Review of Methods for Calculating Pressure Profiles of Explosive Air Blast and its Sample Application

by

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(ABSTRACT)

Blast profiles and two primary methods of determining them were reviewed for use in the creation of a computer program for calculating blast pressures which serves as a design tool to aid engineers or analysts in the study of structures subjected to explosive air blast. These methods were integrated into a computer program, BLAST.F, to generate air blast pressure profiles by one of these two differing methods. These two methods were compared after the creation of the program and can conservatively model the effects of spherical air blast and hemispherical surface burst.

The code, BLAST.F, was used in conjunction with a commercial finite element code (NASTRAN) in a demonstration of method on a 30 by 30 inch aluminum 2519 quarter plate of fixed boundary conditions in hemispherical ground burst and showed good convergence with 256 elements for deflection and good agreement in equivalent stresses of a point near the blast between the 256 and 1024 element examples. Application of blasts to a hypothetical wing comprised of aluminum 7075-T6 was also conducted showing good versatility of method for using this program with other finite element models.

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I would also like to thank my fellow student and project partner, John Coggin, for helping me with my NASTRAN problems in the application of the blast methods. I would also like to thank my girlfriend Leah for her help and support during this project.

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Parameter	Symbol	Equation
Distance (range)	R	
Weight of explosive charge	W	
Energy of blast	E	$W \times E/W$
Weight specific energy of explosive	E/W	
Sea level atmospheric pressure	p_o	14.695957 lb/in^2
Speed of sound, sea level	a_o	13397.390 in/sec
Sea level atmospheric density	r_o	1.146267E-7 lb-sec^2/in^4
Sea level atmospheric temperature	T_o	518.67°R = 59.0°F
Gravitational acceleration	g_o	386.08858 in/sec^2
Hopkinson scaled distance	Z	$R/W^{1/3}$ or $R/E^{1/3}$
Sachs scaled distance	$\bar{R}$	$(R\, p_o^{1/3})/E^{1/3}$
Sachs scaled Peak side-on overpressure	$\bar{P}_s$	P_s/p_o
Sachs scaled Peak normally reflected overpressure	$\bar{P}_r$	P_r/p_o
Sachs scaled peak dynamic pressure	$\bar{Q}$	Q/p_o
Sachs scaled side-on overpressure	$\bar{p}_s$	p_s/p_o
Sachs scaled normally reflected overpressure	$\bar{p}_r$	p_r/p_o
Sachs scaled dynamic pressure	$\bar{q}$	q/p_o
Sachs scaled density	$\bar{\rho}$	ρ/ρ_o
Sachs scaled temperature	$\bar{\theta}$	θ/θ_o
Sachs scaled shock velocity	$\bar{U}$	U/a_o
Sachs scaled peak particle velocity	$\bar{u}_s$	u_s/a_o
Sachs scaled particle velocity	$\bar{u}$	u/a_o
Sachs scaled time of arrival	$\bar{t}_a$	$(t_a a_o p_o^{1/3})/E^{1/3}$
Sachs scaled duration of positive side-on overpressure	$\bar{T}_s$	$(T_s a_o p_o^{1/3})/E^{1/3}$
Sachs scaled duration of positive normally reflected overpressure	$\bar{T}_r$	$(T_r a_o p_o^{1/3})/E^{1/3}$
Sachs scaled time	$\bar{t}$	$(t a_o p_o^{1/3})/E^{1/3}$
Sachs scaled side-on positive impulse	$\bar{I}_s$	$(I_s a_o)/(p_o^{2/3} E^{1/3})$
Sachs scaled normally reflected positive impulse	$\bar{I}_r$	$(I_r a_o)/(p_o^{2/3} E^{1/3})$
Positive phase side-on pressure	P_s^+	
Positive phase time of duration	T^+	
Positive phase side-on impulse	I_s^+	
Reflected temperature	θ_r	
Side-on temperature	θ_s	
gamma, ratio of specific heats	γ	
Time of arrival	T_a	
Time of duration	T_o	
Decay coefficient	b	

Decay coefficient, reflected	b_r	
Explosive weight being scaled to	Q_1	
Explosive weight being scaled	Q_2	
Ambient Temperature	T_a	
Ambient atmospheric pressure	p_a	
Peak side-on overpressure (non-scaled)	P_s	
Pressure scaling factor	S_p	p_a/p_o
Distance scaling factor	S_d	$(Q_2/Q_1)^{1/3}(p_o/p_a)^{1/3}$
Time scaling factor	S_t	$(Q_2/Q_1)^{1/3}(p_a/p_o)^{1/3}(T_o/T_a)^{1/2}$
Impulse scaling factor	S_i	$(Q_2/Q_1)^{1/3}(p_o/p_a)^{1/3}(T_o/T_a)^{1/2}$

1.0 INTRODUCTION

While the technology and computational methods for finite element analysis of structures has been around for many years, there is a lack of a design tool for the engineer to use in the accurate analysis of structures to specific blast loadings. This became clear to the author while recently attached to a project for industry.

Such a tool should be easy to use and at the same time, correct to the recorded values of parameters for a specific threat condition. This would provide a tool for both an engineer working in design and also an analyst examining the predicted, or after effects, of an explosive blast. Thus, the design of structures which have some resistance or inherent protection to specific blast threats is possible. This would also allow the design of structures which would have qualities which would protect the structure's occupants.

Engineers within the military or their contractors have access to some codes which will predict, based on that code's method, the pressure results, and thus the blast effects, of the explosive blast itself. This has a wide application both for government and civilian use, but also in this age of terrorism, in the application of the design of civilian facilities to minimize both structural damage and collateral damage to personnel.

After beginning work, it became clear that there was no effective design tool that could do this while still providing an output that could be used in presentations, or more importantly, commercial finite element codes with a minimum of hassle. The author attempted to make use of a commercial code and a reference text in an effort to generate a pressure profile for a specific threat. Upon review of the method used by another scientist, it became clear that while a result had been obtained by that researcher, that result made use of the reference material in a manner so as to render those results questionable. This provided essential motivation to create a simple and versatile program that would do this easily and effectively.

First a method for determining these blast loads had to be arrived at, but upon review of literature, it was found that there were two primary methods. Then, these methods had to be accurately duplicated, first by hand calculations, then by tested computer subroutines.

The computer code developed, BLAST.F, is platform independent, small, and easy to use. This program has the capability of generating profiles for both conventional and nuclear blast pressure effects, giving it that wide application that would be needed in an protective design, analysis, or an academic environment studying such loadings on structures and the protective design of buildings, structures, and vehicles, well as the analysis of a specific's threats effects, both potential and real.

This paper will first cover the background of the material including two methods of blast scaling. This research will then review two primary methods of determining the explosive blast pressure profiles which can be applied to a finite element model. The program, BLAST.F, and it's capabilities will be covered. Examples of this computer program loading applied to differing finite element models will be reviewed, in this case an aluminum plate and a model based on the geometry of an aeroelastic wing model.

2.0 REVIEW OF LITERATURE

Due to the nature of explosives and their potential threat to the public in the hands of the ignorant as well as those who would inflict harm, the publically available literature on the exact effects of explosives is restricted. This restriction confined most of the referenced literature in the reviewed works inaccessible to this researcher. Much of this field's research and results are held in the U.S. Army's Ballistics Research Laboratory at Aberdeen's technical memos and works by the English Ministry of Defense, thus they are in some cases mentioned in passing throughout this work, but may not be specfically mentioned in the References at the end of this paper.

Of the works that were available in the open literature, the first and most informative was W.E. Baker's *Explosions in Air* (1973). This work covers the basics of explosive air blast analysis, theoretical computational methods, experimental blast analysis, and the equipment used in its analysis and data gathering. It roughly parallels a hand book of a similar title by the U.S. Army Materiel Command, *Explosions In Air* (1975). While both cover similar material, in a similar manner, especially in the useful chapter on air blast parameters, the Army reference covered the topic of critical angle for reflected pressure waves and the calculation of reflected pressure waves that strike a target at an angle to the normal of a surface. Both of these references use a method of fitting to experimental scaled blast parameters, but they did not specifically make use of a separate ground reflection technique. Such a technique was mentioned in passing in both *Explosions in Air* when discussing the scaling of experimental data that had been gathered in hemispherical ground reflection. Also of good use, Baker's book includes three large scale (three foot square) graphs of blast parameters, which were of great help in finding interim values between tabulated values presented in Baker's and the Army's texts. However, these graphs had to be used with caution as they had the wrong axis markings or in some cases, the correct trend was drawn through the wrong points.

Kingery and Bulmash (1984) present similar data that has been scaled for use with a different form of scaled parameters. They then fitted functions to these parameters by computers within a Log-Log domain so that these parameters can be more easily determined, providing a second method that can be programmed and implemented. This work also provided some insight into ground reflection, while providing a specific set of results for that condition, and the application to nuclear weapons in ground burst.

Goodman's (1960) paper was gathered from test detonation of pentolite and was closer to Explosions in Air, but provided insight in the gathering and comparison of blast data.

Bulson (1997) provided a book on *The Explosive Loading of Engineering Structures* and made a great deal of discussion of loadings that have been determined from nuclear tests as well as smaller scale conventional explosives. This book specifically mentions a method for the determination of blasts in ground reflection which matched, with the exception of a factor, the method extrapolated from *Explosions in Air*.

Finally, the Army Technical Manual (1992) on the protective design of structures for conventional weapons effects, TM5-855-1, essentially presented methods found in Kingery and Bulmash for calculation of blast loads, but provided some insight in what should be considered in a design tool.

More recently, a work by Türkmen and Mecitoğlu, the prediction of blast loads was instead replaced with an experimental result, then these experimental results were applied to a finite element model of a stiffened composite plate. In this setup, a shock tube was used to generate a dynamic pressure shock which was measured by a wooden board with pressure transducers. This is notable because unlike the other works, Türkmen and Mecitoğlu used an overpressure profile with a large negative phase. Using this, they were able to get a good correlation to experimental results with the same type of dynamic loading.

3.0 METHODS

3.1 Blast Profiles

In this report, a great deal of time will be spent in the determination of the pressure time history at a point for an explosive blast. These blast profiles are the result of pressure waves that are created by the sudden and violent release of energy in the explosive charge which causes a sharp rise in the pressure of the surrounding gas or liquid medium. A generic blast profile at a point is shown in Figure 1. This profile is a time history of a blast overpressure wave that impinges on a point in space, where there is a positive and a negative phase denoted by T^+ and T^-, respectively. It is this positive phase that is deemed the most important of the two phases, and is what is generally studied. This curve of the profile and to which a curve is "fit" concerns most researchers in this field.

In the calculation and presentation of the pressure blast profiles, numerous methods have been proposed. Baker reports [1] that Flynn proposed a linear decay of pressure given by:

$$p(t) = p_o + P_s^+(1 - t/T^+), \quad 0 < t \le T^+ \tag{1}$$

where p_o is the ambient pressure, P_s^+ is the peak side-on overpressure, T^+ is the positive phase duration and t is the time measured from the time of blast wave arrival. The peak side-on overpressure can usually be preserved at the original value, but the positive time duration, T^+, is altered to preserve the true positive duration impulse, I_s^+, which can be found by integrating the pressure over the positive phase [1]:

$$I_s^+ = \int_{t_a}^{t_a+T^+} \left[p(t) - p_o\right] dt \tag{2}$$

again where t is measured from the time of arrival, t_a. Thus, this simplified form can be altered to fit the desired profile curve.

As the pressure profile is of a decaying nature, a better form was presented by Ethridge in his 1965 work as reported by Baker [1]:

$$p(t) = p_o + P_s^+ e^{-ct} \tag{3}$$

where t is measured from the time of arrival, P_s^+ is the peak side-on overpressure and is left at its original value, and p_o is the ambient atmospheric pressure. Thus, by curve fitting to two parameters, the peak pressure and initial decay rate or the peak pressure and positive impulse, Equation (3) can be used to better fit transducer gathered data.

The next extension of this process is to curve fit experimental results by using three different parameters. This form is usually the modified Friedlander's equation as given in Baker [1]:

$$p(t) = p_o + P_s^+ \left(1 - \frac{t}{T^+}\right) e^{-b\frac{t}{T^+}} \qquad \textbf{(4)}$$

where again t is measured from the time of arrival, P_s^+ is the peak side-on overpressure, p_o is the ambient atmospheric pressure, and b is the decay coefficient. Thus, a curve fitting of experimental data may be done by matching any three of four blast characteristics: peak side-on overpressure, P_s^+, positive phase impulse, I^+, positive phase duration, T^+, and initial decay rate. The peak overpressure is the highest pressure the initial blast wave creates over the ambient atmospheric pressure. The positive phase impulse is the area under the pressure curve for the duration of the time period of positive overpressure, that same time period is the positive phase duration, and the initial decay rate is a measure of how quickly the pressure returns from the spike of peak over pressure to the ambient pressure.

Similar curve fitting may be done to four or five parameters, but for the purposes of this paper and for the computer program that was written, using Friedlander's equation was considered to be adequate and simple to program, while matching methods used by other researchers.

Ignored in this study and not implemented by the computer program is the examination and use of the negative phase of the blast. Indeed, Baker [1] reports he could find only one proposed functional form for this phase from the works of Brode (1955):

$$p(t) = p_o - P_s^- \left(\frac{t}{T^-}\right)\left(1 - \frac{t}{T^-}\right) e^{-4\frac{t}{T^-}} \qquad \textbf{(5)}$$

where p_o is the ambient pressure, P_s^- is the peak negative phase overpressure, T^- is the duration of the negative phase, and t is measured from the end of the positive phase (t_a+T^+). In a recent work, in the Journal of Sound and Vibrations,Türkmen and Mecitoğlu [10] used a shock tube to generate dynamic shocks for experimental determination of pressure values for use on Finite Element models. In this work, the authors found a rather large negative phase result, however there was no method for determining this phase given in the work. The present researcher would hypothesize that the negative phase determined was of a large portion due to the experimental setup of the shock tube and the wooden plate on which the pressure transducers were placed.

As explosives can vary in both composition and manner of destructive force, they are usually compared by the shattering effect of the sudden release of energy of each explosive (brisance) or their blast pressures. Thus, this work makes use of TNT as a reference explosive, with the adjustment to be made in altering the energy or weight of the explosive to match a desired, non-TNT explosive.

An incident, or side-on, blast wave is a blast wave that travels parallel to a surface. Thus, side-on pressure is the pressure on a surface parallel to the direction of the blast wave's direction of trave. This direction is assumed to be radial to the blast center. Reflected pressures are much higher and result when an incident wave impinges on any rigid reflecting surface at any angle not parallel to the direction of wave travel [5]. The relationship of angle vs. reflected pressure will be examined later in Section 3.2.1. The conceptual difference in these two different types of waves is shown in Figure 2.

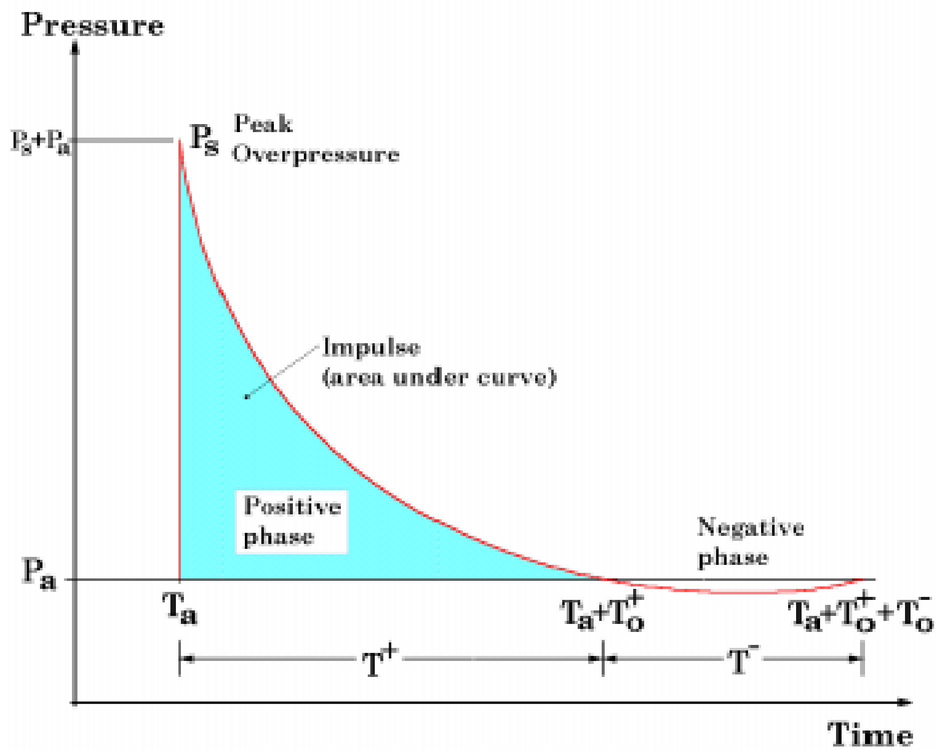

Figure 1 An example of a canonical blast profile showing the positive phase and peak pressure of the blast after its time of arrival.

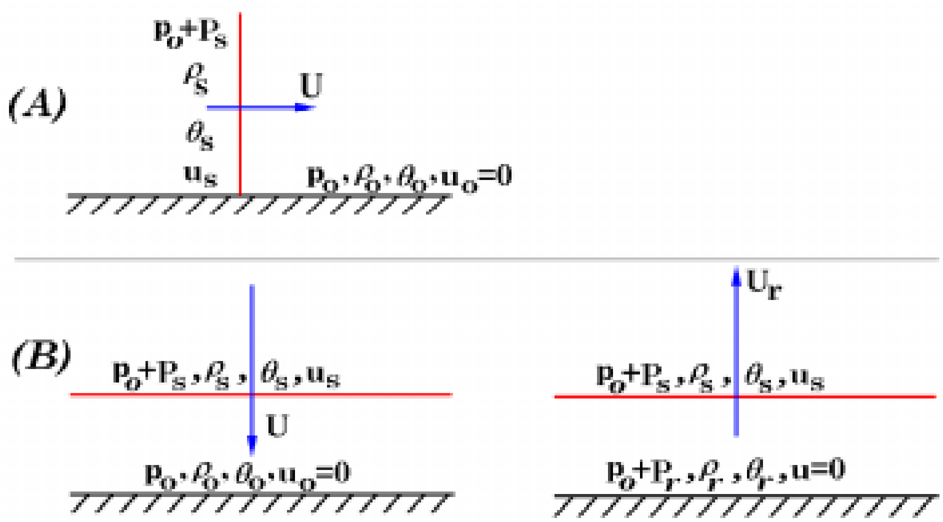

Figure 2 Comparison of (A) an incident blast wave of speed U traveling across a surface and (B) an incident blast wave traveling at speed U in normal reflection against a solid reflecting surface and leaving at speed U_r.

3.2 Blast Scaling

In blast analysis, there are many differing methods of scaling blast parameters. By scaling the parameters determined from experimental results of an explosion, the results are generalized and thus can be utilized for the simulation of blasts of varying energy or varying distances. The two most common methods, and the ones used here, are Hopkinson and Sachs blast scaling methods. These are described below.

3.2.1 Hopkinson Blast Scaling

Hopkinson blast scaling is based on cube root scaling and is referenced by Baker [1] as being formulated by Hopkinson in his 1915 paper. Essentially, Hopkinson put forth the idea that if you had two differing weights of the same explosive, say a one pound and a five pound charge of Composition B, and they were both detonated in similar atmospheric conditions, then at some identical scaled distance, both charges produce similar blast waves. Using this idea, he presented the idea of a dimensional scaled distance that will be used later in this work:

$$Z = \frac{R}{W^{\frac{1}{3}}} \quad or \quad Z = \frac{R}{E^{\frac{1}{3}}} \tag{6}$$

where R is the distance (range) from the explosive blast center, W is the weight of the charge, and E is the energy of the charge. However, Baker [1] footnotes this explanation by noting that W is usually used only for a weight of standard explosives such as TNT, but energy E is a "much more physically realistic parameter."[1] Thus, at some distance R from a blast, a transducer could detect a blast characteristic of some explosive of weight W, (or dimension d of a charge from which a weigh can be determined) with some peak pressure P, impulse I, time of duration T_o, and time of arrival T_a. Therefore, at some distance kR one detects a blast of some peak pressure P, impulse kI, time of duration kT_o, and time of arrival kT_a for a blast characteristic of an explosive weight or dimension kd, as seen in Figure 3. Thus all distance and time factors are scaled by some factor k but the pressure and velocity remain unchanged at similarly analogous times. This also assumes that gravity and viscosity effects are negligible. [1]

Baker reports [1] that Kennedy in his 1946 work found that this scaling can be applied for varying distances if the geometry of the explosives being scaled is roughly similar. However, he notes that while the method is capable of being applied for varying distances, in some respects, the trends of reported scaled values have the same form, but can vary as much as a factor of two. Kingery found in his 1952 work that close agreement could be found between small charge blasts (one to eight pounds) and its larger 100 pound counterparts. Thus Kingery's paper as referenced by this work makes use of Hopkinson

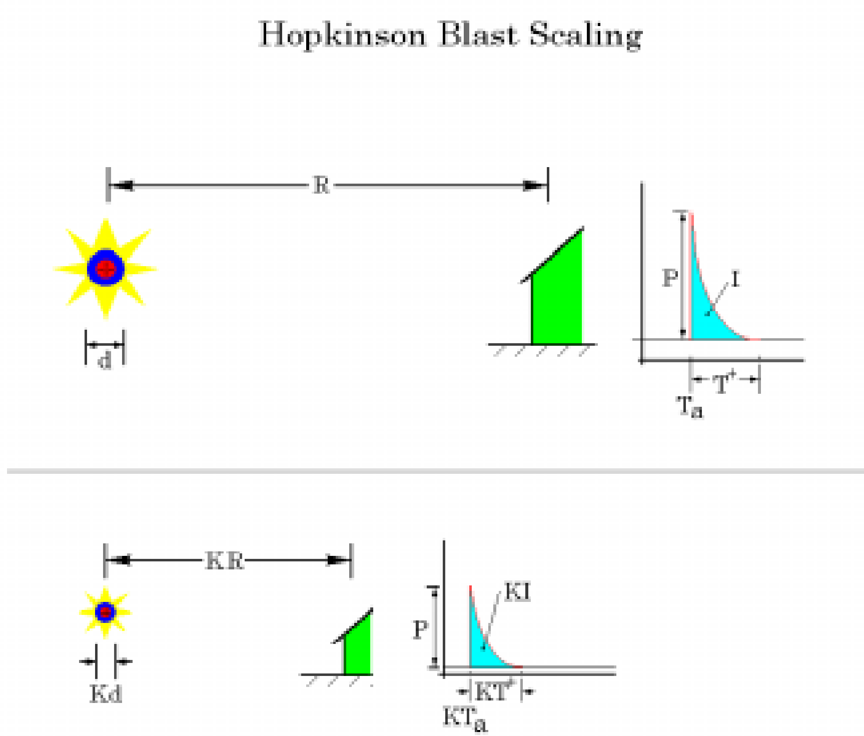

Figure 3 Graphical sample representation of Hopkinson blast scaling where the effects of a blast at distance R for a charge of dimension d is equivalent to a factor, K, multiplied against the equivalent parameters for a blast of dimension Kd at a distance of KR.

scaling.

3.2.2 Sachs Blast Scaling

Sachs scaling was used by both Baker's *Explosions in Air* [1] and by the Army Materiel Commands *Explosions in Air* design manual [2]. Where Hopkinson scaling is based on the scaling of a blast in air conditions equivalent to those for the experimental test blast from which data was gathered, Sachs scaling was proposed in 1944 as a more general blast scaling law which is based on the blast parameters being unique functions of a scaled distance: [1]

$$\bar{R} = \frac{R p_o^{1/3}}{E^{1/3}} \tag{7}$$

where R is the distance (range), p_o is the ambient pressure, and E is the energy of the explosive charge. Thus Sachs scaling law states that pressure, time, impulse, and other parameters can be expressed as functions of this scaled distance, but assumes that air behaves as a perfect gas and assumes gravity and viscosity are negligible. [1]

Having been confirmed by many experimenters, Dewey and Sperazza's 1950 work involved the detonation of bare pentolite spheres in an altitude simulation chamber so as to vary temperature and pressure. In that work, Hopkinson scaling was shown to be consistent for varying distances but not for varying pressure. Therefore, each test at a different pressure produced a different impulse prediction. This was not true with Sachs scaling which produced excellent scaled results that were consistent for each change in blast distance and in pressure.

Thus, it could be shown that Hopkinson scaling is a special case of Sachs scaling (i.e., Sachs scaling reduces to Hopkinson scaling when there are no atmospheric changes between the explosive test data and the actual conditions of the desired explosive to which one is predicting for modeling or similar research). [1] Also, because of the perfect gas assumption, shock strengths must be low enough for a gaseous medium to behave as a perfect gas. Therefore, for some strong shock waves or for distances that are particularly close to the explosive, this law can no longer apply.

3.3 Air Blast and Hemispherical Surface Blast methods

The methods reviewed below cover the determination of air blast parameters by the fitting of results to experimental data as presented by other researchers in differing design manuals.

3.4 Air Blast Parameters by Methods in *Explosions in Air*, both Baker and U.S. Army

Methods used in *Explosions in Air*, both the Army design manual [2] and Baker's book [1], make use of data compiled for Sachs scaling methods. Both the *Explosions in Air* and Kingery methods make use of some form of Friedlander's Equation, in this case [1]:

$$p = P_s \left(1 - \frac{(t - t_a)}{t_s} \right) e^{-b \frac{(t-t_a)}{t_s}} \quad \textbf{(8)}$$

where P_s is the peak side-on overpressure, t_a is the time of arrival, t_s is the positive phase duration for the side-on overpressure, and b denotes the decay coefficient.

As the blast parameters are functions of the scaled distance, $\bar{R}$, this parameter must be found first. The pertinent equation is:

$$\bar{R} = \frac{R p_o^{1/3}}{E^{1/3}} \quad \textbf{(9)}$$

where the range is R, the ambient atmospheric pressure is p_o, and the energy of the blast is denoted by E. This energy of the blast may be found by multiplying the weight specific energy, E/W, from Table 1 for the desired explosive by the weight of the charge.

Baker's and the Army's data are compiled from various sources for bare free air explosions of pentolite, and all parameters are presented for standard conditions. Baker references Shear and Day (1959) as the source for overpressure data for $\bar{P}_s \leq 3.5$ [1]:

$$\bar{u}_s^2 = \frac{2\bar{P}_s^2}{\gamma\left[(\gamma+1)\bar{P}_s + 2\gamma\right]} \quad \textbf{(10)}$$

$$\bar{U}^2 = 1 + \frac{\gamma+1}{2\gamma}\bar{P}_s \quad \textbf{(11)}$$

$$\bar{\rho}_s = \frac{(\gamma+1)\bar{P}_s + 2\gamma}{(\gamma-1)\bar{P}_s + 2\gamma} \quad \textbf{(12)}$$

$$\bar{\theta}_s = 1 + \frac{(\gamma-1)\bar{P}_s\left(\bar{P}_s + 2\right)}{(\gamma+1)\bar{P}_s + 2\gamma} \quad \textbf{(13)}$$

where $\bar{P}_s$ is the scaled peak side on pressure, and γ=1.4, the ratio of specific heats. Baker continues by assuming that acoustic approximations hold for $\bar{P}_s \leq 10^{-3}$. The acoustic approximations are [1]:

$$\bar{P}_s = \frac{0.1153}{\bar{R}} \quad \textbf{(14)}$$

$$\bar{u}_s = \frac{\bar{P}_s}{\gamma} = \frac{0.0824}{\bar{R}} \quad \textbf{(15)}$$

$$\bar{\rho}_s = 1 + \frac{\bar{P}_s}{\gamma} = 1 + \frac{0.0824}{\bar{R}} \quad \textbf{(16)}$$

$$\bar{U} = 1 + \bar{P}_s\frac{\gamma+1}{4\gamma} = 1 + \frac{0.0494}{\bar{R}} \quad \textbf{(17)}$$

$$\bar{\theta}_s = 1 + \bar{P}_s\frac{\gamma-1}{\gamma} = 1 + \frac{0.0330}{\bar{R}} \quad \textbf{(18)}$$

The basic parameter necessary is the scaled peak side on over pressure $\bar{P}_s$. Baker combines the methods of Goodman (1960) and Lehto and Larson (1969) so as to take advantage of those ranges over which each researcher's method agrees with experimental data. Thus, over the range of $\bar{R}$=0.01423 (at the surface of the explosive) to $\bar{R}$=1004, Goodman's method is used by Baker, and for $\bar{R}$ > 1004 the acoustic approximations in Equations (14) to (18) are used.

So, from $\bar{R}$=0.01423 to $\bar{R}$=1.2, Baker and the Army make use of the Hugoniot tables of Shear and Day (1959). For larger $\bar{R}$, Equations (10) and (13) are used with γ=1.4, and with peak dynamic pressure $\bar{Q}$ determined from: [1]

$$\bar{Q} = \frac{\gamma}{2}\bar{\rho}_s\bar{u}_s^2 \tag{19}$$

Both Baker and the U.S. Army manual then take scaled arrival time for the shock front from Goodman (1960). Thus, the compiled data can then be tabulated, and is presented in Tables 2a and 2b and in graphical form in Figure 4.

Table 1: Properties of Differing Explosives

Explosive	Specific Gravity	Density, ρ_E ($lb_m\ sec^2/in^4$)	Weight Specific Energy, E/W ($in\text{-}lb_f/lb_m$)	Volume Specific Energy, E/V ($in\text{-}lb_f/in^3$)	Radius, r, of 1-lb sphere, inches
Pentolite (50/50)	1.66	1.551E-4	20.50E6	1.230E6	1.584
TNT	1.60	1.496E-4	18.13E6	1.048E6	1.604
RDX	1.65	1.542E-4	21.50E6	1.283E6	1.588
Composition B	1.69	1.580E-4	20.80E6	1.271E6	1.575
HBX-1	1.69	1.580E-4	15.42E6	0.944E6	1.575

Taken from *Explosions in Air*, U.S. Army Materiel Command, 1975, Ch. 6, pp. 6-4.

Table 2a: Non-dimensional, Sachs Scaled, Shock-Front Air Blast Parameters for Incident (side-on) Blast waves. (0.01423 $\leq \bar{R} \leq$1.5)

Scaled Range, $\bar{R}$	Peak Side-on overpressure, $\bar{P}_s$	Time of Arrival, $\bar{T}_a$	Side-on (specific) impulse, $\bar{I}_s$	Time of Duration, $\bar{T}_s$	Particle velocity, $\bar{u}_s$	Shock velocity, $\bar{U}$	Density, $\bar{\rho}_s$	Peak dynamic pressure, $\bar{Q}$	Temp., $\bar{\theta}_s$
0.01423	819	0	--	--	23.2	25.2	12.18	4570	39.9
0.016	703	7.16E-5	--	--	21.5	23.6	11.9	3850	36.7
0.018	605	1.66E-4	--	--	19.8	21.9	11.6	3240	34.7
0.02	531	2.58E-4	--	--	18.6	20.6	11.3	2760	33.1
0.03	324	8.05E-4	--	--	14.4	16.1	10.1	1450	26.0
0.04	225	1.48E-3	--	2.06E-2	12.0	13.5	9.28	935	21.1
0.05	170	2.27E-3	--	1.84E-2	10.4	11.7	8.88	670	17.7
0.08	90.5	4.95E-3	8.95E-2	1.75E-2	7.5	8.78	7.49	305	11.8
0.09	77.5	6.06E-3	8.24E-2	1.82E-2	6.9	7.8	7.25	245	10.7
0.1	67.9	7.62E-3	7.85E-2	1.91E-2	6.47	7.5	7.02	205	9.85
0.125	48.8	1.07E-2	7.5E-2	2.43E-2	5.38	6.27	6.36	127	7.85
0.15	37.2	1.54E-2	7.88E-2	3.41E-2	4.61	5.55	5.91	87.2	6.20
0.2	20.4	2.55E-2	0.106	8.85E-2	3.5	4.27	4.92	44.1	4.31
0.22	16.6	2.84E-2	0.108	0.126	3.13	3.78	4.55	34.4	3.44
0.24	13.4	3.29E-2	0.107	0.148	2.84	3.42	4.37	25	3.34
0.25	11.9	3.82E-2	0.103	0.157	2.69	3.33	4.20	20.8	3.21
0.3	7.28	5.41E-2	8.85E-2	0.171	1.95	2.66	3.59	9.45	2.48
0.4	3.46	9.90E-2	6.95E-2	0.158	1.25	2.00	2.66	2.79	1.68
0.5	2.05	0.157	5.7E-2	0.162	0.888	1.67	2.09	1.08	1.43
0.6	1.38	0.218	4.82E-2	0.181	0.672	1.48	1.81	0.570	1.30
0.8	0.772	0.340	3.71E-2	0.232	0.427	1.28	1.49	0.212	1.18
0.9	0.618	0.392	3.35E-2	0.254	.363	1.21	1.39	.144	1.16
1.0	0.506	0.466	3.02E-2	0.268	0.302	1.19	1.33	9.40E-2	1.12
1.5	0.254	0.830	2.07E-2	0.328	0.165	1.11	1.17	1.96E-2	1.07

Compiled from Baker, *Explosions in Air* with some values determined from large scale graphs in Baker.

Table 2b: Non-dimensional, Sachs Scaled, Shock-Front Air Blast Parameters for Incident (side-on) Blast waves. ($2.00 \leq \bar{R} \leq 1000$)

Scaled Range, $\bar{R}$	Peak Side-on overpressure, $\bar{P}_s$	Time of Arrival, $\bar{T}_a$	Side-on (specific) impulse, $\bar{I}_s$	Time of Duration, $\bar{T}_s$	Particle velocity, $\bar{u}_s$	Shock velocity, $\bar{U}$	Density, $\bar{\rho}_s$	Peak dynamic pressure, $\bar{Q}$	Temp., $\bar{\theta}_s$
2.00	0.161	1.26	1.58E-2	0.362	0.107	1.0733	1.11	7.58E-3	1.0436
2.50	0.115	1.71	1.28E-2	0.39	7.97E-2	1.0481	1.0809	4.23E-3	1.0306
3.00	8.89E-2	2.20	1.08E-2	0.414	6.31E-2	1.0374	1.0628	2.70E-3	1.0247
4.00	6.16E-2	3.21	8.12E-3	0.445	4.41E-2	1.0257	1.0436	1.37E-3	1.0172
5.00	4.68E-2	4.21	6.56E-3	0.477	3.36E-2	1.0198	1.0332	8.20E-4	1.0134
6.00	3.74E-2	5.19	5.46E-3	0.495	2.68E-2	1.0159	1.0266	5.15E-4	1.0107
7.00	3.06E-2	5.84	4.67E-3	0.517	2.19E-2	1.0133	1.0223	3.67E-4	1.00895
8.00	2.61E-2	7.15	4.10E-3	0.532	1.90E-2	1.0111	1.0186	2.50E-4	1.00745
9.00	2.27E-2	7.64	3.62E-3	0.548	1.61E-2	1.00973	1.0162	1.98E-4	1.00650
10.0	1.98E-2	9.10	3.25E-3	0.564	1.44E-2	1.00850	1.0141	1.43E-4	1.00565
20.0	8.70E-3	18.9	1.58E-3	0.666	6.21E-3	1.00372	1.00620	2.76E-5	1.00248
30.0	5.43E-3	28.8	1.04E-3	0.737	3.90E-3	1.00232	1.00387	1.07E-5	1.00155
40.0	3.91E-3	38.9	7.64E-4	0.781	2.79E-3	1.00167	1.00279	5.52E-6	1.00112
50.0	3.04E-3	48.9	6.05E-4	0.825	2.17E-3	1.00130	1.00217	3.31E-6	1.000870
60.0	2.48E-3	58.8	4.98E-4	0.856	1.77E-3	1.00106	1.00177	2.19E-6	1.000709
80.0	1.81E-3	78.5	3.68E-4	0.916	1.28E-3	1.000618	1.00103	1.15E-6	1.000413
100	1.41E-3	98.5	2.93E-4	0.96	1.00E-3	1.000494	1.000824	6.95E-7	1.000330
250	5.17E-4	224	1.16E-4	1.16	3.79E-4	1.000775	1.000453	1.02E-7	1.000180
500	2.42E-4	499	5.75E-5	1.24	1.73E-4	1.0000988	1.000173	2.03E-8	1.0000660
1000	1.153E-4	1000	2.88E-5	1.25	8.20E-5	1.0000494	1.0000824	4.71E-9	1.0000330

Compiled from Baker, *Explosions in Air* with some values determined from large scale graphs in Baker.

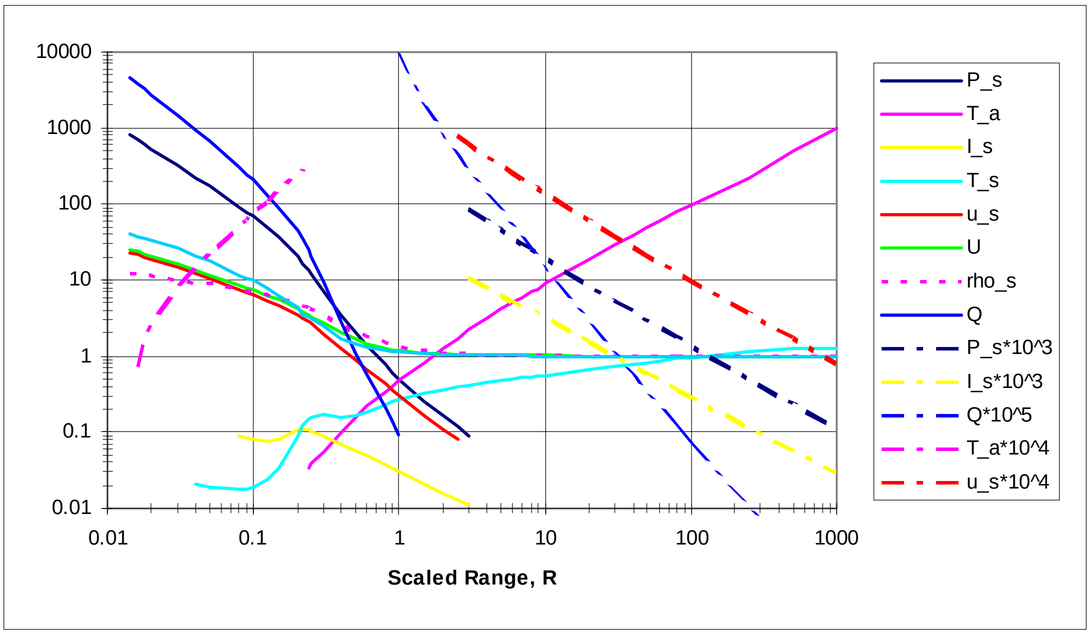

Figure 4 Graphical representation in Log-Log scale, of the side-on, Sachs scaled blast parameters as presented in Table 2. Note that some parametric ranges of parameters have been scaled over a portion of the domain to fit the axes.

Making use of the condition that there is no velocity at a rigid reflecting surface, one can determine the parameters behind a shockwave that would be normally reflected [2].

