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REDUCED GRAVITY TESTING AND RESEARCH CAPABILITIES AT QUEENSLAND UNIVERSITY OF TECHNOLOGY'S NEW 2.0 SECOND DROP TOWER

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Abstract

Reduced gravity experimentation is important to many research groups working in various fields investigating both fundamental and applied aspects of diverse physical phenomena. Very few terrestrial or extra-terrestrial experimental facilities are currently available that allow researchers access to reduced gravity environments. The Queensland University of Technology's has recently (2006) decommissioned a 1.9 second drop tower adapted for operation within an unused lift well of a building and has fabricated a purpose built, stand alone 2.0 second drop tower specifically to accommodate reduced gravity experimentation. The specifications and operational procedures of this new research facility are presented. Information concerning current and future areas of research is also presented and discussed. These research areas include: 1) cellular biology, 2) fluid dynamics and multiphase flow, 3) nanomaterial production including silica sol-gels and carbon nanotubes, and 4) heterogeneous combustion with a focus on bulk metallic materials burning in oxygen enriched atmospheres performed in collaboration with NASA and industry partners. Opportunities will also be discussed regarding both collaborative research and the provision of reduced gravity test services.

Introduction The operational characteristics of a reduced gravity testing facility located in the School of Engineering Systems at Queensland University of Technology (QUT) are presented. The facility is a 2.0-second drop tower capable of producing high quality reduced-gravity environments for large experimental packages. The Phenomena in Microgravity Laboratory (PML) operates the tower, and runs several research programs investigating gravity dependent phenomena. Several of these programs are outlined in this paper in the areas of combustion, fluid dynamics and nanomaterials.

Background Research under reduced-gravity conditions allows the investigation of physical phenomena that are typically masked by gravitational forces. This has implications for fundamental and applied research. Applications of reduced-gravity research have resulted in many new products with further applications emerging from these studies [1]. Most research in reduced gravity has typically been commercially motivated in an effort to optimise and understand various processes. Major research areas include materials science, fluid dynamics and combustion. Within the field of materials science, current areas of commercial interest are 'containerless' processing, crystal growth and metal/alloy/composite fabrication. Studies show that it is possible to grow crystals which are virtually defect free and are up to 400 times larger in size than their terrestrial counterparts. In the field of fluid dynamics, the study of single and multiphase flows and transport phenomena in reduced gravity is also important. Fluids research has produced a greater understanding of cavitation and capillary flow important in the design of fluidic systems (fuel tanks, cooling loops etc.) both in space and on the ground. Combustion research is mainly concerned with fundamental research, fire safety and propulsion studies. Fire safety is an ongoing concern as the destructive effects of uncontrolled burning in space is potentially life threatening, as demonstrated by the fire onboard the MIR space station [10].

Reduced Gravity Facilities The ability to conduct tests in a reduced-gravity environment is made possible though a number of testing facilities, which are ground-, flight- or space-based. Ground-based facilities include drop towers and drop tubes; flight-based facilities use planes, sounding rockets or balloons; and space-based facilities currently are limited to the space shuttle, the ISS or remote platforms. The operating characteristics of each of these test facilities are defined in relation to microgravity quality, test duration and cost per test. Table 1 provides a relative estimate of the microgravity quality (or g-level magnitude), test duration and test cost between various reduced-gravity test facilities.

Facility Parameters			
Facility Type	**Quality**	**Duration**	**Cost per test**
Drop Tower	Very Good	Short	Low
Sounding Rckt	Low	Medium+	High
Aircraft	Low	Medium	Medium
Space Shuttle	Good	Long	Very High-
Space Station	Good+	Very Long	Very High
Space Platform	Very Good	Very Long+	Very High+

Table 1. Relative Quality, Duration, and Cost of Reduced Gravity Facilities.

