# Vehicle's crew survivability using Julia

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## Abstract

Assessing the chances of survival of a vehicle's crew under attack involves the computation of outcomes from a large number of attack scenarios.

For each scenario, the chances of crew survival are estimated using probabilistic computations involving a wide range of stochastics factors such as attack conditions, vehicle/armor structural failure, projectiles/debris path etc...

The aim of this research is to build a framework that would ensure the propagation of uncertainties across the complete chain of computational models. It would then be possible to make an estimation of the main factors that contribute to crew survivability. This kind of simulations requires constant code extension with new models to simulate for instance outcomes from a collision between a "new" projectile and a "new" armor. A hierarchy of type is used with multiple-dispatch to build a generic code which generate specialized code at compile time. To achieve our goal of code maintainability and extensibility, modularity is key. This is achieved using discrete event simulations, whereby simulations advances by stepping through a list of events. Events are broken down into modules/tasks. To simulate a scenario is then a matter of combining tasks using SimJulia.

## Introduction

Survivability computations involve the simulation of a series of models from a variety of applications. Therefore, there is a need to build a framework where experts from different disciplines can implement the models of their field, and survivability analysts can use them as a whole. To achieve a certain degree of accuracy, the models are becoming increasingly complex, becoming more and more computationally hungry. Julia is a good candidate to implement such an efficient cross collaborative platform [1].

In this study we present a preliminary study of a vehicle's survivability using Julia. Existing Julia functionality are used in order to perform the study. This study serves as a proof of concept upon which we will learn in order to build our framework.

## Methodology

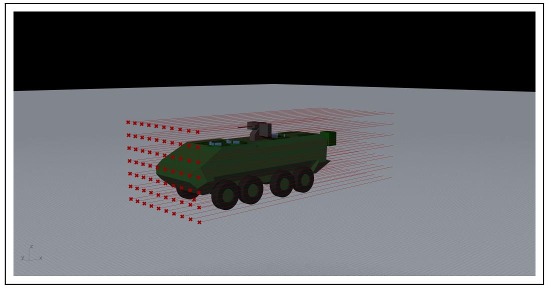

Figure 1: Geometric representation of the AIV Piranha with shotlines generated from a grid.

The survivability of a vehicle's crew is the probability that the crew survives if the vehicle is under attack. There are several approach for modeling depending on the type of threat that is encountered. In this study we consider that the vehicle is under attack from a shooter with a rifle. To model all possible attack conditions, the shotline method can be used [2].
First, a geometric representation of the vehicle with the crew, the armor and all critical components have to be generated (figure 1). Then, the intersection of the bullet trajectory and the vehicle's components have to be computed. Bullet trajectory is represented by a straight line (shotline). Given that the exact position of the shooter is unkown, it is assume that the shooter can be anywhere. Therefore, from each defined direction we generate parallel shotlines distributed on a grid that covers the entire vehicle (figure 1). The components intersected by each shotline are recorded along with the intersection conditions (figure 2), then material penetration computations allow us to determine whether or not there is penetration. In case of penetration, residual velocity is computed and there is a check to see if there is penetration for the following component and so on until the shotline is out of the vehicle. If a critical component is hit by the bullet, damage assessment computations can be performed.

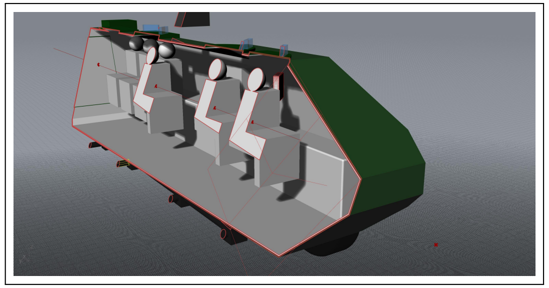

Figure 2: See through of components intersected by a shotline.

