Liberté • Égalité • Fraternité
RÉPUBLIQUE FRANÇAISE

MINISTÈRE DE LA DÉFENSE

Weapons Curvilinear trajectory and smart fuze calculations suitable for hard target defeat modeling

52nd Annual Fuze Conference

Sparks, NV, USA, 13-15 May 2008

DGA

DÉLÉGATION GÉNÉRALE POUR L'ARMEMENT

Centre d'Etudes de Gramat
BP 80200
F-46500 GRAMAT

J-M Sibeaud
Th. Lacaze
A. Lefrançois

CEG's mission

CEG is a Technical Center of the French MoD procurement Agency (DGA)

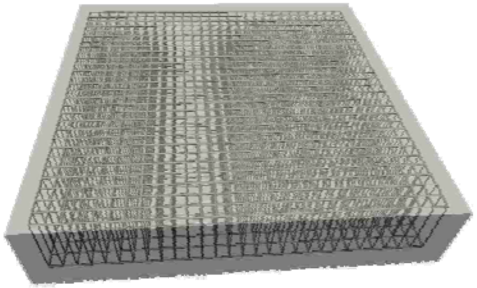
- Bring better knowledge of **Terminal effectiveness** of Conventional Air-to-Ground weapons and missiles
- Provide support to program managers for new weapons development (SCALP/EG, AASM, MdCN, LRM NG)
- Provide *Armée de l'air* and *Aéronavale* (French Air Force and Navy Air Force) with means for determining effectiveness of strikes and perform mission planning
  - Capabilities against hardened targets (Hard target defeat)
  - Improve warhead lethality
  - Capability to control weapon's depth of burst
  - Minimize collateral damage

➔ Develop smart fuzing capabilities

Schedule

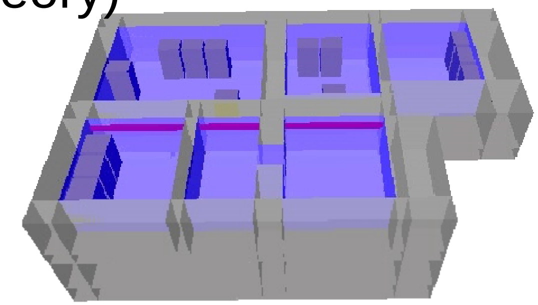
- Calpen3D, an analytical tool for smart fuzing
- Validation against direct finite element simulations
- Validation against experiments
- Smart fuzing use

CalPen 3D : basic theory of curvilinear penetration

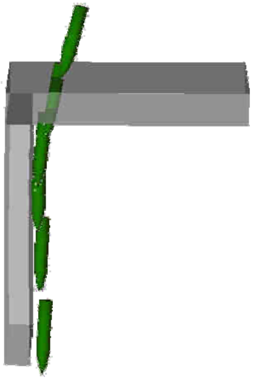


- Penetration module of **PLEIADES/I – the Vulnerability / Lethality code currently in operation within the French MoD**

- Rigid body kinematics (Based on DAFL and SCE theory)
- Curvilinear trajectory



- Hard and soft targets formulations
  - Standard Concrete
  - High resistance concrete
  - Reinforcement
  - Soils (Wayne Young's S number)
- Output
  - Residual post perforation velocity and attitude …



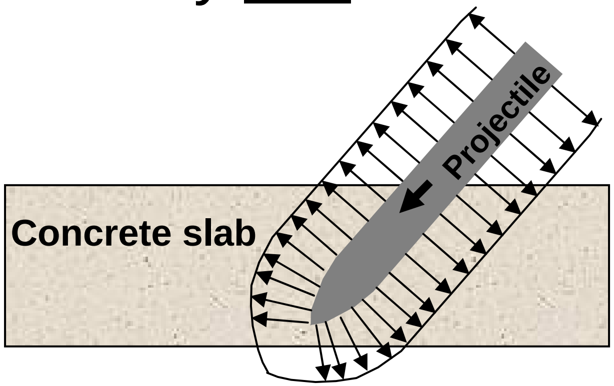
Enhanced perforation algorithm

- Perforation modeled with Interface Proximity Index (IPI)
  - IPI value based on user experience

➔ **Enhanced algorithm based on**

  - ➔ **differential treatment of ogive and afterboby**
  - ➔ **Ogive IPI is slab thickness dependant**

- Goal : Predict accurately Projectile velocity <u>and</u> orientation



Schedule

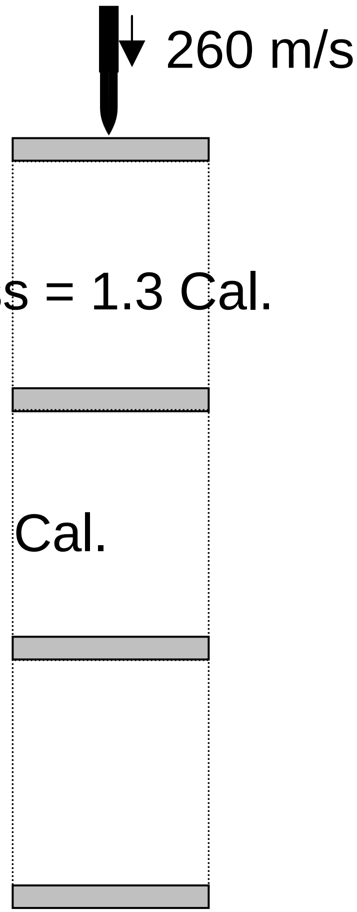
- calpen3D, an analytical tool for smart fuzing
- Validation against direct finite element simulations
- Validation against experiments
- Smart fuzing use

