# Determining the Effectiveness of Damping Structures on Small Open Top Containers

*Research Proposal*


## Abstract
This research aims to determine the effectiveness of baffles on the reduction of sloshing in small open top containers. With a focus on determining the best configuration of damping structures so as to prevent spillages. From this, the rigour of current theoretical models will be assessed so as to determine their accuracy at these scales. Upon, concluding this research it is hoped this information could be applied so as to reduce dangerous spills from hot Beveridge's and consequentially help manage the environmental impacts created by plastic lids currently used to prevent spillages.


## Introduction
Worldwide beverages are served in takeaway cups or are made in ceramic mugs. These containers are subject to liquid sloshing when moved. This sloshing motion can lead to the spillage of the liquid, this liquid is often dangerously hot and as such poses a safety hazard. This problem is currently solved, through the addition of plastic lids in the case of takeaway cups. However, in the case of ceramic mugs, no protection is used and the issue is mitigated only through user intervention and care when moving the mug. Given the danger of these scolding liquids and the economic and environmental impact of plastic lids a better solution is proposed. To stop the sloshing from reaching an amplitude that would allow for spillage to occur.

Currently, large-scale liquid movement efforts employ damping structures that act to reduce sloshing. These structures are collectively labelled as baffles. A versatile set of baffle designs are prevalent, these have been tested experimentally and their effectiveness has been recorded in the literature. Much of the focus is on their applications in the transport industry. This is due to the propensity of tankers and trucks to suffer catastrophic structural damage should sloshing be left undamped. Overall, baffles reduce the sloshing motion through changing the shape of the container and adding variation to the flow of the liquid. The changing of the shape effects the resonance frequency allowing for control regarding the critical frequency.

The application and effectiveness of baffles regarding small containers have not been comprehensively studied. Some generalised models have been proposed but are derived from information pertaining to larger containers. As such we will attempt to consider the response to baffles in small containers experimentally so that such models can be confirmed. Further, this information will be used to determine the most effective configuration of the baffles so that they can attempt to prevent spillages in small open top containers.

## Aim, Expected Outcomes and Research Questions

### *Aim*
To determine the effectiveness of baffles on the reduction of sloshing in small open top containers and subsequently identify the best parameters for preventing spillage.

### *Expected Outcomes*
- Confirming whether existing models and experimental results are suitable when applied to small containers.
- Determining the variance in damping constants for different configurations of baffles pertaining to small containers.
- Identifying the parameters that best prevent spillage for standard cup sized containers.

### *Research Questions*
How can damping structures be applied to small open top containers?
How effective are these damping structures when applied to small open top containers?
How do current models of baffles stand up when applied to small open top containers?
What configuration of damping structures best acts to reduce spillage in small open top containers?

# Study Design/Approach

For this research, we will endeavour to assess three things. Firstly, how baffles can be implemented in small open top containers which represent a coffee mug or cup. Secondly, the most effective configuration of the baffles so that they reduce the spillage. Finally, the damping constants for each configuration needs to be determined and considered against existing models such as that found in Miles' paper [1] and that of Hasheminejad and Aghabeigi [2].

The first step will be to manufacture suitable containers, these will be simplified to cylindrical containers without a taper. We will use additive manufacturing methods, specifically accessible and cheap 3D printing, as that will allow the containers to be made transparent as well as to include versatile shapes. Geometry added during printing to the internal walls of the cup will act to represent the baffles. Two types of baffle will be considered. A ring type baffle and a non-ring type straight baffle. The ring baffle will be placed at various points along the container's height. For each of these positions the radius of the baffle will also be varied. The straight type baffle will instead run from the bottom to top of the container. The number of these straight baffles will be incremented. For each increment the radius will also be varied.

The next step will be to take these containers and consider their response to a spectrum of frequencies. The transparency of the containers will allow for the recording of the sloshing height at the various frequencies. A frequency amplitude graph will then be plotted from this data. This will allow for the comparison of the various baffle configurations to a control container (no damping structures).

Finally, this data will be used to calculate damping coefficients for each configuration and to find the configuration that best demonstrates a reduction in the max-amplitude around the critical frequency of 4hz [3]. The damping coefficients can then be compared against the theoretical results obtained from applying the models outlined in [1] and [2].

# Experimental

## *Materials*

Anycubic 355-410nm Clear Eco-resin

- This will allow for the production of strong and transparent containers.
- The transparency is required to allow for accurate data collection.

