# Geometric Optimization of APCs anti Explosion Blades using LS-DYNA Finite Element Software

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**Abstract:** In this research, several different types of geometries have been compared to prevent the influence of an explosion wave on the glasses of the APCs. This was done using validation and then using LS-DYNA software. Pre and post-processing was done in LS-PrePost software. So, a mathematical function in this software was used to generate the pressure of the wave on the structure. In order to compare, the displacement parameter was used and the minimum total displacement of the structure as a criterion for optimal performance was considered. Also, two types of cosine curves, two types of polynomial curves (third and fourth order) and a flat blade are investigated. The results showed that for the use of a 150*100 mm2 square flat blade (which is half simulated according to the model's symmetry), the explosion of a wave coming from a distance of 75 mm on the adjacent sheet requires a sheet with a thickness of 11 mm. Using a curved blade, this thickness is reduced to 3 mm. According to the recent issue, the use of curved blades will lead to a sharp decrease in the weight of armored equipment.

**Keywords:** APC LS-DYNA, Blast, Explosion, Optimization, Wave

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## 1 INTRODUCTION

After the surge of explosive attacks and caused deaths and financial losses of these attacks in recent decades, exploring the effects of the explosion and its destructive effects on various structures, are specially considered, and it has led to the publication of numerous articles on the explosion.

On the other hand, given the geographical location of Iran and its location in one of the most dangerous places in the world, in terms of war and terrorist attacks, addressing the issue of defense, in various fields and particularly in relation to important structures and infrastructure is highly important. Therefore, it is necessary to investigate important parameters in this field. The result of past wars, especially the eight years of sacred defense, 43 day-war in 1991 Allies Against Iraq (Gulf War), NATO's 11-week 1999 war against Yugoslavia, 2003 the U.S.A and Britain war against Iraq, and Israel's recent 33-day war against Lebanon confirms the view that the invading country pays particular attention to bombing and destroying vital, sensitive, and important centers to disrupt the will of the nation and the political, economic and military power of the invaded country by adopting a strategy of destruction of the centers of gravity [1].

The history of the first explosions dates back to the 1870s and 1880s, with the aim of measuring the pressure from the explosion at various distances from the underwater explosion location [2]. Preliminary studies on structural explosion have investigated the underwater structure and investigated their dynamic deformation. Taylor [3] described experiments on large steel sheets measuring about 1.22 x 1.83 meters against underwater explosions located at different distances from the center of the sheet. The main measurements performed in cases where the sheet was not fractured included the insulating volume between the deformed sheet plate, its initial position, and maximum displacement [4].

Given the growing popularity of computer methods, the main focus of the explosion in the last three decades has been on these methods. Kivity and his colleagues [5] investigated the response of a structure to an internal explosion. In fact, they developed a computer model of the structural response to a wave of explosive substances that explode indoors. This simulation was performed using three-dimensional code by explicit method and considering the MSC / DYTRAN and fluid structure contrast. The modeled structure consisted of parts for explosion resistance such as panels in different parts of the structure [5].

Jacob et al. [6] carried out experimental experiments on fully bound rectangular sheets of 4 different thicknesses and varying length-to-width ratios under local explosive loading. Also, the distance and mass of the disk-shaped explosive material which was affected by the spacing and concentricity of the sheet, caused the center of the sheet to deform twice as thick as the sheet to its rupture. In this paper, the effect of changing load conditions and sheet geometry on deformation is described. In addition, numerical predictions have been made and comparisons have been made between these predictions and experiments for a limited number of geometries.

Mittal et al. [7] investigated the dynamic analysis of groundwater storage tanks under blast load. They examined cylindrical steel containers with a thin wall. These steel tanks were simulated in 3D using the finite element method in the Abacus software. The method used in this paper is the Eulerian-Lagrangian coupling formulation. In this paper, 4 tanks with constant cross-section radius and different heights and thicknesses are considered. Each of these tanks is designed to be filled in 50, 75, and 100% tanks, under explosive loads of large magnitudes modeled and investigated. Also, the support conditions of each of the tanks are considered as three types of support, fixed support, simple support, and rigid support. The magnitude of the explosion pressure is also taken from different burst distances in the modified equation. Finally, in this paper, after modeling the reservoirs, the shear stresses and shear stresses in the tank wall under the blast load and the maximum water wave height within the reservoir are investigated and compared. For this purpose, model the metal reservoir under explosive load by considering fluid-structure interaction using Eulerian-Lagrangian coupling formulation in Abacus software and analyze the parametric analysis of the structures against the parameters affecting the behavior of the structure using the obtained results. One of the benefits of the Eulerian-Lagrangian coupling method is to eliminate the limitations of the Eulerian and Lagrangian methods and to provide the conditions for simultaneous modeling of the Eulerian and Lagrangian domains interacting with one another.

