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DNA 4825F

# FAB CODE COMPUTATIONS OF A 1-KT NUCLEAR FREE-AIR BLAST WAVE TO LOW SHOCK OVERPRESSURES



Kaman AviDyne
83 Second Avenue
Burlington, Massachusetts 01803

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The FAB hydrodynamic computer code was developed for computing the blast flow characteristics of a nuclear free-air blast wave. The flow field is represented by a multi-cell moving grid with fluid properties calculated by Godunov's method. The shock wave at the blast front is represented by the Hugoniot relation. Real air properties may be represented by either Brode (1965) or Doan-Nickel equations of state. Thermal radiation is taken into account.

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20. ABSTRACT (Continued)

Calculation results are presented and compared with nuclear test data summaries and with other predictions. Predicted FAB shock front overpressures below 10 psi are generally near to or between the extremes of the nuclear test data summaries in DASA 1200 as obtained from ground-based and airborne measurements.

# PREFACE

This work was performed by the AviDyne Division of the Kaman Sciences Corporation for the Defense Nuclear Agency under Contract DNA 001-78-C-0374. Mr. James F. Moulton, Jr., Chief, Aerospace Systems Division, Shock Physics Director, DNA, served as technical monitor.

Dr. J. Ray Ruetenik of Kaman AviDyne was the project leader under Dr. Norman P. Hobbs, Technical Director of KA.

Appreciation is expressed to Mr. Moulton for his continuing interest and significant support of this program.

## CONVERSION FACTORS FOR U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT.

| To Convert From | To | Multiply By |
|---|---|---|
| angstrom | meters (m) | 1.000 000 X E -10 |
| atmosphere (normal) | kilo pascal (kPa) | 1.013 25 X E +2 |
| bar | kilo pascal (kPa) | 1.000 000 X E +2 |
| barn | meter$^2$ ($m^2$) | 1.000 000 X E -28 |
| British thermal unit (thermochemical) | joule (J) | 1.054 350 X E +3 |
| calorie (thermochemical) | joule (J) | 4.184 000 |
| cal (thermochemical)/$cm^2$ | mega joule/$m^2$ ($MJ/m^2$) | 4.184 000 X E -2 |
| curie | giga becquerel (GBq)* | 3.700 000 X E +1 |
| degree (angle) | radian (rad) | 1.745 329 X E -2 |
| degree Fahrenheit | degree kelvin (K) | $t_K = (t°f + 459.67)/1.8$ |
| electron volt | joule (J) | 1.602 19 X E -19 |
| erg | joule (J) | 1.000 000 X E -7 |
| erg/second | watt (W) | 1.000 000 X E -7 |
| foot | meter (m) | 3.048 000 X E -1 |
| foot-pound-force | joule (J) | 1.355 818 |
| gallon (U.S. liquid) | meter$^3$ ($m^3$) | 3.785 412 X E -3 |
| inch | meter (m) | 2.540 000 X E -2 |
| jerk | joule (J) | 1.000 000 X E +9 |
| joule/kilogram (J/kg) (radiation dose absorbed) | Gray (Gy)** | 1.000 000 |
| kilotons | terajoules | 4.183 |
| kip (1000 lbf) | newton (N) | 4.448 222 X E +3 |
| kip/$inch^2$ (ksi) | kilo pascal (kPa) | 6.894 757 X E +3 |
| ktap | newton-second/$m^2$ ($N-s/m^2$) | 1.000 000 X E +2 |
| micron | meter (m) | 1.000 000 X E -6 |
| mil | meter (m) | 2.540 000 X E -5 |
| mile (international) | meter (m) | 1.609 344 X E +3 |
| ounce | kilogram (kg) | 2.834 952 X E -2 |
| pound-force (lbf avoirdupois) | newton (N) | 4.448 222 |
| pound-force inch | newton-meter (N·m) | 1.129 848 X E -1 |
| pound-force/inch | newton/meter (N/m) | 1.751 268 X E +2 |
| pound-force/$foot^2$ | kilo pascal (kPa) | 4.788 026 X E -2 |
| pound-force/$inch^2$ (psi) | kilo pascal (kPa) | 6.894 757 |
| pound-mass (lbm avoirdupois) | kilogram (kg) | 4.535 924 X E -1 |
| pound-mass-$foot^2$ (moment of inertia) | kilogram-$meter^2$ ($kg·m^2$) | 4.214 011 X E -2 |
| pound-mass/$foot^3$ | kilogram/$meter^3$ ($kg/m^3$) | 1.601 846 X E +1 |
| rad (radiation dose absorbed) | Gray (Gy)** | 1.000 000 X E -2 |
| roentgen | coulomb/kilogram (C/kg) | 2.579 760 X E -4 |
| shake | second (s) | 1.000 000 X E -8 |
| slug | kilogram (kg) | 1.459 390 X E +1 |
| torr (mm Hg, 0° C) | kilo pascal (kPa) | 1.333 22 X E -1 |

*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The Gray (Gy) is the SI unit of absorbed radiation.

A more complete listing of conversions may be found in "Metric Practice Guide E 380-74," American Society for Testing and Materials.

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# SECTION 1
# INTRODUCTION

The various existing predictions of free-air nuclear blast wave properties for low overpressures (e.g., Refs. 1 to 7) have had unresolved differences that have been of concern to the technical community for a number of years. When these differing predictions are employed as inputs to techniques used for the formulation of height-of-burst charts at low shock overpressures, the differences become magnified. That is, the resulting height-of-burst curves differ to even a markedly greater degree.

A principal question concerning these prediction methods is the deterioration of the predicted properties near the shock front at low shock overpressures. Most distributions of predicted overpressure, for example, exhibit a pressure rise at the blast front that is smeared over a considerable distance, differing significantly from the characteristic sharp rise and smooth decay of measured blast waves.

In order to provide a blast prediction method of improved accuracy for the low overpressure range which does not smear the blast front, Kaman AviDyne developed for the Defense Nuclear Agency the FAB (free-air-burst) hydrocode, described herein, which represents the blast front as a Hugoniot shock wave. This code was developed in a manner similar to that for the REFLECT code developed by KA for DNA for computer computation of the ground reflection of a free-air nuclear blast wave (Ref. 8).

Section 2 of this report briefly discusses some background information on the free-air-blast problem, with respect to existing code predictions and experimental data. Section 3 describes the major features of the FAB code and Section 4 presents results from the principal code runs made. Section 5 presents a discussion of the FAB code results with respect to other predictions and test data. Conclusions are presented in Section 6.

# SECTION 2
# BACKGROUND

This section briefly reviews some features and limitations of the existing test data and methods of predicting free-air-blast conditions, with particular attention to the low overpressure range from about 7 to 0.3 psi.

First, considering the nuclear test data for the variation of shock front overpressure with range, there are several useful data summaries (Ref. 2). Ground based nuclear test measurements from tower gages and event photography are represented by the U.S.-'59 empirical curve (Ref. 2), which is used as one basis for comparisons in this report. Airborne measurements from gages mounted on aircraft and in canisters have been represented by various polynominals (Ref. 2). A convenient summary table of these airborne measurements which is used as a basis for comparisons in this report is given in Table 3.2-6 of Reference 2. Generally in the low pressure range below 5 psi the airborne data indicate higher overpressures than the ground based data, with differences of about 15 percent at the 2 psi level. No satisfactory explanation for these differences has yet been established.

With regard to theoretical predictions, there are available a number of useful codes and numerical results, such as the M-problem (Ref. 2), Brode's point source solution (Ref. 1), the Hull code (Ref. 3), the AFWL Revised Nuclear Blast Standard code (Ref. 7) and the NOL code (Refs. 4 and 5). These various codes have all produced useful results, roughly in agreement with the test data. However, for high accuracy at low overpressures these code results are generally somewhat suspect because of their inability to achieve accurate resolution of blast wave properties at the blast front. Because of inherent instability of these numerical methods, either artificial viscosity or equivalent numerical differencing methods have been employed. Artificial viscosity results in the smearing of shock waves into a compression wave instead of a

shock wave. To steepen compression waves, methods using artificial viscosity have resorted to fine mesh spacing. This has improved the pressure distributions insofar as the extent of the compression wave has been reduced and the peak pressure has increased. Unfortunately to reduce the cell size to anything approaching the thickness of a shock wave would result in prohibitive computer times. Extrapolation schemes have been employed for extrapolation of the computed profiles to a point within the compression wave for assigning shock properties. But the extrapolations become particularly large at low shock overpressures.

In view of these problems, there does not appear to exist in the literature an analytical procedure for calculating free-air-burst shock front characteristics in the low pressure range with a high enough accuracy to resolve the existing questions of significant differences between ground based and airborne nuclear test measurements.

# SECTION 3
# THE FAB CODE

The FAB computer code was developed to solve the spherically symmetrical one-dimensional transient fluid-flow problem of the expansion of an initially prescribed flow into an initially undisturbed uniform atmosphere. In the present application this code deals specifically with the problem of modeling the fluid flow produced by the detonation of a 1KT nuclear explosion in a uniform sea-level atmosphere.

The code computes the flow in a moving cell coordinate system similar to the one shown in Figure 1. The cells are symmetrical with respect to the origin of coordinates, so that each cell represents a spherical shell region, initially prescribed by any arbitrary inner and outer radii. The outer boundary of the cell system represents the outer limit of the disturbed flow region, which is initially specified and grows radially thereafter at the speed of the shock wave created between the outermost cell of the disturbed region and the outer undisturbed atmosphere.

All inner cell radial boundaries are taken to increase similarly, at speeds proportional to the ratio of their initial radial distances from the origin of coordinates to the initial shock front radius.

The flow between adjacent cells in the moving coordinate system is computed using the Godunov technique (e.g., see Ref. 9 or 10) in the manner previously used in nuclear blast-field calculations by Thompson and Ruetenik (Ref. 8). More specifically, in the interior of the disturbed region, the flux conditions at cell boundaries are computed as locally isentropic shock-expansion phenomena for large pressure and velocity differences between cells, using an isentropic exponent ($\gamma_e = (d\ln(p)/d\ln(\rho))_s$) which is the average of the values for the two adjacent cells; for small pressure and velocity differences between adjacent cells a linearized approximation is used. For the outermost

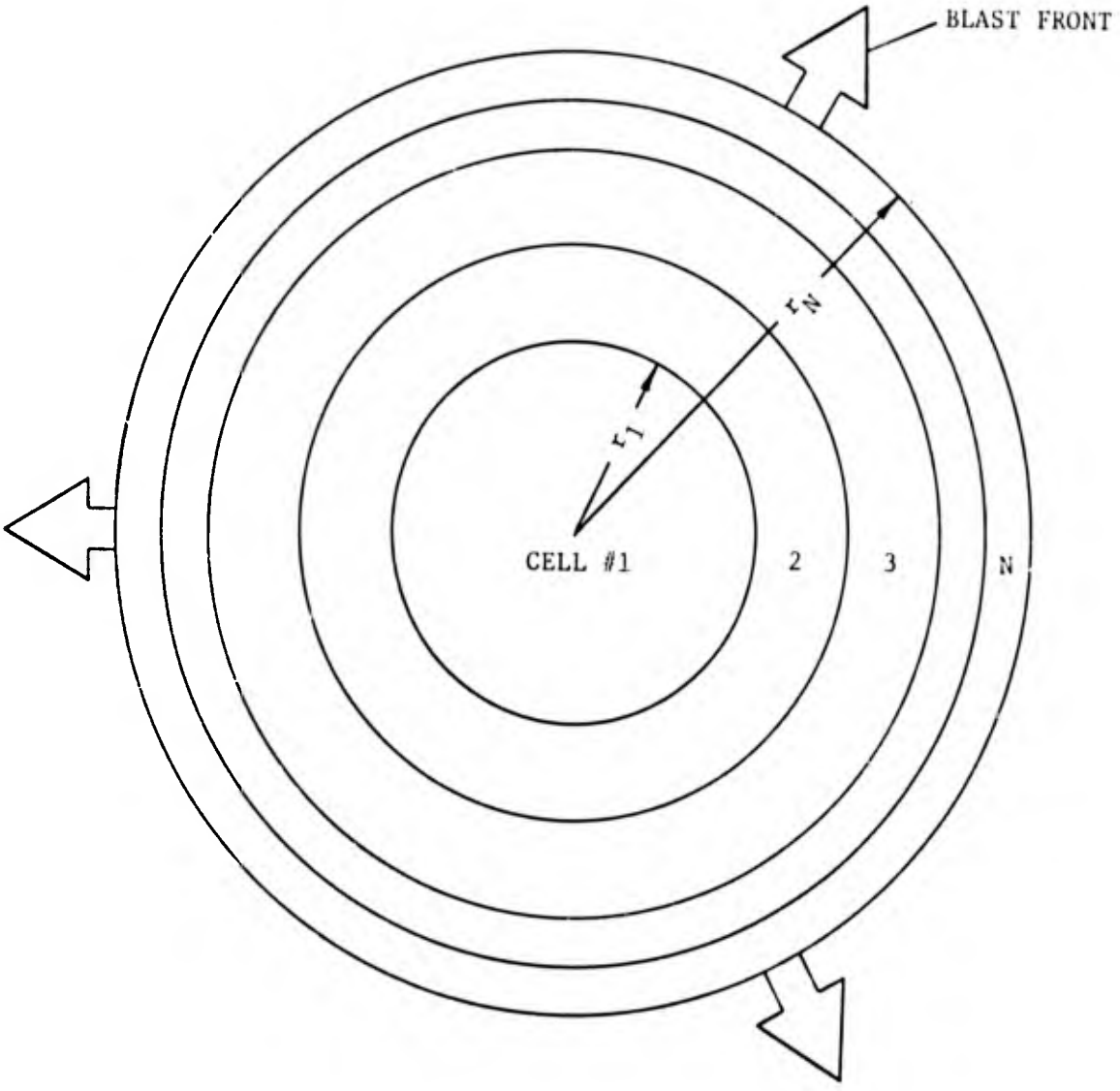


Figure 1. Sketch illustrating the FAB model.

cell boundary of the disturbed region, the shock front velocity and associated fluxes are calculated on the basis of the exact Hugoniot relationships for a real gas.

The code assumes a real air medium with thermodynamic equation-of-state properties given by a choice of two analytical representations, designated as Brode 1965 (Ref. 11) and Doan-Nickel (Ref. 7, see AIR subroutine).

In addition to hydrodynamic phenomena, the code takes into account the thermal radiation of a nuclear (1KT) blast, with the total radiation flux computed as a function of time according to Reference 12 and the spatial distribution of radiated energy being calculated according to the model used in Reference 6.

Input to the code consists of the specification of the initial pressure, density and velocity in the entire disturbed fluid field or, alternatively, the specification of density, internal energy and velocity. In the former case, initial conditions are generated from early-time predictions of the AFWL Nuclear Blast Standard (1KT) code (Ref. 7); in the second case inputs may be prepared from Sputter code results (e.g., Ref. 13).

