DESIGN OF BLAST SIMULATORS FOR NUCLEAR TESTING

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ABSTRACT

A quasi-one-dimensional computational technique is used to model the flow of a large, complicated shock tube. The shock tube, or Large Blast Simulator, is used to simulate conventional or nuclear explosions by shaping the pressure history. Results from computations show favorable agreement when compared with data taken in the facility at Gramat, France. Such future shock tubes will include a thermal irradiation capability to better simulate a nuclear event. The computations point to the need for venting of the combustion products since the pressure history will be considerably altered as the shock propagates through these hot gases.

I. INTRODUCTION

There are currently two techniques used to simulate thermal and blast effects produced by tactical nuclear weapons: thermal pulse simulators in combination with blasts produced by high explosives and thermal simulators in special shock tubes. Since the former technique is relatively expensive and is restricted to the simulation of small yield weapons, 1-10 kilotons, the use of specialized shock tube facilities is becoming increasingly attractive. A number of moderate-sized facilities exist in the U.S. and abroad, with the largest at the Centre d'Etudes de Gramat (CEG), France; see References (1) and (2). This facility, shown schematically in Figure 1, is large enough to accommodate full-sized tactical equipment such as tanks and trucks. Its total length is approximately 150 m, with the drivers being about 44 m long. The tunnel width is approximately 12 m at the floor.

A computational technique was used to investigate designs and predict the performance of complex shock tubes, such as the CEG facility. This computational technique is described in the present paper. Data taken by the Ballistic Research Laboratory in recent tests in the CEG facility have been compared with predictions from the present computational technique and used as a point of departure for extrapolating the performance for a possible U.S. facility. Since the present U.S. Large Blast/Thermal Simulator (LB/TS) concept includes a combined thermal and blast simulation capability, the effects of blast wave modification by hot combustion products from a thermal radiation simulator (TRS) are also described.

II. THEORETICAL CONSIDERATIONS

The computational technique employed in this paper is the implicit finite-difference scheme described by Warming and Beam (3). It is applied to the quasi-one-dimensional Euler equations in their weak conservation form.

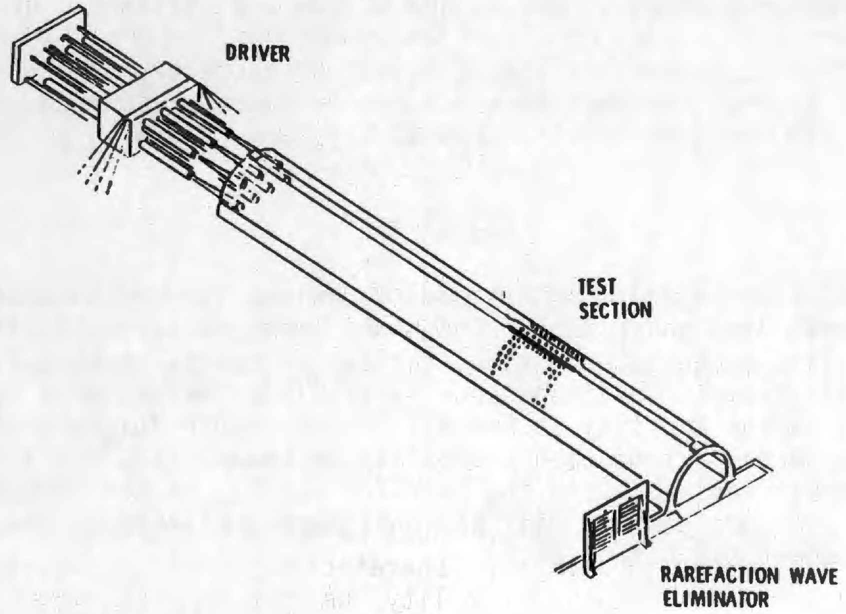

Figure 1. Blast simulator at Centre d'Etudes de Gramat, France.