For values of $\bar{P}_r < 3.5$, the equations for a normally reflected shockwave in a perfect gas are [2]:

$$\bar{P}_r = 2\bar{P}_s + \frac{(\gamma+1)\bar{P}_s^{\,2}}{(\gamma-1)\bar{P}_s + 2\gamma} \quad \textbf{(20)}$$

$$\bar{\rho}_r = \frac{\gamma\left(\bar{P}_s+1\right)\left[(\gamma+1)\bar{P}_s+2\gamma\right]}{\left[(\gamma-1)\bar{P}_s+\gamma\right]\left[(\gamma-1)\bar{P}_s+2\gamma\right]} \quad \textbf{(21)}$$

$$\bar{\theta}_r = \frac{\left[(\gamma-1)\bar{P}_s+\gamma\right]\left[(3\gamma-1)\bar{P}_s+2\gamma\right]}{\gamma\left[(\gamma+1)\bar{P}_s+2\gamma\right]} \quad \textbf{(22)}$$

where again γ is the ratio of specific heats and $\bar{P}_s$ is the side-on pressure coefficient. The acoustic asymptotes for the above parameters are given by [2]:

$$\bar{P}_r = 2\bar{P}_s = \frac{0.2306}{\bar{R}} \quad \textbf{(23)}$$

$$\bar{\rho}_r = 1 + \frac{2\bar{P}_s}{\gamma} = 1 + \frac{0.1648}{\bar{R}} \quad \textbf{(24)}$$

$$\bar{\theta}_r = 1 + \frac{2(\gamma-1)\bar{P}_s}{\gamma} = 1 + \frac{0.0660}{\bar{R}} \quad \textbf{(25)}$$

The Army design manual goes on to tabulate shock front parameters based on Jack's data (1963) for $\bar{P}_r$ for high pressures, Shear and McCane's data (1960) for intermediate pressures, and Equations (23) to (25) for low pressures ($\bar{P}_r < 3.5$). The compiled data for the reflected shock waves are listed in Table 3 and shown in Figure 5.

Table 3: Compiled Sachs Scaled Shock Front Parameters for Reflected Shock Waves

Scaled distance, $\bar{R}$	Peak reflected pressure, $\bar{P}_r$	Time of duration, $\bar{T}_r$	Reflected (specific) Impulse, $\bar{I}_r$	Density, $\bar{\rho}_r$	Temperature, $\bar{\theta}_r$
0.0538	1840	--	--	--	--
0.07	1110	--	--	--	--
0.08	860	1.8E-2	1.86	37.8	20.7
0.09	699	1.98E-2	1.503	35.2	18.5
0.10	585	2.19E-2	1.27	33.2	16.8
0.125	397	2.67E-2	0.894	28.6	13.6
0.15	277	3.15E-2	0.667	24.4	12.1
0.20	146	4.25E-2	0.456	18.1	7.46
0.22	116	4.7E-2	0.408	16.1	6.41
0.24	91	5.2E-2	0.368	14.3	5.52
0.25	80.3	5.42E-2	0.355	13.5	5.15
0.30	37.7	6.84E-2	0.294	10.0	3.71
0.40	15.3	0.103	0.222	6.10	2.42
0.50	9.4	0.147	0.178	4.16	1.90
0.60	6.05	0.195	0.15	3.14	1.65
0.80	2.63	0.232	0.112	2.12	1.39
0.90	1.86	0.254	9.89E-2	1.86	1.32
1.00	1.31	0.268	8.85E-2	1.66	1.26
1.50	0.58	0.328	5.29E-2	1.32	1.13
2.00	0.358	0.362	3.77E-2	1.22	1.088
2.50	0.25	0.39	2.9E-2	1.16	1.0612
3.00	0.188	0.414	2.37E-2	1.12	1.0594
4.00	0.126	0.445	1.73E-2	1.087	1.0344
5.00	9.48E-2	0.477	1.37E-2	1.0664	1.0268
6.00	7.65E-2	0.495	1.12E-2	1.0532	1.0214
7.00	6.33E-2	0.517	9.49E-3	1.0457	1.0179
8.00	5.36E-2	0.532	8.40E-3	1.0392	1.0149
9.00	4.61E-2	0.548	7.31E-3	1.0334	1.0130
10.0	4.01E-2	0.564	6.58E-3	1.0282	1.0113
20.0	1.76E-2	0.666	3.20E-3	1.0124	1.00496
30.0	1.1E-2	0.737	2.08E-3	1.00774	1.00310
40.0	7.88E-3	0.781	1.54E-3	1.00558	1.00224
50.0	6.12E-3	0.825	1.22E-3	1.00434	1.00174
60.0	4.96E-3	0.856	9.96E-4	1.00354	1.00142
80.0	3.58E-3	0.916	7.39E-4	1.00206	1.000825
100	2.80E-3	0.96	5.86E-4	1.00165	1.000660
250	1.03E-3	1.16	2.33E-4	1.000898	1.000359
500	4.86E-4	1.24	1.15E-4	1.000330	1.000132
1000	2.31E-4	1.25	5.76E-5	1.000165	1.0000660

From *Engineering Design Handbook, Explosions in Air.* U.S. Army Materiel Command and from graphs found in Baker's *Explosions in Air*, 1973.

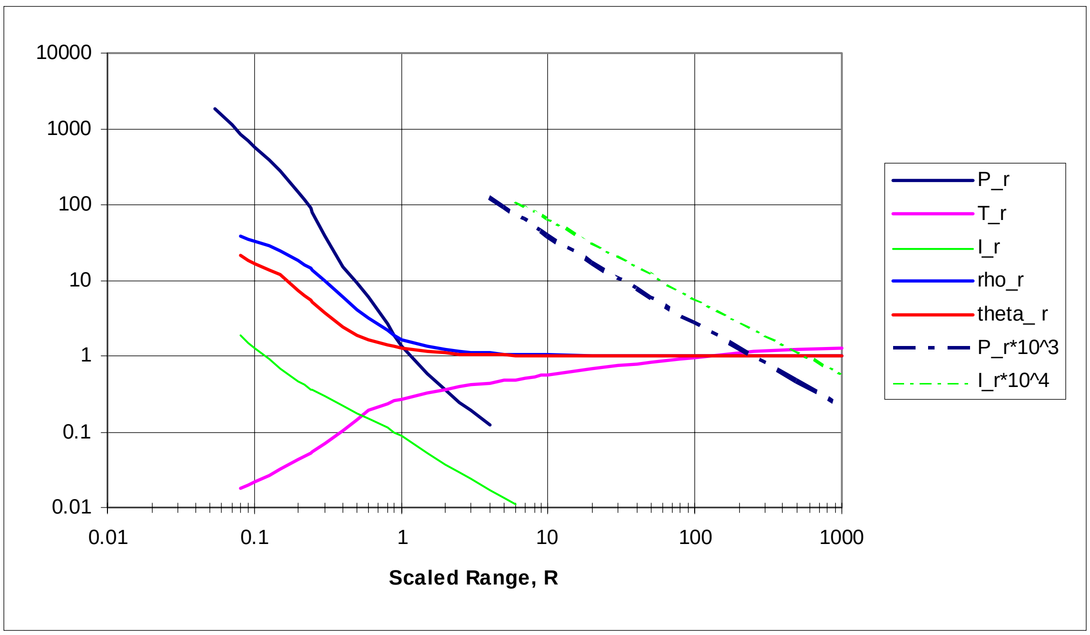

Figure 5 Graphical representation in Log-Log scale of the normally reflected, Sachs scaled blast parameters as presented in Table 3. Note that some parametric ranges of parameters have been scaled over a portion of the domain to fit the axes.

Also shown in Tables 2a, 2b, and 3 are tabulated values of the specific impulse. Kingery's data from 1966, gathered from ground detonations and Goodman's data from 1960 were drawn upon by the Army and by Baker in the creation of the tables. Baker makes note of the acoustic asymptote for the specific side-on impulse, $\bar{I}_s$ as:

$$\bar{I}_s = \frac{0.0288}{\bar{R}} \qquad \textbf{(26)}$$

where $\bar{R}$ is the scaled blast distance for very large $\bar{R}$. For $\bar{R} < 0.8$, Baker uses the data of Kingery (1966).

For the reflected specific impulse, Jack presented [1]:

$$\bar{I}_r = \bar{I}_s \frac{\bar{P}_r}{\bar{P}_s} \qquad \textbf{(27)}$$

where $\bar{P}_r$ is the reflected pressure parameter, $\bar{P}_s$ is the side-on pressure parameter, and $\bar{I}_s$ is the specific side-on impulse parameter and is considered valid for a $0.6 \le \bar{R} \le 100$. Beyond this range, the acoustic approximation may be used [2]:

$$\bar{I}_r = 2\bar{I}_s \qquad \textbf{(28)}$$

Baker reports that the data for $\bar{T}_r$ do not exist for $\bar{R} > 0.7$, but that Hoffman and Mills (1956) experiments suggested that the data for $\bar{T}_s$ can be used instead. This procedure was used in this researcher's computer program BLAST.F.

The determination of the impulse can also be obtained by integrating the Friedlander's equation given in Equation (8) over the positive phase. The decay constant value can then be determined by iteratively solving for the constant, *b*, in the transcendental equation [1]:

$$\bar{I}_s = \frac{\bar{P}_s \bar{T}_s}{b}\left[1 - \frac{\left(1 - e^{-b}\right)}{b}\right] \qquad \textbf{(29)}$$

where $\bar{P}_s$ is the side-on pressure parameter, $\bar{T}_s$ is the side-on positive phase duration parameter, and $\bar{I}_s$ is the specific side-on impulse parameter. Similarly, the decay value for the reflected pressure case, b_r, can be found from:

$$\bar{I}_r = \frac{\bar{P}_r \bar{T}_r}{b_r}\left[1 - \frac{\left(1 - e^{-b_r}\right)}{b_r}\right] \qquad \textbf{(30)}$$

where $\bar{P}_r$ is the side-on pressure parameter, $\bar{T}_r$ is the side-on positive phase duration parameter, and $\bar{I}_r$ is the specific side-on impulse parameter. The decay coefficients and the time constants used in their determination are presented in Table 4 for side-on decay coefficients and Table 5 for reflected decay coefficients. Both side-on decay values and reflected decay values are presented graphically in Figure 6. This researcher did not find compiled data for both of these parameters as the decay value b is typically given, but not b_r. Thus the compiled values for both is usefully compiled here, but calculated in the program BLAST.F for each specific case using the manner described above.

Once the data is in tabular or graphical form and $\bar{R}$ has been determined, the appropriate values can be interpolated from the data tables. As the data and trends are typically presented in a Log-Log format, the interpolation routine used must take the logarithmic form into account. The computer program BLAST.F reads in these tabular forms of the data and converts it into Log-Log format for interpolation with splines. Linear interpolation has been used for quick estimates, but the graphical trend of the data should be checked as well as using a Log-Log form of the interpolation as it is easy to miss changes in data that occur between tabulated values. For example, the original data tables from Baker and the Army did not contain any points between $\bar{R}$ = 0.1 and $\bar{R}$ = .15 and this missing range would not show a local maximum in $\bar{I}_s$ between these points. If used, this error would provide an incorrect decay coefficient. Thus, for the computer program, more points were gathered for areas where distinct changes in the plots of the data took place so that the program would more accurately interpolate parameters.

Conversion of the determined Sachs scaled parameters to their dimensionalized forms can then occur and they can then be used in the empirical form of Friedlander's Equations shown in Equation (8).

Table 4: Compiled Sachs Scaled Decay Time Constant, *b*, for Incident Shock Waves

Scaled distance, $\bar{R}$	Peak reflected pressure, $\bar{P}_s$	Time of duration, $\bar{T}_s$	Reflected (specific) Impulse, $\bar{I}_s$	Decay Constant, *b*
0.08	90.5	4.95E-3	8.95E-2	16.6
0.09	77.5	6.06E-3	8.24E-2	16.1
0.10	67.9	7.62E-3	7.85E-2	15.5
0.125	48.8	1.07E-2	7.5E-2	14.7
0.15	37.2	1.54E-2	7.88E-2	15.0
0.20	20.4	2.55E-2	0.106	16.0
0.22	16.6	2.84E-2	0.108	18.3
0.24	13.4	3.29E-2	0.107	17.5
0.25	11.9	3.82E-2	0.103	17.1
0.30	7.28	5.41E-2	8.85E-2	13.0
0.40	3.46	9.90E-2	6.95E-2	6.69
0.50	2.05	0.157	5.7E-2	4.56
0.60	1.38	0.218	4.82E-2	3.87
0.80	0.772	0.340	3.71E-2	3.48
0.90	0.618	0.392	3.35E-2	3.32
1.00	0.506	0.466	3.02E-2	3.11
1.50	0.254	0.830	2.07E-2	2.59
2.00	0.161	1.26	1.58E-2	2.20
2.50	0.115	1.71	1.28E-2	1.98
3.00	8.89E-2	2.20	1.08E-2	1.86
4.00	6.16E-2	3.21	8.12E-3	1.82
5.00	4.68E-2	4.21	6.56E-3	1.86
6.00	3.74E-2	5.19	5.46E-3	1.84
7.00	3.06E-2	5.84	4.67E-3	1.84
8.00	2.61E-2	7.15	4.10E-3	1.84
9.00	2.27E-2	7.64	3.62E-3	1.90
10.0	1.98E-2	9.10	3.25E-3	1.90
20.0	8.70E-3	18.9	1.58E-3	2.17
30.0	5.43E-3	28.8	1.04E-3	2.38
40.0	3.91E-3	38.9	7.64E-4	2.55
50.0	3.04E-3	48.9	6.05E-4	2.72
60.0	2.48E-3	58.8	4.98E-4	2.86
80.0	1.81E-3	78.5	3.68E-4	3.12
100	1.41E-3	98.5	2.93E-4	3.26
250	5.17E-4	224	1.16E-4	3.89
500	2.42E-4	499	5.75E-5	3.91
1000	1.153E-4	1000	2.88E-5	3.68

Decay constants are calculated by fixed point iteration of Equation (29).

Table 5: Compiled Sachs Scaled Decay Time Constant, b_r, for Reflected Shock Waves

Scaled distance, $\bar{R}$	Peak reflected pressure, $\bar{P}_r$	Time of duration, $\bar{T}_r$	Reflected (specific) Impulse, $\bar{I}_r$	Decay Constant, b_r
0.08	860	1.8E-2	1.86	7.16
0.09	699	1.98E-2	1.503	8.07
0.10	585	2.19E-2	1.27	8.96
0.125	397	2.67E-2	0.894	10.8
0.15	277	3.15E-2	0.667	12.0
0.20	146	4.25E-2	0.456	12.5
0.22	116	4.7E-2	0.408	12.3
0.24	91	5.2E-2	0.368	11.8
0.25	80.3	5.42E-2	0.355	11.2
0.30	37.7	6.84E-2	0.294	7.62
0.40	15.3	0.103	0.222	5.90
0.50	9.4	0.147	0.178	6.59
0.60	6.05	0.195	0.15	6.69
0.80	2.63	0.232	0.112	4.16
0.90	1.86	0.254	9.89E-2	3.43
1.00	1.31	0.268	8.85E-2	2.52
1.50	0.58	0.328	5.29E-2	2.09
2.00	0.358	0.362	3.77E-2	1.90
2.50	0.25	0.39	2.9E-2	1.81
3.00	0.188	0.414	2.37E-2	1.71
4.00	0.126	0.445	1.73E-2	1.66
5.00	9.48E-2	0.477	1.37E-2	1.73
6.00	7.65E-2	0.495	1.12E-2	1.83
7.00	6.33E-2	0.517	9.49E-3	1.91
8.00	5.36E-2	0.532	8.40E-3	1.85
9.00	4.61E-2	0.548	7.31E-3	1.92
10.0	4.01E-2	0.564	6.58E-3	1.90
20.0	1.76E-2	0.666	3.20E-3	2.17
30.0	1.1E-2	0.737	2.08E-3	2.44
40.0	7.88E-3	0.781	1.54E-3	2.55
50.0	6.12E-3	0.825	1.22E-3	2.72
60.0	4.96E-3	0.856	9.96E-4	2.86
80.0	3.58E-3	0.916	7.39E-4	3.05
100	2.80E-3	0.96	5.86E-4	3.22
250	1.03E-3	1.16	2.33E-4	3.81
500	4.86E-4	1.24	1.15E-4	3.93
1000	2.31E-4	1.25	5.76E-5	3.69

Reflected constants are calculated by fixed point iteration of Equation (30).

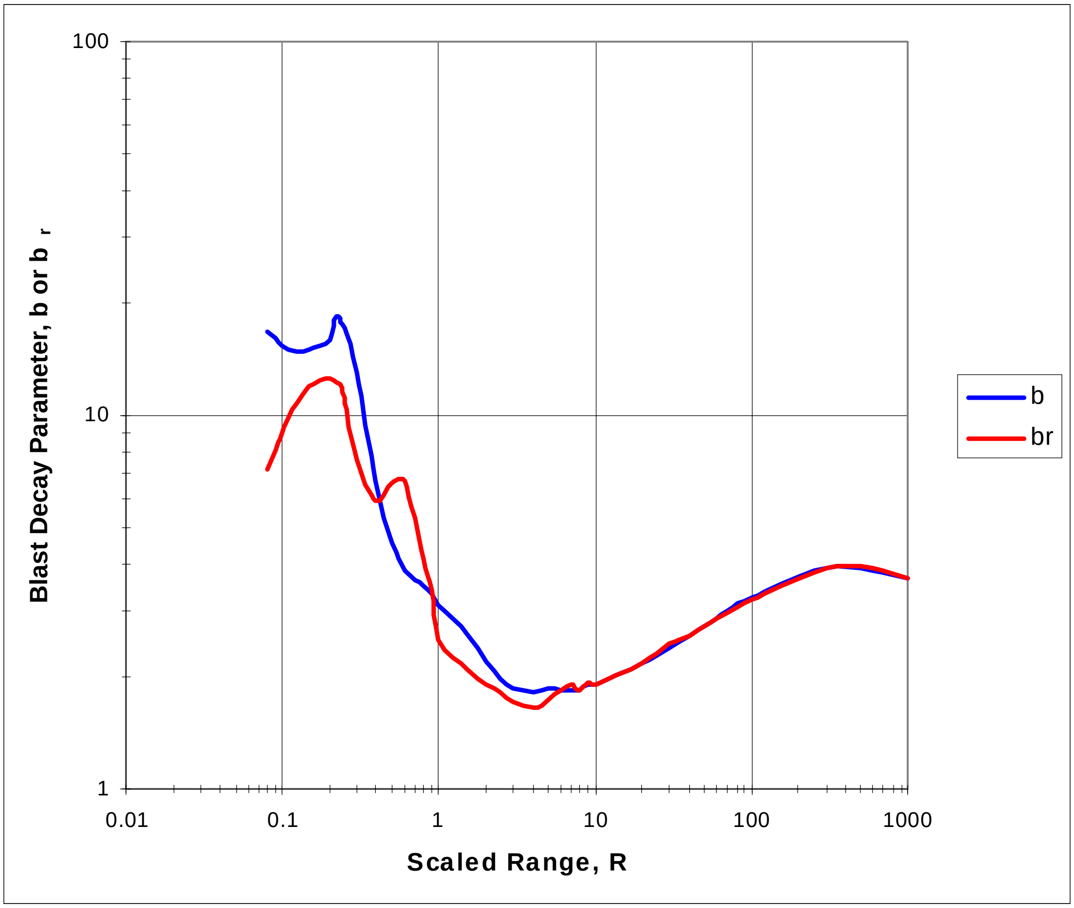

Figure 6 Graphical representation, on Log-Log axes, of the decay parameters for side-on and normal reflection, b and b_r, respectively, for use in the empirical Friedlander's equation.

3.5 Air Blast Parameters for Air and Surface Burst as found by Kingery and Bulmash

Kingery and Bulmash [3] gathered their data by detonating various charges from one kilogram to 400,000 kilograms. This data was then scaled using Hopkinson and Sachs scaling laws to standard atmospheric sea level conditions.

Measurement of shock arrival was recorded by various methods including photographic analysis, electric switches which close at blast arrival so that there can be an electric time stamp, and also by using overpressure transducers. These values were scaled using the reciprocal of a distance scaling factor:

$$S_d = \left(\frac{Q_2}{Q_1}\right)^{\frac{1}{3}} \left(\frac{p_o}{p_a}\right)^{\frac{1}{3}} \tag{31}$$

where S_d is the scaling factor, Q_2 is the other explosive mass (in kilograms) being scaled to the reference weight of one kilogram Q_1, p_o is the standard atmospheric sea level pressure, and p_a is the ambient atmospheric pressure. And the times were also scaled using the reciprocal of a time scaling factor:

$$S_t = \left(\frac{Q_2}{Q_1}\right)^{\frac{1}{3}} \left(\frac{p_a}{p_o}\right)^{\frac{1}{3}} \left(\frac{T_o}{T_a^{+273}}\right)^{\frac{1}{2}} \tag{32}$$

where T_o is the standard atmospheric temperature (288°K), and T_a is the ambient temperature in degrees Centigrade, Q_2 is the other explosive mass (in kilograms) being scaled to the reference weight of one kilogram Q_1.

Measured values of peak overpressure were taken by direct transducer measurement of the shock wave and were also inferred from the velocity of the shock front. The data were scaled to standard atmospheric pressures by using the reciprocal of a pressure scaling factor:

$$S_p = \frac{P_a}{P_o} \tag{33}$$

where P_a is the ambient pressure, and P_o is the standard atmospheric pressure at sea level. And distances were scaled again by using the inverse of Equation (31).

Kingery and Bulmash measured the impulse as an area under the curve formed by the pressure profile. This made it a function of the overpressure, duration, and decay rate of the blast. These impulses were scaled to one kilogram and one pound charge weights by using the reciprocal of an impulse blast scaling factor:

$$S_i = \left(\frac{Q_2}{Q_1}\right)^{\frac{1}{3}} \left(\frac{P_o}{P_a}\right)^{\frac{2}{3}} \left(\frac{T_o}{T_a^{+273}}\right)^{\frac{1}{2}} \qquad \textbf{(34)}$$

where again, Q_2 is the other explosive mass (in kilograms) being scaled to the reference weight of one kilogram Q_1, p_o is the standard atmospheric sea level pressure, p_a is the ambient atmospheric pressure, T_o is the standard atmospheric temperature (288°K), and T_a is the ambient temperature in degrees Centigrade. English units would be used in lieu of metric when scaling to pounds.

Positive durations from various sources were scaled by Kingery and Bulmash to one kilogram of charge mass by using the reciprocals of the distance scaling factor, in Equation (31), and the time scaling factor in Equation (32).

For the reflected pressure data, Kingery and Bulmash gathered data from other sources noting that the reflected pressure data is not usually measured directly and that their data presented was only from cases where blasts impinged upon a surface from the normal direction. They [3] note that the following relationship is used for calculating the peak reflected overpressure:

$$P_r = (P_s + p_o)\frac{\left(2+\frac{\gamma+1}{\gamma-1}\right)\left(\frac{P_s+p_o}{p_o}\right) - 1}{\frac{\gamma+1}{\gamma-1} + \frac{P_s+p_o}{p_o}} - p_o \qquad \textbf{(35)}$$

where P_s is the peak side-on overpressure, p_o is the ambient pressure, and γ is the variable ratio of specific heats. Kingery and Bulmash state that γ is a function of peak overpressure and that this relationship can be found in graphical format in Kingery and Pannill's BRL report of 1964.

Their [3] tabulated data was then converted in a computer code to equations within the Log-Log domain in the form of:

$$Y = C_0 + C_1 U + \ldots + C_{\mathrm{N}}^{N} \qquad \textbf{(36)}$$

where:

$$U = K_0 + K_1 T \qquad \textbf{(37)}$$

and where Y is the common logarithm of the parameter under evaluation, T is the common logarithm of the scaled distance, and N is the order of fit. Parameters C and K are calculated and will not be explicitly listed here, but can be found for English units in the computer program BLAST.F in Appendix I.

Upon completion of their tabulation of their [3] data, Kingery and Bulmash compared it to the results of other sources by graphically comparing the fits of their results to graphical representations of their source data and found that they had what they considered to be very favorable results.

Once the common log of a desired parameter has been determined, it is desirable to convert them to a dimensional form for use. For English units, pressures would be converted by taking an inverse common logarithm of the parameter to get pounds per square inch, and for times and impulses, the inverse common log must be multiplied against the cube root of the charge weight to get units of psi-milliseconds and milliseconds respectively. Once the parameters of peak overpressure, time of arrival, and time of duration have been determined, they can be used in a form of the Modified Friedlander's Equation: [5]:

$$p = P_o \left(1 - \frac{(t - t_a)}{t_s} \right) e^{-\frac{(t-t_a)}{\theta}} \tag{38}$$

where P_o is the peak overpressure, t_a is the time of arrival, and t_s is the positive phase duration. While the, decay coefficient, b, can be determined by fixed point iteration of Equation (29) again, they must be converted to a dimensional form in units of milliseconds: where b is the determined decay coefficient, P is the peak overpressure, t_o is the time of

$$\theta = \frac{t_o}{b - \dfrac{b^2 - \dfrac{P_o}{I}\left(b + e^{-b} - 1\right)}{2b - \dfrac{P t_o}{I}\left(1 - e^{-b}\right)}} \tag{39}$$

duration for the positive phase, and I is the specific impulse.

3.6 Application to Hemispherical Surface Blasts

While Kingery and Bulmash present equations for the simulation of hemispherical surface blast, similar methods were not explicitly presented by Baker in his book or by the Army in their handbook. Thus, a third method was developed in consultation with other weapons effects specialists at General Dynamics Land Systems and with mentioned references in the Army manual and in Bulson. For a perfect reflecting surface, the shock waves would be instantaneously “reinforced” by the reflecting waves as shown in a generic representation in Figure7. This would give the effect of twice the weight of the actual charge. Similar to representing sources or sinks by its mirror image, the ground would, in effect, be creating a mirror charge at its surface at the point of explosion. As the ground is not a perfect reflector, a ground reflectivity value greater than one but less than two would be appropriate. Thus, Bulson suggests that the number is close to 1.7 [7] and references the work of Reisler in 1966 as proof that the free air equations can be used with only the alteration of $1.7W$ replacing W. Thus, the weight of the explosive would be multiplied by this ground reflectivity value and then the new weight would be used in the calculation of explosive blast profiles. Other specialists suggested a number closer to 1.8, and both Kingery and the Army Design Manual, *Explosions in Air*, makes use of a 1.8 ground reflectivity factor in converting other references data from hemispherical surface bursts to their equivalent free air values. The default value used in the computer program is 1.7, but the input file allows for the use of any value.

In this case, the tables and figures in the Army's *Explosions in Air* and W.E. Baker's *Explosions in Air*, 1973 were used for the generation of blast profiles for a completely reflected ground blast. In this method, the equivalent TNT weight is multiplied by a ground reflectivity factor of 1.7 (i.e. 70% ground reflectivity). The new equivalent TNT is used at the same normal blast distance in the spline calculated values of time of arrival (t_a), reflected time of duration (t_r), reflected impulse (I_r), and peak reflected overpressure (p_o). A new reflected value of the blast decay profile is calculated from the reflected impulse, overpressure, and time parameters and used in the Modified Friedlander's equation for the creation of the blast profiles. In this way the same routines used for free air explosions could be used for the calculation of hemispherical surface bursts.

It is interesting to note that Kingery and Bulmash conclude that the application of their parameters (and indeed, also the parameters determined in other methods) could be extended to the blast parameters of surface burst nuclear devices beyond a Hopkinson scaled distance of 2 ft/lbm$^{1/3}$, if the assumption is made that one half of the charge weight goes into production of the parameters. Thus, the charge weight of a two kiloton tactical nuclear device in ground burst could be modeled by modifying the ground reflectivity factor to 0.5 as its surface burst condition.[3]

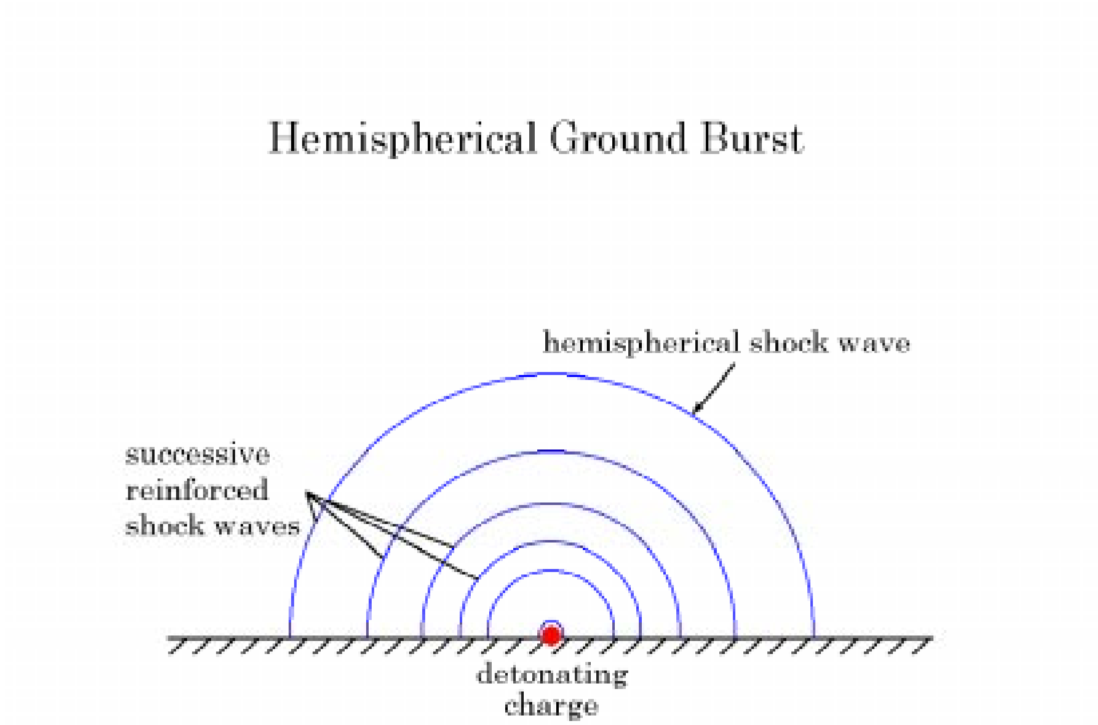

Figure 7 Depiction of a generic, hemispherical surface detonation of an explosive charge on a rigid, reflecting surface in which successive shock waves are reinforced.

3.7 Reflected Pressure vs. Angle of Incidence

An approximation for the area of normal reflection can be made by assuming that the limit of normal reflection will be within an area of a structure that lies within an unobstructed 45° angle of attack cone to the explosion. While this can be considered a simple rule of thumb that is easy to implement for use in commercial FEM codes, a different method is presented in the Army's *Engineering Design Handbook* based on the work of Kingery and Panill. [2] For the calculation of this reflected pressure, the side-on pressure value is interpolated in Figure 8, then a coefficient is determined for the angle of incidence. This coefficient is then multiplied by that side-on pressure for the reflected pressure value on the surface. This figure is given, in a tabular format, to the program BLAST.F which has the option of correcting calculated blast pressures for angle of incidence.

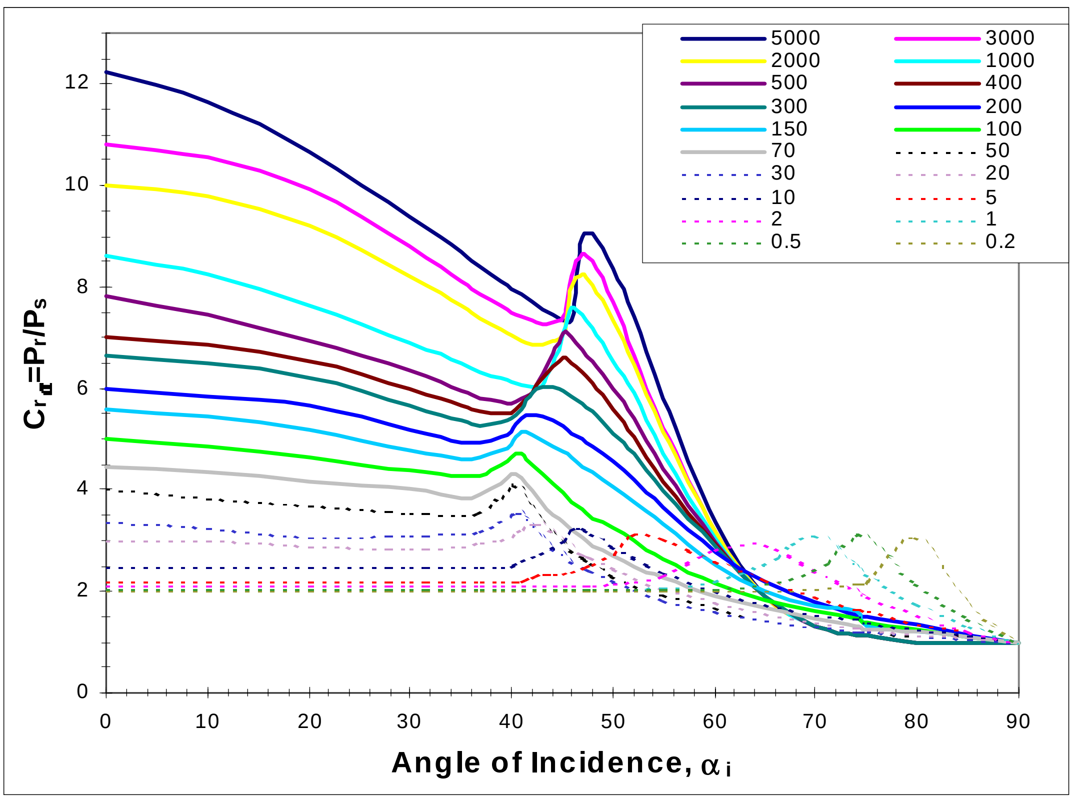

Figure 8 Reflected pressure coefficient vs. angle of attack for incident waves that reflect from oblique surfaces. The number in the legend corresponding to each curve indicates the peak side-on overpressure, P_s, in pounds per square inch.

3.8 Limit of Regular Reflection

An approximation for the area of normal reflection can be made by assuming that the limit of normal reflection will be within an area of a structure that lies within an unobstructed 45° angle of attack cone to the explosion. While this can be considered a simple rule of thumb that is easy to implement for use in commercial FEM codes, a different method is presented in the Army's *Engineering Design Handbook* based on the work of Kingery and Panill. [2]

As an example of how this is used, we will examine the case for which one of the later examples will be done, that of a quantity of TNT detonating 16 inches from a plate in hemispherical surface burst. The side-on overpressure can be determined at a point on the plate some distance from the blast. This side-on overpressure can then be used to interpolate the value of the critical angle given in Table 6. Thus, a point can then be shown to be inside or outside of the area of normal reflectivity. Similarly, the general critical angle can be determined by interpolating with the slant distance, *R*, to the blast from a point or by interpolating with the height of the blast.

A canonical detonation is shown to demonstrate the parameters shown in Table 6.

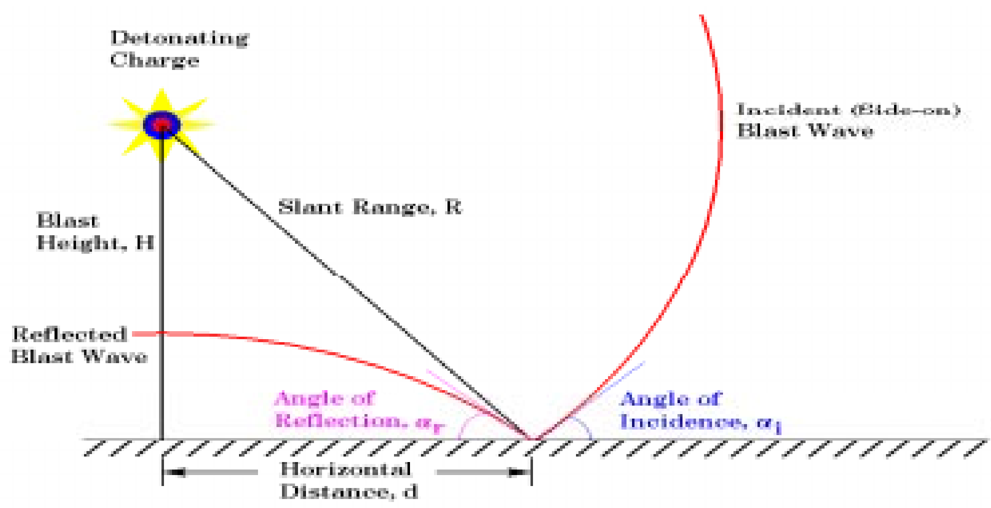

Figure 9 A canonical detonation to demonstrate the different parameters tabulated in Table 6 for determining the critical angle for normal reflection.

Table 6: Limit of Regular Reflection $\alpha_{extreme}$ vs the shock strength.

ξ (p_o/P_s+P_o)	$\alpha_{extreme}$ α_{ex}, deg	Peak Side-on Overpressure, P_s (psi)	Slant Range, R (ft)	Height of Burst, H (ft)	Horizontal diatance, d (ft)
0.002	46.57	7335	0.1969	0.1353	0.1430
0.003	45.52	4885	0.2734	0.1915	0.1951
0.004	45.02	3660	0.3452	0.2440	0.2442
0.005	44.80	2925	0.4134	0.2933	0.2913
0.006	44.50	2435	0.4779	0.3408	0.3350
0.007	44.16	2085	0.5397	0.3871	0.3760
0.008	43.79	1822	0.5989	0.4323	0.4145
0.009	43.45	1618	0.6556	0.4759	0.4509
0.01	43.15	1455	0.7099	0.5179	0.4855
0.02	41.51	720.3	1.154	0.8642	0.7650
0.03	40.72	475.3	1.482	1.123	0.9674
0.04	40.32	352.8	1.745	1.330	1.129
0.05	40.04	279.3	1.968	1.507	1.266
0.06	39.83	230.3	2.165	1.662	1.386
0.07	39.67	195.3	2.340	1.801	1.494
0.08	39.56	169.0	2.502	1.929	1.594
0.09	39.48	148.6	2.653	2.048	1.687
0.1	39.42	132.3	2.795	2.159	1.775
0.15	39.26	83.30	3.414	2.643	2.160
0.2	39.32	58.80	3.955	3.059	2.506
0.25	39.53	44.10	4.462	3.441	2.840
0.3	39.88	34.30	4.960	3.806	3.180
0.35	40.34	27.30	5.467	4.167	3.539
0.4	40.93	22.05	5.997	4.530	3.929
0.45	41.65	17.96	6.567	4.906	4.365
0.5	42.52	14.70	7.158	5.275	4.838
0.55	43.55	12.02	7.914	5.735	5.453
0.6	44.77	9.800	8.731	6.198	6.150
0.65	46.22	7.915	9.734	6.734	7.029
0.7	47.97	6.300	10.99	7.363	8.169
0.75	50.09	4.900	12.69	8.146	9.740
0.8	52.73	3.675	15.16	9.179	12.06
0.85	56.15	2.594	19.16	10.67	15.92
0.9	60.82	1.633	27.13	13.22	23.69
0.95	68.02	.7736	50.88	19.03	47.18

Data compiled for 1lb. pentolite spheres. (From *Explosions In Air*, U.S. Army)

3.9 Program

The code written and used, BLAST.F, is a program written as in modular form to examine the two different methods for determining explosive blast pressure profiles. It is a user input file driven program in which all pertinent run parameters are put into the input file titled BLAST.INP. BLAST.INP requires the input of the charge weight in TNT, type of method desired (Kingery & Bulmash or *Explosions in Air*), type of output desired (air blast or hemispherical surface burst/mine blast), time step controls, and the radial values (x and y coordinate pairs are converted to radial values) of the loading areas from the point normal to the blast center.

The program, written in FORTRAN 77, formerly made use of more dynamic data storage structures, but this was abandoned so as to allow more platform independence when it came to compiler choice. Time step controls and an epsilon value are specified in the input file to facilitate this independence, where the epsilon value is used in the fixed point iteration decay function.

After the reading of the user input file, the program selects the appropriate subroutine, one duplicating Kingery's method or one duplicating the method presented in *Explosions in Air*. Both subroutines first determine the correct blast parameters, then the blast profiles, these are stored in a subroutine passable array structure. These profiles, one for each loading area, are then output to the file BLAST.OUT, in English units. The structure of the program is presented in the flowchart in Figure 10.

The program has the option for making an adjustment of reflected pressure waves with varying angles of incidence, but does not determine if the areas given the program lie within the area for which normal reflection of blast waves occurs. BLAST.F makes use of the information in Figure 8 such that the blast pressures determined have not only a correction in the reflected pressure for varying incident angles of incidence, but the new decay coefficient is calculated accordingly to correspond to this new pressure.

