NUMERICAL BENCHMARK SIMULATION OF EXPLOSION PROBLEMS ACCORDING TO NATO TTA 705 USING ALTAIR HYPERWORKS RADIOSS

MÔ PHỎNG SỐ CÁC BÀI TOÁN NỔ ĐỐI CHỨNG THEO TÀI LIỆU NATO TTA 705 SỬ DỤNG PHẦN MỀM ALTAIR HYPERWORKS RADIOSS

Hoang Van Nam*, Do Xuan Thanh, Bui Van Phat
Military Ship Design Institute, General Department of Defence Industry
**Email: nam.mt.vtktqs@gmail.com*

ABSTRACT

This study presents a numerical benchmarking investigation to evaluate the reliability of Altair RADIOSS in blast dynamics simulations. Two configurations are examined: (i) spherical air burst explosion (diameter 100 mm) located 2 m above ground; and (ii) cutting failure of a 30 mm thick steel plate according to NATO TTA 705 standard. The multi-material ALE method is applied for air domain modeling, while hybrid FEM-SPH technique is used for structural failure simulation. Peak overpressure results show 26-32% deviation compared with Sadovsky empirical formulation but preserve the physical attenuation trend. The steel cutting mechanism is accurately reproduced with stable energy balance. The results confirm the applicability of RADIOSS in blast-resistant military structure design.

Keywords: *Blast simulation; ALE; FEM-SPH; Johnson-Cook model; NATO TTA 705.*

TÓM TẮT

Bài báo trình bày nghiên cứu xây dựng và kiểm chứng mô hình mô phỏng số các bài toán nổ đối chứng nhằm đánh giá độ tin cậy của việc ứng dụng phần mềm Altair RADIOSS trong tính toán động lực học nổ. Hai cấu hình điển hình được khảo sát gồm: (i) lan truyền sóng xung kích của khối thuốc nổ hình cầu đường kính 100 mm đặt cách mặt đất 2 m trong môi trường không khí; (ii) phá hủy tấm thép quân sự dày 30 mm theo tài liệu NATO TTA 705. Mô hình sử dụng phương pháp ALE đa vật liệu cho miền khí và kỹ thuật lai phần tử hữu hạn – hạt trơn (FEM-SPH) cho kết cấu thép. Kết quả đối chứng cho thấy sai số áp suất dư cực đại dao động từ 26-32% so với công thức thực nghiệm Sadovsky nhưng bảo toàn quy luật suy giảm theo khoảng cách. Mô hình phá hủy thép tái hiện rõ cơ chế cắt đứt và phân mảnh vật liệu. Kết quả nghiên cứu khẳng định khả năng ứng dụng của RADIOSS trong phân tích và thiết kế kết cấu quân sự chịu tải trọng nổ.

Từ khóa: *Mô phỏng nổ; ALE; FEM-SPH; Johnson-Cook; NATO TTA 705.*

1. INTRODUCTION

Blast loading represents one of the most severe dynamic loads acting on military ships and defense structures. Full-scale explosive experiments are costly, hazardous, and difficult to reproduce under controlled boundary conditions. Therefore, numerical simulation using hydrocode software has become an essential tool in blast-resistant design.

However, numerical models must be validated through standardized benchmark problems to ensure predictive capability. The NATO document TTA 705 provides reference configurations for explosive effects and structural cutting tests.

This study focuses on two benchmark cases:

- Air blast wave propagation in open environment with ground reflection.

- Explosive cutting of steel plate according to NATO TTA 705.

The objective is to evaluate the applicability of Altair RADIOSS in blast dynamics and structural failure simulations.

2. PROBLEM

2.1. Theoretical foundations

According to [1], the detonation products are described by the Jones-Wilkins-Lee (JWL) equation of state:

$$P_{jwl} = A\left(1-\frac{\omega}{R_1V}\right)e^{-R_1V} + B\left(1-\frac{\omega}{R_2V}\right)e^{-R_2V} + \frac{\omega(E+Q)}{V} \quad (1)$$

Where: P_{jwl} denotes the pressure of the detonation products, V is the relative volume (V/V_0), E is the internal energy per unit initial volume, Q represents the optional afterburn energy term, and A, B, R_1, R_2, and ω are empirical constants determined experimentally for a specific explosive. For PLA-NP explosive [3], parameters equivalent to Comp B are adopted with slight reduction of detonation velocity. Detonation velocity: D = 7980 m/s. Chapman-Jouguet pressure: P_{CJ} = 28 GPa.

