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Simulation of 85 mm Shaped Charge Jet tip Velocity and Penetration

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Abstract

The shaped charge jet formation depends on different parameters like explosive type, liner thickness, liner material and target material which can have effect on jet behavior such as jet velocity, jet breakup and penetration.

The objective of this work to simulate shaped charge jet velocity and penetration by using different methods.

The well-known 85 mm shaped charge simulated by using hydrodynamic theory for jet formation and penetration which is also known as Birkhoff theory and 2D-Autodyn simulation. In this simulation Autodyn explicit dynamic basing on finite element used to simulate jet velocity and compared with Birkhoff theory output.

Also the jet velocity for different four types of explosive and jet velocity distribution was studied through jet path by using Autodyn and Birkhoff theory.

Experimental penetration of 85 mm shaped charge was done to highlight the efficiency of our work.

Good agreement observed between experimental results and analytical and simulation results.

Autodyn simulation can improved to use in investigating protective shield materials which used in armor and car and to simulate multi layers target like oil well perforation which is too difficult to investigate with Birkhoff method.

Keywords: *Shaped Charge, Penetration, Jet Tip Velocity, Autodyn.*

1. Introduction

Shaped charge (SC) is an explosive with a hollow cavity in one end and detonator at the opposite end. The term shaped charge was taken from the shape formed at the explosive end. [1, 2, 3]

Today, it is employed for both military and civilian purposes in the oil well perforation and steel industries; in geophysical prospecting, mining, in demolition work and for hypervelocity impact studies. [4, 5]

These shapes can be made by fitting a concaved shaped metal liner which will provide density to the hydrodynamic jet produced by the blast for improved penetration .The liner shape is usually hemisphere, conical or trumpet and the most material used is copper cone liner. [6]

In the beginning of twentieth century Birkhoff et al. introduced the first theory of shaped charge jet formation and penetration, after that many researchers used and developed this theory.

This preliminary jet formation theory was advocated by Birkhoff (1943, 1947), and the steady-state, hydrodynamic theory of jet formation was formulated by Birkhoff et al. (1948). [7, 8, 9]

The penetration effect observed when a hollow charge is detonated near to the target. The penetration is produced by high-pressure, high-velocity gas erosion (the Munroe effect). The penetration in a target has to start from following facts:

The mechanical properties have substantial influence on jet penetration and the penetration stops when the jet tip velocity reaches jet tail velocity. [10, 11]

2. Model Description

The 85 mm shaped charge consist of copper conical liner, Aluminum confinement case, thermoplastic wave shaper, detonator and phlegmatize RDX as main explosive charge as shown in figure 1.

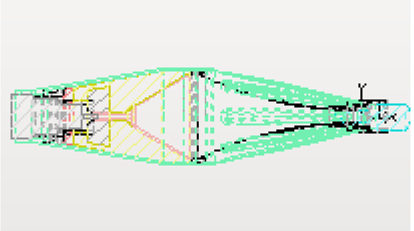

Figure 1: 85 mm Shaped Charge

3. Birkhoff Solution

3.1 Jet Formation

When the detonation wave impacts the conical liner with explosive velocity U_D, the pressure on all sides of the liner is assumed to be equal and the liner walls are assumed to collapse inward at a constant velocity V_0. The conical liner is symmetric, so α represents one-half of the liner apex angle and β represents the collapse angle as shown in figure 2 which describes the geometry of the collapse process, so we can calculate the jet tip velocity by using equation 1. [8]

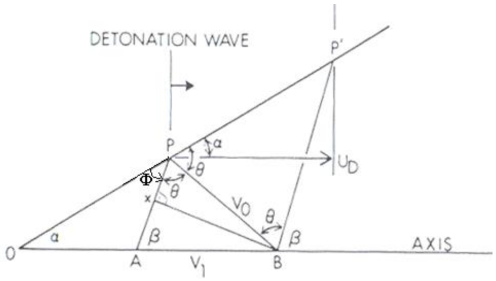

Figure 2: Geometry of the Collapse Process

$$\mathrm{Vj} = V0\left(\frac{\cos\left(\frac{\beta-\alpha}{2}\right)}{\sin\beta}+\frac{\cos\left(\frac{\beta-\alpha}{2}\right)}{\tan\beta}+\sin\left(\frac{\beta-\alpha}{2}\right)\right) \qquad (1)$$

