Combined Approach for Characterization of Shaped Charge Jet Penetration

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General description of the approach

Stage 1: Simulate the shaped charge jet formation

An Eulerian solver with a special simulation setup is used for an accurate derivation of the jet mass-velocity distribution

Stage 2: Evaluate the jet breakup mechanism

The jet parameters derived in Stage 1 along with a “Breakup distance” approach are used to describe the jet particulation process

Stage 3: Calculate the time-resolved penetration depth and crater profile

The jet data with the fitted particulation mechanism is used along with an appropriate penetration model and crater growth analytical equations

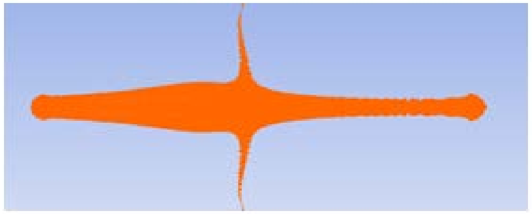
Shaped charge jet formation process simulation

- The shaped charge used throughout this work in the simulations as well as in the experiments is of a 45mm caliber with a 60^{0} conical copper liner and a uniform wall thickness of 0.9mm

- An AUTODYN Eulerian solver with an axi-symmetric analysis was used for the shaped charge jet formation simulation

- The simulated jet formation process was first validated against the experimental results
  - The simulated jet and the flash X-Ray are taken at the same time

X-Ray photograph

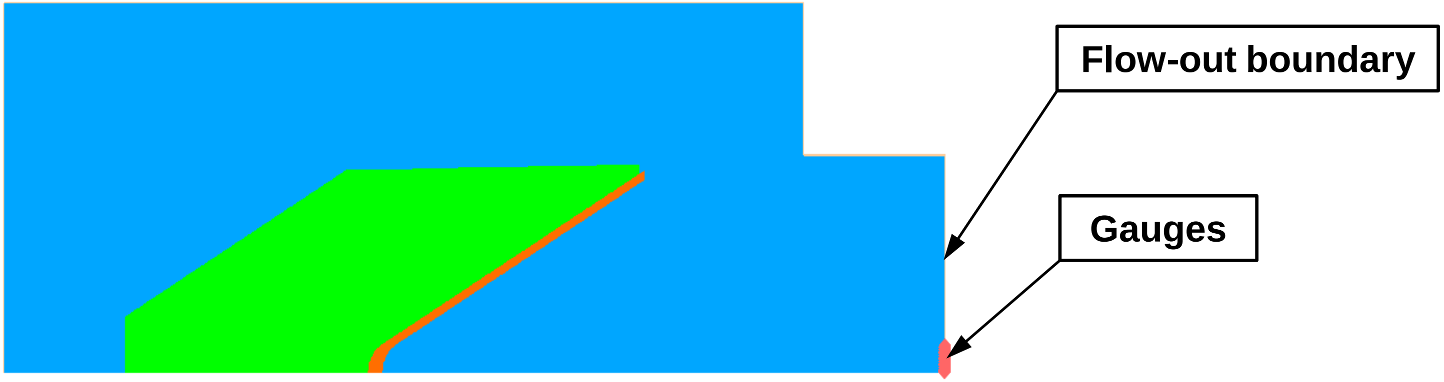


Simulation

Special simulation setup

- **When the jet stretches in the Eulerian simulation more than a few charge diameters, the jet shape begins to distort numerically due to interface reconstruction problems, which are inherent in Eulerian solvers**

