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REPORT

MRL-R-1095

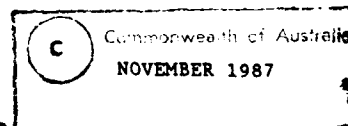
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NUMERICAL SIMULATION OF THE EXPLOSIVES EFFECTS OF
TWO CLOSELY SPACED PYROTECHNIC PODS



J.A. Waschl

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ABSTRACT

This report describes some computer simulations to study the effects of two pyrotechnic noise-generating pods which deflagrate in close proximity, at, or nearly at, the same time. Some modifications to the computer code HULL, to improve the efficiency of the calculations, are described. The calculations show that though there is reinforcement of the shock wave between adjacent pods, the increased effect on nearby personnel is small. The effect of non-synchronous deflagrations is less than synchronous ones. The overall conclusion is that the problem of multiple pods can be treated as one of single pods as far as hazard is concerned, though with more pods in a confined space there is an increased chance of a person being located in a hazard region.

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NUMERICAL SIMULATION OF THE EXPLOSIVES EFFECTS OF

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1. INTRODUCTION

MRL has recently become interested in the effects of deflagration of noise generating pyrotechnic devices such as battlenoise simulators. In particular, there has been some concern about possible interactions between the pressure waves generated by two or more components of these devices (known as pods) which initiate in close time and space proximity. It is thought that pressure waves might reinforce, leading to damage to surroundings greater than that for which the pods (and the grenade containing them) were intended. Of particular interest is the effect such an accidental reinforcement might have on personnel located nearby. In this report we examine in detail the possible constructive interference of the pressure waves from deflagration of two pods, initiated either simultaneously, or in rapid succession. The effects of a single pod deflagrating near a reflective surface have been reported earlier [1].

One method of investigating the interaction of two deflagrating pods is to place one above the other at a fixed separation. The overpressure and positive phase duration can then be measured at various locations between the pods.

In multiple deflagrations, the resultant superposition of the colliding pressure waves may provide regions of high risk to personnel. Changing the distance between the pods, or the time delay between the ignition of the two pods will change the pressure contour map. The situation is thus quite complex, and though it is feasible to observe the effects experimentally, it would be both expensive and time-consuming to do so. We have restricted our attention to a numerical study of the effects of two pods, in order to reduce the problem to manageable proportions.

The HULL code [2], version 20, was employed to model the problem. To do so, it was necessary to make some extensive modifications, which are described below. HULL was used as it had proved capable of simulating a single pod deflagration in our earlier work [1]. The modifications enabled the calculation for a single pod to be performed up to the point where the pressure wave had developed. Two pods in proximity were then simulated by placing the same pressure wave contours in two locations in the calculation domain. These pressure waves were then allowed to develop further and to interact as required. In this way, considerable computing time was saved by removing the need for a fine numerical grid for the entire calculation. The fine grid was only required for the initial single-pod calculation, and the subsequent dual pod calculation was done on a coarser grid over a larger space domain.

In this study, a comparison is made between two pods in synchronous deflagration, and two in asynchronous deflagration. Results are compared to the work already reported for a single pod. We also describe our improvements to HULL to enable the calculation to be performed. Our results are then discussed in terms of their likely effects on nearby personnel, and the hazard region is assessed.

2. PROBLEM DEFINITION

The problem to be modelled consisted of two pods at a nominal separation of 1 m as depicted in Figure 1. The pods were positioned over a perfectly reflecting surface. Cylindrical space symmetry was used. The computational space was continuous in both radius and altitude.

Modelling this system directly would involve an excessive use of computer resources because the initial deflagration and expansion of the pressure wave requires a fine grid mesh in order to resolve the important initial small-scale details. This fine grid would need to cover the entire domain, including the two pods and the far-field region. Thus many variables would be involved, and the solution would be both expensive and time-consuming to obtain. For this reason, the following technique was developed.

HULL was initially run with a fine grid and a single pod. The pod was initiated and allowed to burn to completion, with the build-up of a pressure wave. The calculation was halted when the pressure wave had reached a stable state but had not interacted with the boundaries. The data generated by this calculation was then manipulated to permit a larger scale calculation of the same problem on a coarser grid. The calculation on two pods was begun when the pressure waves had spread enough. The mesh was made coarser in the process.

Some changes to the HULL code were necessary to implement this new scheme and were incorporated into the subroutines GENER, FIROUT, FIRIN and HULLIN. They enabled the data from a previous run to be used to redefine zones within the more complex final calculation, as well as to expand the region of the single pod calculation, as required.

With these changes installed, it became possible to reduce the calculation to a 'characteristic region' as shown in Figure 2. The calculation on two pods was done in two main stages.

Stage 1 Only a single pod was treated and the calculation was stopped after the pressure wave had progressed to near any one of the boundaries but had not interacted with them. The characteristic region was then redefined to a larger size in the code KEEL, which defines HULL models. This increase in the size of the characteristic region was repeated until the pressure wave had expanded far enough for treatment of the full two-pod calculation.