R. Monfared and his colleagues [8] investigated the effect of blast load on non-buried concrete tanks using LS-DYNA software. The results showed that for the explosive charge, the local degradation is greater in the range where the wave reaches earlier than elsewhere. As the blast distance extends beyond the structure, local degradation becomes volumetric and total degradation. In fact, according to the results of this paper, the wave development on the structure and its effective strength at the TNT constant mass are two effective factors whose simultaneous effect causes more explosive effects on the structure.

Aghakouchak et al. [9] investigated the effect of blast wave on cylindrical-shaped structures. This was taken into account because the creation of complex vortices and currents on cylindrical geometrical components complicates the study of the pressure distribution on them. In this work, numerical simulation is used and pressure distribution for different cylinder diameters is obtained.

Sahoo et al. [10] investigated the performance of blasted single and multilayer homogeneous sheets using Abacus software. In this paper, several cannabis species were studied using Canop 1 method. Their results showed that among the three alloys of aluminum, magnesium and steel, magnesium with a similar weight had less deformation than the others. Under the influence of lamination, the behavior of aluminum and steel improved, but the behavior of magnesium did not change significantly. Also, different compounds of these three metals were considered in the study.

Saber et al. [11] examined the curvature and curvature of the blast walls used to reflect the blast wave and to create turbulence in the blast wave to reduce the wave intensity. In this work, with the geometry of the canopy, 14% was added to the wave attenuation.

McDonald and his colleagues [12] investigated four types of armor and high strength blast resistance. Their work focused on the initiation of local blast failure and the extraction of a new dimensionless number to predict the blast empirically. Their work showed that the alloys listed are suitable for use in armor use and are safe and reliable armors.

The purpose of the present study is to propose the installation of curved blades on armored side glass in order to prevent the explosion wave and direct targeting of the inside armor. In this study, various geometries have been proposed and numerical simulations have been performed using LS-DYNA software and LS-PrePost preprocessor / postprocessor.

## 2 PROBLEM DESCRIPTION AND SIMULATION

### 2.1. Problem Description

Military equipment is generally made of materials that are sufficiently resistant to blast waves. Due to the operating conditions, some of the materials are not used. Among these materials and components are glass mounted on armor used to create visibility and ambient light. In this study, a variety of metal blades are introduced to prevent glass explosion from entering the glass. The blade schema mounted on the armored body is in “Fig. 1”.

### 2.2. GEOMETRIC Model

The dimensions of the blade were 150 x 100 mm square, with two dimensions of 100 mm and one side of 150 mm. Another 150mm (lower edge) is assumed to be free. According to the model symmetry, half of the model and the inner edge boundary conditions were defined as symmetry fit. The thickness of the base of the blade is designed to prevent them from bending against the blast. For this reason, the base effect is replaced by the creation of a fully clamped clamp on the blade in the simulation. The malfunction model used in this study is a strain that has a deletion element in the software after reaching this strain.