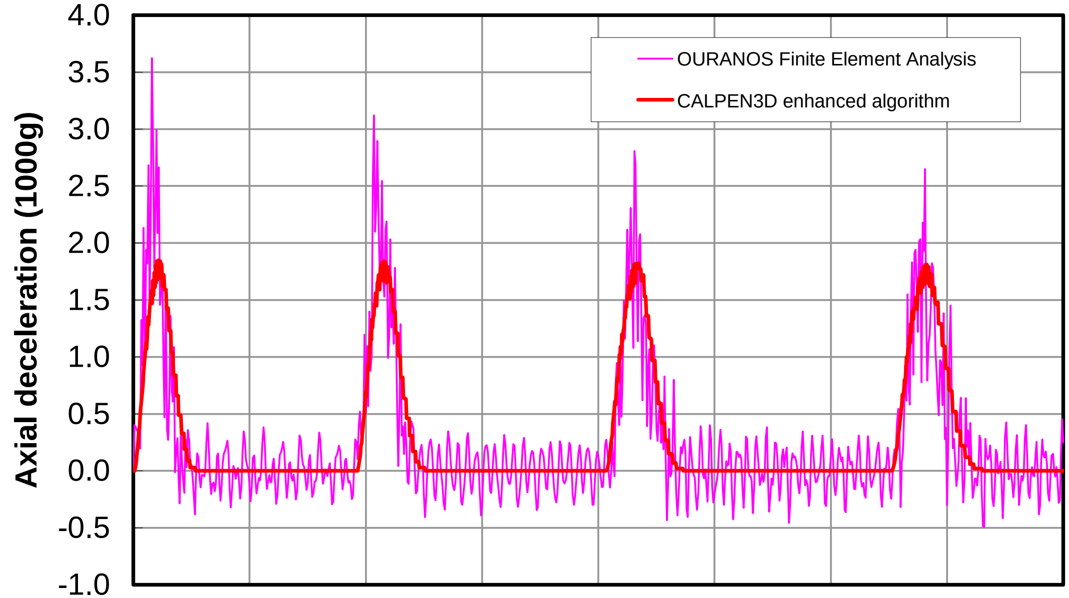
Validation against numerical simulation

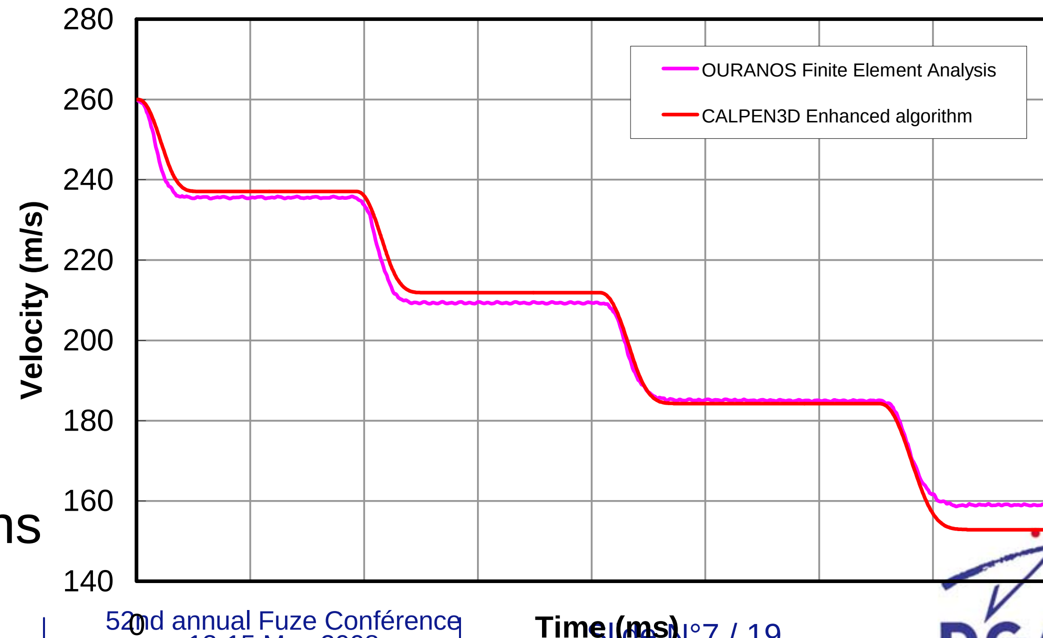
(4-slab)

Concrete thickness = 1.3 Cal.

Air thickness = 13 Cal.



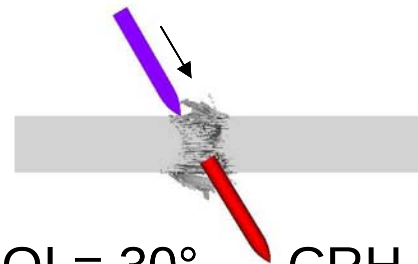




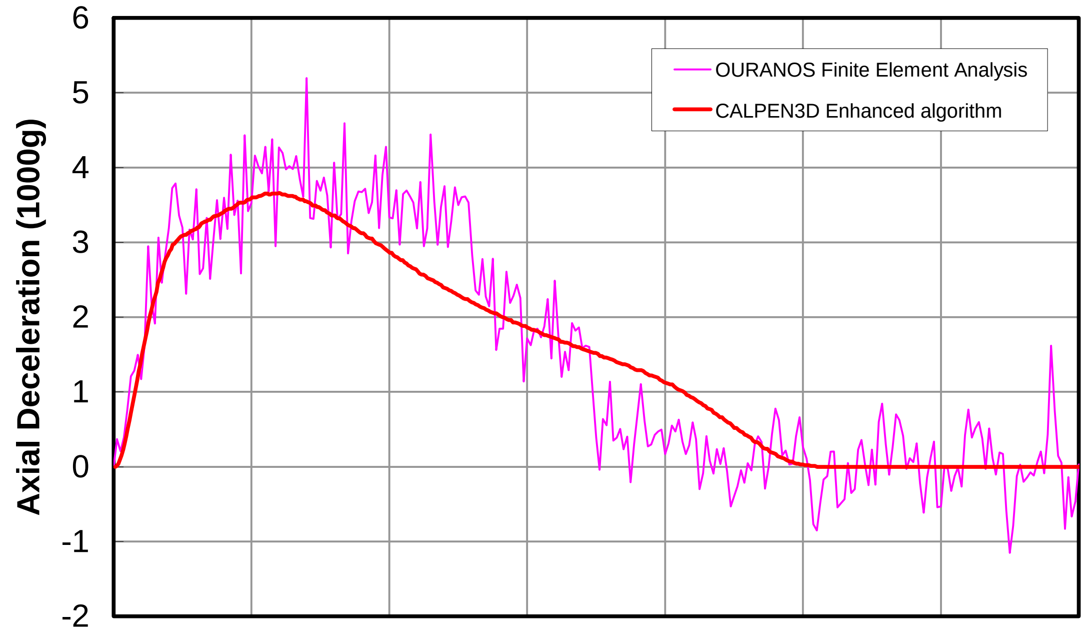
Reference data provided by fully validated Ouranos FE calculations

