Research paper

Jet profile estimations over different standoffs for shaped charges and jet projectile charges, a computational approach

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Abstract

In this paper, using a computational approach, we interpolated and presented jet profiles over different standoffs for two broad classes of copper liners namely, Shaped Charges (SCs) and Jet Projectile Charges (JPCs). The results show that this approach can produce the stretching jet profiles at any time instance or at any standoff for SCs and JPCs with good accuracy. Therefore, this approach has the meaningful application in saving experiments and providing desktop information needed by scientists and engineers to design and develop various warheads without doing laborious simulations.

Keywords: Shaped Charges, Jet Projectile Charge, Jet velocity profile, Standoff.

1. Introduction

SCs are characterized by high tip velocity and a large gradient between jet's head and tail elements, which may be of the order of 2–10 mm.μs^{-1} whereas JPCs have a moderate velocity gradient; in the range 2–5 mm.μs^{-1}. The optimization of jet velocity profiles is an important task for a warhead designer and for that, one needs to have information about the jet characteristics such as velocity and mass distribution. These information play a very vital role in determining the penetration predictions into a target. In literature we find many empirical or semi empirical formulas that require knowledge of jet length or jet distribution at various times [1) 2)]. The jet particulation time, being a very important parameter, has also been included in various models, which can also be deduced by the jet velocity profiles. In present studies, we only considered copper liners although other low melt materials such as titanium, zirconium, depleted uranium may also be used [3)]. The computational approach is applied to the two these two classes of metal liners to find jet velocity profiles at various standoffs. Any type of SCs or JPCs can be studied in this way to obtain the tabular velocity profiles data at any standoff or time instant.

In this approach, two JPCs and two SCs were selected as shown in Fig.1. Each of them is loaded with HMX-Inert (90:10) explosive without casing and initiated at one point on the central axis. Flash radiographs were taken from previously performed experiments for two JPCs [4)].

AUTODYN 2D [5)] simulations were then run to match the JPCs collapsing shapes and three sets of jet velocity versus jet location data at three standoffs (or time instances) were obtained. For same material models, two SCs models were simulated and same data was obtained

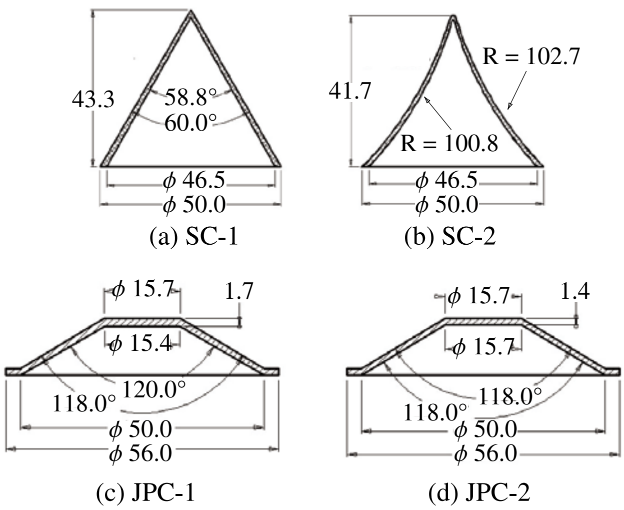


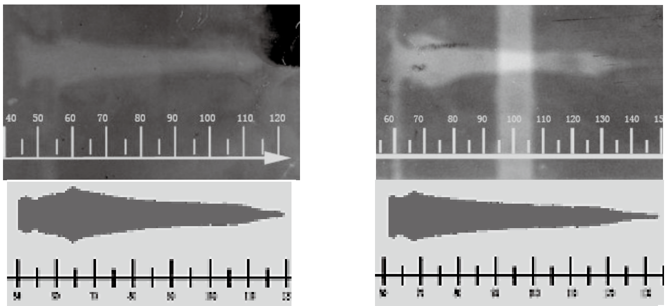
Fig. 1 SCs and JPCs designs.

Table 1 Explosives model for simulation.

HMX-Inert (90:10) JWL EOS								
ρ ($g \cdot cm^{-3}$)	D ($mm \cdot us^{-1}$)	P_{CJ} GPa	A GPa	B GPa	R_1	R_2	ω	E_0 $kJ \cdot m^{-3}$
1.745	8.40	31	943.3	8.805	4.7	0.9	0.35	1.02E7

Table 2 Copper model for simulation.

