Shock-Wave Interaction with Two-Dimensional Bodies

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Theme

A NUMERICAL study has been made of the shock-wave-induced, unsteady flow over various two-dimensional bodies near a ground plane. Results are given herein which show the effect of varying the body aspect ratio, the height of the body above ground and the shielding of the body by placing it in a rectangular trench. The effect of shock strength on the body forces is investigated for flows ranging from nearly incompressible to supersonic. Dimensionless coordinates are used to facilitate interpolation and extrapolation of the results.

Contents

The physical problem considered in this paper is that of a plane shock wave interacting with a two-dimensional body on or near a ground plane in an initially stagnant flow. The fluid is assumed to be an inviscid, perfect gas with a constant specific heat ratio of 1.4. The method developed by Godunov, Zabrodyn, and Prokopov[1] used to numerically solve the unsteady gas dynamic equations is stable because it implicitly contains an artificial viscosity. The numerical scheme is first-order accurate in both space and time. However, comparative studies done by Taylor, Ndefo, and Masson[2] indicate that the Godunov method gives good results when compared with higher-order numerical techniques. Each of the calculations described herein required 30 to 60 minutes on an IBM 370. (Recent experience running the code on a CDC 7600 indicates that this corresponds to 5 to 10 min of 7600 running time.)

Although the Godunov method can successfuly treat shock waves in the flowfield, it has the drawback of smearing the shock waves out over five or six finite difference cells rather than modeling the wave as a discontinuity. This shock smearing has no effect on either the shock wave strength or speed but it does introduce some irregularities in the results described herein. For example, the numerical model predicts that the drag on a rectangular body will rise continuously, when a shock propagates over it, rather than in the expected discontinuous fashion.

The numerical calculations have been compared with the experimental data of Bleakney, White and Griffith.[3] Typical results are given in Fig. 1, which shows the pressure distribution on a semicircular body at two different times. (The dimensionless time, T, in Fig. 1 is the time after the shock first contacts the body divided by the time required for the undisturbed shock wave to travel one body width; p_o and p_s are the pressures ahead of and behind the undisturbed shock wave, respectively.) The agreement between the experimental data and the numerical calculations in Fig. 1 is good except in regions where shocks and rarefaction waves intersect the body.

When a shock interacts with the rather blunt, nonaerodynamic shapes considered in this study the drag force

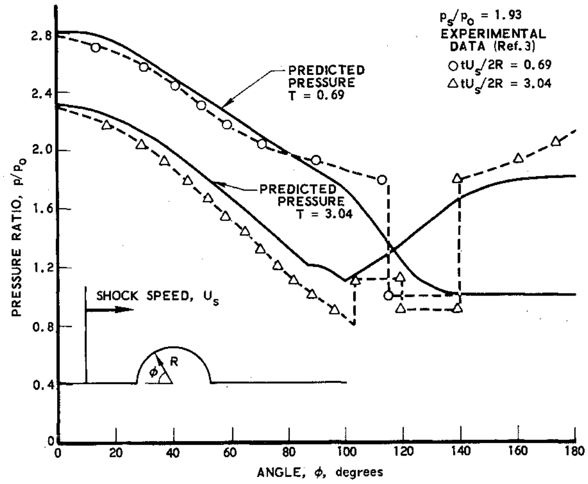

Fig. 1 Comparison of predicted and experimental pressures on a semicircular cylinder.

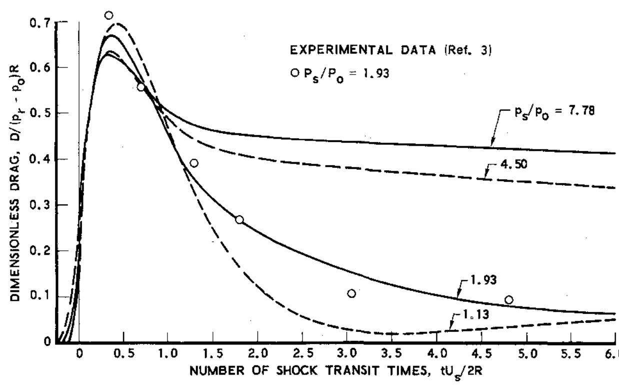

Fig. 2 Drag of a semicircular cylinder for various shock strengths.

is typically much higher than the lift force. (The drag force is of the order of the reflected shock pressure, p_r, times a frontal area, while the lift force is of the order of the pressure behind the undisturbed shock, p_s, times a plan area.) For this reason the results presented, herein, will emphasize the drag force.

Figure 2 shows the effect of variable shock strength on the drag of a semicircular cylinder. The drag has been normalized with the difference between the reflected shock pressure p_r and the initial pressure p_o. This normalization gives a drag of unity at time zero plus for a rectangular body. Figure 2 shows that the peak dimensionless drag decreases with shock strength, while the steady-state value increases. At a shock pressure ratio of 1.93, where experimental data are available, the agreement between the calculation and experimental data is good.

