X760 Bumper Automation and Optimisation Process

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Currently the bumper system is developed through a wide variety of individual virtual test methods, the majority of which also have to be verified with physical testing. This paper will describe a new process that produced a one combined virtual process to encompass the full bumper as a system development method by creating One model for a bumper as one system with multiple attributes and requirements and using only one code " LS-DYNA and LS-OPT".

To facilitate this, improvements are required in both CAE prediction confidence and test method interactions for the following requirements: low speed impact, pedestrian leg impact, thermal stability, stone chipping, firmness feel and NVH. The benefit of this approach is to reduce bumper system cost and mass through integrated system design strategy, at early stages, considering all requirements together and have a potential to reduce reliance on physical testing.

1 Bumper Automation Process

Load Case Development

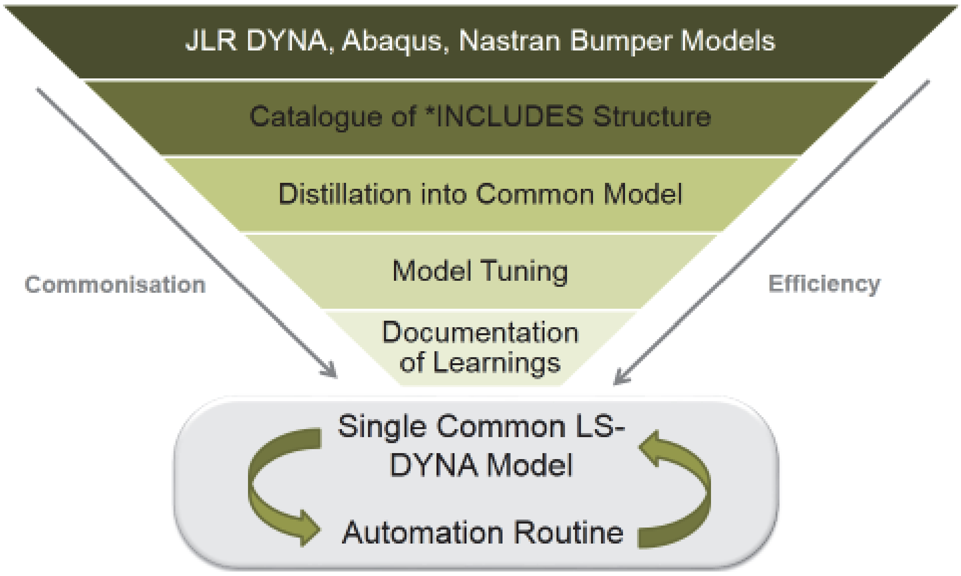
Objective

- To develop a series of load cases based on existing models at JLR

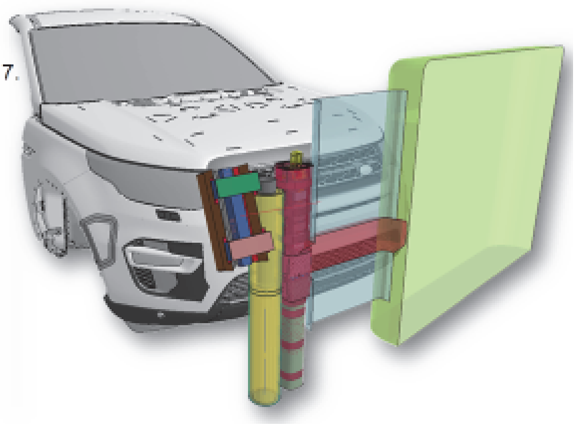
Steps

1. Cataloguing of existing load case build 'include' files.
2. Build a common vehicle model using this catalogue.
3. Create clean and consistent load case set.
4. Carry out a multi disciplinary optimisation for the bumper as a system