A drop tower typically produces very high quality reduced gravity but the test time is typically short. However, it is inexpensive to test in a drop tower and easily accessible to researchers, allowing multiple tests to be performed at a low price. Test times for a drop tower vary from 1 to 10 seconds, with gravity levels of 10-4 g to 10-6 g reproducibly attained. However, it is necessary to allow for the large decelerations (~10-25 g) present at the completion of a test. Research is often first conducted in a drop tower, at low cost, to determine if longer duration test times and more expensive facilities are warranted [10]. Aircraft, such as the NASA KC-135, which is a modified four engine turbojet Boeing 707, are used to fly a parabolic trajectory to achieve reduced gravity. Test times are typically 25 seconds; however, the gravity quality is only 10-2 g to 10-4 g. The gravity level can also vary during flight due to a phenomena referred to as 'g-jitter' from engine vibrations. Flight path variations can also cause negative gravity vectors to be produced. Sounding rockets are capable of longer test times (1 - 5 minutes) and are also subject to similar drawbacks in the quality of reduced gravity achievable (10-1 g to 10-3 g). The space shuttle, International Space Station and other orbiting platforms allow testing times of the order of days, weeks and months, respectively. Good quality reduced gravity is produced, but testing on space platforms is both expensive and subject to international competition.

QUT Drop Tower Infrastructure and Test Support The QUT drop tower, schematically shown in Figure 1, is a facility developed for use by the scientific and engineering community. Capable of 2.0 seconds of high quality reduced gravity, at relatively inexpensive testing costs, it provides an excellent testing environment for any investigation requiring access to reduced-gravity conditions. Table 2 provides the functional parameters for the drop tower. Test duration is 2.0 seconds (in reduced gravity), and it is possible to conduct between 15-20 tests per day, as required.

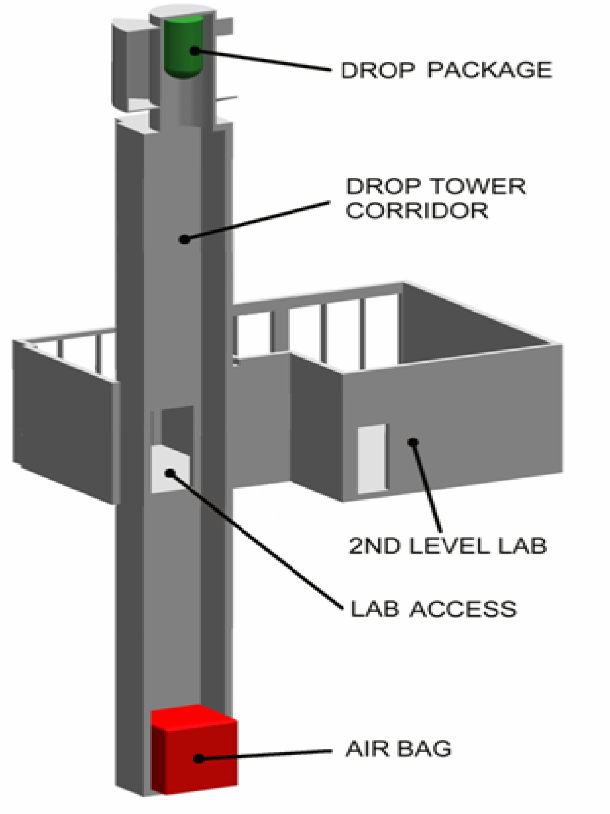


Figure 1. Drop Tower Schematic.

The drop package comprises both the drag shield and the experiment platform. The experiment platform measures 800 mm in diameter and is 900 mm high and is able to support an experimental apparatus weighing a maximum of 150 kg. All objects mounted on the experiment platform experience reduced-gravity conditions.

There are several support facilities available for use within the drop tower:

1. A National Instruments Data Acquisition and Control System (NI DACS)
2. AC/DC Power
3. Compressed Gases
4. Multiple drop tower access points
5. Technical and drop test staff support
6. Visitors area with computer access

The NI DACS has a 233 MHz CPU controlling an E-series DAC card able to simultaneously receive 16 analog channels, sending 2 analog outputs and sending and receiving up to 32 digital I/O's at 200 kHz. The system is rated to a 30 g shock loading, and is available prior to and during a test. Compressed gases and many fluids are available in the laboratory. The drop tower can be accessed at multiple levels, with the second-level laboratory typically used for most interaction with the experimental payload. At the top and base of the tower, the package can be accessed for minor adjustments, if necessary, before and after a drop.

