International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 11 Nov. 2022, pp: 911-923 www.ijaem.net ISSN: 2395-5252

Experimental investigation of Embedded Concave Baffle in a Long Moving Vessels at Gravity and Microgravity Environments

Matthew Adebayo, Ademola A. Dare and Tajudeen A.O.Salau
Address of authors: Department of Mechanical Engineering, University of Ibadan, Nigeria.

Date of Submission: 21-11-2022 Date of Acceptance: 30-11-2022

ABSTRACT

Flat Rigid-ring Baffle (FRB) is used mostly to suppress slosh-induced oscillation in Long Moving Vehicles (LMV) but, its performance is marred by relative low damping effectiveness couples with its flat configuration that gives room for splashing. The splashing is accompanied by hydrodynamic pounding on the tank's walls hence; cumulative impact of this force can lead to buckling of the tank and thereby structural failure of the system. These defects necessitate the quest to investigate other baffle configurations. The objective of this work was to investigate experimentally sloshing characteristics of LMV equipped with Concave Rigid-ring Baffles (CARB).A model cylindrical tank at 75% water-filled capacity was excited at 2Hz using an oscillator. Two geometries namely Concave Rigid-ring Baffle-1 (CARB1) of 0.04m pitch, Concave Rigid-ring Baffle-2 of (CARB2) at gravity and microgravity environment ($g=9.81$ m/s^2; $g=0.1$ m/s^2) were investigated. Damping Ratio (DR) was evaluated from the cylindrical tank by wall force measurement using load cells at both gravity and microgravity conditions. The experimentally obtained DR were compared with literature values obtained numerically for same geometries Data were analysed using descriptive statistics and ANOVA at $\alpha_{0.05}$.The results obtained for both CARB1 and CARB2 at gravity and microgravity environments showed higher values of damping ratio at 72% and 59% filled level of the tank.

Keywords: Sloshing, Damping-ratio, Dynamic-System, Instability, Microgravity.

I. INTRODUCTION

Intuitive reasoning requires careful handling of a cup of tea and adjustment of the carrier's motion while moving with it to avoid spillage. Hence, container partly-filled with liquid with its free surface oscillating within the boundary's wall requires adjustment of its motion to avoid sloshing of the contained liquid. Sloshing could be defined as to and fro of free surface motion of liquid in a not-filled to the brim container, due to disturbances by way of perturbations. Long Moving Vehicles (LMV) provides good example and illustration of where the response of liquid in storage may be of important criterion to be considered by designers of dynamic systems: such as fuel tanks of aircrafts, liquid rocket engine, ships, automotive vehicles, etc. Holistic study of sloshing captures oscillations of water in lakes and harbours which results in earthquakes, further illustrates typical example of this phenomenon (NASA SP-106).

The magnitude of fluid sloshing depends on the container geometry, fluid properties, fluid-filled level, perturbing motion of the container, acceleration field and damping capability of the system (NASA SP-8009).The problem of liquid sloshing majorly involves the estimation of hydrodynamic pressure distribution, forces, moments and natural frequencies of the free-liquid surface. These parameters have a direct effect on the dynamic stability and performance of moving vessels. To eschew catastrophic sloshing in LMVs, its frequencies must be widely separated from the sloshing-fluid frequencies (Ibrahim, 2005). Non-linear nature of sloshing is a serious challenge hence, solving such a problem analytically or computationally, involves many assumptions thereby cause deviations in the actual values of the solution. Experimental and Computational Fluid Dynamic (CFD) analysis offers an important tool to analyse the liquid dynamics and the resulting sloshing forces and moments which are the critical quantities in modeling control and stability of dynamic systems. Experimental studies have been the most popular approach for liquid sloshing and have provided valuable insights into the physics (Eswaran, 2011).

During the past few years a great deal of research has been conducted on the problem of sloshing of liquid propellants in missile and space vehicles. Liquid sloshing in tank usually results from the processes of spacecraft orbital transferring, rendezvous and docking as reported by (Yang et al.2019). It has been observed that, in any rocket flight the vehicle body is subjected to translatory, rotational and oscillatory perturbations from external forces such as guidance and control inputs, aerodynamic perturbation, acoustic perturbation, thrust-induced oscillation, structural flexibility-induced oscillation, dynamic load such as bird's shock and many more hence, result in disturbances of the contained liquid. Coupling any of these oscillation modes result in resonance and structural failure of the system. Bauer (Bauer, 1964) remarked that with the increasing size of space vehicles and their larger tank's diameter which lower the natural frequencies of the propellant, the effects of propellant sloshing upon the stability of the vehicle become extremely critical; especially since at launch, usually more than ninety per cent of the total mass is in the form of liquid propellant. A space vehicle under external perturbation may deviates from its original trajectory and must be returned quickly to its pre-programmed flight path. This function is performed by the control and guidance system and is executed by vectoring the thrust of the space vehicle. A deficient designed control system can therefore continuously excite the motion of the propellant in the fuel tank hence, the forces and moments due to liquid undergoing harmonic oscillations in a particular container must be determined and their influence upon the stability and structural integrity must be investigated.

Baffles are obstructing plates primarily secured within a container to curtail or suppress slosh. Obstruction of the slosh in the course of its oscillatory motion breaks up its waves and dies out hence lessen hydrodynamic pressures on the container's wall. Cruciform baffles, Vertical baffles and Horizontal (Ring) baffles are the commonly used baffles (NASA SP-8031 1969). Their performance are yet to be fully satisfactory. The objective of this work was to investigate experimentally sloshing characteristics of LMV equipped with Concave Rigid-ring baffles of varying geometries.

II. LITERATURE REVIEW

Baffles of different geometries have been employed in the past such as: horizontal, vertical, and annular or ring baffles Pal et al. 2001, Akyildiz and Unal 2005, Panigrahyet al. 2009.

Jing-Han et al. (2019) studied sloshing and the effect of vertical baffle attached to the bottom of a tank. Linear velocity potential theory (VPT) was employed in the study. Their conclusion was that, motion of the baffle both magnitude and phase can be adjusted simultaneously in reducing the free surface elevation and significant reduction of sloshing wave.