3.9.1 Subroutine KINBUL

KINBUL, an abbreviation of **KIN**gery and **BUL**mash, makes use of Kingery and Bulmash's Log-Log curve fitting routines to TNT scaled explosive charges, as presented in their April, 1984 paper. This routine makes use of a large number of arrays all containing the appropriate curve fitting values used in doing Kingery's Log-Log fitting. The arrays are initialized for spherical surface burst parameters and if the logical flag, mine (short for mine blast), informs the routine that air blast is desired, the routine then resets the values as appropriate for the determination of spherical air blast.

First, the Hopkinson scaled distance is determined and stored for each radial value. Then each appropriate parameter for the determination of the complete blast profile is calculated through the use of the predetermined Log-Log curves and stored in an appropriate array. The blast decay coefficient is first determined by the use of the fixed point iteration DECAY function using the epsilon value from the user input file, but the decay value is then converted to dimensionalized form by way of Equation (39). The individual arrays storing blast parameters for each loading area are then used by the Modified Friedlander's equation in Equation (38) to generate the full blast profiles over the desired time lengths using the time step controls from the input file, BLAST.INP. The stored profiles are then passed to the output routine OUTFIL and output to BLAST.F.

3.9.2 Subroutine EIA

The EIA subroutine (an abbreviation of **E**xplosions **I**n **A**ir) first reads in the input file EIA.DAT, found in Appendix II, which contains the Sach's scaled parameters from both Baker's and the Army's *Explosions in Air*. This file contains the side-on and reflected parameters to be interpolated. These selected values can be found in tabular form in Tables 2a, 2b, 3, 4, and 5, or graphical form in Figures 4, 5, and 6. These values are converted to their Logarithmic form for interpolation within the code to avoid the alteration of the interpolation routines to the Log-Log domain. EIA makes use of the spline routines XSPLINT and XSPLINE found in Numerical Recipes [9] to cubically extrapolate the values necessary for the *Explosions in Air* routines. After reading in these converted Sach's scaled parameter values, the routine determines the first derivative of each paramter's curve at the end points, as this is required by the SPLINT routine. For each parameter, SPLINT is called once which establishes the second derivatives needed in the SPLINE routine. Then for each parameter, the SPLINE routine is called, cubically interpolating or extrapolating a parameter. This parameter is stored, converted to dimensional form and stored again. The non-dimensional form is used by the DECAY function with the epsilon value from BLAST.INP in the determination of the blast decay parameter, b. The dimensional form is used in the Empirical Friedlander's equation, Equation (8), to generate the blast profiles over the desired time periods using the BLAST.INP time step controls. As in KINBUL, the stored profiles are then passed to the output routine OUTFIL and stored in the outfile BLAST.F.

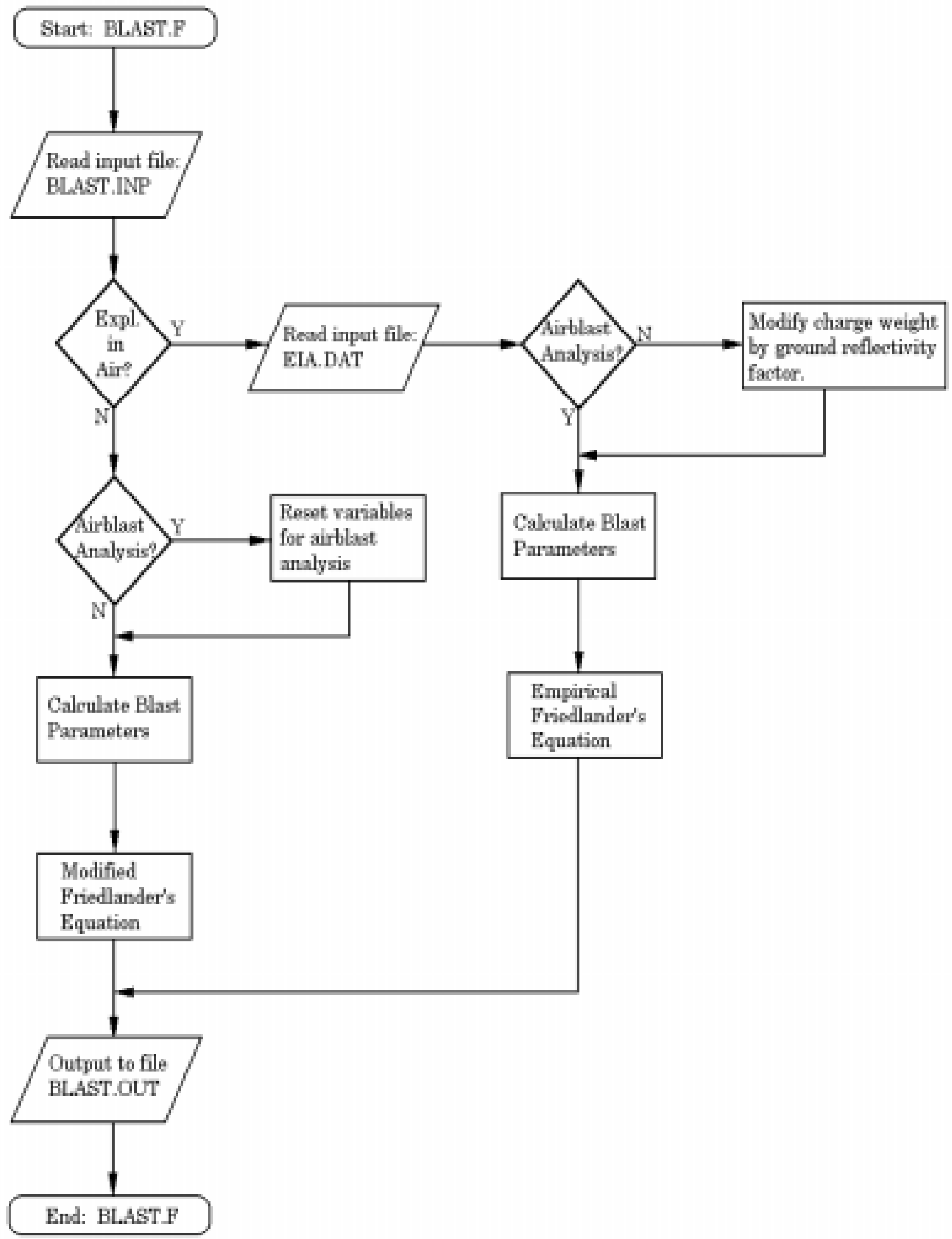

Figure 10 Flowchart showing the structure and process by which the explosive blast profile generation program BLAST.F (ver 2.3), written by the author, works during a typical run.

4.0 RESULTS AND DISCUSSION

4.1 Comparison of Air Blast Pressure Profile Methods

The *Explosions in Air* method when compared to the method by Kingery and Bulmash produce results that are similar, as seen in Figure 11 for a spherical air burst of 25 pounds at 24 inches normal distance to a target. In this case, the reflected peak pressures are on a similar order of magnitude with over 14,300 psi peak overpressure for Kingery's method and over 13,700 psi for the methods in *Explosions in Air*. The difference lies not in the pressures, but mostly in the specific impulses delivered to the target. The *Explosions in Air* method results in a reflected specific impulse of about 700.6 psi-msec and 1212 psi-msec for the methods by Kingery and Bulmash. Additionally, the *Explosions in Air* method has an arrival time in advance of Kingery and Bulmash. Unfortunately, as both of these methods are based on experimental data, without repeatedly detonating explosives, this researcher cannot determine which one is most likely to be correct on this point.

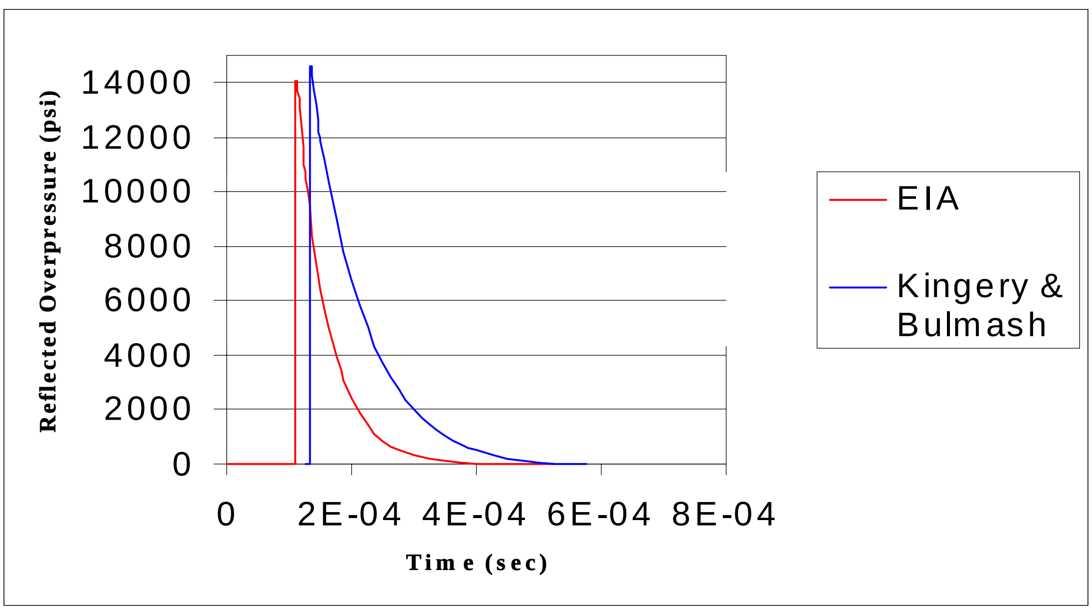

Figure 11 Comparison of reflected overpressures by the *Explosions in Air* and Kingery and Bulmash methods for a 25 pound charge of TNT in a spherical air burst above a target at two feet blast normal distance.

4.2 Comparison of Hemispherical Surface Blast Pressure Profile Methods

The *Explosions in Air* method when compared to the method by Kingery and Bulmash produce results that are similar, as seen in Figure 12 for a hemispherical surface burst of five pounds charge at 16 inches normal distance to a target. In this case, the peak pressures are on a similar order of magnitude with over 13,300 psi peak overpressure for Kingery's method and over 15,550 psi and almost 15,000 psi for the methods in *Explosions in Air* for 1.8 and 1.7 ground reflectivity values, respectively. Also, the *Explosions in Air* method results in a specific impulse of about 577 psi-msec and 541 psi-msec for 1.8 and 1.7 ground reflectivity values respectively, and 958 psi-msec for the methods by Kingery and Bulmash.

Though a ground reflectivity value of 1.7 is closer to Kingery's method both *Explosions in Air* methods have a lower impulse and an early arrival time, just as with the spherical air burst. This arrival time disagreement can be reduced if the arrival time for an unmodified blast is used. That is, using the original amount of TNT before modification by a ground reflectivity factor. But that changes the arrival time to near 0.08 milliseconds, which is still earlier than Kingery's arrival time of near 0.09 milliseconds, so though an

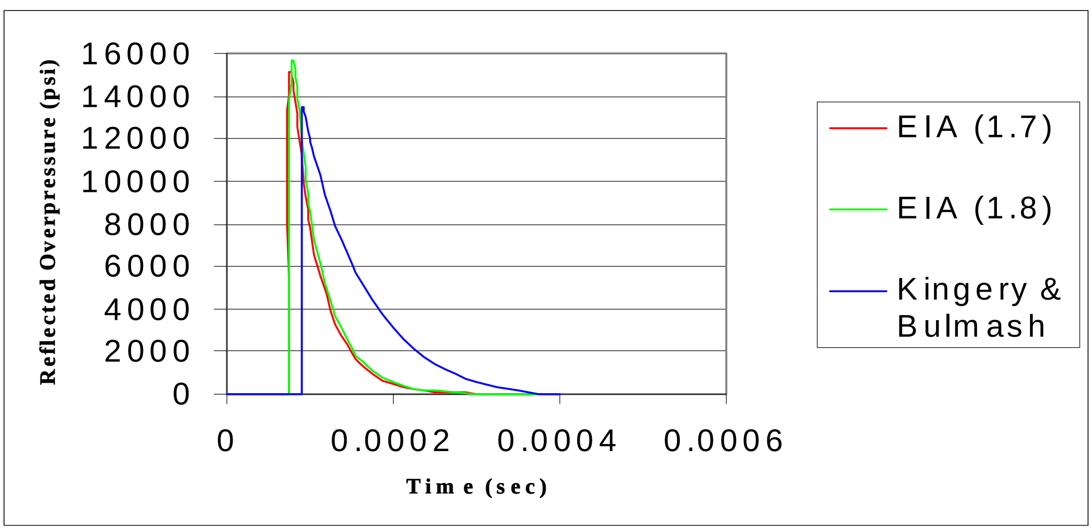

Figure 12 Comparison of reflected overpressures by the *Explosions in Air* (for a ground reflectivity value of 1.7 and 1.8) and Kingery and Bulmash methods for a five pound charge of TNT in a spherical air burst above a target at sixteen inches blast normal distance.

improvement that would allow closer agreement, it really doesn't seem like that much of an improvement. This raises the question of why are there differences in two seemingly accepted methods. Goodman, Baker, and Bulson make a point of the fact that due to conditions, differing materials, differing instruments, and other things, that it is hard to get two explosions by differing researchers to agree. Both *Explosions in Air* and Kingery and Bulmash make use of research data from others, and Kingery notes that various parameters have been measured in different ways [3]. Thus, though the pressures are close, the impulses differ by a lot. This could be attributed to differing values for the length of duration of a blast as well as a change in the way that the decay values were determined, thus differing impulses.

4.3 Example and Comparison of Time Varying Pressure Distribution of Blast Pressure Across a Plate: 20lb of TNT at 24 inches Normal Blast Distance

BLAST.F was used to demonstrate the pressure distribution and comparision of the time varying pressure across a plate due to a 20 pound charge of TNT 24 inches from the plate. Figure 13 show six timesteps of a pressure distribution across a plate. In this Figure, one can see the way in which a pressure wave translates across the plate. This Figure also compares the blasts calculated with the Kingery & Bulmash methods both with and without the adjustment for angle of incidence of the blast waves ("Angle" and "Normal," in the Figure, respectively).

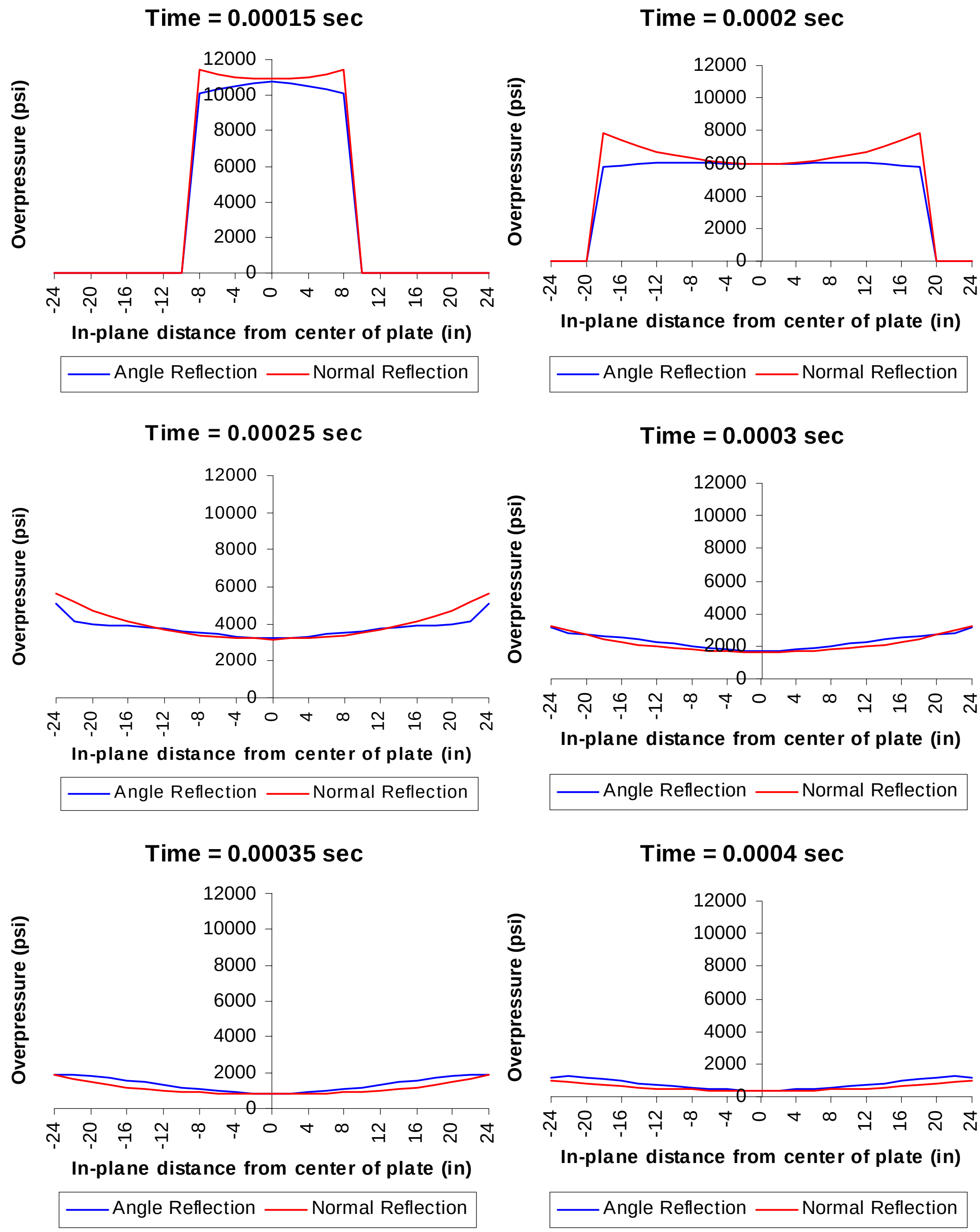

Figure 13 A family of curves over six time steps showing the time varying overpressure across the surface of a plate. The pressure curves compare the results of normal reflection and adjustment for angle of incidence for 20lbs of TNT at 24 inches calculated by the methods found in Kingery & Bulmash.

4.4 Example Semi-Hemispherical Ground Blast: a 5lb TNT mine

In order to demonstrate the usefulness of the program and how the method works, a test case was done. This test case was an assumed five pound charge of TNT in hemispherical ground blast against a plate. No adjustment was made for angle of attack as was explained above where the reflected pressure is adjusted for the incident angle of the blast wave to render the test conservative. The area covered was set to be the area within an area with an angle of incidence to the blast at 45 degrees. These models were analyzed with NASTRAN using non-linear analysis with double strain hardening curves for the material, that is, the stress strain curve was represented by two linear segments for the elastic and plastic regions of the material.

In order to show a convergence of the tests, blasts were done for four by four, eight by eight, 16 by 16, and 32 by 32 quadrilateral elements in a quarter plate analysis for a simulated 60 by 60 inch plate of fixed boundary conditions. The plate was made of aluminum 2519 and set for a thickness of one inch, simulating an unstiffened floor of a lightly armoured vehicle. The blast normal distance was 16 inches as this distance is the U.S. Army's minimum ground clearance distance for combat vehicles.

For the four by four quarter plate, the blast was done for three different loading areas, and four of the elements were loaded for blasts of radial distances of six, 12,and 16 inches. These loading areas are shown in Figure 14.

The equivalent stresses from NASTRAN for the 16 element quarter plate are plotted in Figures 15 to 23. These plots are all on deformed displacement geometry that has been scaled to 10% of the model dimensions. By keeping the fringe scale the same through the plots, it is possible to observe the stress waves traveling across the material from the point of blast application

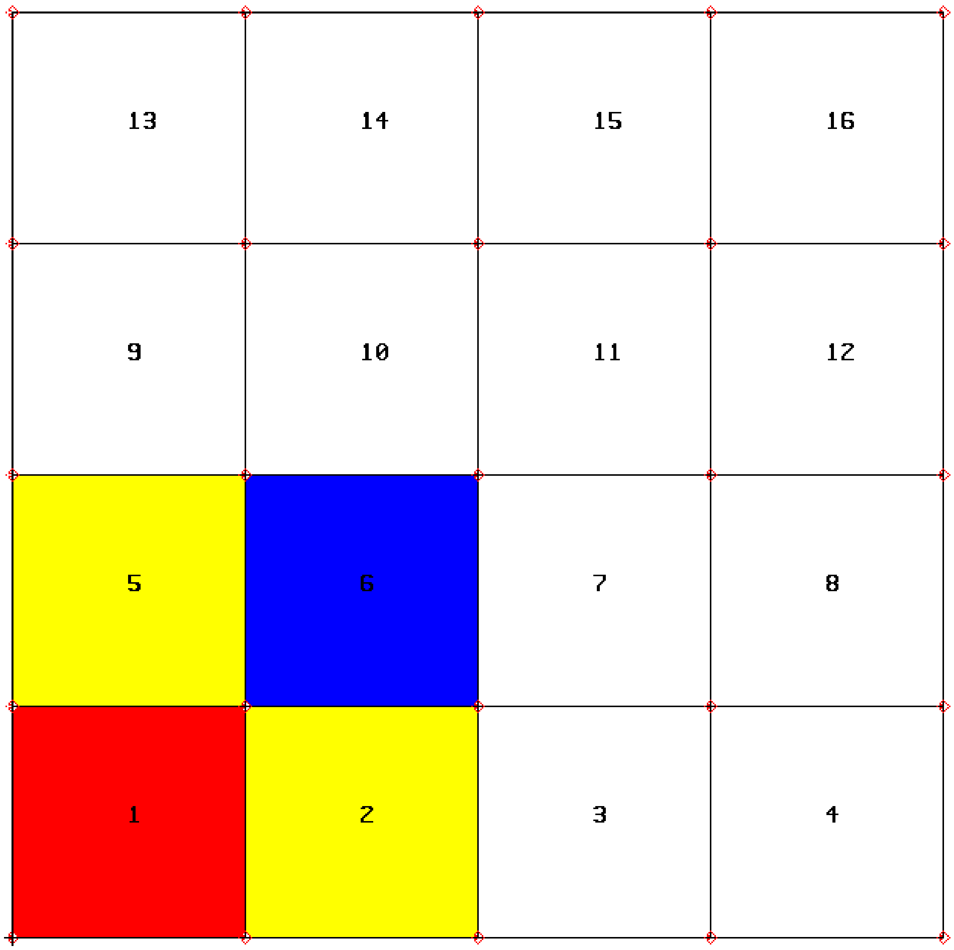

Figure 14 Display of the four by four quadrilateral element quarter plate of fixed boundary conditions, with the three colors denoting the loading areas for six, 12, and 16 inch radial distances from the blast center at the lower left corner.

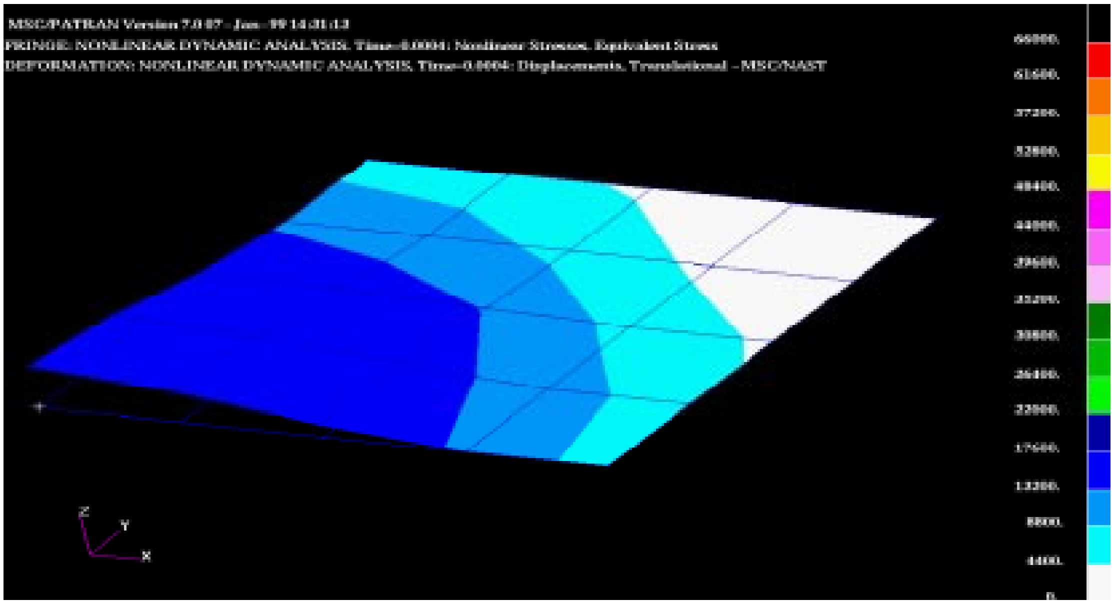

Figure 15 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 16 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0004 seconds. Displacements have been scaled to 10% of the model dimensions.

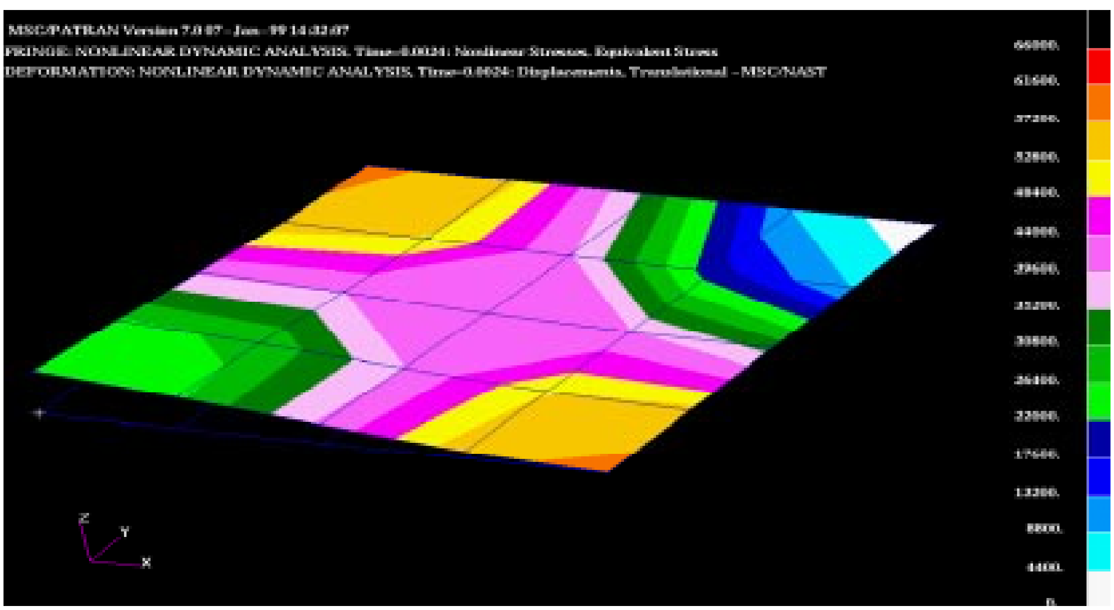

Figure 16 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 16 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0024 seconds. Displacements have been scaled to 10% of the model dimensions.

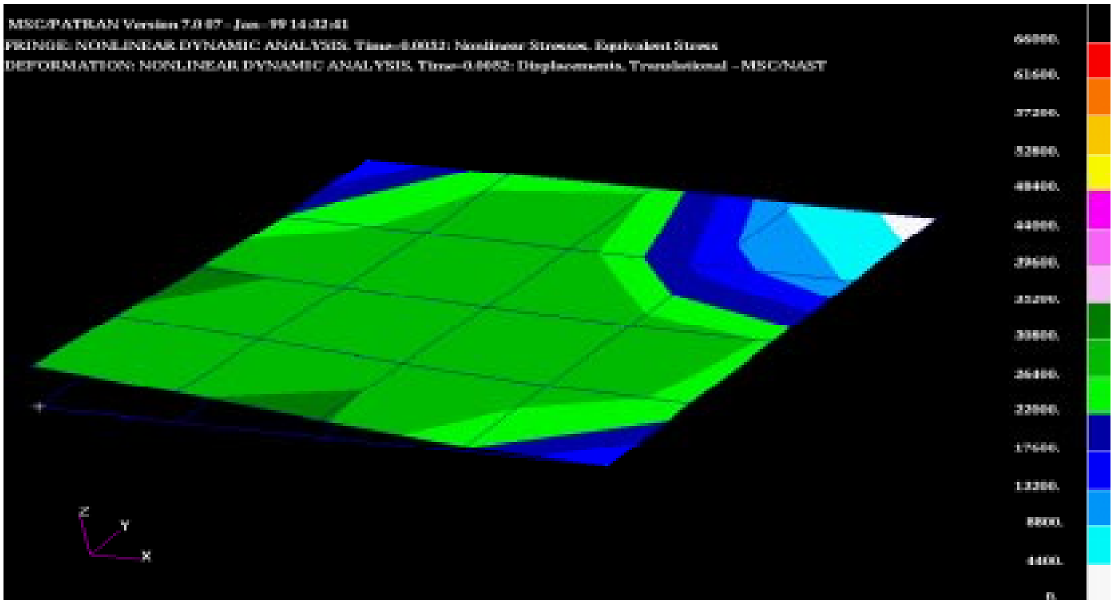

Figure 17 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 16 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0052 seconds. Displacements have been scaled to 10% of the model dimensions.

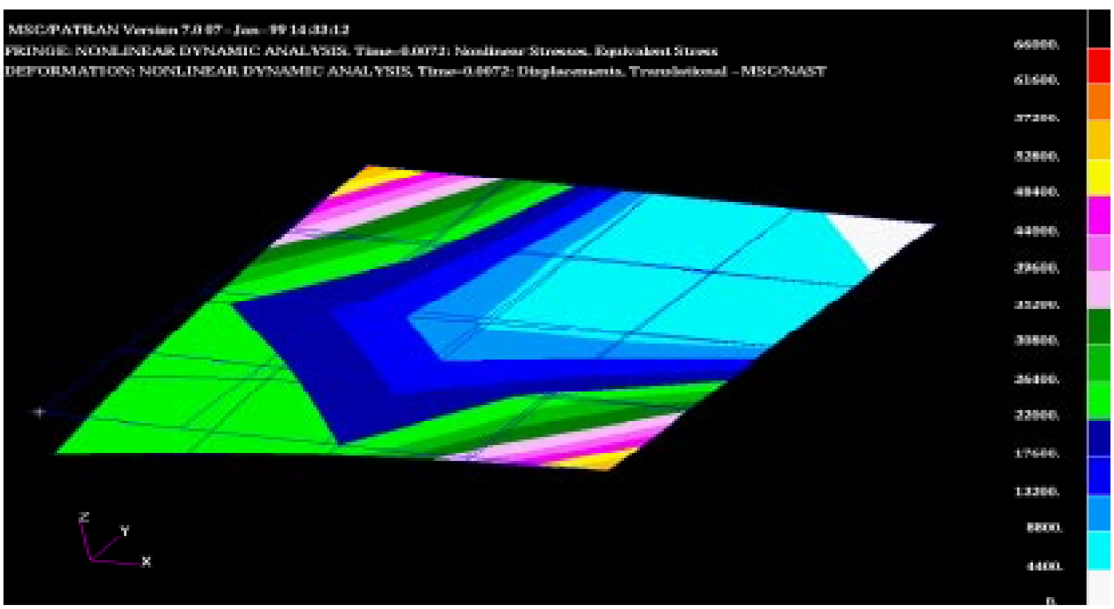

Figure 18 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 16 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0072 seconds. Displacements have been scaled to 10% of the model dimensions.

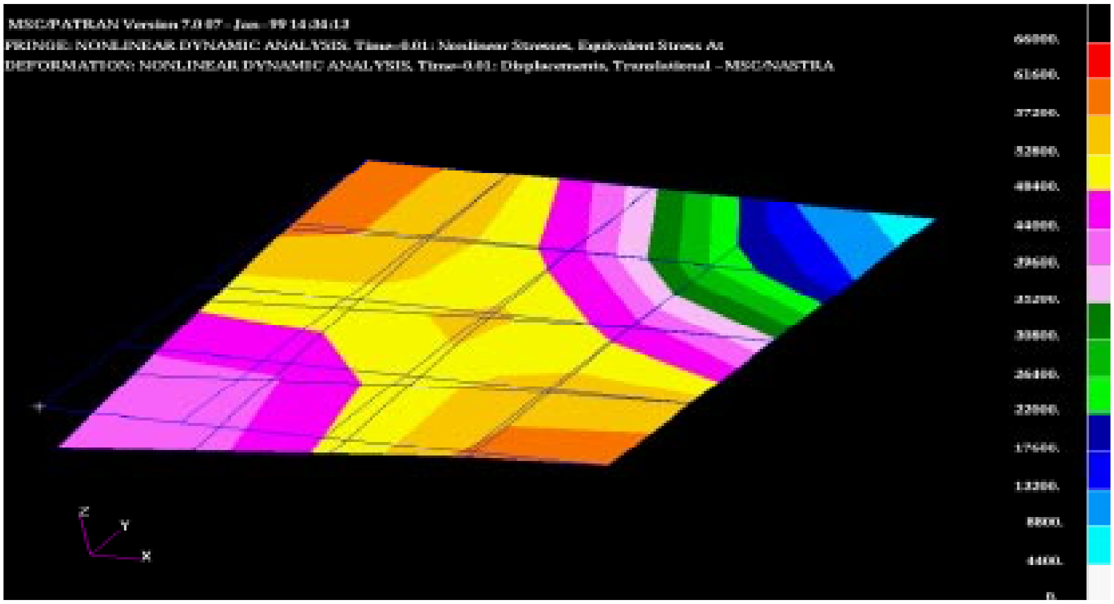

Figure 19 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 16 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.01 seconds. Displacements have been scaled to 10% of the model dimensions.

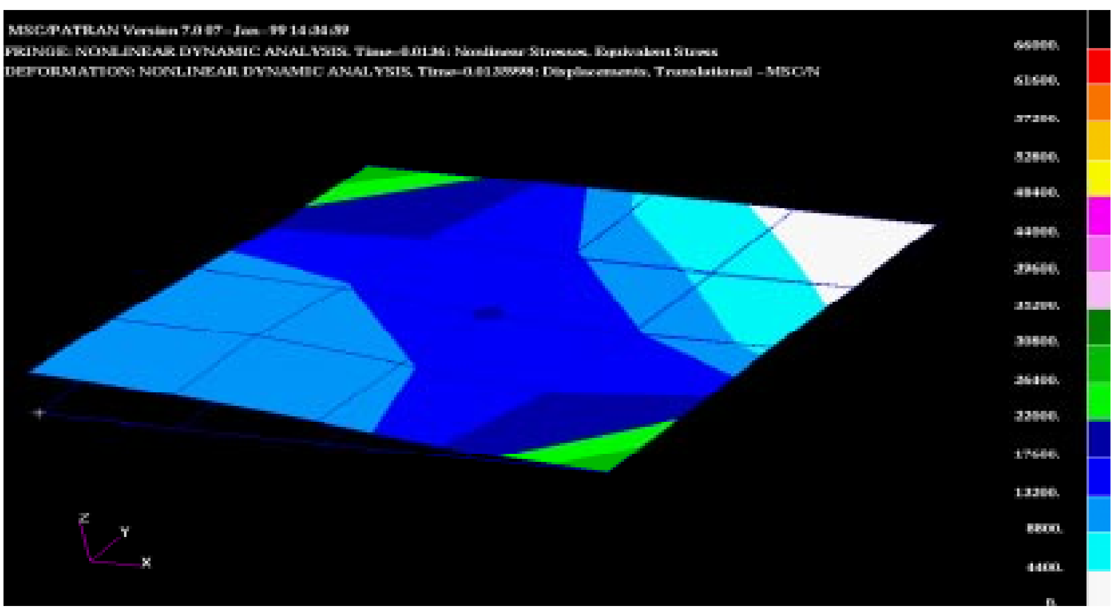

Figure 20 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 16 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0136 seconds. Displacements have been scaled to 10% of the model dimensions.

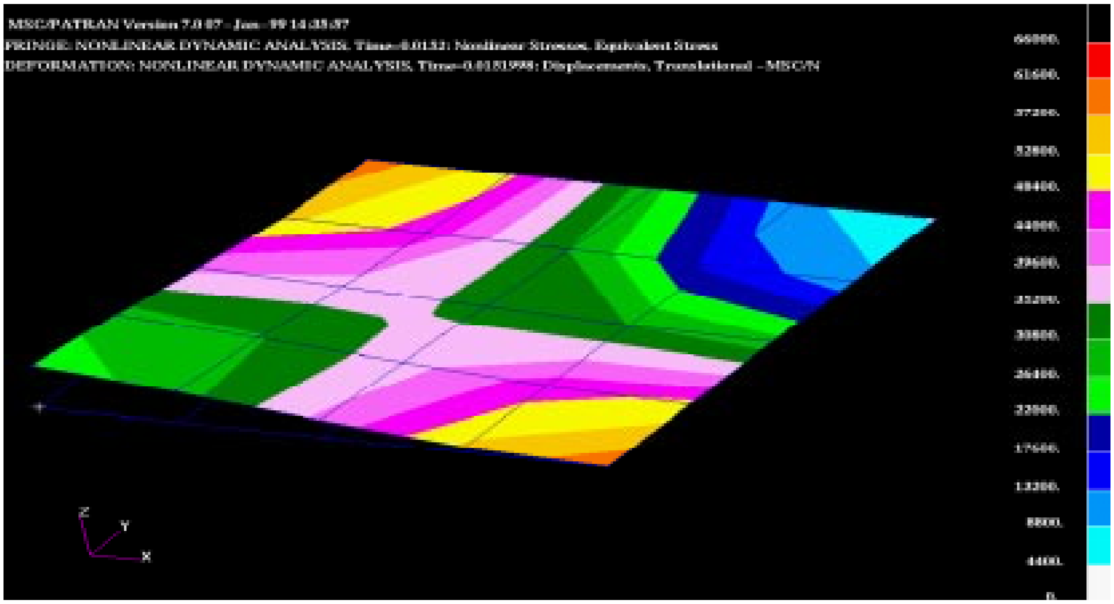

Figure 21 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 16 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0152 seconds. Displacements have been scaled to 10% of the model dimensions.

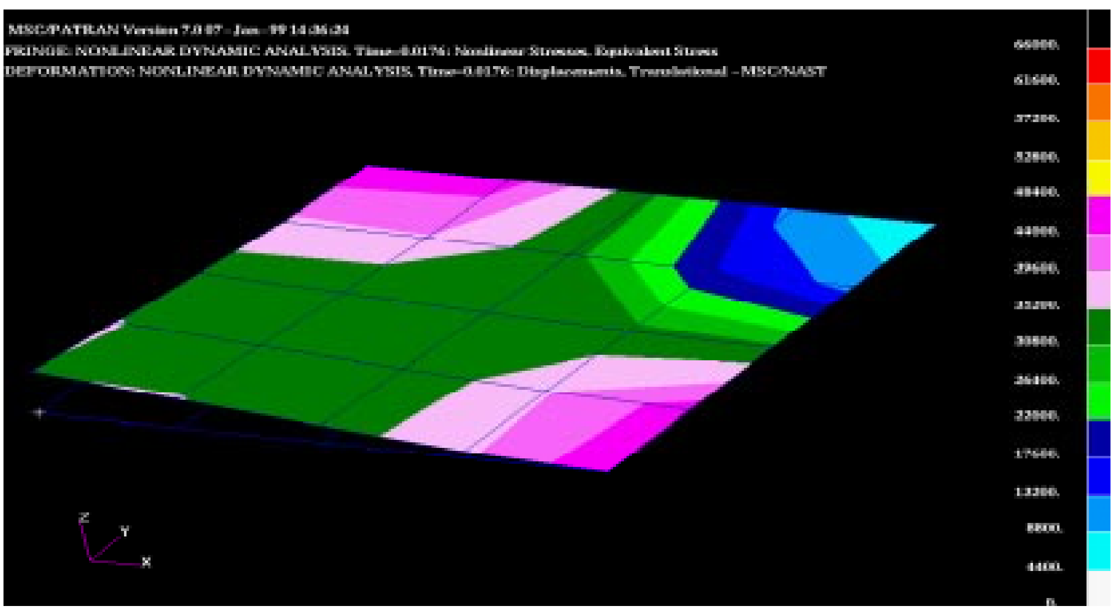

Figure 22 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 16 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0176 seconds. Displacements have been scaled to 10% of the model dimensions.