Stage 2 The two-pod problem was set up. This incorporated the data from the first calculation.

In our calculations, the single pod (first stage) calculation was run until the pressure wave had expanded to an altitude of just under 0.5 m. At that point, the calculation was redefined to include the two pods (stage 2) with a 1 m separation distance. Each pod was replaced by the same calculated blast wave up to that point, centered on its original location (Fig 1). The calculation then proceeded with the two waves eventually interacting with each other, and with the reflective boundary.

A larger separation distance could easily be accommodated by mapping the two pods further apart for the re-started calculation. Differences in the initiation times of the two pods could also be easily achieved by mapping two separate time dumps into the defined space. These modifications have improved the flexibility of the HULL code and at the same time reduced computer resource requirements.

The characteristic region was modelled in two-dimensional cylindrical geometry. The base of the single cylindrical pod was initially positioned 0.015 m above the reflective surface. The height was chosen to delay the interaction of the shock from the pod with the surface. The axis of symmetry is shown in Figs 1 and 2 as the left boundary. The right and top boundaries are transmissive to the pressure wave. The dimensions of the region were increased as the stage 1 calculation progressed. As the region was increased in size, the distance of the pod from the surface was increased up to the final height (base of the pod from the surface) of 0.135 m.

The initial characteristic region was divided into 50 cells in the x (radial) direction and 150 cells in the y (altitude or axial) direction to form a cylinder 0.018 m radius and 0.15 m height with a fixed rectangular grid of 0.36 mm by 1 mm. The grid dimensions for the final composite (two pod) calculation were 3.57 mm by 10 mm for a region radius of .621 m and a height

of 1.65 m. These grid sizes were all chosen to ensure stability of the calculation and to provide adequate accuracy.

The pod had the dimensions 0.115 m in height and 0.005 m in radius. The pyrotechnic filling was modelled by the Tillotson equation of state [2] assuming a cylinder of bare explosive. The explosive was treated as initially being in two states consisting of two cylinders, one within the other as shown in Figure 3. State 1 refers to the unburnt material which has a density of 660 kg/m^3 and an internal energy of $5.2 \times 10^5 \text{ J/kg}$. Initiation of the pyrotechnic began in the preburnt material (state 2) which has the same density as the unburnt material, but a higher internal energy of $9.8 \times 10^6 \text{ J/kg}$. These values have already been used and verified [1]. The mass of explosive was $5.98 \times 10^{-3} \text{ kg}$. The non-central location of state 2 shown in Fig. 1 represents the non-symmetric initiation of each pod.

3. RESULTS AND DISCUSSION

A single pod deflagrating above a reflective surface was simulated using the HULL code. For stage 1, the calculation was run for $9 \mu\text{s}$ calculation time in the original grid. (Fig. 3 shows the initial characteristic region.) At that stage the hydrodynamic variables were saved and used as input for a subsequent run in a larger grid of the same single pod system. This procedure was continued until a time of $100 \mu\text{s}$ was reached. Details of these steps are given in Table 1.

At $100 \mu\text{s}$ the pressure wave had travelled a significant distance compared to the original space dimensions. Stage 2 of the calculation was then commenced. By mapping the results of this calculation into an enlarged computational space, a final two-pod simulation was conducted. In this calculation the interaction of two pods deflagrating simultaneously was studied. Figures 4a, 4b and 4c depict the pressure contours at the indicated times for this simulation.

The highest pressures were found in a horizontal plane at an altitude of about 0.75 m (i.e. approximately midway between the two pods) and also along the bottom reflective surface. Table 2 lists the overpressure, impulse and positive phase duration along a radial line at a height of 0.75 m. No impulse data is available beyond 0.2 m as the positive phase duration is not complete after that point. The high pressure region in the lower right of Fig. 4a is due to the incident wave reflecting off the bottom surface, and has been discussed previously [1].

The high pressure in the horizontal plane 0.75 m above the surface defines a collision zone between the pressure waves of the two interacting pods (see Fig 4c). The average peak values of parameters within this zone are given in Table 3. These averages were taken along the 0.75 m horizontal, out from the axis as far as the results permitted. The values are compared with

the HULL calculated values for a single pod over the same horizontal plane at 0.75 m. The shock wave parameters within the collision zone are much higher than those obtained from a single pod in free air at an equivalent distance. Both impulse and positive phase duration were expected to fall off at distances greater than the 0.15 m to which it was possible to calculate. It is expected, however, that their magnitudes will still be higher than those for the single pod at the same location.

Note from Table 3 that the peak overpressure does not occur along the axis of symmetry. This is due to the vertical orientation of the pods. The same effect can be noted in Figs. 4, where the isobars in the horizontal direction are closer together than those in the vertical direction.