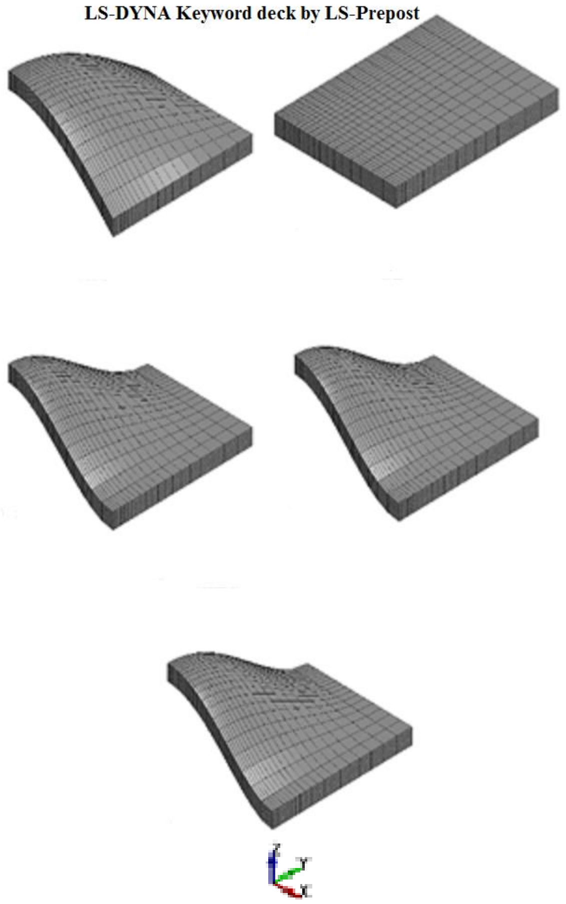

**Fig. 1** Blade schema mounted on the armored body.

In this study, five different blades have been investigated and four models have been proposed and investigated since the flat blade is provided for comparison purposes only. These models are based on two cosine shells and two polynomial shells. The equations of these shells are as follows:

The first cosine equation type:

$$z = A * \cos((\pi/(2 * 0.075)) * x) * \cos((\pi/(2 * 0.1)) * y) \quad (1)$$

The second cosine equation type:

$$z = A * 0.25 * (\cos(x * \pi/0.075) + 1) * (\cos(y * \pi/0.1) + 1) \quad (2)$$

Order polynomial equation (3):

$$z = A * (20.0753\,x3 - 30.0752\,x2 + 1) * (20.0753\,y3 - 30.0752\,y2 + 1) \quad (3)$$

Order polynomial equation 4:

$$z = A * (10.0754\,x4 - 42 * 0.0752\,x2 + 1) * (10.14\,y4 - 42 * 0.12\,y2 + 1) \quad (4)$$

An example of each blade is shown in “Fig. 2”.

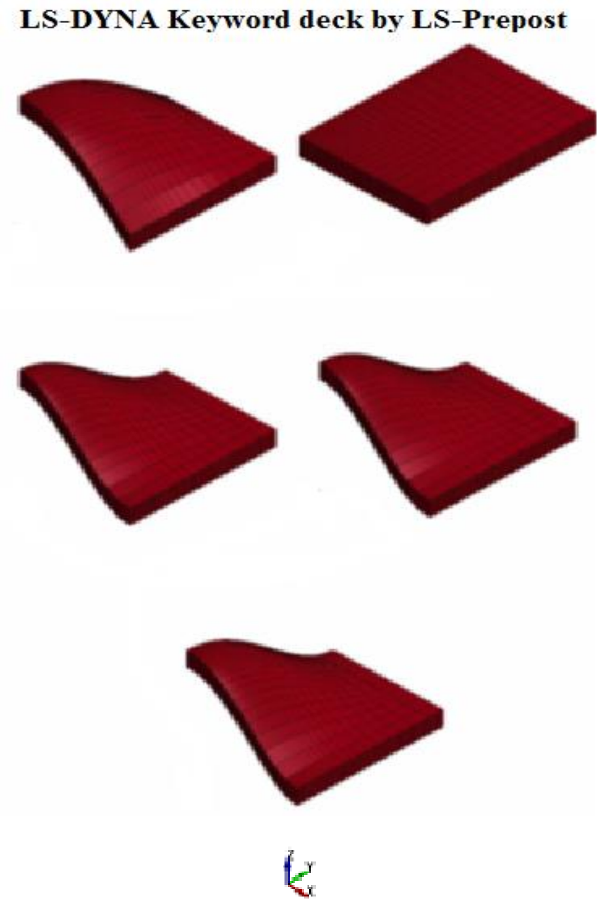

**Fig. 2** Blade image using surfaces: (a): Flat, (b): Type I cosine, (c): Type II cosine, (d): Polynomials of the third order and (e): Polynomials of the fourth order.

As can be seen in “Fig. 2”, the grid grows smaller at the blast site as it reaches the blade.

### 2.3. Materials

The material model used for the blade is Model 003 or MAT_PLASTIC_KINEMATIC. The material model mentioned is a simple model with isotropic strain hardening and strain rate dependence. The properties of the material are shown in “Table 1”.

