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TITLE INTERFEROMETRY, STREAK PHOTOGRAPHY, AND STEREO PHOTOGRAPHY OF LASER-DRIVEN MINIATURE FLYING PLATES

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Interferometry, streak photography, and stereo photography of laser-driven miniature flying plates*

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ABSTRACT

Optical diagnostics to evaluate the velocity, acceleration profiles, planarity, and integrity of miniature (≤5 μm thick x ≤600 μm diam) plates of aluminum and other metals will be reported. By correlating various optical techniques and collected data, a complete understanding of the flying plate can be determined. Velocity Interferometer system for any reflector (VISAR), with ≤120 ps resolution per data point, is used to record plate acceleration and terminal velocity. Electronic-streak and pulsed-laser stereo photography can determine planarity and integrity. Flyer-plate performance data are related to the properties of the laser beam that accelerates the plate. Laser parameters, such as energy density, power density, and spatial profile, affect the flying-plate performance parameters, i.e, planarity, acceleration, and velocity. Flying-plate accelerations of $\geq 10^{10}$ G and terminal velocities of ≥6 mm/μs have been recorded, via a 10–ns–Nd:YAG laser pulse delivered to a tamped, 5–μm-aluminum plate.

1. INTRODUCTION

Laser interaction with metals and other materials have been studied since the early days of the laser. Coupling laser energy and/or power into these materials depends on numerous parameters, including laser power, energy, wavelength, and pulse duration. Material thermal properties, reflectivity, absorption, and confinement of the laser plasma should also be included. In most applications, the laser beam impinges on an unconfined surface of an absorbing material. The dynamic properties of the laser and the material determine the interaction that takes place.[1,2] Generally, one would like to deposit the laser energy on the material's surface. Because unconfined plasma velocities can be quite high, the absorption of the expanding plasma tends to attenuate and decouple the remaining incoming laser energy from the material's surface.

2. TECHNIQUE FOR LAUNCHING LASER-DRIVEN MINIATURE FLYER PLATES

For our experiments, aluminum, copper, or other metals, 0.2–20 μm thick, are physically vapor deposited (PVD) onto quartz substrates that are transparent to a 1.06–μm-Nd:YAG laser beam. A 10-ns pulse of a high-power (0.5–5.0 GW/cm^2, typical) laser beam is directed through the quartz substrate to the quartz/metal interface (Fig. 1). The laser pulse is initially reflected from the metal. But, as the power density on the metal surface increases, a skin-depth (~50 nm) of metal is converted to an optically absorbing plasma. The remaining laser-pulse energy is deposited in the metal plasma, increasing the temperature and pressure (10 eV and 4 GPa, typical). The confined plasma rapidly expands, accelerating the remaining metal foil as a one-dimensional plate away from the quartz substrate.[3,4] A laser-material interaction computer code, LASNEX, has provided 1-D simulations of the laser-absorption/flyer-plate acceleration. LASNEX results confirm the experimental results, suggesting

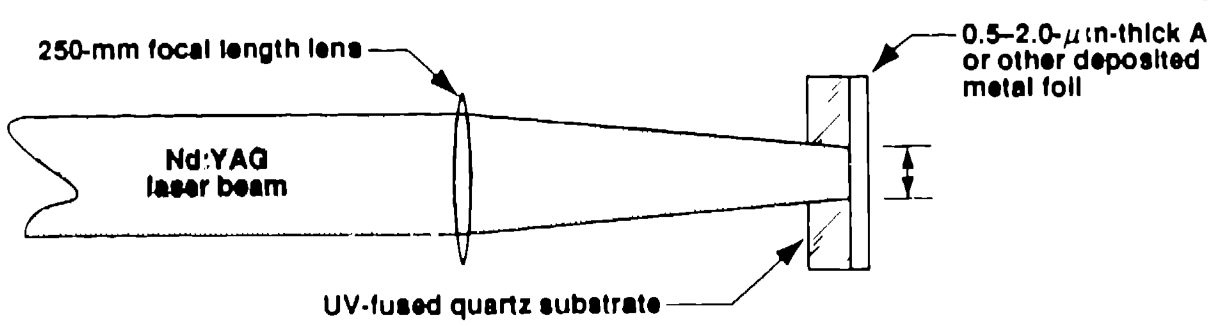

Figure 1. The experimental set-up for launching miniature metal flyer plates by confined plasma.

