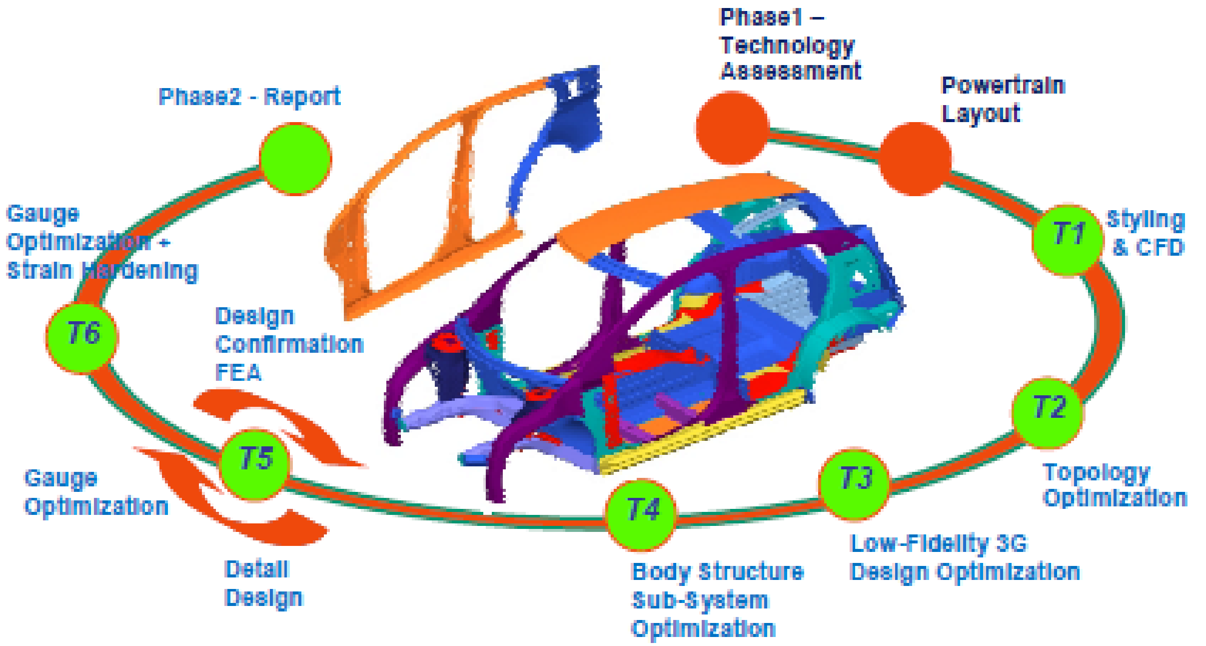
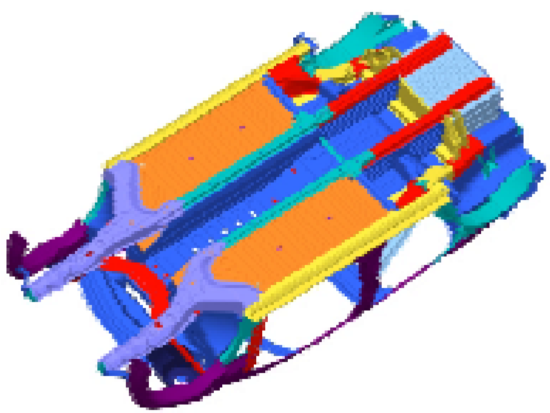
FutureSteelVehicle

Phase 2 – Report
April 20, 2011



Detailed Design, Engineering and Cost Analysis of Advanced High Strength Steel Body Structures for Advanced Powertrain Vehicles



FSV Project Phases Overview

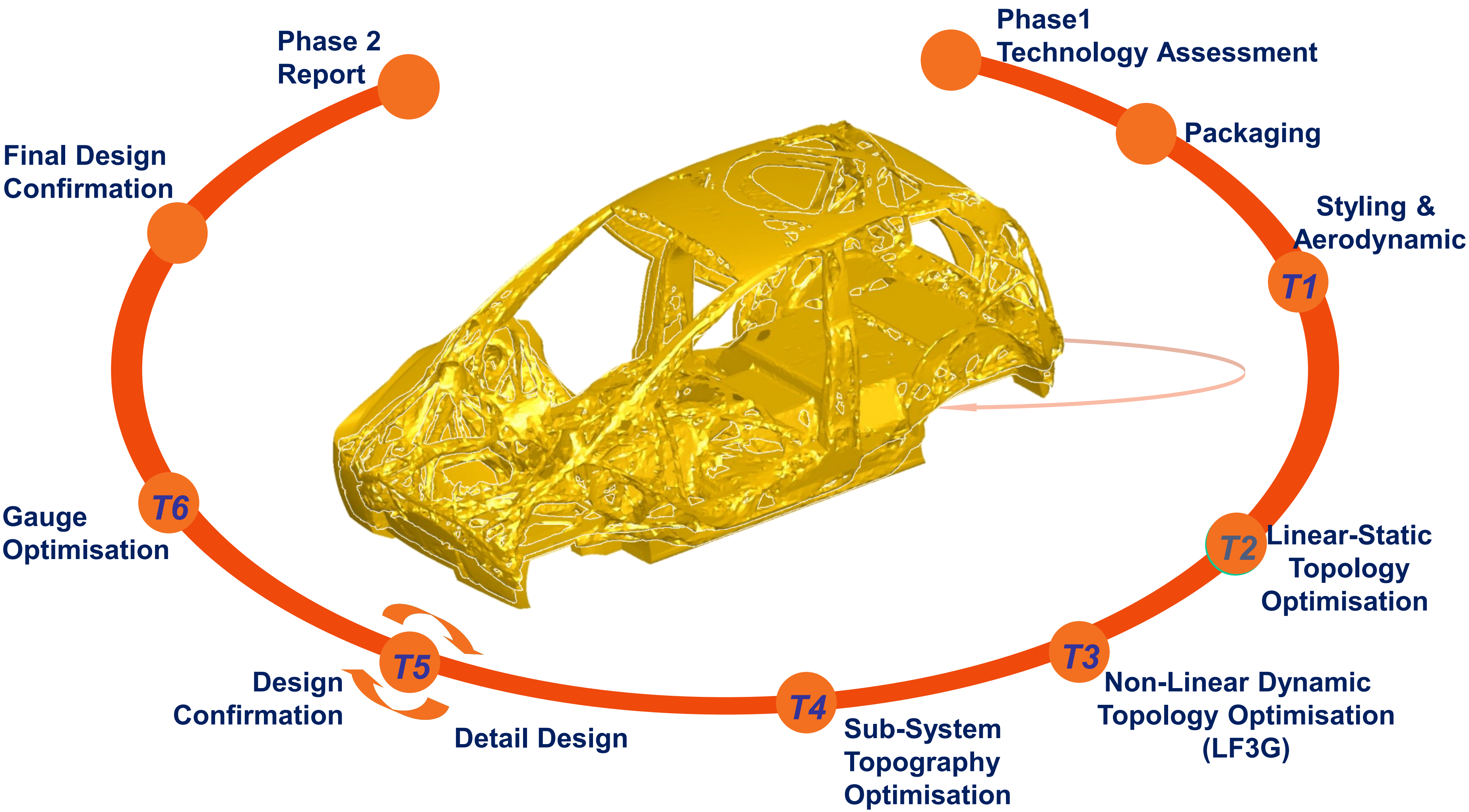
- Phase 1: Engineering study (2008 - July, 2009)
  - comprehensive assessment and identification of advanced powertrains
  - future automotive technology applicable to year 2020 high volume vehicle production
- Phase 2: Concept design (August, 2009 - 2010)
  - detailed design concepts for a Battery Electric Vehicle (BEV)
  - how they can be applied to Plug-In Hybrid Electric Vehicles (PHEV) and Fuel Cell Electric Vehicles (FCEV)

Vehicle	BIW Mass (kg)	Length (mm)	Width (mm)	Height (mm)	Wheelbase (mm)	Track Frt/Rr (mm)	Powertrain Mass (kg)	Curb Mass (kg)	GVW (kg)
BEV	187.5	3820	1705	1495	2524	1470	328.7	958	1433
PHEV-20	176.4	3820	1705	1495	2524	1470	335.4	988	1463
PHEV-40	200.8	4350	1805	1495	2800	1570	460.7	1195	1670
FCEV	200.8	4350	1805	1495	2800	1570	293.2	1029	1504

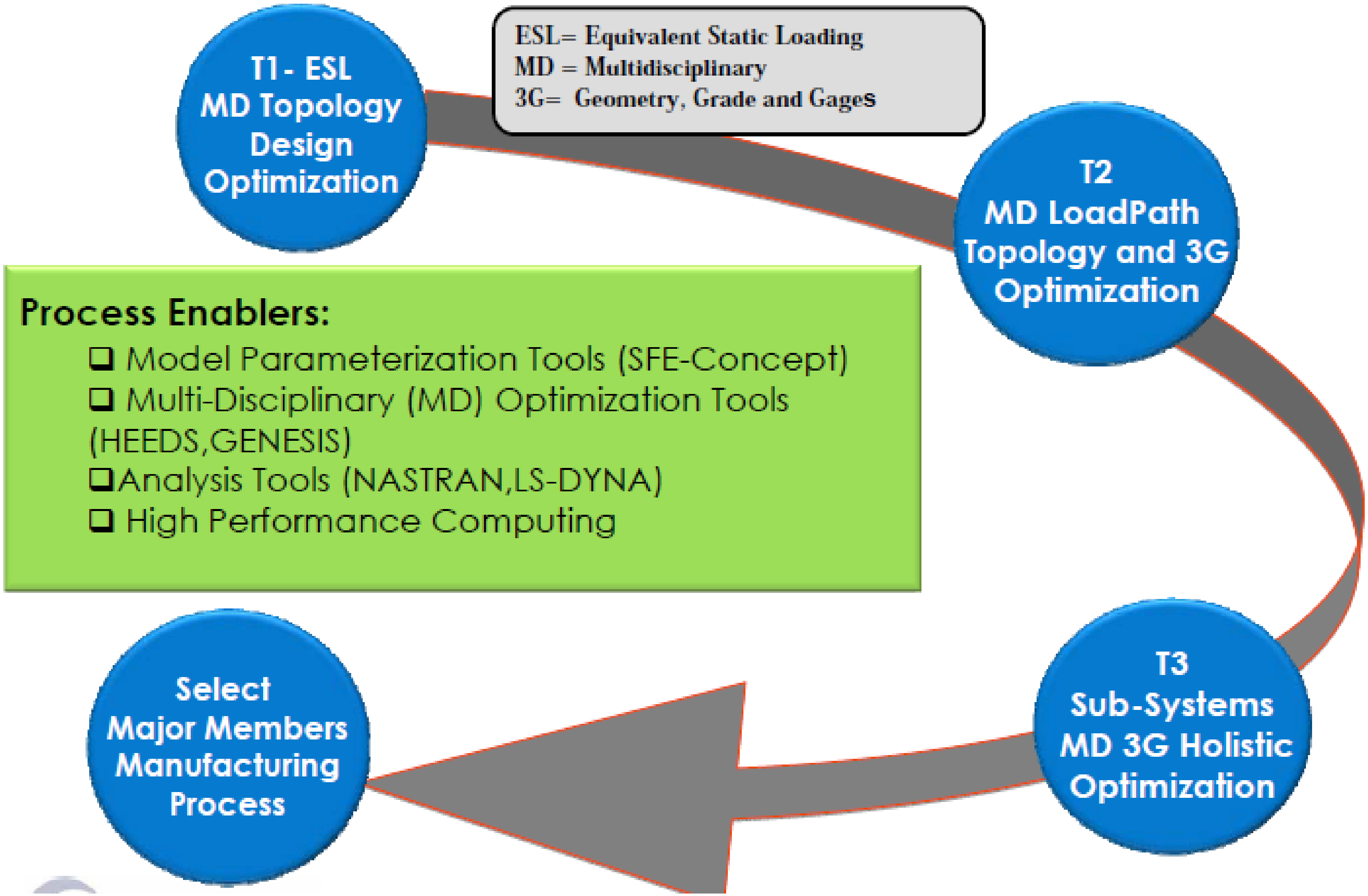
7 Key Achievements

- State-of-the-future design innovations that exploit steel's versatility and strength
- Achieves 35% body structure mass savings compared to a benchmark vehicle
- Uses 97% High-Strength (HSS) and Advanced High-Strength Steel (AHSS)
- Uses nearly 50% GigaPascal steels
- Enables 5-star safety ratings
- Reduces total Lifetime Emissions by nearly 70%
- Reduces mass and emissions at no cost penalty

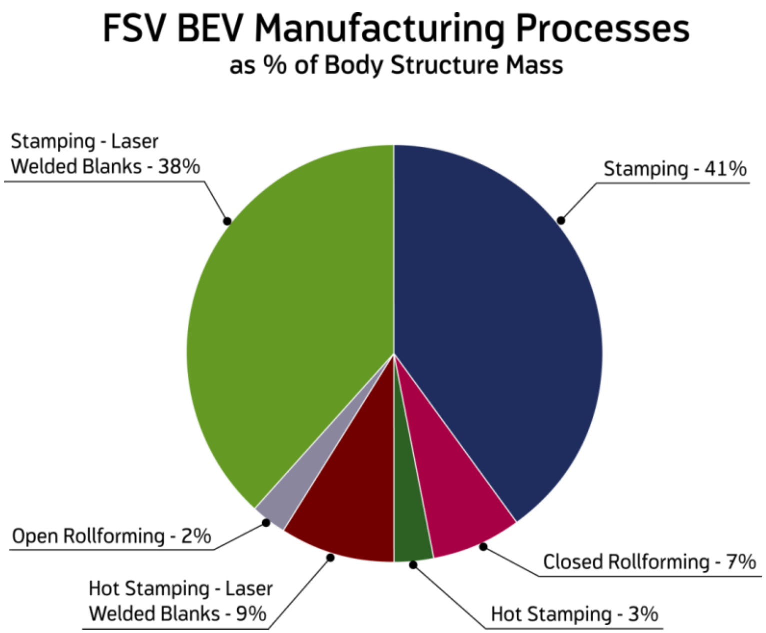
#1 – State of the Future Design Innovations



Design Optimization Process

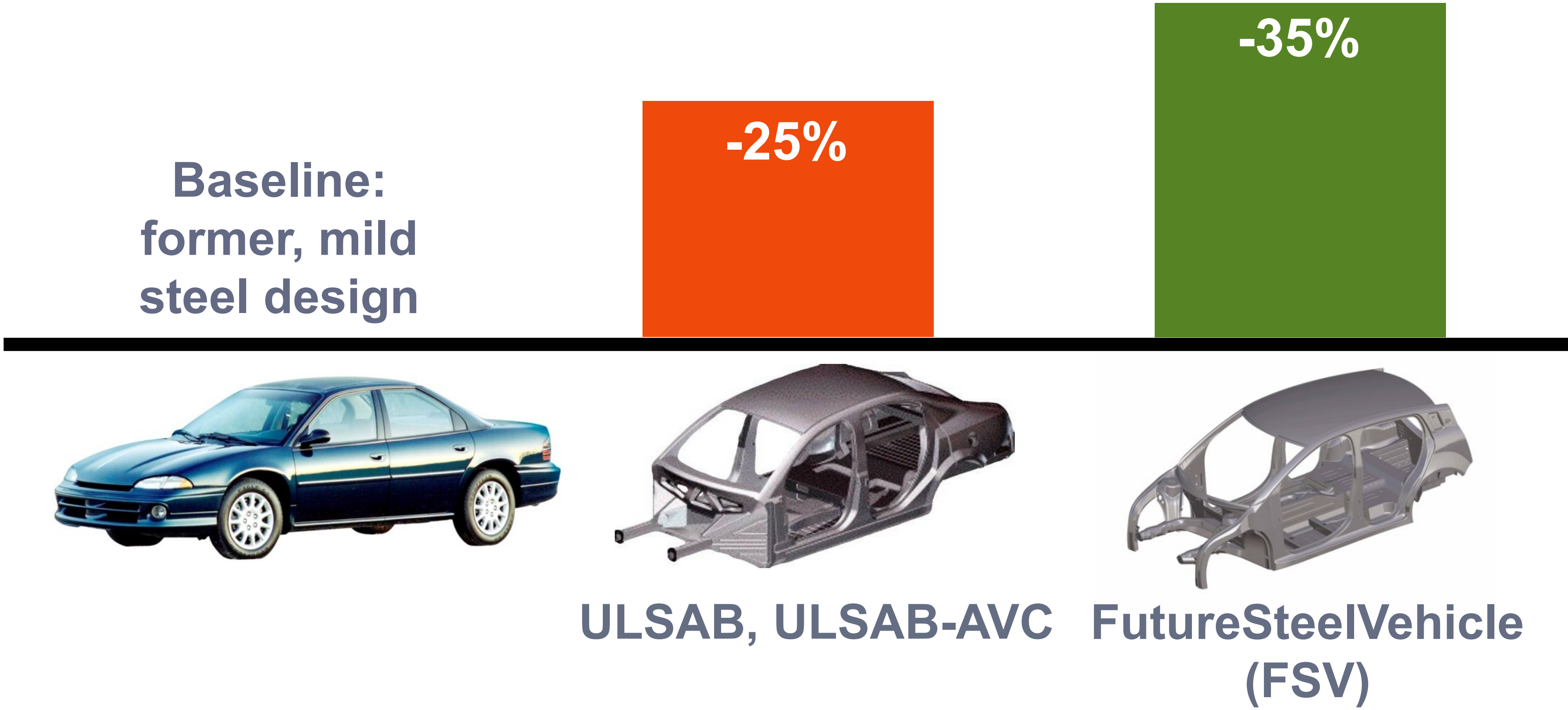


#2 – 35% Mass Savings



Body Structure	FSV-1 BEV Mass (kg)
Benchmark	290
Target	190
Achieved	187.7

Mass Targets



	WorldAutoSteel		FSV-1
	ULSAB	ULSAB AVC C Class	BEV
	1997	2004	2015-2020
Vehicle Mass kg	1350	966	1232
Powertrain Mass kg		195	449
		20%	36%
References	1994 Ford Taurus (1450kg)	243	268
Reference/Benchmark BIW Mass	271	268	290
ULSAB - Achieved BIW Mass	203		
	25%		
***Mass reduction from ULSAB for C-class target		20	
*Additional mass - Crash requirements for 2004		25	
ULSAB AVC - Target BIW Mass		208 (=203-20***+25*)	
ULSAB AVC - Achieved BIW Mass		202	
		3%	
ULSAB AVC - Achieved BIW Mass relative to Reference Benchmark		25%	
Updates to ULSAB-AVC			
Additional mass - Crash requirements 2020			5
Additional mass for: Higher Mass Powertrain (mass compounding)			38
Mass reduction for 2020 Technology Implementation			-10
Mass reduction Efficient Front-end Package			-11
** Total Updates to ULSAB-AVC for 2020			22
FSV-1 - Interim BIW Mass Target (Current AHSS Steel Solution)			224 (=202+22**)
			-23%
Additional Mass Reduction Advanced Steel Technology	-15%		-33.6
FSV-1 - Final BIW Mass Target (Advanced Steel Solution)			190
			-34%

Body In Prime (BIP)