**Table 1** Properties of steel in the simulation

| Numerical value | Parameter |
|---|---|
| 7800 | Density |
| 210 | Yang coefficient |
| 3.74 | Tangent coefficient |
| 1070 | Initial yield stress |
| 0.3 | Poisson's Ratio |
| 0.17 | The Meises strain broke |

### 2.4. Explosion

In the field of explosion simulation, a function (canopy) was used to calculate the pressure of the explosive charge at different distances from the structure. This method is suitable for simple geometries and has been used to model all parts of the Lagrangian approach. The LS-DYNA explosion-proof key is displayed as Load_Blast_Enhanced. The explosive, a 200-gram TNT-type ball, without cracking and its center distance from the blade was assumed in two different ways. In the first assumption, the distance to the nearest point to the blade was assumed to be 12.9 cm. In the second assumption, the distance was assumed to be constant relative to the location of the blades (or armored body).

### 2.5. Verification

The validation of the simulations was carried out according to the reference [12]. In this reference, the sheet deformation with four bound edges is investigated. One of these situations was simulated in this study. Figure 3 shows the deformation of the sheet (which was simulated for symmetry, a quarter of it) against blast and vertical displacement contour. The sheet size was 40 x 40 cm 2 and 40 grams of PE4 explosive at a distance of 50 mm. In this simulation, the maximum displacement was 0.0247 m, which was in accordance with the reference results.

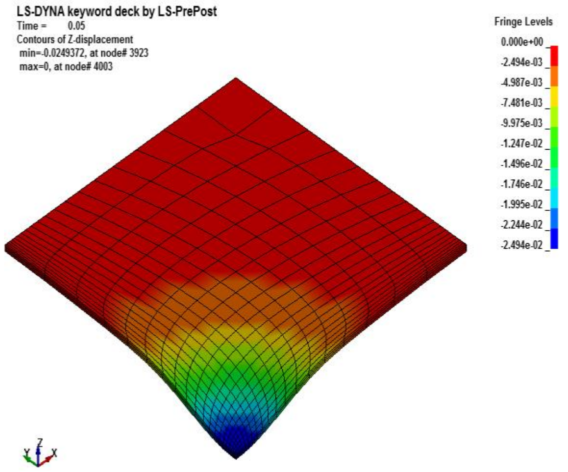

**Fig. 3** Vertical displacement contour for a quarter of a sample of 54.8 g TNT in 0.05 seconds (displacement to Meter).

## 3 RESULTS

### 3.1. The Thickness of the Blade

As the purpose of the study was to prevent the initial blast wave from passing through the blade, the study was conducted to find a thick range of blades that did not occur at the thickness of the blade.

