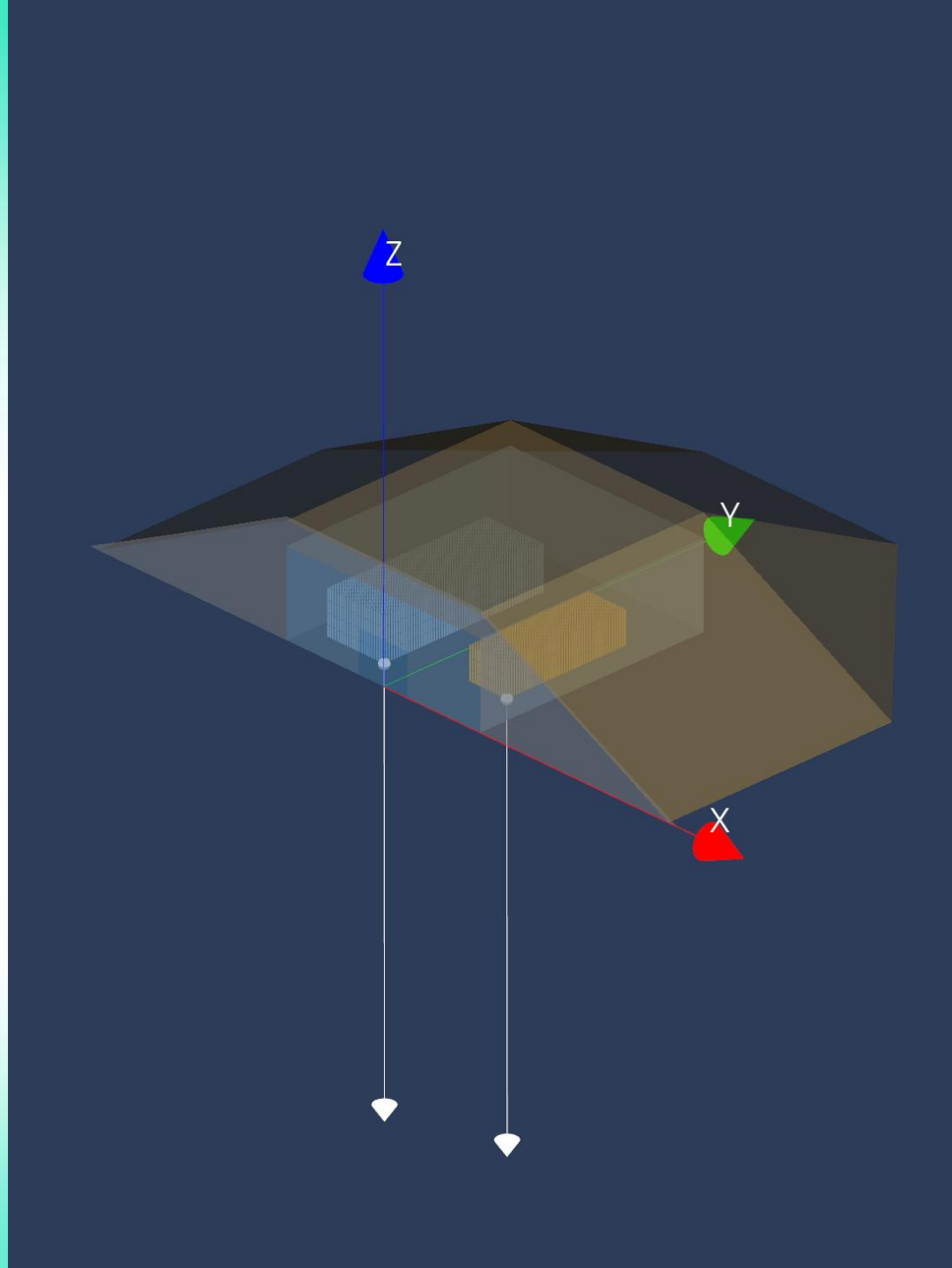
Ammunition and Explosives Consequence Analysis Tool (AECAT)

Physics-Based Modelling of Earth-Covered Magazine (ECM) Breakup and Consequences Using AECAT

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Lloyd's Register Advisory (Martec Limited)
Halifax, NS, Canada

26 November 2026
PARARI 2026 Australian Explosive Ordnance Safety Symposium
Canberra, ACT, Australia



Ammunition and Explosives Consequence Analysis Tool (AECAT)



ECM explosive scenario rendered in AECAT Virtual Globe

1 Introduction and Software Overview

2 AECAT Modelling Approaches

3 ECM Modelling

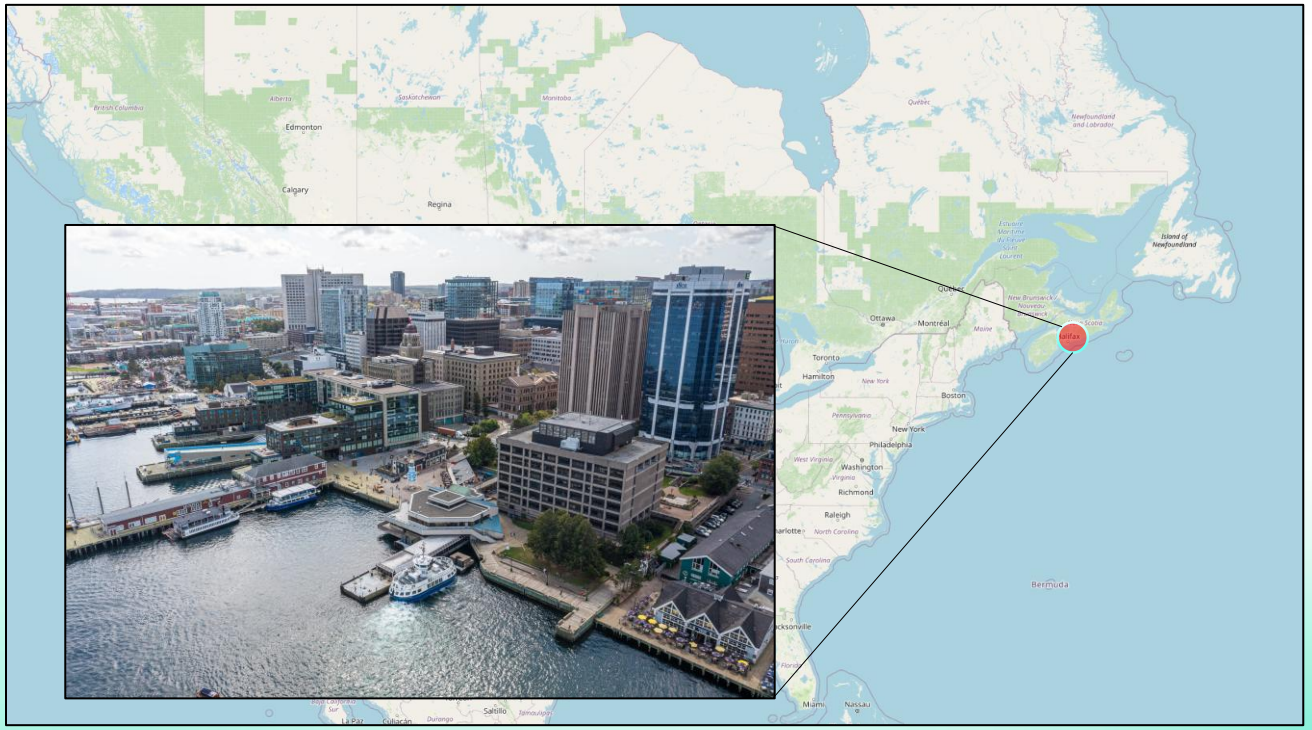
4 Validation and Future Work

Introduction and Software Overview

Ammunition and Explosives Consequence Analysis Tool (AECAT)

AECAT Development Team

- Lloyd's Register Advisory (Martec Ltd.) based in Halifax, Nova Scotia
- **Explosion & Fluid Dynamics Team**
  - Modelling explosive events and blast effects on structures, personnel
    - Threat assessments
    - Vulnerability, damage, and injury prediction
    - Advanced modelling: FSI, UNDEX
  - In-house software development: **Chinook** (20+ years), **Integrated Platform** (e.g., RCP) (10 years)
- Leading development of AECAT for Canadian Department of National Defence / DAER

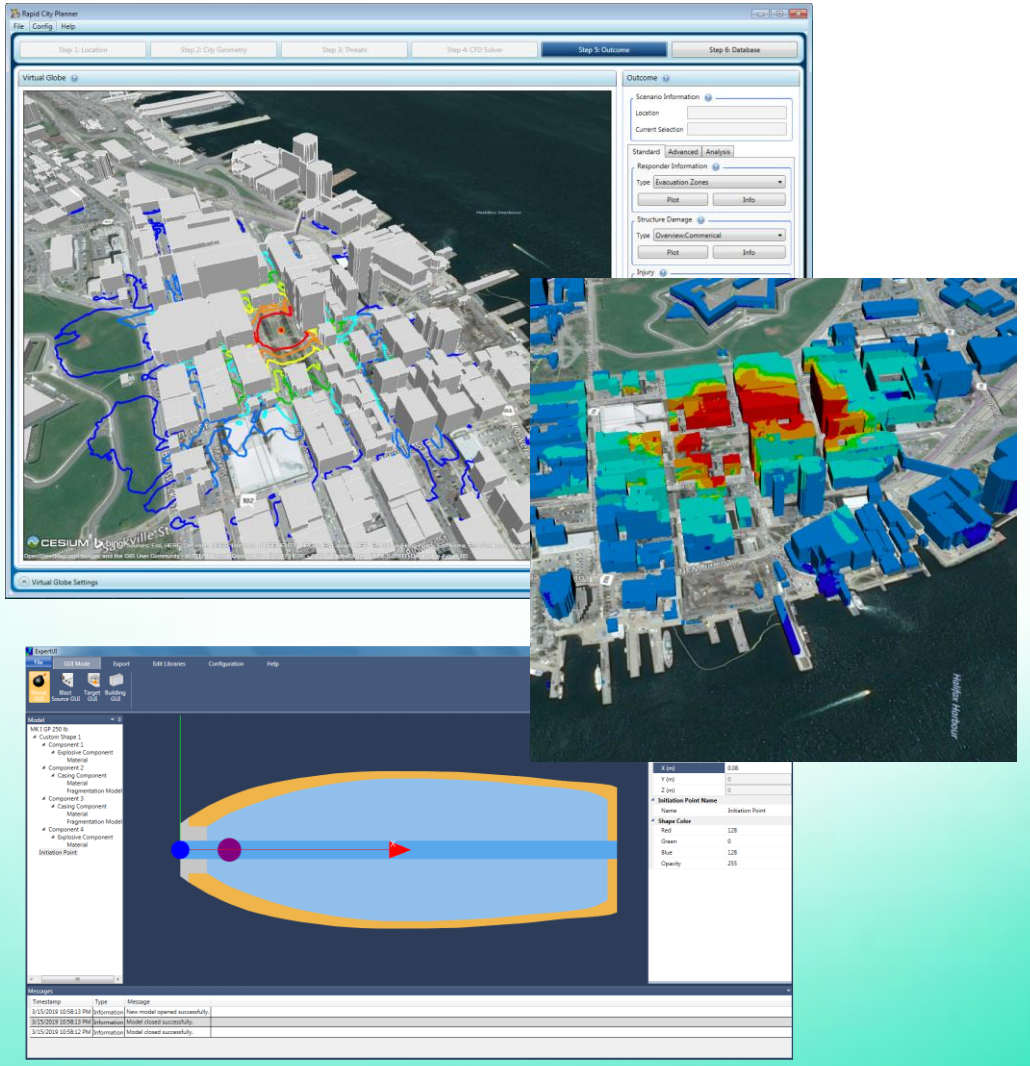


Halifax Waterfront and Downtown Halifax [Source: developns.ca]

Ammunition and Explosives Consequence Analysis Tool (AECAT)

Integrated Data Fusion Platform

- Fast and physically-accurate blast assessments in real-world, **GIS**-based coordinates
- **Fusion** of geospatial data from multiple sources
- Capability highlights:
  - CFD-based fast air blast solver (blast effects)
  - Fast primary fragmentation and trajectory solver (frag effects)
  - Detailed threat modelling with continuum breakup
  - Fragment injury/lethality (statistical)
- Target performance on laptops / workstations
  - **10 minutes** (minimal fidelity)
  - **60 minutes** (standard fidelity)

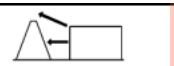
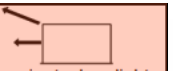


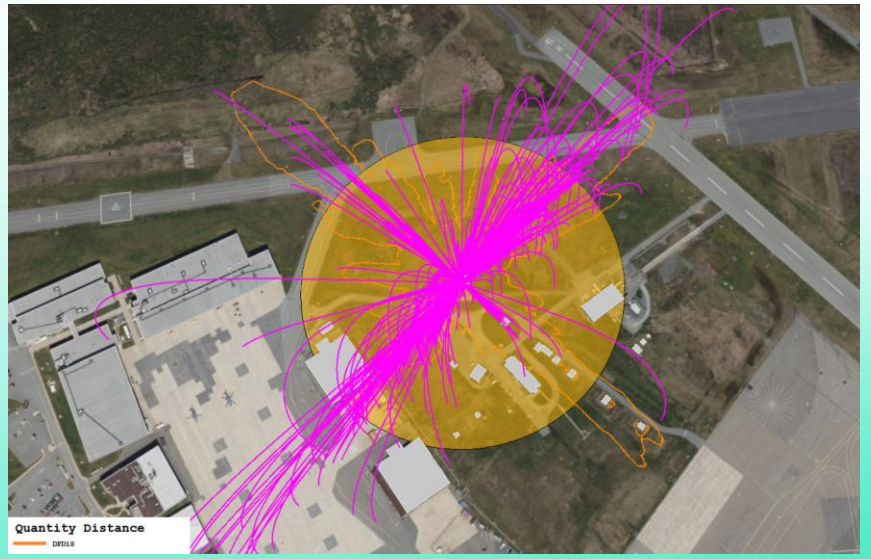
Example urban blast outcomes from RCP calculation (top, right), detailed threat definition in RCP Expert User Interface (bottom)

Ammunition and Explosives Consequence Analysis Tool (AECAT)

