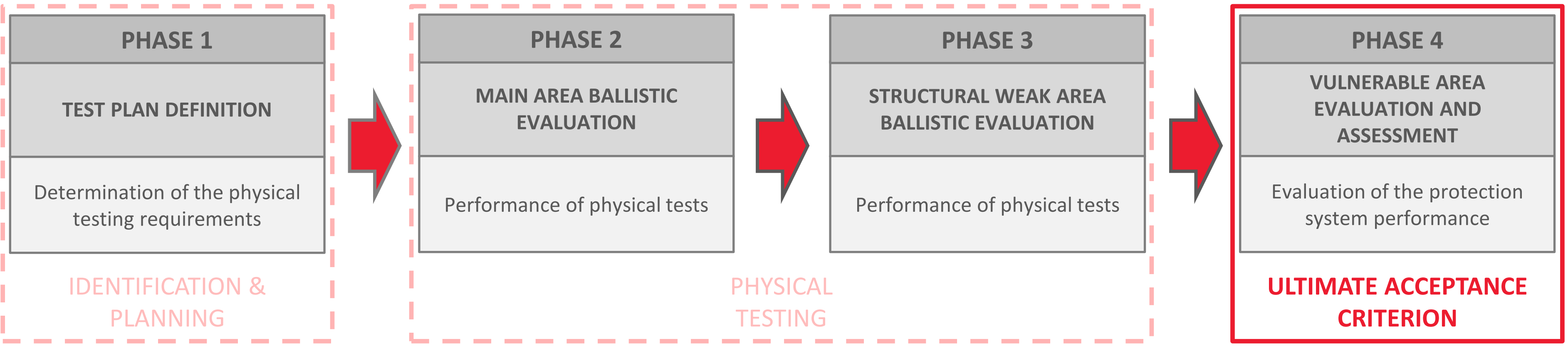
Software Aided Ballistic Vulnerability Analysis

BACKGROUND – AEP 55 Vol. 1 REQUIREMENTS

- Armoured vehicles designed with STANAG 4569 Level ballistic protection require the performance of a Ballistic Vulnerability Analysis in accordance with AEP 55 Vol.1, Ed 2:
  - *The complete acceptance process used to establish the Protection Level of a defined vehicular protection system consists of four sequential phases:*



- The above sequential process is required in its entirety for STANAG 4569 Level Ballistic Certification, **however**, armoured vehicle manufacturers and designers generally have enough information available (vehicle CAD models, historical ballistic test data and knowledge) at their disposal to perform a preliminary PHASE 4 evaluation prior to the other phases.
- PRONEX has developed a software aided method to accurately facilitate PHASE 4 above. This allows for these results to drive design decisions and reduce the ultimate time and cost when the full sequence of Phases 1 - 4 is performed.

BACKGROUND – AEP 55 Vol. 1 METHOD

- The adjacent image (Figure 4 from AEP 55 Vol. 1) is provided for reference.
- The method developed by Pronex provides a quicker and more accurate replication of this process, both in preparation and execution with an additional benefit of iterability towards optimisation.

