External blast load on structures – Empirical approach

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ABSTRACT

Modeling structures response to blast loads interests more and more people concerned about industrial accidents and/or terrorism. Today, two approaches are available: one can either use an ALE model (*ALE) with a lagrangian-eulerian coupling (*CONSTRAINED_LAGRANGE_IN_SOLID) or a pure lagrangian approach where an analytical loading of the structure replaces the computation of the propagation.

The lagrangian approach allows the use of a much smaller model since only the structure is modeled. This kind of approach, based on the empirical model described in the TM5-855 US army handbook (CONWEP), is currently available in LS-DYNA (*LOAD_BLAST). However, it is limited to the treatment of the explosions of hemispherical charges on the ground or spherical charges in the air without ground interaction. In many cases, the interaction of the shockwave with the ground induces blast reinforcement.

CRIL TECHNOLOGY, in order to get more precise blast load evaluation with a pure lagrangian approach, has developed a new user-loading model (evolution from *LOAD_BLAST) to take into account new abacuses for TNT and for reflecting coefficients, ground effects and Mach stem. Major evolutions are based on empirical models described in the TM5-1300 US army handbook. This new user-loading, in many cases leads to more precise and more conservative load while retaining a reasonable model size as the method is purely lagrangian.

1 INTRODUCTION

Shock waves generated by the explosions of high explosive charges can damage or destroy structures. Numerical models are used to study these phenomena. To precisely evaluate the shock propagation around the structure and the structure's response, FEM models have to be used. Using a fluid-structure interaction method (which does exist in LS-DYNA: *ALE, *CONSTRAINED_LAGRANGE_IN_SOLID) is possible. Nevertheless, this generates big models (fine 3D mesh, to define air from explosive to structure). Another possibility (also available in LS-DYNA. *LOAD_BLAST) is to use an empirical model to compute the load on the structure. This solution is far less expensive in CPU usage.

2 AIR BLAST PHENOMENA - GENERALITY

When a high explosive detonates, a pressure front propagates into surrounding atmosphere. This strong incident shock called the blast wave, is characterized by an instantaneous increase from ambient pressure to peak incident pressure. Generally this shock is characterized by use of a Friedlander formulation (positive phase) (1, 3, 4):

$$P_s(t) = P_{so} \cdot \left(1 - \frac{t - t_A}{t_o}\right) \cdot \exp\left(-\beta \frac{t - t_A}{t_o}\right)$$

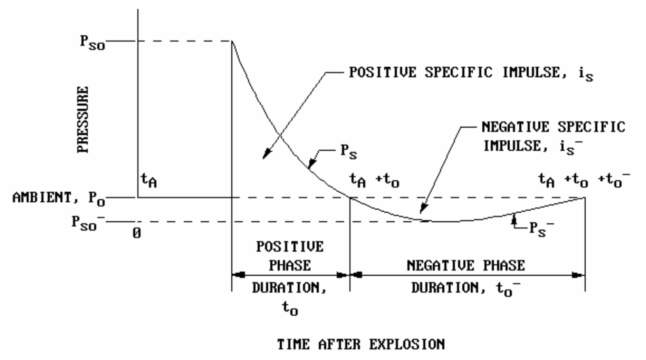


Figure 1: Pressure-time evolution (3).

Incident shock wave is characterized by: Pso, Ta, To and Is.

Air blasts phenomena can be separated into three categories: Free air burst, Ground reflection effects and Surface air burst.

2.1 Free Air Burst

Free Air Burst occurs when the incident wave reaches the structure before being reinforced. The main wave reinforcement takes place during ground impact.