3.2 Jet Penetration

Due to hyper velocities associated with shaped charge jets, the pressures produced during jet - target impact far exceed the yield strength of most materials. Thus, to a first approximation, the strengths and viscosities of the jet and target materials can be neglected, allowing usage of the familiar hydrodynamic assumption of incompressible, inviscid fluid flow. [12, 13, 14] Consider a shaped charge jet of length L_j, density ρj and velocity V_j penetrating a semi infinite target of density ρ_T can be calculated from equation 2. [2, 15]

$$P = L_j\sqrt{\frac{\rho_j}{\rho_T}} \qquad (2)$$

3.3 Steps of Solution Approach

1- Divide liner to (n) segments with (h) increment to calculate volume for each liner element as shown in figure 3.
2- Find mass of jet mji created from every segment of liner (from volume and given liner density).
3- Calculate radiuses of jet segments
4- Obtain penetration depth li for every part of liner involved in process of liner collapse.
5- Calculate the total penetration depth and jet tip velocity by using inputs data as shown in table 1.

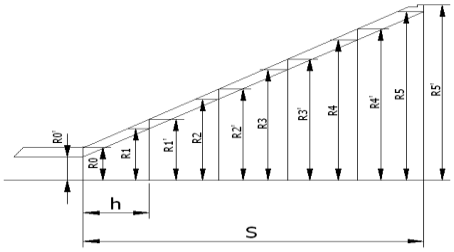

Figure 3: Liner Segments

Table 1: Birkhoff Inputs Data

n	Parameter	Unit
1	Cone apex angle	degree
2	metal confinement mass	kg
3	Total explosive mass	kg

4	shaped charge liner mass	kg
5	detonation velocity	m/s
6	Liner Thickness	m
7	Liner height	m
8	Stand Off Distance	m
9	Density of Jet	Kg/m^3
10	Density of Target	Kg/m^3

4. Autodyn Model Preprocessing

2D Autodyn model of 85 mm shaped charge was prepared by concentrated mesh at jet path as shown in figure 4 and penetration area and set six gauges to measure jet velocity figure 5.[16]

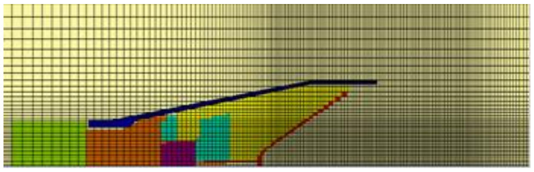

Figure 4: Mesh Distribution

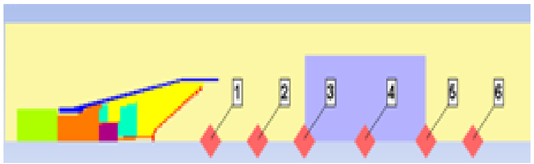

Figure 5: Gauges Setting

5. Experimental Work Setting

We fixed the shaped charge model with horizon angle 30 degree on 130 mm thickness steel plate to get 260 mm depth axial to shaped charge axis as shown in figure 6.

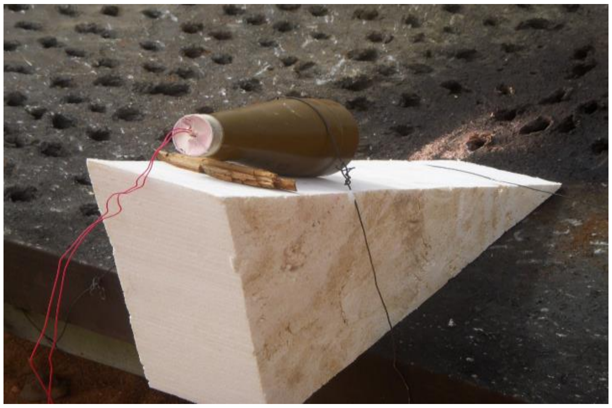

Figure 6: Penetration Test Setting

6. Results and Discussion

6.1 Jet Velocity

6.1.1 Birkhoff Methods

By using hydrodynamic theory of jet formation and made calculation base on equation 1 and input data in table 1 we calculated jet tip velocity of 85 mm for different four types of explosive TNT, Composition B, RDX and HMX. The results tabulated in table 2 which shown that increasing of explosive velocity lead to increase jet tip velocity.