Copper Shock EOS					Vonmises Strength Model	
ρ ($g \cdot cm^{-3}$)	C ($mm \cdot us^{-1}$)	S_1	S_2 ($s \cdot m^{-1}$)	γ_0	Shear Modulus (GPa)	Yield Stress (MPa)
8.93	3.94	1.49	6×10^{-4}	1.99	47.7	450



(a) (b)

Fig. 2 X-ray and simulation, shapes comparison at 40.6 μ s for (a) JPC-1 (b) JPC-2.

at three standoffs. A computer code built in Matlab [6] was then used to find jet profiles at any time instance for JPCs and SCs by first converting the data into surface form and then doing 3 D interpolation. Broadly speaking, explosively formed projectiles (EFPs) also belong to shaped charge family. They have a typical velocity gradient of 2–3 mm.μs $^{-1}$ but in this paper, no consideration was given to EFPs because their velocity profile is very simple and gradient is too small and thus jet velocity profile is straightforward to interpolate.

2. Simulations

For JPC-1 and JPC-2 models, the material models for AUTODYN 2D simulation were selected so that the experimental data was reproduced accurately. The material model summary is given in Tables 1 and 2. Comparisons of simulation results with the experimental results at 40.6 μ s for JPC-1 and JPC-2 are shown in Fig.2 (a) and 2 (b), respectively. Simulations reproduced the jet elongations and shapes at this time instance. In our simulations, t = 0 is taken as the initiation time so 40.6 μs is a big time interval for such small sized JPCs as employed in this paper. If jet shape and position are correctly reproduced at this time instance, this implies that interim processes from initiation to this time instance are also correctly modeled by AUTODYN with employed material models. With same material models, SCs were also simulated to get the shapes and collapsing pattern of copper jet. Collapsing shapes of JPCs and SCs at three different times are shown in Fig.3 and 4 respectively. It is to be noted that although standoff is defined as the distance between the base of a cone to the target surface, in the absence of a physical target, these time instances correspond to various standoffs. In our simulations, these standoffs were 50, 100 and 150 mm for JPCs and 100, 150 and 200 mm for SCs. The resulting velocity profiles are shown in Fig.5. The reason for choosing comparatively smaller standoffs for SCs is the far more stretching capability of SCs jets as compared to JPCs jets. At longer standoffs, shaped charge jets tend to break.

In all velocity profiles, the zero of jet axis corresponds to the cone base at t = 0 μs. For SCs, the jet originating from virtual standoff is visible as there are negative values for jet axis. For JPCs, there is no such phenomenon as all jet elements lie on positive jet axis well ahead of the cone base. This phenomenon also differentiates JPCs from SCs. There are three very interesting feature common to all jet profiles to observe. Going forward in time, all jet profiles tend to stretch, translate and lean. Therefore, an accurate two-dimensional interpolation of intermediate profiles is not possible. For that, a Matlab program was developed which took the three velocity profiles of the design from AUTODYN simulations as input. New jet profiles were then found at various time instances corresponding to new standoff for SCs and JPCs designs, based on 3D interpolation. A comparison was then made between the two sets of data.

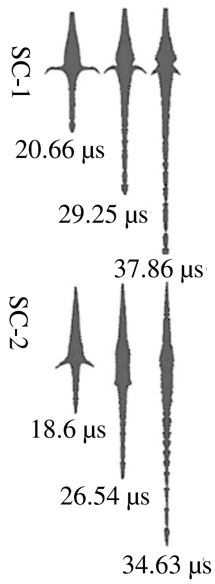


Fig. 3 Shapes of SCs liners at three time instances corresponding to 50, 100 and 150 mm standoffs.

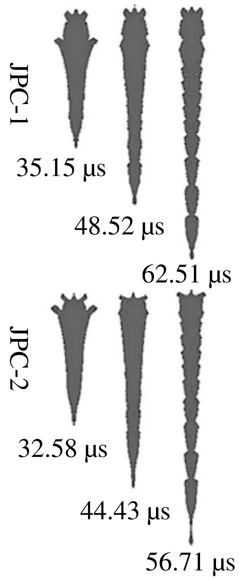


Fig. 4 Shapes of JPCs liners at three time instances corresponding to 100, 150 and 200 mm standoffs.

