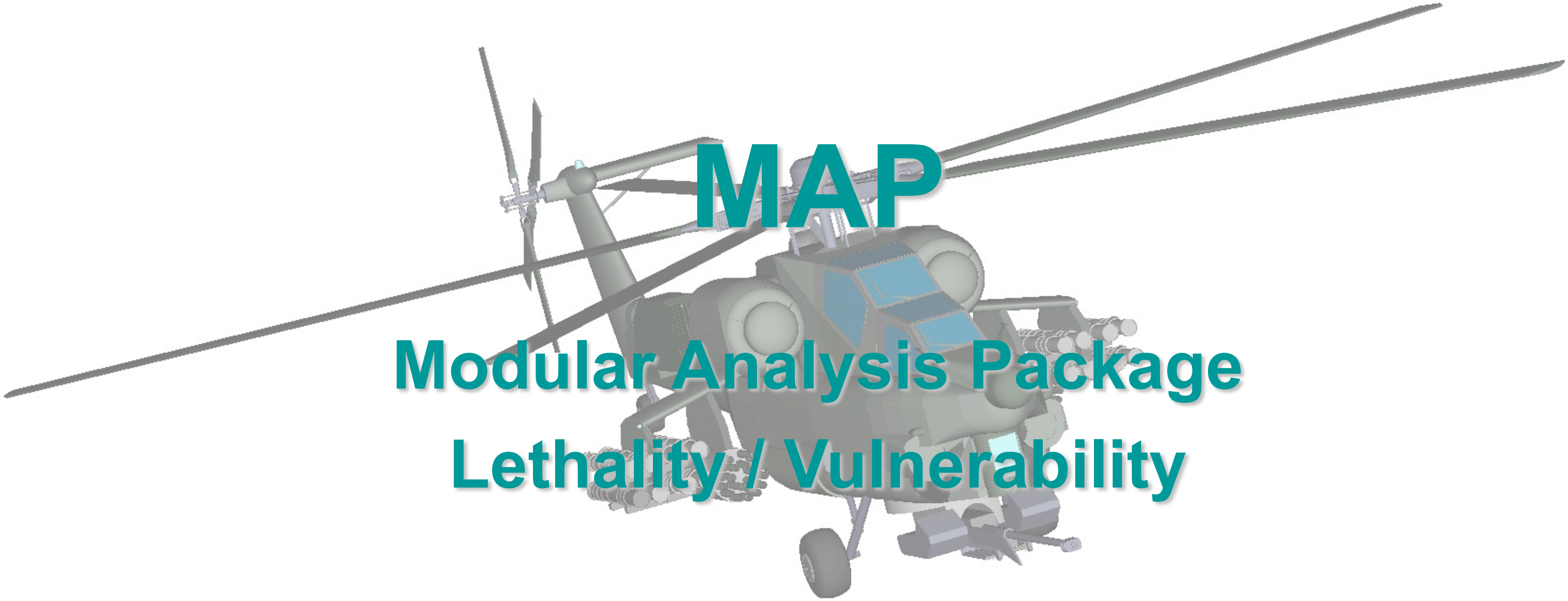
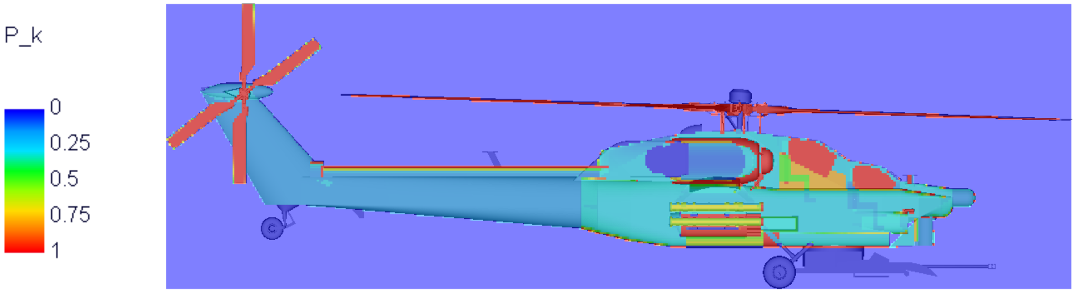


MAP

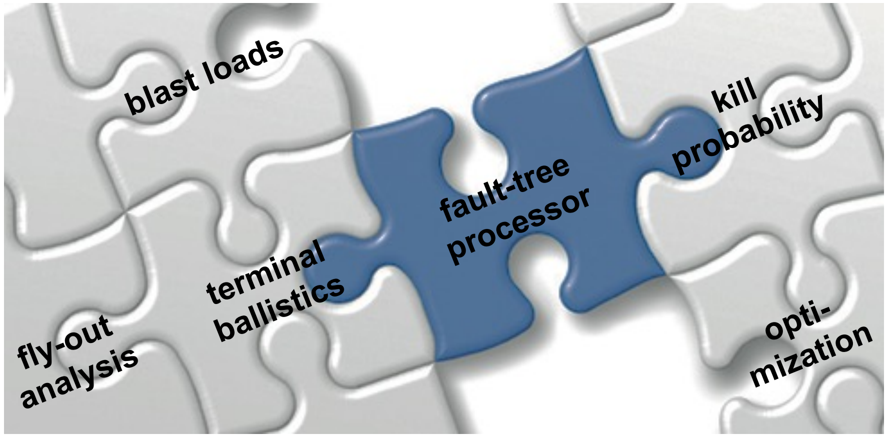
Modular Analysis Package

Lethality / Vulnerability



What is MAP?

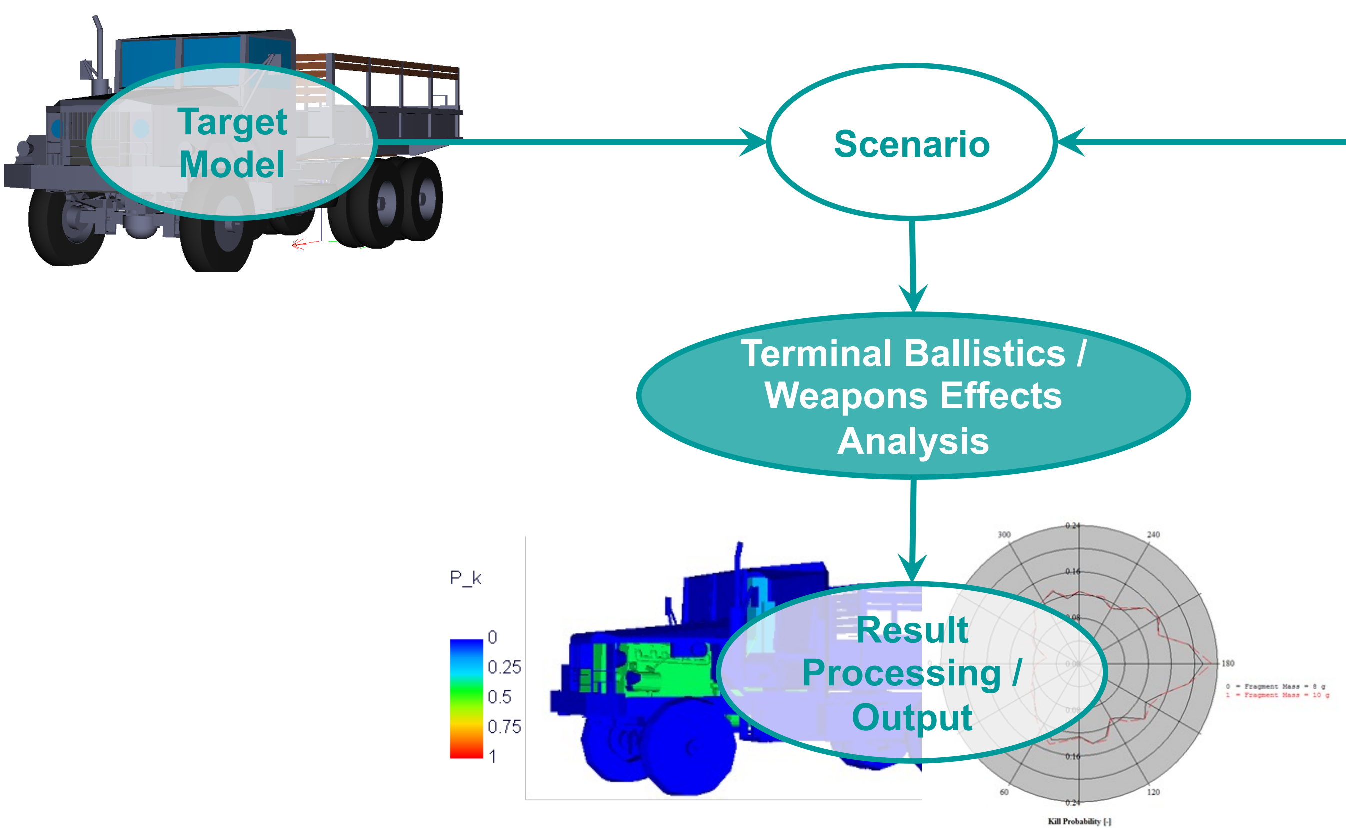
MAP (Modular Analysis Package) is a „unit assembly system“ for customized weapons effects (WE) and lethality / vulnerability (L/V) codes.