Program output consists of tables of pressure, density and velocity printouts for selected times.

The FAB code has been run primarily on a CDC CYBER 176 computer. The code has a core requirement of 117K octal for a 1000 cell configuration. Approximately 10 CP minutes are required for a complete run with 273 cells.

# SECTION 4
# FAB CODE RUNS

This section describes and lists the principal FAB code runs made, presents the numerical results obtained for two runs with 273 cell configurations and discusses some factors related to code accuracy.

## 4-1 CELL CONFIGURATIONS.

Runs were made with the FAB code for a variety of conditions with either a 134 or 273 cell configuration. The runs of principal interest are listed in Table 1. The cell sizes used in these runs are listed in Table 2, where cell radial widths are listed in order of increasing distance from the origin of coordinates. These cell sizes were selected so that absolute pressure changes between adjacent cells were generally less than 2 percent for the 134 cell case and less than 1 percent for the 273 cell case.

Near the shock front absolute pressure changes between adjacent cells were generally less than the above values. In terms of percent of shock front overpressure, the pressure changes between adjacent cells in this region were generally less than 1.2 percent for the 134 cell configuration and less than 0.6 percent for the 273 cell configuration. For shock front overpressures below 1 psi the percentage changes were greater but the pressure differences between adjacent cells here were generally below 0.01 psi.

## 4-2 CODE RESULTS FOR 273 CELL CONFIGURATION.

Results of the principal FAB code runs for the 273 cell configuration are presented in Tables 3 and 4, for Runs 273-5 and 273-7, corresponding to Brode and Doan-Nickel equations-of-state, respectively. The tables present values of shock front radius, shock front overpressure (FAB) and shock arrival time for radii from about 150 to 23,000 feet and for overpressures from 343 to 0.1 psi. These same shock front overpressure data are also shown in Figure 2. In addition to the FAB code results, Tables 3 and 4 also present calculated overpressures for the same radii according to the AFWL Revised 1-KT-Standard (Ref. 7).

Table 1

PRINCIPAL FAB CODE RUNS[a]

| RUN NO. | NO. CELLS | INPUT[b] | YIELD (KT)[d] | EQ. OF STATE |
|---|---|---|---|---|
| 134-18 | 134 | AFWL-1KT-STD-REV | 1.028 | Brode |
| 134-19 | 134 | SPUTTER FB21 | 0.994 | Brode |
| 134-20 | 134 | AFWL-1KT-STD-REV | 1.011 | Doan-Nickel |
| 134-21 | 134 | AFWL-1KT-STD-REV | 1.025 | Brode[c] |
| 273-5 | 273 | AFWL-1KT-STD-REV | 1.028 | Brode |
| 273-7 | 273 | AFWL-1KT-STD-REV | 1.010 | Doan-Nickel |

[a] All code runs made for ambient atmosphere conditions of 2117 psfa and 0.002378 slug/ft$^3$.

[b] All inputs for a nominal 1 KT detonation; initial conditions specified at 0.01 second after detonation.

[c] Thermal radiation neglected in Run 134-21 only.

[d] Yields computed on the basis of 1KT = $4.189 \times 10^{19}$ erg. Yields are the sum of gas internal energy and kinetic energy at 0.01 seconds and thermal energy radiated to this time. Yields given are dependent upon the particular equation of state used and accuracy of the input.

Table 2

CELL CONFIGURATIONS FOR FAB CODE RUNS

| CELL RADIAL WIDTH (PERCENT OUTER RADIUS) | NO. CELLS THIS WIDTH |
|---|---|
| 134 cell case | |
| 10[a] | 2 |
| 5 | 4 |
| 2.5 | 8 |
| 1.25 | 8 |
| .833 | 12 |
| .40 | 25 |
| .20 | 25 |
| .10[b] | 50 |
| 273 cell case | |
| 2.5[a] | 16 |
| 1.25 | 16 |
| .625 | 16 |
| .40 | 25 |
| .20 | 50 |
| .10 | 50 |
| .05[b] | 100 |

[a]Innermost cells

[b]Outermost cells

Table 3.

CODE RESULTS FOR RUN FAB-273-5

(Brode Equation of State)

| RADIUS (FT) | SHOCK FRONT OVERPRESSURE (PSI) | | FAB BLAST ARRIVAL TIME (SEC) |
|---|---|---|---|
| | FAB | 1KT-STD | |
| 153.6 | 541.637 | 543.315 | .0100 |
| 168.4 | 414.412 | 421.363 | .0125 |
| 184.0 | 323.472 | 330.779 | .0155 |
| 200.5 | 255.442 | 262.103 | .0190 |
| 218.3 | 202.619 | 208.759 | .0233 |
| 237.1 | 162.425 | 167.739 | .0283 |
| 257.0 | 131.659 | 136.074 | .0341 |
| 277.7 | 107.861 | 111.506 | .0407 |
| 299.3 | 89.290 | 92.351 | .0482 |
| 321.4 | 74.601 | 77.310 | .0565 |
| 344.3 | 62.758 | 65.380 | .0657 |
| 367.7 | 53.416 | 55.791 | .0757 |
| 391.7 | 45.516 | 48.077 | .0866 |
| 416.2 | 39.182 | 41.747 | .0985 |
| 441.4 | 34.076 | 36.510 | .1112 |
| 467.2 | 29.943 | 32.148 | .1249 |
| 493.6 | 26.564 | 28.489 | .1394 |
| 520.6 | 23.754 | 25.393 | .1548 |
| 548.2 | 21.362 | 22.753 | .1711 |
| 576.5 | 19.291 | 20.486 | .1882 |
| 605.5 | 17.479 | 18.525 | .2063 |
| 635.2 | 15.885 | 16.821 | .2252 |
| 665.7 | 14.479 | 15.331 | .2451 |
| 696.9 | 13.236 | 14.021 | .2659 |
| 729.0 | 12.135 | 12.863 | .2877 |
| 762.0 | 11.156 | 11.836 | .3105 |
| 795.8 | 10.284 | 10.921 | .3343 |
| 830.6 | 9.503 | 10.101 | .3591 |
| 866.4 | 8.802 | 9.365 | .3850 |
| 903.2 | 8.171 | 8.701 | .4119 |
| 941.0 | 7.599 | 8.100 | .4400 |
| 980.0 | 7.081 | 7.555 | .4692 |
| 1020.2 | 6.610 | 7.058 | .4997 |
| 1061.5 | 6.176 | 6.605 | .5313 |
| 1104.2 | 5.779 | 6.190 | .5641 |
| 1148.1 | 5.418 | 5.810 | .5983 |
| 1193.4 | 5.085 | 5.460 | .6338 |
| 1240.1 | 4.779 | 5.137 | .6706 |
| 1288.2 | 4.496 | 4.839 | .7089 |
| 1337.9 | 4.234 | 4.563 | .7486 |
| 1389.1 | 3.991 | 4.308 | .7898 |
| 1442.0 | 3.765 | 4.070 | .8326 |

Table 3. Continued.

CODE RESULTS FOR RUN FAB-273-5

(Brode Equation of State)

| RADIUS (FT) | SHOCK FRONT OVERPRESSURE (PSI | | FAB BLAST ARRIVAL TIME (SEC) |
|---|---|---|---|
| | FAB | 1KT-STD | |
| 1496.5 | 3.555 | 3.849 | .8769 |
| 1552.8 | 3.360 | 3.643 | .9229 |
| 1610.9 | 3.177 | 3.451 | .9706 |
| 1670.9 | 3.007 | 3.271 | 1.0201 |
| 1732.9 | 2.848 | 3.103 | 1.0714 |
| 1796.8 | 2.698 | 2.945 | 1.1245 |
| 1862.8 | 2.559 | 2.797 | 1.1796 |
| 1931.0 | 2.427 | 2.658 | 1.2366 |
| 2001.4 | 2.304 | 2.527 | 1.2957 |
| 2074.2 | 2.188 | 2.404 | 1.3570 |
| 2149.3 | 2.079 | 2.288 | 1.4204 |
| 2226.9 | 1.977 | 2.178 | 1.4861 |
| 2307.0 | 1.880 | 2.075 | 1.5542 |
| 2389.8 | 1.789 | 1.977 | 1.6247 |
| 2475.3 | 1.703 | 1.885 | 1.6976 |
| 2563.7 | 1.622 | 1.797 | 1.7732 |
| 2655.0 | 1.545 | 1.714 | 1.8514 |
| 2749.3 | 1.472 | 1.636 | 1.9324 |
| 2846.7 | 1.403 | 1.561 | 2.0163 |
| 2947.4 | 1.338 | 1.490 | 2.1030 |
| 3051.5 | 1.277 | 1.423 | 2.1929 |
| 3159.0 | 1.218 | 1.360 | 2.2858 |
| 3270.1 | 1.163 | 1.299 | 2.3821 |
| 3384.9 | 1.110 | 1.241 | 2.4816 |
| 3503.6 | 1.060 | 1.186 | 2.5847 |
| 3626.2 | 1.013 | 1.134 | 2.6913 |
| 3752.9 | .967 | 1.085 | 2.8017 |
| 3883.9 | .925 | 1.037 | 2.9159 |
| 4019.2 | .884 | .992 | 3.0340 |
| 4159.1 | .845 | .949 | 3.1562 |
| 4303.7 | .808 | .908 | 3.2827 |
| 4453.1 | .773 | .869 | 3.4136 |
| 4607.5 | .740 | .832 | 3.5489 |
| 4767.1 | .708 | .796 | 3.6889 |
| 4932.1 | .677 | .762 | 3.8338 |
| 5102.6 | .648 | .730 | 3.9837 |
| 5278.9 | .621 | .699 | 4.1387 |
| 5461.1 | .594 | .669 | 4.2990 |
| 5649.4 | .569 | .641 | 4.4649 |
| 5844.0 | .545 | .614 | 4.6364 |
| 6045.2 | .522 | .588 | 4.8139 |
| 6253.1 | .500 | .564 | 4.9974 |

Table 3. Concluded.

CODE RESULTS FOR RUN FAB-273-5

(Brode Equation of State)

| RADIUS (FT) | SHOCK FRONT OVERPRESSURE (PSI) | | FAB BLAST ARRIVAL TIME (SEC) |
|---|---|---|---|
| | FAB | 1KT-STD | |
| 6468.1 | .479 | .540 | 5.1872 |
| 6690.3 | .459 | .517 | 5.3835 |
| 6919.9 | .440 | .496 | 5.5866 |
| 7157.4 | .422 | .475 | 5.7966 |
| 7402.8 | .405 | .456 | 6.0138 |
| 7656.4 | .388 | .437 | 6.2384 |
| 7918.7 | .372 | .419 | 6.4707 |
| 8189.7 | .357 | .402 | 6.7109 |
| 8469.9 | .342 | .385 | 6.9593 |
| 8759.6 | .328 | .369 | 7.2162 |
| 9059.0 | .315 | .354 | 7.4819 |
| 9368.5 | .302 | .340 | 7.7567 |
| 9688.4 | .291 | .326 | 8.0408 |
| 10019.2 | .280 | .313 | 8.3346 |
| 10361.1 | .269 | .300 | 8.6384 |
| 10714.5 | .259 | .288 | 8.9526 |
| 11079.9 | .249 | .276 | 9.2775 |
| 11457.6 | .239 | .265 | 9.6134 |
| 11848.1 | .230 | .254 | 9.9608 |
| 12251.7 | .221 | .244 | 10.3200 |
| 12668.9 | .212 | .234 | 10.6914 |
| 13100.3 | .204 | .225 | 11.0754 |
| 13546.2 | .196 | .216 | 11.4725 |
| 14007.2 | .188 | .207 | 11.8831 |
| 14483.7 | .181 | .199 | 12.3077 |
| 14976.3 | .174 | .191 | 12.7467 |
| 15485.6 | .167 | .184 | 13.2006 |
| 16012.0 | .161 | .176 | 13.6699 |
| 16556.2 | .154 | .169 | 14.1552 |
| 17118.8 | .148 | .163 | 14.6569 |
| 17700.4 | .143 | .156 | 15.1757 |
| 18301.7 | .137 | .150 | 15.7120 |
| 18923.3 | .132 | .144 | 16.2666 |
| 19565.8 | .127 | .139 | 16.8400 |
| 20230.1 | .122 | .133 | 17.4329 |
| 20916.8 | .117 | .128 | 18.0458 |
| 21626.7 | .113 | .123 | 18.6796 |
| 22360.5 | .108 | .118 | 19.3348 |
| 23119.2 | .104 | .114 | 20.0123 |

Table 4.

CODE RESULTS FOR RUN FAB-273-7

(Doan-Nickel Thermodynamics)

| RADIUS (FT) | SHOCK FRONT OVERPRESSURE (PSI) | | FAB BLAST ARRIVAL TIME (SEC) |
|---|---|---|---|
| | FAB | 1KT-STD | |
| 153.6 | 541.964 | 543.315 | .0100 |
| 168.3 | 414.215 | 421.742 | .0125 |
| 183.9 | 322.958 | 331.096 | .0155 |
| 200.4 | 255.010 | 262.252 | .0190 |
| 218.3 | 202.450 | 208.791 | .0233 |
| 237.1 | 162.413 | 167.730 | .0283 |
| 257.0 | 131.689 | 136.094 | .0341 |
| 277.7 | 107.798 | 111.586 | .0407 |
| 299.1 | 88.994 | 92.477 | .0482 |
| 321.2 | 74.054 | 77.459 | .0565 |
| 343.9 | 62.082 | 65.537 | .0657 |
| 367.3 | 52.434 | 55.970 | .0757 |
| 391.2 | 44.677 | 48.211 | .0867 |
| 415.8 | 38.446 | 41.852 | .0987 |
| 441.0 | 33.428 | 36.593 | .1116 |
| 466.8 | 29.379 | 32.216 | .1254 |
| 493.1 | 26.090 | 28.545 | .1400 |
| 520.1 | 23.369 | 25.440 | .1555 |
| 547.7 | 21.059 | 22.793 | .1719 |
| 576.0 | 19.054 | 20.518 | .1892 |
| 605.0 | 17.293 | 18.553 | .2073 |
| 634.8 | 15.739 | 16.843 | .2264 |
| 665.3 | 14.363 | 15.349 | .2464 |
| 696.5 | 13.141 | 14.035 | .2673 |
| 728.7 | 12.052 | 12.875 | .2892 |
| 761.6 | 11.085 | 11.846 | .3121 |
| 795.5 | 10.220 | 10.928 | .3360 |
| 830.3 | 9.445 | 10.107 | .3609 |
| 866.1 | 8.748 | 9.370 | .3869 |
| 902.9 | 8.119 | 8.705 | .4140 |
| 940.8 | 7.551 | 8.103 | .4422 |
| 979.8 | 7.036 | 7.557 | .4715 |
| 1020.0 | 6.567 | 7.060 | .5020 |
| 1061.4 | 6.138 | 6.607 | .5338 |
| 1104.0 | 5.747 | 6.192 | .5668 |
| 1147.9 | 5.388 | 5.811 | .6011 |
| 1193.2 | 5.058 | 5.461 | .6367 |
| 1239.9 | 4.749 | 5.138 | .6736 |
| 1288.1 | 4.465 | 4.840 | .7120 |
| 1337.8 | 4.205 | 4.564 | .7519 |
| 1389.0 | 3.964 | 4.308 | .7932 |
| 1441.9 | 3.745 | 4.070 | .8361 |

Table 4. Continued.