Primary AECAT Programme Objectives

- **Physics-based** M&S capability to support risk assessment of A&E storage and licensing
  - First-principles computation of **blast** and **fragmentation** effects in A&E storage environments
  - **Fragmentation** and **debris** effects from A&E storage structures and bulk ammunition
- Build upon established **data fusion platform** for consequence analysis of storage-based explosive scenarios
- Prediction of **vulnerability** and **damage** from explosive event at PES
- Fusion of **physics-based** and **QD-based** outcomes

PES → E S ↓	EFFECT	 Open-air stack or light structure, barricadedd. Truck, trailer, rail-car or freight container loaded with munitions, barricaded. (i)	 Open-air stack or light structure, unbarricaded. Truck, trailer, rail-car or freight container loaded with munitions, unbarricaded. (j)
 **19** Explosives Workshop without protective roof, barricaded (1.3.1.12)	BLAST	BD18 Limited degree of protection for personnel	BD18 Limited degree of protection for personnel
	DEBRIS & FRAG	DFD20 Limited degree of protection for personnel	DFD18 Limited degree of protection for personnel

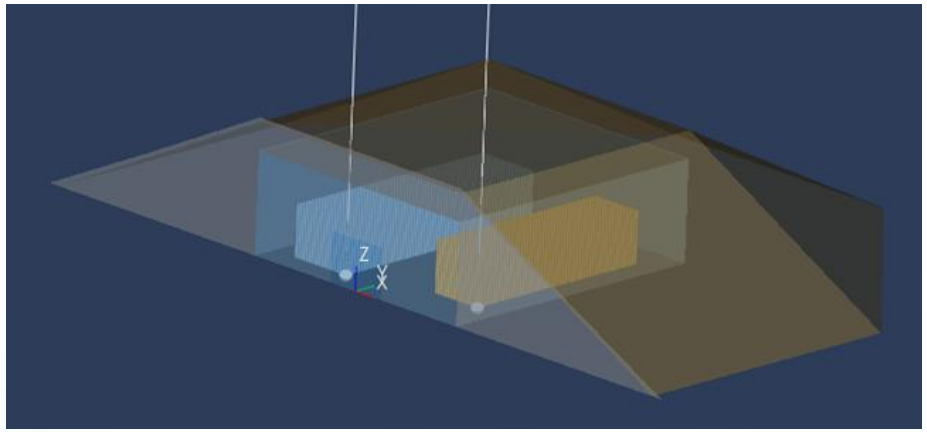


Primary fragmentation outcome in AECAT (bottom), and DFD18 QD table entry (top) *[Source: AASTP-1 Ed. C]*

Ammunition and Explosives Consequence Analysis Tool (AECAT)

AECAT Motivation and Use Cases

- Provide support for A&E **risk-based licensing** tasks
- Review existing QD approaches with site-specific details not captured in standard approaches
    - Effects of **terrain**, **structures**, **barricades**, **infrastructure**, etc.
- Facilitate analyses for:
    - Marginal and/or atypical storage scenarios
    - Expeditionary/deployed storage scenarios
    - Consequence mitigation / sensitivity studies
    - Risk and loss assessments
    - Forensic or event reconstruction





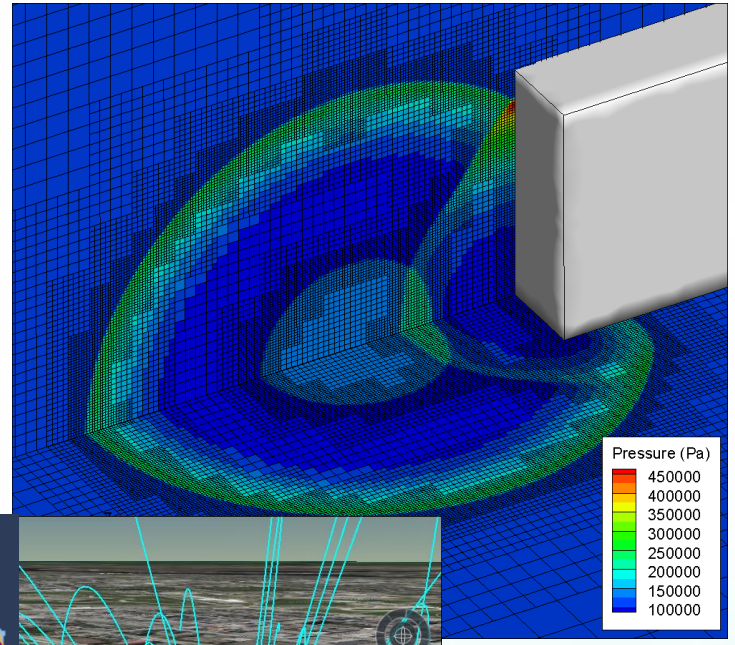
ECM and stacks modelled in AECAT (top), and non-standard ammunition storage magazines at CFAD Bedford (bottom)
[Source: Google Maps]

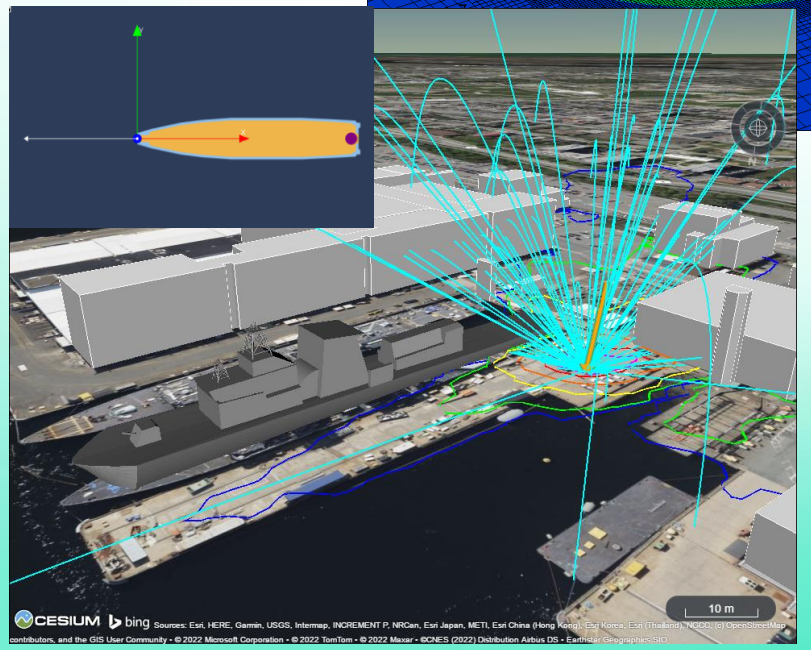
AECAT Modelling Approach

Ammunition and Explosives Consequence Analysis Tool (AECAT)

Blast and Fragmentation Modelling

- Full-physics, **computational fluid dynamics** (CFD)
  - Fast blast solver
  - Detailed solver (continuum breakup, scientific tool)
- **Fast primary fragmentation** solver
  - Generalized 3D Gurney model (initial fragments)
  - Fragment size distribution
    - Grady theory (strain based)
    - Mott size distribution
  - Equivalent bare charge
- **Fragment/debris trajectories** solver





Ammunition and Explosives Consequence Analysis Tool (AECAT)

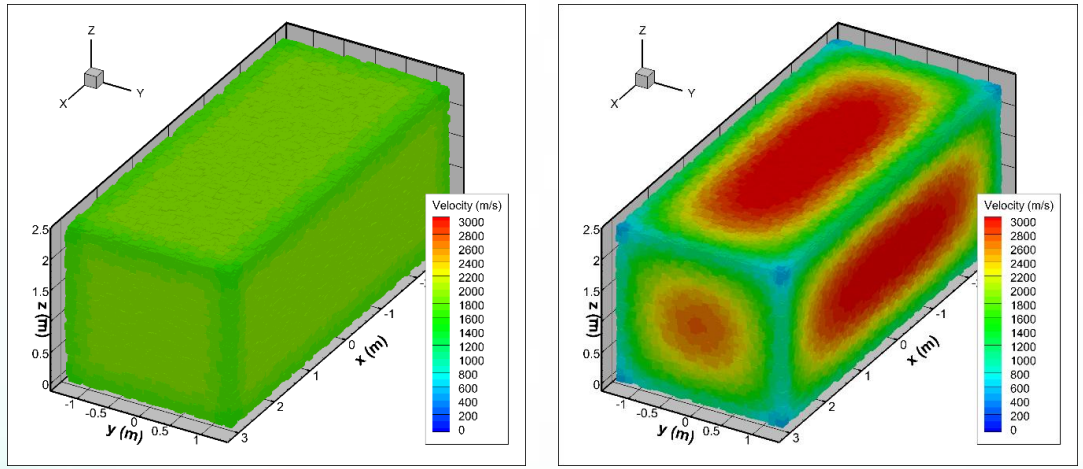
Debris Velocity Prediction

- Initial fragment **velocities**
  - Generalized 3D Gurney theory (discretized on CFD grid)

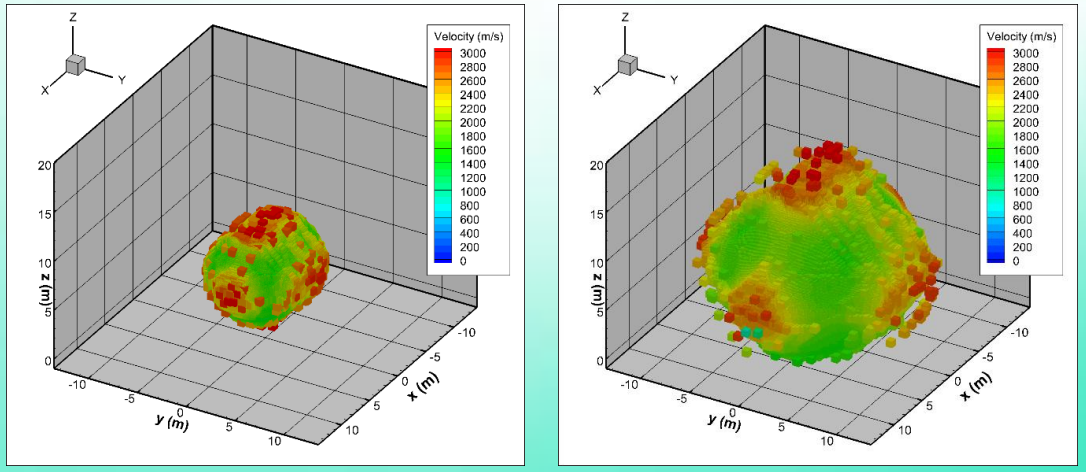
$$V = \sqrt{2E}\left(\frac{M}{C} + \frac{1}{2}\right)^{-1/2}$$

Packing density (% full)	NEQ (kg)	Continuum breakup (m/s)	GGT (m/s) (*% difference*)	DLV (m/s) (*% difference*)
12.5%	6 400	560	650 (*16%*)	670 (*20%*)
25%	12 800	850	890 (*5%*)	950 (*12%*)
50%	25 600	1260	1280 (*2%*)	1350 (*7%*)
100%	55 000	1950	2180 (*12%*)	1920 (*-2%*)

Debris Launch Velocity (DLV)



Continuum breakup *2 ms* *4 ms*



Light confinement debris launch verification using Debris Launch Velocity (DLV), Generalized 3D Gurney, and detailed continuum breakup

Ammunition and Explosives Consequence Analysis Tool (AECAT)

Debris Size Prediction

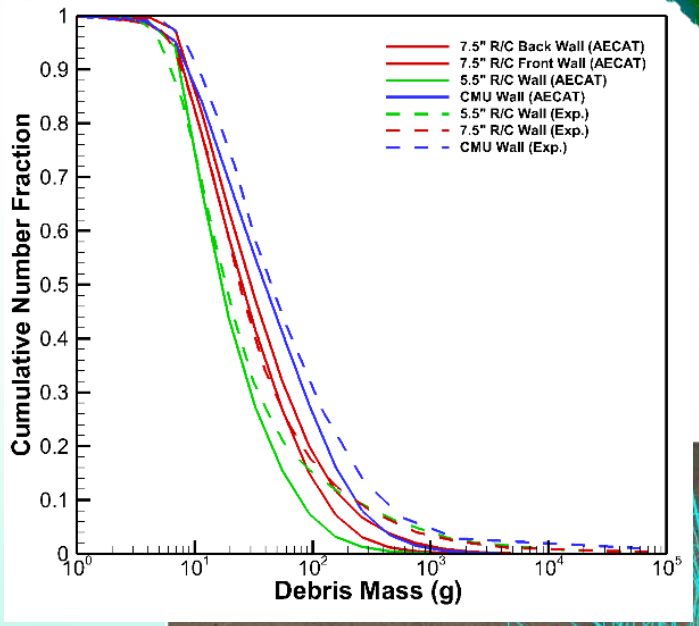
- Fragment **size distribution**
  - Grady theory (mean size from strain)

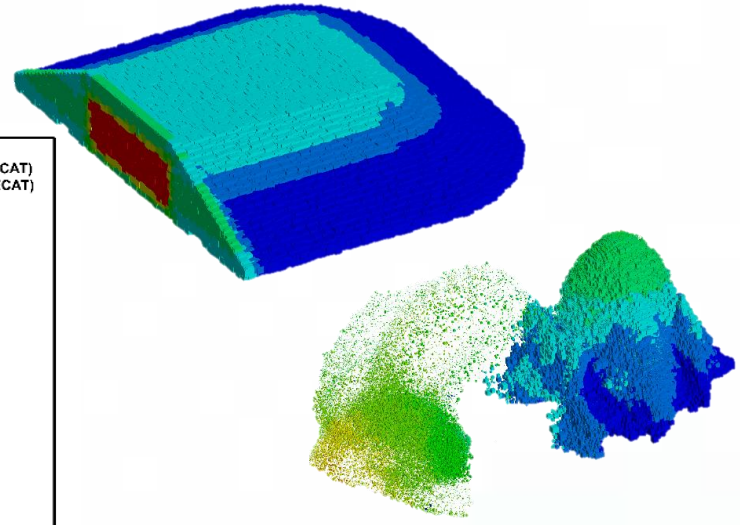
$$\bar{s} = \left(\frac{24\Gamma}{\rho\dot{\epsilon}^2}\right)^{1/3} = \left(\frac{24K_c^2}{2E\rho\dot{\epsilon}^2}\right)^{1/3}$$

