

Effect of “U” Shaped and Dome Shaped Baffles on Damping for Slosh Supression

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Abstract - Propellant sloshing in launch vehicles is a general problem of concern to space technologists. Sloshing can be suppressed by several techniques and one of them is by using baffles. Here, a study of some of the novel baffle configurations for the suppression of sloshing is carried out. Experiment is conducted on “U” shaped and Dome shaped baffle configurations. When compared to the Dome shaped baffle, “U” shaped baffle is giving a higher maximum value of damping ratio. In comparison to the flat annular ring baffle, it is surprising that both the “U” shaped and Dome shaped baffles are found to yield lower value of maximum damping. This is surmised to be perhaps due to the liquid interior to the inner edge surface of baffle behaving as a liquid mass in a separate container with the baffle being unable to restrain this oscillation.

Keywords: Propellant, slosh, baffles, “U”shaped baffle, Dome shaped baffle, damping ratio.

NOMENCLATURE

- X_o - Tank oscillatory displacement(0 to peak)
- W - Width of the baffle
- R - Radius of the tank
- D - Diameter of the tank
- H - Height of the liquid free surface from tank bottom
- γ - Damping ratio
- dS - Depth of the baffle below the liquid free surface
- h - Height of the baffle

1. INTRODUCTION

Propellant sloshing in launch vehicles is a general problem of concern to space technologists. These launch vehicles have a fairly high percentage of their initial mass as fuel and consequently, the dynamic forces resulting from the motions of these large liquid masses could be very substantial, even beyond the capabilities of the control system to counteract them or the structure to resist them [1].

Several methods have been employed to minimise the effects of liquid motion. Baffles of various configurations have been devised which reduce the damping of the liquid [2,3,4,5,6,7]. Flat annular ring baffles are commonly used in the propellant tanks of rockets and spacecrafts to reduce the effects of propellant sloshing [8,9]. Ring baffles are most effective when they are at a depth of $dS/R = 0.1$ below the liquid free surface. Although these baffles are extensively used in practice, the precise

mechanism of fluid and mechanical action of the baffle appears to have remained obscure. A modification of the ring baffle in the form of a “U” shaped baffle, Dome shaped baffle etc., is considered worthy of detailed investigation to see whether they would provide enhanced value of slosh damping. Here, an effort is made in this direction and details of these studies are discussed in this paper.

II. EXPERIMENTAL DETAILS

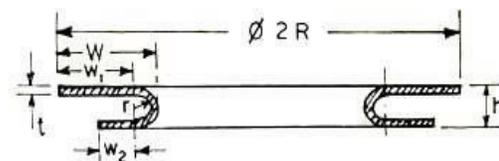
Water is used as model liquid medium in these studies [10]. Experiments are conducted using “U” shaped baffle and Dome shaped baffle. The tank is held firmly on a horizontal movable platform mounted on frictionless guide ways. Forced sinusoidal vibration is given to the platform through a crank and connecting rod mechanism, driven by a variable speed eddy current drive. Constant amplitude of the tank oscillation is maintained throughout the experiment ($X_o/D = 0.0036$). Diameter of tank consider is 274 mm and baffle material is Perspex.

The liquid is brought to the first resonant frequency. At this frequency, after the liquid has settled to a steady-state value, the excitation is cut off and the oscillating platform is brought to rest suddenly by using quick stop facility [11, 12]. Only the liquid continues to oscillate primarily at its fundamental frequency, as the oscillation decays with time. A trace of the decaying force signal is taken for computing the logarithmic decrement and the damping ratio. The experiment is continued by varying the liquid height (H) in suitable increments.

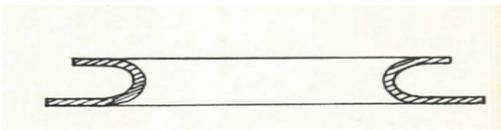
III. “U” SHAPED BAFFLE

A. Concept

It is felt that the flat annular ring baffle can be modified such that the fluid interacting with it can be made to turn around thereby providing increased resistance to fluid motion parallel to the tank walls. It is envisaged that this may be feasible by using a “U” shaped baffle (Figs. 1a & 1b).



