USING DIGITAL TWINS TO IMPROVE ROLL CAGE DESIGN

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Safety Devices International Ltd

BACKGROUND & HISTORY

Safety Devices®
TECHNOLOGY OF PROTECTION

- Safety Devices have been producing ROPS and supporting products for over 50 years.
- We initially developed ROPS for Motorsport, although evolved to cover many more sectors using the same founding principles.
- Now producing over 2500 different ROPS designs, supplied to over 125 countries.

SECTORS OF EXPERTISE

- **Automotive** – Seat belt anchorages, suspension components, subframes, vehicle chassis’
- **Motorsport** – Roll cages to suit modern and historic racing and rallying regulations
- **Expedition** – ROPS and accessories primarily for the Land Rover Defender
- **Fleet** – ROPS to suit mining, quarries, oil & gas exploration and NGO’s
- **Military** – ROPS for UK Army fleet amongst many others

ROLL OVER EXAMPLE

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Renault Clio 182 rollover with R016 ROPS Installed *(Credit: Philippe Vla)*

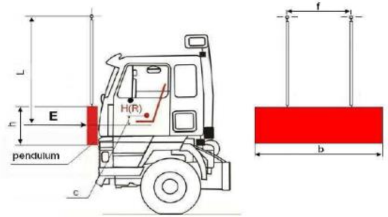
ENGINEERING OF ROPS FOR LARGE VEHICLES

- Specific challenges of Commercial and Off-Highway Vehicle ROPS design
  - Material availability can be limited due to scale of platform
  - Methods of embodiment, complex integration requirements
  - Modular construction, base platform may need to accommodate multiple variants
- Variables to be considered
  - Vehicle role: Speed, terrain, environment, driving style - likely hazards to propagate roll over event
  - Vehicle type: Open architecture, converted (change of application), commercial
  - ROPS scope: Areas / level of protection required
  - Constraints: Vehicle architecture, packaging, operational requirements

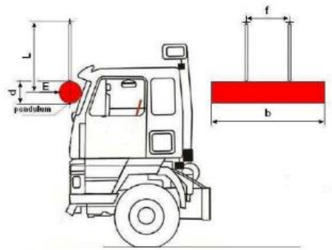
ROPS REGULATIONS

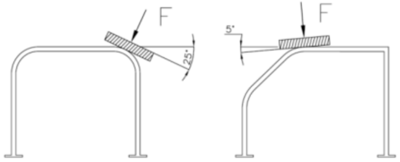
- Various ROPS regulations available, generally loadcase requirements are categorised by vehicle mass and sector:
- Higher mass/lower speed – lower load multiplier
  - ISO 8082, ISO 3471, ECE R66, ECE R29,
- Higher speed/lower mass – higher load multiplier
  - FMVSS216, Corporate specifications (Oil & Gas), FIA, DefAust
- Design specification may include the requirement to meet more than one standard on different areas of the structure

Front impact test (test A)

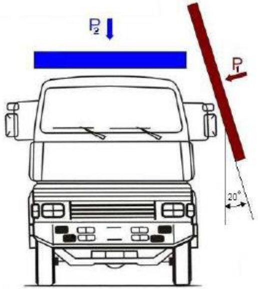


Front pillar impact test (Test B)





Roof strength test (Test C)