Load Case Development

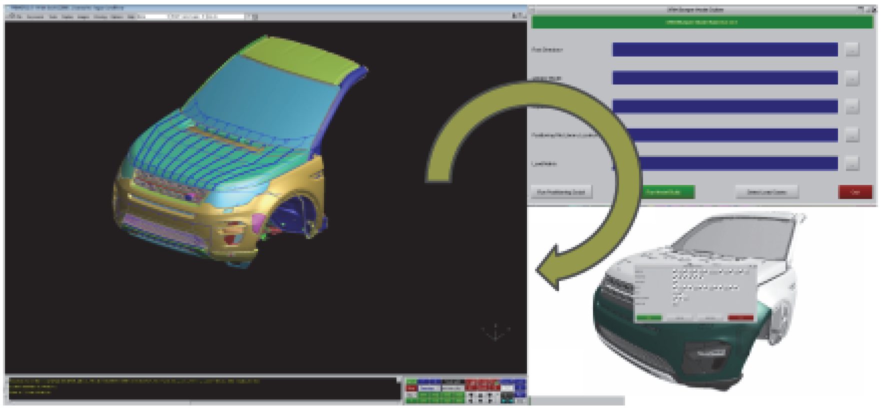


Load Case List



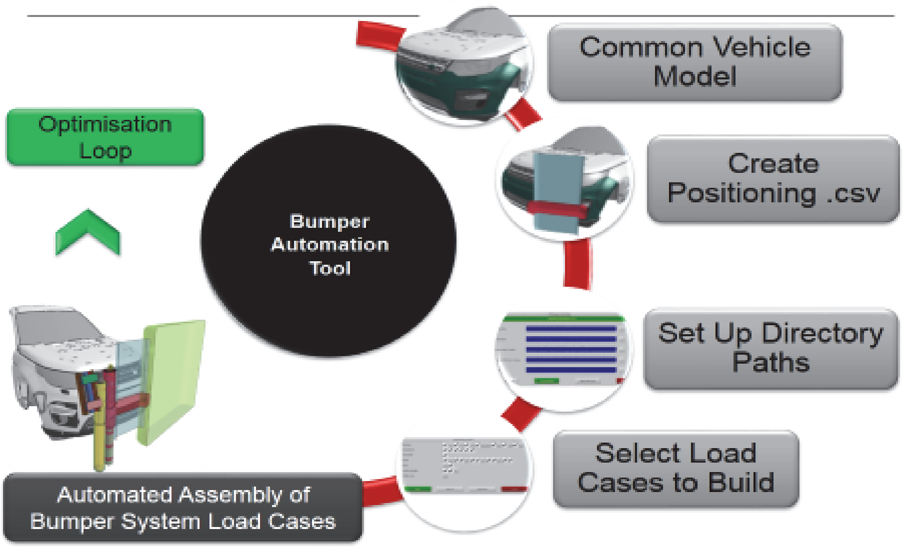
1. Pedestrian:
   - Upper Leg.
   - Lower Leg – FLEX PLI and WG17.
2. Low Speed Impact:
   - RCAR/FC11.
   - Thatcham/FC08.
   - FED581 Pendulum and Barrier.
3. Thermal Stability:
   - Heat Cycling.
4. Extreme Strength.
5. Firmness Feel (Zones A, B: Push and Pull, C and D - Grille).

Primer Integration



- The Bumper Automation Module is integrated into standard JLR toolsets (Oasys Primer) and allows the automated build of front bumper load case models, improving model consistency and build efficiency.

Flow Chart

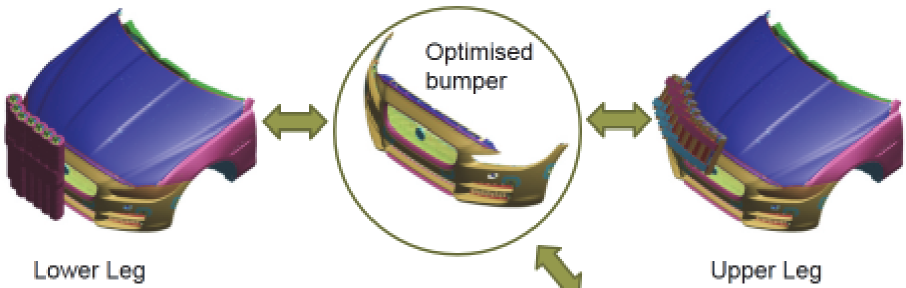


2 Bumper Optimisation Process

Objective

- To optimise the bumper system considering all major loadcases
- Setup a multi-criteria optimisation to obtain a set of design variables that fulfil all design requirements
  - The optimisation setup is assisted by the automated model build process since all the necessary loadcases can be considered due to the use of a common model
  - Also the optimisation setup is quicker and consistent as the includes considered for optimisation have to be defined once only