An estimate of the probable injury to personnel in a confined space can be made by scaling the incident overpressure to the ambient atmospheric pressure and the impulse to the mass of a typical person [3]. Considering the worst case of a collision zone with an average distance of 0.5 m from the source of the two explosions and a human mass of 70 kg, the scaled pressure would suggest that no lung damage is possible. The average overpressure within the collision zone, however, is high enough to cause approximately 50% of the occupants within that region to sustain ruptured ear drums. This result is slightly better than that found at ground level where greater than 50% of personnel at 0.5 m from the centre line would suffer ruptured ear drums [1].

To investigate the effect of asynchronous deflagration, the initiation time of the lower pod was delayed by 400 μ s. This was simply done by mapping the 800 μ s result and the 400 μ s result into the new problem before continuing the simulation. The collision zone for this case is shown in Figures 5a, 5b and 5c in the form of pressure contour maps.

Comparing the series of Figures 4 and 5 it can be seen that the growth of the collision zone is very similar for both scenarios although the average pressure within these zones is not equivalent. For the asynchronous deflagration, the average peak overpressure is found to be about 65 kPa with an impulse of about 16 Pa.s. (There is no positive phase duration data available due to limitations of the calculation.) This represents a weaker pressure than the synchronous one (compare 65 kPa with 100 kPa Table 3). The impulse, however, is quite high, meaning that the threshold for ear drum rupture will still be reached. No lung damage will occur.

These results indicate that the hazard region associated with a two pod deflagration is strongly dependent on the separation of the pods and on the time delay between initiation of each pod. Typically the deployed pods from a grenade simulator would land fairly widely spaced (greater than 1 m) and time delays between ignitions of about 1 ms are expected. The hazard to personnel in a confined space should therefore not be greater from a multi-pod grenade than from a single pod. The probability of an individual being within a single pod hazard region, however, will obviously be increased.

4. CONCLUSIONS

The flexibility and power of the HULL code has been improved to enable it economically to simulate multiple sources for air blast waves. A method has been derived for reducing these complex models to a simpler form.

A larger region within which there is a significant risk of injury to personnel (hazard region) has been found for a two-pod deflagration than for a single pod one. The region is greatest if the pods deflagrate simultaneously. The differences arising from asynchronous deflagration compared to synchronous ones have been studied in detail, with the result that maximum interaction occurs with simultaneity. The interaction takes place in the region equidistant from the two pods. The effects of the interaction on the hazard to nearby personnel are found to be small, and negligible additional damage is likely to occur over that expected from a single pod. Hence each pod may be treated individually in determining the overall effect of a multi-pod battle noise simulator.

The most hazardous region is therefore that determined for a single pod (1), namely the region close to a reflecting surface or ground, and near to a pod. The main effect of multiple pods is to increase the chances of an individual being within one of these hazardous regions.

5. REFERENCES

1. J. Waschl and E.H. Van Leeuwen, Experimental and Numerical Determination of the Explosives Effects of a Pyrotechnic Deflagration Against Reflective Surfaces, MRL-R-1008, 1986.
2. D.A. Matuska, HULL User's Manual, Air Force Armament Laboratory Report AFATL-TR-84-59, 1984.
3. W.E. Baker, P.A. Cox, P.S. Westine, J.J. Kulesz and R.H. Strehlow, Explosion Hazards and Evaluation, Elsevier Scientific Publishing Co, Amsterdam, 1983.

TABLE 1

Size of the computational space and total problem time
for each of the steps during the simulation

Grid Dimensions (mm)		Problem Time (μs)	Computational Space Dimension (mm)	
Radius	Height		Radius	Height
0.357	1.0	9	17.85	150
0.357	1.0	18	46.41	180
0.357	1.0	27	74.97	200
0.357	1.0	30	82.11	210
0.893	2.5	53	160.65	365
1.785	5.0	100	207.06	450
3.570	10.0	1400	621.18	1650

TABLE 2

Overpressure impulse and positive phase duration along
a radial line at an altitude of 0.75 m for the
simultaneous initiation of two pods

Horizontal Distance Along a Line 0.75 m Above Ground (m)	Overpressure (kPa)	Impulse (Pa.s)	Positive Phase Duration (ms)
0	96	24.5	0.48
0.05	98	24.4	0.48
0.10	101	24.2	0.47
0.15	105	23.8	0.47
0.20	108	-	-
0.25	108	-	-
0.30	107	-	-
0.35	106	-	-
0.40	104	-	-
0.45	100	-	-
0.50	97	-	-
0.55	93	-	-

TABLE 3

Average peak overpressure within the collision zone for a
two pod simultaneous initiation, and a single
pod at the same distance

	Overpressure (kPa)	Impulse (Pa.s)	Positive Phase Duration (ms)
Two pods	100	24.2	0.48
One pod	65	10.1	0.35