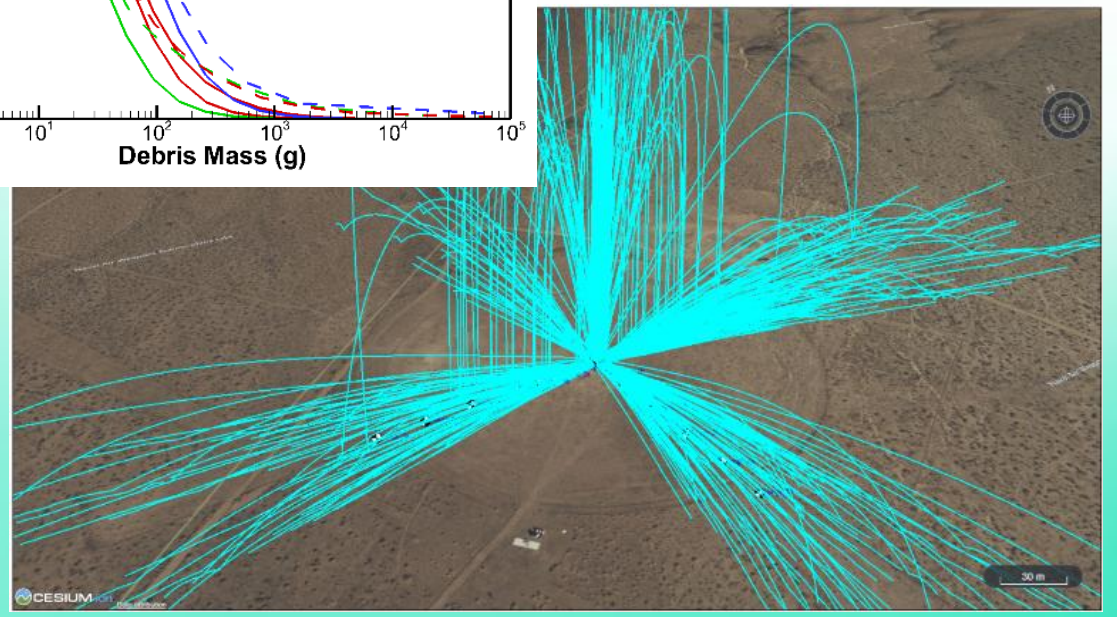
  - 3D Mott distribution

$$N(m) = e^{-\left(\frac{m}{\mu}\right)^{\lambda}}$$

- Secondary breakup (shattering)



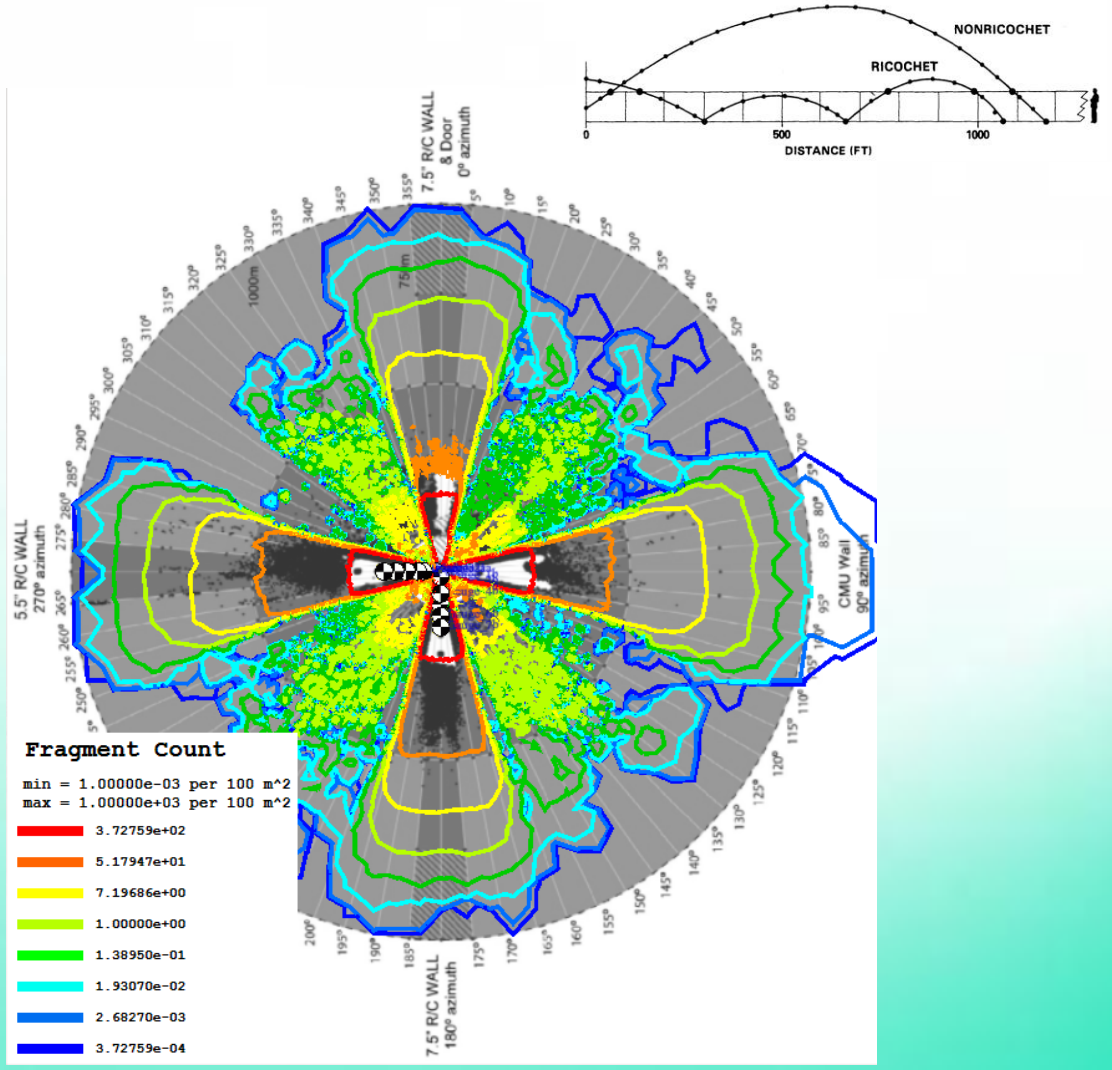




Ammunition and Explosives Consequence Analysis Tool (AECAT)

Debris Transport and Consequence Assessment

- Lagrangian transport framework to compute **debris trajectories**
- Conversion of **debris source terms** into **physics-based consequence estimates**
- Modelling features:
  - Aerodynamic drag
  - Gravity
  - Terrain interaction
  - Ricochet
  - Impact lethality

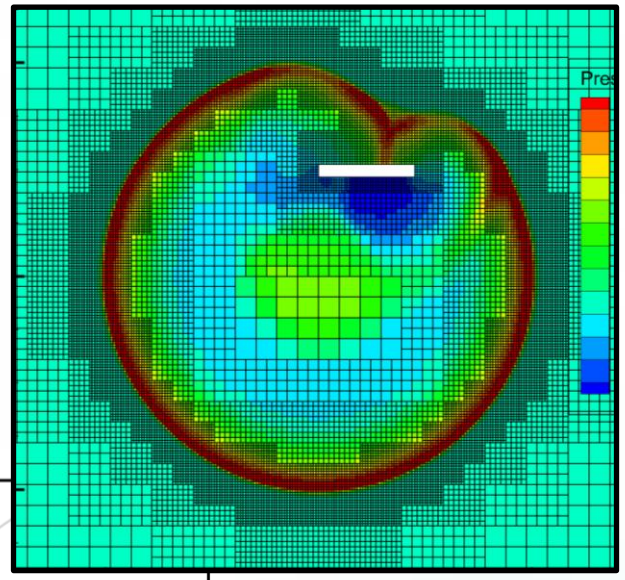


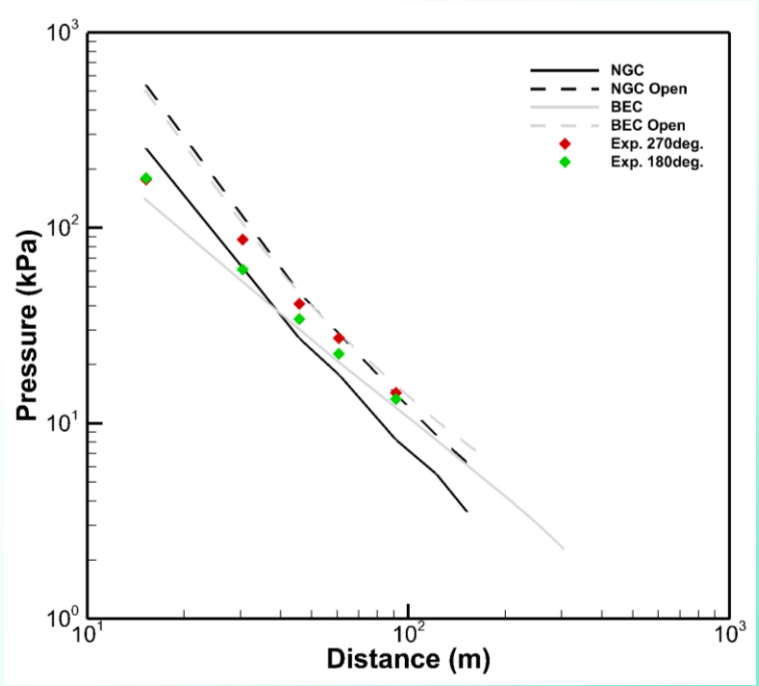
Ammunition and Explosives Consequence Analysis Tool (AECAT)

Blast Consequence Methodology

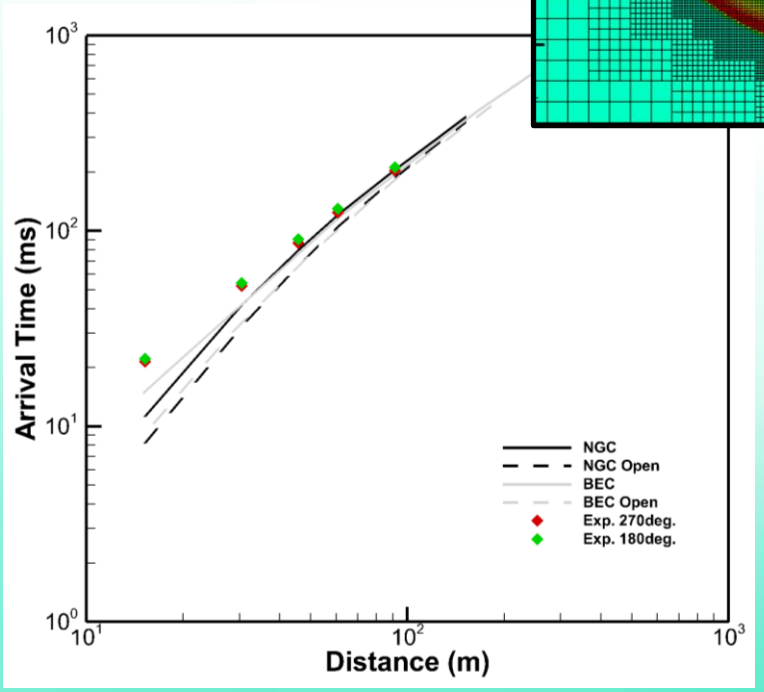
- Blast **energy reduction** from Equivalent Bare Charge (EBC)

$$EBC = C\left(0.4 + \frac{0.6}{1 + 2M/C}\right)$$





Overpressure



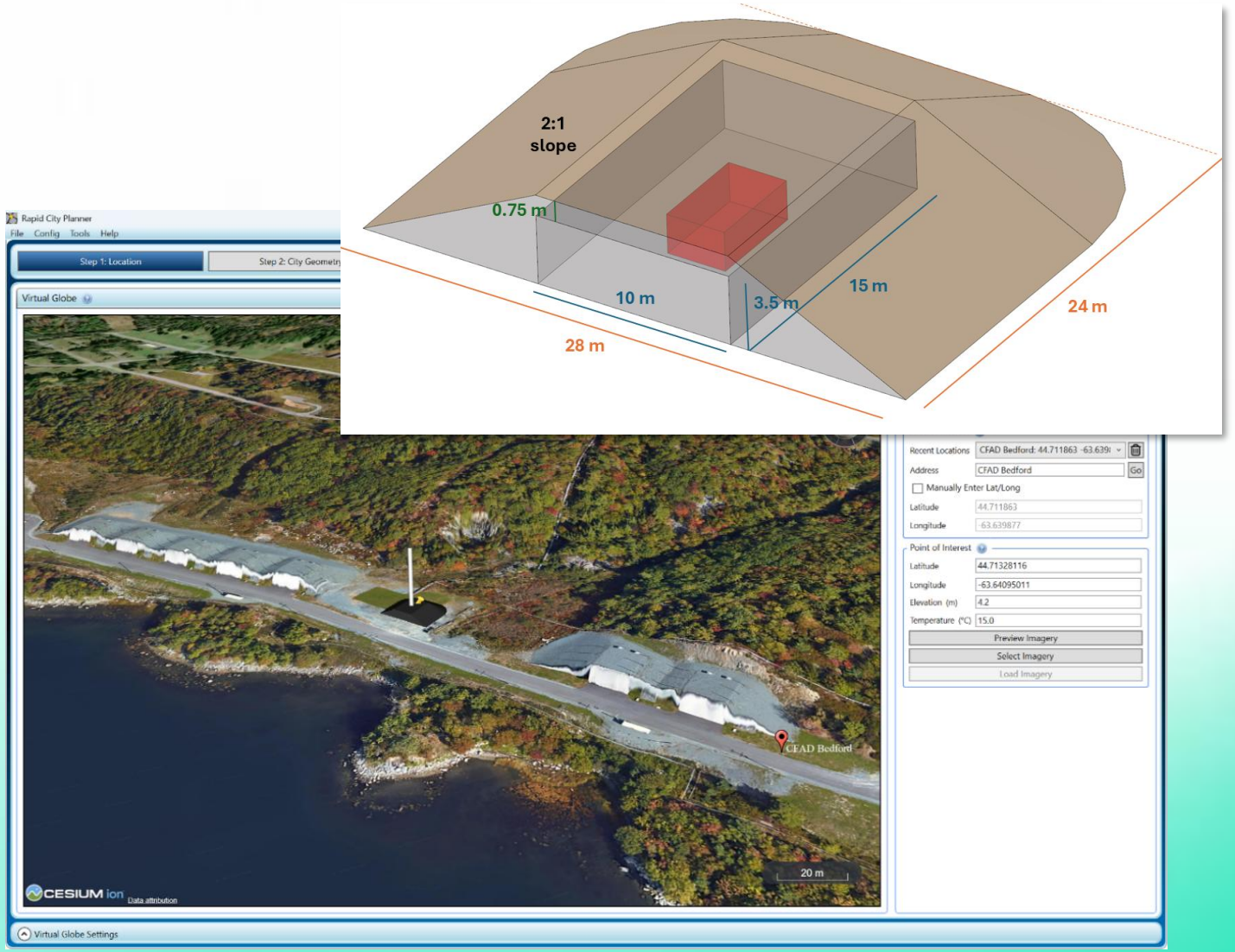
Arrival Time

Earth Covered Magazine (ECM) Modelling in AECAT

Ammunition and Explosives Consequence Analysis Tool (AECAT)