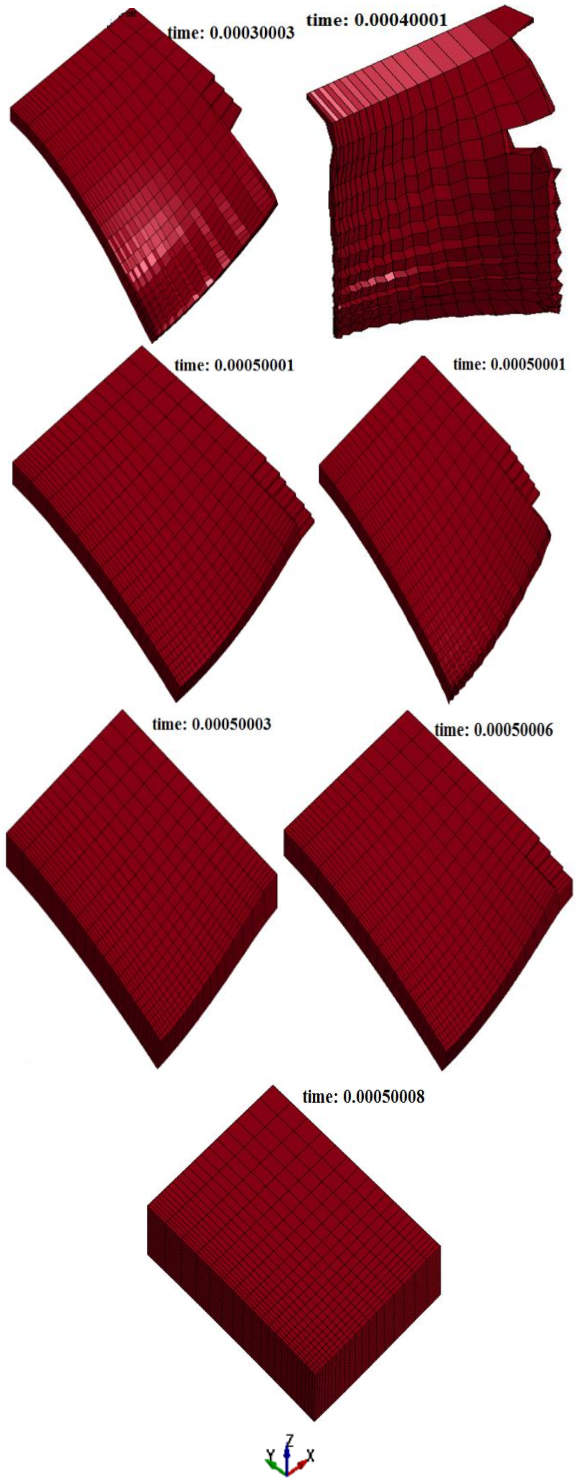

**Fig. 4** Flat blade deformation with a number of different elements in line with the blast thickness.

Considering the optimum thickness of each element (which is compared to the results of simulation with other reference results and the convergence of the network was about one millimeter in thickness for the best result), the number of layers with the thickness ranging from 2 to 15 was considered to be different, so 7 layers were obtained to prevent perforation (“Fig. 4”). Considering the design factor of 1.5, the number of layers reached 11 to prevent perforation. Other studies of this study are carried out in the following sections based on 11 thickness elements, otherwise the number of elements is mentioned.

### 3.2. Results of the First Type Cosine Model

In this section, the results of the first cosine model (Equation (1)) are compared. In order to investigate different simulation modes, rigid body displacement was used, which is an appropriate criterion to consider the overall displacement of the model. Coefficient A given in the details section of the simulations is optimization criterion in this section. By changing this coefficient, the model shape is modified and the results of maximum displacement are investigated. Considering manufacturing constraints, the coefficient A was evaluated between 0.01 and 0.2. For example, when the coefficient A is assumed 0.01, the rigid body displacement over time is shown in “Fig. 5”.

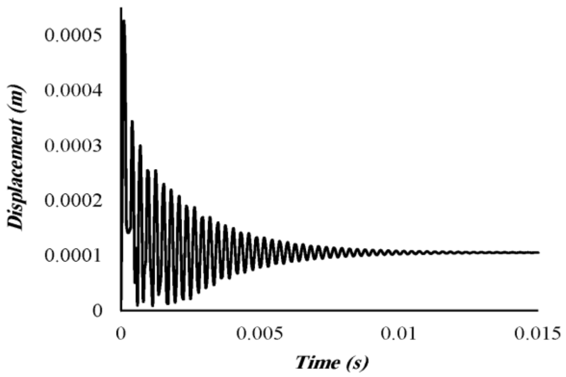

**Fig. 5** Time-displacement of rigid object for type I cosine geometry with coefficient A = 0.01.

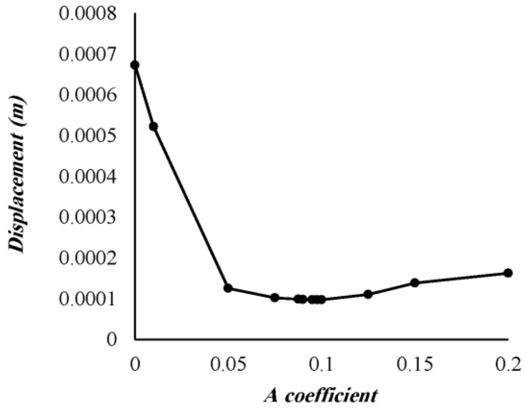

**Fig. 6** Maximum displacement of rigid object type cosine geometry for values of A ranging from zero to 0.2.

The maximum displacement values for the first cosine type geometry and the values of A ranging from zero to 0.2 are compared in “Fig. 6”. According to the results, geometry A = 0.095 can be a good choice with respect to the maximum displacement criterion.