In addition, air is modeled using the ideal gas equation of state [4]:

$$P(\mu, E) = (\gamma - 1)(1 + \mu)E \quad (2)$$

where P is the pressure, E is the internal energy per unit reference volume, μ is the volumetric strain defined as $\mu = \rho/\rho_0 - 1$, and γ is the ratio of specific heats. For air, γ = 1.4.

The steel plate is modeled using the Johnson-Cook elastoplastic material model [2]. In this study, the strain hardening behavior is expressed as $\sigma = A + B\varepsilon_p^n$ according to the RADIOSS material formulation. Here, σ is the flow stress, ε_p is the equivalent plastic strain, A is the initial yield stress of the material, B is the strain hardening coefficient, and n is the strain hardening exponent.

2.2. Numerical methods

2.2.1. Multi-material ALE formulation

The Arbitrary Lagrangian-Eulerian (ALE) method is used for air domain modeling. The mesh remains fixed in space while materials flow through elements, preventing severe mesh distortion during detonation product expansion.

2.2.2. Hybrid FEM-SPH technique

The steel plate is initially modeled with Lagrangian finite elements. When equivalent plastic strain reaches failure strain, elements are converted into SPH particles. This approach improves numerical stability and accurately captures fragmentation.

3. RESULTS AND DISCUSSION

3.1. Air blast benchmark

3.1.1. Model configuration

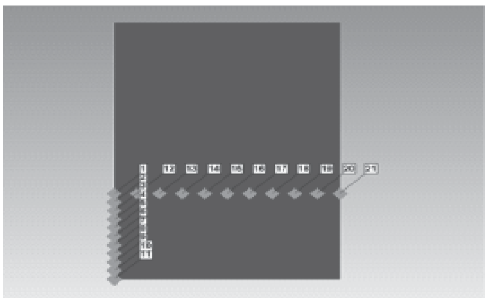
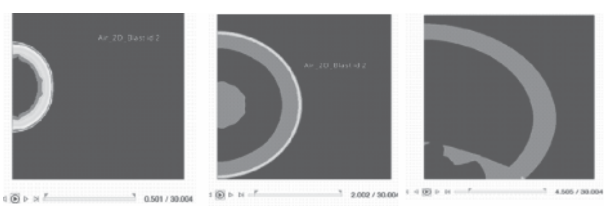


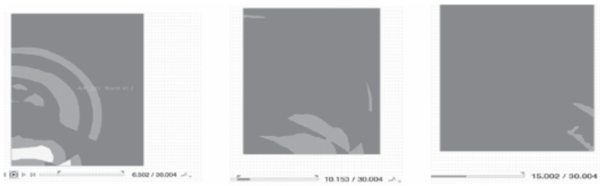
Figure 1. Numerical configuration of the spherical explosive charge positioned 2 m above the ground and the locations of pressure sensors.

A spherical explosive charge with diameter 100 mm is positioned 2 m above rigid ground. The air domain is discretized using Euler elements with mesh size 10 × 10 mm. Pressure gauges are placed at distances from 1.2 m to 4.0 m from the explosion center. Ground is assumed to be perfectly reflecting.

3.1.2. Overpressure comparison



0.5ms *2.0ms* *4.5ms*



6.5ms *10ms* *15ms*

Figure 2. Pressure-time histories obtained from the numerical simulation.

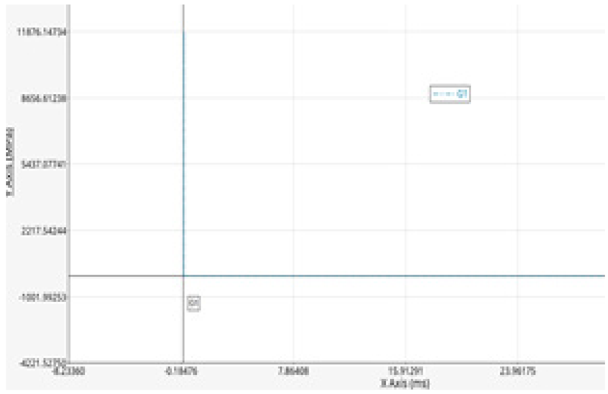


Figure 3. Pressure-time history at Gauge 1.