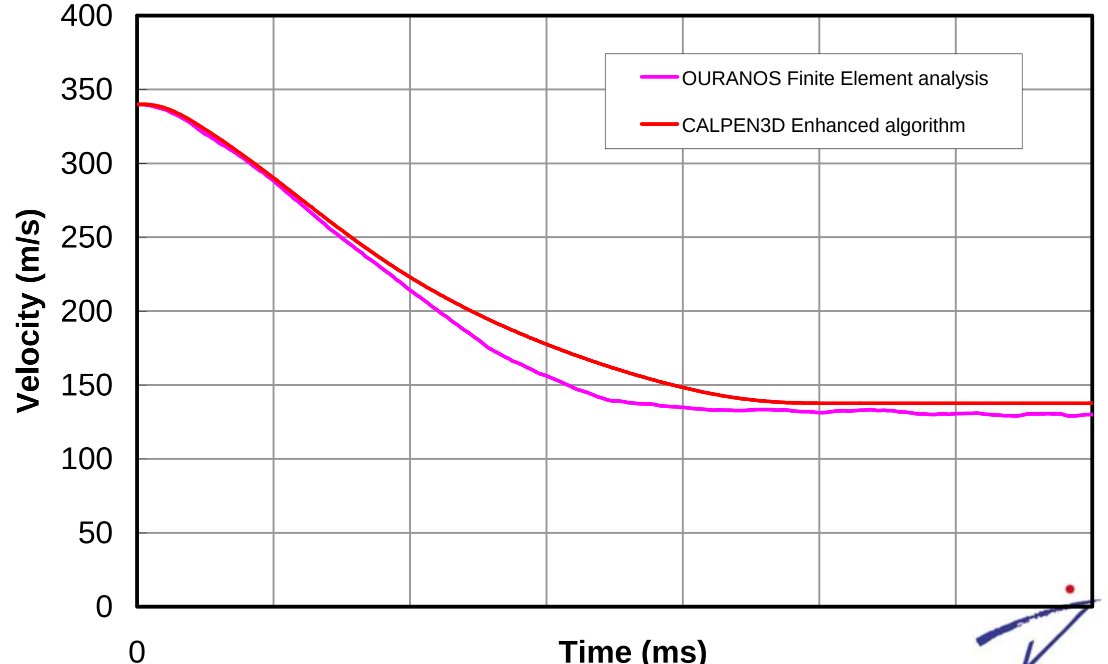
Validation

340 m/s



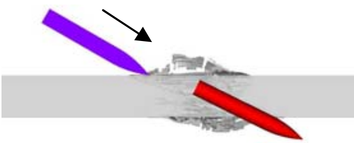
AOI = 30° CRH = 3
Slab thickness = 6.4 Cal.



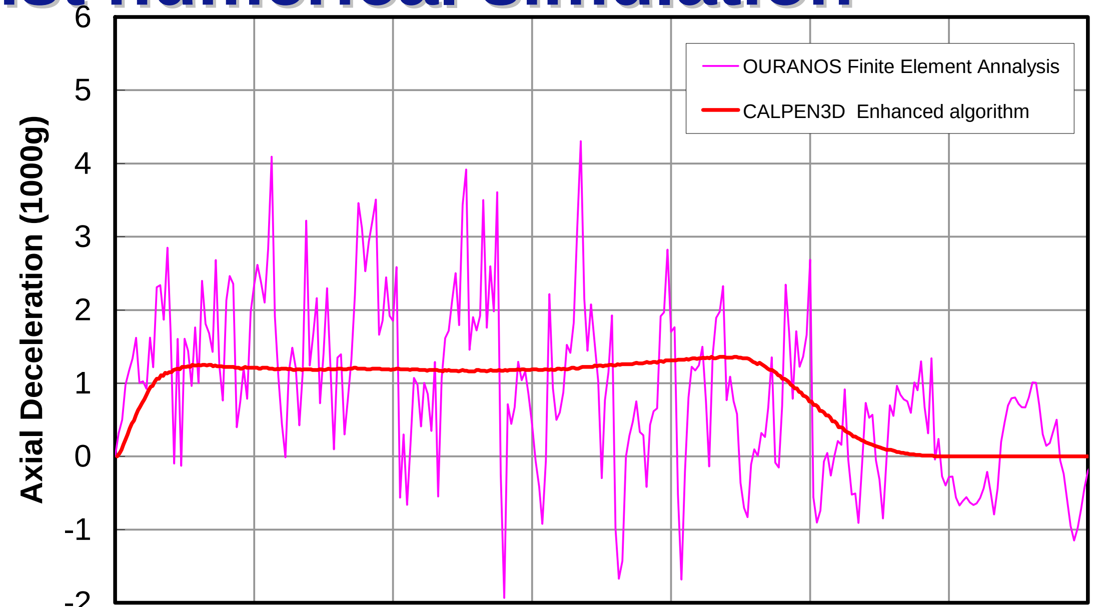


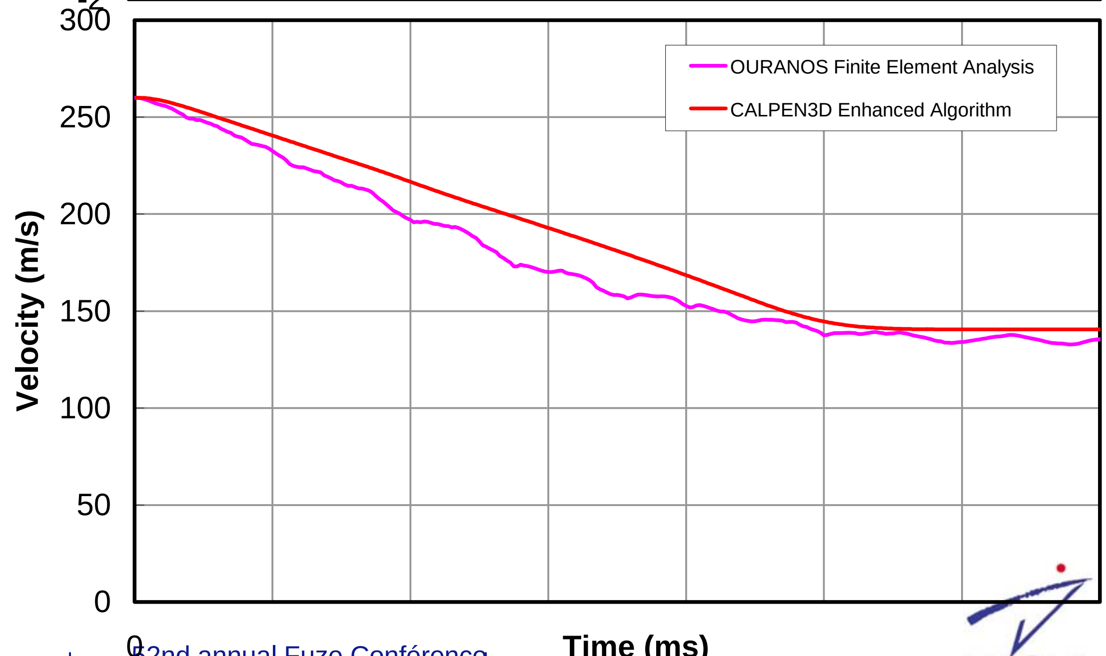
Validation against numerical simulation

260 m/s



AOI = 60°   CRH = 3
Slab thickness = 2.6 Cal.