Table 2: Birkhoff Jet Tip Velocity

N	Charge Type	explosive velocity (m/s)	Jet tip Velocity (m/s)
1	TNT	6930	5757
2	Comp B	7980	6659
3	RDX	8330	7001
4	HMX	9110	7602

6.1.2 Autodyn Methods

6.1.2.1 Maximum Jet Velocity

The jet tip velocity of four different types of explosive TNT, Composition B ,RDX and HMX at gauge number 3 shown in figures 7,8,9 and 10 and comparison between Birkhoff jet velocity and Autodyn jet velocity tabulated in table 3. Also comparison between two methods plotted in figure 11 which shown that the results of them are too closed.

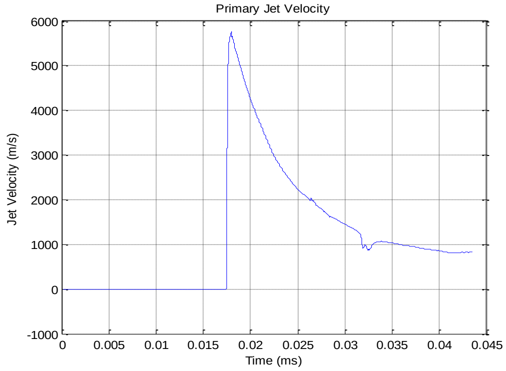

Figure 7: Jet Velocity of TNT

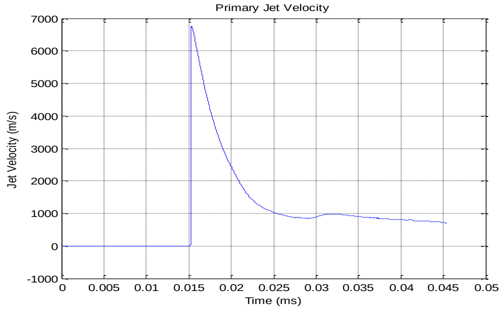

Figure 8: Jet Velocity of Composition B

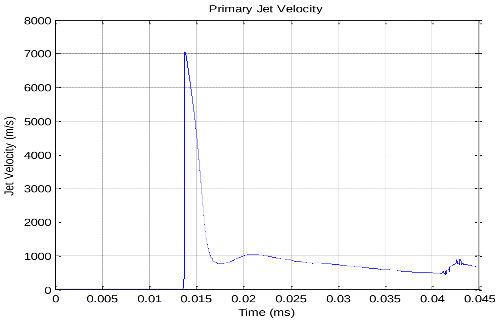

Figure 9: Jet Velocity of RDX

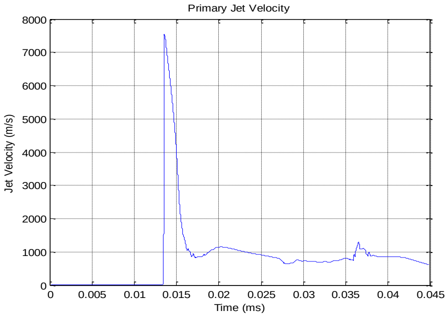

Figure 10: Jet Velocity of HMX

Table 3: Comparison between Jet and Explosive Velocities

N	Charge Type	explosive velocity (m/s)	Jet tip Velocity (m/s)	
			Birkhoff	Autodyn
1	TNT	6930	5757	5760
2	Comp B	7980	6659	6748
3	RDX	8330	7001	7049
4	HMX	9110	7602	7545

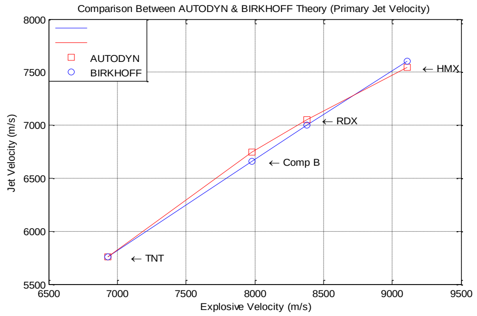

Figure 11: Comparison between Birkhoff and Autodyn methods

6.1.2.2 Jet Velocity Distribution

The jet tip velocity at different position through jet path for RDX charge shown in figure 12 which explained the maximum jet tip velocity decreasing with time and far away from original position as shown in figures 13 and 14.