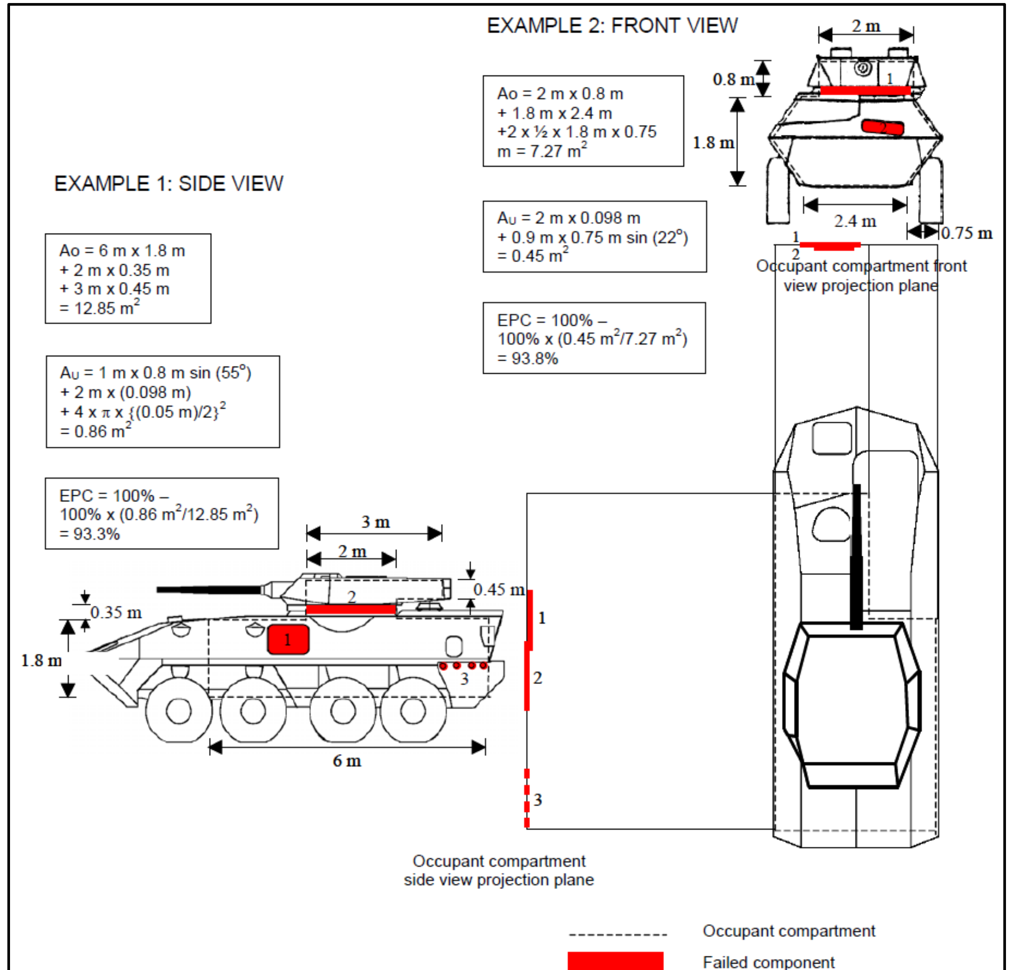


Figure 4 – Example of Vulnerable Area assessment method

BACKGROUND – AEP 55 Vol. 1 METHOD

- The tables provided below indicate the AEP 55 ballistic testing requirements (and subsequent vulnerability assessments) for STANAGE 4569 different threat levels.
  - Dependent on the selected threat level, a significant number of Analysis Plots may be required, with each requiring the application of the Figure 4 method provided on the previous slide.
  - Traditional manual plotting and measuring methods as described in AEP 55 Vol. 1, even CAD assisted, can require a significant amount of time, may be subjective and prone to error and are a challenge to iterate design changes
  - A faster, more accurate method of analysis that allows iteration can definitely provide benefit

AEP 55 Vol. 1, TABLE A1

LEVEL	KE THREAT					ARTILLERY THREAT (FSP 20mm)			
	AMMUNITIONS	V_{PROOF} *[M/S]	AZIMUTH	ELEV.	ANALYSIS $ PLOTS	V_{PROOF} *[M/S]	AZIMUTH	ELEV.	ANALYSIS $ PLOTS
6	30 mm x 173 APFSDS-T	n.a.**	30° - 330°	0°	5	1250	0° - 360°	0° - 90°***	145
	30 mm x 165 AP-T	810	30° - 330°	0°	5				
5	25 mm x 137 APFSDS-T MB 3134	1336	30° - 330°	0°	5	960	0° - 360°	0° - 90°***	145
	25 mm x 137 APDS-T, PMB 073	1258							
4	14.5 mm x 114 API/B32	911	0° - 360°	0°	24	960	0° - 360°	0° - 90°***	145
3	7.62 mm x 51 AP (WC core)	930	0° - 360°	0° - 30°	72	(770)****	0° - 360°	0° - 30°	****
	7.62 mm x 54R B32 API	854							
2	7.62 mm x 39 API BZ	695	0° - 360°	0° - 30°	72	(630)****	0° - 360°	0° - 22°	****
1	7.62 mm x 51 NATO ball	833	0° - 360°	0° - 30°	72	(520)****	0° - 360°	0° - 18°	****
	5.56 mm x 45 NATO SS109	900							
	5.56 mm x 45 M193	937							

Testing with projectiles specified for the lower Protection Levels will be necessary whenever there is reason to believe that the protection system may be vulnerable to such threats.