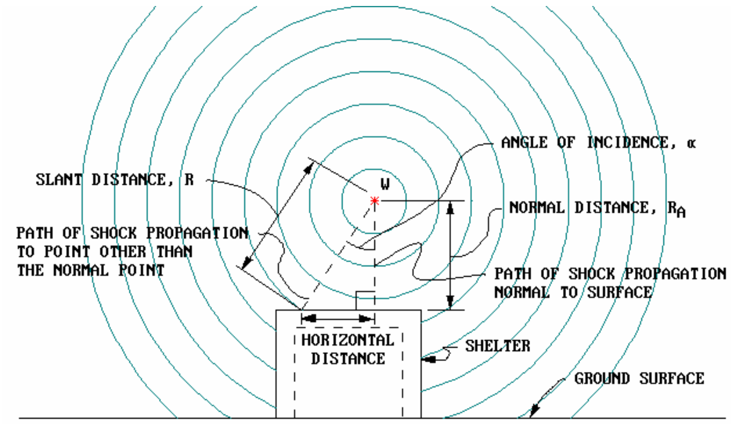


Figure 2: Free Airburst configuration (3)

2.2 Ground reflection

It is necessary to take in account the ground effect when the incident wave is reinforced by it. Two phenomena can occur: either a classical reflection (figure 3) or a reinforcement reflection (Mach Front, figure 4).

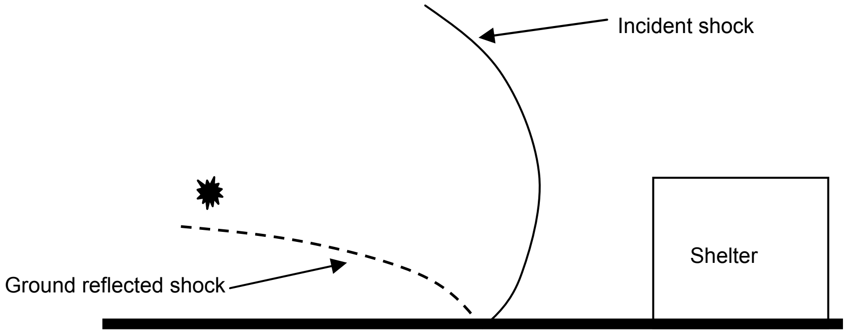


Figure 3: Ground reflection configuration – classical.

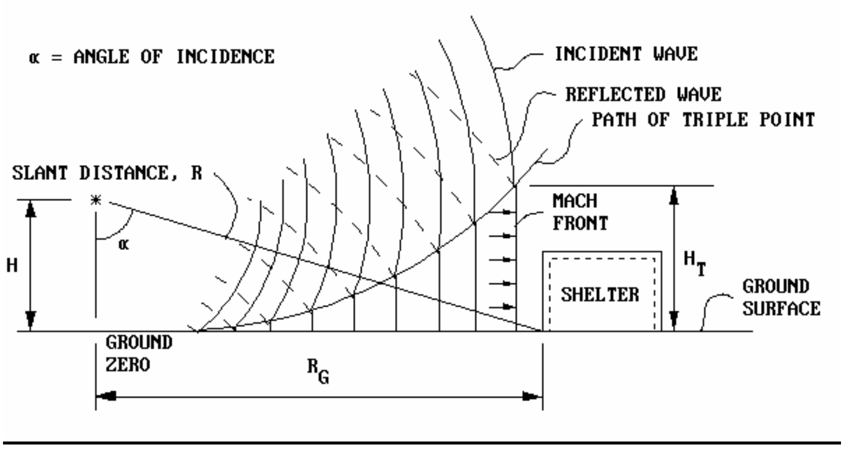


Figure 4: Ground reflection configuration – Mach Front (3).

The Mach Front is formed by the interaction between incident and reflected pressure waves. This interaction depends on the angle of incidence between ground and incident wave. The critical angle is of around 40°. The pressure-time variation of the Mach front is similar to that of the incident wave except that the magnitude is somewhat larger.

2.3 Surface burst

Surface airburst occurs when the charge detonation takes place close or on the ground. Unlike what happens in an air burst, the incident and reflected wave are merged near the detonation point to form a single reinforced wave. The created wave is hemispherical.