24 Containers with damping structures plus a control

- 2 Sets. 12 Ring type and 12 Straight type.
  - Ring types are placed at heights along the cup. 20mm, 40mm, 60mm, 80mm.
  - Straight types are spaced at equal distances around the container. Run from the bottom to the top of the container. The number of baffles increments for each configuration, 3, 6, 8, 12.
- Each baffle type is tested at 10%, 20% and 30% of the container's radius.
- Both baffle type has a constant thickness of 2mm.
- Control container is based on typical manufacturing dimensions for a regular takeaway cup [4]. Which is height 92mm and radius 40mm.

Water

- Stable fluid that doubles as a good stand in for coffee, as it is the primary component of all hot Beveridge's.
- Used at room temperature to reduce evaporation and to minimise variance in thermal expansion and viscosity.

*Instruments*

| INSTRUMENT | PURPOSE |
|---|---|
| VAT POLYMERIZATION 3D PRINTER | This will manufacture the containers. Ideally this will be outsourced as the process is lengthy, around a day per container. Also, outsourcing will reduce variance between containers. |
| HIGH-RESOLUTION VIDEO CAMERA | Used to record the experiment and will be reviewed to determine the amplitude and acceleration of the liquid. |
| LABORATORY OSCILLATOR | Need to have fine frequency control and movement in all 3 translational degrees of freedom. Allows for the application of vibrational motion to the container. This represents the input force. |
| DIGITAL CALLIPERS | These will be used to validate the containers significant dimensions. These being: height, internal radius, baffle height, baffle radius, baffle width, distance between baffles and variance between baffle parameters for a given configuration. |
| RULER | To determine the fluid fill height on each container. Volume is not a valid measure as the volume varies due to the displacement caused by the baffles. This also helps control for thermal expansion. |
| PC | Needs to be capable of 3D Modelling with Solidworks and analysing the final data. |

*Methods*

Each of the 24 containers will be filled to a height of 75mm this is to allow for the testing of configurations where the ring baffle is above the liquid. They will subsequently in turn be exposed to a frequency spectrum from 1hz - 8hz. This spectrum is chosen to fit the relevant resonance frequency when walking. Which is 4hz as determined by Mayer and Krechetnikov [3] in their paper. The frequency will increase in increments of 0.2hz and at each increment the fluid will be allowed to settle into a stable state. Each non-symmetrical axis will be tested separately, so in the case of the ring baffle only the vertical and one horizontal axis needs to be tested. Similarly, each axis will be evaluated five times to allow for an average to be taken. The order each container is tested will be random to remove any unexpected environmental biasing effects.

*Data Analyses Methods*

The data will be recorded using a high-resolution video camera. The recorded variables will consist of the liquid's maximum amplitude and its related frequency. These variables will be determined from the footage manually. The experiment is run in a way that allows for the averaging of the data. Doing this will remove error and allow for the easier identification of outliers. The data for each configuration can be scatter plotted and checked for any outliers. Special care should be taken when considering values close to 4hz as this is the critical frequency. After the removal of outliers, the data can be collated onto a single line plot [frequency-amplitude graph] and compared with the results of the control container. Any configurations that show a reduction around the 4hz frequency are determined to be successful. Returning to the recorded data we can consider the most successful configurations and expand these sets of data, with the aim being to extract acceleration data so we can determine the damping ratio. Plotting this data on a line graph [frequency-response graph] will allow for the calculation of the damping ratios. These can then be compared against the expected results predicted from theoretical models [1][2].

# Limitations

The main limitations in this research stem from only testing a limited set of configurations. Due to the lack of existing research it is unknow whether or not existing models accurately predict the behaviour of baffles at these scales. As such this research will seek to determine whether further research into the behaviour of baffles at these scales in required. Should the existing models match the results of this research, further consideration will be unnecessary. For this reason, wasting resources and time on testing a larger set of configurations and/or varying further parameters such as the baffle thickness was decided against. A further limitation is the spectrum of frequencies tested. The scope of this research was kept focused on how baffles can prevent spillages. As such considering frequencies far in excess of 4hz (the critical frequency) was thought unnecessary.