Chia Chu et al. (2018) employed both experimental and numerical simulation to investigate sloshing with embedded multiple baffles fixed at bottom of a rectangular tank containing water. Volume of Fluid (VOF) method was employed in solving free surface equation. Validation of the simulation results was performed with shaking-table experiment. Determination of the impact of baffle's height and the space between them on slosh suppression was the objective of the study. Simulation results shows that the natural frequency of the tank was affected significantly due to the present of multiple baffles. The reduction of the hydrodynamic force (HF) by the multiple baffle is much than a single baffle also, forces from the tank's sidewall due to integrated pressure can be represented by slosh-wave amplitude. Slosh-wave amplitude and HF reduced while, baffles height and its numbers increased hence, there was reduction in impact of baffles on slosh suppression when this equation holds: $hd/hw \geq 0.75$ holds.

Mi-AnXue et al. (2017) studied four types of baffles and its effectiveness in slosh suppression under a forcing frequencies of 0.4 $\omega1$ to 1.4 $\omega1$.Effectiveness of the vertical baffle near the free surface is significant in slosh suppression than the one fixed at the bottom of the container. Slosh suppression of perforated baffle of vertical geometry is more significant than surface-piercing counterpart of vertical geometry mounted at the bottom of the tank at broad band frequency. It was observed that the tank-liquid system first-mode natural frequency was changed with the present of the vertical baffles. The result of the experiment showed that alteration of flow fields and natural frequency may significantly damp HF on the tank walls.

Wenjing et al. (2017) studied prediction of sloshing characteristic in a tank undergoing a motion using numerical approach, and the results was compared with measurements of a model test. Four numerical techniques namely finite Volume-of-Fluid (VoF) technique, none-compressible VoF technique, compressible VoF method and none-compressible coupled Level-Set (clsVoF) were investigated. Their results showed that method of compressible VoF was better in obtaining more precise predictions of sloshing.

Mi-AnXue et al. (2012) investigated sloshing characteristic using double-phase fluid to solve the governing Navier-Stokes equations. Horizontal, perforated-vertical and their combination excited harmonically were considered. The results, shows that serious dynamic impact pressures often occurred at the neighbourhood of free surface. The result also showed that the nonconventional combinatorial baffles possess better damping characteristics than conventional baffles. Perforated baffle reduced weight without compromising the rigidity.

Rakheja et al. (2010) investigated impact of different baffle geometries on liquid sloshing. Conventional lateral baffle perform better than oblique baffle in damping the slosh under longitudinal acceleration excitation but, oblique baffle minimised longitudinal, lateral forces and moment when the tank accelerated longitudinally and laterally.

Takabatake et al. (2008) studied structural failure caused by liquid sloshing. Their observation was that, some petroleum tanks were damaged due to fuel slosh during 2003 Tokachi-oki, Japan. There was a prediction of occurrence of severe earthquake within 50 years, likely to cause havochence; splitting wall was developed as a novel technique to suppress slosh. Experiments were performed to validate numerical simulation for the study. Results obtained from the experiment indicated that the technique will reduce sloshing excited by sinusoidal force effectively. The results of both investigations agreed and they concluded that the proposed device could be effective in preventing ground motion.

Pal et al.(2002) employed Finite Element Method to investigate dynamics of none-viscous, none-compressible liquid contained in a flexible, composite, thin-walled cylindrical tanks under small excitation. They formulated motion equation to analyse the slosh characteristics on the rigid and flexible tank and how it's material properties (flexibility) affects the tank and its structural response. Numerical simulation was validated by experiment and their conclusion was that, a reduction in slosh frequencies of rigid container along the depth of the liquid and increment as the container width increases was observed.

Panigrahy (2006) investigated sloshing experimentally in a rectangular tank with pressure as varying parameter with time. The result of the investigation showed that ring baffle is much more effective in reducing slosh.

Wei Chen et al. (1996) investigated sloshing of liquid in a storage container, excited harmonically with large-amplitude. It was concluded that design of seismic-resistant tank should employ non-linear analysis. Also, cognisance must be taking of the real sloshing amplitudes which may exceed linear predictions for avoidance of potential damage to the tank roof due to hydrodynamic wave pounding. It was inferred that peak HF could be predicted effectively with linear theory but, non-conservative in the sloshing amplitude.

Sakai et al.(1984) studied sloshing on a tank containing oil with floating roof analytically and with model testing. They employed theory of Fluid Structure Interaction to analyse the interaction and its effects between the roof and the contained liquid. Analytical results were validated experimentally with the aid of shaking-table, model of single and double deck roof. It was concluded that the presence of this device does not affect the natural frequency but, subsequent modes affected the double deck type significantly in determination of stresses associated with it.

