

## Research on Rapidly Shaped Charge Cutting Technology of Aircraft Damaged Thin-Wall Structure

A. Y. Cui,<sup>1</sup> F. Y. Hu, H. K. Wei, H. D. Liu, Z. Wang, and X. L. Dong

Aerial Mechanical Department, Qingdao Branch, Naval Aeronautical Engineering College, Qingdao, China

<sup>1</sup> caylaser@163.com

*Shaped charge cutting technology has been introduced into the field of aircraft structure repair to rapidly reshape irregular holes in thin-walled structures. In the present research, numerical calculation of the dynamic cutting process by ANSYS and experiments of shaped charge cutting on a 2A12 aluminum alloy plate with 2 mm thickness have been carried out. It was found that fast kerf is smooth, producing a neat edge and good linearity. The incision fracture section is arranged in neat rows on a corrugated strip, and the lines are clear. Otherwise, the lower part is slightly messy without obvious distribution rules. The target plate separation method of cumulative cutting is a kind of "pre-penetration" and "late tear" method. The application of shaped charge cutting technology can aid in repair of aircrafts' thin-walled structural damage.*

**Keywords:** cumulative cutting, jet penetration, fracture morphology.

**Introduction.** Skin damage is a typical aircraft failure mode. It comes in many forms, including broken holes, pitting, grooves, and deformation. When the damaged area is cleaned, dynamic tools are usually used for cutting and filing [1, 2]. These methods often have high workload, high consumption of time, high technical requirements for the operator, low efficiency, and difficulty as an effective means of rapid repair [3–6].

Cumulative cutting is a cutting technology that has been developed in recent years. Its operating principle is that explosive energy can be converted into kinetic energy of a metal covering. Thus, the penetration [7–13] of the target plate is done by a high-speed metal jet. This special cutting method has advantages of high speed and efficiency, convenient operation and no environmental limitations, which provides a new means to solve the fast cutting and dressing of damaged aircraft skin. This process is incomparable to conventional mechanical cutting methods. The introduction of shaped charge cutting technology into the field of aviation maintenance could be highly significant to engineering applications.

**1. Experimental Materials and Methods.** The dynamic process of shaped charge cutting was simulated by ANSYS finite element software. The resulting data was treated with the help of LS-DYNA program and LS-REPOST software [14, 15].

The experiment material was 2A12 aluminum alloy plate with 2 mm thickness. The metal covering was lead alloy, filled with RDX explosives.

**2. Numerical Calculation.** The model consists of RDX explosives, lead shell, air and a target plate. The charge density was 2.2~2.6 g/m, as shown in Fig. 1. The propagation path of the detonation wave is shown in Fig. 2. The detonation wave was diffused from the detonation point to its surroundings. The waveform was hemispherical, and the moving direction was lower. Over the course of 0.2  $\mu$ s, the detonation wave swept over most of the medicine core region, but in the medicine type at the bottom of the cover, the material was not influenced by the action of the waves. At 0.3  $\mu$ s, while the detonation wave was continuing to spread, burst detonation waves were sweeping the whole body of the cover.

The shapes and targets of the jet damage at different points in time are shown in Fig. 3. It is apparent that 0.5  $\mu$ s after initiation, the liner was crushed. The compressed deforming lead material fell to pieces. These pieces form into high-speed metal jets immediately, and pool toward the direction of the axes. At 0.9  $\mu$ s, the metal jet had reached the target plate

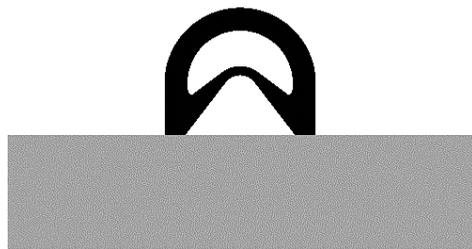


Fig. 1. ANSYS/LS-DYNA finite element model.