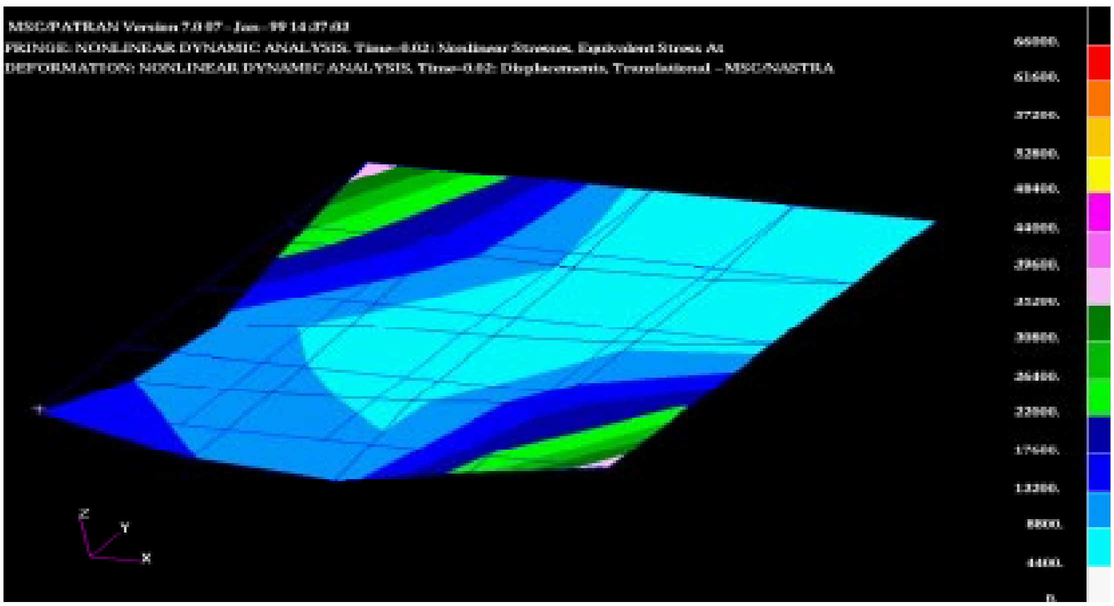

Figure 23 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 16 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.02 seconds. Displacements have been scaled to 10% of the model dimensions.

For the eight by eight element quarter plate, the blast was done for four different loading areas, and thirteen elements of the elements were loaded for blasts of radial distances of six, 12, and 16 inches. These loading areas are shown in Figure 24.

The equivalent stresses from NASTRAN for the 64 element quarter plate are plotted in Figures 25 to 33. These plots are all on deformed displacement geometry that has been scaled to 10% of the model dimensions. By keeping the fringe scale the same through the plots, it is possible to observe the stress waves traveling across the material from the point of blast application.

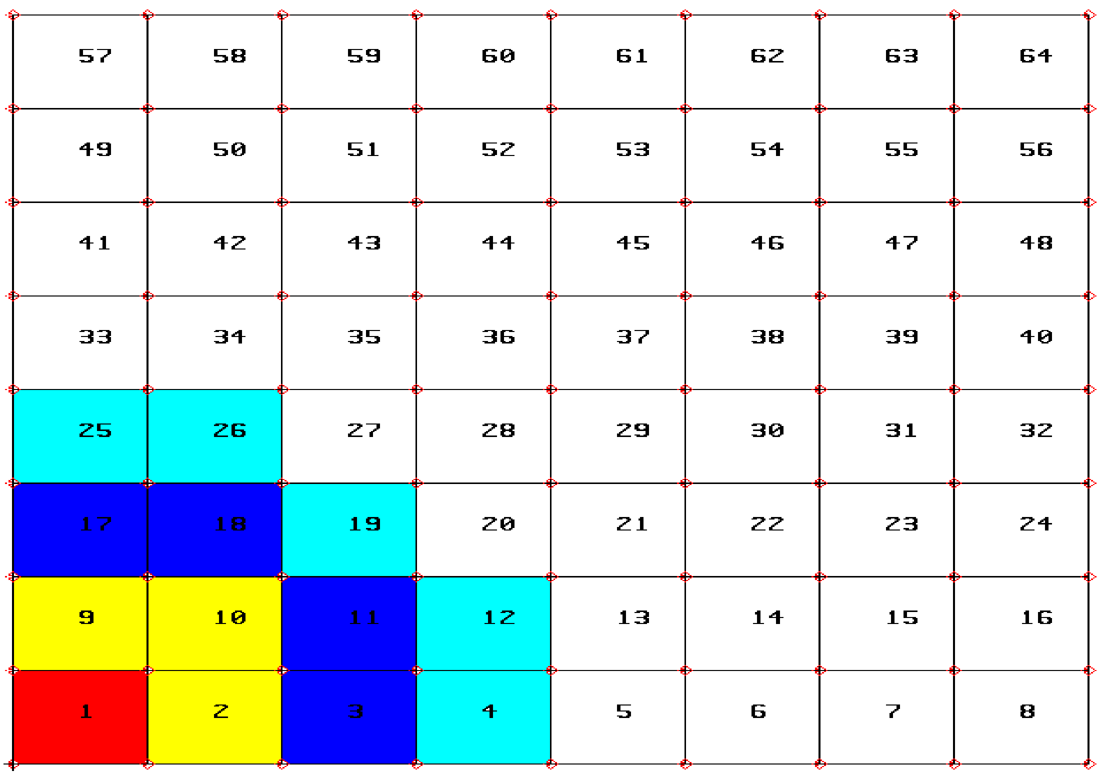

Figure 24 Display of the eight by eight quadrilateral element quarter plate of fixed boundary conditions, showing the four loading areas for six, 12, and 16 inch radial distances from the blast center at the lower left corner.

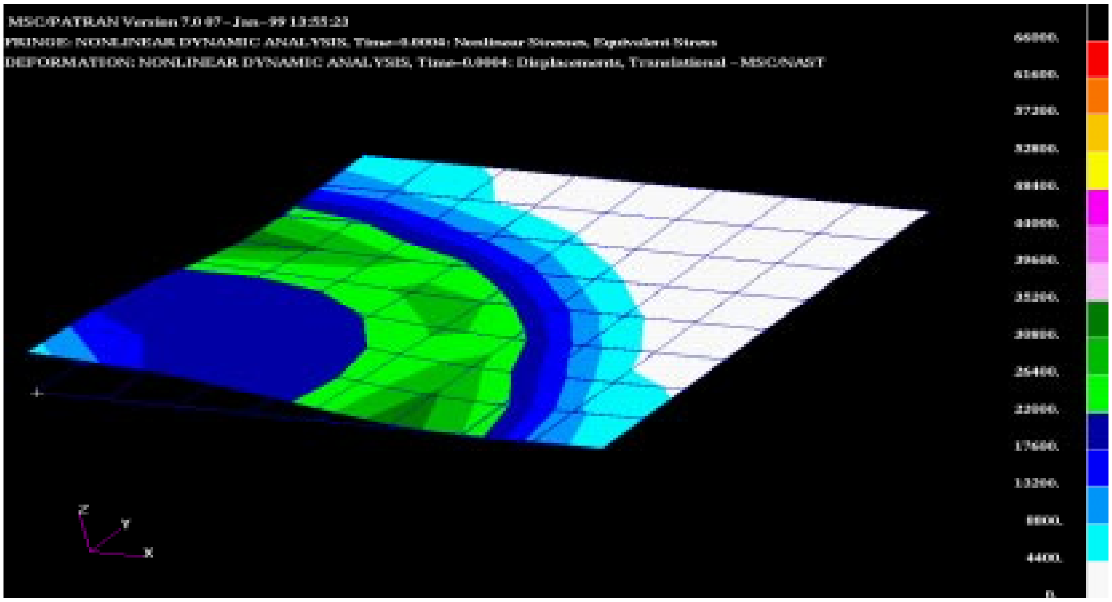

Figure 25 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 64 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0004 seconds. Displacements have been scaled to 10% of the model dimensions.

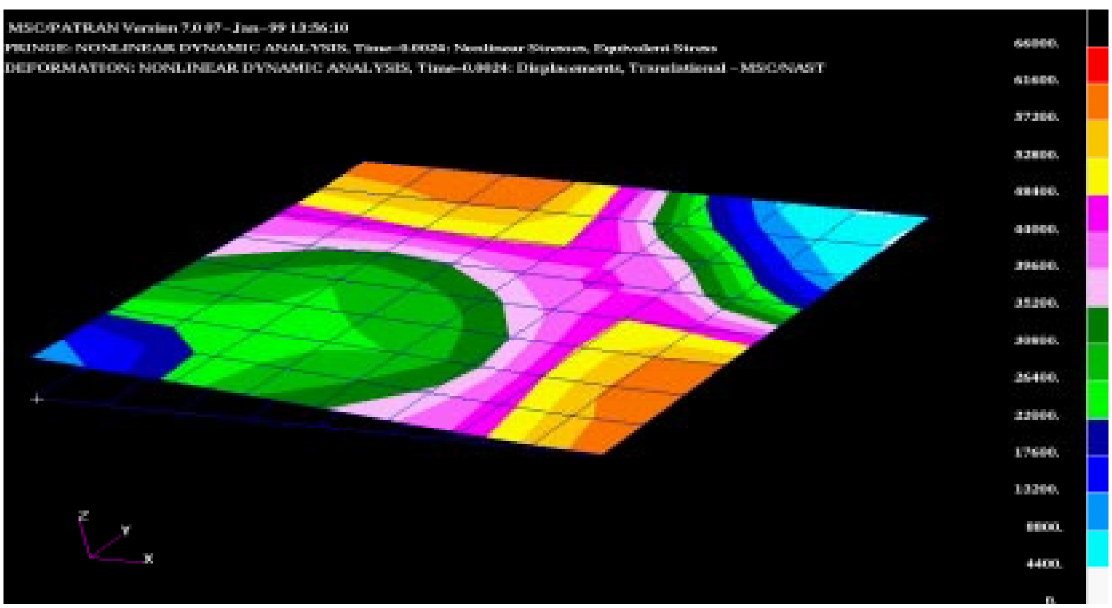

Figure 26 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 64 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0024 seconds. Displacements have been scaled to 10% of the model dimensions.

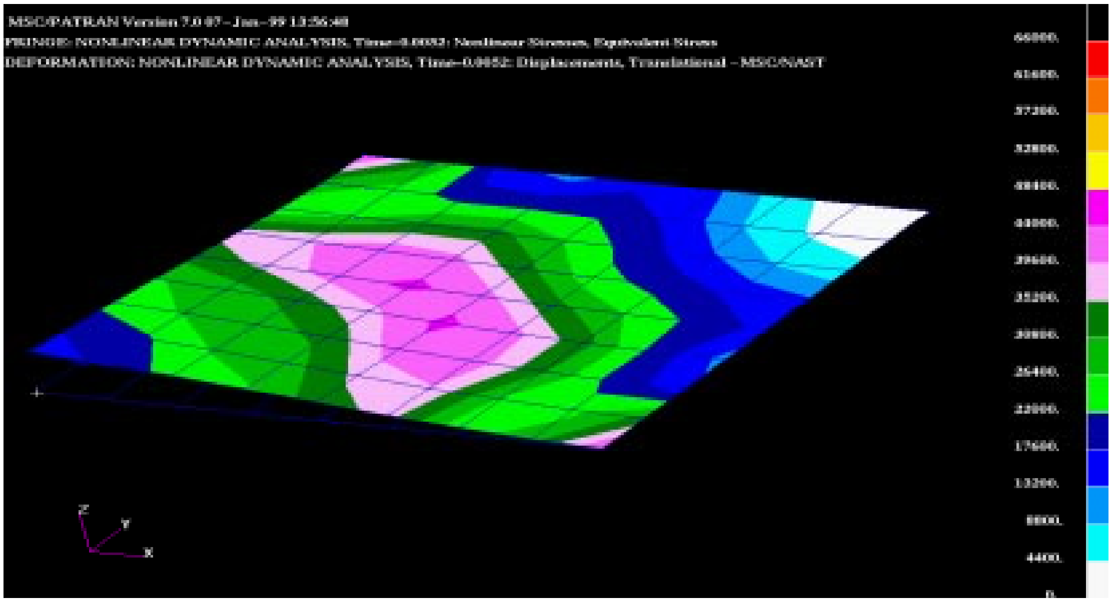

Figure 27 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 64 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0052 seconds. Displacements have been scaled to 10% of the model dimensions.

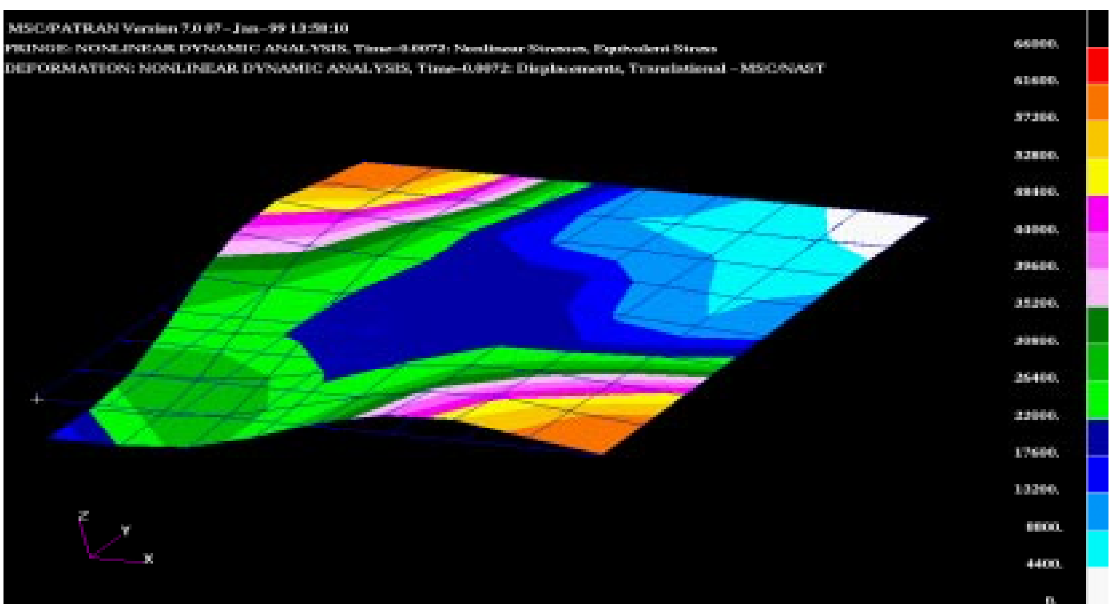

Figure 28 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 64 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0072 seconds. Displacements have been scaled to 10% of the model dimensions.

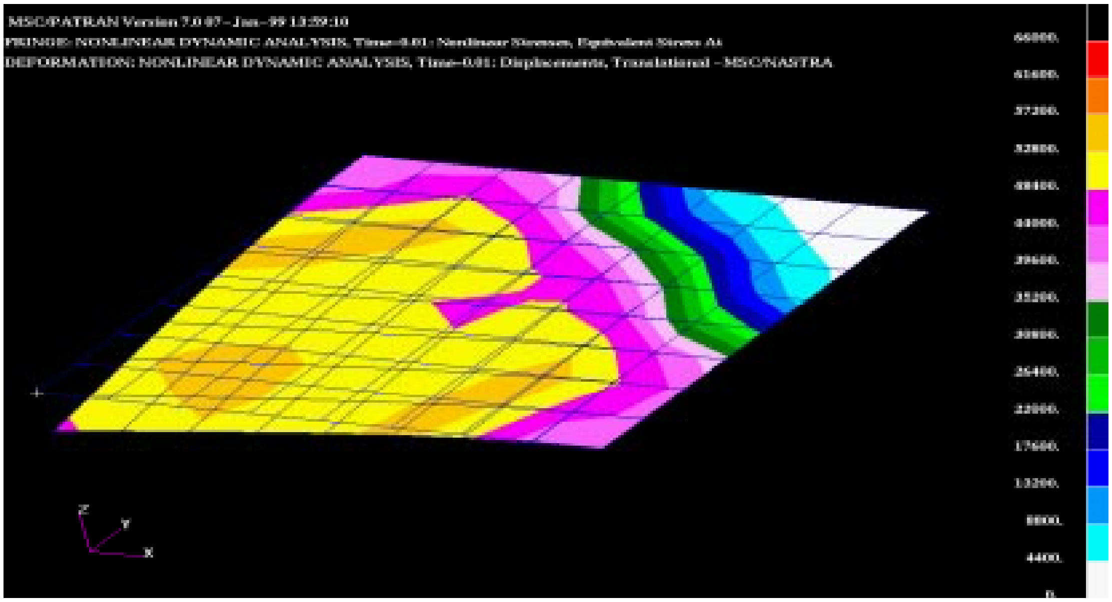

Figure 29 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 64 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.01 seconds. Displacements have been scaled to 10% of the model dimensions.

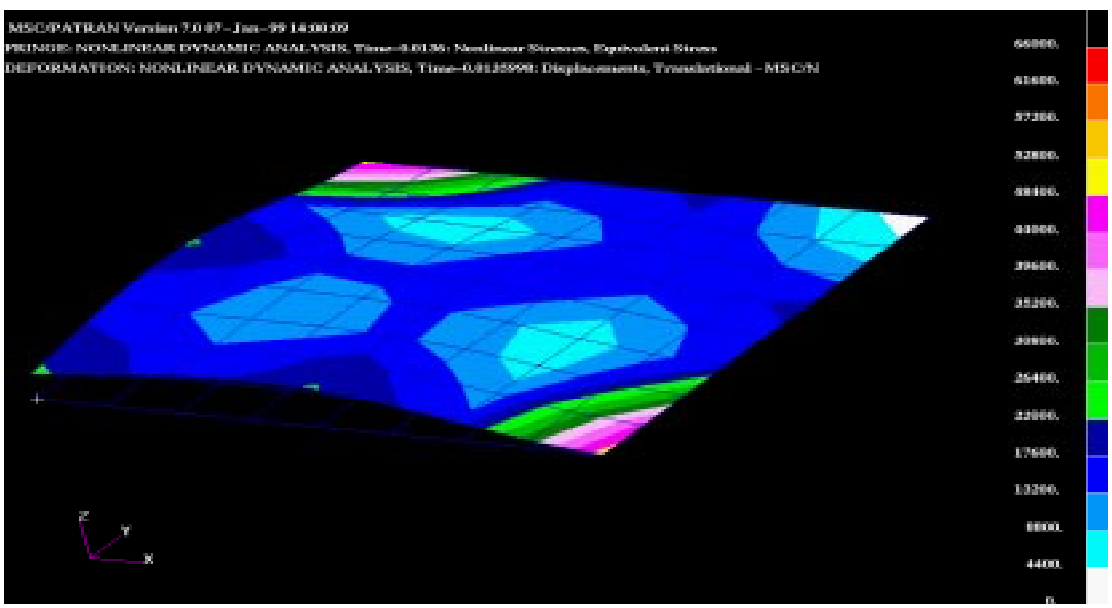

Figure 30 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 64 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0136 seconds. Displacements have been scaled to 10% of the model dimensions.

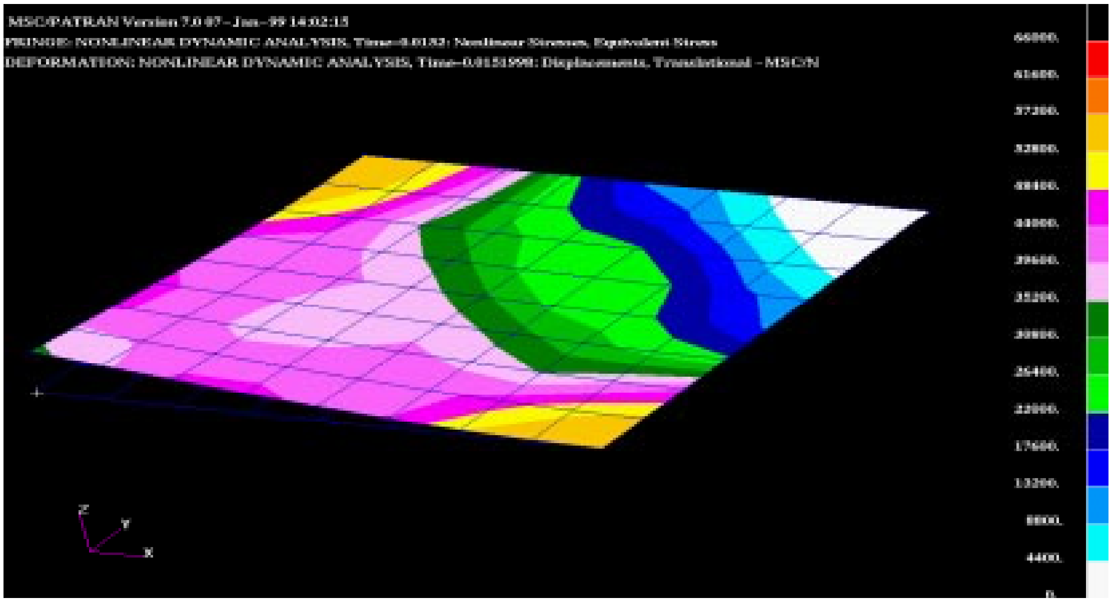

Figure 31 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 64 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0152 seconds. Displacements have been scaled to 10% of the model dimensions.

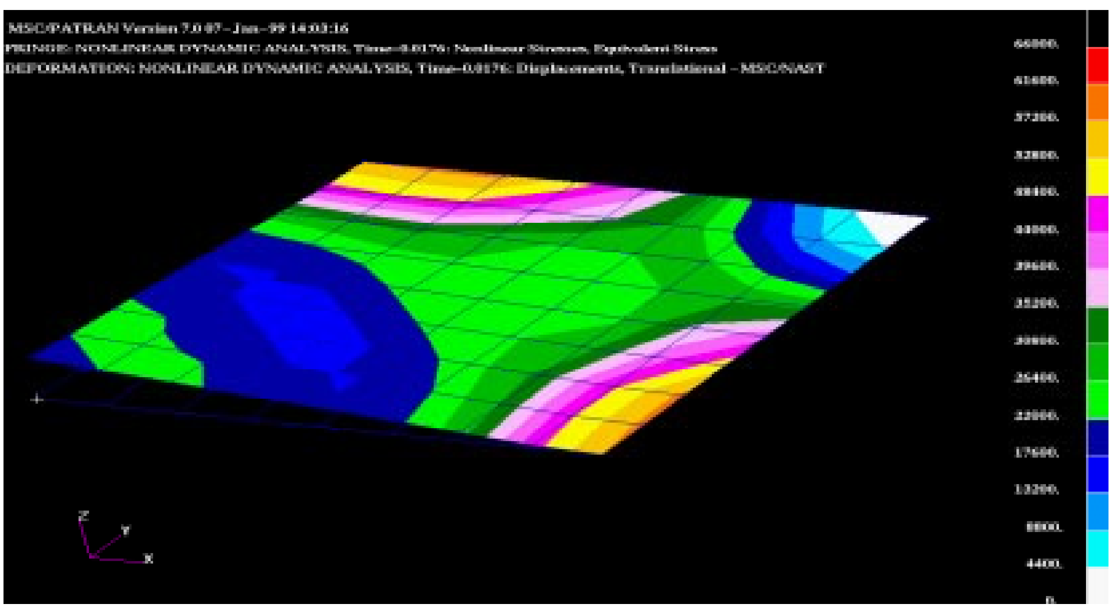

Figure 32 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 64 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0176 seconds. Displacements have been scaled to 10% of the model dimensions.

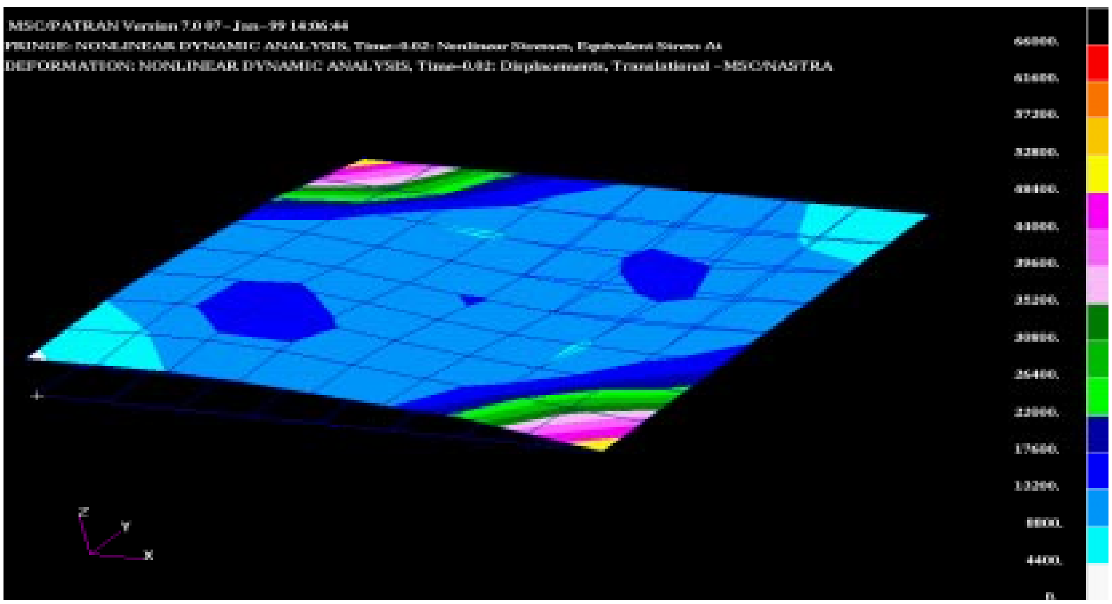

Figure 33 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 64 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.02 seconds. Displacements have been scaled to 10% of the model dimensions.

For the 16 by 16 quarter plate, the blast was done for eight different loading areas, and the appropriate elements were loaded for blasts of radial distances of one, three, five, seven, nine, 11, 13, and 15 inches from the point under the center of the blast. These loading areas are shown in Figure 34.

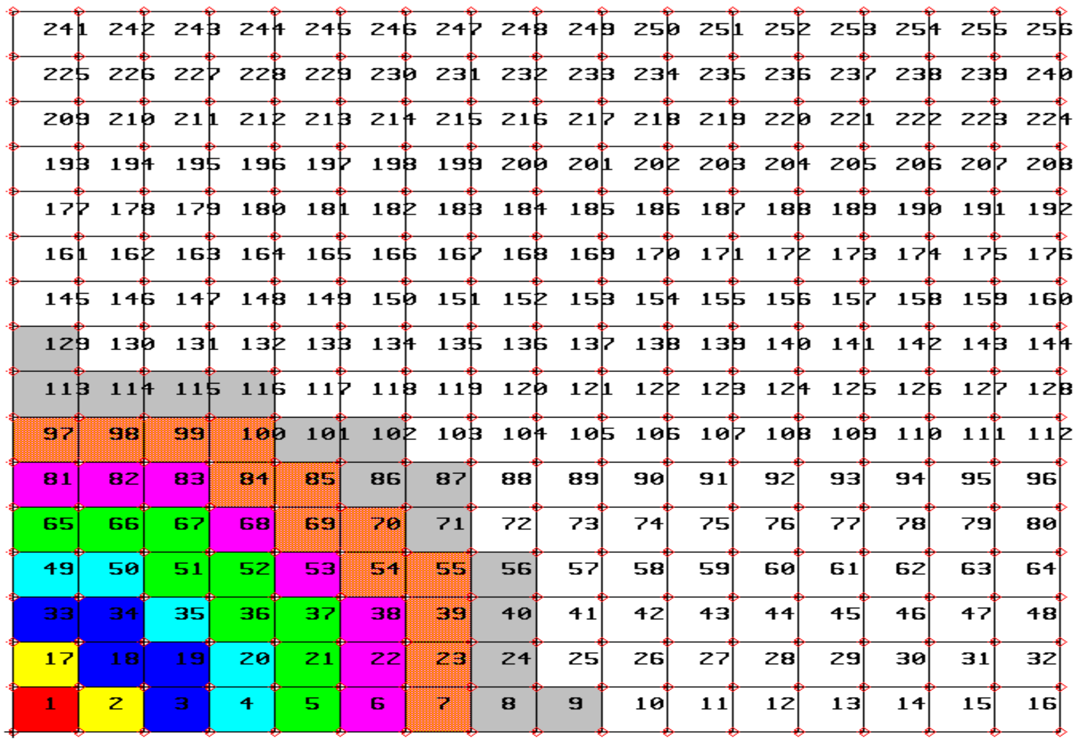

Figure 34 Display of the 16 by 16 quadrilateral element quarter plate of fixed boundary conditions, showing the loading areas for one, three, five, seven, nine, 11, 13, and 15 inch radial distances from the blast center at the lower left corner.

The equivalent stresses from NASTRAN for the 256 element quarter plate are plotted in Figures 35 to 43. These plots are all on deformed displacement geometry that has been scaled to 10% of the model dimensions. By keeping the fringe scale the same through the plots, it is possible to observe the stress waves traveling across the material from the point of blast application. It is at this point where this researcher thinks the most accurate results due to increased resolution begin in the selection of the mesh. In Figure 35, right after the application of the blast loads, it can be seen here, and later in the 32 by 32 element case, that this initial application of the blast causes dramatic deformation in the immediate area of the blast while being rapid enough that the stress waves have not yet begun to travel out from the center of the plate, thus the rest of the plate remains stress free.

Through out the time spans, the stress waves can be seen to be traveling across the plate, and with very little exception, the points of greatest stress are seen to be the corners of the quarter plate that are on the lines of symmetry, while the least stress can be found at the corner formed by the two edges of fixed boundary conditions (upper right).

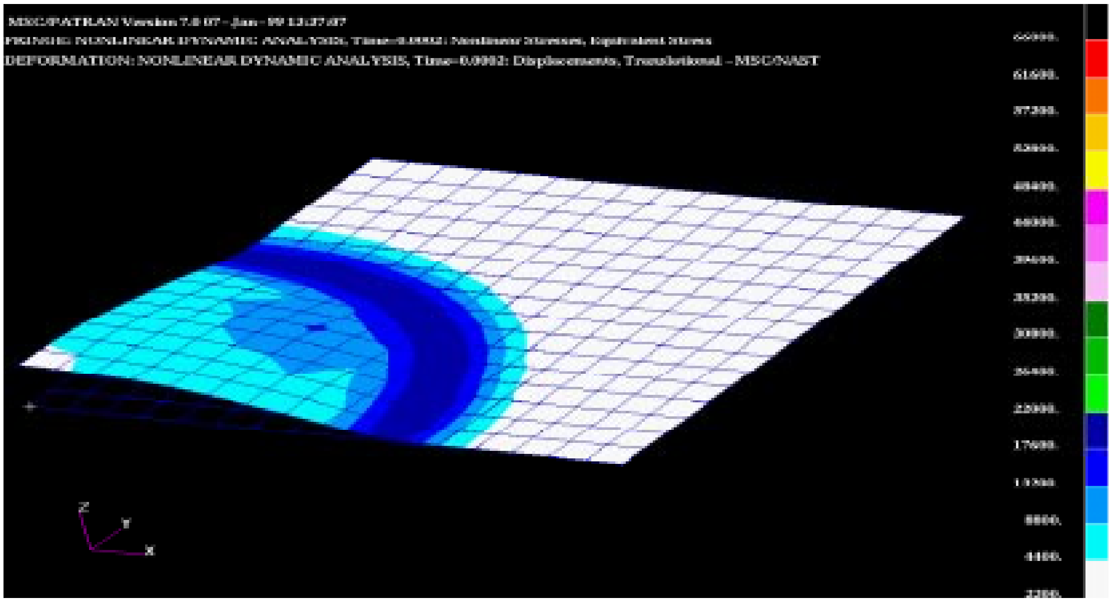

Figure 35 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 256 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0002 seconds. Displacements have been scaled to 10% of the model dimensions.

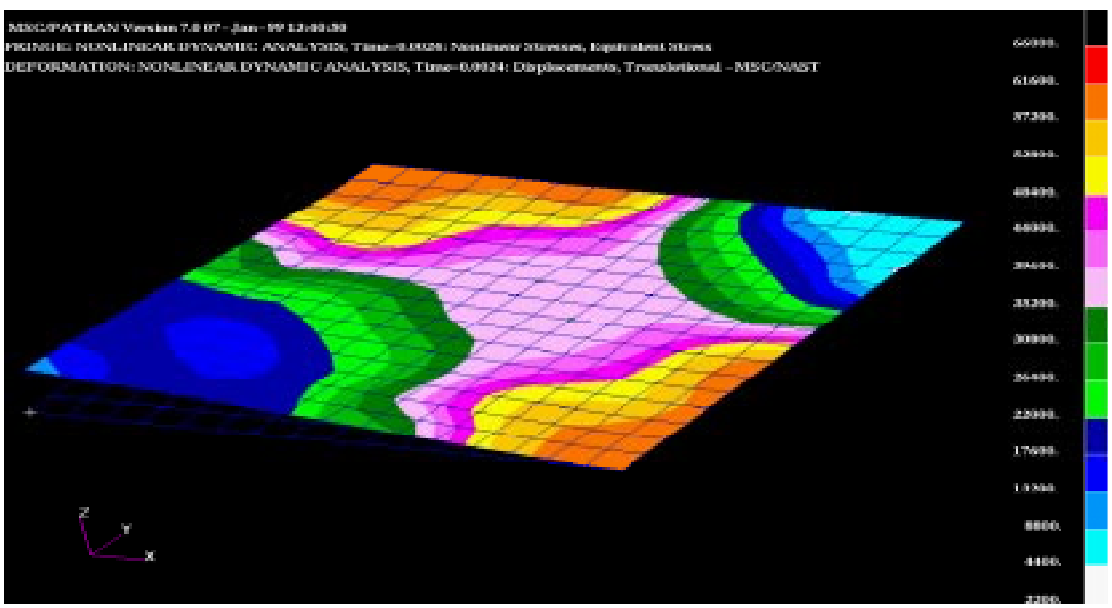

Figure 36 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 256 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0024 seconds. Displacements have been scaled to 10% of the model dimensions.

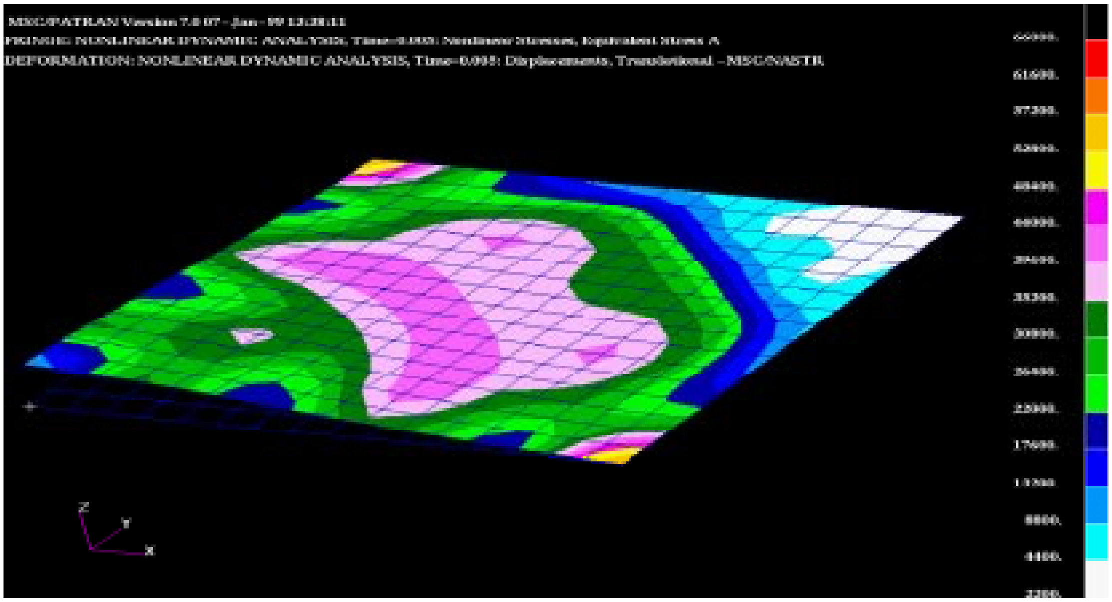

Figure 37 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 256 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.005 seconds. Displacements have been scaled to 10% of the model dimensions.

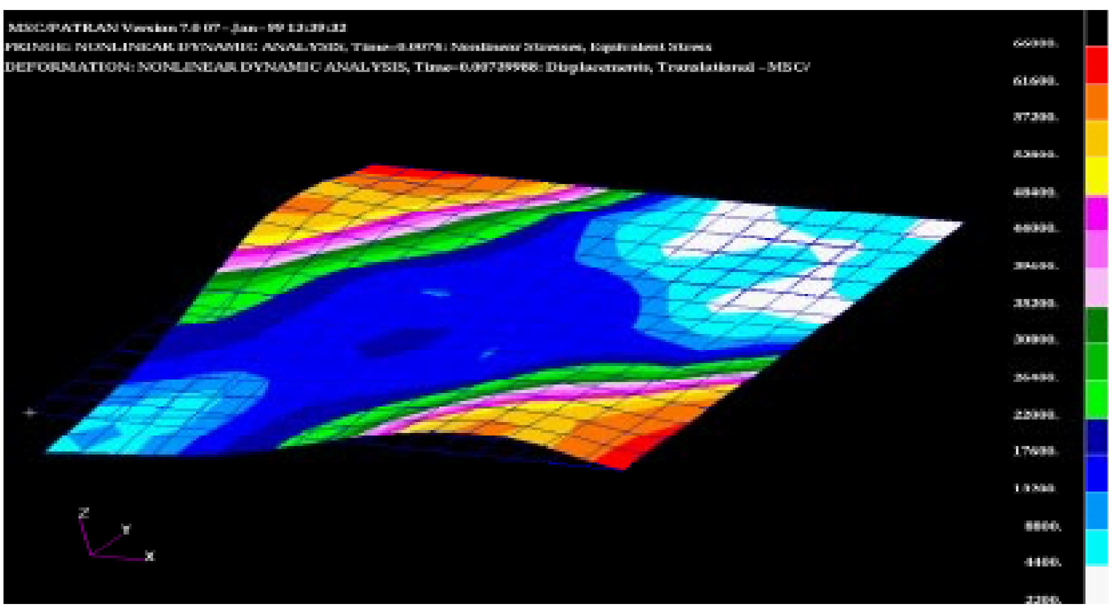

Figure 38 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 256 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0074 seconds. Displacements have been scaled to 10% of the model dimensions.

