A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

1

LA-UR 83 2181

Conf-830719--14

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--83-2181

DE83 015912

TITLE: MACH DISC FORMATION IN CYLINDRICAL RECOVERY SYSTEMS

AUTHOR(S): C. E. Morris
R. G. McQueen
S. P. Marsh

NOTICE
PORTIONS OF THIS REPORT ARE ILLEGIBLE.
It has been reproduced from the best available copy to permit the broadest possible availability.

SUBMITTED TO APS 1983 Topical Conference, Santa Fe, NM, July 18-21, 1983.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy

MASTER

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

FORM NO. 836 R4

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MACH DISC FORMATION IN CYLINDRICAL RECOVERY SYSTEMS*

C. E. Morris, R. G. McQueen and S. P. Marsh

Dynamic Testing Division
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Cylindrical recovery systems have been used to shock-load polymers to pressures exceeding 50 GPa. In order to determine the pressures generated in these recovery systems the formation of the Mach disc on axis and its approach to steady state was monitored. The relation of the Mach disc diameter to the lateral dimension of the high explosive used to compress the polymer samples was also investigated.

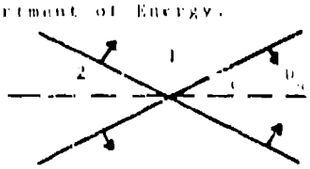
INTRODUCTION

There has been an extensive amount of Hugoniot data taken on polymers at Los Alamos. To identify the physical processes occurring along the Hugoniot shock recovery experiments were done which duplicated these one-dimensional single shock states. The experimental geometry in which these single shock states could be readily achieved was in the cylindrical recovery systems initially pioneered by Riabinin. (1) These cylindrical capsules had the additional feature that hermetically sealed capsules could be routinely recovered so that the dissociation products of the polymers could be examined.

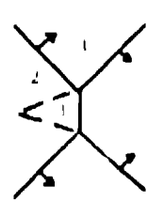
In discussing Mach disc formation in cylindrical geometry it is informative to contrast this flow with Mach stem formation as a result of colliding plane waves. In Fig. 1A the reflection of two equal strength plane shock waves is illustrated. For small impact angles regular reflection occurs. States 1 and 2 denote respectively single and double shock states. Above a critical angle α_c (usually of the order of 45°) mach reflection occurs. This results in the triple-shock configuration shown in Fig. 1B. As in the previous example states 1 and 2 denote respectively single and double shock states. The additional feature of the Mach wave not seen in regular reflection is the presence of the Mach stem region denoted as state 3. The Mach stem region is a single shock state whose lateral dimensions increase linearly with time. On the Mach stem axis the flow is one-dimensional. Consequently these shock states lie on the principal Hugoniot. Pressure gradients, if present in the Mach stem, are manifested in curvature of the Mach stem front. At the triple point where the Mach stem (state 3), the incident shock (state 1) and the reflected shock (state 2) all come together, by necessity, a slipline is present. The region of flow above the slipline is the result of a two shock process, whereas the flow below the slipline is the result of a single shock process (the Mach stem). The pressure must be the same on both sides of the slipline s that the material velocity is in general different across the slipline. This is because single and double shock states at the same pressure are at different strain (entropy) states.

The hydrodynamic flow present in our cylindrical recovery systems is schematically shown in Fig. 1C. A cylinder of high explosive surrounding our recovery capsule is plane wave initiated. The nature of the flow in these cylindrical systems differs appreciably from the wave structure observed in the interaction of plane shock waves even though superficially these flows appear similar. When the diametrically opposite conical shock waves interact regular reflection is not possible. For "normal" equations of state a Mach disc has to form on axis. (2,3) In analogy with the previous discussion the regions 1 and 2 denote the states behind the conically convergent incident shock and conically divergent reflected shock. State 3 denotes the Mach disc region of the flow. In contrast to the plane wave case after the Mach wave flow becomes steady the diameter of the Mach disc remains constant. Also the velocity of

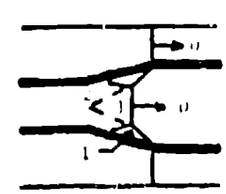
* Work supported by the United States Department of Energy.



