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ANALYSIS OF RADIATION-DRIVEN JETTING EXPERIMENTS ON NOVA AND Z

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Abstract. We have used the shock-physics code ALEGRA to study radiation-driven jetting experiments on both NOVA and Z. Emphasis is on validating the numerical techniques with NOVA measurements, and examining the feasibility of scaling up those experiments by an order of magnitude for the Z-pinch facility. The jetting problem involves a 100-μm-scale aluminum pin surrounded by a gold washer that was exposed to a 5-ns x-ray load from a NOVA hohlraum. The configuration leads to jetting phenomena along the cylindrical axis of symmetry. This setup has been scaled up physically by an order of magnitude for qualitatively similar experiments on the Z-pinch machine using a nominal 50-ns-wide radiation pulse. Post-processing of the ALEGRA output using the spectral analysis code SPECT3D shows that diagnostics using the Z-Beamlet Backlighter are feasible with this larger geometry. Comparisons with the NOVA results show that the simulations represent the actual phenomena well, and give confidence in the accuracy of the calculations for the proposed Z experiments

INTRODUCTION

The ALEGRA shock physics code[(1)] is one of the principal computer codes being supported by the Department of Energy's Accelerated Strategic Computing Initiative (ASCI) program. It solves shock physics problems in three spatial dimensions using Lagrangian, Eulerian, and/or ALE coordinates. The code runs on massively parallel computers, and contains a large variety of physics options including MHD, hydrodynamics, material strength and failure, radiation transport, conduction, and others. The code is being used widely to study such diverse phenomena as, for example, the response of complex systems to high velocity impacts, the behavior of components under high explosive loading conditions, and MHD-driven Z-pinch phenomena. Another area that has been addressed recently considers the response of solid targets to short high-power and high-energy radiation loads.

In particular, the present problem involves a 100-micron-scale aluminum pin surrounded by a gold washer, which was exposed in a NOVA laser-driven hohlraum[(2)] at Lawrence Livermore National Laboratory (LLNL). The differences in material properties lead to extensive jetting phenomena along the cylindrical axis of symmetry, behavior that is well-simulated with ALEGRA. We have used the code to predict qualitatively similar response using a configuration that has been scaled up by an order of magnitude in size for experiments on the Z-pinch machine at Sandia National Laboratories (SNL). Subsequent calculations employing the ALEGRA output and using the imaging and spectral

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analysis code SPECT3D[3] show that diagnostics using the Z-Beamlet Backlighter[4] are feasible with this scaled up geometry.

EXPERIMENTAL ENVIRONMENTS

To investigate the complex phenomena involved in jet formation when short high-power radiation pulses are incident on cylindrical configurations of dissimilar materials, we have used the ALEGRA code to study two different situations. The first case involves the simulation of actual experiments conducted on the NOVA laser facility at LLNL, for which Rosen et al.[2] provide the details. The second is associated with a factor-of-ten scale-up of the geometry for exposure on the SNL Z-pinch facility.

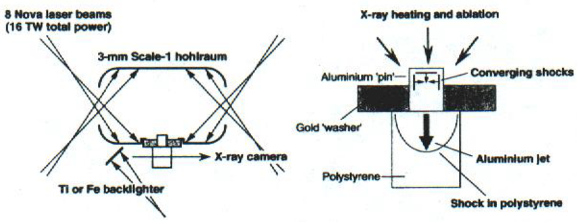

FIGURE 1. Setup for NOVA experiments. Shown are the target in the hohlraum and the backlighter location (***left***), and the details of the target (***right***). The aluminum 'pin' has a diameter of 200 μm and is 150 μm long, the gold 'washer' is 50 μm thick, and the polystyrene backing has a diameter of 380 μm.

The configuration and geometry for the NOVA experiments are shown in Fig. 1, and the radiation environment for these experiments is given in Fig. 2. For comparison, the latter figure also gives one of several possibilities for the radiative drive from the Z-pinch machine. Both represent Planckian time histories. The geometric scale-up was driven by the radiation pulse widths, which are 5 ns for NOVA and ~50 ns for Z. The estimated total energy fluences on the samples are high—about 0.25 MJ/cm^2 for the NOVA source, and almost 0.7 MJ/cm^2 for the Z-pinch. The peak powers for the two cases are ~130 TW/cm^2 and ~70 TW/cm^2 respectively. Thus Z gives an energy fluence higher by a factor of about three, but NOVA yields a peak power greater by nearly a factor of two.