* V_{PROOF} = Figures are mean values: tolerance of striking velocity for individual shot is ± 20 m/s

** not available

*** See AEP 55 Vol. 1, Annex C, paragraph 4 for test options

**** At the long ranges of artillery engagement appropriate to Protection Levels 1 - 3, the low obliquity of attack achievable on a vehicle roof coupled with low fragment impact velocity on account of their high drag coefficients leads to the KE projectile threats dominating the armour demand. The chance of impact from a large fragment from a single shell detonation at ranges of 60 - 100 m is also extremely low. Hence, no testing against Level 1 - 3 fragment threats is required by STANAG 4569, but is optional to the National Authority.

$ Based on an increment and of 15° in both Az. And Elev. Gives a required 24 analysis plots per 360° Az. With 3 iterations for 15° Elev. Resulting in a minimum total of 72 Analysis plots

$ Based on an increment and of 15° in both Az. And Elev. Gives a required 24 analysis plots per 360° Az. With 6 iterations for 0-75° Elev plus 1 final 90° Elev. plot. Resulting in a minimum total of 145 Analysis plots.

AEP 55 Vol. 1 TABLE 2

LEVEL	THREAT AND TEST ANGLES TO BE CONSIDERED		
	5-6	4	3
5-6	Az: ±30°; Elev: 0°	Az: ±30°; Elev: 0°	Az: 360°; Elev: 0° to 30°
4	---	Az: 360°; Elev: 0°	Az: 360°; Elev: 0° to 30°
3	---	---	Az: 360°; Elev: 0° to 30°

Components positioned outside the attack angle interval of one Protection Level, but inside the interval of a lower Level shall be tested at the Level of threat to which they are exposed. Table 2, derived from AEP 55 Vol. 1, Annex A, illustrates the hierarchy of Protection Levels, the subordinate KE threats and their angles of attack to be considered.

PRONEX ANALYSIS PROCESS

- The software aided process Pronex has developed is detailed below:

GATHER AND REVIEW INPUT DATA

- Historical ballistic test data
- Material properties and known ballistic performance
- Vehicle manufacturing detail
- Vehicle cad model (protected volume)
- Customer work sessions

CAD MODEL PROCESSING AND INPUT DATA PREPARATION

- Classification and identification of the protection areas
  - *Main Areas (MA)*
  - *Excluded Zones (EZ)*
  - *Structural Weak Areas (SWA)*
- Preparation of analysis input plots (automated and live linked to pre-processed cad model)

BALLISTIC VULNERABILITY ASSESSMENT

- Assessment analysis model setup and calibration
- Perform ballistic vulnerability assessment
- Export results and compile summaries

RESULTS REVIEW AND DESIGN CHANGE IMPLIMENTATION

- Review results & determine recommendations
- Implement design changes
- Perform further assessment iterations and results review as required