			ULSAB-AVC				
	FSV-BEV (kg)	VW Polo (kg)	C-Class	PNGV	Ford Focus	Peugeot 206	Audi A6
Model Year	**2020**	**2010**	**2004**	**2004**	**2005**	**2003**	
Body Structure w/Paint		242.5			294.5	220	347.5
Body Structure minus Paint	187.7	231.0	201.8	218.1	282.5	208.0	335.5
Engine Cradle	13.9	10.5	44.2	44.2	19.3	12.4	14.1
Bumper Beam Front	5.9	7.5	4.58	4.58	9.6	1.45	4.3
Bumper Beam Rear	3.2	4.7	3.4	3.9	4.6	n/a	4.5
Windshield	15.0	11.1	9.7	9.7	13.2	15.4	13.0
Battery Tray	12.02						
Radiator Support	1.83						
Total	**239.5**	**264.9**	**263.7**	**280.5**	**329.2**	**237.2**	**371.3**

** Assuming paint & Sealer is 12kg*

ULSAB-AVC C-Class benchmark vehicles were the Ford Focus & Peugeot 206
ULSAB-AVC PNGV benchmark vehicles were the Audi A6 & DaimlerChrysler E-Class
Ford Focus and Peugeot data from A2Mac1
ULSAB-AVC data from WorldAutoSteel (http://www.worldautosteel.org/projects/ulsab-avc)

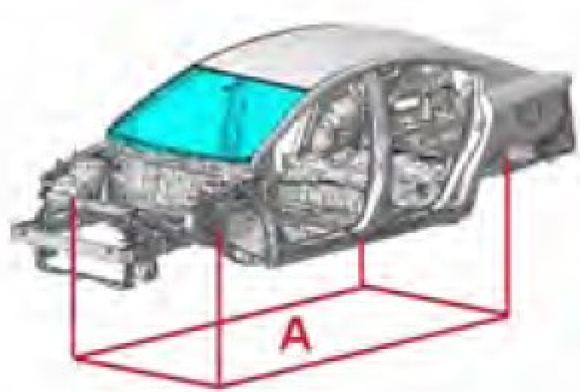
Body Structure - Lightweight Index

$$\frac{M_{BIW}}{C_T \cdot A}\left[\frac{kg}{N \cdot m / \deg \cdot m^2} \cdot 10^3\right] = 4.01$$

M_{BIW} [kg]: BIW mass including bolted elements and glued windscreen

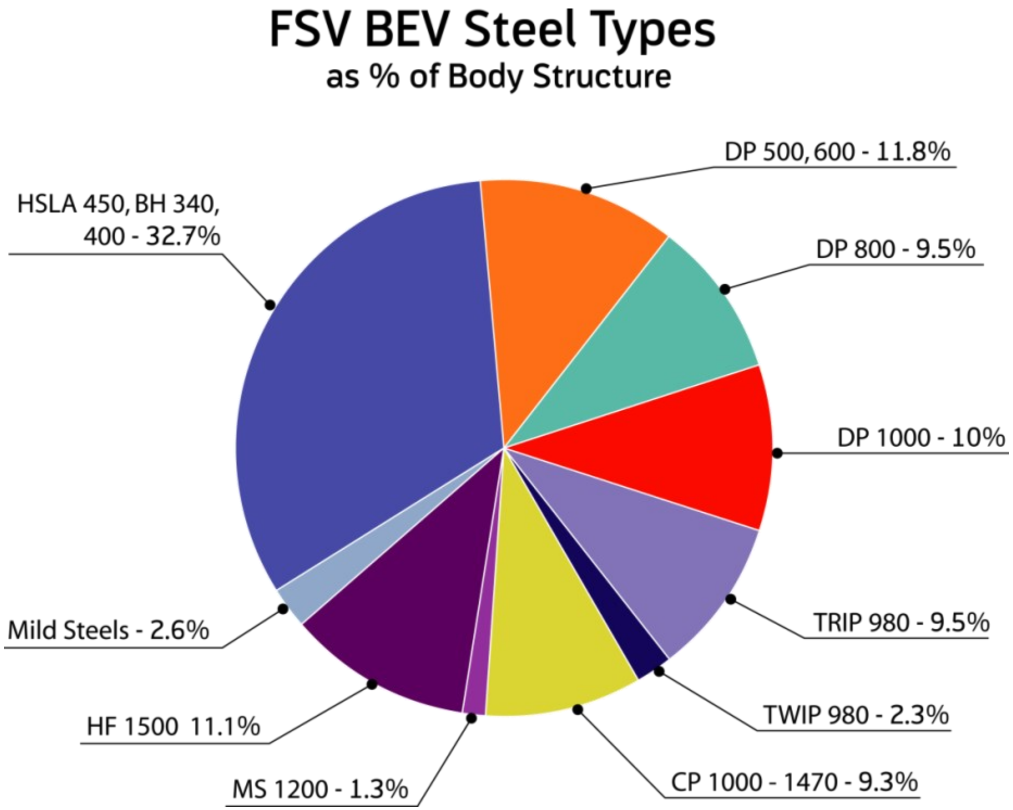
C_t[kNm/deg] : Torsion stiffness of BIW including bolted elements and glued windscreen

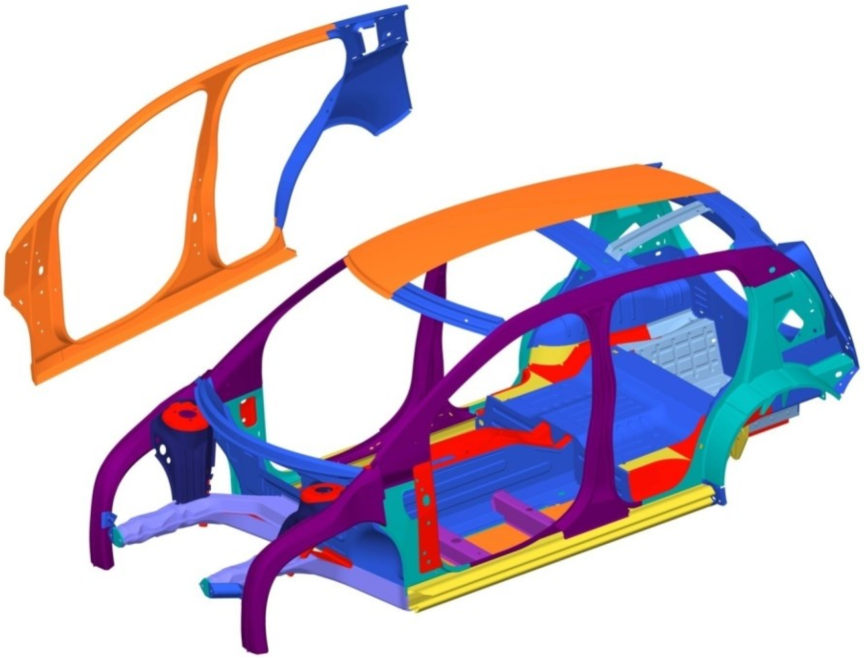
A [m²]: Projected area (wheel base · tread)



Vehicle	Lightweight Index (L)	Torsional Stiffness (kN-m/deg)	Body Mass (kg)	Contact Area (m^2)
FSV-BEV	2.56	20	190	3.71
SLC	1.8	25.5	180	3.9
VW Polo V (2010)	3.5	18	227	3.6
VW Golf V	2.88	25	281	3.9
Toyota Avensis (2008)	4.01	n/a	n/a	3.99

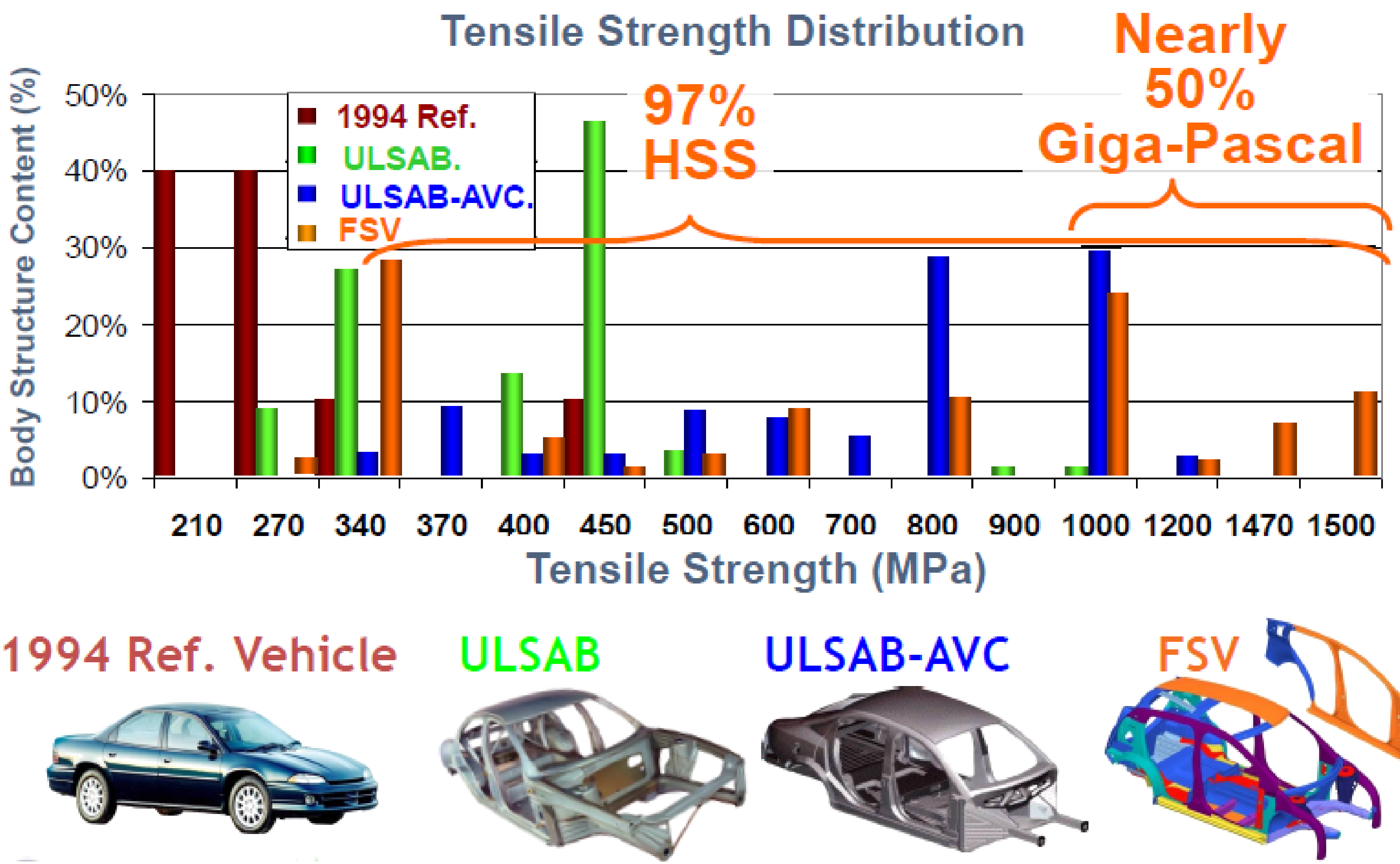
#3 – 97% HSS and AHSS



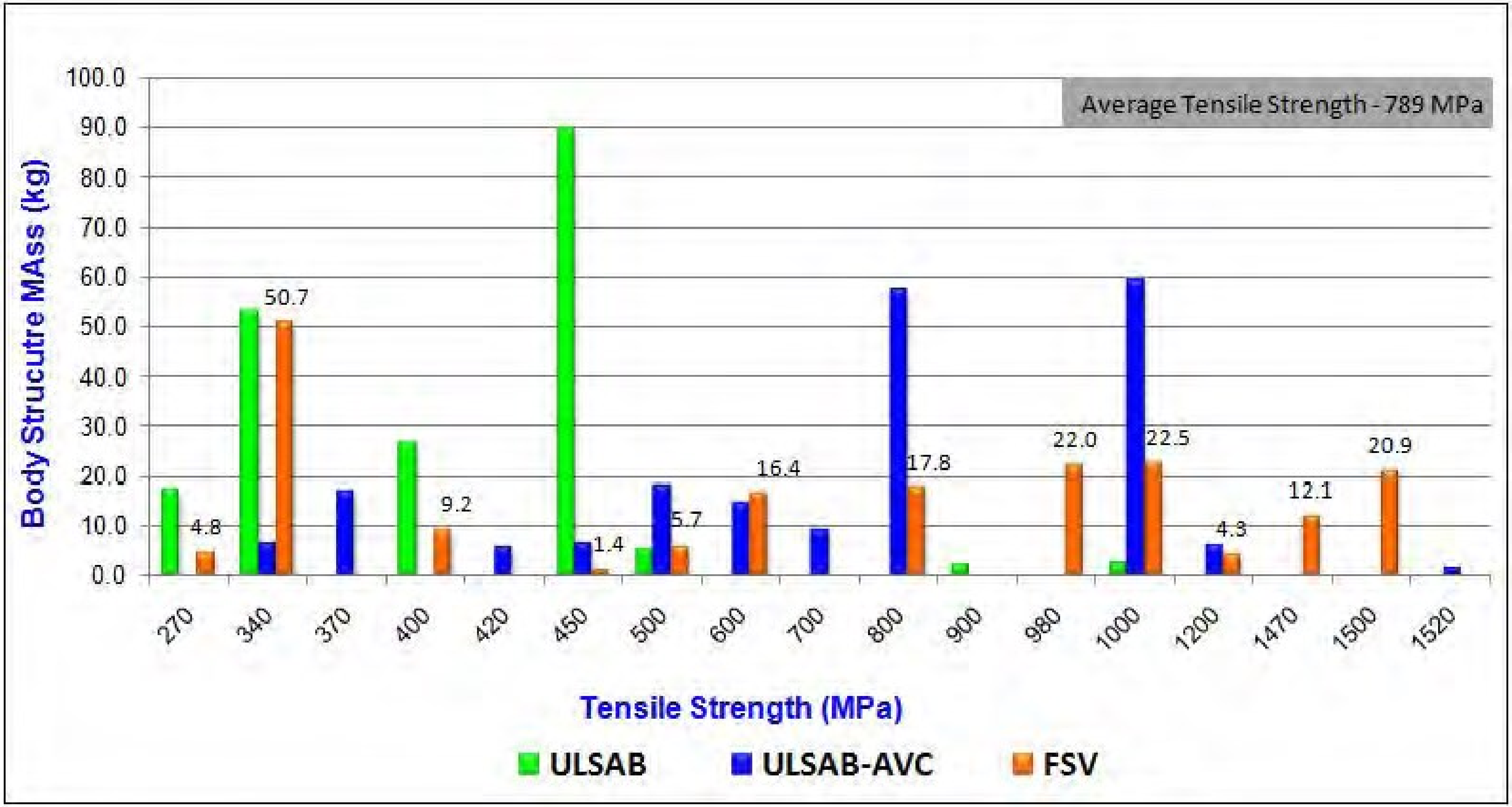


Body Structure	FSV-1 BEV Mass (kg)
Benchmark	290
Target	190
Achieved	187.7

#4 – Nearly 50% GigaPascal Steels

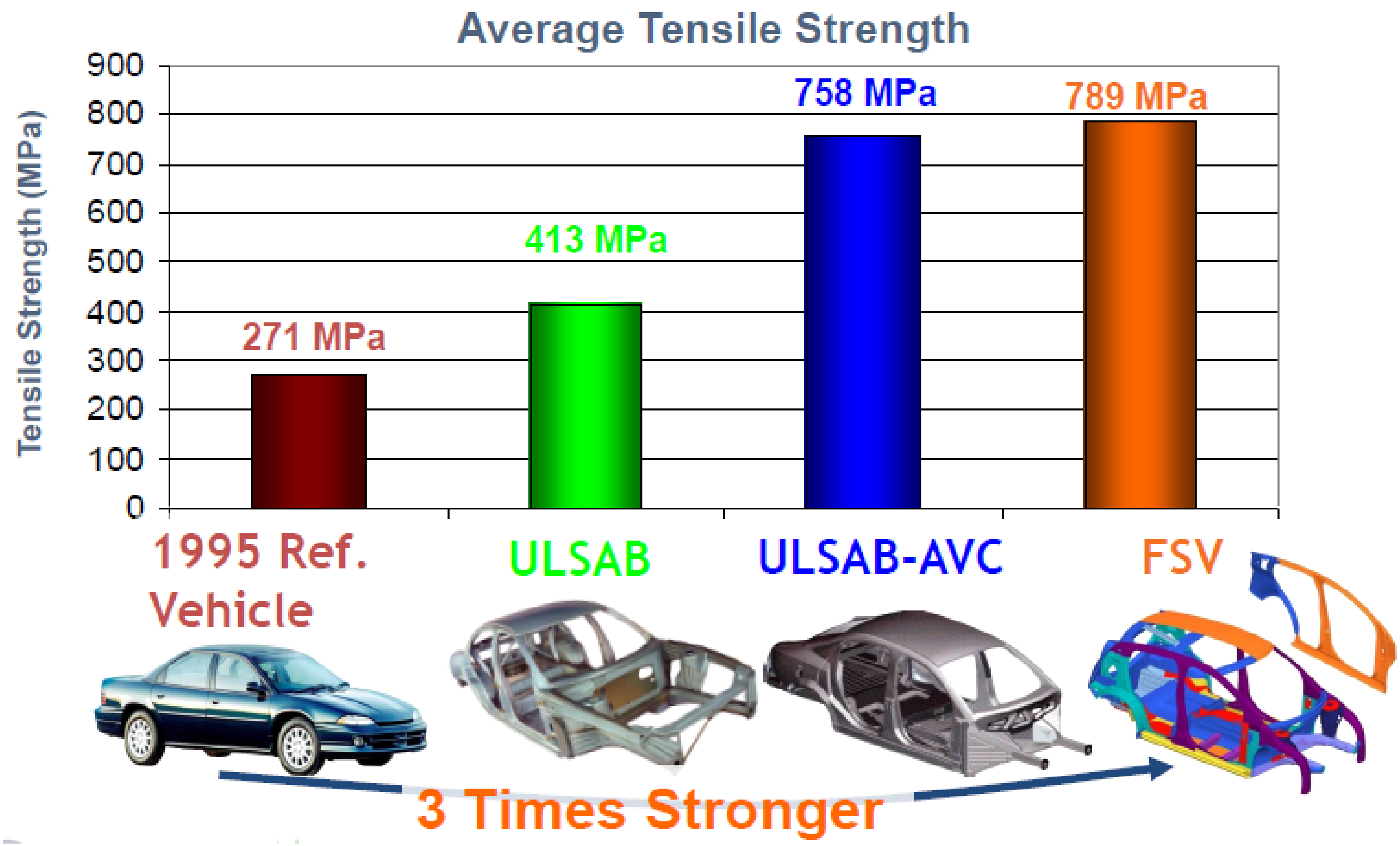


FSV materials tensile strengths

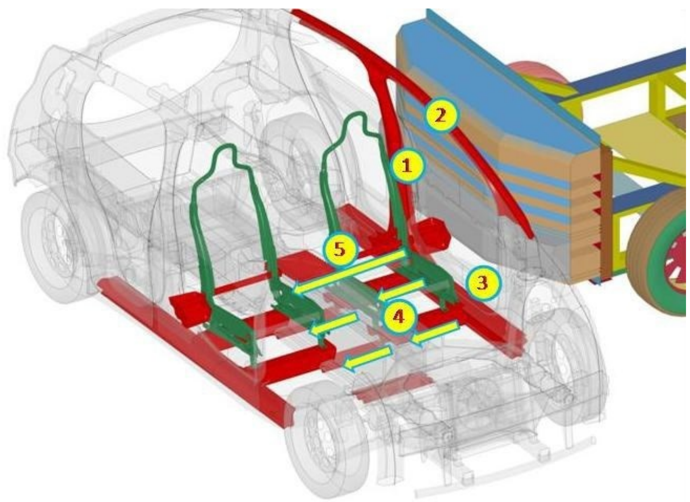


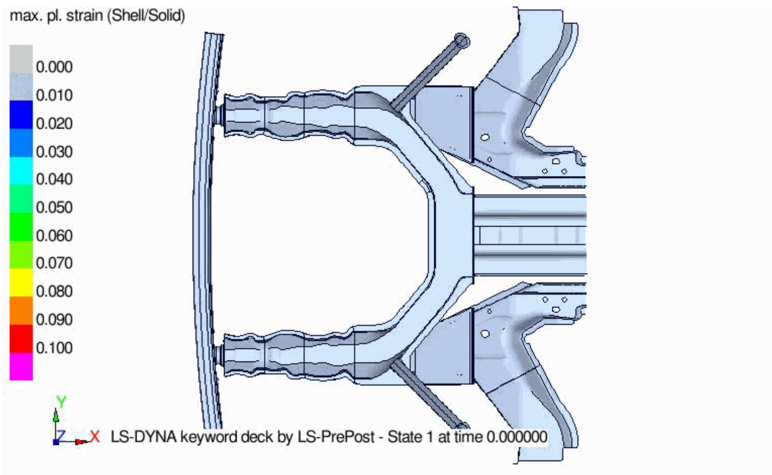
Vehicle	Tensile Strength (MPa)	Average Material Thickness (mm)
ULSAB	413	1.16
ULSAB-AVC	758	1.00
FSV BEV	789	0.98