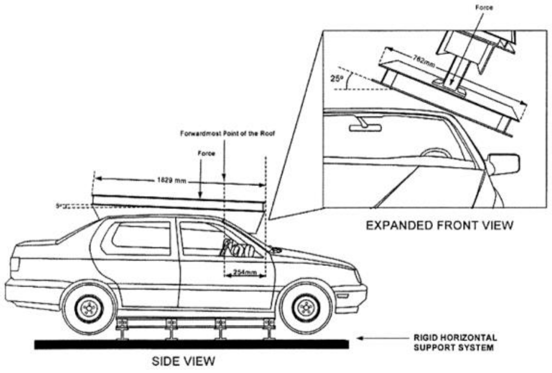


Figure 1. Test Device Orientation

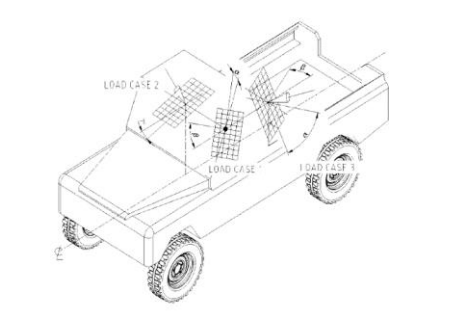
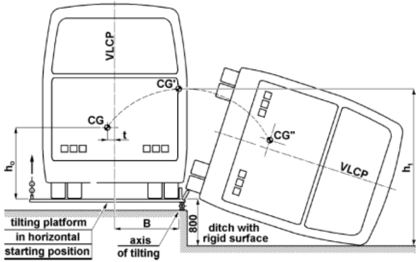
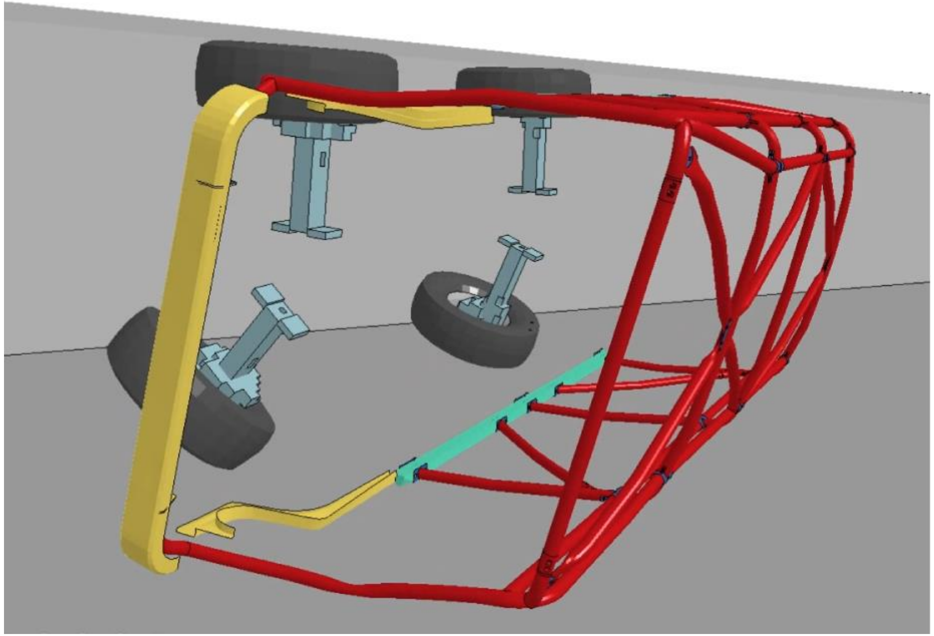
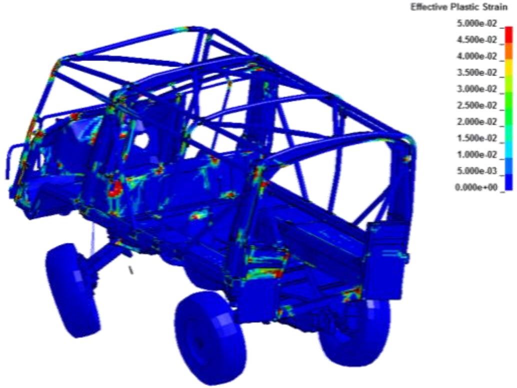


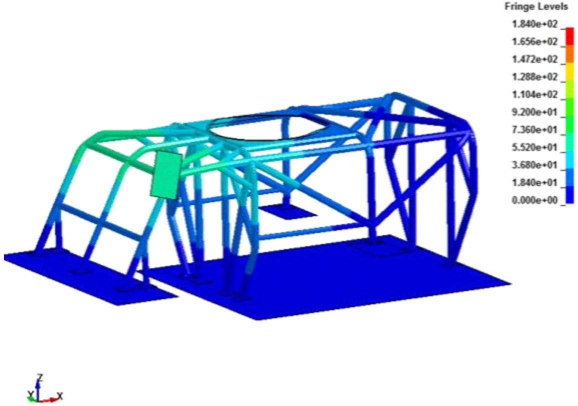
Figure B-1: Loading Sequence for vehicle cab, where vehicle has an open rear tray area