ITERATION AND OPTIMISATION

ITERATION AND OPTIMISATION

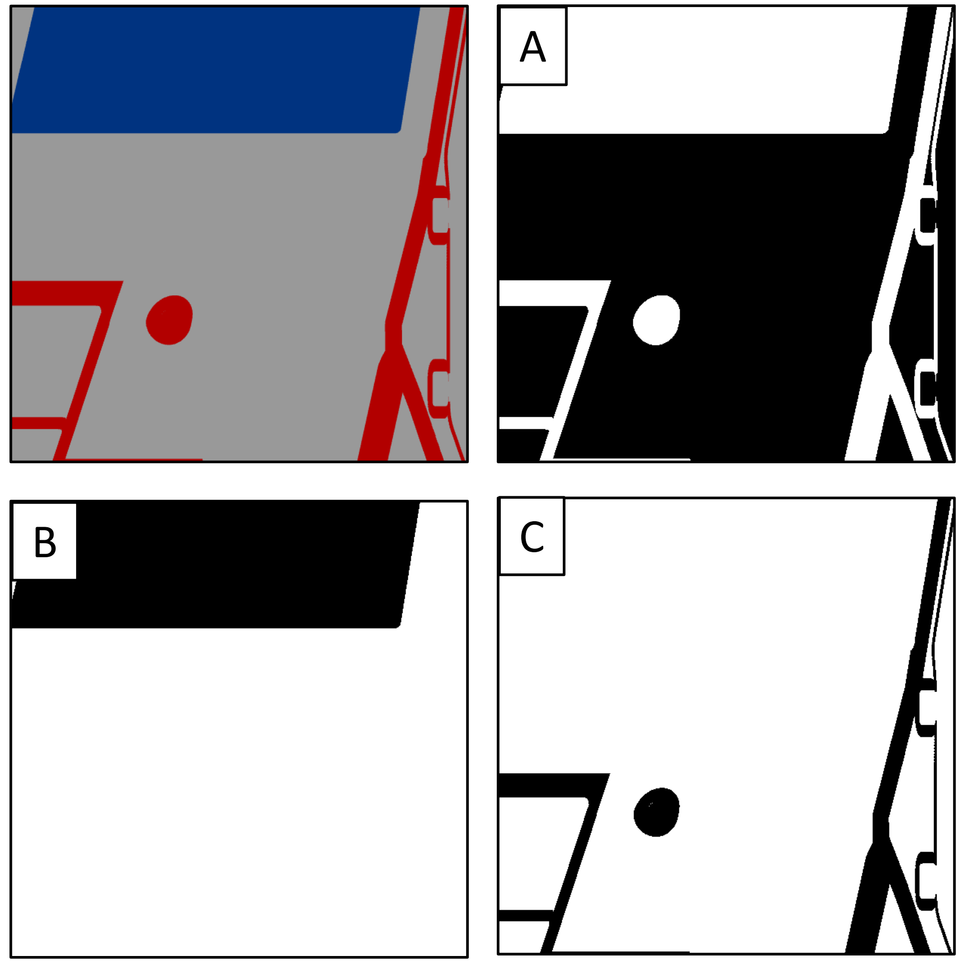
- The software aided workflow PRONEX has developed facilitates the automated creation of the analysis input plots allowing for efficient and accurate iteration of the analysis lending towards optimisation.

KEY FEATURES & ADVANTAGES

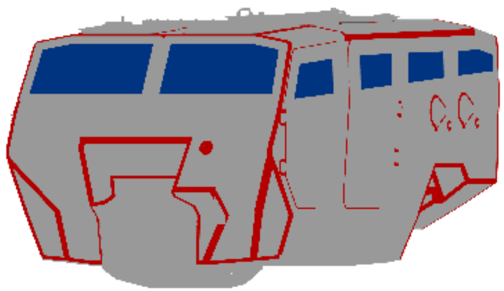
- The following key features and advantages are noted:
  - Allows for the Phase 4 evaluation to be performed as a Preliminary Analysis to provide design input prior to formal AEP 55 phase testing and evaluation.
  - Good iterability is inherent due to live link between the analysis plot creation and the CAD model
    - *Minimal post processing of the analysis input plots is required*
    - *CAD model updates are quickly captured in the input plots and subsequent analysis*
  - Obstructions and material layering are inherently taken into account
    - *Layered combinations of plate / area types can be identified and accounted for.*
    - *In multi-layer models the same initial model setup can be used to evaluate both single and multi-layer protection solutions. (refer to the provided multi-layer example)*
  - Solution output is quick and accurate with easy to follow result sheets.
  - Being in-house developed, the method has a high level of adjustability and customisability
    - *Additional regions of interest are easily added*
      - *Glass, bolt heads, other armour types/layers, etc.*
    - *Higher resolution analyses are easily performed (Azimuth and Elevation increments of smaller than the STANAG required 15° are easily implemented.*
  - A method for threat angle of incidence determination and evaluation is past proof of concept and currently being developed as an additional analysis feature

