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THE ROLE OF DRIVE SYMMETRY IN ICF CAPSULE PERFORMANCE: DATA AND ANALYSIS (U)

by

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ABSTRACT (SRD)

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We also discuss work in progress on mechanisms for drive asymmetry inducing performance degradation, including shear-induced Kelvin-Helmholtz instability growth and turbulence transport, and we also discuss the implications of our work on the directions of future research in ICF.

In summary, then, no 1-D model has yet been successful in providing a satisfactory picture of ICF capsule performance. We hypothesize that radiation drive asymmetry induces shear-driven hydrodynamic instabilities which dominate the degradation in small capsules. We discuss in this report the experimental and calculational evidence that supports this hypothesis.

II. EVIDENCE FROM THE DATA

A. The Double-Shell Capsule Experience

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The results, however, were disappointing.

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[redacted] b(3) This noise is no longer introduced at higher temperatures, but if it is at first introduced at lower temperatures it will grow with time because of the spherical convergence and Rayleigh-Taylor instabilities. Furthermore, the 2-D implosion calculations show that the fuel cavity asymmetry is approximately the same at equivalent times in the implosion (at least at early times) whether the drive asymmetry is imposed only on the foot of the pulse or only on the main pulse. [redacted] b(3) It is clear that an imposed percentage drive asymmetry only on the foot of the pulse has a comparable effect on the implosion symmetry to the same drive asymmetry imposed only on the main pulse. If the drive asymmetry is imposed on the <u>whole</u> pulse, the resulting fuel cavity asymmetry is larger.

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[redacted] As the center of the fuel heats up just before ignition, the electron thermal conduction tends to symmetrize the hot spot. By ignition time, the hot spot is a spherical volume embedded inside the distorted fuel volume. Thus, the different hot spot formations in the equator-hot and pole-hot cases probably do not have any effect on capsule performance. The larger effect on capsule performance is likely to result from the different fuel cavity distortions produced in the two cases. We have found that equator-hot drive asymmetries produce greater fuel cavity distortion than do pole-hot drive asymmetries. We have also found that early-time drive asymmetries are as deleterious to implosion symmetry as late-time drive asymmetries.

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The pressure-driven LASNEX calculations give a result intermediate between these two. [redacted]

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In addition, the pressure-driven calculations do not account for the geometrical smoothing that takes place for a radiation drive. [redacted]

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Accordingly, we do this problem in two steps. [redacted]

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Figure 15 is a schematic representation of how Hoffman's viewfactor calculation is done. [redacted] Account is taken of the different photon flight times to the capsule from different places on the wall, so that the flux arriving at a point on the capsule surface at a given time originated at different times from different surface zones. This integration is done as a function of latitude. The flux at the capsule surface is then decomposed into its Legendre components. [redacted] Furthermore, these calculations assume an infinitesmal capsule size, so account is not taken of the variation in the viewfactors seen from an expanding capsule surface (the asymmetries are imposed at the capsule surface in the implosion calculations discussed in the preceeding section).

[redacted]

[redacted]

This asynchrony is equivalent to a P_1 flux asymmetry at the capsule. This P_1 asymmetry was calculated in a manner very similar to that described above. [redacted]

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We do not know, however, what the mechanism is for drive asymmetries inducing turbulence, mix, and hence performance degradation. This is the major missing piece in support of our contention that shear-induced instabilities, rather than acceleration-induced instabilities, are the dominant cause of performance degradation in ICF capsules. Some work is now being expended in understanding and evaluating various mechanisms and developing models; this work will be the subject of a future report.

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In any model of mix and degradation based on acceleration-induced instabilities, most of the instability growth and mix at the fuel/pusher interface occurs during the time when the compressionally-heated, lower-density fuel decelerates the colder, higher-density pusher. Thus, the amount of instability growth and mix is roughly proportional to the distance the fall-line moves in the time from peak pusher velocity to stagnation. The fall-line is the trajectory the fuel/pusher interface would follow if it were to continue moving inward at its peak velocity. [redacted] b(3)

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The evidence from the data in support of this hypothesis is, as we have already shown, very compelling. Unlike the situation for acceleration-induced instabilities, however, we do not have calculational models to bring to bear on this question and to produce performance predictions that we can test with experiment. Thus, we do not yet have a complete and fully self-consistent picture of ICF capsule performance. This is a serious deficiency, and we hope that more future resources of the ICF research effort can be devoted to removing this deficiency. Nevertheless, we feel much like Richard Feynman did in describing his quantum-mechanical model for hadron-hadron collisions: "I am more sure of the conclusions," wrote Feynman[23], " than of any single argument which suggested them to me."

What are the mechanisms then, that cause instabilities, turbulence, and/or mix-and hence performance-degradation from drive asymmetries? One possibility is that momentum exchange of material in the lateral direction at the sheared interface leads to an enhancement of the collisional mean free path in the radial direction, as in Kelvin-Helmholtz instability growth. [redacted] b(3)

In addition, turbulent flow will alter the transport properties of the plasma, as illustrated schematically in Fig. 21.