ECM Modelling in AECAT

- Application of two magazine debris breakup and launch methodologies:
  - Fast debris breakup (Gurney)
  - Detailed continuum breakup
- ECM scenario:
  - NEQ = 50 000 kg TNT (uncased)
  - 10 m x 15 m x 3.5 m
  - Concrete thickness: 30 cm
  - Soil cover: 75 cm thick, 2:1 slope
- Location:
  - CFAD Bedford, Nova Scotia, Canada

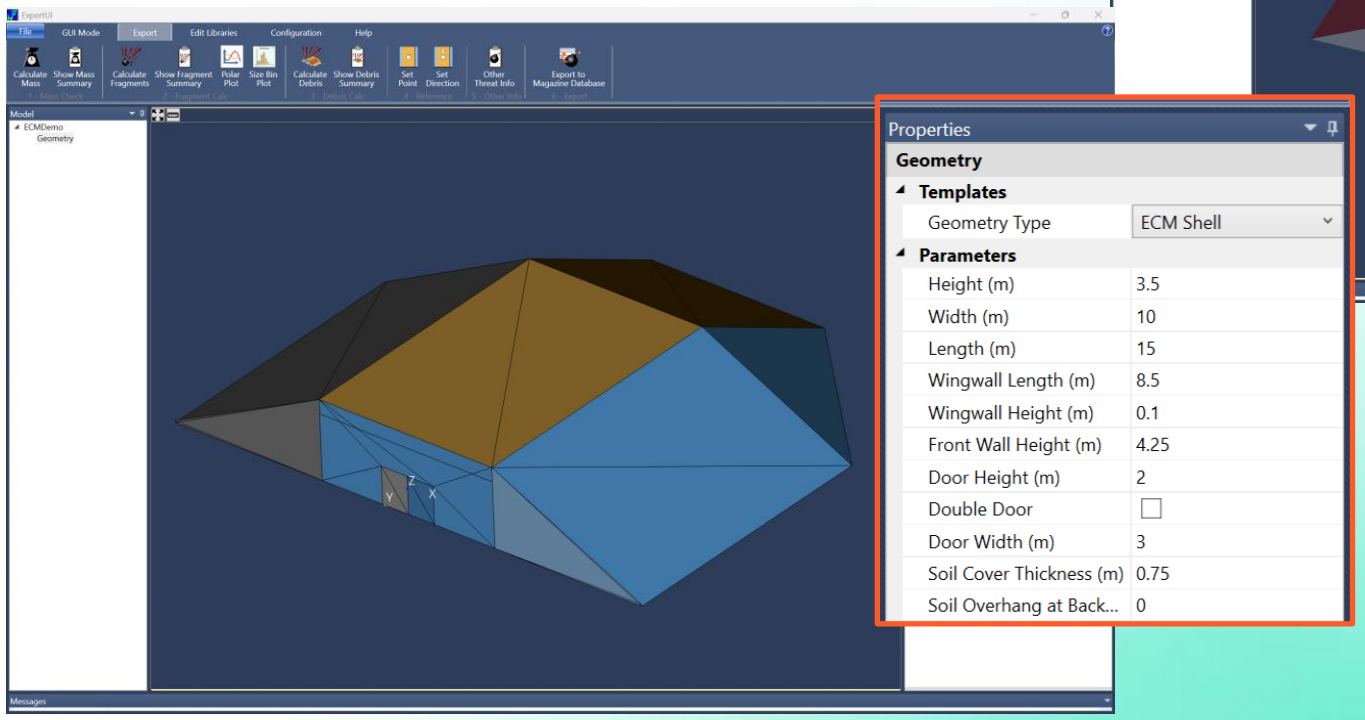


ECM demonstration scenario geometry (top), ECM scenario setup in AECAT Virtual Globe, including terrain visualization (bottom)

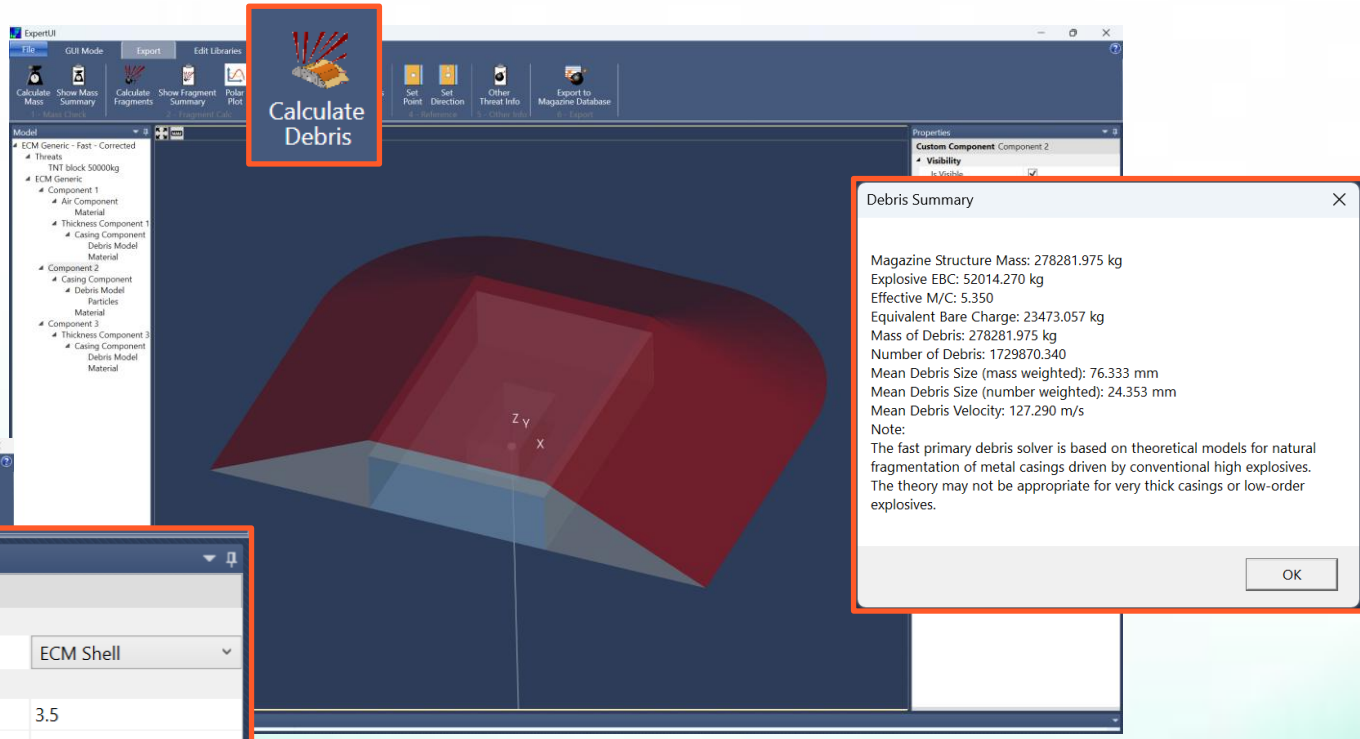
Ammunition and Explosives Consequence Analysis Tool (AECAT)

ECM Scenario Setup in AECAT

Magazine Builder



Magazine Builder in AECAT to define magazine geometry

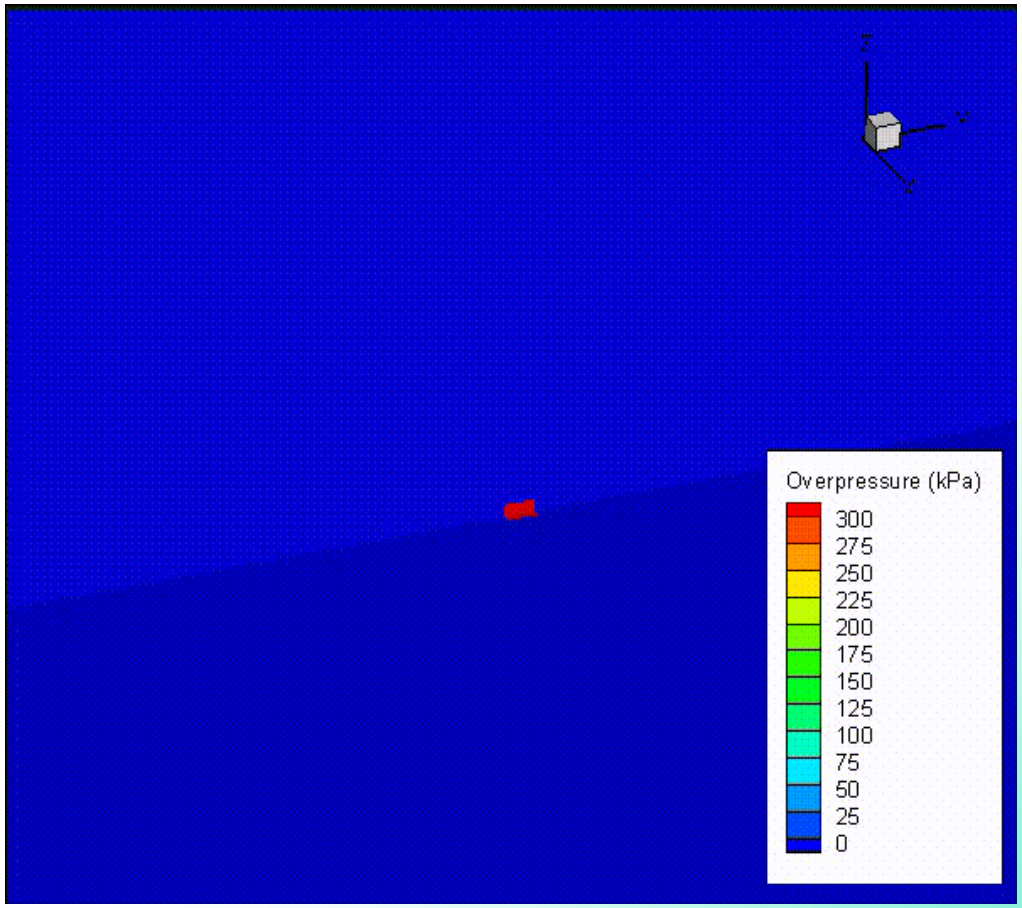


Magazine GUI to define ECM explosive and structure model

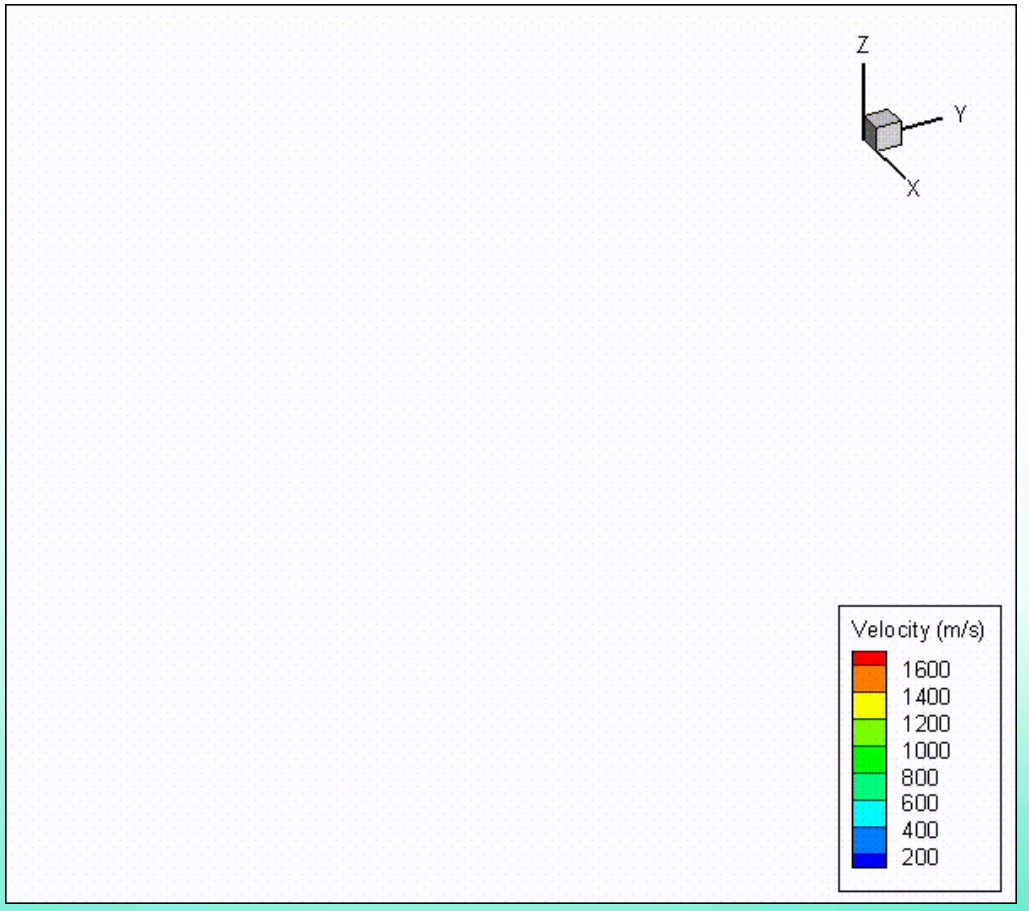
Magazine GUI

Ammunition and Explosives Consequence Analysis Tool (AECAT)