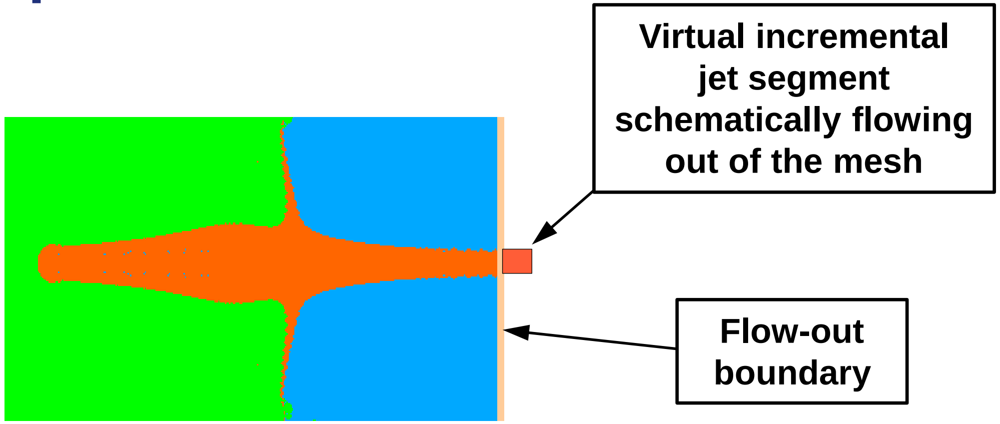
- **To avoid the mentioned numerical inaccuracy, a special simulation setup is suggested**



Jet parameters derivation

- As a result, the jet flows out of the eulerian mesh while accurately preserving its shape and its free interface

- Every time-step Δt_i the incremental jet segment ΔL_i with a given mass m_i and a given velocity gradient ΔV_i flows out of the eulerian mesh



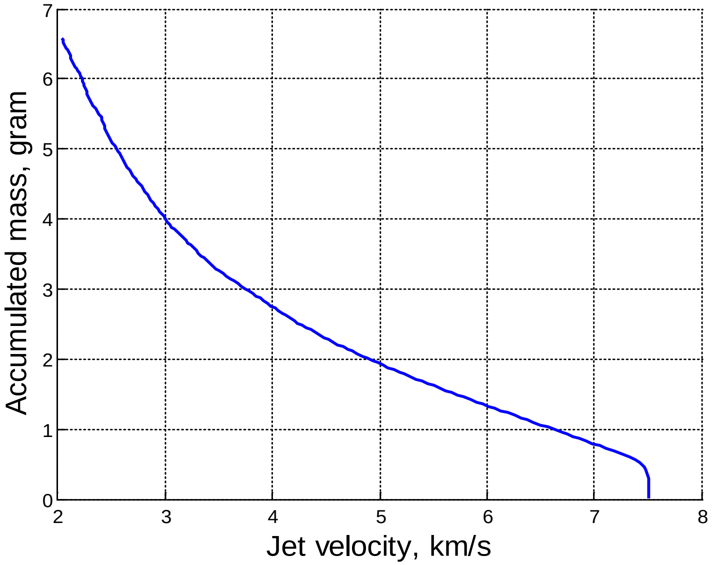
Virtual incremental jet segment schematically flowing out of the mesh

Flow-out boundary

- The jet data is collected through the whole formation process providing all the relevant jet parameters:
  - jet segment mass
  - jet segment velocity and gradient
  - jet segment length and diameter at exiting the mesh
  - jet segment time at exiting the mesh

