AIAA 81-4055

Experiments on the Stability of Converging Cylindrical Shock Waves

James H. T. Wu*
McGill University, Montreal Canada
Rafik A. Neemeh†
Concordia University, Montreal, Canada
and
P. Perry Ostrowski‡
University of Maryland, College Park, Md.

Abstract

STABILITY of converging cylindrical shock waves is investigated experimentally in an annular shock tube. Initially symmetric shocks are found to retain their symmetry during implosion except at small radius where a breakdown in shock front curvature eventually occurs. Artificially generated shock front perturbations are observed to promote this type of instability. In all cases, instability is manifest by the appearance of vortex pairs during the expansive shock motion which follows the implosion.

Contents

The design, construction, and operation of a 16.8 cm o.d. annular shock tube used to generate converging cylindrical shock waves has been described in an earlier paper.[1] In that study, symmetrical wave fronts were observed at larger shock radii although an ultimate breakdown in shock front curvature was always noted as the shock collapsed into a small but finite region surrounding its implosion center. Since such behavior has been predicted by the approximate analyses of Butler[2] and Whitham,[3] the present study has been undertaken to experimentally investigate certain aspects of the stability of converging cylindrical shocks by introducing two kinds of artificial perturbations on the imploding wave front.

All experiments were conducted in the same shock tube facility as before. The details are given in Ref. 1. Spark shadow photography having a viewing diameter of 2.54 cm was accomplished with the aid of a plane mirror mounted flush to the inner wall of the cylindrical implosion chamber and with a plate glass window in the outer wall. A single photograph was obtained from each test and events were monitored from successive tests by using a transducer triggered variable time delay spark unit.

Artificial shock front perturbations were produced prior to shock entry into the implosion chamber by removing the wedge fairings from the shock tube support flange webs (Ref. 1) which are located 45 deg to the implosion chamber quadrant axes. As shown in Fig. 1 the converging shock is locally retarded by those rectangular webs, and so the shock initially takes on a somewhat square appearance, although with smoothly distributed curvature. Then, as convergence continues, the shock front breaks down corresponding to a transition to Mach reflection with the appearance of transverse reflected waves which tend to travel around the periphery of the collapsing shock front. This phenomenon is a consequence of the nonuniform flowfield behind, and vortex

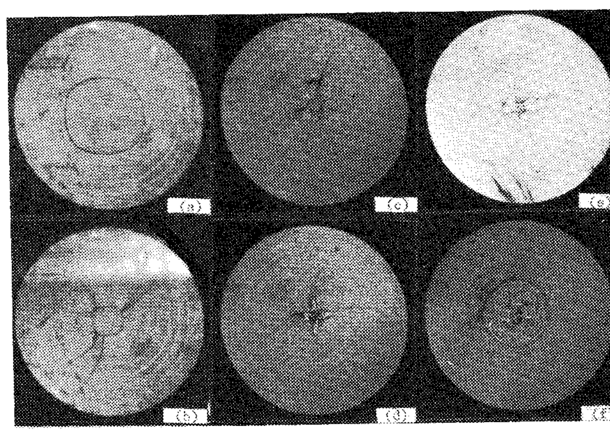

Fig. 1 Shadowgraphs showing converging cylindrical shock wave perturbed by four rectangular webs upstream of the cylindrical implosion chamber.

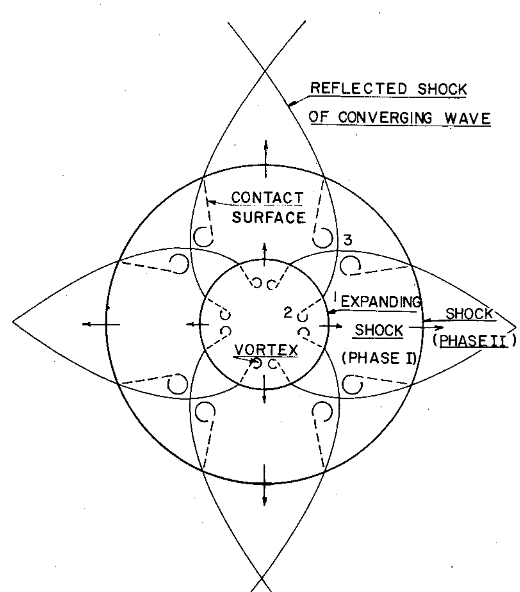

Fig. 2 Schematic demonstrating the mechanism of vortex formation behind the diverging cylindrical shock at two separate instants.

Received Feb. 19, 1980; synoptic received Sept. 4, 1980. Full paper available from National Technical Information Service, Springfield, Va., 22151 (available upon request by title).

*Associate Professor, Dept. of Mechanical Engineering; presently, Professor, Dept. of Mechanical Engineering, Concordia University, Montreal. Member AIAA.

†Associate Professor, Dept. of Mechanical Engineering. Member AIAA.

‡Assistant Professor, Dept. of Mechanical Engineering; presently, Research Engineer, Naval Ordnance Station, Indian Head, Mmd.