- Tailored software solutions are assembled from existing functional modules and adaped to customers‘ specific requirements
  → relatively short project time
  → tested and proven models
- Further modules can be added if the functional requirements change
  → high flexibility and adaptivity for future demands

General Approach

Target and threat model are set up independently and combined in a scenario that is analysed in a calculation module.
Results may be further processed (e.g. fault tree analysis) and are output in the required form



Target Model

Scenario

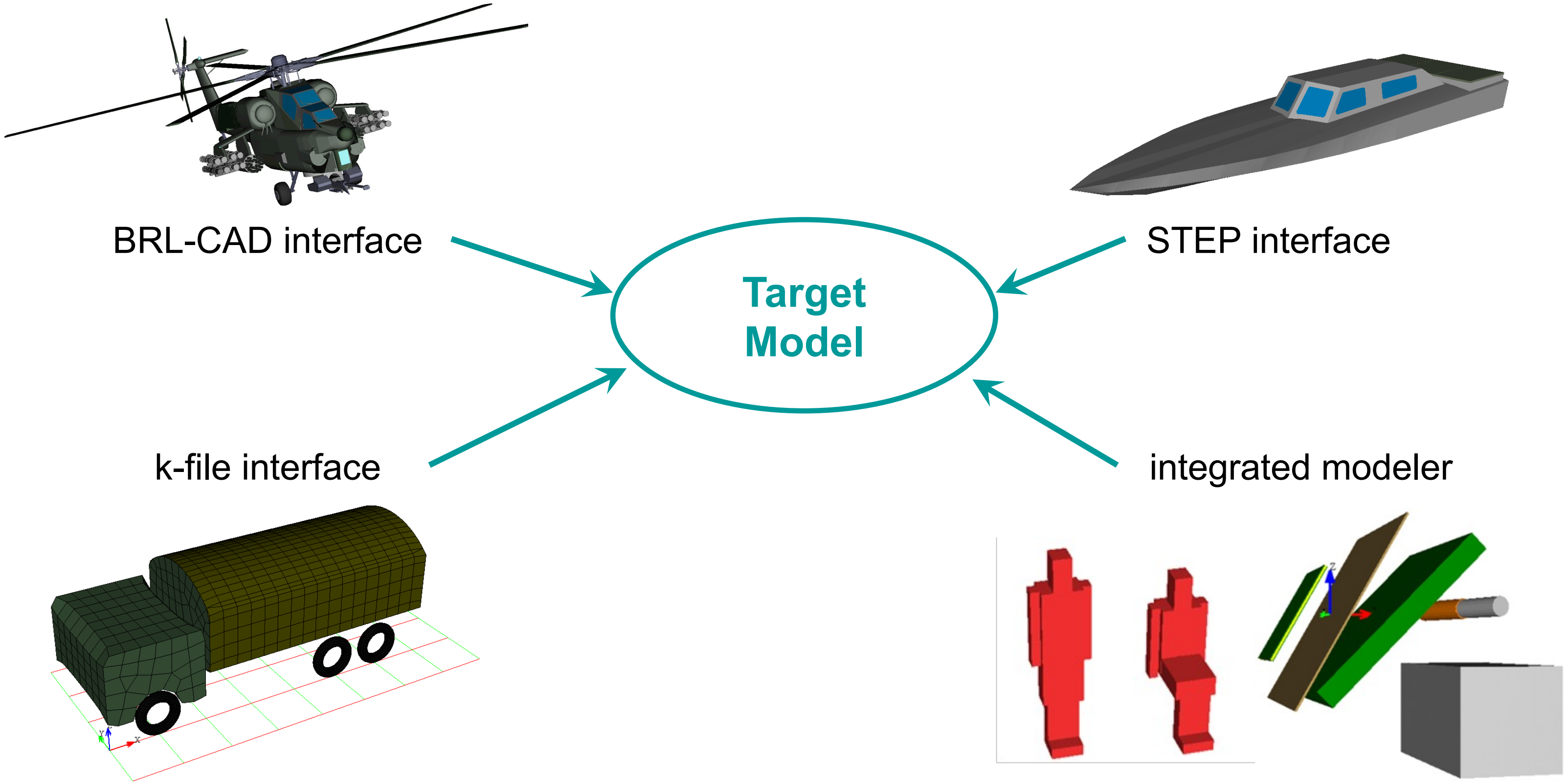
Threat Model

Terminal Ballistics / Weapons Effects Analysis

Result Processing / Output

Target Modeling Modules

Targets can either be modeled with an integrated modeler or import of different formats can be implemented.



