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Status of Navy "Dirty Air" Breakdown Research

A. Edwards and J. A. Fleck, Jr.

December 1976

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Status of Navy "Dirty Air" Breakdown Research

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Abstract

The LAGNEX code has been upgraded to include optical ray tracing of laser light through the dynamically changing Lagrangian hydrodynamic mesh. Calculations have been carried out to simulate the absorption of laser light by a two-dimensional breakdown plasma initiated by a vaporizing dust particle.

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As is well known, the propagation of high energy laser beams through the atmosphere can be limited by the effects of thermal blooming and air breakdown. The latter effect is, of course, only operative in the case of multipulse laser beams. While thermal blooming is now well understood, there exists as yet almost no quantitative theoretical basis for understanding the dirty air breakdown that occurs in normal propagation environments. It is known that the phenomenon of dirty air breakdown somehow involves the initiation of LSD waves by exploding aerosol particles, but the details of what happens are enormously complicated and involve shock hydrodynamics, nonequilibrium energy transfer, and the propagation of laser light through ionized media.

At LLL we developed under ARPA funding a version of the laser target interaction code LASNEX that applied to metal target interaction in a low (few eV) temperature air environment. The code was used to model in considerable detail experiments on the generation, maintenance, and propagation of two-dimensional LSD waves.⁽¹⁾ In this code the laser energy propagation was modeled only crudely since detailed ray tracing was not essential for modeling the progress of quasi-planar LSD waves.

Under Navy funding this version of LASNEX has now been upgraded to treat the laser propagation by detailed optical ray tracing through the plasma in the expanding Lagrangian mesh. A typical number of rays for a problem might be of the order of 60, but there is no limitation on the actual number that the

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code can treat. The code generates an electron density distribution, which is a piecewise planar function of r and z over each two-dimensional Lagrangian zone. This planar function in turn creates a parabolic ray path through the zone in question. Each individual laser ray is accordingly tracked along the appropriate segmented parabolic paths through the entire mesh. When such rays encounter a critical electron density (at which the plasma frequency equals the light frequency) backward reflection of the ray direction may take place, although absorption tends to be very high in the neighborhood of a critical density.

The ray trace features of the code are illustrated in Figs. 1a-1g. In this problem a 60 μm diameter sphere of normal density air has been heated to a 2 eV electron temperature and a 1 eV ion temperature. The laser intensity is 2×10^7 w/cm. Laser rays are followed only until they have lost 99% of their initial energy. They are then dropped from the calculation and their paths on the plot are terminated. The present calculation clearly indicates the light refraction by the plasma but no LSD wave has developed by the end of the calculation.

Figures 2 and 3 give results of a series of calculations for laser fluxes varying from .2 MW/cm² to 100 MW/cm². The calculation assumes initially that a 100 μm diameter blast wave has formed from an exploding aerosol. The initial temperatures at the center of the blast wave are $T_e = 1$ eV and $T_i = 0.5$ eV. The densities within the blast sphere are configured in conformity with those for a blast wave. Figure 2 shows the total space integrated laser energy absorption on an area projected by the curved shock front on the laser beam. The existence of a maintenance threshold

and therefore a dirty air breakdown threshold at just under $7 \times 10^6 \text{ w/cm}^2$ is clear. Below 7 Mw/cm^2 an optically thick shock is unable to form. Figure 3 contains plots of electron temperature, shock density, pressure, longitudinal and transverse plasma expansion speeds, and absorption fraction as a function of incident laser intensity obtained from the same set of calculations.

Although no detailed comparison with specific experiments has yet been attempted, all values displayed are in general conformity with experimental measurements. These calculations should indicate the potentialities of the new LASNEX code for studying the all important phenomenon of dirty air breakdown.

References

1. A. Edwards, N. Ferriter, J. A. Fleck, Jr. and A. M. Winslow, "A Theoretical Description of the Interaction of a Pulsed Laser and a Target in an Air Environment", UCRL-51489 (Nov. 26, 1973).

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FIG 12

FIG 16

FIG 1c

FIG 1d

Z, CM. TIME= 6.0217E-01
RAY PATHS THROUGH LASER MESH.

BOM Y66 DUSTU

+144
DUSTU

FIG 1e

Z, CH. TIME= 1.0027E+00
RAY PATHS THROUGH LENSED MESH.

BOX Y03 DUSTU

+223
DUSTU

FIG 1f

FIG 19

Fraction of laser beam impinging on shock front that is absorbed

FIG 2

LASER GUST PARTICLE CALCULATIONS

FIG 3

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