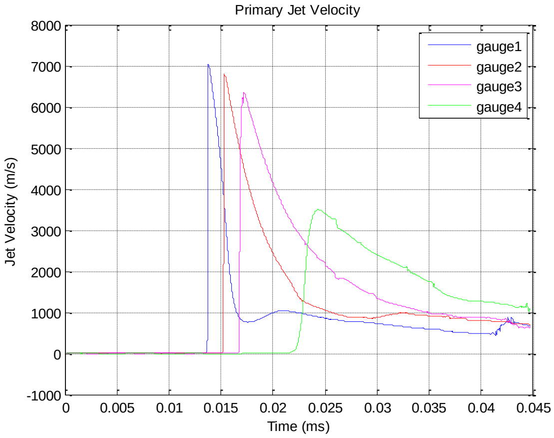

Figure 12: Jet Velocity at Gauges 1 to 4

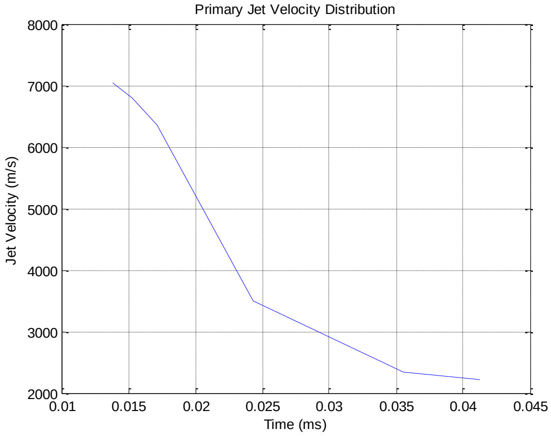

Figure 13: Jet Velocity Distribution with Time

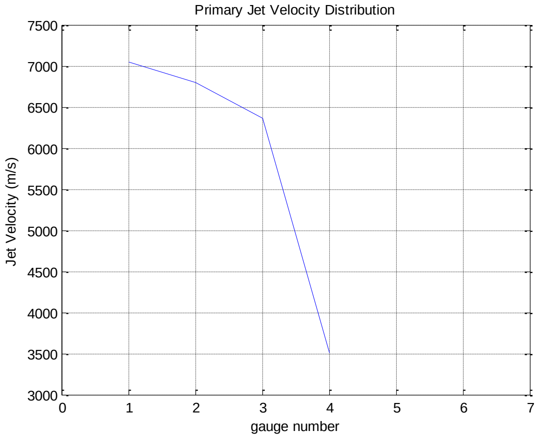

Figure 14: Jet Velocity Distribution with Distance

6.2 Penetration

6.2.1 Birkhoff Methods

By using equation 2 we calculated penetration depth is 261 mm on steel target.

6.2.2 Autodyn Methods

For phlegmatize RDX charge the jet tip velocity is equal to jet tail velocity at time 0.03 ms, so the penetration depth is 265 mm as shown in figure 15 and 16.

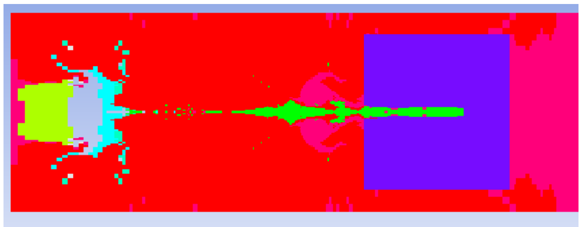

Figure 15: Jet Target Interaction

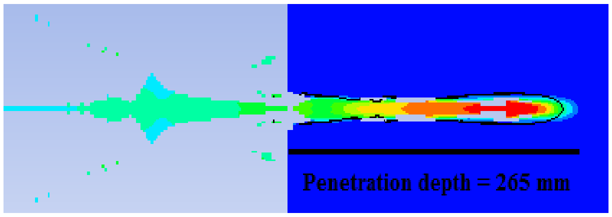

Figure 16: Penetration Depth on Steel Target

6.2.3 Experimental Methods

We did experimental test of our model to measure penetration depth as shown in figure 17 which is 260 mm and compared the experimental result with two previous methods Birkhoff and Autodyn.