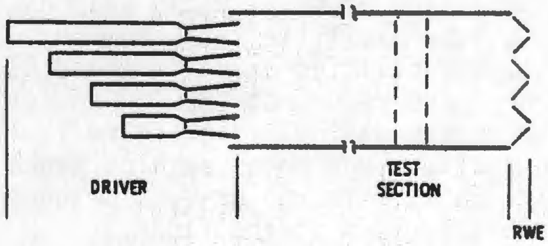

Figure 2. The CEG facility model.

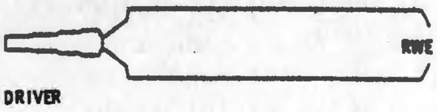

Figure 3. Quasi-one-dimensional computational model of the CEG facility.

This form is retained when the equations are transformed to a uniform computational grid. Central spatial differencing casts the difference equations into a tridiagonal structure which is solved for the increments in the dependent variables at each successive time step with the "delta" form of the algorithm; namely:

$$\left[\bar{\bar{I}} + \Delta\tau\delta_{\xi}(\bar{\bar{A}})\right]^{n}_{j} \cdot (\Delta\bar{Q})_{j} = - \Delta\tau\delta_{\xi}(\bar{E})^{n}_{j} - \Delta\tau(\bar{h})^{n}_{j}. \tag{1}$$

The reflective boundary at the solid wall of the grid was computed by means of image points, such that $\rho_1 = \rho_3$, $u_1 = -u_3$, $e_1 = e_3$, and $u_2 = 0$. The outflow was computed from one-sided differences at the exit plane.

III. RESULTS AND DISCUSSION

For large shock tubes, the driver must be made of a number of smaller tubes for practical reasons. This is schematically shown in Figure 2. In order to computationally model the facility the crossectional area at any location was simply lumped giving the configuration of Figure 3.

A. COMPARISON WITH CEG DATA

Overpressure histories from the French blast simulator at CEG are available for comparison with the computational results. The experimental record for a case with a peak static overpressure of 52 kPa was matched computationally, and the results are compared in Figure 4. In this figure the smoother, solid line is the computational result whereas the "noisier" curve is the experimental data. In the same figures the dashed lines are the computed dynamic pressures.

The comparisons show that the general features (wave reflections and expansion) of the pressure histories are replicated in the computational simulations. This degree of agreement between computation and experiment however, was obtained only after increasing the initial driver pressure by about 20% and decreasing the driver volume by 30% from the actual conditions used in the CEG tests. Without these two adjustments the overpressure was underpredicted at the start of the pressure-time curve and overpredicted toward the end.

It is indeed surprising that a crude quasi-one-dimensional model can at all approximate the complicated three-dimensional nature of the flow process. Consider, for example, the seven CEG drivers of different lengths. As they are emptied on bursting of the diaphragms, rarefaction waves empty the tubes at different rates. Subsequent compression and expansion waves from the throat and RWE influence the flow differently in these tubes. As they are lumped in the computational model, the influence cannot be the same. Furthermore, the flow at the exit of the driver nozzles experiences a sudden change in area. In the seven driver CEG configuration, the shock waves emerging from each nozzle form a spherical-like shock and coalesce forming a complicated array of Mach Stems and spherical shocks. This array of Mach Stems forms a higher pressure than would result from an equivalent single nozzle such as in

