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Morton Lutzky*

**EULERIAN HYDROCODE CALCULATIONS OF THE DETONATION
OF AN EXPLOSIVE CYLINDER ABOVE A WATER SURFACE:
AN INTERIM REPORT**

BY MORTON LUTZKY

RESEARCH AND TECHNOLOGY DEPARTMENT

3 JANUARY 1978

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A description is given of the current status of the Eulerian computations of a detonating cylinder above water. Calculations were made of pressure-time histories in the water resulting from the detonation of a one-pound cylinder of pentolite initially one foot above the surface. A two-dimensional Eulerian hydrodynamic code (CSQ) was used to obtain reflected pressures at the surface (considered rigid). These pressures were then used as input to a linear acoustic code for the propagation in the water. | | |

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Pressure and impulse at various points in the water were calculated and compared with results from experiments. The validity of the method is discussed, and possible checks and extensions are described.

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SUMMARY

This report is part of a continuing study of the pressures produced in water by the detonation of high explosives above the surface. It describes and gives results for one of several computational approaches which are currently being pursued. This method involves the use of a two-dimensional Eulerian code to calculate reflected pressures at a rigid surface; these pressures are then used as input boundary conditions for a linear acoustic code which calculates propagation in the water. Although comparison with experiment indicates that the method has promise, its precise range of validity is not known, and additional work to test the method is outlined.

This work was sponsored by the Strategic Systems Project Office under SSPO Task Assignment 77402.

Julius W. Enig

JULIUS W. ENIG
By direction

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INTRODUCTION

This is an interim report of computational work being done on a task for the Strategic Systems Project Office. The work consists of calculating the pressure field in water resulting from a high explosive detonation above the surface of the water. In particular, a computation has been carried out to determine pressure-time histories at various points below the water surface, due to the detonation of a one-pound pentolite cylinder, the center of which initially lies one foot above the water surface. Figure 1 shows the initial geometric configuration, together with the dimensions of the charge. The computation was carried out in two stages: in the first, the two-dimensional Eulerian hydrocode CSQ¹ was used to develop pressure-time histories at the water surface (considered as rigid wall). In the second stage, the surface pressures calculated by CSQ were used as boundary conditions to calculate pressures at points beneath the surface, using a linear acoustic code². (The validity of this two-stage technique will be discussed in a later section.)

The CSQ calculation used a 130 X 130 mesh, and was run on a CDC 7600, using an extended storage capability. Because of the symmetry of the problem, only one quarter of the explosive cylinder needs to be covered by the computational grid (cross-hatched region in Figure 1). Since the cylinder is centrally detonated, the $Z = 0$ plane can be considered a plane of symmetry until such time as the shock reflected from the rigid surface ($Z = 1$ foot) reaches the plane $Z = 0$. This is the reason that the upper half of the cylinder may be neglected. Furthermore, the Z axis is an axis of cylindrical symmetry, so that only one quarter of the cylinder is computationally relevant.

In the present calculation, there were 297 computational zones in the explosive, 9 in the R (radial) direction, and 33 in the Z (axial) direction. It should be noted that the cylinder of explosive had rounded corners, the radius of curvature of each corner being one centimeter.

1. S. L. Thompson, "A Two-Dimensional Hydrodynamic Program with Energy Flow and Material Strength," SAND74-0122, Sandia Laboratories, August 1975.
2. A. Van Tuyl, NSWC/WOL, private communication.

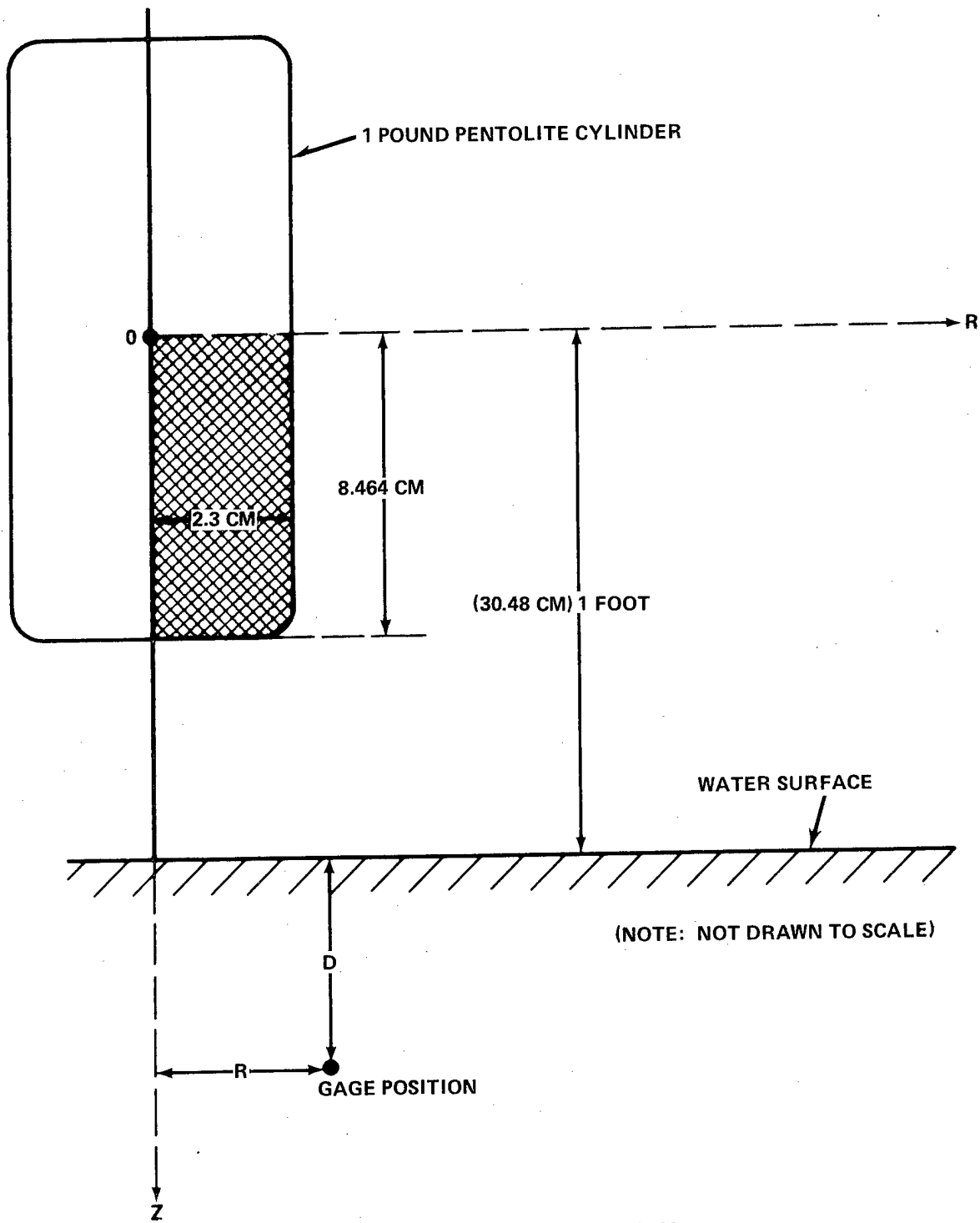


FIG. 1 PROBLEM GEOMETRY

The complete calculational grid covered a physical distance of 42.3 cm (1.39 ft) in the R direction, extending from the axis of cylindrical symmetry to the right-hand boundary. In the Z direction (measured positive downward) the calculational grid covered a distance of 30.48 cm (1 ft), extending from the center of the charge to the water surface. In the Z direction, the zone size $\Delta Z \approx .25$ cm; in the R direction, $\Delta R \approx .25$ cm for the first 90 zones, at which point ΔR gradually increased, attaining a maximum of $\Delta R \approx 1.00$ cm at the right-hand boundary. The precise zone sizes are given for the radial direction in Table 1, and for the axial direction in Table 2.