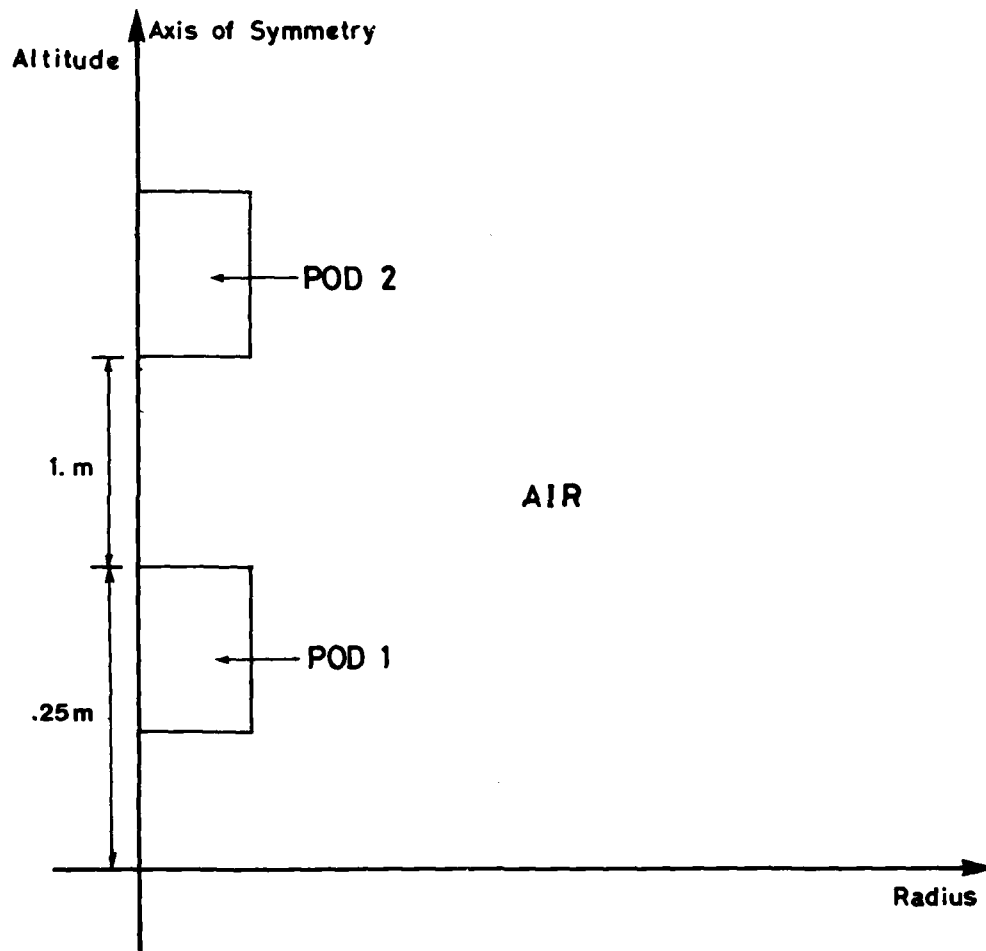


FIGURE 1 Two pods, one above the other and both over a reflective surface. The vertical axis is an axis of rotation. Not to scale.