BRL-CAD interface

STEP interface

Target Model

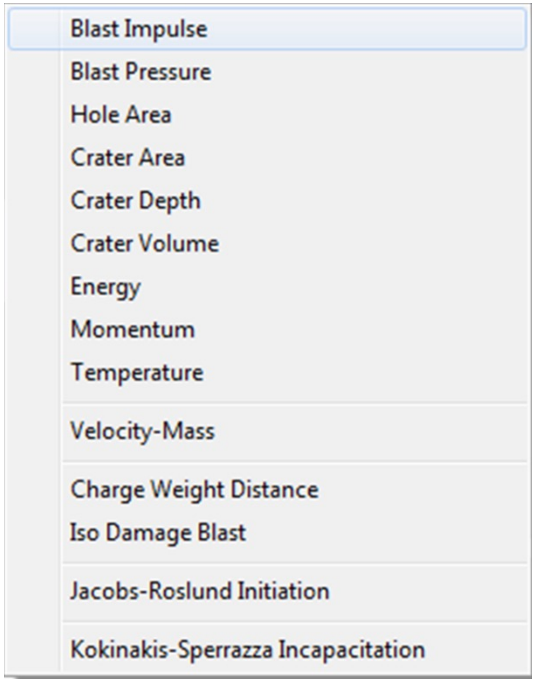
k-file interface

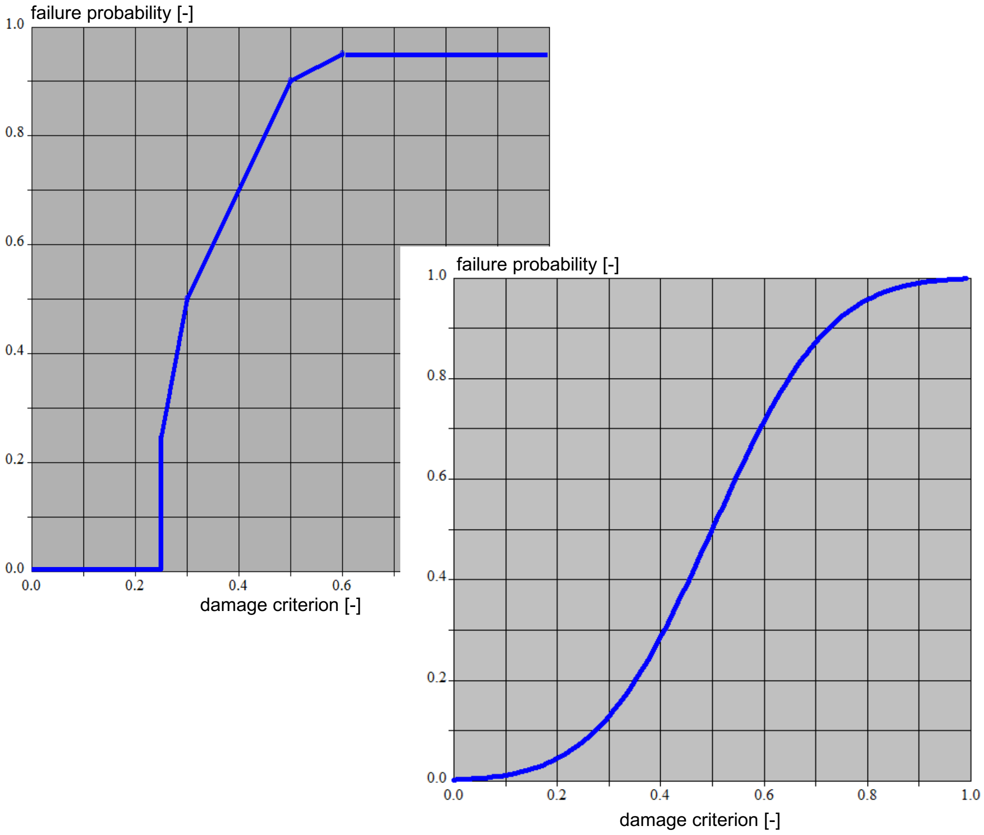
integrated modeler

Target Functional Modeling (L/V-Module)

The functional model consists of two parts:

1. Damage criteria definition (Type + Failure Probablilities)

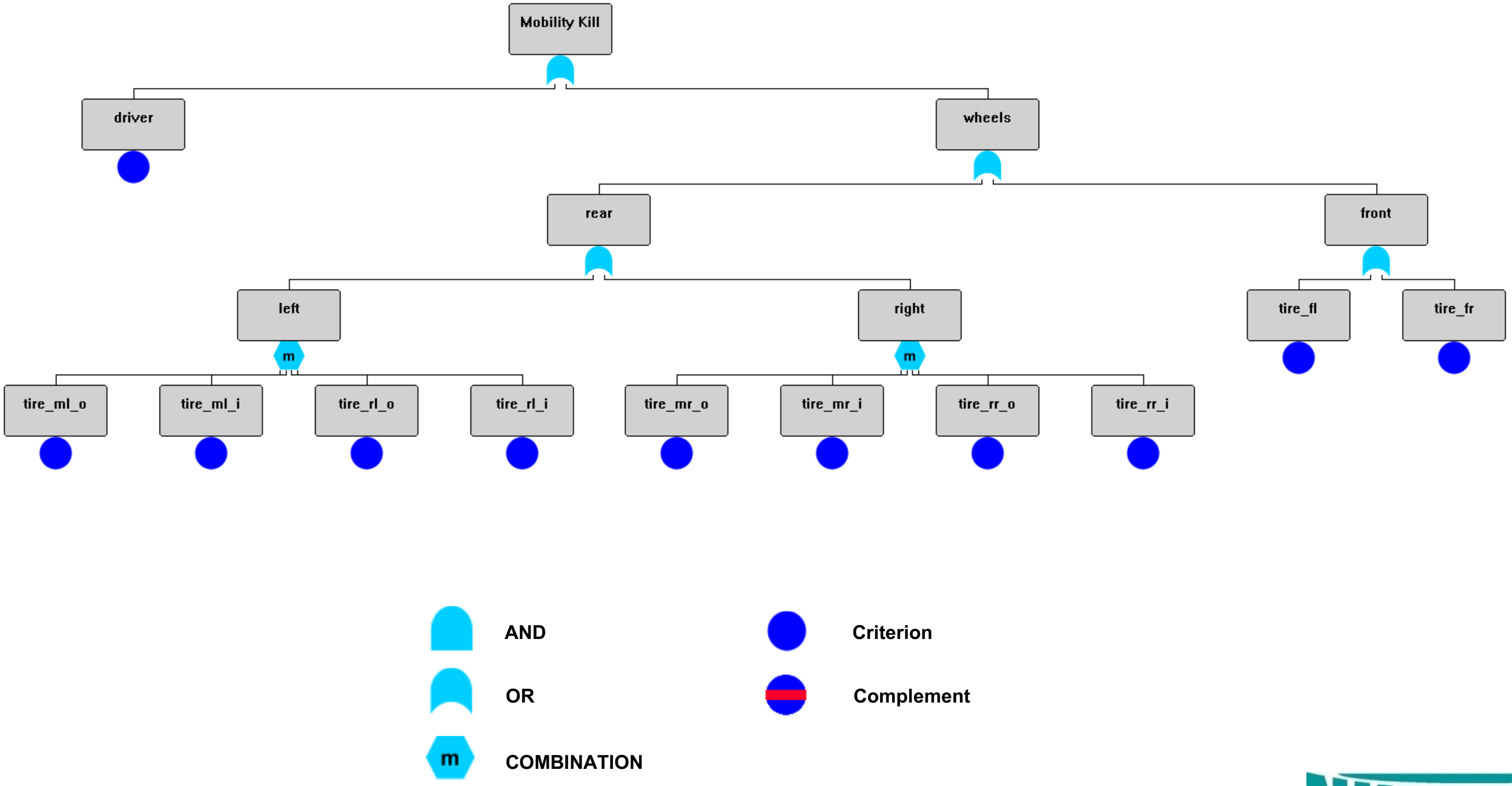




Target Functional Modeling (L/V-Module)

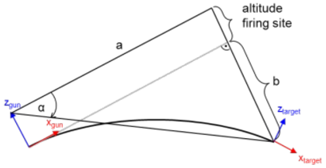
The functional model consists of two parts:

2. Fault Tree

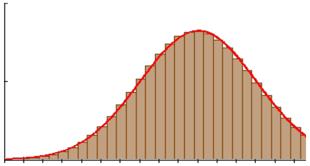


Threat Model

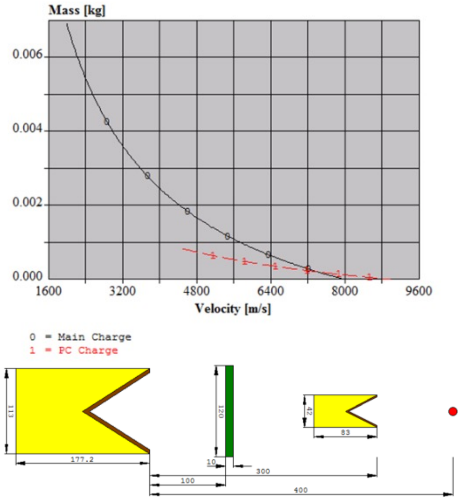
Different threat types (modelers) can be implemented