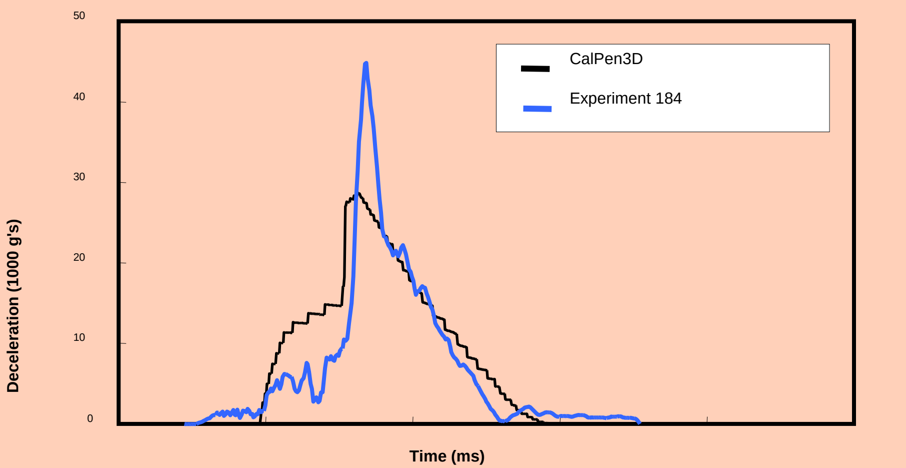
ISIEMS sept 2007 in Orlando
paper for full description

Schedule

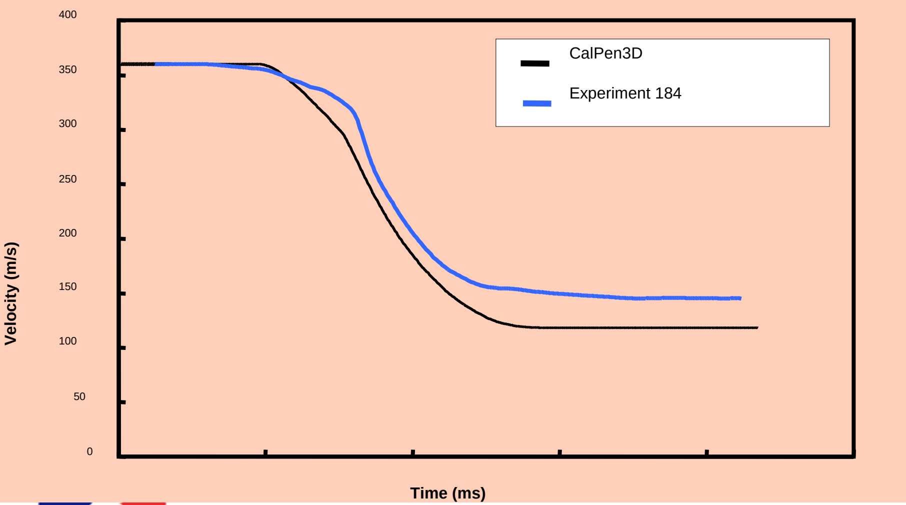
- Calpen3D, an analytical tool for smart fuzing
- Validation against direct finite element simulations
- Validation against experiments
- Smart fuzing use