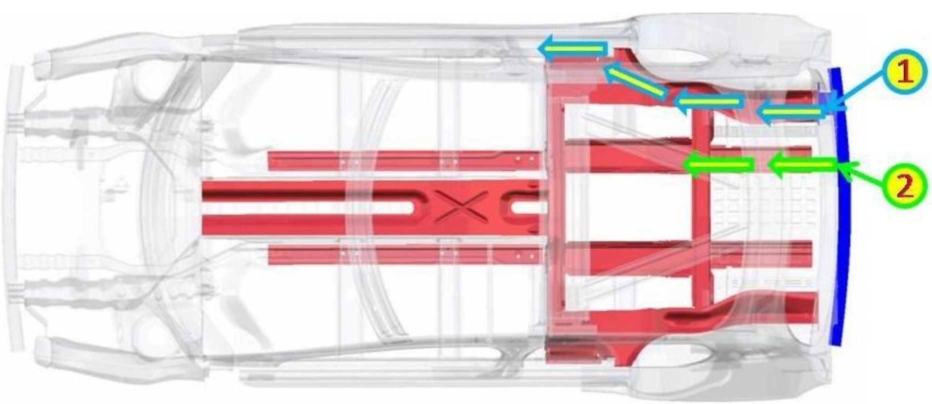
FSV vs. UltraLight: Tensile Strength

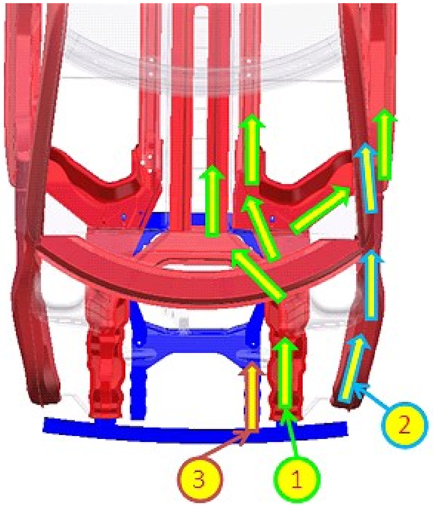


#5 – Enables 5-Star Safety Rating

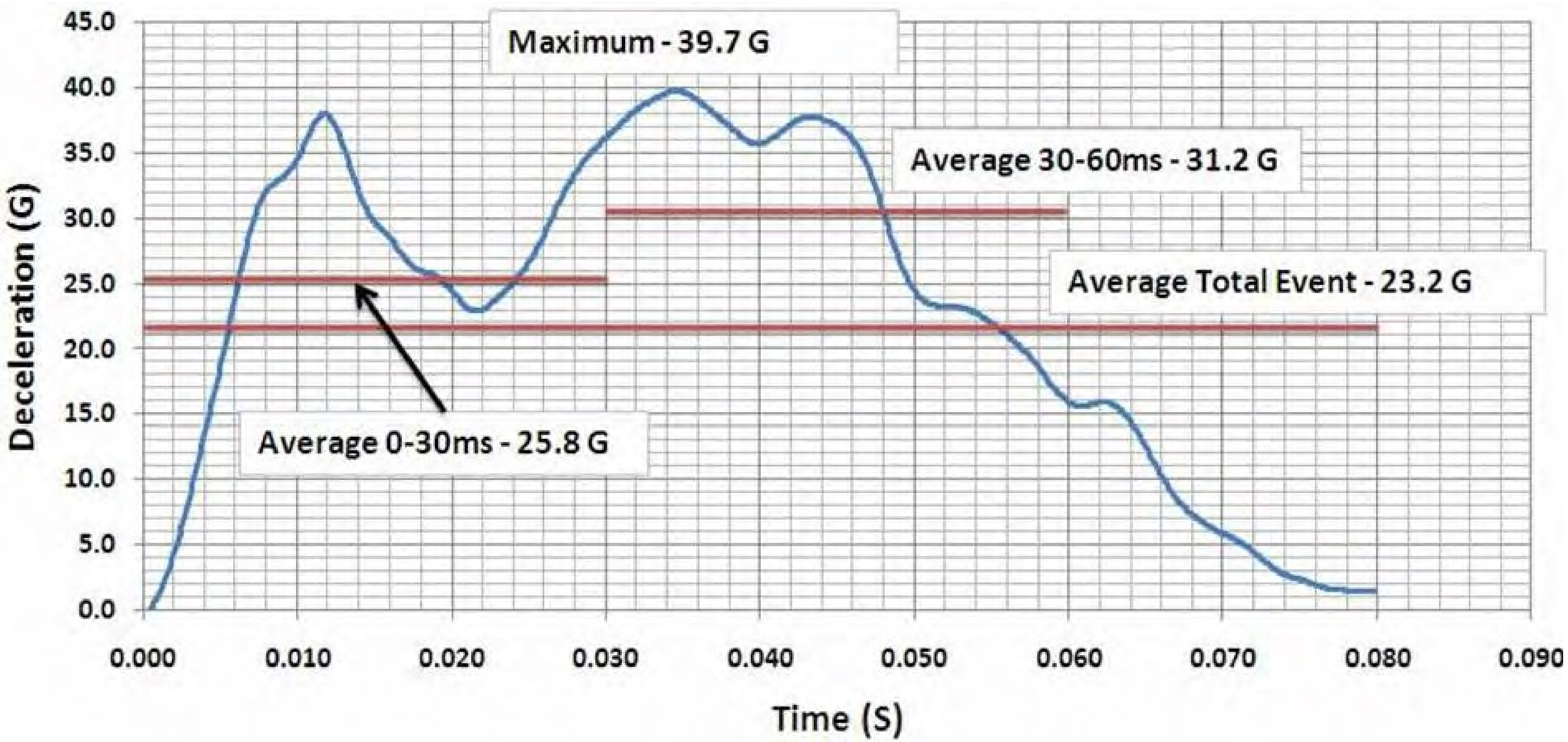






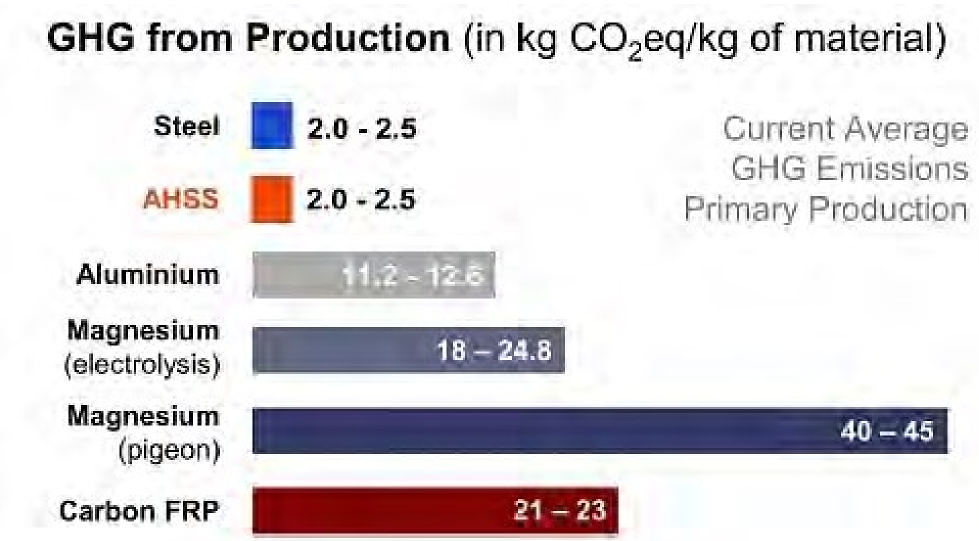


US NCAP 35 mph front rigid barrier pulse at B-Pillar



#6 – Reduces Life Cycle Emissions

Vehicle/Powertrain	Material & Recycling ($kg\ CO_2e$)	Use Phase ($kg\ CO_2e$)	Total Life Cycle ($kg\ CO_2e$)
Benchmark V ICEg	**1,479**	**32,655**	**34,134**
FSV BEV USA grid	**1,328**	**13,844**	**15,172**
FSV BEV Europe grid	**1,328**	**9,670**	**10,998**
FSV vs. Benchmark – USA Grid - 56% CO_2e reduction			
FSV vs. Benchmark – Europe Grid - 68% CO_2e reduction			



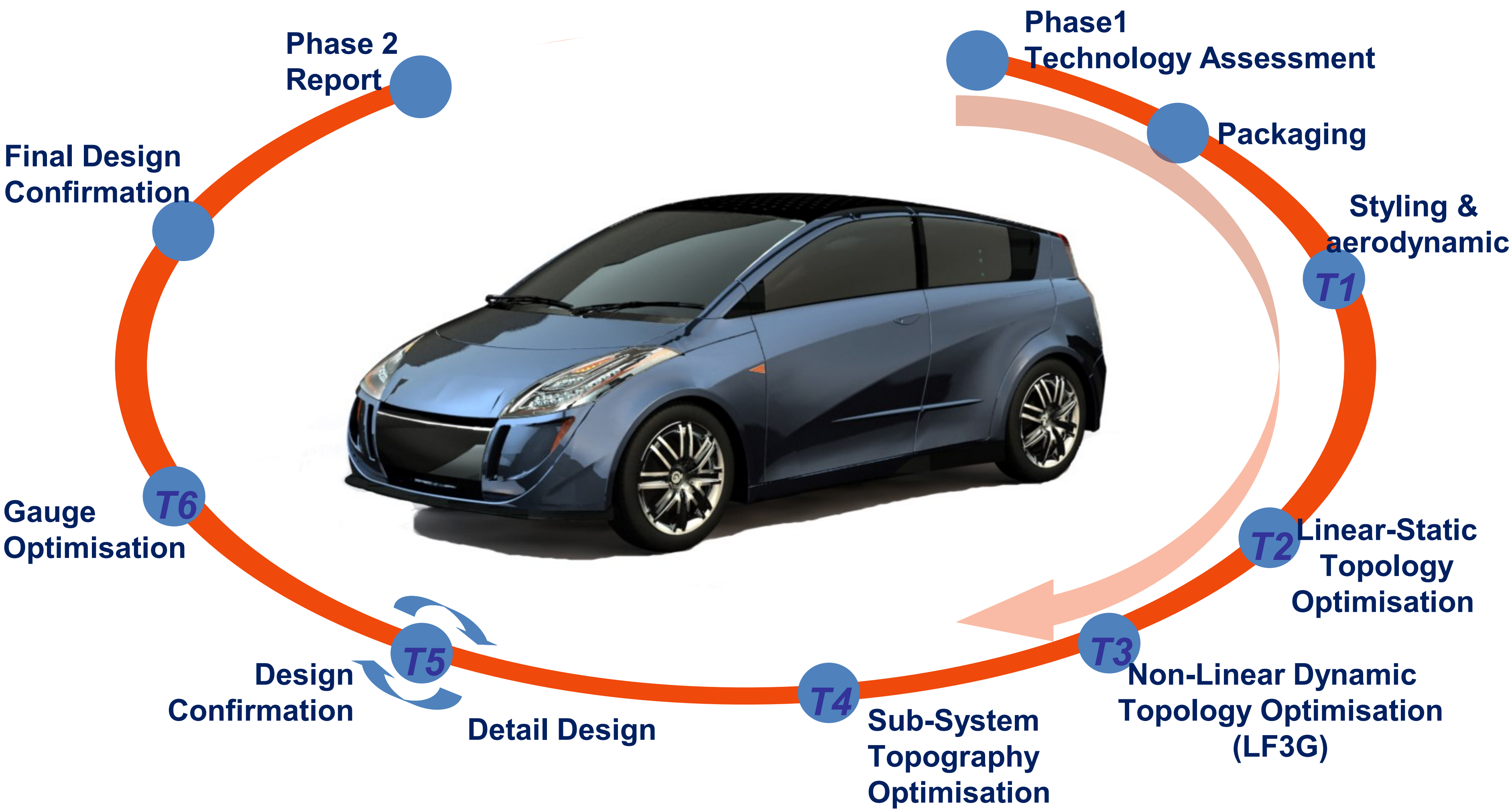
#7 – No Cost Penalty

	Cost (US$)
Body Structure Manufacturing Costs	$775
Body Structure Assembly Costs	$340
Total Body Structure Manufacturing & Assembly	**$1,115**

Phase 2 Summary

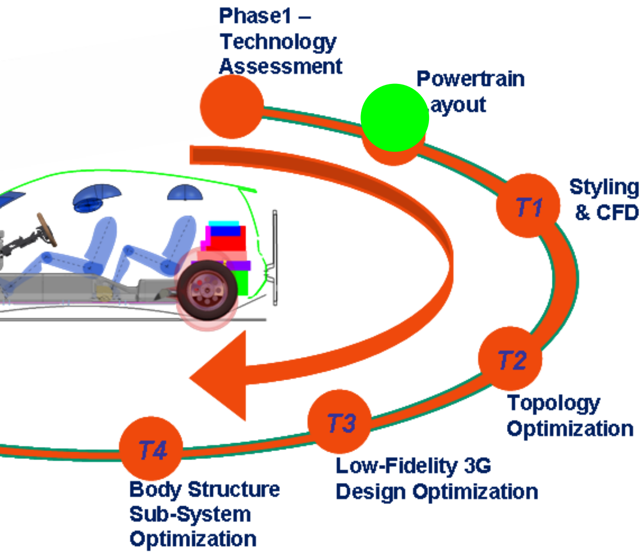
- Overview
- T1: styling and CFD
- T2: topology optimization
- T3: low fidelity 3G(Geometry, Grade, Gauge) optimization
- T4: body structure sub-system optimization
- T5: detailed body structure design
- T5: body structure performance CAE analysis
- T6: final 2G(Grade, Gauge) optimization
- Body structure cost assessment
- Life cycle assessment

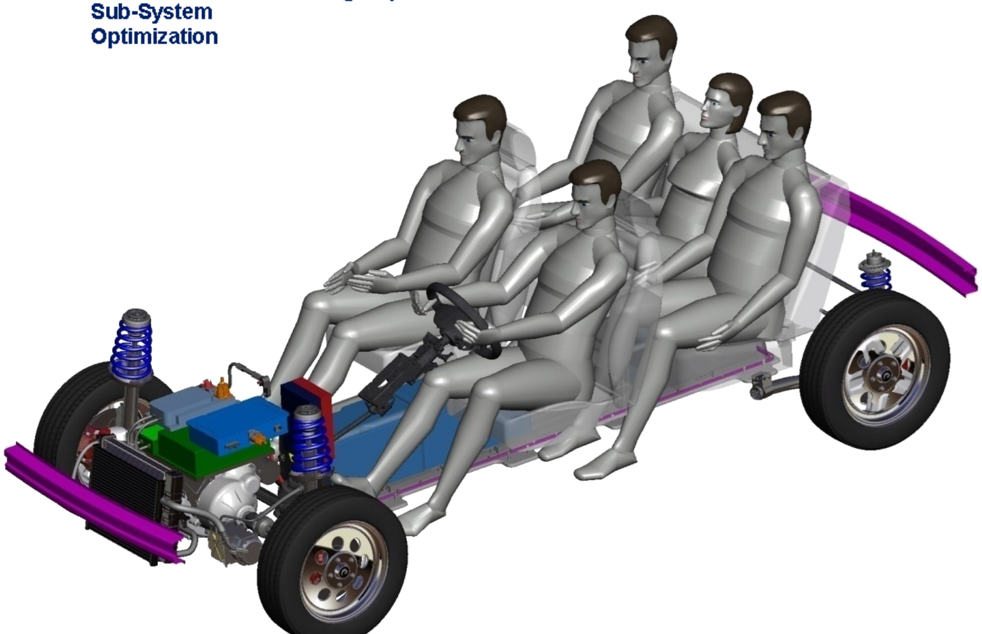
Overview

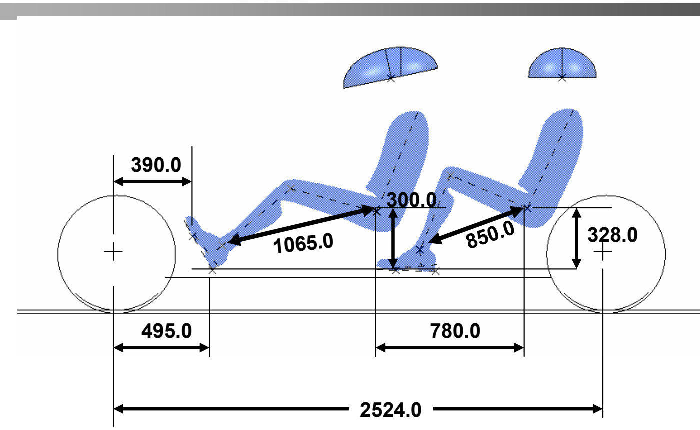


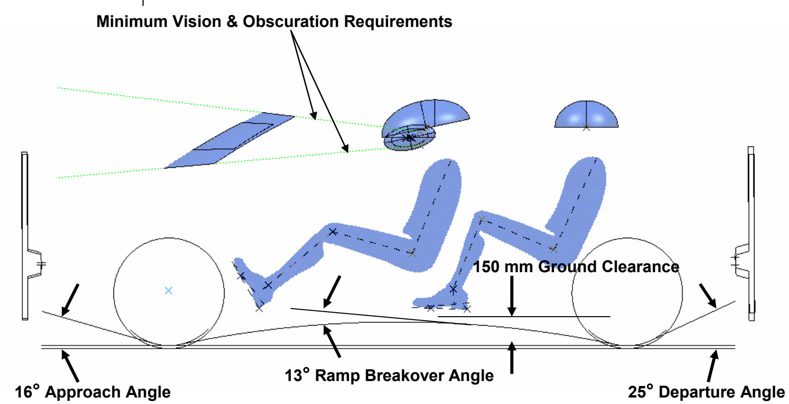
Phase1
Technology Assessment
Packaging
Styling &
aerodynamic
T1
T2
Linear-Static
Topology
Optimisation
T3
Non-Linear Dynamic
Topology Optimisation
(LF3G)
T4
Sub-System
Topography
Optimisation
Detail Design
T5
Design
Confirmation
T6
Gauge
Optimisation
Final Design
Confirmation
Phase 2
Report