LOADCASE EXAMPLES



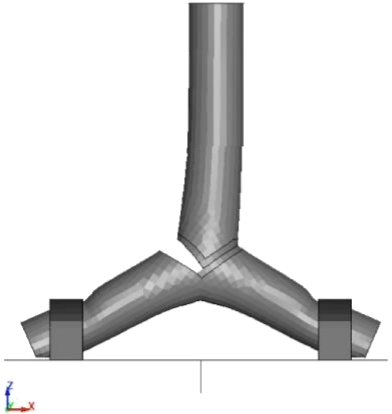




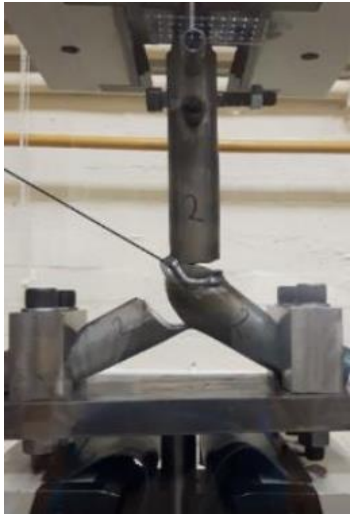
DIGITAL TWIN CORRELATION

- Confidence in the digital twin is critical to a successful design process
- GRM have correlated many FE models to physical tests conducted by Safety Devices.

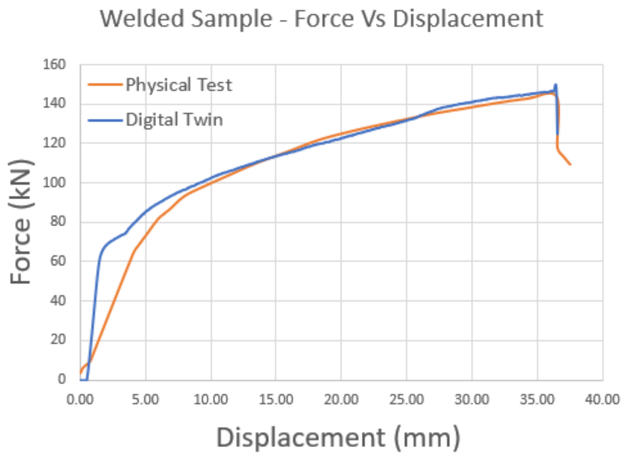
Tested Sample



Digital Twin



Failure Mode



Correlation

DIGITAL TWIN CORRELATION

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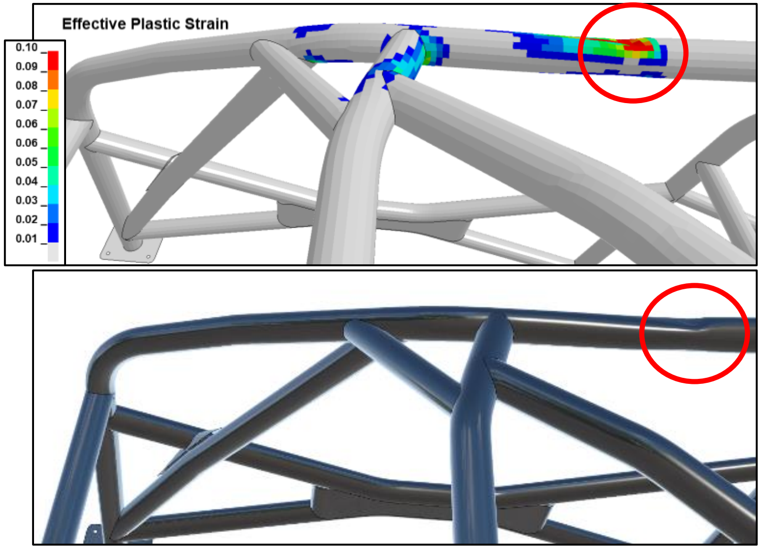
Tested ROPS



Digital Twin

Post Test

THE CHALLENGE

- Military vehicle required to meet Reg. 66 which dictates a roll-over event and a cabin intrusion limit.