The equation-of-state used for the detonation gases was the JWL equation for pentolite, while a gamma law gas ($\gamma = 1.4$) was used for the air. Total running time for the CSQ portion of the calculation was 4245 seconds (1.18 hours) and the estimated cost was approximately \$900. Elapsed problem time was 122 μ secs and the portion of the rigid surface engulfed by the air shock extended 25 centimeters out from the axis of symmetry.

RESULTS

Pressure-time histories, as calculated by CSQ, are given for two points on the rigid surface in Figures 2 and 3. (In all of the figures, R = distance in feet radially out from the axis of symmetry; D = depth in feet below the water surface.) In these and most subsequent figures, there will be two distinct pressure peaks; the first peak is due to the air shock, while the second peak is believed to be caused by the arrival of the detonation gases impacting on the water surface. An alternative explanation ascribes subsequent pressure peaks after the first peak to successive reflections of the air shock between the rigid surface and the explosive gas-air interface. Further discussion of this point will appear in a later section.

Figures 4, 5, and 6 show results calculated using the acoustic code, and give overpressure (total pressure-ambient pressure) versus time at three depths below the surface, at points lying on the axis of symmetry (R = 0). Figure 7 gives a typical off-axis result, and shows the overpressure-time history at a point one foot below the surface (D = 1) and 0.5 foot from the symmetry axis (R = 0.5).

Table 3 gives peak overpressures (in bars) at various points below the surface of the water. For each position, the upper number is the pressure at the first peak, while the lower number (in parentheses) is the pressure at the second peak.

Table 1

Zoning in R (Radial) Direction*

Region Between 0.0 and 2.30000E+00

Width of First Zone = 2.55555E-01

Ratio = 1.00000E+00

Total Number of Zones = 9

Width of Last Zone = 2.55556E-01

Number of Zones in Region = 9

Region Between 2.30000E+00 and 2.55555E+01

Width of First Zone = 2.55555E-01

Ratio = 1.00000E+00

Total Number of Zones = 100

Width of Last Zone = 2.55580E-01

Number of Zones in Region = 91

Region Between 2.55555E+01 and 4.23000E+01

Width of First Zone = 2.55555E-01

Ratio = 1.04919E+00

Total Number of Zones = 130

Width of Last Zone = 1.02862E+00

Number of Zones in Region = 30

* Zone Widths are given in centimeters.

Table 2

Zoning in Z (Axial) Direction*

Region Between 0.0 and 8.46400E+00

Width of First Zone = 2.56485E-01

Ratio = 1.00000E+00

Total Number of Zones = 33

Width of Last Zone = 2.56483E-01

Number of Zones in Region = 33

Region Between 8.46400E+00 and 3.04800E+01

Width of First Zone = 2.56485E-01

Ratio = 9.97401E-01

Total Number of Zones = 130

Width of Last Zone = 1.99815E-01

Number of Zones in Region = 97

*Zone Widths are given in centimeters.

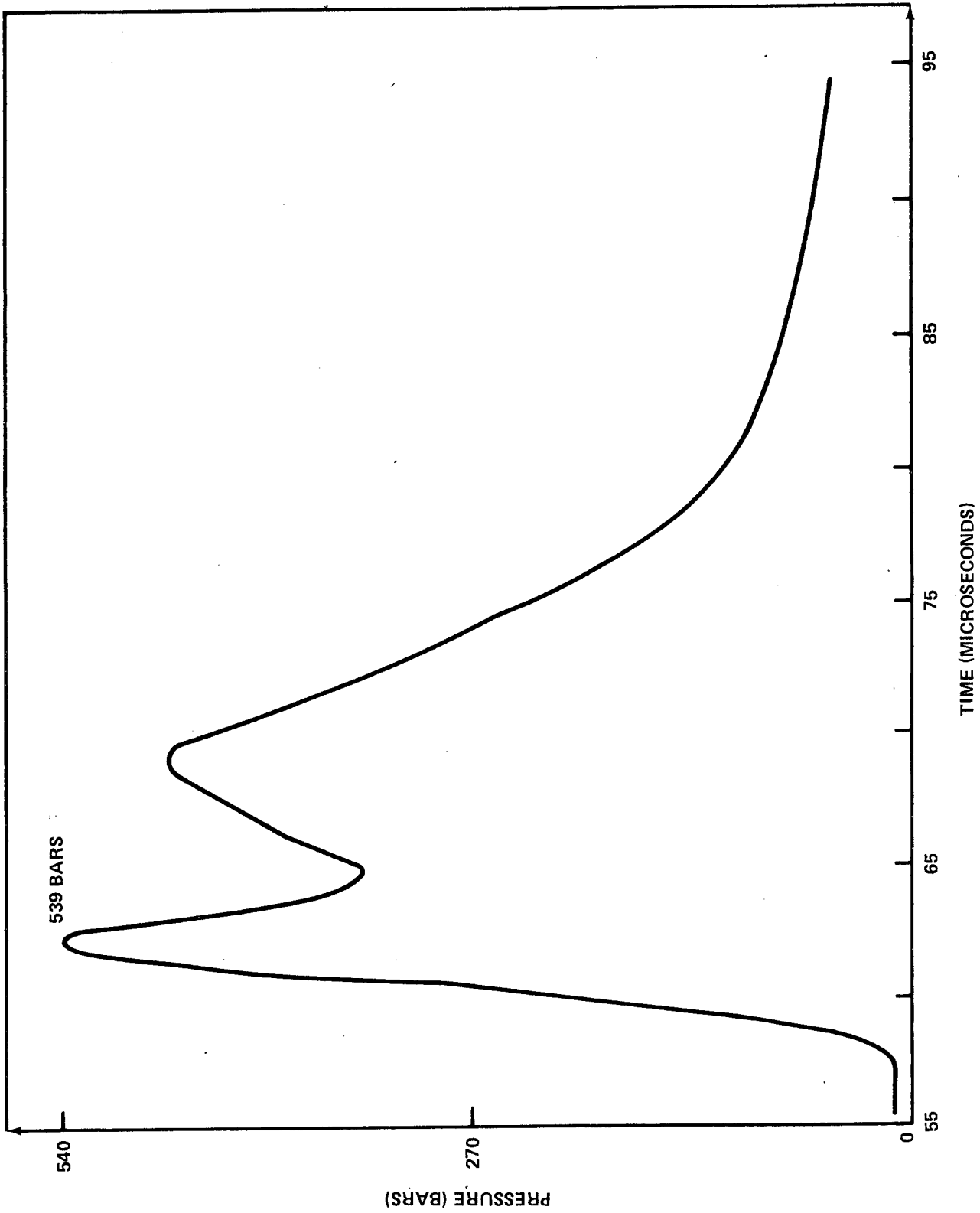


FIG. 2 PRESSURE VS TIME (D = 0 FT, R = 0 FT)