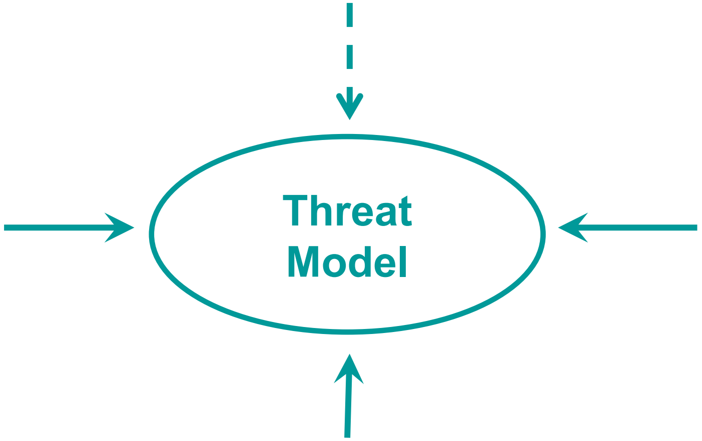
flyout analyzer



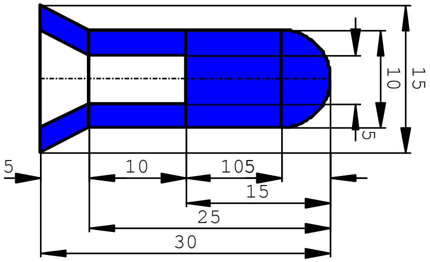
uncertainties



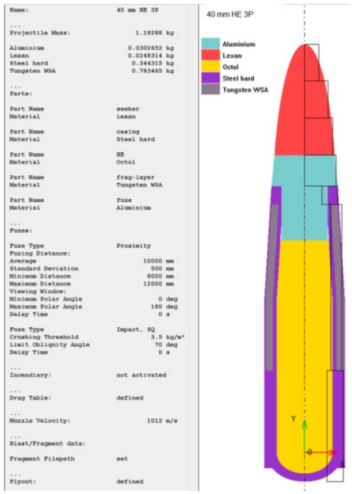
shaped charge modeler



Threat Model



simple penetrator modeler

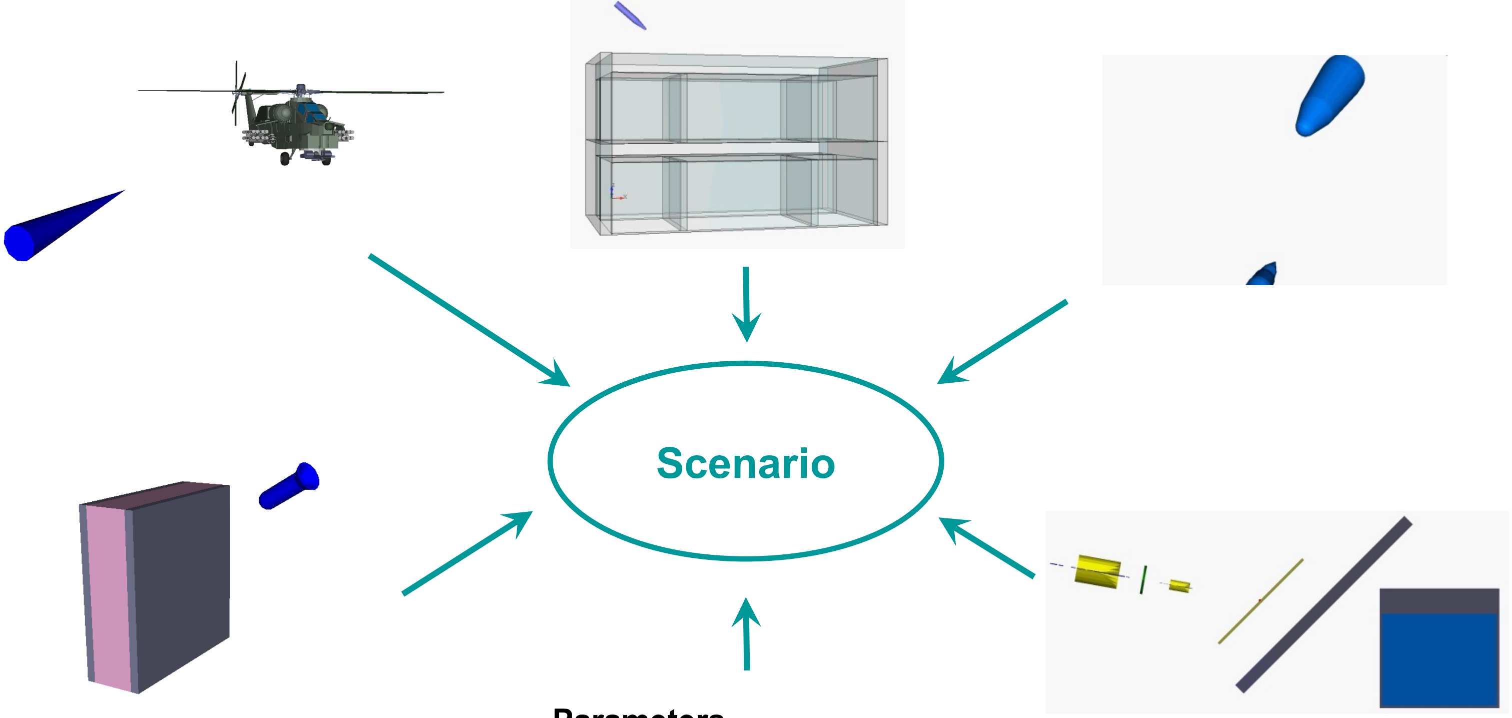


```
Name:                         40 mm HE 3P

...
Projectile Mass:                 1.18288 kg

Aluminium                      0.0302652 kg
Lexan                          0.0248314 kg
Steel hard                      0.344315 kg
Tungsten WSA                    0.783465 kg

...
Parts:

Part Name                     seeker
Material                      Lexan

Part Name                     casing
Material                      Steel hard

Part Name                     HE
Material                      Octol

Part Name                     frag-layer
Material                      Tungsten WSA

Part Name                     fuze
Material                      Aluminium

...
Fuzes:

Fuze Type                     Proximity
Fuzing Distance:
Average                            10000 mm
Standard Deviation                   500 mm
Minimum Distance                    8000 mm
Maximum Distance                   12000 mm
Viewing Window:
Minimum Polar Angle                    0 deg
Maximum Polar Angle                  180 deg
Delay Time                             0 s

Fuze Type                     Impact, SQ
Crushing Threshold                   3.5 kg/m²
Limit Obliquity Angle                 70 deg
Delay Time                             0 s

...
Incendiary:                   not activated

...
Drag Table:                   defined

...
Muzzle Velocity:                    1012 m/s

...
Blast/Fragment data:

Fragment Filepath             set

...
Flyout:                       defined
```

multi-material penetrator
+
blast / fragmentation warhead modeler

Scenario

The encounter / endgame situation is defined separately in a scenario. The scenario and analysis parameters thereby depend on customer requirements



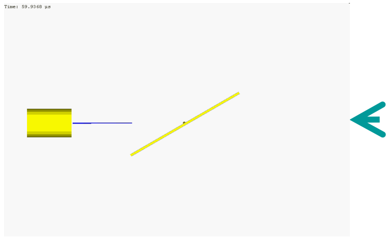
Scenario

Parameters

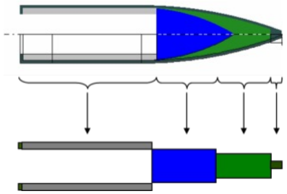
- threat / target position
- threat / target velocity
- pitch, yaw, roll
- analysis settings
- …

Analyzer

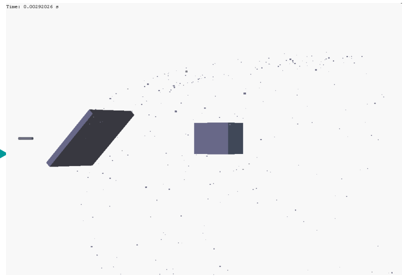
The analyzer can handle gridded as well as M/C simulations that can be parameterized if required. Add-ons for BAD and ERA are also available.



ERA module



penetration algorithms

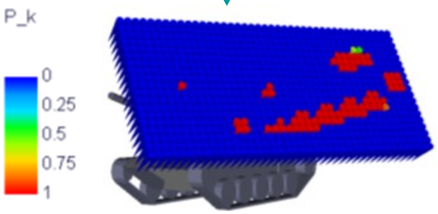


BAD module

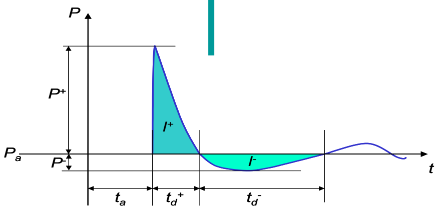
Parameterization

Analyzer

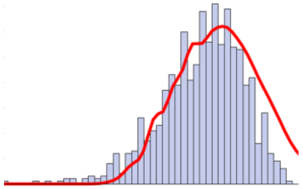
Parameterization



gridded analyses module (vulnerability)



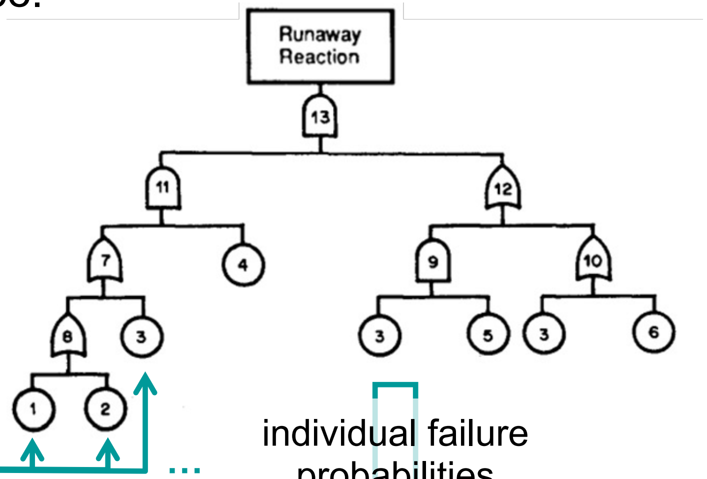
blast algorithms



Monte Carlo analyses module (lethality)

Fault Tree Processor

The single failure probabilities are combined according to their relationship defined in the fault tree.