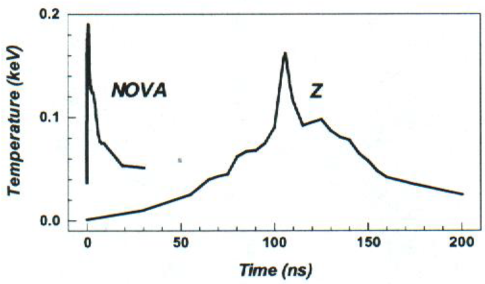

FIGURE 2. Assumed black-body temperature histories for the NOVA hohlraum and the Z-pinch source. NOVA has a peak temperature of ~190 eV and a FWHM pulse width of ~5 ns; the Z-pinch source has a peak at ~160 eV and a pulse width of ~50 ns. The long rise-time for Z could be reduced easily by the use of a thin burn-through foil.

RESULTS FOR NOVA

The ALEGRA calculations simulating the NOVA experiments employed a two-dimensional Eulerian mesh, with either 10-μm or 5-μm resolution. The former mesh had 4,500 elements and the latter had 18,000. The radiation flow was treated with a single-group SN_1 approximation. Both the coarse-zoned and fine-zoned calculations gave similar results, with the latter showing more detail in the jetting regions, as anticipated. The fine-zoned problem showed slightly faster (~9%) on-axis jet motion, so it is possible that the solution is not quite converged.

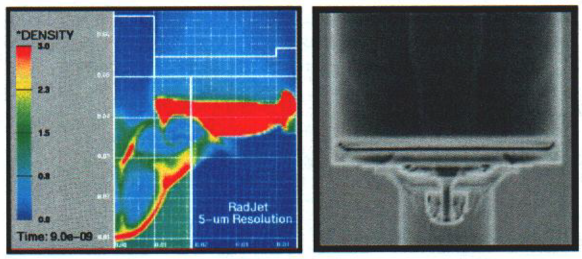

FIGURE 3. Plots from the fine-zoned NOVA-driven jet calculation at t = 9 ns. The half-frame (***left***) shows the density from ALEGRA, and the full-frame (***right***) shows a simulated radiograph as generated by SPECT3D.

Selected results of the calculations are shown in Fig. 3. Included in the figure is a numerical simulation of the radiographs taken with the backlighter indicated in Fig. 1. In Table 1 we compare the present results with actual experimental radiographs (similar to that in Fig. 3, but with less detail), and with code calculations[2] from the Atomic Weapons Establishment (PETRA), LLNL (CALE), and Los Alamos National Laboratory (RAGE). We have listed the axial positions of the leading edge of the jet as a function of time. These values show a fairly wide variation, but the ALEGRA results are

TABLE 1. Axial jet displacement (in μm) for various codes and the experiment. Although there is a wide variation, the ALEGRA calculations are consistent with the other results.

Code	ALEGRA (*Eulerian*)	PETRA (*Eulerian*	CALE (*ALE*)	RAGE (*AMR*)	Experiment (*Estimated*)
Time = 6 ns	265	245	300	280	~260
Time = 9 ns	380	345	405	380	300+

consistent with the other analyses. The 9-ns experimental position seems to lag all the numerical results, but this may be due to lack of resolution in the experimental radiograph. Even though the agreement is not ideal, we feel that ALEGRA is modeling the relevant phenomena in a realistic manner, and is consistent with other numerical approaches.

SCALE-UP FOR Z-PINCH

In considering how similar experiments would be conducted on the SNL Z-pinch machine, we first noted that radiation pulse widths about an order of magnitude longer were available. This immediately suggested that we should be able to scale up the physical dimensions of the configuration by a comparable factor. Although the phenomena associated with radiation transport will not scale in the simple manner that should apply to purely mechanical and time variables, the overall response should be qualitatively similar. Other, but smaller departures from homologous behavior result from the differences in the shapes of the radiation histories shown in Fig. 2, in particular the slower rise time for the Z-pinch source. Nonetheless, when we plot computational results for comparable stages in the evolution of the response, the material densities look quite similar, as shown in Fig. 4. It should be mentioned that the temperatures and pressures show greater differences, especially in terms of their