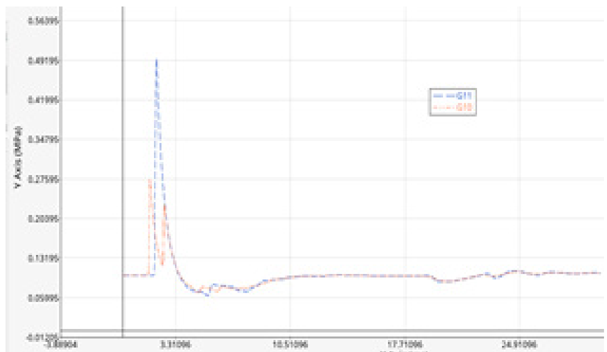


Figure 4. Pressure-time histories at Gauges 10 and 11 (near the ground surface).

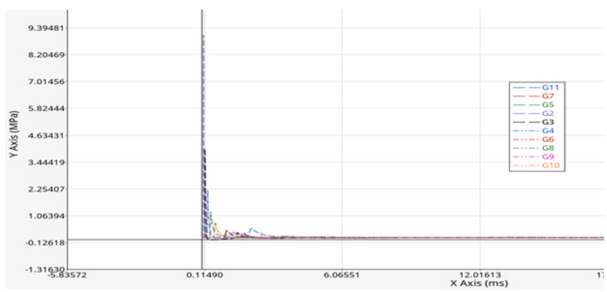


Figure 5. Pressure-time histories recorded at Gauges 2 to 9, corresponding to measurement heights ranging from 400 mm to 2000 mm.

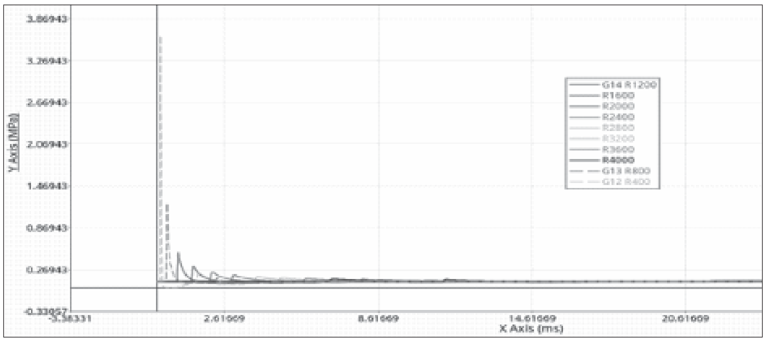


Figure 6. Pressure-time histories recorded at gauges located 2 m above the ground surface.

Table 1. Comparison between simulated peak overpressure and the analytical formulation of Mikhail Sadovsky

Distance r (m)	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
Scaled distance Z (m/kg$^{1/3}$)	1.3	1.7	2.1	2.5	2.9	3.3	3.7	4.2
Sadovsky analytical solution Δpm (kPa)	606.4	302.5	182.1	123.0	89.7	69.1	55.4	45.8
Numerical simulation (mesh size 10 mm × 10 mm) pm (kPa)	514	316.9	230	189.5	165.8	151.3	141.8	134
Simulated overpressure Δpm (kPa)	412.7	215.6	128.7	88.2	64.5	50.0	40.5	32.7
Absolute error (kPa)	193.7	86.9	53.4	34.8	25.2	19.1	14.9	13.1
Relative error (%)	31.9	31.9	29.3	28.3	28.1	27.6	26.9	28.6