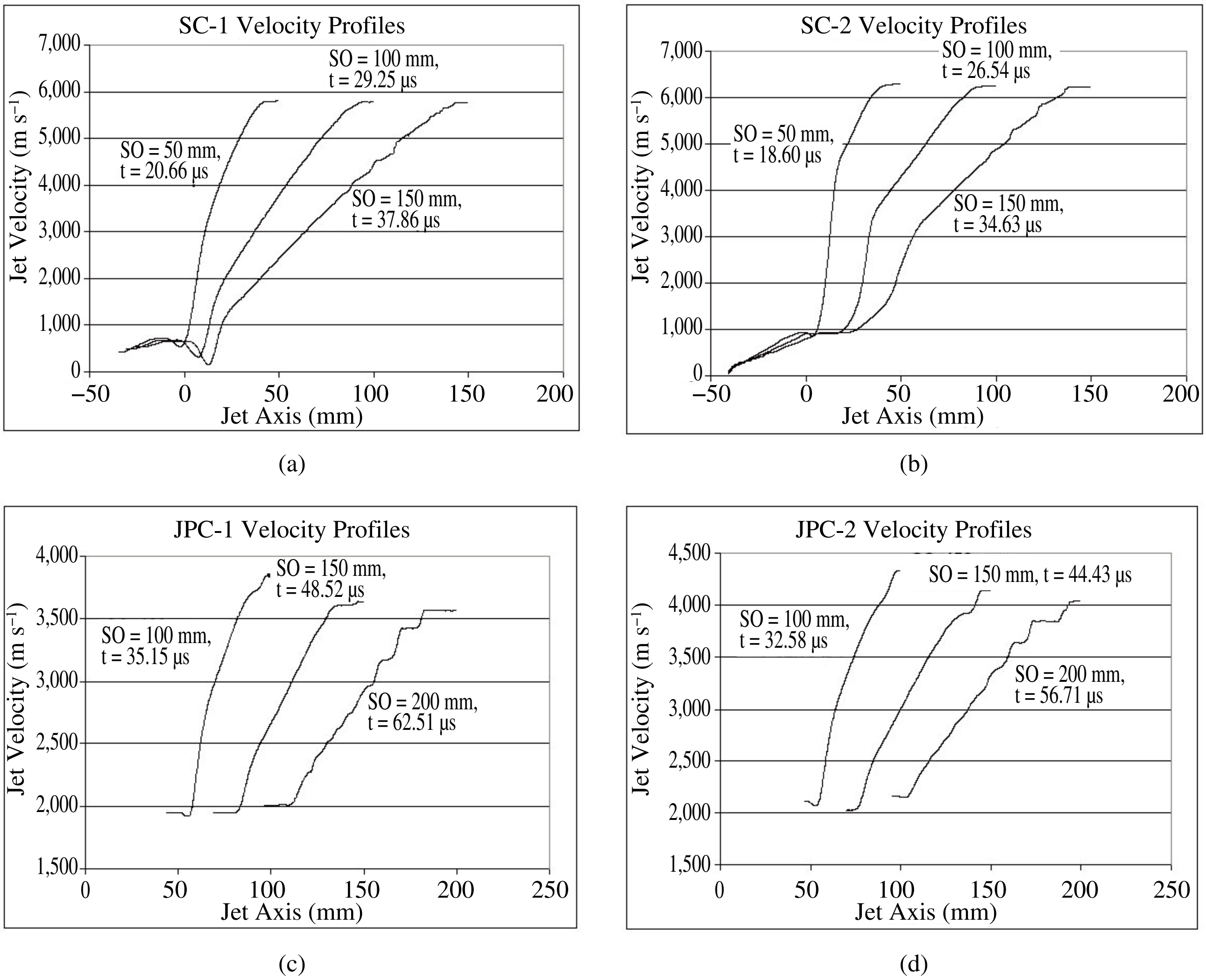


Fig. 5 Jet profile for (a) SC-1 (b) SC-2 (c) JPC-1 (d) JPC-2.