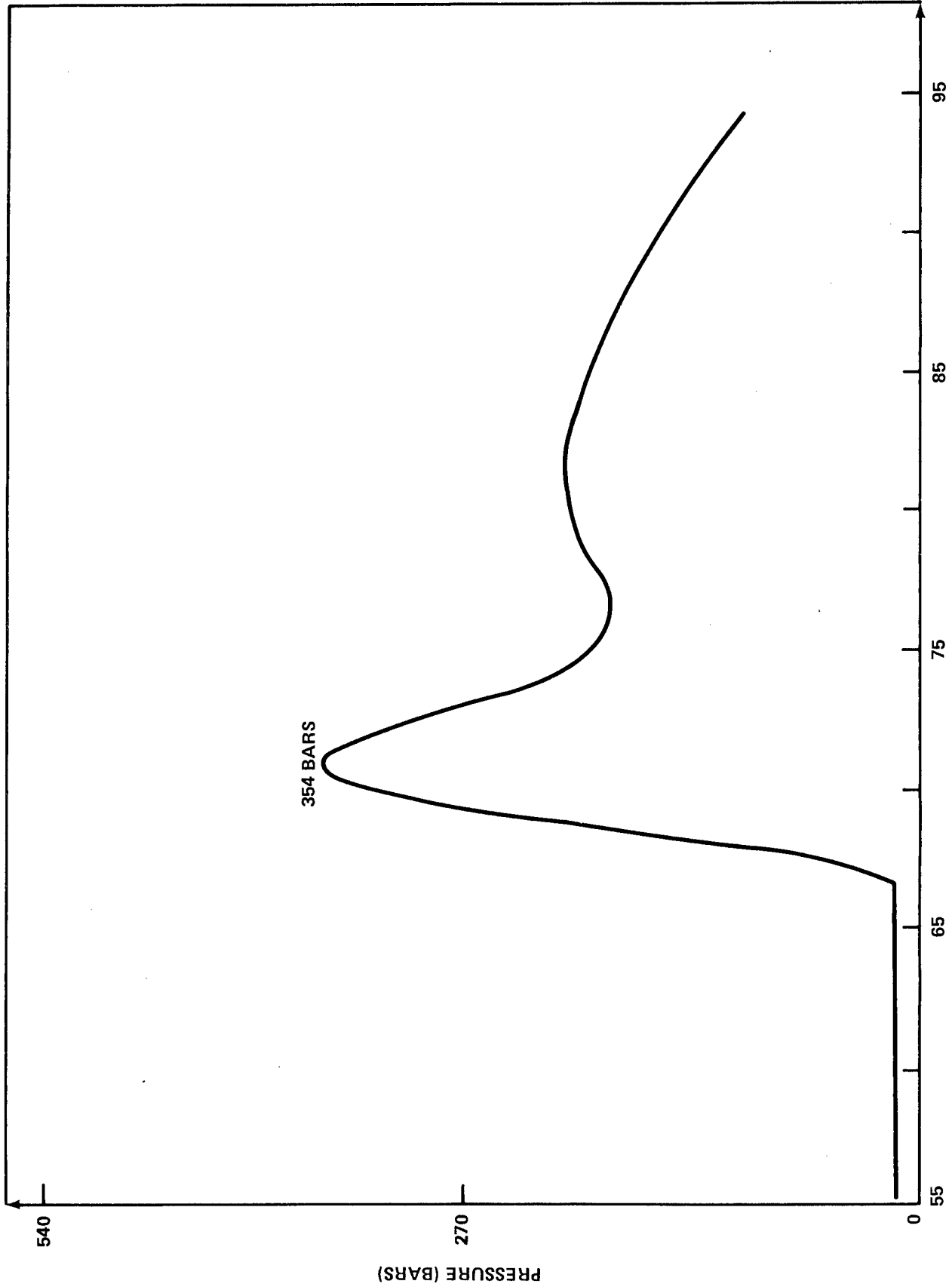


FIG. 3 PRESSURE VS TIME (D = 0 FT , R = 0.247 FT)

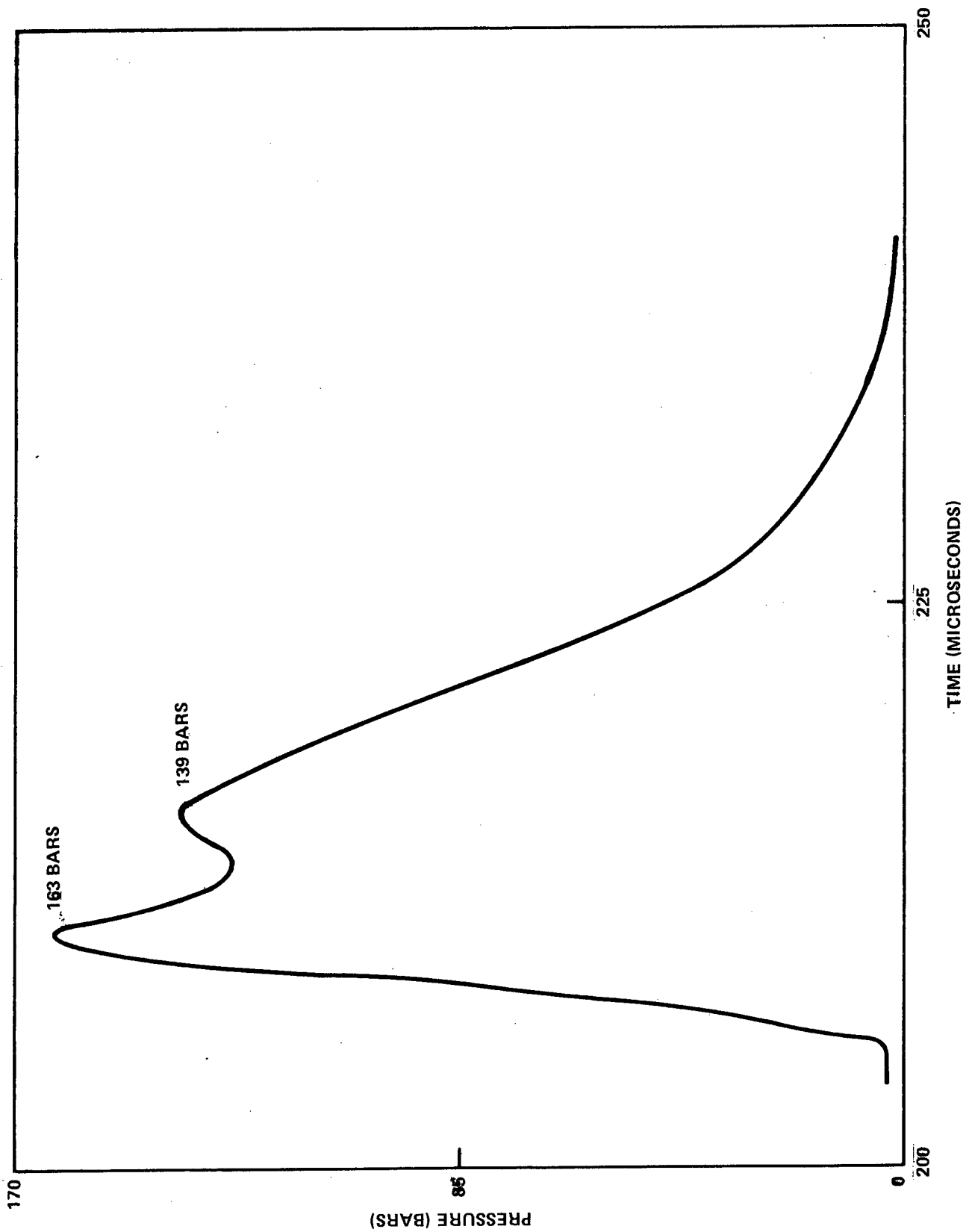


FIG. 4 OVERPRESSURE VS TIME (D = 1 FT, R = 0 FT)