Test Time	2.0 seconds
Gravity Level	Better than 10^{-4} g
Tower Height	23.5 m
Maximum Deceleration	25 g
Duration of Deceleration	0.25 s
Max. Experiment Dimension	800 mm dia x 900 mm high
Max. Experiment Mass	150 kg

Table 2. QUT Drop Tower Functional Parameters.

At the beginning of each test, the drop package is winched to the top of the tower and suspended from a thin wire release mechanism. The wire is then cut and the experiment is released so it can free fall to the base of the tower, where it is decelerated by a large vented air bag. Controlled venting of the air ensures that the package is brought to a stop quickly and safely. During a drop, the experiment platform is enclosed within the drag shield, as shown in Figure 2. This protects the experiment against the effects of aerodynamic drag and the large deceleration forces. Excellent levels of reduced gravity can be achieved with the use of a drag shield.

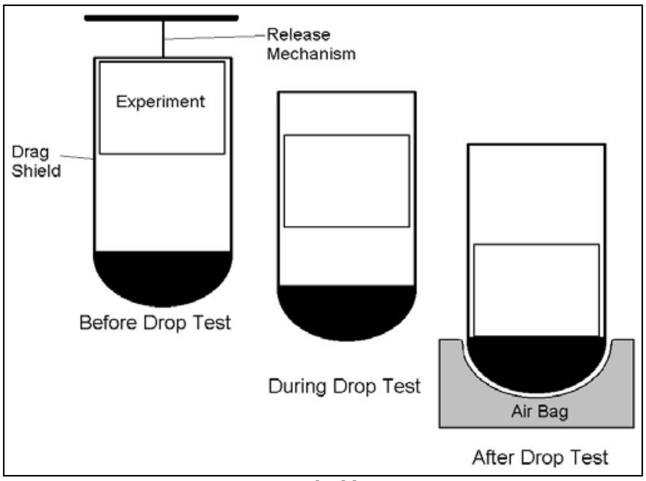


Figure 2. Drag shield operation.

The drop tower incorporates an innovative method of decelerating the drop package at the conclusion of a test. This is achieved by a vented air bag, capable of absorbing large amounts of kinetic energy. The design of this air bag was based on the work of Snyder et al [9] for the NASA Glenn Research Center drop tower. A typical trace of the deceleration from an on-board accelerometer is shown in Figure 3.

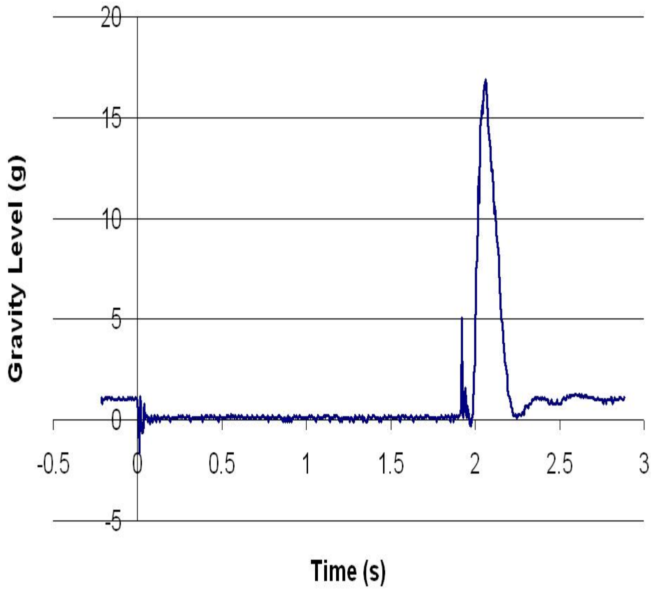
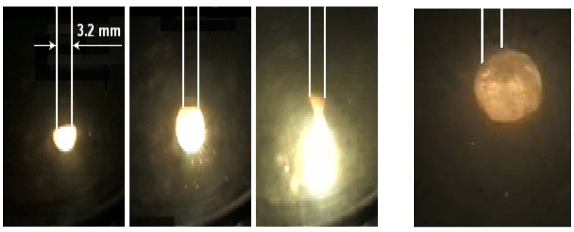


Figure 3. Gravity level traces for a typical test.