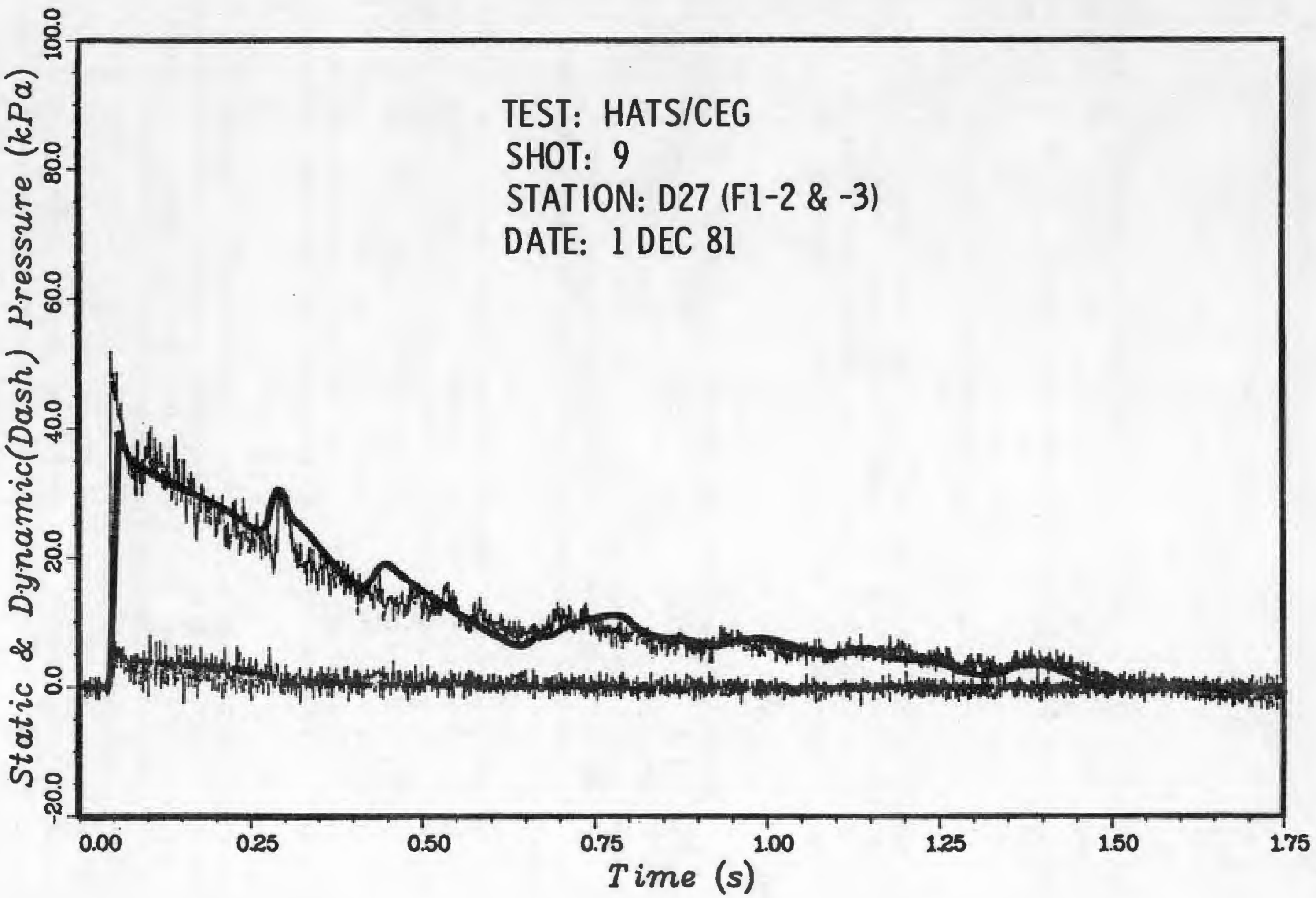

Figure 4. Computed quasi-one-dimensional versus CEG - experimental data comparison of overpressure history for a peak overpressure of 52 kPa (7.5 psi).

our model. This accounts for the adjustment in initial pressure. Losses in a number of locations could account for the volume reduction.

B. INFLUENCE OF THERMAL RADIATION SIMULATOR

Thus far, we have discussed the blast-only modeling aspects of large-scale shock tubes. In order for these shock tubes to be more realistic in simulating nuclear bursts, a thermal source should also be considered. This is true both for the physical and computational shock tube models.