- SDI wanted the ability to quickly determine the consequences on the design based on:
  - Tube availability
  - Costs
  - Mass

- A number of approaches were considered.

- Design of Experiment (DOE) was determined to be the optimal method.

WHAT IS A DOE?

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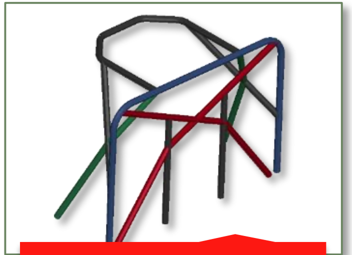
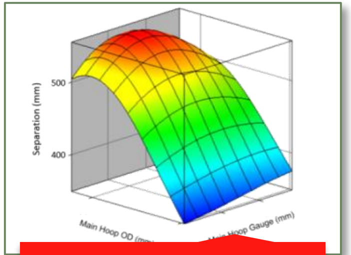
- Design of experiments (DOE) is a systematic, efficient method that enables engineers to study the relationship between multiple input variables and key output variables.



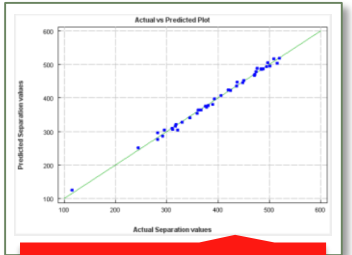
Input Variables

- Any number of variables can be used and investigated
- More variables, more datapoints needed, more simulations



Output Response

- Response surface created using results at each datapoint
- Surface allows for prediction using input variables not simulated, saving time and resource



Validation

- Line of best fit is plotted and compared against real data points
- Convergence of the data points around this line suggests high quality results

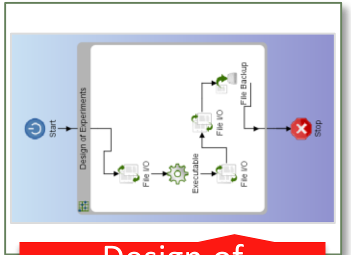
DOE PROCESS OVERVIEW

Initial Condition

- Pre-impact simulation
- Accurate initial condition
- Efficient DOE runtime

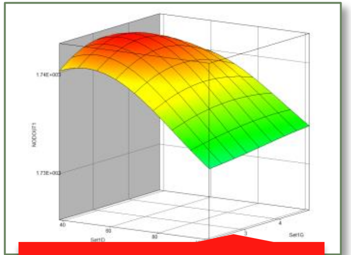
Baseline Analysis

- Verify simulation
- Investigate key performance metrics



Design of Experiments

- Generate roll hoop member size matrix
- Setup DOE study using Iliad.



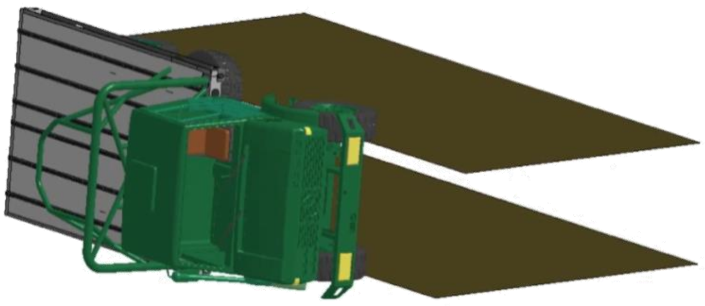
Predictor Output

- Generate DOE surface
- Output performance formula
- Generate performance predictor