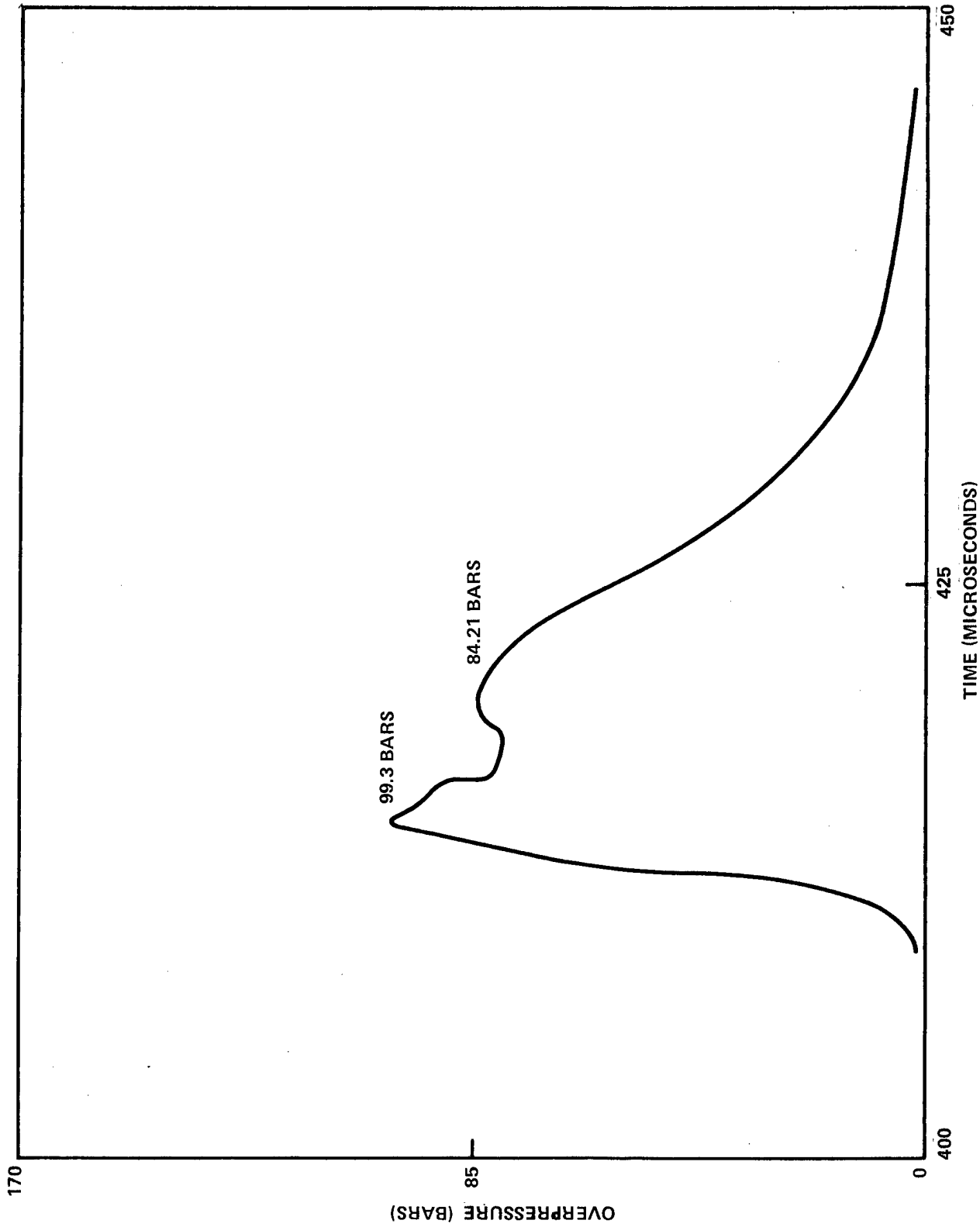


FIG. 5 OVERPRESSURE VS TIME (D=2 FT , R = 0 FT)