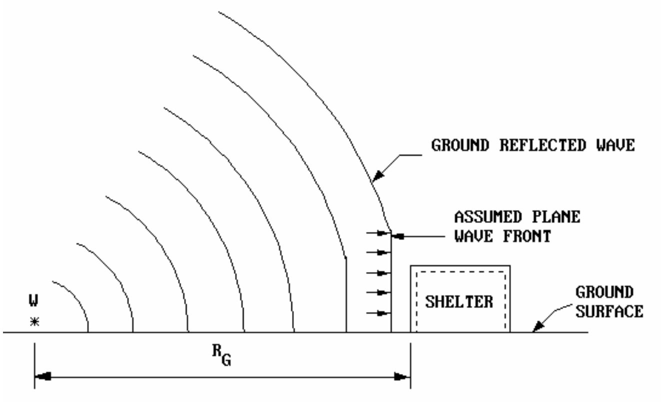


Figure 5: Surface burst configuration (3).

This wave merging can also take place very far from the detonation point when the height of burst is important (4).

3 AIRBLAST EMPIRICALS MODELS

Empirical model that enable the computation of the structure blast loading are based on abacuses which are themselves functions of the scaled distance *Z:*

$$Z=\frac{D}{\sqrt[3]{W}}$$

where D is the distance to the charge and W is the charge's mass

These abacuses define parameters which in turn define incident and reflected pressure shock waves. Only the positive phase of the wave is defined. As a result, the pressure profile could be defined by abacuses interpolations (1, 2, 3, 4).

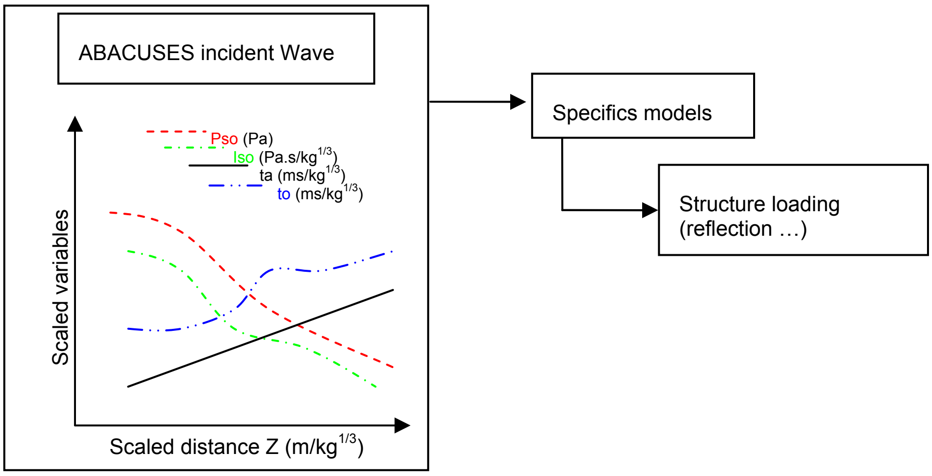


Figure 6: Schematic Empirical model.

Today, the *LOAD_BLAST keyword in LS-DYNA uses this kind of model to determine the structure blast loading. This model, described by Randers and Bannister, is partially based on the CONWEP model. The main modification consists in considering the incidence effect as the reflected impulsion on a semi-infinite target. Another method is possible. It is described in the TM5-1300 and is the method of choice today. The reflected pressure and reflected impulsion are computed using specific abacuses. In addition, methods presented in TM5-1300 permit to describe another important effect: the creation of the Mach Front.

The aim of this work is to implement the TM5-1300 empirical model in LS-DYNA using *USER_LOADING (dyn21.f) (5). In user loading model implemented by CRIL TECHNNOLOGY, five options are available:

- CONWEP – Surface Burst (similar to LS-DYNA *LOAD_BLAST)
- CONWEP – Air Burst (similar to LS-DYNA *LOAD_BLAST)
- TM5-1300 – Air Burst
- TM5-1300 – Surface Burst
- TM5-1300 – Air Burst + Ground Reflection

Models of ground reflection have to encompass both the Mach Front formation and the reflected wave on the ground. To simulate the ground reflected wave (without Mach Front occurrence) the method of image (M.O.I) is used. This method assumes that the reflection is perfect and that the reflected wave propagates in the ambient medium. As a result, it is possible to consider a virtual charge which is symmetrical to the real charge about the ground plane. The structure blast loading is obtained by linear shock addition.