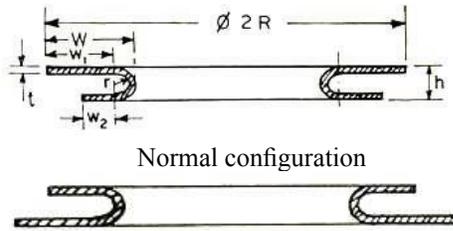
Normal configuration



Inverted configuration

$$\begin{aligned}
 r &= 0.084R & W &= 0.248R \\
 W_1 &= 0.128R & h &= 0.226R \\
 L &= 0.0365R & W_2 &= 0.091R
 \end{aligned}$$

Fig. 1a “U” shaped baffle – Type I geometry



Normal configuration



Inverted configuration

$$\begin{aligned}
 r &= 0.03R & W &= 0.248R \\
 L &= 0.018R & W_1 &= 0.186R \\
 H &= 0.095R & W_2 &= 0.062R
 \end{aligned}$$

Fig. 1b “U” shaped baffle – Type II geometry

When the baffle is of this shape, there is a possibility of air entrapment in the crown portion of the curved baffle. The air bubbles are likely to suppress the actual function of the “U” shaped baffle. This can be avoided by providing vent holes on the curved surface of the baffle; in the present case, 16 holes of 3.5mm diameter have been used.

During initial model experiments it was felt that “U” shaped baffles of different cross sectional geometry could be examined. Hence, the experiment is conducted using baffles of slightly different geometries viz., Type I and Type II baffles (Figs. 1a & 1b).

IV. RESULTS AND DISCUSSION

After necessary calculations, the results are reported in Table I. Comparison graphs are plotted between damping ratio vs dS/R values for the following configurations of “U” shaped baffle:

- (i) Normal and Inverted configurations (Fig. 1a – type I & Fig. 2)
- (ii) Type I and Type II geometries (Fig. 1a & 1b & fig.3)
- (iii) With and without vent holes in the curved surface (Type I, Fig. 4)

From fig. 2, one can find that when the baffle is in the normal configuration, the maximum damping value is obtained for $dS/R = -0.146$. This value gets shifted to $dS/R = 0.073$ for the inverted configuration. This effect seems to be primarily due to the shift in position of shorter limb of the baffle when it is inverted.

When the baffles of different geometry viz., Type I and Type II geometries are used (refer fig.3), an appreciable change in the damping value is observed. The maximum damping value is observed for Type II baffle, but it is effective for a narrower range of dS/R values. This effect seems to be due to the Type II baffle having a smaller radius of curvature in the curved portion when compared to Type I baffle. The increased curvature in Type I baffle appears to promote a more free movement of liquid mass interacting with the inner baffle edge, thus contributing to a reduction of the damping value.

TABLE 1 “U” SHAPED BAFFLE - VARIATION OF DAMPING RATIO WITH dS/R

| dS/R | TYPE I | | TYPE II | |
|---------|----------------------|-----------------|------------------------|----------------------|
| | Normal configuration | | Inverted configuration | Normal configuration |
| | With out vent holes | With vent holes | Without vent holes | Without vent holes |
| *-0.219 | 6.2 | 8.3 | 1.0 | 1.5 |
| -0.146 | 10.6 | 13.2 | 3.0 | 4.2 |
| -0.109 | 7.4 | 9.2 | 3.2 | 5.9 |
| -0.073 | 5.8 | 7.8 | 3.2 | 13.5 |
| 0.000 | 5.3 | 5.9 | 9.0 | 9.4 |
| 0.073 | 4.1 | 5.8 | 10.5 | 6.7 |
| 0.109 | 4.7 | 5.7 | 7.8 | 4.9 |

* Negative sign corresponds to the baffle crown surface being above the liquid level

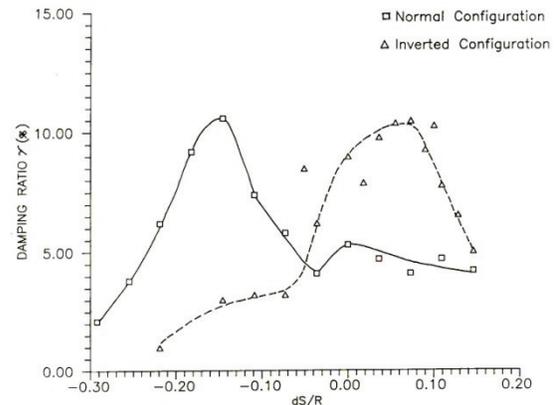


Fig. 2 Effect of the baffle configuration on damping in “U” shaped baffle of type I cross section