CODE RESULTS FOR RUN FAB-273-7

(Doan-Nickel Thermodynamics)

| RADIUS (FT) | SHOCK FRONT OVERPRESSURE (PSI) | | FAB BLAST ARRIVAL TIME (SEC) |
|---|---|---|---|
| | FAB | 1KT-STD | |
| 1496.5 | 3.532 | 3.849 | .8806 |
| 1552.8 | 3.338 | 3.643 | .9268 |
| 1610.9 | 3.157 | 3.451 | .9746 |
| 1670.9 | 2.989 | 3.271 | 1.0242 |
| 1732.8 | 2.831 | 3.103 | 1.0756 |
| 1796.8 | 2.683 | 2.945 | 1.1289 |
| 1862.8 | 2.544 | 2.797 | 1.1841 |
| 1931.0 | 2.414 | 2.658 | 1.2414 |
| 2001.5 | 2.292 | 2.527 | 1.3007 |
| 2074.2 | 2.178 | 2.404 | 1.3621 |
| 2149.3 | 2.070 | 2.288 | 1.4257 |
| 2226.9 | 1.968 | 2.178 | 1.4916 |
| 2307.1 | 1.872 | 2.075 | 1.5598 |
| 2389.9 | 1.782 | 1.977 | 1.6305 |
| 2475.5 | 1.697 | 1.884 | 1.7037 |
| 2563.8 | 1.616 | 1.797 | 1.7795 |
| 2655.2 | 1.540 | 1.714 | 1.8579 |
| 2749.5 | 1.468 | 1.636 | 1.9391 |
| 2847.0 | 1.400 | 1.561 | 2.0232 |
| 2947.7 | 1.354 | 1.490 | 2.1102 |
| 3051.9 | 1.297 | 1.423 | 2.2003 |
| 3159.5 | 1.221 | 1.359 | 2.2936 |
| 3270.6 | 1.162 | 1.299 | 2.3901 |
| 3385.5 | 1.110 | 1.241 | 2.4899 |
| 3504.2 | 1.060 | 1.186 | 2.5933 |
| 3626.9 | 1.013 | 1.134 | 2.7002 |
| 3753.7 | .969 | 1.084 | 2.8108 |
| 3884.7 | .926 | 1.037 | 2.9253 |
| 4020.1 | .886 | .992 | 3.0438 |
| 4160.1 | .847 | .949 | 3.1664 |
| 4304.7 | .811 | .908 | 3.2932 |
| 4454.2 | .776 | .869 | 3.4244 |
| 4608.8 | .743 | .831 | 3.5601 |
| 4768.5 | .711 | .796 | 3.7005 |
| 4933.6 | .681 | .762 | 3.8458 |
| 5104.2 | .653 | .729 | 3.9961 |
| 5280.6 | .625 | .698 | 4.1515 |
| 5462.9 | .599 | .669 | 4.3123 |
| 5651.3 | .574 | .641 | 4.4786 |
| 5846.1 | .550 | .614 | 4.6506 |
| 6047.4 | .528 | .588 | 4.8285 |
| 6255.6 | .506 | .563 | 5.0126 |

Table 4. Concluded.

CODE RESULTS FOR RUN FAB-273-7

(Doan-Nickel Thermodynamics)

| RADIUS (FT) | SHOCK FRONT OVERPRESSURE (PSI) | | FAB BLAST ARRIVAL TIME (SEC) |
|---|---|---|---|
| | FAB | 1KT-STD | |
| 6470.7 | .485 | .540 | 5.2029 |
| 6693.1 | .466 | .517 | 5.3998 |
| 6923.0 | .447 | .496 | 5.6034 |
| 7160.6 | .429 | .475 | 5.8140 |
| 7406.2 | .411 | .455 | 6.0318 |
| 7660.1 | .395 | .437 | 6.2570 |
| 7922.6 | .379 | .419 | 6.4900 |
| 8193.9 | .364 | .401 | 6.7309 |
| 8474.4 | .349 | .385 | 6.9800 |
| 8764.4 | .335 | .369 | 7.2377 |
| 9064.1 | .322 | .354 | 7.5041 |
| 9373.9 | .310 | .339 | 7.7796 |
| 9694.2 | .297 | .326 | 8.0645 |
| 10025.3 | .293 | .312 | 8.3592 |
| 10367.6 | .286 | .300 | 8.6640 |

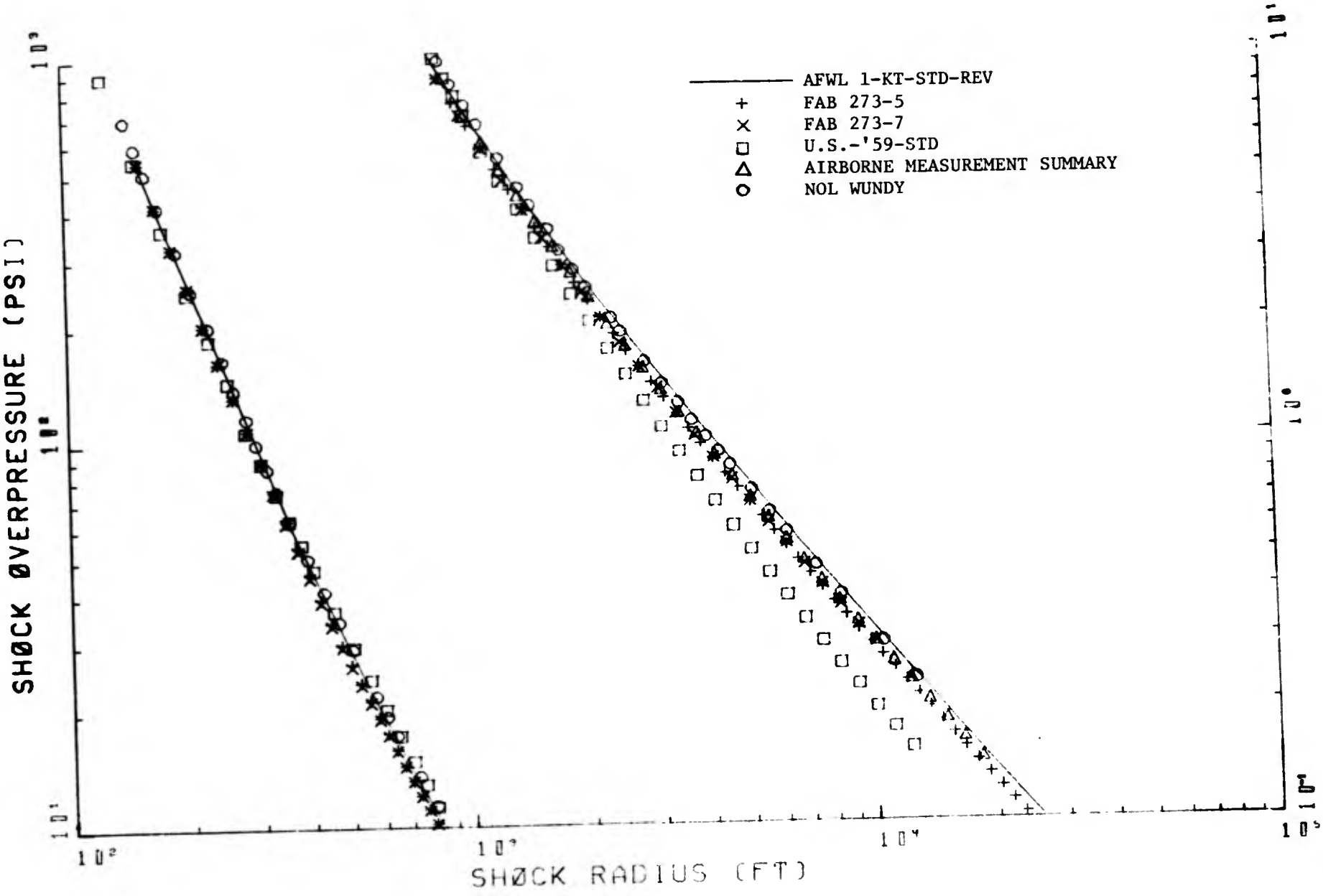


Figure 2. Comparison of Shock Front Pressures.

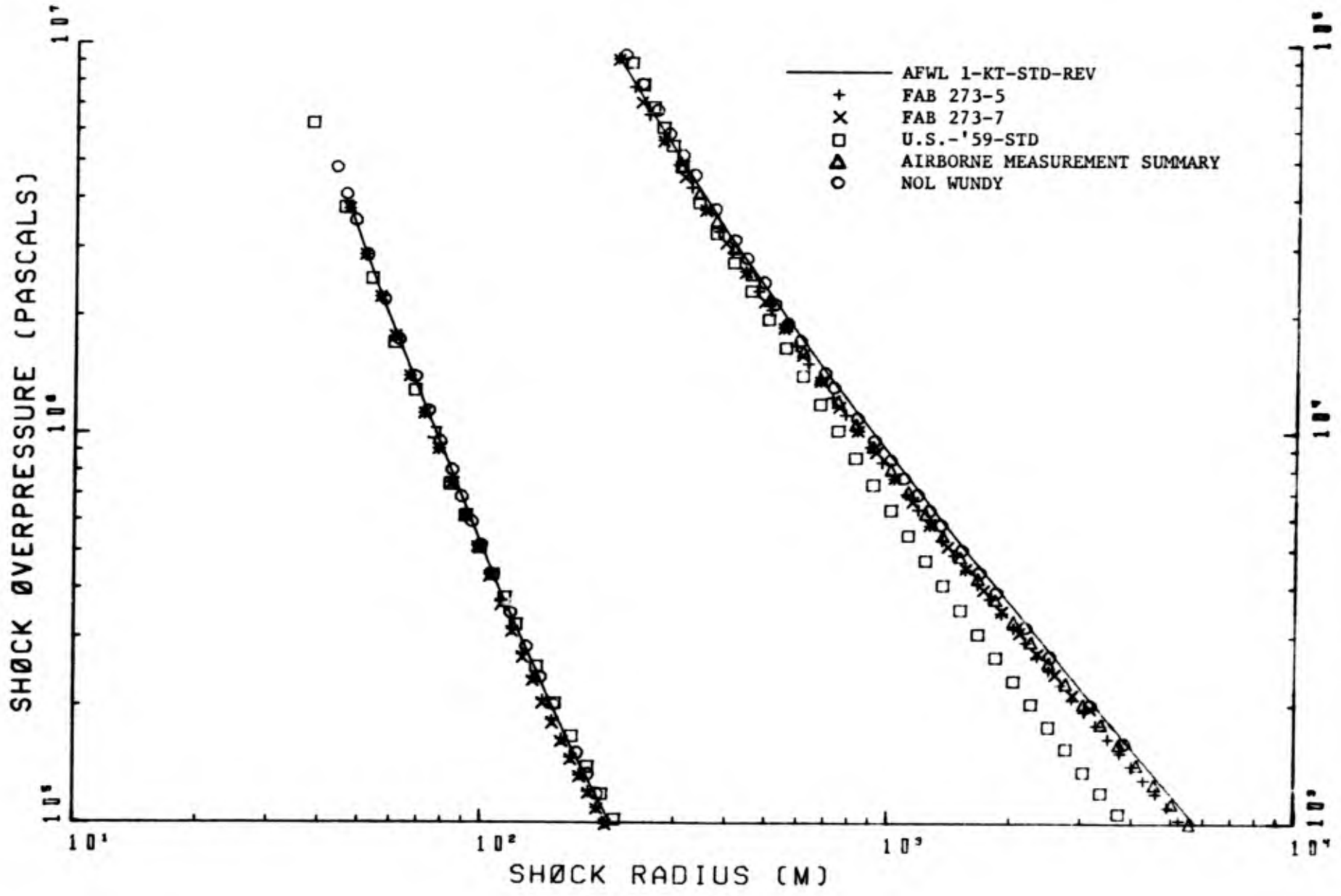


Figure 2. Concluded.

Typical overpressure, overdensity and material velocity distributions in the blast field are presented in Figures 3 to 6 for Run 273-5 for times after detonation of 0.010, 0.102, 1.020 and 10.32 seconds. Also shown in these figures are the corresponding distributions calculated from the AFWL Revised 1-KT Standard (Ref. 7) for the same blast front radius. (Metric units are used in Figures 3 to 6 to permit convenient reference to similar curves in Ref. 7.) The distributions shown in Figure 3 for 0.010 second represent the initial conditions for the FAB computations, which for this run were taken equal to the shown AFWL 1-KT-STD-REV distributions.

The distributions shown in Figures 3 to 6 were computed with use of the Brode (1965) equation-of-state. Essentially the same distributions were obtained from a similar run made with the Doan-Nickel equation-of-state (Run 273-7).

## 4-3 COMPARISON OF 134 AND 273 CELL RESULTS.

Results from the 134 cells and 273 cell code runs were generally in good agreement with each other. For overpressures above 1 psi, shock front overpressures for the two cases generally agreed within 1 percent and for lower pressures within 0.01 psi. In the lower overpressure range below 1 psi, the 134 cell configuration gave slightly lower shock overpressures, generally in agreement with what would be expected for the larger cell sizes used. In view of these considerations, it appears that the 273 cell results presented in Tables 3 and 4 represent a fine enough cell division such that no significant changes in shock front overpressure would be expected to be obtained by increasing the number of cells further.