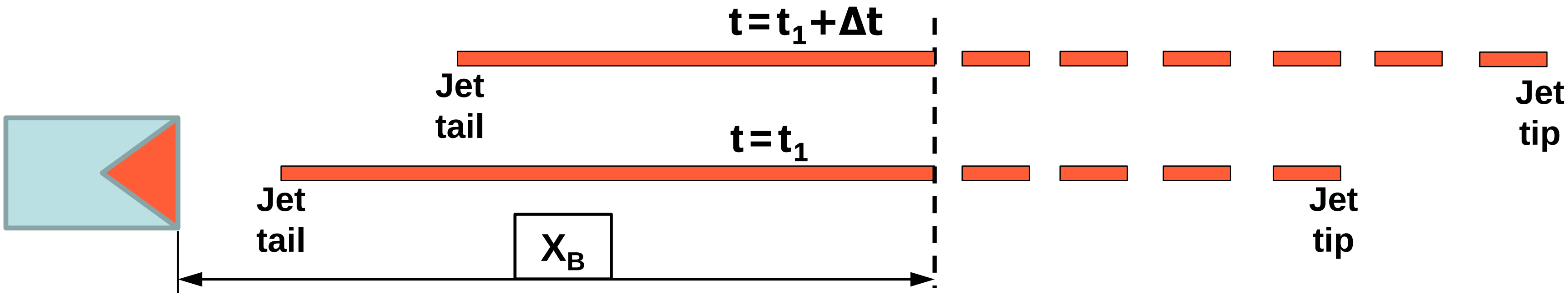
Time-dependent jet shape reproduction

- By post-processing the collected jet data, the jet shape can be reproduced for every point of time or distance
  - ➢ jet particulation will be taken into account, as will be detailed further in this talk
- The jet mass-velocity distribution of the representative charge as derived by the suggested simulation scheme



Jet breakup characterization

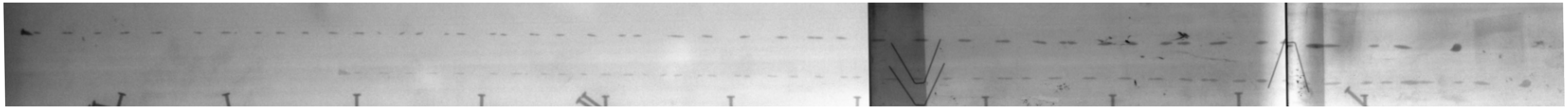
- **The "Breakup distance" approach** [M. Mayseless et al., 1989] **is exploited to describe the jet particulation process**
- **According to this approach, for each specific shaped charge can be assumed the average distance X_B from the liner base beyond which the jet is fully particulated, and prior to which the jet is still continuous, or has a partial necking**



- **This particulation mechanism is incorporated in the calculation scheme such that the jet segment no longer elongates when reaches a given breakup distance X_B**

Breakup distance approach validation

- **To validate the breakup distance approach, the fully particulated jet was flashed twice at two different times on the same X-ray photograph**



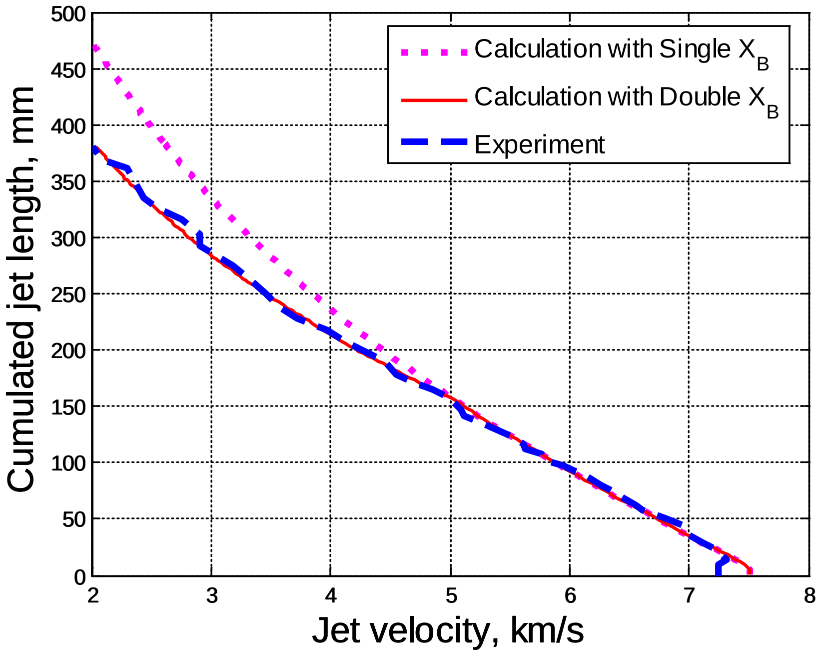
- **The cumulated jet length as function of the jet segment velocity was measured from the flash X-Ray photograph**
- **Different breakup distances X_B were applied in the calculation scheme to optimally fit the experimental results**

Breakup distance approach validation

- **As a first trial, a single breakup distance X_B was used in the calculation to match the experimental curve**