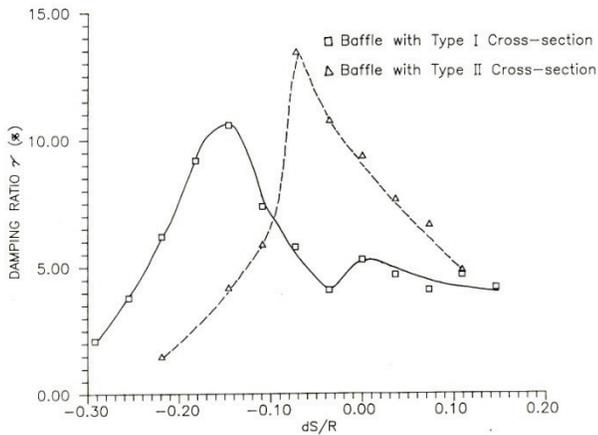


Fig. 3 Effect of the cross section on damping in “U” shaped baffle

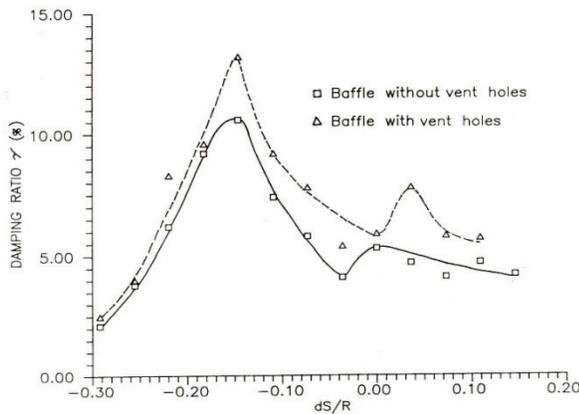


Fig. 4 Effect of vent holes in “U” shaped baffle of type I cross section

On observation of the results in Table I, one may notice that upto $dS/R = -0.109$, damping ratio values for Type I baffle without vent holes (column 2 of table I) are higher than the values of Type II baffle (column 5 of table I). This is due to the fact that baffle of Type I geometry has thicker profile; hence, the baffle interaction with the slosh mass begins at a lower liquid level.

When compared to the flat annular ring baffle results [9], it is found that “U” shaped baffle is giving a lesser maximum damping value. For flat annular ring baffle ($W/R = 0.24$) the maximum damping ratio is 21% when $dS/R = 0.14$; for “U” shaped baffle with vent holes (Type I baffle) the damping ratio is 13.2% (table I column 3) when $dS/R = -0.146$. This is surmised to be due to the liquid interior to the inner edge surface of baffle behaving as a liquid mass in a separate container with the baffle being unable to restrain this oscillation.

When vent holes on the curved portion of baffle are present, a slight increase in the damping ratio value is observed. For Type I baffle in normal configuration and without vent holes, the maximum damping ratio is 10.6%, but, for baffles with vent holes, the maximum damping ratio is 13.2%.

V. DOME SHAPED BAFFLE

A. Concept

A further modification of “U” shaped baffle concept leads

to the concept of dome shaped baffle [13]. By this modification, the fluid is made to turn around 180 degrees and it is felt that it would be able to provide better momentum change and thereby cause even better slosh suppression. This is also examined in the present study. The effect of cross sectional geometry (Figs. 5a & 5b) and vent holes in the crown of the baffle is also studied as in the “U” shaped baffle.

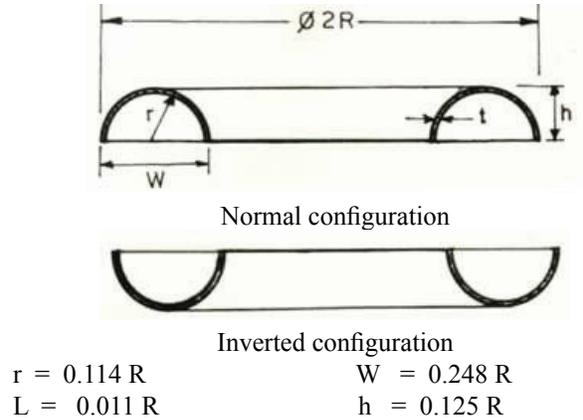


Fig. 5a Dome shaped baffle – type I geometry

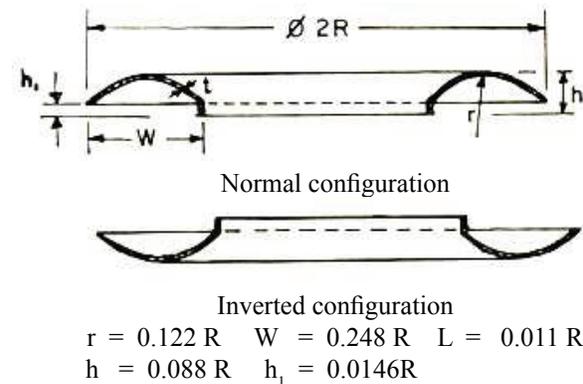


Fig. 5b Dome shaped baffle – type II geometry

VI. RESULTS AND DISCUSSION

After necessary calculations with logarithmic decrement method, the results are tabulated in Table II. Comparison graphs are plotted between damping ratio Vs. dS/R values for the following configurations of Dome shaped baffle;