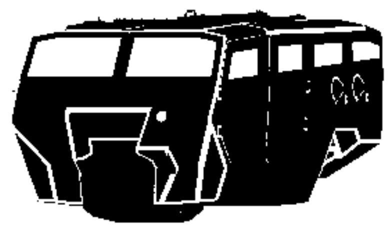
SAMPLE RESULTS – SINGLE LAYER PROTECTION CONCEPT ANALYSIS

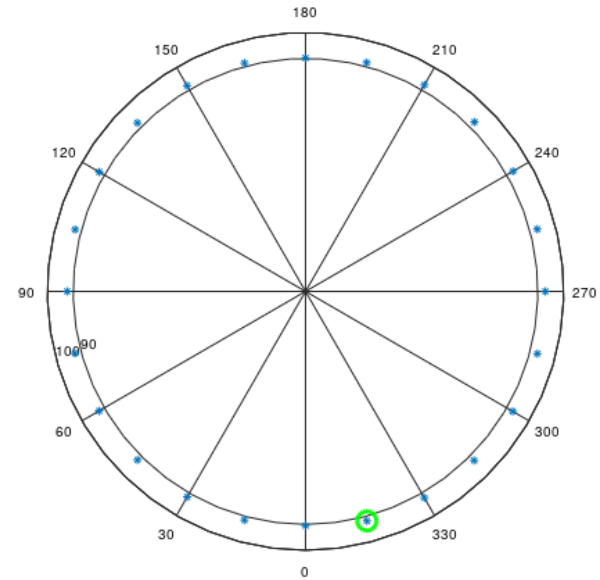
- The adjacent images demonstrate samples of the identified areas of interest which are used to determine the Relative Vulnerable Area (RVA) and Expected Protection Capability (EPC) of a given input plot.
  - A – *Main Area*
  - B – *Glass (included for demonstration, same threat resistance as Main Area)*
  - C – *Structural Weak Areas*
- The analysis results for 0° Elev. & 360° Azim. At 15° increments (24 plots) is provided on the next slide.