➢ **Single X_B=7.6CD results in a good agreement, but only for a partial range of the jet velocity**

$$5\,km/\sec \le V_{jet} \le V_{tip}$$



- **To improve the agreement, a double breakup distance was suggested**

$$\begin{cases} X_{B1} = 7.6CD \quad ; \quad 5\,km/\sec \le V_{jet} \le V_{tip} \\ X_{B2} = 5.4CD \quad ; \quad V_{tail} \le V_{jet} < 5\,km/\sec \end{cases}$$

➢ **Excellent agreement is demonstrated for a whole range of the jet velocity**

Penetration depth calculation

- **The jet data with the fitted particulation mechanism is used for the time-resolved penetration depth calculations**
- **The calculations were performed according to the pure hydrodynamic penetration model with allowance of the target strength resistance R_t**

$$\begin{cases} \frac{1}{2}\rho_j (V-U)^2 = R_t + \frac{1}{2}\rho_t U^2 \\ dP = dL\frac{U}{V-U} \end{cases}$$

Bernoulli's modified equation

- dP - the incremental penetration depth created by the incremental jet segment length dL
- V and U – are the jet and penetration velocities, respectively
- ρ_j and ρ_t – are the jet and target densities, respectively

Crater diameter calculation

- **The fitted jet data is used for the calculation of the jet penetration crater profiles based on analytical models**
- **Two analytical models for calculating the maximal crater diameter were examined:**
  - **Szendrei's model - 1983**

$$D_c = D_j \frac{V}{\sqrt{2Y_t(1/\sqrt{\rho_j}+1/\sqrt{\rho_t})}}$$

  - **Shinar's model - 1995**

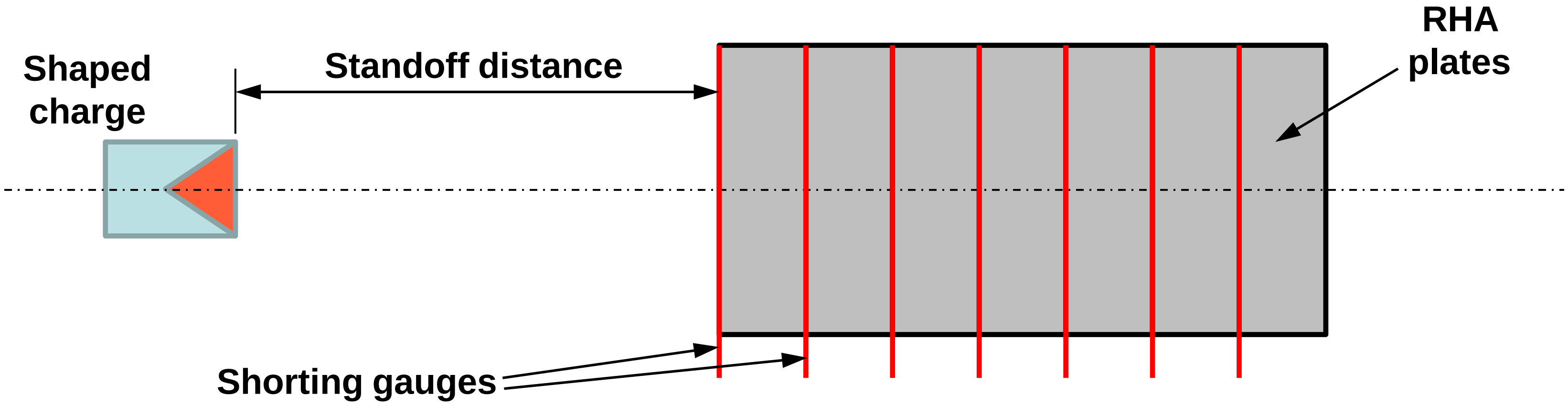
    (slightly modified form of Szendrei's model)

$$D_c = D_j \left(1+\frac{\sqrt{3}V^2}{4Y_t(1/\sqrt{\rho_j}+1/\sqrt{\rho_t})}\right)^{0.5}$$