Models characteristics are given in Table I.

Table I: Models characteristics.

<table>
<tr><th rowspan="2">MODELS</th><th rowspan="2">Incident wave</th><th rowspan="2">Ground reflection</th><th colspan="2">STRUCTURE LOADING</th></tr>
<tr><th>P reflected</th><th>I reflected</th></tr>
<tr><td>CONWEP Air Burst</td><td rowspan="2">Abacuses TM5-855</td><td>Not consider</td><td rowspan="2">trigonometric law integration reflected impulse</td><td rowspan="2">trigonometric law</td></tr>
<tr><td>CONWEP Surface Burst</td><td>partially, close to surface hemispherical charge</td></tr>
<tr><td>TM5-1300 Air Burst</td><td rowspan="3">Abacuses TM5-1300</td><td>Not consider</td><td rowspan="2">Abacuses Pr/Pso=G(Pso,α)</td><td rowspan="2">Abacuses Ir=F(Pso,i α)</td></tr>
<tr><td>TM5-1300 Surface Burst</td><td>partially, close to surface hemispherical charge</td></tr>
<tr><td>TM5-1300 Ground reflection</td><td>yes, plane Mach Front and classical reflection (M.O.I)</td><td>idem Air and Surface Burst Time recalling M.O.I linear shock addition</td><td>idem Air and Surface Burst</td></tr>
</table>

The models described in TM5-1300 are implemented because they enable the user to model the effects of reinforcement waves induced by Mach Front or reflection on the structure (angle of incidence around 40°).

4 EXAMPLES – LS-DYNA MODELS

A few examples are given here. The aim is demonstrate the differences between implemented models.

4.1 Pressure load compute by user loading model

This LS-DYNA model is based on Bannister works. It simulates the response of a column of high density fluid. This is just to test the user loading program and is not really a physical application. Due to the way that user loading is defined, it is necessary to use shell element to apply the blast loading. This is a restriction of LS-DYNA. As a result, the behavior law associated to shell element is *MAT_NULL. The model is presented in figure 7.

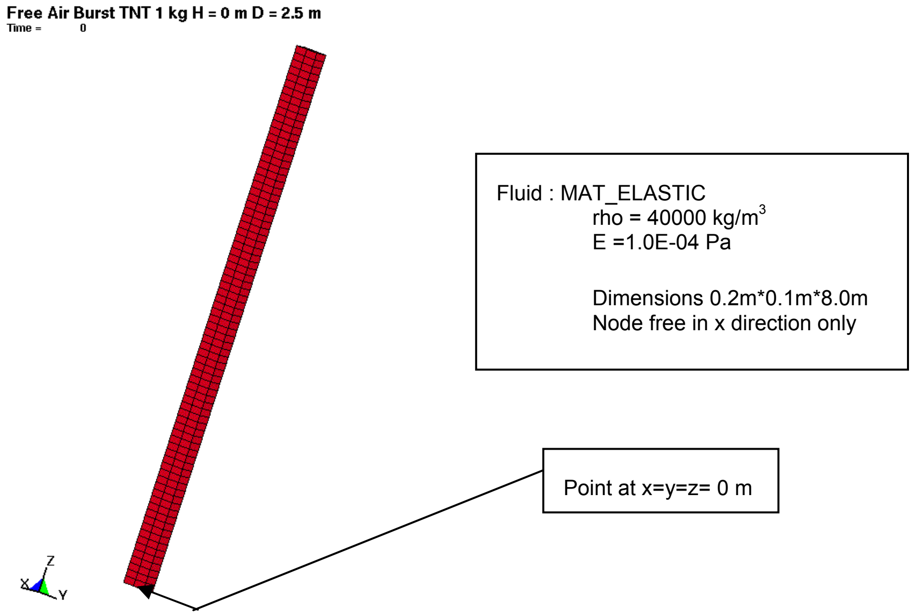


Figure 7: Model – user-loading test.