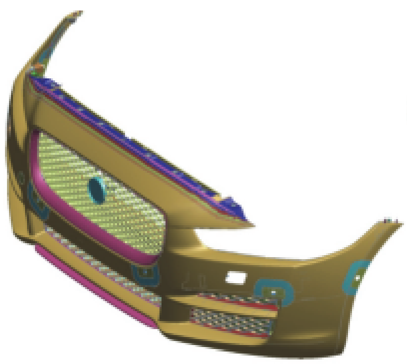
Multiple Loadcases

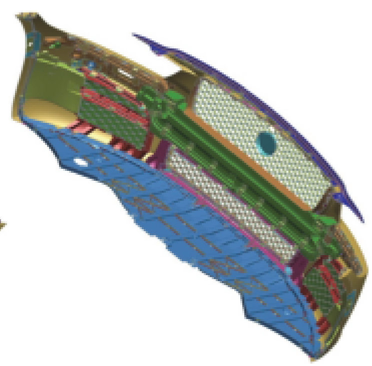


- Pedestrian and firmness feel loadcases considered
- Other loadcases can be easily added due to the common model approach

Optimisation Setup – Objective

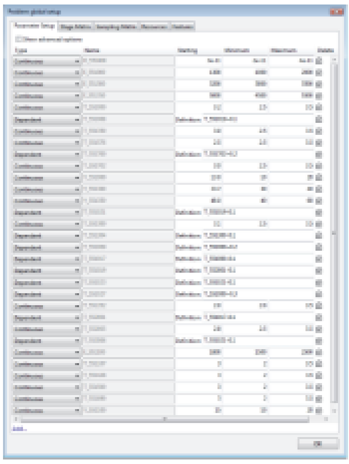
- the multi-objective setup is to ***minimise the mass*** and ***maximise the leg score*** while keeping the performance levels of the baseline design





Optimisation Setup – LS-OPT Inputs

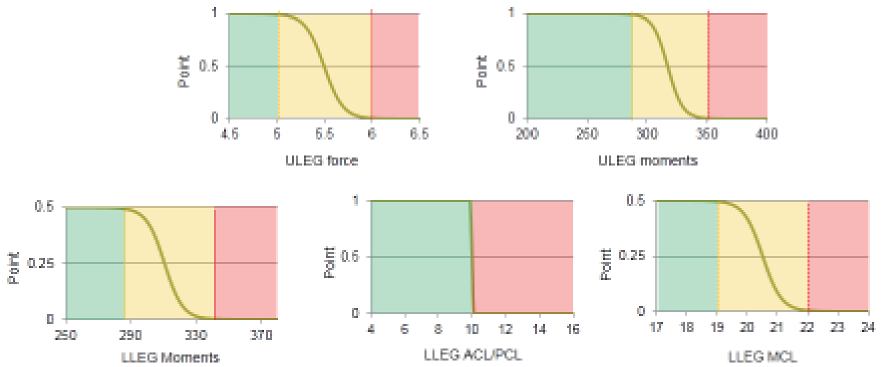
All design variables



Loadcase specific design variables

Optimisation Setup – Responses (Scores)

- Composites are created to use leg impact points and EuroNCAP scoring in the optimisation as constraints
- The functions used for scoring of the leg impact are shown below with the performance limits



Optimisation Setup - Responses

- The monitored responses are loadcase dependent

Upper Leg	Ligament Elongations			Tibia Moments			
	PCL	ACL	MCL	Upper	Mid Upper	Mid Lower	Lower

