple, low-cost, and direct measurement of the acceleration vector direction in support of users.

II. Experiment Setup

Astronaut Dr. Donald Pettit began a series of informal activities he called Saturday Morning Science while he was on-board the ISS as the ISS Science Officer from November 23, 2002 to May 3, 2003. In the Saturday Morning Science activities[11], Dr. Pettit used equipment and supplies available on-board the ISS such as food, wire, water, shampoo, locking plastic bags, soldering irons, bolts, compact disk players, and cameras.

Dr. Pettit had studied particle motion[2] in microgravity and conferred with Dr. J. Iwan Alexander several times about the PAS which has flown twice on microgravity Shuttle missions. In preparation for his work on ISS during Increment 6, Dr. Pettit brought several plastic culture flasks in his personal kit specifically to do experiments without knowing how he might use them. It was fortuitous that he included a 250 ml polycarbonate culture flask with plane-parallel walls of optical quality. On orbit, all these ideas came together and the bubble motion experiment using time lapsed video was possible.

The 250 ml flask was 120 mm long x 70 mm wide x 29.5 mm thick. The flask was filled with 200 ml of ISS drinking water and 0.1 ml of shampoo[††] from the crew supplies. The shampoo was added to help keep the bubbles from coalescing. The flask was manually agitated to produce a variety of bubbles inside. The flask was then mounted on an adjustable camera arm in front of a dark blue cloth (crew tee shirt) to enhance visibility by the video

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[††] No-Rinse shampoo, N/R Laboratories, Centerville, Ohio

camera in the normal lighting of the United States laboratory (US Lab) module. The digital video camera was adjusted for slow motion photography to acquire one-half second (fifteen frames) of video every thirty seconds. This apparatus was then left in place for several hours to enable the bubble motion to be observed over one or two orbits of the ISS.

Dr. Pettit performed these operations over several days in the rack locations and ISS orbital attitudes listed in Table 1. Acceleration data was collected for nearly all of these intervals of experimentation. Unfortunately, the data for the ISS vehicle motions is not acquired continuously and therefore the coverage is ‘spotty’ for these time intervals. The best conditions of interesting bubble motion, continuous MAMS data, and adequate vehicle data was for the experiment done on December 19, 2002 from Greenwich Mean Time (GMT) 00:32 to 03:32. GMT is the standard time used by the ISS Program for mission events.

III. Analysis Methods

Motion of the bubbles in the digital video frames were digitized with Spotlight, a NASA Glenn-developed, image-analysis software tool[12]. The position data in pixels were then related to ISS mission time according to the time recorded on the digital video tape. The bubble position in pixels for the experiment was converted to millimeters using on-orbit calibration video as explained above.

The quasi-steady acceleration data were obtained from the MAMS - Orbital Acceleration Research Experiment Sensor System (MAMS-OSS). These low-frequency acceleration data are most often used for long spans of time, namely days or weeks. Vehicle motions (rotations and/or translations) introduce low-frequency accelerations which are dependent on the distance and direction from the vehicle center of mass and the nature of the vehicle motion. In the present case, the MAMS instrument was approximately two meters from the bubble motion experiment sites. The MAMS-OSS data was transformed from the MAMS location to the experiment sites using standard PIMS processes (see Appendix E.2.2 of Reference 3 for more details). The processed MAMS data is oriented according to the ISS Analysis coordinate system.

IV. Bubble motion and acceleration levels on GMT day 353, 2002

Figure 3 illustrates the bottle orientation for this experiment in relation to the right-handed ISS Analysis coordinate system (X_A, Y_A, Z_A). The position of three bubbles labeled A, B, and C were tracked through video frames spanning three hours with the resultant bubble motion tracks shown in Figure 4. The X and Z components of this motion compared with the corresponding MAMS-OSS quasi-steady accelerations are shown in Figure 5. The Z axis position decreases when the Z axis acceleration is greatest (e.g. $t = 0.4$ hr) and that motion essentially stops when the acceleration approaches zero (e.g. $t = 0.7$ hr).

The X axis motion is primarily a steady movement driven by the nearly constant X axis acceleration component and limited by the terminal velocity of the bubble in water. The estimated terminal velocity of air bubble A, of diameter 2.4 mm +/-0.2 mm, is roughly 13 mm/hr. This compares well with the measured velocity of 11.2 mm/hr for the first 2.5 hours of Figure 5. The theoretical terminal velocity includes a correction term for small Reynolds number, but does not reflect the effect of bulk fluid flow in the system, nor the interaction of the bubble with boundaries and other bubbles.