*Work performed under the auspices of the U.S. Department of Energy only a few per cent of the metal foil is converted to a plasma and that 30–60% of the laser energy is converted to kinetic energy of the flyer plate.[5] Plate accelerations of 10^{10}–10^{12} m/s^2 and terminal velocities of ≥5 km/s are routinely obtained. Data from three, distinct, optical-diagnostic techniques (velocity interferometry, electronic-streak-, and pulsed-laser stereo photography) have been correlated to quantify and visualize plate performance and laser interaction with metals.

3. OPTICAL DIAGNOSTIC TECHNIQUES FOR PLATE PERFORMANCE

Optical-diagnostic techniques have been the only method to obtain valuable quantitative information on plate integrity, planarity, acceleration profile, and terminal velocity, as well as plate impacts with other materials. The 1-mm area of interest usually requires >20X magnification. Several different diagnostic techniques have been used and their synergism provides a complete understanding of plate performance.

4. VELOCITY INTERFEROMETRY (VISAR)

Velocity interferometry (VISAR, ORVIS, Fabry-Perot)[6–9] records velocity histories of surfaces moving toward the interferometer (Fig. 2) and the merits of each recording system have been discussed.[10] The usual method of evaluating the quality and ability of the recording system used to track the interferometer signals is to generate a Lissajous pattern from the phase difference of the *s* and *p* signals. The quality of the Lissajous pattern represents the total system performance: the reflection of the moving surface, the optical and mechanical performance of the VISAR, and the recording system. VISAR data reduction is accomplished by summing the Lissajou phase angle per unit time and multiplying by the fringe constant (km/s/360°) Optically recorded instead of electronically recorded VISAR signals are best suited for these high accelerations (10^{10}–10^{12} m/s^2) because of the improved time resolution.

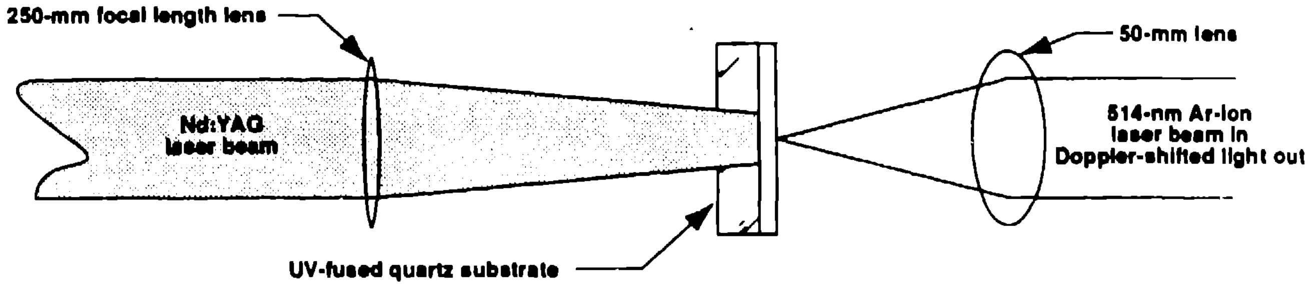

Figure 2: Velocity interferometer signal is the Doppler-shifted laser light reflected from the plate accelerated toward the interferometer.