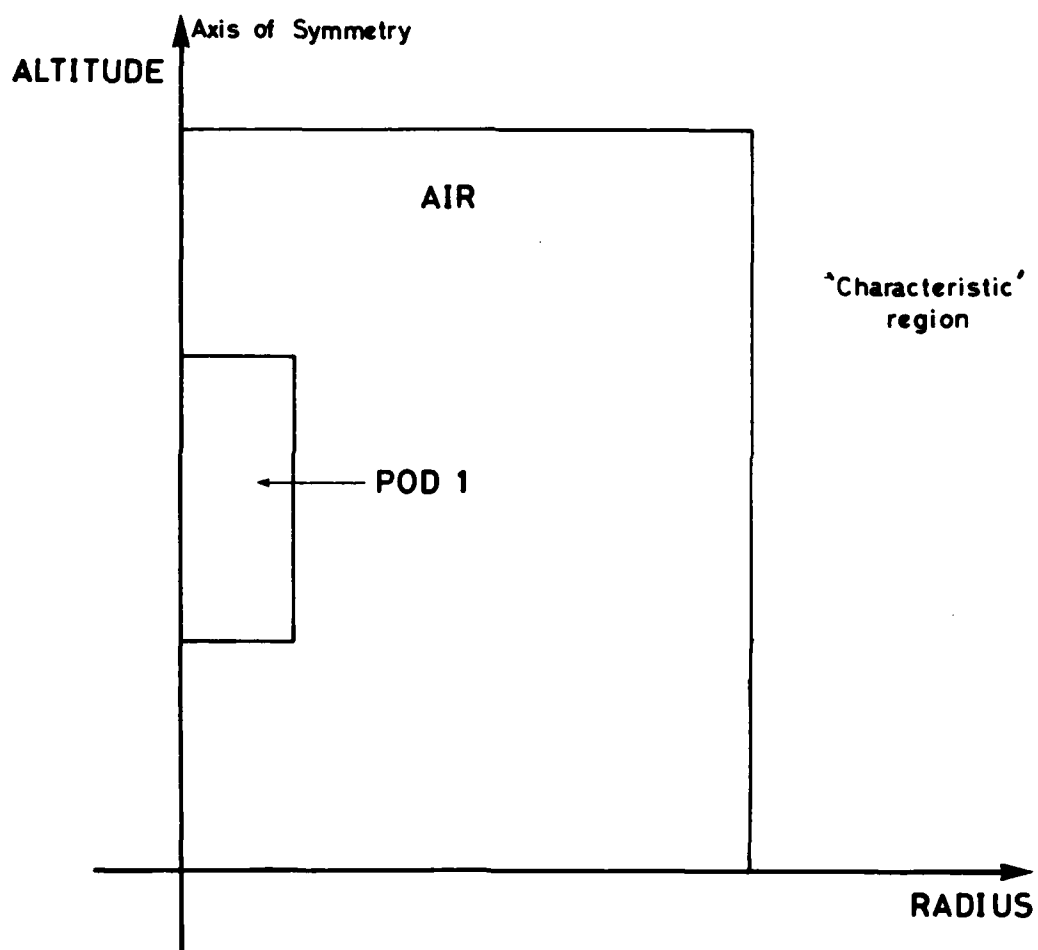


FIGURE 2 Characteristic region as defined for this simulation.

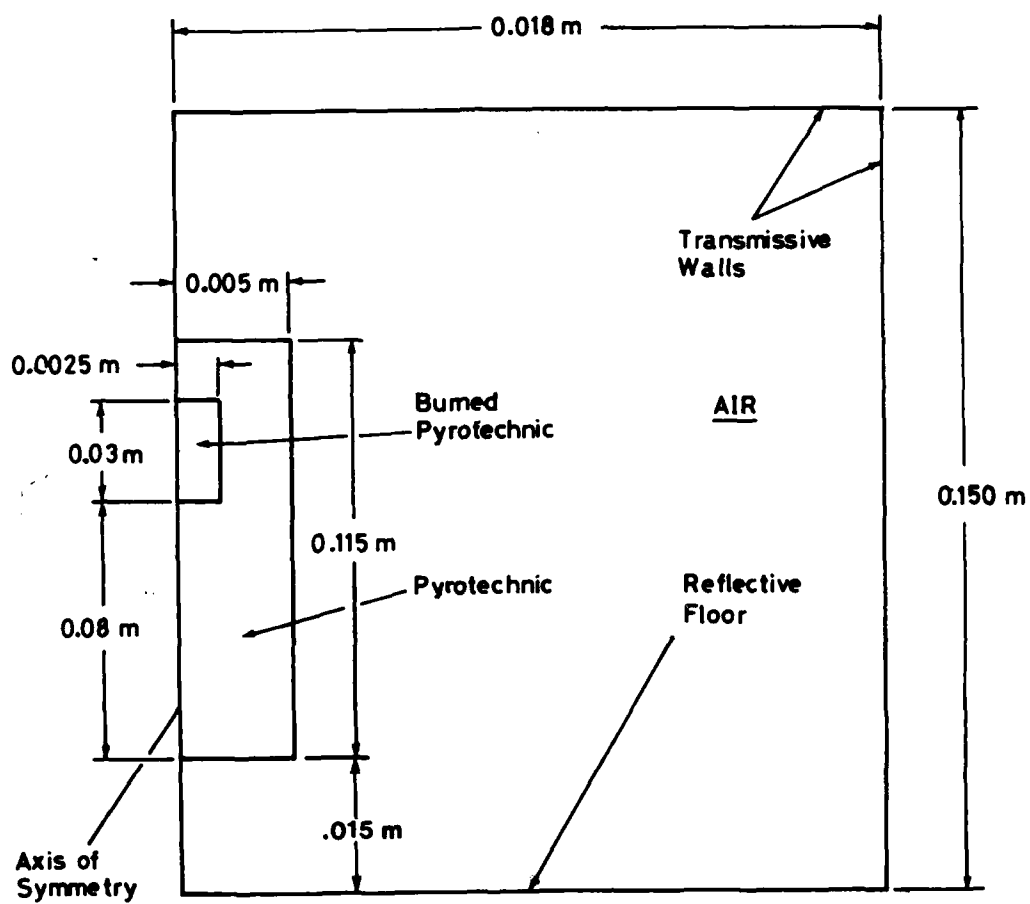


FIGURE 3 Description of the pod in its characteristic region for the initial (stage 1) simulation.