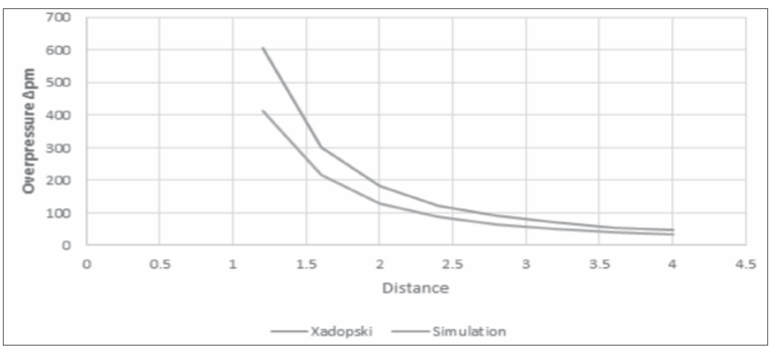
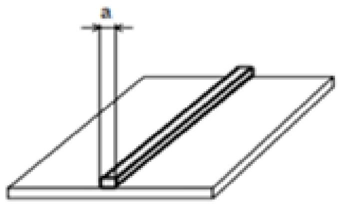


Figure 7. Graph of pressure as a function of distance.

Peak overpressure values are compared with Sadovsky empirical formulation. Relative deviation ranges from 26% to 32%. Although simulated values are lower than empirical predictions, attenuation trend with distance is preserved. The ALE formulation correctly reproduces shock front propagation and reflection behavior.

3.2. Steel cutting benchmark according to NATO TTA 705

EXPLOSIF	DISPOSITION DES CHANGES	MASSE D'EXPLOSIF NÉCESSAIRE : C	REMARQUES
PAINS	 Fig. 66 – Rupture d'une plaque simple avec du PLA-NP	**C = 0,4 kg/m** pour e < 0,4 cm **C = e** pour 0,4 ≤ e < 5 cm **C = 2 e** pour 5 ≤ e ≤ 8 cm avec: C: masse en kg par m de coupure e: épaisseur de la plaque en cm	**Mise en place:** la section transversale de la charge doit être proche de celle d'un carré de côté a. Pour aider à la mise en place du plastique, on peut calculer « a » par la formule approximative suivante: $a \approx 2,6\sqrt{C}$ C étant la charge en kilogramme par mètre de coupe

I1 convient de disposer de l'explosif sur toute la longueur à couper.

Au-delà de 8 cm d'épaisseur de la plaque. l'utilisation de charges spéciales est nécessaire.

Figure 8. Theoretical mechanism of steel plate cutting with PLA-NP explosive.

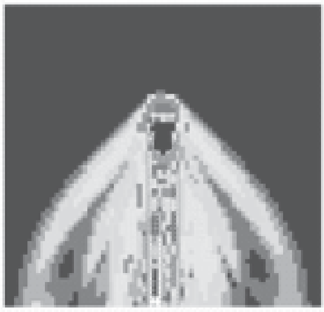
According to NATO TTA 705/GEN301 [5], explosive linear charge required for cutting 30 mm thick steel plate is: C = e = 3 kg/m. For 1 m cutting length, explosive mass equals 3 kg. In this study, the steel plate material is Hardox 500 TUF, which is widely used for high-strength and impact-resistant applications. The material exhibits a high yield strength of approximately 1250 MPa, providing significant resistance to plastic deformation under explosive loading conditions.

$$a \approx 2,6\sqrt{C} \approx 4,5 \text{ cm} \quad (3)$$

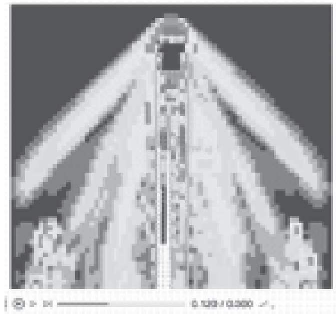
3.2.1. Failure evolution

At t = 0.03 ms, peak pressure forms at contact interface. At t = 0.15 ms, crack initiation and SPH conversion occur. At t = 0.30 ms, complete separation is achieved.