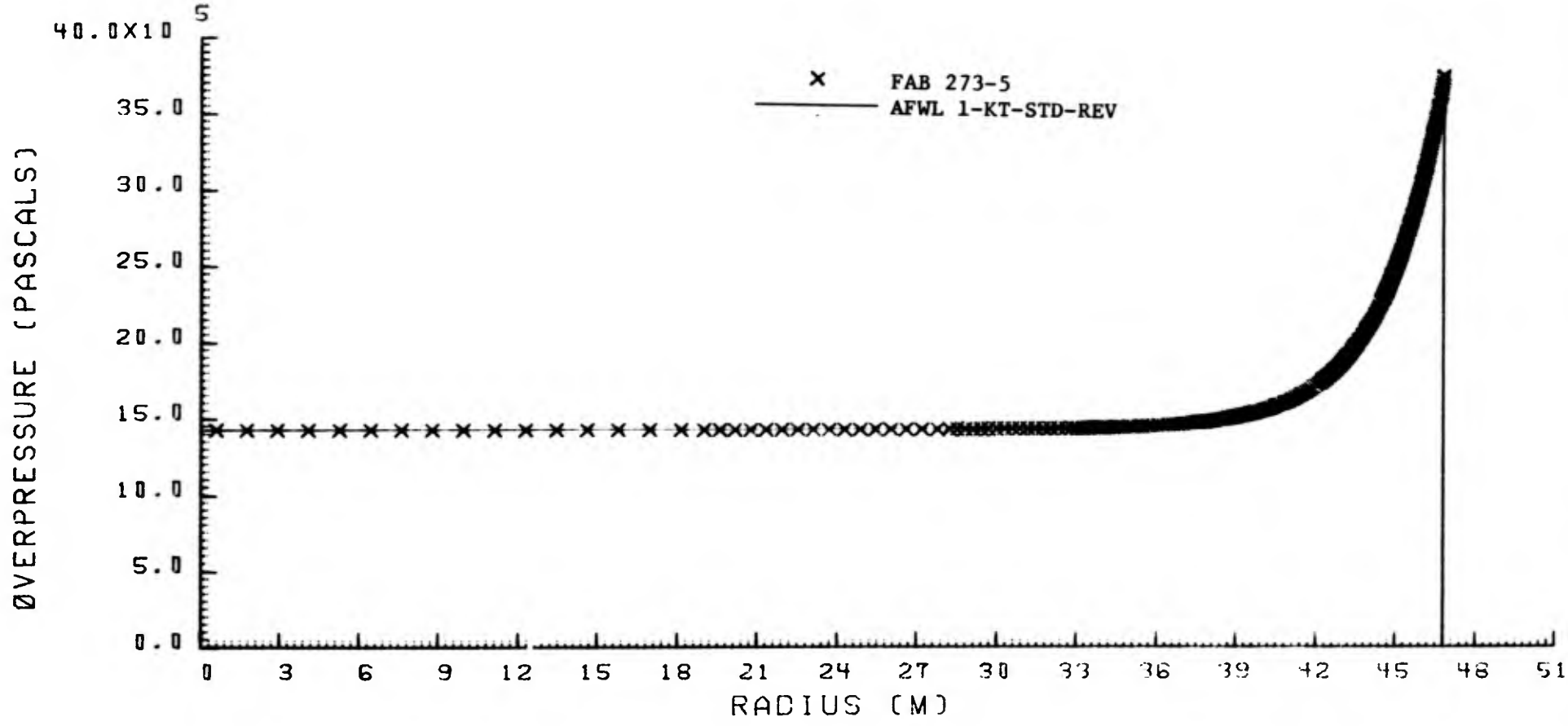


Figure 3. Comparisons of Pressure, Density and Velocity Distributions at 0.010 Seconds After Detonation.

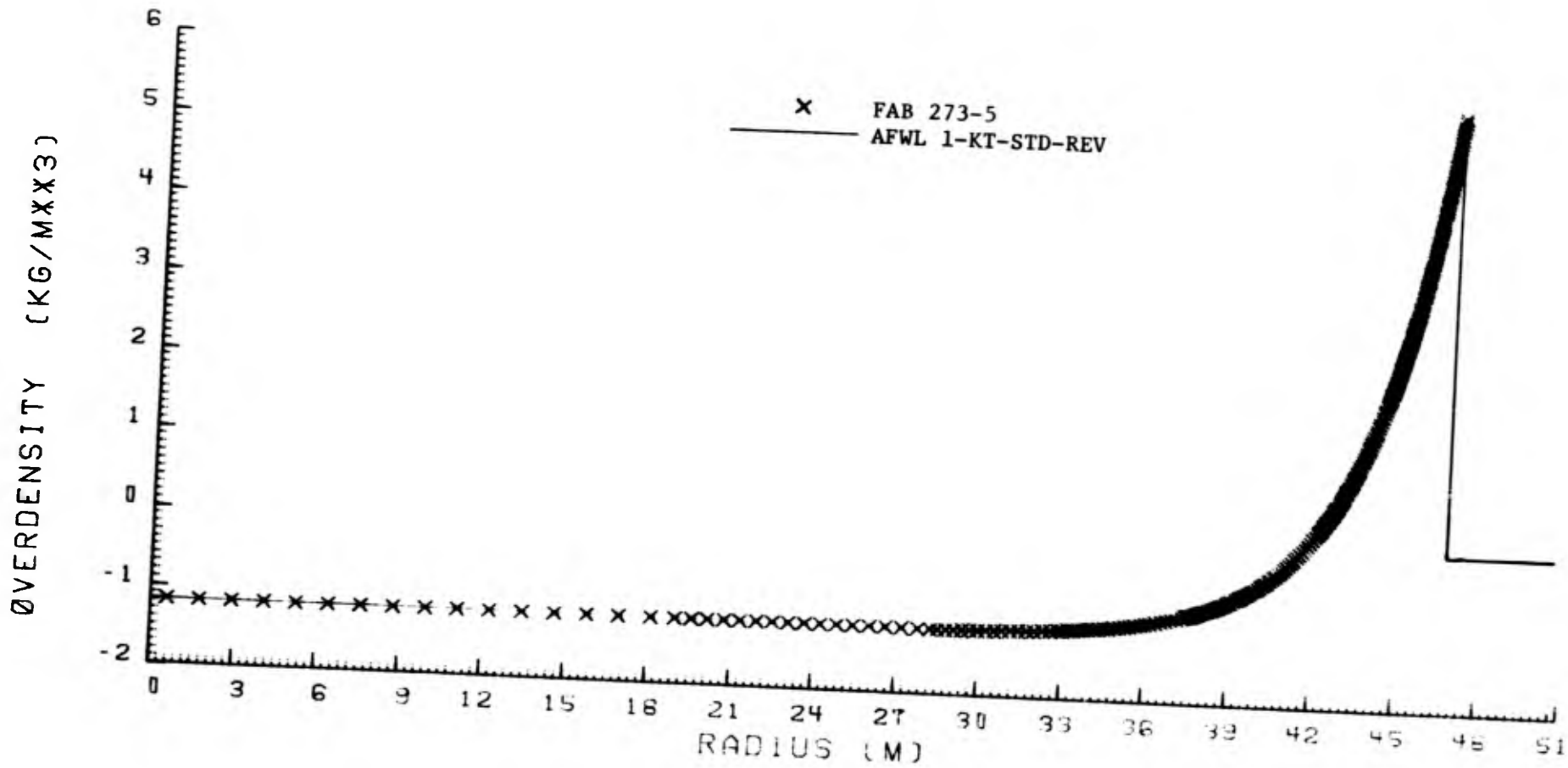


Figure 3. Continued.

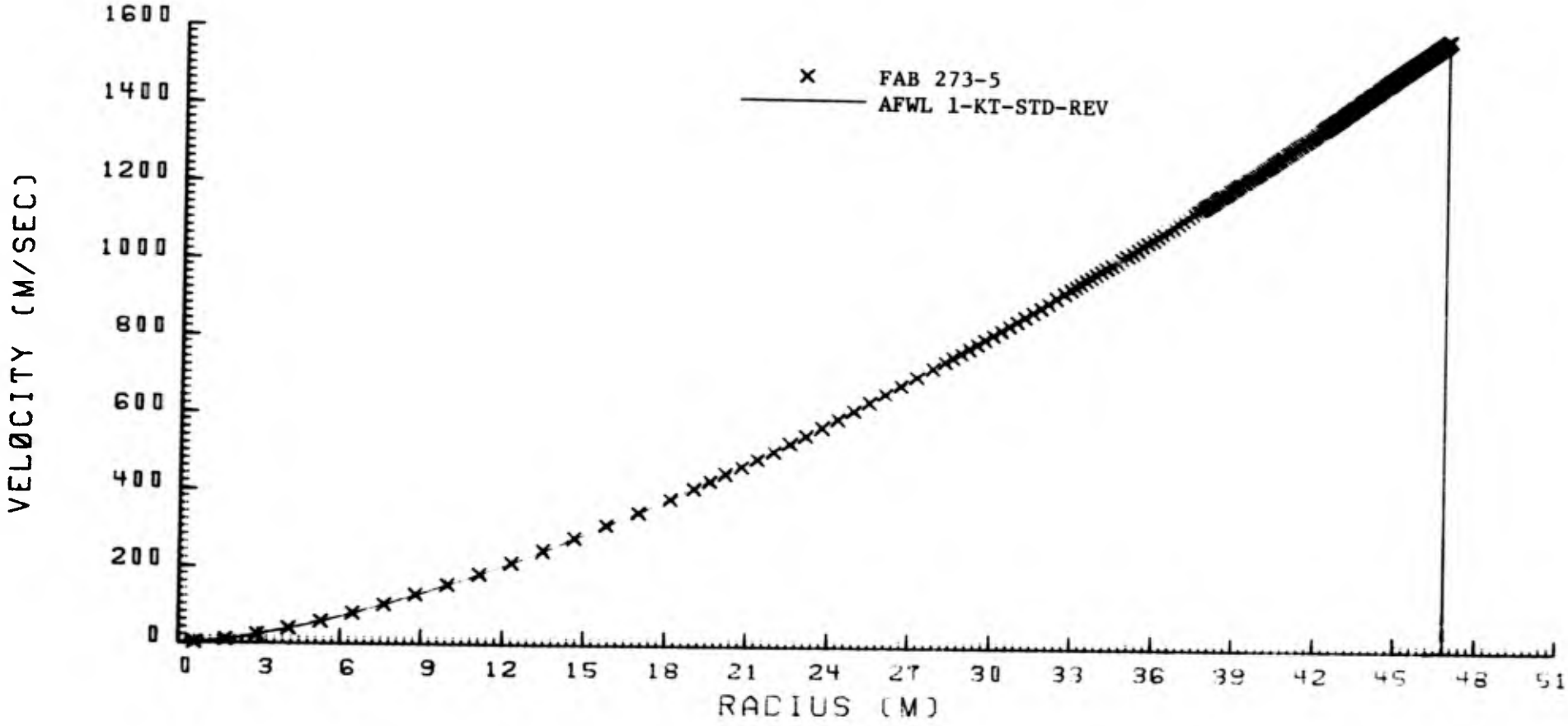


Figure 3. Concluded.

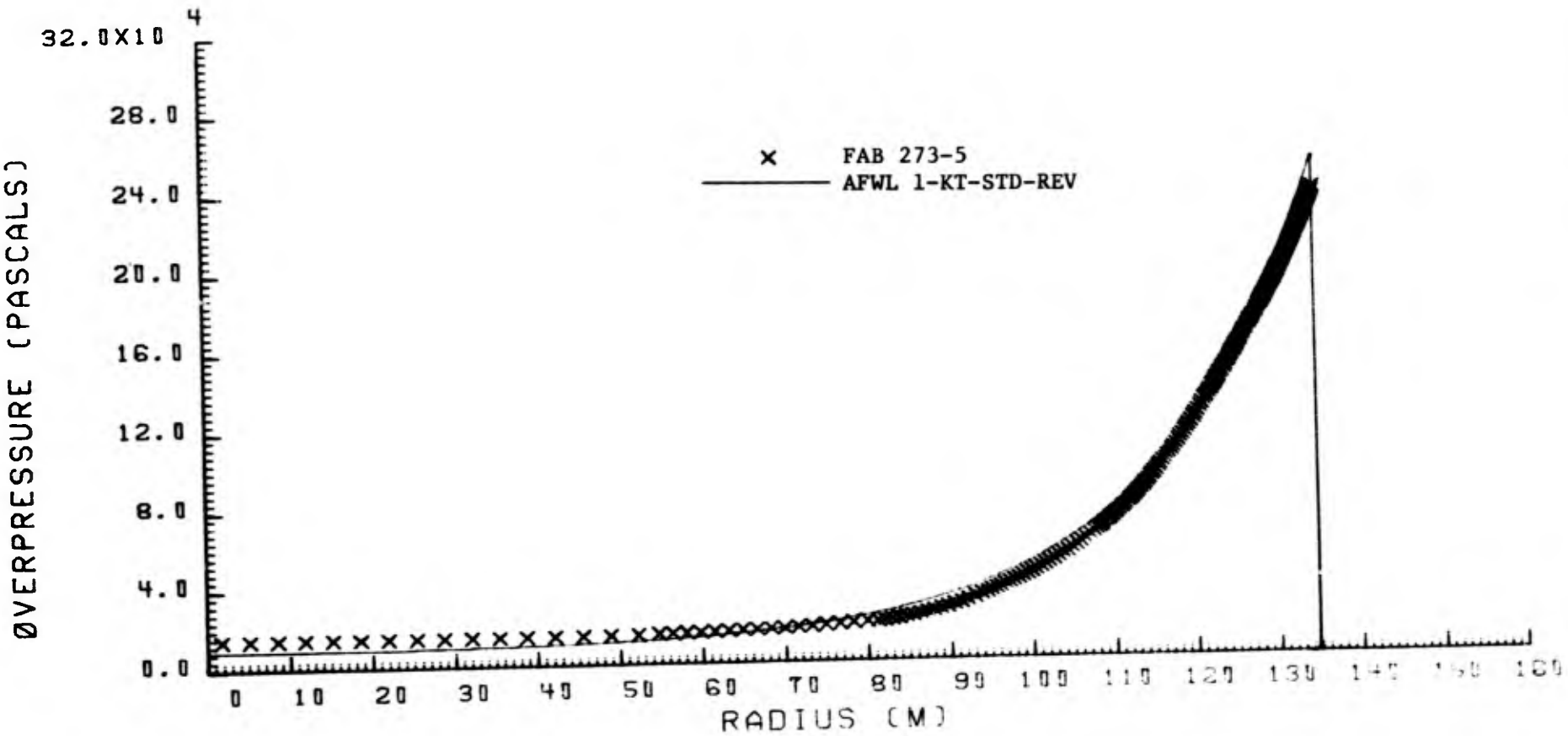


Figure 4. Comparisons of Pressure, Density and Velocity Distributions at 0.102 Seconds After Detonation.