Motion in the Y axis direction is difficult to interpret from these video segments, since this motion would need to be measured by the change in apparent size of the bubble as it moved closer to and farther from the camera. These small bubbles measure about 10 pixels in diameter which makes accurate measurements of the changing bubble size essentially impossible. Bubble C (Figure 3) was chosen for observation because of its actions when it moves adjacent to the large bubble in the corner. At $t = 2.1$ hr, the Y axis acceleration forces the small bubble away from the camera but motion in that direction is blocked by the large bubble. The resultant motion of the small bubble is then along the periphery of the large bubble and is seen here as motion in the –X and –Z directions. When the Y axis acceleration reverses at $t = 2.4$ hr, this motion of the small bubble along the periphery of the large bubble is reversed and the small bubble goes in the +X direction again.

Figure 5 shows the X-Z plane acceleration levels superimposed on the motion of the bubbles. This illustrates the correlation between the acceleration and the bubble motion except for bubble C when the Y axis acceleration influences its motion near the large bubble (as explained above).

V. Further study

Dr. Pettit acquired interesting video of bubble motions in microgravity, not all of which has been analyzed to date. Attempts will be made to further correlate other video sequences with acceleration and vehicle data in the future. Difficulties exist in the aforementioned lack of vehicle orientation data and occasional missing MAMS-OSS data. Of particular interest is one video segment showing a circular motion of bubbles which, apparently, is due to the spiral motion of the acceleration vector during XPOP. Another interesting sequence shows bubbles moving vertically (transverse to the direction reported here).

VI. Summary

Scientists have long expressed concerns for the influence the low-level, low-frequency quasi-steady acceleration may have on experiments which contain a density difference. This informal experiment video has shown the direct correlation between air bubble motion in a container of water when influenced by acceleration levels of less than one-millionth of 1-g. This illustrates the effects which occur in high temperature materials experiments (for example) where these low-level, low-frequency accelerations cause motion due to the fluid density differences.

References

1. Hakimzadeh, R., McPherson, K. M., Matisak, B. P., and Wagar, W. O., "Effects of Experiment Location and Orbiter Attitude on the Residual Acceleration On-Board STS-73 (USML-2), June 1997," NASA TM-107483, Prepared for the Materials Research in Low Gravity Conference sponsored by the Society of Photo-Optical Instrumentation Engineers, San Diego, California, July 27-August 1, 1997.
2. Alexander, J, I, D. and Lundquist, C. A., "Residual Motions Caused by Micro-Gravitational Accelerations," *Jour. Astro. Sci.*, Vol (35), no. 2, pp 193-211, 1987
3. Jules, K., Hrovat, K., Kelly, E., McPherson, K., and Reckart, T., "International Space Station Increment-4/5 Microgravity Environment Summary Report, December 2001 to December 2002," NASA/TM-2003-212460, July 2003.
4. Hamacher, H., Spacecraft Low-Frequency Residual Acceleration. *Spac. Rock.,* vol. 32, no. 2, pp. 324–327, 1995.
5. DeLombard, R.; McPherson, K., Moskowitz, M., and Hrovat, K., "Comparison Tools for Assessing the Microgravity Environment of Missions, Carriers and Conditions," NASA TM-107446, 1997.
6. Wiedemeier, H., "Vapor Transport Crystal Growth of Mercury-Cadmium-Telluride in Microgravity," Proceedings of the Joint Launch + One Year Science Review of USML-1 and USMP-1 with the Microgravity Measurement Group, Ramachandran, N., Frazier, D.O., Lehoczky, S.L., and Baugher, C.R., eds., NASA Conference Publication 3272, pp. 263-270, 1994.
7. Matisak, B. P., Rogers, M. J. B., and Alexander, J. I. D.. "Analysis of the Passive Accelerometer System Measurements during USML-1," 32nd Aerospace Sciences Meeting, January 10- 13, Reno NV, AAIA 94-0434, 1994.
8. Fripp, A. L., Debnam, W. J., Woodell, G. A., Rosch, W. R., Narayanan, R., "The effect of microgravity direction on the growth of PbSnTe," 35th Aerospace Sci. Meeting, AIAA 97-0676, 1997.
9. Kassemi, M., Kaforey, M., and Matthiesen, D., "Effect of Void Generated Thermocapillary Convection on Dopant Segregation in Microgravity Solidification Experiments," *J. of Thermophysics and Heat Transfer*, Vol.15, No.1, January 2001.
10. DeLombard, R., Nelson, E. S. and Jules, K., "Quasi-Steady Acceleration Direction Indicator in Three Dimensions," NASA/TM—2000-209931 / AIAA–2000–0570, 38th Aerospace Sciences Meeting and Exhibit, Reno, Nevada, January 10–13, 2000.
11. Don Pettit Space Chronicles web page URL: http://spaceflight.nasa.gov/station/crew/exp6/spacechronicles.html, last accessed November 17 2004.
12. Spotlight Image Analysis and Object Tracking software, Robert Klimek and Dr. Ted Wright, NASA Glenn Research Center: http://microgravity.grc.nasa.gov/spotlight/, last accessed October 2004.
13. NASA Johnson Space Center, Space Station Interior and Exterior Operational Location Coding System, International Space Station Program document SSP 30575, Rev. C, September 1997.