Lower Leg	Femur Forces	Femur Moments		
	Sum of femur forces	Upper	Middle	Lower

Firmness Feel	Displacement
	Displacement in the direction of push/pull

Optimisation Setup - Constraints

- The constraints are also loadcase dependent
  - For the leg impact loadcases, the sum of scores of the upper leg and lower leg is used

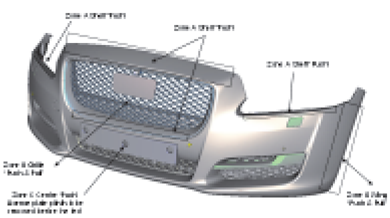
$$Score_{Leg} \geq 10$$

  - The firmness feel constraint is dependent on the position where the load is applied
    - The loading positions and the respective displacement limits are given in the table below

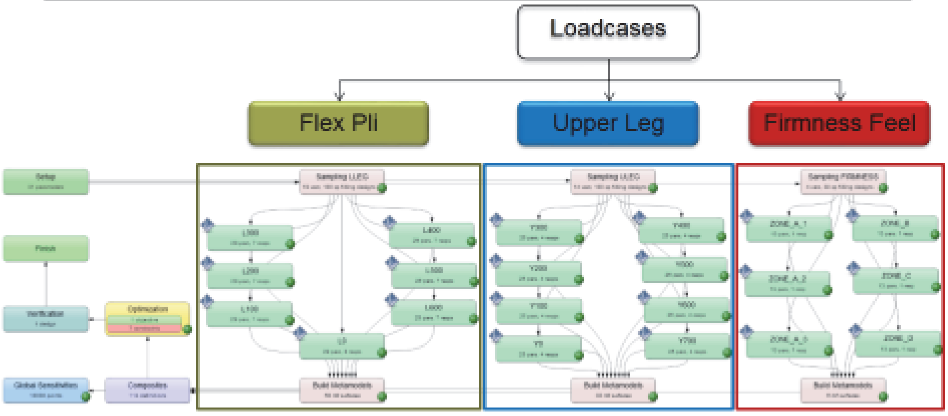
Table 1. Front Bumper System Firmness & Feel Chart

Load (Newtons)	Maximum Allowable Deflection (mm)					
Front Bumper System	Zone A Push (Top Shelf)	Zone B Push (Wing)	Zone B Pull (Wing)	Zone C Push (Centre)	Zone D Push (Grille)	Zone D Pull (Grille)
49.0	3.0	5.0	5.0	5.0	N/A	N/A
65.0	N/A	N/A	N/A	N/A	5.0	5.0
98.0	6.0	10.0	10.0	N/A	N/A	N/A
147.0	9.0	N/A	N/A	N/A	N/A	N/A

Figure 1. Front Bumper with Integrated Radiator Grille

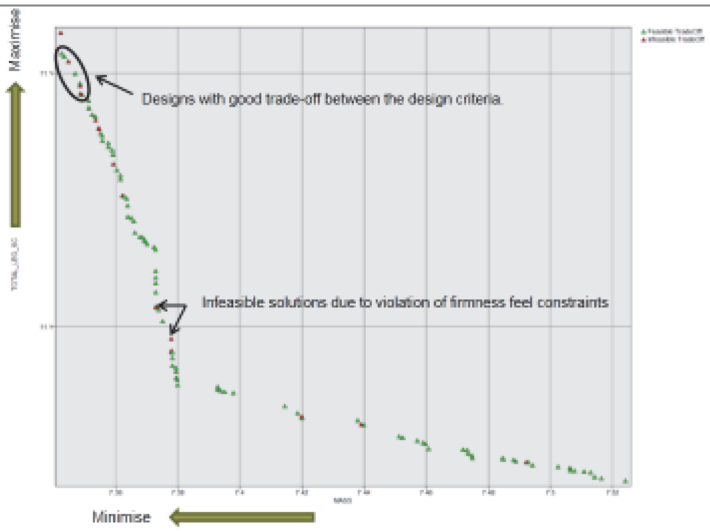


LS-OPT Setup



- Other loadcases can be easily considered in the optimisation loop
- 100 samples for upper leg and lower leg and 30 samples for firmness
- Response surface based optimisation

