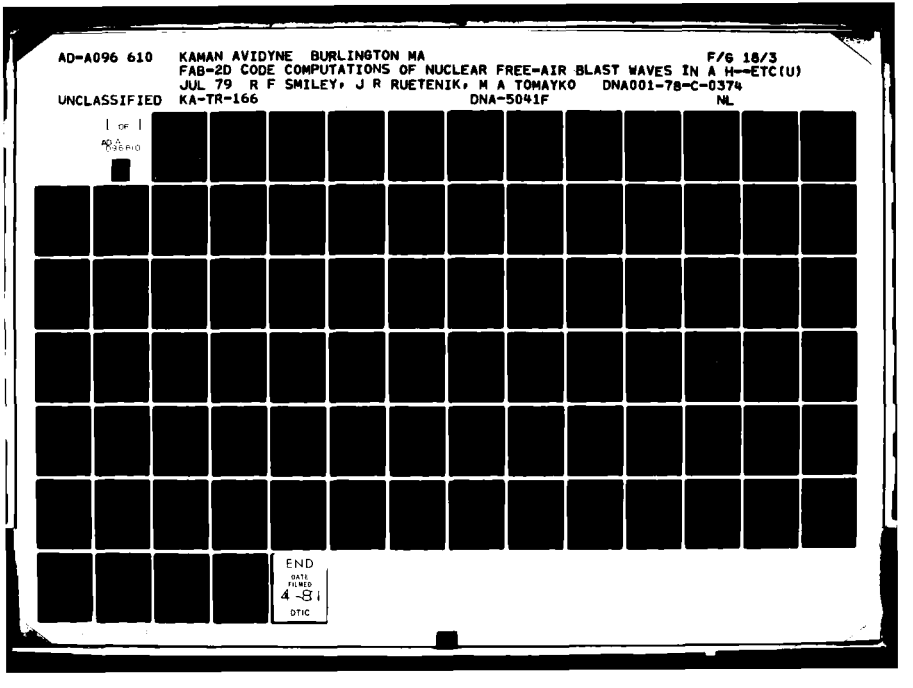
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FAB-2D CODE COMPUTATIONS OF NUCLEAR FREE-AIR BLAST WAVES IN A HORIZONTALLY STRATIFIED STANDARD ATMOSPHERE

Kaman AviDyne
83 Second Avenue
Burlington, Massachusetts 01803

16 July 1979

Final Report for Period 1 March 1979—16 July 1979

CONTRACT No. DNA 001-78-C-0374

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

The FAB-2D two-dimensional hydrodynamic computer code was developed for computing the blast flow characteristics of a nuclear free-air blast wave in a non-homogeneous atmosphere. 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 are represented by Brode's (1965) equation of state. Thermal radiation is taken into account.

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20. ABSTRACT (Continued)

Numerical results are presented for overpressure, dynamic pressure, positive impulses, positive pressure durations and arrival times for a 1-KT burst in a uniform sea-level atmosphere, a 1-KT burst at a 1000-ft height-of-burst and a 1-MT burst at a 10,000-ft height of burst, both in a standard non-homogenous atmosphere.

Blast parameters for the case of a uniform atmosphere are generally in good agreement with predictions of the one-dimensional FAB code.

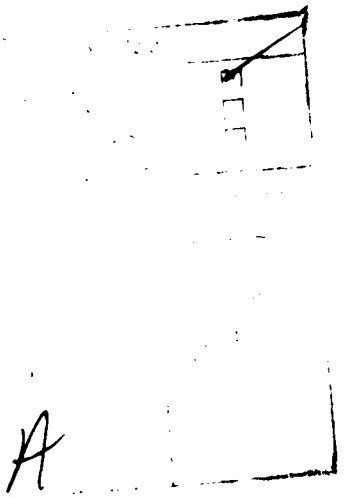
Blast properties calculated by the FAB-2D code are generally in good agreement with the corresponding properties obtained by modified Sachs scaling (MSS) of predictions of the one-dimensional FAB code, especially for altitudes near to or below the burst altitude. For a 1-MT burst at altitudes well above the burst altitude the MSS FAB overpressures and dynamic pressures are somewhat larger than the corresponding FAB-2D pressures. Blast overpressures and dynamic pressures from the FAB-2D code are generally less than those obtained by MSS scaling of results from the AFWL-1-KT-STD-REV code.

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. The authors appreciate the considerable contributions made toward the success of this project by the following Kaman AviDyne personnel: Dr. Hobbs and Messrs. Thomas A. Dalton, William N. Lee, Thomas R. Stagliano and Garabed Zartarian.

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	gree 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

This report is concerned with the problem of accurately predicting the blast effects of a nuclear explosion in a horizontally stratified non-homogeneous atmosphere. It differs from previous work in this area in that the problem is analyzed here by a basically two-dimensional code (FAB-2D), obtained by generalizing the FAB one-dimensional code of Reference 1, which represents the blast front as a sharp shock. Blast properties are computed to overpressure levels down to as low as 0.1 psi.

This study was undertaken because the previously existing methods for predicting the blast effects of nuclear explosions (e.g., see References 2-5) have not yet been demonstrated to provide a fully reliable and practical method for taking into account the effects of the non-homogeneous ("exponential") atmosphere on blast properties to low overpressure levels. Present prediction methods generally consist of a basically one-dimensional theory or an empirical test data base which is adapted to the two-dimensional non-homogeneous atmosphere case in one of several ways.

Probably the best known adaption approach is to relate blast effects in a non-homogeneous atmosphere to those in a uniform atmosphere by the method of modified Sachs scaling (e.g., see References 2, 3 or 4). This approach is easy to apply and has been supported for some conditions by the theoretical studies of References 3 and 4. Those theoretical studies also indicate some conditions where modified Sachs scaling is less accurate (see also Reference 5), but since the theories are approximations in themselves they do not provide a firm basis for assessing the reliability and limitations of modified Sachs scaling.

With regard to experimental evidence, shock overpressure tower data from nuclear tests, as modified Sachs scaled to sea-level conditions and represented by the U.S.-'59 data in Reference 2, have been compared

with predictions of the FAB and AFWL-1-KT-STD-REV codes (see Reference 1). For both codes, large differences in shock overpressures have been found between the code predictions and the test data for overpressures below about 7 psi. The question arises whether modified Sachs scaling may be in error or whether some other effect of the atmosphere such as an inversion layer near the ground may alter the blast wave.

A second useful approach to non-homogeneous atmospheric effects on nuclear blast effects is provided by Naval Ordance Laboratory methods (e.g., see Reference 2), which take into account the variation of atmospheric properties through use of analytical studies of the one-dimensional problem of an explosion in a spherically symmetric non-uniform atmosphere.

Other more simplified approaches to the non-homogeneous atmosphere blast problem are discussed in Reference 2.

The rest of this report presents a description of the FAB-2D computer code in Section 2, a summary of calculational results for 1-KT and 1-MT bursts in Section 3, and an evaluation of the reliability of the modified Sachs scaling method in Section 4. Conclusions are presented in Section 5.

SECTION 2
THE FAB-2D CODE

2-1 GENERAL DESCRIPTION OF CODE.

The FAB-2D computer code was developed as a generalization of the FAB-1D code of Reference 1* to solve the axially symmetrical two-dimensional transient fluid-flow problem of the expansion of an initially prescribed flow into an initially undisturbed horizontally stratified atmosphere, including gravitational effects. In the present application this code deals specifically with the problem of modeling the fluid flow produced by the detonation of a nuclear explosion in a non-homogeneous horizontally stratified standard atmosphere.

The code computes the flow in a moving cell coordinate system similar to the one shown in Figure 1. The cell system consists of an arbitrary number of "sectors",** 5 indicated in Figure 1 (designated J=1 to 5) each of which is subdivided into an arbitrary number of axi-symmetrical radial toroidal-like cells, as illustrated in the figure for sector 2 (J=2) for a 5 radial cell configuration (I=1 to 5). Cell dimensions and distances are expressed in terms of the radial distance r and the polar angle θ, with the origin of coordinates being taken at the burst point.

The outer boundary of the cell system represents the outer limit of the disturbed flow region, which is initially specified and grows radially thereafter for each sector according to the speed of the shock wave created between the outermost cell of the sector and the local outer undisturbed atmosphere. The inner and outer boundaries of all cells, such as aa', bb' in Figure 1, 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 for the same polar angle.

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*The FAB code of Reference 1 is referred to hereafter as the FAB-1D code to emphasize the one-dimensional character of this code compared to the FAB-2D code.

**These shapes are not precisely true sectors in that their outer boundaries deviate slightly from circular arcs.

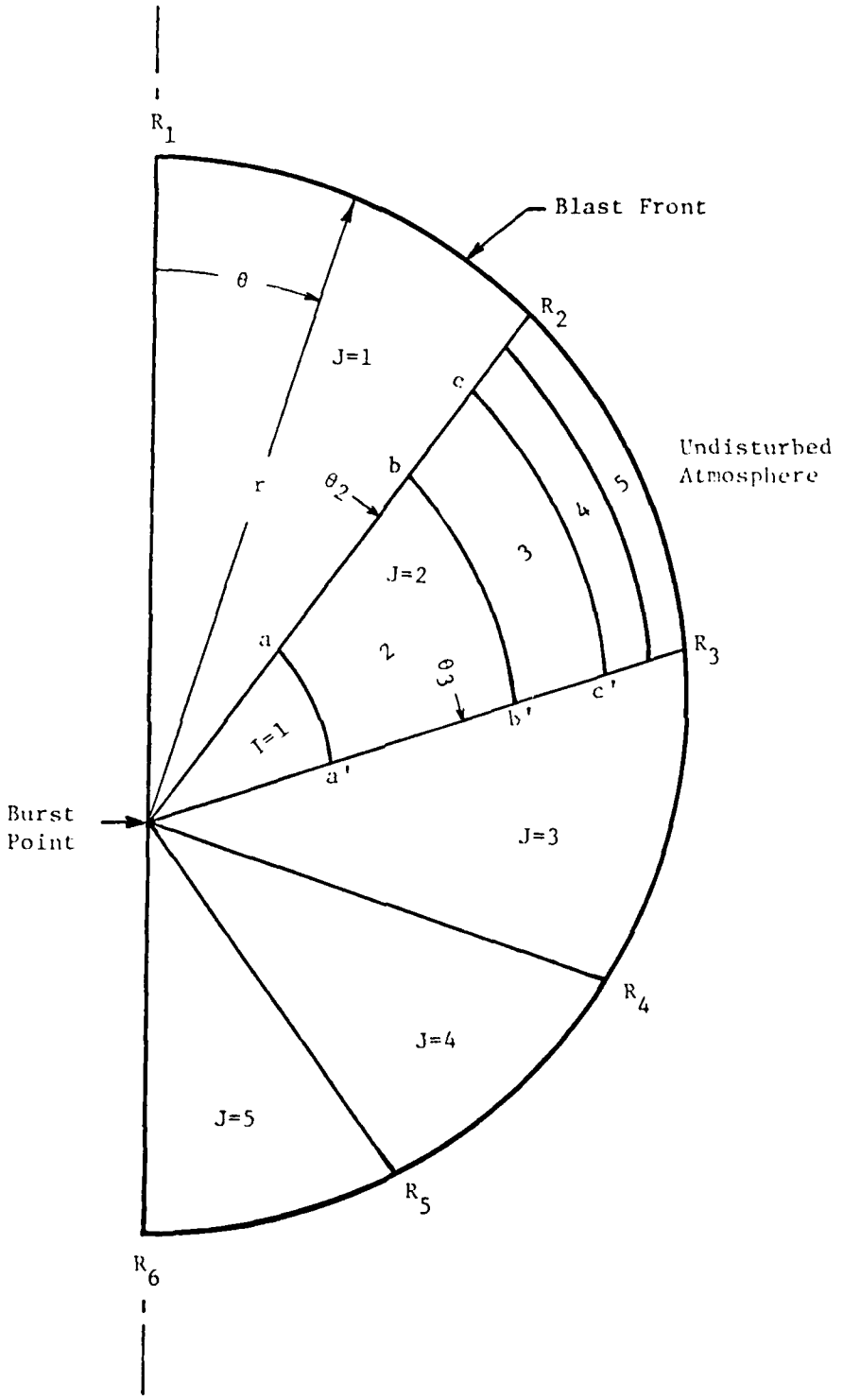


Figure 1. Sketch Illustrating the FAB-2D Model.

Within each sector the radius from the origin of coordinates to the curved circumferential cell boundaries (aa', etc.) is taken to vary linearly with the polar angle between the values at the two rays designating the sector boundaries.

Except for effects of gravity (discussed below) the pressure, density and velocity components in each cell (abb'a'a, etc.), as expressed in spherical polar coordinates, are taken to be constant throughout the cell.

The flow between adjacent cells in the moving coordinate system is computed using the Godunov technique (e.g., see Reference 6 or 7) in a manner similar to that previously used in nuclear blast-field calculations by Thompson and Ruetenik (Reference 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 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.

Gravitational potential energy is taken into account in computing the flux of energy across cell boundaries and the gravitation force is taken into account in the momentum equations. In addition, because of very large cell sizes experienced in late time blast calculations, it proved necessary to take into account the vertical variation of the pressure and density between cell centers and boundaries due to the gravitational force. This pressure variation (Δp) was calculated as $\Delta p = \rho g \Delta z$, where Δz is the vertical distance from the center of the cell to the center of a cell boundary. The corresponding density variation was taken as an isentropic function of the pressure variation (with γ=1.4).

The code assumes a real air medium with thermodynamic equation-of-state properties given by Brode's 1965 analytical representation (Reference 9).

In addition to hydrodynamic phenomena, the code takes into account the thermal radiation of a nuclear blast, with the total radiation flux computed as a function of time according to Reference 10 and the spatial distribution of radiated energy being calculated according to the model used in Reference 11.

Input to the code consists of the specification of the initial pressure, density and velocity in the entire disturbed fluid field. These initial conditions are presently generated from early-time predictions of the AFWL Nuclear Blast Standard (1KT) code (Reference 12).

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

The FAB-2D code has been run primarily on a CDC CYBER 176 computer. The code has a core requirement of 123K octal SCM and 400K octal LCM for a 5000 cell configuration. Approximately 200 CP minutes are required for a complete run with 4290 cells. This is discussed further in Section 3-2.

2-2 SHOCK FRONT PROPERTIES.

The procedure used to determine shock front properties from the code results for presentation here is described below.

Studies of the FAB-1D code results indicated that, because of the finite thickness of the cells, slightly greater accuracy can be achieved in determining the shock overpressures at the lowest overpressures by linear extrapolation of the cell pressures to the outer boundary of the outer cell, rather than simply using the pressure for the outermost cell. The improvement is greatest at the lowest overpressures and amounts to at most a few percent.

With the 273 radial cells used in the FAB-1D code calculations of Reference 1, shock overpressures accurate within about 0.01 psi were obtained down to 0.1 psi overpressure by taking the pressure in the

outer cell as the shock pressure. A comparable accuracy was achieved in the present calculations using the FAB-2D code with 110 cells by linear extrapolation of the pressure in the outermost cells near the shock front. The effect is only important at the lowest shock overpressures where the small error can be reduced to below one percent. The shock front properties presented in this report were determined in this way.

SECTION 3
FAB-2D CODE RUNS

This section describes and lists the principal FAB-2D runs made, presents selected numerical results for three runs with a 110 radial cell configuration, and presents some comparable modified Sachs scaled one-dimensional code results. Code reliability is tested here by comparisons of FAB-2D and FAB-1D code predictions for the case of a 1-KT burst in a uniform atmosphere.

3-1 CELL CONFIGURATIONS.

Developmental runs were made with the FAB-2D code for a large variety of cell configurations, covering from 3 to 39 sectors and from 37 to 110 radial cell groups up to a maximum of 39 sectors with 110 radial groups for a total of 4290 cells. These runs were made primarily to determine the minimum number of sectors to be used to achieve accurate predictions. It was found that 19 sectors were required for prediction of overpressure effects of a 1 KT burst at an altitude of 1000 ft for overpressures down to about 0.2 psi and that 39 sectors were required for a 1 MT burst at an altitude of 10,000 ft.

The principal FAB-2D code runs made are listed in Table 1. The radial cell size distribution of the 110 cell groups used is listed in Table 2, where cell radial widths are listed in order of increasing distance from the origin of coordinates. Cell radial widths were selected so that absolute pressure changes between adjacent cells did not generally exceed about 2 percent.

In addition to the FAB-2D code runs several runs were made with the FAB-1D code (Reference 1). These runs included 1 KT and 1 MT sea level runs made with the same 110 radial cell configuration used for the FAB-2D runs. These FAB-1D results were used as one set of reference conditions to compare with the FAB-2D results.

TABLE 1

FAB-2D CODE

BLAST WAVE CALCULATIONS

CASE NO	CODE RUN NO	CELL CONFIGURATION (SECTORSxRAD.CELLS)	YIELD[a] (KT)	ALTITUDE (FT)	ATMOSPHERE	TIME AFTER BURST (SEC) START	TIME AFTER BURST (SEC) STOP
1	46	9 x 110	1.029	0	UNIFORM[b]	0.010	20
2	45	19 x 110	1.029	1,000	U.S. 62[c]	0.010	20
3	44	39 x 110	1,035	10,000	U.S. 62[c]	0.117	200

[a]Initial conditions taken from AFWL 1-KT-STD-REV blast wave model, Reference 12, modified Sachs scaled to nominal yields of 1-KT or 1-MT for the indicated atmosphere and altitude at the indicated start time. Yields computed on the basis of 1-KT = 4.189×10^{19} erg. The actual yields shown here differ slightly from the nominal yields because the equation of state for air used in this report differs slightly from that used in Reference 12.

[b]Ambient pressure and density taken as 2117 psfa and 0.002378 s/ft^3.

[c]1962 U.S. Standard temperate atmosphere as modelled in Reference 12.

TABLE 2

CELL CONFIGURATION FOR PRINCIPAL FAB-2D CODE RUNS

CELL RADIAL WIDTH (PERCENT OUTER RADIUS)	NO. CELLS THIS WIDTH
10[a]	2
6	2
4	2
3.5	2
3.0	3
2.0	6
1.125	4
1.0	6
0.7	5
0.5	8
0.45	10
0.225	20
0.125[b]	40

[a]Innermost cells

[b]Outermost cells

3-2 COMPUTER TIME.

The computer time required, in terms of the central processor (CP) time, was found to be essentially proportional to the number of sectors and nearly proportional to the square of the number of radial cells. The accuracy of the calculations was found to improve by increasing the number of sectors and radial cells. The number of sectors and cells must be increased together to accomplish an increase in accuracy while maintaining a minimum of CP time.

The CP times used for calculation of the 1-KT burst at a 1,000 ft altitude (Run 45) and the 1-MT burst at a 10,000 ft altitude (Run 44) were respectively 3.5 and 1.3 hours. The calculations were performed to post-burst times of 20 and 200 seconds, respectively.

3-3 ACCURACY.

The "internal" accuracy of the calculations with respect to effects of number of sectors and cells used was established by making many developmental runs in which the cell configurations were varied, primarily by varying the number of sectors and number of radial cells, as well as their distributions in the radial direction.* Analysis of these results enabled the assessment of the internal accuracy of the final runs.

The internal accuracy of the calculations with reference to peak shock overpressure for the 1-KT burst at 1,000 feet altitude was one percent or better down to an overpressure of 0.15 psi. For the 1-MT burst at 10,000 feet the one-percent accuracy extends down to an overpressure of 0.2 psi.

The internal accuracy of the positive overpressure duration for the final runs is found to be generally within one percent out to the overpressure limits given above.

---

*Internal accuracy as defined and discussed here covers the major sources of error which have been observed in running the FAB-2D code which can be discussed in a quantitative manner. There are, however, some indications of other sources of small errors associated with code details which are not covered by this internal accuracy appraisal.