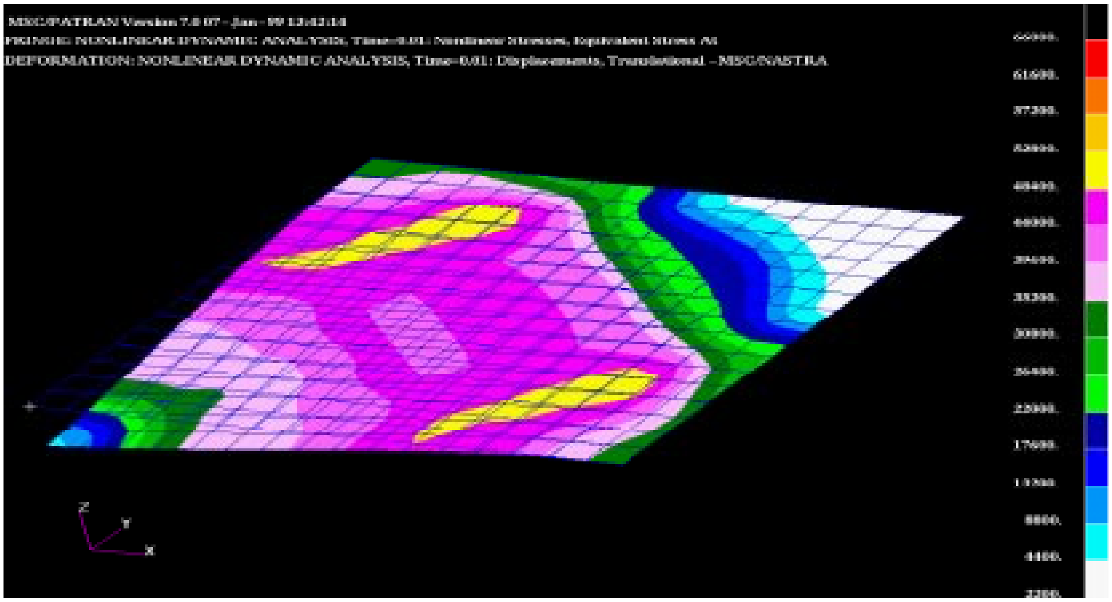

Figure 39 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 256 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.01 seconds. Displacements have been scaled to 10% of the model dimensions.

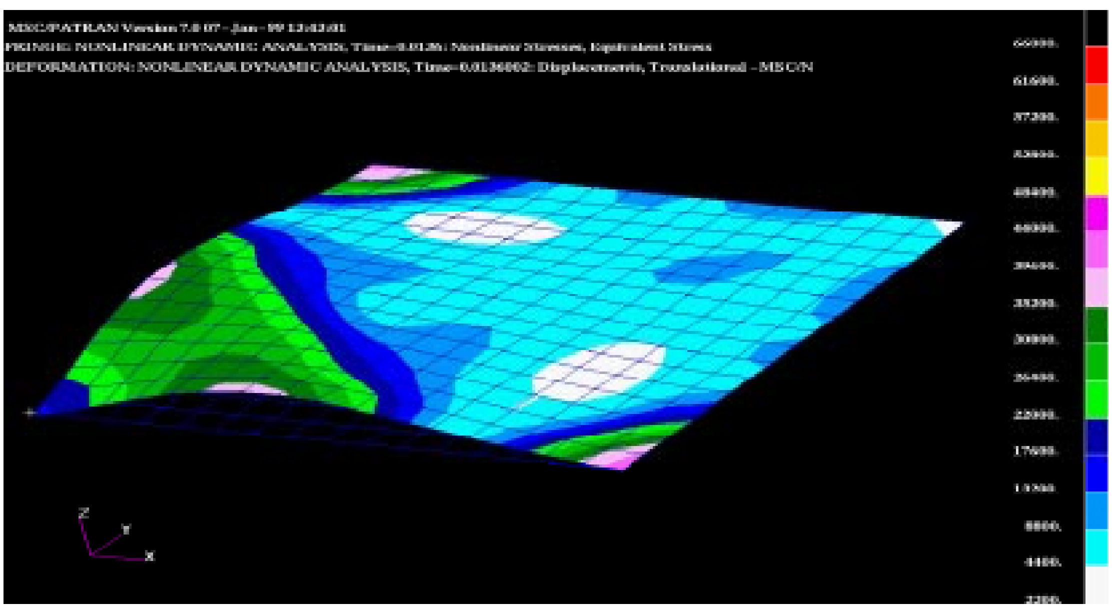

Figure 40 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 256 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0136 seconds. Displacements have been scaled to 10% of the model dimensions.

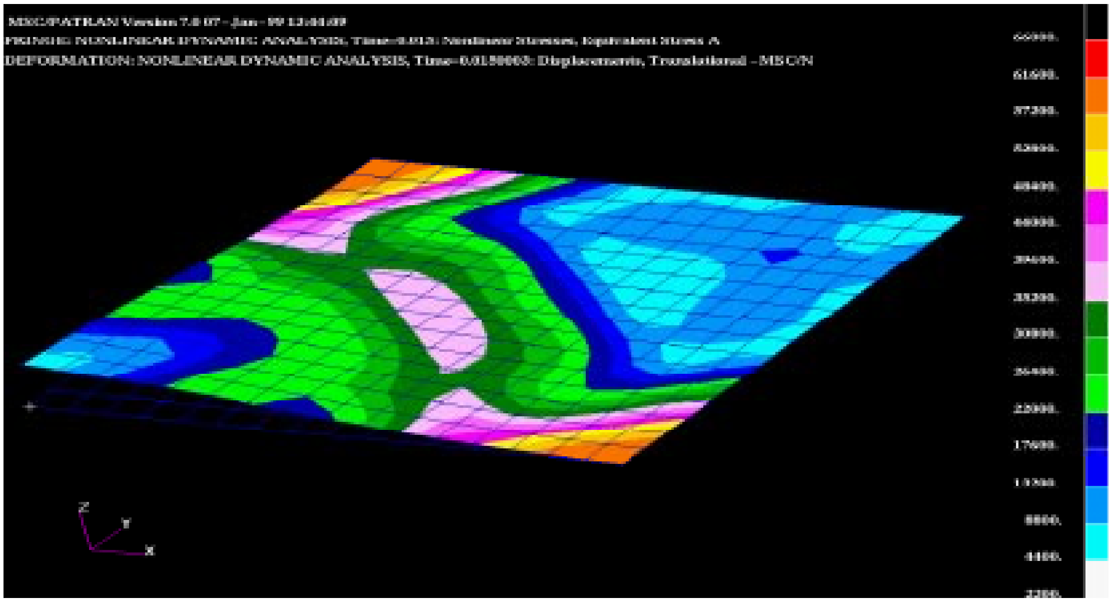

Figure 41 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 256 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.015 seconds. Displacements have been scaled to 10% of the model dimensions.

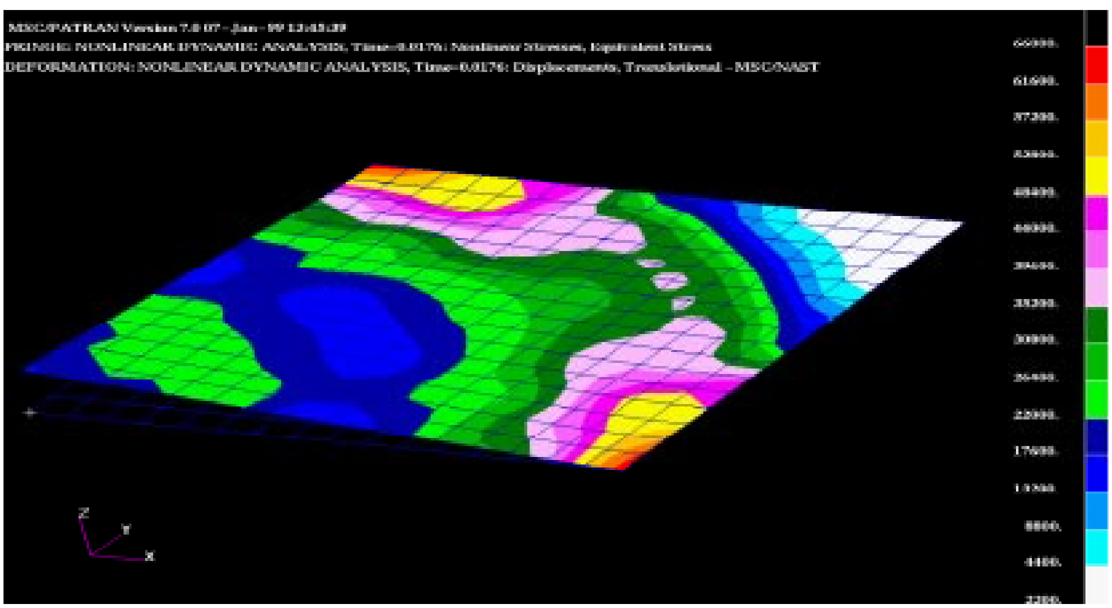

Figure 42 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 256 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0176 seconds. Displacements have been scaled to 10% of the model dimensions.

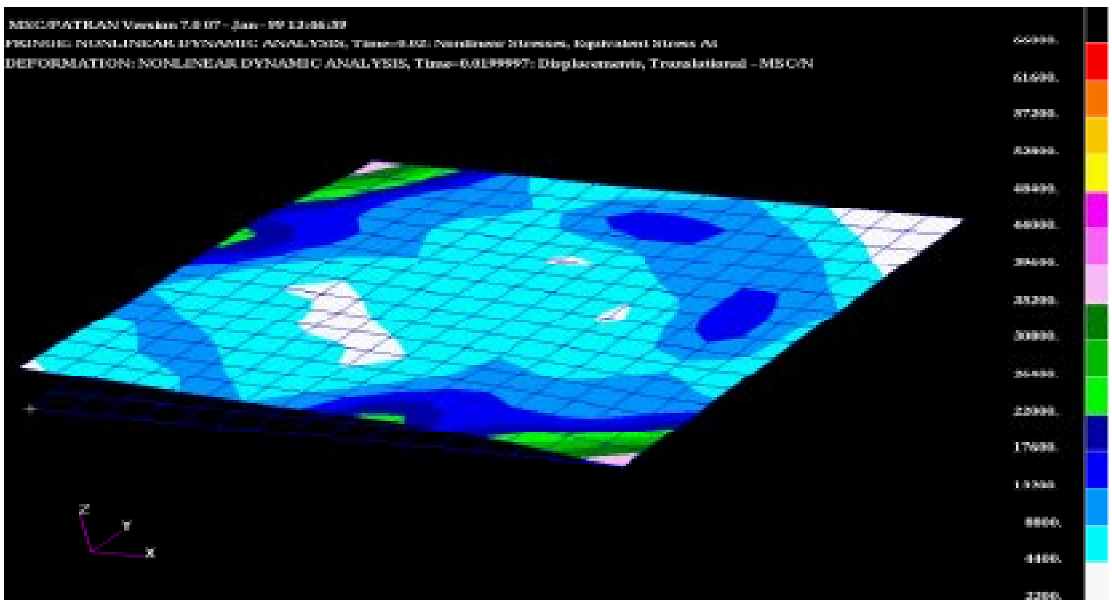

Figure 43 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 256 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.02 seconds. Displacements have been scaled to 10% of the model dimensions.

For the 32 by 32 quarter plate, the blast was done for eight different loading areas, and the appropriate elements were loaded for blasts of radial distances of one, three, five, seven, nine, 11, 13, and 15 inches. These loading areas are shown in Figure 44, though the element numbers are not shown for clarity. The blast center is at the lower left corner.

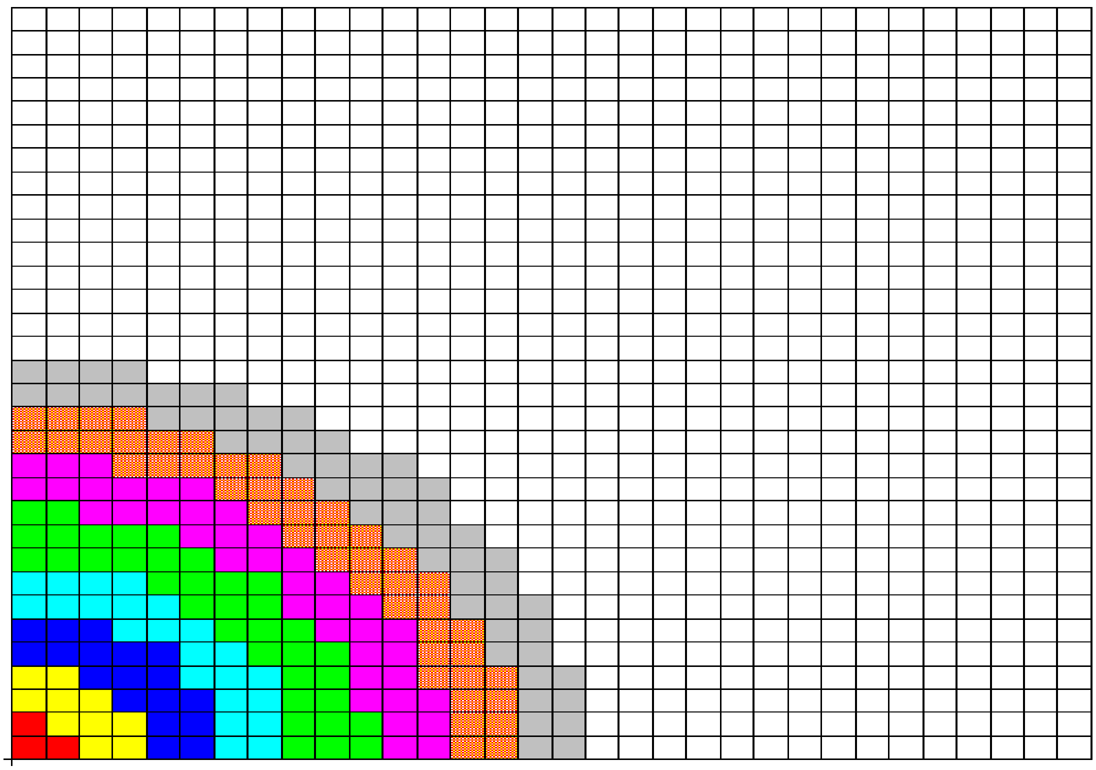

Figure 44 Display of the 32 by 32 quadrilateral element quarter plate of fixed boundary conditions, showing the loading areas for one, three, five, seven, nine, 11, 13, and15 inch radial distances from the blast center at the lower left corner. Element numbers are not shown.

The equivalent stresses from NASTRAN for the 1024 element quarter plate are plotted in Figures 45 to 53. These plots are all on deformed displacement geometry that has been scaled to 10% of the model dimensions. By keeping the fringe scale the same through the plots, it is possible to observe the stress waves traveling across the material from the point of blast application. This example was done to obtain better resolution of the effects of the blast seen in the 256 element quarter plate, but also to check the convergence of the 16 by 16 element mesh. While obvious advantages in increased accuracy can be obtained with 32 by 32 element size, for this model, it corresponds to less than one inch square per element, for a different model, this could become compuationally expensive to implement with such a small element, thus a larger element for roughly the same results would be desired.

Again, it can be seen that great deformation occurs as the blast strikes the plate, but that the effect is so rapid that stresses have not formed far beyond the area being loaded. This model showed similar deflections and stresses, but the resolution provided a much clearer picture of the behaviour of the plate. As a design tool, this would be very helpful, however, computationally limiting for large models. The vibration of the plate is interesting to observe and compare over the increasing resolution of the mesh as the coarse mesh does not show the rotation and deformation of the model under load as well as the fine model does, especially near time = 0.0136 seconds.

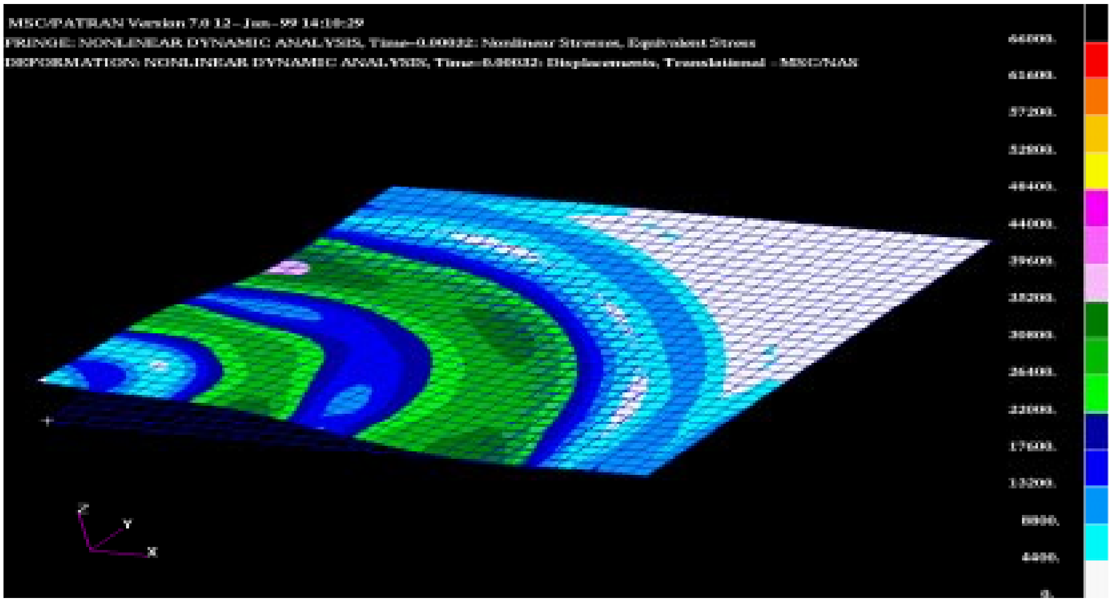

Figure 45 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 1024 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.00032 seconds. Displacements have been scaled to 10% of the model dimensions.

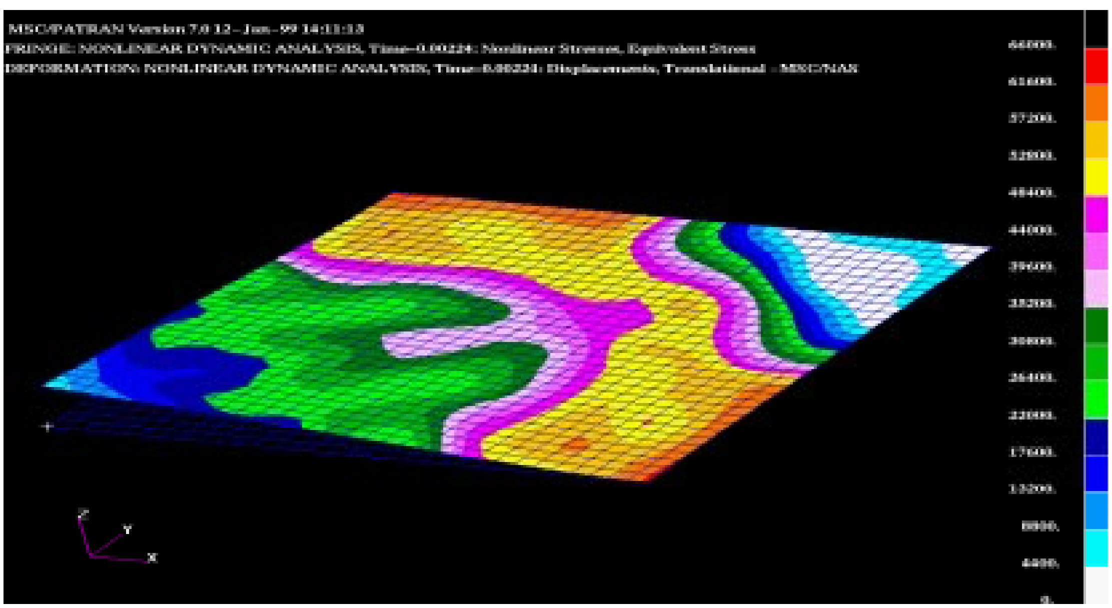

Figure 46 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 1024 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.00224 seconds. Displacements have been scaled to 10% of the model dimensions.

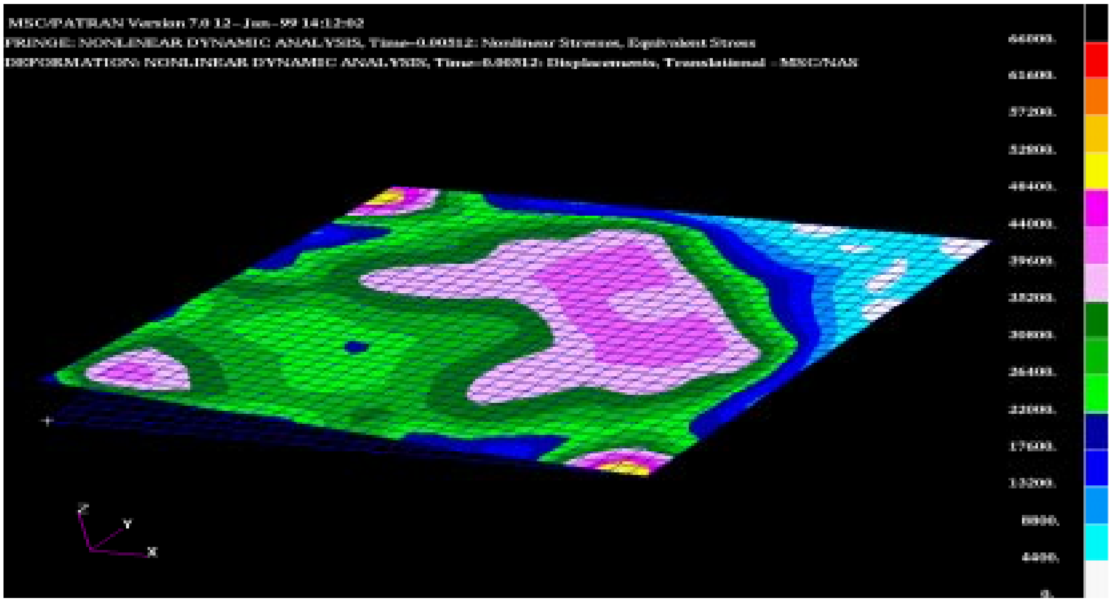

Figure 47 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 1024 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.00512 seconds. Displacements have been scaled to 10% of the model dimensions.

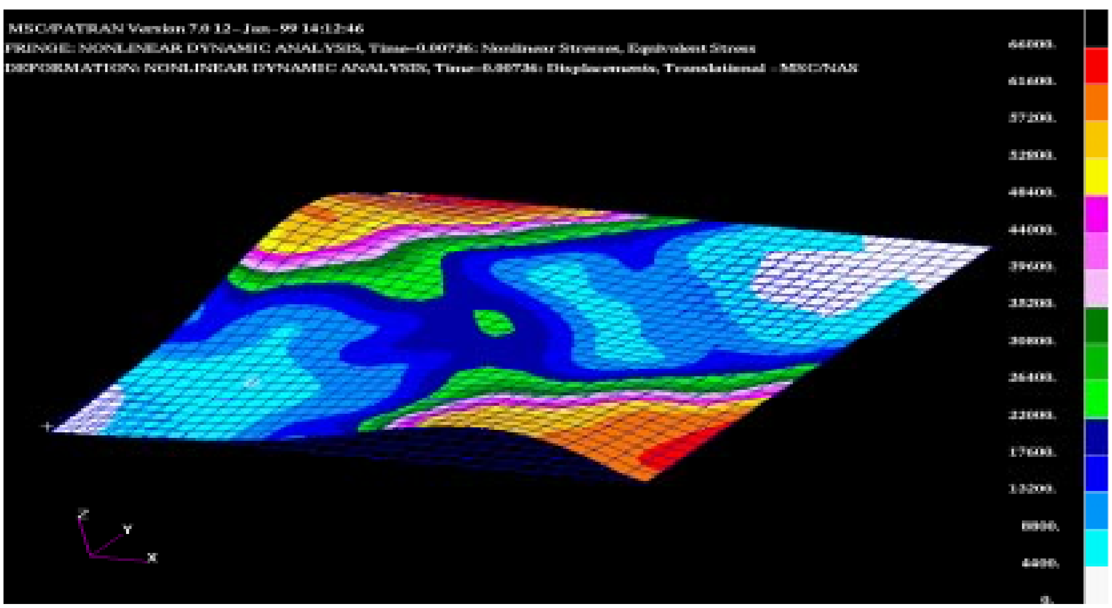

Figure 48 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 1024 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.00736 seconds. Displacements have been scaled to 10% of the model dimensions.

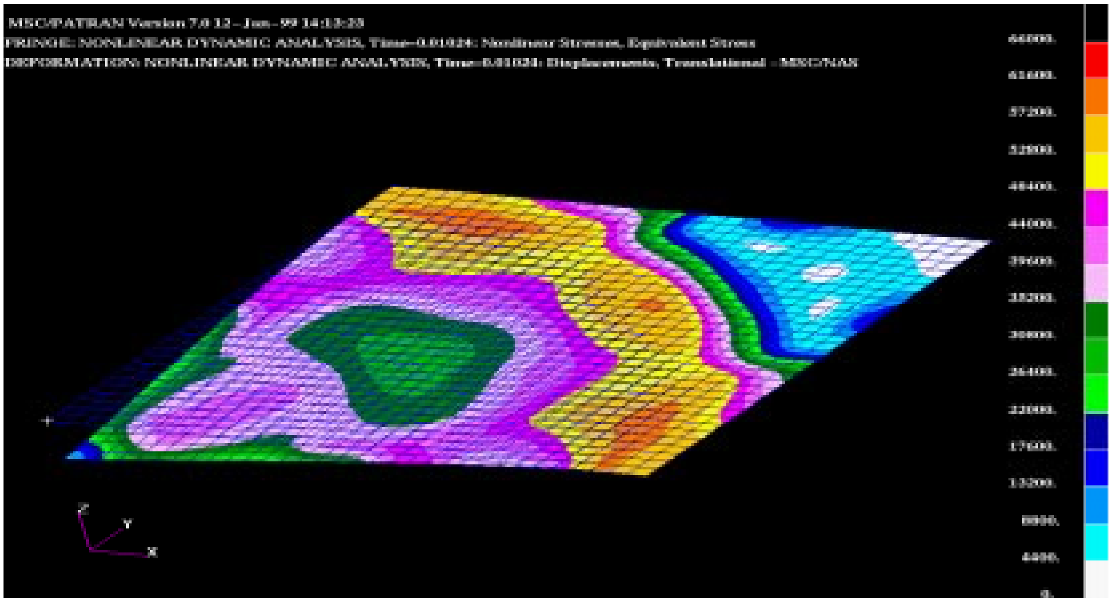

Figure 49 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 1024 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.01024 seconds. Displacements have been scaled to 10% of the model dimensions.

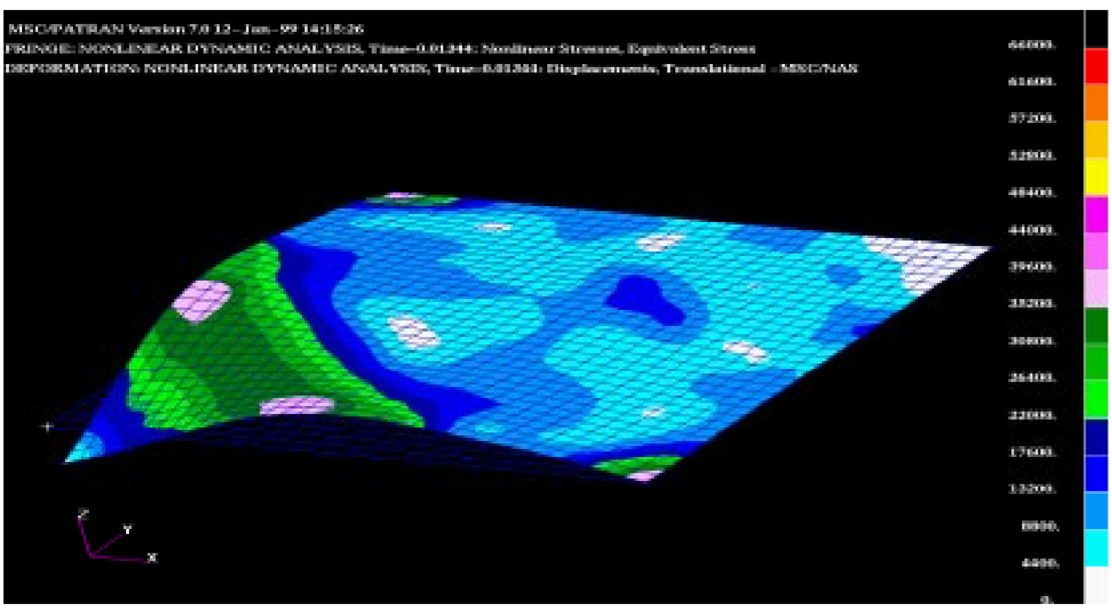

Figure 50 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 1024 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.01344 seconds. Displacements have been scaled to 10% of the model dimensions.

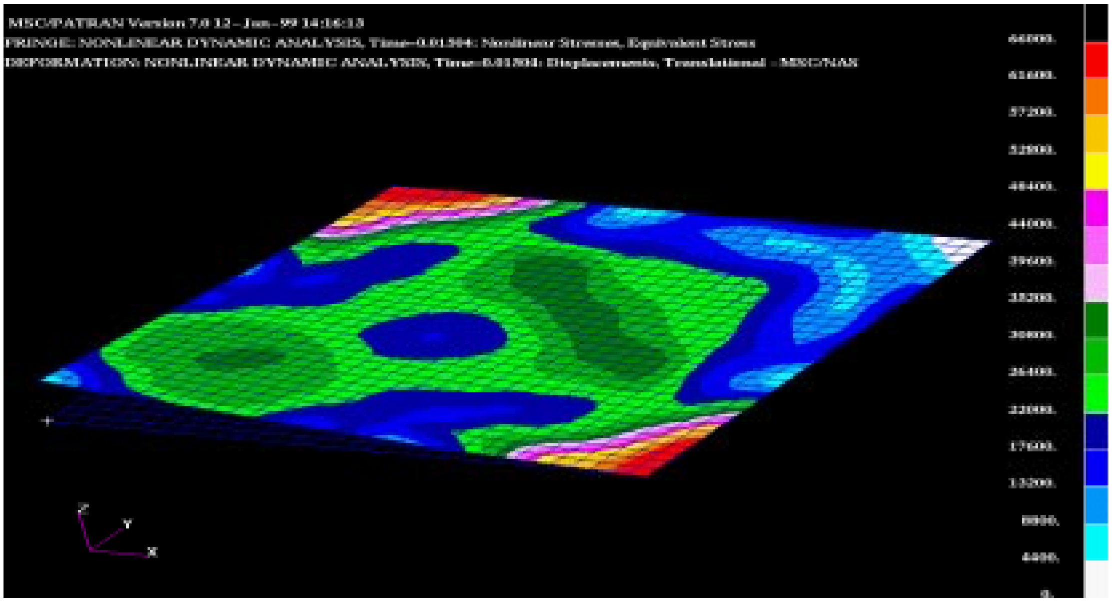

Figure 51 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 1024 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.01504 seconds. Displacements have been scaled to 10% of the model dimensions.

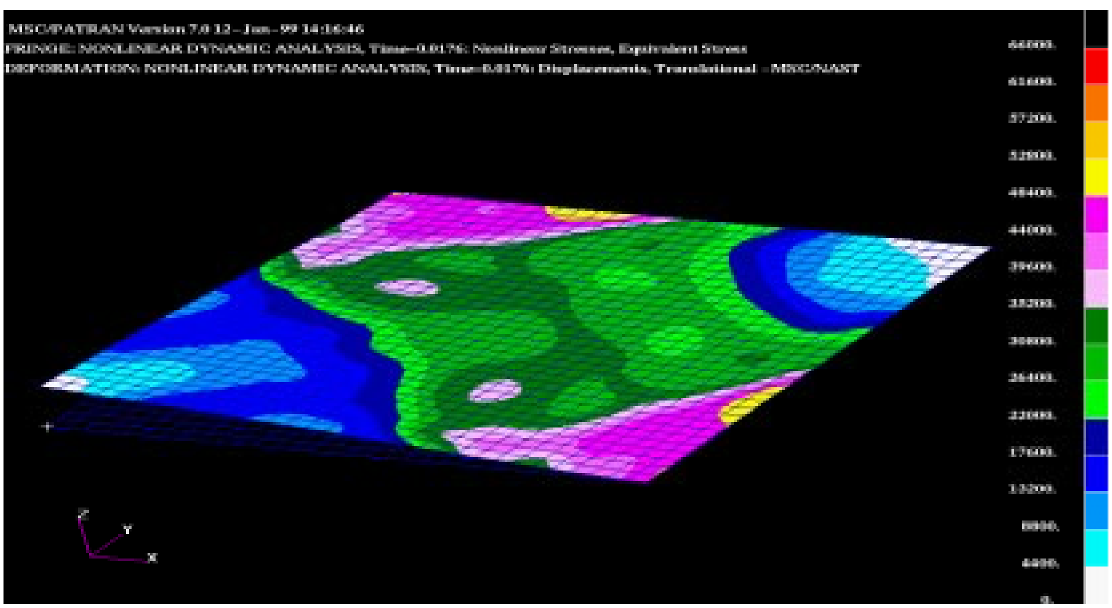

Figure 52 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 1024 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.0176 seconds. Displacements have been scaled to 10% of the model dimensions.

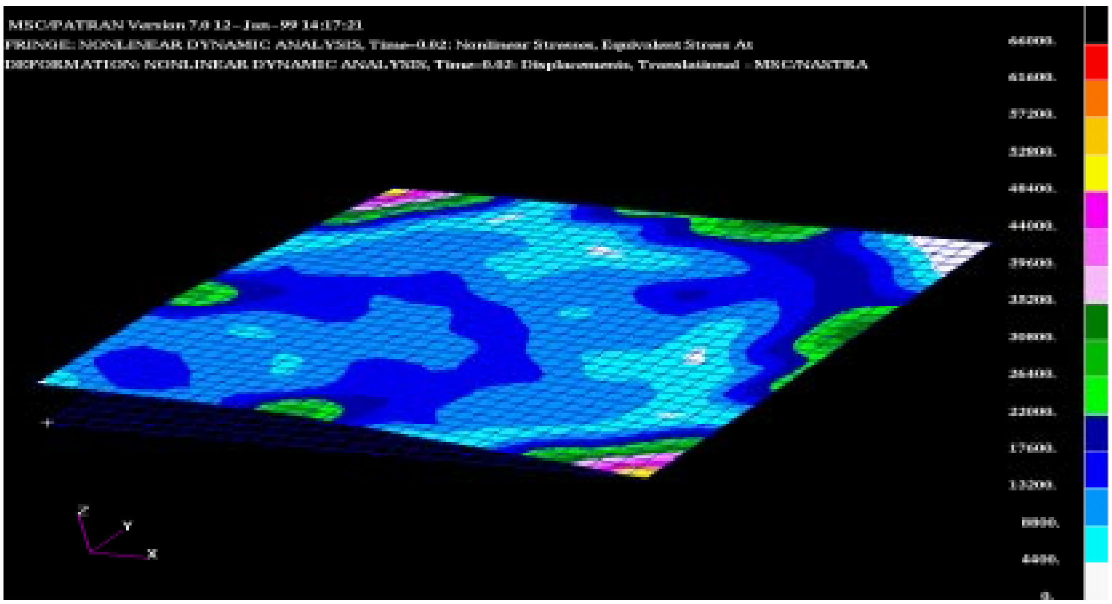

Figure 53 Equivalent stress plots on a deformed representation of an Aluminum 2519, 30 inch by 30 inch quarter plate of fixed boundary conditions with 1024 elements subjected to a five pound charge in hemispherical ground detonation at the lower left corner at time = 0.02 seconds. Displacements have been scaled to 10% of the model dimensions.

As can be seen in Figure 54, the displacements of the plate converged rapidly for the model, even with the refinement of both the blast loading areas and the mesh itself. The displacements for the center point under the immediate area of blast loading are plotted. Not only does the displacements converge rapidly, but they can almost be approximated as being a decaying oscillation.

As any finite element model cannot be considered to be converged for displacements alone, the stresses are shown in Figure 55 for the corner elements under load. As this corner element decreases in area by a factor of four with each refinement of the mesh, the point for which the stress is being analyzed changes too, as that point lies at the center of the element, with that center point "moving" towards the corner point by half the distance with each mesh refinement. This trend, similarly, can be seen to almost halve with the refinement of the mesh first from 16 (four by four) elements, to 64 (eight by eight) elements, then to 256 (16 by 16) elements. The stress plotted for the 1024 (32 by 32) element case is not the stress at the center of the corner element. Instead, the stress for the four corner elements was averaged to determine the average stress at what was formerly the center of the corner element of the 256 element case. This enabled a more direct comparison of the stresses and showed that though the exact values of the stresses had not converged, they were of a closer order of magnitude and showed the same trends.

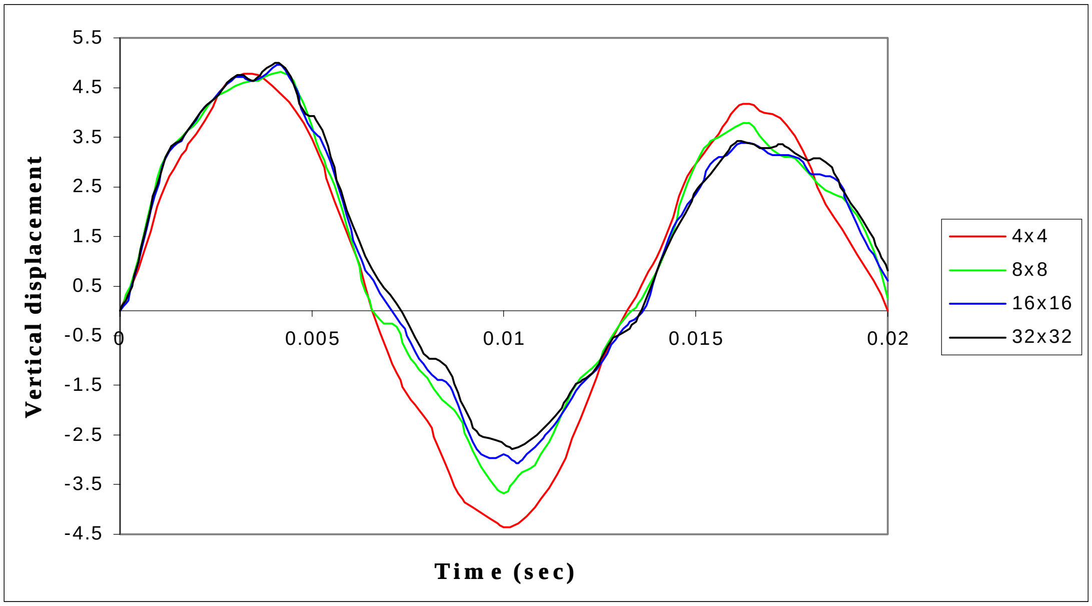

Figure 54 Plot of the vertical displacement for the corner of the quarter plate subjected to the five pound surface blast showing gradual convergence with the increase in the number of elements.

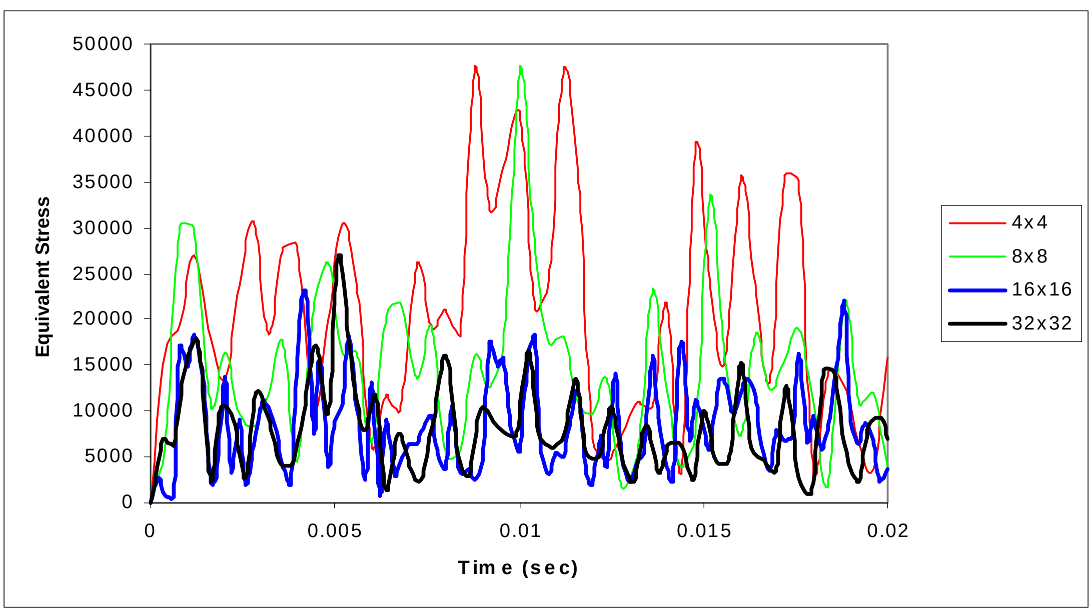

Figure 55 Plot of the equivalent stress for the center point of the element near the corner of the quarter plate subjected to the five pound surface blast showing gradual convergence with the increase in the number of elements.