Cole (1966) investigated the effect of baffle thickness on slosh suppression experimentally in a cylindrical tank. In his conclusion, baffle effectiveness decreases by fifty percent (50 %) with increase of baffle thickness at moderate amplitudes of oscillation. Zhao DY et al.(2018) studied nonlinear sloshing in rectangular tank while, Wang, W.Y. et al.(2016) investigated sloshing in a partially filled tank, partially excited. Takabatake et al. (2008)investigated sloshing reduction effect of splitting wall in cylindrical tank. Sakai et al. (1984)studied sloshing behaviour of floating-roof oil storage tanks. Scholl H.F.et al. (1967)investigated the effectiveness of flexible and rigid ring baffles for damping liquid oscillations in large-scale cylindrical tanks. Also, Silveira et al. (1961) worked on an experimental investigation of the damping of liquid oscillations in cylindrical tanks with various baffles. Modaressi-Tehrani et al. (2007) studied three-dimensional analysis of transient slosh within a partially-filled tank equipped with baffles, Mohan,(2014) worked on Finite element analysis on trapezoidal tank to suppress sloshing effect, Moiseyev, N.N. and Rumyantsev, V.V., (2012)studied dynamic stability of bodies containing fluid .Maleki, A. and Ziyaeifar, M., (2008)investigated damping of sloshing in cylindrical liquid storage tanks with baffles. Masica, W.J. and Salzman, J.A., (1965) worked on experimental investigation of the dynamic behaviour of the liquid-vapour interface under adverse low-gravitational conditions while, Miles, J.W., (1956) studied sloshing of Liquid in a Cylindrical Tank. Evans, D.V. and McIver, (1987)studied resonant frequencies in a container with a vertical baffle, Gazra L. R.,(1966)investigated theoretical and Experimental Pressures and Forces on a Ring Baffle under sloshing conditions. Gordon D. Stubley, (2008) investigated Computational Fluid Dynamics for Fluids Engineering Design. Gurinder Singh Brar and Simranjit Singh (2014) studied experimental and CFD Analysis of Sloshing in a Tanker. Hastings, L.J., et al. (1965) investigated SaturnV low gravity fluid mechanics problems and their investigation by full-scale orbital experiment. Heng Jin, et al.(2020) studied analytically the effect of a horizontal perforated plate on sloshing motion in a rectangular tank. Jiadong Wang et. al.(2019) studies Coupled Responses in a Partially Liquid-Filled Cylindrical Tank. Chen, , Kelecy,. and . Pletcher (1994) studied numerical and experimental study of three-dimensional liquid sloshing flows.Chintalapatiet al. (2010) worked on enhancement of Numerical Modeling in Simulation of a Generic Propellant Tank Slosh Baffle while, Chu CR et al.(2018) studied Slosh-induced hydrodynamic force in a water tank with multiple baffles. The efforts aforementioned, concave baffle configurations were not researched as done numerically by Adebayo et al.(2022). However, Adebayo et al. investigated only the numerical part of this baffle while, present study aims at experimental investigation of the concave baffle geometries.

III. EXPERIMENTAL PROCEDURE FOR CYLINDRICAL TANK WITH CONCAVE BAFFLE AT GRAVITY ENVIRONMENT

Setup and procedures for the experimental work at gravity Environment

The components of the experimental setup for gravity environment included:Cylindrical tank with concave baffle, Power hacksaw, DC motor, Load cell, Data acquisition, Operational amplifier and 12Volt batteries.

- Scaled model of cylindrical tank was attached to the front of a power hack-saw blade's holder mechanism,this provides to and fro movement to the tank with the help of a DC motor.
- Load cell was attached to the walls of the tank as it is shown in plates 2 and 3 below.
- The output of the Load cell was fed to the channels of the data acquisition system that was coupled to a laptop.
- The data were decrypted using software data acquisition software (WinDaq) that displayed the output in Newton.
- The output was exported to excel sheet software, saved in delaminated comma(Gurinder et al. 2014).

This experimental work results were compared to the corresponding numerical results obtained from baffle of same configuration in litrature (Adebayo et al. 2022).

Plate1. Front view of the fabricated Baffles

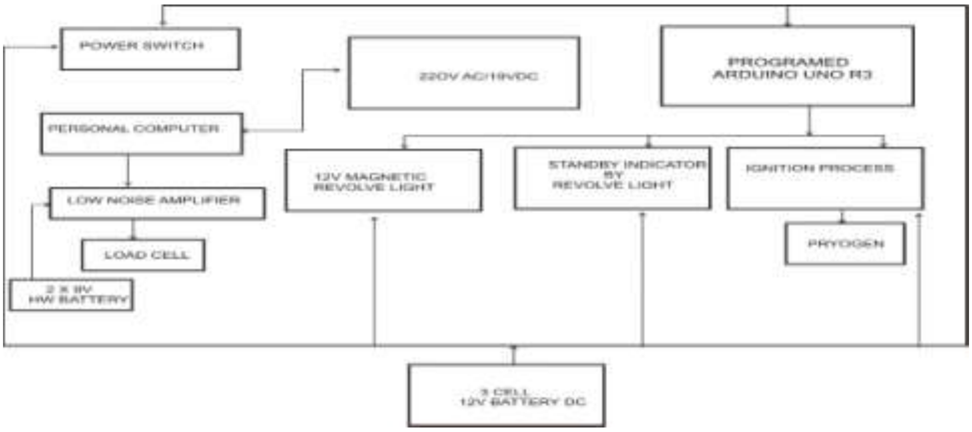

Figure 1. Layout of Data Acquisition Components (DAQ)

Figure 2 is the load cell module that consist of pressure/force sensor to measure the hydrodynamic pressure at the wall of the cylinder that will be decrypted to obtain slosh wave amplitude as a main input parameter in semi empirical Mile's equation to obtain damping ratio which is the main performance index. It also consists of power source of 12V or 12 V AC/ DC power adaptor, signal channels and personal computer with software data acquisition software (WinDaq).

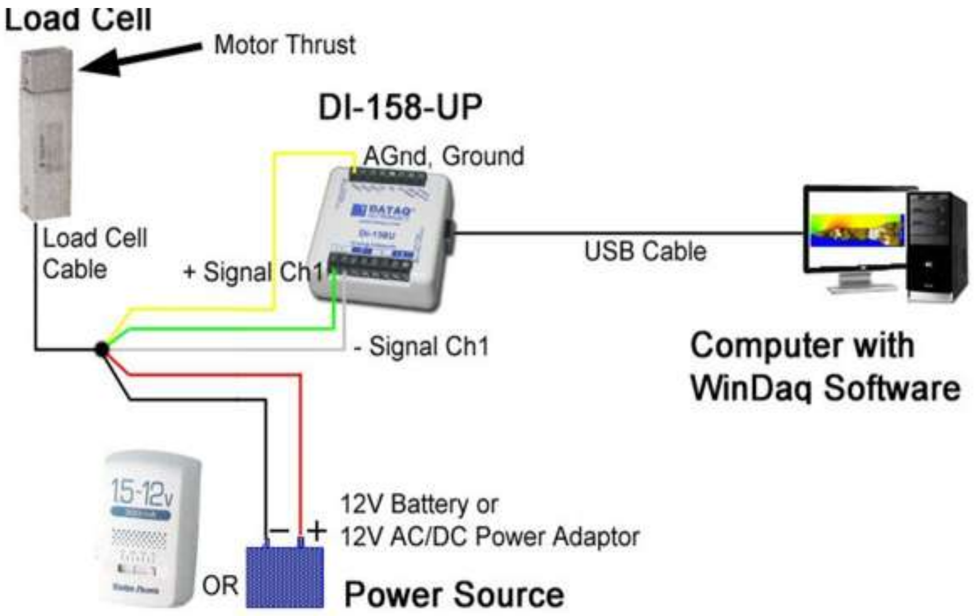

Figure 2. Layout of Load cell Module

Plate 2. One of the research team working on Experimental Set-up

Plate 3. The Experimental Set-up

Experimental Set-up and performance Evaluation Technique for Microgravity Environment