The overall accuracy of the code remains to be tested by comparison with test data. This would be accomplished through comparison with nuclear test data.

3-4 CODE RESULTS FOR PRINCIPAL RUNS.

Results of the principal FAB-2D code runs for the 110 cell configuration have been recorded on magnetic tapes. Tables 3 to 5 and Figures 2 to 18 present representative data interpolated from these run results in a form convenient for comparison with other results. Figures 2 to 6 and Table 3 present results for a nominal 1-KT burst in a uniform sea-level atmosphere, neglecting gravity effects (Run 46). Figures 7, 9, 11, 13, 15 and 17 and Table 4 present FAB-2D results for a nominal 1-KT burst in a non-homogeneous atmosphere at a 1000-ft altitude. Figures 8, 10, 12, 14, 16 and 18 and Table 5 present similar results for a 1-MT burst at a 10,000-ft altitude.

Tables 4 and 5 and Figures 7 and 8 present shock overpressures as functions of altitude and range from the burst point. Figures 9 to 18 present altitude-range contours for shock dynamic pressure (Figures 9 and 10), positive overpressure impulse (Figures 11 and 12), positive dynamic pressure impulse (Figures 13 and 14), duration of positive overpressure (Figures 15 and 16) and time of shock arrival (Figures 17 and 18).

Also presented in Tables 4 and 5 and Figures 7 to 18 are modified Sachs scaled (MSS) data based on FAB-1D code results or 1D predictions of the AFWL-1-KT-STD-REV code (Reference 12). These 2D and modified Sachs scaled 1D results are compared and discussed in Section 4.

3-5 COMPARISON OF FAB-2D AND FAB-1D CODES.

As an initial test of the reliability of the FAB-2D code, Table 3 and Figure 2 present comparisons of FAB-2D and FAB-1D predicted shock front overpressures versus slant range for the case of a nominal 1-KT sea-level burst in a uniform atmosphere. The FAB-2D results are

TABLE 3

COMPARISON OF SHOCK OVERPRESSURES

FOR A 1-KT BURST IN A UNIFORM

SEA LEVEL ATMOSPHERE FROM THE

FAB-2D AND FAB-1D CODES

Run 46 for the FAB-2D Code (110 radial cells);

Run FAB 273-5 from Ref. 1 for the FAB-1D Code (273 rad. cells).

YIELD = 1KT; SEA LEVEL BURST

SLANT RANGE (FT)	OVERPRESSURE (PSI)	
	FAB-1D Run 273-5	FAB-2D Run 46
175	371.883	372.001
200	257.092	256.948
225	186.813	186.619
250	141.446	141.404
275	110.618	110.594
300	88.730	88.670
325	72.550	72.435
350	60.260	60.154
375	50.822	50.768
400	43.205	43.226
450	32.607	32.704
500	25.848	25.922
550	21.219	21.218
600	17.798	17.775
650	15.174	15.155
700	13.123	13.117
750	11.495	11.501
800	10.184	10.197
850	9.111	9.129
900	8.222	8.241
950	7.475	7.493
1000	6.840	6.857
1105	5.772	5.791
1221	4.900	4.915
1350	4.174	4.185
1492	3.572	3.581
1649	3.067	3.074
1822	2.644	2.650
2014	2.283	2.289
2226	1.978	1.983

YIELD = 1KT; SEA LEVEL BURST

SLANT RANGE (FT)	OVERPRESSURE (PSI)	
	FAB-1D Run 273-5	FAB-2D Run 46
2460	1.718	1.723
2718	1.496	1.500
3004	1.304	1.309
3320	1.139	1.144
3669	.997	1.001
4055	.874	.878
4482	.767	.771
4953	.674	.678
5474	.592	.597
6050	.522	.526
6686	.460	.464
7389	.406	.410
8166	.358	.362
9025	.316	.320
9974	.282	.283
11023	.250	.251
12182	.222	.222
13464	.197	.197
14880	.175	.175
16445	.156	.155
18174	.138	.138
20086	.123	.122
22198	.109	.108

TABLE 4

SHOCK FRONT OVERPRESSURES FROM THE FAB-2D CODE

AS A FUNCTION OF ALTITUDE AND SLANT RANGE

FOR A 1-KT BURST AT 1000-FT ALTITUDE

AND COMPARISONS WITH MODIFIED

SACHS SCALED 1D DATA

Run 45 for FAB-2D code;

Run FAB 110-50 for FAB-1D code;

both runs with 110 radial cells.

YIELD = 1 KT; HOB = 1 KFT: HOT = 0.0 KFT*

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
1000	7.300	6.861	6.853
1100	6.229	5.839	5.832
1200	5.412	5.058	5.053
1300	4.771	4.446	4.442
1400	4.257	3.955	3.951
1500	3.836	3.553	3.549
1600	3.485	3.219	3.216
1700	3.190	2.938	2.935
1800	2.937	2.699	2.696
1900	2.719	2.493	2.489
2000	2.530	2.313	2.310
2250	2.147	1.954	1.951
2500	1.859	1.685	1.682
2750	1.635	1.477	1.474
3000	1.456	1.312	1.309
3250	1.310	1.177	1.175
3500	1.188	1.066	1.064
3750	1.086	.973	.971
4000	0.998	.894	.892
4500	0.857	.767	.765
5000	0.749	.670	.668
5500	0.663	.593	.591
6000	0.594	.532	.530
6500	0.537	.481	.479
7000	0.489	.438	.437
8000	0.413	.372	.370
9000	0.357	.322	.320
10000	0.313	.283	.281
11000	0.279	.252	.250
12000	0.250	.226	.225

*HOB designates burst altitude; HOT designates target altitude.

YIELD = 1 KT; HOB = 1 KFT: HOT = 0.0 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
13000	0.227	.206	.204
14000	0.207	.188	.187
15000	0.191	.173	.172
16000	0.176	.160	.159
17000	0.164	.149	.148
18000	0.153	.139	.139
19000	0.143	.131	.130
20000	0.135	.123	.122
22500	0.117	.107	.107

YIELD = 1 KT; HOB = 1 KFT: HOT = 0.5 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
500	27.563	25.801	25.743
550	22.474	21.112	21.058
600	18.762	17.680	17.636
650	15.969	15.072	15.034
700	13.812	13.042	13.011
750	12.110	11.432	11.406
800	10.740	10.134	10.112
850	9.619	9.070	9.051
900	8.689	8.185	8.169
950	7.907	7.441	7.427
1000	7.243	6.808	6.796
1100	6.178	5.792	5.782
1200	5.366	5.017	5.009
1300	4.730	4.409	4.402
1400	4.219	3.921	3.915
1500	3.801	3.522	3.517
1600	3.454	3.191	3.186
1700	3.160	2.912	2.908
1800	2.910	2.674	2.670
1900	2.694	2.470	2.466
2000	2.505	2.292	2.288
2250	2.126	1.936	1.932
2500	1.841	1.669	1.666
2750	1.619	1.463	1.460
3000	1.441	1.299	1.296
3250	1.296	1.166	1.164
3500	1.176	1.056	1.054
3750	1.075	.963	.962
4000	0.988	.885	.883
4500	0.849	.759	.758

YIELD = 1 KT; HOB = 1 KFT: HOT = 0.5 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
5000	0.741	.663	.662
5500	0.656	.587	.586
6000	0.588	.526	.525
6500	0.531	.476	.475
7000	0.484	.434	.433
8000	0.409	.368	.367
9000	0.353	.318	.317
10000	0.310	.280	.279
11000	0.276	.249	.248
12000	0.248	.224	.223
13000	0.225	.203	.203
14000	0.205	.186	.186
15000	0.189	.171	.171
16000	0.175	.159	.158
17000	0.162	.148	.147
18000	0.151	.138	.138
19000	0.142	.129	.129
20000	0.133	.122	.122
22500	0.116	.106	.106

YIELD = 1 KT; HOB = 1 KFT: HOT = 1.0 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
175	377.846	371.176	370.912
200	262.796	256.402	256.044
225	191.814	185.996	185.897
250	145.443	140.758	140.781
275	113.736	110.019	110.067
300	91.233	88.184	88.208
325	74.758	72.048	72.019
350	62.377	59.755	59.739
375	52.860	50.492	50.398
400	45.402	42.956	42.867
450	34.645	32.442	32.381
500	27.426	25.668	25.627
550	22.353	20.993	20.952
600	18.654	17.575	17.536
650	15.872	14.978	14.941
700	13.724	12.958	12.924
750	12.028	11.356	11.326
800	10.665	10.063	10.037
850	9.550	9.005	8.981
900	8.624	8.125	8.105
950	7.847	7.385	7.367
1000	7.186	6.755	6.739
1100	6.127	5.746	5.733
1200	5.321	4.975	4.965
1300	4.689	4.371	4.362
1400	4.182	3.887	3.879
1500	3.767	3.491	3.485
1600	3.422	3.162	3.157
1700	3.131	2.886	2.880
1800	2.882	2.650	2.645

YIELD = 1 KT; HOB = 1 KFT: HOT = 1.0 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
1900	2.668	2.447	2.443
2000	2.481	2.270	2.267
2250	2.106	1.917	1.914
2500	1.823	1.653	1.650
2750	1.603	1.448	1.446
3000	1.427	1.286	1.284
3250	1.283	1.154	1.152
3500	1.164	1.045	1.044
3750	1.064	.954	.952
4000	0.978	.876	.875
4500	0.840	.751	.750
5000	0.734	.656	.655
5500	0.649	.581	.580
6000	0.581	.521	.520
6500	0.525	.471	.470
7000	0.479	.429	.429
8000	0.405	.364	.363
9000	0.350	.315	.315
10000	0.307	.277	.277
11000	0.273	.246	.246
12000	0.245	.222	.222
13000	0.222	.201	.201
14000	0.203	.184	.184
15000	0.187	.169	.170
16000	0.173	.157	.157
17000	0.160	.146	.146
18000	0.150	.136	.137
19000	0.140	.128	.128
20000	0.132	.120	.121
22500	0.115	.105	.105

YIELD = 1 KT; HOB = 1 KFT: HOT = 1.5 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
500	27.290	25.538	25.513
550	22.233	20.875	20.848
600	18.547	17.470	17.437
650	15.775	14.886	14.848
700	13.635	12.874	12.837
750	11.947	11.280	11.245
800	10.590	9.994	9.962
850	9.480	8.940	8.912
900	8.560	8.065	8.040
950	7.787	7.329	7.307
1000	7.130	6.703	6.683
1100	6.077	5.700	5.683
1200	5.276	4.934	4.921
1300	4.648	4.334	4.323
1400	4.144	3.853	3.844
1500	3.733	3.460	3.452
1600	3.390	3.134	3.127
1700	3.102	2.859	2.853
1800	2.855	2.625	2.620
1900	2.643	2.424	2.419
2000	2.457	2.249	2.245
2250	2.085	1.899	1.896
2500	1.805	1.637	1.634
2750	1.587	1.434	1.432
3000	1.412	1.273	1.272
3250	1.270	1.142	1.141
3500	1.152	1.035	1.034
3750	1.053	.944	.943
4000	0.968	.867	.867
4500	0.831	.744	.743

YIELD = 1 KT; HOB = 1 KFT: HOT = 1.5 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
5000	0.726	.649	.649
5500	0.643	.575	.575
6000	0.575	.515	.515
6500	0.520	.466	.466
7000	0.474	.425	.425
8000	0.401	.360	.360
9000	0.346	.311	.312
10000	0.303	.274	.274
11000	0.270	.244	.244
12000	0.242	.219	.220
13000	0.220	.199	.200
14000	0.201	.182	.183
15000	0.185	.168	.168
16000	0.171	.155	.156
17000	0.159	.144	.145
18000	0.148	.135	.136
19000	0.139	.126	.127
20000	0.131	.119	.120
22500	0.113	.103	.105

YIELD = 1 KT; HOB = 1 KFT: HOT = 2.0 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
1000	7.074	6.652	6.627
1100	6.027	5.654	5.634
1200	5.231	4.894	4.877
1300	4.607	4.298	4.284
1400	4.107	3.820	3.809
1500	3.699	3.430	3.420
1600	3.359	3.106	3.098
1700	3.073	2.833	2.827
1800	2.828	2.601	2.595
1900	2.617	2.402	2.396
2000	2.434	2.228	2.224
2250	2.065	1.881	1.877
2500	1.787	1.621	1.618
2750	1.571	1.420	1.418
3000	1.398	1.260	1.259
3250	1.257	1.131	1.130
3500	1.140	1.024	1.024
3750	1.042	.934	.934
4000	0.958	.858	.858
4500	0.822	.736	.736
5000	0.718	.643	.643
5500	0.636	.569	.569
6000	0.569	.510	.510
6500	0.514	.461	.461
7000	0.469	.420	.421
8000	0.396	.356	.357
9000	0.342	.308	.309
10000	0.300	.271	.272
11000	0.267	.241	.242
12000	0.240	.217	.218

YIELD = 1 KT; HOB = 1 KFT: HOT = 2.0 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
13000	0.217	.197	.198
14000	0.199	.180	.181
15000	0.183	.166	.167
16000	0.169	.153	.155
17000	0.157	.143	.144
18000	0.147	.133	.135
19000	0.137	.125	.127
20000	0.129	.118	.119
22500	0.112	.102	.104

YIELD = 1 KT; HOB = 1 KFT: HOT = 3.0 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
2000	2.387	2.186	2.181
2250	2.024	1.845	1.841
2500	1.751	1.589	1.587
2750	1.539	1.392	1.391
3000	1.370	1.235	1.235
3250	1.232	1.108	1.108
3500	1.117	1.003	1.004
3750	1.020	.915	.916
4000	0.938	.841	.842
4500	0.805	.721	.722
5000	0.703	.629	.631
5500	0.623	.557	.599
6000	0.557	.499	.501
6500	0.504	.451	.453
7000	0.459	.411	.413
8000	0.388	.348	.350
9000	0.335	.301	.303
10000	0.294	.265	.267
11000	0.261	.236	.238
12000	0.235	.212	.215
13000	0.213	.193	.195
14000	0.194	.176	.179
15000	0.179	.162	.165
16000	0.165	.150	.153
17000	0.154	.140	.142

YIELD = 1 KT; HOB = 1 KFT: HOT = 3.0 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
18000	0.143	.130	.133
19000	0.134	.122	.125
20000	0.126	.115	.118
22500	0.110	.100	.103

YIELD = 1 KT; HOB = 1 KFT: HOT = 4.0 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
3000	1.342	1.211	1.211
3250	1.206	1.086	1.086
3500	1.094	.983	.984
3750	0.999	.897	.898
4000	0.919	.823	.825
4500	0.789	.706	.708
5000	0.689	.616	.619
5500	0.610	.545	.548
6000	0.546	.468	.491
6500	0.493	.441	.444
7000	0.449	.402	.405
8000	0.380	.341	.344
9000	0.328	.295	.297
10000	0.288	.259	.262
11000	0.256	.231	.233
12000	0.230	.208	.211
13000	0.208	.188	.192
14000	0.190	.172	.176
15000	0.175	.159	.162
16000	0.162	.147	.150
17000	0.150	.137	.140
18000	0.140	.128	.131
19000	0.131	.120	.123
20000	0.124	.113	.116
22500	0.107	.098	.101

TABLE 5

SHOCK FRONT OVERPRESSURES FROM THE FAB-2D CODE

AS A FUNCTION OF ALTITUDE AND SLANT RANGE

FOR A 1-MT BURST AT 10,000-FT ALTITUDE

AND COMPARISONS WITH MODIFIED

SACHS SCALED 1D DATA

Run 44 for FAB-2D code;

Run FAB 110-51 for FAB-1D code;

both runs with 110 radial cells.

YIELD = 1 MT; HOB = 10 KFT: HOT = 0 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
10000	7.300	7.045	7.043
11000	6.229	5.991	5.995
12000	5.412	5.187	5.193
13000	4.771	4.556	4.563
14000	4.257	4.050	4.056
15000	3.836	3.636	3.641
16000	3.485	3.293	3.296
17000	3.190	3.004	3.005
18000	2.937	2.758	2.757
19000	2.719	2.546	2.544
20000	2.530	2.362	2.358
22500	2.147	1.994	1.987
25000	1.859	1.719	1.710
27500	1.635	1.506	1.495
30000	1.456	1.337	1.325
32500	1.310	1.199	1.187
35000	1.188	1.086	1.074
37500	1.086	.991	.978
40000	0.998	.910	.897
45000	0.857	.781	.768
50000	0.749	.682	.669
55000	0.663	.603	.591
60000	0.594	.541	.529
65000	0.537	.489	.477
70000	0.489	.446	.435
80000	0.413	.378	.367
90000	0.357	.327	.317
100000	0.313	.287	.277
110000	0.279	.256	.245
120000	0.250	.230	.218
130000	0.227	.209	.195

YIELD = 1 MT; HOB = 10 KFT: HOT = 5 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
5000	26.365	25.130	24.781
5500	21.416	20.584	20.181
6000	17.816	17.223	16.907
6500	15.115	14.652	14.442
7000	13.035	12.644	12.512
7500	11.397	11.056	10.968
8000	10.083	9.778	9.716
8500	9.010	8.733	8.687
9000	8.122	7.866	7.831
9500	7.377	7.139	7.110
10000	6.746	6.520	6.497
11000	5.736	5.530	5.513
12000	4.970	4.776	4.763
13000	4.371	4.186	4.176
14000	3.892	3.714	3.706
15000	3.501	3.329	3.322
16000	3.176	3.010	3.004
17000	2.903	2.743	2.736
18000	2.670	2.515	2.509
19000	2.470	2.320	2.313
20000	2.295	2.150	2.143
22500	1.945	1.811	1.804
25000	1.682	1.559	1.551
27500	1.478	1.364	1.356
30000	1.314	1.209	1.201
32500	1.182	1.084	1.076
35000	1.071	.981	.973
37500	0.979	.894	.887
40000	0.900	.821	.814
45000	0.772	.703	.696

YIELD = 1 MT; HOB = 10 KFT: HOT = 5 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
50000	0.674	.614	.607
55000	0.597	.543	.536
60000	0.534	.486	.480
65000	0.482	.439	.433
70000	0.439	.400	.394
80000	0.371	.339	.333
90000	0.321	.293	.288
100000	0.281	.258	.252
110000	0.250	.229	.222
120000	0.225	.206	.198
130000	0.204	.187	.177

YIELD = 1 MT; HOB = 10 KFT: HOT = 10 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
1750	367.713	366.749	366.680
2000	254.515	249.665	249.611
2250	184.860	180.328	179.957
2500	139.478	135.273	135.128
2750	108.532	105.049	104.980
3000	86.630	83.850	83.805
3250	70.641	68.415	68.385
3500	58.660	56.806	56.780
3750	49.477	47.788	47.832
4000	42.302	40.736	40.757
4500	31.996	30.530	30.415
5000	25.120	23.865	23.785
5500	20.317	19.418	19.316
6000	16.834	16.210	16.102
6500	14.229	13.767	13.664
7000	12.229	11.856	11.766
7500	10.658	10.340	10.260
8000	9.402	9.120	9.050
8500	8.379	8.126	8.063
9000	7.535	7.304	7.246
9500	6.829	6.615	6.562
10000	6.231	6.031	5.983
11000	5.279	5.098	5.058
12000	4.559	4.392	4.358
13000	3.999	3.840	3.811
14000	3.553	3.401	3.376
15000	3.189	3.043	3.021
16000	2.889	2.747	2.728
17000	2.637	2.499	2.483
18000	2.422	2.289	2.274