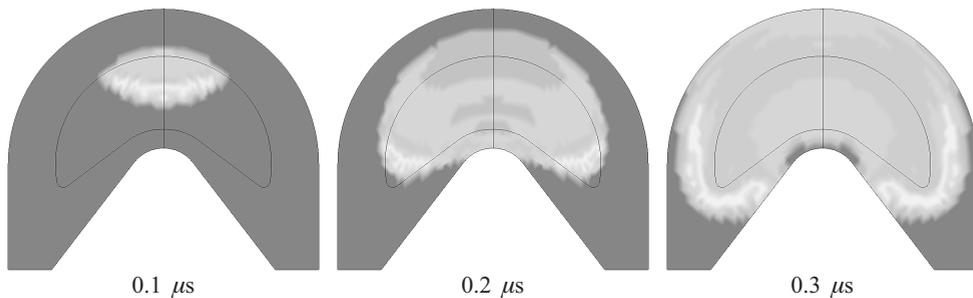


Fig. 2. Detonation wave propagation process.

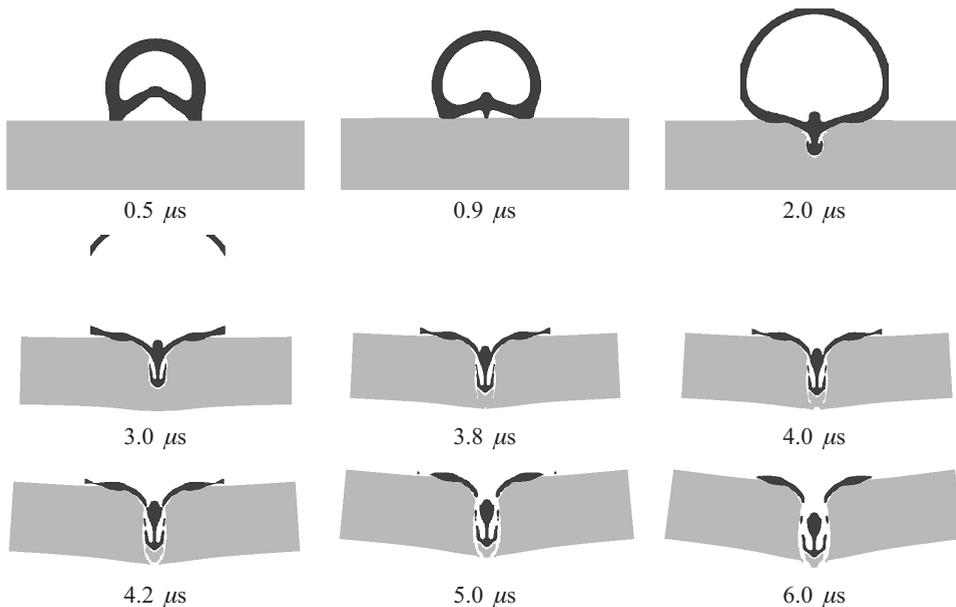


Fig. 3. Damage of jet shape and target for different times.

surface. The penetration process has begun. At 3  $\mu$ s, the cutting depth of aluminum alloy plate was over 50%. The jet stretched gradually because of its velocity gradient. The boundaries between the slug and jet became increasingly obvious. At 3.8  $\mu$ s, the target had not been penetrated. However, metal materials in the bottom of the plate had cracked. These cracks gradually became more and more severe. At the same time, the crack expanded down quickly, outpacing even the jet penetration. At the final time of 6  $\mu$ s, the target plate was separated completely into two parts. The penetration process of the metal jet as essentially over, as shown in Fig. 4.

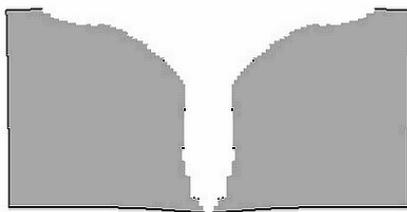


Fig. 4. Indication that the target plate is just the cut effect.