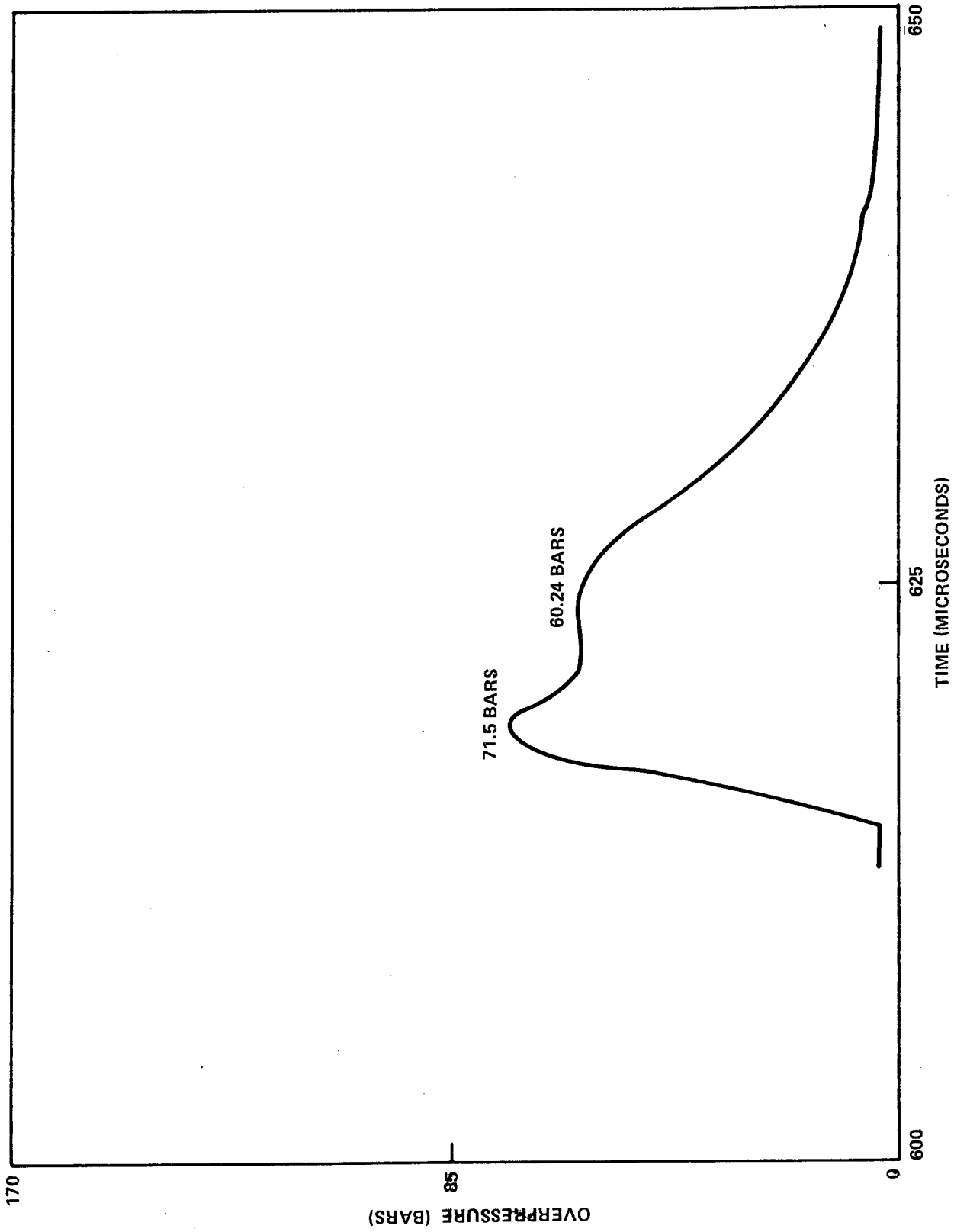


FIG. 6 OVERPRESSURE VS TIME (D = 3 FT, R = 0 FT)

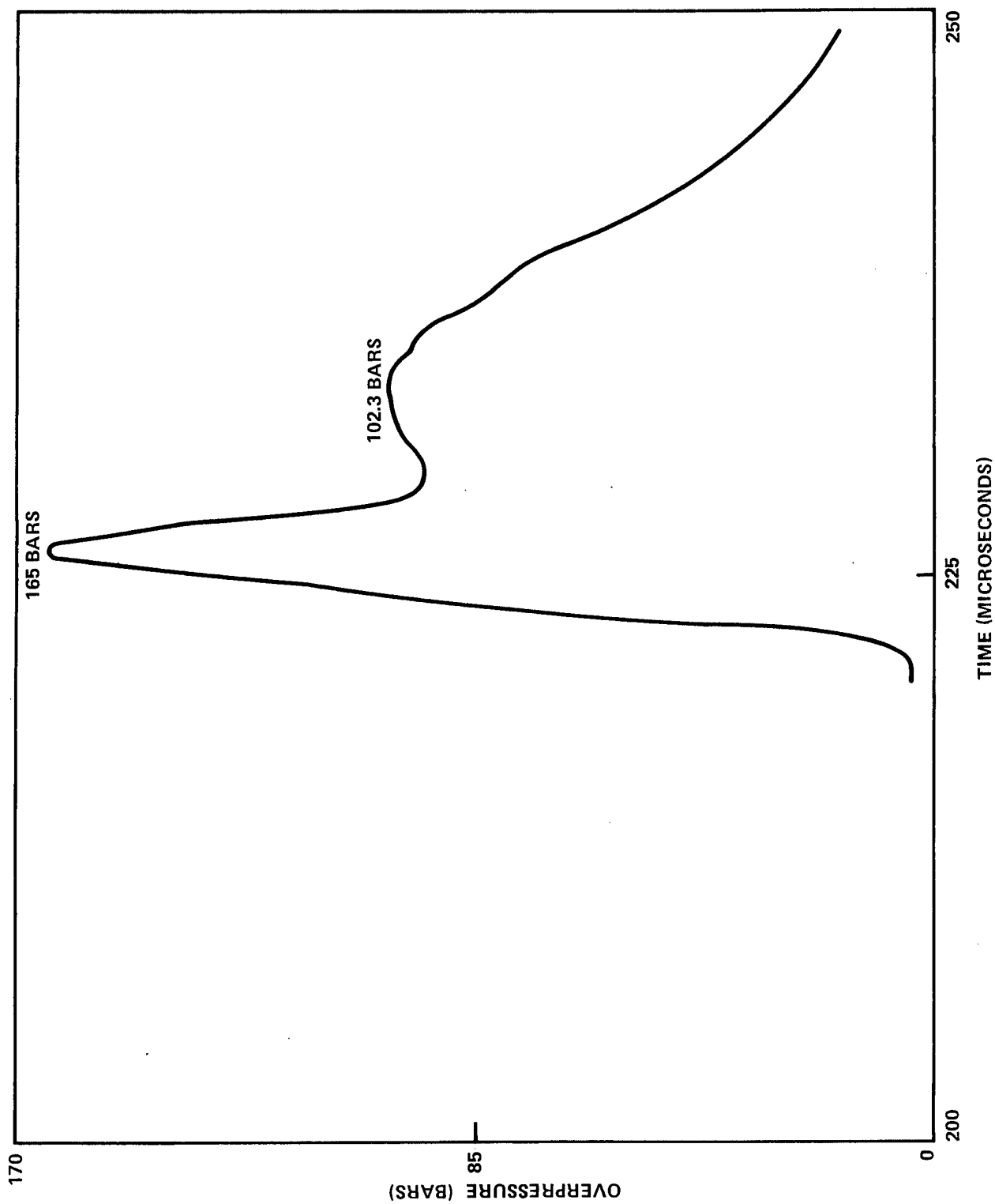


FIG. 7 OVERPRESSURE VS TIME (D = 1 FT, R = 0.5 FT)

Table 3
Overpressure (bars) at Points (D,R) Under Water

| R(FT) D(FT) | 0 | 0.5 | 0.625 | 0.689 | 1.0 |
|----------------|--------------------|--------------------|-------------------|-------------------|------------------|
| 1 | 163.31 (139.06) | 164.94 (102.29) | 150.97 (88.38) | 138.54 (80.04) | 87.26 (52.21) |
| 2 | 99.28 (84.21) | 101.45 (75.00) | 104.64 | | |
| 3 | 71.53 (60.24) | 72.57 (55.42) | 73.77 | | |
| 4 | 54.86 (46.86) | 55.81 (44.45) | | | |
| 5 | 45.12 (38.39) | 46.18 (37.10) | | | |
| 6 | 39.00 (32.66) | 39.12 (31.69) | | | |

COMPARISON WITH EXPERIMENT

The results of the previously described computations have been compared with data from experimental tests performed at Stump Neck, Maryland, in February of 1976³. In these tests a one-pound pentolite cylinder was centrally detonated one foot above the water surface, and gages were placed at various points below the surface. Comparisons have been made for three points on the axis of symmetry (i.e., directly below the charge and in the water), and the results are shown in Figures 8, 9, and 10. In each of these figures, experimental results are plotted for three different shots, and the experimental values quoted are average values. Because of the limitations on the calculation imposed by the position of the right-hand computational boundary (at 42.3 cms), results were not calculated at any of the off-axis gages (the nearest being two feet from the axis of symmetry).

In all cases, the experimental time duration of the positive phase seems to be well reproduced by the calculation. The second peaks which appear on some of the experimental traces are also present in the calculated results; however, unlike the experimental situation, the pressure at the computed second peak is smaller than the pressure at the first. The discrepancy between the experimental and calculated values of pressure at the first peak is greatest at the shallowest depth, with the agreement improving as the depth increases.

The positive impulse of a wave is an important factor in assessing structural damage, and so this quantity has been computed for the three gage positions on the axis, and compared with the experimental measurements. This information appears in Table 4, and it can be seen that the accuracy of the computed value (relative to the experiment) improves as the depth increases, similar to the behavior of the peak pressures.