4.1. VISAR recording with photomultiplier tubes (PMT's)

Optical interference signals from a VISAR typically use photomultiplier tubes (PMTs) to receive, amplify, and convert the four, unique, optical signals to electrical-intensity versus time. These electrical signals are then recorded on digital oscilloscopes or transient digitizers. The bandwidth of the recording system is usually limited by the PMTs to a time resolution of ~1–3 nanoseconds/point. Amplifiers and digitizers can further reduce the time resolution and the ability to accurately

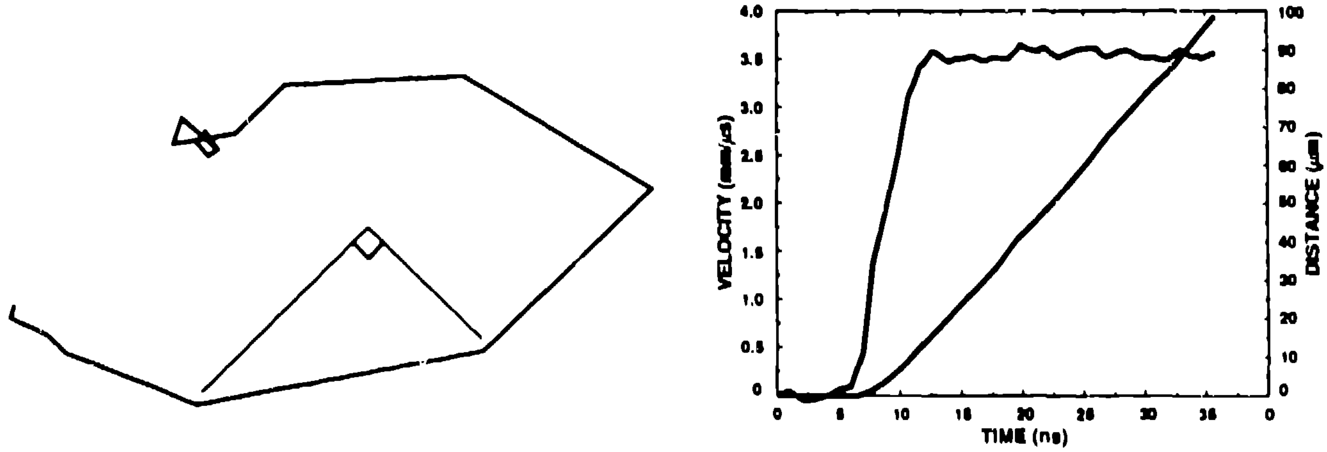

Figure 3: VISAR Lissajous and reduced velocity profile from data recorded with PMT/digitizer system at ~2–3 ns/pt.

synchronize four or more optical signals. This reduction results in considerable loss of information for high accelerations. Most experimenters will agree that 2–4 fringes (360°/fringe) is usually desirable for following an acceleration to its terminal velocity The time delay (tau) of the interferometer is typically 100–300 ps. Since the velocities of interest here can attain 6 mm/µs in 20 ns, and a fringe constant of 2 mm/µs/fringe, one fringe (360°) would be generated in <7 ns— equivalent to >51°/ns. A recording time resolution of 3 ns would produce >153°/recorded data point. Fig. 3 presents the Lissajous pattern, large phase angle, and final reduced-velocity profile of a high acceleration recorded with PMT/digitizer system.

4.1.2 VISAR recording with electronic-streak camera

By transmitting the optical VISAR signals through optical fibers directly to an electronic streak camera (Fig. 4), the temporal variations in intensity (fringe phase-angle information) can be resolved to ≤100 ps. Recording-time resolution is equal to the VISAR time delay (tau = 100–300 ps) or even less. Streak-camera recording improves bandwidth, minimizes time-correlation uncertainties between signals, and usually has a higher dynamic range when compared to electronic digitizers. The output of the streak camera is coupled by a fiber-optic taper to a 14-bit, 384x576-pixel CCD, permitting a direct readout to a microcomputer for ease of data reduction. Fig. 5 represents typical reduced Lissajous signals and velocity profiles.