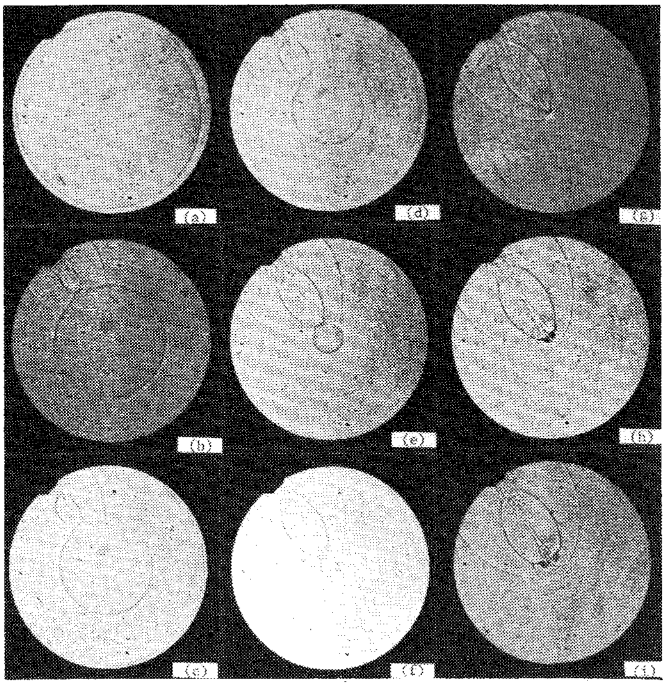

Fig. 3 Shadowgraphs showing the shock front perturbations produced by a 4.4-mm-diam rod located at $R = 2.54$ cm.

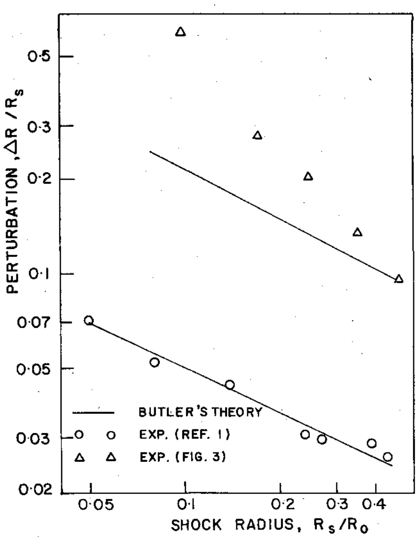

Fig. 4 Growth of shock front perturbation produced by the cylindrical rod at $R = 2.54$ cm.

pairs are observed behind the expanding shock. Modeling of a strong converging square shock by Whitham's shock-shock theory[3] indicates that it will repeatedly alternate from square to octagonal during implosion.

More importantly, these results need an explanation of the vortex formation as noted above. Figure 2 is an interpretation of the flowfield behind the expanding shock front at two different instants, as compared to Fig. 1e and 1f, which proposes that vortex formation results from the rolling up of contact discontinuities as the expanding shock overtakes the trailing transverse shocks generated during converging. Clearly, the implication is that any converging cylindrical shock with a perturbed wave front will eventually break down and that the appearance of vortex pairs behind the expanding shocks signals and verifies this ultimate breakdown in shock front curvature.

Perturbations produced by a 4.4 mm diameter cylindrical rod placed in the path of the converging cylindrical shock are shown in Fig. 3. The rod is located 2.54 cm from the center of the chamber and is obscured by a chip in the glass window (dark area in the upper left corner). In this case, two pairs of Mach stems and transverse reflected waves are produced by the shock diffraction around the cylindrical rod.[3] Although the latter tend to propagate transversely, a significant portion of the imploding shock is seen to be unaffected by the disturbance and the shock does not regain its symmetry. Nevertheless, no measurable shift in the implosion center has been observed. As anticipated, vortex pairs are again generated by the rolling up of the contact discontinuities behind the expanding shock. In this case, however, the vortices associated with each pair of transverse reflected shocks appear to have merged together.

Figure 4 presents the shock perturbations (ΔR) normalized with respect to the instantaneous shock radius Rs as measured from the photographs of Fig. 3 and those given in Ref. 1 for converging shocks without rod. In the latter the perturbations are produced by the imperfections present in the symmetry of the apparatus (0.1%). In both cases presented in Fig. 4, the relative size of perturbations is found to increase as implosion proceeds. The experimental results for the smallest initial perturbations are found to agree well with Butler Theory[2] which predicts that $\Delta R/R_s \sim (R_s/R_0)^{**}(-0.5987)$. Since the relative size of perturbations increases as implosion proceeds, it is evident that converging cylindrical shocks are unstable to this type of disturbance.

The present investigation supports the popular contention that converging cylindrical shocks are inherently unstable. Experiments with artificially produced perturbations have demonstrated that a breakdown in shock front curvature leads to the formation of vortex pairs behind the expanding shock wave resulting from reflected shocks during the converging phase. Such vortex formation is observed even for converging shocks initially possessing a high degree of symmetry and thereby signals an ultimate instability.

Acknowledgments

This work was supported by the National Research Council of Canada under Grant Nos. A-1255 (Wu) and A-4206 (Neemeh) and The General Research Board of The University of Maryland (Ostrowski). The assistance of N. Elabdin, O. Muehling, J. Kelly, and G. Dedic is acknowledged.

References

[1] Wu, J.H.T., Ostrowski, P.P., Neemeh, R.A., and Lee, P.H.W., "Experimental Investigation of a Cylindrical Resonator," *AIAA Journal,* Vol. 12, 1974, pp. 1076-1078.

[2] Butler, D.S., "The Stability of Converging Spherical and Cylindrical Shock Waves," Armament Research and Development Establishment, Report (B) 18/56, 1956.

[3] Bryson, A.E. and Gross, R.W.F., "Diffraction of Strong Shocks by Cones, Cylinders and Spheres," *Journal of Fluid Mechanics,* Vol. 10, 1960, pp. 1-16.