DISCUSSION

In this section we shall discuss some approximations which are implicit in our approach, and also some possible sources of numerical error in our computations. First we discuss the validity of the two-stage approach, in which CSQ is used to calculate pressures on the water surface, considered rigid, and then an acoustic code is used to propagate into the water. The correctness of the procedure depends first of all on how accurately the water surface may be considered to be rigid, since surface motion will affect the calculated pressures at the surface. Since these pressures are used as boundary conditions for the acoustic code, it is of course necessary that they be calculated as accurately as possible. Another factor to be considered is whether pressures are sufficiently high in the water to invalidate the assumption of linearity implicit in the use of the acoustic code. Both of these effects depend on the height of burst; that is, for sufficiently

3. J. Pittman, NSWC/WOL, Private Communication

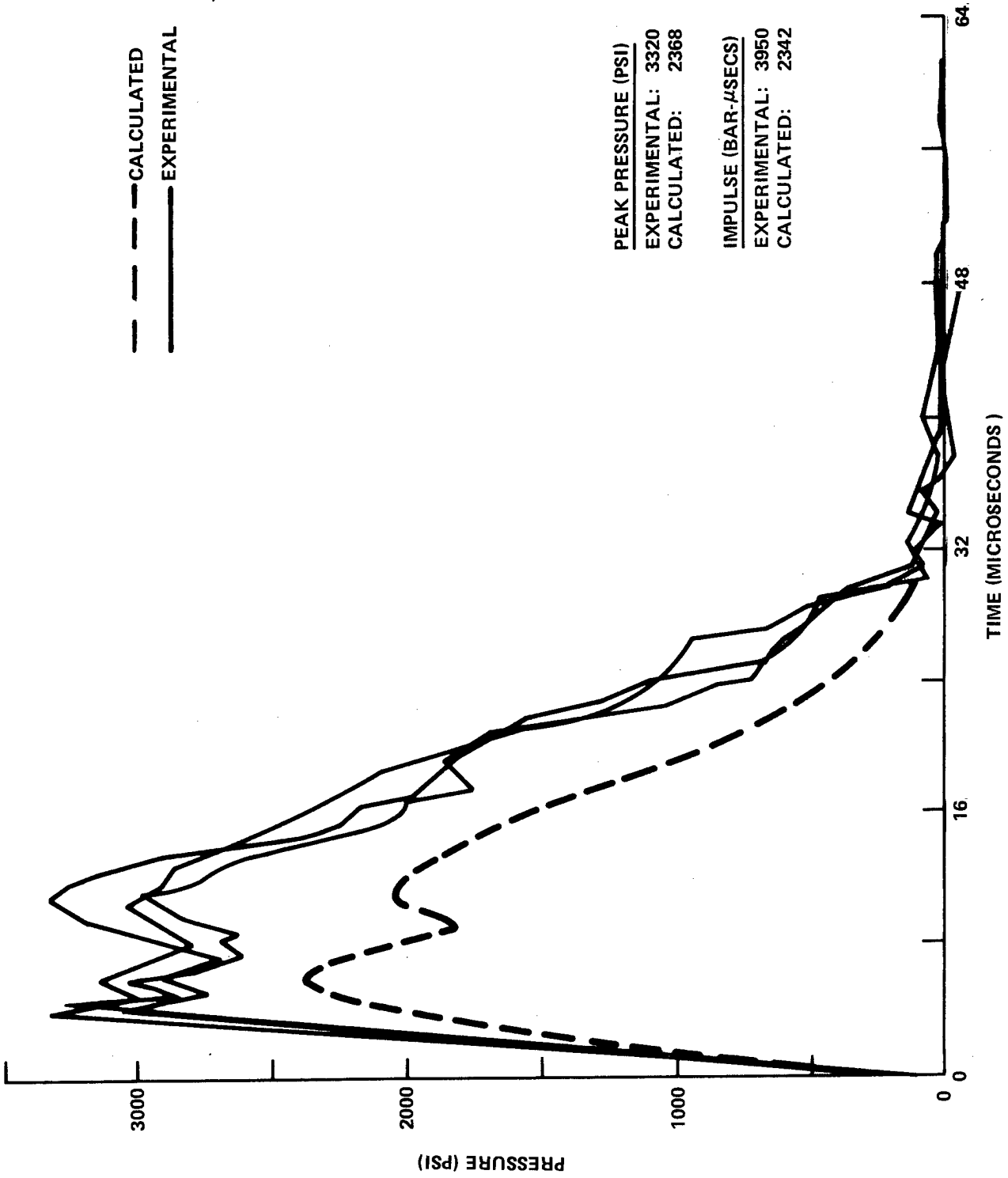


FIG. 8 COMPARISON WITH EXPERIMENT (D = 1 FT, R = 0 FT)