The incision morphologies are shown in Fig. 5. It can be clearly seen that the upper part of the incision is regular, without obvious penetration pits. This is due to the scouring of the metal jet. The lower part of the incision is very different. The breakage is caused by avulsion of the material itself. Upon further observation of the tearing process, it can be seen that the tears start at 22,405 point, 0.49834 mm to bottom edge. That is to say, the section of tear width is 0.49834 mm. Visibly, shaped charge cutting is a kind of “pre-penetration,” “late tear” target plate separation method.

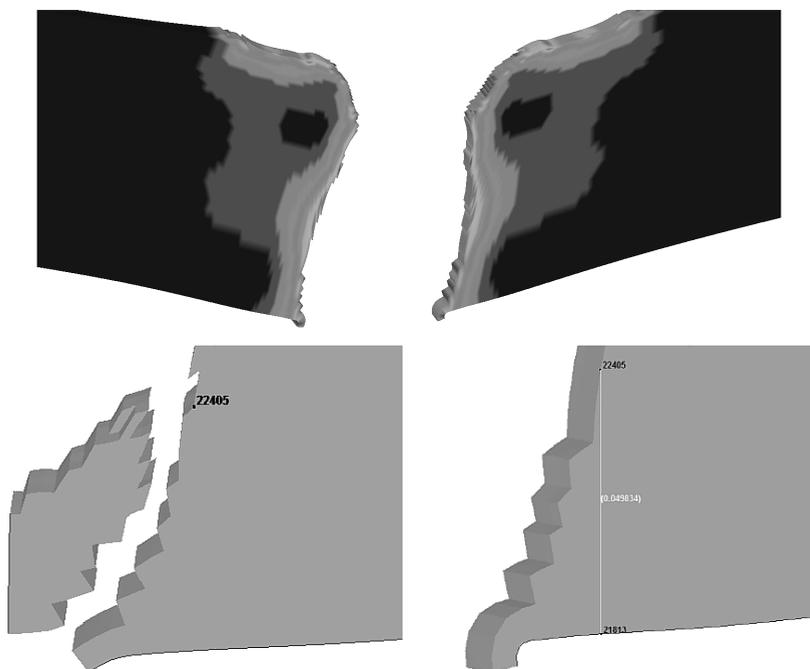


Fig. 5. The cut morphology, obtained by numerical calculation.

As shown in Fig. 6, by the order from top to bottom of the region where the jet flowed, six nodes from A to F were selected arbitrarily. Among them, at node A, B, and C, numbered 10,693, 10,698, and 10,703, respectively, the metal jet does not touch the target. At node D, E, and F, numbered 10,708, 10,718, and 10,738, the jet has begun to penetrate the target plate. The speed at different nodes is shown in Fig. 7. It can be seen that lead metal jet passes node A, B, and C successively, with increasing velocity. The speed of node C (1812.4 m/s) corresponds to the lowest point of the curve in the graph, at which the longitudinal coordinate is  $-0.18124 \text{ cm}/\mu\text{s}$ .

Observation of the curves at A, B, and C reveals that the speed begins to decrease immediately after it peaks, which suggests that there is indeed jet velocity gradient, and that

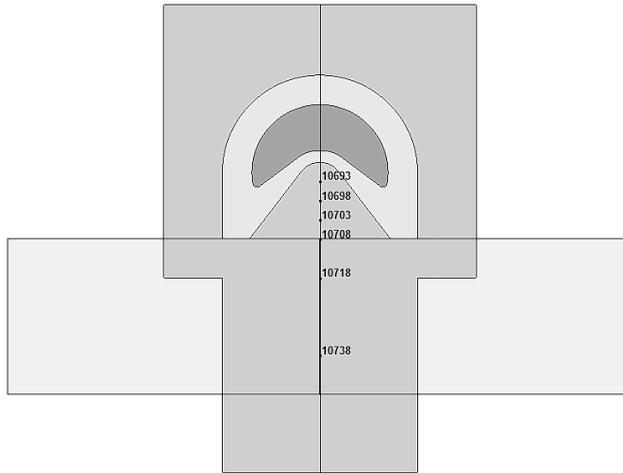


Fig. 6. Locations of selected nodes in FEM.

