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Title: SHOCK COMPRESSION EXPERIMENTAL CAPABILITIES OF THE ATLAS FACILITY (REVISED)

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SHOCK COMPRESSION EXPERIMENTAL CAPABILITIES OF THE ATLAS FACILITY

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Abstract. Atlas is a high-energy pulsed-power facility under construction at Los Alamos National Laboratory. When completed in late 2000, Atlas will provide a laboratory environment to perform shock compression experiments in regimes presently unattainable by other methods. The high-energy-density environment on Atlas will be produced by the rapid (~4 µs) implosion of a 20-40 gram, ~4 cm radius, 4 cm length cylindrical aluminum or aluminum/high-Z composite liner, driven by a fast current pulse of ~32 MA from a 24 MJ capacitor bank. Implosion velocities up to 20 km/s are predicted, allowing Hugoniot experiments to ~20 Mbar and quasi-adiabatic compression to several Mbar. However, many issues face us in performing such experiments, including how to diagnose conditions inside the imploding liner, how to correct results for distortions and density gradients created by the cylindrical geometry and magnetic drive, and how to prevent geometric distortions and instabilities from degrading results. In this paper, liner performance is predicted for a shock compression experiment utilizing 1-D MHD simulations, and the effect of gradients in density, pressure, and velocity in the impactor prior to collision are discussed.

INTRODUCTION

The Atlas facility, a 24 MJ, 4 µs half-cycle pulsed power machine, has about 6 times the stored energy of the Pegasus II machine that it replaces. When completed in late-2000, Atlas should be able switch a current of about 32 MA axially through a cylindrical "liner" of 4 cm length, imploding it radially due to the J×B force. This implosion will accelerate a 4 cm radius, 1 mm thick, 27 g, aluminum liner to approximately 20 km/s when the inner radius reaches 0.5 cm, while maintaining a solid inner surface. Whether a liner accelerated to these velocities will remain intact, or be torn apart by instabilities is currently being investigated with 2-D MHD simulations and explosively driven pulsed power experiments. An example of a 2-D Eulerian MHD calculation of Atlas driving an aluminum liner into an aluminum target is shown in Fig. 1. The molten outer surface of the aluminum liner is fingered by a Rayleigh-Taylor instability, and the copper glide planes are disrupted by a Kelvin-Helmholtz instability. 2-D effects are clearly important, and much more numerical and

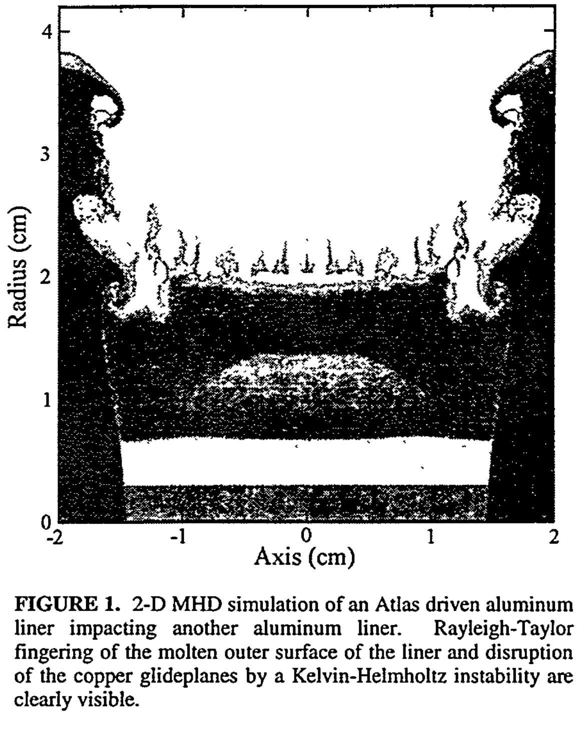

FIGURE 1. 2-D MHD simulation of an Atlas driven aluminum liner impacting another aluminum liner. Rayleigh-Taylor fingering of the molten outer surface of the liner and disruption of the copper glideplanes by a Kelvin-Helmholtz instability are clearly visible.

experimental work remains to be done to determine the extent to which these instabilities imprint themselves upon the inner surface of the liner, where measurements are to be made. Nevertheless, 1-D simulations can be performed very quickly on desktop machines, and are a useful first step in developing experimental configurations. The Atlas facility is described in more detail in Ref. (1).