4.5 Example of an Arbitrary Aircraft Wing: 20lb TNT charge at 6 ft.

Using NASTRAN, the model of the NASA's Aeroelastic Research Wing-2 (ARW-2) was modified to represent a more generic, full sized aircraft wing. The ARW-2 model has a leading edge sweep of 28.8 degrees and an aspect ratio of 10.8. The mesh of the ARW-2 wing model consists of an 11 x 13 mesh of 312 nodes. There are 952 elements including 56 two-dimensional stiffener elements with the remaining 896 elements being triangular three noded shell elements including elements comprising the ribs and spars of the wing model. An isotropic material was selected for application of the loads [11].

To do this scaling, the geometric coordinates of the ARW-2 wing were changed from units of inches to units of feet. This provided a larger wing with which to work while not modifying the properties of the wing itself, essentially providing a wing 12 times larger than the original model. This model can be seen in a captured image from PATRAN in Figure 56. This wing was then further modified by adjusting the material properties to feet. The material selected was aluminum 7075-T6, a common aircraft material. This was input into the NASTRAN input deck as a two linear segment elastic (until yield stress) and plastic (until ultimate stress) stress-strain curve which provided the model with non-linear properties. Thus, a non-linear dynamic response analysis was run.

To provide the blast loads, BLAST.F was used to generate the angle of incident adjusted curves from the Kingery and Bulmash calculation routine for 20lbs of TNT at a six foot normal distance. This was done for four loading areas seen in Figure 57. The 20 pound charge was an arbitrarily chosen value based on warhead sizes of common air-to-air missile threats [7] [8].

For simplification of the model, and also because this is a demonstration of the method and this model is not a design tool, the wing body joint was replaced with fixed boundary conditions along the length of the wing root edge of the finite element model. The runtime for this model was limited to a short time beyond the time of blast load application due to file size constraints on the system running NASTRAN. Figures 58 to 65 have the stresses plotted on the deformed model. The deformed model is not scaled in any way and shows the correct, unaltered deformations. After Figure 61, the scale of the fringe plot was changed to a higher maximum, there by allowing better stress resolution for the earlier time steps. The runs used approximately 10 hours of CPU time per run including several aborted runs, though the limiting factor seemed to be not the queue's run time limits, but the storage space allowed for the scratch files used by NASTRAN in conducting the runs. This limitation was solved by using an Aerospace Department computer account with a much larger storage space allocation. The number of elements and the load application changed not only the run time, but also the necessary storage space.

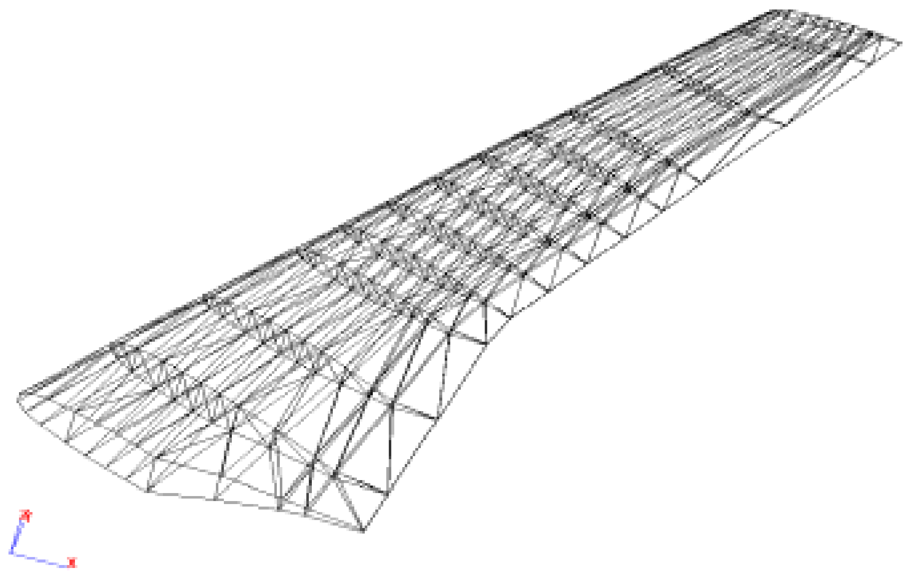

Figure 56 Three-dimensional view of the ARW-2 wing model to which blast loads were applied. The boundary conditions at the wing root were fixed during analysis.

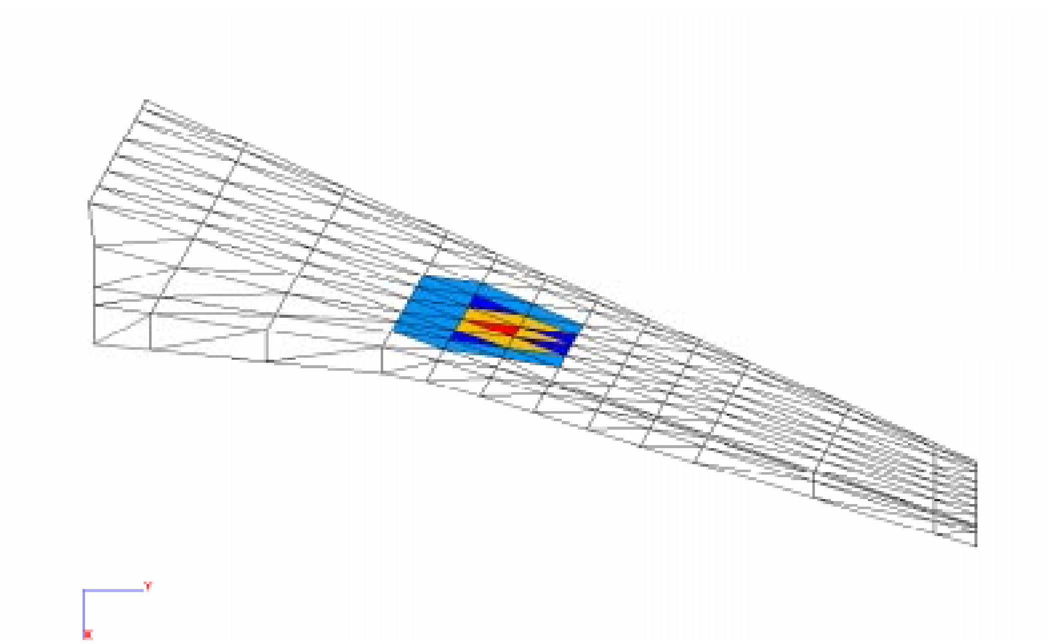

Figure 57 View of the underside of the hypothetical wing model showing blast load application areas.

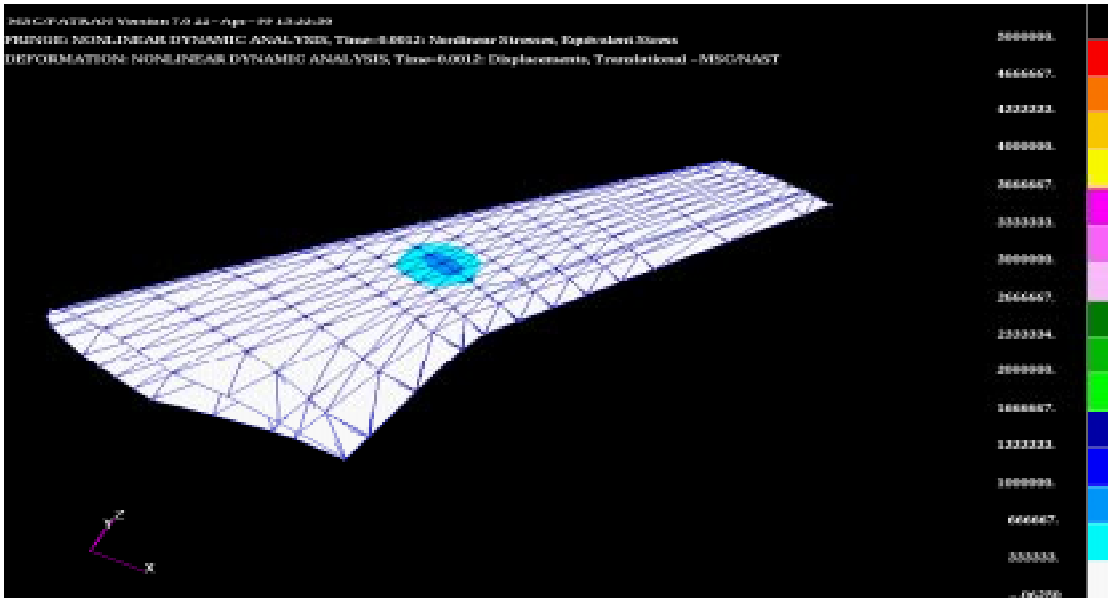

Figure 58 The hypothetical wing model at time = 0.0012 seconds subjected to a 20 pound TNT blast at six feet (72 inches) blast normal distance. The stress waves have not traveled far beyond the loading area.

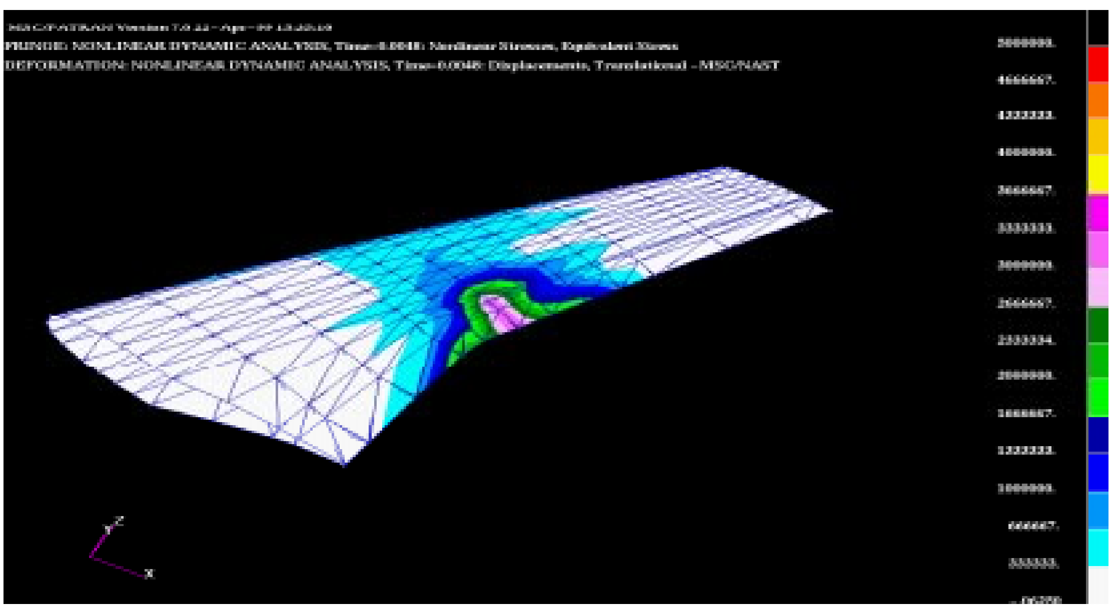

Figure 59 The hypothetical wing model at time = 0.0048 seconds subjected to a 20 pound TNT blast at six feet (72 inches) blast normal distance. Stresses have begun building up at the control surfaces where the wing thickness is least.

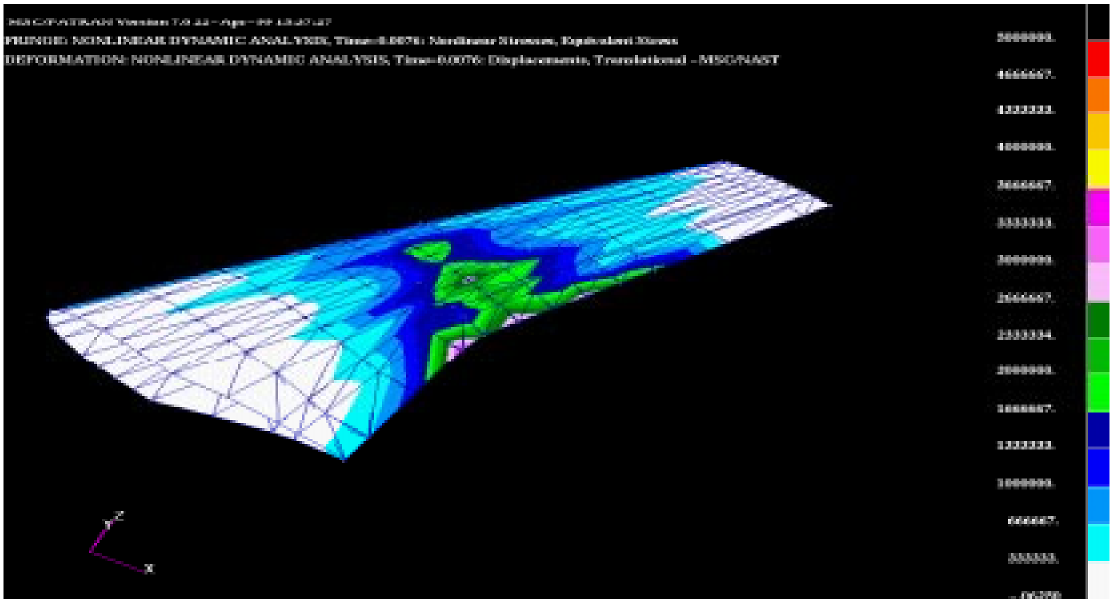

Figure 60 The hypothetical wing model at time = 0.0076 seconds subjected to a 20 pound TNT blast at six feet (72 inches) blast normal distance. The stress waves have begun traveling the length of the wing while highest stresses can still be found at the control surfaces.

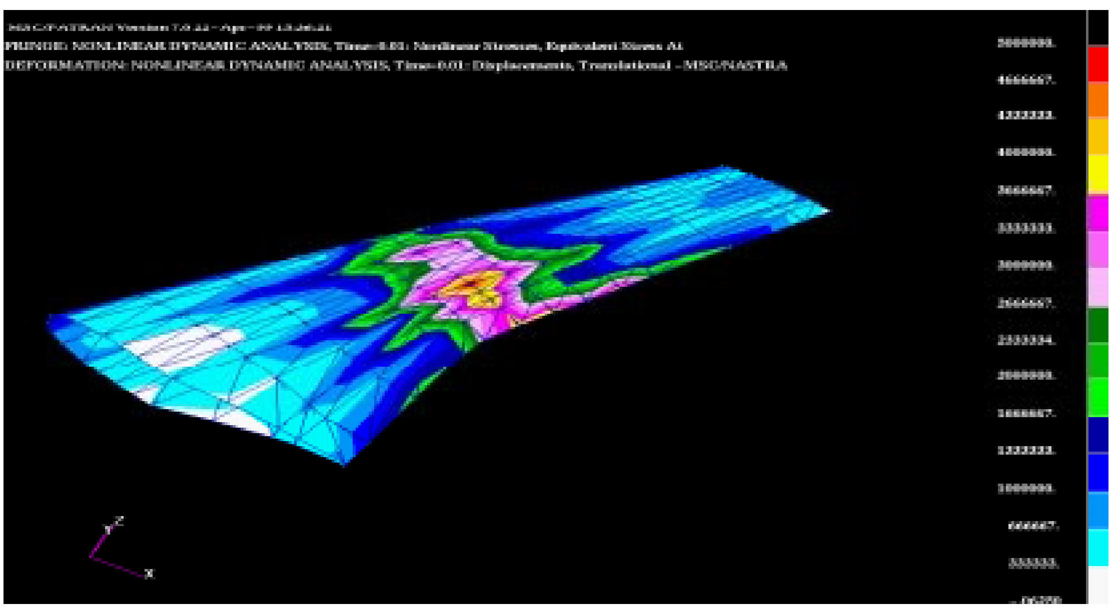

Figure 61 The hypothetical wing model at time = 0.01 seconds subjected to a 20 pound TNT blast at six feet (72 inches) blast normal distance. Stresses have traveled the length of the wing model.

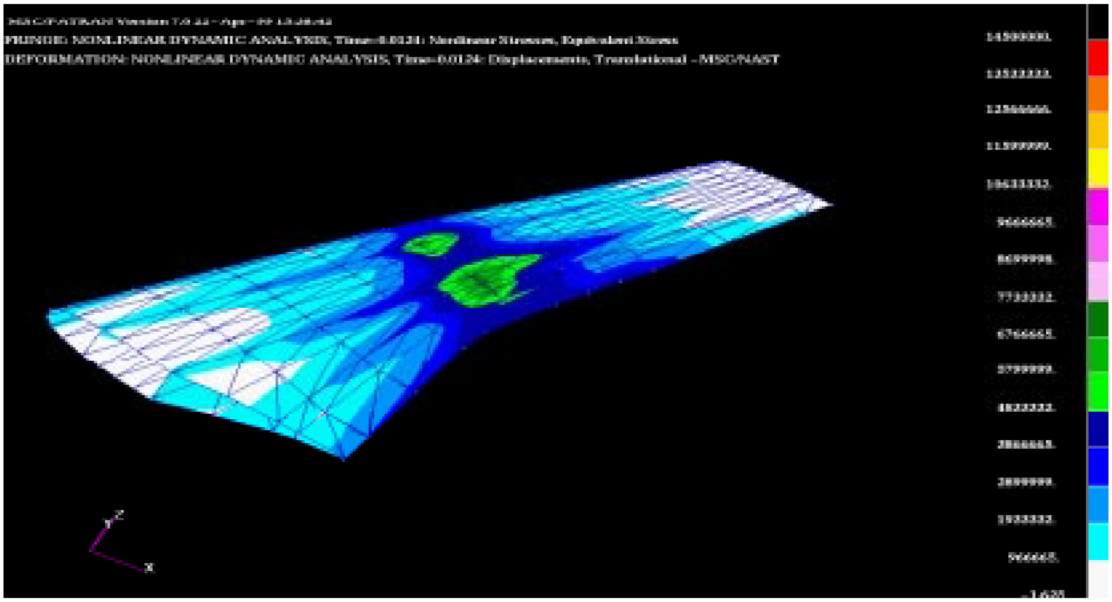

Figure 62 The hypothetical wing model at time = 0.0124 seconds subjected to a 20 pound TNT blast at six feet (72 inches) blast normal distance. The stress waves have traveled the length of the wing. This and subsequent Figures of the ARW-2 wing have a different scale for the stress fringe plot.

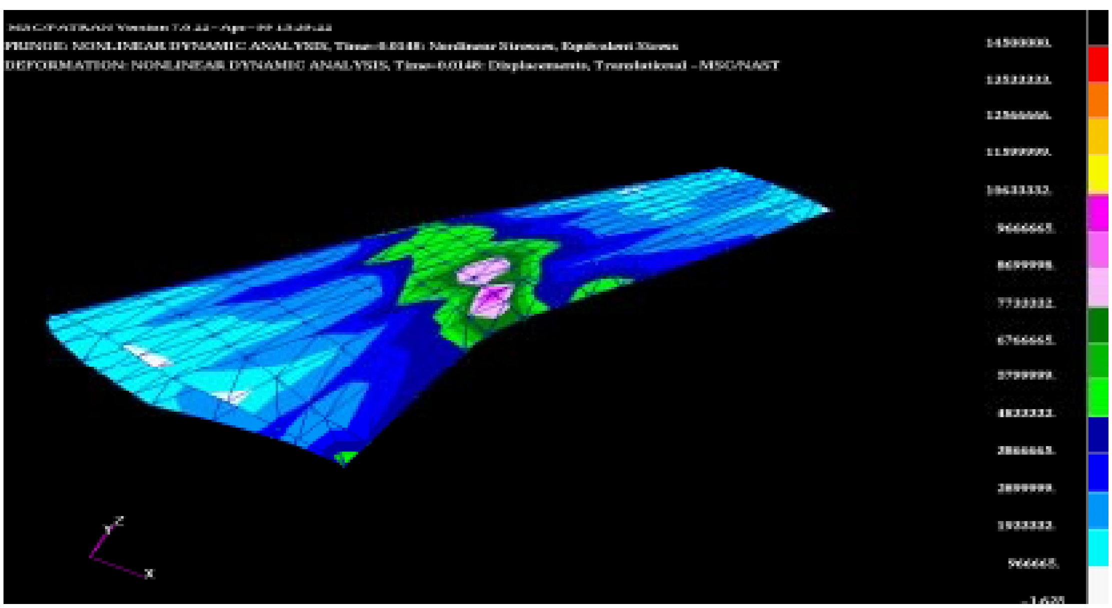

Figure 63 The hypothetical wing model at time = 0.0148 seconds subjected to a 20 pound TNT blast at six feet (72 inches) blast normal distance. The stress waves have traveled the length of the wing and deflection of the wing can now be seen easily.

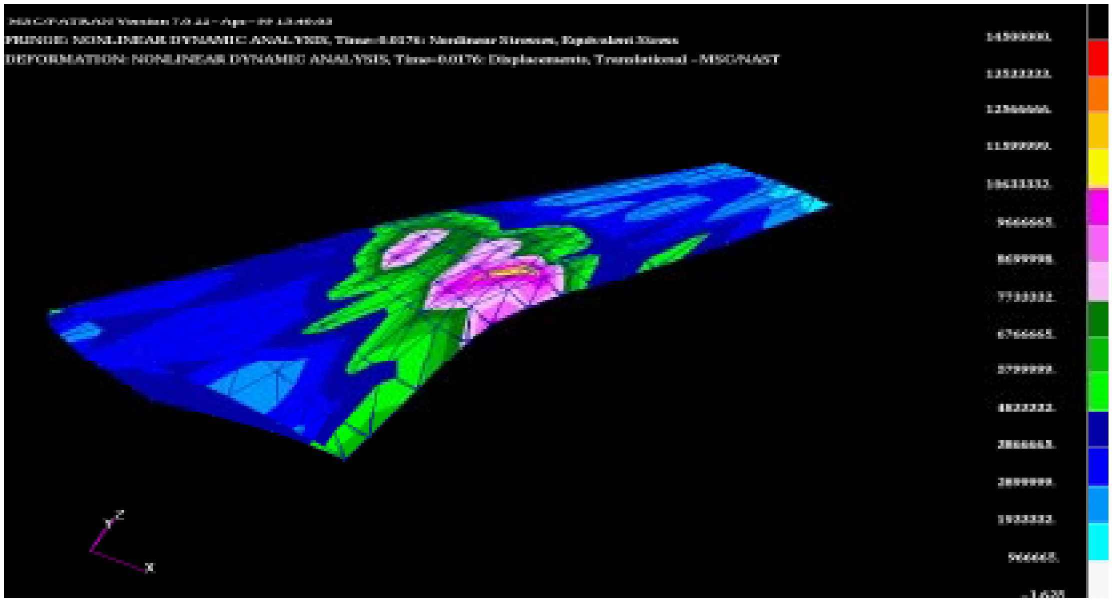

Figure 64 The hypothetical wing model at time = 0.0176 seconds subjected to a 20 pound TNT blast at six feet (72 inches) blast normal distance. The stress waves have traveled the length of the wing and are prevalent in the loading area and control surfaces. The formerly loaded areas of the wing can be seen to have deflected.

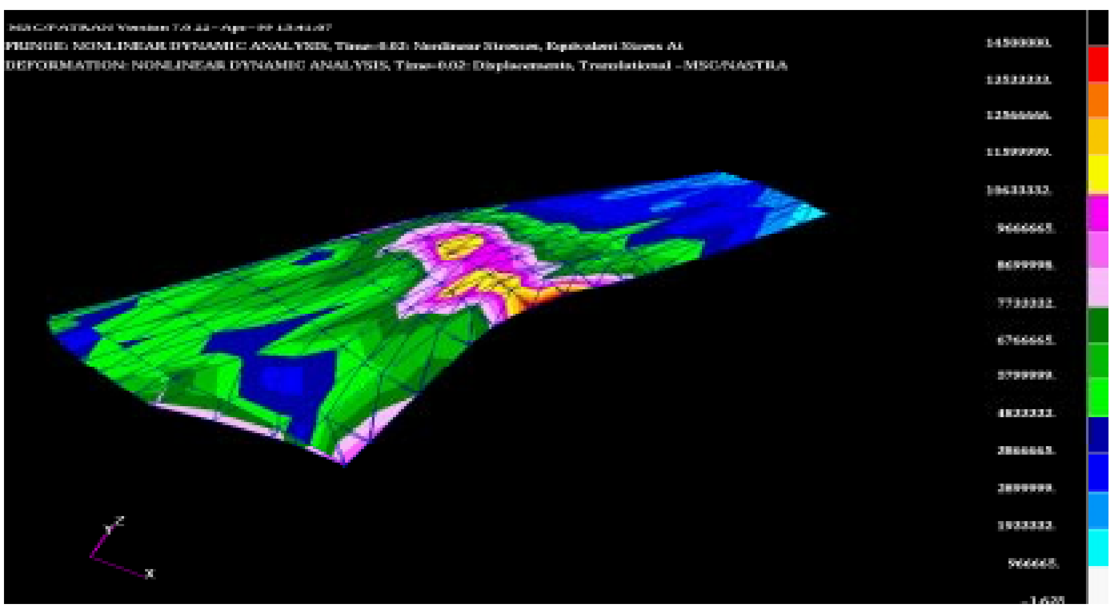

Figure 65 The hypothetical wing model at the final time step of the run, time = 0.02 seconds, subjected to a 20 pound TNT blast at six feet (72 inches) blast normal distance. The stress waves have traveled the length of the wing and deflection of the wing can now be seen easily in the loading area, with stress concentration in the control surface area near the loading area.

5.0 CONCLUSIONS

Blast profiles and two methods of blast scaling were covered. Kingery and Bulmash as well as both Baker's and the U.S. Army's *Explosions in Air* methods of determining pressure profiles were likewise reviewed for use in the creation of an automated design tool to aid engineers or analysts in the study of structures subjected to blast pressures. Flexibility of this tool provided increased resolution and calculation of blast parameters not found in the tabulated data in the sources reviewed, providing other researchers another resource. Ground reflection and reflected pressures due to varying angles of incidence were also reviewed as a matter of course in this work.

The program created for use as a design tool works well with commercial codes and lends itself towards modular integration with other programs. It provides a user flexibility with two differing methods of determining the pressure profiles of explosive air blast. These two methods may exist due to the differing ways of analysis and equipment used in the compilation of blast parameters which, while similar, produce profiles of differing impulses and differing arrival times which this researcher cannot resolve without the use of explosives (and its accompanying training in their safe use) and an experimental facility to handle that type of study. These two methods have been successfully integrated into a single program that can conservatively model the effects of spherical air blast and hemispherical surface burst, can later be expanded to include alteration of the peak reflected pressure with changes in the angle of incidence.

This tool was used with a commercial code (NASTRAN) in a demonstration of method on a 30 by 30 inch aluminum 2519 quarter plate in hemispherical ground burst and showed good convergence with 256 elements for deflection and good agreement in equivalent stresses of a point near the blast between the 256 and 1024 element examples.

The method was also used to demonstrate blast response of wings and to validate the versatility of the code by applying a blast load to an aeroelastic wing model.

Using this loading, one can observe stresses and oscillations in structures struck by dynamic loadings, in this case, explosive blast loads. While it was observed that a limitation of this method is that a structure, without enough mass, will deform rapidly and massively under extreme loadings resulting in diverging FEM solutions, it also shows that it can simulate the massive damage associated with this type of blast source.

Due to the modular nature of the code, it can be incorporated into a different program to facilitate the creation of loaded FEM models. In future work, this program could be expanded to account for non-normal reflection. Future studies with this tool should include the application of blasts to points not symmetrical in the geometry of the target to observe blast reaction and migration of stress waves, as well as the application to composite structures subjected to an explosive blasts high impulse loading.