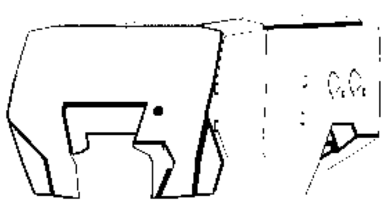


SAMPLE RESULTS – SINGLE LAYER PROTECTION CONCEPT ANALYSIS









345 Degrees

Glass 13.2 %

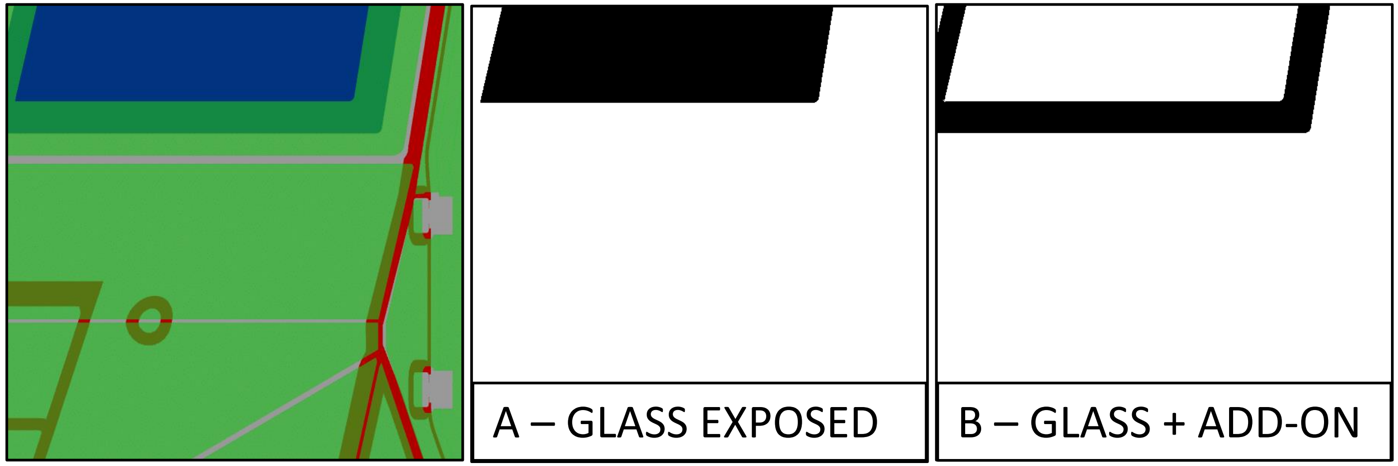
Armour 78.6 %

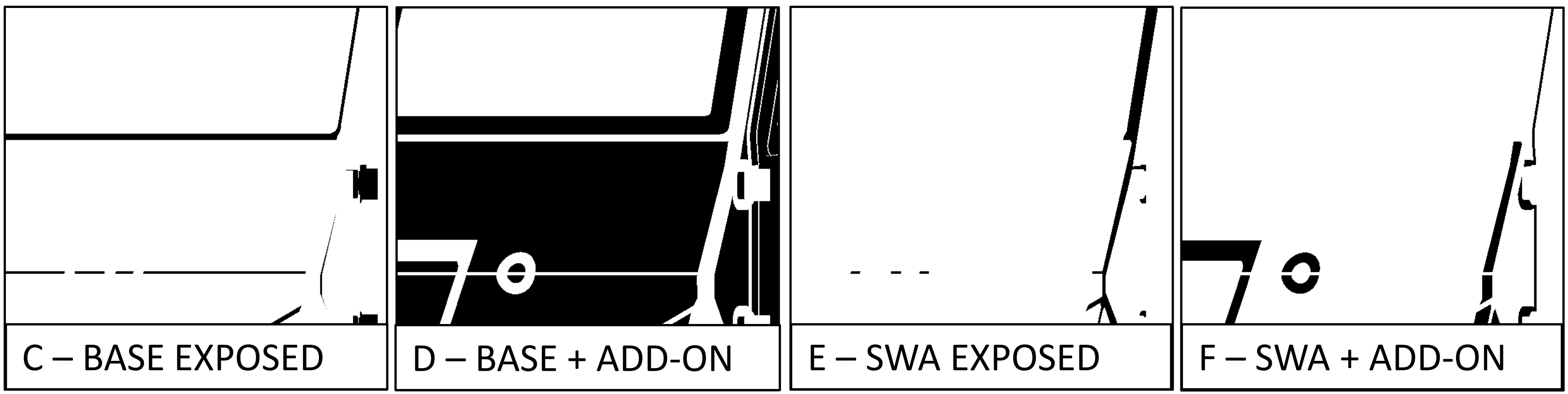
Expected Protection Capability 91.8 %

Relative Vulnerable Area 8.22 %

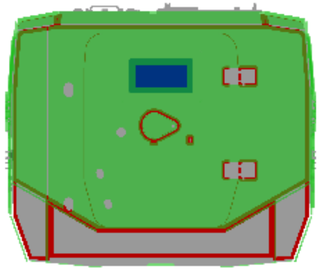
SAMPLE RESULTS – MULTI- LAYER (ADD-ON ARMOUR) ANALYSIS

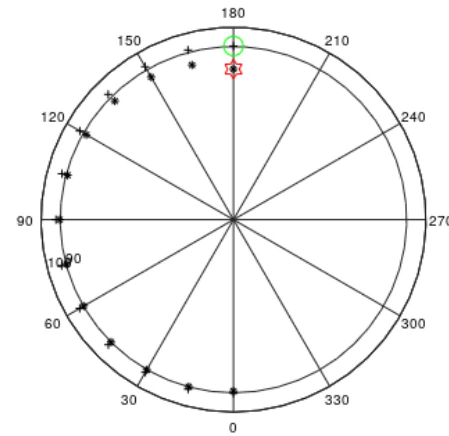
- The adjacent images demonstrate samples of the identified areas of interest which are used to determine the RVA and EPC in a case with Add-On Armour fitted.
- In this instance a multilayer model was prepared where it is then possible to evaluate both the Base L1 and Add-on L3 protection solutions using the same input plots as demonstrated on the next slide