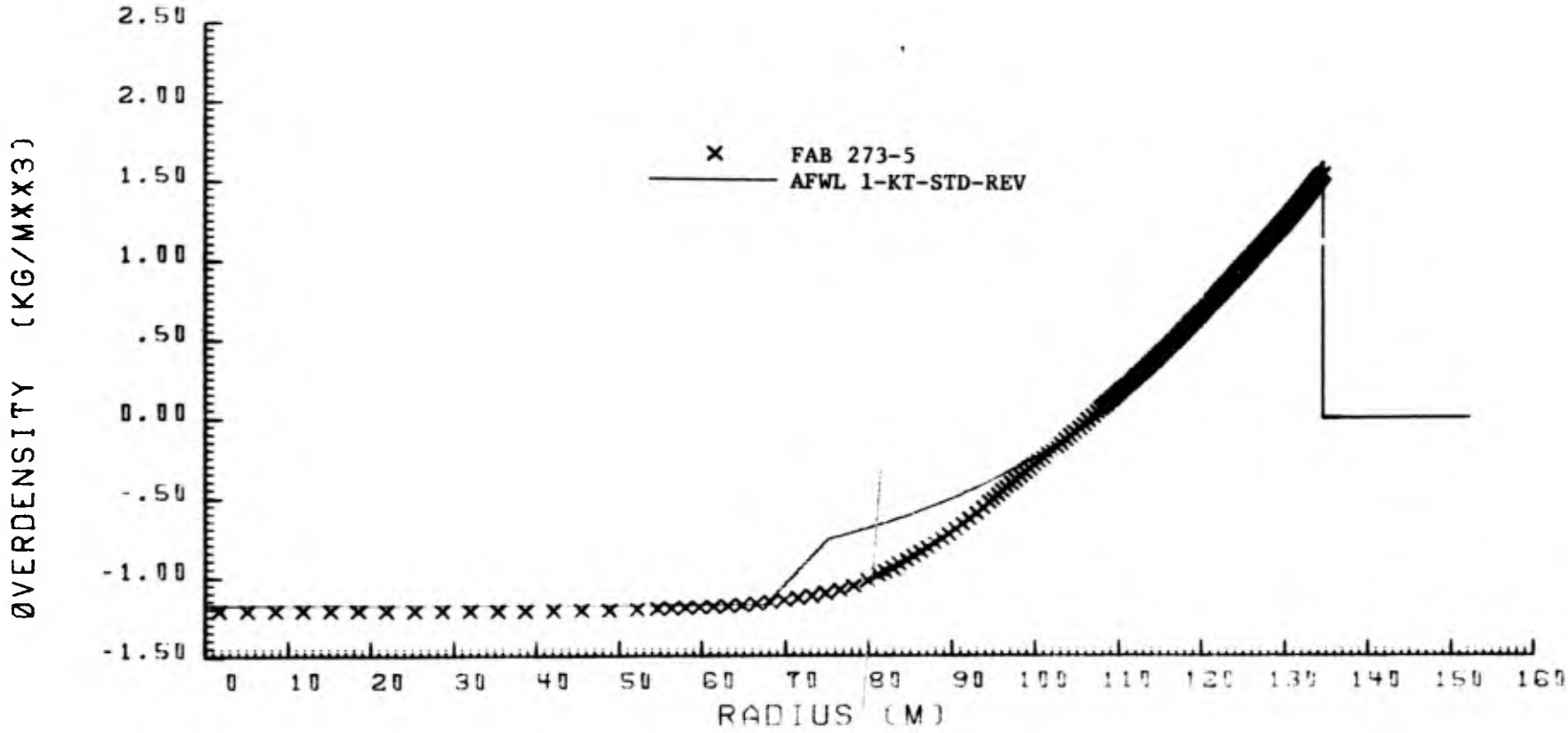


Figure 4. Continued.

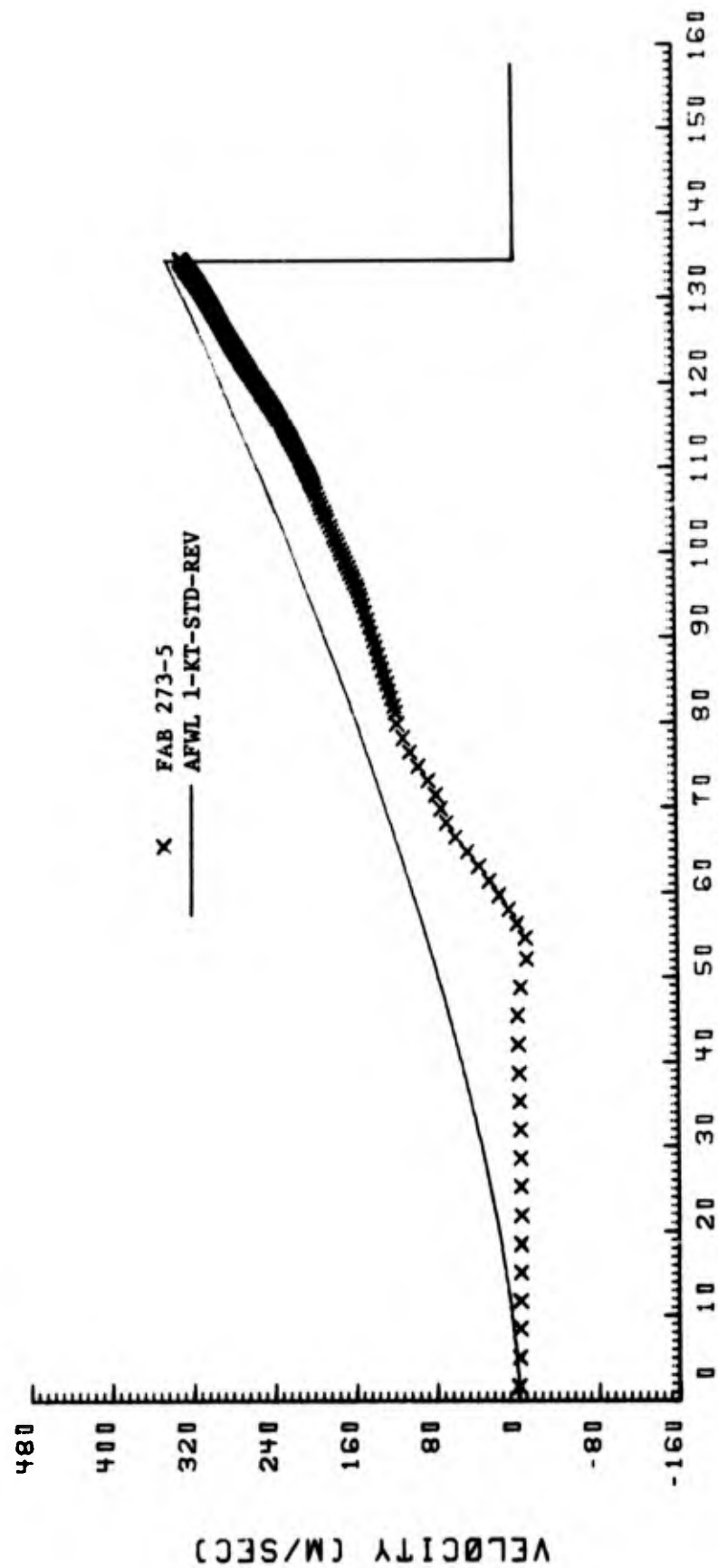


Figure 4. Concluded.

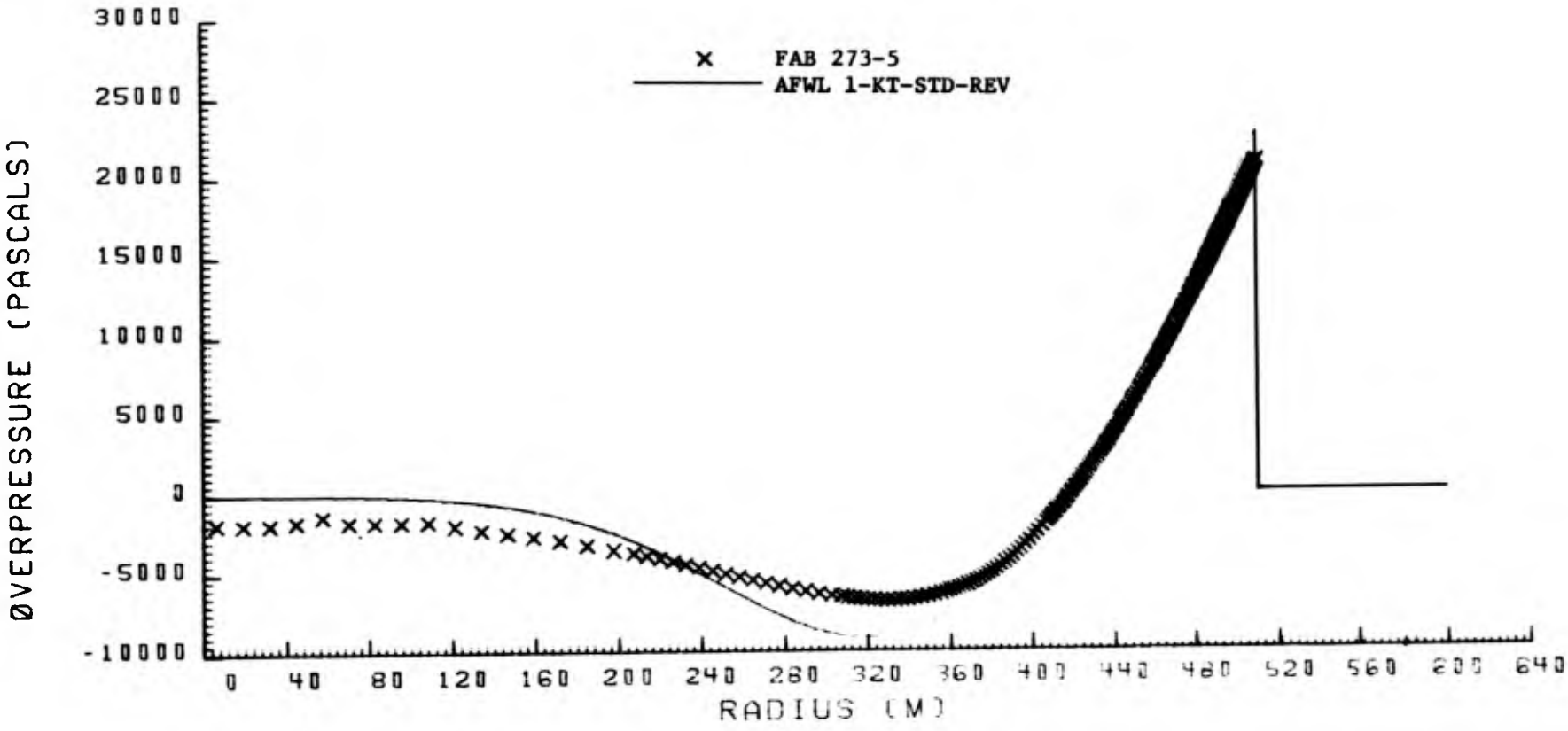


Figure 5. Comparisons ot Pressure, Density and Velocity Distributions at 1.020 Seconds After Detonation.

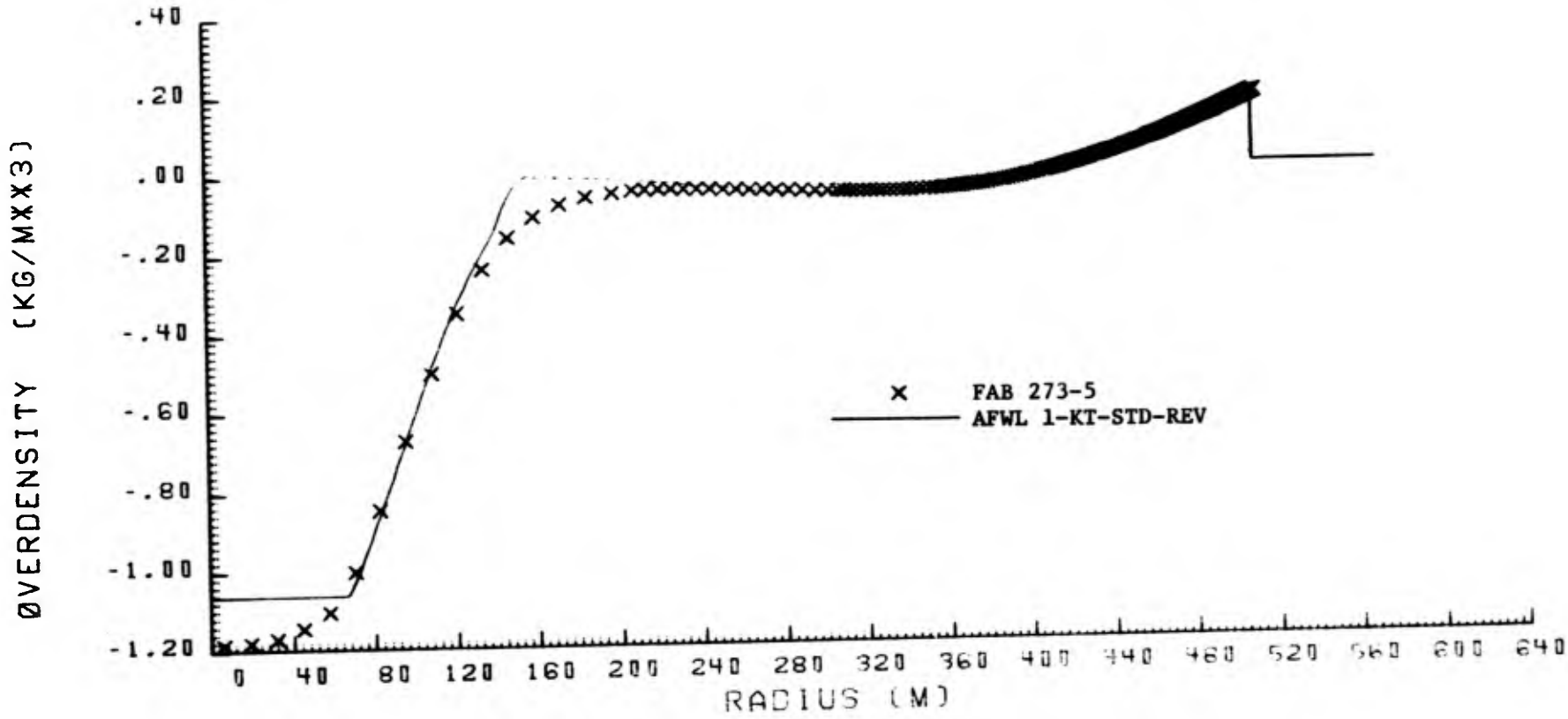


Figure 5. Continued.