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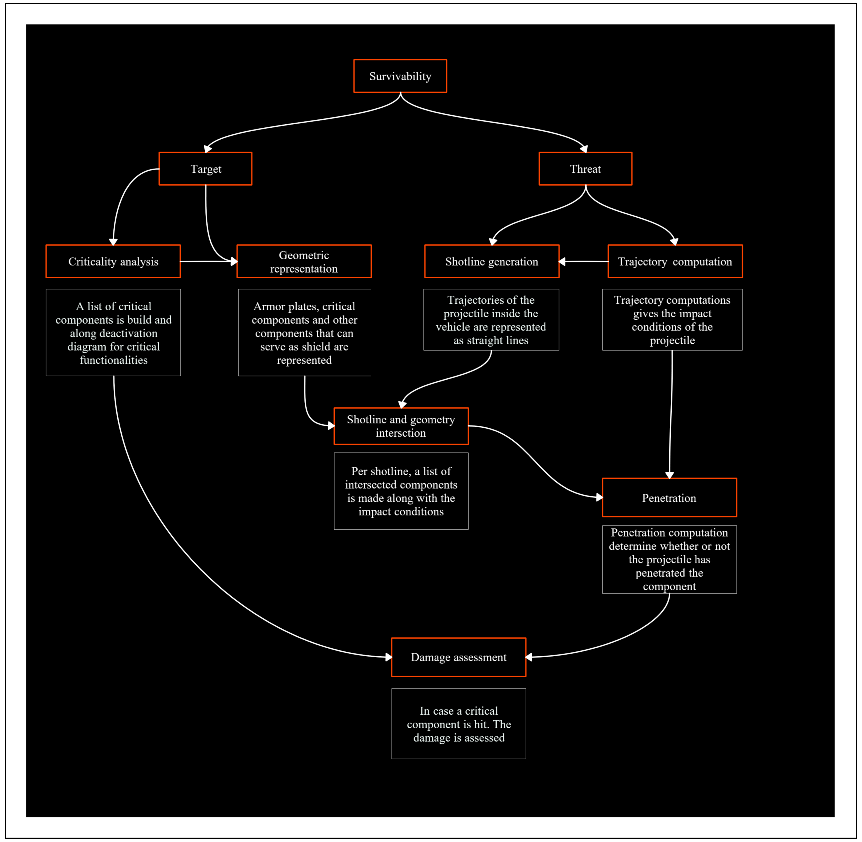


Figure 3: Survivability assessment process.

## Models

The survivability assessment process is represented in figure 3. It consists of an hierarchy of processes (red boxes) that interact with each other. Inside each red box there are also operation that can be represented as an interaction of processes. This paper will focus on the tasks inside the penetration process (figure 4). Penetration models are based on semi-empirical models which are used to compute ballistic limit velocities ($v_{50}$). These are velocities for which there is a 50% probability that there would be penetration. These models rely heavily on predefined parameters such as the type of projectile and the target material properties. Using Julia's type hierarchy, we were able to create a specialized generic code for penetration.

## Implementation

Multiple dispatch is used for the selection of the right functions. Three main types where defined at the top of the type hierarchy (figure 5):

- **AbstractPenetrator**, under which we define the different types of projectiles
- **AbstractTarget**, under which we define the class of the different components
- **AbstractMaterial**, here we define the list of materials and their properties