YIELD = 1 MT; HOB = 10 KFT: HOT = 10 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
19000	2.238	2.109	2.095
20000	2.078	1.953	1.940
22500	1.757	1.641	1.631
25000	1.517	1.410	1.401
27500	1.331	1.232	1.224
30000	1.183	1.091	1.084
32500	1.063	.977	.971
35000	0.963	.883	.878
37500	0.879	.805	.800
40000	0.808	.738	.734
45000	0.693	.632	.628
50000	0.605	.551	.548
55000	0.535	.487	.484
60000	0.479	.436	.433
65000	0.432	.393	.391
70000	0.394	.358	.356
80000	0.333	.303	.301
90000	0.287	.262	.260
100000	0.252	.230	.227
110000	0.224	.205	.200
120000	0.201	.184	.178

YIELD = 1 MT; HOB = 10 KFT: HOT = 15 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
5000	23.962	22.796	22.929
5500	19.295	18.357	18.546
6000	15.922	15.246	15.346
6500	13.406	12.922	12.924
7000	11.481	11.112	11.054
7500	9.973	9.670	9.587
8000	8.771	8.508	8.419
8500	7.795	7.561	7.472
9000	6.991	6.780	6.694
9500	6.320	6.127	6.045
10000	5.754	5.575	5.498
11000	4.856	4.697	4.630
12000	4.180	4.034	3.976
13000	3.655	3.519	3.468
14000	3.239	3.109	3.065
15000	2.902	2.777	2.739
16000	2.623	2.503	2.469
17000	2.390	2.273	2.244
18000	2.192	2.079	2.054
19000	2.023	1.913	1.891
20000	1.876	1.769	1.749
22500	1.583	1.484	1.469
25000	1.364	1.272	1.261
27500	1.196	1.110	1.101
30000	1.062	.982	.974
32500	0.953	.878	.873
35000	0.863	.793	.789
37500	0.787	.722	.719
40000	0.723	.662	.659
45000	0.620	.566	.564

YIELD = 1 MT; HOB = 10 KFT: HOT = 15 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
50000	0.540	.492	.492
55000	0.478	.435	.435
60000	0.427	.389	.389
65000	0.386	.351	.351
70000	0.351	.320	.320
80000	0.297	.270	.271
90000	0.256	.233	.234
100000	0.224	.205	.204
110000	0.199	.182	.180
120000	0.179	.164	.160

YIELD = 1 MT; HOB = 10 KFT: HOT = 20 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
10000	5.314	5.152	5.041
11000	4.465	4.324	4.227
12000	3.829	3.702	3.617
13000	3.338	3.221	3.146
14000	2.950	2.839	2.774
15000	2.636	2.530	2.473
16000	2.378	2.276	2.227
17000	2.163	2.064	2.021
18000	1.981	1.885	1.847
19000	1.825	1.732	1.699
20000	1.690	1.600	1.571
22500	1.422	1.338	1.317
25000	1.224	1.145	1.129
27500	1.071	.997	.985
30000	0.949	.880	.872
32500	0.851	.787	.780
35000	0.770	.710	.705
37500	0.702	.645	.643
40000	0.645	.591	.589
45000	0.552	.505	.504
50000	0.481	.439	.440
55000	0.425	.387	.389
60000	0.380	.346	.348
65000	0.343	.312	.314
70000	0.312	.284	.286
80000	0.263	.240	.242
90000	0.227	.207	.209
100000	0.199	.181	.182
110000	0.177	.161	.160

YIELD = 1 MT; HOB = 10 KFT: HOT = 30 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
20000	1.362	1.299	1.248
22500	1.139	1.080	1.042
25000	0.975	.919	.892
27500	0.850	.797	.777
30000	0.751	.701	.686
32500	0.672	.625	.614
35000	0.607	.562	.555
37500	0.552	.510	.505
40000	0.506	.467	.463
45000	0.432	.397	.396
50000	0.376	.344	.345
55000	0.332	.303	.306
60000	0.296	.270	.274
75000	0.267	.243	.247
70000	0.243	.221	.225
80000	0.205	.186	.190
90000	0.176	.161	.163
100000	0.154	.141	.142
110000	0.137	.125	.126
120000	0.123	.112	.110

YIELD = 1 MT; HOB = 10 KFT: HOT = 40 KFT

SLANT RANGE (FT)	OVERPRESSURE (PSI)		
	MOD SACHS SCALED AFWL 1-KT-STD-REV	MOD SACHS SCALED FAB-1D	FAB-2D
30000	0.587	.552	.524
32500	0.523	.490	.469
35000	0.471	.440	.423
37500	0.428	.398	.386
40000	0.391	.363	.354
45000	0.333	.308	.303
50000	0.289	.266	.264
55000	0.255	.234	.234
60000	0.227	.208	.210
65000	0.205	.187	.190
70000	0.186	.169	.173
80000	0.156	.142	.147
90000	0.134	.122	.127
100000	0.118	.107	.111
110000	0.104	.095	.097
120000	0.093	.085	.086
130000	0.084	.077	.078

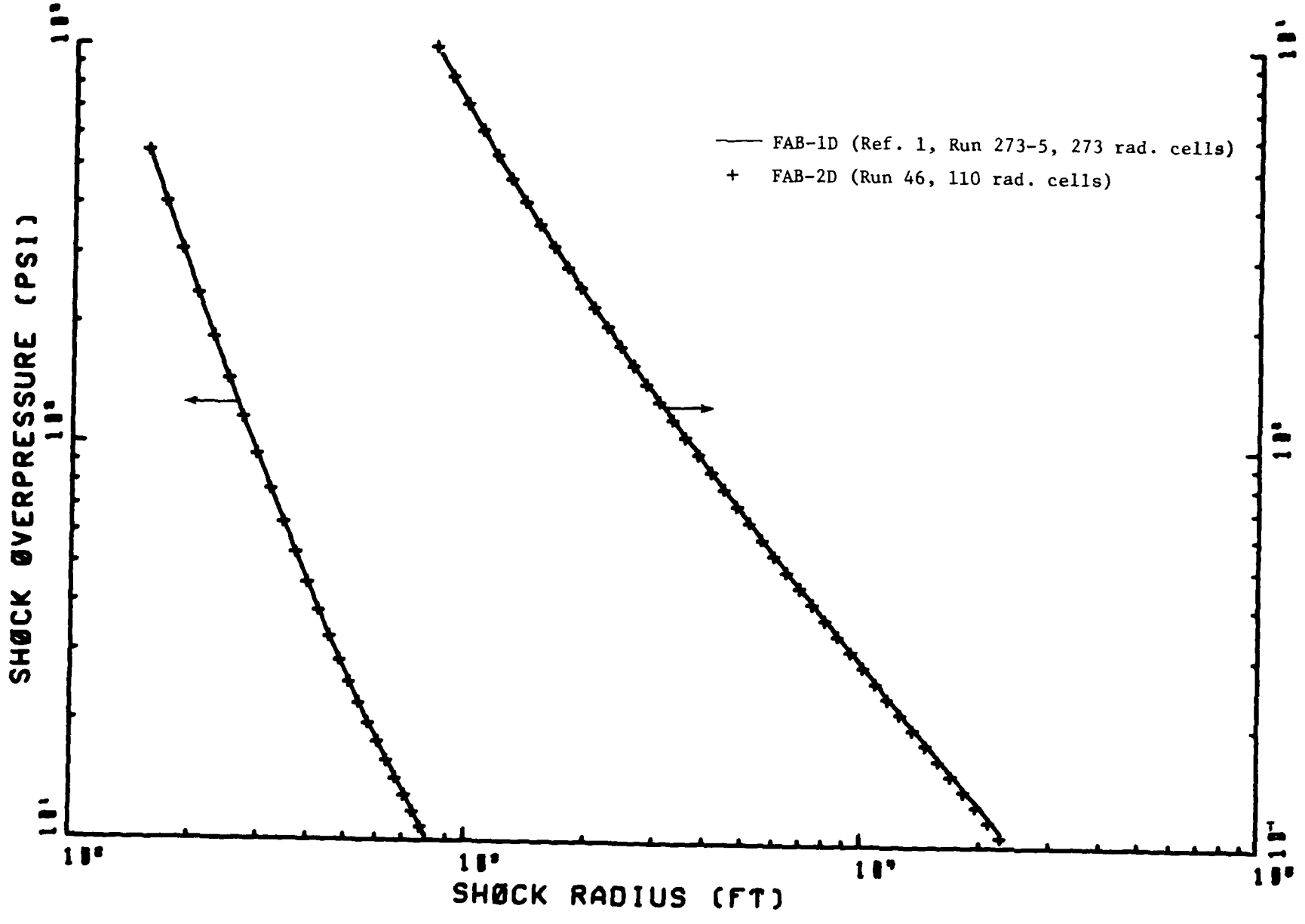


Figure 2. Comparison of Shock Front Overpressures from the FAB-2D and FAB-1D Codes for a 1-KT Burst in a Uniform Atmosphere.

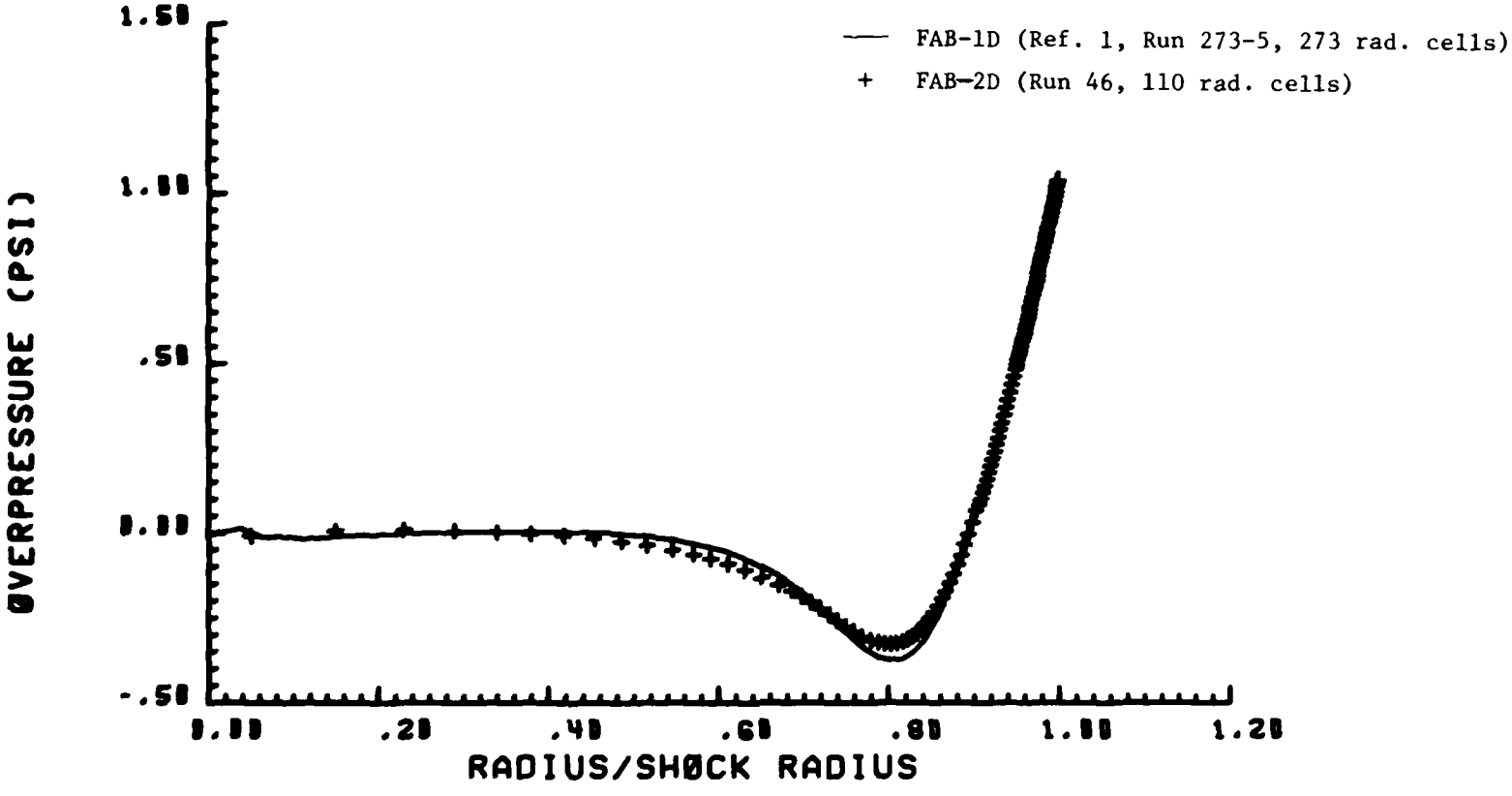


Figure 3. Comparison of Overpressure Distributions from the FAB-2D and FAB-1D Codes for a 1-KT Burst in a Uniform Atmosphere.

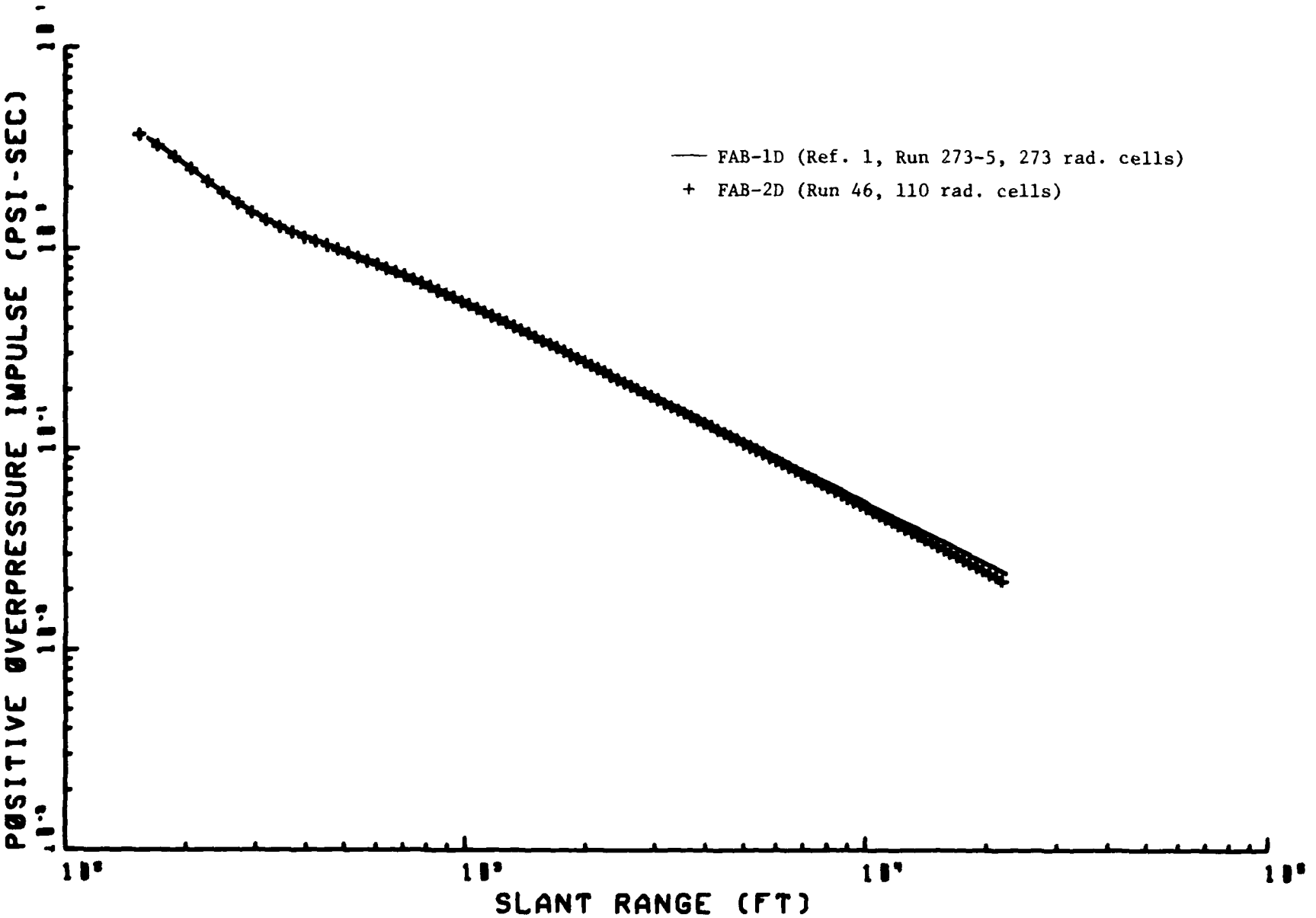


Figure 4. Comparison of Positive Overpressure Impulses from the FAB-2D and FAB-1D Codes for a 1-KT Burst in a Uniform Atmosphere.

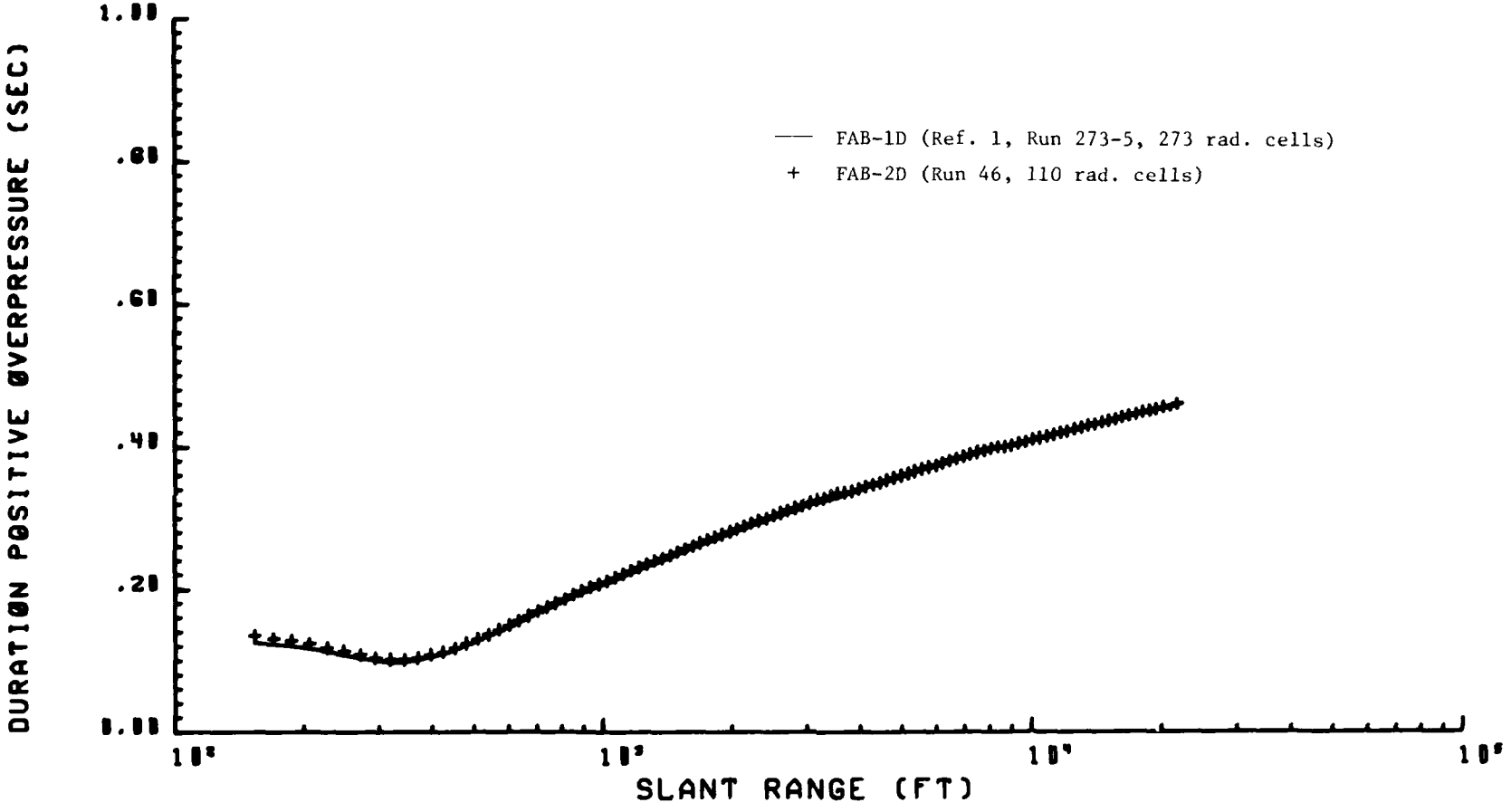


Figure 5. Comparison of Durations of Positive Overpressure from the FAB-2D and FAB-1D Codes for a 1-KT Burst in a Uniform Atmosphere.