4.1.1 Incidence effect

The difference of the angle of incidence influence on the reflected wave, between ''CONWEP'' and ''TM5-1300'' air bursts, is presented in table II and figures 8 and 9. At low angle of incidence the overpressure are similar (Figure 8) but at high angle TM5-1300 approach leads to greater overpressure (Figure 9).

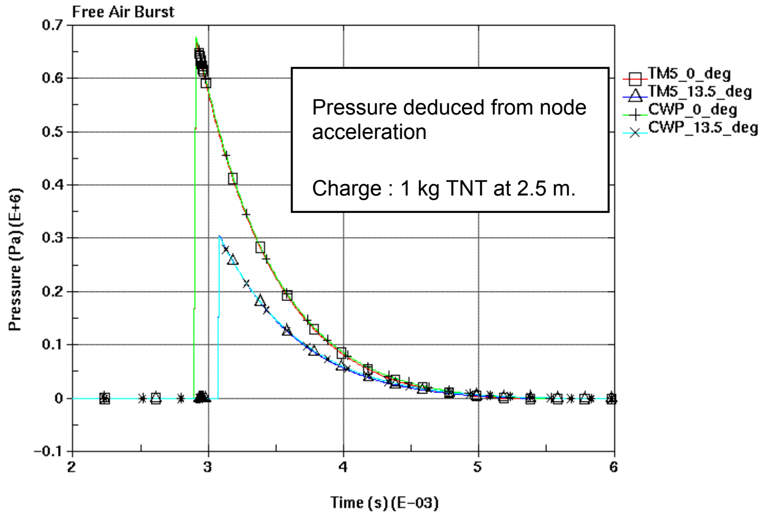


Figure 8: Time-pressure – angle of incidence < 13.5°.

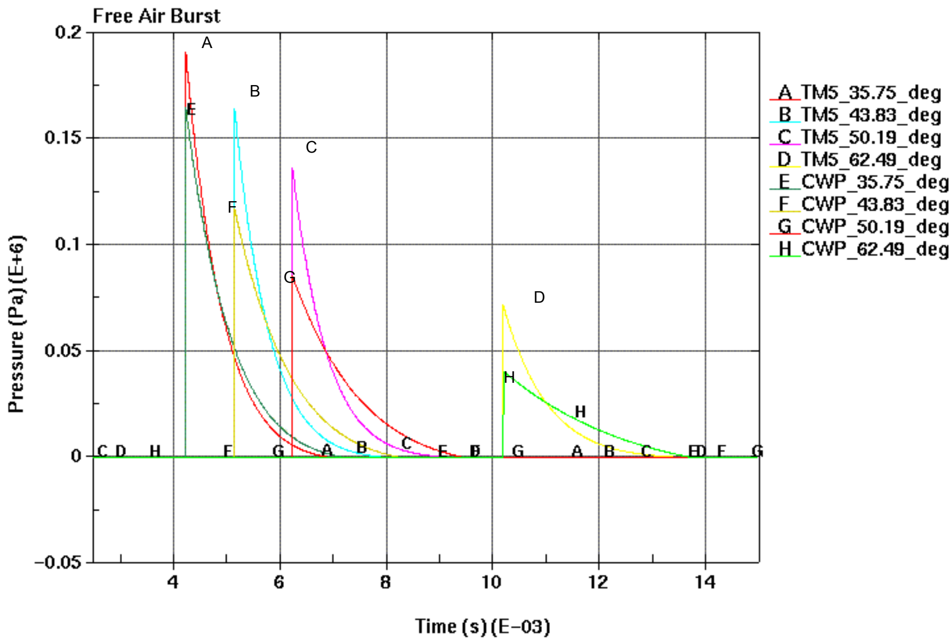


Figure 9: Time-pressure – angle of incidence > 13.5°.