The conditions accessible on Atlas are of great interest for shock compression Hugoniot experiments, allowing the experimenter to examine regimes which are inaccessible with most other techniques, on an experimental facility which can be cycled perhaps twice weekly. However, the convergent cylindrical geometry and magnetic drive of these experiments can produce density, pressure, and velocity gradients across the impactor which complicate interpretation of diagnostic results.

In the remainder of this paper, we will describe a prototype Hugoniot experiment which has been designed for Atlas, paying particular attention to conditions which might complicate diagnostic interpretation. Liner simulations were performed using the 1-D MHD code CRUNCH (2).

PROPOSED HUGONIOT EXPERIMENT

The "composite liner" used in a typical experiment to determine the Hugoniot curve in tungsten is shown in Fig. 2. It consists of an aluminum liner with a 75 μm, high-Z layer (the tungsten impactor) on the inner surface, which is imploded into a tungsten target.

In this configuration, the impactor has a velocity of 14 km/s at impact. Plots of density and pressure in the target and impactor just prior to impact are shown in Figs. 3a and 3b, respectively. Note the 9.5% density gradient across the impactor shown in Fig. 3a. This is caused by the 300 kbar pressure across the impactor caused by the magnetic drive, as shown in Fig. 3b. Due to cylindrical convergence (impact occurs at a convergence ratio of 5 in this example), there is also a 3.9% velocity gradient across the impactor. These gradients complicate solution of the Rankine-Hugoniot equations. Collision of the impactor and target more than doubles the density and launches an 18 Mbar shock into the target, as shown by the solid lines in Fig. 4a and 4b, respectively. Note in Fig. 4a that the shock has reached the front surface of the 300 μm thick target step (now compressed to a thickness of 130 μm) before the backward shock has reached the back of the impactor. The impactor could have been made even thinner - simulations

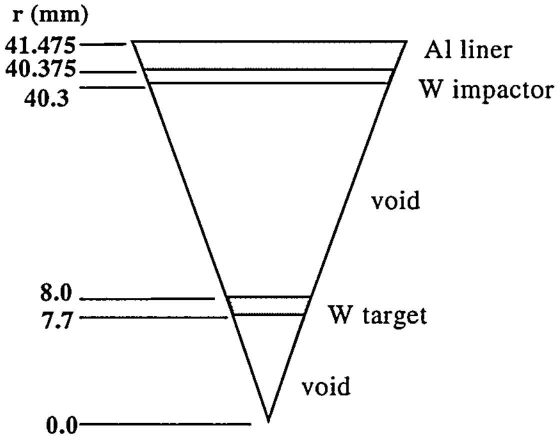

FIGURE 2. Atlas composite liner for Hugoniot experiments.

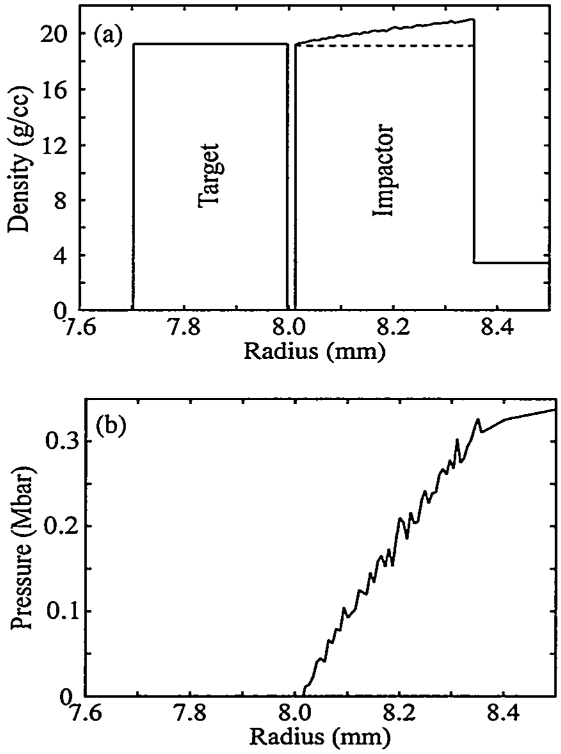

FIGURE 3. Density (a) and pressure (b) of the target and impactor just prior to impact.