The thermal pulse from a nuclear burst precedes the air blast at the target. For typical distances of interest for tactical equipment from ground zero, the time between the thermal and blast pulses is of the order of 1 second. Adding the capability of thermally irradiating a target and then applying a blast loading is a step closer to a real simulation. This can be done physically by incorporating a thermal radiation simulator in front of the target. The drawback in the physical shock tube is that the hot thermal products may still be in the target area when the shock arrives. As the shock passes through the hot gases its wave characteristics are altered. This section points to the fact that, in attempting to reproduce both the thermal and blast characteristics of a nuclear weapon in a LB/TS, we need to concern ourselves with the thermal radiation simulator combustion products produced within the tube.

One can obtain a qualitative insight into this thermal-blast interaction process by computationally modeling the CEG facility, including a region of remnant thermal combustion products. Such a model is depicted in Figure 5, where the shaded area represents the distribution of hot products and point "A" is the measuring station in the test section. The solid line in Figure 6 represents the predicted static overpressure for the blast-only test, while the dashed line represents a combined thermal/blast test. The hot products were modeled with air having a sound speed 1.73 times the ambient value. The shock wave which arrives at the measuring station is attenuated by about 25 percent in amplitude and arrives somewhat sooner since it traveled for some distance through higher sound speed air. The perturbation on the thermal/blast wave at $t \approx .35$ s occurs because the active rarefaction wave eliminator is now "detuned" for this type of wave. All these anomalies point to the fact that a venting mechanism needs to be incorporated into the design of a LB/TS if realistic combined testing is to be expected.

REFERENCES

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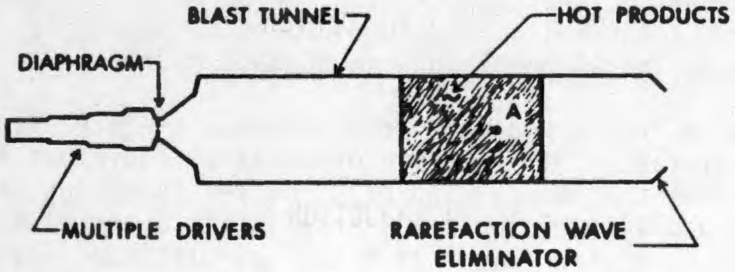

Figure 5. Quasi-one-dimensional computational model of CEG facility with thermal radiation simulator products.

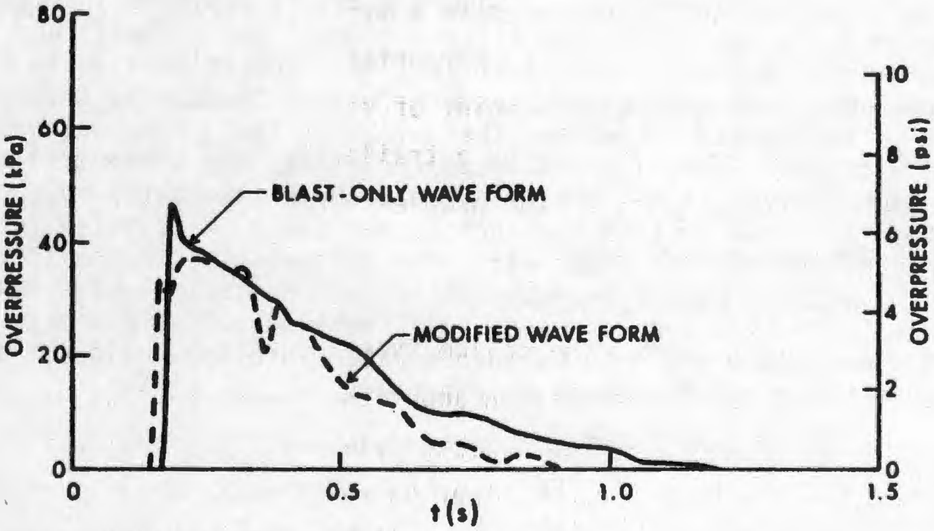

Figure 6. Predicted static overpressure modifications in CEG facility without venting TRS product.