Table II: Peak of reflected pressure and reflected impulse gaps.

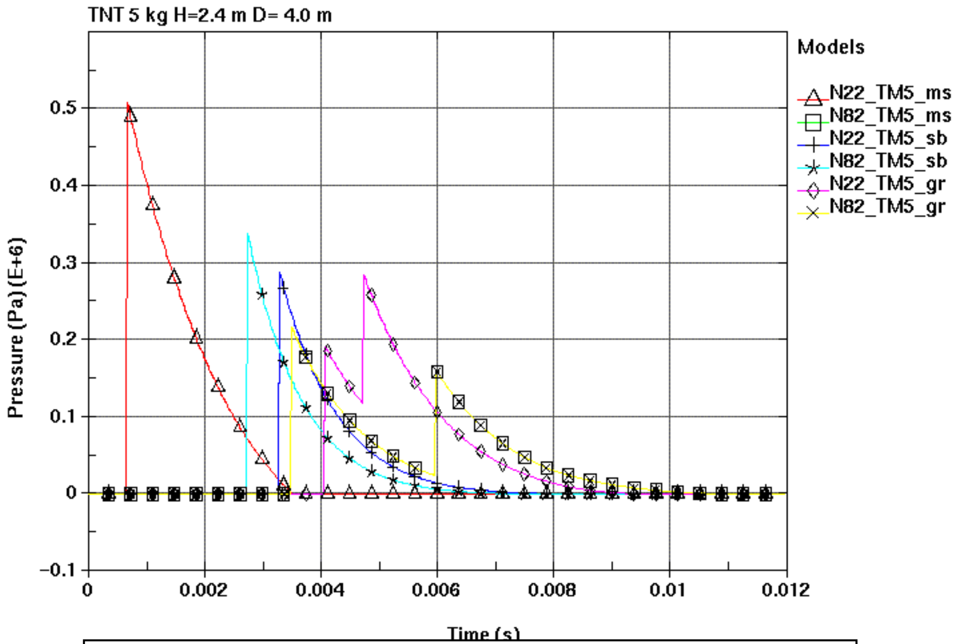
Angle (°)	Pr gap *	Ir gap*
0,00	-1,04%	-2,50%
13,50	-0,62%	-3,14%
35,75	13,65%	-1,62%
43,83	28,88%	-2,81%
50,19	37,39%	-3,84%
62,49	43,38%	-1,44%

* $\frac{TM5 - CWP}{TM5}$

As presented in table II, reflected impulses are similar with both approaches (gap very small). However, reflected pressure, at great incidence, computed with LOAD_BLAST approach (integration of the impulsion) is lower that the one computed with TM5-1300 approach (abacuses interpolations).

4.1.2 Ground reflection effects

The same LS-DYNA model is used here but the charge mass and position are different (5 kg TNT at (4.0,0.0,2.4)). The ground reflection effects that are only implemented in the user loading model are presented in figure 10 and Table III.



Nxx_TM5_tt with XX node number and tt model type
ms : Ground reflected + Mach Front
sb : Surface Burst
gr : Ground reflected only (M.O.I)

Nodes 22 and 82 are respectively at an altitude of 0.3 m and 1.3 m.
Node 22 is under triple point and 82 above.
Pressure is deduced from nodal acceleration in x direction.

Figure 10: Influence of ground reflected models.

Table III: Results.

Models	reflected pressure (Pa)		reflected impulse (Pa.s)	
	N22	N82	N22	N82
Mach Front	5,10E+05	2,85E+05	550,01	422,13
Surface Burst	2,89E+05	3,38E+05	270,2	299,64
M.O.I only	2,85E+05	2,85E+05	439,58	422,132

Overpressure under the triple point is greater when the model takes the Mach Front formation into account. Furthermore the Mach Front arrives before the incident shock computed with both the surface burst and MOI models.