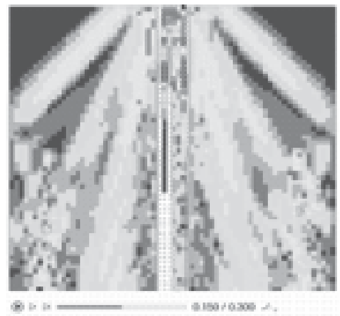
At t = 0.01ms *At t = 0.03ms* *At t = 0.06ms*



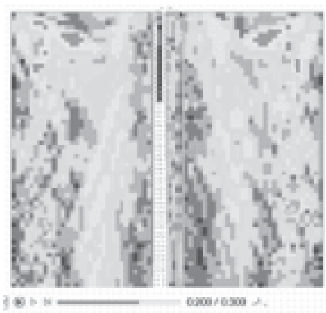
At t = 0.09ms



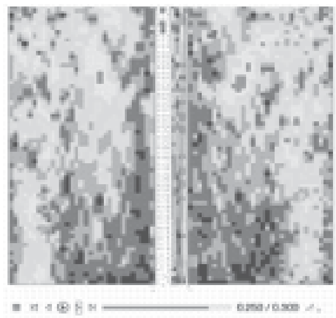
At t = 0.12ms



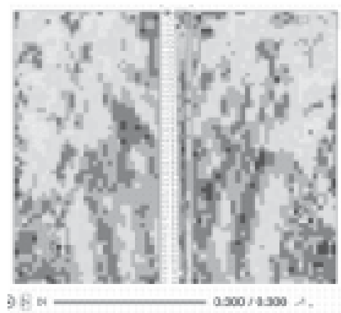
At t = 0.15ms



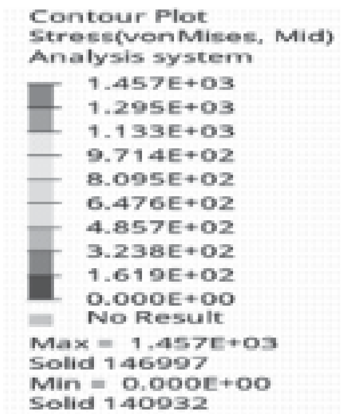
At t = 0.2ms



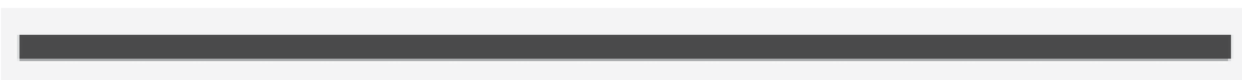
At t = 0.25ms



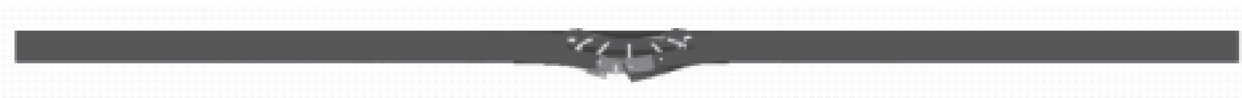
At t = 0.3ms



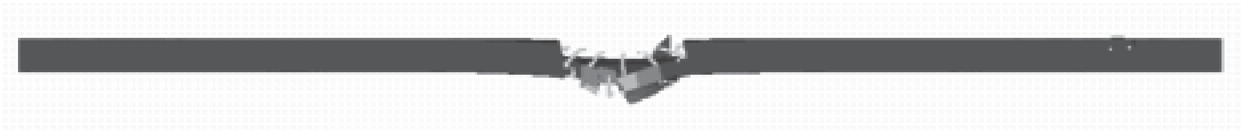
Von Mises stress distribution on the steel plate.