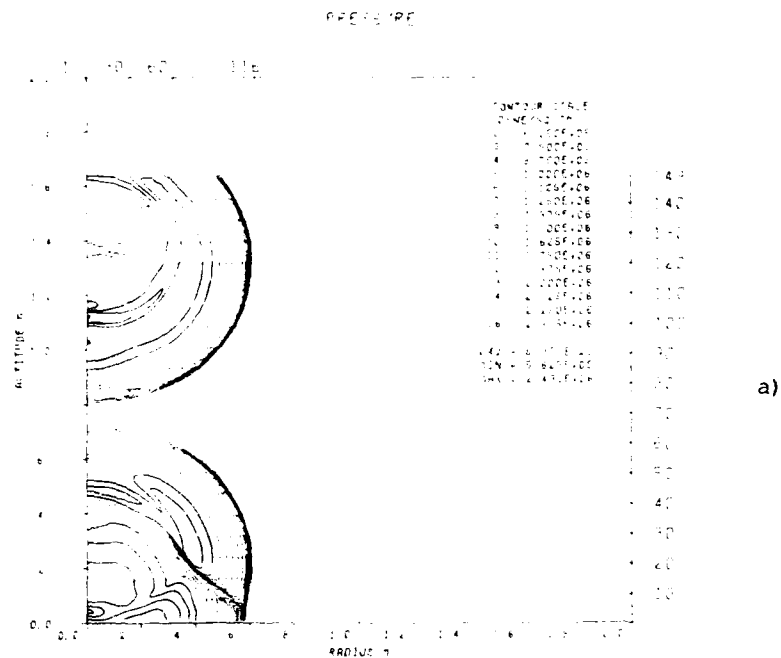
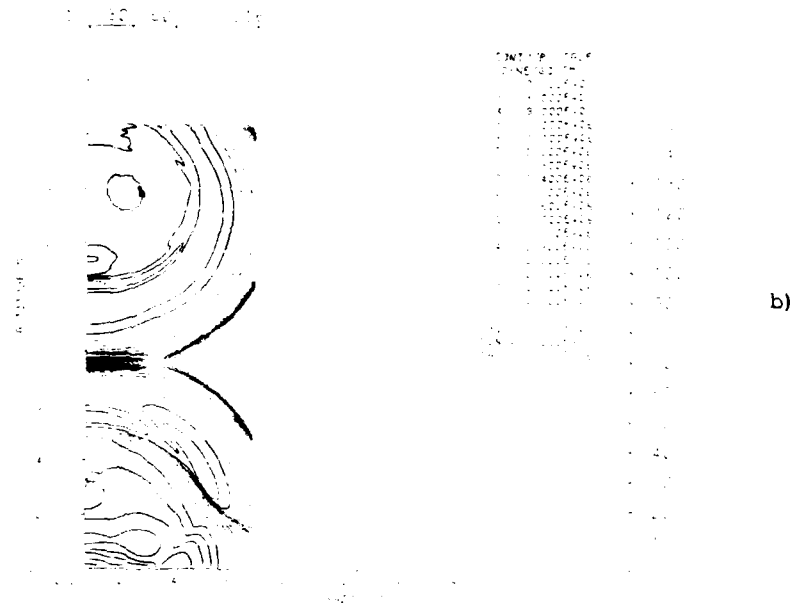


FIGURE 4 Pressure profiles for the simultaneous deflagration of two pods. The profiles presented are for times after initiation of a) 800 μ s, b) 1000 μ s, and c) 1200 μ s.