The comparison tabulated in table 4 to highlight the efficiency of our work.

Figure 17: Penetration Test on Steel Target

Table 4: Comparison between Experimental and Birkhoff, Autodyn Method

No	Method	Penetration (mm)	Differences (%)
1	Experimental	260	0.00
2	Birkhoff	261	0.38
3	Autodyn	265	1.90

7. Conclusion

In this work we used Autodyn-2D simulation to simulate the jet velocity and penetration which is cited in Birkhoff theory.

The results about the jet velocity and penetration show good results and was much closed, so we can use Autodyn to simulate other different parameters.

Analytical method and Software simulation can integrated to design shaped charge and solve many kinds of problem because it’s very economic and safe and more faster than experimental tests.

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References

[1] Downes, D. and Bouamoul, “Development of an efficient numerical model for shaped charge analysis”, The Journal of Defense Modeling and Simulation: Applications, Methodology. DOI:1548512916643768,2016,pp 1-8.

[2] Freitas, P. J. And Gerace, D. M, “Demonstration of Lightweight Engineering Solutions for a Low-Cost Safe Explosive Ordnance Destruct Tool, 2007, DTIC Document.

[3] Walters, W. P. & Zukas J. A. “Fundamentals of shaped charges”, New York :Wiley Puplication, 1989.

[4] Zuklic S., Myers, B. & Satti, “Field Application Study of Zinc Based, Low Debris Perforating Charges”, SPE International Conference and Exhibition on Formation Damage Control: Society of Petroleum Engineers, 2016, SPE-178934-MS.

[5] Satti R., White R., Ochsner, D., Osarumwense O., Zuklic S. & Sampson, “New Insights into Optimizing Perforation Clean Up and Enhancing Productivity with Zinc-Case Shaped Charges”, SPE International Conference and Exhibition on Formation Damage Control: Society of Petroleum Engineers, 2016, SPE-178934-MS.

[6] Short J. A. , “Drilling: a source book on oil and gas well drilling from exploration to completion”, Oklahoma:PennWell Books, 1983.

[7] Walters W. & Segletes S., “Shaped charge devices with multiple confinements”, United States Patents, Patent Number: 5-847-312, 1998.

[8] Carleone, J. ,”Tactical missile warheads”, Clorado:AIAA Inc., 1993.

[9] Lloyd, R. M. , “Conventional Warhead Systems Physics and Engineering Design”, AIAA Inc., 1998.

[10] Slobodan Jaramaz, “Warhead Design and Terminal Ballistics”, Belgrade: University of Belgrade, 2000.

[11] Micković, Jaramaz & Elek, “Model for shaped charge warhead design”, Journal of Mechanical Engineering,Vol 58, 2012, pp 403-410.

[12] Kleiser & Lambert, “Control of Shaped Charge Jets Through Non-uniform Confinement”, Procedia Engineering, 2015, Vol 103, pp302-309.
[13] FU J., CHEN Z., HOU X. , LI, S. , Li S. & WANG J. , “Simulation and experimental investigation of jetting penetrator charge at large stand-off distance”, Defence Technology, 2013, Vol 9, pp 91-97.
[14] Kamarudin K.. , ZAIDI A. , ABDULLAH S. & KOSLAN S. , “Establishment of Shaped Charge Optimum Parameters for Small Scale Hydrodynamic Penetration”, Modern Applied Science, 2016, Vol. 10, No. 1, pp 82-92.
[15] ZHAO Z., LIU J., GUO W., Li S. & WANG G. , “Effect of Zn and Ni added in W–Cu alloy on penetration performance and penetration mechanism of shaped charge liner”, International Journal of Refractory Metals and Hard Materials, 2016 , Vol 54, pp 90-97.
[16] Johnston M. & LIM S. , “Numerical Observation of the Jet Flight Patterns of Linear Shaped Charges”, Applied Sciences, 2012, Vol 2, pp 629-640.