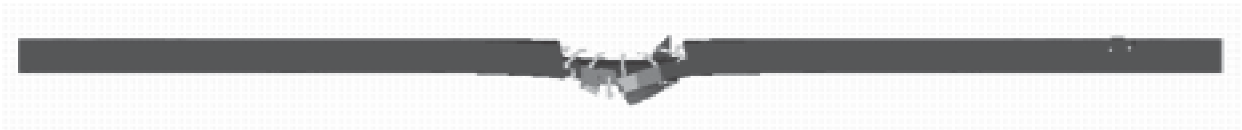
At t = 0ms



At t = 0.1ms

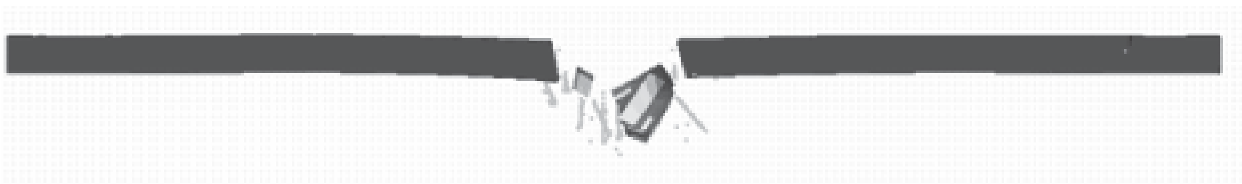


At t = 0.15ms



At t = 0.2ms

At t = 0.25ms



At t = 0.3ms

Figure 9. Propagation of failure stress in the steel plate at different time instants.

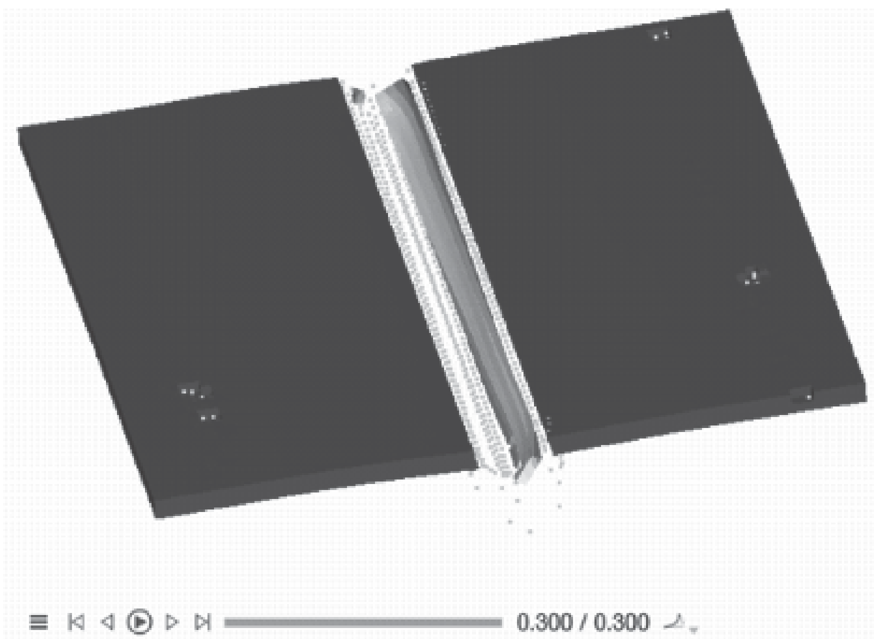


Figure 10. Overall view of the simulation results.

☞

Maximum equivalent von Mises stress reaches approximately 1457 MPa.

4. CONCLUSIONS

This study developed and validated numerical models for blast benchmark problems according to NATO TTA 705/GEN301. For instance, multi-material ALE formulation effectively simulates air blast propagation and ground reflection. Hybrid FEM-SPH technique accurately reproduces explosive cutting and fragmentation. Peak overpressure deviation (26-32%) remains within acceptable engineering range. Altair RADIOSS is suitable for blast-resistant military structural analysis and design. Future work will focus on mesh refinement study, sensitivity analysis of material parameters, and coupling with fluid-structure interaction for naval applications.

Acknowledgement:

The authors acknowledge the support of the Military Ship Design Institute.❖

References:

[1]. Altair Engineering, "*RADIOSS Theory and User Guide: Multi-Material, Fluid and Explosive Materials*". Altair HyperWorks 2023 Documentation.
[2]. Altair Engineering, "*RADIOSS Example Guide – User's Material Law for Shell Elements: Johnson-Cook Material Model Example*". Altair Engineering Inc.
[3]. Predrag M. Elek, Vesna V. Dingalašević, Slobodan S. Jaramaz, and Dejan M. Micković, "*Determination of Detonation Products Equation of State from Cylinder Test: Analytical Model and Numerical Analysis*". Thermal Science.
[4]. Mathis Loverini and Adrien Robert, "*Air Burst Explosion*". Altair Engineering Inc.
[5]. Ministère de la Défense, France, "*TTA 705/GEN301 – Memento sur les explosifs et les destructions*". Ministère de la Défense.