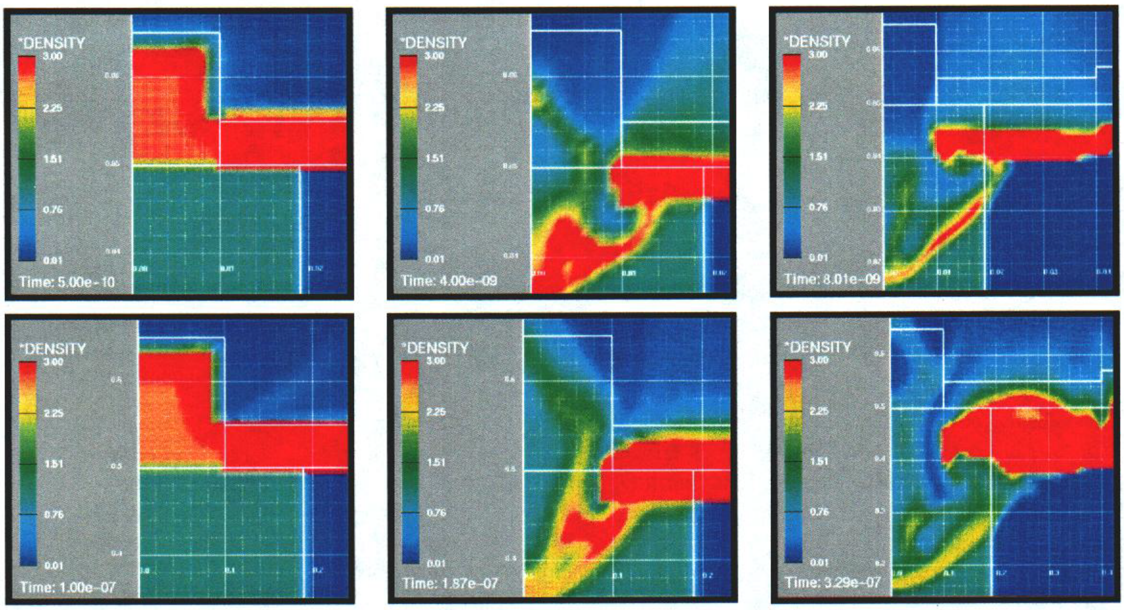

FIGURE 4. Comparisons between NOVA and Z calculations. The first row (***top***) is for the NOVA configuration, and the second row (***bottom***) is for the factor-of-ten scale-up for Z. Times were chosen for similar stages in the evolution of the response. Densities are in g/cm^3, times are in s, and dimensions are in cm.

maximum values. For example, at 4 ns for the NOVA problem and 0.2 μs for Z, the peak temperatures are 130 eV and 50 eV, respectively. Similarly, the peak pressures are 30 Mb and 3 Mb. Later, at 12 ns for NOVA and 0.4 μs for Z, the peak values have decayed, to 70 eV and 20 eV for the temperatures, and to 4 Mb and 0.5 Mb for the pressures. Because of the shorter pulse width and higher power, the NOVA configuration thus gives temperatures greater by nearly a factor of three and pressures higher by roughly a factor of ten, when compared with the Z results.

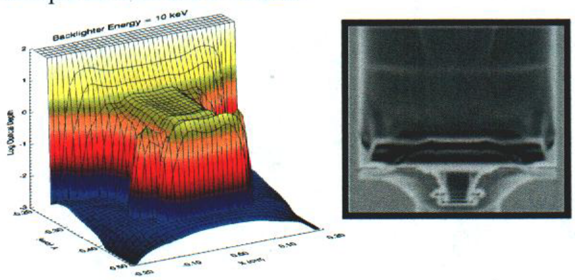

FIGURE 5. Visualization (***left***) and simulated radiograph (***right***) of the jet at 528 ns for the Z calculation. The backlighter photon energy was chosen as 10 keV. On the visualization, the amplitude of each cell represents the optical depth through the jet as a function of axial position (Y) and offset from the axis (X).

With the larger physical size for the Z setup, there is some concern that the main diagnostic tool for observing the experiment, the Z-Beamlet Backlighter,[(4)] may not be able to penetrate the jet. To examine this aspect of the problem, we have used the imaging and spectral analysis code SPECT3D[(3)] to post-process the output from the ALEGRA calculations. Note that backlighter performance depends not only on photon energy but on conversion efficiency and many other issues; we are only looking at the former here. Depending on the backlighter target material, photon energies from 3 to 10 keV should be available. For example, using the lower energies, at reasonable times and through the main body of the jet, the code yields optical depths that are ~20 at 3 keV, ~10 at 6 keV, and 5 to 6 at 8 keV. These optical thicknesses would make this type of measurement very difficult, at best. However, with a backlighter photon energy of 10 keV, which should be possible, the optical depth would be of order unity, or maybe just a little greater, which is an acceptable value. It is this last case that is illustrated in Fig. 5, where we show the optical depth both in a 3-D visualization of the jet and in a simulated radiograph. We thus conclude that with a 10 keV backlighter these experimental measurements should be possible.

CONCLUSIONS

For the radiation-driven jet problem we have provided validation for the ALEGRA models through comparison with the NOVA experiment and other calculations. We have shown that experiments scaled up by an order of magnitude in size on Z yield qualitatively similar dynamic response. Based on the calculations, and with the aid of additional visualization and analysis software, we have also shown that diagnostics using the Z-Beamlet Backlighter for the scaled-up experiments are feasible.

We should emphasize that the ASCI code ALEGRA is under continuing development, but as shown here, it is also being used routinely to address practical issues of real interest associated with experimental design. These calculations are leading to a better understanding of the diverse phenomena that these types of radiation environments can generate, and they are providing direct solutions to important problems in a predictive mode. Further, these studies will thus serve as ideal validation tools for this important shock physics code, and in particular for its radiation transport option.

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