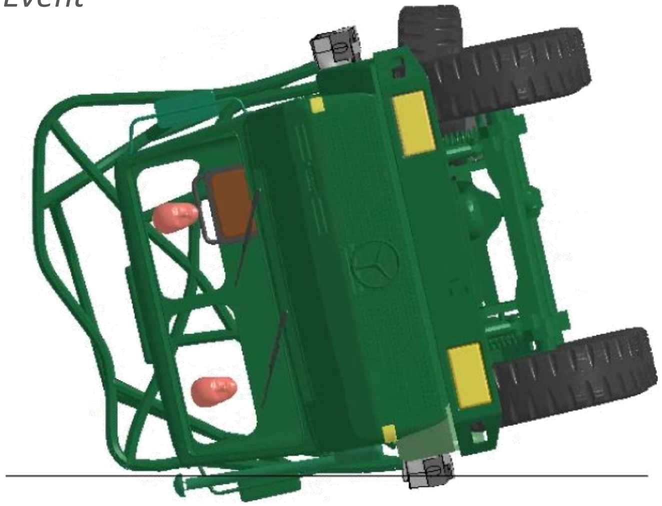
BASELINE ANALYSIS

Rigid Body Kinematics

- Pre-simulation of common motion using R66 conditions as guidance.
- Motion used as input for ROPS impact simulation.



Landing Event



- Extensive Quality Assurance before triggering DOE.
- Determine key performance metrics.
- In this case, separation of head to ground plane.