FSV BEV Packaging

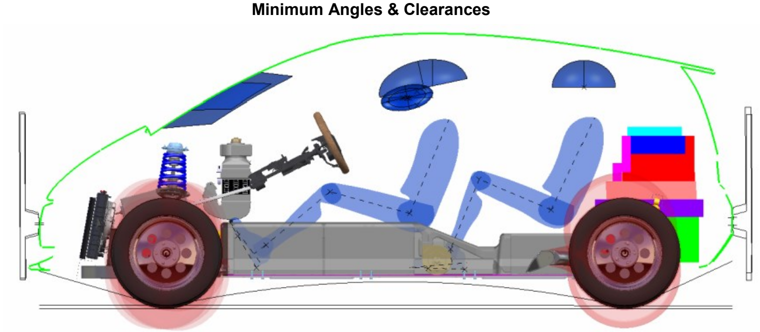






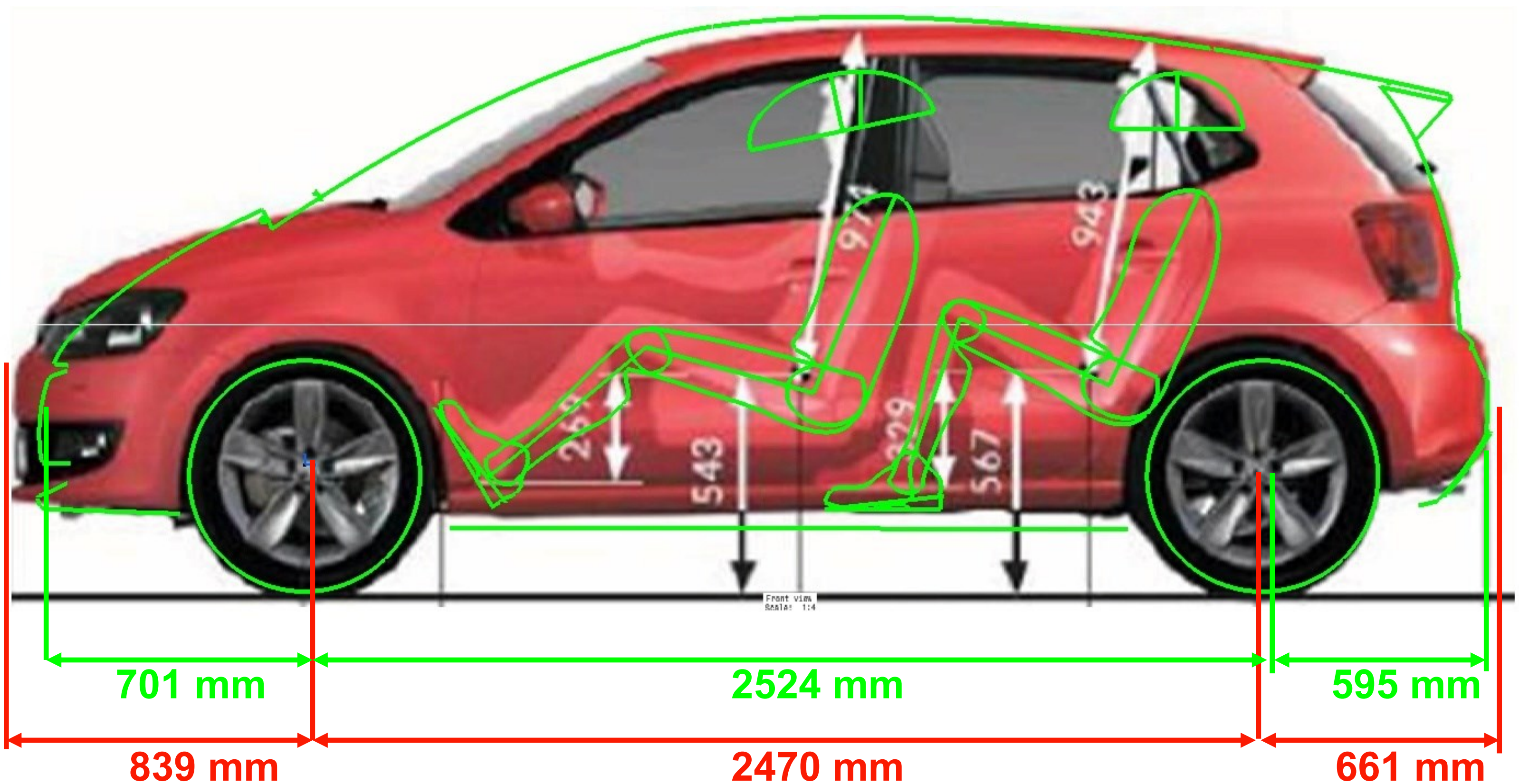


Minimum Angles & Clearances

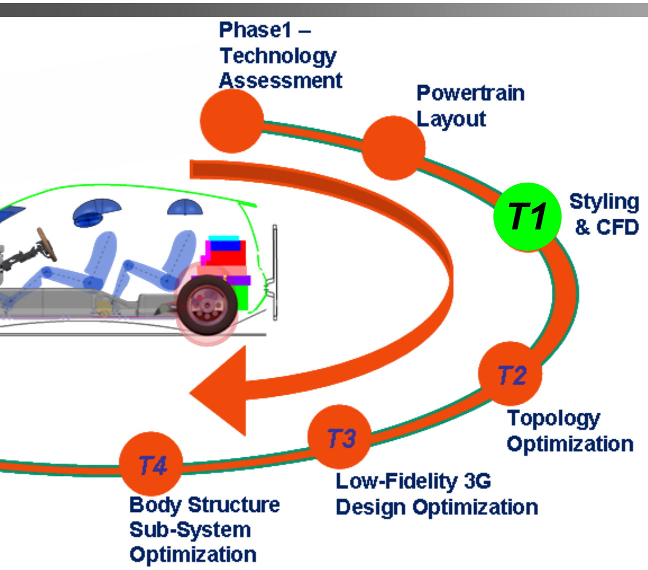


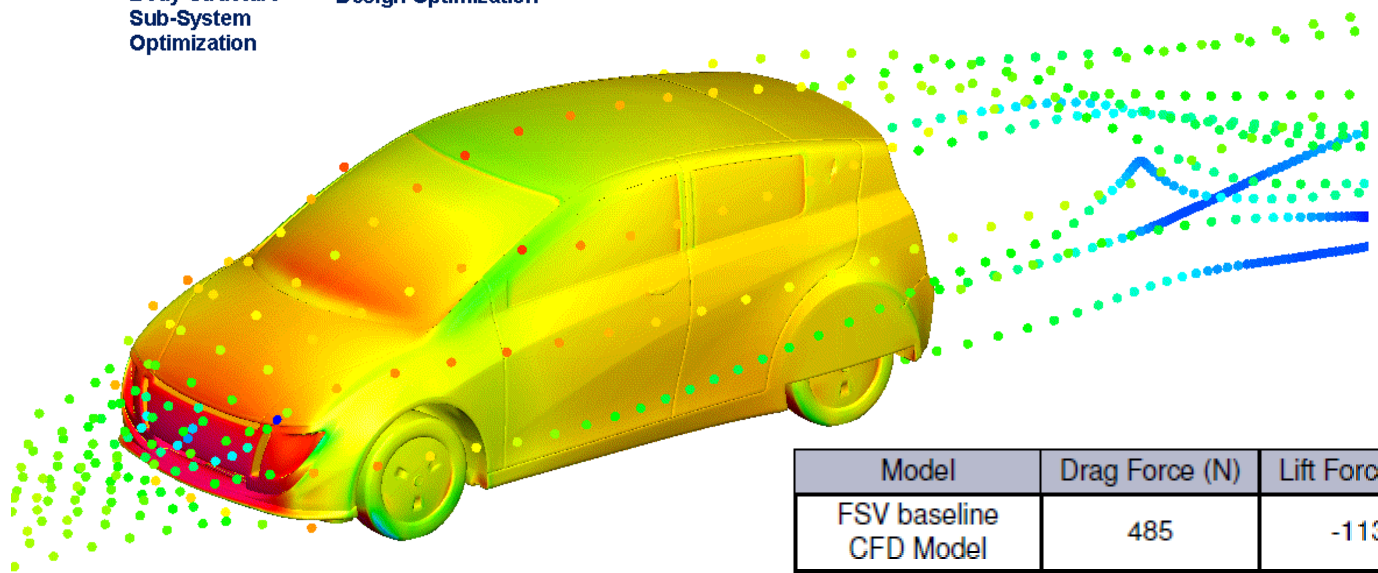
FSV vs. VW Polo 2010

Mass (kg)	Body Structure	Powertrain
FSV	190	329
VW Polo 2010	231	233

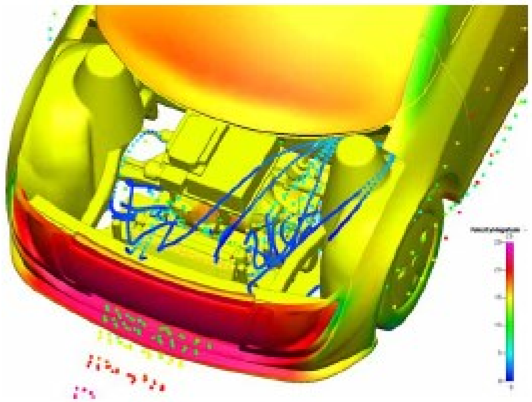


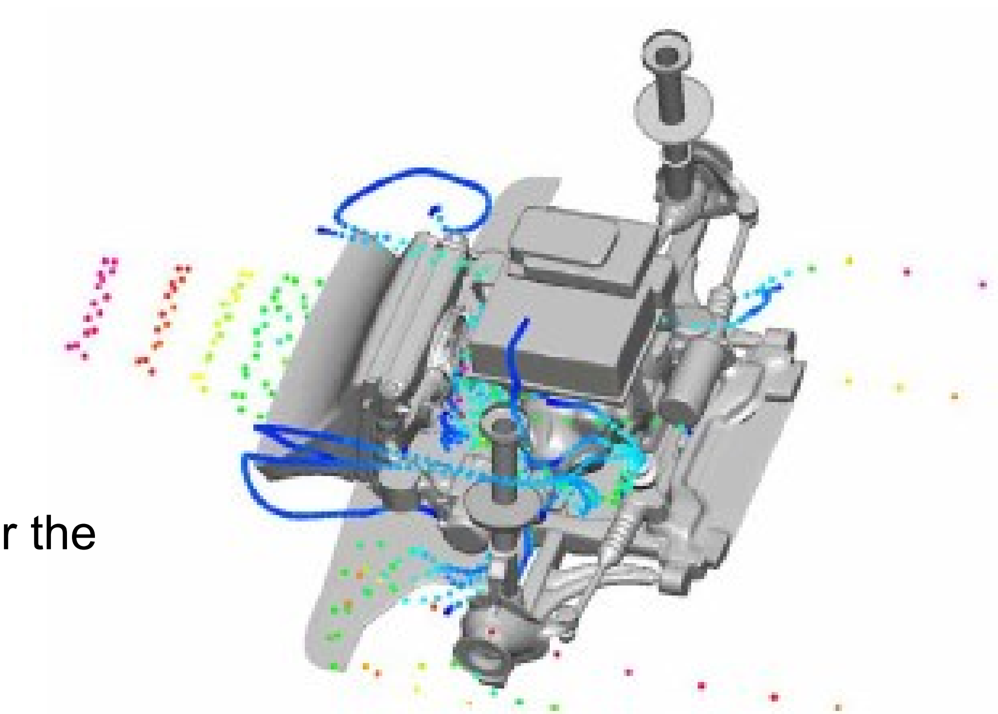
T1: styling and CFD



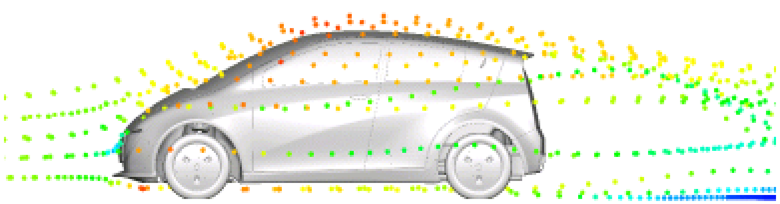


Model	Drag Force (N)	Lift Force (N)	Drag Coefficient	Lift Coefficient
FSV baseline CFD Model	485	-113	0.354	-0.082
Latest FSV styling model	325	101	0.237	0.073