Analysis result

…

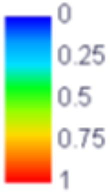
individual failure probabilities

Fault Tree Processor

statistically independent events
→ direct calculation

statistically dependent events
→ recursive algorithm (Page & Perry)

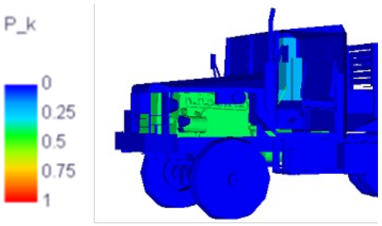
Kill Probability P_k



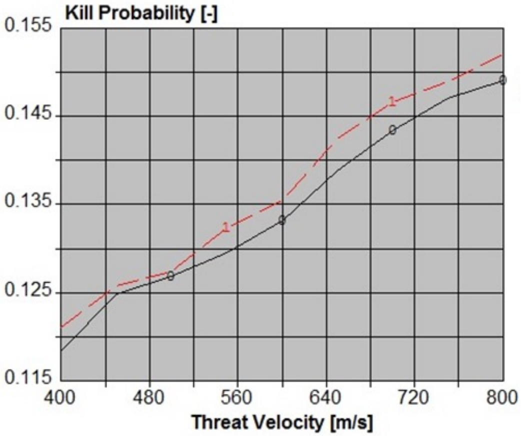
Output

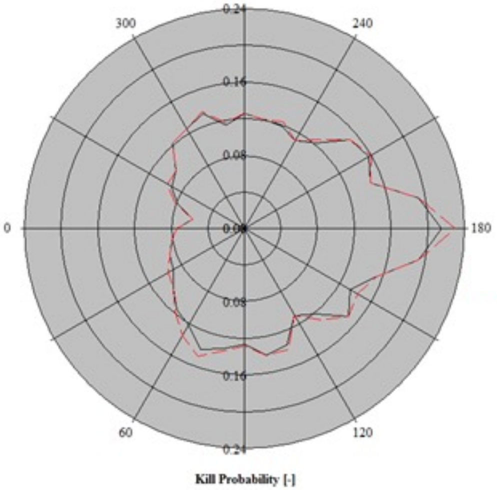
Output according to user requirements:

- unidirectional (2D) and multi-directional (3D) graphics



- Cartesian and polar diagrams

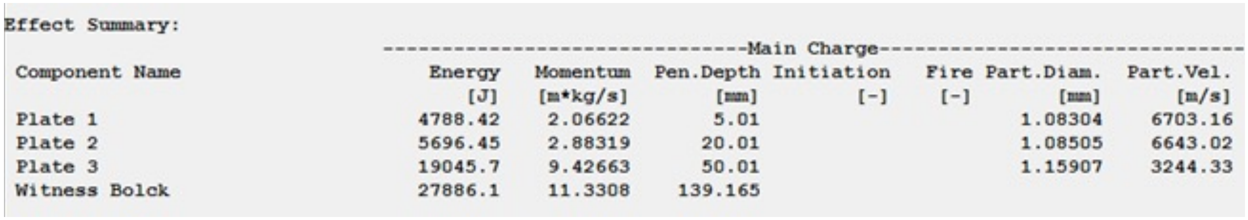




Output

Output according to user requirements:

- displayed text and text file

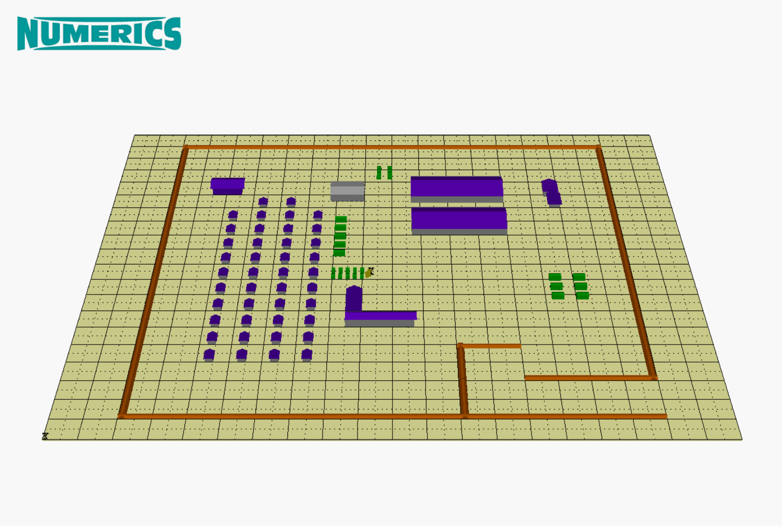


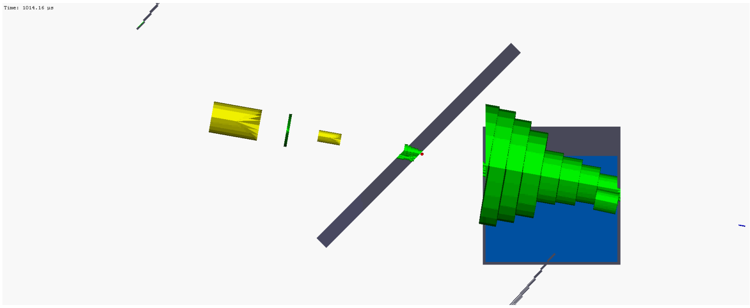
```
Effect Summary:
                                 --------------------------------Main Charge-------------------------------
 Component Name                         Energy   Momentum  Pen.Depth Initiation    Fire Part.Diam.  Part.Vel.
                                           [J]   [m*kg/s]       [mm]        [-]     [-]       [mm]      [m/s]
 Plate 1                               4788.42    2.06622       5.01                       1.08304    6703.16
 Plate 2                               5696.45    2.88319      20.01                       1.08505    6643.02
 Plate 3                               19045.7    9.42663      50.01                       1.15907    3244.33
 Witness Bolck                         27886.1    11.3308    139.165
```

attack_45∞.rst

attack_90∞.rst

- animations



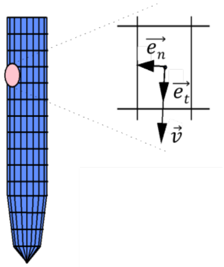


Algorithms for Penetration

Different types of penetration models can be implemented depending on the intended application:

Rigid or deforming (non-eroding) penetrators:

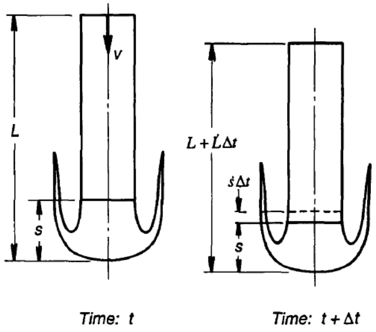
→ Differential Area Force Law (DAFL)



$$-d\vec{F} = \left(\sigma_0 + \tfrac{1}{2}\rho c_D v_n^2\right)\cdot dA\cdot \vec{e}_n + \left(\mu_S\cdot\sigma_0 + \tfrac{1}{2}\rho\mu_D v_n^2\right)\cdot dA\cdot\vec{e}_t$$