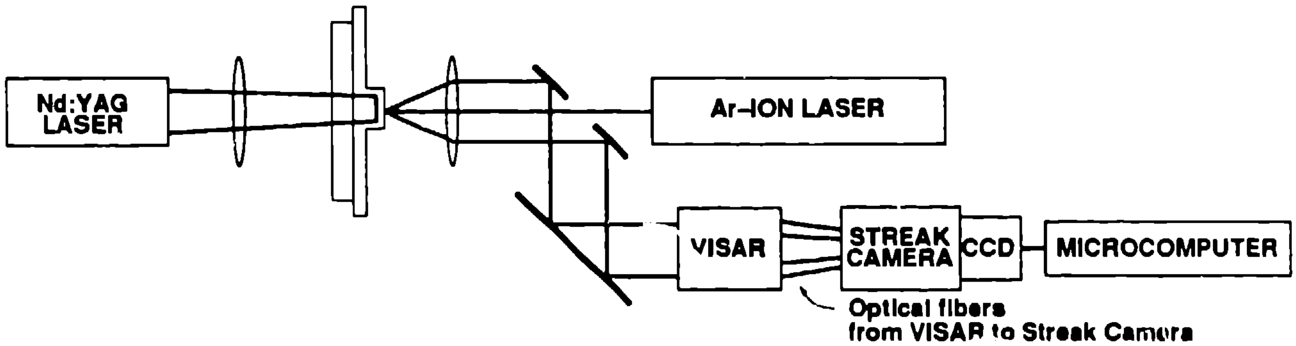

Figure 4: Optical fiber matched to ≤100 ps for transmission of optical signals from VISAR to electronic-streak camera for improved time resolution.

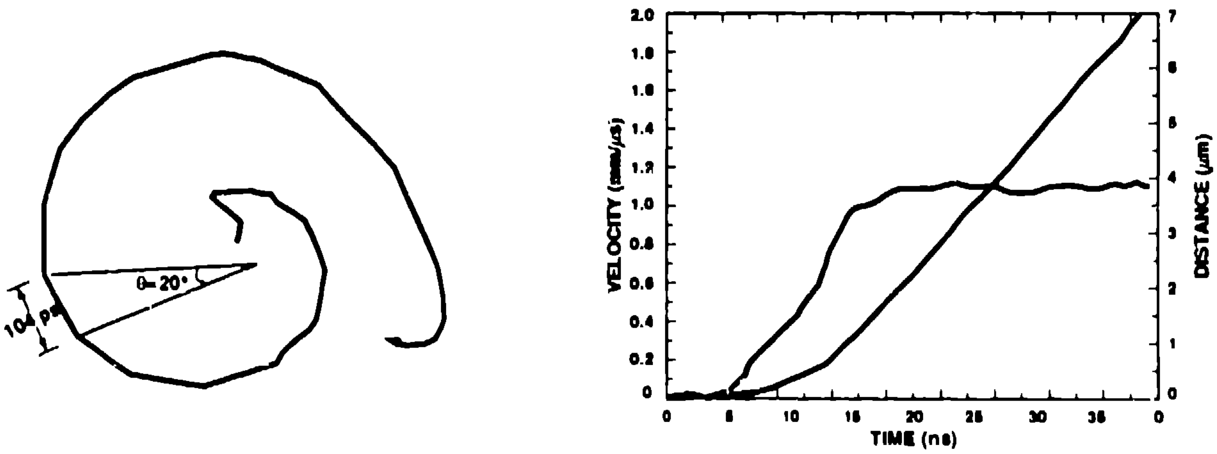

Figure 5: VISAR Lissajous and reduced-velocity profile from data recorded with PMT/digitizer system at ~100 ps/pt.

By comparing both recording methods in Figs. 3 and 5, the streak-camera method provides improved time resolution (smaller phase angle/time) and improved resolution of detailed structure in the velocity profile.