- (i) Normal and Inverted configurations (Fig. 5a – type I & 6)
- (ii) Type I and Type II geometries (Fig. 5a, 5b & 7)
- (iii) With and without vent holes in the crown surface (Type I, Fig. 8)

When the baffle is in normal configuration, a slight increase in the maximum damping ratio is observed. The maximum value is attained at $dS/R = -0.036$. For the inverted configuration, the maximum value of damping is attained at $dS/R = 0$. This change in dS/R appears to be primarily due to the shift in the level of crown of the baffle when it is inverted.

TABLE II DOME SHAPED BAFFLE - VARIATION OF DAMPING RATIO WITH dS/R

| dS/R | TYPE I | | TYPE II | |
|---------|----------------------|-----------------|------------------------|----------------------|
| | Normal configuration | | Inverted configuration | Normal configuration |
| | Without vent holes | With vent holes | Without vent holes | With out vent holes |
| *-0.219 | 2.6 | 2.0 | 1.0 | 2.8 |
| -0.146 | 4.5 | 3.8 | 2.3 | 3.4 |
| -0.109 | 8.1 | 8.2 | 2.7 | 4.8 |
| -0.073 | 10.3 | 11.0 | 4.5 | 6.8 |
| -0.036 | 11.1 | 10.8 | 6.2 | 8.0 |
| 0.000 | 6.5 | 7.0 | 10.5 | 16.0 |
| 0.073 | 4.6 | 5.5 | 6.1 | 7.3 |
| 0.109 | 3.9 | 3.8 | 3.7 | 4.6 |

* Negative sign corresponds to the baffle crown surface being above the liquid level

When compared to the flat annular ring baffle [9], it is found to be giving a lower value of maximum damping ratio. For flat annular ring baffle ($W/R = 0.24$) the maximum value of damping is 21% when $dS/R = 0.14$; for Dome shaped baffle with vent holes the maximum damping value is found to be only 11% when $dS/R = -0.073$ (table II column 3). This is surmised to be due to the liquid interior to the inner edge surface of baffle behaving as a liquid mass in a separate container and the baffle being unable to restrain this oscillation.

When the shape of the baffle changes viz., Type I and Type II geometries, an appreciable change in the damping value is observed. Here maximum damping is observed for Type II geometry. This effect seems to be due to the Type II baffle having lower curvature of the crown portion when compared to the Type I baffle.

When vent holes on crown of the baffle are present, a slight increase in the damping value is observed. For Type I baffle in normal configuration and without vent holes, the maximum damping value is 10.3%, but for baffle with vent holes the maximum value of damping is 11%.

Comparison graphs are plotted for Dome shaped and “U” shaped baffles (Figs. 9a & 9b). The maximum damping ratio value for “U” shaped baffle with vent holes for type I is 13.2% (Table I, column 3 & fig. 4), but for Dome shaped baffle it is 11% (Table II, column 3 & fig. 8) But no change in the maximum damping ratio value is observed for the baffles without vent holes. Hence one may conclude that the influence of trapped air-bubbles appears to be more in “U” shaped baffle when compared to Dome shaped baffle.

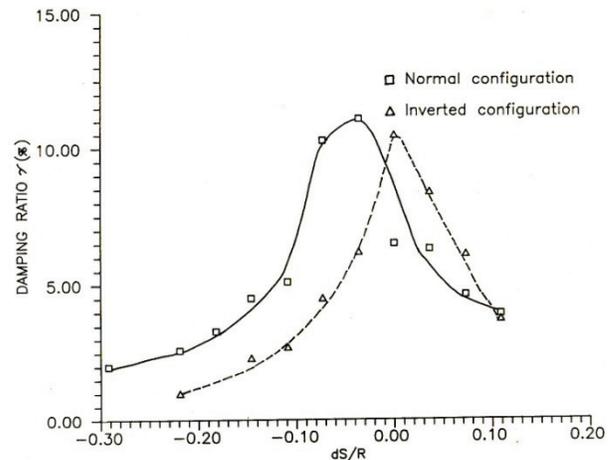


Fig. 6 Effect of baffle configuration on damping in Dome shaped baffle of Type I cross section

