Measurement of Vegetation Sweep-Up at High Shock Overpressure

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Introduction

INVESTIGATORS studying airblast sweep-up of ground cover vegetation[1] are interested in not only the amount of vegetation debris lofted to altitude but also the condition of the postshock ground surface relative to its mass scouring potential.

One vegetation sweep-up model put forward for use with high-explosive hydrocode computations is the shock front lofting model of Carpenter (private communication). This model postulates that high shock loading of typical cropland ground cover will cause near-instantaneous shock front breakoff of the vegetation stalks at ground level without root pull-up. Whether the plant's roots are pulled up is important because, if they are, much loose dirt will be available for subsequent scouring. For intense blast waves, shock overpressures will vary from high to low as a function of distance from the explosion's ground zero location. As a result, ground cover will be removed from the surface out to some threshold overpressure range beyond which stalk bend-over effects will dominate (and thereby attenuate soil scouring). Once vegetation is removed from the ground surface, the exposed soil is similar to fallow ground and can be so treated in soil scouring calculations.

The purpose of the current shock tube investigation was to determine the dependence of vegetation sweep-up (VSU) on shock overpressure ΔP. The problem of shock-induced motion of a plant stem (after breakoff) is not too different from that of a dust particle accelerated by the passage of a shock. Although a number of investigations have been made to study the effects of shock wave propagation through dusty gases,[2,3] similar data on vegetation lofting due to intense airblast flow conditions are limited. A detailed documentation of results from the present experimental study is available in Ref. 4.

Experimental Technique

VSU results reported herein were obtained in a laboratory-scale shock tube at ideal, i.e. nonthermally precursed, shock overpressures varying from 55 to 414 kPa. Both barley and wheat cropland samples were tested, and measurements consisted of shock tube performance data as well as pre/posttest photographs and Hy-Cam shadowgraphy (6000 frames/s). Test samples were obtained from wheat/barley crops planted by the Agricultural Department of the California State Polytechnic University of Pomona (CSPU-P). Biomass magnitudes (expressed as above-ground vegetation weight per unit field area: 0.03–0.07 g/cm^2) and horizontal pull-out forces (9.1 ± 4.5 kg per plant cluster) for the CSPU-P samples were comparable to that for typical Montana crops.

The shock tube used for the VSU experiments is a bursting-diaphragm facility (18-cm-width $\times$ 36-cm-height $\times$ 5.5-m-length test section) and incorporates a burst-on-command capability. Vegetation samples were installed, after trimming stalk tops to accommodate the facility's height constraint, in the floor of the test section in specially prepared core containers. A total of 15 VSU tests were conducted. Both circular (3.8- and 7.6-cm diam) and rectangular (7.6-cm width $\times$ 30.5-cm length) core sample containers (12.7-cm depth) were used.

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Results

Initial VSU experiments were performed with the 3.8-cm-diam core container (tests VSU 1–4, 345-kPa shock overpressure). A typical Hy-Cam result (VSU 2) from these tests is shown in Fig. 1. The shock arrival frame is designated as time zero, and the background horizontal lines are separated at 2-cm spacing. Note that the shock is oriented normal to the flow direction but is seen in the second frame as a left-leaning diagonal line due to the optical interaction between the camera shutter and the film's high-speed motion.

For the VSU 2 result, stem movement is delayed several frames following shock arrival, indicating that the shock progresses downstream without stem bendover effects taking place. Note that the stems initially translate horizontally, thereby causing substantial shear stresses near the stalk–ground interface. As a result, vegetation breaks away within 2 ms of shock arrival, leaving behind a short stubble residue. For this test it is calculated that impact drag loads on the individual stalks, based on stem frontal area and postshock dynamic pressures, were approximately 64 kg. In addition, ruptured stalks were estimated to move about 7.6 cm by the fifth Hy-Cam frame.

Similar results were observed for the other three 345-kPa experiments. Although some soil scouring occurred in these tests, partly due to core leading-edge disturbances, negligible root pull-up was observed. This root retention finding is consistent with the fact that the airblast, simultaneously with flow onset, imposes a high surface pressure on the ground and thereby seals in the embedded root structure. For example, with a typical root pod diameter of 6.4 cm and a shock overpressure of 345 kPa, a hold-down force of approximately 110 kg is estimated.

Although these initial VSU results support the shock front lofting model for VSU, additional experiments were performed to clarify VSU dependence on shock overpressure and sample size and shape. In general, it was found that, for a sufficiently high overpressure, the basic failure mode at the stalk/ground interface for the VSU 1–4 tests also held true for the larger sample experiments. In fact, vegetation removal was as extensive at the 345-kPa test condition for the rectangular sample as when a stalk clump (10–30 stalks) was tested in a single cylindrical container.

