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Pulsed Laser-Generated Impulse on a Surface in Supersonic Flow

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Abstract

IT is now well known that pulsed CO_2 laser radiation can generate high pressures over a surface through formation of laser-supported detonation (LSD) waves at fluxes greater than 10^7 W/cm^2 (Refs. 1-3). It is also possible for hot, dense plasmas to be produced in the strong laser-supported combustion (LSC) wave regime at fluxes between 10^6-10^7 W/cm^2 (Refs. 4 and 5). The impulse generated at the surface by these phenomena are reasonably well understood.[6] Previous analytical and experimental work has dealt with a static environment. The phenomenology should be different with a supersonic crossflow over the surface. This work examines the behavior of the laser/surface/supersonic flow interaction and presents impulse data from aluminum targets.

Contents

A 200-J-pulse CO_2 laser with 10 μs pulse length was used for these experiments. A mobile supersonic free jet wind tunnel was used as a flow facility. It was operated at a 2.8 Mach number. The wind tunnel nozzle was 5×7.5 cm in cross section, allowing a laser spot size of a few centimeters in diameter to be used.

Two diagnostic systems were used in these experiments. A shadowgraph system was used to study the phenomenology. A Hycam movie camera equipped with a one-quarter frame shutter allowed a framing rate of 40,000/s to be obtained. Impulse data were obtained from Kistler quartz pressure gages. Figure 1 shows the arrangement of the pressure gages. The target plate was attached to the free jet wind-tunnel nozzle blocks. Side windows of optical quartz were provided for the shadowgraph movies. The target plate carried a Kistler pressure gage (active surface diameter of 0.56 cm) which was always under the center of the laser spot, and gages around the laser spot on a 2.5-cm-diam circle. The active surface of each of the gages was covered with a 0.020-in. thickness of the material to be tested adhered to the gage with double-sided tape. Direct illumination of the gages with the laser causes baseline drift on the time scale of the laser pulse; 0.020 in. of aluminum is adequate as thermal insulation over the time scales of interest (< 1 ms).

In plotting the data and making comparisons with analysis, the flux is taken to be the peak value following the leading-edge spike. The spike is approximately 0.3 μs in duration, as compared to the nominal 10 μs duration of the main part of the pulse. The main part of the pulse contained approximately 80% of the laser energy, the remainder being contained in the spike and a low-intensity tail. For the conditions of this experiment, the fluid mechanic decay times are typically less than 3 μs and, as a consequence, the dominant effect upon impulse being the flux level, the peak post spike flux is used as the characteristic laser intensity.

The phenomenology of the supersonic flow/blast wave interaction was observed by the high-speed cine. Examples of the flowfield are shown in Fig. 2. At low fluxes, there appears to be little direct interaction; however, at high fluxes, leakage

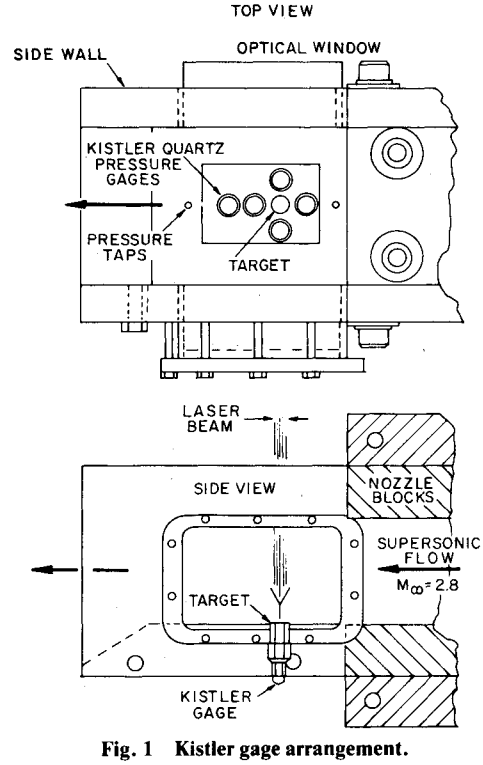

Fig. 1 Kistler gage arrangement.

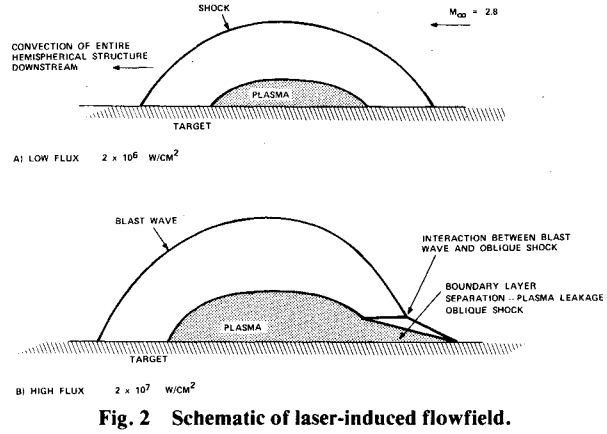

Fig. 2 Schematic of laser-induced flowfield.

Received April 12, 1978; synoptic received May 31, 1979. Full paper available from National Technical Information Service, Springfield, Va. 22151 as N79-26012 at the standard price (available upon request).
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Index categories: Lasers; Nonsteady Aerodynamics; Shock Waves and Detonations.