Table 1. Rack location and ISS attitude during bubble motion experiments in the US Laboratory module

Date	**Location** [13]	**ISS Attitude**
December 18, 2002	Rack P4 High	XPOP +ZNN TEA
December 19, 2002	Rack P4 High	XPOP +ZNN TEA
December 20, 2002	Rack P2 Low	XPOP +ZNN TEA
December 21, 2002	Rack P2 Low	XPOP +ZNN TEA
December 22, 2002	Rack P2 Low	XPOP +ZNN TEA

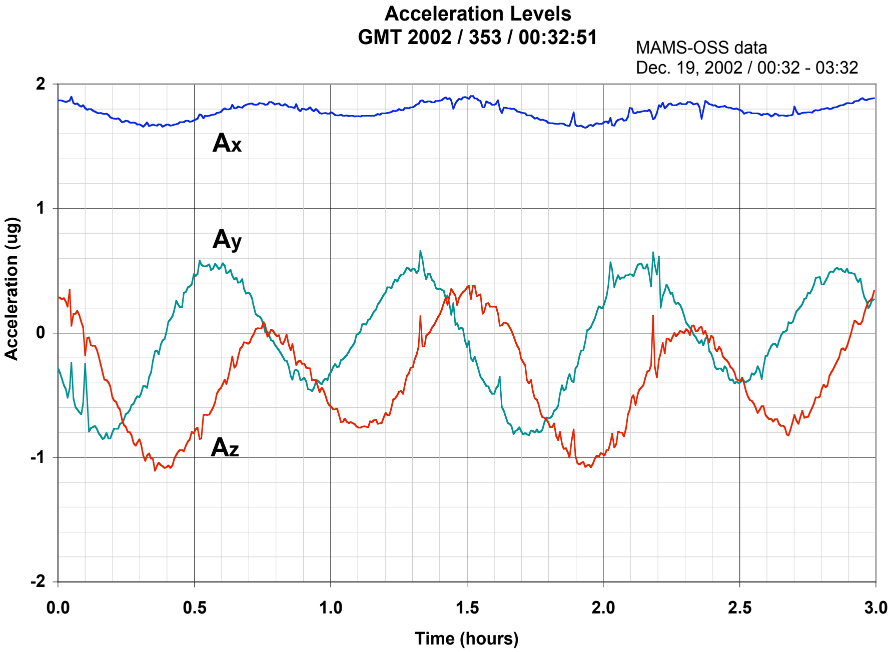

Figure 1. Acceleration levels at bubble experiment site on ISS from GMT time 00:32 to 03:32 (hr:min) on December 19, 2002