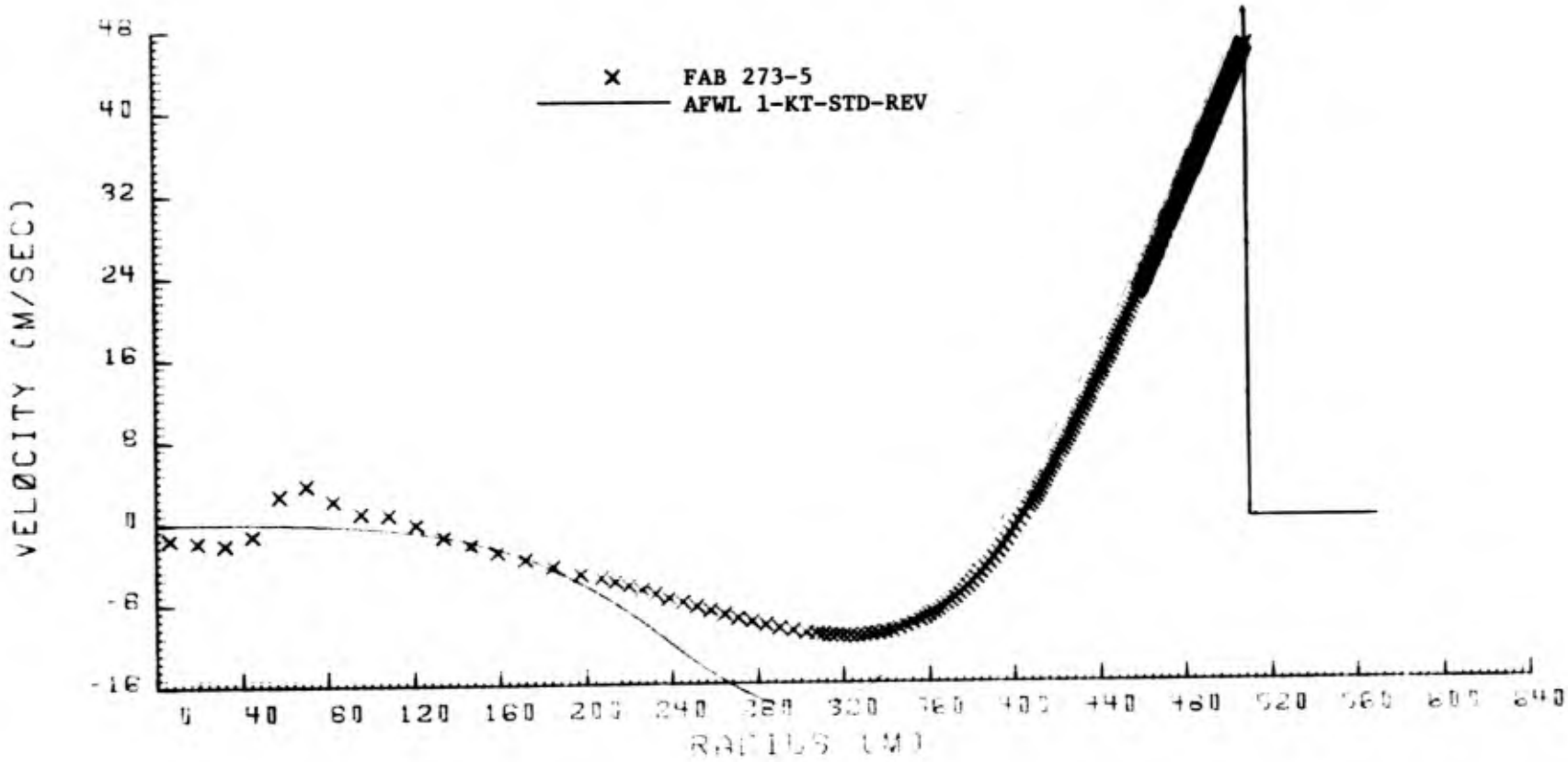


Figure 5. Concluded.

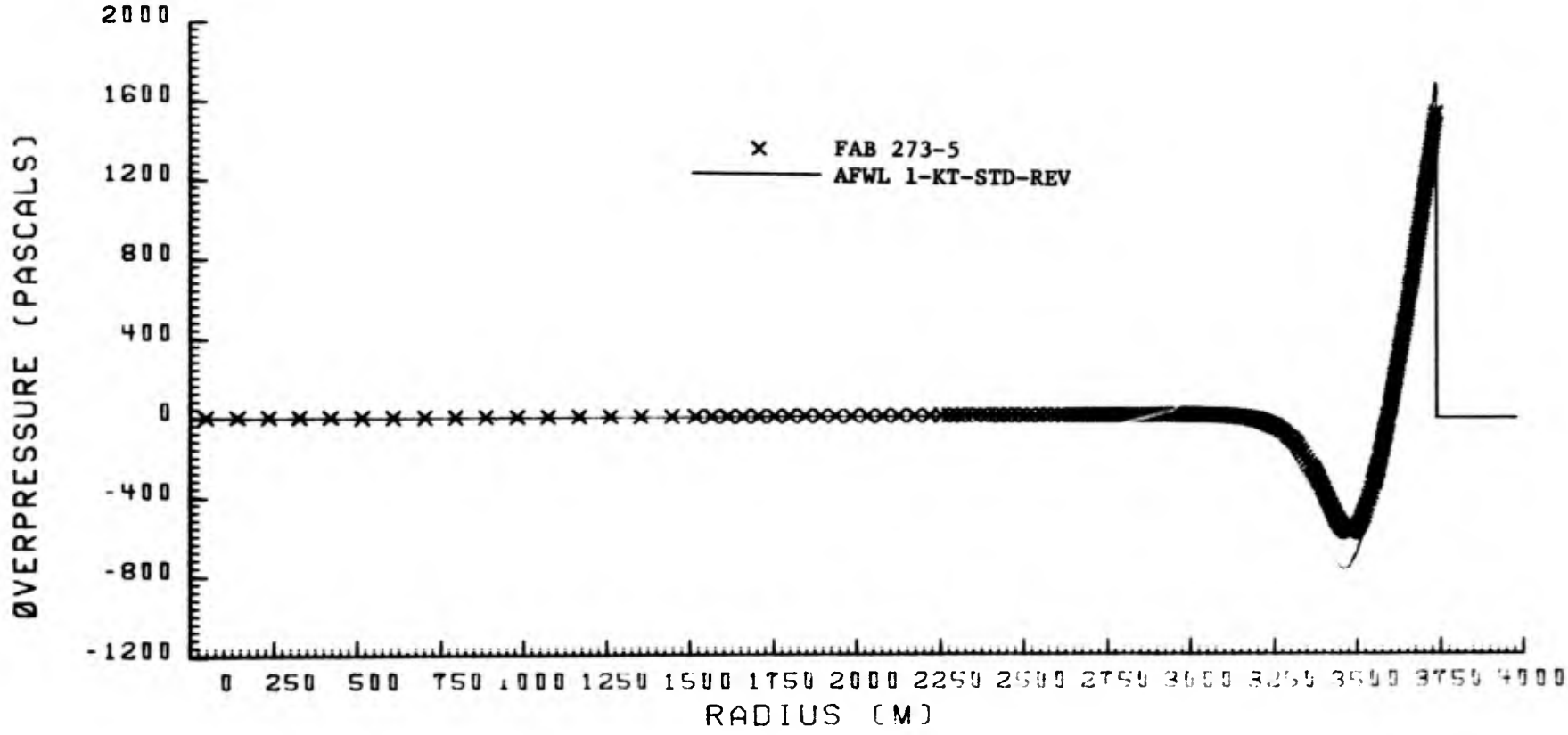


Figure 6. Comparisons of Pressure, Density and Velocity Distributions at 10.32 Seconds After Detonation.

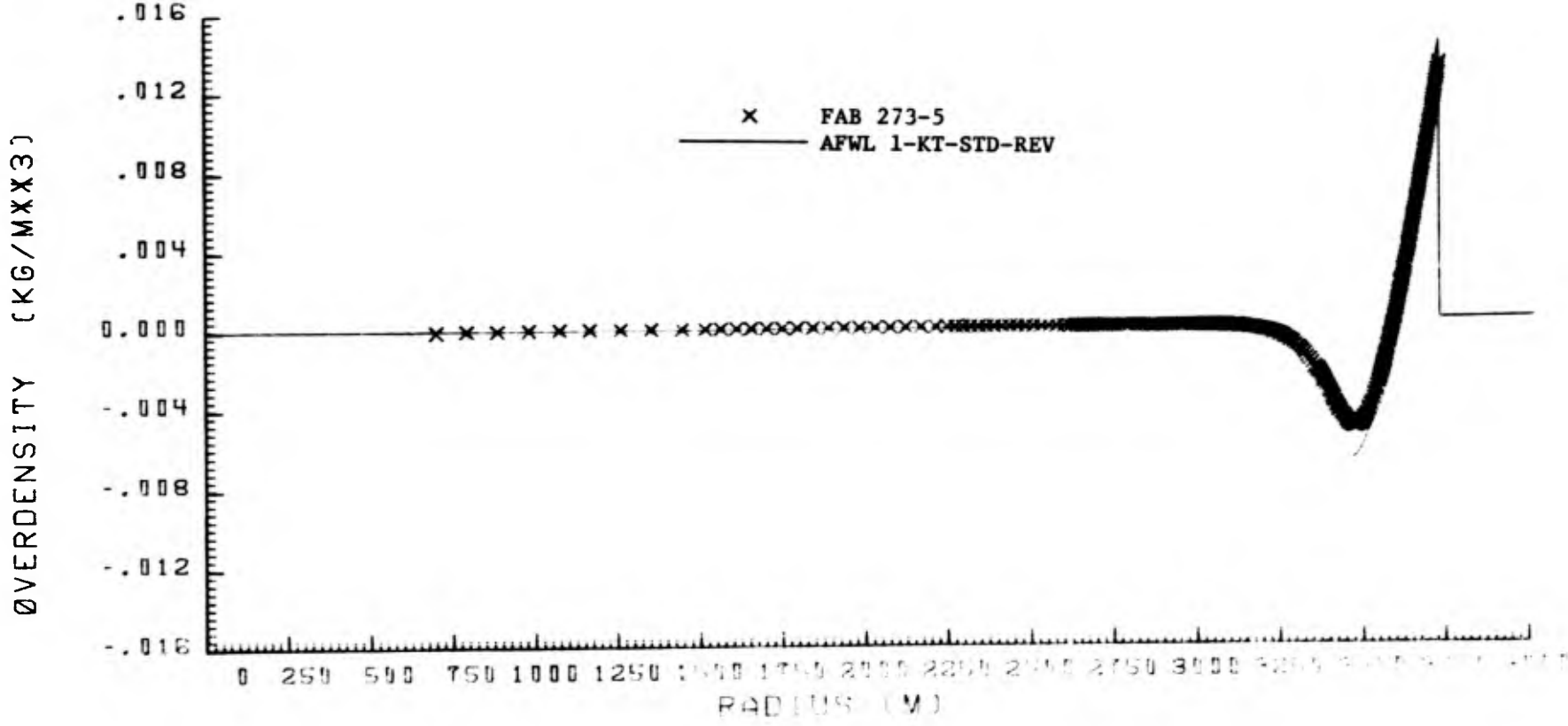


Figure 6. Continued.

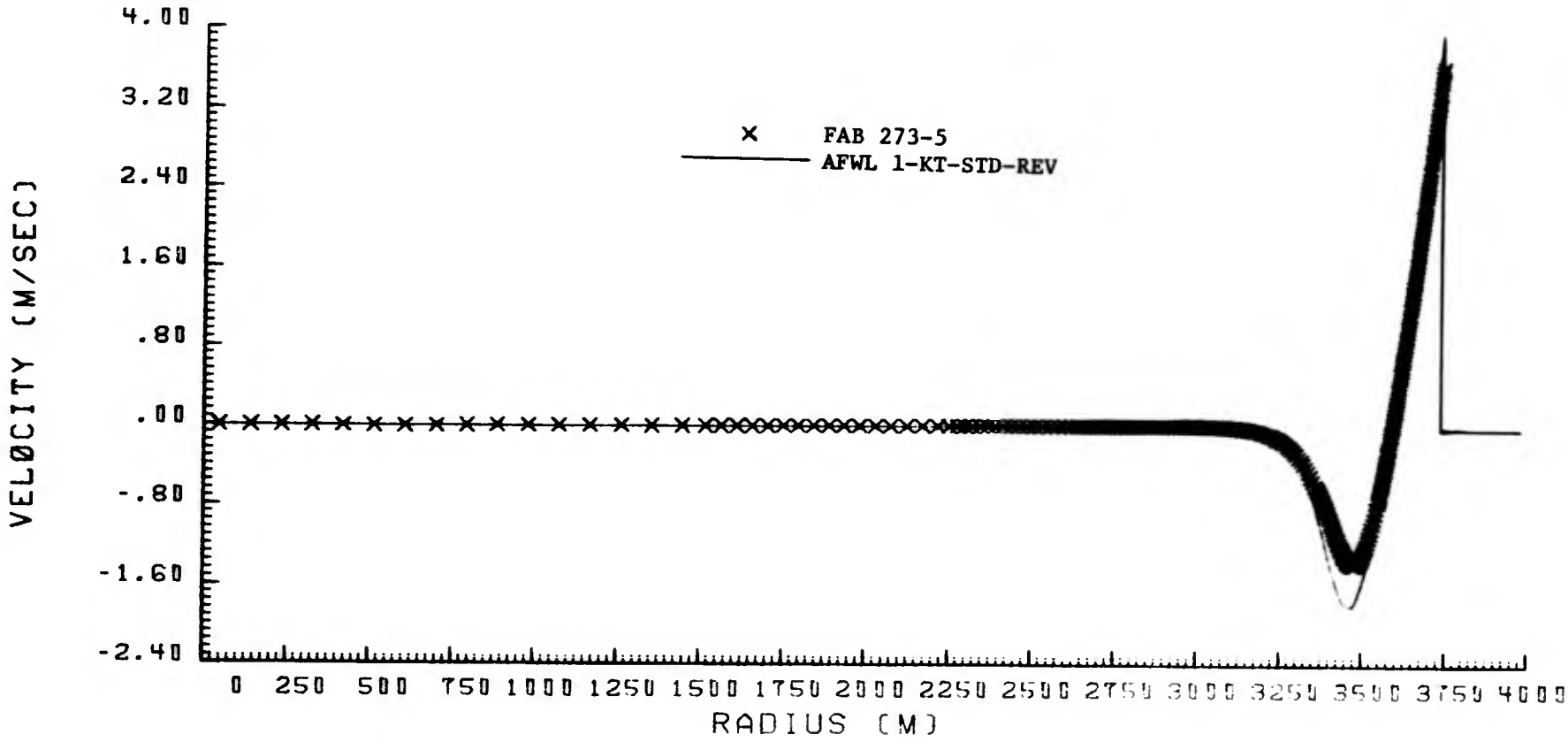


Figure 6. Concluded.

# SECTION 5
# COMPARISONS WITH OTHER PREDICTIONS AND TEST DATA

This section presents a comparison of FAB code predictions with the commonly used nuclear test data summaries, U.S.-'59-STD (Ref. 2), representing ground based measurements, and the combined Airborne-Measurement data representation given in Table 3.2-6 of Reference 2. Also compared are the predictions of the Revised AFWL 1-KT Standard (Ref. 7) and the NOL WUNDY Code (Ref. 5).

Tables 5 to 9 and Figures 2 to 6 present comparisons of the various code predictions and test data summaries for shock front radii from 175 to 50,000 feet, corresponding to overpressures from 380 to 0.04 psi.

## 5-1 SHOCK FRONT PRESSURES.

Considering first the shock front pressures, Figure 2 and Table 5 present a comparison of shock overpressures as given by the FAB code (interpolated to the indicated radii for the table), by other prediction methods and by nuclear test data summaries.

### 5-1.1 Equation-of-State.

Comparing the results of the FAB code results for the two different equations of state used (Brode 1965 and Doan-Nickel), it can be seen from Figure 2 or Table 5 that there is little difference in the computed overpressures using these two equations-of-state. Overpressure differences are generally below 1 percent at the highest overpressures and below about 0.02 psi at the lowest overpressures.