REGULAR REFLECTION OF PLANE SHOCKS
FIGURE 1A



MACH REFLECTION OF PLANE SHOCKS
FIGURE 1B



MACH WAVE FORMATION IN CYLINDRICAL GEOMETRY
FIGURE 1C

the Mach disc is equal to the detonation velocity of the explosive independent of the contents of the recovery capsule. This rather dramatic result deserves some further elaboration. Since the detonation velocity of the explosive is the characteristic velocity of the experiment, failure of the Mach disc to travel at this velocity will result in modification of the flow such that the Mach disc (MD) velocity comes into coincidence with the detonation velocity. For example if the MD velocity lags behind the detonation velocity the incident conical shock wave will be inclined more toward the axis resulting in a buildup of pressure in the MD and the resultant increase in its velocity. Conversely, if the MD travels faster than the detonation velocity ultimately the pressure in the MD will decrease due to the divergent nature of this type of flow. This will result in the slowing down of the MD to bring it into coincidence with the detonation velocity. These statements characterize the fundamental nature of Mach wave formation in cylindrical recovery systems. However, some important questions still need to be addressed. The purpose of this paper is to determine how long it takes to achieve steady state conditions in these recovery systems. Another important consideration in achieving well characterized recovery experiments is how can the experimental geometry be made such that the entire sample cavity is subjected to a uniform stress state. One way to do this is to vary the amount of high explosive and the capsule geometry so that the entire sample cavity is compressed by the Mach disc. If the EOS of the sample is known the pressure and compression of the sample can be readily calculated.

EXPERIMENT

The Mach disc experiment in Fig. 2 is representative of the experiments which will be discussed in this report. Composition C-4 is the explosive used to compress the cylindrical capsules. It is of putty-like consistency and can be readily tamped into various experimental geometries. The explosive is initiated by a plane wave lens and there is a 25 mm run before the detonation wave interacts with the capsule. This is done to ensure a steady detonation wave has been formed. This initial boundary condition is used in all our Mach wave experiments. The experimental capsule in Fig. 2 consists of a series of polymethylmethacrylate (PMMA) discs spaced 0.1 mm apart. These discs are positioned in a steel tube (38 mm OD, 25 mm ID) which simulates the walls of the recovery capsule. Argon (or xenon) gas is introduced into these 0.1 mm gaps to provide an optical record of the Mach wave arrival at each flash gap. The progression of the Mach wave is recorded by a sweep camera looking down the axis of the cylindrical capsule through a slit plate. This experimental technique was initially used by Adadurov (4) et al. to characterize their

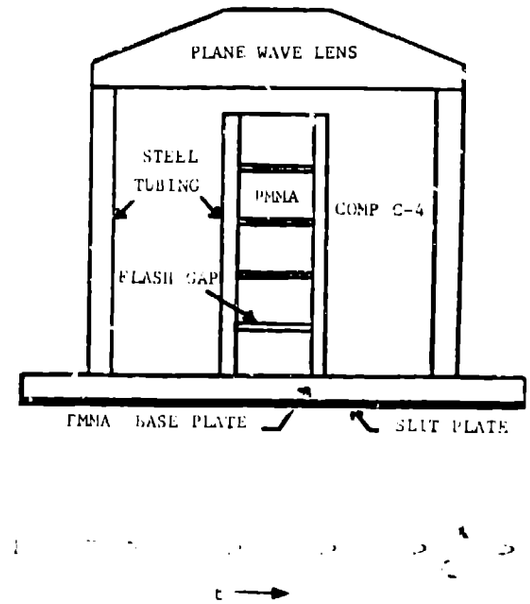


Figure 2. Mach wave experimental assembly. Sweep camera record shows progress of Mach wave along the composite cylinder.

recovery systems. The photographic record for this experiment is presented in Fig. 2. From the boundary conditions of this experiment we would expect an initial plane shock to be transmitted into the PMMA cylinder at a pressure consistent with the impedance-match solution with Comp. C-4. This initial plane shock wave would travel at a velocity of about 6 km/s. Since the detonation velocity of Comp. C-4 is 8.0 km/s the outside edges will lead the central portion of the Mach wave. The Mach wave will continue to change shape until the pressure in the Mach disc is consistent with the principal Hugoniot pressure at this shock velocity. This is exactly what is observed in this record. The slit plate through which this record was observed extended over the Comp. C-4 so that the break out of the detonation wave at the PMMA base plate could be recorded. It is apparent from these traces that the plane wave lens was not positioned squarely on this assembly. Also because the detonation velocity of the explosive at the edges of the assembly lags the central region, curvature in the traces is present. This curvature is related to the finite width of the reaction zone in this HE.