Estimates of percent material survival (vegetation mass remaining posttest relative to initial sample mass) for all VSU tests have been made from pre/posttest photographic results.[4] A plot of the noted data set ($\pm 10\%$ uncertainty due to subjective nature of measurement method) is provided in Fig. 2, and a strong decay of percent survival with increasing shock overpressure is evidenced. This dependence

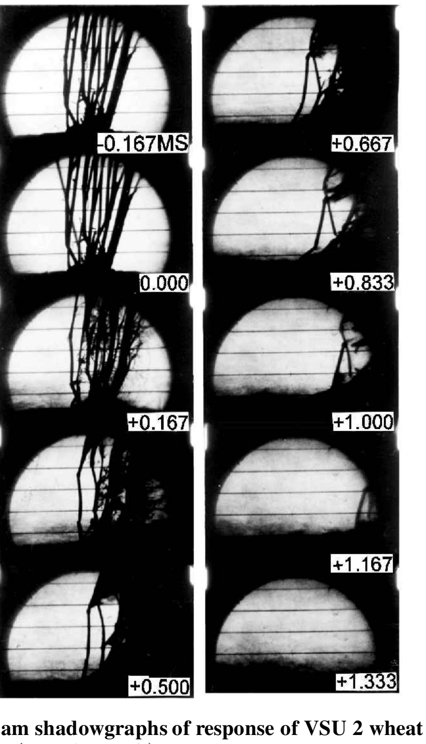

Fig. 1 Hy-Cam shadowgraphs of response of VSU 2 wheat sample to 345-kPa shock (6000 frames/s).

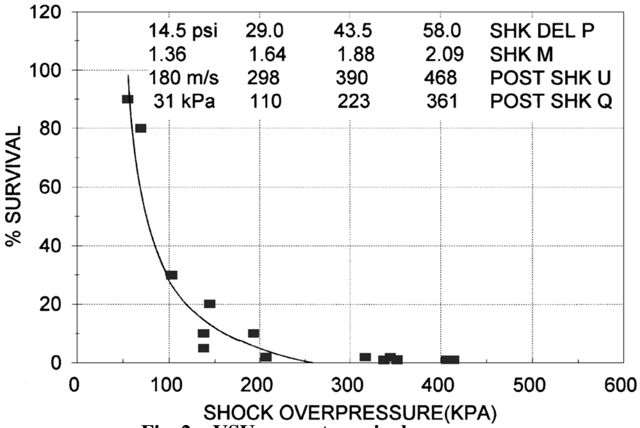

Fig. 2 VSU percent survival summary.

Fig. 3 Photographs of posttest VSU samples illustrating survival dependence on shock overpressure.

is also pictorially demonstrated by the photograph in Fig. 3 of several posttest samples. These data, as well as companion Hy-Cam results, illustrate that, for shock ΔP greater than approximately 207–276 kPa, essentially all wheat vegetation was lofted within 2 ms of shock passage without root pull-up. Because stem shear stresses vary as a function of stem-length-to-diameter ratio, it is expected, however, that the noted breakoff threshold values will tend to increase with stem diameter and decrease with stem length. The airblast sweep-up experiments of Refs. 4 and 5 for grass vegetation samples, which indicate that minor vegetation lofting occurred, support this viewpoint.

Scale-up verification of the VSU results was made in Stanford Research Institute's (SRI's) 2.4-m shock tube[4] upon completion of the VSU experiments. These large-scale tests were performed at shock overpressures of 207 kPa for decaying blast waves with long positive-phase durations (≅100 ms). Three tests were conducted with full-scale wheat samples mounted in planter beds (1.2–1.4 m in width) on floor-mounted pallets. Stalk spatial densities were comparable to the TRW shock tube values, and bed lengths varied from 1.2 to 4.9 m.

In general, the SRI experiments indicate that the primary removal mechanism for the wheat vegetation was similar to that for TRW's VSU tests, namely, stem rupture near the shock front without root pull-up. All broken and removed wheat stalks were pulverized by the shock impact process into small pieces, the largest of which were 2.5–10 cm in length. This shredding of vegetation debris was also typical of the TRW shock tube results.

Conclusion

Shock tube measurements have been made of the response of typical cropland vegetation to airblast flow conditions. Results demonstrate that, at shock overpressures greater than approximately 242 kPa, complete breakoff of vegetation stalks occurred without root pull-up within 2 ms of shock passage. Some additional testing may be warranted, however, to complement these first-look results, with particular attention focused on the sensitivity of vegetation breakoff to stalk diameter, length, spatial density, etc.

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Limitations of a Reduced Model for the Simulation of Hydrogen/Air Combustion

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Introduction

PROBLEMS involving the combustion of hydrogen/air mixtures have received an increased amount of attention in recent years, mostly due to the drive toward the design of hypersonic airbreathing engines.[1] Numerous investigations in the kinetics of hydrogen burning in air have resulted in the development of several models for the detailed kinetic processes, which involve relatively large numbers of gaseous species and chemical reactions.[2,3] Unfortunately, the practical utilization of large chemistry models for the simulation of reactive flows in realistic geometries is severely hindered, due to the extremely heavy computational requirements. (The most favorable estimate of the operation count for a simulation involving N gaseous species in chemical nonequilibrium is that it will scale as $N \ln N$; in addition, a significant amount of CPU time is typically spent evaluating chemistry source terms, which scale linearly with the number of chemical reactions.)

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