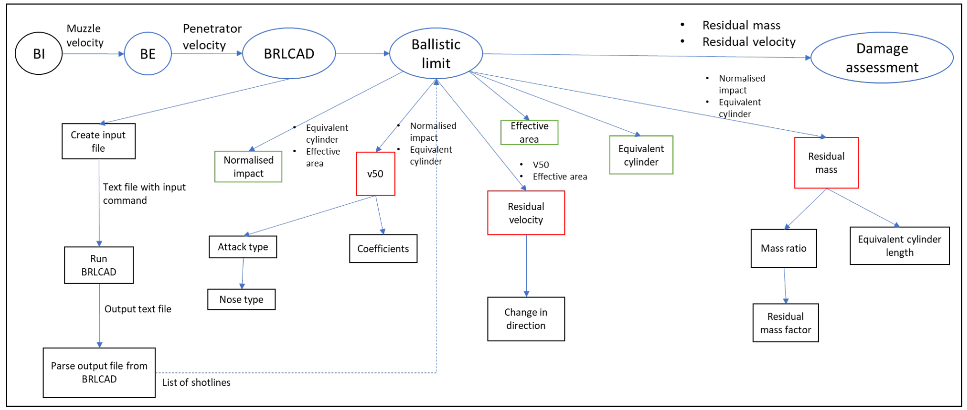


Figure 4: Hierarchy of functions

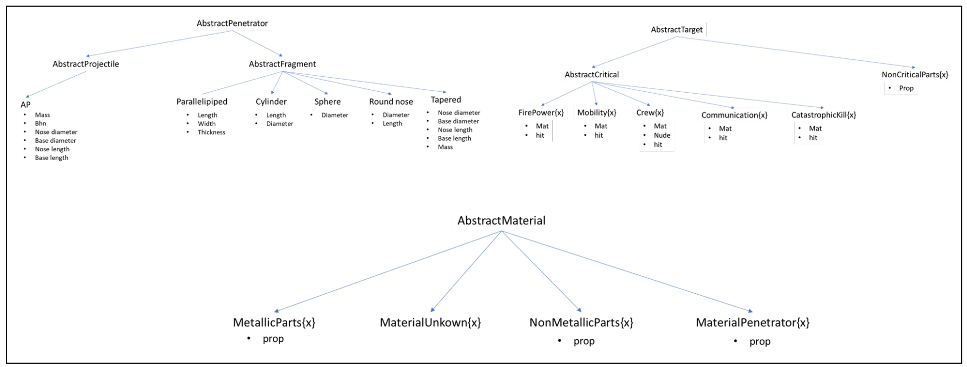


Figure 5: Hierarchy of types

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## Simulation

A vehicle with 4 crew members is under consideration (commander, gunner, loader and driver). Shotlines are generated from grids. The directions considered are all around the vehicle (azimuth angles) for different elevation angles. In this study we present only results for the 0°, and 45°elevation angles. The shotlines are generated using BRLCAD. The command line is launched from Julia. For each direction, a cartesian grid which covers the vehicle is used to generate shotlines separated by 12.7 cm (5 inches). A preview of the number of shotlines generated per direction is presented in table 1. These grids are also used for the computation of vulnerable areas of each crew member in each direction.

| Direction (Az, el) | (0 °, 45°) | (45 °, 45°) | (90 °, 45°) | (135 °, 45°) | (180 °, 45°) | (225 °, 45°) | (270 °, 45°) | (315 °, 45°) |
|---|---|---|---|---|---|---|---|---|
| Number of shotlines | 803 | 1006 | 1114 | 1049 | 852 | 1049 | 1114 | 1006 |

Table 1: Directions used for a shooter at 45°elevation and the number of shotlines generated.

Along each shotline a projectile is launched with impact conditions provided by external ballistics simulations. In this study impact velocities are input parameters which depends on the type of projectile and the range. Penetration calculations are computed along the projectiles path on the shotline. If a projectile penetrates a components its velocity is modified. The computation is done until the projectile is stopped by a component (cannot penetrate). If the projectile hit a crew member, it is also stopped. With a more accurate wound ballistic models, we could compute residual velocities of such impact. In the absence of such models, we choose a simplified approach. If the projectile is at the end of the shotline, then the penetration computations are terminated. The number of hit of a crew member per direction are recorded in a mutable structure. Combining this values with the vulnerable areas computed in BRLCAD, we get the hit probability for each crew member for a given direction [3].

```
using ResumableFunctions
using SimJulia
@resumable function BE(sim::Simulation, projectile::Penetrator)
    #compute external ballistics
end
@resumable function BRLCAD_burst(sim::Simulation, target::Target)
    # raytracing from grid
end
@resumable function BRLCAD_rtarea(sim::Simulation, target::Target)
    # raytracing for presented area computation
end
@resumable function penetration(sim::Simulation,shotline::Shotline,projectile::Penetrator, target::Target)
    # compute penetration along a shotline
end
@resumable function vulnerability(sim::Simulation, target::Target, vulnerable_area)
    #compute the vulnerability of the system
end
@resumable function main(sim::Simulation, projectile::Penetrator, target::Target)
    shotline_list = @yield @process BRLCAD_burst(sim, target)#generates the list of shotlines
    vulnerable_area = @yield @process BRLCAD_rtarea(sim,target)#computes the vulnerable areas of critical components
    for s in shotline_list
        @yield @process penetration(sim, s, projectile, target)# a loop over the shotlines to compute penetration depth of the projectile
    end
    @yield @process vulnerability(sim,target, vulnerable_area) # for impacted critical component , compute the hit probability
end
for dir in attack_direction
    sim = Simulation()
    projectile = @yield @process BE(sim, projectile) #(computes impact conditions)
    @process main(sim, projectile, target)
    run(sim)
end
```

Figure 6: Code squeleton

Survivability analysts want to answer questions related to the performance of a given armor material, how a vehicle may perform against a given threat and from which range is the crew safe. To illustrate these types of analyses, two types of vehicles where considered: a vehicle with aluminum armor and another with steel armor. Steel is stronger but it is also heavier, therefore, it is interesting to use aluminum if one can. For the threat, we consider a shooter with a .50 rifle. Two types of projectiles are considered:and armor piercing ammunition (steel core) with muzzle velocity of 900m/s and an armor piercing shell (tungsten core) with muzzle velocity of 1200 m/s. A close range shooter (< 100 m) and a long range shooter (>500m) are considered.