# The Effect of Surface Texturing on the Reduction of Coffee Cup Sloshing

A common problem faced by many an individual is the spilling of coffee in open containers. This issue occurs commonly when walking with coffee cups. This problem is of concern from both an environmental and safety perspective. The current solution in the case of takeaway coffee cups is to include a lid or a hot stopper (a kind of plastic plug for the drinking hole), this plastic creates a large amount of environmental waste [11] so finding a way to stop this spillage could lead to a reduction in plastic waste as well as a cost reduction due to not needing to include these components. Further, from a safety perspective, both standard (ceramic) and takeaway (with a lid) cups can splash scolding liquid on a person should it spill. This spill can cause injury [9] to the individual and makes the coffee drinking experience less than ideal. The proposed solution is a change to the texture of the cup. The idea is that this could lead to a reduction in the sloshing of the liquid [10]. This texturing could be catered to the dimensions of each cup so that spillage is made unlikely. The body of research relating to the spilling phenomenon and potential reduction methods are outlined in this report.

Mayer and Krechetnikov [8] initially attempted to describe the mechanics underlying the coffee spilling phenomenon. They explain that it is a confluence of biomechanics, liquid sloshing engineering, and dynamical systems [8]. In the wake of this, they aimed to develop a simple mechanical model that could accurately represent the system. They based this on the fully nonlinear spherical pendulum with forced oscillations equations [8] and found they could use their model to describe the sloshing in a coffee cup accurately. This is also the approach Han [4] takes stating that the fluid acts as a simple pendulum in the sense that the centre of mass oscillates with respect to a fixed point above the liquid surface. Hans [4] further expands upon this idea however, when considering methods to reduce the sloshing effect. They do this by modelling the problem as an oscillating double pendulum [4] which represents an added degree of freedom. Kulczycki, Kwasnicki and Siudeja [6] take a different approach to both [8] and [4], they instead model the problem using linear water-wave theory [6]. All these papers attempt to explain the mechanics behind sloshing and build upon the initial work of [8]. Further papers and [4] consider methods that can reduce the sloshing.

A number of methods to reduce sloshing have been proposed. Han [4] considered three methods that could bring about a reduction in sloshing. The first of which is the claw-grip method, this method of holding the cup introduces an extra degree of freedom and has a significant effect on the frequency spectrum of the cup motion [4]. This posture can successfully reduce resonance and subsequent spillage [4]. Secondly, [4] considers the effect of walking backwards on sloshing and found that doing so can significantly change the frequency characteristics of the hand motion. Comparing this to normal walking the spectrum is more evenly distributed and the higher frequency modes are reduced [4]. Finally, Han [4] outlined the effect of foam and how it relates to sloshing reduction. This is analogous to the head on a beer or coffee froth. This effect is explored deeper by Sauret, Boulogne, Cappello, et al in their short paper [15] and subsequent paper [14]. They deduce that the addition of foam to a liquid surface has a considerable effect on sloshing reduction [15]. In [14] they clarify that this is due to an increase in the damping coefficient and a reduction in the amplitude of the free surface oscillations [14]. They identify the source of the reduction as a result of energy dissipation in the wall boundary layer [15]. Abramson [12], explains that most research efforts are focused on the effects of baffles on fluid damping. The reason for this focus is due to the large damping they provide for a relatively low weight [12]. There are many types of baffles and the research into their application is extensive.

Baffles act to change the container's resonance frequency and so can reduce sloshing and the consequential spilling effect [4]. Abramson [12] discusses the use of baffles and describes them as structures that absorb part of the energy of the liquid and change the container's resonance frequency. Baffles can be split into two types: floating movable-lid-type baffles and fixed-type baffles [12]. The fixed-type baffles can be classified again into both non-ring type and ring-type baffles [12]. Miles [13] in his paper constructed a mathematical model describing ring-type baffles in cylindrical containers and consequentially the damping factor these baffles provide. Hasheminejad and Aghabeigi [1] consider vertical fixed baffles in horizontal cylindrical tanks and their effectiveness, they point out that the placement of the baffles below the free surface is of considerable importance [1] and that the closer the baffle is to the free surface the better it will perform [1]. Similarly [1], showed that extending the vertical baffle above the free surface also reduces the effectiveness of the baffle. In both cases, the effectiveness is measured concerning the influence on the natural frequencies of the fluid [1].

Notably, the consideration of sloshing mechanics in research frequently disregards containers on the scale of a coffee cup. Being mainly concerned with fuel tanks, tankers and other large moving containers [1][8]. Further, the research into the effects of baffles is primarily on a macro scale and the baffles when implemented tend to be designed as separate structures and attached later as opposed to being manufactured as part of the same structure.

# References | Research Proposal

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