DOE VARIABLES & MATRIX

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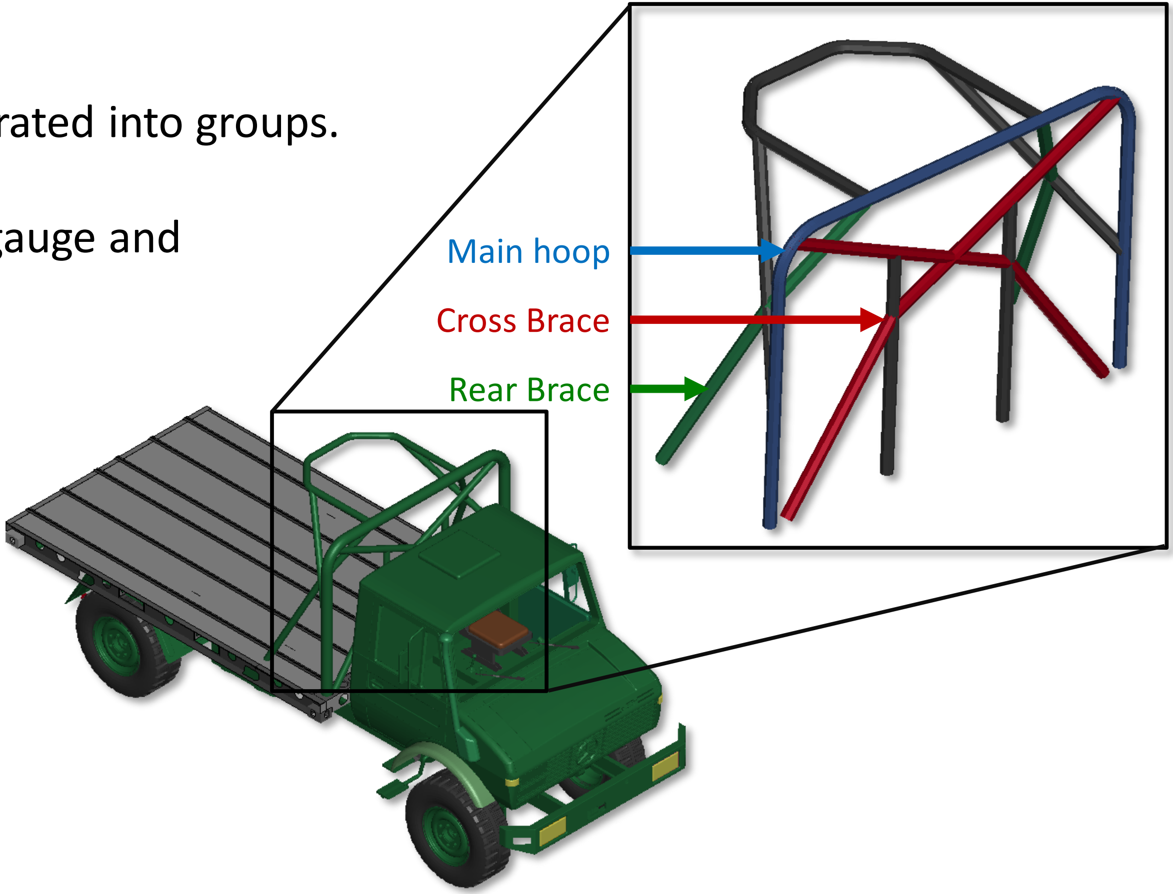
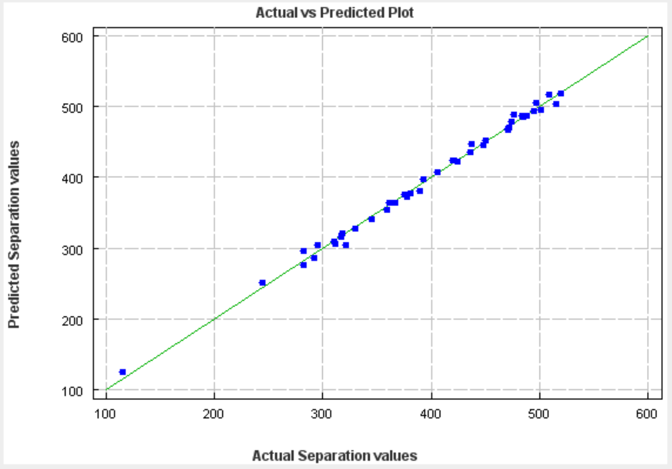
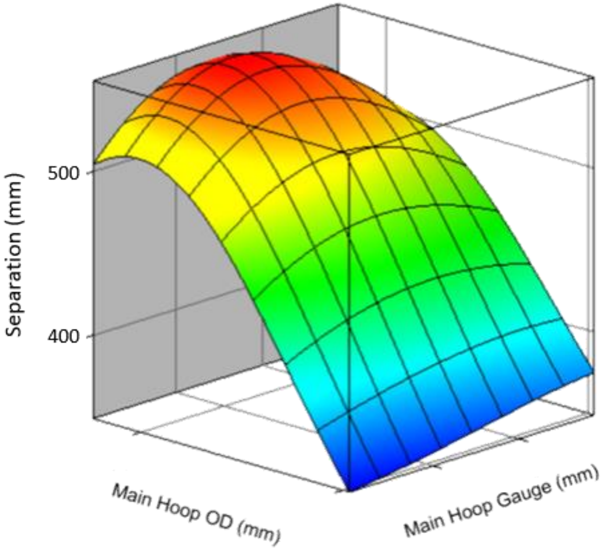
- The ROPS assembly was separated into groups.
- Each group assigned unique gauge and diameter limits.
- DOE required 43 simulations to generate accurate response surface.



DOE RESULTS & VALIDATION

- Response prediction was generated.
- Validation achieved via strong correlation.





- Days of simulation time saved due to the many DOE loops to come.
- Key performance metric determined to be separation of head to ground plane.

SURFACE FORMULA EXTRACTION

- The complex response surface equation can be extracted from within Iliad.
- Equation can be used to precisely predict performance within the input variable limits.

$Separation$ = -1405.6970937813 + (0.498262921426*M1D) – (17.722736480402*M1T) + (12.533439156319*M2D) + (161.740798724788*M2T) + (12.544469569229*M3D) + (135.986514518046*M3T) – (0.062569413345*M1D*M1T) – (0.022800937523*M1D*M2D) – (0.390807319286*M1D*M2T) + (0.00885708445*M1D*M3D) + (0.32762789824*M1D*M3T) + (0.348812807245*M1T*M2D) + (5.212491914681*M1T*M2T) – (0.070583420177*M1T*M3D) + (8.402499135207*M1T*M3T) – (0.450149502255*M2D*M2T) – (0.025609968053*M2D*M3D) – (0.432921630091*M2T*M3T) – (0.063537472267*M2T*M3D) – (1.715881301432*M2T*M3T) – (0.559693838803*M3D*M3T) + (0.006794988868*M1D^2) – (6.53550764517*M1T^2) – (0.0306142813 1*M2D^2) – (6.859624909152*M2T^2) – (0.058651834535*M3D^2) – (3.326580274538*M3T^2)