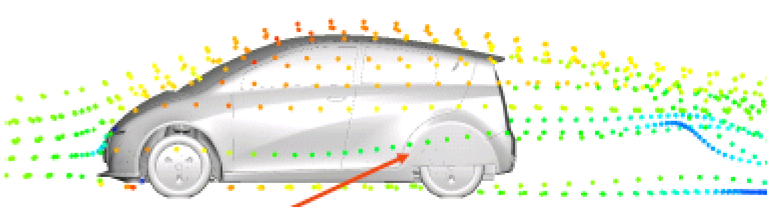




Front air intake opening optimized for the required cooling flow

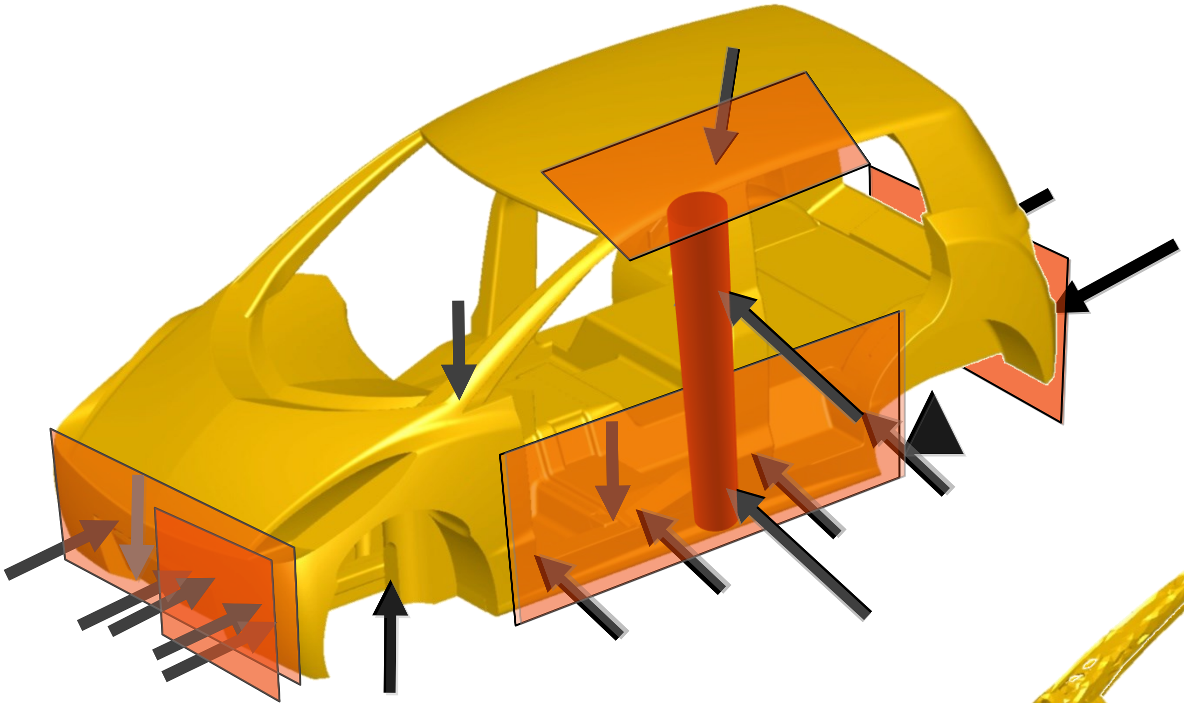


Drag Coefficient 0.27

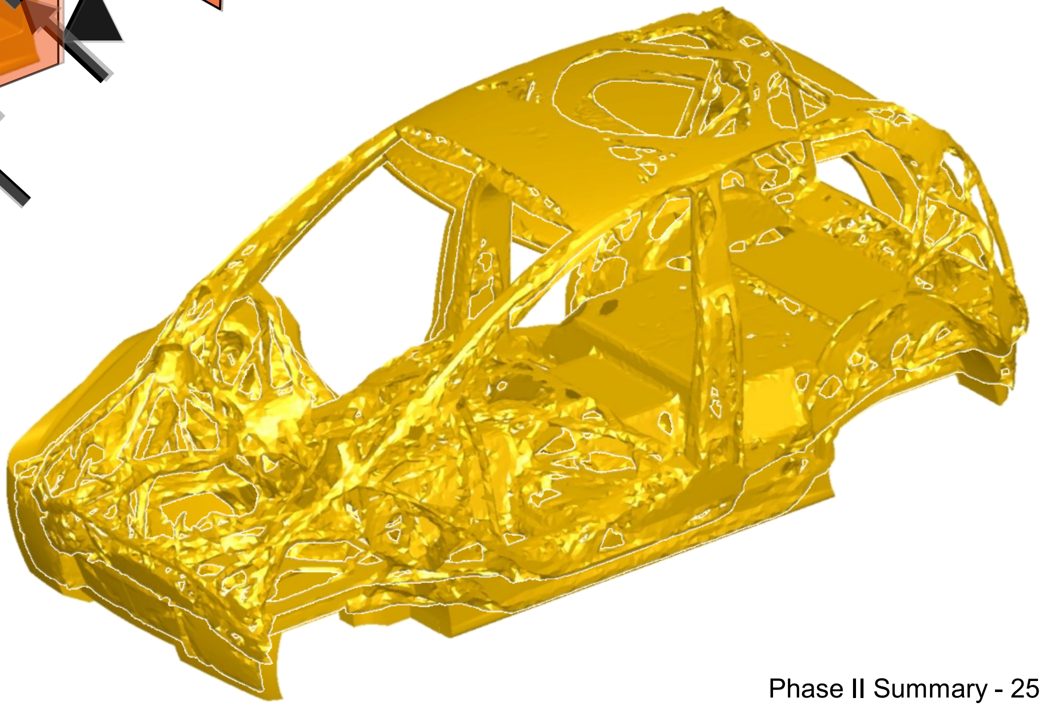


Drag Coefficient 0.24 with rear wheel skirt

T2: topology optimization



Load Cases

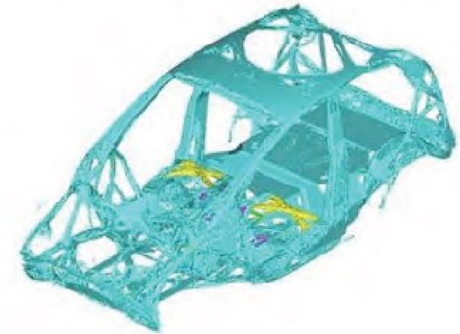


Topology Optimization: Mass Fractions

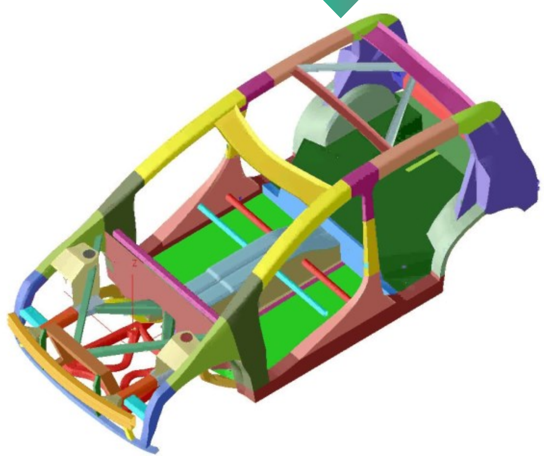
30% Mass Fraction

20% Mass Fraction

10% Mass Fraction



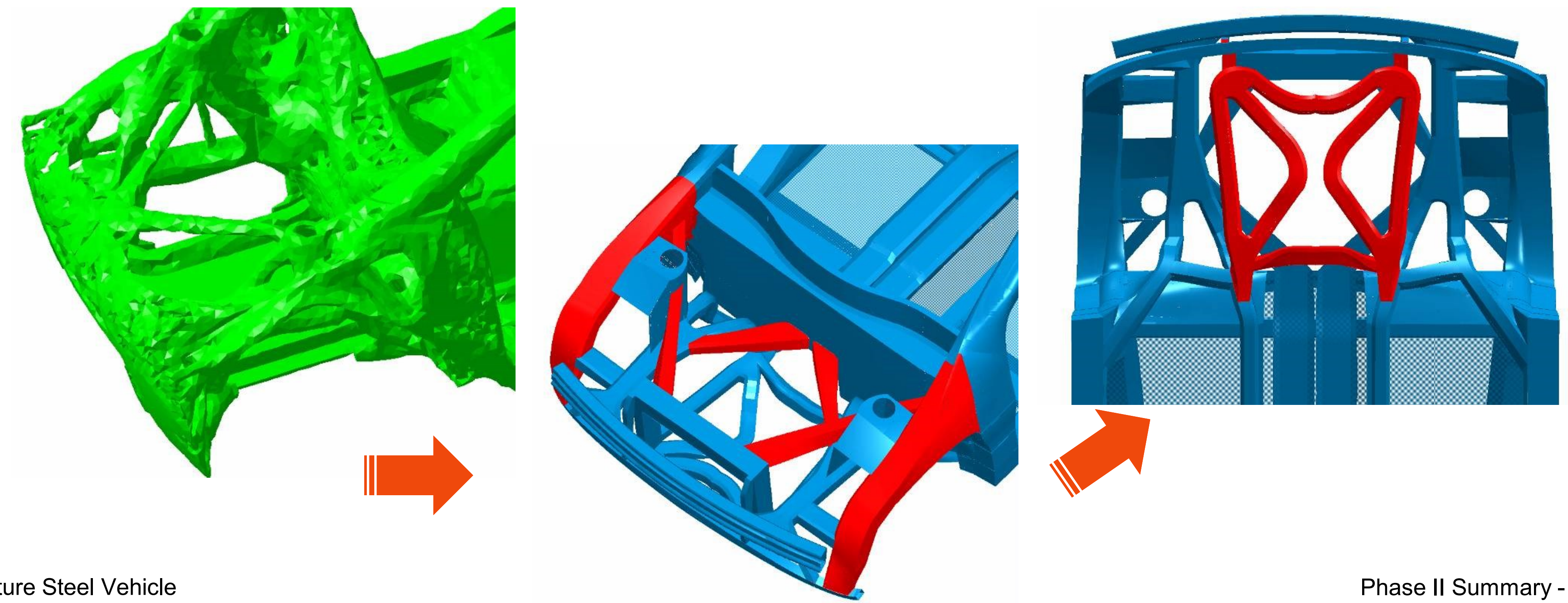
Engineering Judgment



Interpreted CAD Geometry

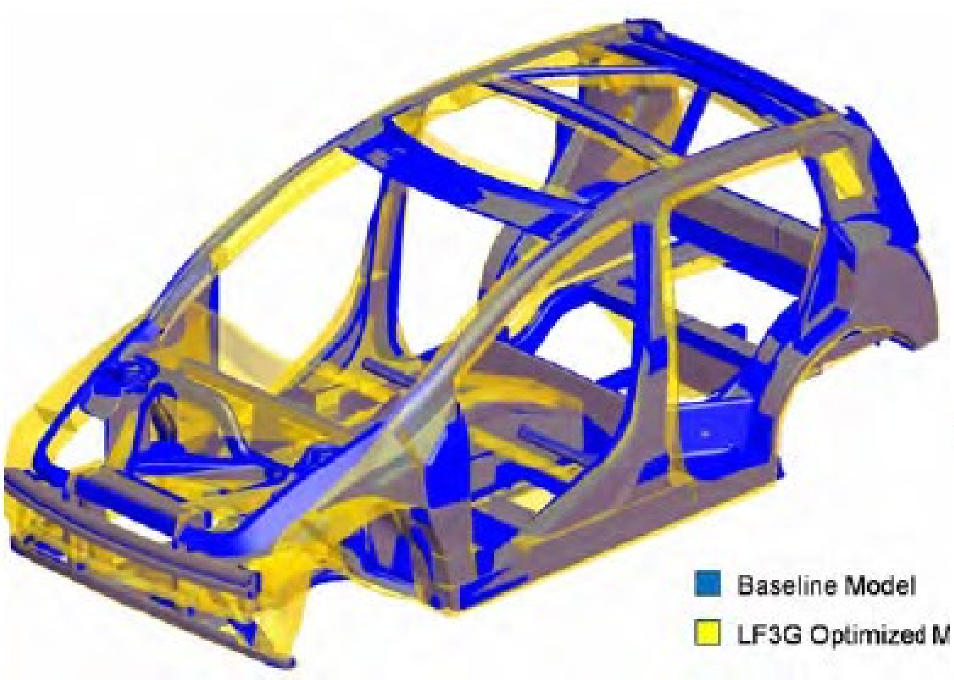
Linear-Static Topology Optimization Results

- Topology optimization drives the material of structure to where it is most effective.
- Allow Topology Load Path Optimization to influence locations and shape of components based on Packaging.
- Topology Optimization is interpreted by engineering judgment.

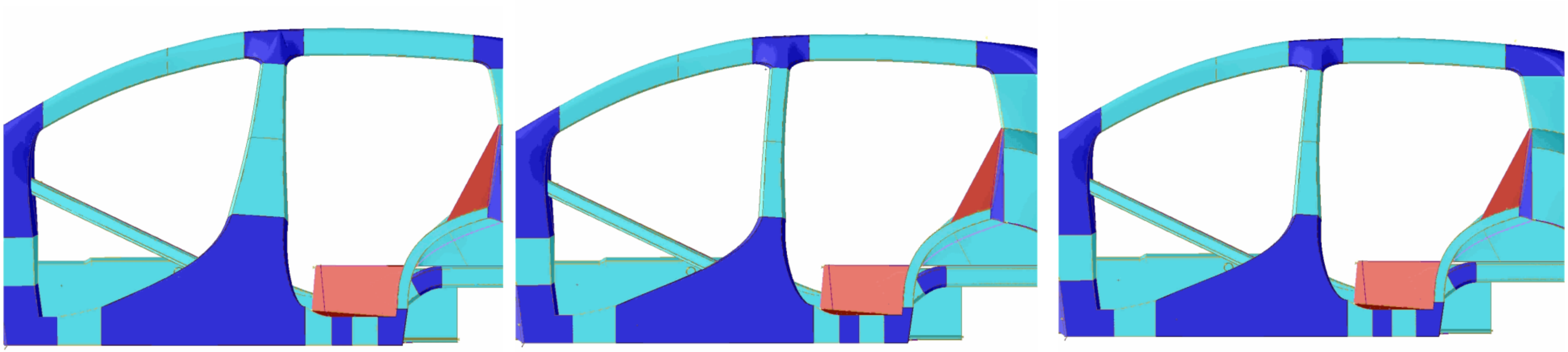


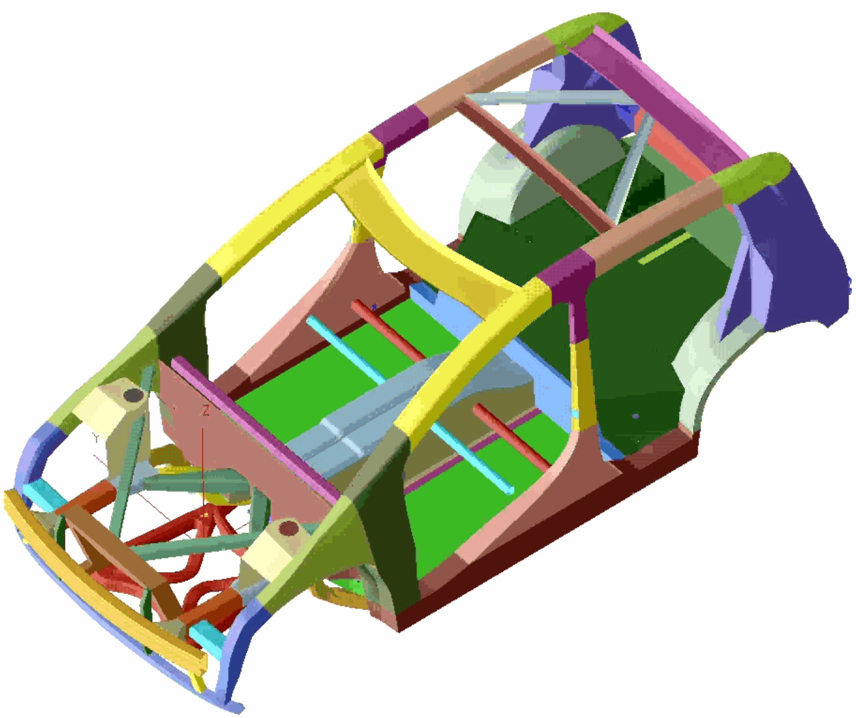
T3: low fidelity 3G(Geometry, Grade, Gauge) optimization

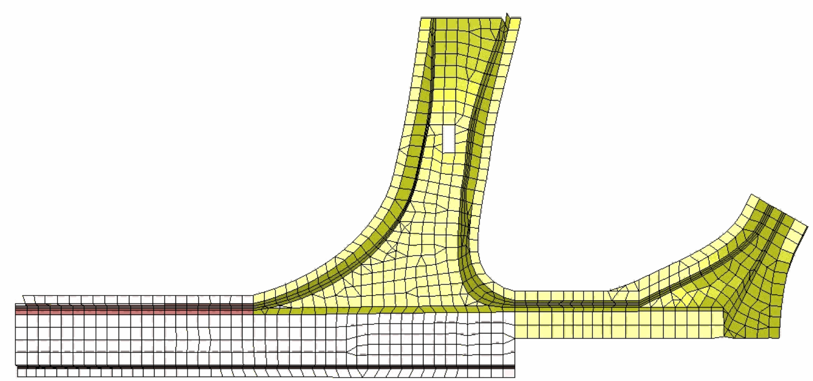
- LF3G design
  - Address topology and a rough estimate of grade, gauge and geometry (section) in the dynamic domain
  - provide a starting place for detailed design which will address manufacturing, joint design, and local section geometries