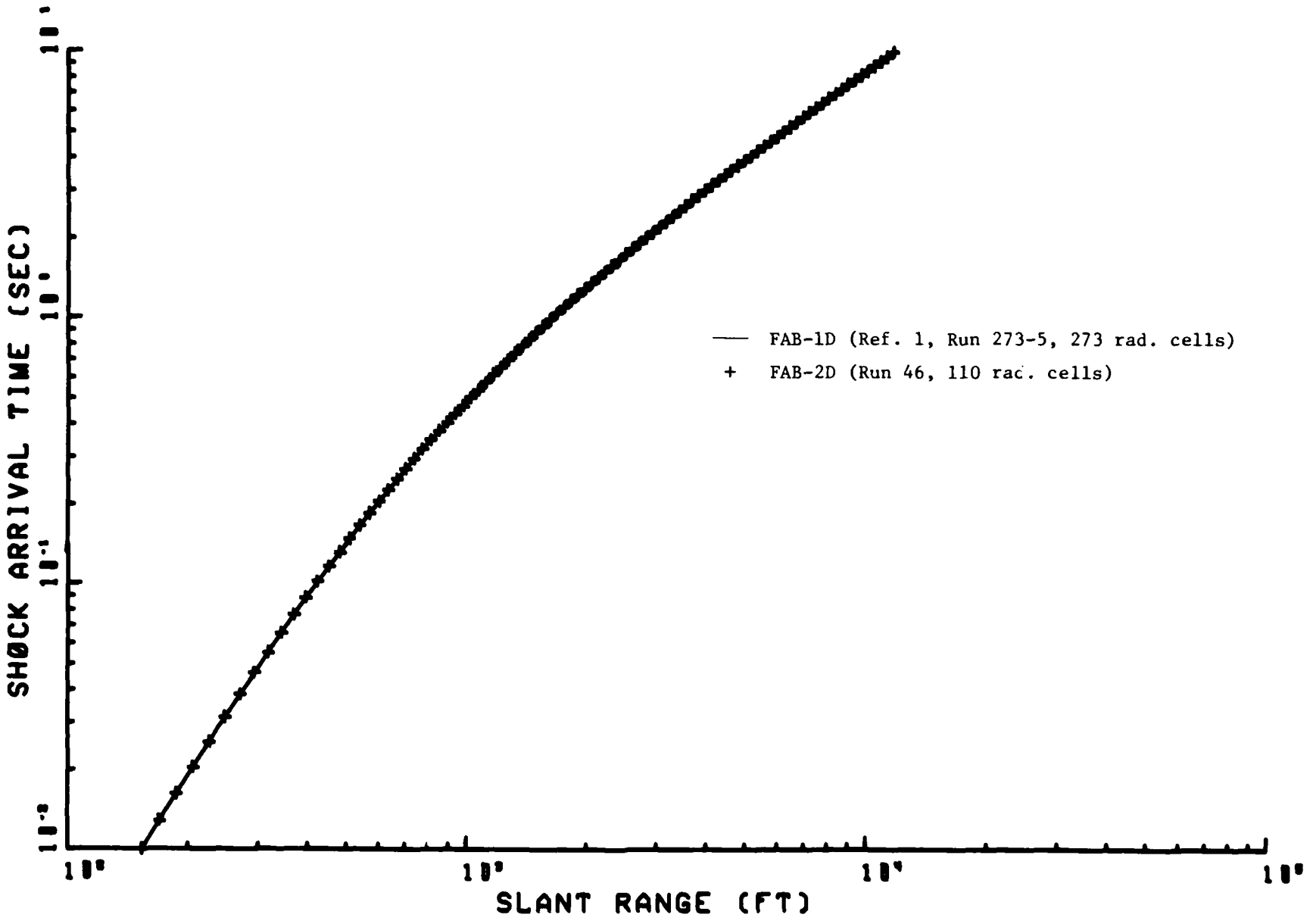
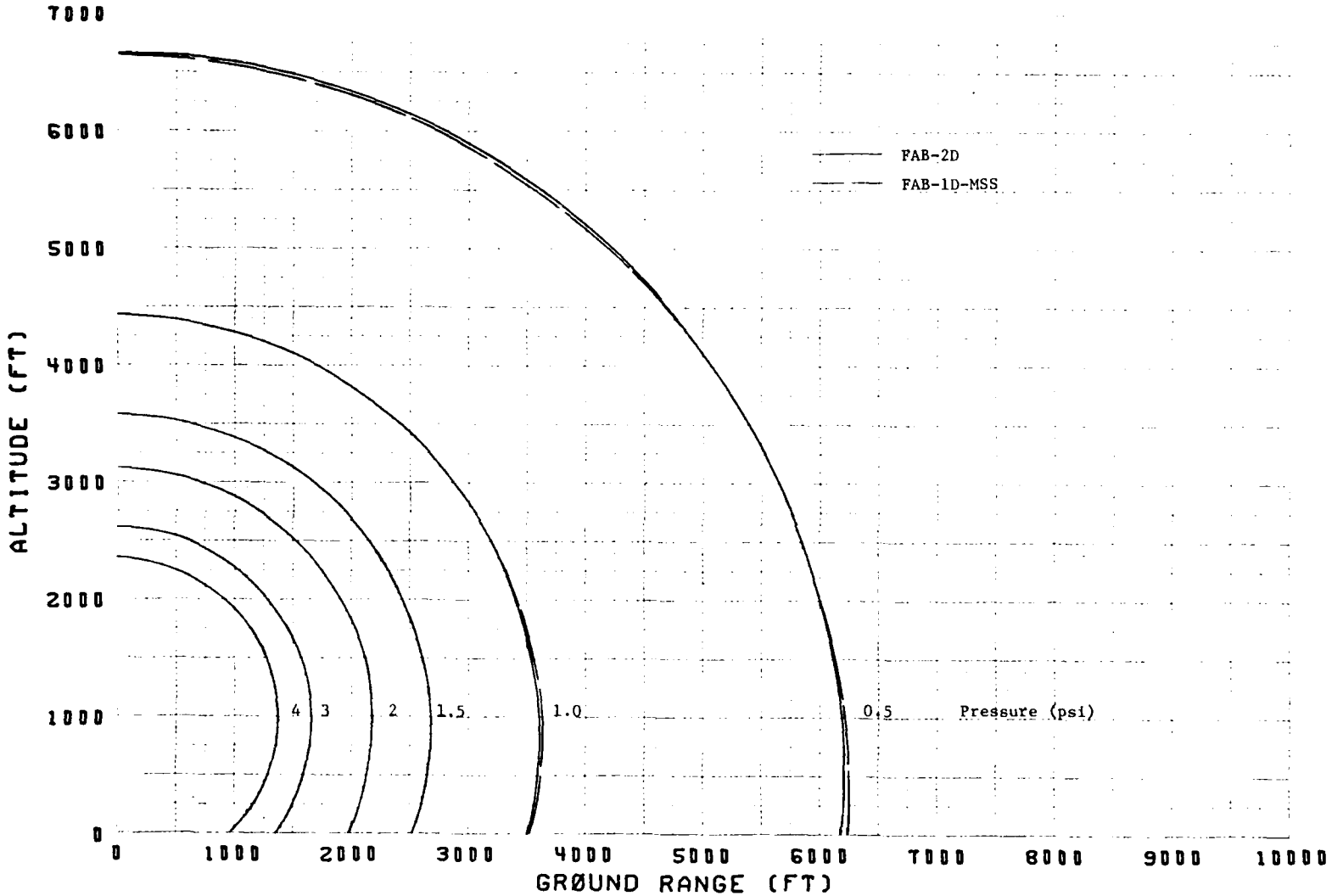
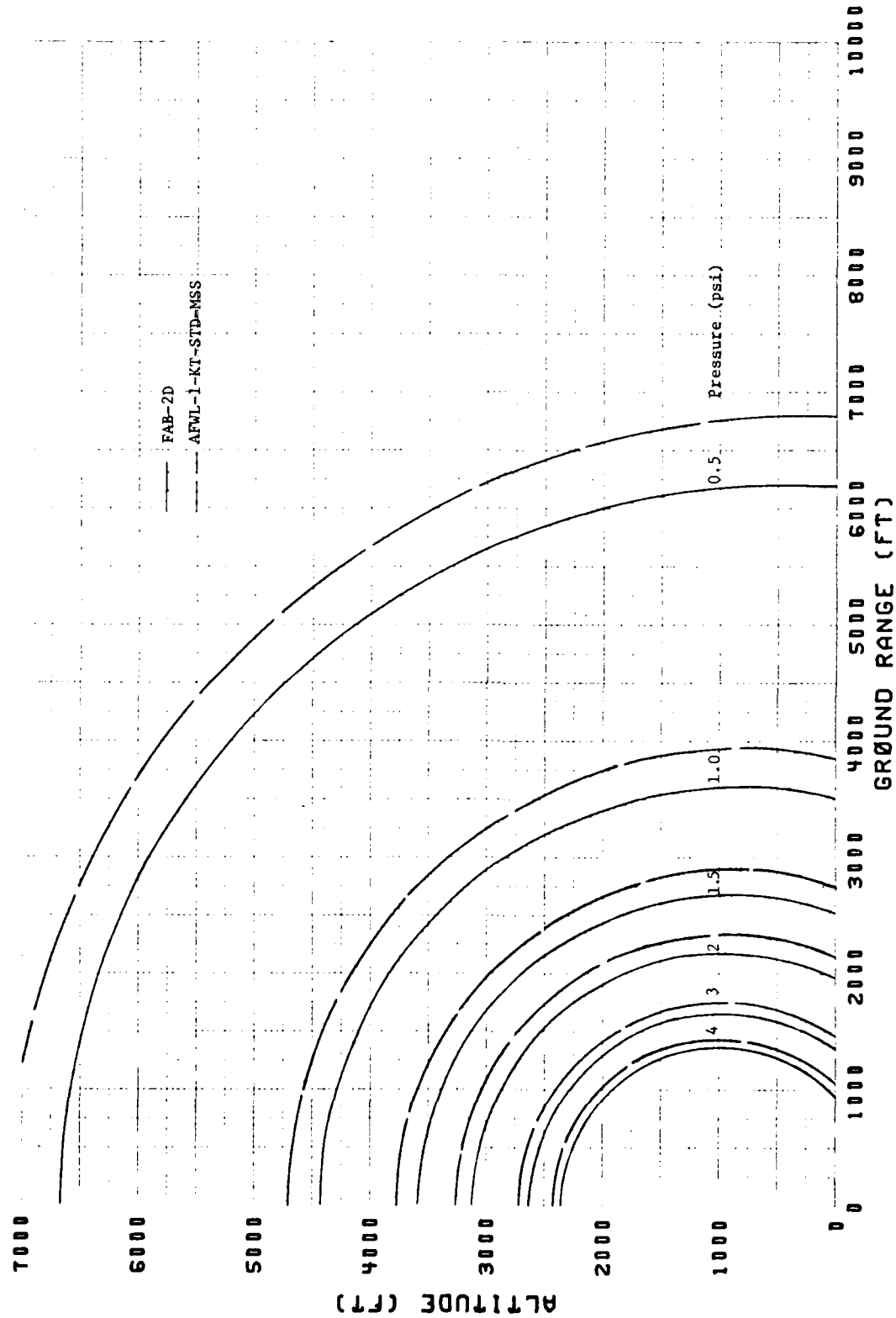


Figure 6. Comparisons of Shock Arrival Times from the FAB-2D and FAB-1D Codes for a 1-KT Burst in a Uniform Atmosphere.



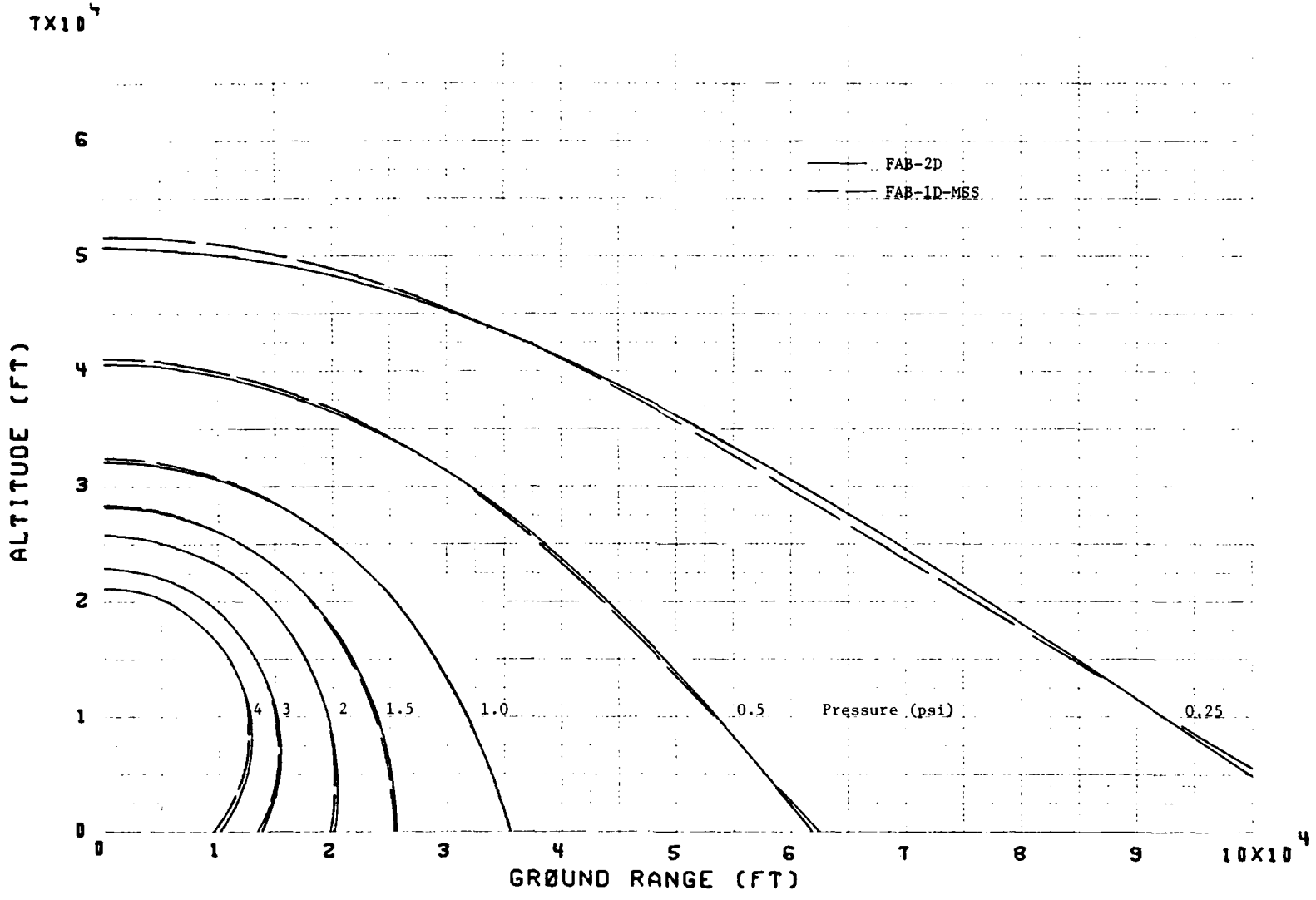
(a) FAB-2D and FAB-1D-MSS

Figure 7. Comparison of Overpressure Contours for a 1-KT Burst at 1,000-ft Altitude.



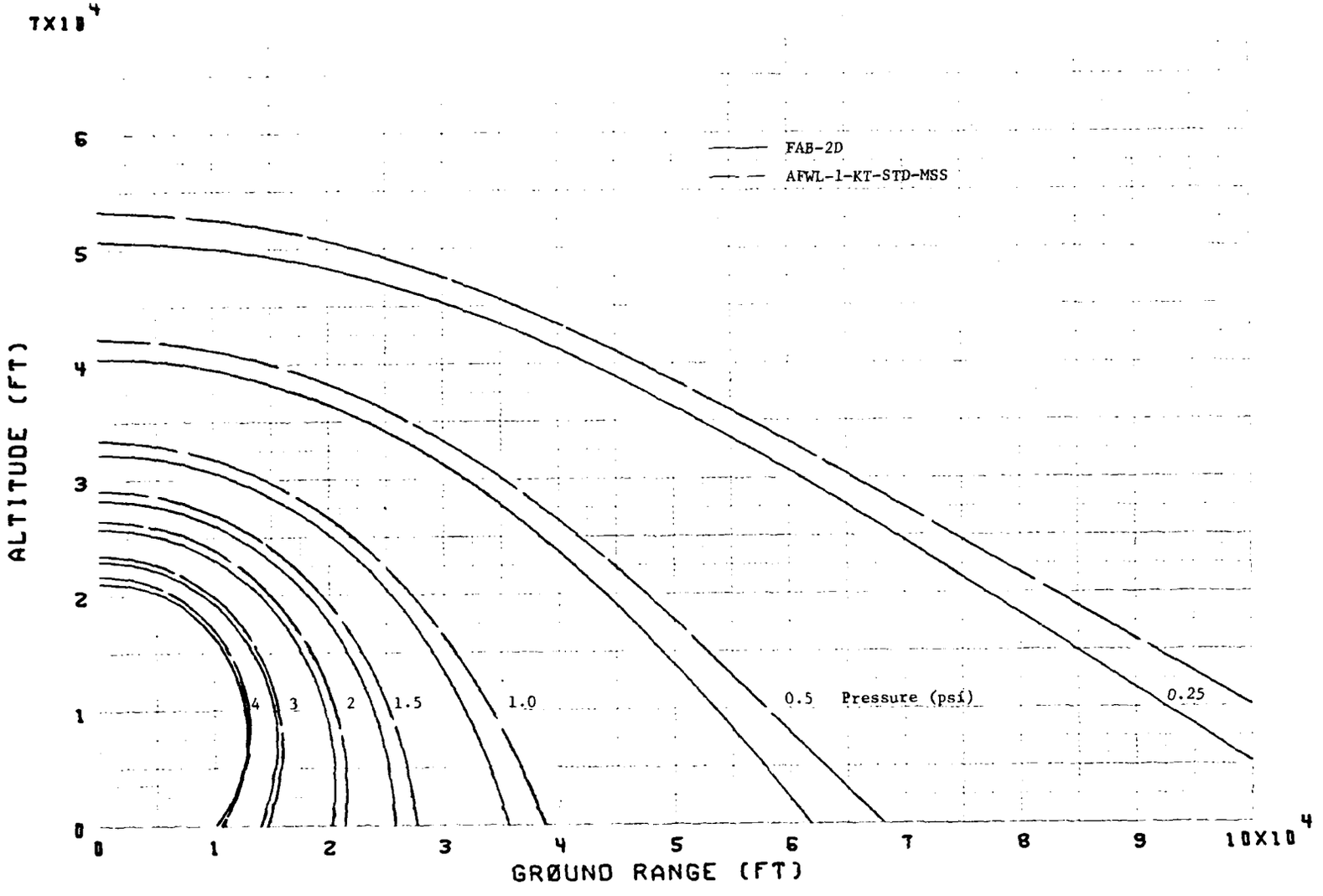
(b) FAB-2D and AFWL-1-KT-STD-MSS

Figure 7. Concluded.