CALCULATOR & USE AT SDI

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- Response surface was converted into a calculator for rapid iterative design.
- A 3 hours simulation was reduced down to mere seconds.

UNIMOG ROPS Intrusion Calculator

Provided by: GRM

Project ID: GRM-SDI-110-18

Engineer: Martin Gambling

Contact Details: Telephone: 01926 889 300 · Email: martin@grm-consulting.co.uk

INPUTS

Enter desired design parameters below
Ideally, values should be within range shown below.
This tool should be capable of approximately predicting outside this range

Parameter	Minimum	Maximum	Defined
Set 1 Diameter	38.1	102	40
Set 1 Wall Thickness	2.03	4.88	3.25
Set 2 Diameter	38.1	102	100
Set 2 Wall Thickness	2.03	4.88	3.25
Set 3 Diameter	38.1	102	72
Set 3 Wall Thickness	2.03	4.88	4.25

Input Parameters

OUTPUT

Ground to Head Separation Below

Predicted Separation	457.2mm
Predicted Mass	107.4kg

WHAT'S NEXT?

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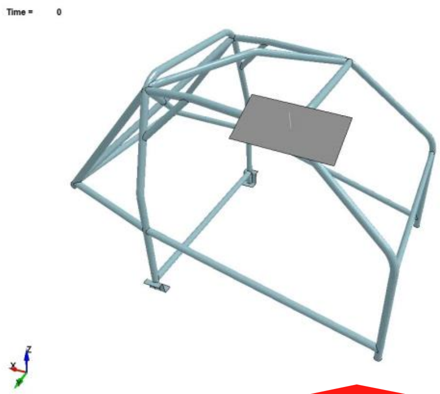
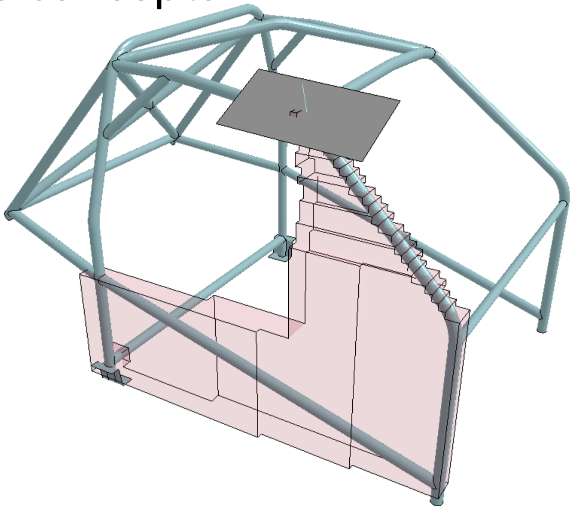
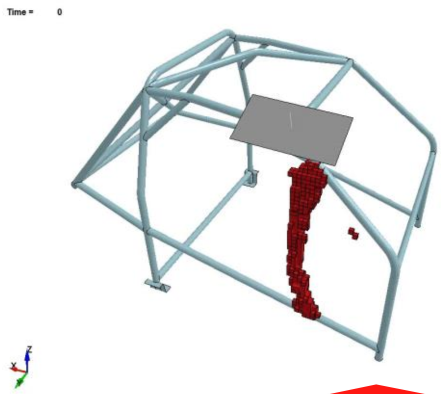
- Extensive studies expected in Motorsport and Defence arenas to ensure applicability of regulations and to extend approval to encapsulate advances in simulation.
- RDM® Dyna for roll cage concepts.



Initial Rollcage Design


RDM® DYNA Design Region



RDM® Reinforced Design