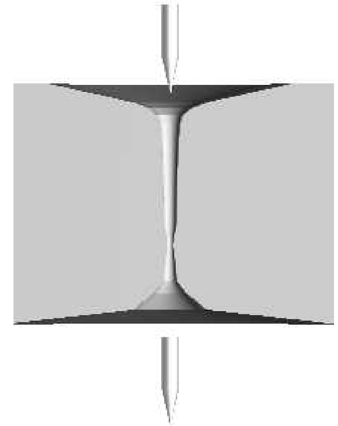
Validation against experiments

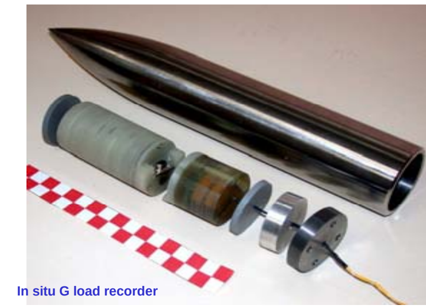
- Pre-damaged concrete target



Large pre-damage => perforation complete

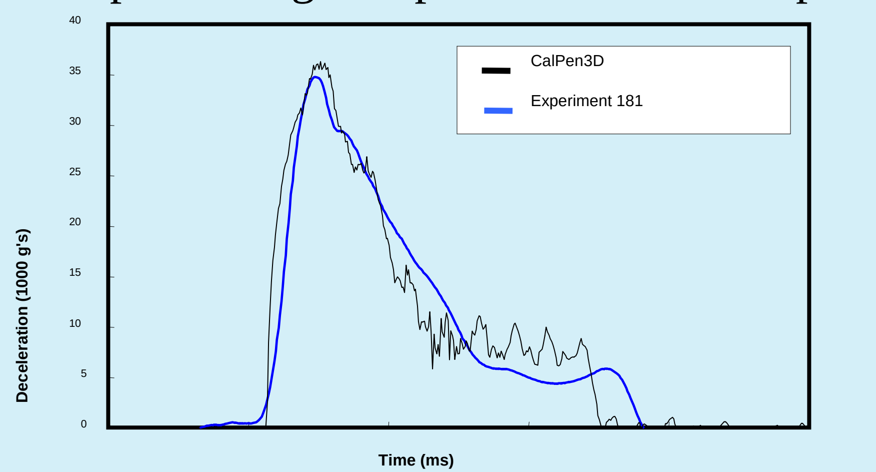






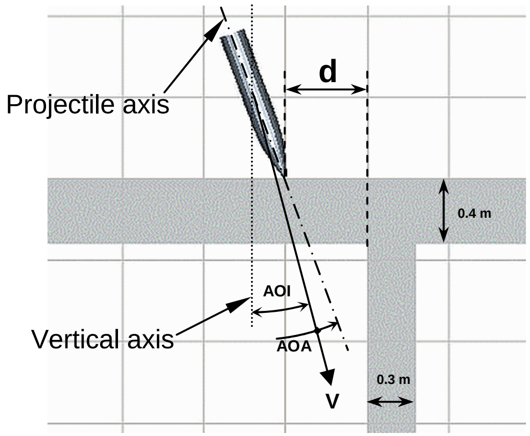
Siami sensor provided by **T2M**

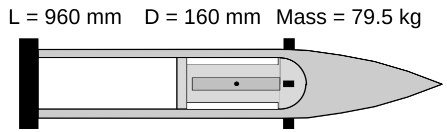
Small pre-damage => perforation not complete

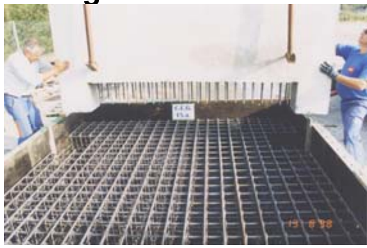


Validation in more complex configurations resulting from vertical attacks against real building: the corner effect

- **Configurations of impact representative of nearly vertical attacks of multi-story buildings**
  - ➔ Vertical wall next after horizontal slab
  - ➔ Perform CalPen3D runs on these configurations

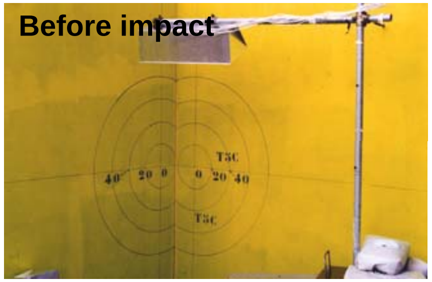






Configuration	V (m/s)	AOI (°)	AOA (°)	d (m)
T5-c	359	41	0	0.5
T5-d	349	29.7	+1.5	1.09

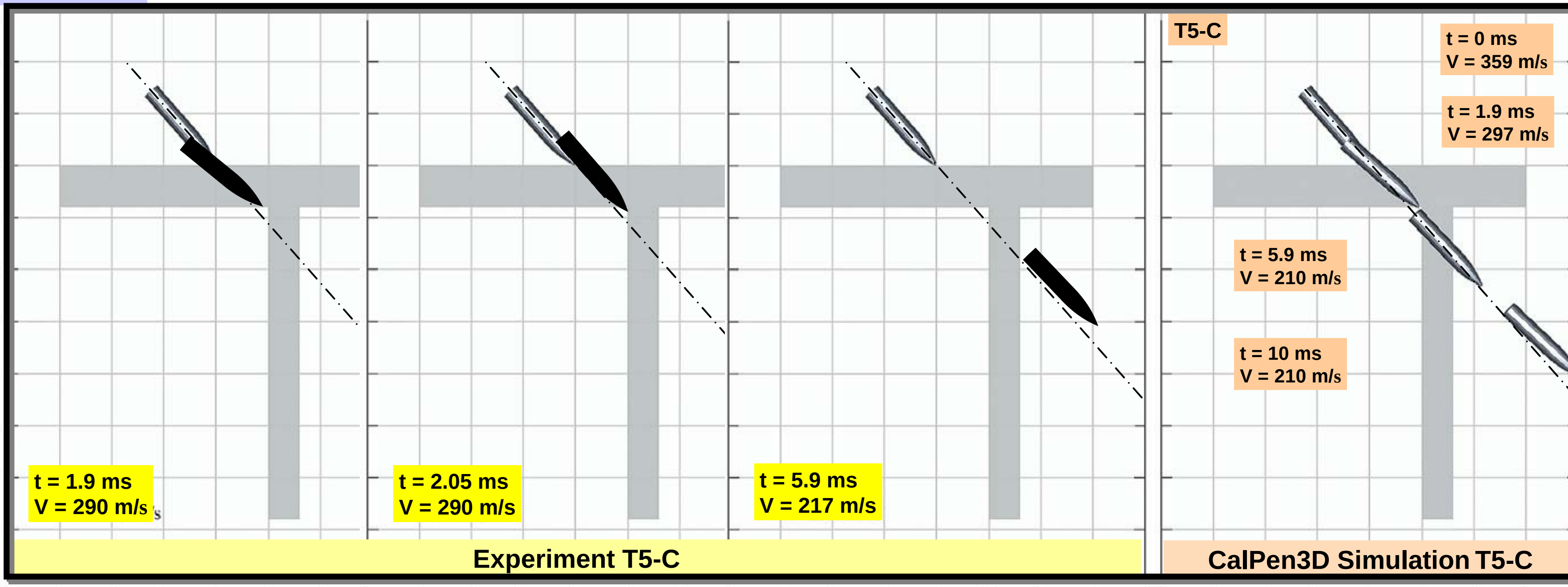
Reference :
model scale experiments (scale .7) performed in CEA/DAM test site, France, reported by E. Buzaud CEG (see paper published in ISIEMS 11 in Germany (2003)