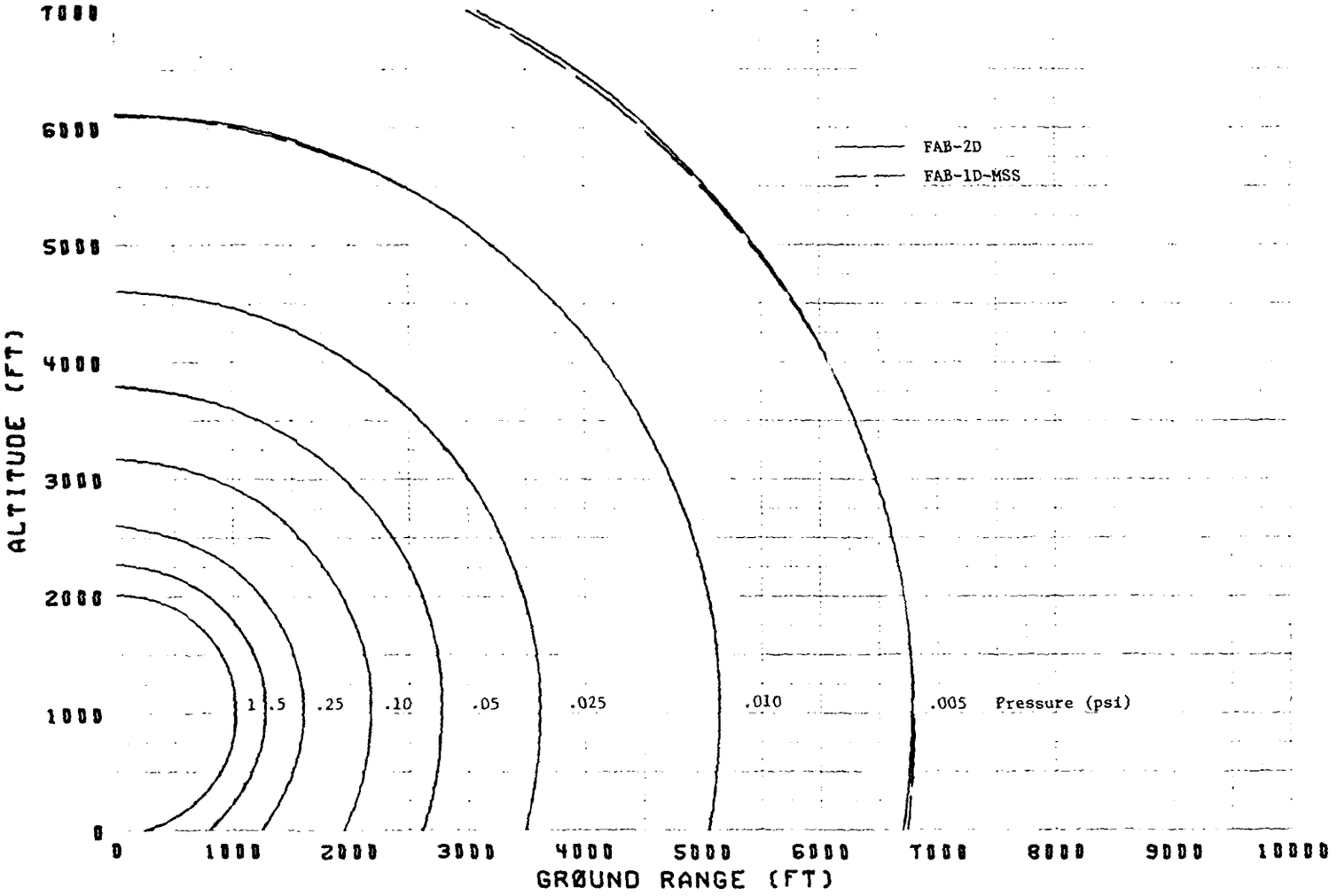
(a) FAB-2D and FAB-1D-MSS

Figure 8. Comparison of Overpressure Contours for a 1-MT Burst at 10,000-ft Altitude.



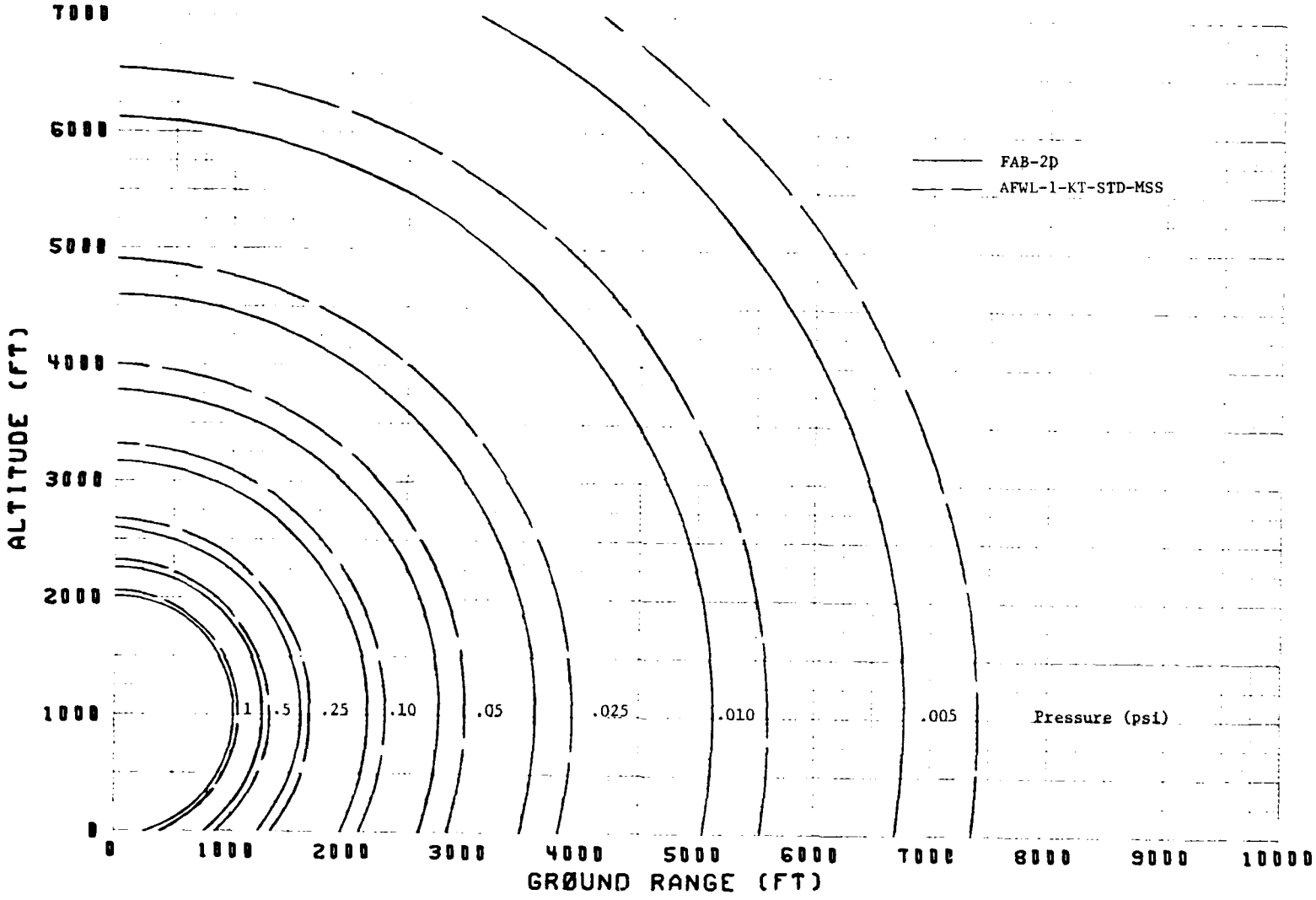
(b) FAB-2D and AFWL-1-KT-STD-MSS

Figure 8. Concluded.



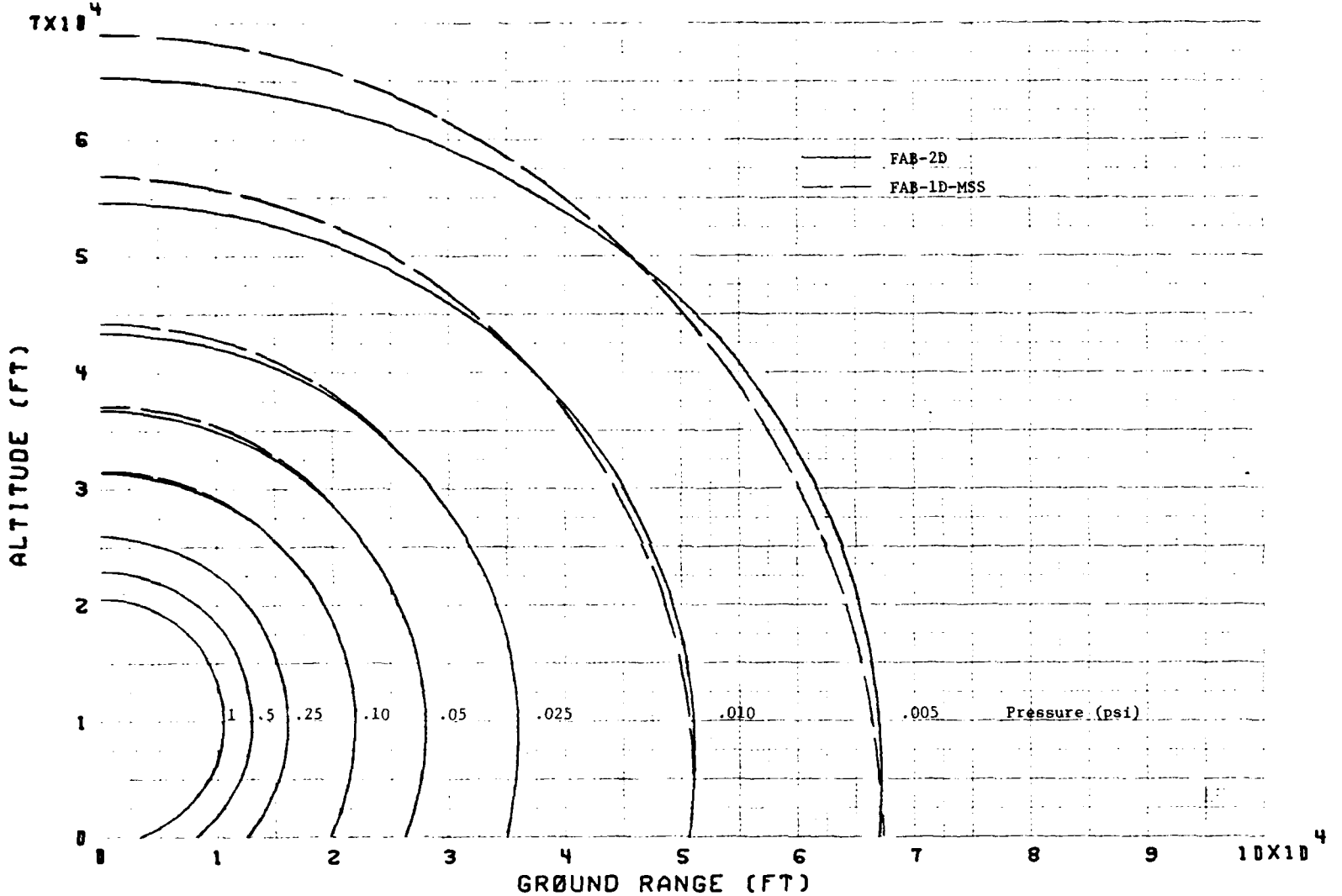
(a) FAB-2D and FAB-1D-MSS

Figure 9. Comparison of Dynamic Pressure Contours for a 1-KT Burst at 1,000-ft Altitude.



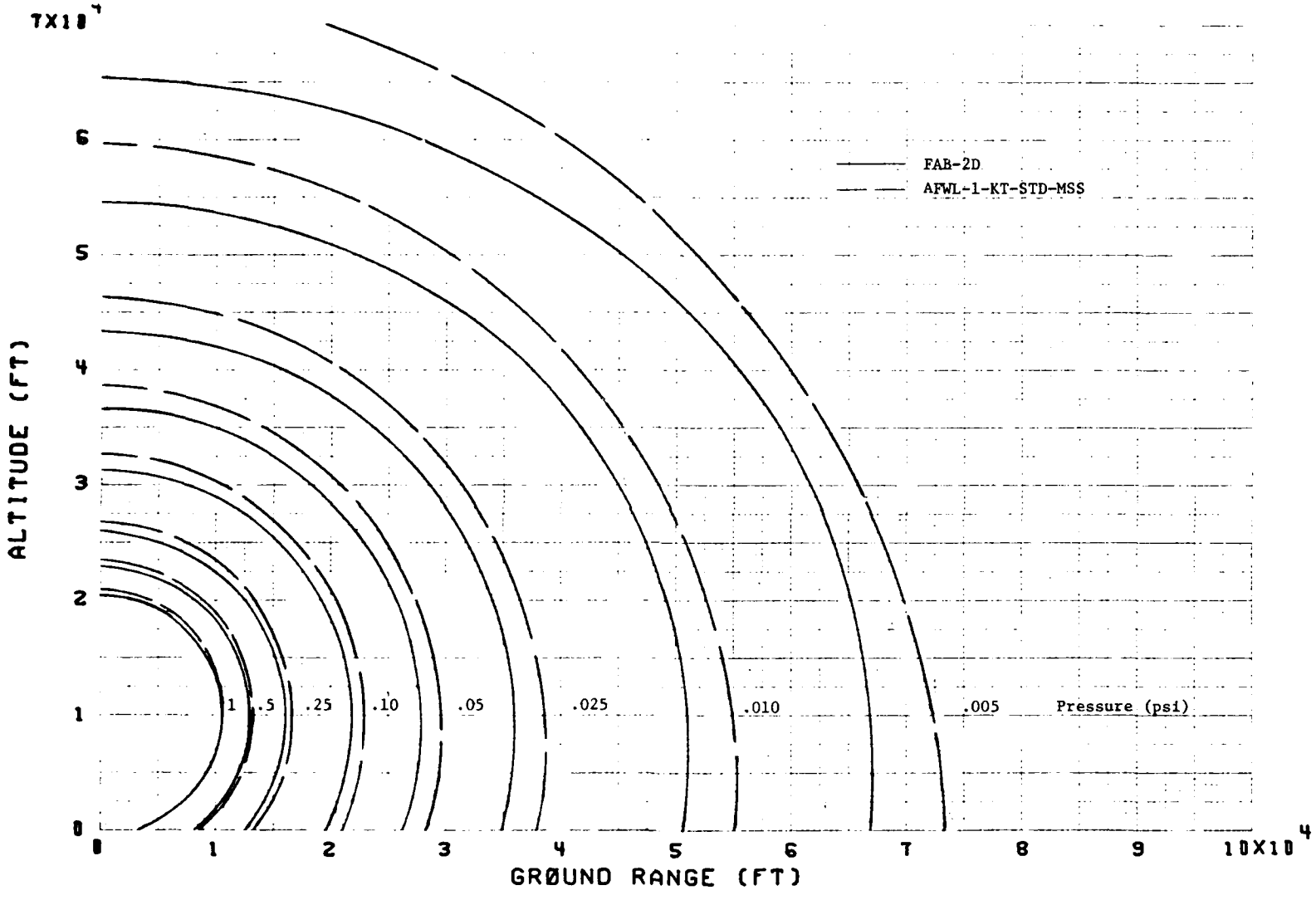
(b) FAB-2D and AFWL-1-KT-STD-MSS

Figure 9. Concluded.



(a) FAB-2D and FAB-1D-MSS

Figure 10. Comparison of Dynamic Pressure Contours for a 1-MT Burst at 10,000-ft Altitude.



(b) FAB-2D and AFWL-1-KT-STD-MSS

Figure 10. Concluded.

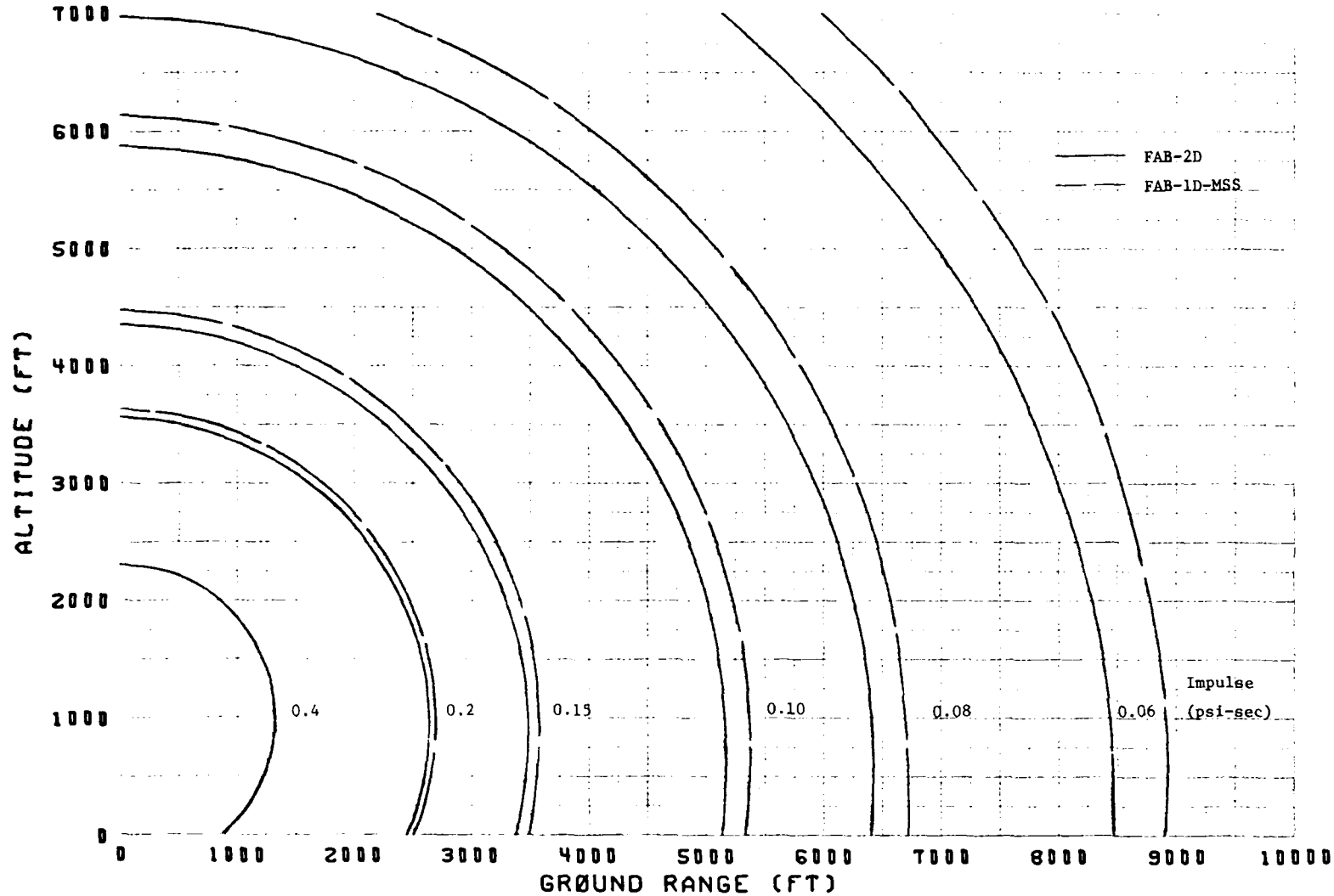


Figure 11. Comparison of Positive Overpressure Impulse Contours for a 1-KT Burst at 1,000-ft Altitude.