Current Experimental Programs There are several research programs being conducted at QUT within the drop tower, under the direction of the PML. Current programs in the fields of combustion, fluid dynamics, and nanomaterials are briefly presented.

Combustion The study of combustion in both normal gravity and reduced gravity often provides critical insight into burning phenomenology. In reduced gravity, burning occurs in the absence of buoyancy. The PML is studying the burning of bulk metallic and polymer materials. It has been clearly demonstrated that most materials burn in oxygen-enriched environments, however, in reduced gravity, some metals burn faster and more readily than in normal gravity [11]. This is an effect contrary to the results for non-metals that are burned in reduced gravity. The causes of these unusual results are the subject of an investigation currently being conducted by the group. This will directly contribute to spacecraft fire safety, but will also contribute to oxygen system fire safety in general, by providing insight into heterogeneous burning. In addition, the group also investigates the influence of sample ignition and sample geometry on standard flammability testing results, which will lead to improved test methods and better use of existing data.



(a) t = -0.92 s t = -0.64 s t = -0.36 s (b) t = 1.50 s

Figure 4. A metallic rod sample burning in (a) normal gravity and (b) in reduced gravity.

Fluid Dynamics Research by the PML into fluid dynamics has looked at surface tension dominated flows. Liquid jetting and dripping [6] and the transition between the two is being investigated under normal gravity and reduced gravity [4]. Figure 5 shows a dripping mode observed in reduced gravity with necking of the attached drop occurring due to surface tension effects not observed in normal gravity tests. These preliminary results, from work conducted on board the NASA KC-135 [3], are being further investigated in the drop tower. Experimentation in the drop tower is favorable for this type of phenomena as the process occurs quickly and requires a higher quality reduced gravity environment [5] than was provided by the KC-135. Currently, three physically different modes of fluid flow are being investigated (periodic dripping, chaotic dripping and jetting) along with their associated break up mechanisms. Three physically different modes of jetting and associated break-up mechanisms have been observed in the experiments and are shown in Fig. 6.

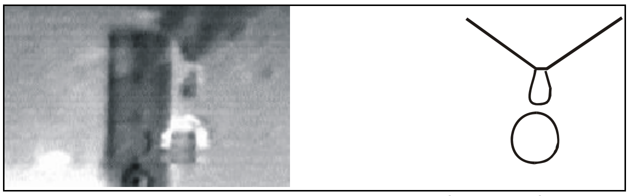


Figure 5. Dripping observed in reduced gravity (left is photo from test and on right is schematic created for clarity.

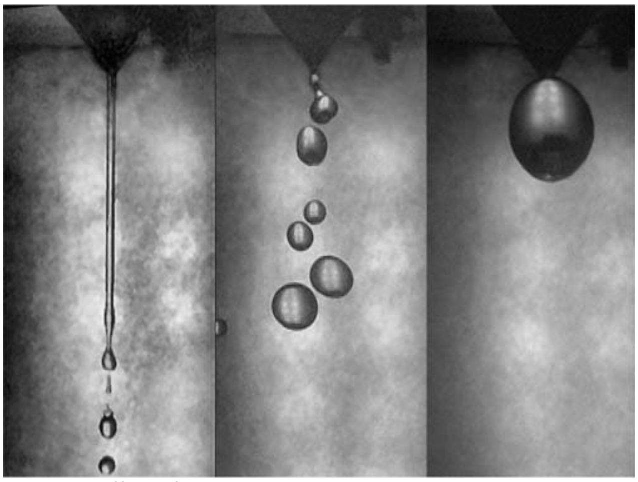
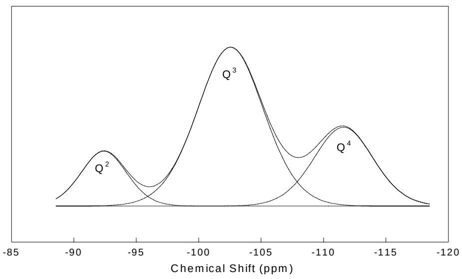