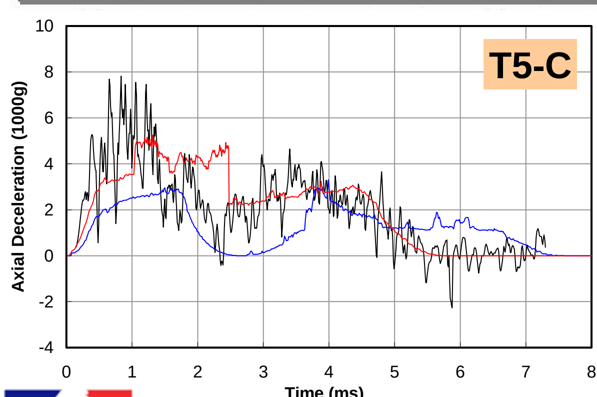


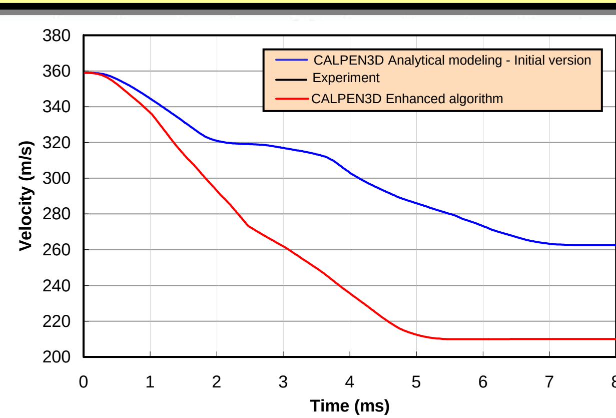
- high speed cameras (HYCAM, 8000 f/s or 16000 f/s)
- AOI, AOA
- Tri-axis acceleration recording at projectile CoG
- Scabbing process (HYCAM, 8000 f/s)
- Residual damage topography

Experiment T5-C

359 m/s AOI 41° AOA 0° d 0.5



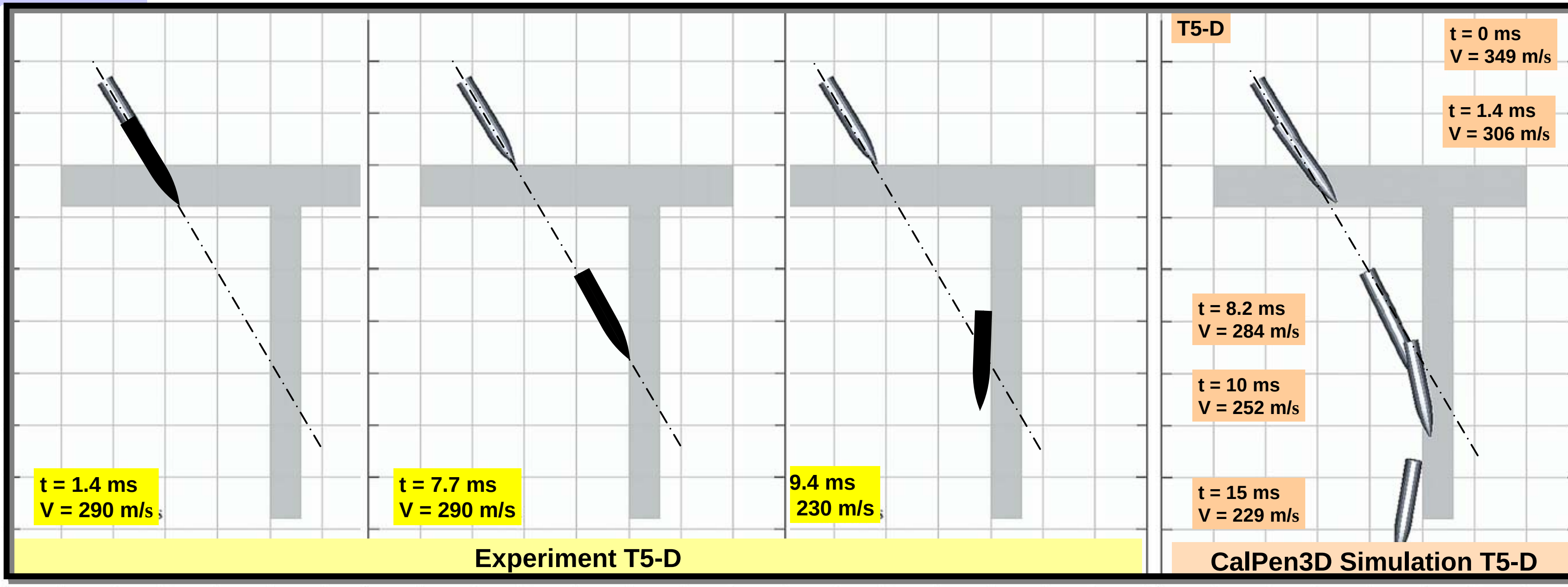


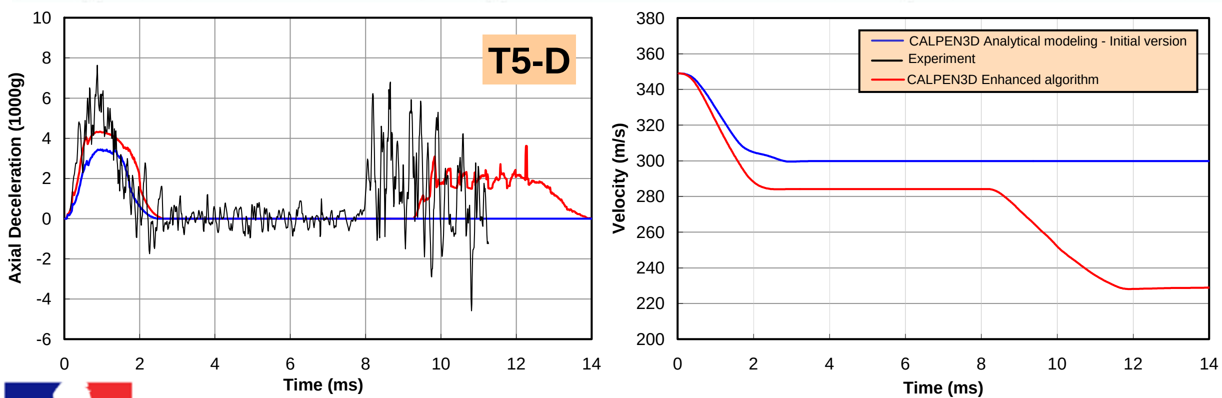


- Projectile perforates both slabs as observed during the experiment
- Velocity and deviation of projectile wrt the original line of fire is accurately predicted