suggest 30 μm. The temperature behind the shock is about 5.5 eV, as shown in Fig. 4c, allowing the shock velocity measurement to be made with fiber optic pins which observe the light from the shock, as shown in Fig. 5. This can produce a highly accurate shock velocity measurement, since it does not require precise radial positioning of the pins, unlike conventional pins which rely on physical impact to produce a signal. A temporal resolution of 30 ps should be easily achieved, taking into account dispersion in the fibers and the resolution of the streak camera used to record the signals. This is very adequate to resolve the 20 ns transit time of the shock over a 300 μm step. The resolution achieved with this diagnostic should be significantly better than the accuracy that can be achieved in liner fabrication and fixturing. By utilizing a multiply stepped or wedged target, it may be possible to measure the time dependence of the shock velocity, as discussed in the next section.

THE EFFECT OF IMPACTOR GRADIENTS

What are the effects of the gradients in density, pressure, and velocity of the impactor? To determine these, we present results from two additional 1-D simulations in Figs. 4a-c. In the first (results shown with a dashed line in Figs. 4a-c), we have run the same cylindrically convergent simulation as previously described, but have manually removed the density and pressure gradients in the impactor just prior to collision. The resulting density profile prior to impact is shown as the dashed line in Fig. 3a. In the second (results shown as the dotted line in Figs. 4a-c) we have run a planar simulation using as an initial condition the velocity of the impactor from the cylindrical simulations prior to impact. This effectively removes the velocity gradient in the impactor, in addition to the density and pressure gradients. As seen in Figs. 4a-c, the target pressure in these additional simulations is about a 5% lower than in the original, with smaller differences in density and temperature. The difference between the two additional simulations themselves is very small in the target. This demonstrates that the effect of the convergent geometry, by itself, is insignificant. In this pressure regime, a 5% accurate measurement would be a valuable and important result.

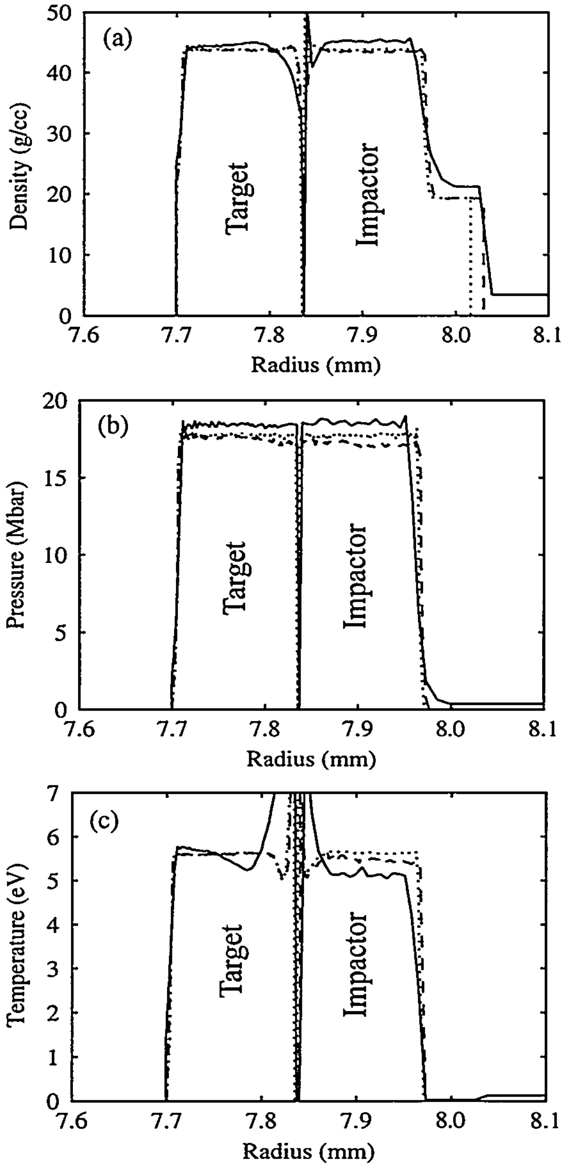

FIGURE 4. Density (a), pressure (b), and temperature (c) of the target and impactor as the shock reaches the inner surface of the target. The solid line is from the full cylindrical liner simulation. The dashed line is from a cylindrical simulation in which the density and pressure gradients in the impactor have been removed immediately before collision, as shown by the dashed line in Fig. 3a. The dotted line is from a planar simulation in which the convergent-geometry-derived velocity gradient has been removed, in addition to the density and pressure gradients.