Figure 6. Different fluid jets and their break-up into drops as observed in reduced gravity: Jetting, chaotic dripping and (attached) quasi-stable growth (left to right, by decreasing velocity).

Nanomaterials The sol-gel process is a simple and attractive means of producing a glass like compound with atomic sized pores [2]. These compounds, called xerogels, find applications in areas such as quantum devices and films for hydrogen fuel cells [8]. Current research conducted by the PML has shown that reduced gravity affects the final microstructure of the xerogel. Bulk gelation and film formation [7] experiments are being carried out in both the drop tower and on board the KC-135. Bulk gelation allows a larger sample of xerogel to be formed and analysed thoroughly, allowing the material to be characterised. Acid catalysed sol-gel's were investigated in conjunction with NASA in reduced gravity. This work, completed last year provided some excellent results validating the need for continued work under reduced-gravity conditions. The structure of the gel formed in reduced gravity was compared to a normal-gravity control sample using standard NMR spectroscopic techniques. The results of this analysis are shown in Figure 7. It was observed that the reduced-gravity sample had a substantial peak area of strongly branched fractals (siloxane - Q4 groups), while the normal-gravity sample showed a large proportion of weakly branched fractals (silanols - Q2 and Q3 groups). In principle, Q4 groups oppose capillary stress and a sol-gel structure with a larger pore size, surface area and pore volume is usually formed. The greater concentration of Q2 and Q3 groups and the dominance of surface tension affects in normal gravity would result in a microporous structure. According to the adsorption isotherms obtained for both samples, the reduced-gravity sample contained mesopores that are absent in the microporous normal gravity sample. These results also suggest that a reduced-gravity environment favours both rapid hydrolysis and condensation reactions (which results in the formation of Q4) while terrestrial conditions limit the condensation reactions. Clearly the absence of gravity forces affected reaction rates, leading to silica structural changes although further studies are immediately required to validate, understand, and use these effects in the production of better nanomaterials.



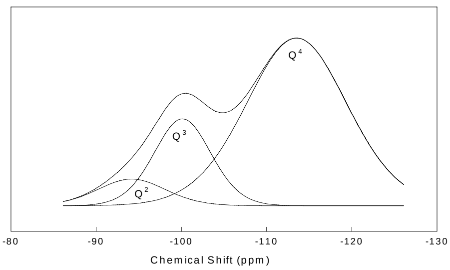


Figure 7. Deconvoluted NMR spectrum: normal gravity sample (top) and microgravity sample (bottom).

Collaborative Work The research programs described typically involves collaboration with various institutions, both internal and external (domestic and international) to the University. Metals combustion is being conducted jointly with NASA White Sands Test Facility and ASTM International. The Faculty of Life Sciences and The Faculty of Built Environment and Engineering at QUT, along with the European researchers (at KU Lueven) are working on the nanomaterials research in work partially supported by the ARC. The Fluid dynamics research is being conducted as a joint investigation with Clarkson University in the United States and NASA White Sands Test Facility. Other programs are likewise typically collaborative in nature and the PML actively solicits collaborative or commercial utilization of the drop tower facility in broad or specific research programs. Potential users are encouraged to contact the author concerning tower utilization.

Conclusion The QUT drop tower provides an economical and accessible reduced-gravity facility for use by scientists and industry both nationally and internationally. Calibration of the facility has been performed, and it is currently used to conduct research in diverse disciplines with novel and useful results being obtained.

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