The set up for the microgravity experiment consists of a cylindrical tank hanging over a lever which is counterbalanced by a weight as shown in Figure 5 .When the counterweight is more than the weight of the cylindrical tank, there is vertical acceleration which leads to loss weight (the weightlessness). The upward acceleration of the cylinder is given as :

$$a= g (m -M)/(m+M)$$

where M= total mass of cylinder + liquid and baffle

m = mass of the counterweight

g= acceleration due to gravity.

If m is selected such that a is close to g, then a weightless condition is closely imitated. For this work, m is selected such that a = 0.1 m/s^2. With the microgravity condition achieved using the above concept, the cylinder is agitated by applying a horizontal force momentarily as shown in Figure 5. The procedure was repeated five times. At each time, an attached load cell was used to measure the cylinder wall displacements and the acquired data was used to measure the damping ratio.

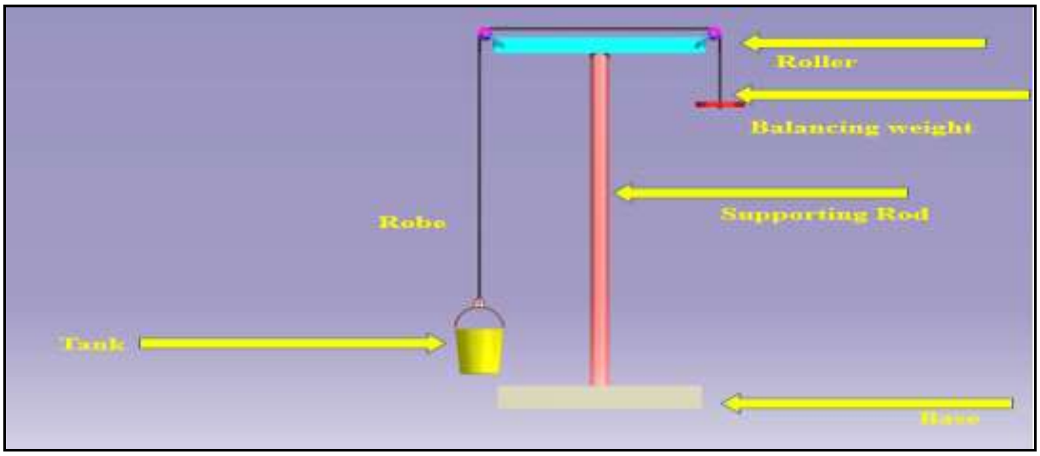

Figure 3. The Solid Works Illustration of different Components of Microgravity Test-Rig

Plate 4. The video capture of Microgravity experiment

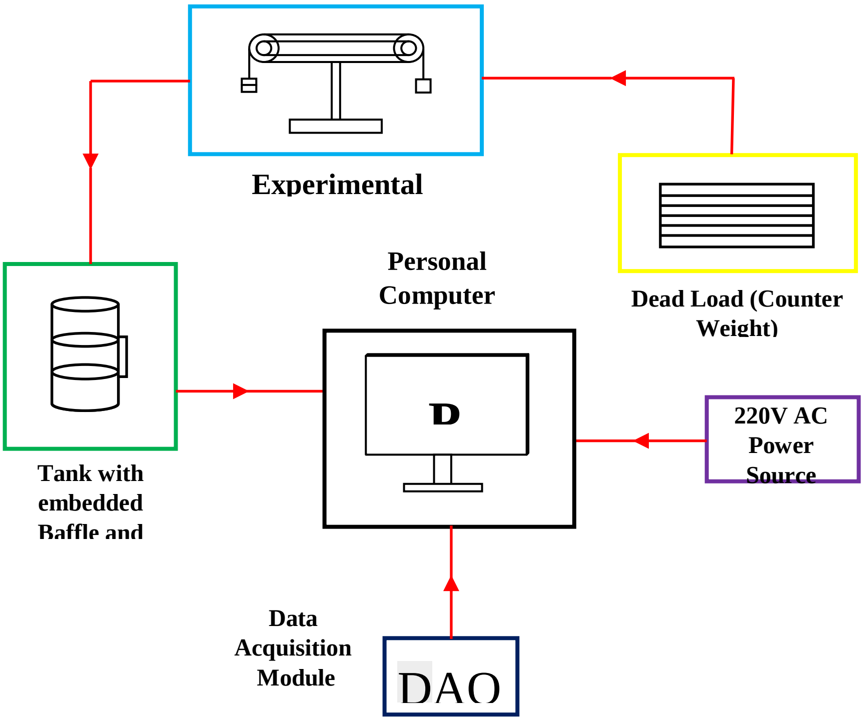

Figure 3. Layout of Microgravity Experimental Set-up

Evaluation of damping ratio as the main performance index

Miles (1958) equation (1) refers. The equation applies to cases of rigid-ring baffle in a cylindrical tank, with the damping ratio as a function of baffle depth d. A measure of the baffle performance is then estimated from semi empirical Mile's equation (Miles, 1958) stated as equation (1).

$$\zeta = \frac{\delta}{2\pi} = 2.83e^{-4.60\frac{d}{R}}\left[\frac{2w}{R} - \left(\frac{w}{R}\right)^2\right]^{3/2}\left(\frac{\eta}{R}\right)^{1/2} \tag{1}$$

Where damping ratio (ζ);baffle width (w); maximum slosh-wave amplitude at the wall (η); the damping factor (or logarithmic decrement-δ) and tank radius (R). The term in brackets is the fraction of the tank area covered by the baffle as detailed by (Gazra, 1966). Slosh wave amplitude η was obtained from the measured force using load cell. Likewise the values of SWA obtained from experimental were used to obtain the Damping ratio.