## Results & Discussion

| | Commander | | Gunner | | Loader | | Driver | |
|---|---|---|---|---|---|---|---|---|
| | 0°El | 45°El | 0°El | 45°El | 0°El | 45°El | 0°El | 45°El |
| **0°Az** | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 13 |
| **45°Az** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 11 |
| **90°Az** | 13 | 0 | 10 | 0 | 7 | 0 | 21 | 6 |
| **135°Az** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| **180°Az** | 11 | 0 | 18 | 0 | 15 | 0 | 10 | 0 |
| **225°Az** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **270°Az** | 8 | 0 | 14 | 0 | 10 | 0 | 9 | 8 |
| **315°Az** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |

Table 2: Number of hit per direction for a vehicle in aluminum against steel core bullets in close range.

| | Commander | | Gunner | | Loader | | Driver | |
|---|---|---|---|---|---|---|---|---|
| | 0°El | 45°El | 0°El | 45°El | 0°El | 45°El | 0°El | 45°El |
| **0°Az** | 0 | 26 | 0 | 21 | 0 | 7 | 0 | 13 |
| **45°Az** | 16 | 7 | 8 | 1 | 10 | 7 | 22 | 11 |
| **90°Az** | 20 | 6 | 10 | 1 | 10 | 7 | 21 | 26 |
| **135°Az** | 14 | 1 | 2 | 5 | 8 | 0 | 23 | 2 |
| **180°Az** | 21 | 17 | 19 | 13 | 19 | 16 | 10 | 12 |
| **225°Az** | 0 | 1 | 23 | 3 | 8 | 0 | 8 | 4 |
| **270°Az** | 12 | 12 | 18 | 7 | 16 | 9 | 9 | 8 |
| **315°Az** | 6 | 11 | 21 | 0 | 1 | 8 | 0 | 3 |

Table 3: Number of hit per direction for a vehicle in aluminum against tungsten core bullets in close range.

The simulations showed that the crew is safe in a steel armored vehicle. Whereas, the in a aluminum armored vehicle, the results more contrasted in some situation the crew is quite vulnerable and for others it is safe.For instance, in close range, table 2 shows that the crew is shielded for certain directions against steel core bullets. Whereas, for tungsten core bullets table 3 shows that it is not safe for the crew! Visually, the results can be presented on a polar plot (figure 7). On such plot we can directly identify the weak sides of the vehicle, which need extra armor. As the range increases the impact velocity decreases and the crew is better protected. Simulations showed that for ranges >700 m, the crew is also safe against tungsten core bullets in a aluminum armored vehicle.

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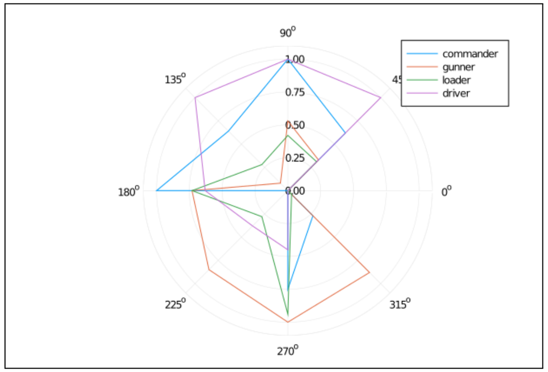


Figure 7: Polar plot of the hit probability for the crew members for close range shooter under 0°attack direction with tungsten core bullets.

## Conclusion & Outlook

The simulations show that to ensure that the crew in an aluminum armored vehicle is safe against the specified threat, some armor modifications are needed.

Julia's multiple dispatch features made it possible to implement a specialized extendable code. Function describing the behavior can be now easily implemented by specialist in each field without other modification. New armor materials or new projectiles can be easily integrated using the defined type hierarchy. More accurate models can also integrated to improve the accuracy of the results.

Our next steps in building the framework is to extend the current capabilities to other fields such as internal and external ballistics. For instance, in this study the impact of the range was accounted for only as a modification an input parameter (impact velocity). But, we could imagine to include a task that solves directly the external ballistics equations for the trajectory of the projectile. The communication between tasks have to be formalized in order to improve modularity.

Although, some hurdles still need to be overcome ,the current observed performance are very encouraging and we are excited about the capability demonstrated by Julia so far.

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