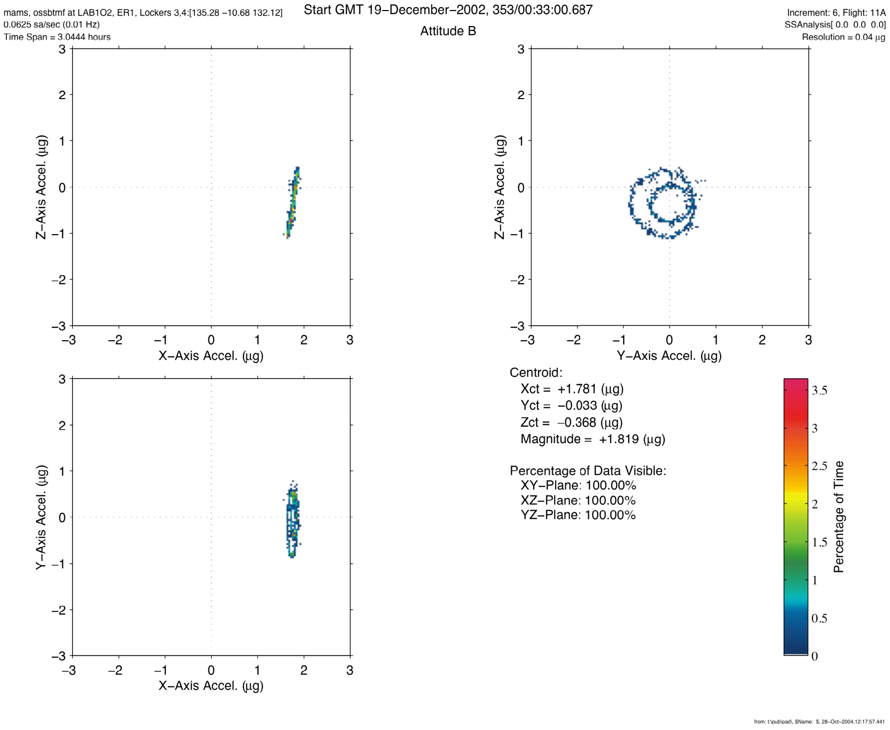

Figure 2. The acceleration levels plotted in a three-dimensional histogram (Ref. 5).