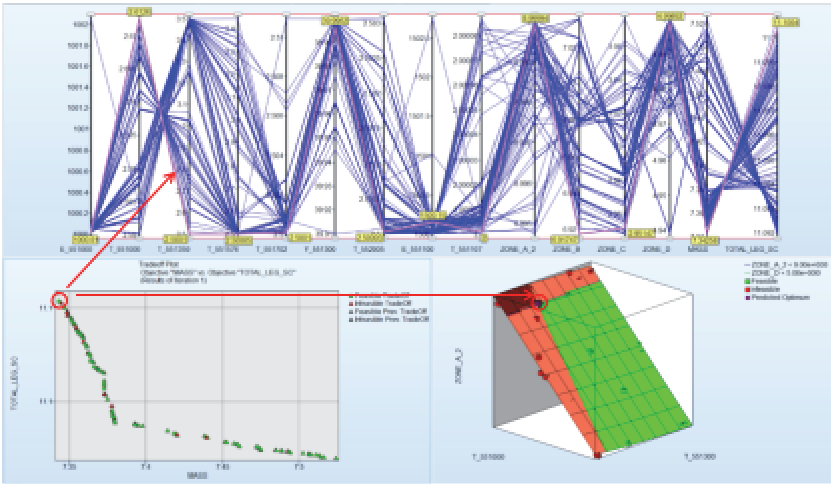
Optimisation Results



Trade-off plot: Trade-off between leg points and mass

Optimisation Results

Corresponding design variables setting of the predicted optimum



Best trade-off between the objectives

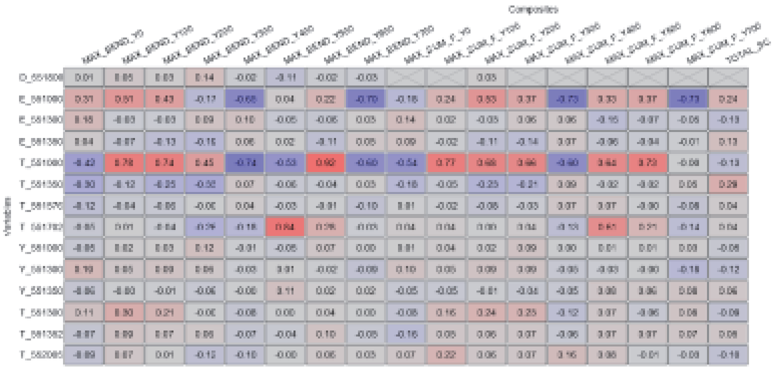
Predicted optimum at the boundary of the feasible design space

Optimisation Results

- The mass of the designed parts has reduced from 9.47 kg to 7.34 kg (mass saving of 22.5%)
- The optimisation is driven by the firmness feel loadcases since this is the only constraint violated during the optimisation
- The predicted optimum is at the boundary of the feasible design space since it narrowly satisfies the firmness feel constraint
- The optimum variables and its comparison to the starting variables are given in the following slides
- Also the important design variables for each loadcases are identified

Important Design Variables - ULEG

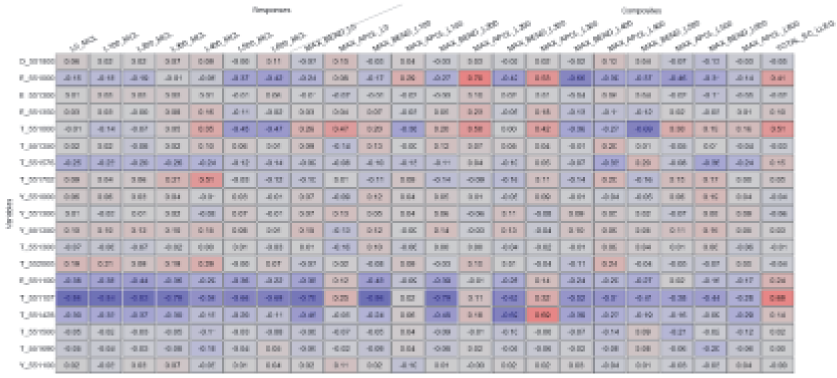
- Linear Correlations



- Most important variables, for total upper leg score, are Young's modulus of bumper (skin, bezel, grill) materials, bumper skin thickness and bezel thickness