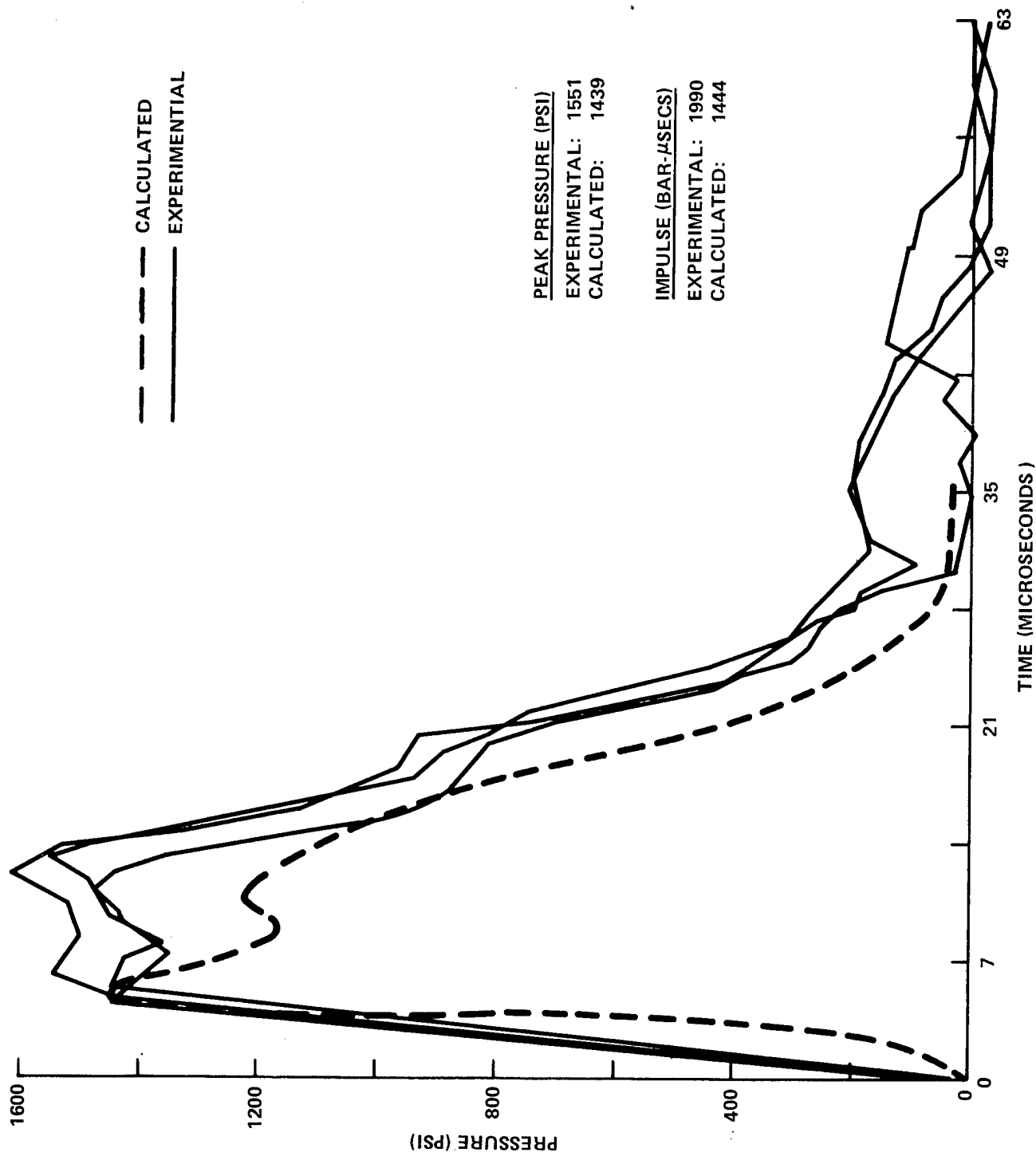


FIG. 9 COMPARISON WITH EXPERIMENT (D = 2 FT , R = 0 FT)

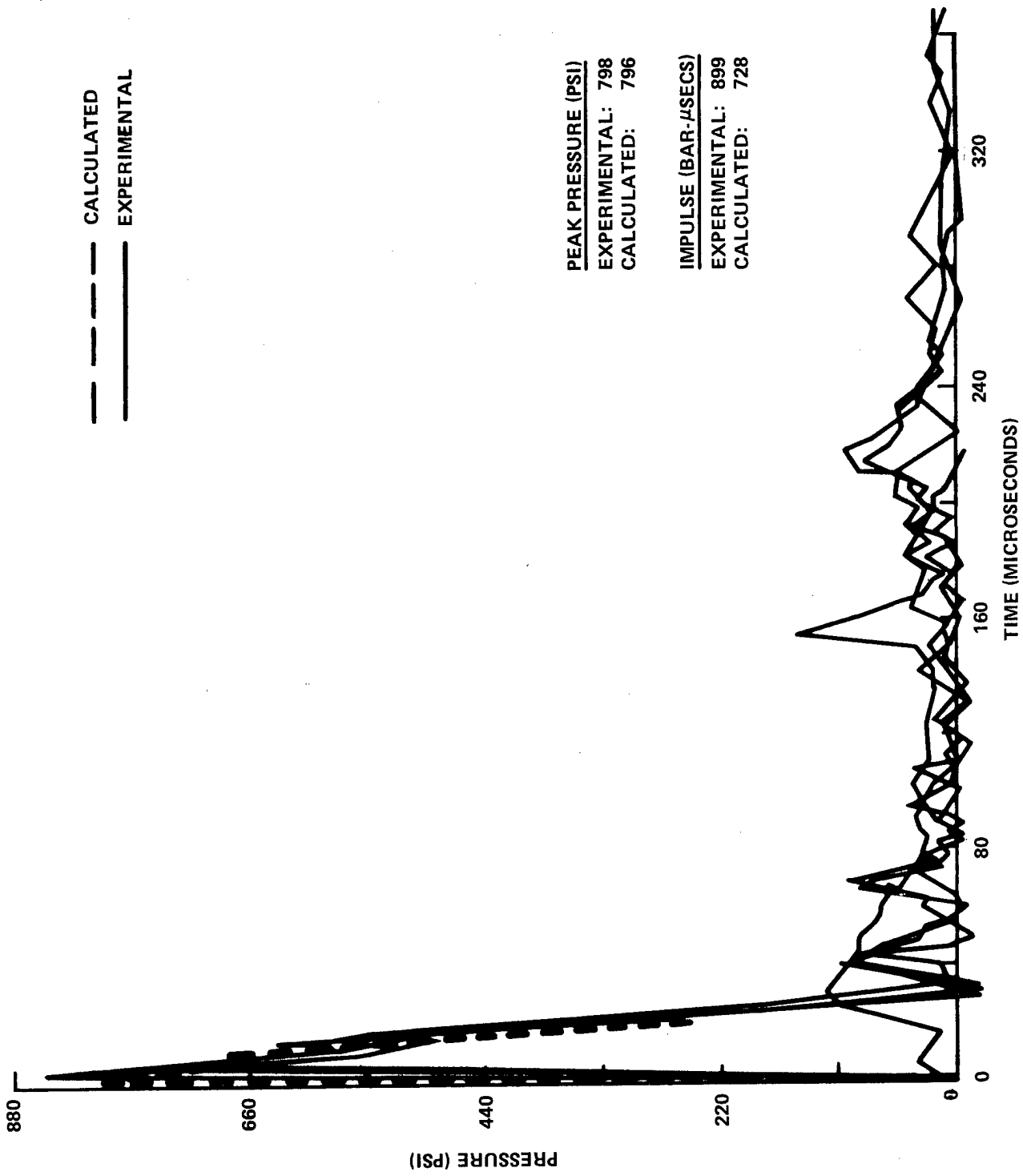


FIG. 10 COMPARISON WITH EXPERIMENT (D = 4 FT, R = 0 FT)

Table 4

Positive Impulse (bar- μ secs) at Points (D,R) Under WaterIMPULSE (BAR- μ SECS)

| GAGE POSITION (FT) | CALCULATED | EXPERIMENTAL |
|-----------------------|------------|--------------|
| D = 1 R = 0 | 2342 | 3950 |
| D = 2 R = 0 | 1444 | 1990 |
| D = 4 R = 0 | 728 | 899 |

high HOB, the water surface will be essentially stationary, and the pressures in the water will be small enough to allow use of the acoustic approach. The actual range of HOB for which the calculated results are sufficiently accurate is not yet known; however, several test computations are planned to settle this question. One possibility involves the use of CSQ II, an improved version of CSQ which allows the use of more than two materials in a calculation. With this code a single computation could be carried out in which the water is included from the beginning, and no separate matching of different codes at the boundary would be required. Another possibility is to use CSQ to calculate shock propagation in water due to prescribed pressures on a boundary, and compare the results with those obtained by using the acoustic code to solve the same problem.

Another source of error arises from the inability of the CSQ Eulerian Code to adequately resolve the shock in air. The reason for this difficulty is that the boundary between the explosion products and the shocked air follows very closely behind the air shock. Consequently, since the Eulerian spatial zones are fixed in size, only very few zones exist between the detonation gases and the ambient air. In fact, for our case, in which the center of the cylinder is initially one foot above the surface, only two or three zones exist in the shocked region when the air shock reaches the rigid surface. This causes the computed peak pressure to be low, a conclusion which seems to be borne out by comparison with the experimental results. It is noteworthy that the correspondence between calculation and experiment is as close as it is, in view of the coarseness of the shock region zoning. In this connection, it should be emphasized that the problem of shock resolution is not individual to the CSQ code, but is present in any 2-D Eulerian hydrocode. This is because the zones in any Eulerian code are fixed in size, precluding the zone compression at the shock front that allows Lagrangian codes to resolve shocks as well as they do.