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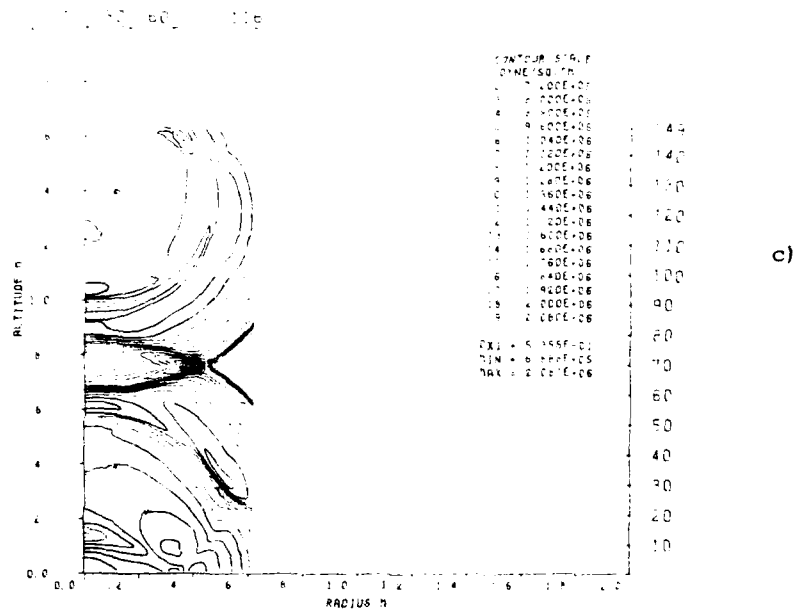
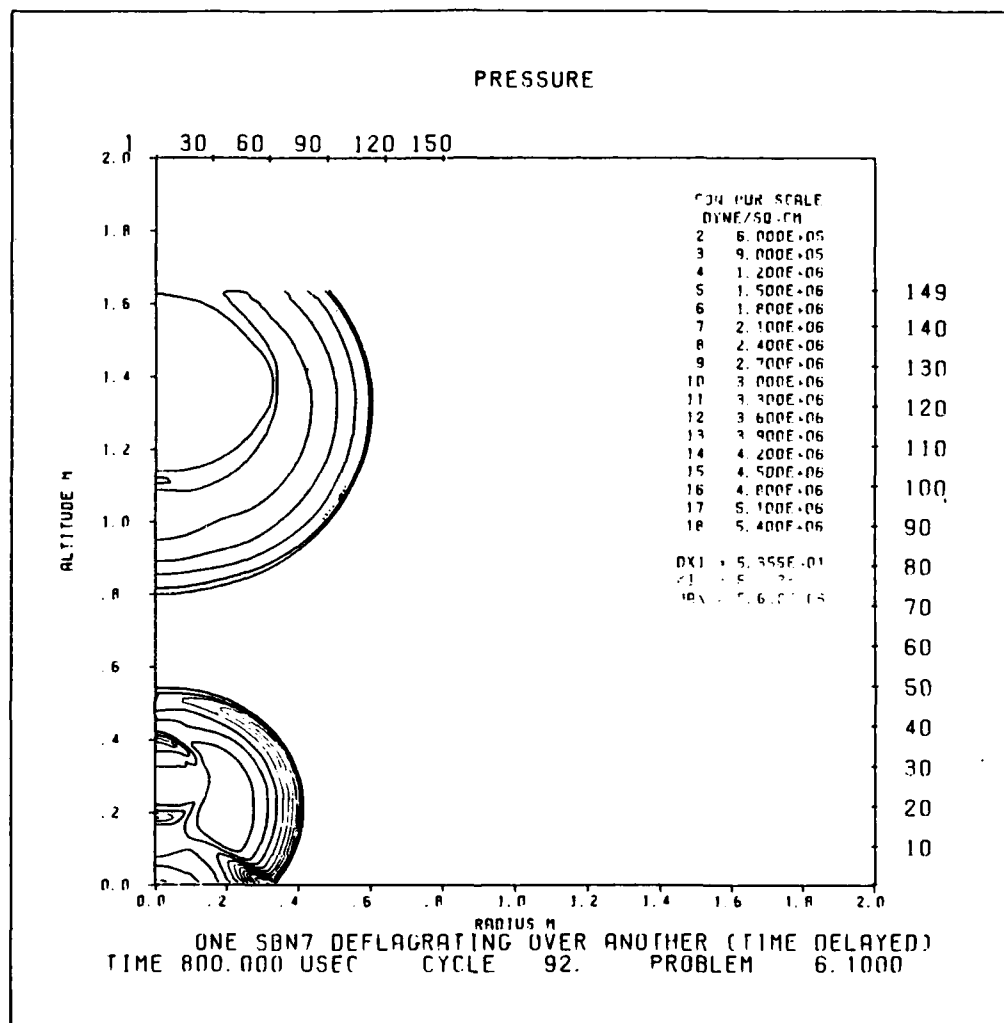


FIGURE 4 Continued



(a)

FIGURE 5 Pressure profiles for the asynchronous deflagration of two pods. The top pod was effectively initiated 400 μ s before the bottom one. The profiles presented are for times after initiation of a) 800 μ s, b) 1200 μ s, and c) 1400 μ s.