Experiment T5-D

349 m/s AOI 29.7° AOA +1.5° d 1.09 m





- ➔ Ricochet on vertical wall and velocity appear well predicted

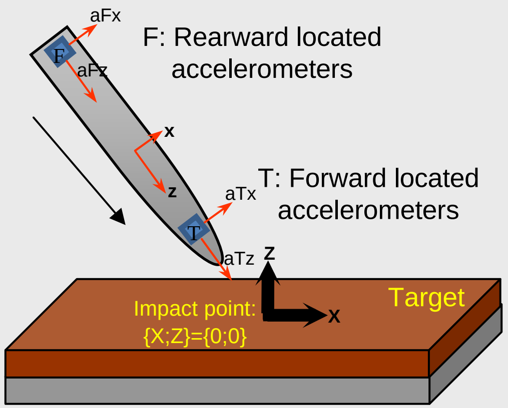
Schedule

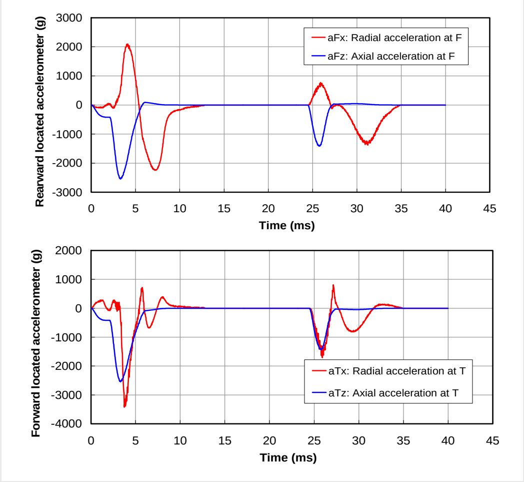
- calpen3D, an analytical tool for smart fuzing
- Validation against direct finite element simulations
- Validation against experiments

- Smart fuzing use

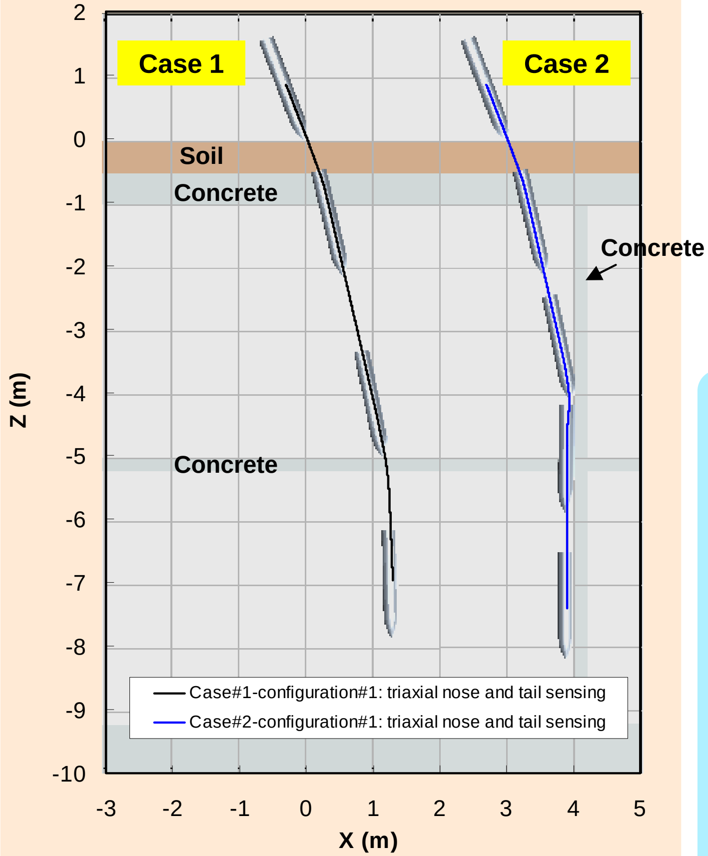
Smart fuzing

Assuming : projectile not spinning, plane trajectory in (X,Z) = (z,x)



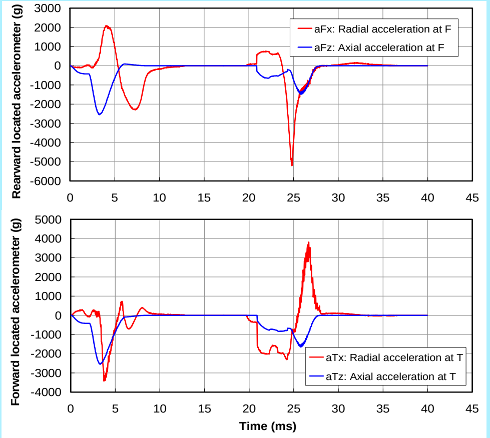


Case 1 : T and F sensors output



Full knowledge of projectiles paths into the target from embedded sensors output provided that initial attitudes and velocities are known