### 3.3. Type II Cosine Model Results

As it was illustrated in Equation (2), one of the types of geometry considered in this study is type II cosine geometry. The coefficients A were used ranging from zero to 0.2.

The permanent deformation of the blades was less than 0.2 mm after the initial blast wave. It is important to note that in the simulations and for any of the A values, no damage to the structure occurred.

In order to investigate the optimal value for the coefficient A, the maximum displacement values of type II cosine geometry for the values of A in the range of zero to 0.2 are shown in “Fig. 7”. According to these values, the lowest displacement value was the coefficient A = 0.1.

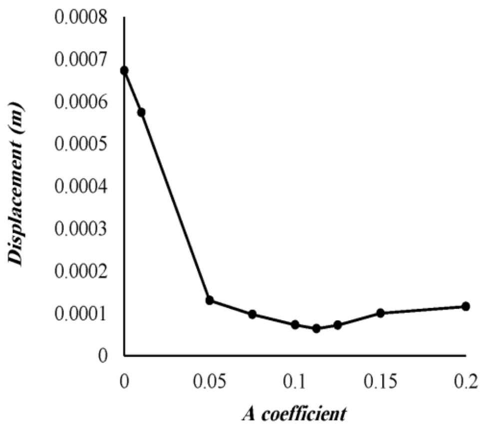

**Fig. 7** Maximum displacement of rigid object type cosine geometry for values of A ranging from zero to 0.2.

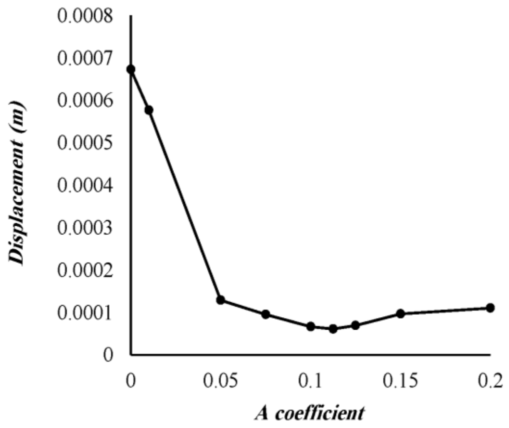

**Fig. 8** Maximum displacement rigidity geometry of third order polynomials for values of A ranging from zero to 0.2.

### 3.4. Results of the Third Order Polynomial Model

After examining two types of cosine models, three-order polynomial model was considered. The model shown in Equation (3), like the other models in terms of boundary conditions and maximum elevation point, is suitable for modeling.

Figure 8 shows the maximum displacement of the rigid polynomial of the third order polynomial for values of A ranging from zero to 0.2. Considering these values, A = 0.1125 can be a good option to prevent large displacements from blasting against the blade, because the rigid body displacement in it is minimal compared to other A values.

### 3.5. Results of the Fourth-Order Polynomial Model

Figure 9 shows the amount of rigid body displacement in a blade with a fourth-order polynomial geometry. From this figure we can see that A = 0.1125 gives the best result for reducing the displacement in this geometry.