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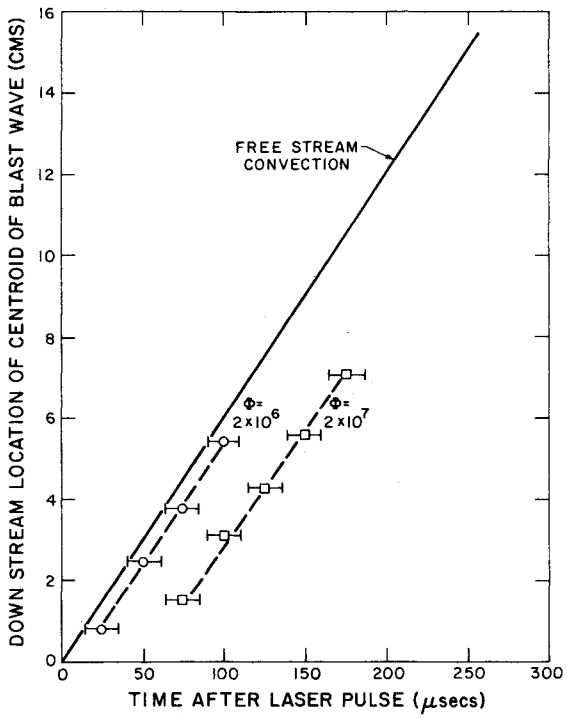

Fig. 3 Position of blast wave centroid as a function of time after laser pulse, $R_s = 0.5$ cm.

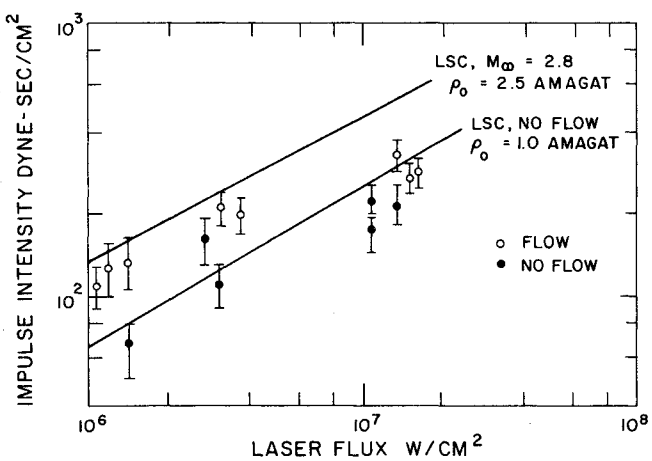

Fig. 4 Comparison of impulse data with LSC model, $R_s = 0.5$ cm.

of plasma into the upstream boundary layer produces an oblique shock which interacts with the blast wave producing secondary shock structures. The clearing of the irradiated region is noticeably different—the higher flux curves taking noticeably longer to accelerate to the convective velocity of the flowfield (Fig. 3).

The impulse generated on the surface by a 1 cm diameter laser beam is shown in Fig. 4. The data points are compared with a parametric model developed for no-flow conditions.[6] For supersonic flow conditions, the impulse was calculated on the basis of a uniform convection of the blast wave downstream with the freestream, which provides lower bound on

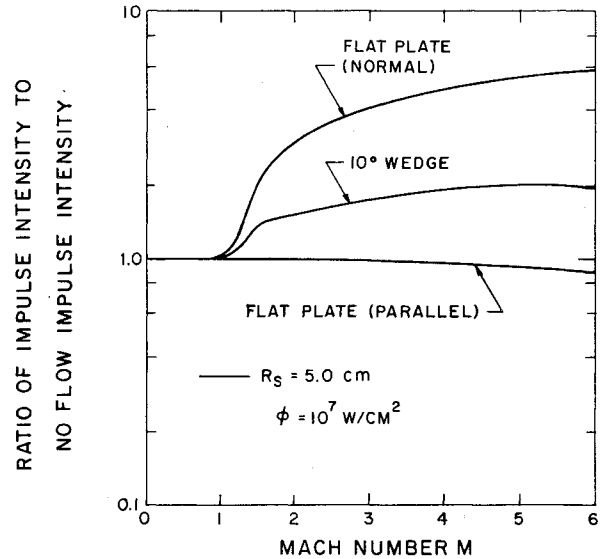

Fig. 5 Effects of Mach number and flow geometry on impulse.

the calculated impulse. (This is only a small effect at this particular flow condition.) The measured impulse is higher in the case of supersonic conditions. This is a consequence of the different ambient density in the two cases. The stagnation conditions in the wind tunnel are 25 bar, 300 K, which leads to a 2.5 amagat density over the target. This increases the LSC/LSD peak pressures and increases the relaxation time for pressure decay.[6] The high-flux impulses appear to decrease relative to the simple LSC prediction; this is a consequence of transition to LSD conditions.

The implication of the measurements and modeling of the impulse loading in supersonic flow can be seen in Fig. 5. The consequence is a change in flow direction, such that of a two-dimensional wedge. This produces an enhanced impulsive coupling to the surface. A surface normal to the flow produces the largest enhancement. (The high Mach number rolloff of impulse is a consequence of the assumption of freestream convection of the high-pressure gas downstream.) The conditions of the experiments correspond to that of a 16.5 deg wedge at a 3.9 Mach number.

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