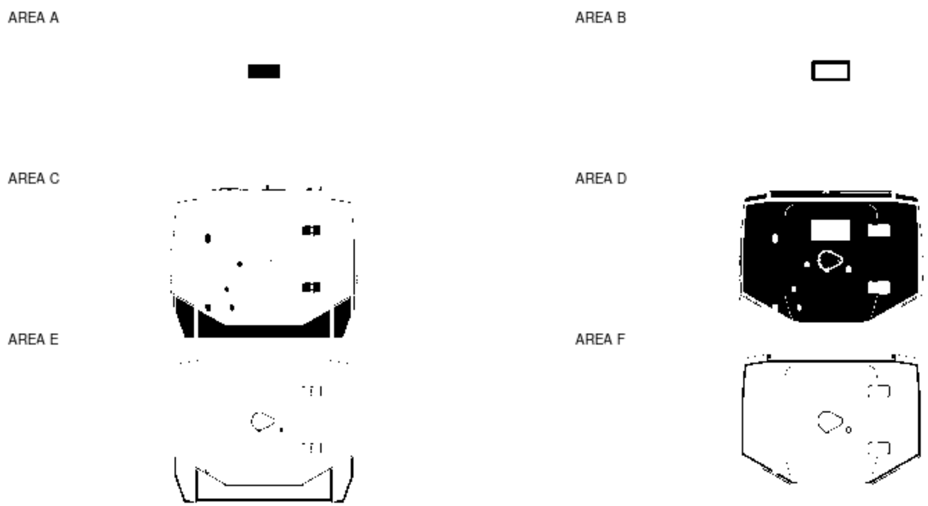




SAMPLE RESULTS – MULTI- LAYER (ADD-ON ARMOUR) ANALYSIS







180 Degrees

[A] :Glass EXPOSED: 1.636 %

[B] :Glass + ADD-ON: 1.369 %

[C] :Base EXPOSED: 17.51 %

[D] :Base + ADD-ON: 69.72 %

[E] :SWA EXPOSED: 4.239 %

[F] :SWA + ADD-ON: 5.535 %

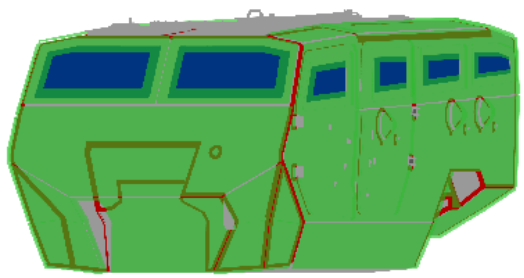
+[A+B+C+D] :L1 Expected Protection Capability: 90.23 %

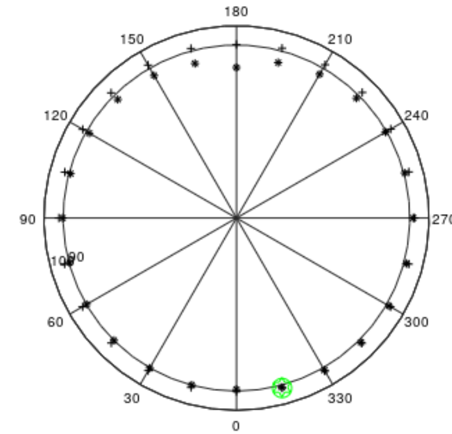
+[E+F] :L1 Relative Vulnerable Area: 9.774 %