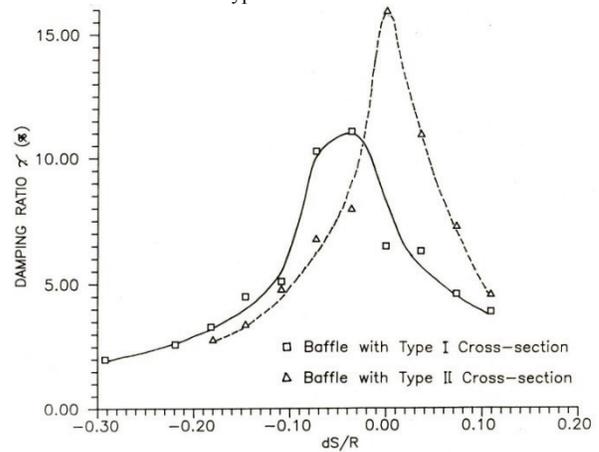


Fig. 7 Effect of cross section on damping in Dome shaped baffle

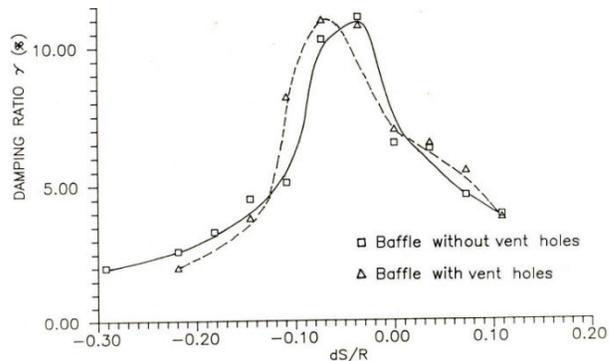


Fig. 8 Effect of vent holes on damping in Dome shaped baffle of Type I cross section

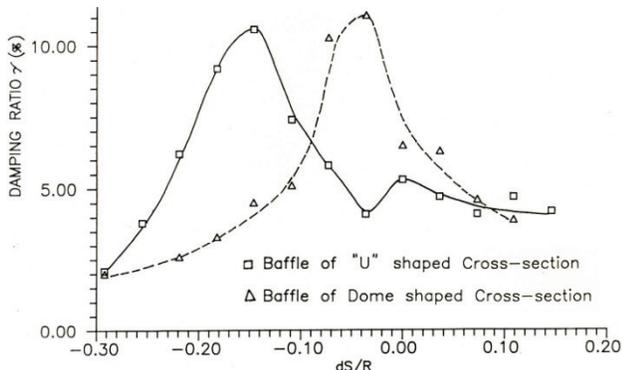


Fig. 9a Comparison of damping ratio variation in “U” shaped and Dome shaped baffle of Type I cross section

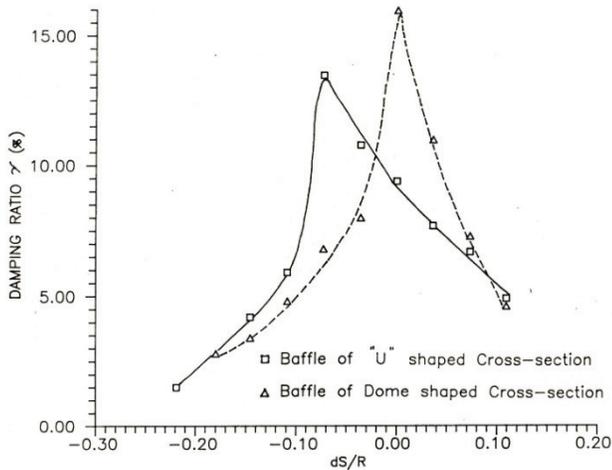


Fig. 9b Comparison of damping ratio variation in “U” shaped and Dome shaped baffle of Type II cross section

VI. CONCLUSION

Slosh damping characteristics of “U” shaped and Dome shaped baffles are examined. It is seen that the “U” shaped baffle is giving a higher maximum value of damping when compared to Dome shaped baffle. In comparison with the optimized flat annular ring baffle ($W/R = 0.24$) it is found that “U” shaped and Dome shaped baffles are giving lower maximum damping values contrary to original expectation. This is surmised to be perhaps due to the liquid interior to

the inner edge surface of baffle behaving as a liquid mass in a separate container with the baffle being unable to restrain the oscillation.

It is further concluded that the flat annular ring baffles are better configuration when compared to “U” shaped and Dome shaped baffle configurations. But for wider dS/R values with lower damping requirements, one can use the “U” shaped and dome shaped baffles.

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