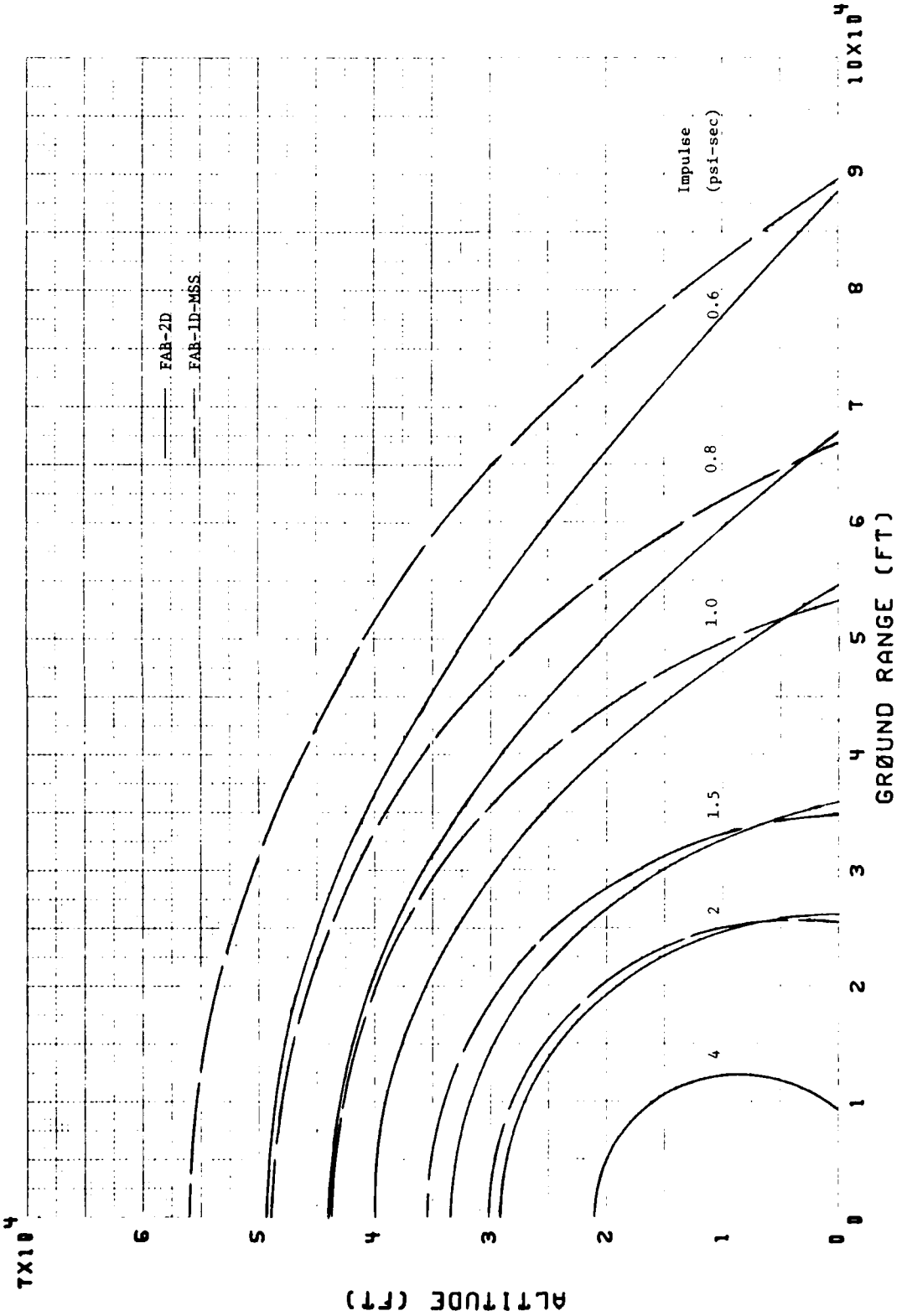


Figure 12. Comparison of Positive Overpressure Impulse Contours for a 1-MT Burst at 10,000-ft Altitude.

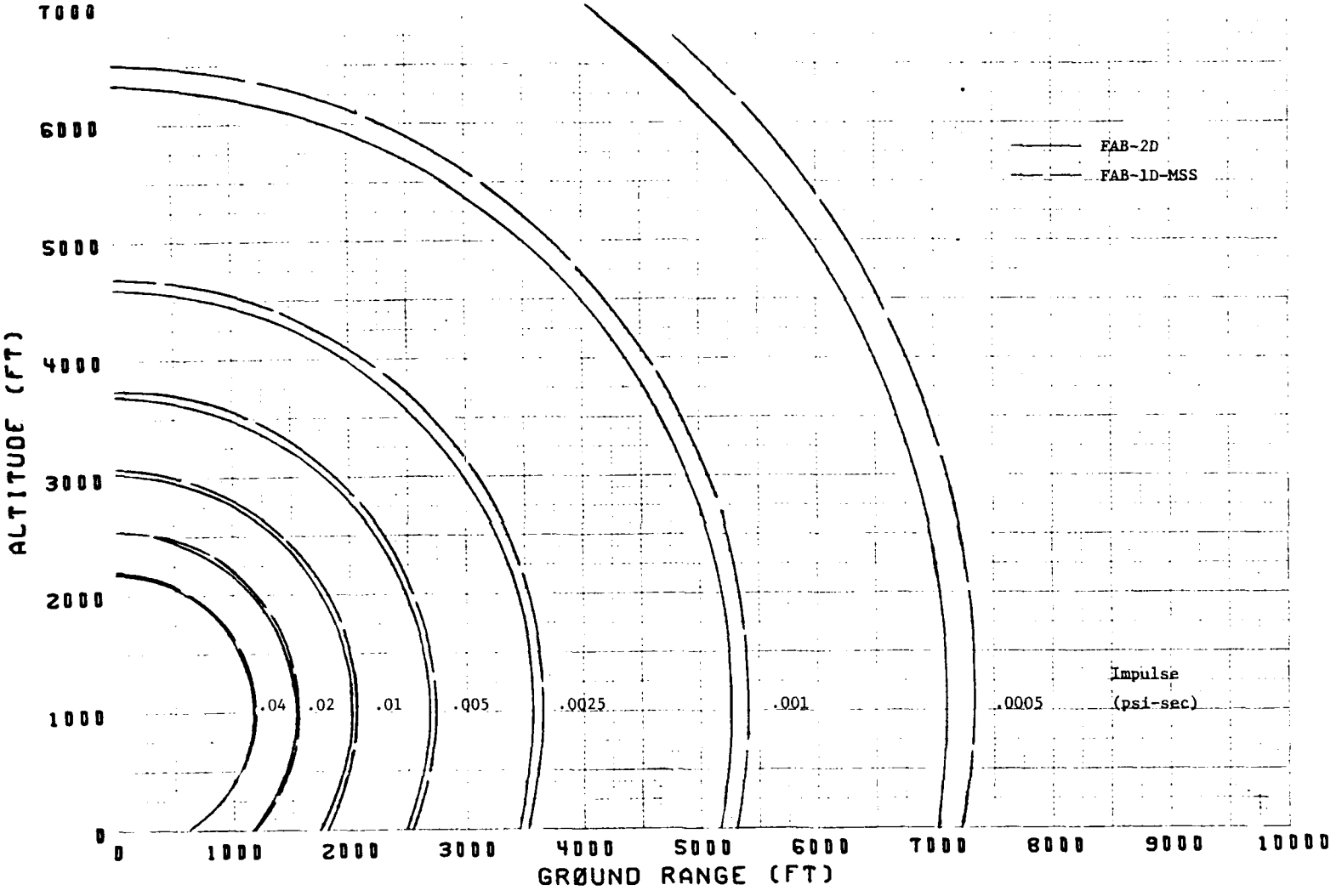


Figure 13. Comparison of Positive Dynamic Pressure Impulse Contours for a 1-KT Burst at 1,000-ft Altitude.

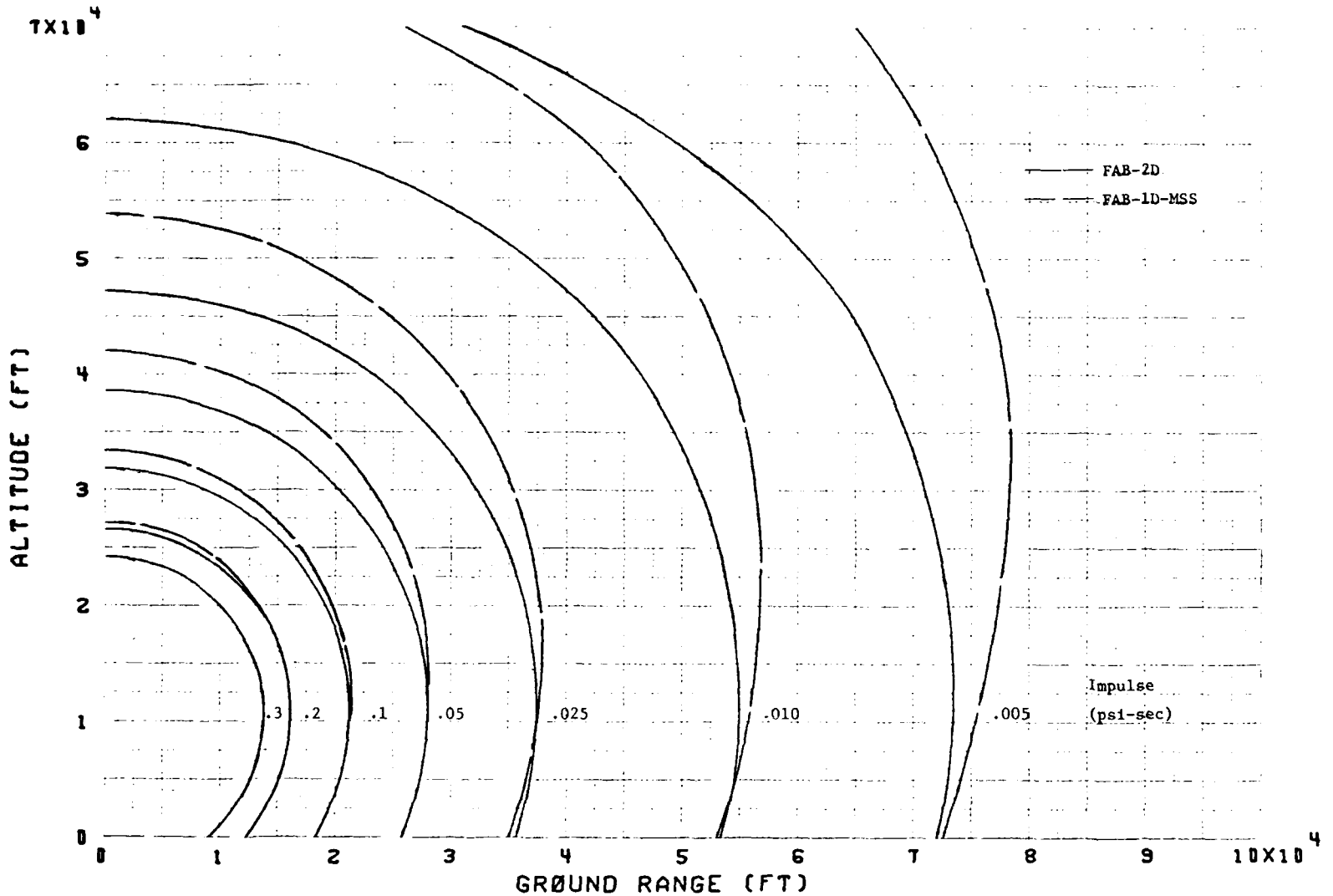


Figure 14. Comparison of Positive Dynamic Pressure Impulse Contours for a 1-MT Burst at 10,000-ft Altitude.

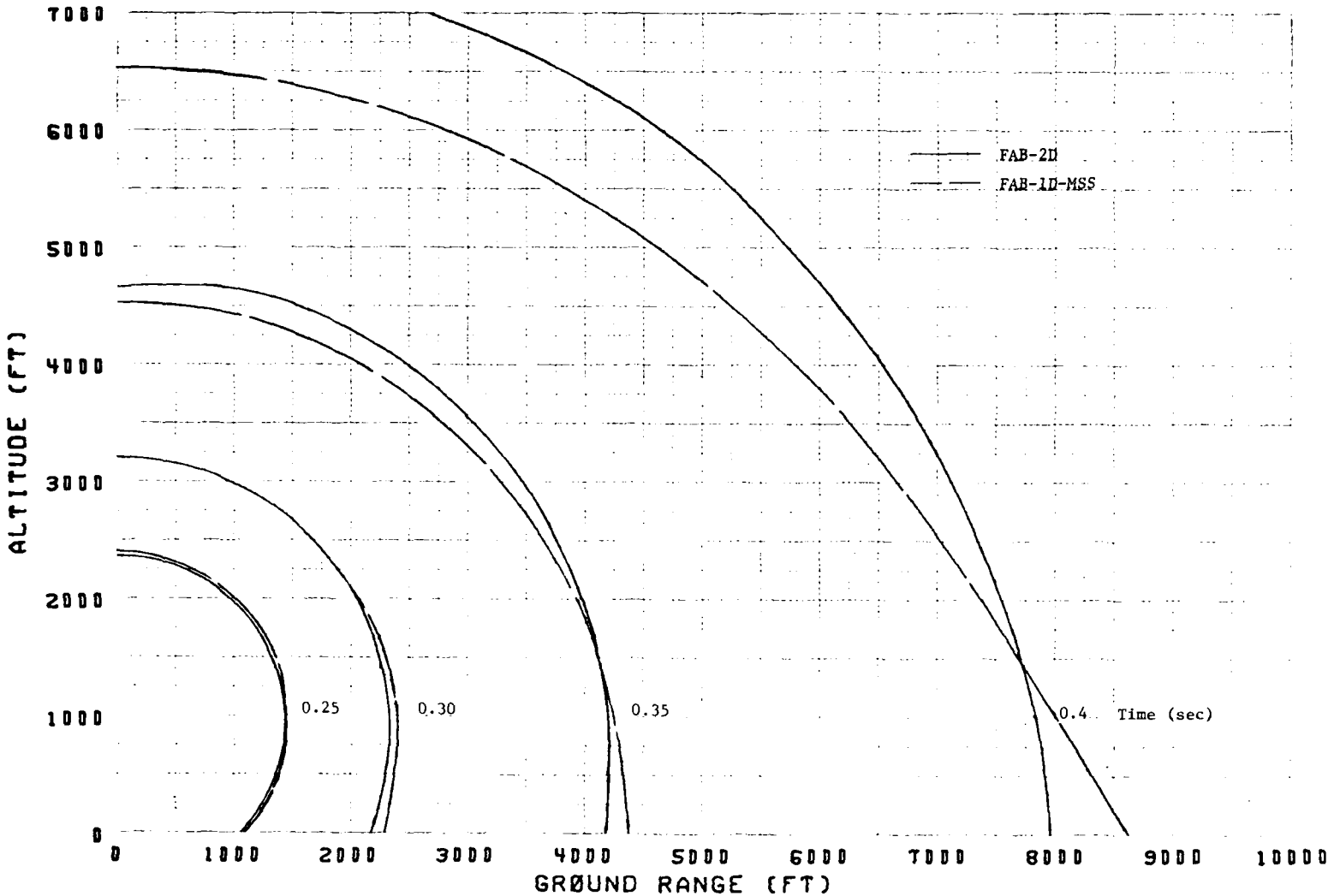


Figure 15. Comparison of Positive Overpressure Duration Contours for a 1-KT Burst at 1,000-ft Altitude.

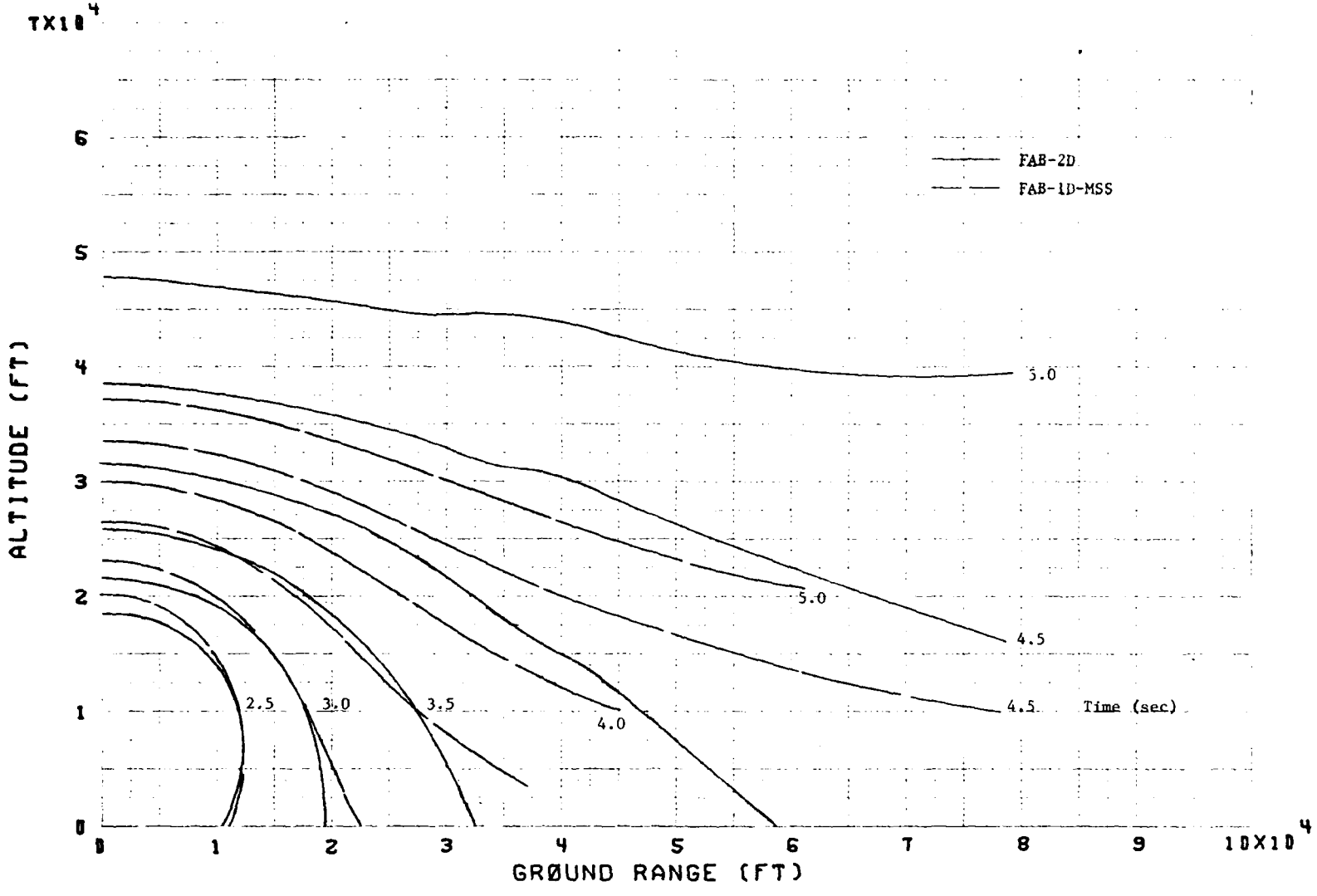


Figure 16. Comparison of Positive Overpressure Duration Contours for a 1-MT Burst at 10,000-ft Altitude.