### 5-1.2 Initial Conditions.

In order to determine the effect of initial blast field conditions on FAB code results, code runs were made for two different inputs (at 10 msec. after detonation), one run (134-18) with input conditions from the AFWL-1KT-STD-REV (Ref. 7) and another (134-19) with input conditions from a Sputter code run (Usertape FB21, Ref. 13).

Table 5.

COMPARISON OF SHOCK FRONT PRESSURES

| RADIUS (FT) | OVERPRESSURE (PSI) | | | | |
|---|---|---|---|---|---|
| | U.S.-'59-STD | FAB-273-5 (BRODE EQ. STATE) | FAB-273-7 (DOAN-NICKEL EQ. STATE) | AIRBORNE MEASUREMENT POLYNOMIALS | AFWL 1-KT-STD (REV.) |
| 175.0 | 360.000 | 371.883 | 371.178 | | 379.037 |
| 200.0 | 246.000 | 257.092 | 256.508 | | 263.771 |
| 225.0 | 186.000 | 186.813 | 186.692 | | 192.635 |
| 250.0 | 144.000 | 141.446 | 141.452 | | 146.148 |
| 275.0 | 107.000 | 110.618 | 110.493 | | 114.352 |
| 300.0 | 88.800 | 88.730 | 88.297 | | 91.778 |
| 325.0 | 73.500 | 72.550 | 71.828 | | 75.246 |
| 350.0 | 62.700 | 60.260 | 59.334 | | 62.817 |
| 375.0 | 54.500 | 50.822 | 49.722 | | 53.262 |
| 400.0 | 46.600 | 43.205 | 42.283 | | 45.770 |
| 450.0 | 36.400 | 32.607 | 31.918 | | 34.961 |
| 500.0 | 29.300 | 25.848 | 25.350 | | 27.700 |
| 550.0 | 24.100 | 21.219 | 20.885 | | 22.596 |
| 600.0 | 20.200 | 17.798 | 17.579 | | 18.871 |
| 650.0 | 17.200 | 15.174 | 15.025 | | 16.068 |
| 700.0 | 14.800 | 13.123 | 13.016 | | 13.902 |
| 750.0 | 12.900 | 11.495 | 11.410 | | 12.192 |
| 800.0 | 11.300 | 10.184 | 10.114 | | 10.816 |
| 850.0 | 9.900 | 9.111 | 9.050 | | 9.689 |
| 900.0 | 8.800 | 8.222 | 8.166 | | 8.754 |
| 950.0 | 7.900 | 7.475 | 7.424 | | 7.968 |
| 1000.0 | 7.000 | 6.840 | 6.793 | 6.99 | 7.300 |
| 1105.0 | 5.630 | 5.772 | 5.739 | 5.95 | 6.183 |
| 1221.0 | 4.720 | 4.900 | 4.870 | 5.07 | 5.265 |
| 1350.0 | 3.970 | 4.174 | 4.145 | 4.33 | 4.500 |
| 1492.0 | 3.350 | 3.572 | 3.549 | 3.70 | 3.867 |
| 1649.0 | 2.830 | 3.067 | 3.048 | 3.18 | 3.335 |
| 1822.0 | 2.390 | 2.644 | 2.628 | 2.73 | 2.887 |
| 2014.0 | 2.030 | 2.283 | 2.272 | 2.35 | 2.505 |
| 2226.0 | 1.720 | 1.978 | 1.969 | 2.00 | 2.179 |
| 2460.0 | 1.470 | 1.718 | 1.712 | 1.75 | 1.901 |
| 2718.0 | 1.250 | 1.496 | 1.492 | 1.53 | 1.661 |
| 3004.0 | 1.070 | 1.304 | 1.322 | 1.34 | 1.453 |
| 3320.0 | .921 | 1.139 | 1.139 | 1.17 | 1.273 |
| 3669.0 | .792 | .997 | .998 | 1.03 | 1.117 |
| 4055.0 | .682 | .874 | .876 | 0.902 | .981 |

Table 5. Concluded.

COMPARISON OF SHOCK FRONT PRESSURES

| RADIUS (FT) | OVERPRESSURE (PSI) | | | | |
|---|---|---|---|---|---|
| | U.S.-'59-STD | FAB-273-5 (BRODE EQ. STATE) | FAB-273-7 (DOAN-NICKEL EQ. STATE) | AIRBORNE MEASUREMENT POLYNOMIALS | AFWL 1-KT-S1D (REV.) |
| 4482.0 | .589 | .767 | .770 | 0.793 | .862 |
| 4953.0 | .510 | .674 | .678 | 0.698 | .758 |
| 5474.0 | .442 | .592 | .596 | 0.615 | .667 |
| 6050.0 | .385 | .522 | .527 | 0.542 | .588 |
| 6686.0 | .335 | .460 | .466 | 0.478 | .518 |
| 7389.0 | .293 | .406 | .412 | 0.422 | .457 |
| 8166.0 | .256 | .358 | .365 | 0.374 | .403 |
| 9025.0 | .225 | .316 | .324 | 0.331 | .356 |
| 9974.0 | .197 | .282 | .294 | 0.293 | .314 |
| 11023.0 | .174 | .250 | | 0.260 | .278 |
| 12182.0 | .154 | .222 | | 0.231 | .246 |
| 13464.0 | .135 | .197 | | 0.205 | .218 |
| 14880.0 | .121 | .175 | | 0.183 | .193 |
| 16445.0 | .107 | .156 | | 0.163 | .171 |
| 18174.0 | .096 | .138 | | 0.145 | .151 |
| 20086.0 | .085 | .123 | | 0.129 | .134 |
| 22198.0 | .076 | .109 | | 0.116 | .119 |

Table 6.

EFFECT OF INITIAL CONDITIONS ON SHOCK FRONT PRESSURES

| RADIUS (FT) | OVERPRESSURE (PSI) | |
|---|---|---|
| | FAB-134-18 (1KT-STD INPUT) | FAB-134-19 (SPUTTER FB21 INPUT) |
| 200.0 | 256.358 | 252.088 |
| 225.0 | 186.257 | 187.931 |
| 250.0 | 141.050 | 140.695 |
| 275.0 | 110.310 | 108.117 |
| 300.0 | 88.479 | 86.478 |
| 325.0 | 72.311 | 71.542 |
| 350.0 | 60.064 | 59.935 |
| 375.0 | 50.689 | 50.780 |
| 400.0 | 43.137 | 43.416 |
| 450.0 | 32.601 | 32.982 |
| 500.0 | 25.836 | 26.150 |
| 550.0 | 21.176 | 21.390 |
| 600.0 | 17.754 | 17.896 |
| 650.0 | 15.143 | 15.232 |
| 700.0 | 13.106 | 13.155 |
| 750.0 | 11.488 | 11.510 |
| 800.0 | 10.182 | 10.185 |
| 850.0 | 9.112 | 9.101 |
| 900.0 | 8.223 | 8.203 |
| 950.0 | 7.475 | 7.448 |
| 1000.0 | 6.839 | 6.808 |
| 1105.0 | 5.775 | 5.738 |
| 1221.0 | 4.901 | 4.860 |
| 1350.0 | 4.173 | 4.132 |
| 1492.0 | 3.570 | 3.530 |
| 1649.0 | 3.065 | 3.027 |
| 1822.0 | 2.631 | 2.596 |
| 2014.0 | 2.271 | 2.240 |
| 2226.0 | 1.966 | 1.938 |
| 2460.0 | 1.706 | 1.681 |
| 2718.0 | 1.484 | 1.462 |
| 3004.0 | 1.293 | 1.274 |
| 3320.0 | 1.129 | 1.112 |
| 3669.0 | .987 | .972 |
| 4055.0 | .864 | .851 |

Table 6. Concluded.

EFFECT OF INITIAL CONDITIONS ON SHOCK FRONT PRESSURES

| RADIUS (FT) | OVERPRESSURE (PSI) | |
|---|---|---|
| | FAB-134-18 (1KT-STD INPUT) | FAB-134-19 (SPUTTER FB21 INPUT) |
| 4482.0 | .757 | .746 |
| 4953.0 | .664 | .654 |
| 5474.0 | .584 | .575 |
| 6050.0 | .513 | .506 |
| 6686.0 | .452 | .445 |
| 7389.0 | .398 | .392 |
| 8166.0 | .350 | .345 |
| 9025.0 | .309 | .304 |
| 9974.0 | .276 | .272 |
| 11023.0 | .246 | .243 |
| 12182.0 | .219 | .216 |
| 13464.0 | .194 | .191 |
| 14880.0 | .172 | .170 |
| 16445.0 | .153 | .151 |
| 18174.0 | .135 | .134 |
| 20086.0 | .120 | .119 |
| 22198.0 | .107 | .105 |
| 24532.0 | .095 | .093 |
| 27113.0 | .084 | .083 |
| 29964.0 | .074 | .074 |
| 33115.0 | .066 | .065 |
| 36598.0 | .059 | .058 |
| 40447.0 | .052 | .051 |
| 44701.0 | .046 | .046 |
| 50000.0 | .040 | .040 |

Table 7.

EFFECT OF INITIAL CONDITIONS ON SCALED SHOCK FRONT PRESSURES

| SCALED RADIUS ($FT/KT^{1/3}$) | OVERPRESSURE (PSI) | |
|---|---|---|
| | FAB-134-18 (1KT-STD INPUT) | FAB-134-19 (SPUTTER FB21 INPUT) |
| 200.0 | 249.977 | 253.227 |
| 225.0 | 181.738 | 188.915 |
| 250.0 | 137.708 | 141.479 |
| 275.0 | 107.709 | 108.694 |
| 300.0 | 86.439 | 86.894 |
| 325.0 | 70.644 | 71.872 |
| 350.0 | 58.729 | 60.222 |
| 375.0 | 49.523 | 51.021 |
| 400.0 | 42.174 | 43.625 |
| 450.0 | 31.926 | 33.151 |
| 500.0 | 25.335 | 26.261 |
| 550.0 | 20.780 | 21.478 |
| 600.0 | 17.430 | 17.968 |
| 650.0 | 14.871 | 15.293 |
| 700.0 | 12.875 | 13.206 |
| 750.0 | 11.290 | 11.553 |
| 800.0 | 10.010 | 10.222 |
| 850.0 | 8.961 | 9.134 |
| 900.0 | 8.089 | 8.232 |
| 950.0 | 7.356 | 7.475 |
| 1000.0 | 6.732 | 6.831 |
| 1105.0 | 5.687 | 5.757 |
| 1221.0 | 4.828 | 4.876 |
| 1350.0 | 4.113 | 4.145 |
| 1492.0 | 3.520 | 3.541 |
| 1649.0 | 3.023 | 3.036 |
| 1822.0 | 2.595 | 2.604 |
| 2014.0 | 2.241 | 2.246 |
| 2226.0 | 1.940 | 1.943 |
| 2460.0 | 1.684 | 1.686 |
| 2718.0 | 1.465 | 1.466 |
| 3004.0 | 1.277 | 1.277 |
| 3320.0 | 1.115 | 1.114 |
| 3669.0 | .975 | .974 |
| 4055.0 | .853 | .853 |

Table 7. Concluded.

EFFECT OF INITIAL CONDITIONS ON SCALED SHOCK FRONT PRESSURES

| SCALED RADIUS ($FT/KT^{1/3}$) | OVERPRESSURE (PSI) | |
|---|---|---|
| | FAB-134-18 (1KT-STD INPUT) | FAB-134-19 (SPUTTER FB21 INPUT) |
| 4482.0 | .748 | .748 |
| 4953.0 | .656 | .656 |
| 5474.0 | .577 | .576 |
| 6050.0 | .507 | .507 |
| 6686.0 | .446 | .446 |
| 7389.0 | .393 | .393 |
| 8166.0 | .346 | .346 |
| 9025.0 | .305 | .305 |
| 9974.0 | .273 | .273 |
| 11023.0 | .243 | .243 |
| 12182.0 | .216 | .216 |
| 13464.0 | .192 | .192 |
| 14880.0 | .170 | .170 |
| 16445.0 | .151 | .151 |
| 18174.0 | .134 | .134 |
| 20086.0 | .119 | .119 |
| 22198.0 | .105 | .105 |
| 24532.0 | .094 | .094 |
| 27113.0 | .083 | .083 |
| 29964.0 | .074 | .074 |
| 33115.0 | .065 | .065 |
| 36598.0 | .058 | .058 |
| 40447.0 | .051 | .051 |
| 44701.0 | .046 | .046 |
| 50000.0 | .040 | .040 |

Table 8.

EFFECTS OF THERMAL RADIATION ON SHOCK FRONT PRESSURES

| RADIUS (FT) | OVERPRESSURE (PSI) | | | |
|---|---|---|---|---|
| | RADIATION | NO RADIATION | | AFWL 1-KT-STD-REV |
| | FAB-134-18 | FAB-134-21 | NOL | |
| 175.0 | 370.997 | 370.998 | 386.624 | 379.037 |
| 200.0 | 256.358 | 256.358 | 268.013 | 263.771 |
| 225.0 | 186.257 | 186.258 | 202.266 | 192.635 |
| 250.0 | 141.050 | 141.069 | 151.850 | 146.148 |
| 275.0 | 110.310 | 110.431 | 118.717 | 114.352 |
| 300.0 | 88.479 | 88.771 | 93.316 | 91.778 |
| 325.0 | 72.311 | 72.712 | 76.126 | 75.246 |
| 350.0 | 60.064 | 60.502 | 63.105 | 62.817 |
| 375.0 | 50.689 | 51.164 | 53.960 | 53.262 |
| 400.0 | 43.137 | 43.649 | 46.747 | 45.770 |
| 450.0 | 32.601 | 33.287 | 36.029 | 34.961 |
| 500.0 | 25.836 | 26.703 | 28.757 | 27.700 |
| 550.0 | 21.176 | 22.025 | 23.431 | 22.596 |
| 600.0 | 17.754 | 18.485 | 19.616 | 18.871 |
| 650.0 | 15.143 | 15.780 | 16.602 | 16.068 |
| 700.0 | 13.106 | 13.677 | 14.358 | 13.902 |
| 750.0 | 11.488 | 12.012 | 12.730 | 12.192 |
| 800.0 | 10.182 | 10.667 | 11.309 | 10.816 |
| 850.0 | 9.112 | 9.562 | 10.141 | 9.689 |
| 900.0 | 8.223 | 8.642 | 9.066 | 8.754 |
| 950.0 | 7.475 | 7.865 | 8.208 | 7.968 |
| 1000.0 | 6.839 | 7.202 | 7.554 | 7.300 |
| 1105.0 | 5.775 | 6.090 | 6.386 | 6.183 |
| 1221.0 | 4.901 | 5.173 | 5.375 | 5.265 |
| 1350.0 | 4.173 | 4.408 | 4.576 | 4.500 |
| 1492.0 | 3.570 | 3.773 | 3.912 | 3.867 |
| 1649.0 | 3.065 | 3.240 | 3.356 | 3.335 |
| 1822.0 | 2.631 | 2.785 | 2.818 | 2.887 |
| 2014.0 | 2.271 | 2.402 | 2.432 | 2.505 |
| 2226.0 | 1.966 | 2.079 | 2.131 | 2.179 |
| 2460.0 | 1.706 | 1.804 | 1.835 | 1.901 |
| 2718.0 | 1.484 | 1.570 | 1.605 | 1.661 |
| 3004.0 | 1.293 | 1.368 | 1.403 | 1.453 |
| 3320.0 | 1.129 | 1.194 | 1.232 | 1.273 |
| 3669.0 | .987 | 1.043 | 1.075 | 1.117 |
| 4055.0 | .864 | .913 | 0.948 | .981 |

Table 8. Concluded.