- Y_t – is the dynamic strength of the target material
- D_c and D_j – are the crater and jet diameters, respectively
- V – is the jet velocity
- ρ_j and ρ_t – are the jet and target densities, respectively

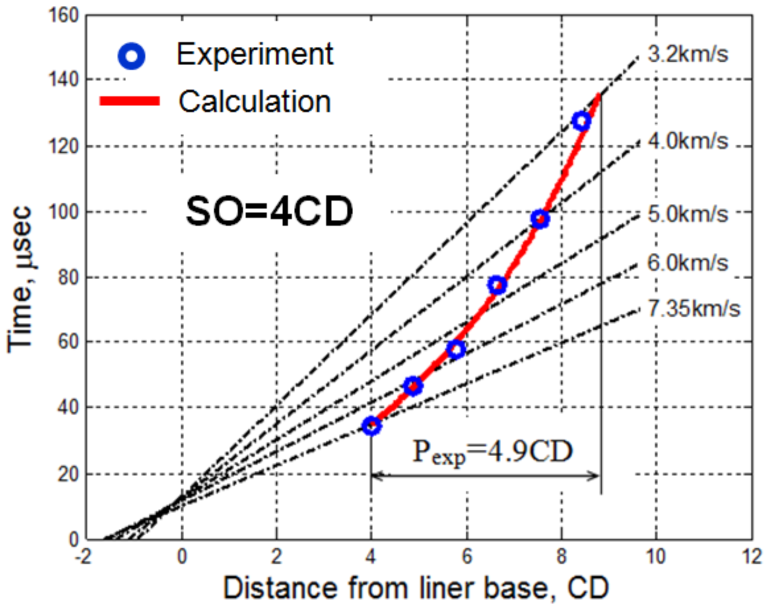
Penetration experiments

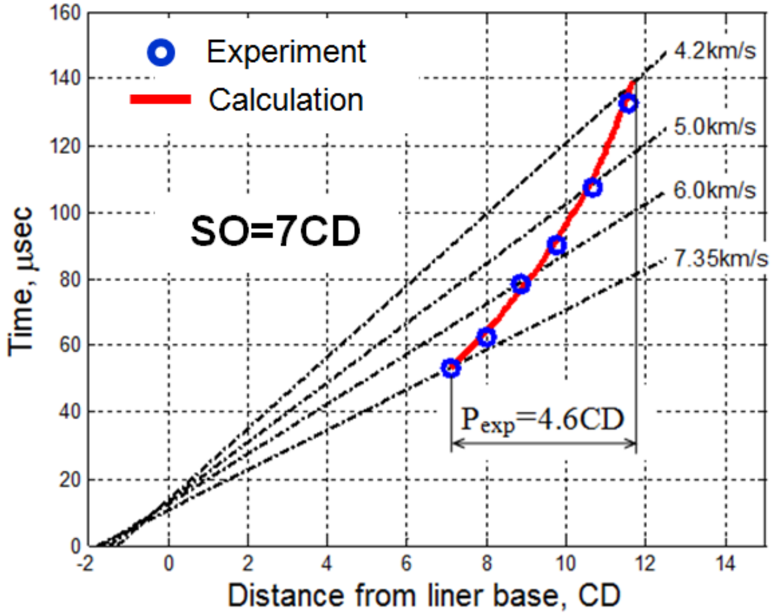
- To validate the calculation results, the penetration experiments were carried out with the representative charge against semi-infinite RHA targets consisted of the 40mm thick plates
- The charge was fired at three different Standoff distances: 2CD, 4CD and 7CD
- Two penetration experiments (at SO's of 4CD and 7CD) included the shorting gauges between the target plates for measuring the jet crater deepening as function of time



Penetration calculations validation

- **The time-distance diagrams of the jet penetration history are presented for comparing the experimental and calculated data**
  - ➢ **The dash-dot lines are the trajectories of the jet segments with the specific constant velocity, as derived from the simulation**