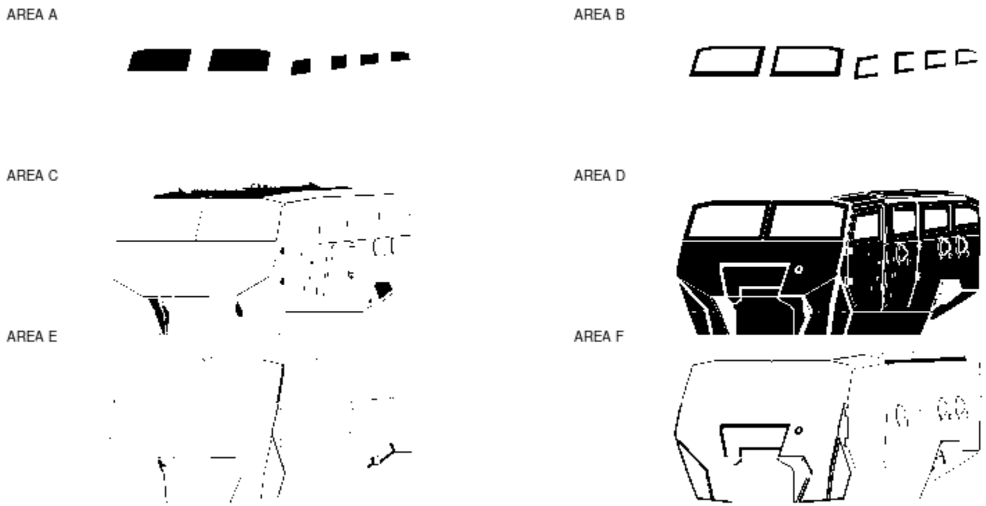
***[A+B+D+F] :L3 Expected Protection Capability: 78.26 %**

*[C+E] :L3 Relative Vulnerable Area: 21.74 %

SAMPLE RESULTS – MULTI- LAYER (ADD-ON ARMOUR) ANALYSIS







345 Degrees

[A] :Glass EXPOSED: 8.243 %

[B] :Glass + ADD-ON: 5.654 %

[C] :Base EXPOSED: 7.537 %

[D] :Base + ADD-ON: 70.09 %

[E] :SWA EXPOSED: 1.35 %

[F] :SWA + ADD-ON: 7.13 %

+[A+B+C+D] :L1 Expected Protection Capability: 91.52 %

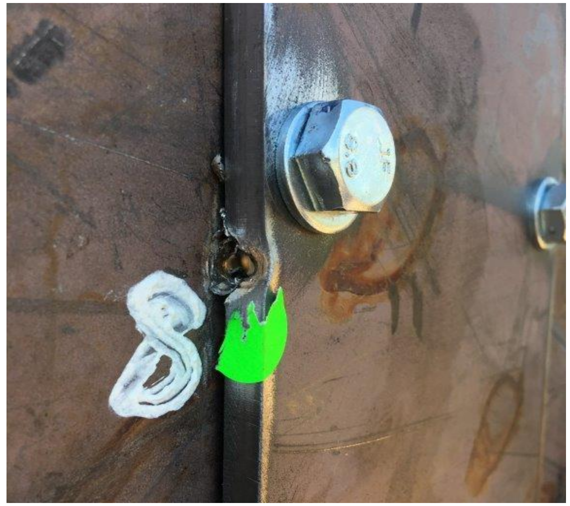
+[E+F] :L1 Relative Vulnerable Area: 8.479 %

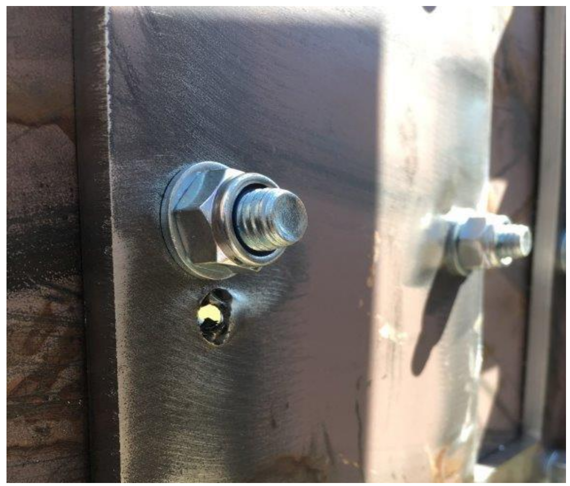
***[A+B+D+F] :L3 Expected Protection Capability: 91.11 %**

*[C+E] :L3 Relative Vulnerable Area: 8.887 %

BALLISTIC TESTING – MAIN AREAS

BALLISTIC TESTING – ENGINEERED TEST PIECES





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