4.2 Electronic-streak camera for recording impacting plates

Most VISARs record acceleration and terminal velocities for an individual point on a surface[11] and an electronic-streak camera can image a line across the surface of a plate.[12] By impacting a plate onto a transparent material, e.g., PMMA, a known distance away, flight time and average velocity as well as plate planarity and integrity can be determined (Fig. 6). This technique also produces information directly comparable with VISAR data for displacement versus time. However, this technique gives only the planarity, integrity, and average velocity along a diameter of the plate. Axial symmetry is assumed, but is not always extant.

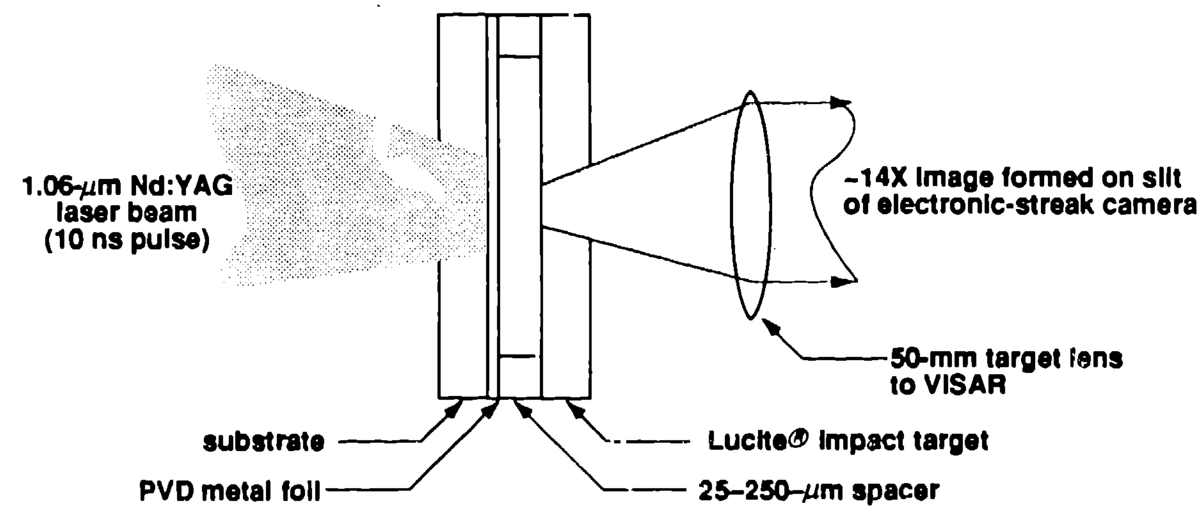

Figure 6(a). Test method for evaluating plate-impact conditions.