The impulse transmitted to the plate is greater for Mach front and MOI models. Nevertheless, when the load point is above the triple point, this impulse could be slightly overestimated due to theoretical perfect ground reflection (no energy lost).

4.2 Example of Application.

A simple example is presented here. The plate response of a clamped steel plate to blast loading is simulated. The model is presented in figure 11.

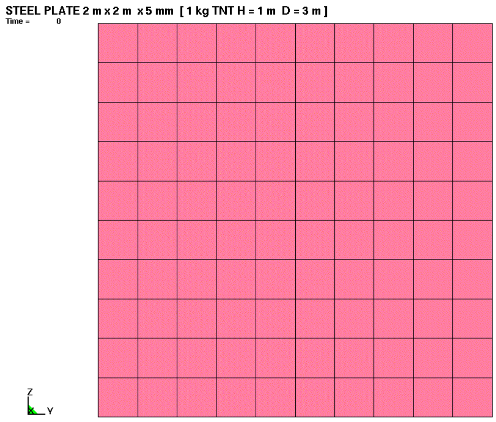


Figure 11: Influence of ground reflected models.

Results are briefly described in figure 12.

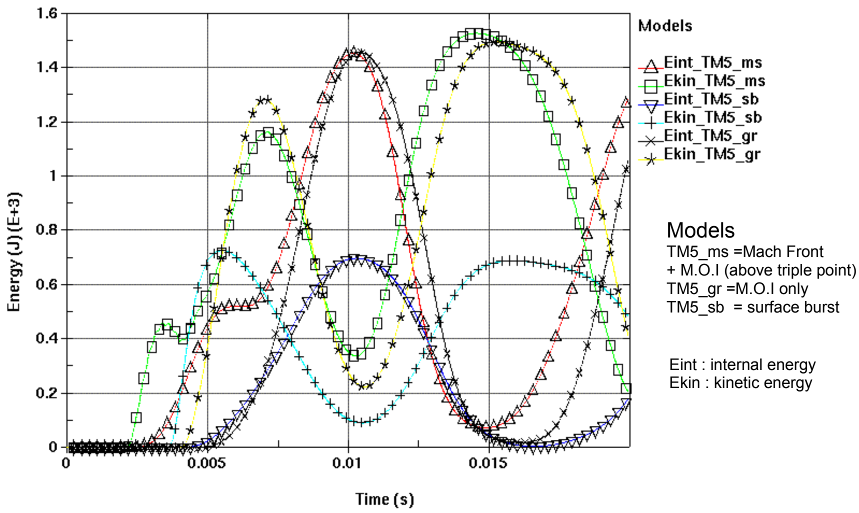


Figure 12: Energetic balance.

The energetic transmitted is greater when ground reflection is simulated due to greater impulsion with ground reflection models.

These new empirical blast load model has been successfully used by Cril Technology to study structure response of building and vehicle.

5 CONCLUSIONS

Compare to load blast approach, the use of models based on TM5-1300 in pure lagrangian approach for blast evaluation leads to more precise and conservative load. This is due to three main factors:

- Reflected pressure is more important

- Using the reflection coefficient from abacuses instead of integration of impulsion seems better.
- Simulation of a perfect ground reflection (M.O.I)
- Simulation of the Mach front

The *LOAD_BLAST option also works just fine when used within its domain of validity (Free air burst or surface Burst configurations). Its main flaws are the underestimation of reflected overpressure for angle of incidence greater than 40° and the lack of ground reflection models. As presented, the TM5-1300 approach corrects these limitations. Furthermore Using the TM5-1300 approach for blast load evaluation seems more appropriate as this handbook is the reference manual for pyrotechnic safety studies.

The user loading developed by CRIL TECHNOLOGY could be improved through different ways including:

- Better treatment of triple point junction
- Drag effect and dynamic load
- Clearing effect (finite target)
- Better treatment of classical ground reflection.
- Internal blast

One limitation of the LS-DYNA user loading procedure is the mandatory use of shell elements, the possibility to use a segment set would add appreciable flexibility.

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