An indication of the accuracy of CSQ may be obtained by using it to compute a case which may also be solved with a one-dimensional hydrocode. We chose the detonation of a sphere (1 cm radius) of pentolite in air, which has been calculated using a 1-D Lagrangian computer code containing a shock tracking capability⁴. The Lagrangian calculation is extremely accurate, and gives a sharp discontinuity at the shock front. The 2-D computation used a 130 X 130 grid, with $\Delta Z = \Delta R = 0.05$ cm, so that 20 zones spanned a radius from the origin to the initial surface of the 1 cm explosive sphere.

The results of the comparison are shown in Figure 11, which displays the pressure-distance distribution for both computations, at the time $t = 11.4$ μ secs. At this point, the pressure at the

4. H. M. Sternberg and H. Hurwitz, Calculated Spherical Shock Waves Produced by Condensed Explosives in Air and Water, Sixth Symposium on Detonation, August 1976 (in publication).

shock front calculated by the Lagrangian (1-D) code exceeds that calculated by the Eulerian (2-D) by about 10%. The shock has reached a distance of six charge radii, and yet there are only five zones between the explosive-air interface and the air shock, in the Eulerian computation. Although 10% accuracy in peak shock-pressure is not too bad, it is clear that in our 2-D cylinder calculation we cannot achieve that much, since in that case there are only two or three zones in the shock wave.

The discrepancy observable in Figure 11 at the pressure peak in the explosion gases (at about 2 cm radius) is not serious. This is because the pressure there is decreasing very rapidly in time. Thus, if the results of the 2-D computation had been displayed at about 11.6 μ secs, instead of at 11.4 μ secs, the peaks in the explosion gas would be at the same pressure in both calculations, whereas the ratio of pressures at the air shock would be essentially unchanged.

One further point involves the presence of the second pressure peak, observable in the computed pressure-time histories (Figures 2 through 7). An examination of the results of the CSQ Eulerian code calculation shows that the second peak occurs at the time the explosion products come in contact with the rigid surface. Since air was initially present in the space between the contact surface and the rigid wall, it is necessary to examine more closely just what happens when the explosion gases come in contact with the wall.

The mechanism for the process mentioned above in an Eulerian computation is that the zones adjacent to the rigid wall become mixed zones, i.e., zones which contain both explosive gases and compressed air. Thus the explosive gases can be said to come in contact with the surface. If, on the other hand, a Lagrangian computation had been made, the zones next to the surface would contain pure air at all times, and it would be impossible for the explosive gases to reach the surface. In this case the air shock would be reflected and re-reflected between the rigid surface and the explosive boundary, thus giving rise to additional pressure peaks following the initial peak.

In the actual experimental situation, what occurs is probably a combination of the above two effects. One could expect some subsidiary pressure peaks due to the reflections of the incident shock between the contact surface and the water. In addition, the contact surface becomes somewhat turbulent and mixing occurs between the explosive gases and the air; photographic evidence⁵ shows that the explosive gases do reach the water surface, for the case of the one foot height of burst. Thus, neither an Eulerian nor a Lagrangian calculation should be expected to accurately reproduce the conditions after the first peak: the Eulerian code cannot resolve the series of rapid reflections between the water

5. J. Pittman, Private Communication.

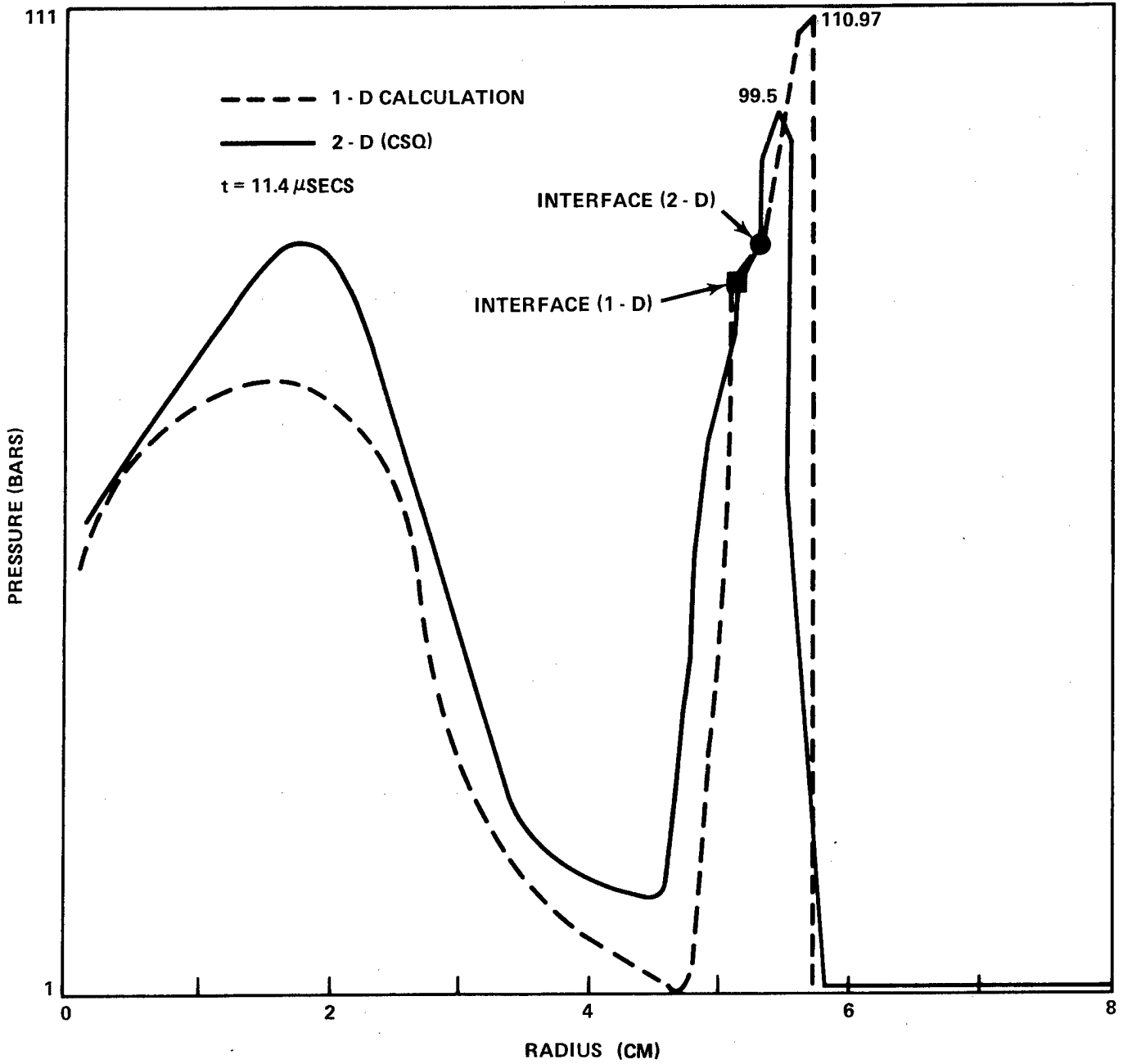


FIG. 11 PRESSURE VS. DISTANCE (PENTOLITE SPHERE, 1-CM RADIUS)

surface and the contact surface, while the Lagrangian code does not allow the explosion gases to reach the water. Neither code, of course, adequately treats the turbulent mixing. Nevertheless, in view of the comparison between the experimental and calculated results, it is clear that reasonable accuracy (for impulse and pressure at the first peak) is obtainable by means of an Eulerian calculation.

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