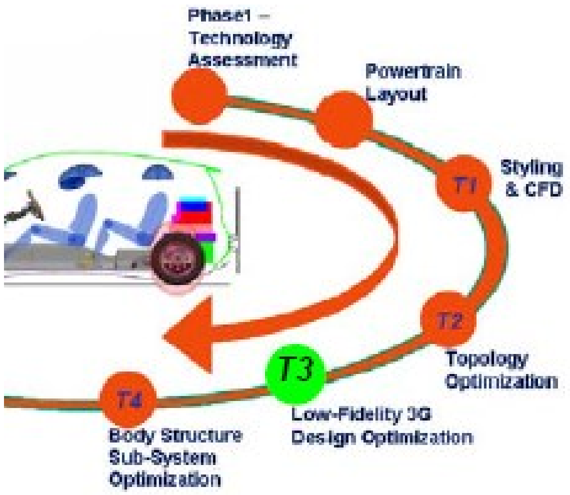
Morphing



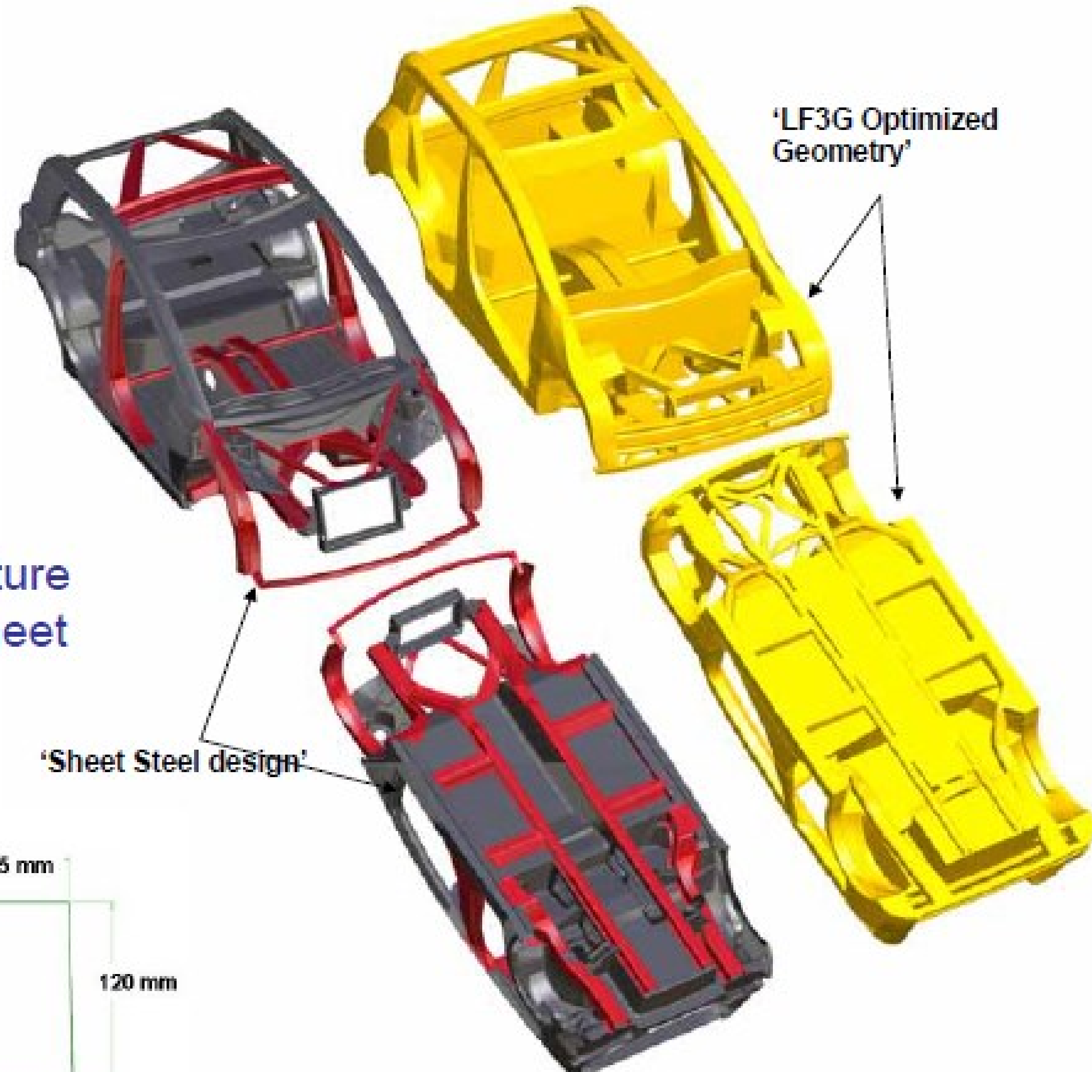


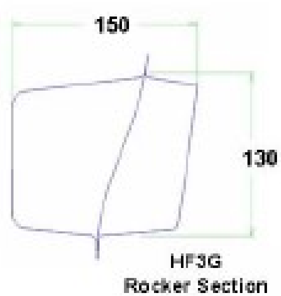


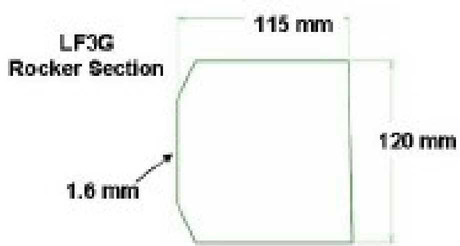
LF3G Optimization: Results



LF3G Optimized Body Structure Geometry – interpreted to sheet steel design



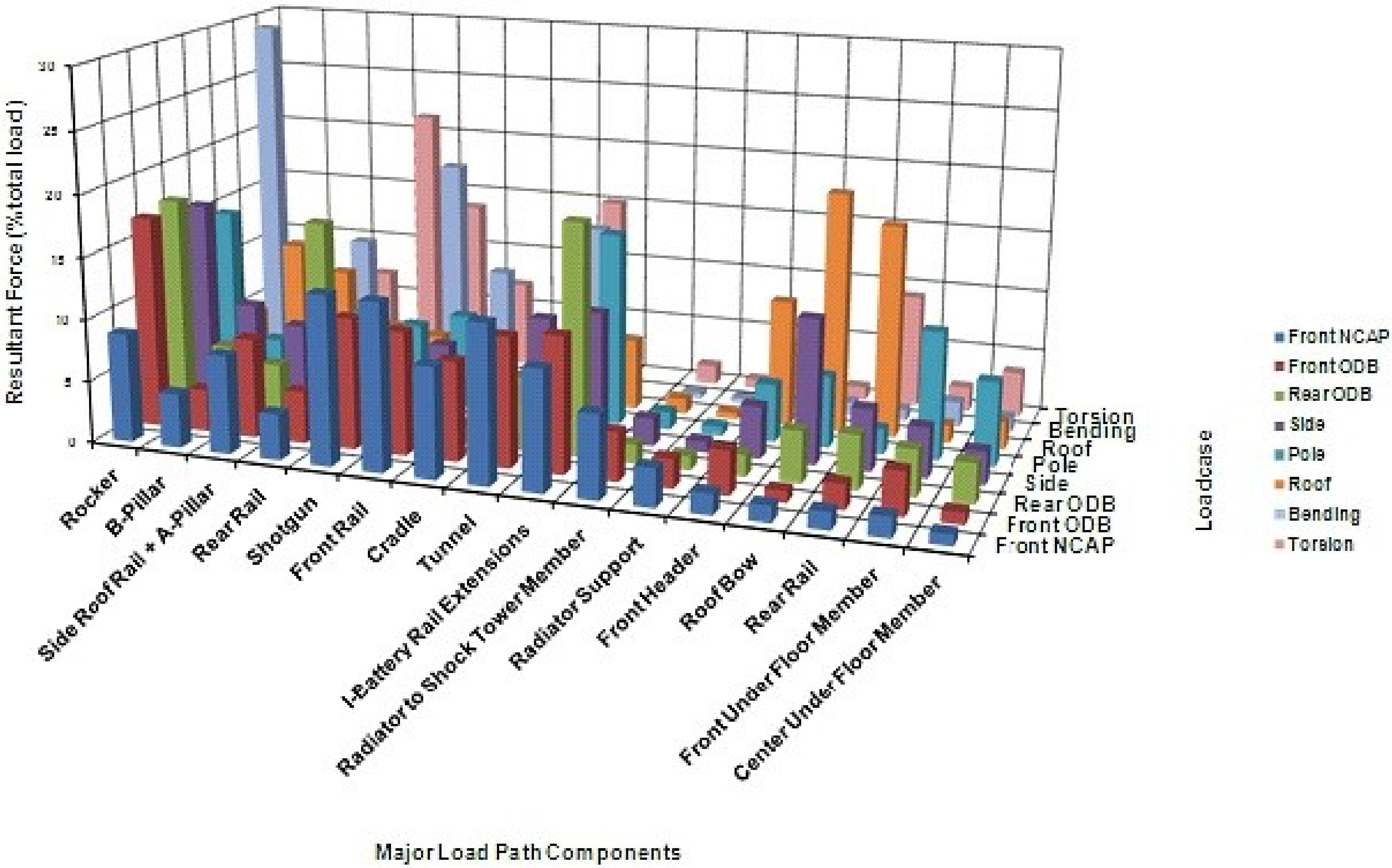




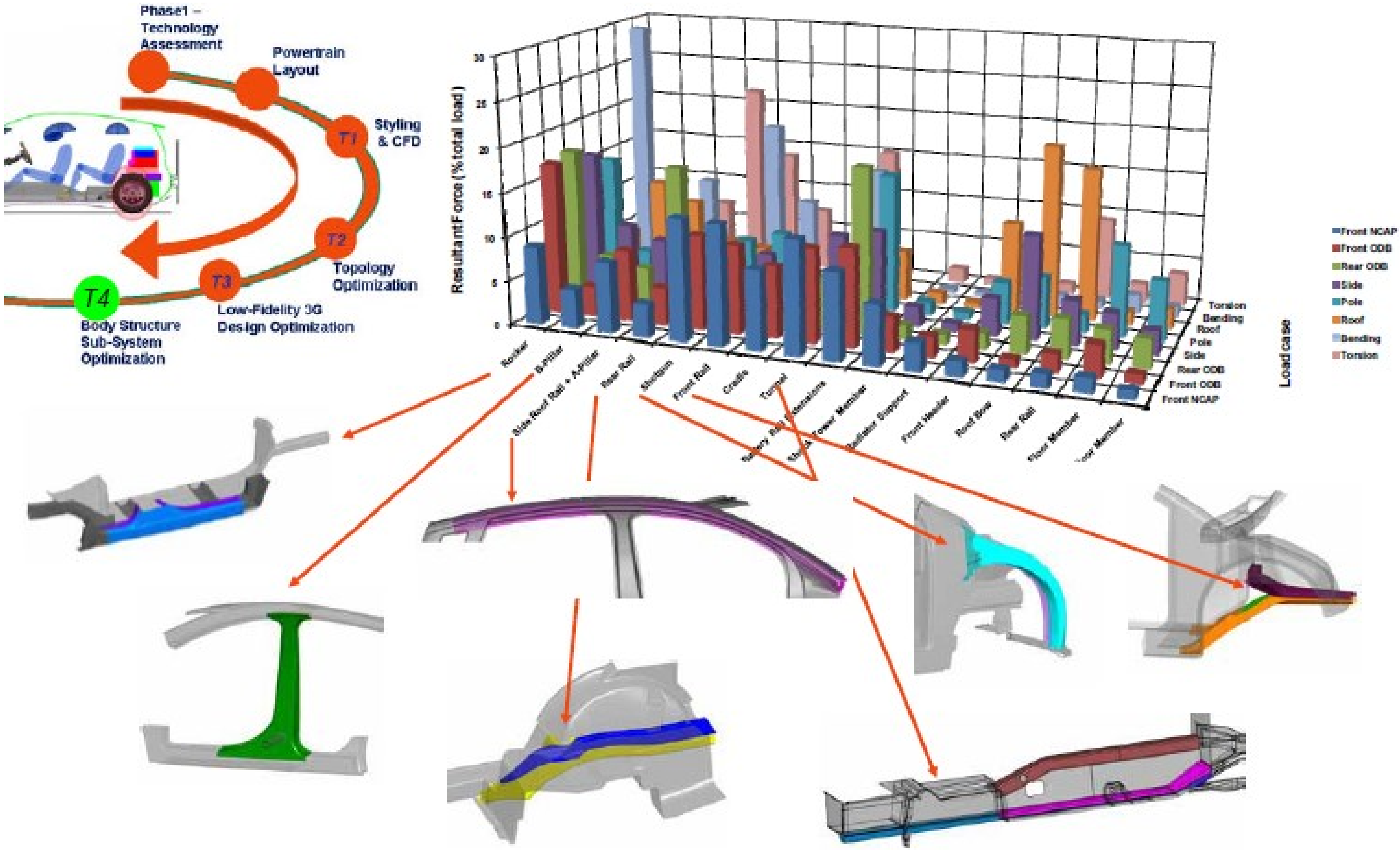
T4: body structure sub-system optimization

- Basic steps for the sub-system optimization
  - Sub-system development and validation
  - Initial design representing manufacturing approach
  - Establish design space
  - Parameterize geometry
  - Time history, constraints and targets from LF3G
  - Detailed 3G optimization; geometry (shape), grade (material) and gauge

Load Path Mapping

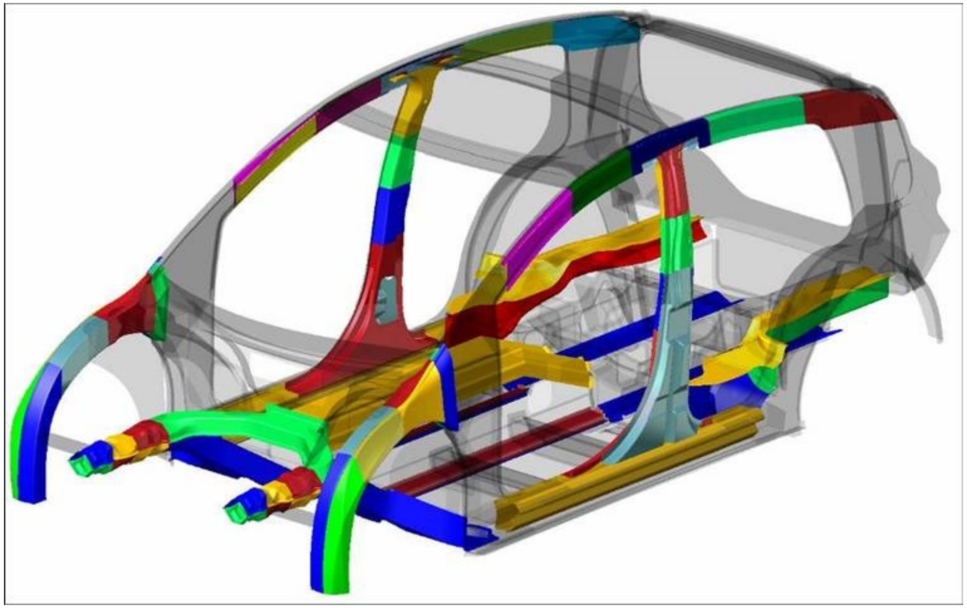


Sub-systems Selection



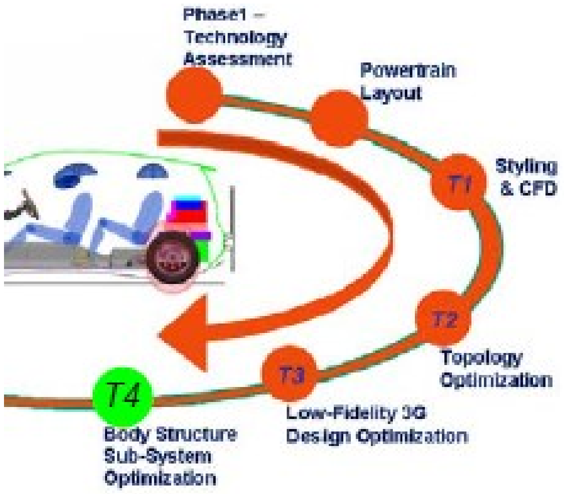
Selected Sub-Systems

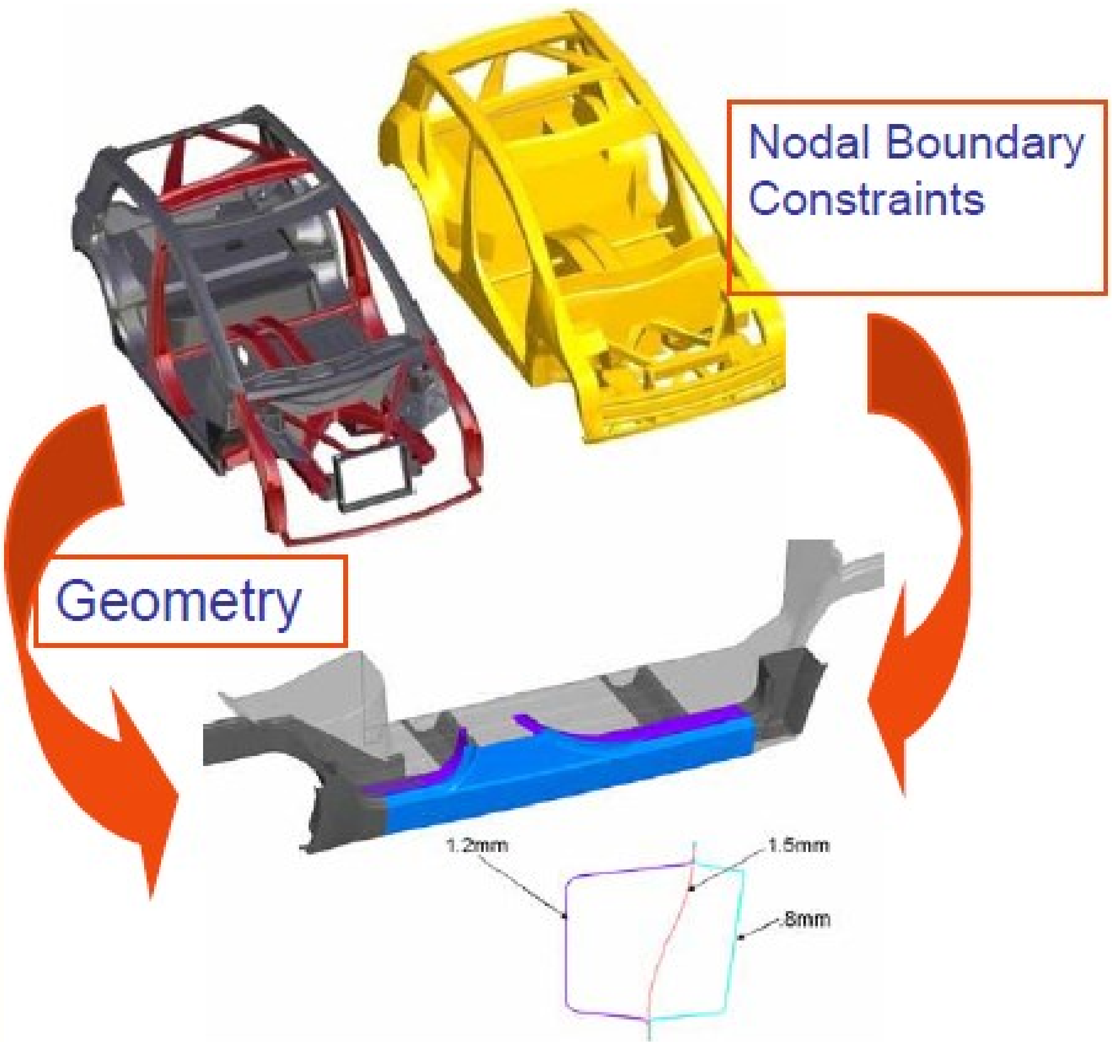
Sub-System	Loadcase				
	1	2	3	4	5
Rocker	Front NCAP	Front ODB	Rear ODB	IIHS Side	Pole
B-Pillar	IIHS Side	Roof Crush			
Side Roof Rail	Front ODB	Rear ODB	IIHS Side	Pole	Roof Crush
Rear Rails	Rear ODB	Torsional Stiffness			
Tunnel Rails	Front ODB	Rear ODB	IIHS Side	3G Jounce	
Shotgun	Front NCAP	Front ODB			
Front Rail	Front ODB				



3G Optimization

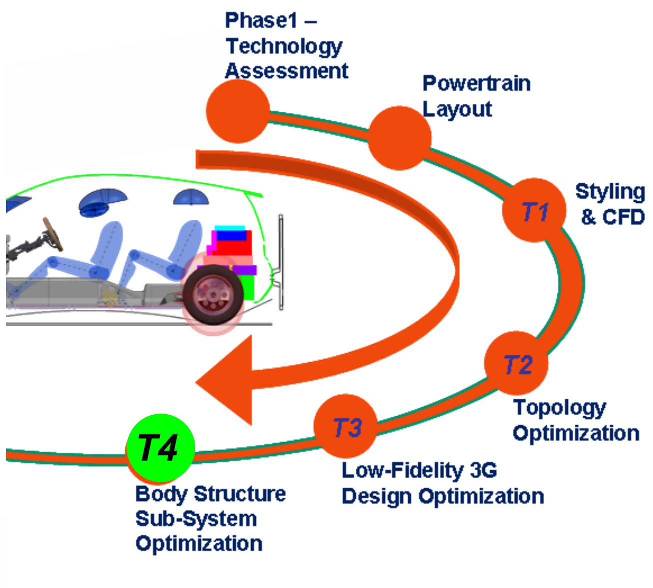
- Initial geometry: baseline sheet steel body structure
- Boundary conditions: nodal displacement time history
- Constraint: energy absorbed
  - Plastic deformation: $\pm$15% of the LF3G's performance
  - Elastic deformation: at a level less than that of LF3G's performance

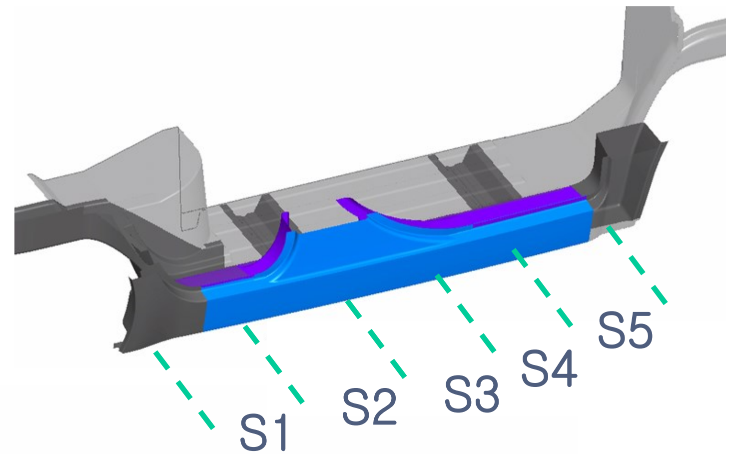


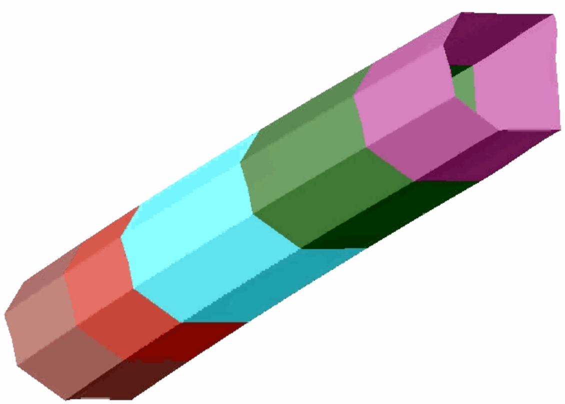


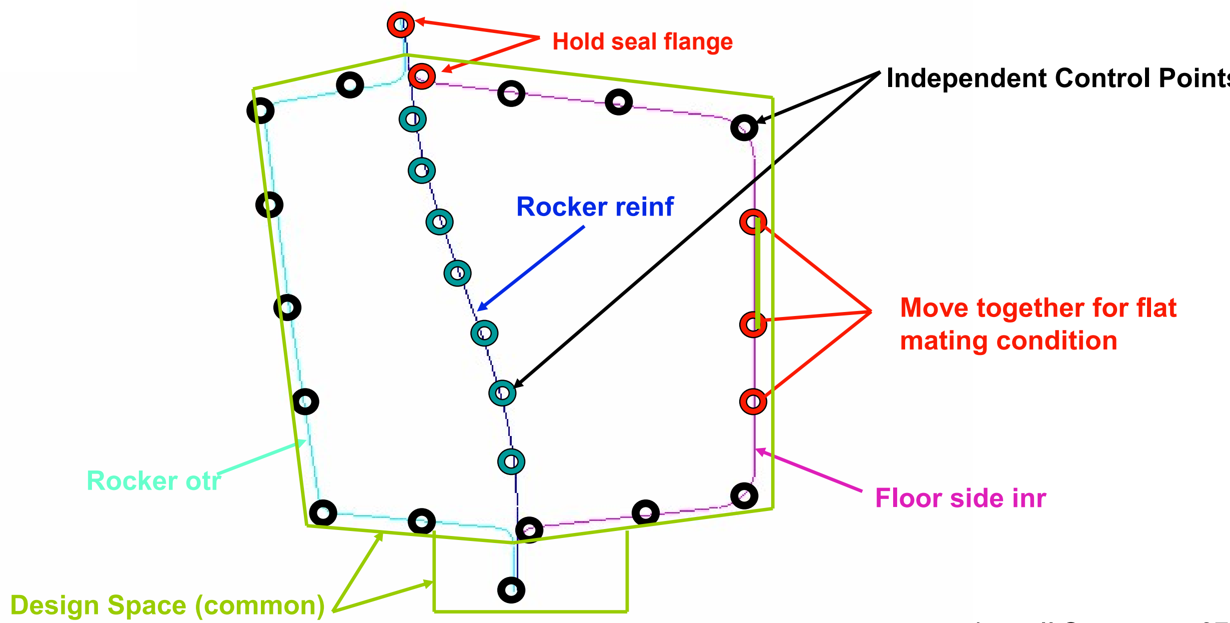
Variables for optimization:

1. Section Geometry using control points
2. Material Grade
3. Panel Gauge

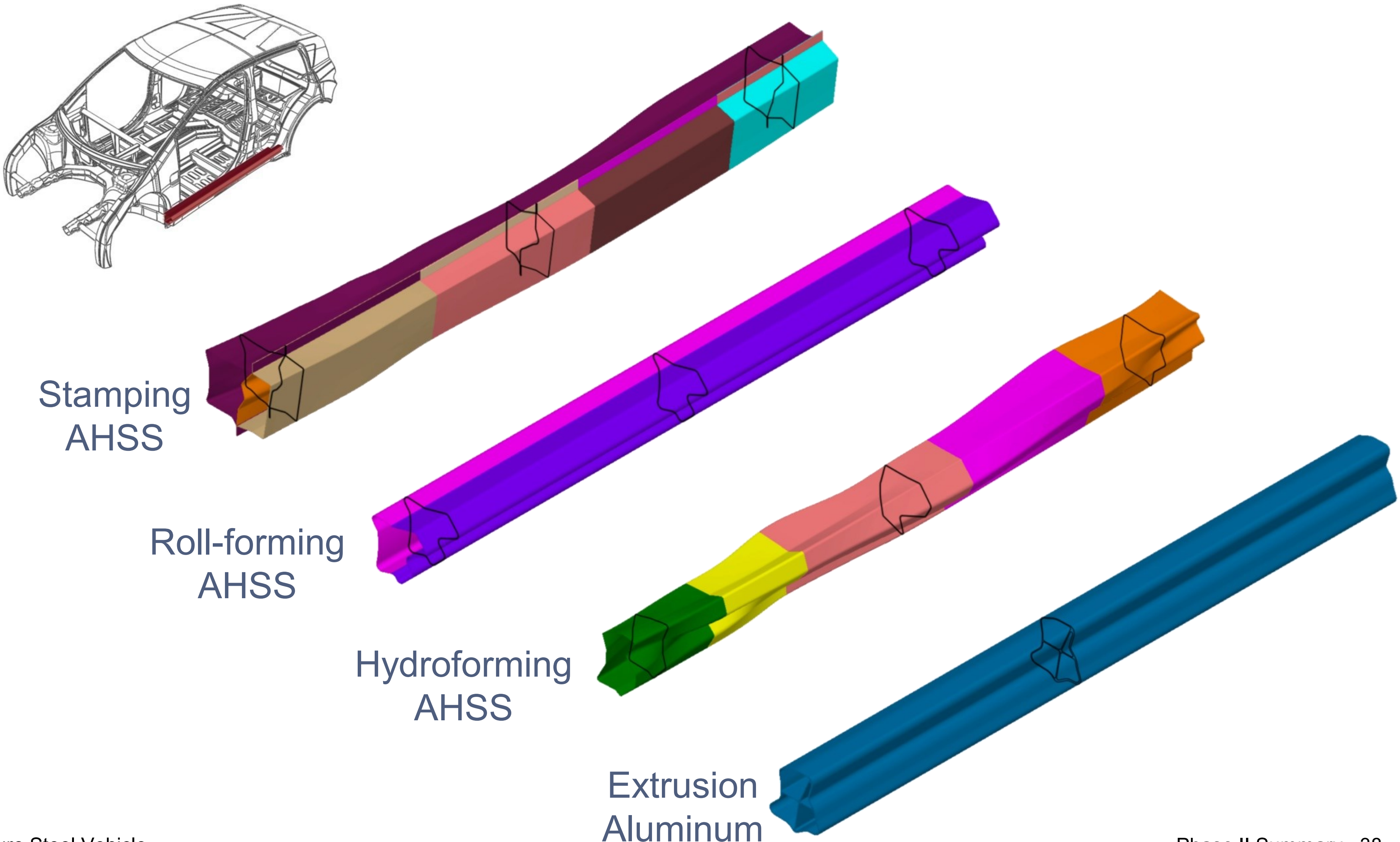

Phase1 –
Technology
Assessment
Powertrain
Layout
T1
Styling
& CFD
T2
Topology
Optimization
T3
Low-Fidelity 3G
Design Optimization
T4
Body Structure
Sub-System
Optimization


S1
S2
S3
S4
S5

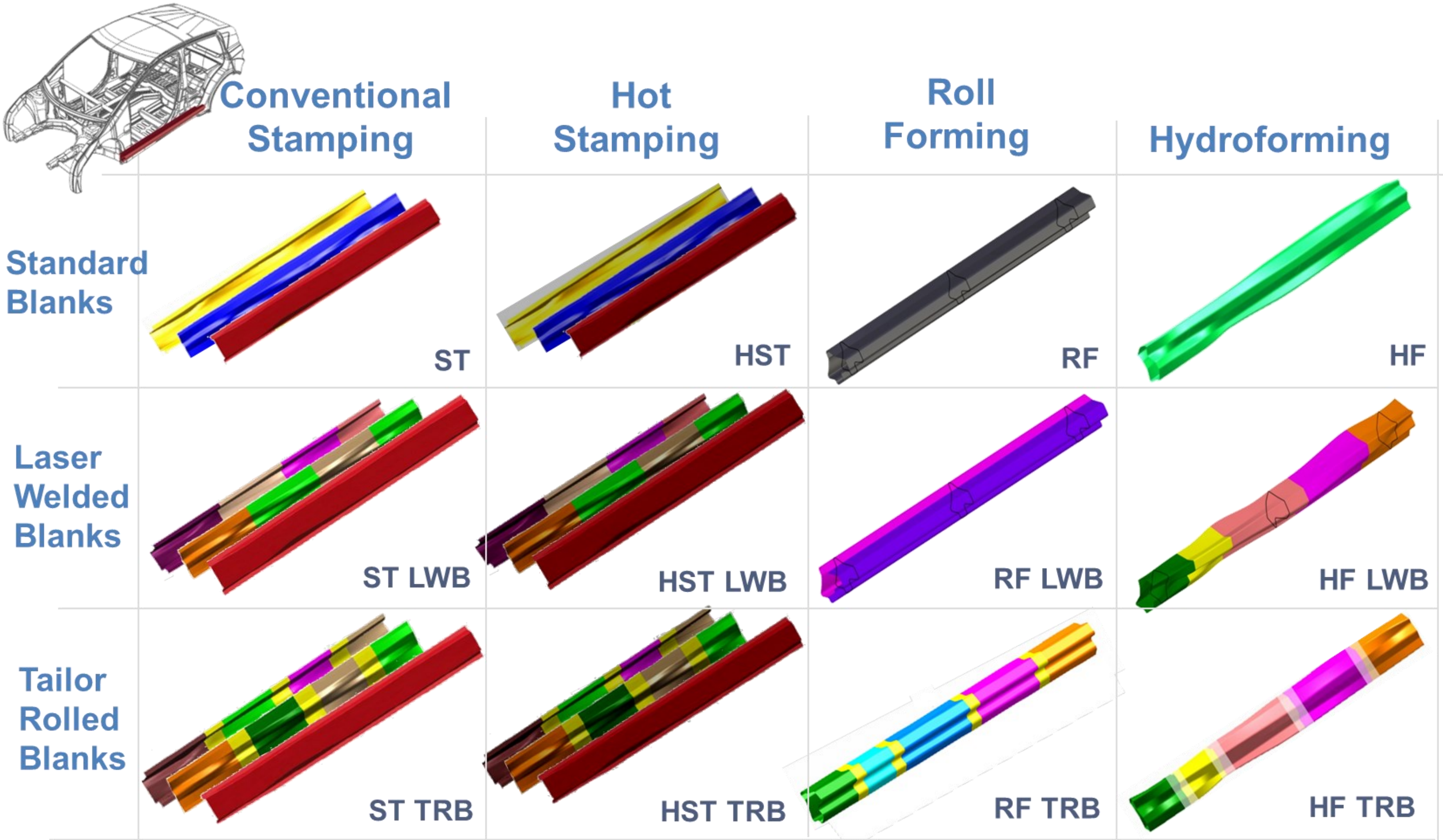



Hold seal flange
Independent Control Points
Rocker reinf
Move together for flat
mating condition
Rocker otr
Floor side inr
Design Space (common)

Rocker Solutions (1)



Rocker Solutions (2)



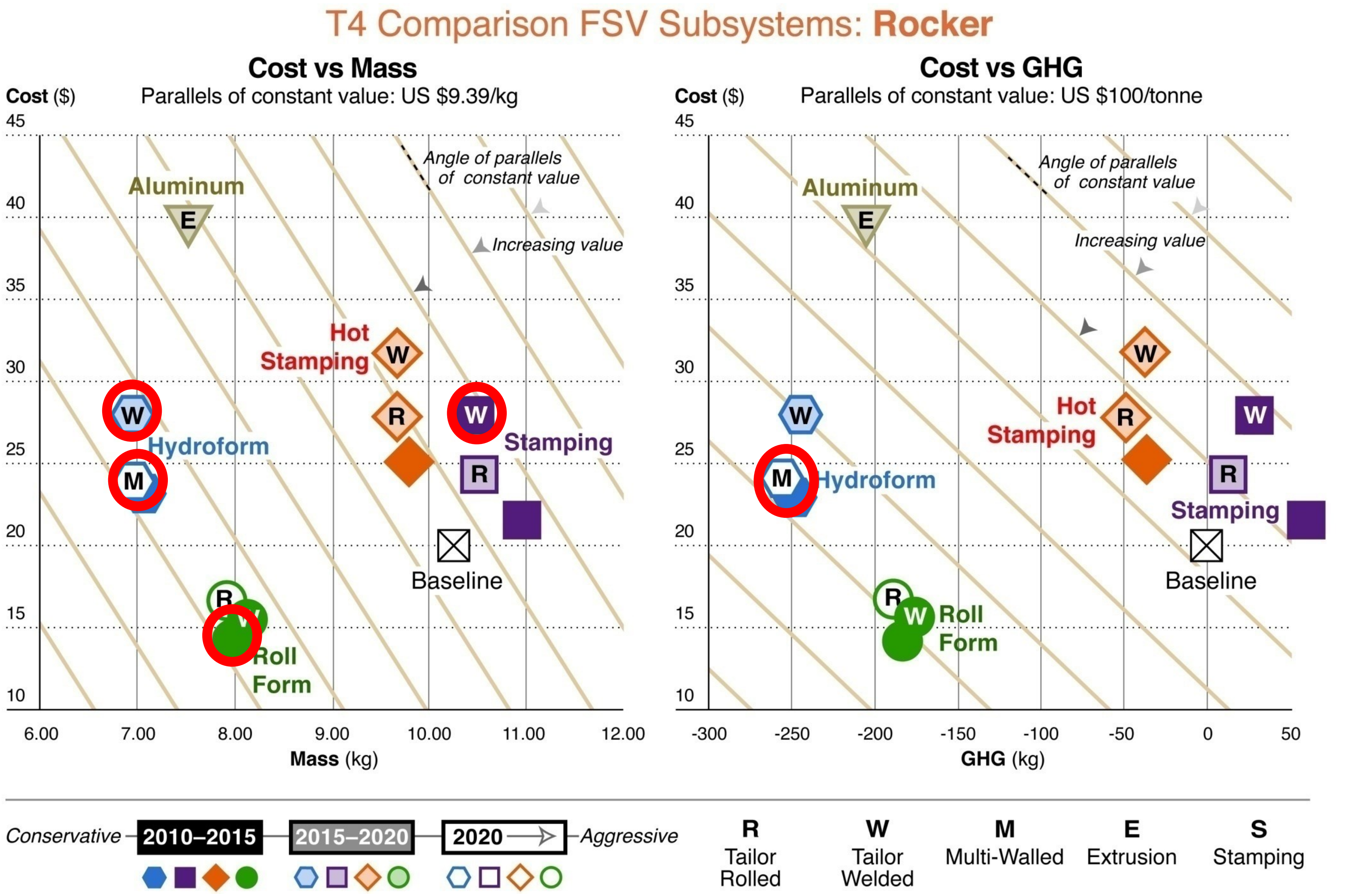
T5: detailed body structure design

- Sub-systems selection
  - Higher priority to mass savings
  - Categories based on the level of difficulty of manufacturing technology
- Selection criteria
  - Mass
  - Cost: "technical cost modeling" approach
  - Life Cycle Assessment for CO_2e: extended Greenhouse Gases (GHG) emissions comparison model

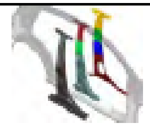
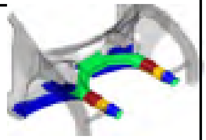
Total Life Cycle Assessment- GHG (kg): Rocker

	Total Life Cycle	Material & Mfg.	Mfg baseline - rocker	Vehicle Use Phase	Vehicle Recycling
Baseline - Rocker 10.26 kg	**15,980**	**2291**	**5.7**	**14,640**	**-956.8**
Solution 1 - Stamping	**+53.2**	**8.6**	**0.4**	**48.0**	**-3.8**
Solution 2 - Hot Stamp	**-37.1**	**-18.0**	**3.9**	**-32.1**	**9.1**
Solution 3 - Roll Form	**-182.6**	**-44.9**	**-0.7**	**-158.6**	**21.5**
Solution 4 - Hydroform	**-248.2**	**-67.5**	**10.1**	**-223.4**	**32.5**

T4 Comparison FSV Sub-Systems: Rocker

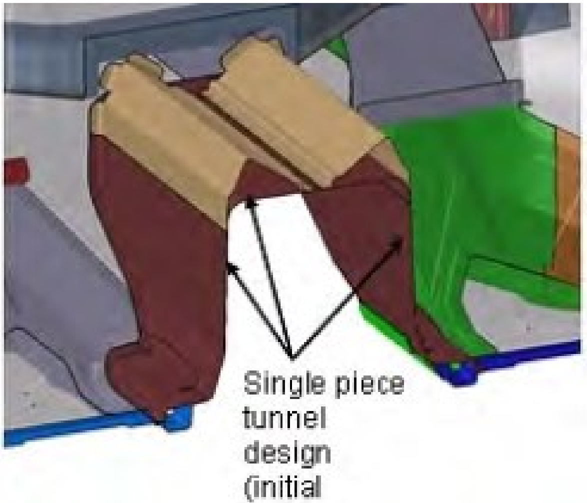


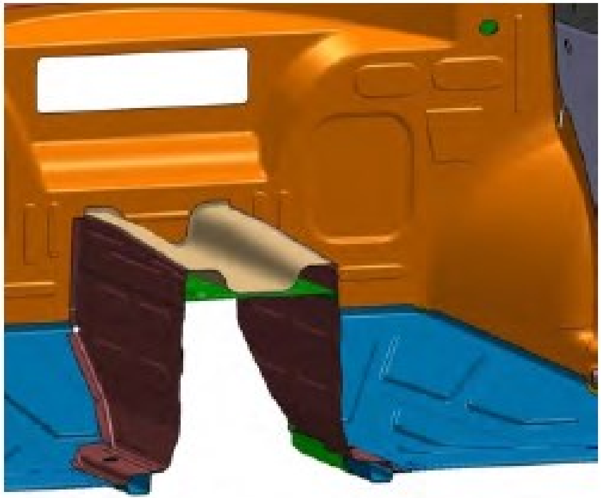
FSV BEV sub-system selection summary

FSV Sub-system	FSV Selection (Mid-Term)	Baseline Weight (kg)	Baseline Manufacturing Cost ($ USD)	FSV Selected Sub-system Weight (kg)	FSV Selected Sub-system Manufacturing Cost ($ USD)	FSV Selected Sub-system LCA CO_2e Savings (kg)	FSV Selected Sub-system Illustration
Rocker	Rollformed single thickness or rollformed TWC (with conventional outer)	10.26	$19.99	7.98 / 8.07	$14.27 / $15.7	-183 / -177	
Rear Rail	Stamping LWB/TRB	6.28	$12.73	4.98 / 5.19	$16.86 / $12.95	-92 / -86	
B-Pillar	Hot stamping LWB with conventional B-pillar outer	8.79	$30.84	5.48	$30.44	-247	
Roof Rail	Hot stamping LWB	12.73	$27.71	9.31	$31.71	-256	
Shotgun	Hot stamping LWB (with tailor quench)	4.2	$14.24	4.98	$22.11	73	
Tunnel	Open rollform	7.72	$20.20	4.29	$11.56	-277	
Front Rail	Stamped LWB	6.24	$28.91	5.72	$20.91	-65	

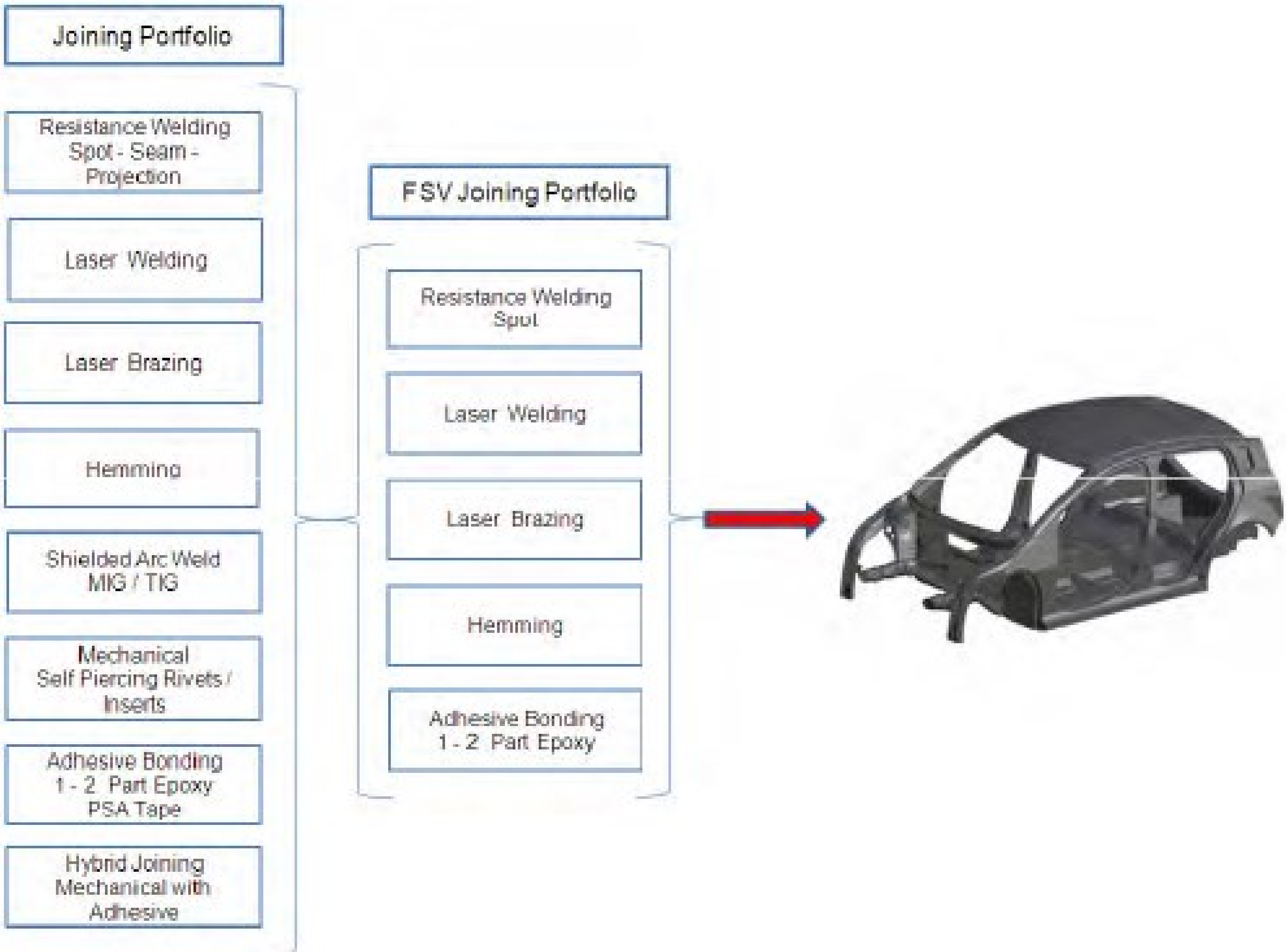
Sub-System Integration into Body Design

- Design changes driven by the manufacturability analysis and design for assembly considerations
- Tunnel sub-system 3G optimization
  - open roll formed design (one piece)
  - side walls to be designed as individually stamped parts
  - strengthening of the side walls (additional stiffening beads)
  - additional stiffening feature along the critical loadpath within the tunnel sub-system (tunnel bulkhead)