APPENDIX I

```
C*****************************************************************C
C                                                                 C
C   EXPLOSIVE AIR BLAST PRESSURE PROFILE GENERATION PROGRAM  v2.3 C
C                                              BY J.M.K. CHOCK    C
C                                                                 C
C*****************************************************************C
C                                                                 C
C   DESCRIPTION:  THIS PROGRAM IS TO GENERATE THE PRESSURE PROFILES   C
C                 DUE TO EITHER A MINE BLAST (IE A SEMI-HEMISPHERICAL C
C                 SURFACE EXPLOSION) OR EXPLOSIVE AIR BURST.          C
C                 IT WILL DUPLICATE THE METHOD PRESENTED BY KINGERY   C
C                 AND BULMASH, AS WELL AS DUPLICATE THE METHODS USED  C
C                 BY THE ARMY MANUAL "EXPLOSOINS IN AIR, PART 1,"     C
C                 DENOTED BY EIA.  THE KINGERY/BULMASH METHOD WILL BE C
C                 DENOTED BY KINBUL.                                  C
C                 DUE TO THE DIFFERING METHODS (AND SIMILARITIES      C
C                 BETWEEN ETC AND EIA METHODS) THERE WILL BE TWO      C
C                 MAIN BRANCHES.  THE TWO RESPECTIVE BRANCHES         C
C                 OF THE PROGRAM (ONE FOR KINBUL, THE OTHER FOR       C
C                 E.I.A.) WILL USE TERMS AS SIMILAR TO THE ORIGINAL   C
C                 REFERENCE AS POSSIBLE.                              C
C                 THIS PROGRAM IS Y2K COMPLIANT.                      C
C                 BLAST.F DOES MAKE ADJUSTMENT FOR A BLAST'S ANGLE OF C
C                 INCIDENCE                                           C
C                                                                     C
C                 EXPLOSION IN AIR PARAMETERS ARE TAKEN FROM TABLES   C
C                 IN CHAPTER SIX AND FROM FULL SIZE LOG-LOG GRAPHS    C
C                 FROM W.E. BAKER'S BOOK OF THE SAME TITLE.           C
C                                                                     C
C   DEFINITION OF                                                     C
C   OF SYMBOLS:   Psb  ->Ps bar  ->SCALED PEAK SIDE-ON (INCIDENT)     C
C                                  OVERPRESSURE                       C
C                 Prb  ->Pr bar  ->SCALED PEAK REFLECTED              C
C                                  OVERPRESSURE                       C
C                 Rb   ->R  bar  ->SCALED DISTANCE                    C
C                 Tab  ->Ta bar  ->SCALED TIME OF ARRIVAL             C
C                 Tsb  ->Ts bar  ->SCALED TIME, SIDE-ON (INCIDENT)    C
C                                  DURATION                           C
```

```
C                 Trb  ->Tr bar  ->SCALED TIME, DURATION (REFLECTED)   C
C                 Irb  ->Ir bar  ->SCALED REFLECTED IMPULSE            C
C                 Isb  ->Is bar  ->SCALED SIDE-ON (INCIDENT) IMPULSE   C
C                 Ub   ->U  bar  ->SHOCK SPEED                         C
C                 EW             ->ENERGY/WEIGHT OF EXPLOSIVE          C
C                 E              ->ENERGY OF CHARGE                    C
C                 b              ->DECAY COEFFICIENT (DIMENTIONLESS)   C
C                 THETA          ->DECAY COEFFICIENT (MSEC)            C
C                 TNT            ->equivalent pounds of TNT            C
C                 THE FOLLOWING ARE STANDARD CONDITIONS                C
C                 a0             ->SPEED OF SOUND (IN/SEC)             C
C                 rho0           ->DENSITY (LB SEC^2/IN^4)             C
C                 g0             ->GRAVITATIONAL ACCELERATION          C
C                                  (IN/SEC^2)                          C
C                 theta0         ->TEMPERATURE (deg F)                 C
C                 p0             ->PRESSURE (PSI)                      C
C                                                                      C
C   REVISION HISTORY:                                                  C
C      v0.5 BASIC STRUCTURE OF PROGRAM CREATED                         C
C      v1.0 KINBUL SECTION AND INPUT FILE STRUCURE CREATED FOR         C
C           "EIA.DAT" AND "MINEBLST.INP" v1.x WILL ONLY DEAL WITH      C
C           MINE BLASTS.                                               C
C      v1.1 SPLINE/SPLINT STRUCTURE ADDED FOR USE IN EIA PROCEDURE     C
C      v1.2 EIA DEBUGGED, CH6 STRUCTURE ADDED TO EIA.                  C
C      v1.3 FILE OUTPUT PROBLEMS SOLVED.  STRUCTURE ADDED TO ALLOW     C
C           MORE FLEXIBLE OUTPUT OF BLAST PROFILES.  DEBUGGING OUTPUTS C
C           ADDED TO PROGRAM IN KINBUL AND EIA SECTIONS FOR OUTPUT     C
C           OF DETERMINED PARAMETERS.                                  C
C      v1.4 DEBUGGING COMPLETE.  INPUT FILE STRUCTURE FOR MINE BLAST   C
C           COMPLETE.                                                  C
C      v2.0 AIR BLAST PARAMETERS ADDED TO KINBUL PROCEDURE.  INPUT     C
C           PARAMETERS CHANGED TO ALLOW MORE FLEXIBILITY IN PROGRAM.   C
C           NAME OF PROGRAM CHANGED TO "BLAST.F" AND INPUT FILE        C
C           CHANGED TO "BLAST.INP."  SORTING ROUTINE ADDED TO OUTFILE  C
C           SUBROUTINE (BUBBLE SORT).                                  C
C      v2.1 MODIFICATION OF CH6 METHOD TO INCLUDE AIR BLAST            C
C           CALCULATION.                                               C
C      v2.2 DELTA-T, EPSILON, AND NUMBER OF STEPS MOVED TO INPUT FILE, C
C           THIS DECREASES DYNAMIC STRUCTURE OF PROGRAM FOR INCREASED  C
C           PLATFORM FLEXIBILITY.                                      C
C      v2.3 ADJUSTMENT FOR BLAST ANGLE OF INCIDENCE.  USER DICTATED    C
C           DEBUGGING OUTPUT OF CALCULATION ROUTINES ALLOWED IN INFILE.C
```

```
C                                                                        C
C234567****************************************************************C
C$ NOEXTENSIONS NOWARNINGS
      PROGRAM BLAST

C============================MAIN PROCEDURE==============================C
C cnwpYN (KinBUL Y/N) is a logical for determining the use of ETC or
C KINBUL profiles.  etcYN (ETC Y/N) is a logical for determining if
C the program should duplicate ETC's results or what is probably the
C correct way of using the Explosions In Air Chapter 6 Data tables.
      LOGICAL cnwpYN, etcYN, mine, radial, reflYN, dbugYN, aoaYN
      INTEGER nmax, numR, Nsteps
      PARAMETER (nmax=64)
      REAL TNT, xy(nmax,2), r(nmax), Gref, alpha(nmax)
      DOUBLE PRECISION deltaT, epsiln

      PRINT *, 'Air Blast Pressure Profile Generation Program v2.3'
      PRINT *, 'by J.M.K. Chock, March 2, 1999'

C Get the (x,y) or R values for use in the program, including
C determining to use EIA or KINBUL blast profiles.  The amount of TNT,
C ground reflectivity, normal to distance to blast, and equivalent TNT
C factor are input in this file.  The (x,y) pairs are radial distances
C on the surface of the plate, and will be converted to radial distances
C from the blast center.
      CALL RdFile (nmax, r, xy, NumR, TNT, cnwpYN, etcYN, mine, radial
     |, Gref, reflYN, Nsteps, DeltaT, epsiln, alpha, dbugYN, aoaYN)

C Calculate the Blast Profiles
      CALL Clcbls (nmax, r, xy, NumR, TNT, cnwpYN, etcYN, mine, radial
     |, Gref, reflYN, Nsteps, DeltaT, epsiln, alpha, dbugYN, aoaYN)

      PRINT *, 'Done.'

      STOP
      END

C===============================FUNCTIONS================================C

      FUNCTION FRIED (p,t,ta,ts,b)
C PRE:     Blast profile parameters have been calculated and handed to
C          the function
```

```
C POST:    The pressure at a time, t, is calculated for the positive
C          phase
C ACTION:  Friedlander's Equation as a function is used
      REAL FRIED, p, t, ta, ts, b
         FRIED=p*(1-(t-ta)/ts)*EXP(-b*(t-ta)/ts)
      RETURN
      END

C=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-C

      FUNCTION MFRIED (p,t,ta,to,b)
C PRE:     Blast profile parameters have been calculated and handed to
C          the function
C POST:    The pressure at a time, t, is calculated for the positive
C          phase
C ACTION:  Modified Friedlander's Equation as a function is used
      REAL MFRIED, p, t, ta, to, b
         MFRIED=p*(1-(t-ta)/to)*EXP(-(t-ta)/b)
      RETURN
      END

C=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-C

      FUNCTION Cintrp (x, x0, x1, x2, x3, y0, y1, y2, y3)
C PRE:     The x and y values are input
C POST:    An interpolated/extrapolated value of y(x) is stored in
C          the Cintrp variable by cubic interpolation
C ACTION:  A function for cubic interpolation/extrapolation is used
      REAL Cintrp, x, x0, x1, x2, x3, y0, y1, y2
          Cintrp=y0+(y1-y0)/(x1-x0)*(x-x0)+((y2-y1)/(x2-x1)-(y1-y0)/(x1-
     |x0))/(x2-x0)*(x-x0)*(x-x1)+(x0**2*(x1*(y2-y3)+x2*(y3-y1)+x3*(y1-y2
     |))-x0*(x1**2*(y2-y3)+x2**2*(y3-y1)+x3**2*(y1-y2))+x1**2*(x2*(y0-y3
     |)+x3*(y2-y0))-x1*(x2**2*(y0-y3)+x3**2*(y2-y0))+x2*x3*(x2-x3)*(y0-
     |y1))/((x0-x1)*(x0-x2)*(x0-x3)*(x1-x2)*(x1-x3)*(x2-x3))*(x-x0)*(x-
     |x1)*(x-x2)
      RETURN
      END

C============================PROCEDURES===============================C

      SUBROUTINE Clcbls (nmax, r, xy, NumR, TNT, cnwpYN, etcYN, mine,
     |radial, Gref, reflYN, Nsteps, deltaT, epsiln, alpha, dbugYN,
```

```
     |aoaYN)
C PRE:     all control variables from input are created and input
C POST:    The blast loads and histories have been calculated and output
C ACTION:  The blast loads are calculated by the appropriate procedure
C          as selected in the input.
      LOGICAL cnwpYN, etcYN, mine, radial, reflYN, dbugYN, aoaYN
      INTEGER nmax, numR, Nsteps
      REAL    TNT, xy(nmax,2), r(nmax), Bprofl(0:(128+3),2,64)
      REAL    Gref, alpha(nmax), PvsA(0:38,0:20)
      DOUBLE PRECISION deltaT, epsiln

C Call appropriate subroutines for desired calculation methods
         IF (cnwpYN) THEN
               CALL KINBUL(nmax, r, NumR, TNT, Nsteps, deltaT, Bprofl,
     |mine, reflYN, epsiln, alpha, dbugYN, aoaYN, PvsA)
            ELSE
         CALL EIA(nmax, r, NumR, TNT, etcYN, Nsteps, deltaT, Bprofl,
     |mine, Gref, reflYN, epsiln, alpha, dbugYN, aoaYN, PvsA)
            END IF

C Output the blast profiles
      CALL Outfil (Bprofl, Nsteps, NumR, XY, Radial, nmax)

      RETURN
      END

C=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-C

      SUBROUTINE RdFile (nmax, r, xy, NumR, TNT, cnwpYN, etcYN, mine,
     |radial, Gref, reflYN, Nsteps, deltaT, epsiln, alpha, dbugYN,
     |aoaYN)
C PRE:     all variables are empty
C POST:    The selection of program options and input is complete as is
C          the array of selected values (of radial distances from blast
C          center) for use in the program
C ACTION:  The values are input from an infile MINEBLST.INP
      LOGICAL cnwpYN, etcYN, mine, radial, reflYN, dbugYN, aoaYN
      INTEGER isel, NumR, nmax, Nsteps
      REAL    rsel, TNT, bndist, r(nmax), xy(nmax,2), rval
      REAL    Gref, alpha(nmax)
      DOUBLE PRECISION deltaT, epsiln, Pi
```

```
C Have computer calculate a value of pi and store it
      Pi = 4.*DATAN(DBLE(1.))

C To store the (x,y) or radial values, it will be stored in xy, where
C xy(I,1) is x and xy(I,2) is y.  R values will be stored in xy(I,1) if
C only r values are given.
      DO 100 I = 1, nmax, 1
         xy(I,1) = 0.
100      xy(I,2) = 0.

      OPEN (unit=12, FILE='blast.inp')

C determine selection, KINBUL or EIA w/ground reflection.
C                         cnwpYN    etcYN
C   KINBUL                .TRUE.    .FALSE.
C   EIA ch. 6 w/ground    .FALSE.   .FALSE.
      cnwpYN = .FALSE.
      etcYN = .FALSE.
      READ (12,110) isel
110   FORMAT (1I19)
      IF (isel .EQ. 1) cnwpYN = .TRUE.
      IF (isel .EQ. 2) etcYN  = .TRUE.

C read blast normal distance
      READ (12, 120) bndist
120   FORMAT (1F19.2)

C read pounds of TNT
      READ (12,120) TNT

C read equivalent factor and convert TNT
      READ (12,120) rsel
      TNT = rsel*TNT

C read ground reflectivity and convert if necessary for EIA ch. 6
      READ (12,120) Gref
C used before modification to EIA/CH6 for time of arrival adjustment
C      IF ((.NOT. cnwpYN) .AND. (.NOT. etcYN)) TNT = rsel*TNT

C read the number of time steps, Nsteps
      READ (12,110) Nsteps
```

```
C read the length of the time steps, deltaT
      READ (12,130) deltaT
130   FORMAT (1D19.10)

C read the minimum epsilon for the decay function
      READ (12,130) epsiln

C read if mine or airblast calculation is desired
      read (12,110) isel
      mine = .FALSE.
      IF (isel .EQ. 1) mine = .TRUE.

C Read if step-by-step debugging output is desired from the calculation
C routines
      read (12,110) isel
      dbugYN = .FALSE.
      IF (isel .EQ. 1) dbugYN = .TRUE.

C Read if adjustment in reflected pressure for angle of incidence is to
C be made in the calculations
C routines
      read (12,110) isel
      aoaYN = .FALSE.
      IF (isel .EQ. 1) aoaYN = .TRUE.

C Read if normally reflected values are desired.  This will only be
C used if the air blast function is used.  All mine calculations will be
C done with normally reflected blast values.
      read (12,110) isel
      reflYN = .FALSE.
      IF (isel .EQ. 1) reflYN = .TRUE.

C read if radial or (x,y) values are given in listing
      READ (12, 110) isel
      radial = .FALSE.
      IF (isel .EQ. 1) radial = .TRUE.

C read the number of values given in the list
      READ (12, 110) NumR
C allow for blank/skipped line:
      Read (12,*)
```

```
C read the list and make appropriate radial values from blast center
C in array for use in program.  This assumes the (x,y) pairs are in the
C same plane as the object being struck by the blast.
      DO 150 I = 1, NumR, 1
      IF (radial) THEN
            READ (12,120) xy(I,1)
            rval = xy(I,1)
C            PRINT *, xy(I,1), rval
         ELSE
            READ (12,140) xy(I,1), xy(I,2)
140         FORMAT (2F9.2)
            rval = (xy(I,1)**2 + xy(I,2)**2)**0.5
C            PRINT *, xy(I,1), xy(I,2), rval
      END IF
      r(I) = (rval**2 + bndist**2)**0.5
      alpha(I) = ATAN(rval/bndist)*180./Pi
      IF (cnwpYN) r(I)=r(I)/12.
C      PRINT *, r(I)
150      continue
      CLOSE (12)

      RETURN
      END

C=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-C

      SUBROUTINE RdPVA (PvsA)
C PRE:     all variables are empty
C POST:    The values of the coefficients for Pressure vs. incident
C          angle have been read into an array structure.
C ACTION:  The values are input from an infile PVSA.DAT
      INTEGER I, J
      REAL    PvsA(0:38,0:20)

      DO 1000 I = 0, 38, 1
         DO 1000 J = 0, 20, 1
1000        PvsA(I,J) = 0.

      OPEN (unit=14, FILE='PVSA.DAT')
C Read past header line
      READ (14,*)
```

```
C Read the tabular values for reflected pressure coefficients vs. angle
C of incidence
      DO 1007 I = 0, 38, 1
         READ (14,1005) (PvsA(I,J), J=0,20,1)
1005  FORMAT (21F6.3)

C The following lines are for debugging only to assure values are being
C read correctly by the program
C      DO 1020 I = 0, 38, 1
C         WRITE  (*,1022) (PvsA(I,J), J=0,20,1)
C1022     FORMAT (21F7.3)

1007  continue

      CLOSE (14)

      RETURN
      END

C=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-C

      SUBROUTINE PAitrp (PvsA, Ps, alpha, Pr)
C PRE:     The array of side-on pressure vs. incident angle, the
C          incident angle, and the side-on pressure (psi)
C POST:    The reflected pressure is returned in psi
C ACTION:  Pr is calculated by cubic interpolation routines
      REAL PvsA(0:38,0:20), Ps, alpha, Pr, Pval(0:3)
      INTEGER I, J, a(0:3)

C Make adjustments in angle for those angles greater out of the range
C of 0 <= alpha <= 90
C      PRINT *, alpha
C      IF (ABS(alpha) .LT. 0.001) alpha = 0.
      IF (alpha .GT. 90.) alpha = 180. - alpha
      IF (alpha .LT.  0.) alpha =   0. - alpha

C Determine the interpolation domain for the angles of incidence
      IF (alpha .LT. PvsA(2,0)) THEN
            a(0) = 1
            a(1) = 2
            a(2) = 3
            a(3) = 4
```

```
C            print *, 'a=1'
         END IF
      DO 2000 I = 2, 36, 1
         IF ((alpha .GE. PvsA(I,0)).AND.(alpha .LT. PvsA(I+1,0))) THEN
               a(0) = I-1
               a(1) = I
               a(2) = I+1
               a(3) = I+2
C               print *, 'a=', I
            END IF
2000  continue
      IF (alpha .GE. PvsA(37,0)) THEN
            a(0) = 35
            a(1) = 36
            a(2) = 37
            a(3) = 38
C            print *, 'a=38'
         END IF

C Determine the reflected pressure coefficient by the use of
C interpolation routines.  First an interpolated pressure curve for a
C short area is determined, then this is used to calulate the
C interpolated value for the correct alpha.
      IF (Ps .GT. PvsA(0,2)) THEN
            DO 2100 I=0,3,1
2100        Pval(I) = Cintrp (Ps,PvsA(0,1),PvsA(0,2),PvsA(0,3),PvsA(0,4)
     |,PvsA(a(I),1),PvsA(a(I),2),PvsA(a(I),3),PvsA(a(I),4))
C            print *,'p<2'
         END IF

      DO 2115 J = 2, 18, 1
         IF ((Ps .LE. PvsA(0,J)).AND.(Ps .GT. PvsA(0,J+1))) THEN
            DO 2110 I=0,3,1
2110        Pval(I) = Cintrp (Ps,PvsA(0,J-1),PvsA(0,J),PvsA(0,J+1)
     |,PvsA(0,J+2),PvsA(a(I),J-1),PvsA(a(I),J),PvsA(a(I),J+1)
     |,PvsA(a(I),J+2))
C            print *,'p=', J
         END IF
2115  continue

      IF (Ps .LE. PvsA(0,19)) THEN
            DO 2120 I=0,3,1
```

```
2120        Pval(I) = Cintrp (Ps,PvsA(0,17),PvsA(0,18),PvsA(0,19)
     |,PvsA(0,20),PvsA(a(I),17),PvsA(a(I),18),PvsA(a(I),19)
     |,PvsA(a(I),20))
C            print *,'p>19'
         END IF

C Determine reflected pressure and return it.
      Pr = Ps*Cintrp(alpha,PvsA(a(0),0),PvsA(a(1),0),PvsA(a(2),0),
     |PvsA(a(3),0),Pval(0),Pval(1),Pval(2),Pval(3))

C      PRINT *, 'Pr/Ps =', Pr/Ps
C      PRINT *, Pr

      RETURN
      END

C=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-C

      SUBROUTINE KINBUL (nmax, r, NumR, W, Nsteps, deltaT, Bprofl, mine
     |, reflYN, epsiln, alpha, dbugYN, aoaYN, PvsA)
C PRE:     The input variables from the input file are filled.
C POST:    The pressure, duration, arrival time, and decay coefficients
C          for calculations by the methods in Kingery & Bulmash
C ACTION:  Kingery & Bulmash's methods of Log-Log fitting to pentolite
C          results are used to calculate results for blast
C          pressure profiles.

      INTEGER nmax, tmax, nnmax
      DOUBLE PRECISION PrC(0:11), PrK(0:1), IrC(0:3), IrK(0:1)
      DOUBLE PRECISION TaC(0:11), TaK(0:1), ToC1(0:8), ToK1(0:1)
      DOUBLE PRECISION ToC2(0:8), ToK2(0:1), deltaT, epsiln
      DOUBLE PRECISION PsK(0:1), IsK1(0:1), IsK2(0:1), ToK3(0:1)
      DOUBLE PRECISION PsC(0:11), IsC1(0:4), IsC2(0:8), ToC3(0:7)
      DOUBLE PRECISION UC(0:14), UK(0:1)
      PARAMETER (tmax=64, nnmax=64)
      INTEGER Nsteps, NumR, I, J, M, K(nnmax)
      REAL    R(nmax), Bprofl(0:(128+3),2,64), Clow, Cmid, Chigh
      REAL    Z, W, Pr(nnmax), Ir(nnmax), Ps(nnmax), Is(nnmax), Mfried
      REAL    Ta(nnmax), To(nnmax), B(nnmax), T, T1, Br(nnmax)
      REAL    PrLogU, rY03, rY47, rY811, IrLogU, IrLogY, alpha(nmax)
      REAL    PsLogU, sY03, sY47, sY811, IsLogU, IsLogY, U(64)
      REAL    TaLogU, aY03, aY47, aY811, ToLogU, ToLogY
```

```
      REAL    ULogU, uY03, uY47, uY811, uY1214, PvsA(0:38,0:20)
      LOGICAL Peak(nnmax), mine, reflYN, dbugYN, aoaYN

C Data needed for Log-Log interpolation and determination of mine
C blast parameters
      DATA PrK(0),  PrK(1)  /-0.789312405513,    1.36637719229   /
      DATA PsK(0),  PsK(1)  /-0.756579301809,    1.35034249993   /
      DATA IrK(0),  IrK(1)  /-0.781951689212,    1.33422049854   /
      DATA IsK1(0), IsK1(1) / 0.832468843425,    3.0760329666    /
      DATA IsK2(0), IsK2(1) /-2.91358616806,     2.40697745406   /
      DATA TaK(0),  TaK(1)  /-0.755684472698,    1.37784223635   /
      DATA ToK1(0), ToK1(1) /-0.1790217052,      5.25099193925   /
      DATA ToK2(0), ToK2(1) /-5.85909812338,     9.2996288611    /
      DATA ToK3(0), ToK3(1) /-4.92699491141,     3.46349745571   /
      DATA UK(0),   UK(1)   /-0.755684472698,    1.37784223635   /
      DATA PrC(0),  PrC(1)  / 2.56431321138,    -2.21030870597   /
      DATA PrC(2),  PrC(3)  /-0.218536586295,    0.895319589372  /
      DATA PrC(4),  PrC(5)  / 0.24989009775,    -0.569249436807  /
      DATA PrC(6),  PrC(7)  /-0.11791682383,     0.224131161411  /
      DATA PrC(8),  PrC(9)  / 0.0245620259375,  -0.0455116002694 /
      DATA PrC(10), PrC(11) /-0.00191930738887,  0.00361471193389/
      DATA PsC(0),  PsC(1)  / 1.9422502013,     -1.6958988741    /
      DATA PsC(2),  PsC(3)  /-0.154159376846,    0.514060730593  /
      DATA PsC(4),  PsC(5)  / 0.0988534365274,  -0.293912623038  /
      DATA PsC(6),  PsC(7)  /-0.0268112345019,   0.109097496421  /
      DATA PsC(8),  PsC(9)  / 0.00162846756311, -0.0214631030242 /
      DATA PsC(10), PsC(11) / 0.0001456723382,   0.00167847752266/
      DATA IrC(0),  IrC(1)  / 1.75291677799,    -0.949516092853  /
      DATA IrC(2),  IrC(3)  / 0.112136118689,   -0.0250659183287 /
      DATA IsC1(0), IsC1(1) / 1.57159240621,    -0.502992763686  /
      DATA IsC1(2), IsC1(3) / 0.171335645235,    0.0450176963051 /
      DATA IsC1(4)          /-0.0118964626402                    /
      DATA IsC2(0), IsC2(1) / 0.719852655584,   -0.384519026965  /
      DATA IsC2(2), IsC2(3) /-0.0260816706301,   0.00595798753822/
      DATA IsC2(4), IsC2(5) / 0.014544526107,   -0.00663289334734/
      DATA IsC2(6), IsC2(7) /-0.00284189327204,  0.0013644816227 /
      DATA IsC2(8)          / 0.0                                /
      DATA TaC(0),  TaC(1)  /-.173607601251,     1.35706496258   /
      DATA TaC(2),  TaC(3)  / 0.052492798645,   -0.196563954086  /
      DATA TaC(4),  TaC(5)  /-0.0601770052288,   0.0696360270891 /
      DATA TaC(6),  TaC(7)  / 0.0215297490092,  -0.0161658930785 /
      DATA TaC(8),  TaC(9)  /-0.00232531970294,  0.00147752067524/
```

```
      DATA TaC(10), TaC(11) / 0.0,               0.0            /
      DATA ToC1(0), ToC1(1) /-0.728671776005,    0.130143717675  /
      DATA ToC1(2), ToC1(3) / 0.134872511954,    0.0391574276906 /
      DATA ToC1(4), ToC1(5) /-0.00475933664702, -0.00428144598008/
      DATA ToC1(6), ToC1(7) / 0.0,               0.0            /
      DATA ToC1(8)          / 0.0                               /
      DATA ToC2(0), ToC2(1) / 0.20096507334,    -0.0297944268976 /
      DATA ToC2(2), ToC2(3) / 0.030632954288,    0.0183405574086 /
      DATA ToC2(4), ToC2(5) /-0.0173964666211,  -0.00106321963633/
      DATA ToC2(6), ToC2(7) / 0.00562060030977,  0.0001618217499 /
      DATA ToC2(8)          /-0.000686018944                    /
      DATA ToC3(0), ToC3(1) / 0.572462469964,    0.0933035304009 /
      DATA ToC3(2), ToC3(3) /-0.0005849420883,  -0.00226884995013/
      DATA ToC3(4), ToC3(5) /-0.00295908591505,  0.00148129868929/
      DATA ToC3(6), ToC3(7) / 0.0,               0.0            /
      DATA UC(0),   UC(1)   / 0.449774310005,   -0.698029762594  /
      DATA UC(2),   UC(3)   / 0.158916781906,    0.443812098136  /
      DATA UC(4),   UC(5)   /-0.113402023921,   -0.369887075049  /
      DATA UC(6),   UC(7)   / 0.129230567449,    0.19857981197   /
      DATA UC(8),   UC(9)   /-0.0867636217397,  -0.0620391900135 /
      DATA UC(10),  UC(11)  / 0.0307482926566,   0.0102657234407 /
      DATA UC(12),  UC(13)  /-0.00546533250772, -0.000693180974  /
      DATA UC(14)           / 0.0003847494916                   /

C If the program is to do the air blast profile, different parameters
C will be needed:
      IF (.NOT. mine) THEN
         PrK(0)  = -0.756579301809
         PrK(1)  =  1.35034249993
         IrK(0)  = -0.757659920369
         IrK(1)  =  1.37882996018
         IsK1(0) =  1.04504877747
         IsK1(1) =  3.24299066475
         IsK2(0) = -2.67912519532
         IsK2(1) =  2.30629231803
         TaK(0)  = -0.80501734056
         TaK(1)  =  1.37407043777
         ToK1(0) =  0.209440059933
         ToK1(1) =  5.11588554305
         ToK2(0) = -5.06778493835
         ToK3(0) = -4.39590184126
         ToK3(1) =  3.1524725264
```

```
UK(0)    = -0.756579301809
UK(1)    =  1.35034249993
PrC(0)   =  2.39106134946
PrC(1)   = -2.21400538997
PrC(2)   =  0.035119031446
PrC(3)   =  0.657599992109
PrC(4)   =  0.0141818951887
PrC(5)   = -0.243076636231
PrC(6)   = -0.0158699803158
PrC(7)   =  0.0492741184234
PrC(8)   =  0.00227639644004
PrC(9)   = -0.00397126276058
PrC(10)  =  0.0
PrC(11)  =  0.0
PsC(0)   =  1.77284970457
PsC(1)   = -1.69012801396
PsC(2)   =  0.00804973591951
PsC(3)   =  0.336743114941
PsC(4)   = -0.00516226351334
PsC(5)   = -0.0809228619888
PsC(6)   = -0.00478507266747
PsC(7)   =  0.00793030472244
PsC(8)   =  0.0007684469735
PsC(9)   =  0.0
PsC(10)  =  0.0
PsC(11)  =  0.0
IrC(0)   =  1.60579280091
IrC(1)   = -0.903118886091
IrC(2)   =  0.101771877942
IrC(3)   = -0.0242139751146
IsC1(0)  =  1.43534136453
IsC1(1)  = -0.443749377691
IsC1(2)  =  0.168825414684
IsC1(3)  =  0.0348138030308
IsC1(4)  = -0.010435192824
IsC2(0)  =  0.599008468099
IsC2(1)  = -0.40463292088
IsC2(2)  = -0.014272194608
IsC2(3)  =  0.00912366316617
IsC2(4)  = -0.0006750681404
IsC2(5)  = -0.00800863718901
IsC2(6)  =  0.00314819515931
```

```
IsC2(7) =  0.00152044783382
IsC2(8) = -0.0007470265899
TaC(0)  = -0.0423733936826
TaC(1)  =  1.36456871214
TaC(2)  = -0.0570035692784
TaC(3)  = -0.182832224796
TaC(4)  =  0.0118851436014
TaC(5)  =  0.0432648687627
TaC(6)  = -0.0007337367834
TaC(7)  = -0.00436073555033
TaC(8)  =  0.0
TaC(9)  =  0.0
TaC(10) =  0.0
TaC(11) =  0.0
ToC1(0) = -0.801052722864
ToC1(1) =  0.164953518069
ToC1(2) =  0.127788499497
ToC1(3) =  0.00291430135946
ToC1(4) =  0.00187957449227
ToC1(5) =  0.0173413962543
ToC1(6) =  0.00269739758043
ToC1(7) = -0.00361976502798
ToC1(8) = -0.00100926577934
ToC2(0) =  0.115874238335
ToC2(1) = -0.0297944268969
ToC2(2) =  0.0306329542941
ToC2(3) =  0.0183405574074
ToC2(4) = -0.0173964666286
ToC2(5) = -0.00106321963576
ToC2(6) =  0.0056206003128
ToC2(8) = -0.0006860188944
ToC3(0) =  0.50659210403
ToC3(1) =  0.0967031995552
ToC3(2) = -0.00801302059667
ToC3(3) =  0.00482705779732
ToC3(4) =  0.00187587272287
ToC3(5) = -0.00246738509321
ToC3(6) = -0.000841116668
ToC3(7) =  0.0006193291052
UC(0)   =  0.371369593444
UC(1)   = -0.650507560471
UC(2)   =  0.291320654009
```

```
         UC(3)   =  0.307916322787
         UC(4)   = -0.183361123489
         UC(5)   = -0.197740454538
         UC(6)   =  0.0909119559768
         UC(7)   =  0.0898926178054
         UC(8)   = -0.0287370990248
         UC(9)   = -0.0248730221702
         UC(10)  =  0.00496311705671
         UC(11)  =  0.00372242076361
         UC(12)  = -0.0003533736952
         UC(13)  = -0.0002292913709
         UC(14)  =  0.0

      END IF

C Tell user which routine is running:
      PRINT *,'Kingery & Bulmash calculation routine'

C Read in the reflected pressure coeffients vs. angle of incidence
C if needed.
      IF (aoaYN) CALL RdPVA(PvsA)

C recall Log10(ZZ)=LOG(ZZ)/LOG(10)
      DO 400 I = 1, NumR,1
C Calculate the scaled distance (scaled, non-dimentional, detonation
C parameter) for this iteration's radial distance, r.  Hopkinson
C scaling.
         Z = R(I)/W**(1./3.)
      IF (dbugYN) PRINT *, 'Distance, R:', R(I)
      IF (dbugYN) PRINT *, 'Scaled Distance, Z:', Z

C Calculations for Log-Log fit for side-on pressure, Ps
         PsLogU = PsK(0) + Log10(Z)*PsK(1)
         sY03  = PsC(0)+PsLogU*(PsC(1)+PsLogU*(PsC(2)+PsLogU*PsC(3)))
         sY47  = (PsC(4)+PsLogU*(PsC(5)+PsLogU*(PsC(6)+PsLogU*PsC(7))))*
     |PsLogU**4
         sY811 = (PsC(8)+PsLogU*(PsC(9)+PsLogU*(PsC(10)+PsLogU*PsC(11)))
     |)*PsLogU**8
         Ps(I) = 10.**(sY03 + sY47 + sY811)
      IF (dbugYN) PRINT *,'Incident Pressure, Ps (psi):', Ps(I)

C adjust the ranges for mine or air blast:
```

```
      IF (mine) THEN
            Clow = 0.17
            Cmid = 2.41
         ELSE
            Clow = .134
            Cmid = 2.0
         END IF

C Calculation for Log-Log fit for side-on (specific) impulse, Is
         IF ((Z .LE. Cmid) .AND. (Z .GE. Clow))  THEN
            IsLogU = IsK1(0) + Log10(z)*IsK1(1)
            IsLogY = IsC1(0)+IsLogU*(IsC1(1)+IsLogU*(IsC1(2)+IsLogU*
     |(IsC1(3)+IsLogU*IsC1(4))))
         ELSE
            IF ((Z .LE. 100.) .AND. (Z .GT. Cmid))  THEN
               IsLogU = IsK2(0) + Log10(z)*IsK2(1)
               IsLogY = IsC2(0)+IsLogU*(IsC2(1)+IsLogU*(IsC2(2)+IsLogU*
     |(IsC2(3)+IsLogU*(IsC2(4)+IsLogU*(IsC2(5)+IsLogU*(IsC2(6)+IsLogU*
     |IsC2(7)))))))
            ELSE
              IsLogY = 0.
            ENDIF
         END IF
         Is(I) = (10.**IsLogY)*W**(1./3.)
      IF (dbugYN) PRINT *,'Incident Impulse, Is (psi-msec):', Is(I)

C Calculations for Log-Log fit for reflected pressure, Pr
         IF (aoaYN) THEN
               CALL PAitrp (PvsA, Ps(I), alpha(I), Pr(I))
            ELSE
               PrLogU = PrK(0) + Log10(Z)*PrK(1)
               rY03  = PrC(0)+PrLogU*(PrC(1)+PrLogU*(PrC(2)+PrLogU*PrC
     |(3)))
               rY47  = (PrC(4)+PrLogU*(PrC(5)+PrLogU*(PrC(6)+PrLogU*PrC
     |(7))))*PrLogU**4
               rY811 = (PrC(8)+PrLogU*(PrC(9)+PrLogU*(PrC(10)+PrLogU*
     |PrC(11))))*PrLogU**8
               Pr(I) = 10.**(rY03 + rY47 + rY811)
            END IF
      IF (dbugYN) PRINT *,'Reflected Pressure, Pr (psi):', Pr(I)

C Calculations for Log-Log fit for the reflected (specific) impulse, Ir
```

```
         IrLogU = IrK(0) + Log10(Z)*IrK(1)
         IrLogY = IrC(0)+IrLogU*(IrC(1)+IrLogU*(IrC(2)+IrLogU*IrC(3)))
         Ir(I)  = (10.**IrLogY)*W**(1./3.)
      IF (dbugYN) PRINT *,'Reflected Impulse, Ir (psi-msec):', Ir(I)

C Calculations for Log-Log fit for blast time of arrival, Ta
         TaLogU = TaK(0) + Log10(Z)*TaK(1)
         aY03  = TaC(0)+TaLogU*(TaC(1)+TaLogU*(TaC(2)+TaLogU*TaC(3)))
         aY47  = (TaC(4)+TaLogU*(TaC(5)+TaLogU*(TaC(6)+TaLogU*TaC(7))))*
     |TaLogU**4
         aY811 = (TaC(8)+TaLogU*(TaC(9)+TaLogU*(TaC(10)+TaLogU*TaC(11)))
     |)*TaLogU**8
         Ta(I) = (10.**(aY03 + aY47 + aY811))/1000.*W**(1./3.)
         IF (dbugYN) PRINT *,'time of arrival, Ta (msec):', Ta(I)*1000.

C adjust the ranges for mine or air blast:
      IF (mine) THEN
            Clow  = 0.45
            Cmid  = 2.54
            Chigh = 7.0
         ELSE
            Clow  = 0.37
            Cmid  = 2.24
            Chigh = 5.75
         END IF

C Calculation for Log-Log fit for positive blast duration, To
         IF ((Z .LE. Cmid) .AND. (Z .GE. Clow))  THEN
            ToLogU = ToK1(0) + Log10(z)*ToK1(1)
            ToLogY = ToC1(0)+ToLogU*(ToC1(1)+ToLogU*(ToC1(2)+ToLogU*
     |(ToC1(3)+ToLogU*(ToC1(4)+ToLogU*ToC1(5)))))
         ELSE
            IF ((Z .LE. Chigh) .AND. (Z .GT. Cmid))  THEN
               ToLogU = ToK2(0) + Log10(z)*ToK2(1)
               ToLogY = ToC2(0)+ToLogU*(ToC2(1)+ToLogU*(ToC2(2)+ToLogU*
     |(ToC2(3)+ToLogU*(ToC2(4)+ToLogU*(ToC2(5)+ToLogU*(ToC2(6)+ToLogU*
     |(ToC2(7)+ToLogU*ToC2(8)))))))
            ELSE
               IF (Z .GT. Chigh)  THEN
                  ToLogU = ToK3(0) + Log10(z)*ToK3(1)
                  ToLogY = ToC3(0)+ToLogU*(ToC3(1)+ToLogU*(ToC3(2)+
     |ToLogU*(ToC3(3)+ToLogU*(ToC3(4)+ToLogU*ToC3(5)))))
```

```
               ELSE
                  ToLogY = 0.
               ENDIF
            ENDIF
         END IF
         To(I) = (10.**ToLogY)/1000.*W**(1./3.)
         IF (dbugYN) PRINT *,'time of duration, To (msec):', To(I)*1000.

C Calculations for Log-Log fit for shock velocity, U
         ULogU = UK(0) + Log10(Z)*UK(1)
         uY03  = UC(0)+ULogU*(UC(1)+ULogU*(UC(2)+ULogU*UC(3)))
         uY47  = (UC(4)+ULogU*(UC(5)+ULogU*(UC(6)+ULogU*UC(7))))*
     |ULogU**4
         uY811 = (UC(8)+ULogU*(UC(9)+ULogU*(UC(10)+ULogU*UC(11)))
     |)*ULogU**8
         uY1214 = (UC(12)+ULogU*(UC(13)+ULogU*UC(14)))*ULogU**12
         U(I) = (10.**(uY03 + uY47 + uY811 + uY1214))/1000.*W**(1./3.)
         IF (dbugYN) PRINT *,'Shock Velocity, U (in/sec):', U(I)*1000.

C Use DECAY procedure to help calculate the blast decay values for the
C side-on and reflected cases
         CALL DECAY(Ir(I), Pr(I), To(I)*1000, Br(I), epsiln)
         Br(I)=To(I)/(Br(I)-(Br(I)**2-Pr(I)*To(I)*1000/Ir(I)*(Br(I)+
     |EXP(-Br(I))-1))/(2*Br(I)-Pr(I)*To(I)*1000/Ir(I)*(1-EXP(-Br(I)))))
      IF (dbugYN) PRINT *,'Reflected Decay coefficient (msec), Br:', Br
     |(I)*1000.

         CALL DECAY(Is(I), Ps(I), To(I)*1000, B(I), epsiln)
         B(I)=To(I)/(B(I)-(B(I)**2-Ps(I)*To(I)*1000/Is(I)*(B(I)+
     |EXP(-B(I))-1))/(2*B(I)-Ps(I)*To(I)*1000/Is(I)*(1-EXP(-B(I)))))
      IF (dbugYN) PRINT *,'Decay coefficient (msec), B:', B(I)*1000.

400   continue

C Initialize the blast profile structure.
      DO 401 I = 0, 128+3, 1
         DO 401 J = 1,2,1
            DO 401 M=1,64,1
401            Bprofl(I,J,M)=0.

C Set the variable to determine if the peak has already been arrived at
C to FALSE ie, "not yet."
```

```
      DO 405 M = 1, NumR, 1
405      Peak(M) = .FALSE.

C Actually calculate the blast profiles based on the determined values
C from above.  This will work for mine or air blast profiles.
      DO 410 I = 1, NumR, 1
410      K(I) = 0
      DO 415 M = 1, Nsteps, 1
      DO 415 J = 1, NumR, 1
         IF (Peak(J)) THEN
               T = (Float(K(J))-2.)*deltaT
            ELSE
               T = Float(K(J))*deltaT
         END IF
         T1 = (Float(K(J))+1.)*deltaT
         Bprofl(K(J),1,J) = T

C All "reflYN" calls are to check if the reflected values are to be
C returned.  This will only be the case for air bursts.  All mine
C blasts (hemispherical surface blasts) are considered to be producing
C normally reflected values.
         IF (reflYN) THEN
               Bprofl(K(J),2,J) = MFried(Pr(J), T, Ta(J), To(J), Br(J))
            ELSE
               Bprofl(K(J),2,J) = MFried(Ps(J), T, Ta(J), To(J), B(J))
            END IF
         IF (T .LE. Ta(J)) Bprofl(K(J),2,J) = 0.
         IF ((T .LE. Ta(J)) .AND. (T1 .GT. Ta(J))) THEN

            Bprofl(K(J)+1,1,J) = Ta(J) - deltaT/5.
            Bprofl(K(J)+2,1,J) = Ta(J)
            Bprofl(K(J)+3,1,J) = T1
            Bprofl(K(J)+1,2,J) = 0.
            IF (reflYN) THEN
                  Bprofl(K(J)+2,2,J) = MFried(Pr(J),Ta(J),Ta(J),To(J),
     |Br(J))
                  Bprofl(K(J)+3,2,J) = MFried(Pr(J),T1,   Ta(J),To(J),
     |Br(J))
               ELSE
                  Bprofl(K(J)+2,2,J) = MFried(Ps(J),Ta(J),Ta(J),To(J),
     |B(J))
                  Bprofl(K(J)+3,2,J) = MFried(Ps(J),T1,   Ta(J),To(J),
```

```
     |B(J))
               END IF

            K(J)               = K(J)+3
            Peak(J) = .TRUE.
         END IF
         IF (T .GE. (Ta(J)+To(J))) Bprofl(K(J),2,J) = 0.
         K(J) = K(J)+1
415   continue

      RETURN
      END

C=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-C

      SUBROUTINE ReadIn (Rb, Psb, Prb, Tab, Tsb, Trb, Isb, Irb, Ub,size)
C PRE:  all variables are empty
C POST:  The variables and arrays are filled with the respective table
C        values from Baker's _Explosions in Air,_ 1974, Chapter 6.

C ACTION:  The values are input from an infile EIA.DAT

      INTEGER I, size
      REAL Rb(size), Psb(size), Prb(size), Tab(size), Isb(size)
      REAL Tsb(size), Trb(size), Irb(size), Ub(size)

C Open the input file, EIA.DAT, which contains the blast parameters
C from Explosions in Air, Chapter 6 and other data points taken from
C full scale Log-Log plots of that data.
      OPEN (unit=8, FILE='eia.dat')

C Read past a header line in EIA.DAT
      READ (8,*)
C Iteratively read in the values of EIA.DAT
      DO 210 I = 1, size, 1
         READ (8,200) Rb(I),Psb(I),Prb(I),Tab(I),Tsb(I),Trb(I),Isb(I),
     |Irb(I),Ub(I)
200      FORMAT (1F9.4, 7F10.7, 1F13.9)

C Convert the data to Log-Log format so that the interpolation routines
C will work without alteration to Log-Log domain. The commenting out
C the following lines is necessary to prevent conversion of the data
```

```
C to Log-Log format
         Rb(I)  = LOG10(Rb(I))
         Psb(I) = LOG10(Psb(I))
         Prb(I) = LOG10(Prb(I))
         Tab(I) = LOG10(Tab(I))
         Tsb(I) = LOG10(Tsb(I))
         Trb(I) = LOG10(Trb(I))
         Isb(I) = LOG10(Isb(I))
         Irb(I) = LOG10(Irb(I))
         Ub(I)  = LOG10(Ub(I))
C End commenting out of lines if removing Log-Log alteration.

210      continue
      CLOSE (8)

      RETURN
      END

C=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-C

      SUBROUTINE EIA (nmax, r, NumR, TNT, etcYN, Nsteps, deltaT,
     |Bprofl, mine, Gref, reflYN, epsiln, alpha, dbugYN, aoaYN, PvsA)
C PRE:     Subroutine is handed the input values of the explosion
C          parameters
C POST:    The values of the necessary pressures, decay values,
C          durations are calculated and the pressure profiles output for
C          use in other programs for the desired x translation across
C          the plate surface.
C ACTION:  The appropriate coefficients are calculated via 3rd order
C          Legendre interpolation for the respective values of the
C          scaled range.  These values are then converted from their
C          scaled form back into their english unit equivalents.
C          These values are then used in Friedlander's modified equation
C          for the desired timesteps for the calculation of the
C          appropriate blast pressure profiles.  The order of
C          calculation/interpolation is Prb, Tab, Isb, b, then the
C          profiles.

      INTEGER size, nmax, tmax, Nsteps, I, J, K(64), M
      DOUBLE PRECISION deltaT, a0, rho0, g0, theta0, p0, epsiln
      PARAMETER (size=37, tmax=64)
      LOGICAL etcYN, mine, Peak(64), reflYN, dbugYN, aoaYN
```

```
      REAL    Rb(size), Psb(size), Prb(size), Tab(size), Isb(size)
      REAL    Irb(size), Ub(37), Tsb(size), BB(size), BBr(size)
      REAL    Psb2(size), Prb2(size), Tab2(size), Isb2(size), Irb2(size)
      REAL    Tsb2(size), Trb(size), Trb2(size), alpha(nmax), Ub2(37)
      REAL    R(nmax), Bprofl(0:(128+3),2,64), Gref, Is(size)
      REAL    Rrb(size), Pr(size), Ta(size), Ts(size), Ir(size), U(37)
      REAL    Tr(size), Ps(size), PPr, PPs, IIs, IIr, TTa, TTs, TTr
      REAL    PvsA(0:38,0:20)

C Tell user which routine is running:
      PRINT *, 'EIA Routine', TNT, ' equivalent pounds of TNT.'
      IF ((mine) .AND. .NOT.(etcYN)) PRINT *, 'Ground reflectivity
     |value:', Gref

C Sea level parameters for the atmosphere from Minzner, Champion, and
C Pond (1969)
      a0     = 13397.324
      rho0   = 1.146277e-7
      g0     = 386.08859
      theta0 = 518.688
      p0     = 14.695951

C Find energy of the TNT
      EW = 18.13e6
C Alter the amount of TNT for use in the calculation of the "mine"
C blasts for ground reflectivity.
      IF ((mine) .AND. (.NOT. etcYN)) TNT = Gref*TNT
      E  = EW*TNT

C Get the Explosions In Air Blast Parameters
      CALL ReadIn (Rb, Psb, Prb, Tab, Tsb, Trb, Isb, Irb, b, size)

C Call Spline to make the second derivative sets needed for splint for
C each parameter, yp1 and ypn are the derivatives at the end segments
      yp1 = (Psb(2)-Psb(1))/(Rb(2)-Rb(1))
      ypn = (Psb(size)-Psb(size-1))/(Rb(size)-Rb(size-1))
      CALL Spline (Rb, Psb, size, yp1, ypn, Psb2)

      yp1 = (Prb(2)-Prb(1))/(Rb(2)-Rb(1))
      ypn = (Prb(size)-Prb(size-1))/(Rb(size)-Rb(size-1))
      CALL Spline (Rb, Prb, size, yp1, ypn, Prb2)
```

```
      yp1 = (Tab(2)-Tab(1))/(Rb(2)-Rb(1))
      ypn = (Tab(size)-Tab(size-1))/(Rb(size)-Rb(size-1))
      CALL Spline (Rb, Tab, size, yp1, ypn, Tab2)

      yp1 = (Tsb(2)-Tsb(1))/(Rb(2)-Rb(1))
      ypn = (Tsb(size)-Tsb(size-1))/(Rb(size)-Rb(size-1))
      CALL Spline (Rb, Tsb, size, yp1, ypn, Tsb2)

      yp1 = (Trb(2)-Trb(1))/(Rb(2)-Rb(1))
      ypn = (Trb(size)-Trb(size-1))/(Rb(size)-Rb(size-1))
      CALL Spline (Rb, Trb, size, yp1, ypn, Trb2)

      yp1 = (Isb(2)-Isb(1))/(Rb(2)-Rb(1))
      ypn = (Isb(size)-Isb(size-1))/(Rb(size)-Rb(size-1))
      CALL Spline (Rb, Isb, size, yp1, ypn, Isb2)

      yp1 = (Irb(2)-Irb(1))/(Rb(2)-Rb(1))
      ypn = (Irb(size)-Irb(size-1))/(Rb(size)-Rb(size-1))
      CALL Spline (Rb, Irb, size, yp1, ypn, Irb2)

      yp1 = (Ub(2)-Ub(1))/(Rb(2)-Rb(1))
      ypn = (Ub(size)-Ub(size-1))/(Rb(size)-Rb(size-1))
      CALL Spline (Rb, Ub, size, yp1, ypn, Ub2)

C The interpolation of the values from EIA.DAT.  Certain commented
C lines are for the conversion of the interpolation from Log-Log to
C simple interpolation of the straight data.  This requires
C conversion of some of the following lines (shown but commented),
C changes in the ReadIn procedure where the data is converted to
C Log-Log format, and a change in the splint procedure.  Print
C statements are for debugging or output use, but are also commented
C out.

C Additional lines are provided for potential output of determined
C values for hard copy and debugging use.

      DO 301 I=1, NumR, 1
C Calculate the Sach's scaled distances
        RRb(I)=r(i)*p0**(1./3.)/E**(1./3.)

C For debugging purposes, this line allows the hard coding of a
C scaled distance value and the output of that value.
```

```
C         rrb(I) = .314
         IF (dbugYN) PRINT *, 'Scaled distance, Rbar:', RRb(I)

C         IF (mine) etcYN = .FALSE.
         IF (etcYN) THEN

         PRINT *, 'ETC calculation subroutine'

C Determine side-on pressure, Ps
            IF (LOG10(Rrb(I)) .LT. Rb(1)) THEN
                  Ps(I)=Cintrp(LOG10(Rrb(I)), Rb(1), Rb(2), Rb(3), Rb(4)
     |, Psb(1), Psb(2), Psb(3), Psb(4))
               ELSE
                  IF (LOG10(Rrb(I)) .GT. Rb(size)) THEN
                        Ps(I)=Cintrp(LOG10(Rrb(I)), Rb(size-3), Rb(size-
     |2), Rb(size-1), Rb(size), Psb(size-3), Psb(size-2), Psb(size-1),
     |Psb(size))
                     ELSE
                        CALL Splint (Rb, Psb, Psb2, size, RRb(I), Ps(I))
                  END IF
            ENDIF
               IF (dbugYN) PRINT *, 'Ps_bar=',10.**Ps(I)
               IF (dbugYN) PRINT *, 'LOG(Ps)=', Ps(I)
               PPs = 10.**Ps(I)
               Ps(I) = 2.*10.**Ps(I)*p0
C               IF (dbugYN) Ps(I) = 2.*Ps(I)*p0
               IF (dbugYN) PRINT *, 'Peak side-on overpressure, Ps
     |(psi):',Ps(I)

C Determine reflected pressure, Pr
            IF (LOG10(Rrb(I)) .LT. Rb(1)) THEN
                  Pr(I)=Cintrp(LOG10(Rrb(I)), Rb(1), Rb(2), Rb(3), Rb(4)
     |, Prb(1), Prb(2), Prb(3), Prb(4))
               ELSE
                  IF (LOG10(Rrb(I)) .GT. Rb(size)) THEN
                        Pr(I)=Cintrp(LOG10(Rrb(I)), Rb(size-3), Rb(size-
     |2), Rb(size-1), Rb(size), Prb(size-3), Prb(size-2), Prb(size-1),
     |Prb(size))
                     ELSE
                        CALL Splint (Rb, Prb, Prb2, size, RRb(I), Pr(I))
                  END IF
            ENDIF
```

```
               IF (dbugYN) PRINT *, 'Pr_bar=',10.**Pr(I)
               IF (dbugYN) PRINT *, 'LOG(Pr)=', Pr(I)
C ETC doubled the reflected impulse values for ground reflection, but
C left all other variables untouched.
               PPr = 10.**Pr(I)
               Pr(I) = 2.*10.**Pr(I)*p0
C               IF (dbugYN) Pr(I) = 2.*Pr(I)*p0
               IF (dbugYN) PRINT *, 'Peak reflected overpressure, Pr
     |(psi):',Pr(I)

C Determine time of arrival, Ta
            IF (LOG10(Rrb(I)) .LT. Rb(1)) THEN
                  Ta(I)=Cintrp(LOG10(Rrb(I)), Rb(1), Rb(2), Rb(3), Rb(4)
     |, Tab(1),Tab(2), Tab(3), Tab(4))
               ELSE
                  IF (LOG10(Rrb(I)) .GT. Rb(size)) THEN
                        Ta(I)=Cintrp(LOG10(Rrb(I)), Rb(size-3), Rb(size-
     |2), Rb(size-1), Rb(size), Tab(size-3), Tab(size-2), Tab(size-1),
     |Tab(size))
                     ELSE
                        CALL Splint (Rb, Tab, Tab2, size, RRb(I), Ta(I))
                  END IF
            ENDIF
C               PRINT *, 'Ta_bar=',10.**Ta(I)
C               PRINT *,'LOG(Ta)=', Ta(I)
               TTa = 10.**Ta(I)
               Ta(I) = 10.**Ta(I)*E**(1./3.)/(a0*p0**(1./3.))
C               Ta(I) = Ta(I)*E**(1./3.)/(a0*p0**(1./3.))
               IF (dbugYN) PRINT *, 'Time of arrival, Ta (sec):', Ta(I)

C Determine positive phase duration, Ts
C ETC used the Ts instead of Tr in its calculations
            IF (LOG10(Rrb(I)) .LT. Rb(1)) THEN
                  Ts(I)=Cintrp(LOG10(Rrb(I)), Rb(1), Rb(2), Rb(3), Rb(4)
     |,Tsb(1), Tsb(2), Tsb(3), Tsb(4))
               ELSE
                  IF (LOG10(Rrb(I)) .GT. Rb(size)) THEN
                        Ts(I)=Cintrp(LOG10(Rrb(I)), Rb(size-3), Rb(size-
     |2), Rb(size-1), Rb(size), Tsb(size-3), Tsb(size-2), Tsb(size-1),
     |Tsb(size))
                     ELSE
                        CALL Splint (Rb, Tsb, Tsb2, size, RRb(I), Ts(I))
```

```
                  END IF
            ENDIF
               IF (dbugYN) PRINT *, 'Ts_bar=',10.**Ts(I)
               IF (dbugYN) PRINT *,'LOG(Ts)=', Ts(I)
               TTs = 10.**Ts(I)
               Ts(I) = 10.**Ts(I)*E**(1./3.)/(a0*p0**(1./3.))
C               Ts(I) = Ts(I)*E**(1./3.)/(a0*p0**(1./3.))
               IF (dbugYN) PRINT *, 'Side-on duraion, Ts (sec):',Ts(I)

C Determine side-on impulse, Is
            IF (LOG10(Rrb(I)) .LT. Rb(1)) THEN
                  Is(I)=Cintrp(LOG10(Rrb(I)), Rb(1), Rb(2), Rb(3), Rb(4)
     |,Isb(1), Isb(2), Isb(3), Isb(4))
               ELSE
                  IF (LOG10(Rrb(I)) .GT. Rb(size)) THEN
                        Is(I)=Cintrp(LOG10(Rrb(I)), Rb(size-3), Rb(size-
     |2), Rb(size-1), Rb(size), Isb(size-3), Isb(size-2), Isb(size-1),
     |Isb(size))
                     ELSE
                        CALL Splint (Rb, Isb, Isb2, size, RRb(I), Is(I))
                  END IF
            ENDIF
               IF (dbugYN) PRINT *, 'Is_bar=',10.**Is(I)
               IF (dbugYN) PRINT *, 'log(Is)=', Is(I)
               IIs = 10.**Is(I)
               Is(I) = 10.**Is(I)*(E**(1./3.)*p0**(2./3.))/a0
C               Is(I) = Is(I)*(E**(1./3.)*p0**(2./3.))/a0
               IF (dbugYN) PRINT *, 'Side on impulse, Is (psi-sec):',
     |Is(I)

C Determine the non-dimentional decay coefficient, br
C ETC used b instead of br
C               CALL Decay (Is(I), Ps(I), Ts(I), BB(I), epsiln)
               CALL Decay (IIs, PPs, TTs, BB(I), epsiln)
               PRINT *, 'Decay value, B',BB(I)

C End of ETC calculation section
      ELSE

         PRINT *, 'EIA', TNT, ' lbs'

C Explosions in Air calculation section, used for air/mine blast.
```

```
C Calculate the reflected pressure, Ps
            IF (LOG10(Rrb(I)) .LT. Rb(1)) THEN
                  Ps(I)=Cintrp(LOG10(Rrb(I)), Rb(1), Rb(2), Rb(3), Rb(4)
     |,Psb(1),Psb(2), Psb(3), Psb(4))
               ELSE
                  IF (LOG10(Rrb(I)) .GT. Rb(size)) THEN
                        Ps(I)=Cintrp(LOG10(Rrb(I)), Rb(size-3), Rb(size-
     |2), Rb(size-1), Rb(size), Psb(size-3), Psb(size-2),Psb(size-1),
     |Psb(size))
                     ELSE
                        CALL Splint (Rb, Psb, Psb2, size, RRb(I), Ps(I))
                  END IF
            END IF
               IF (dbugYN) PRINT *, 'Ps_bar=',10.**Ps(I)
               IF (dbugYN) PRINT *, 'LOG(Ps)=', Ps(I)
               PPs = 10.**Ps(I)
               Ps(I) = 10.**Ps(I)*p0
C               Ps(I) = Ps(I)*p0
               IF (dbugYN) PRINT *, 'Peak side-on overpressure, Ps (psi)
     |:',Ps(I)

C Calculate the reflected pressure, Pr
            IF (aoaYN) THEN
                  CALL PAitrp (PvsA, Ps(I), alpha(I), Pr(I))
                   Pr(I) = LOG10(Pr(I)/p0)
               ELSE
                  IF (LOG10(Rrb(I)) .LT. Rb(1)) THEN
                        Pr(I)=Cintrp(LOG10(Rrb(I)), Rb(1), Rb(2), Rb(3),
     |Rb(4),Prb(1),Prb(2), Prb(3), Prb(4))
                     ELSE
                        IF (LOG10(Rrb(I)) .GT. Rb(size)) THEN
                              Pr(I)=Cintrp(LOG10(Rrb(I)), Rb(size-3),
     |Rb(size-2), Rb(size-1), Rb(size), Prb(size-3), Prb(size-2),Prb(
     |size-1), Prb(size))
                           ELSE
                              CALL Splint (Rb, Prb, Prb2, size, RRb(I),
     |Pr(I))
                        END IF
                  END IF
            END IF
               IF (dbugYN) PRINT *, 'Pr_bar=',10.**Pr(I)
```

```
               IF (dbugYN) PRINT *, 'LOG(Pr)=', Pr(I)
               PPr = 10.**Pr(I)
               Pr(I) = 10.**Pr(I)*p0
C               Pr(I) = Pr(I)*p0
               IF (dbugYN) PRINT *, 'Peak reflected overpressure, Pr (ps
     |i):',Pr(I)

C Calculate time of arrival, Ta
            IF (LOG10(Rrb(I)) .LT. Rb(1)) THEN
                  Ta(I)=Cintrp(LOG10(Rrb(I)), Rb(1), Rb(2), Rb(3), Rb(4)
     |, Tab(1),Tab(2), Tab(3), Tab(4))
               ELSE
                  IF (LOG10(Rrb(I)) .GT. Rb(size)) THEN
                        Ta(I)=Cintrp(LOG10(Rrb(I)), Rb(size-3), Rb(size-
     |2), Rb(size-1), Rb(size), Tab(size-3), Tab(size-2), Tab(size-1),
     |Tab(size))
                     ELSE
                        CALL Splint (Rb, Tab, Tab2, size, RRb(I), Ta(I))
                  END IF
            ENDIF
               IF (dbugYN) PRINT *, 'Ta_bar=',10.**Ta(I)
               IF (dbugYN) PRINT *,'LOG(Ta)=', Ta(I)
               TTa = 10.**Ta(I)
               Ta(I) = 10.**Ta(I)*E**(1./3.)/(a0*p0**(1./3.))
C               Ta(I) = Ta(I)*E**(1./3.)/(a0*p0**(1./3.))
               IF (dbugYN) PRINT *, 'Time of arrival, Ta (sec):', Ta(I)

C Calculate the time of reflected duration, Tr
            IF (LOG10(Rrb(I)) .LT. Rb(1)) THEN
                  Tr(I)=Cintrp(LOG10(Rrb(I)), Rb(1), Rb(2), Rb(3), Rb(4)
     |, Trb(1), Trb(2), Trb(3), Trb(4))
               ELSE
                  IF (LOG10(Rrb(I)) .GT. Rb(size)) THEN
                        Tr(I)=Cintrp(LOG10(Rrb(I)), Rb(size-3), Rb(size-
     |2), Rb(size-1), Rb(size), Trb(size-3), Trb(size-2), Trb(size-1),
     |Trb(size))
                     ELSE
                        CALL Splint (Rb, Trb, Trb2, size, RRb(I), Tr(I))
                  END IF
            ENDIF
               IF (dbugYN) PRINT *, 'Tr_bar=',10.**Tr(I)
               IF (dbugYN) PRINT *,'LOG(Tr)=', Tr(I)
```

```
               TTr = 10.**Tr(I)
               Tr(I) = 10.**Tr(I)*E**(1./3.)/(a0*p0**(1./3.))
C               Tr(I) = Tr(I)*E**(1./3.)/(a0*p0**(1./3.))
               IF (dbugYN) PRINT *, 'Time of reflected duration, Tr (sec
     |):',Tr(I)

C Calculate the time of incident duration, Ts
            IF (LOG10(Rrb(I)) .LT. Rb(1)) THEN
                  Ts(I)=Cintrp(LOG10(Rrb(I)), Rb(1), Rb(2), Rb(3), Rb(4)
     |, Tsb(1), Tsb(2), Tsb(3), Tsb(4))
               ELSE
                  IF (LOG10(Rrb(I)) .GT. Rb(size)) THEN
                        Ts(I)=Cintrp(LOG10(Rrb(I)), Rb(size-3), Rb(size-
     |2), Rb(size-1), Rb(size), Tsb(size-3), Tsb(size-2), Tsb(size-1),
     |Tsb(size))
                     ELSE
                        CALL Splint (Rb, Tsb, Tsb2, size, RRb(I), Ts(I))
                  END IF
            ENDIF
               IF (dbugYN) PRINT *, 'Ts_bar=',10.**Ts(I)
               IF (dbugYN) PRINT *,'LOG(Ts)=', Ts(I)
               TTs = 10.**Ts(I)
               Ts(I) = 10.**Ts(I)*E**(1./3.)/(a0*p0**(1./3.))
C               Ts(I) = Ts(I)*E**(1./3.)/(a0*p0**(1./3.))
               IF (dbugYN) PRINT *, 'Time of duration, Ts (sec):',Ts(I)

C Calculate the reflected specific impulse, Ir
            IF (LOG10(Rrb(I)) .LT. Rb(1)) THEN
                  Ir(I)=Cintrp(LOG10(Rrb(I)), Rb(1), Rb(2), Rb(3), Rb(4)
     |, Irb(1), Irb(2), Irb(3), Irb(4))
               ELSE
                  IF (LOG10(Rrb(I)) .GT. Rb(size)) THEN
                        Ir(I)=Cintrp(LOG10(Rrb(I)), Rb(size-3), Rb(size-
     |2), Rb(size-1), Rb(size), Irb(size-3), Irb(size-2), Irb(size-1),
     |Irb(size))
                     ELSE
                        CALL Splint (Rb, Irb, Irb2, size, RRb(I), Ir(I))
                  END IF
            ENDIF
               IF (dbugYN) PRINT *, 'Ir_bar=',10.**Ir(I)
               IF (dbugYN) PRINT *, 'log(Ir)=', Ir(I)
               IIr = 10.**Ir(I)
```

```
               Ir(I) = 10.**Ir(I)*(E**(1./3.)*p0**(2./3.))/a0
C               Ir(I) = Ir(I)*(E**(1./3.)*p0**(2./3.))/a0
               IF (dbugYN) PRINT *, 'Reflected impulse, Ir (psi-sec)',Ir(I)

C Calculate the incident specific impulse, Is
            IF (LOG10(Rrb(I)) .LT. Rb(1)) THEN
                  Is(I)=Cintrp(LOG10(Rrb(I)), Rb(1), Rb(2), Rb(3), Rb(4)
     |, Isb(1), Isb(2), Isb(3), Isb(4))
               ELSE
                  IF (LOG10(Rrb(I)) .GT. Rb(size)) THEN
                        Is(I)=Cintrp(LOG10(Rrb(I)), Rb(size-3), Rb(size-
     |2), Rb(size-1), Rb(size), Isb(size-3), Isb(size-2), Isb(size-1),
     |Isb(size))
                     ELSE
                        CALL Splint (Rb, Isb, Isb2, size, RRb(I), Is(I))
                  END IF
            ENDIF
               IF (dbugYN) PRINT *, 'Is_bar=',10.**Is(I)
               IF (dbugYN) PRINT *, 'log(Is)=', Is(I)
               IIs = 10.**Is(I)
               Is(I) = 10.**Is(I)*(E**(1./3.)*p0**(2./3.))/a0
C               Is(I) = Is(I)*(E**(1./3.)*p0**(2./3.))/a0
               IF (dbugYN) PRINT *, 'Side-on impulse, Is (psi-sec):',
     |Is(I)

C Calculate the shock velocity, U
            IF (LOG10(Rrb(I)) .LT. Rb(1)) THEN
                  U(I)=Cintrp(LOG10(Rrb(I)), Rb(1), Rb(2), Rb(3), Rb(4)
     |, Ub(1), Ub(2), Ub(3), Ub(4))
               ELSE
                  IF (LOG10(Rrb(I)) .GT. Rb(size)) THEN
                        U(I)=Cintrp(LOG10(Rrb(I)), Rb(size-3), Rb(size-
     |2), Rb(size-1), Rb(size), Ub(size-3), Ub(size-2), Ub(size-1),
     |Ub(size))
                     ELSE
                        CALL Splint (Rb, Ub, Ub2, size, RRb(I), U(I))
                  END IF
            ENDIF
               IF (dbugYN) PRINT *, 'U_bar=',10.**U(I)
               IF (dbugYN) PRINT *,'LOG(U)=', U(I)
               U(I) = 10.**U(I)*E**(1./3.)/(a0*p0**(1./3.))
C               U(I) = U(I)*E**(1./3.)/(a0*p0**(1./3.))
```

```
               IF (dbugYN) PRINT *, 'Shock Velocity, U (in/sec):',U(I)

C Calculate the reflected decay coefficient
C               CALL Decay (Ir(I), Pr(I), Tr(I), BBr(I), epsiln)
               CALL Decay (IIr, PPr, TTr, BBr(I), epsiln)
               IF (dbugYN) PRINT *, 'Reflectd decay value, br:', BBr(I)

C Calculate the decay coefficient
C               CALL Decay (Is(I), Ps(I), Ts(I), BB(I), epsiln)
               CALL Decay (IIs, PPs, TTs, BB(I), epsiln)
               IF (dbugYN) PRINT *, 'Decay value, b:', BB(I)

         END IF
301   continue

C Initialize the blast profile structure
      DO 303 I = 0, 128+3, 1
         DO 303 J = 1, 2, 1
            DO 303 M=1, 64, 1
303            Bprofl(I,J,M) = 0.

C Initialize the flag array for determining if the peak has
C been reached.  False means that it has not.
      DO 305 M = 1, NumR, 1
305      Peak(M) = .FALSE.

C Calculate the blast profiles.
      DO 310 I = 1, NumR, 1
310      K(I) = 0
      DO 315 M = 1, Nsteps, 1
      DO 315 J = 1, NumR, 1
         IF (Peak(J)) THEN
               T = (Float(K(J))-2.)*deltaT
            ELSE
               T = Float(K(J))*deltaT
         END IF
         T1 = (Float(K(J))+1.)*deltaT
         Bprofl(K(J),1,J) = T
         IF (etcYN) THEN
            Bprofl(K(J),2,J) = FRIED(Pr(J),T,Ta(J),Ts(J),BB(J))
         ELSE
C Only if there is not ETC's method, not a mine blast, and the normally
```

```
C reflected values not desired will this program output the side-on
C pressure profiles.  Mine blast will give reflected values always.
C Air blast is the only case in which the refleced value choice works.
C ETC's method will only work for mine blast calculations.
            IF ((.NOT. reflYN) .AND. (.NOT. mine))THEN
                  Bprofl(K(J),2,J) = FRIED(Ps(J),T,Ta(J),Ts(J),BB(J))
               ELSE
                  Bprofl(K(J),2,J) = FRIED(Pr(J),T,Ta(J),Tr(J),BBr(J))
               END IF
         END IF
         IF (T .LE. Ta(J)) Bprofl(K(J),2,J) = 0.
         IF ((T .LE. Ta(J)) .AND. (T1 .GT. Ta(J))) THEN

            Bprofl(K(J)+1,1,J) = Ta(J) - deltaT/5.
            Bprofl(K(J)+2,1,J) = Ta(J)
            Bprofl(K(J)+3,1,J) = T1
            Bprofl(K(J)+1,2,J) = 0.
            IF (etcYN) THEN
               Bprofl(K(J)+2,2,J) = FRIED(Pr(J),Ta(J),Ta(J),Ts(J),BB(J))
               Bprofl(K(J)+3,2,J) = FRIED(Pr(J),T1,   Ta(J),Ts(J),BB(J))
            ELSE
               IF ((.NOT. reflYN) .AND. (.NOT. mine)) THEN
                  Bprofl(K(J)+2,2,J) = FRIED(Ps(J),Ta(J),Ta(J),Ts(J),
     |BB(J))
                  Bprofl(K(J)+3,2,J) = FRIED(Ps(J),T1,   Ta(J),Ts(J),
     |BB(J))
               ELSE
                  Bprofl(K(J)+2,2,J) = FRIED(Pr(J),Ta(J),Ta(J),Tr(J),
     |BBr(J))
                  Bprofl(K(J)+3,2,J) = FRIED(Pr(J),T1,   Ta(J),Tr(J),
     |BBr(J))
               END IF
            END IF

            K(J)            = K(J)+3
            Peak(J) = .TRUE.
         END IF
         IF (etcYN) THEN
               IF (T .GE. (Ta(J)+Ts(J))) Bprofl(K(J),2,J) = 0.
            ELSE
               IF (T .GE. (Ta(J)+Tr(J))) Bprofl(K(J),2,J) = 0.
         ENDIF
```

```
         K(J) = K(J)+1
315   continue

      RETURN
      END

C=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-C

      SUBROUTINE DECAY (Is, Ps, Ts, b, epsiln)
C PRE:     The values of Is, Ps, Ts, and b are input.
C POST:    A calculated/root solved value of the decay coefficient is
C          calculated.
C ACTION:  The new value of b is calculated by fixed point iteration.
      LOGICAL done
      REAL Is, Ps, Ts, b, bnew
      DOUBLE PRECISION epsiln

      b     = 0.1
C Epsiln is the lowest difference between the iterations by which
C convergence is determined.  Epsilon (epsiln) is part of the input
C file to allow platform and flexibility without the need for
C recompiling.  Epsilon must be adjusted if the program enters an
C an infinite Decay loop.
      done  = .FALSE.
500   bnew = Ps*Ts/Is*(1-(1-EXP(-b))/b)
         IF ((ABS(bnew-b)) .LE. epsiln) THEN
            b    = bnew
            done = .TRUE.
         ELSE
            b = bnew
         END IF
      IF (.NOT. done) GOTO 500

      RETURN
      END

C=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-C

      SUBROUTINE Outfil (BProfl, Nsteps, NumR, XY, radial, nmax)
C PRE:     BProfl (Blast profiles) are created in the array
C POST:    The profiles have been tabularly out put to a file
C ACTION:  The profiles have been tabularly out put by iteration.
```

```
      INTEGER I, J, nmax, Nsteps, numR
      REAL    BProfl(0:(128+3),2,64), XY(nmax,2)
      LOGICAL radial

C open the outfile for output of the blast profiles
      OPEN (unit=8, FILE='blast.out')

C sort the profiles so they are in order by time via Bubble Sort
C (an order O(N^2) sort routine).  Includes a swap routine determined
C by the time order.
      DO 600 I = 1, NumR, 1
         DO 600 J = 0, ((128+3)-1), 1
            IF (BProfl(J,1,I) .GT. Bprofl(J+1,1,I)) THEN
               swapT          = BProfl(J,1,I)
               swapP          = BProfl(J,2,I)
               BProfl(J,1,I)   = BProfl(J+1,1,I)
               BProfl(J,2,I)   = BProfl(J+1,2,I)
               BProfl(J+1,1,I) = swapT
               BProfl(J+1,2,I) = swapP
            END IF
600      continue

      DO 650 I = 1, NumR, 1
         IF (radial) THEN

C "ZONE" notation used by NASTRAN input decks.  Comment out if using
C "R" header notation
               WRITE  (8, 610) I
610            FORMAT ('ZONE# =',I11)
C "R = " notation for general use.  Comment out if using "ZONE"
C               WRITE  (8, 610) XY(I,1)
C610            FORMAT ('R = ', 1F8.2)
            ELSE
               WRITE  (8, 620) XY(I,1), XY(I,2)
620            FORMAT ('X = ', 1F8.2,' Y = ',1F8.2)
            END IF

C Print out Nsteps number of steps, not the entire array
         DO 650 J = 0, Nsteps, 1
         WRITE  (8,630) BProfl(J,1,I), BProfl(J,2,I)
630      FORMAT (1F9.7,1F9.3)
```

```
650   continue

      CLOSE (8)
      RETURN
      END

C=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-C

      SUBROUTINE spline(X, Y, N, Yp1, Ypn, Y2)
C PRE:     Yp1 and Ypn have been determined as the slopes at the end
C          points.  X and Y are arrays of the values to be splined.
C          This routine is taken from _Numeric Recipies._
C POST:    The second derivatives have been created for Splint and
C          are stored in Y2
C ACTION:  The second derivatives for interpolation of by piecewise
C          splines are calculated and stored.
      INTEGER I, K, N, Nmax
      PARAMETER (Nmax = 500)
      REAL Yp1, Ypn, X(N), Y(N), Y2(N), P, Qn, sig, Un, U(Nmax)

      IF (Yp1 .GT. .99e30) THEN
         Y2(1) = 0.
         U(1)  = 0.
      ELSE
         Y2(1) = -0.5
         U(1)  = (3./(X(2)-X(1)))*((Y(2)-Y(1))/(X(2)-X(1))-Yp1)
      END IF

      do 700 I = 2, N-1, 1
         sig   = (X(I)-X(I-1))/(X(I+1)-X(I-1))
         P     = sig*Y2(I-1)+2.
         Y2(I) = (sig-1.)/P
700      U(I)  = (6.*((Y(I+1)-Y(I))/(X(I+1)-X(I))-(Y(I)-Y(I-1))/(X(I)-
     |X(I-1)))/(X(I+1)-X(I-1))-sig*U(I-1))/P

      IF (Ypn .GT. .99e30) THEN
         Qn = 0.
         Un = 0.
      ELSE
         Qn = 0.5
         Un = (3./(X(N)-X(N-1)))*(Ypn-(Y(N)-Y(N-1))/(X(N)-X(N-1)))
      END IF
```

```
      Y2(N) = (Un-Qn*(U(N-1)))/(Qn*Y2(N-1)+1.)
      do 701 K = N-1, 1, -1
701      Y2(K) = Y2(K)*Y2(K+1)+U(K)

      RETURN
      END

C=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-C

      SUBROUTINE Splint (Xa, Ya, Y2a, N, XX, Y)
C PRE:     Spline has been run for Xa and Ya and is given in Y2a, the
C          desired value of Y is to be found at X.  This routine is
C          taken from _Numeric Recipies._
C POST:    The value desired at X is returned, stored in Y
C ACTION:  The interpolation of by piecewise splines is done.
      INTEGER N, K, Khi, Klo
      REAL XX, Y, Xa(N), Y2a(N), Ya(N), a, b, H

C Swapping the following lines is necessary if the data is not converted
C to LOG-LOG format for spline interpolation.
C       print *,xx
      X   = LOG10(XX)
C       print *,x
C       X = XX
      Klo = 1
      Khi = N
800   IF (Khi-Klo .GT. 1) THEN
         K = (Khi+Klo)/2
         IF (Xa(K) .GT. X) THEN
               Khi=K
            ELSE
               Klo=K
         END IF
      GOTO 800
      END IF

      H = Xa(Khi) - Xa(Klo)
      IF (H .EQ. 0.) PAUSE 'bad Xa input in splint'
      a = (Xa(Khi)-X)/H
      b = (X-Xa(Klo))/H
      Y = a*Ya(Klo)+b*Ya(Khi)+((a**3.-a)*Y2a(Klo)+(b**3.-b)*Y2a(Khi))*
```

```
|(H**2.)/6.

 RETURN
 END
```