In short, turbulence leads to "spoilage" of the hot spot and an enhanced transport of heat out of the fuel. Thus, in a complete turbulence transport model one must account for momentum, heat, and mass transfer effects. [redacted] b(3) All of this work will be discussed in a future report. Until then we ask only that the reader not dismiss our hypothesis

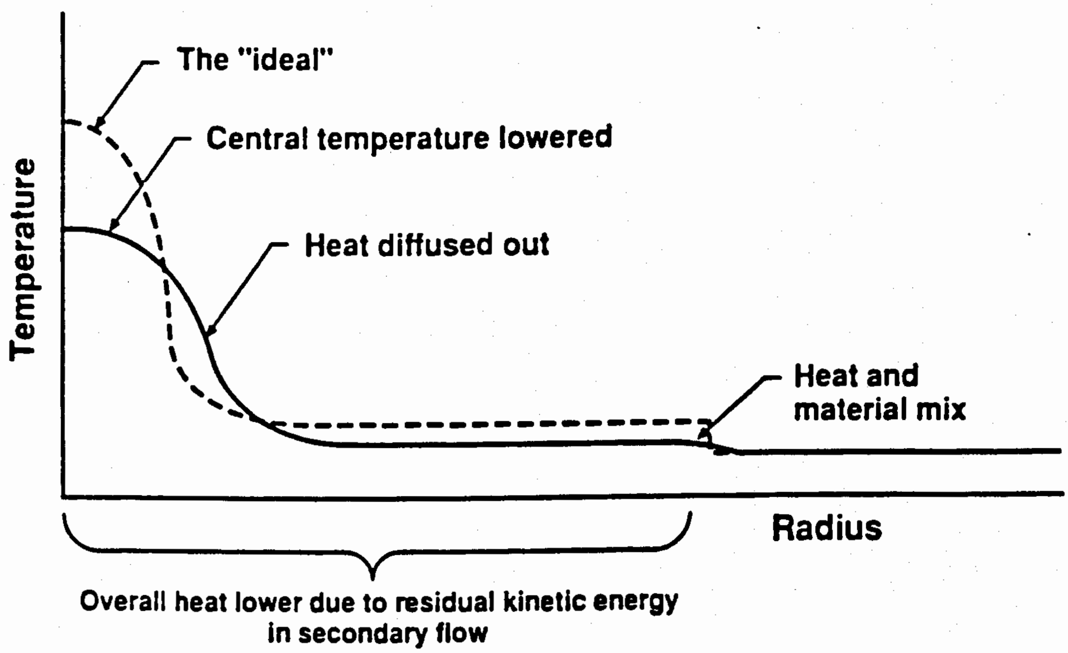

Fig. 21. A schematic representation of the mechanisms for turbulence-induced performance degradation.

as having no merit, even though it is as yet unproven, until all the evidence is in from these model calculations.

B. Implications

If our hypothesis is indeed correct, and shear-induced rather than acceleration-induced instabilities are responsible for observed ICF capsule performance degradation, then this is good news for ICF. It means that the source of degradation is extrinsic rather than intrinsic to the capsule, and can potentially be eliminated, opening the way for as calculated high-gain performance at low energy. The surprising result from this study, however, is that the sensitivity of capsule performance to drive asymmetries is much greater than we had thought previously. [redacted] b(3) b(3) We have already discussed these calculational shortcomings and uncertainties in Sec. III. These calculational uncertainties make it virtually impossible for us at this time to extrapolate these results with any confidence to other parameter regimes. In particular, we do not know what the symmetry requirements are for reactor-scale capsules that have higher convergence ratios at lower absorbed energy ($\lesssim$10 MJ); they may indeed be more severe. [redacted] b(3) With future laser drivers for ICF, peak driving temperatures attainable in laser-driven hohlraums will be $\lesssim$250 eV. We have no information on the effects of peak drive temperature on implosion symmetry. These are all issues that must be resolved before we can confidently specify driver requirements for ICF.

Resolving these issues will take a broad-based calculational and experimental approach. As for experiments, we must first do a carefully controlled symmetry experiment to test our hypothesis that drive asymmetries are the principal cause of performance degradation. [redacted] b(3) b(3) Hence, we need to do good numerical experiments as well. To do these numerical experiments requires, in turn, further developments in our calcula-

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tional tools. [redacted] b(3)

[redacted] We need to verify that 2-D Lagrangian hydrodynamics with nonuniform angular zoning is being done correctly; if not, we must find a way to do it correctly. Further improvements are needed in the viewfactor code. More development is required of the turbulence models, and a better understanding in general of the interplay between shear-induced instabilities and turbulence.

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In conclusion, although we are still far from our goal of having a complete enough understanding of capsule physics to have confidence that ICF will work in the parameter regimes we wish it to, we think this work represents an important step forward in our understanding. We hope that it will inspire the efforts that are needed to get us to our goal.

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REFERENCES

1. b(3)

2. Varnum, W. S., "Effects of Transit Time Delays on Small Capsule Symmetry," Los Alamos National Laboratory Memorandum X-1-80-26, August 1980 (SRD).

3. b(3)

4.

5. Youngs, D. L., "Numerical Simulation of Turbulent Mixing by Rayleigh-Taylor Instability," Physica 12D, 32-44, 1984; Reed, K. I., "Experimental Investigation of Turbulent Mixing by Rayleigh-Taylor Instability," Physica 12D, 45-58, 1984.

6. b(3)

7. Cranfill, C. W., W. P. Crowley, D. L. Youngs, P. E. Stry, "Comparative Analysis of TP-22 Results," in *Proc. of JOWOG-42 Meeting (May 9-13, 1988)*, Los Alamos National Laboratory Report, in press, 1989 (SRD).

8. Colvin, J. D., "Instability Analysis of Experiments," paper presented at JOWOG-37 Meeting, A.W.E., Aldermaston, U.K., 1984; Los Alamos National Laboratory Technical Memo X-1-84-14, 1984 (SRD).

9. b(3)

10. Haan, S. W., "The Onset of Nonlinear Saturation for Rayleigh-Taylor Growth in the Presence of a Full Spectrum of Modes," Lawrence Livermore National Laboratory Report UCRL 98206, June 1988 (U); to appear in *Phys. Rev. A*.

11. b(3)

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