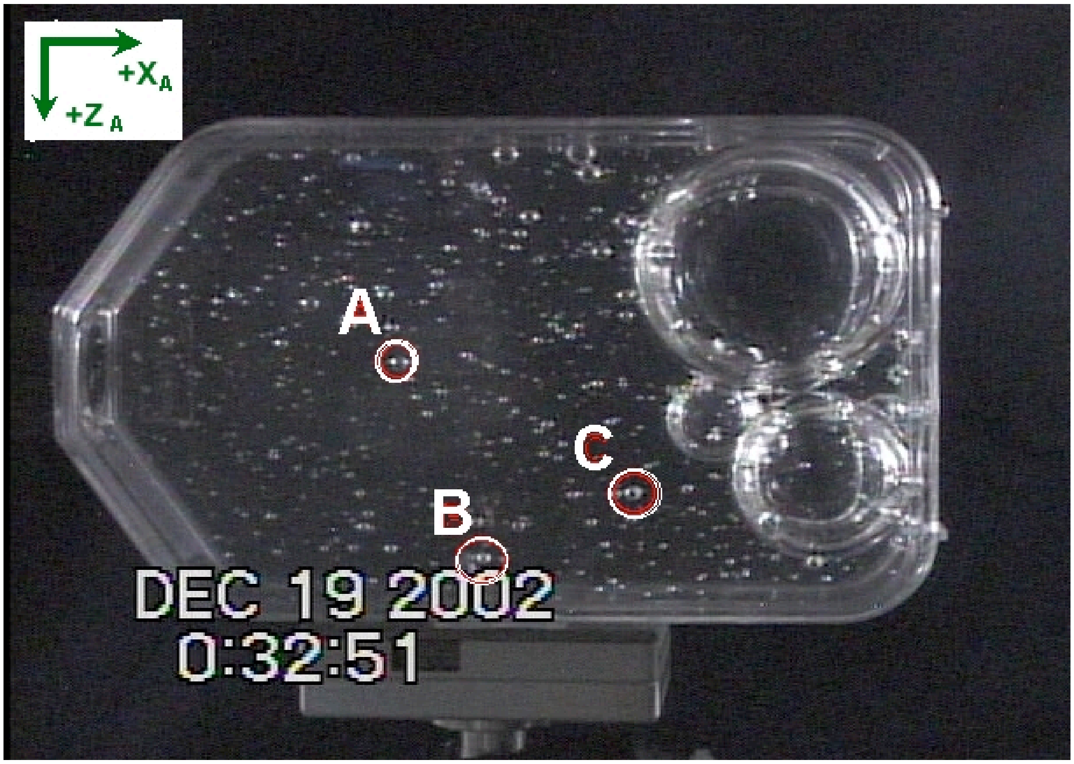

Figure 3. **Axis orientation and initial bubble locations**

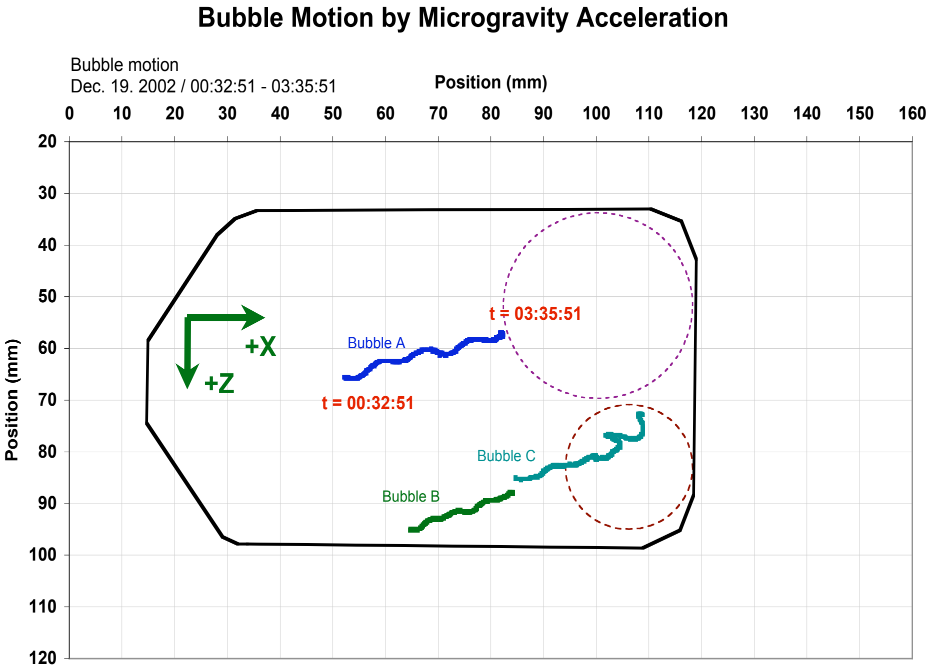

Figure 4. **Bubble motion over a three hour period and relative to interior bottle walls and large, stationary bubbles.**

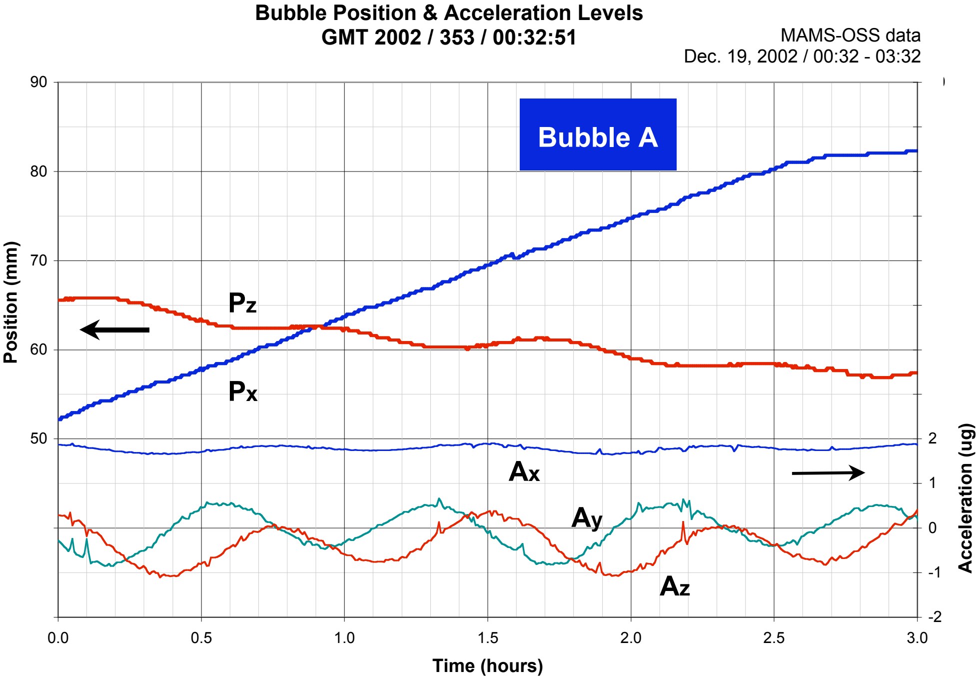

Figure 5. Correlation between bubble position (Px and Py) within the bottle and the three components (Ax, Ay, and Az) of the MAMS-OSS acceleration vector. Changes in the vertical bubble position (Pz) are correlated to the Z-axis acceleration (Az). The nearly constant slope of Px is correlated to the nearly constant Ax.

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13. ABSTRACT ***(Maximum 200 words)***

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