IV. RESULTS

Experimental results of the two baffles with pitch values of 0.0200 m and 0.0400m at gravity and microgravity environment respectively are presented in figures 12 to 15 and tables 2 and 3. These results were compared with numerical results obtained from literature (Adebayo et al. 2022), it has been found that there is no significant variation in the two results.

From figures 12 and 13, it was observed that the damping ratios of CARB1 increased by 14% when the pitch value increased at the first position of the tank, 0.47% reduction at the second position and 8.1 % increment at the third position along the tank's depth, at normal gravity.

Progressive increment of 0.81%, 0.86% and 4.5% were observed on the same baffle configuration at microgravity environment. From the above results it is clearly seen that the baffle will provide significant damping at the near free-surface and near the bottom of the tank at normal gravity environment. Also, the results show that damping effectiveness of the baffle increases progressively along the depth of the tank. Lastly, increment of the pitch of the baffle enhances the damping effectiveness at both normal gravity and microgravity environments.

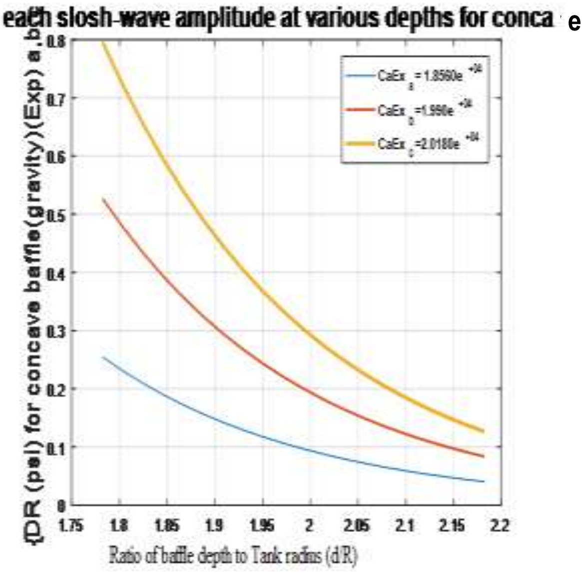

Figure 12. Experimental result of damping ratio for(CARB1) with 0.02 m pitch at normal gravity.

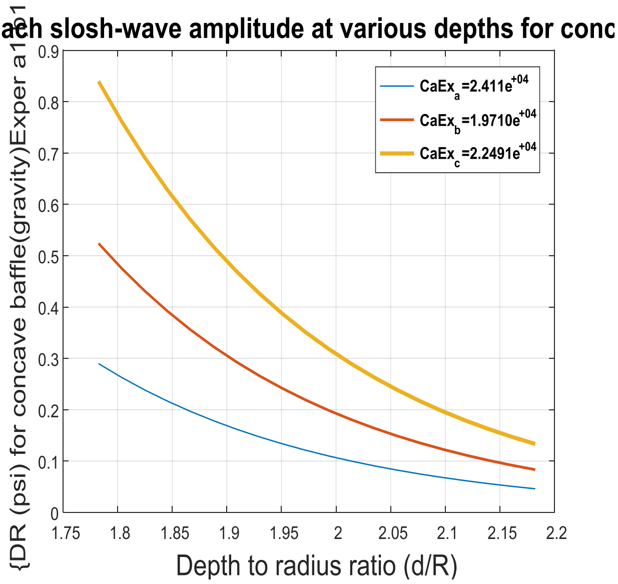

Figure 13. Experimental result of damping ratio for (CARB2) with 0.04 m pitch, at normal gravity.

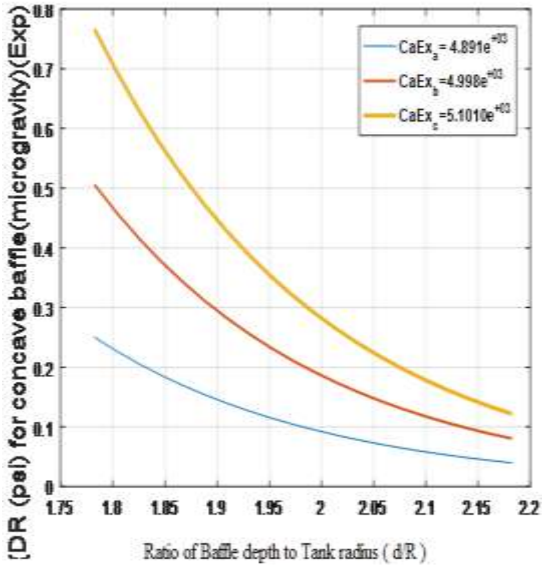

Figure 14. Experimental result of damping ratio for (CARB1) with 0.02 m pitch at microgravity.

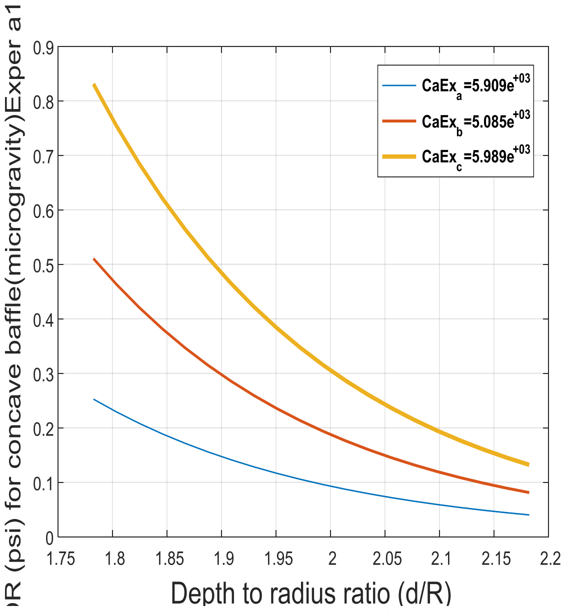

Figure 15. Experimental result of damping ratio for (CARB2) with 0.04 m pitch, at microgravity.