APPENDIX II

An example of the input file BLAST.INP used by the program BLAST.F. This example is for a ground blast ("mine blast") of 5 pounds of TNT at 16 inches normal distance from a target. The file specifies the blast method (*Explosions in Air* in this case), ground reflectivity value (1.7 or 70%), time step parameters (number of steps and Δt), an epsilon value for fixed point iteration convergence (epsilon), and the number of points as well as their radial values. Options for output of debugging statements and the use of the correction routines for angles of incidence are also included.

BLAST.INP:

```
3                     ;1=CONWEP, 3=EIA,ch.6(mine & air burst)
16.                   ;blast normal distance, in inches
5.0                   ;pounds of TNT
1.0                   ;equivalent factor of TNT
1.7                   ;ground reflectivity, default is 70%=1.7
50                    ;number of time steps, nsteps
0.00005               ;length of time step, deltaT
0.00000001            ;epsilon for decay function
2                     ;1=Mineblast, 2=Airblast
0                     ;Calculation debug statements 1=on, 0=off
1                     ;Angle of Incidence Pr adjustment 1=on, 0=off
1                     ;1=use normally reflected values (airblast), 2=side-on
1                     ;1=radial values, 2=(x,y) pairs
9                     ;number of radial or (x,y) values
                      ;blank, (x,y) or r values follow:
0.
0.5
1.5
3.5
5.5
7.5
9.5
11.5
13.5
15.5
```

This is the input file EIA.DAT which contains blast parameters used by the program to calculate the blast profiles in its Explosions in Air routines. This data is converted to Log-Log form by the program and then interpolated by splines for the determination of each profile parameter used in Friedlander's equation. Note that this program does not use all the parameters presented in Chapter 6 of Baker's *Explosions in Air*, or in Chapter 6 of the Army design manual, *Explosions in Air*.

EIA.DAT

R bar	Ps bar	Pr bar	Ta bar	Ts bar	Tr bar	Is bar	Ir bar	b
0.08	90.5	860.	4.95E-03	0.0175	0.018	0.0895	1.86	17.2
0.09	77.5	699.	6.06E-03	0.0182	0.0198	0.0824	1.503	15.8
0.1	67.9	585.	7.62E-03	0.0191	0.0219	0.0785	1.27	15.45
0.125	48.8	397.	0.0107	0.0243	0.0267	0.075	0.894	15.1
0.15	37.2	277.	0.0154	0.0341	0.0315	0.0788	0.667	15.02
0.2	20.4	146.	0.0255	0.0885	0.0425	0.106	0.456	15.96
0.22	16.6	116.	0.0284	0.126	0.047	0.108	0.408	16.7
0.24	13.4	91.	0.0329	0.148	0.052	0.107	0.368	17.2
0.25	11.9	80.3	0.0382	0.157	0.0542	0.103	0.355	17.
0.3	7.28	37.7	0.0541	0.171	0.0684	0.0885	0.294	12.9
0.4	3.46	15.3	0.099	0.158	0.103	0.0695	0.222	6.76
0.5	2.05	9.4	0.157	0.162	0.147	0.057	0.178	4.562
0.6	1.38	6.05	0.218	0.181	0.195	0.0482	0.15	3.871
0.8	0.772	2.63	0.34	0.232	0.232	0.0371	0.112	3.484
0.9	0.618	1.86	0.392	0.254	0.254	0.0335	0.0989	3.27
1.	0.506	1.31	0.466	0.268	0.268	0.0302	0.0885	3.08
1.5	0.254	0.58	0.83	0.328	0.328	0.0207	0.0529	2.51
2.	0.161	0.358	1.26	0.362	0.362	0.0158	0.0377	2.196
2.5	0.115	0.25	1.71	0.39	0.39	0.0128	0.029	1.977
3.	0.0889	0.188	2.2	0.414	0.414	0.0108	0.0237	1.875
4.	0.0616	0.126	3.21	0.445	0.445	8.12E-03	0.0173	1.81
5.	0.0468	0.0948	4.21	0.477	0.477	6.56E-03	0.0137	1.856
6.	0.0374	0.0765	5.19	0.495	0.495	5.46E-03	0.0112	1.84
7.	0.0306	0.0633	5.84	0.517	0.517	4.67E-03	9.49E-03	1.828
8.	0.0261	0.0536	7.15	0.532	0.532	4.10E-03	8.40E-03	1.83
9.	0.0227	0.0461	7.64	0.548	0.548	3.62E-03	7.31E-03	1.85
10.	0.0198	0.0401	9.1	0.564	0.564	3.25E-03	6.58E-03	1.87
20.	8.70E-03	0.0176	18.9	0.666	0.666	1.58E-03	3.20E-03	2.17
30.	5.43E-03	0.011	28.8	0.737	0.737	1.04E-03	2.08E-03	2.382
40.	3.91E-03	7.88E-03	38.9	0.781	0.781	7.64E-04	1.54E-03	2.553
50.	3.06E-03	6.12E-03	48.9	0.825	0.825	6.05E-04	1.22E-03	2.754
60.	2.48E-03	4.96E-03	58.8	0.856	0.856	4.98E-04	9.96E-04	2.87
80.	1.81E-03	3.58E-03	78.5	0.916	0.916	3.68E-04	7.39E-04	3.08
100.	1.41E-03	2.80E-03	98.5	0.96	0.96	2.93E-04	5.86E-04	3.25

250.	5.17E-04	1.03E-03	224.	1.16	1.16	1.16E-04	2.33E-04	3.87
500.	2.42E-04	4.86E-04	499.	1.24	1.24	5.75E-05	1.15E-04	3.911
1000.	1.15E-04	2.31E-04	1000.	1.25	1.25	2.88E-05	5.76E-05	3.67

```
1234567890123456789012345678901234567890123456789012345678901234567890123456789
```

This is the input file PVSA.DAT which contains angle of incident reflected pressure blast parameters used by the program to calculate the blast profiles in either the *Explosions in Air* routines, or those of Kingery & Bulmash. This data is the tabular form of Figure 8.

PVSA.DAT

ang	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
0.	5000.	3000.	2000.	1000.	500.	400.	300.	200.	150.	100.	70.	50.	30.	20.	10.	5.	2.	1.	0.5	0.2
0.	12.25	10.8	10.	8.6	7.8	7.	6.65	6.	5.6	5.	4.45	4.	3.35	3.	2.5	2.2	2.1	2.05	2.05	2.
5.	12.	10.7	9.95	8.45	7.65	6.95	6.6	5.9	5.5	4.95	4.4	3.9	3.3	3.	2.5	2.2	2.1	2.05	2.05	2.
10.	11.65	10.55	9.8	8.25	7.45	6.85	6.5	5.85	5.45	4.85	4.35	3.85	3.25	3.	2.5	2.2	2.1	2.05	2.05	2.
15.	11.2	10.3	9.55	7.95	7.25	6.75	6.35	5.75	5.35	4.8	4.25	3.8	3.2	2.95	2.5	2.2	2.1	2.05	2.05	2.
20.	10.65	9.95	9.2	7.65	6.95	6.55	6.2	5.65	5.2	4.65	4.15	3.7	3.15	2.9	2.5	2.2	2.1	2.05	2.05	2.
25.	10.05	9.4	8.75	7.3	6.7	6.3	5.9	5.45	5.05	4.55	4.1	3.65	3.1	2.85	2.5	2.2	2.1	2.05	2.05	2.
30.	9.4	8.8	8.2	6.9	6.35	6.	5.65	5.2	4.8	4.4	4.	3.55	3.1	2.85	2.5	2.2	2.1	2.05	2.05	2.
35.	8.7	8.125	7.65	6.5	5.95	5.675	5.35	4.925	4.6	4.275	3.85	3.5	3.125	2.9	2.5	2.2	2.1	2.05	2.05	2.
36.	8.55	8.	7.5	6.4	5.85	5.6	5.3	4.9	4.6	4.25	3.85	3.5	3.15	2.9	2.5	2.2	2.1	2.05	2.05	2.
37.	8.4	7.85	7.375	6.325	5.8	5.55	5.275	4.925	4.625	4.275	3.9	3.55	3.175	2.95	2.5	2.2	2.1	2.05	2.05	2.
38.	8.25	7.75	7.25	6.25	5.75	5.5	5.25	4.95	4.65	4.3	3.95	3.6	3.2	2.95	2.5	2.2	2.1	2.05	2.05	2.
39.	8.1	7.625	7.15	6.2	5.725	5.5	5.325	5.05	4.775	4.475	4.125	3.85	3.35	3.	2.5	2.2	2.1	2.05	2.05	2.
40.	7.95	7.5	7.05	6.15	5.7	5.5	5.4	5.15	4.9	4.65	4.3	4.1	3.5	3.05	2.5	2.2	2.1	2.05	2.05	2.
41.	7.85	7.4	6.95	6.05	5.8	5.7	5.6	5.4	5.15	4.7	4.25	4.	3.55	3.2	2.6	2.2	2.1	2.05	2.05	2.
42.	7.7	7.325	6.875	6.025	5.925	5.925	5.9	5.475	5.075	4.5	3.975	3.65	3.3	3.325	2.675	2.275	2.1	2.05	2.05	2.
43.	7.55	7.275	6.85	6.075	6.275	6.2	6.025	5.425	4.975	4.3	3.725	3.375	3.075	3.325	2.725	2.325	2.1	2.05	2.05	2.
44.	7.45	7.3	6.933	6.467	6.7	6.433	6.017	5.35	4.85	4.117	3.517	3.15	2.833	3.167	2.833	2.35	2.1	2.05	2.05	2.
45.	7.35	7.4	7.1	7.1	7.1	6.6	5.95	5.25	4.75	3.95	3.35	2.95	2.75	3.	3.	2.35	2.1	2.05	2.05	2.
46.	7.35	8.2	8.	7.6	7.	6.5	5.85	5.1	4.65	3.75	3.2	2.8	2.6	2.9	3.2	2.37	2.1	2.05	2.05	2.
47.	9.	8.65	8.25	7.45	6.75	6.3	5.7	5.	4.45	3.6	3.05	2.65	2.5	2.75	3.25	2.45	2.1	2.05	2.05	2.
48.	9.05	8.5	8.05	7.2	6.55	6.1	5.55	4.85	4.35	3.45	2.9	2.55	2.4	2.65	3.15	2.52	2.1	2.05	2.05	2.
49.	8.7	8.1	7.7	6.875	6.275	5.85	5.35	4.7	4.2	3.35	2.8	2.425	2.3	2.55	3.025	2.635	2.12	2.05	2.05	2.
50.	8.35	7.7	7.35	6.55	6.	5.6	5.13	4.55	4.05	3.25	2.7	2.3	2.2	2.45	2.9	2.75	2.15	2.05	2.05	2.
51.	7.89	7.18	6.91	6.23	5.7	5.32	4.93	4.37	3.91	3.13	2.6	2.2	2.12	2.35	2.78	2.95	2.17	2.05	2.05	2.
52.	7.43	6.66	6.47	5.91	5.4	5.04	4.71	4.19	3.77	3.01	2.5	2.1	2.04	2.25	2.66	3.15	2.19	2.05	2.05	2.
53.	6.922	6.161	6.033	5.544	5.083	4.756	4.478	4.011	3.622	2.889	2.406	2.028	1.967	2.167	2.556	3.206	2.22	2.056	2.05	2.
54.	6.367	5.683	5.6	5.133	4.75	4.467	4.233	3.833	3.467	2.767	2.317	1.983	1.9	2.1	2.467	3.117	2.267	2.067	2.05	2.
55.	5.811	5.206	5.167	4.722	4.417	4.178	3.989	3.656	3.311	2.644	2.28	1.939	1.833	2.033	2.378	3.028	2.311	2.078	2.05	2.
57.	4.7	4.25	4.3	3.9	3.75	3.6	3.5	3.3	3.	2.4	2.05	1.85	1.7	1.9	2.2	2.85	2.4	2.1	2.05	2.
60.	3.35	3.17	3.19	3.03	2.97	2.91	2.87	2.79	2.52	2.16	1.9	1.67	1.61	1.78	2.02	2.61	2.82	2.19	2.05	2.
65.	1.9	1.9	1.9	1.9	1.9	1.9	1.9	2.2	2.025	1.812	1.663	1.425	1.425	1.578	1.762	2.225	2.937	2.537	2.137	2.
70.	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.8	1.7	1.6	1.45	1.3	1.3	1.4	1.55	1.9	2.4	3.1	2.4	2.05
72.	1.233	1.233	1.233	1.233	1.233	1.233	1.233	1.667	1.667	1.533	1.383	1.267	1.267	1.333	1.517	1.767	2.2	2.8	2.833	2.083
74.	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.55	1.6	1.45	1.3	1.22	1.22	1.27	1.45	1.65	2.	2.5	3.1	2.15
75.	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.5	1.3	1.4	1.25	1.2	1.2	1.25	1.4	1.6	1.9	2.35	3.05	2.2
80.	1.	1.	1.	1.	1.	1.	1.	1.35	1.2	1.25	1.2	1.12	1.12	1.12	1.25	1.35	1.52	1.75	2.15	3.05
85.	1.	1.	1.	1.	1.	1.	1.	1.15	1.1	1.1	1.1	1.05	1.05	1.1	1.15	1.2	1.2	1.3	1.45	1.7
90.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.	1.

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