It is evident from the record in Fig. 2 that the approach to steady state of the Mach wave can be determined from both the shape of the

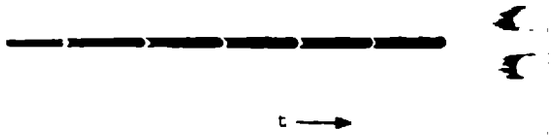


Figure 3. Sweep camera record of Mach wave formation in a steel tube (38mm OD, 25mm ID) filled with CCl_4.

Mach wave and also the approach of the Mach wave velocity to the detonation velocity of Comp. C-4. However, it is difficult to determine from this record the diameter of the Mach disc since the change in curvature between the Mach disc and the wings of the Mach wave is not discontinuous. By replacing the PMMA column in Fig. 2 with carbontetrachloride (CCl_4) the lateral extent of the Mach disc can be easily determined since CCl_4 radiates profusely when shocked. CCl_4 has the added attraction that its shock-impedance is very close to PMMA, so these two materials can be used together without injecting substantial hydrodynamic perturbations in the flow. A record of a Mach wave traveling through a CCl_4 column in a supporting steel tube is shown in Fig. 3. The Mach wave buildup is clearly evident in this record. To record the steady state shape of the Mach wave a 38 mm high PMMA cylinder is placed at the bottom of the steel tube. Upon impact of the Mach wave with the PMMA cylinder the radiation is quenched. From the known detonation velocity of Comp. C-4 and the writing speed of the sweep camera the actual shape of the Mach wave can be calculated.

An experimental assembly which combines effectively the radiation property of CCl_4 with the quenching property of PMMA was accomplished by suspending PMMA discs in a CCl_4 column. From the known spacing of the PMMA discs the shock velocity in CCl_4 can be determined and from the radiation output of

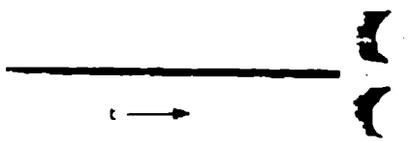


Figure 4. Sweep camera record of Mach wave formation in a composite cylinder consisting of a brass tube (51mm OD, 48mm ID) and a PMMA tube (48mm OD, 38mm ID) filled with CCl_4. PMMA discs are positioned in the CCl_4 to record progress of the Mach wave.

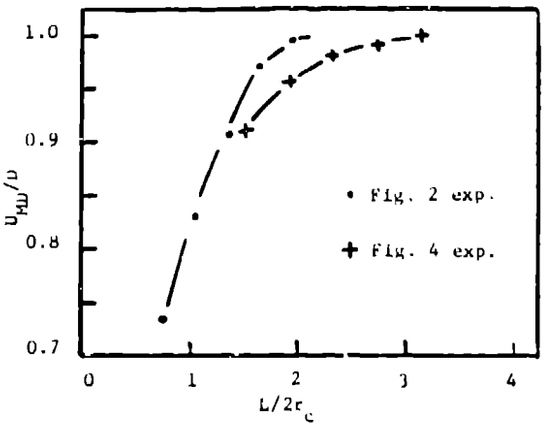


Figure 5. Variation of the Mach disc velocity U_{MD} along the cylindrical axis for the experimental assemblies described in Figs. 2 and 4.

CCl_4 the Mach disc diameter can be measured. A photographic record for this experiment is shown in Fig. 4. In this experiment the composite cylindrical capsule consisted of a brass outer tube 51mm OD and 48mm ID. PMMA rings (48mm OD, 38mm ID) supported 1.5mm thick PMMA discs along the cylinder. As the Mach wave progressed down the cylinder, the radiation turns off upon impact with the PMMA discs and then turns on again when the Mach wave reemerges into CCl_4. As with the previous assembly a 51mm high PMMA disc at the base of the cylinder recorded the final steady state shape of the Mach wave.

The variation of the Mach disc velocity along the cylindrical axis for the experimental records given in Fig. 2 and 4 is shown in Fig. 5. In this figure L is the distance traveled by the Mach disc along the cylinder and r_c is the outside radius of the composite cylindrical capsule (this is also the inside radius of the HE). For these two experiments the flow is essentially steady state after the Mach disc has traveled a distance equal to two capsule diameters. The radiation record in Fig. 3 can also be analyzed to determine when steady state was reached. This record also indicates an aspect ratio ($L/2r_c$) of 2 is required before the Mach flow becomes steady. It has been observed that for simple capsules made of a single material steady state can be achieved for aspect ratios of the order of unity.