Table 2. Comparative experimental results of damping ratios of CARB1 and CARB2 of 0.0200 m and 0.0400 m respectively both at gravity and microgravity environments.

Exp. (grav) (0.02 m)	Exp. (grav) (0.04 m)	Percentage Increment / reduction (gravity)	Exp. (micr) (0.02 m)	Exp. (micr) (0.04 m)	Percentage increment / reduction (microgravity)	Percentage (%) tank filled levels
0.2542 ±0.0001	0.2898 ±0.0003	14%	0.2503 ±0.0005	0.2525 ±0.0001	0.87%	72
0.5265 ±0.0002	0.5240 ±0.0002	-0.47%	0.5061 ±0.0007	0.5105 ±0.0007	0.86%	66
0.7953 ±0.0002	0.8396 ±0.0002	8.1%	0.7964 ±0.0002	0.8310 ±0.0002	4.5%	59

Table 2 refers. At 59% and 72% filled levels of the tank, there was an increment of 14% and 8.1% in damping ratio of the baffle when the pitch value increased from 0.02m to 0.04m at normal gravity. Also at microgravity environment, increment of 4.5% was observed only at 72% filled level. For all other levels studied either at gravity or microgravity there was no appreciable change in the values of damping ratio. These increments in damping ratio signify improvement in damping effectiveness when the pitch values increased at the respective position and environment.

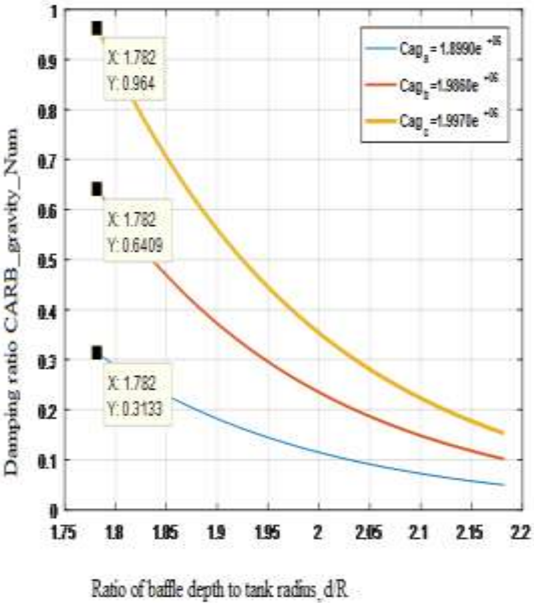

Figure 16. Numerical result of damping ratio (CARB1) with 0.0200 m pitch, at gravity (Adebayo et al. 2022).

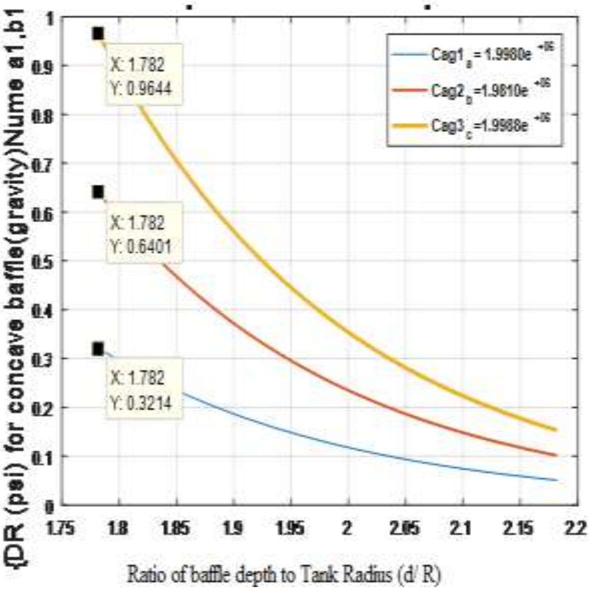

Figure 17. Numerical result of damping ratio (CARB2) with 0.0400 m pitch, at gravity (Adebayo et al. 2022).

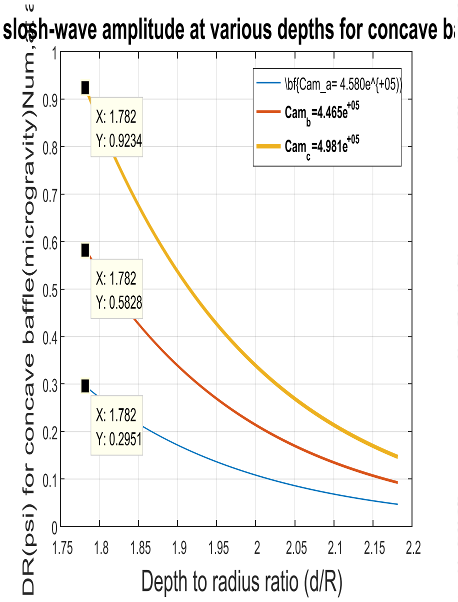

Figure 18. Numerical result of damping ratio (CARB1) with0.0200 m pitch, at microgravity (Adebayo et al. 2022).

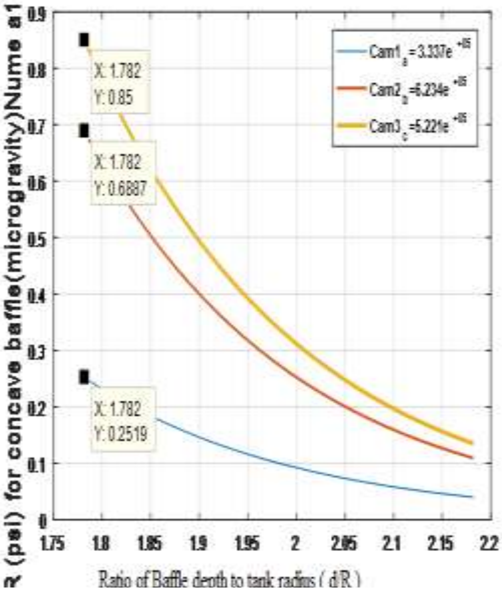

Figure 19. Numerical result of damping ratio(CARB2) with 0.0400 m pitch, at microgravity (Adebayo et al. 2022).