Important Design Variables - LLEG

- Linear Correlations



- Most important variables, for total lower leg score, are Young's modulus of bumper skin material and under tray, bumper skin thickness, headlamp bracket thickness, under tray thickness and lower grill thickness

Important Design Variables - Firmness

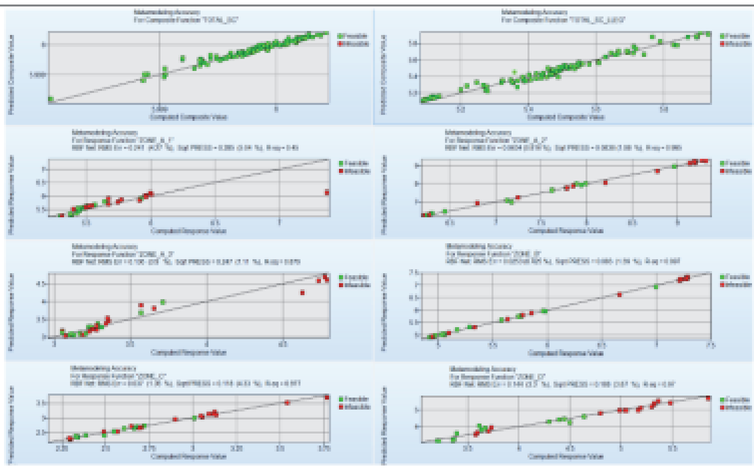
- Linear Correlations

Responses

Variables	ZONE_A_1	ZONE_A_2	ZONE_A_3	ZONE_B	ZONE_C	ZONE_D
T_551000	-0.69	-1.00	-0.66	-0.98	-0.92	-0.18
T_551350	-0.29	0.06	-0.03	0.08	-0.04	-0.00
T_551576	-0.09	0.01	-0.52	-0.05	0.13	0.02
T_551300	-0.05	0.03	0.10	0.08	0.01	-0.95

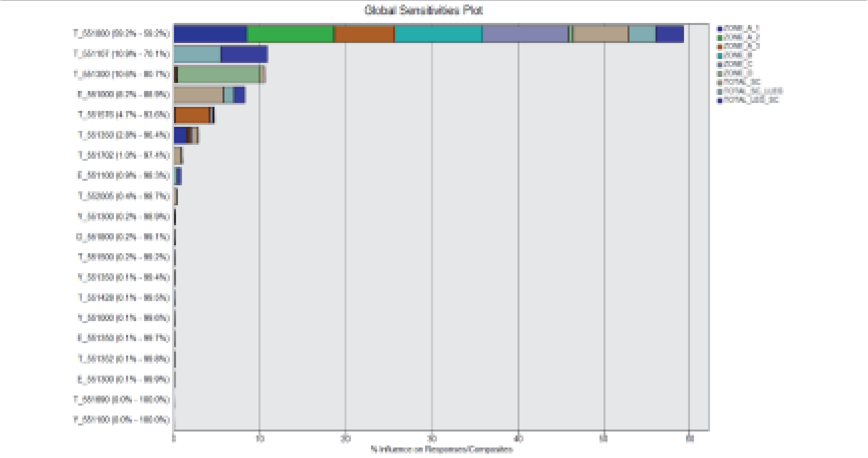
- Most important variable for all firmness feel loadcases is bumper skin thickness
- For zone A, bezel thickness and headlamp bracket thickness is important
- For zone D, grill criss-cross thickness is important

Response Surface Accuracy



The response surfaces represent sufficiently well the observed responses. This could be further improved by ether taking a high order approximation (more simulations required), reducing the design space or by formulating a sequential optimisation.