Case 2 : T and F sensors output

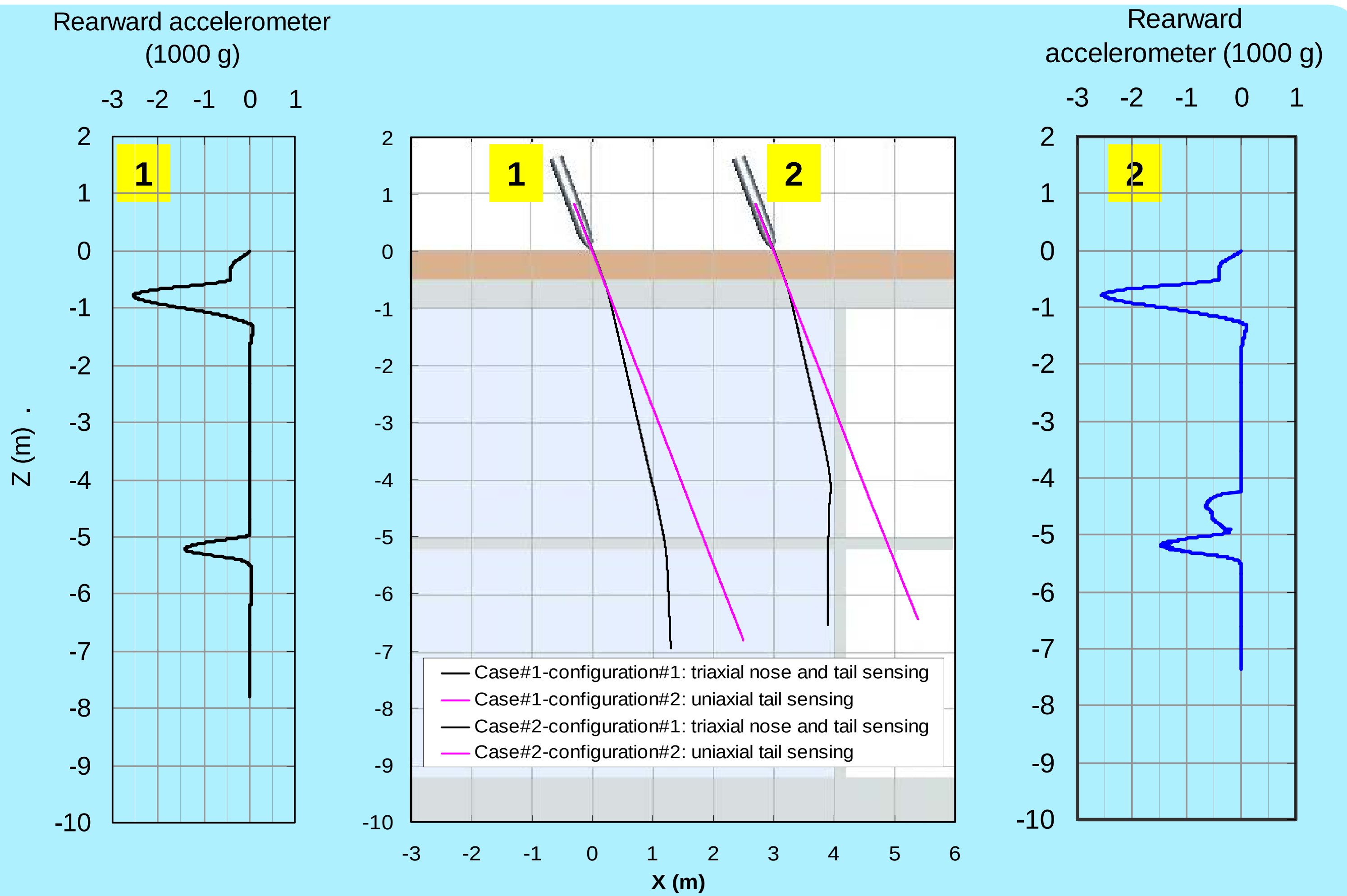


One single G-load recording in the projectile axis

Algorithms for smart fuzing may be based on void sensing and/or slab counting. Initial projectile velocity and attitude must be known upon impact (knowledge of this information can be obtained from the guided munition inertial plateform)

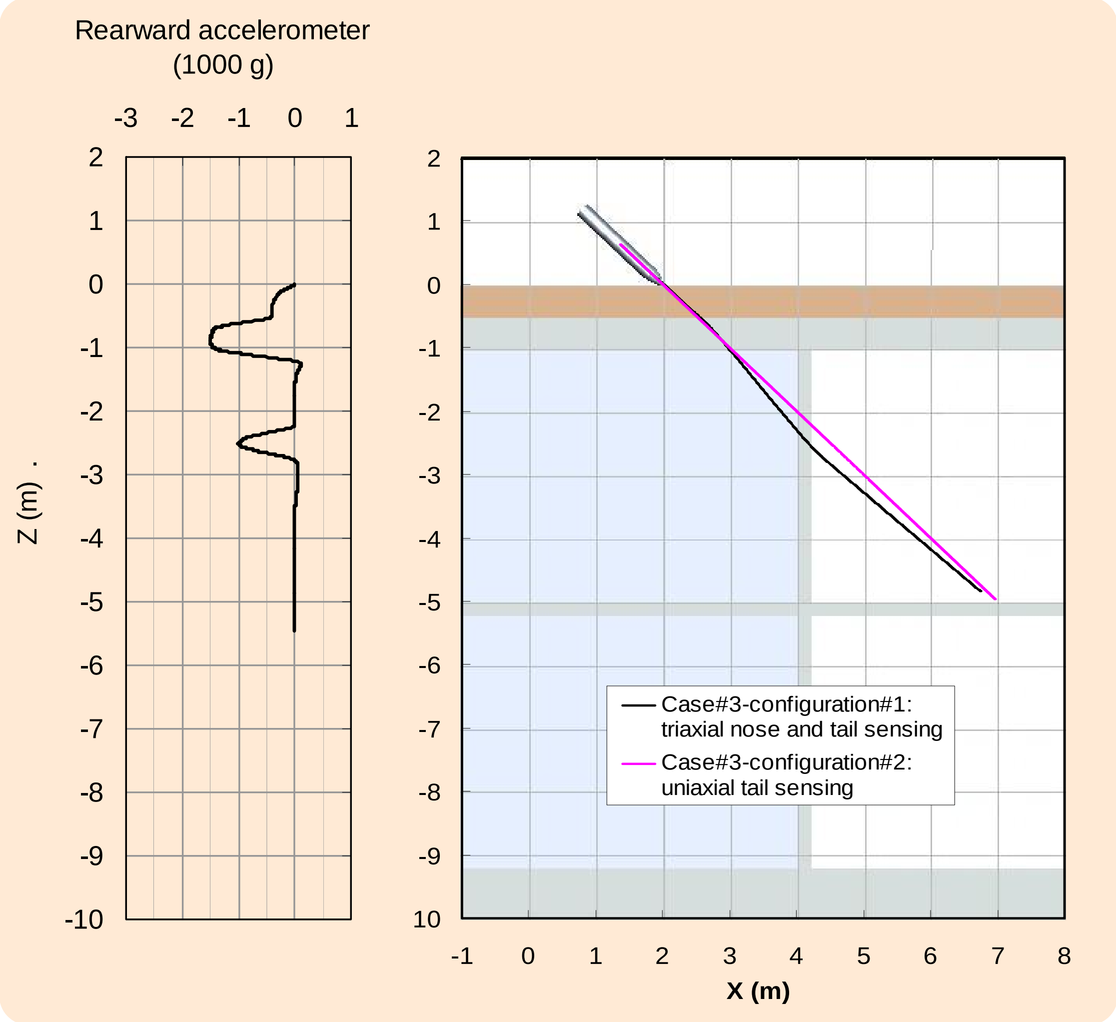
Limitation : 1) projectile rotation – and therefore ricochet - cannot be detected

2) deceleration signature when perforating the soil is similar to the one observed during ricochet



Other limitation of void sensing

Vertical and horizontal slabs cannot be differentiated



Summary and Conclusion

- Modelling of hard target defeat requires that penetration calculations are performed
  - Improving warhead lethality while improving control on weapon's depth of burst requires embedded smart logic

- Paper relates on how making use of CalPen3D to assess smart fuzing algorithms in various representative situations (4 slabs, semi-infinite, pre-damaged targets, corner effects)

- Further effort on real world data
  - Real time kinematics using appropriate filtering and DSP
  - 3D signals (Euler angles)
  - Non perfectly rigid projectile