Figure 3 shows the variation of the drag history of a rectangular body with height. Because it takes less time for a rarefaction wave to propagate down the front of a body as the height decreases, the drag decays faster for lower height bodies. Again, good agreement is found between the calculations and the available data. However, the peak drag is

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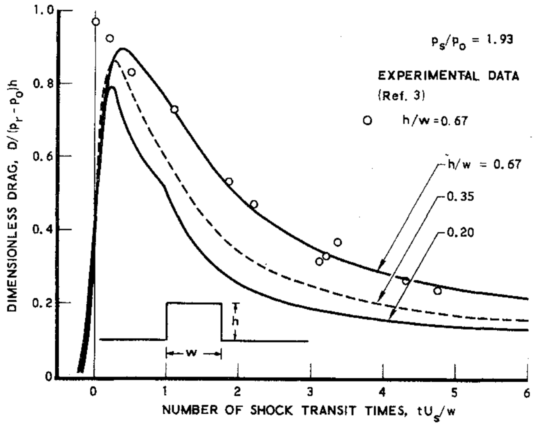

Fig. 3 Drag of various height-to-width ratio rectangular cylinders.

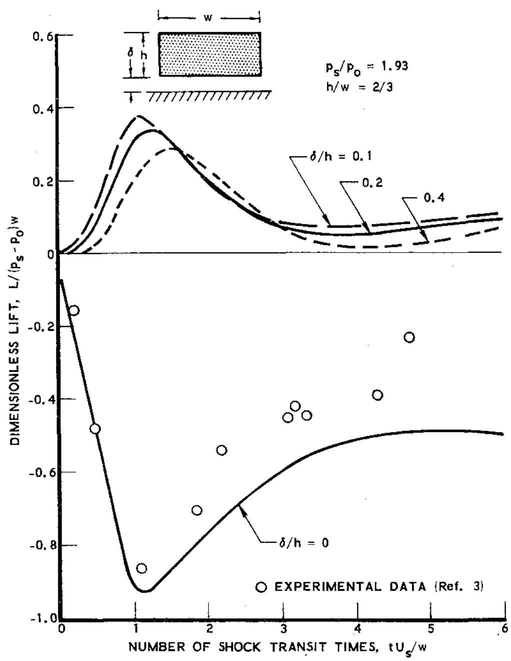

Fig. 4 Lift of a rectangular cylinder near a ground plane.

slightly underpredicted because of the fact that the numerical model smears out the shock wave.

Figure 4 shows the effect on the lift of raising a rectangular body above the ground plane. Note that the lift is normalized with the pressure behind the undisturbed shock wave and not with the reflected pressure. The lift for a body on the ground plane ($\delta/h=0$) is defined as the integral of $p-p_o$ over the projected ground plane area. This definition makes the lift

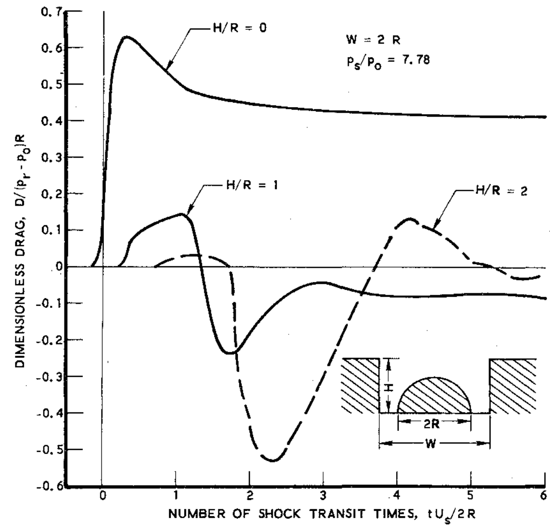

Fig. 5 Effect of trench depth on drag.

zero before the shock arrives, but it is also such that the zero height curve is not approached asymptotically for finite δ/h as $\delta/h \to 0$. The peak in the lift curve for $\delta/h \neq 0$ is caused by a shock wave being driven under the body, with the reflected shock region on the front of the body acting as a reservoir. As δ/h decreases, the strength of this shock wave driven under the body asymptotically approaches the strength of a wave which would occur for a infinitely high body and, therefore, the lift approaches an asymptote. The curve, $\delta/h=0.1$, in Fig. 4 is very nearly this asymptote and, as such, represents the inviscid asymptote of the lift as the height above ground goes to zero. Over the range of parameters considered in Fig. 4, the change in the drag is negligible and is, therefore, that given by the appropriate curve in Fig. 3.

Figure 5 shows the drag reduction which may be obtained by placing a semicircular body in a rectangular trench. The calculations show a marked reduction in the positive drag compared to the unshielded body, but this is to some extent offset by a large negative drag force which is associated with the shock wave reflected off the back wall of the trench.

References

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[2] Taylor, T. D., Ndefo, E., and Masson, B. S., "A Study of Numerical Methods for Solving Viscous and Inviscid Flow Problems," *Journal of Computational Physics*, Vol. 9, Feb. 1972, pp. 99-119.

[3] Bleakney, W., White, D. R., and Griffith, W. C., "Measurements of Diffraction of Shock Waves and Resulting Loading of Structures," *Journal of Applied Mechanics*, Vol. 17, Dec. 1950, pp. 439-445.