Important Variables



The chart shows the influence of design variables on various responses. The most influential design variables for all loadcases being thickness parameter of the bumper skin, under tray and grill.

Optimum Design Validation - ULEG

- The optimised design scores the maximum possible 6 points.

Description	Femur Forces (kN)	Femur Moments (Nm)			Points Scored		
	Sum	Upper Femur	Mid Femur	Lower Femur	Force Point	Moment Point	Point
U0	4.2	227.2	251.9	201.8	1	1	1
U100	3.9	208.8	228.9	184.7	1	1	1
U200	4.0	211.9	239.6	198.5	1	1	1
U300	4.4	215.6	254.4	216.8	1	1	1
U400	4.6	169.0	213.1	198.5	1	1	1
U500	4.6	160.1	208.9	209.6	1	1	1
U600	3.8	122.9	161.4	170.1	1	1	1
U700	3.2	119.1	156.6	162.1	1	1	1
						Total Score	6

	Lower limit	Upper limit
Sum Forces (kN)	5.0	6.0
Bending Moments (Nm)	285.0	350.0

Optimum Design Validation - LLEG

- The optimised design scores 5.3 points, losing some performance at the 500 and 600 locations in-terms of the ligament injuries

Description	Ligament Elongations (mm)			Tibia Bending Moments (Nm)				Points					
	PCL	ACL	MCL	Upper Tibia	Mid Upper Tibia	Mid Lower Tibia	Lower Tibia	PCL	ACL	MCL	Points Elongations	Points Moments	SCORE
L0	4.6	2.3	9.6	144.0	198.9	152.3	75.0	1.0	1.0	0.5	0.5	0.5	1.0
L100	4.2	2.3	10.1	133.4	173.8	133.6	68.6	1.0	1.0	0.5	0.5	0.5	1.0
L200	4.6	2.4	10.6	136.4	178.8	129.5	72.3	1.0	1.0	0.5	0.5	0.5	1.0
L300	4.3	3.7	12.1	157.3	192.3	137.8	80.8	1.0	1.0	0.5	0.5	0.5	1.0
L400	6.2	4.9	17.6	120.4	127.2	91.0	74.3	1.0	1.0	0.5	0.5	0.5	1.0
L500	8.7	6.4	20.7	152.3	147.0	103.2	60.3	1.0	1.0	0.2	0.2	0.5	0.7
L600	8.8	6.5	22.7	142.8	98.8	67.1	61.4	1.0	1.0	0.0	0.0	0.5	0.5
												Total Score	5.3

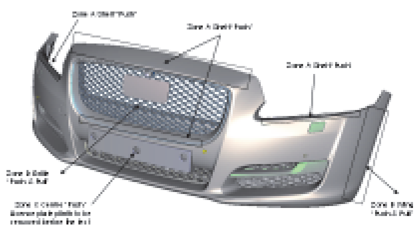
	Lower limit	Upper limit
Tibia Bending	282	340
MCL	19	22
ACL/PCL	10	10

Optimum Design Validation - FIRMNESS

- For the firmness feel loadcases the evaluated optimum satisfies all the constraints but displacement at zone A is its limit

Location	Displacements (mm)
Zone_A_1	5.9
Zone_A_2	9.0
Zone_A_3	4.7
Zone_B	7.0
Zone_C	3.0
Zone_D	4.9

Figure 1. Front Bumper with Integrated Radiator Grille



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98.0	6.0	10.0	10.0	N/A	N/A	N/A
147.0	9.0	N/A	N/A	N/A	N/A	N/A

Summary

- Following from the models generated from the bumper automation process an optimisation is setup considering few of the several possible loadcases
- Material properties and thickness of the bumper parts are chosen as the design variables
- The optimisation was formulated to minimise the mass while satisfying the leg injury criteria and firmness feel displacement requirements
- Key design parameters were identified for each loadcases that could be fine tuned to meet the performance requirements
- An optimum design was obtained which is representative of all the loadcases considered