Eroding penetrators / projectiles:

→ Extended Walker-Anderson Model (XWAM)



$$\rho_p \dot{v}(L-s) + \dot{u}\left(\rho_p s + \rho_t R\frac{\alpha-1}{\alpha+1}\right) + \rho_p\frac{s^2}{2}\frac{d}{dt}\left(\frac{v-u}{s}\right) + \rho_t\dot{\alpha}\frac{2Ru}{(\alpha+1)^2}$$
$$= \frac{1}{2}\rho_p(v-u)^2 - \left(\frac{1}{2}\rho_t u^2 + \frac{7}{3}Y_t\ln(\alpha)\right)$$

Algorithms for Penetration

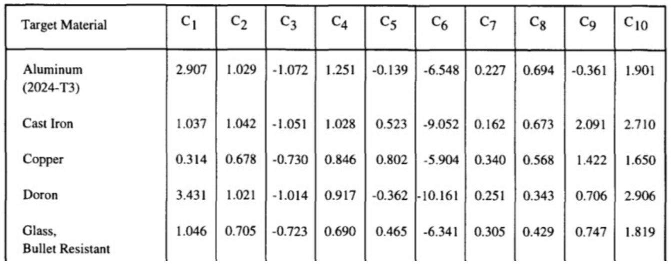
Besides the (semi-)analytical DAFL and XWAM, also empirical models can be implemented:

Fragment penetration:

→ THOR-Equations

$$v_r = v_p - 10^{C_1}(tA)^{C_2} m_p^{C_3}(\cos\Theta)^{-C_4} v_p^{C_5}$$

$$m_r = m_p - 10^{C_6}(tA)^{C_7} m_p^{C8}(\cos\Theta)^{-C9} v_p^{C10}$$



Target Material	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}
Aluminum (2024-T3)	2.907	1.029	-1.072	1.251	-0.139	-6.548	0.227	0.694	-0.361	1.901
Cast Iron	1.037	1.042	-1.051	1.028	0.523	-9.052	0.162	0.673	2.091	2.710
Copper	0.314	0.678	-0.730	0.846	0.802	-5.904	0.340	0.568	1.422	1.650
Doron	3.431	1.021	-1.014	0.917	-0.362	-10.161	0.251	0.343	0.706	2.906
Glass, Bullet Resistant	1.046	0.705	-0.723	0.690	0.465	-6.341	0.305	0.429	0.747	1.819

Special models for specific cases:

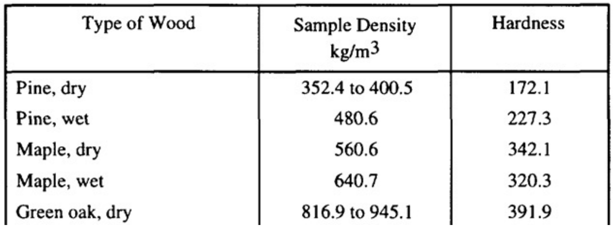
→ e.g. wood penetration (US Army Design Code)

$$P = \frac{7041 \cdot v^{0.411} \cdot m_f^{0.587}}{\rho \cdot H^{0.541}}$$

.

.

.



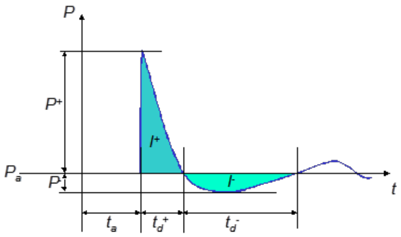
Type of Wood	Sample Density kg/m³	Hardness
Pine, dry	352.4 to 400.5	172.1
Pine, wet	480.6	227.3
Maple, dry	560.6	342.1
Maple, wet	640.7	320.3
Green oak, dry	816.9 to 945.1	391.9

Algorithms for Blast

For blast loads different scenarios can be distinguished

1. Free field

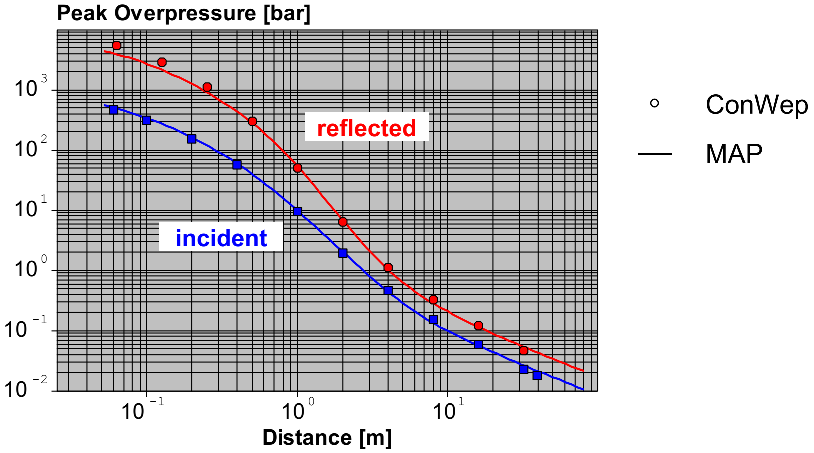
Friedlander function with blast parameters following Kinney / Graham



$$P(t)=\begin{cases} P^{+}\left(1-(t-t_a)/t_d^{+}\right)\exp\left(-(t-t_a)/\theta^{+}\right) & \text{für} \quad t_a \le t \le t_a + t_d^{+} \\ -G\exp\left(-(t-t_a-t_d^{+})/\theta^{-}\right)\sin\left(\dfrac{t-t_a-t_d^{+}}{t_d^{-}}\pi\right) & \text{für} \quad t > t_A + t_d^{+} \end{cases}$$

1 kg TNT (spherical charge):