Detailed continuum breakup model – ECM debris



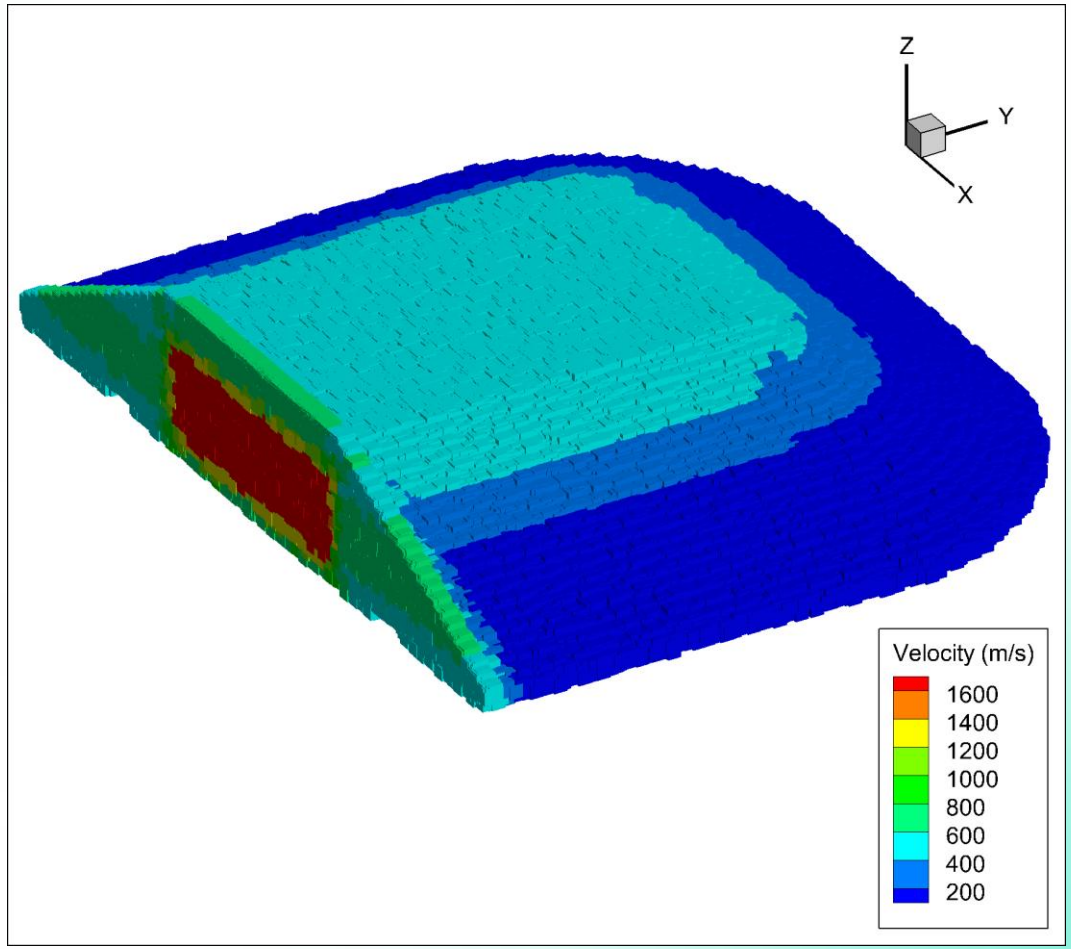
ECM debris generation with blast overpressure contours



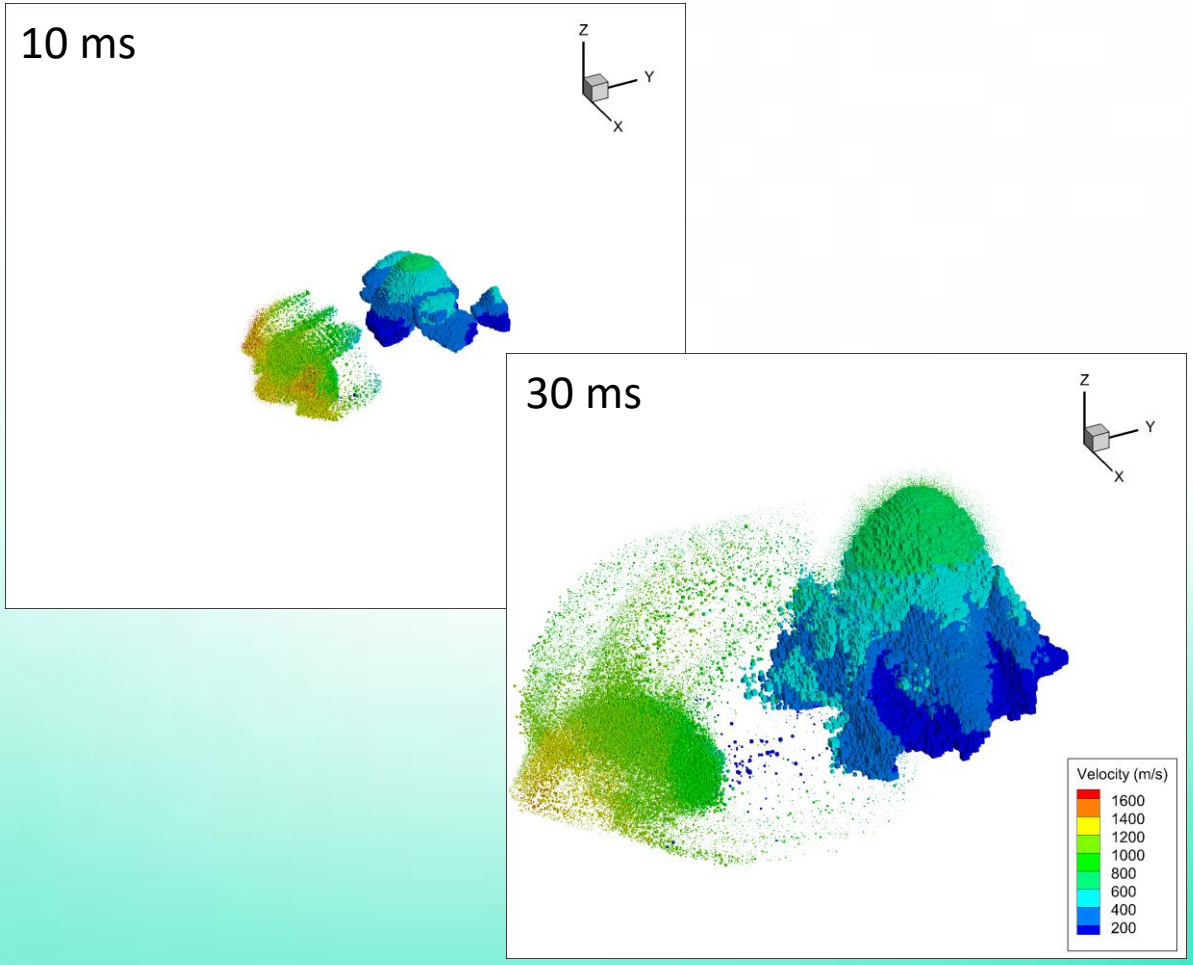
ECM debris generation with debris velocity contours

Ammunition and Explosives Consequence Analysis Tool (AECAT)

Fast debris generation model – ECM debris launch velocity



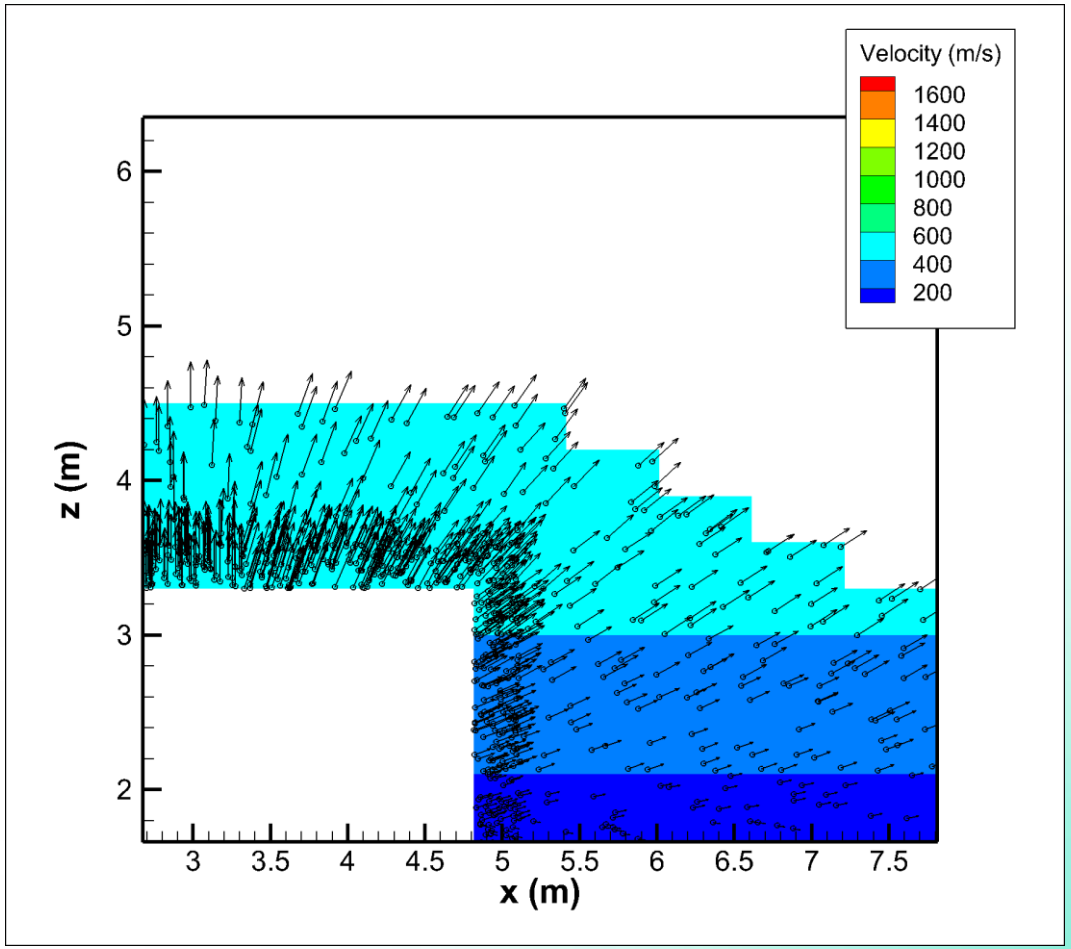
Fast debris solver initial debris velocities



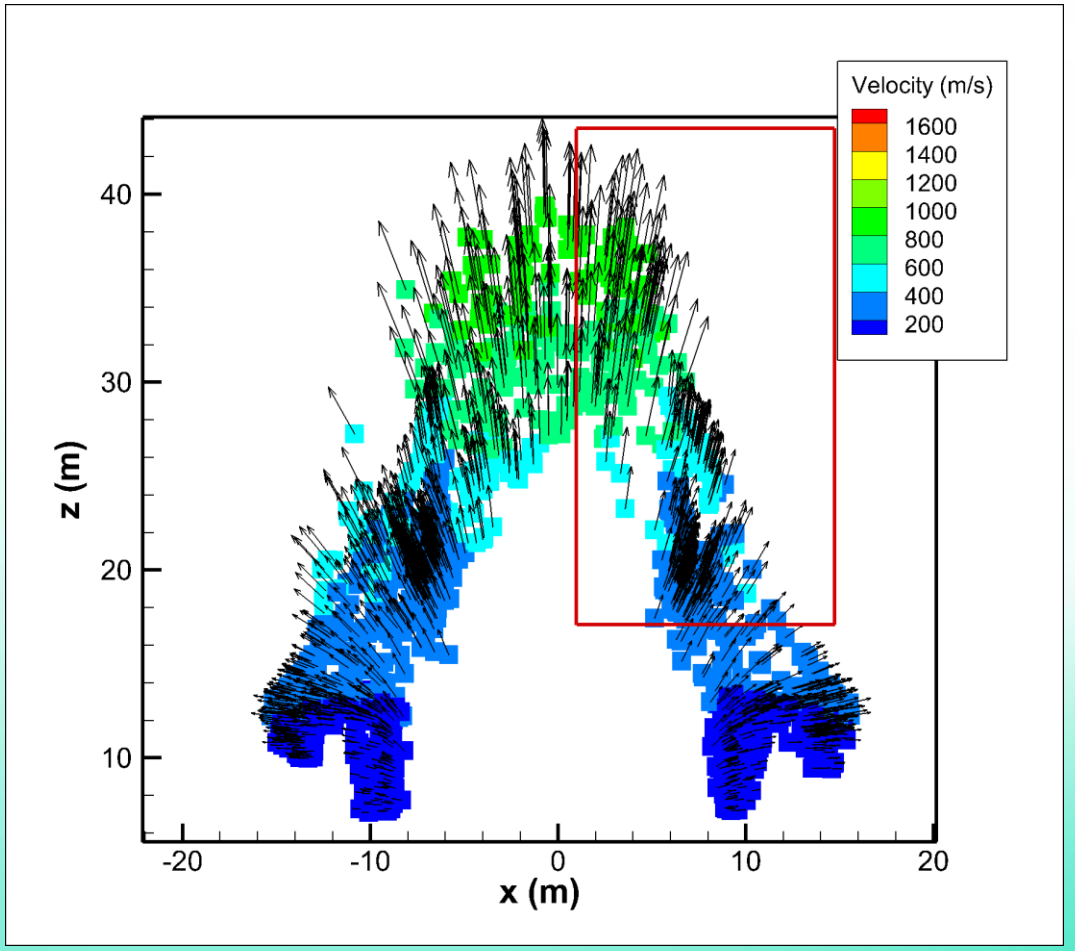
Detailed continuum breakup debris velocities at t = 10 ms (top) and *t* = 30ms (bottom)

Ammunition and Explosives Consequence Analysis Tool (AECAT)

