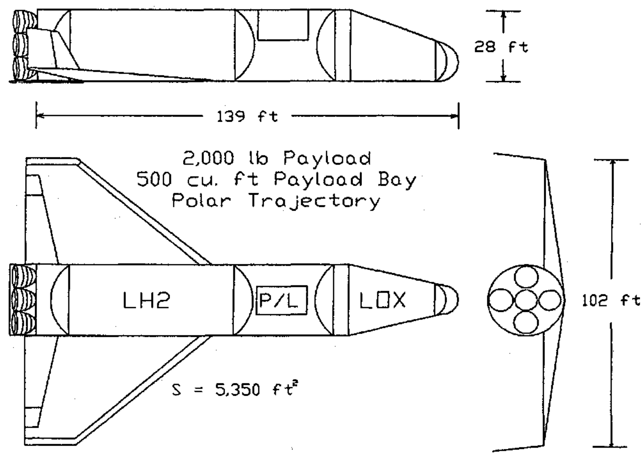

Fig. 2 Resulting air-launch vehicle configuration.

value, but a complete optimization has not been attempted. The final bar demonstrates the effect of modifying the wing loading and wing weight equations to allow for the additional flight loads required to lift the vehicle at gross weight with a load factor of 1.0 and an ultimate safety factor of 1.5. The resulting vehicle has a gross weight of 1.37×10^6 lb and a dry weight of 156,000 lb. Unfortunately, the gross weight is much higher than the lifting capability of existing airplanes. The configuration of this vehicle is illustrated in Fig. 2.

An analysis was also conducted for an air-launched vehicle using hydrocarbon fuel. The results indicated that such a vehicle would be significantly heavier than the hydrogen vehicle.

Concluding Remarks

The analysis of the VTHL vehicle shows that a payload reduction from 25,000 to 2,000 lb and a payload bay reduction from 5300 to 500 ft^3 can reduce the gross weight from 2.91×10^6 to 1.56×10^6 lb. The dry weight is reduced from 274,000 to 156,000 lb. This is a 43% reduction in dry weight, after a 92% reduction in payload weight. Changing from a space-station launch to a polar launch increases the gross weight to 2.22×10^6 lb.

The assisted SSTO air-launch concept was analyzed using the baseline polar configuration sized to fit the modified trajectory. Using a subsonic airplane to obtain an altitude of 25,000 ft and a speed of Mach 0.85 provided significant weight savings. The modified trajectory and wing loading reduced the gross weight to 1.37×10^6 lb and the dry weight to 156,000 lb.

Acknowledgments

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Device to Suppress Vortexing During Draining from Cylindrical Tanks

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Nomenclature

b	= width of the cell in the mesh, mm
D	= diameter of the container, mm
D_1	= base diameter of the suppressor, mm
d	= diameter of the drain port, mm
H_c	= critical height of liquid, mm
H_i	= initial height of liquid, mm
h	= height of the suppressor at the center, mm
l	= length of the cell in the mesh, mm
R	= radius of curvature of the suppressor, mm
t_0	= time of emptying without rotation, s
t_r	= time of emptying with rotation, s
w	= diameter of mesh wire, mm

Introduction

WHEN liquid drains from a cylindrical tank through an axisymmetrically placed circular orifice (drain), a dip develops on the free surface of the liquid as the surface level reaches a certain critical height H_c. The dip quickly develops into a vortex with an air core, which extends to the bottom port, reducing the effective cross-sectional area of the drain outlet[1–4] and consequently the flow rate. The presence of initial rotation can augment the vortex formation and affect the discharge rates further. The formation of a vortex has practical relevance in the fuel feed system in space vehicles and rockets. During the flight of space vehicles and rockets, because of environmental disturbances, rotational motion can be generated in the liquid-propellant tank, which in turn can affect the rate of outflow to the engines.

There have been attempts to suppress the vortex formation or overcome the reduction in flow rate by preventing the extension of the air core to the drain port. Abramson et al.[1] used baffles for suppressing sloshing, and these were found to be effective in reducing the undesirable effects of vortexing. Ramamurthi and Tharakan[4] found that a stepped drain port is effective in arresting vortex formation even when rotational motion is present in the liquid column. Gowda[5] has shown that vortexing can be avoided by using tanks of square and rectangular cross sections. However, a disadvantage in using such shapes is the presence of sharp corners, which give rise to regions of stress concentration.

In the present study a simple device is suggested for preventing vortex formation in a cylindrical container of circular cross section.

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A dish-shaped suppressor is used, and its effectiveness in preventing vortex formation under various conditions is brought out.