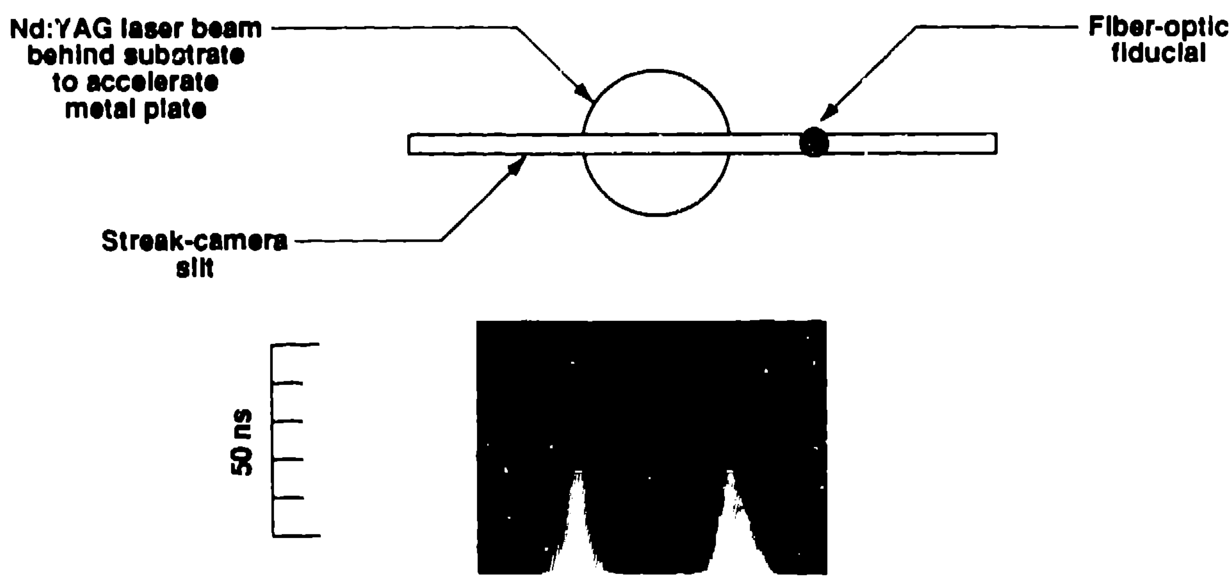

Figure 6(b). A typical impact record yields average velocity, planarity, and inte rity.

4.3 Pulsed-laser stereo photography of flyer plates

Pulsed-laser stereo photography of plates was performed in a manner similar to previously published methods.[13] Pulsed-laser photography consists of synchronizing a short-duration (1–10 ns, typical) laser pulse with the experiment and using the laser pulse for illumination. The combination of incorporating bandpass filters matched to the illuminating laser, coupled with a simple box camera, records only light from the short-duration laser pulse, thereby giving a detailed photograph of the test event at the time of the laser pulse. This technique is especially helpful if the experiment is generating a tremendous amount of self-light that is attenuated by the bandpass filter. However, synchronizing a Q-switched laser pulse to a dynamic event is not always easy to accomplish. Since our experiment uses a laser to launch plates and the desired time delay was typically ≤150 ns, synchronization was relatively easy. Doubling a 1.06- μm-Nd:YAG to 532 nm is ~50% efficient and the 1.06 μm and 532 nm exit the doubling crystal synchronized and collinear. The two wavelengths are separated, and the 1.06μm is directed to the plate to be launched. The 532-nm-beam was directed to several turning mirrors, reflected around the laboratory, which resulted in ~80 ns time delay, and then directed toward the input of a quadfurcated, pseudo-random, fiber-optic bundle. The four output-fiber bundles were used to illuminate the field of view of the stereocamera that contained the approaching 1.06-μm laser-driven metal plate. (Fig. 7). Pulsed-laser stereo photography has an advantage in that the plate can be photographed at a specific time during flight. Flight distance, average velocity, planarity, and integrity can all be determined. Figs. 8 and 9 are image examples and information obtainable. The stereo photographs in Fig. 8 confirm axial symmetry and suggest that previously discussed streak impacts are symmetrical.