NUMERICS implementation compared to ConWep

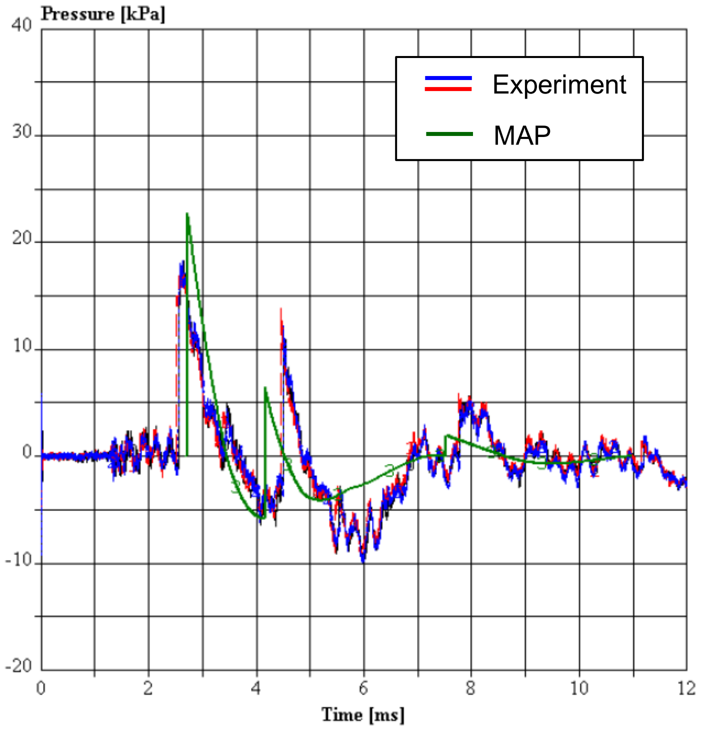


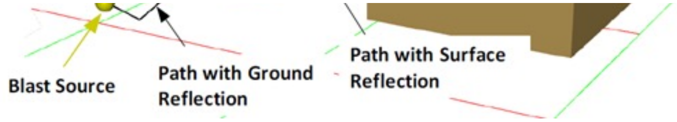
Algorithms for Blast

2. Shaded / with single obstacles

Based on a Shortest-Path Determination applying specific rules for deflection,

three blast propaga stories are superimposed applying the LAMB

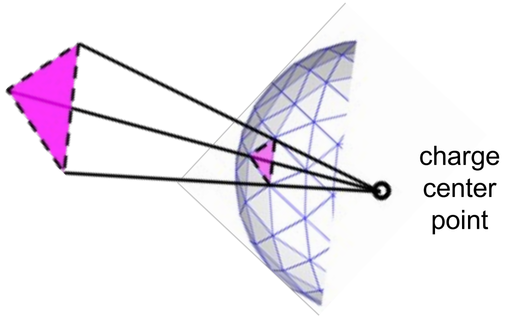


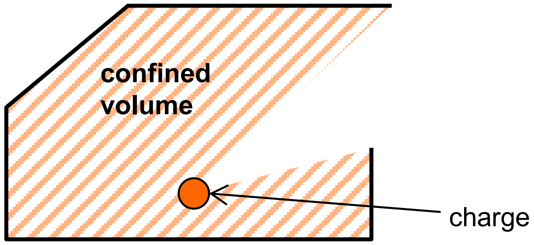


Algorithms for Blast

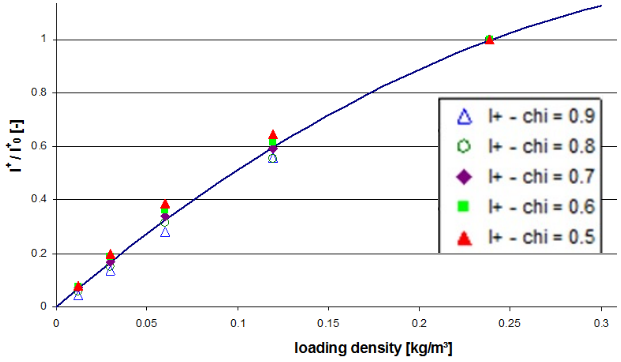
3. Confined / partially Confined (internal detonation)

While the preak pressure is independent from a confinement, the latter is crucial for the impulse. Therefore, an empirical coherence of loading density (m_{HE} / $V_{confined}$)





and the confinement ratio ($A_{confinement}$ / $A_{venting}$) was developed (valid only for low loading densities).



$$I_0^+ [Pa \cdot s] = 46435 \cdot \chi^4 - 86338 \cdot \chi^3 + 53743 \cdot \chi^2 - 10397 \cdot \chi$$

Near Edge Impact Model

Near edge impact is considered by an empirical reduction of the targets (expansion) resistance.

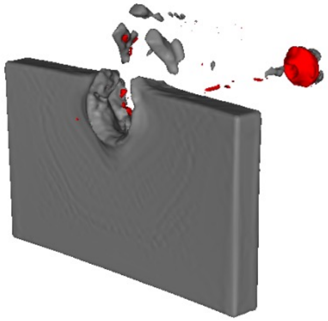
$$E_t = \tilde{E}_t \cdot \omega \qquad \text{with} \qquad \omega = 0.275 \cdot \ln\left(\frac{d}{D}\right) + 0.375 \leq 1$$

(XWAM)

$$\sigma_0 = \tilde{\sigma}_0 \cdot \prod_{i=1}^{6} \max\left(\lambda_i, \lambda_{i,q}\right) \qquad \text{with} \qquad \lambda_i = \min\left(1, \left(\frac{\Delta p_i}{r \cdot \min\left(2, \frac{2 \cdot T}{r}\right)}\right)^2\right)$$

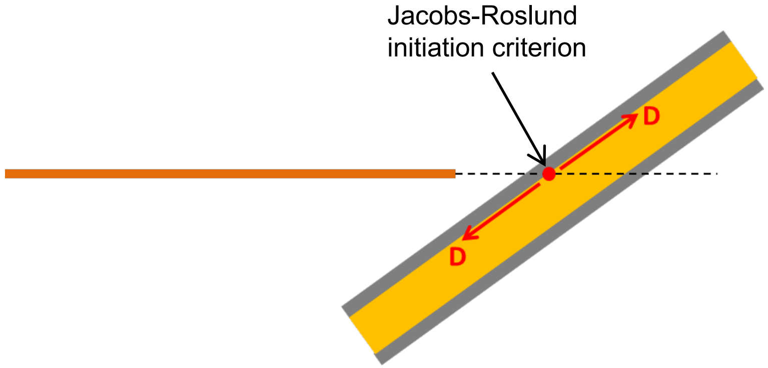
(DAFL)

The models are based on experimental data as well as on a substential amount of hydrocode simulations.

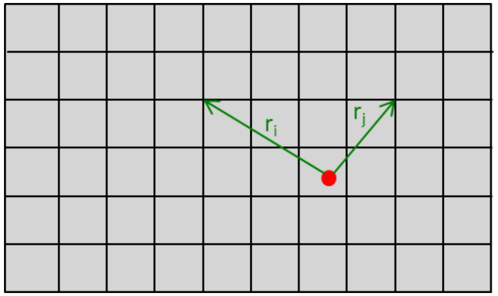


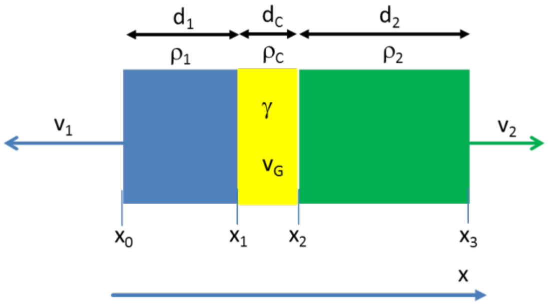
ERA - Model

Explosive reactive armor (ERA) is modeled as a sandwich structure consisting of two independent plates with HE filling. The initiation of the ERA sandwich is assessed applying the Jacobs-Roslund criterion.


Jacobs-Roslund
initiation criterion

For the calculation of the plates‘ motion, the plates are discretized into separate rectangular pieces and the Gurney method is used to determine acceleration.

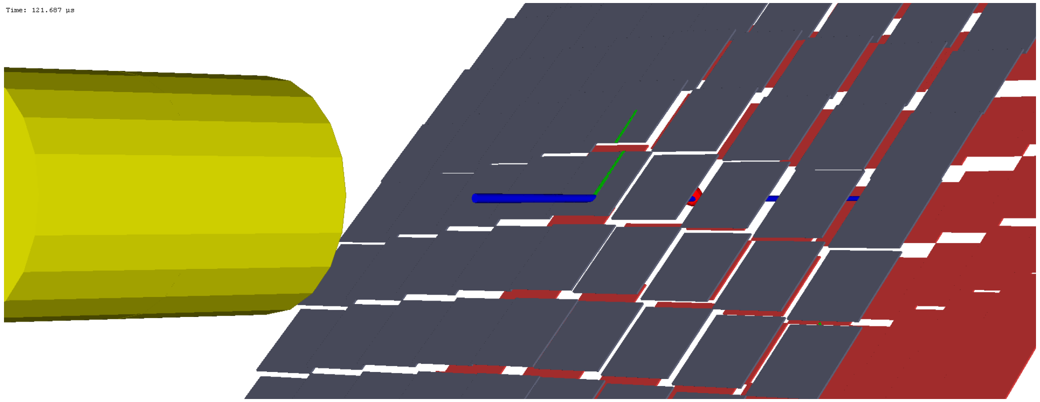


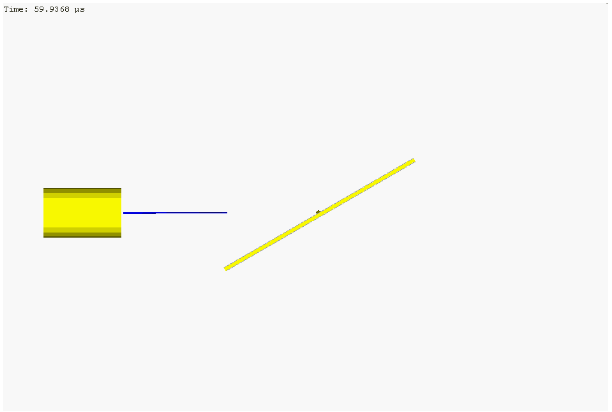


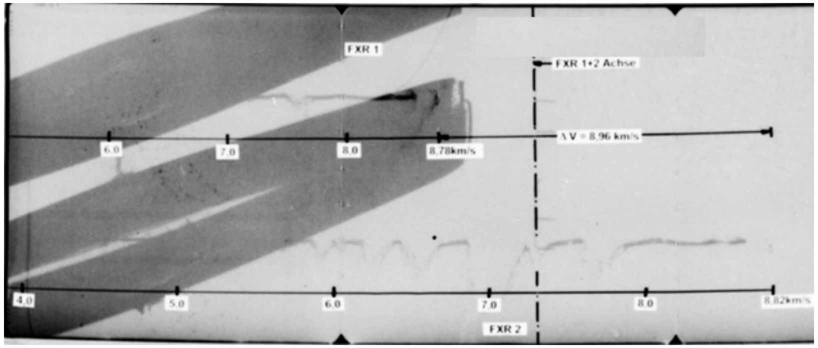
$$V\left(d_C\right)=\frac{1}{2}Cv_G^2$$

ERA - Model

Upon interaction with the front or rear plate each jet particle creates a crater (XWAM). If the subsequent particle passes this crater it stays intact, otherwise it is deleted.