Table 3.Comparative Numerical and Experimental results of damping ratio for both CARB1 andCARB2at gravity and microgravity environments

Numerical, CARB1 (0.02 m) gravity	Experimental CARB1 (0.02 m) gravity	% Increase	Numerical CARB2 (0.04 m) gravity	Experimental CARB2 (0.04m) gravity	% Increase	Numerical CARB1 (0.02 m) microgravity	Experimental CARB1 (0.02 m) microgravity	% Increase	Numerical CARB2 (0.04 m) microgravity	Experimental CARB2 (0.04 m) microgravity	% Increase/(-reduction)	Percentage (%) tank filled levels
0.3133	0.2542 ±0.0001	19	0.3214	0.2898 ±0.000	10	0.2951	0.2503 ±0.0005	15	0.2519	0.2525 ±0.000	-0.2	72
0.6409	0.5265 ±0.0002	18	0.6401	0.5240 ±0.000	18	0.5828	0.5061 ±0.0007	13	0.6887	0.5105 ±0.000	26	66
0.9640	0.7953 ±0.0002	18	0.9644	0.8396 ±0.000	13	0.9234	0.7964 ±0.0002	14	0.8500	0.8310 ±0.000	2	59

Table 3 refers. Numerical results reported by Adebayo et al. 2022 showed increment of 19%, 18% and 18% at 59%, 66% and 72% filled level respectively over the experimental results at normal gravity for CARB1 and 10%, 18% and 13% for CARB2. Similarly at microgravity environment, increment of 15%, 13%, 14% were observed for CARB1 and for respective level. However for CARB2, - 0.2% reduction recorded at 72% filled level and increment of 26% and 2% at 66%, 59% filled level respectively.

V. CONCLUSIONS

Experimental studies enable researchers to check the validity of assumptions of the mathematical model, numerical simulations and to employ the model effectively for design applications. Adequate understanding of any complex physical phenomenon such as sloshing is enhanced to a great extent by the use of experimental techniques. This experimental study investigated damping effects of two type of baffles at three tank filled levels and under gravity as well as microgravity environments. The results obtained for studied geometries codenamed CARB1 and CARB2 at gravity and microgravity environments showed higher values of damping ratio at 72% and 59% tank filled levels. The results had corresponding good pattern and quantitative agreement with the standard literature based numerical results and as such can be deployed for engineering applications.

REFERENCES

[1]. Abramson, H.N.(1966). The dynamic behaviour of liquids in moving containers. Applications to Space Vehicle Technology. NASA SP-106. NASA Special Publication, 106.

[2]. Abramson, H.N.(1969). Slosh suppression report. NASA, Washington DC, SP-8031.

[3]. Adebayo Matthew, Ademola A. Dare, Tajudeen A.O. Salau (2022). Numerical Investigation of Sloshing Characteristics in Long Moving Vessels with Embedded Concave Rigid-ring Baffle in Gravity Environment

[4]. Akyildiz, H. and E.Unal (2005). Experimental studies on liquid sloshing. Technical Report, Department of Ocean Engineering and Hydraulics Division, Istanbul Technical University.

[5]. Anon, (1968). Propellant Slosh Loads. NASA Space Vehicle Design Criteria (Structures), NASA SP-8009.

[6]. ANSYS CFX Reference Guide, November 2013. User's Guide Release 15.0, ANSYS Inc. USA.

[7]. ANSYS CFX-Solver Modelling Guide, November 2013. User's Guide Release 15.0, ANSYS Inc. USA.

[8]. ANSYS CFX-Solver Theory Guide, November 2013. User's Guide Release 15.0, ANSYS Inc. USA.

[9]. Bauer, H.F.(1964). Fluid oscillations in the containers of a space vehicle and their influence upon stability. National Aeronautics and Space Administration: [For sale by the Office of Technical Services, Department of Commerce, Washington, DC 20230].

[10]. Çengel, Y.A. and J. M.Cimbala (2006). Fluid mechanics fundamentals and applications.

[11]. Chen, K.H., Kelecy, F.J. and R.H. Pletcher (1994). Numerical and experimental study of three-dimensional liquid sloshing flows. Journal of thermo physics and heat transfer, 8(3), pp.507-513.

[12]. Chia Chu, (2018).Slosh-induced hydrodynamic force in a water tank with multiple baffles National Central University. Article in Ocean Engineering.

[13]. Chintalapati, S., Faure, J., Zhou, R., Vergalla, M., Kirk, D. and Gutiérrez, H., (2010).Enhanced Numerical Modeling in Simulation of a Generic Propellant Tank Slosh Baffle. In 46thAIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit (p. 6976).

[14]. Chu CR, Wu YR, Wu TR, C-Y. Wang (2018). Slosh-induced hydrodynamic force in a water tank with multiple baffles. Ocean Eng 167:282–292

[15]. Cole Jr, H.A. and B. J. Gambucci (1961). Measured two-dimensional damping effectiveness of fuel-sloshing baffles applied to ring baffles in cylindrical tanks.

[16]. DhawalLeuva (2011). Experimental Investigation and CFD Simulation of Active Damping

[17]. Eswaran, M. and U.K., Saha, (2011). Sloshing of liquids in partially filled tanks–a review of experimental investigations. Ocean Systems Engineering, 1(2), pp.131-155.

[18]. Evans, D.V. and McIver, P., (1987). Resonant frequencies in a container with a vertical baffle. Journal of Fluid Mechanics, 175, pp.295-307.

[19]. Gazra, L. R. (1966). Theoretical and Experimental Pressures and Forces on a Ring Baffle under Sloshing Conditions", AIAA Journal of Spacecraft and Rockets, 3, pp. 276-278.