Fast debris generation model – ECM debris launch directions



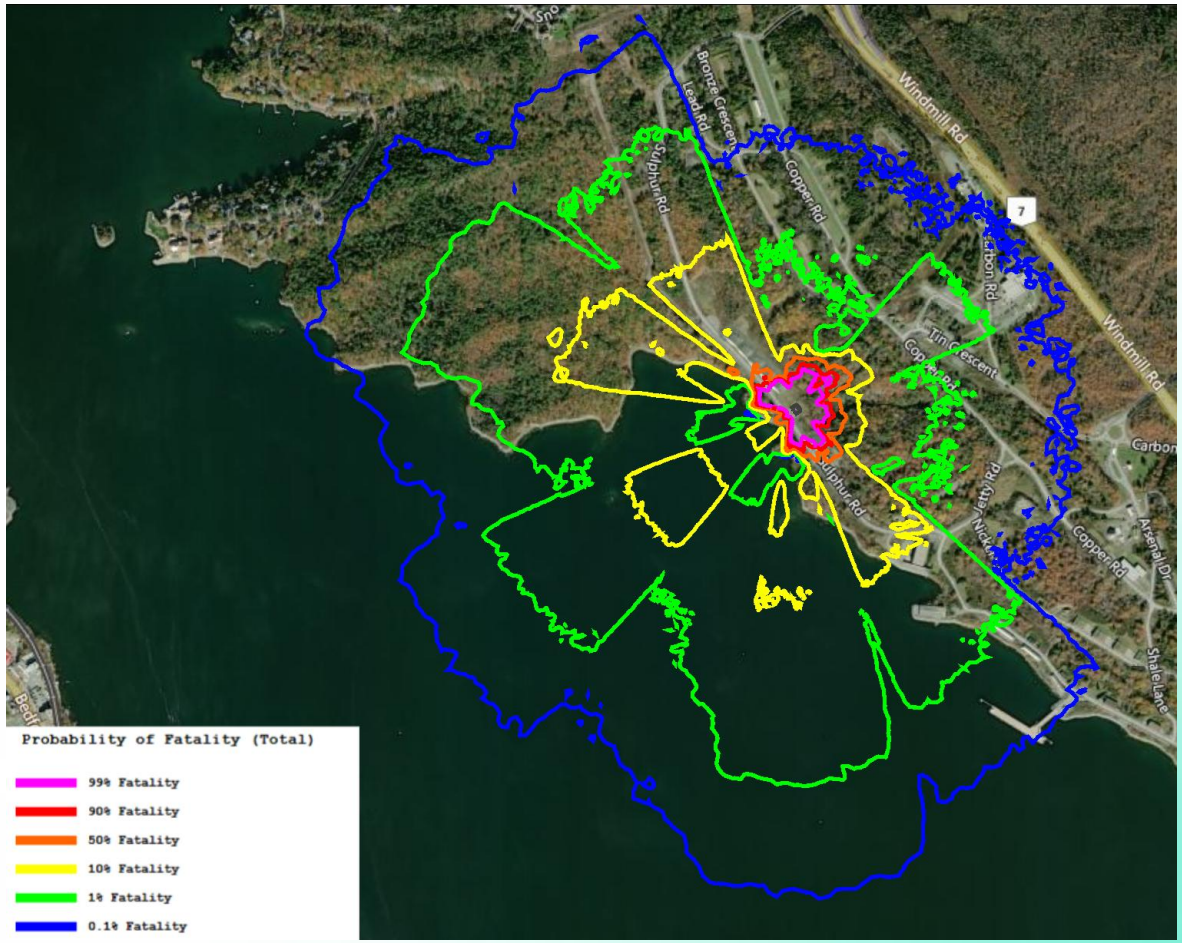
Fast debris solver initial debris launch directions, with directional smoothing for magagine geometries (bottom)

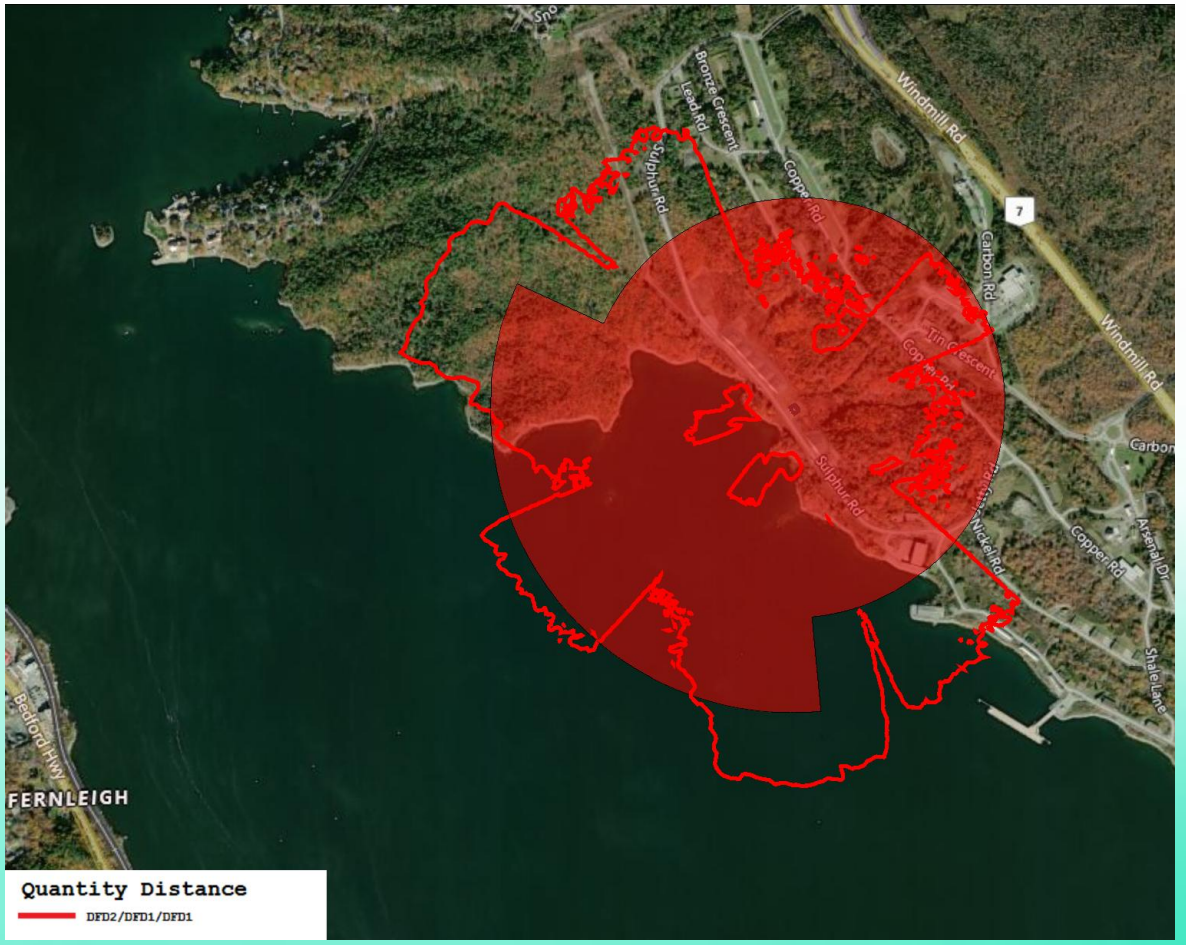


Detailed continuum breakup initial debris launch directions

Ammunition and Explosives Consequence Analysis Tool (AECAT)

Fast debris ECM consequence analysis – Probability of fatality and QD

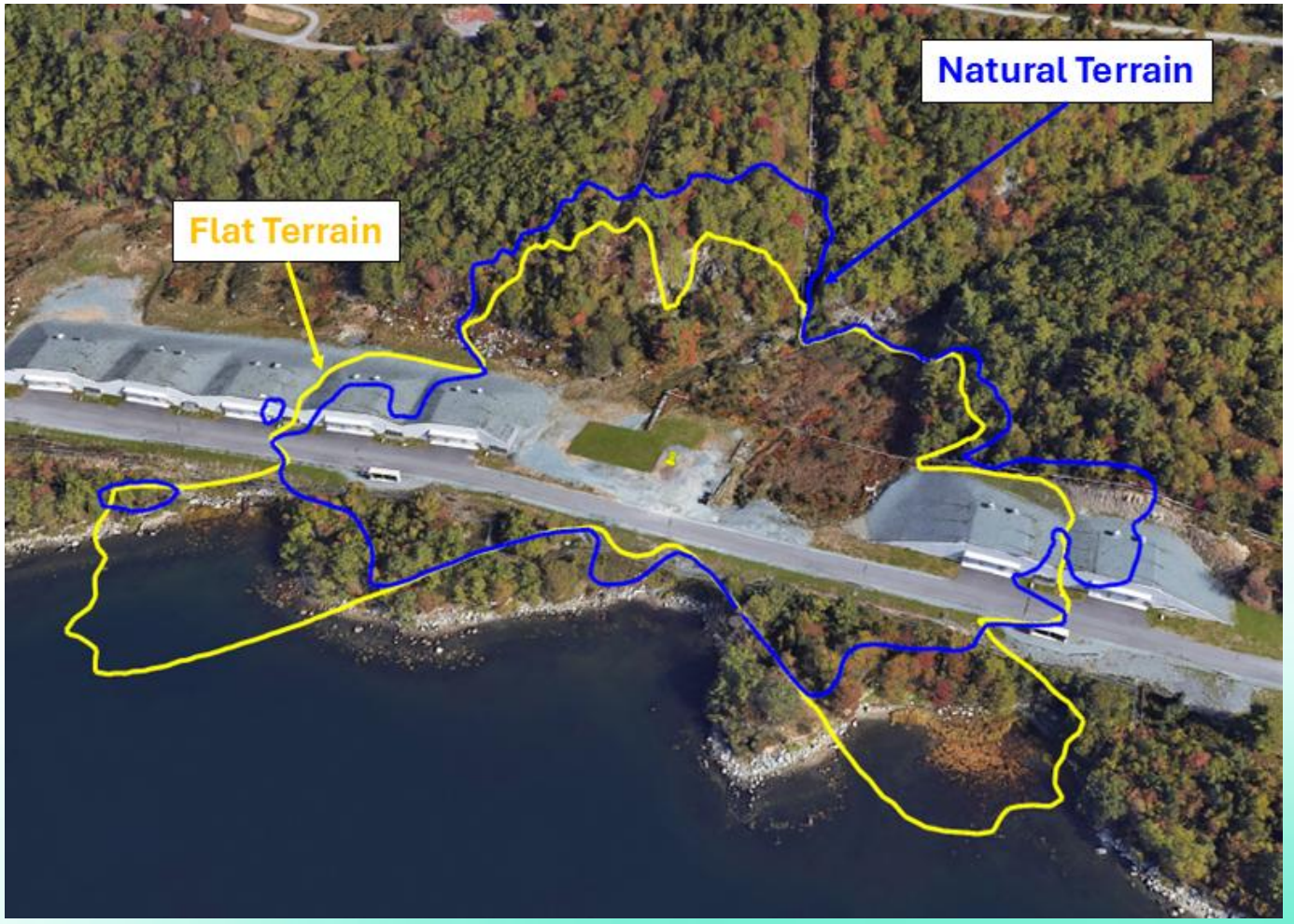




Fast debris ECM consequence analysis in real-world environment shown in AECAT, with probability of fatality isolines (left), and with IBD QD (DFD2/DFD1) with single 1% probability of fatality isoline (right)

Ammunition and Explosives Consequence Analysis Tool (AECAT)

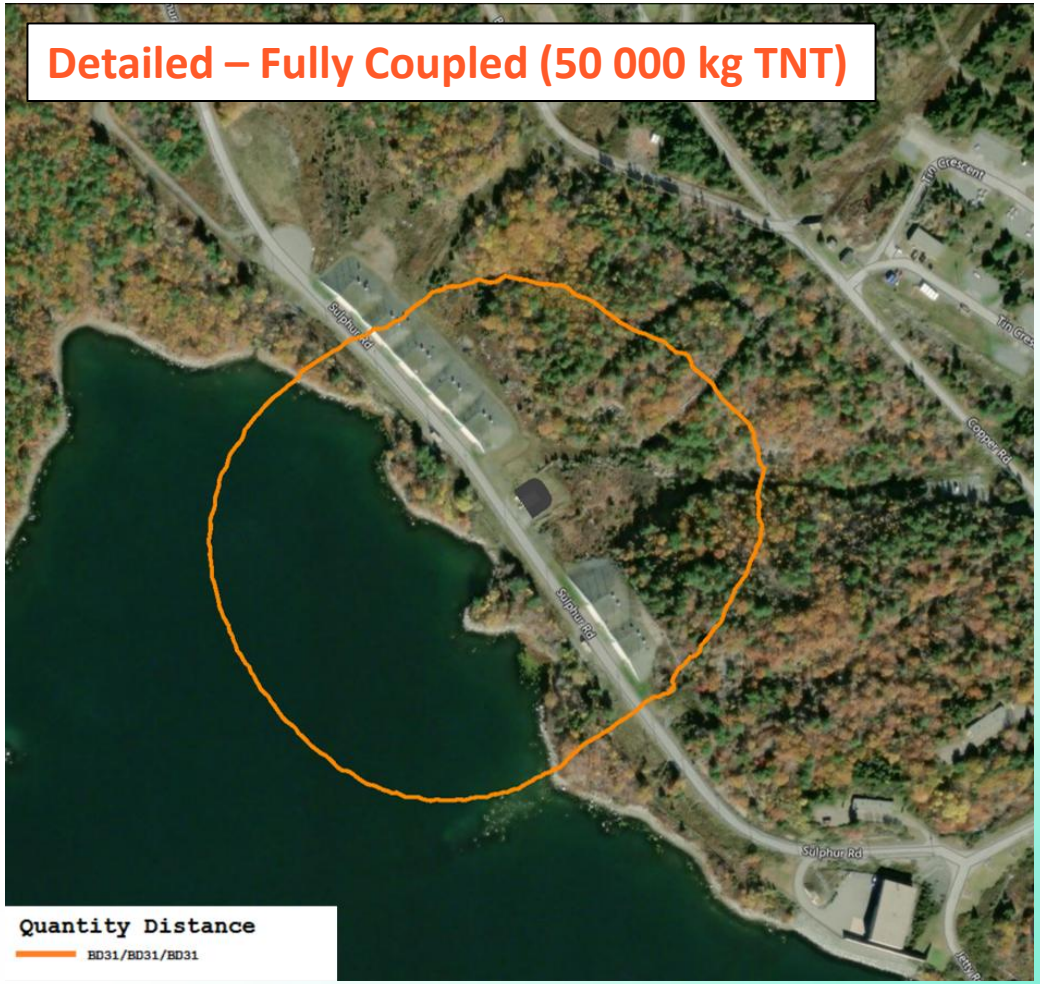
Fast debris ECM consequence analysis – Terrain effects