Experimental Arrangement

The arrangement is essentially the same as that used in Ref. 5. An acrylic cylindrical tank of 92-mm i.d. and 460-mm height with provisions for interchangeable drain holes of diameters 6 and 10 mm was used (Fig. 1). Another tank of 190-mm i.d. and with a drain hole 12 mm in diameter was also fabricated to study the scale effects, if any. The liquid used in the experiments is water at room temperature. The drain holes are centrally located at the bottom of the tanks along the vertical axis. Rotation is imparted to the liquid in the container by controlled stirring (with the drain port closed by a rubber stopper; see Fig. 1), using varying numbers of revolutions of the stirrer over a constant period of time.[5] After imparting the rotation, the rubber stopper is removed and the draining started. Results are obtained at different values of H_i/D.

The dish-type (or cup-shaped) suppressor is made of mild steel mesh of cell size $l \times b \times w$, with different values of l, b, and w. The shape of the dish is defined by R and h. In Fig. 1 the suppressor is shown in position inside the tank. A hole equal in diameter to d is provided at the center of the mesh. The dimensions are such that the dish can be pushed down the tank ($D \approx D_1$) and made to occupy the position at the bottom as shown in Fig. 1.

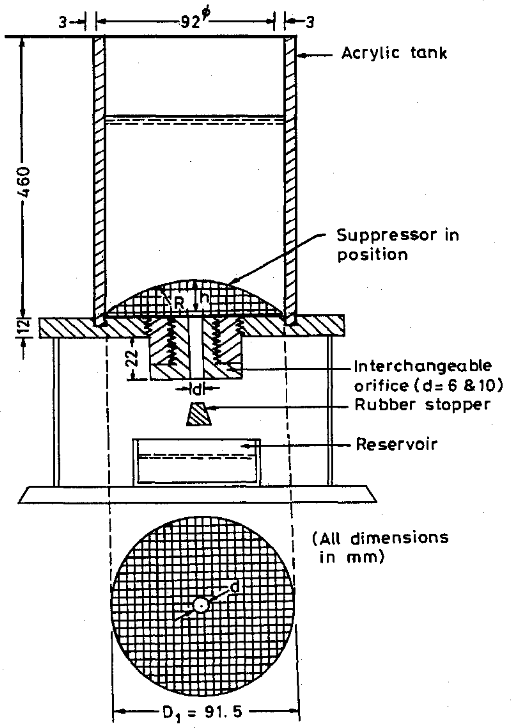

Fig. 1 Experimental arrangement.

Results

To determine the optimum dimension of the dish and also the mesh size to be used for making it, experiments were carried out for different values of $R/D_1(D_1 = 91.5$ mm for all cases) and using different mesh sizes. The critical height (H_c) and the time of emptying (t_r) with the suppressor were obtained at a stirrer rotational speed of 94 rpm (which is a typical value[5]); Fig. 2 shows the results for $D/d = 92/6$. The effectiveness of the device in suppressing vortex formation is clearly seen in Fig. 2a. Further, for $R/D_1 \leq 1.5$, all the shapes and mesh sizes are equally effective. This is very significant from the practical application point of view. From Fig. 2b, it is seen that $t_r/t_0 = 1$ up to $R/D_1 = 3.0$, i.e., in the range $1.5 < R/D_1 < 3.0$, even though the vortex is not completely suppressed (Fig. 2a), it has hardly any effect on the time of draining. Obviously, in this range, though a vortex is formed, its core does not extend into the port area and reduce the effective area of draining.

Experiments were done (for $D/d = 92/6$) at other values of H_i ($H_i = 200$ and 100 mm) and at another rotational speed (143 rpm) to check the effectiveness of the suppressor at other conditions. Also, runs were made with the port diameter $d = 10$ mm for $H_i = 300$, 200, and 100 mm. At each value of H_i, results were obtained at 94 and 143 rpm. For these runs, a mesh size of $0.7 \times 0.7 \times 0.24$ mm was used. The device is found to be very effective at all of these conditions. Further, to see whether there is any scale effect, experiments were conducted in a larger-diameter tank with $D = 190$ mm and $d = 12$ mm, i.e., nearly twice the size of the one with $D/d = 92/6$.