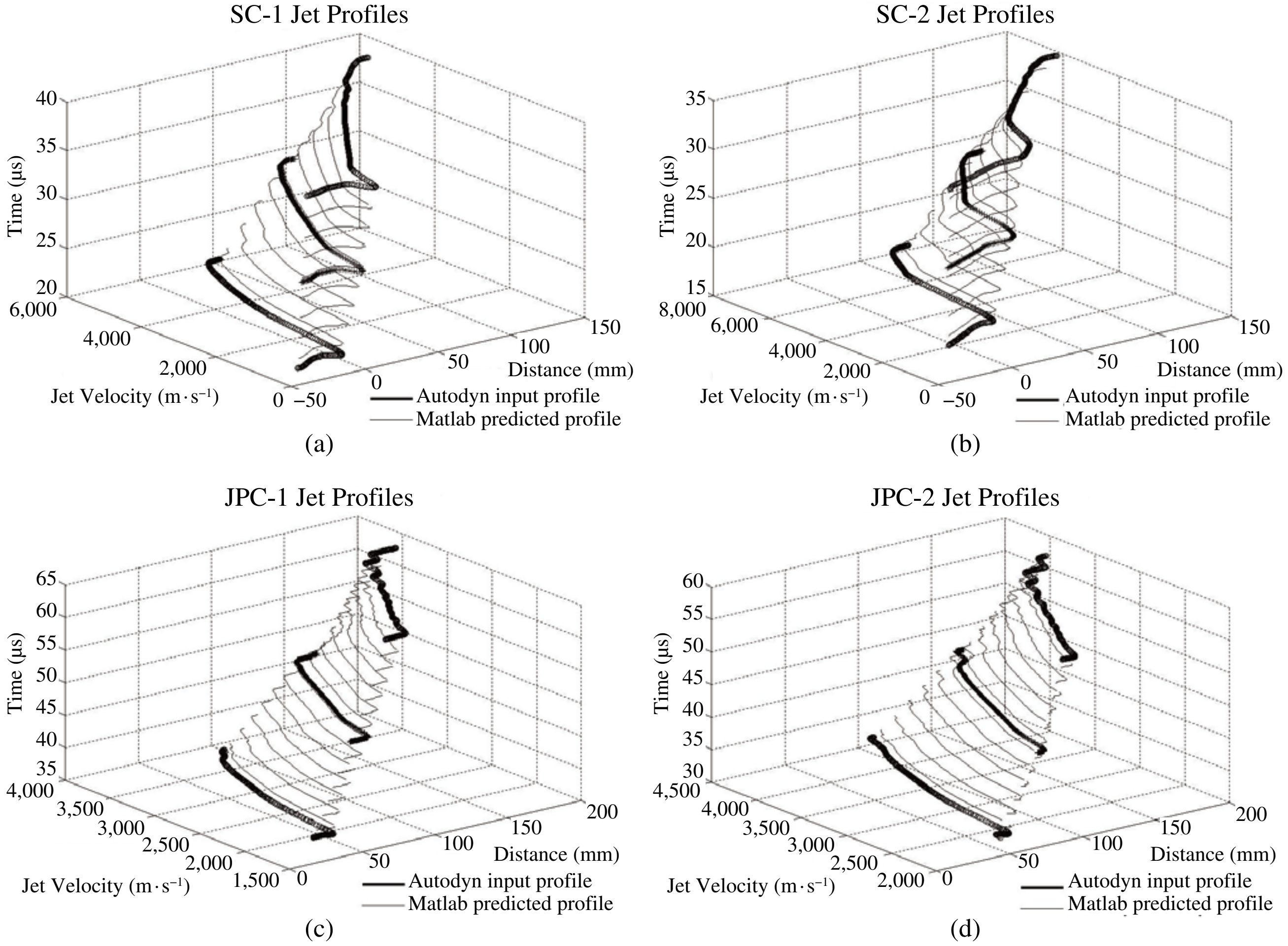


Fig. 6 AUTODYN input and Matlab estimated jet velocity profiles for (a) SC-1 (b) SC-2 (c) JPC-1 (d) JPC-2.

3. Program Structure

This Matlab program processes the data in the following appropriate order:

a. Import AUTODYN distance-velocity data sets for three time instances. It is very important to understand that three time instances correspond to three jet positions and therefore in the absence of a target, they correspond to three standoffs.
b. Since three data sets are generally not equal in number of terms, the program first applies a shape-preserving interpolant (piecewise cubic Hermite interpolation) and then creates three new data sets (for slug and jet regions) depending on the interpolation for distance versus velocity which now contain 51 terms for slug region and 201 terms for jet region.
c. Three matrices are formed for distance, velocity and time (for two regions). Matrices sizes for slug region and jet region are 51 × 3 and 201 × 3 respectively.
d. Having obtained 3 matrices for both regions, the next step is to use Matlab griddata function to evaluate unknown velocity data by interpolation. For each new set, a constant time and a smooth running distance domain has been defined.
e. The new jet position at new intended time can then be calculated based on the deceleration produced between tip velocities of each region and then using the appropriate retardation where required time instant lies.

4. Program Results

The Matlab program was executed for all models and jet profiles predictions in three dimensions with AUTODYN input data have been plotted in Fig.6. The bold lines show the three jet profiles from AUTODYN as input whereas lighter lines are jet profile predictions by Matlab program. For more clarity, Fig.7 shows the comparison between jet profiles obtained by AUTODYN and Matlab program at two time instances for all models in two dimensions.