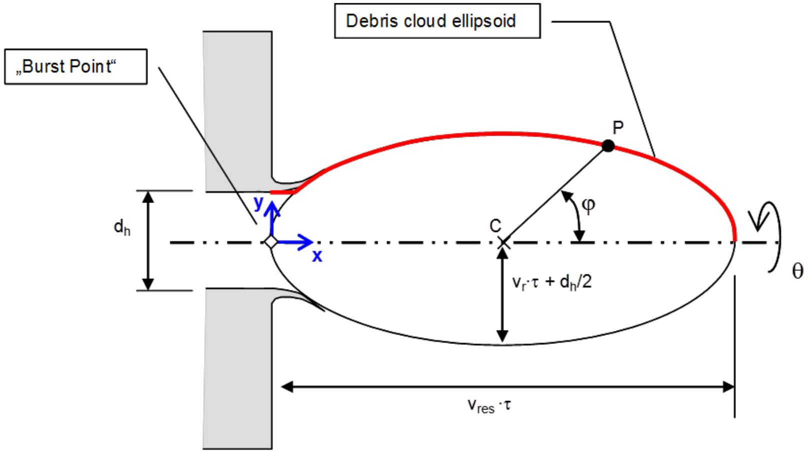


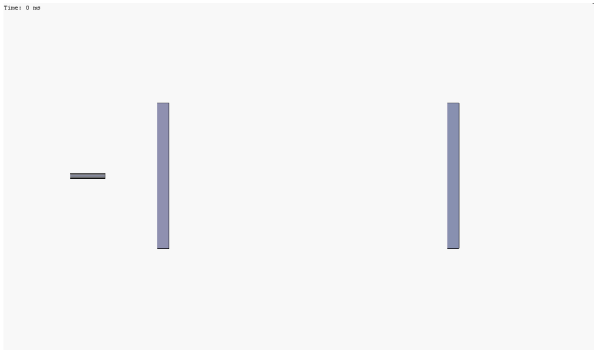




BAD - Model

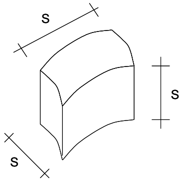
The BAD model assumes an elliptical debris cloud with uniform (for projectiles) or weighted (for SCJ) fragment distribution along the shot axis.



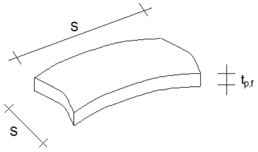


The determination of the characteristic fragment size S is based on the Kipp & Grady relations for mixed mode and tensile fracture, respectively.

$$S = \left(\frac{\sqrt{24} \cdot K_c}{\rho_t \cdot c \cdot \dot{\varepsilon}} \right)^{2/3}$$



$$S = \left(\frac{1.2 \cdot Y_p}{\rho_p \cdot \dot{\varepsilon}^2} \right)^{1/2}$$

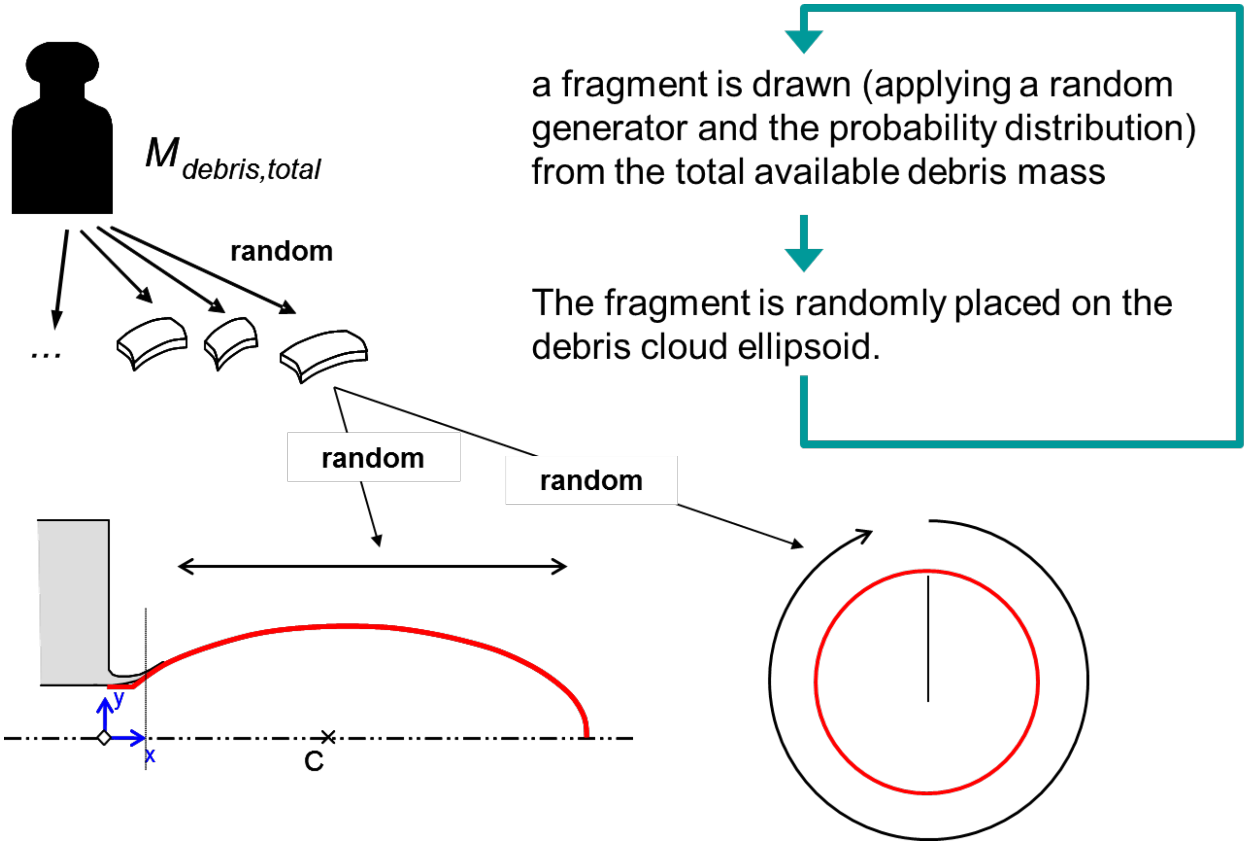


target material fragments

projectile material fragments

BAD - Model

The actual fragment mass distribution is determined applying a random generator.



a fragment is drawn (applying a random generator and the probability distribution) from the total available debris mass

The fragment is randomly placed on the debris cloud ellipsoid.

Note: Model only validated for metal targets

Summary

The presented Modular Analysis Package (MAP) offers a broad variety of modules for customized weapons effects and lethality / vulnerability (L/V) codes.

The existing modules for target, theat and scenario modeling, analysis and output can be combined and adapted to the specific customer requirements: from projectile penetration to ballistic missile defence.

Thereby, MAP offers several advantages:

1. Calculation / analysis algorithms are tested and validated.
2. Customer-specific new model developments can easily be integrated.
3. Building up on existing functional modules significantly reduces the project duration.
4. The modular structure provides the flexibility to include functional extensions to account for future requirements.

Thank You for Your Attention !