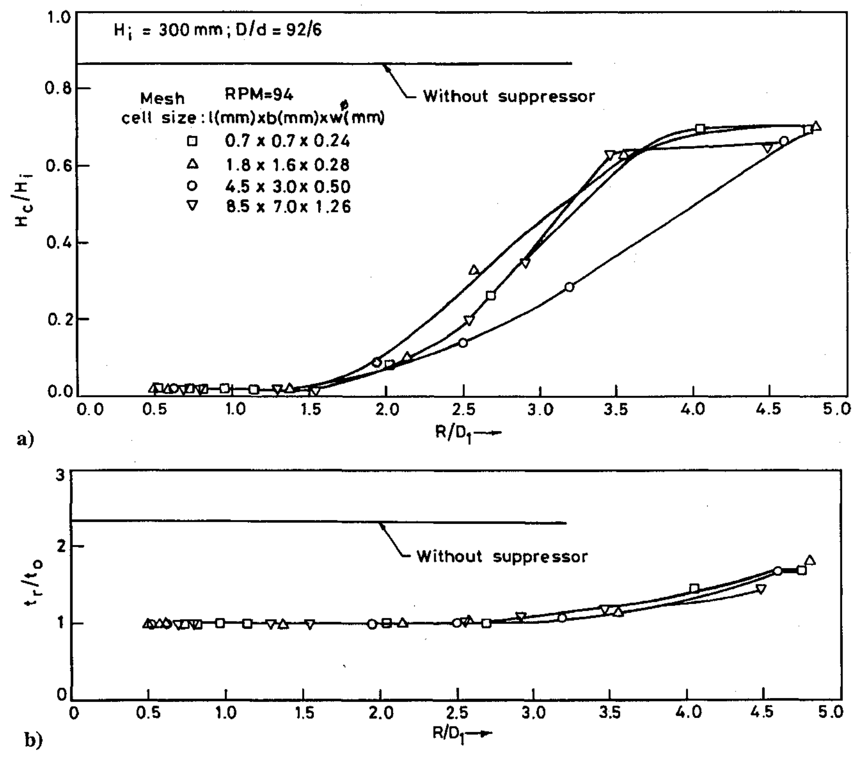

Fig. 2 Influence of suppressor on vortex formation for different mesh sizes.

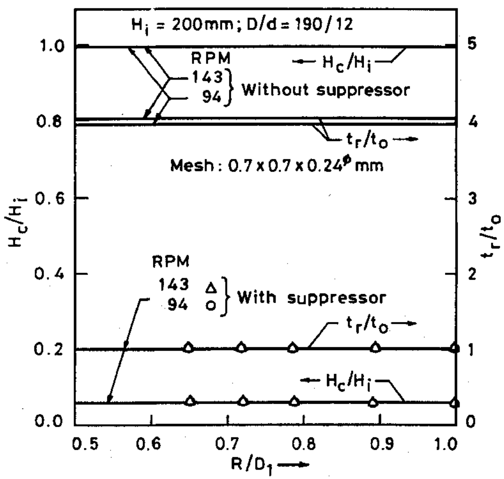

Fig. 3 Influence of suppressor on vortex formation.

The results are shown in Fig. 3. The effectiveness of the suppressor is seen to be unaffected by the increase in the scale.

The possible physical explanation for the effectiveness of the device suggested in preventing the formation of a vortex is as follows. When rotation is imparted to the fluid in the container (without draining), centrifugal forces develop, which are balanced by the radial pressure gradient. But the velocities at the bottom of the container will be low because of boundary-layer formation. However, the magnitude of the radial pressure gradient within the boundary layer will be nearly the same as that outside, and this will lead to an imbalance between the centrifugal forces and the pressure forces, resulting in a radial flow towards the center on the bottom surface. Also, a low pressure is created at the center of the bottom surface. When draining is started (after imparting rotation), the formation of the vortex and the extension of the air core into the port can be attributed to the low pressure mentioned above. The dish-type device suggested in the present study appears to act as a roughness device, preventing the generation of low pressure at the center, i.e., near the position of the port. Vortex formation is thus suppressed.

It may be pertinent to point out here that the results presented are for a inertial system. During flight of space vehicles and rockets, the fuel tank is accelerating or decelerating, i.e., it is a noninertial system. Pasley[2] has mentioned that vortexing is easily induced in a uniform 1-g acceleration. Saad and DeBrock[6] mention that withdrawal of liquid from a vessel at any acceleration produces a surface dip, which can extend to the outlet of the container. It is further stated that this phenomenon is enhanced by reduction in the gravity field. The mechanism leading to vortex formation in noninertial systems can be expected to be not much different from that in an inertial environment. Hence, the suppressor suggested in the present study should be effective in the former case also; however, the effectiveness needs to be confirmed.

Concluding Remarks

A simple device has been suggested to prevent vortexing in the draining of liquids from cylindrical containers. It is shown that the shape of the dish-type device is not very critical as long as $R/D_1 \leq 1.5$. The cost of the device is very small, and the device is very well suited for use in practical situations.

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