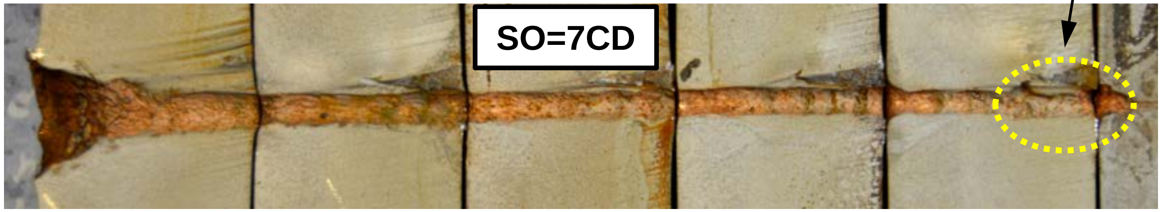




- **The calculations as presented on the graphs, were performed with a zero target strength, following the pure hydrodynamic model**

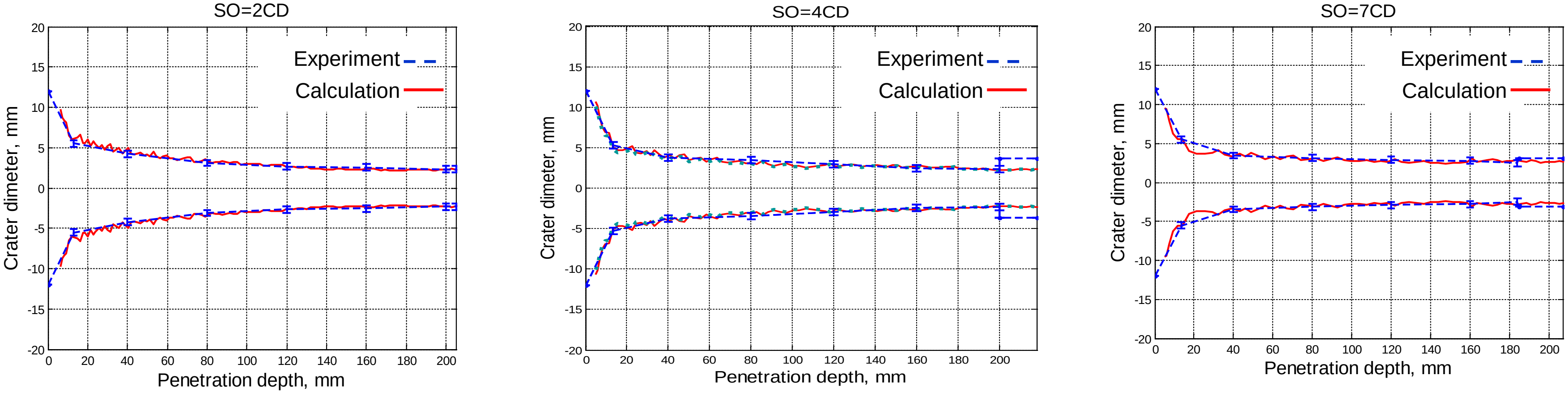
Crater profile calculations validation

- To validate the crater profile calculations, the targets from the penetration experiments were bisected along the crater and the crater diameters were carefully measured



Crater expansion

- The only one parameter should have been varied in the analytical models to fit the experimental results => $\underline{Y_t}$. The fitting was performed based on the 2CD standoff experiment resulting $\underline{Y_t=1.5\text{GPa}}$
- Crater profiles for other SO's were then accurately predicted



Conclusions

- The combined approach for characterization of shaped charge jet penetration process was presented
- The jet formation process was simulated using the AUTODYN Eulerian solver with the special simulation setup, which was shown to produce the correct jet mass-velocity distribution and other relevant jet data
- It was shown that the jet particulation mechanism can be accurately described in terms of the breakup distance approach

Conclusions

- The time-resolved penetration depth calculations based on the pure hydrodynamic penetration model demonstrated very good agreement with the experimental data
- It was shown that the target crater penetration profiles can be correctly predicted using experimentally fitted analytical models

Thank you

for your attention!