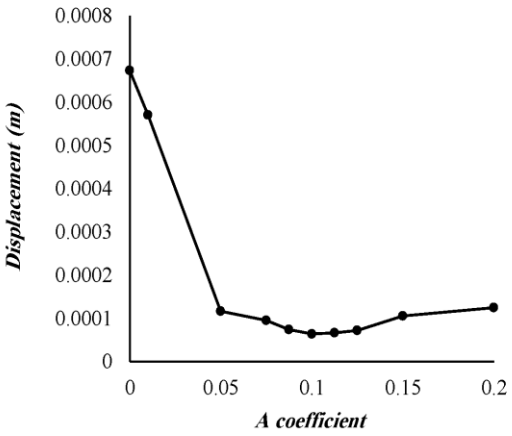

**Fig. 9** Maximum displacement of fourth-order polynomial rigid geometry for values of A ranging from Zero to 0.2.

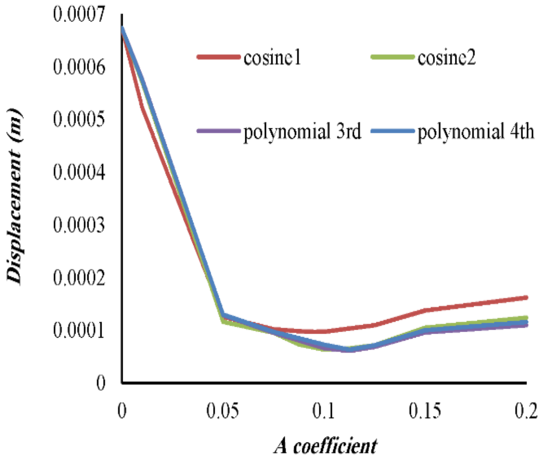

**Fig. 10** The maximum displacement of the rigid body of the curved geometries in the range of A from zero to 0.2.

In “Fig. 10”, the rigid body displacement is shown for all geometries. From this graph we can see that, except for the first cosine type geometry, the other geometries are quite similar in behavior. Even the first type cosine geometry behaves much better than flat geometry.

### 3.6. Results for Fixed Distance Mode from The Armored Body

Prior to this section, comparisons were made for cases where the distance of the center of the explosive from the point of maximum blade height was constant. In this section, the distance to the base of the blade or armored body is fixed. In order to provide a good picture of the displacement against A changes, “Fig. 11” is given for the first cosine type geometry.

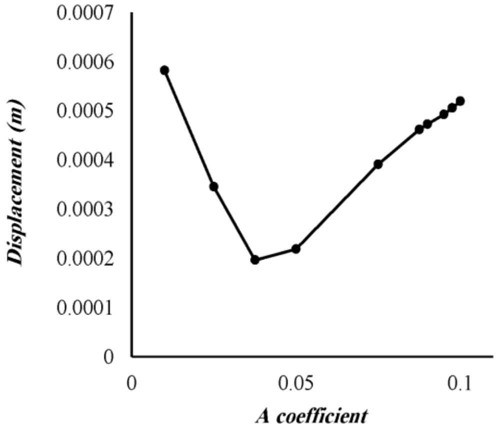

**Fig. 11** Maximum displacement of rigid object type cosine geometry for A ranging from 0 to 0.1 and constant distance from blade base.

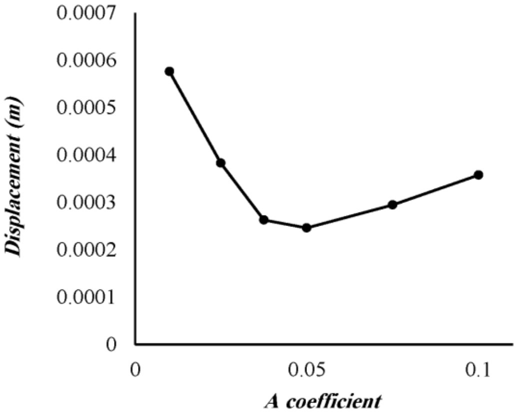

**Fig. 12** Maximum displacement of the third-order polynomial rigid geometry for A ranging from 0 to 0.1 and constant distance from the base of the blade.

In addition to the first cosine case, for the third order polynomials with a constant distance from the base of the blade, the maximum displacement was investigated. Figure 12 shows that the coefficient A = 0.05 leads to the minimum displacement.