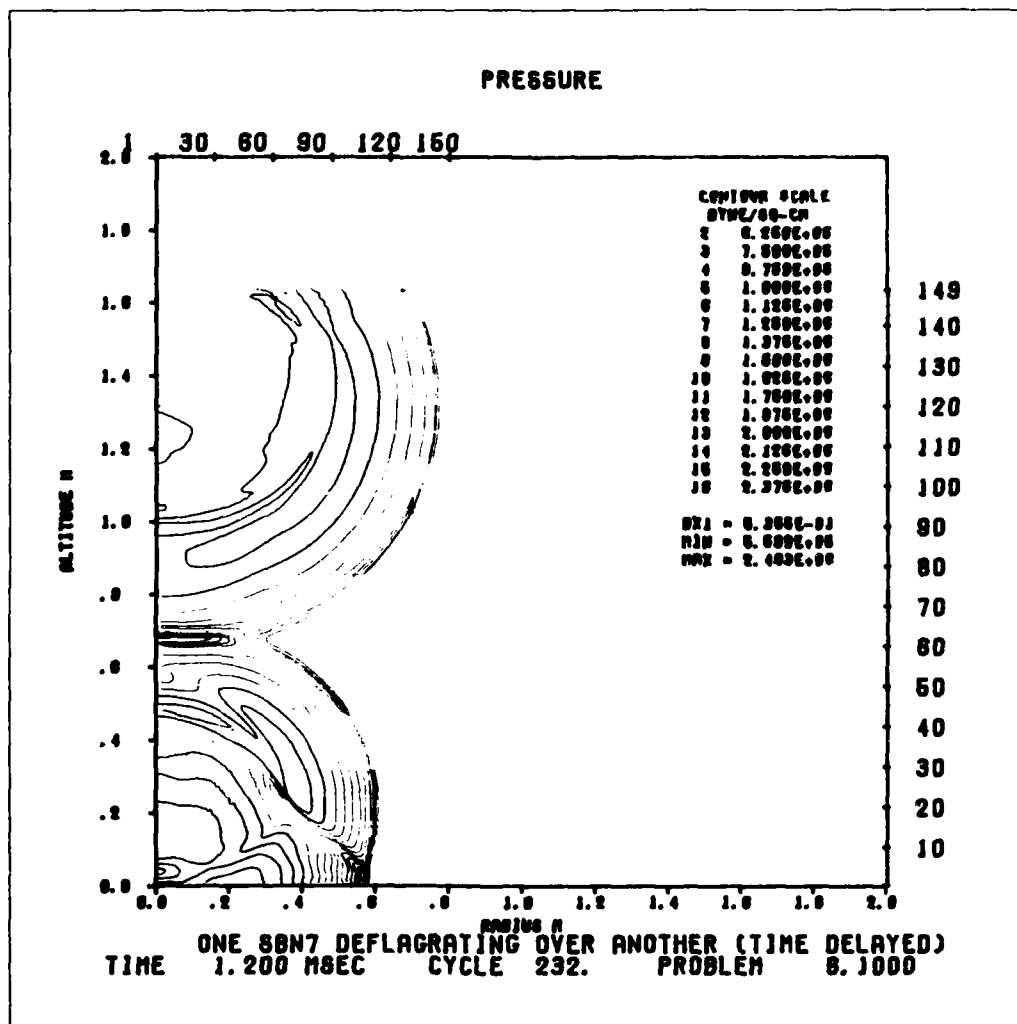


FIGURE 5 (b)

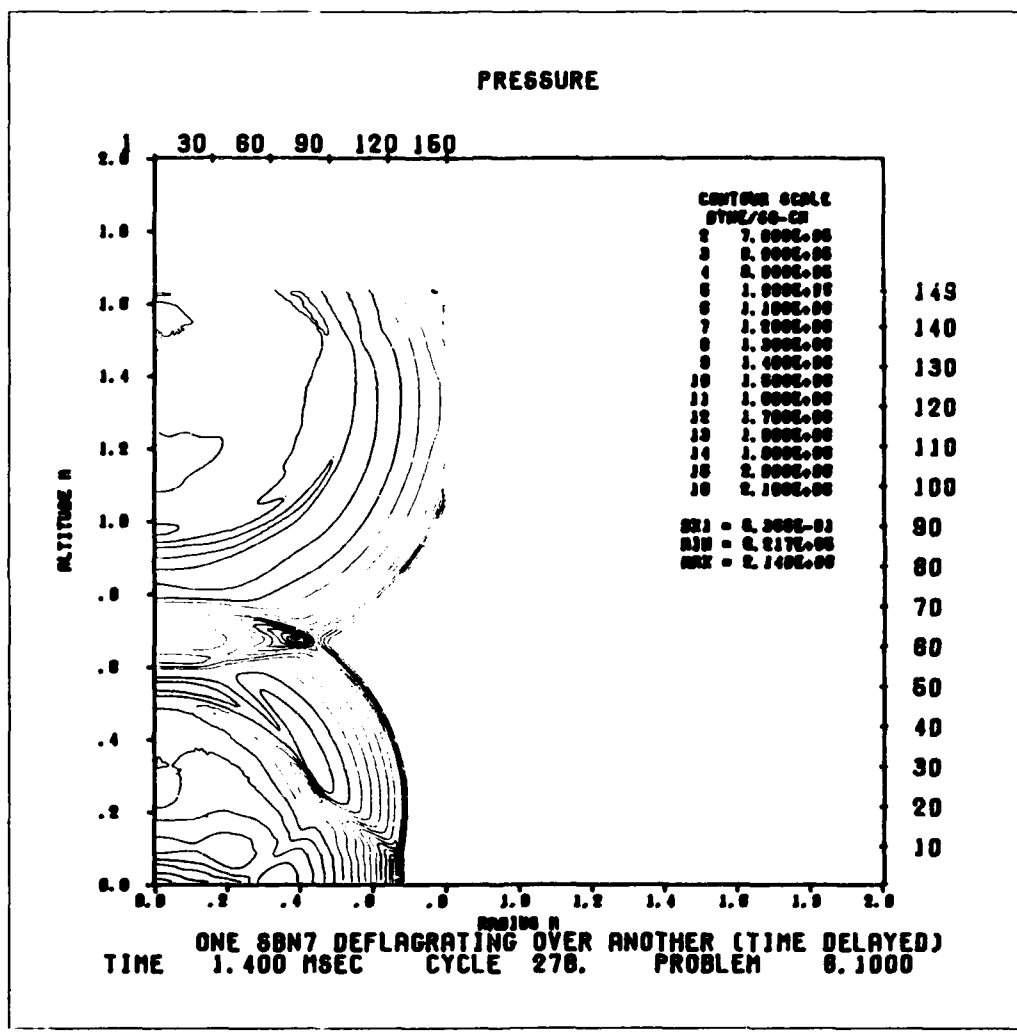


FIGURE 5 (c)

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Two Closely Spaced Pyrotechnic Pods

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