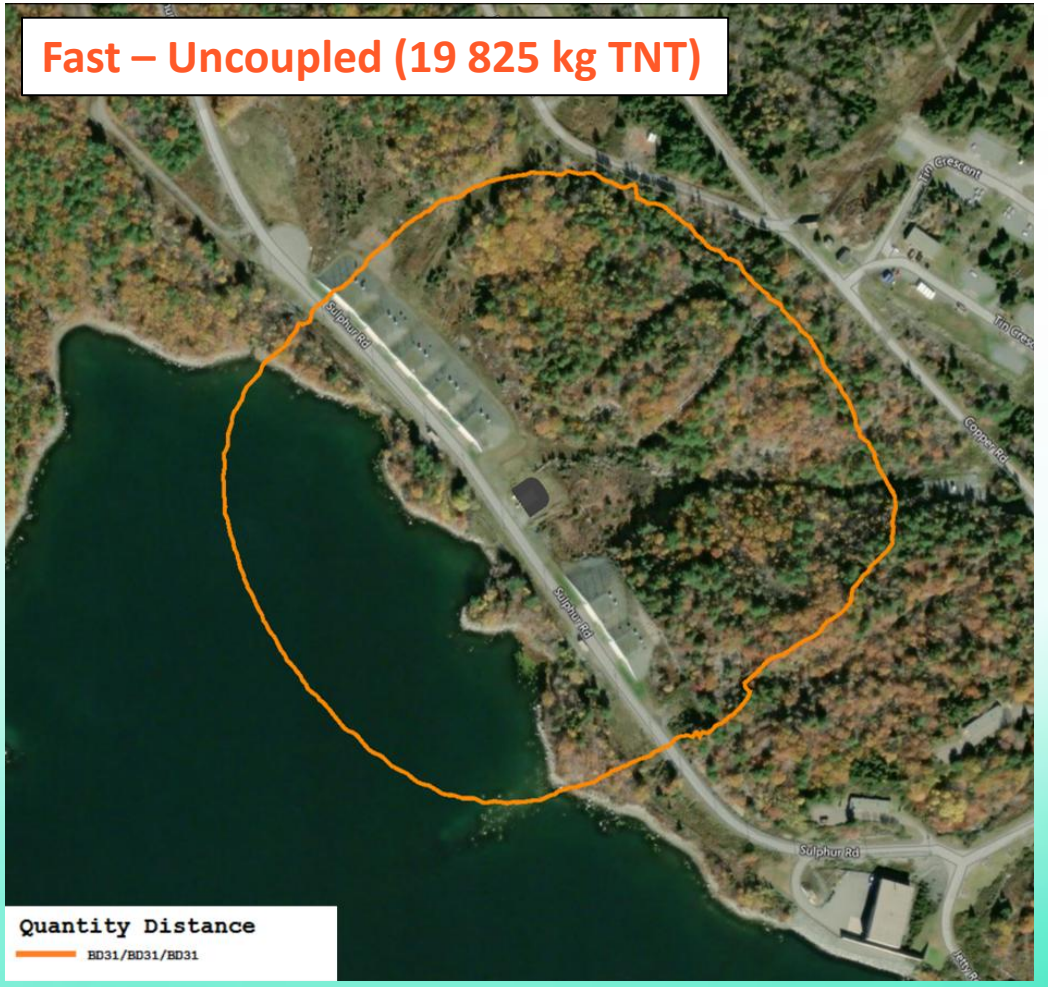


Visualization of terrain effects from AECAT consequence analysis for 50% fatality probability isolines

Ammunition and Explosives Consequence Analysis Tool (AECAT)

Fast debris ECM consequence analysis – Blast considerations





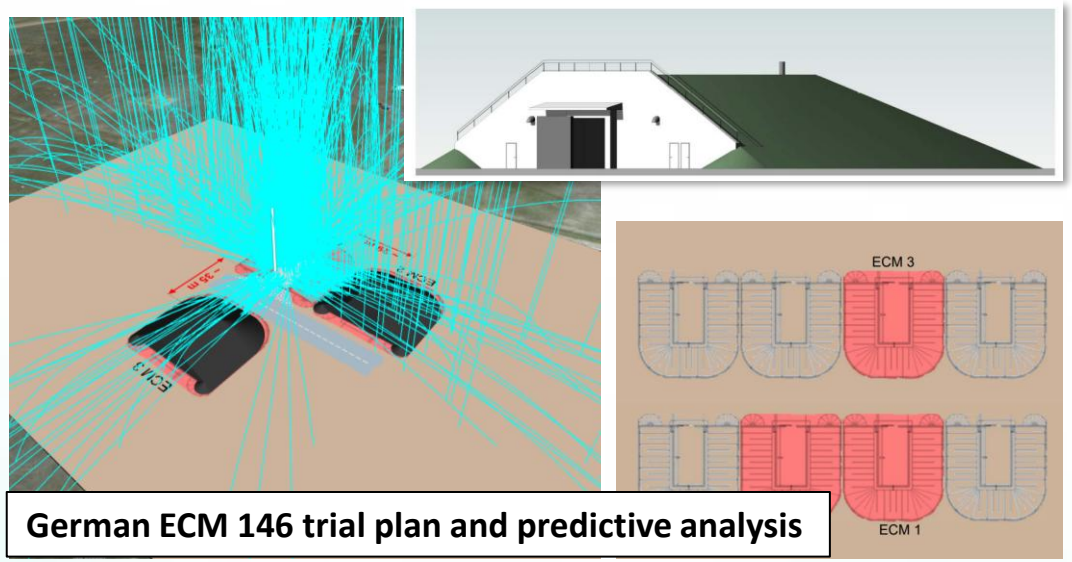
Blast effects results for detailed continuum breakup model (left) and fast debris (uncoupled) model (right).
Isoline at 5.3 kPa blast overpressure. QD shown for IBD, including reduced quantities shown for illustration purposes.

Validation Programme and Future Work

Ammunition and Explosives Consequence Analysis Tool (AECAT)

Validation Status and Future Work

- **Validation of ECM modelling** approaches
  - USA MERCURY 10 Trial (October 2025)
  - Singapore ECM Trial (Planned 2027)
  - Germany NATO ECM 146 (Planned 2028)
- Generation of external **validation documentation**
- System enhancement for **naval storage**
  - Inter-compartment propagation
  - Successive failure of adjacent volumes
  - Sympathetic detonation
- Platform enhancements
  - **Risk assessments** and **event likelihoods**
  - Expanded capability for **siting** and **licensing** activities



German ECM 146 trial plan and predictive analysis

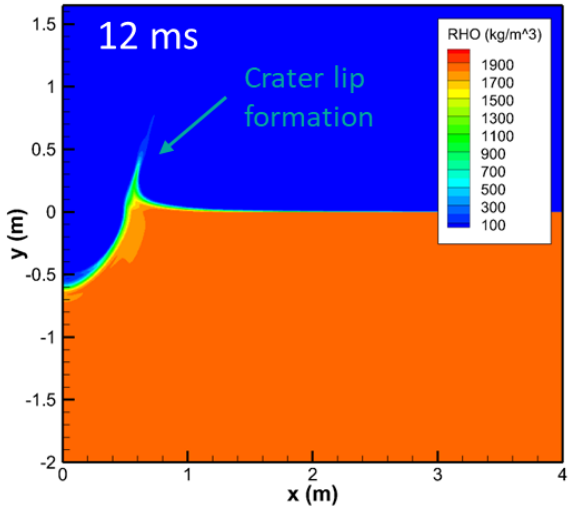


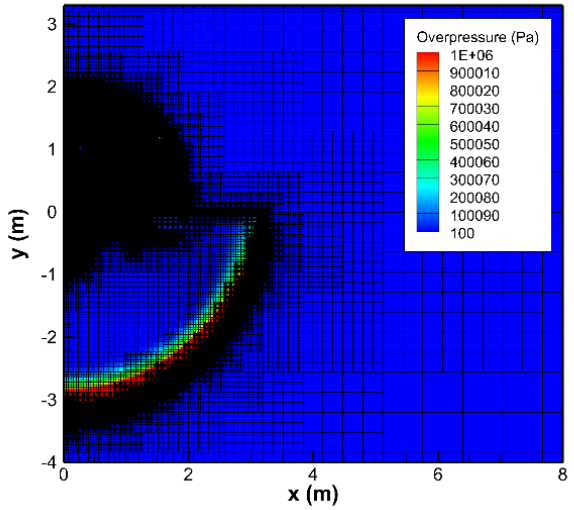
MERCURY 10 trial observation (October 2025)

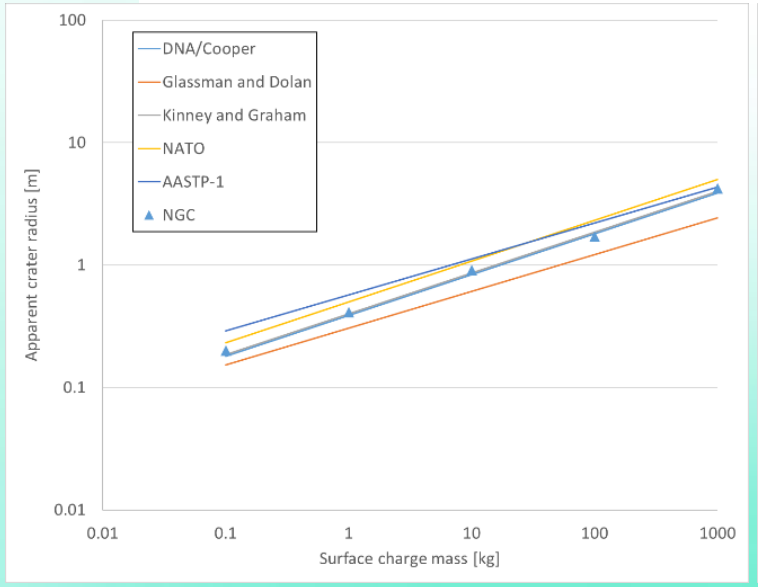
Ammunition and Explosives Consequence Analysis Tool (AECAT)

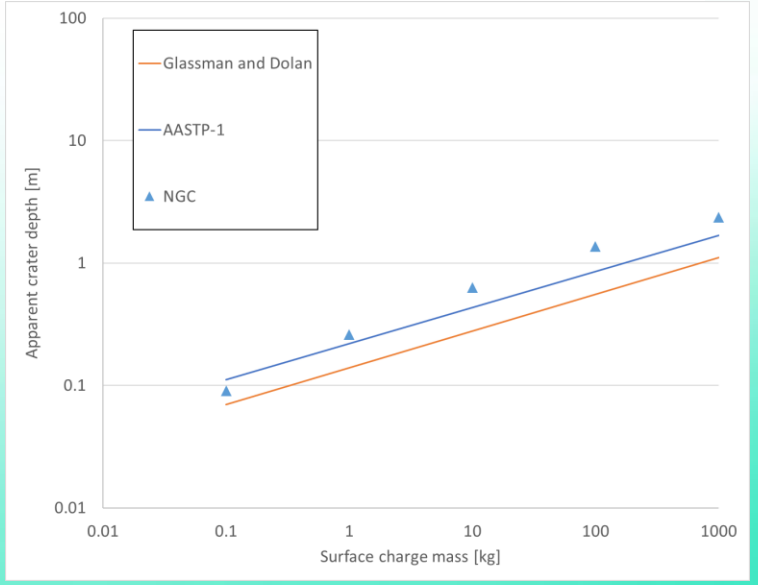
Ground Shock and Cratering

- Expanded capabilities for **crater formation** and **ground shock prediction**
- Support assessments involving buried explosives, underground facilities, etc.
- Initial validation studies have been performed with surface and buried explosive charges







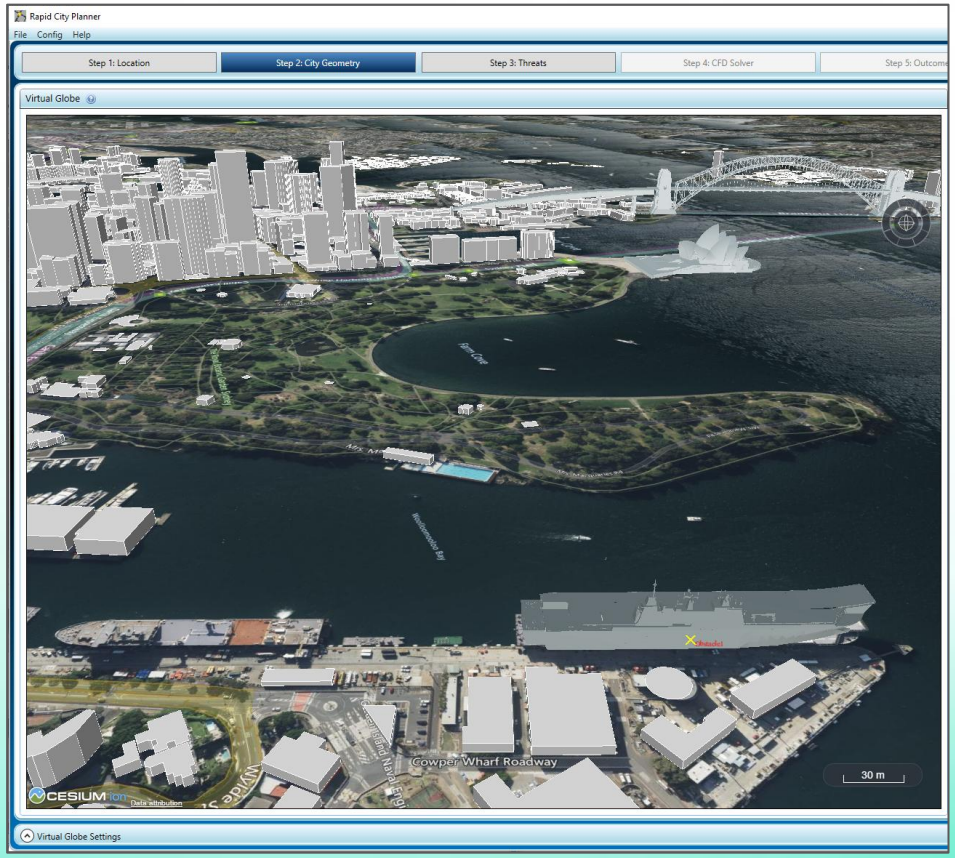


Density contours for half-buried charge showing crater formation (top), AECAT vs. various empirical models of apparent crater radius and depth for various charge masses

Ammunition and Explosives Consequence Analysis Tool (AECAT)

System Enhancement for Naval Storage

- **Advanced capabilities** to support risk analysis of munitions scenarios with **naval ships**
  - Stack/magazine definition within ship compartments
  - 3D terrain visualization and water surface
  - Water response, low energy effects, large fragments, sympathetic detonation
- **Improved performance**, usability, and sustainability
  - Testing and workflow updates
  - Batched calculations for parametric UQ
- **Validation** of modelling approaches
- **Deployment** and support within Canada and abroad