The relative error between Matlab program and AUTODYN simulation generated jet profiles has also been calculated and it is at most 5 % at some point; otherwise it remains oscillating between much lower values. The Matlab program calculated jet position results are as good as AUTODYN results since due to proper interpolation, the retardation of jet tip velocities follows a smooth trend between given standoffs in Matlab program. Table 3 shows a comparison between jet positions calculated by the program and AUTODYN. Again, in the absence of any target surface, each jet position also corresponds to a specific standoff.

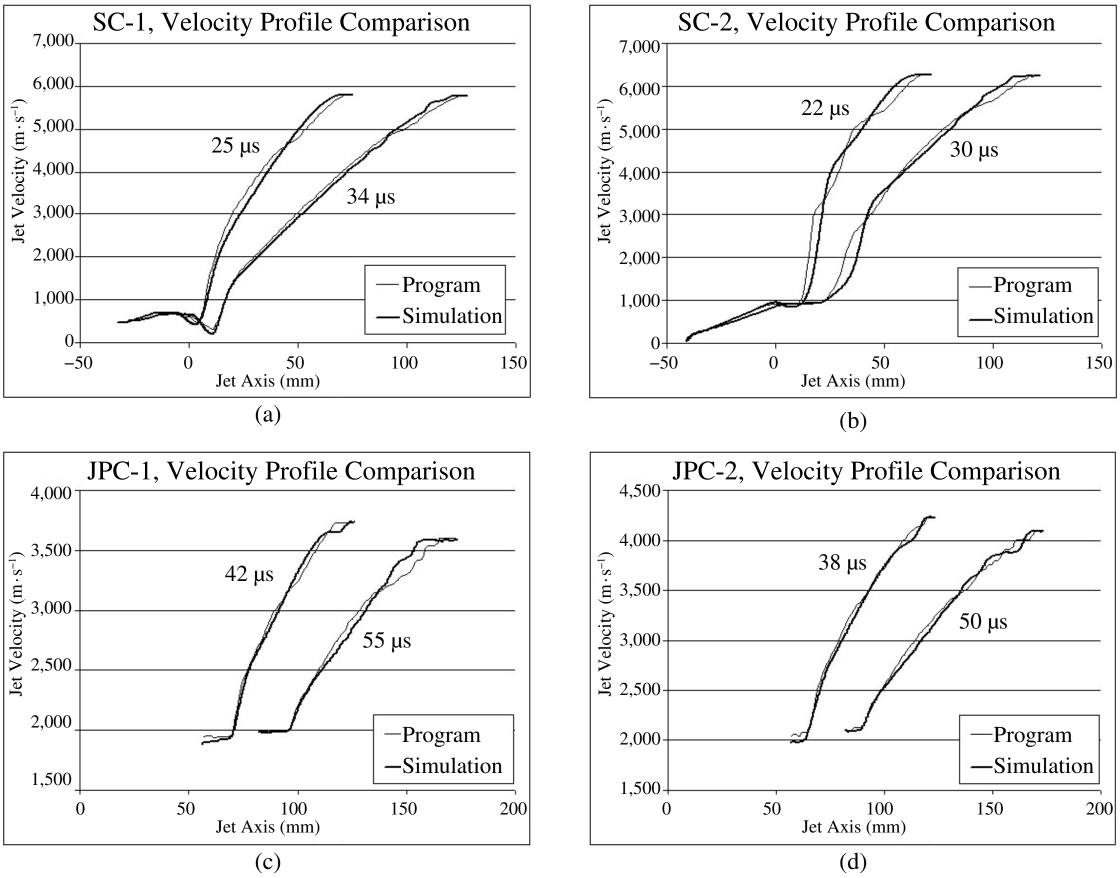


Fig. 7 Comparison between simulation and program outputs for (a) SC-1 (b) SC-2 (c) JPC-1 (d) JPC-2.

Table 3 Comparison between AUTODYN and Matlab results for jet positions.

Model	Time (µs)	Jet Position (mm) AUTODYN	Jet Position (mm) Matlab
SC-1	25.0	75.1	75.2
	34.0	127.6	127.5
SC-2	22.0	71.5	71.4
	30.0	121.5	121.5
JPC-1	42.0	125.9	126.0
	55.0	173.3	173.4
JPC-2	38.0	123.1	123.2
	50.0	173.0	172.9

5. Conclusions

1. A computational approach has been presented to predict jet velocity profiles of JPCs and SCs with good accuracy.
2. Based on this strategy, several data libraries at various time intervals may be constructed for different models so that data would be available for quick reference without doing experiments or laborious simulations.
3. This model is general and can be applied to any distribution. The important characteristic of this 3D technique is the reproduction of stretching, translating and leaning behavior of jets at longer standoffs as we have seen in case of SCs.

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