[20]. Gordon, D.Stubley ''Computational Fluid Dynamics for Fluids Engineering Design'' ANSYS CFX STUDENT USER MANUAL Version 11, Department of Mechanical Engineering, University of Waterloo ©G.D. Stubley 2008.UDF user defined functions ANSYS MP4 Video

[21]. Hastings, L.J., Platt, G.K. and Swalley, F.E., (1965). Saturn V low gravity fluid mechanics problems and their investigation by full-scale orbital experiment.

[22]. Heng Jin, Yong Liu, Ruiyin Song and Yi Liu (2020). Analytical study on the effect of a horizontal perforated plate on sloshing motion in a rectangular tank Journal of Offshore Mechanics and arctic Engineering in Partly Filled Tank Trucks, The, 2010, 4: 23-32

[23]. Jiadong Wang et al. (2019). Coupled Responses in a Partially Liquid-Filled Cylindrical Tank with the Single FB under Pitching Excitations. Journal of Shock and Vibration

[24]. Lecture 1 - The Fourier Transforms and its Applications MP4 video, Stanford Engineering Stanford University.

[25]. M. L. Turner, ''Rocket and Spacecraft Propulsion'', Principles, Practice and New Developments (Second Edition) CBE Department of Physics and Astronomy University of Leicester, UK

[26]. Maleki, A. and Ziyaeifar, M., (2008). Sloshing damping in cylindrical liquid storage tanks with baffles. Journal of Sound and Vibration, 311(1-2), pp.372-385.

[27]. Masica, W.J. and Salzman, J.A., (1965). An experimental investigation of the dynamic behaviour of the liquid-vapour interface under adverse low-gravitational conditions.

[28]. Mechanism for Propellant Slosh in Spacecraft Launch Systems

[29]. Mi-AnXue. Jinhai Zheng PengzhiLinXiaoli Yuan. (2017). The effectiveness of four types of the baffles in suppressing pressure is experimentally investigated under a wide range of forcing frequencies. Schuain University.

[30]. Mi-AnXueA., Zheng, J. andP. Lin (2012). Numerical simulation of sloshing phenomena in cubic tank with multiple baffles. Journal of Applied Mathematics, 2012.Pp.8-16.

[31]. Michael, R. Hatch. ‘‘Vibration using MATLAB and ANSYS. ’’Chapman & Hall/ CRC USA.

[32]. Miles, J.W., (1956). On the Sloshing of Liquid in a Cylindrical Tank. Rep. No.AM 6-5. GM-TR-18, Guided Missile Res. Div., The Ramo-Wooldridge Corp.

[33]. Miles, J.W., (1958). Ring damping of FS oscillations in a circular tank. J. Appl. Mech, 25(2), pp.274-276.

[34]. Modaressi-Tehrani, K., Rakheja, S. and Stiharu, I., (2007). Three-dimensional analysis of transient slosh within a partly-filled tank equipped with baffles. Vehicle System Dynamics, 45(6), pp.525-548.

[35]. Mohan, A., (2014). Finite element analysis on trapezoidal tank to suppress sloshing effect. International Journal of Innovative Research in Advanced Engineering, 1(10), pp.121-125.

[36]. Moiseyev, N.N. and Rumyantsev, V.V., (2012). Dynamic stability of bodies containing fluid (Vol. 6).Springer Science & Business Media.

[37]. NASA Space Vehicle design criteria (Guidance and Control), (2001), pp.36-41

[38]. Gurinder Singh Brar and Simranjit Singh., (2014). An Experimental and CFD Analysis of Sloshing in a Tanker. 2nd International Conference on Innovations in Automation and Mechatronics Engineering, ICIAME 2014 volume 2014, Pages 490-49.

[39]. Rakheja S. et al. (2010). An Analysis of Baffles Designs for Limiting Fluid Slosh in Partly Filled Tank Trucks, The Open Transportation Journal, 2010, 4: 23-32

[40]. Release 12.0 c ANSYS, Inc. March 12, 2009

[41]. Sakai, F., Nishimura, M. and Ogawa, H., (1984).Sloshing behaviour of floating-roof oil storage tanks. Computers & Structures, 19(1-2), pp.183-192.

[42]. Scholl, H.F. and Stephens, D.G., (1967). Effectiveness of flexible and rigid ring baffles for damping liquid oscillations in large-scale cylindrical tanks.

[43]. Silveira, M.A., Stephens, D.G. and Leonard, H.W., (1961). An experimental investigation of the damping of liquid oscillations in cylindrical tanks with various baffles (No. TN D 715).NATIONAL AERONAUTICS AND SPACE ADMINISTRATION WASHINGTON DC.

[44]. Simple and Easy Tutorial on FFT Fast Fourier Transform Matlab Part 1 (1) item type MP4 Video

[45]. Simple and Easy Tutorial on FFT Fast Fourier Transform Matlab Part 2(2) Item type MP4 Video. Reynolds Transport theorem

[46]. Simple FFT and Filtering Tutorial with Matlab – Code Project Simulation of kerosene-liquid tank sloshing with baffles using Fluent, MP4 Video

[47]. Takabatake, D., Sawada, S., Yoneyama, N. and M. Miura (2008), October. Sloshing reduction effect of splitting wall in cylindrical tank. In The 14th World Conference on Earthquake Engineering” October (pp. 12-17).

[48]. The Focus Video Tips- Multiphysics Simulation with ANSYS Maxwell and ANSYS Mechanical - Part 2 mP4 Video

[49]. TUTORIAL 10: Simulation of Multiphase problem with ANSYS CFX-Sloshing in a Tank

[50]. Tutorial: Fuel Tank Sloshing ANSYS, Inc. February 9, 2011.

[51]. Wang, W.Y., Peng Y, Zhou Y, Zhang Q (2016). Liquid sloshing in partly-filled tank, laterally-excited cylindrical tanks equipped with multi baffles. Appl Ocean Res 59:543–563.

[52]. Yang, W. J., T. T. Zhang, C. Li, S. M. Li and X. H. Xu (2019). Numerical Simulation of Pitching Sloshing under Microgravity.

[53]. Zhao DY, Hu ZQ, Chen G, Lim S, S. Wang, (2018). Nonlinear sloshing in rectangular tanks under forced excitation. Int J Nav Arch Ocean Eng 10:545–565