EFFECTS OF THERMAL RADIATION ON SHOCK FRONT PRESSURES

| RADIUS (FT) | OVERPRESSURE (PSI) | | | |
|---|---|---|---|---|
| | RADIATION | NO RADIATION | | AFWL 1-KT-STD-REV |
| | FAB-134-18 | FAB-134-21 | NOL | |
| 4482.0 | .757 | .801 | .834 | .862 |
| 4953.0 | .664 | .703 | .735 | .758 |
| 5474.0 | .584 | .617 | .644 | .667 |
| 6050.0 | .513 | .543 | .568 | .588 |
| 6686.0 | .452 | .478 | .501 | .518 |
| 7389.0 | .398 | .421 | .443 | .457 |
| 8166.0 | .350 | .371 | .391 | .403 |
| 9025.0 | .309 | .327 | .346 | .356 |
| 9974.0 | .276 | .290 | .307 | .314 |
| 11023.0 | .246 | .259 | .272 | .278 |
| 12182.0 | .219 | .231 | .241 | .246 |
| 13464.0 | .194 | .205 | .213 | .218 |
| 14880.0 | .172 | .182 | .189 | .193 |
| 16445.0 | .153 | .161 | .167 | .171 |
| 18174.0 | .135 | .143 | .148 | .151 |
| 20086.0 | .120 | .127 | .132 | .134 |
| 22198.0 | .107 | .113 | .117 | .119 |
| 24532.0 | .095 | .100 | .104 | .106 |
| 27113.0 | .084 | .089 | .092 | .094 |
| 29964.0 | .074 | .079 | .081 | .084 |
| 33115.0 | .066 | .070 | .072 | .074 |
| 36598.0 | .059 | .062 | .064 | .066 |
| 40447.0 | .052 | .055 | .058 | .059 |
| 44701.0 | .046 | .049 | .051 | .052 |
| 50000.0 | .040 | .043 | .045 | .046 |

Table 9.

COMPARISON OF SHOCK ARRIVAL TIMES

| RADIUS (FT) | SHOCK ARRIVAL TIME (SECONDS) | | | | |
|---|---|---|---|---|---|
| | U.S.-'59-STD | FAB-273-5 (BRODE EQ. STATE) | FAB-273-7 (DOAN-NICKEL EQ. STATE) | AIRBORNE MEASUREMENT POLYNOMIALS | AFWL 1-KT-STD (REV.) |
| 175.0 | .01432 | .01378 | .01379 | | .01370 |
| 200.0 | .01954 | .01894 | .01895 | | .01883 |
| 225.0 | .02555 | .02509 | .02510 | | .02482 |
| 250.0 | .03235 | .03206 | .03207 | | .03168 |
| 275.0 | .04032 | .03985 | .03987 | | .03941 |
| 300.0 | .04903 | .04847 | .04851 | | .04799 |
| 325.0 | .05844 | .05793 | .05801 | | .05741 |
| 350.0 | .06853 | .06813 | .06828 | | .06762 |
| 375.0 | .07924 | .07905 | .07930 | | .07857 |
| 400.0 | .09055 | .09064 | .09103 | | .09021 |
| 450.0 | .11481 | .11576 | .11640 | | .11441 |
| 500.0 | .14105 | .14306 | .14396 | | .14110 |
| 550.0 | .16905 | .17216 | .17329 | | .16957 |
| 600.0 | .19860 | .20284 | .20418 | | .19925 |
| 650.0 | .22955 | .23487 | .23638 | | .23013 |
| 700.0 | .26173 | .26801 | .26967 | | .26240 |
| 750.0 | .29501 | .30222 | .30403 | | .29623 |
| 800.0 | .32929 | .33727 | .33922 | | .33111 |
| 850.0 | .36445 | .37313 | .37521 | | .36686 |
| 900.0 | .40041 | .40961 | .41183 | | .40339 |
| 950.0 | .43710 | .44673 | .44908 | | .44059 |
| 1000.0 | .47444 | .48437 | .48684 | .474 | .47838 |
| 1105.0 | .55500 | .56479 | .56755 | .554 | .55935 |
| 1221.0 | .64600 | .65560 | .65865 | .645 | .65102 |
| 1350.0 | .74900 | .75837 | .76174 | .747 | .75484 |
| 1492.0 | .86400 | .87326 | .87698 | .861 | .87095 |
| 1649.0 | .99400 | 1.00201 | 1.00611 | .990 | 1.00104 |
| 1822.0 | 1.14000 | 1.14550 | 1.15000 | 1.13 | 1.14599 |
| 2014.0 | 1.30000 | 1.30632 | 1.31125 | 1.29 | 1.30836 |
| 2226.0 | 1.48000 | 1.48541 | 1.49091 | 1.48 | 1.48908 |
| 2460.0 | 1.68000 | 1.68457 | 1.69047 | 1.68 | 1.68990 |
| 2718.0 | 1.90000 | 1.90555 | 1.91199 | 1.90 | 1.91244 |
| 3004.0 | 2.15000 | 2.15187 | 2.15891 | 2.14 | 2.16065 |
| 3320.0 | 2.43000 | 2.42533 | 2.43299 | 2.42 | 2.43603 |
| 3669.0 | 2.73000 | 2.72862 | 2.73695 | 2.72 | 2.74128 |
| 4055.0 | 3.07000 | 3.06528 | 3.07436 | 3.06 | 3.07993 |

Table 9. Concluded.

COMPARISON OF SHOCK ARRIVAL TIMES

| RADIUS (FT) | SHOCK ARRIVAL TIME (SECONDS) | | | | |
|---|---|---|---|---|---|
| | U.S.-'59-STD | FAB-273-5 (BRODE EQ. STATE) | FAB-273-7 (DOAN-NICKEL EQ. STATE) | AIRBORNE MEASUREMENT POLYNOMIALS | AFWL 1-KT-STD (REV.) |
| 4482.0 | 3.45000 | 3.43890 | 3.44877 | 3.43 | 3.45555 |
| 4953.0 | 3.86000 | 3.85216 | 3.86290 | 3.84 | 3.87086 |
| 5474.0 | 4.32000 | 4.31041 | 4.32208 | 4.30 | 4.33120 |
| 6050.0 | 4.83000 | 4.81812 | 4.83080 | 4.81 | 4.84105 |
| 6686.0 | 5.40000 | 5.37976 | 5.39354 | 5.37 | 5.40490 |
| 7389.0 | 6.02000 | 6.00160 | 6.01655 | 5.99 | 6.02902 |
| 8166.0 | 6.71000 | 6.68988 | 6.70609 | 6.68 | 6.72050 |
| 9025.0 | 7.47000 | 7.45178 | 7.46934 | 7.44 | 7.48532 |
| 9974.0 | 8.32000 | 8.29447 | 8.31355 | 8.28 | 8.35114 |
| 11023.0 | 9.25000 | 9.22688 | | 9.22 | 9.26694 |
| 12182.0 | 10.29000 | 10.25795 | | 10.25 | 10.30171 |
| 13464.0 | 11.43000 | 11.39932 | | 11.39 | 11.44714 |
| 14880.0 | 12.69000 | 12.66085 | | 12.65 | 12.71311 |
| 16445.0 | 14.09000 | 14.05597 | | 14.04 | 14.11310 |
| 18174.0 | 15.64000 | 15.59811 | | 15.59 | 15.66061 |
| 20086.0 | 17.34000 | 17.30429 | | 17.29 | 17.37270 |
| 22198.0 | 19.23000 | 19.18973 | | 19.18 | 19.26467 |

The initial pressure distribution and total energy for these two input conditions were about the same, but the absolute densities and temperatures were considerably different in some regions of the blast field, by about a factor of two near the center of the blast field. Overpressures obtained from these two FAB runs, interpolated to the same radii conditions, are compared in Table 6.

The overpressures for the two input calculations in Table 6 are seen to differ slightly, with differences generally being less than 2 percent. For low overpressures below about 3 psi the difference can be attributed to the about 3 percent yield differences for the two runs (see Table 1). If the code results for these two runs are reduced by standard cube root scaling to a 1-KT basis, as presented in Table 7, the code results for the two different inputs are seen to be essentially identical for overpressures below about 4 psi.

5-1.3 Comparisons with Nuclear Test Data Summaries.

The FAB shock overpressure results are compared in Figure 2 and Table 5 with the nuclear test data summaries presented in Reference 2, the U.S.-'59-STD and an Airborne-Measurement Summary (Tables 3.2-7 and 3.2-6, respectively, of Ref. 2). Also shown for comparison are the AFWL revised 1-KT-STD values. The columns in Table 5 are arranged from left to right in order of ascending shock overpressure at the 1 psi level.

The FAB initial conditions, as mentioned, were generally taken from the AFWL 1-KT-STD-REV values at 0.010 seconds, when the blast radius is 153.6 ft.

At a shock radius of 175 ft (360 psi), the shock overpressure for the FAB results with the Brode equation of state is 3 percent higher than the U.S.-'59-STD value. The 1-KT-STD-REV value is 5 percent above the U.S.-'59-STD value. At a 600 ft blast radius (about 20 psi) the 1-KT-STD-REV and FAB (Brode eq. state) values are respectively 7 and 13 percent below the U.S.-'59-STD values. Below about 20 psi shock overpressure the FAB (Brode eq. state) and 1-KT-STD-REV values increase relative to the U.S.-'59-STD values, being in good agreement at 1000 ft (7 psi) where they are respectively 2 percent below and 4 percent above.

The Airborne Measurement shock overpressure value from Reference 2 is in agreement with the U.S.-'59-STD value at 1000 ft (7 psi). In the overpressure range below 7 psi the U.S.-'59-STD values decrease markedly relative to the Airborne Measurement values. At 2226, 3669 and 14,880 ft where the airborne data are respectively 2.00, 1.03 and 0.183 psi, the U.S.-'59-STD values are respectively 14, 23 and 34 percent less. In this low shock overpressure range from 2 to 0.18 psi the FAB results are only 1 to 4 percent below the airborne data and the 1-KT-STD values are 5 to 9 percent higher than the airborne data.

Predictions of the NOL WUNDY code, shown in Figure 2 (see also Table 8), like those for the AFWL 1-KT-STD-REV, exceed the nuclear test data summaries for overpressures below about 7 psi, due in part to neglect of thermal radiation in the WUNDY code, as is discussed below.

5-1.4 Thermal Radiation.

Since some free-air burst codes such as the NOL WUNDY code do not take into account thermal radiation, it appeared useful to make FAB code runs with and without consideration of thermal radiation to evaluate the importance of this radiation effect. Results of these runs are presented in Table 8 together with predictions of the NOL WUNDY code and the AFWL 1-KT-STD-REV. It is evident by comparison of the FAB results in this table that if thermal radiation is neglected the predicted overpressures are generally about 5 percent too high in the below 10 psi overpressure range. With regard to the NOL WUNDY predictions, which neglect thermal radiation, this observation suggests that the NOL predictions can be expected to be about 5 percent too high in the below 10 psi overpressure range. This suggestion is also supported by the fact that the no-radiation FAB results in Table 9 (for Run 134-21) are in much better agreement with the NOL predictions than are the FAB results with radiation taken into account.

5-1.5 Shock Arrival Time.

Shock arrival time according to the various predictions and test data are compared in Table 9 for ranges from 175 to 22,198 feet. Generally all predicted arrival times are seen to be in reasonable agreement with each other and with the test data summaries.

## 5-2 PRESSURE, DENSITY AND VELOCITY DISTRIBUTIONS.

Overpressure, overdensity and material velocity distributions from the FAB code (Run 573-5) are compared with the corresponding distributions of the AFWL Revised 1-KT Standard in Figures 4 to 6 for times of shock arrival of about 0.1, 1 and 10 seconds after detonation. (The initial conditions for this FAB run were taken from the 1-KT-STD-REV distributions presented in Figure 3 for 0.01 second after detonation.) These distributions correspond to shock front overpressure levels of 34, 3.0 and 0.22 psi (or 235, 21 and 1.5 kilopascals), respectively, at shock radii of 441, 1671 and 12,252 ft (or 135, 509 and 3734 meters).

The two sets of distributions shown in Figures 4 to 6 are seen to be in reasonably good agreement with each other in most respects. Some noticeable differences are seen particularly in the overpressure and velocity distributions at 0.1 and 1 second after detonation (34 and 3 psi shock front overpressure levels) but in the absence of an absolute test data standard, no conclusion can be drawn from this comparison as to which set of distributions is more realistic.

# SECTION 6
# CONCLUSIONS

The FAB hydrodynamic computer code has been developed to compute the blast flow characteristics of a nuclear free-air burst. Runs made with this code for a 1-KT burst at sea level and comparisons of code results with other predictions and nuclear test data summaries indicate the following conclusions.

1. The shock front overpressures predicted by the FAB code are generally close to or between the overpressures for the two groups of nuclear test data summaries as represented by the U.S.-'59-STD and the combined airborne measurement polynomials in DASA 1200.

2. The shock overpressure at a range of 1000 feet is essentially 7.00 psi according to both the U.S.-'59 empirical curve and the airborne measurement polynomials of DASA 1200. The FAB results, using the Brode (1965) equation-of-state, and the AFWL 1-KT-Standard (Revised) function essentially agree with these data, being respectively only 2 percent lower and 4 percent higher. At ranges from 2,226 to 14,880 feet, where the shock overpressure is 2.00 to 0.183 psi according to the airborne measurement data, the U.S.-'59 standard is 14 to 34 percent below the corresponding airborne value. The FAB results in this range are 1 to 4 percent lower than the airborne measurement values and the AFWL 1-KT-Standard (Rev.) values are 5 to 9 percent higher.

3. FAB shock front overpressure calculations using two different air equations-of-state (Brode 1965 and Doan-Nickel) give essentially the same results.

4. FAB shock front overpressures computed from different initial conditions (using inputs from AFWL 1-KT-STD-REV and Sputter FB21, for 0.010 seconds after detonation) give somewhat different results for early times, differences generally below 2 percent, but are in excellent agreement for overpressures below about 4 psi.

5. Comparison of FAB results with NOL WUNDY results indicates that the major differences may be attributed to the neglect of thermal radiation in the WUNDY code. It is shown that WUNDY predictions of shock front overpressures are probably about 5 percent too high at overpressures below 10 psi due to the omission of thermal radiation.

# SECTION 7
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