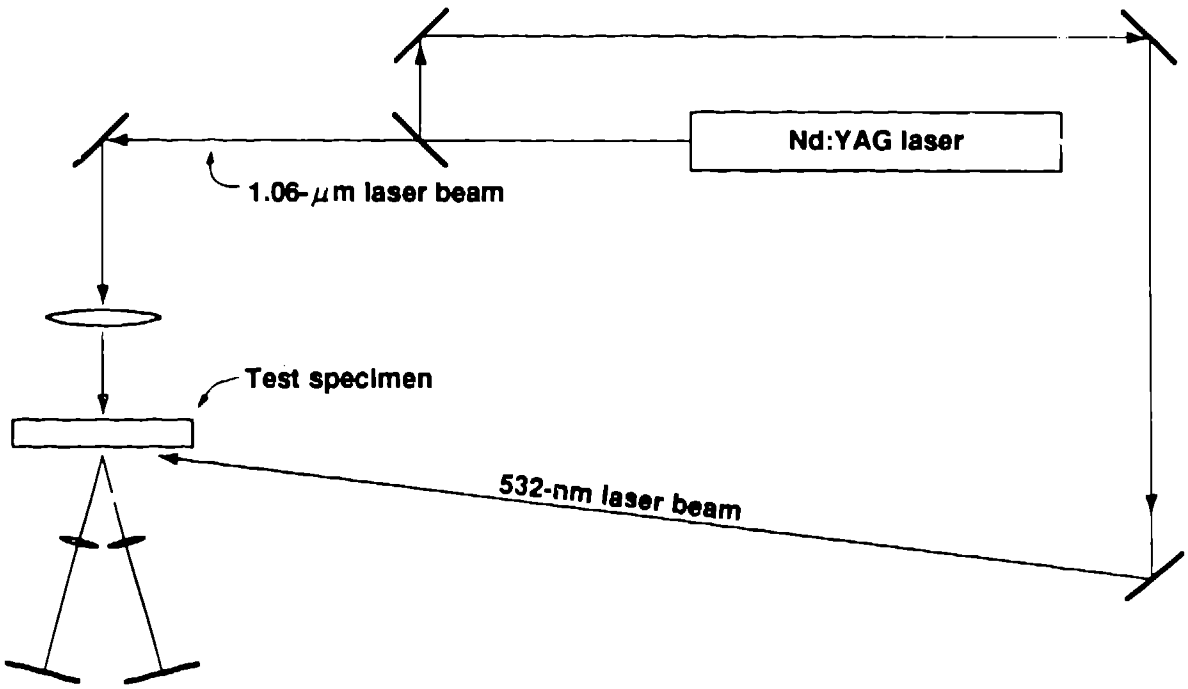

Figure 7. Laser technique for plate launching and in-flight photography.

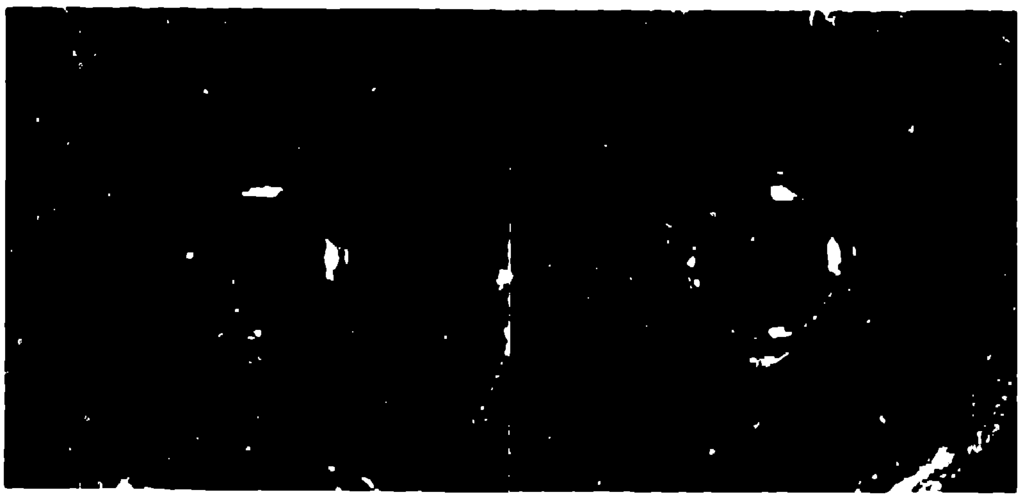

Figure 8: Stereo pair of laser photographs of flyer plate launched toward the optical axis of the stereo camera. This stereo pair can be viewed by standard stereo viewing techniques.

Figure 9: A pulsed laser photograph taken orthogonally to the velocity vector of the plate.

5. CONCLUSIONS

Improved VISAR time resolution (<100 ps) is possible by using optical fibers to directly record the optical-interference signals on an electronic-streak camera. Velocity interferometry of plate accelerations of $\geq 10^{11}$ m/s^2 were quantified. Electronic-streak and pulsed-laser stereo photography were used to help quantify and visualize plate planarity, integrity, and symmetry, with nanosecond time resolution. The synergism of the three techniques produces an understanding of the experiment that could not be obtained by any single diagnostic technique.

6. ACKNOWLEDGEMENTS

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