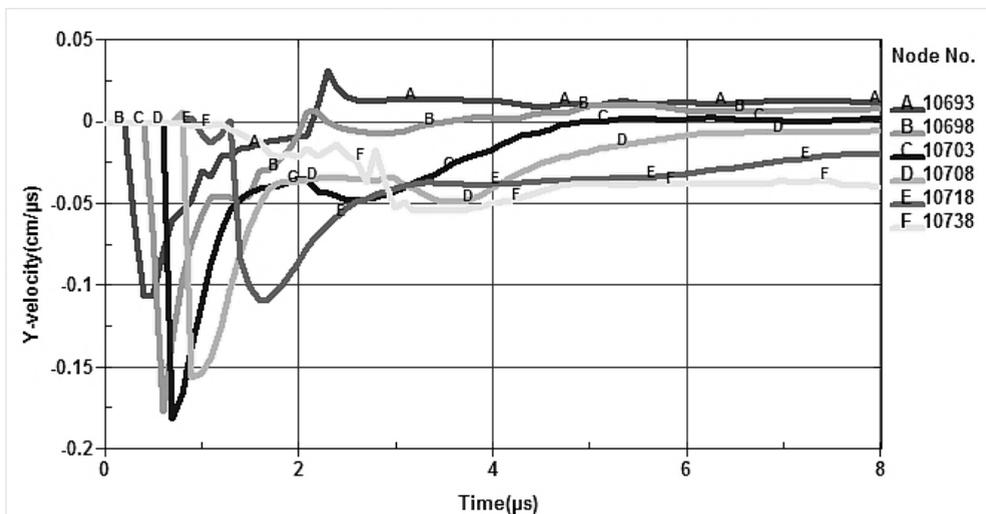


Fig. 7. Velocity curve (μs) of different nodes.

the maximum speed is in the jet head. Further from the head, the velocity of the jet decreases. In the curves of A and B, the values are greater than zero for some time, because part of the detonation product has bounced back after contacting the aluminum plate. Due to the obstruction of target plate, the velocity in the nodes D, E, and F is significantly less than that of A, B, and C, and tends to be stable.

**3. Cutting Experiment.** Experiments of shaped charge cutting on 2A12 aluminum alloy plates with 2 mm thickness were carried out in order to compare them to the simulated data. The cutting effect and fracture morphology of the experiments are shown in Figs. 8 and 9. Fast kerf was shown to be smooth, resulting in a neat edge and good linearity. The incision fracture part was arranged into neat rows of a corrugated strip, and the lines were clear. Otherwise, the lower part was slightly messy with no obvious distribution rules. It can be inferred that the fracture process of aluminum can be divided into two stages: firstly, the high-speed lead jet collides with the surface of the aluminum plate. Then, penetration occurs. Corrugated lines on the upper section were formed by the jet scouring. During the second stage, when the jet penetration reached a certain depth, the material at the bottom of



Fig. 8. Cutting effect chart.

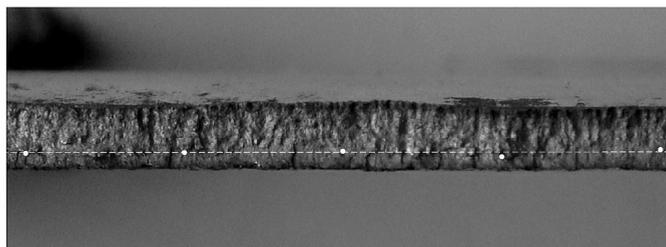


Fig. 9. Fracture morphology.

the aluminum plate reached its ultimate strength. At that point, tearing had occurred without jet penetration traces, which showed good agreement with the simulated results.

## Conclusions

1. Shaped charge cutting technology can conceivably be applied to the repair of aircraft thin-walled structural damage. Fast kerf is smooth, with a neat edge and good linearity.

2. The incision fracture section is arranged into neat rows of a corrugated strip, and the lines are clear. Otherwise, the lower part of the incision is slightly messy, with no obvious distribution rules.

3. The target plate separation method of cumulative cutting is a kind of pre-penetration and late tear.

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Received 03. 08. 2015