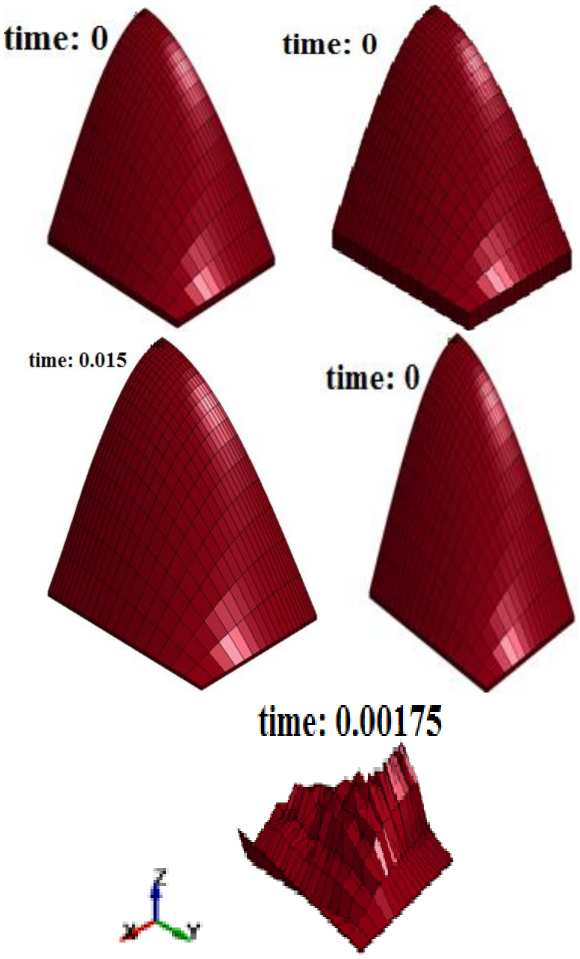

**Fig. 13** First type cosine geometries with coefficient A = 0.0975 and different number of elements along the thickness.

### 3.7. Study of the Number of Elements Along the Thickness for Non-Flat Blades

In the previous sections, the number of elements along the thickness of the rectangular flat blade was taken into account, taking into account the design coefficient and to prevent the hole in the blade, 11 numbers are obtained. Since the thickness of each element was 1 mm, the thickness was 11 mm. The thickness could be different for non-flat blades because they were more resistant to blasting. For this purpose, in this section, the effect of reducing the number of elements along the thickness of the blades on the blade perforation is studied. For this purpose, the first type cosine blade with different number of elements and coefficient A = 0.0975 was placed against the blast wave which was at a constant distance from the maximum point of blade height. By reducing the number of elements according to “Fig.13”, numerical instability has occurred for 1 element, but even with the two elements, the blade is not easily damaged by an explosion. Considering the design coefficient, with this geometry, 3 elements (3 mm thick) is sufficient to prevent the blade from piercing. The important thing is that the 1mm thickness may also be suitable for acceptable results considering the requirements for numerical stability. Due to the 7 elements in the line of thickness (regardless of the design coefficient) for the flat blade, the use of 2 elements for the curved blades reduces the volume of consumables to two-sevenths of the initial value. According to “Fig. 14”, as expected, the displacement increased with decreasing thickness.

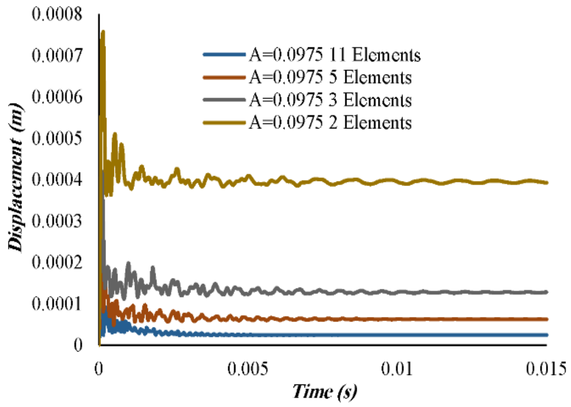

**Fig. 14** Displacement of rigid object cosine geometry type I with respect to time and A = 0.0975 and different number of elements.

## 4 CONCLUSION

Based on the results, the following conclusions are presented:

1. If the sheets and sheets mentioned in the blade research are used, the thickness required is greater than the curved modes and will be 11 mm considering the design factor of 1.5.
2. The use of the aforementioned curve modes (cosines of the first and second types, or polynomials of the order of three and four), greatly reduces the material used in making the blade. Considering the design factor of 1.5, the required thickness will be only 3 mm.
3. If the distance between the explosive and the point of maximum height of the blade geometry is considered constant, the first-order cosine model, the second-type cosine, the third-order polynomial, and the fourth-order polynomial, have an optimal A coefficient of 0.095, 0.1, 0.1125 and 0.1125 respectively. If this distance is assumed to be constant relative to the body of the armor or blade base, a smaller coefficient A will be required, so for the first type cosine and the third order polynomial, the optimal coefficient A is 0.0375 and 0.05 respectively.

## 5 LIST OF SYMBOLS

| | |
|---|---|
| A | The coefficient corresponding to the shell peak |
| x | Location variable (m) |
| y | Location variable (m) |
| z | Location variable (m) |

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