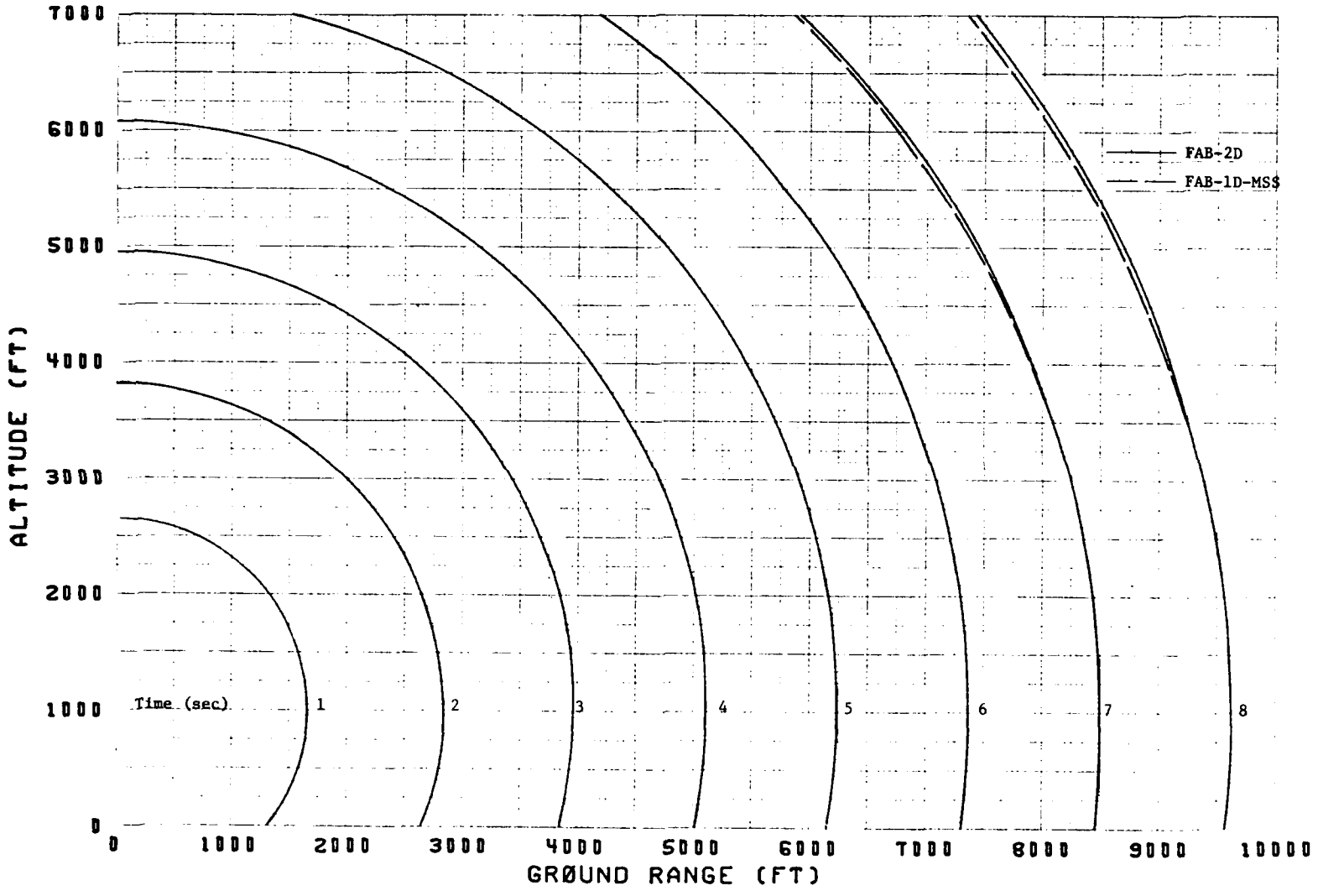


Figure 17. Comparison of Blast Arrival Time Contours for a 1-KT Burst at 1,000-ft Altitude.

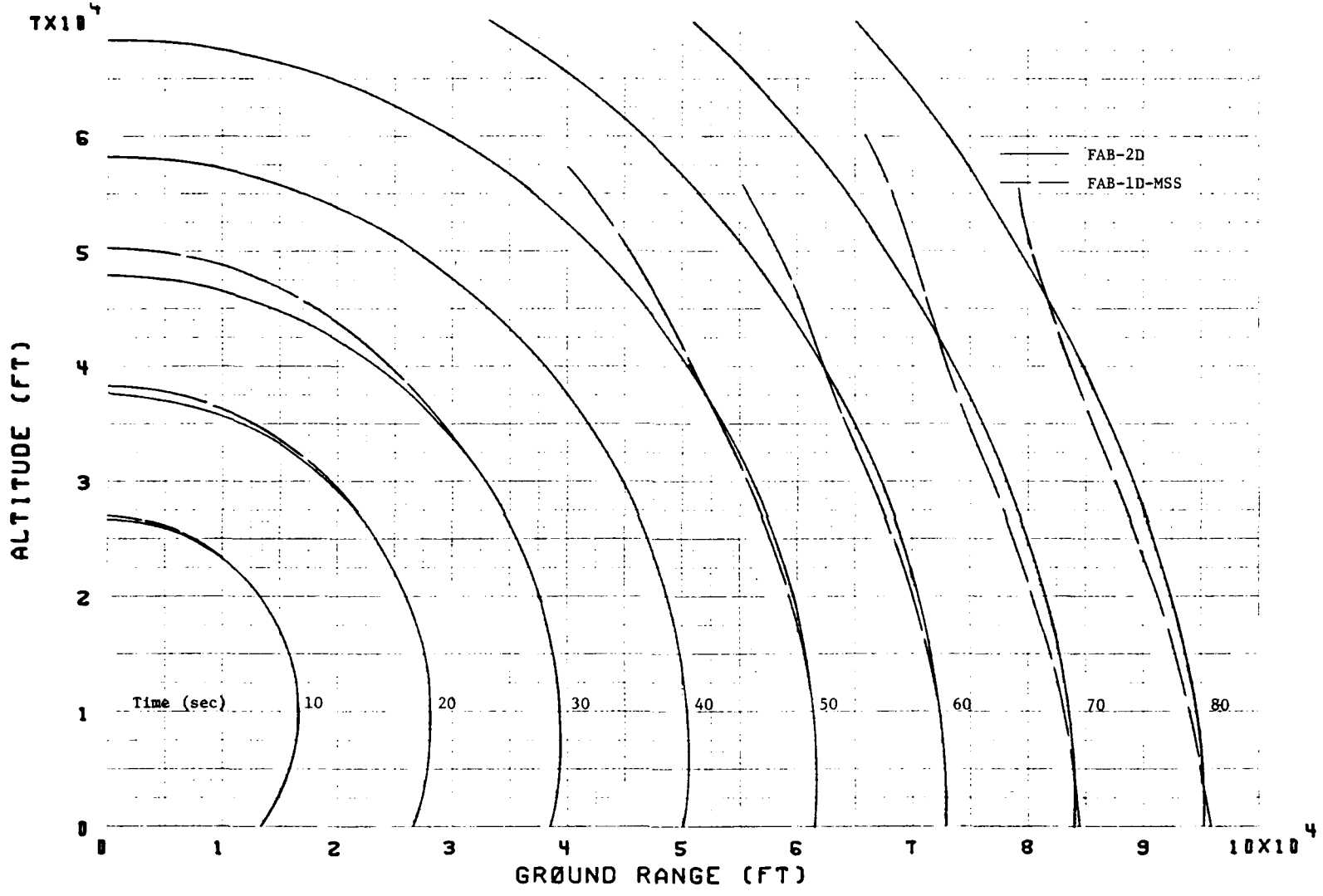


Figure 18. Comparison of Blast Arrival Time Contours for a 1-MT Burst at 10,000-ft Altitude.

for a 9 sector by 110 cell configuration (Run 46). The FAB-1D results in Table 3 are for the same 110 cell configuration; the FAB-1D results in Figure 2 are for the more detailed 273 cell configuration of Reference 1 (Run FAB 273-5).* The FAB-2D predictions in the table and figure are seen to be in good agreement with the FAB-1D results with differences generally near to or less than one percent for shock overpressures down to about 0.1 psi.

Similar comparisons between the FAB-2D and FAB-1D results for these same runs are shown in Figures 3 to 6 for overpressure distribution, positive overpressure impulse, duration of positive overpressure and blast arrival time.

The overpressure distributions, shown in Figure 3 for a shock overpressure of about 1 psi, are seen to be essentially the same for the 2D and 1D codes near the blast center and near the blast front, with some small differences occurring in the negative overpressure range.

Positive impulses for the two codes, shown in Figure 4, are generally in good agreement. The FAB-2D code does appear to predict slightly lower impulses at the largest slant ranges, but differences are less than 3 percent in range or impulse for ranges corresponding to shock overpressures down to 1 psi.

Durations of positive overpressure for the two codes, shown in Figure 5, are in good agreement, with differences generally less than one percent for ranges over 1,000 feet, and not over 8 percent at very short ranges.

Blast arrival times for the two codes, shown in Figure 6, are essentially identical.

In summary, the above comparisons indicate that the FAB-2D code, as applied to the one-dimensional blast problem, gives predictions which are generally in good agreement within a few percent with the corresponding predictions of the FAB-1D code. This result supports the overall reliability of the major features of the FAB-2D code.

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*Some comparisons in this report use 110 cell FAB-1D data and others use 273 cell FAB-1D data. The 110 cell case is of interest since it is the same as for the FAB-2D runs; the 273 cell case is of interest because it is a slightly more accurate standard.

SECTION 4
DISCUSSION

This section presents a comparison of the FAB-2D code results with modified Sachs scaled results of the one-dimensional FAB-1D (Reference 1) and AFWL-1-KT-STD-REV (Reference 12) codes.

4-1 MODIFIED SACHS SCALING.

A major purpose of the present study was to assess the accuracy of the Modified Sachs Scaling method for predicting two-dimensional blast field properties from calculations or data for blasts in a uniform (one-dimensional) atmosphere (e.g., see Reference 2, 3 or 4). This method assumes that the blast pressure, density and velocity at a target at a given altitude and slant range from a two-dimensional detonation are the same as the blast properties from a detonation of the same yield in a uniform atmosphere with the ambient atmospheric properties of the target altitude.

In order to partially assess the accuracy of modified Sachs scaling, altitude-range contour plots for various blast properties as obtained from the FAB-2D code (Run 45 for 1-KT and Run 44 for 1-MT) are compared in Figures 7 to 18 with the corresponding contour plots obtained by modified Sachs scaling (MSS) of results of a 273 cell one-dimensional FAB-1D run for a 1-KT burst in a uniform sea-level atmosphere (FAB-273-5, Reference 1). Also presented and discussed are contour plots indicating the accuracy of modified Sachs scaling for shock overpressure and dynamic pressure based on comparisons of FAB-2D and MSS FAB-1D calculations made with the same 110 radial cell configuration (Figures 19 to 22).

4-2 SHOCK OVERPRESSURE.

Considering shock overpressure first, it is seen from Figure 7a that for a 1-KT burst at a burst altitude of 1000 feet the modified Sachs scaled FAB-1D 273 cell results are generally in very good agreement with the two-dimensional FAB-2D results. For a 1-MT burst at a burst altitude

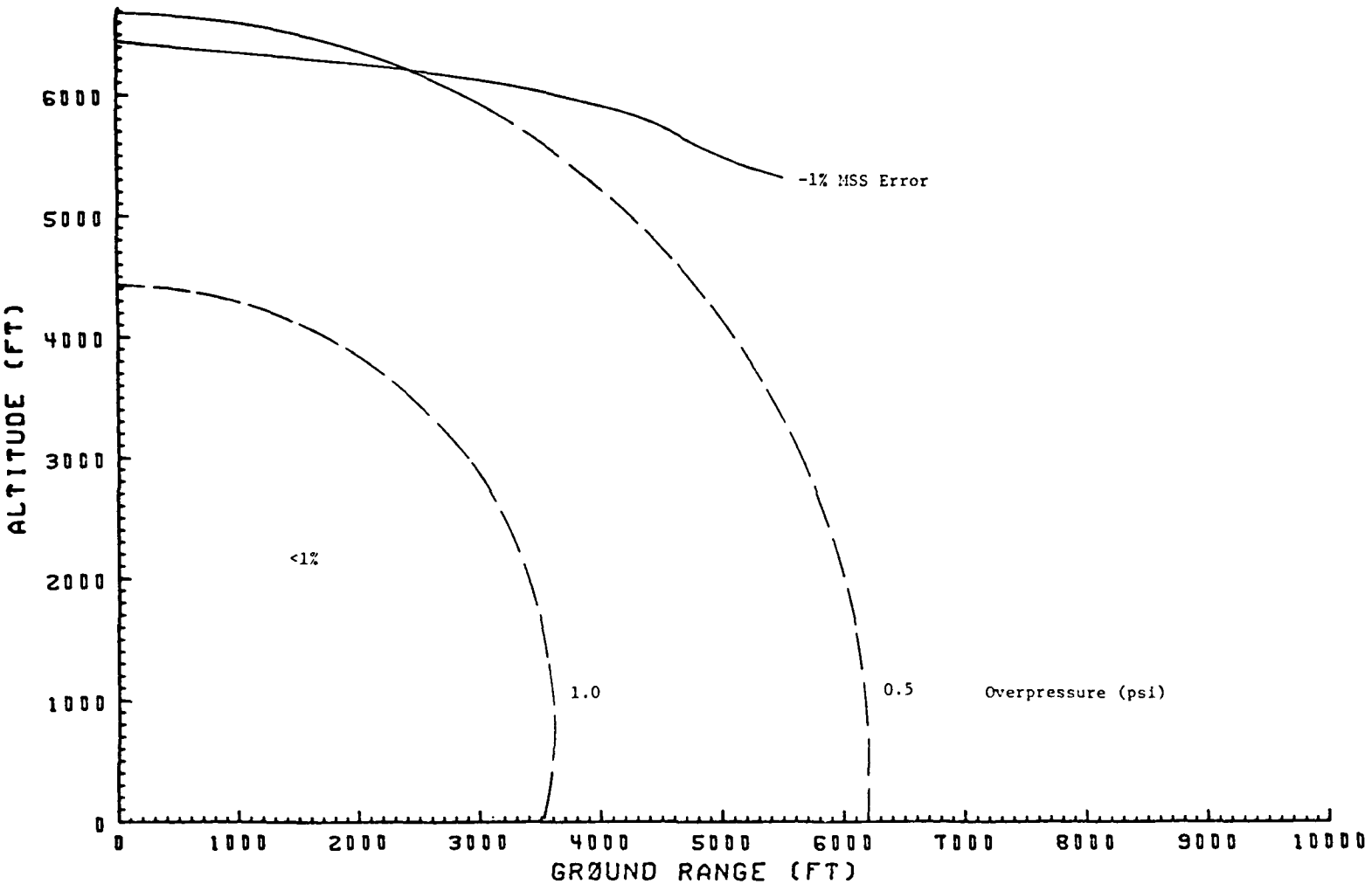

Figure 19. Shock Overpressure Error from Modified Sachs Scaled FAB-1D Data Compared with FAB-2D Data for a 1-KT Burst at 1,000-ft Altitude. FAB-1D Run 110-50, FAB-2D Run 45, both with 110 radial cells.

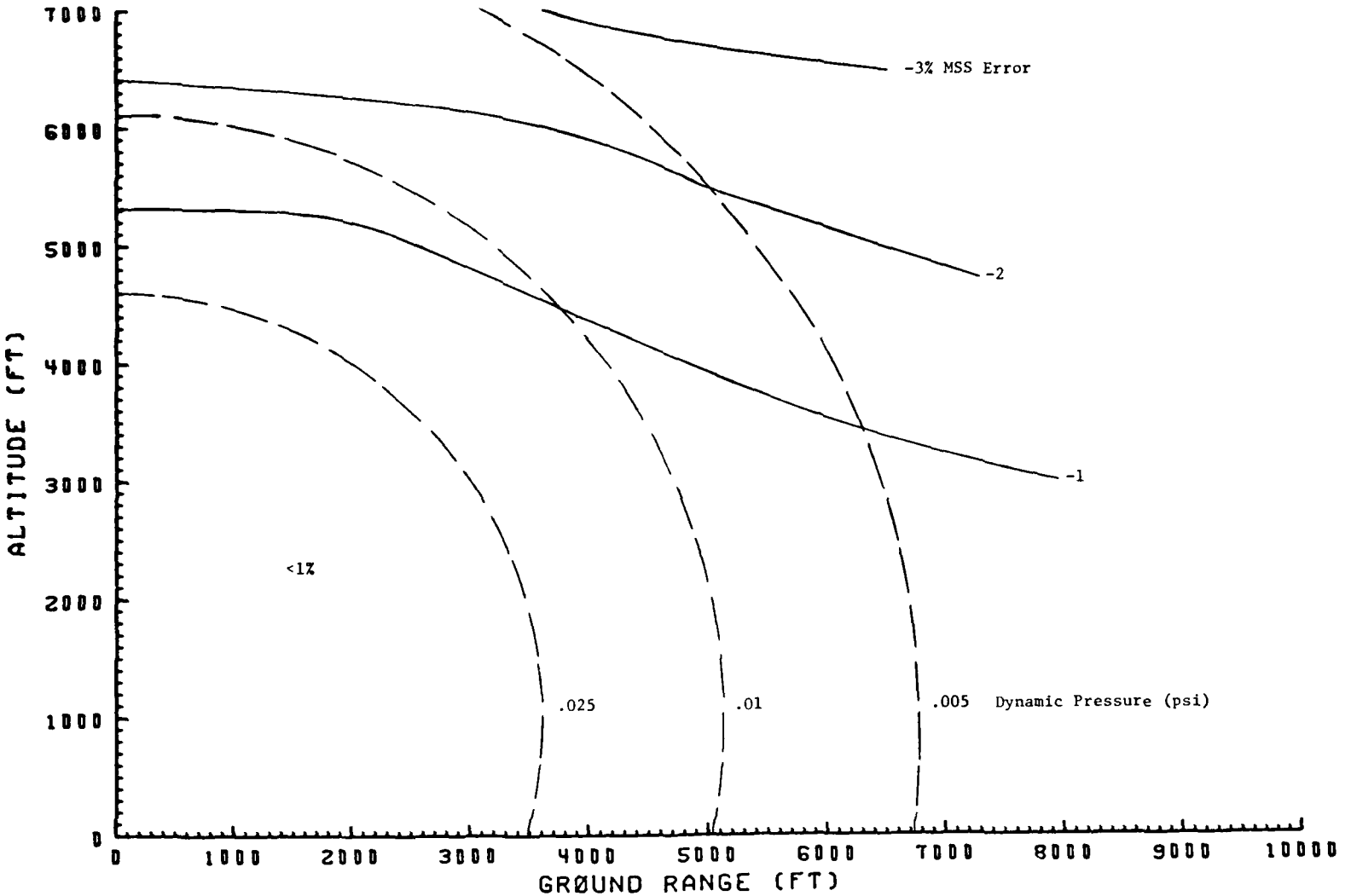

Figure 20. Shock Dynamic Pressure Error from Modified Sachs Scaled FAB-1D Data Compared with FAB-2D Data for a 1-KT Burst at 1,000-ft Altitude. FAB-1D Run 110-50, FAB-2D Run 45, both with 110 radial cells.