The other relationship we want to establish is the variation of the Mach disc diameter when the lateral extent of the HE is varied. Four shots were fired with the CCl_4 capsule geometry described in Fig. 3. The Comp C-4 thickness expressed in normalized units of capsule diameters ($\Delta r_{HE}/2r_c$) was varied from

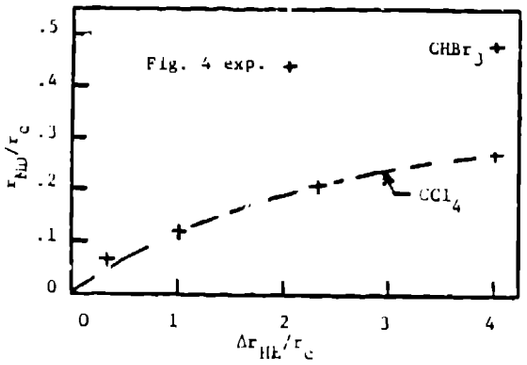


Figure 6. Variation of the Mach disc radius r_{MD} with HE thickness Δr_{HE} for the experimental assemblies described in Figs. 3 and 4.

0.3 to 4. With this variation in HE thickness the Mach disc radius r_{MD} expressed in normalized units (r_{MD}/r_c) varied from 0.07 to 0.27. Results of these experiments are shown in Fig. 6. It is evident from this figure that after a normalized HE thickness ($\Delta r_{HE}/r_c$) of about 2 is reached the Mach disc diameter changes very little with additional high-explosive. To illustrate the effect of how relative shock-impedances of the components of the capsule affect the diameter of the Mach disc one shot was fired with the radiating sample being bromoform ($CHBr_3$) rather than CCl_4. Bromoform has a factor of 2 greater impedance that CCl_4. Consequently a better impedance match with the outer steel tubing is achieved. This change in shock impedance resulted in almost a factor of two increase in the Mach disc diameter for the same explosive system. This illustrates the dramatic role that the relative shock impedances of the component parts play in influencing the hydrodynamic flow. The other datum point in Fig. 6 also illustrates this point. The experimental system for this datum point is described in the Fig. 4 caption. For the most part the composite cylinder consisted mainly of CCl_4 and PMMA, materials with similar shock-impedances. This composite capsule had a substantially larger Mach disc for a given HE geometry than the steel-CCl_4 capsules.

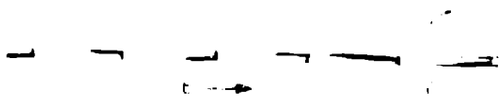


Figure 7. Sweep camera record of the Mach disc traveling down the central portion of a composite cylinder consisting of a steel tube (51 mm OD, 25 mm ID) and a brass tube (25 mm OD, 12.5 mm ID) in which PMMA discs with flash gaps were inserted.

For the experiments so far described in this report the Mach disc region occupied at most 50% of the total capsule diameter. Ideally in a shock recovery experiment it is desirable to shock-load the entire sample to the same stress state. In capsule geometries where we have successfully accomplished this goal, the sample cavity was 10% to 25% of the total capsule diameter. In Fig. 7 is a sweep camera record where a Mach disc occupied the entire sample cavity. In this experiment the capsule consisted of a steel tube (51 mm OD, 25 mm ID) in which a brass tube (25 mm OD, 12.5 mm ID) was inserted. Inside the brass tube a series of PMMA discs were placed which had a flash gap between each disc to record the Mach wave profile. This was the only geometry we tested where the Mach disc region exhibited no curvature. This implies the pressure gradients in the Mach disc region are very small. Scaled down versions of this assembly have been used to successfully recover hermetically sealed capsules of several polymers shocked to pressures exceeding 50 GPa.

REFERENCES

1. Rizbinin, Yu. N., Zh. Techn. Fiz. 26 (1956) 2575-2579.

2. Courant, R. and Friedricks, K. O., Supersonic Flow and Shock Waves (Interscience Publishers, Inc., New York, 1948) 416.

3. Fowles, G. R. and Isbell, W. M., J. Appl. Phys. 36 (1965) 1377-1379.

4. Adadurov, G. A., Dremin, A. N., Kanel, G. I. and Pershin S. V., Fizika Gorenlya i Vzryva 3 (1967) 175-177.