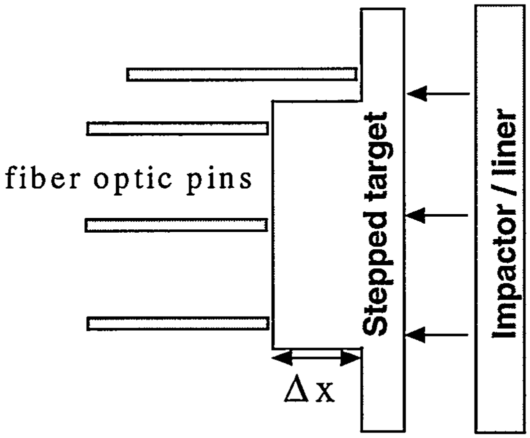

FIGURE 5. Fiber optic pin array used to measure shock velocity for Hugoniot measurement. The step Δx is typically 300 μm. Steps of multiple sizes may be used in a single experiment.

Can we determine and account for these gradients in density, pressure, and velocity with the diagnostic previously described? Fig. 6a shows the timing of the breakout of the shock signal as a function of step height, for the three simulations shown in Fig. 4. The results from the cylindrical-undriven and planar simulations lie directly on top of one another. The difference between these three curves and a linear best fit to the planar simulation is shown in Fig. 6b. The dc value of the driven cylindrical simulation (solid line) is arbitrary with respect to the other two, but there is a difference of a few hundred picoseconds between it and the constant velocity shock curves. The diagnostic described in Fig. 5 should be able to resolve this difference, allowing some determination of the gradients shown in Fig. 3 to be made. However, inaccuracies in fabrication and assembly of the liner may result in timing differences which are comparable in size to the differences resulting from the gradients.

SUMMARY

We have presented a preliminary design for a shock Hugoniot experiment to near 20 Mbar, based on 1-D MHD simulations, and have examined the magnitude of the gradients produced in the impactor by the magnetic drive and convergent geometry. We have found that the presence of these gradients should create a difference of about 5% in pressure following impact, compared to a flat, undriven impactor at similar velocities. This suggests that a measurement accurate enough to be of interest can be made, even if we are unable to correct for these gradients in the data analysis. However, a simulation of the expected breakout time of the shock shows differences in timing which may be within our measurement resolution, allowing these gradients to be deduced. Instabilities in the liner are being investigated with 2-D MHD simulations and explosive pulsed power experiments.

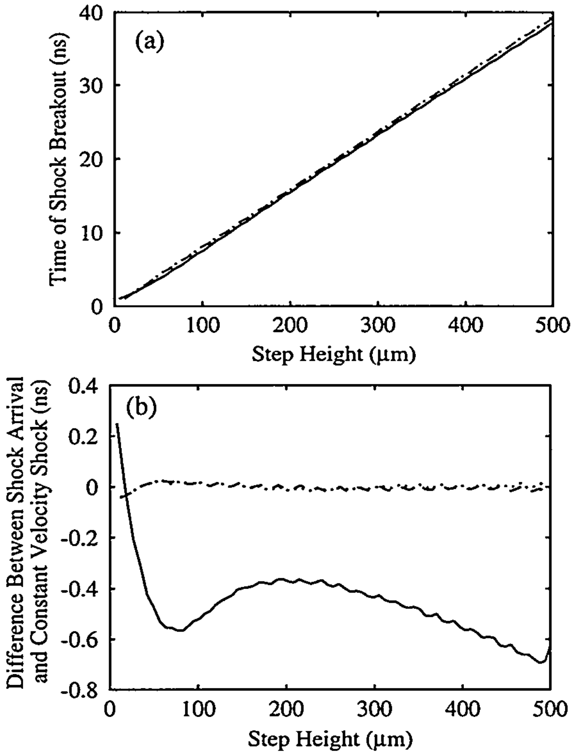

FIGURE 6. (a) Time of shock breakout versus step height. (b) Difference between the curves in (a) and a linear best fit to the planar simulation, representing a constant velocity shock. The different lines represent the same simulations as in Figs. 4a-c.

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