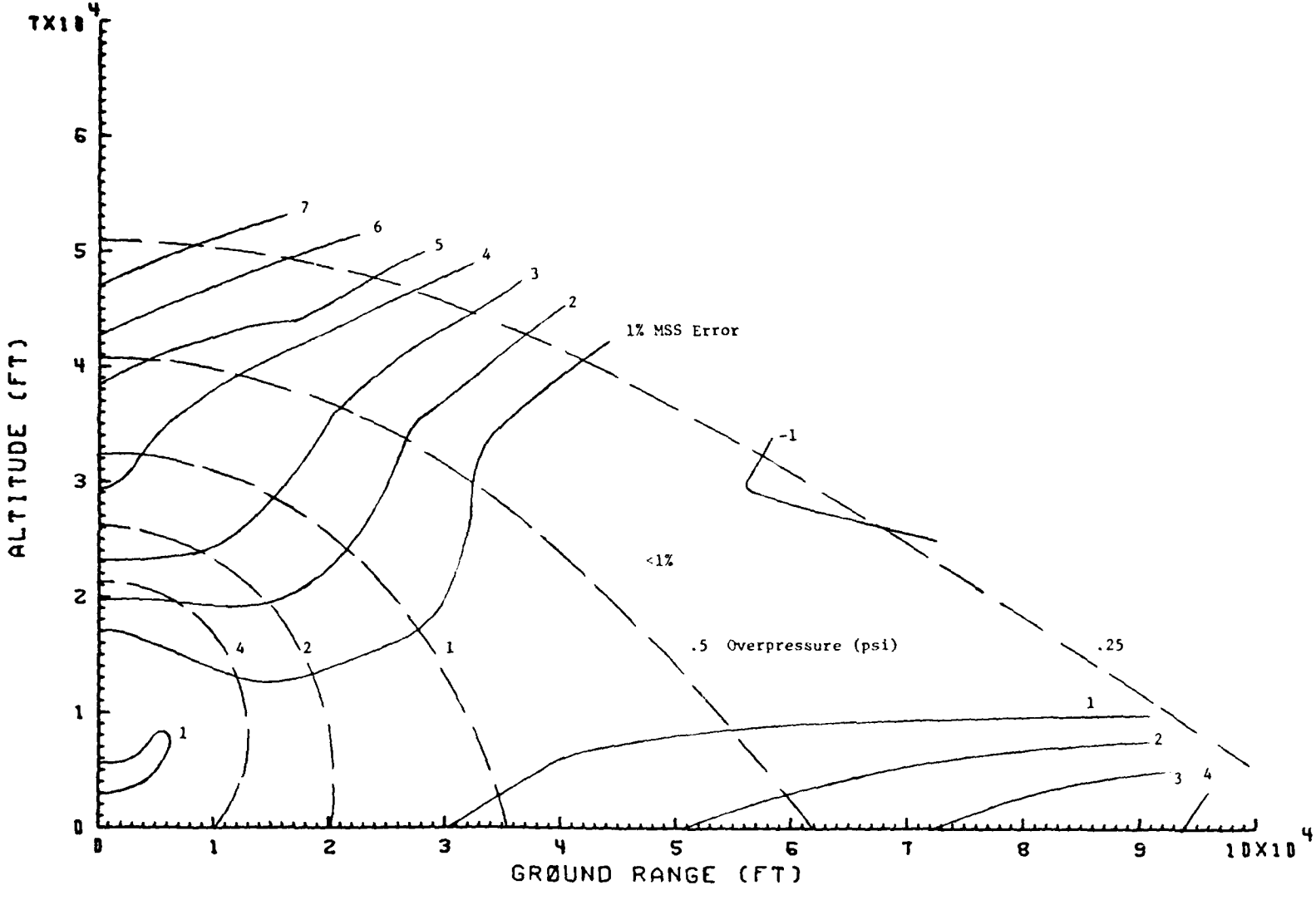

Figure 21. Shock Overpressure Error from Modified Sachs Scaled FAB-1D Data Compared with FAB-2D Data for a 1-MT Burst at 10,000-ft Altitude. FAB-1D Run 110-51, FAB-2D Run 44, both with 110 radial cells and 1-MT yield.

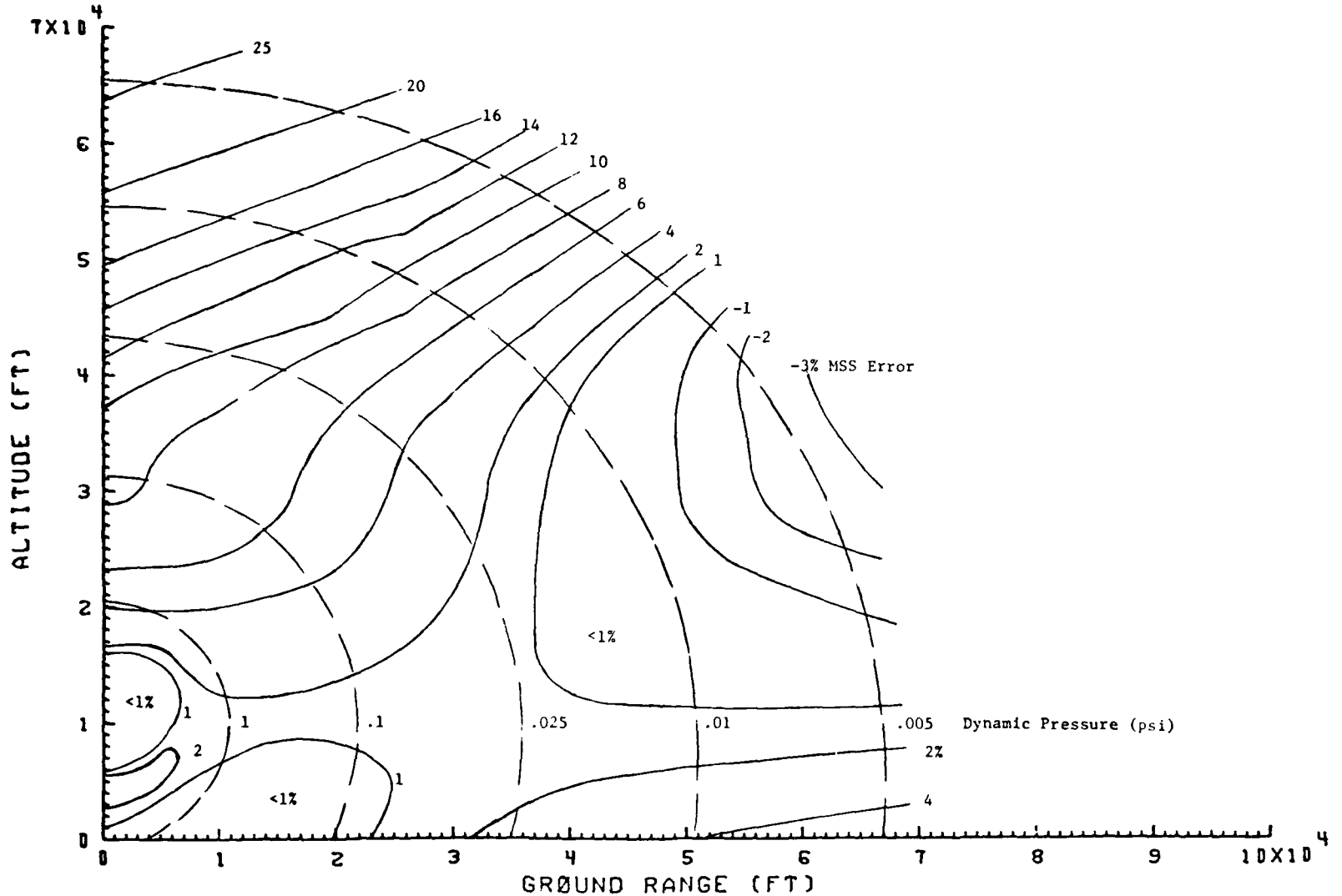

Figure 22. Shock Dynamic Pressure Error from Modified Sachs Scaled FAB-1D Data Compared with FAB-2D Data for a 1-MT Burst at 10,000-ft Altitude. FAB-1D Run 110-51, FAB-2D Run 44, both with 110 radial cells and 1-MT yield.

of 10,000 feet, Figure 8a, agreement is also generally good but with slightly larger differences than for the 1-KT case.

Other comparisons of FAB-2D and modified Sachs scaled overpressures are presented in Tables 4 and 5, for FAB-2D and FAB-1D calculations having the same yield and radial cell configuration (110 radial cells). The results in these tables indicate the same type of good agreement as for the above-described comparisons using the 273 cell FAB-1D data.

4-3 SHOCK DYNAMIC PRESSURE.

Comparisons of shock dynamic pressure contours, shown in Figures 9a and 10a for 1-KT and 1-MT bursts, respectively, indicate the same type of trends discussed above for the overpressure. For the 1-KT burst the two-dimensional results are generally in very good agreement with the modified Sachs scaled one-dimensional results. For the 1-MT burst (Figure 10a) agreement is also generally good. However for very high altitudes above the burst point the modified Sach scaled results are seen to overestimate the ground range for a given level of dynamic pressure.

4-4 SHOCK OVERPRESSURE AND DYNAMIC PRESSURE ACCURACIES.

As a more precise assessment of the accuracy of modified Sachs scaling (MSS), calculations were made of the error involved by comparing FAB-2D and FAB-1D-MSS shock overpressures and dynamic pressures for the same yield and the same 110 radial cell configuration (see Figures 19 to 22 and Tables 4 and 5), for both 1-KT and 1-MT conditions. Results of these calculations are shown in Figures 19 to 22, where the error parameter indicates the percentage values by which the modified Sachs scaled pressures exceed the FAB-2D pressures.

For the 1-KT burst at 1,000 foot altitude, the MSS overpressure error is seen to be less than 1 percent for overpressure levels down to 1 psi and also for overpressures down to 0.5 psi for altitudes up to somewhat over 6,000 feet (Figure 19).

The corresponding shock dynamic pressure percentage error for the 1-KT burst (Figure 20) is essentially twice the overpressure error.* It amounts to less than one percent error for dynamic pressures down to 0.005 psi for altitudes below and near the burst altitude, up to altitudes between 3,500 and 5,300 ft, depending on ground range. The error remains less than 3 percent for altitudes up to 7,000 feet down to the 0.005 pressure range.

For the 1-MT burst at 10,000 foot altitude, the MSS overpressure error is generally less than one percent for altitudes below or near to the burst altitude out to at least 30,000 foot ground range (Figure 21). The error is always less than about 4 percent for overpressures down to 1 psi. Near zero altitude the error increases to about 4 percent at 100,000 foot ground range and directly above the burst it increases to about 7 percent at the 0.25 psi level near 50,000 feet altitude.

The corresponding dynamic pressure MSS error for the 1-MT burst (Figure 22) is essentially twice the overpressure error* and does not exceed about 9 percent for conditions corresponding to overpressures down to 1 psi. It generally amounts to less than two percent for altitudes below or near to the burst altitude in the below 0.005 psi dynamic pressure range, up to 70,000 foot ground range. Near zero altitude the error increases to about 5 percent at the 0.005 psi level near 70,000 foot ground range. Directly above the burst the error increases up to about 25 percent at the 0.005 psi level at about 65,000 feet altitude.

4-5 POSITIVE OVERPRESSURE IMPULSE.

Positive overpressure impulses contours are shown in Figures 11 and 12 for the 1-KT and 1-MT burst conditions. For the 1-KT condition (Figure 11) it is seen that the modified Sachs scaled contours have generally the same shape as the FAB-2D contours and differ by less than 3 percent in slant range or 5 percent in impulse down to the 1 psi overpressure level. The slightly smaller ranges observed for the FAB-2D results are not due entirely to MSS errors, judging from the comparison of the FAB-2D and FAB-1D code impulse results for the uniform atmosphere case discussed in Section 3-5.

*This follows from the fact that the shock dynamic pressure is proportional to the square of the overpressure for small overpressures.

For the 1-MT burst, Figure 12, the FAB-2D and modified Sach scaled FAB-1D results are in reasonably good agreement near or below the burst altitude. For altitudes well above the burst altitude, the MSS results generally indicate appreciably larger impulses than are given by the FAB-2D code, the differences being considerably larger than the differences noted above for the 1-KT case. However, down to the 1 psi overpressure level, the MSS values at worst do not exceed the FAB-2D values by much over 6 percent in range or 12 percent in impulse.

4-6 POSITIVE DYNAMIC PRESSURE IMPULSE.

Positive dynamic pressure impulses are shown in Figures 13 and 14 for the 1-KT and 1-MT burst conditions, respectively. For the 1-KT condition (Figure 13), the modified Sachs scaled contours are the same shape as the FAB-2D contours, differing at most by about 3 percent in range or 4 percent in impulse. The slightly smaller ranges observed for the FAB-2D results are probably not due entirely to MSS errors for the same reasons discussed in the previous section regarding the positive overpressure impulse. For the 1-MT burst, Figure 14, agreement is generally good below the burst altitude, but well above the burst altitude the MSS contours indicate significantly larger ranges and impulses than are given by the FAB-2D code.

4-7 POSITIVE OVERPRESSURE DURATION.

Positive overpressure durations are shown in Figures 15 and 16 for the 1-KT and 1-MT burst conditions, respectively. For the 1-KT condition the FAB-2D and modified Sachs scaled contours are similar for altitudes near to or below the burst altitude, but the modified Sachs scaled FAB-1D results indicate significantly shorter contour ranges (larger durations for a given range) at much higher altitudes. For overpressure levels down to 1 psi the MSS results differ at most by about 5 percent in range or 2 percent in duration. For the 1-MT condition the modified Sachs scaled FAB-1D results indicate shorter contour ranges (larger overpressure durations) than the FAB-2D values for slant ranges from the burst greater than about 30,000 feet. For overpressure

levels down to 1 psi the MSS results differ at most by about 19 percent in range or 5 percent in duration. These differences are consistent with the positive overpressure impulse differences discussed above.

4-8 BLAST ARRIVAL TIME.

Blast arrival time contours are shown in Figures 17 and 18 for the 1-KT and 1-MT burst conditions, respectively. For the 1-KT condition (Figure 17) the FAB-2D and the modified Sachs scaled FAB-1D results are generally in good agreement everywhere. For the 1-MT case (Figure 18), agreement is also good but the modified Sachs scaled FAB-1D code gives slightly larger contour ranges (shorter arrival times) at high altitudes.

4-9 COMPARISONS WITH AFWL-1-KT-STD CODE.

Comparisons are shown in Figures 7b, 8b, 9b and 10b between shock front overpressures and dynamic pressure contours from the FAB-2D code with modified Sachs scaled results of the AFWL-1-KT-STD-REV code (Reference 12) for the 1-KT and 1-MT finite burst altitude conditions (see also Tables 4 and 5). In each figure the pressure contour shapes are similar for the two code results but the pressures given by the AFWL-1-KT-STD-REV code are seen to be always significantly larger than those obtained from the FAB-2D code. These differences are consistent with the differences between the FAB-1D and AFWL-1-KT-STD-REV code results observed in Reference 1.

SECTION 5
CONCLUSIONS

The FAB-2D hydrodynamic code has been developed to compute the blast flow characteristics of a nuclear free-air burst in a non-homogeneous atmosphere. Numerical results have been obtained on a CDC CYBER 176 computer for a 1-KT burst in a uniform atmosphere, for a 1-KT burst at a 1000-ft altitude, and for a 1-MT burst at a 10,000-ft altitude, where the last (longest) run required about 3.5 hours of CP time for computations to 200 seconds after burst time. Evaluation of these results and comparisons with modified Sachs scaled results from the one-dimensional FAB-1D code and the AFWL-1-KT-STD-REV code indicate the following conclusions.

1. The internal accuracy of the FAB-2D calculations of shock overpressure and positive overpressure duration, in regard to cell size, is about one percent or better down to overpressures of 0.2 psi.

2. For the case of a 1-KT blast in a uniform atmosphere, overpressures, pressure distributions, positive overpressure impulses, positive dynamic pressure impulses and shock arrival times calculated from the FAB-2D and FAB-1D codes are in good agreement to slant ranges of about 20,000 feet and down to overpressures of about 0.1 psi.

3. For a 1-KT burst at a 1000-ft altitude and a 1-MT burst at a 10,000-ft altitude, shock overpressures, shock dynamic pressures and shock arrival times calculated by the FAB-2D code are generally in good agreement with modified Sachs scaled (MSS) FAB-1D results. For the 1-MT burst the FAB-2D code indicated somewhat lower overpressures and dynamic pressures than the MSS values at altitudes well above the burst altitude, with at most about 4 percent differences for overpressure and 9 percent for dynamic pressure for overpressure levels down to 1 psi.

4. For the 1-KT 1000-ft burst altitude condition, positive overpressure impulse and dynamic pressure impulse from the FAB-2D and the modified Sachs scaled FAB-1D code were generally similar. For the 1-MT 10,000-ft burst altitude condition, results of the two codes were similar for altitudes near to or below the burst altitude, but the FAB-2D code indicated appreciably lower impulses at much higher altitudes.

5. Overpressure and dynamic pressures obtained by modified Sachs scaling of results of the AFWL-1-KT-STD-REV code were found to be generally larger than those predicted by the FAB-2D code. These differences are consistent with the differences between the FAB-1D and the AFWL-1-KT-STD-REV code results observed in Reference 1.

SECTION 6
REFERENCES

1. Smiley, R.F., Ruetenik, J.R., and Tomayko, M.A., FAB Code Computations of a 1-KT Nuclear Free-Air Blast Wave to Low Shock Overpressures. Kaman AviDyne Report TR-158, DNA 4825F, 31 January 1979.

2. Ellis, P.A., et al, Nuclear Weapons Blast Phenomena, Volume 1 - Source and Development of Blast Waves in Air, General Electric - TEMPO, Unpublished.

3. Laumbach, D.D., and Probstein, R.F., A Point Explosion in a Cold Exponential Atmosphere, J. Fluid Mech., Vol. 35, Pt. 1, pp. 53-75, 1969.

4. Lutzky, M., and Lehto, D.L., Shock Propagation in Spherical Symmetric Exponential Atmospheres, Physics of Fluids, Vol. 11, No. 7, pp. 1466-1472, 1968.

5. Lehto, D.L., Shock Propagation in a Decreasing-Density Spherically Symmetric Exponential Atmosphere, NOLTR 72-275, 21 November 1972.

6. Godunov, S.K., A Difference Method for Numerical Calculation of Discontinuous Solution of the Equations of Hydrodynamics, Mat. Sb. 47, p. 271-306, 1959.

7. Holt, M., Numerical Methods in Fluid Dynamics, Springer-Verlag, New York, 1977.

8. Thompson, J.H., REFLECT Computer Code for Ground-Reflected Blast Waves, Vol. II, Computer Code Description, Kaman AviDyne Report TR-96, Vol. II, DNA 3470F-2, 21 April 1975.

9. Brode, H.L., Theoretical Description of the Fireball, Blast and Thermal Radiation from a Nuclear Explosion at 60,000 Ft., RAND Corporation, Unpublished.

10. Sharp, A.L., A Thermal Source Model from SPUTTER Calculations, AFWL-TR-72-49, March 1973.

11. McNamara, W., Jordano, R.J., and Lewis, P.S., Air Blast from a 1 KT Nuclear Burst at 60 Metres over an Ideal Surface, General Electric-TEMPO, BRL Contract Report 353, November 1977.

12. Needham, C.E., Havens, M.L., and Knauth, C.S., Nuclear Blast Standard (1KT), AFWL-TR-73-55, (REV), April 1975.

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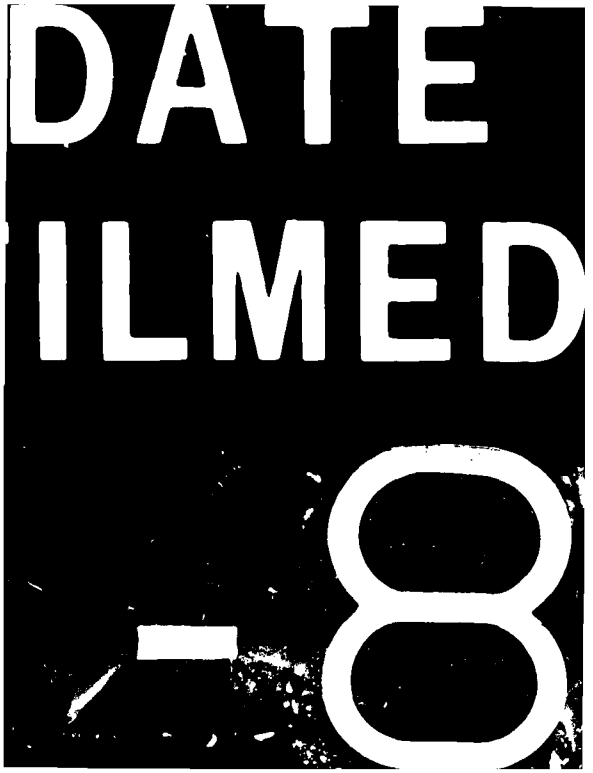
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