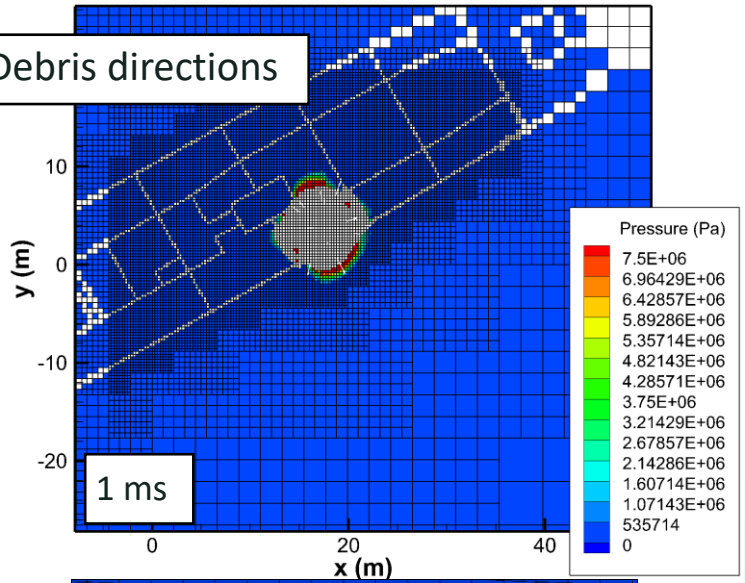


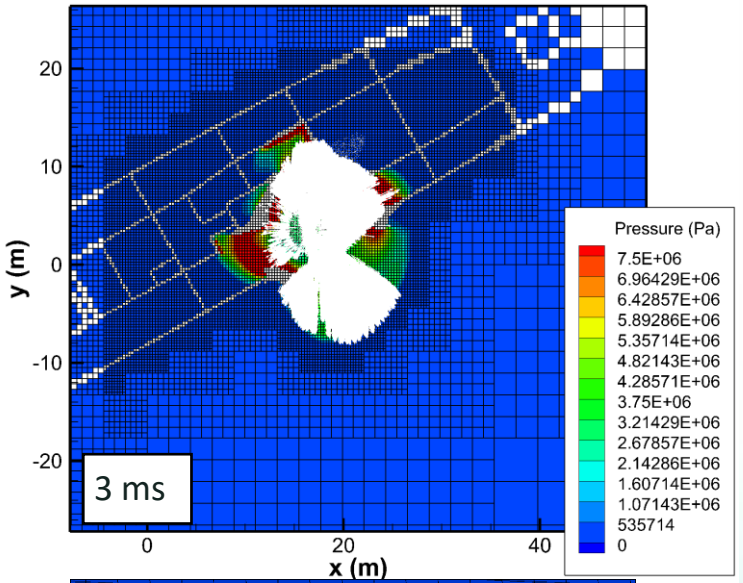
Hypothetical naval ship storage scenario in Sydney Harbour in AECAT

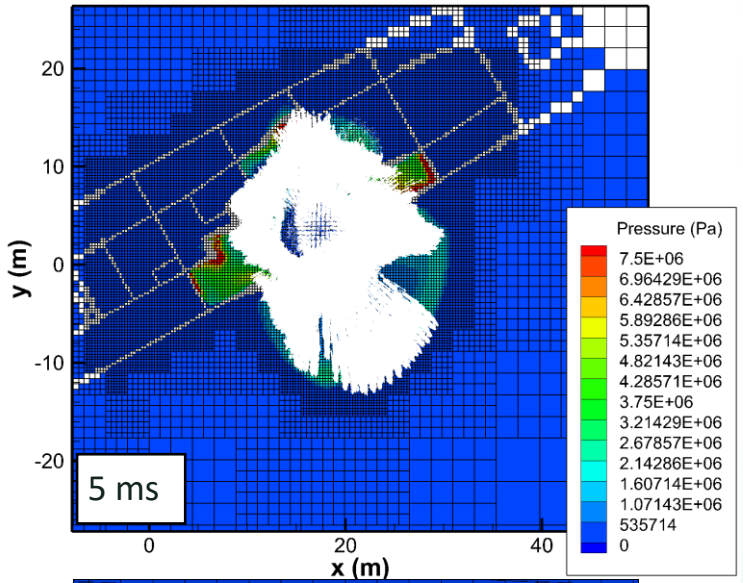
Ammunition and Explosives Consequence Analysis Tool (AECAT)

Naval Storage Enhancements – Debris breakup (Detailed solver)

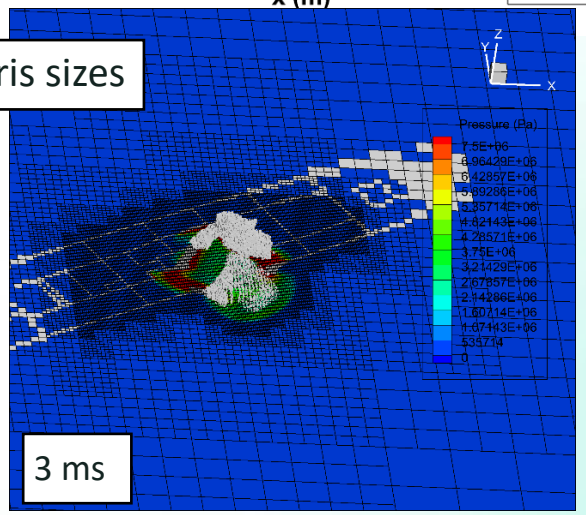
Debris directions

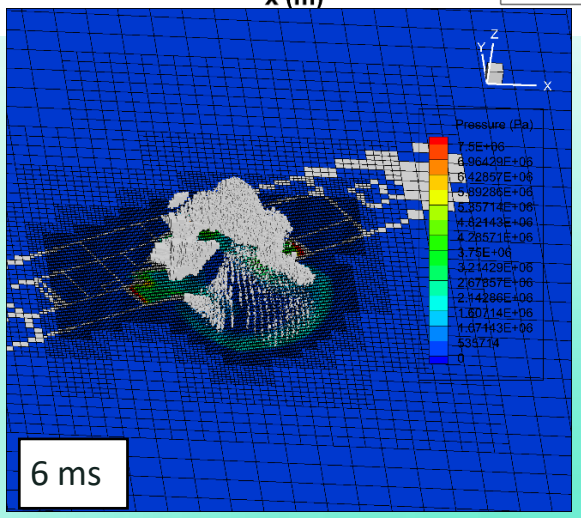


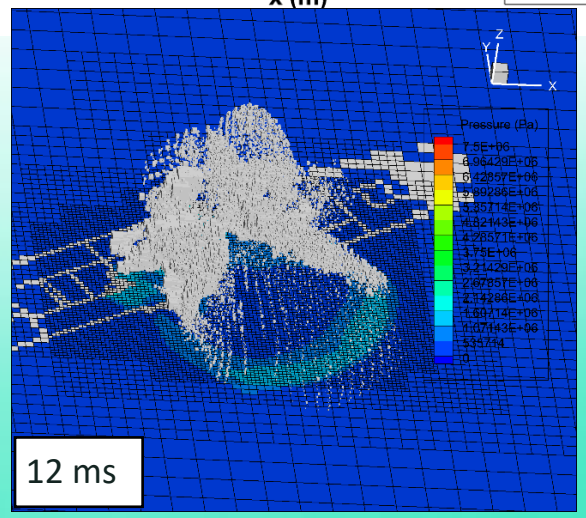




Debris sizes

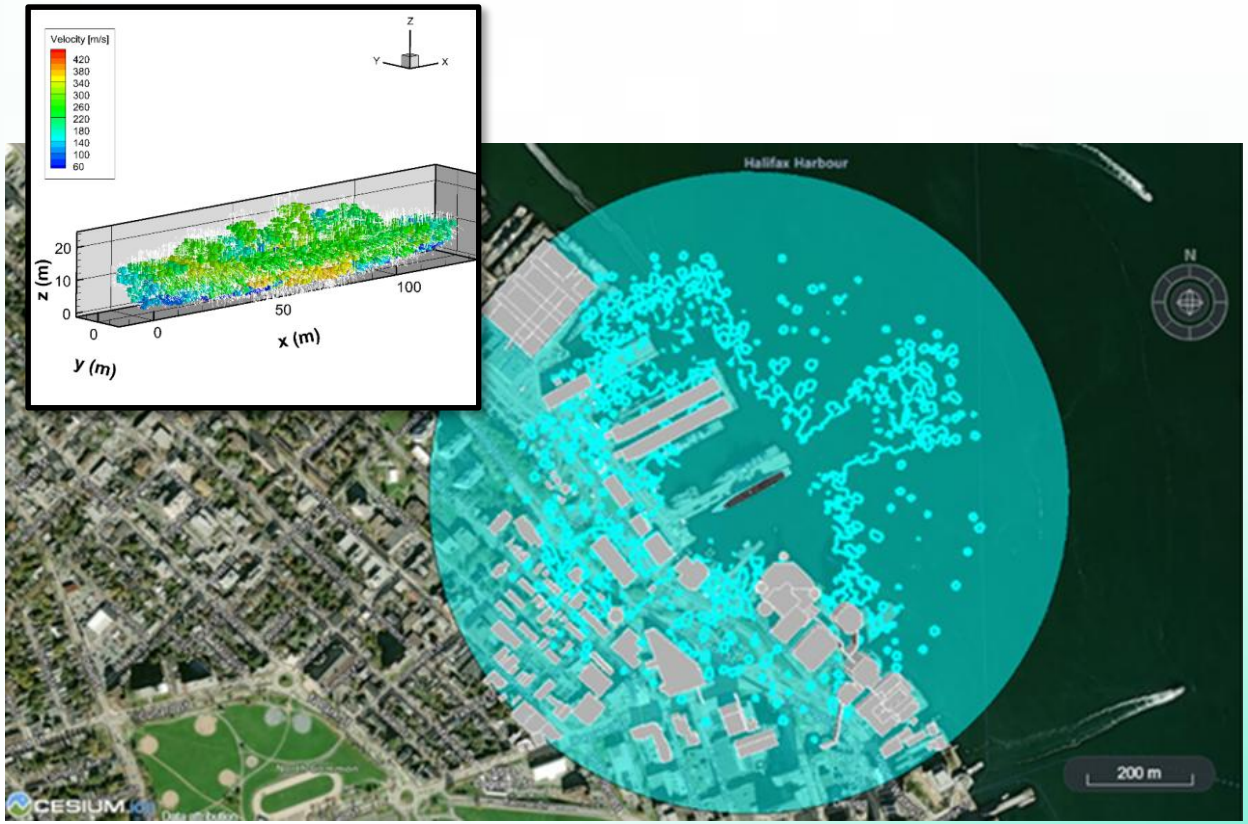




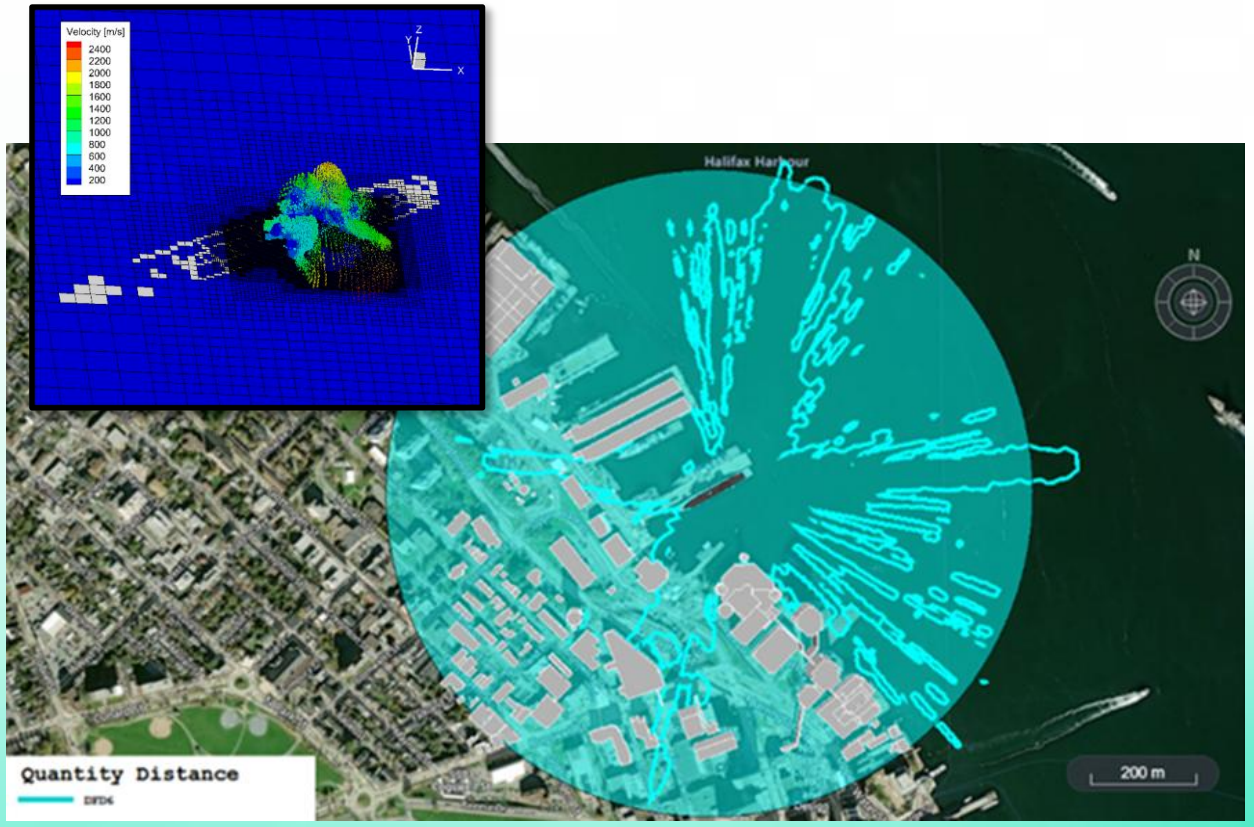


Ammunition and Explosives Consequence Analysis Tool (AECAT)

Naval Storage Enhancements – 1% prob. Fatality and DFD6 (IBD)



Fast fragmentation (3D Generalized Gurney) – Preliminary Result



Detailed (continuum) breakup

Thank you

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