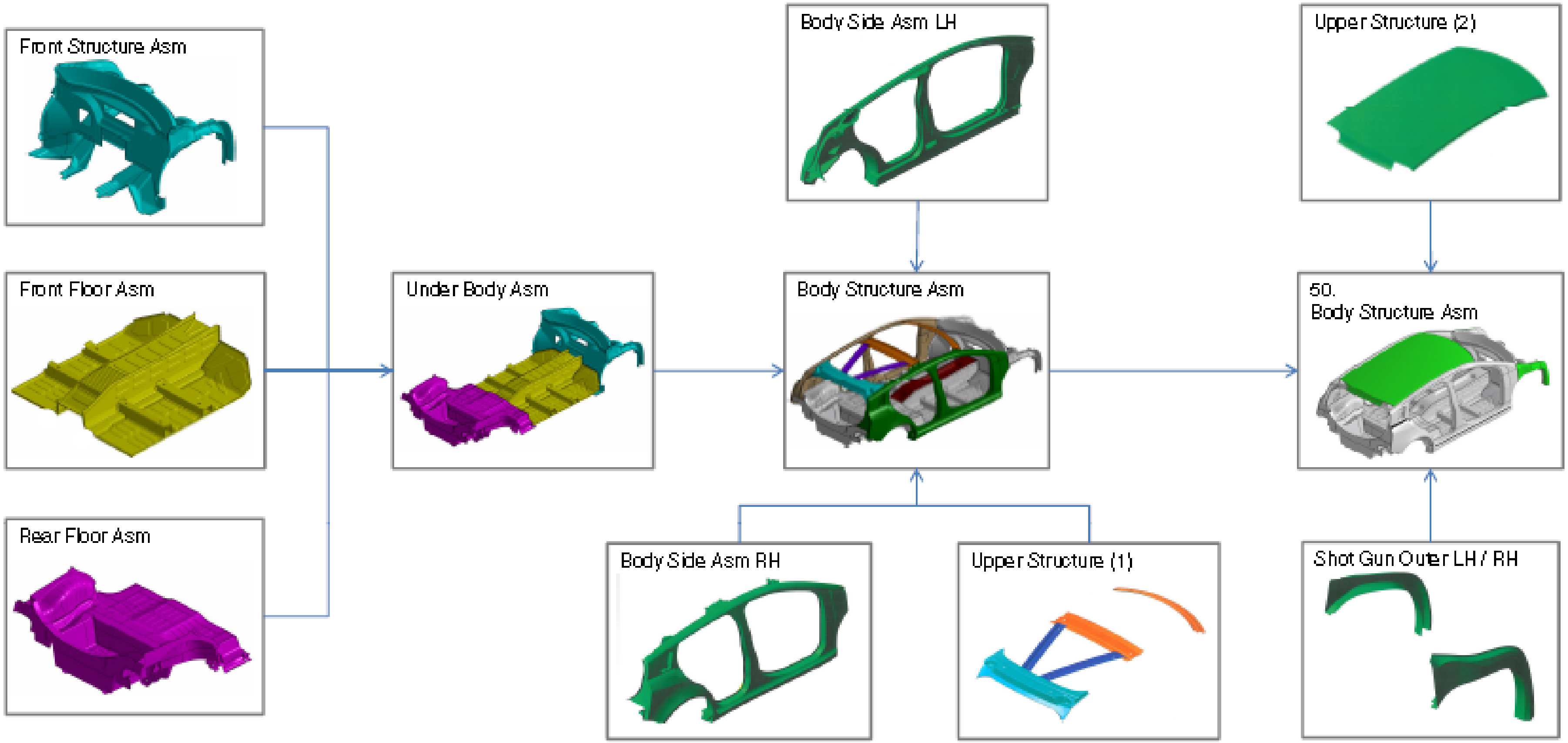


FSV Assembly Joining Process Portfolio



Body Structure Assembly

– Front structure, front floor, rear floor, underbody, body side LH/RH, upper structure, shotgun



T5: Body Structure Performance CAE Analysis

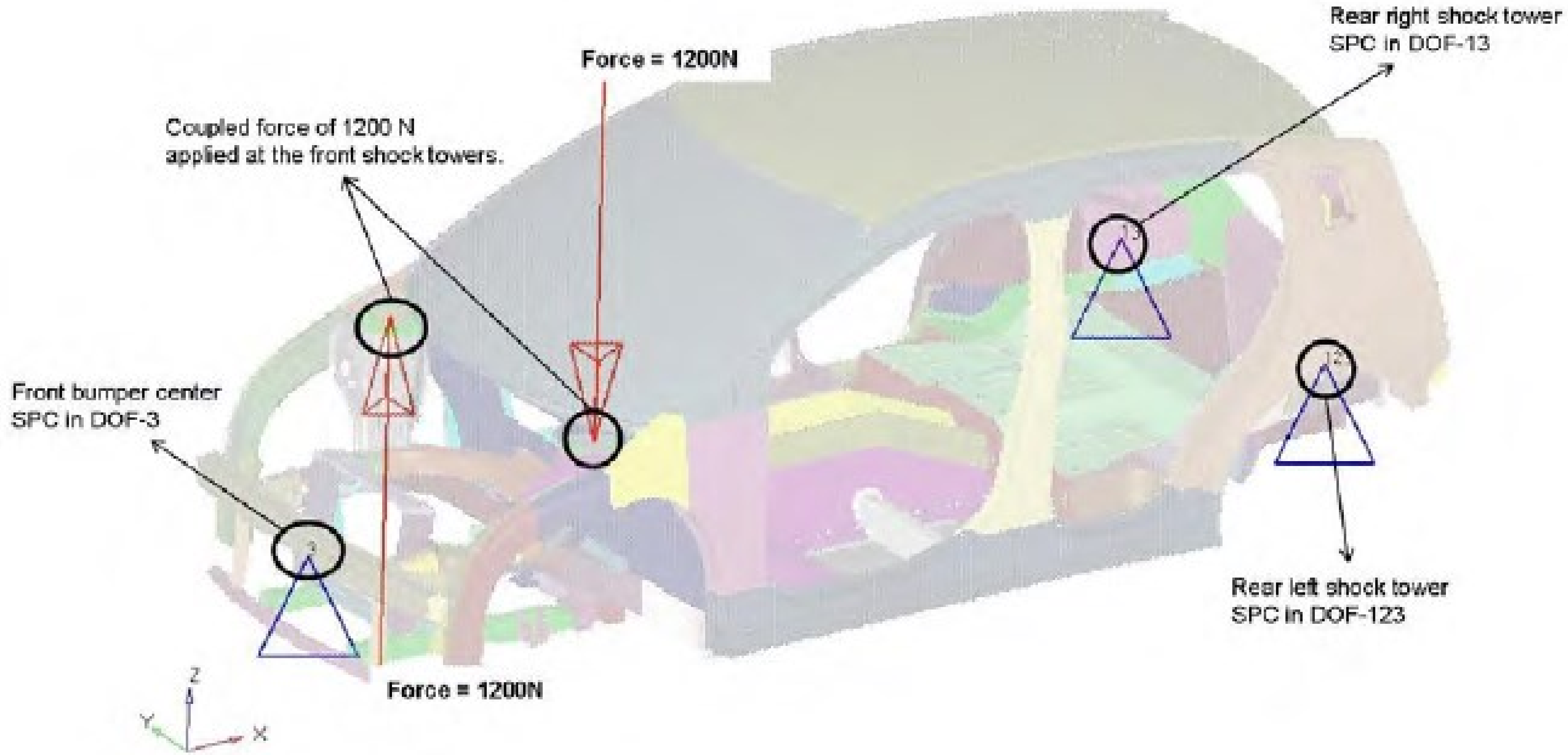
- Static Stiffness

Analysis Type	Target	FSV Model Results
Torsion stiffness (KN-m/deg)	20.0	19.604
Bending stiffness (N/mm)	12.0	15.552
Global Modes	**Target**	**Frequency (Hz)**
Torsion	>40 Hz (both modes), separated by 3 Hz	54.8
Vertical bending		60.6

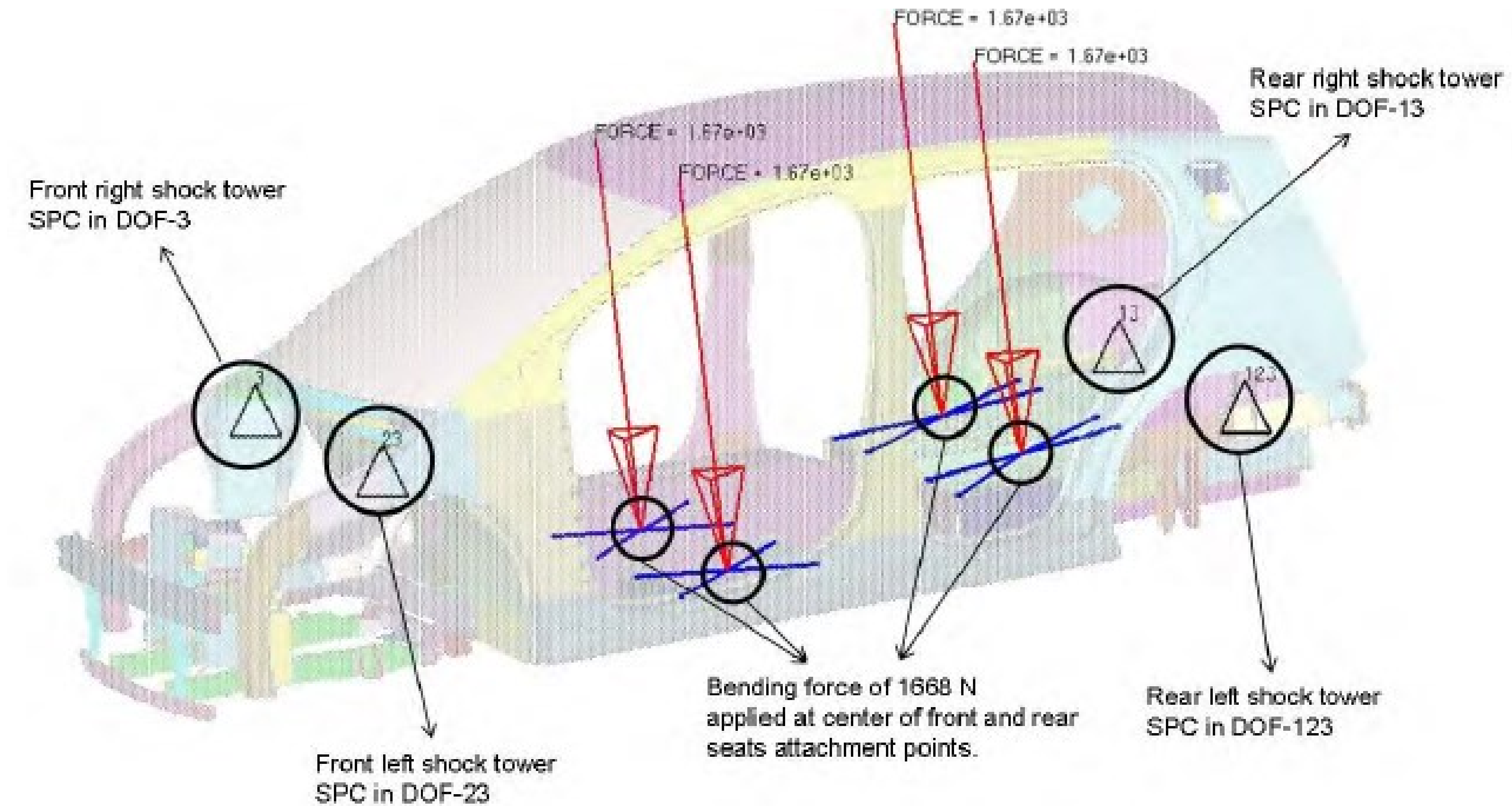
- Durability

Analysis Type	Target life cycles	Predicted life cycles (FSV Model)
3 g pot hole	200,000	927,100
0.7 g cornering	100,000	1,676,000
0.8 g forward braking	100,000	274,700 (engine cradle life), 17,340,000(body life)

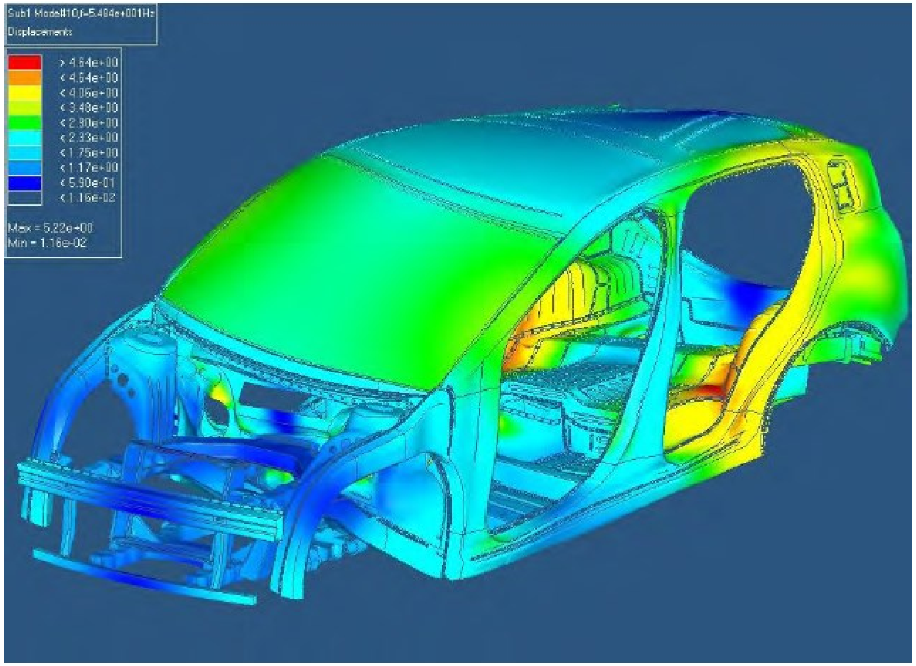
Torsion: Constraints and Loading



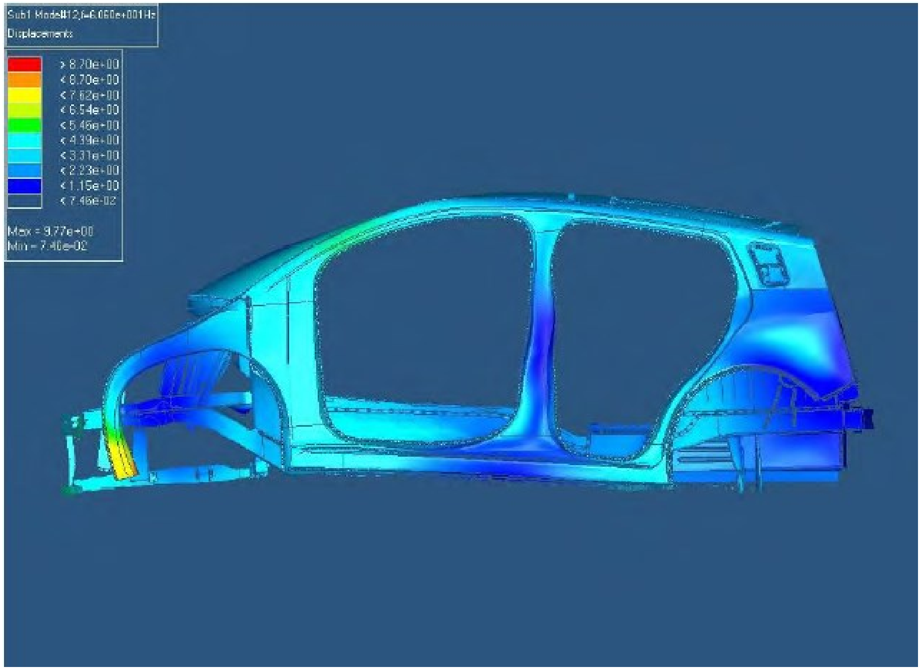
Bending: Constraints and Loading



Dynamic Stiffness



Torsion mode at 54.84 Hz



Vertical bending mode at 60.60 Hz

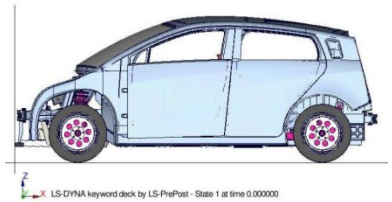
T5: Body Structure Performance CAE Analysis

- Full Vehicle Dynamic Analysis
  - Fish-hook test
  - Double lane change maneuver (ISO 3888-1)
  - 3 g pothole test
  - 0.7 g constant radius turn test
  - 0.8 g forward braking test
- Crashworthiness
- NVH

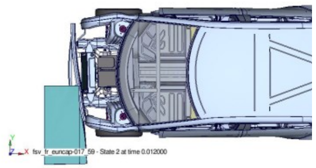
Crashworthiness

Analysis Type	Target	FSV Model Results
US NCAP frontal	Peak pulse range < 35 to 38 g, footwell intrusion < 100 mm	Peak pulse - 39.7 g, footwell intrusion 90.0 mm (average)
Euro NCAP/IIHS	Peak pulse (driver side) < 42 g, footwell intrusion < 150 mm	Peak pulse 41.2 g, footwell intrusion 101.0 mm (average)
IIHS Side Impact	B-pillar intrusion with respect to driver seat centerline $\geq$ 125 mm	134 mm
US SINCAP Side Impact	B-pillar intrusion with respect to driver seat centerline $\geq$ 125 mm	215 mm
FMVSS 301 Rear Impact	Battery remains protected and should not contact other parts after the crash	Battery is protected and there is no contact with other parts after crash
ECE R32 Rear Impact	Battery remains protected and should not contact other parts after the crash	Battery is protected and there is no contact with other parts after crash
FMVSS 214 Pole Impact	Door inner intrusion with respect to driver seat centerline $\geq$ 125 mm	159 mm
Euro NCAP Pole Impact	Door inner intrusion with respect to driver seat centerline $\geq$ 125 mm	169 mm
FMVSS 216a and IIHS Roof Crush	Driver and passenger side roof structure should sustain load > 28.2 kN within the plate movement of 127 mm (FMVSS 216a), > 37.5 kN (IIHS)	Sustains load = 55 kN for driver side, = 53 kN for passenger side
RCAR/IIHS Low Speed Impact	Damage is limited to the bumper and crashbox	No damage to components other than the bumper and crashbox

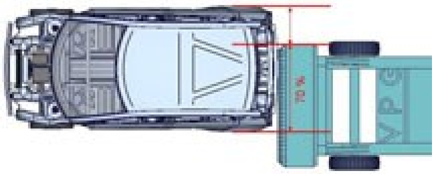
FSV Crash Safety Analyses



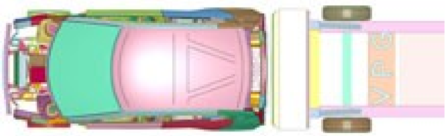
US NCAP



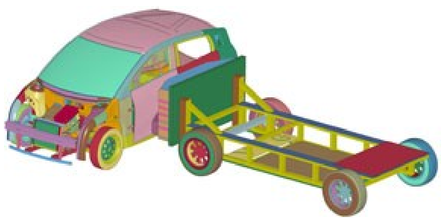
EURO NCAP



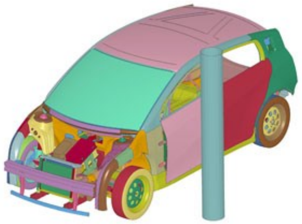
FMVSS 301 Rear



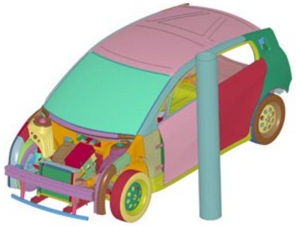
ECE R32



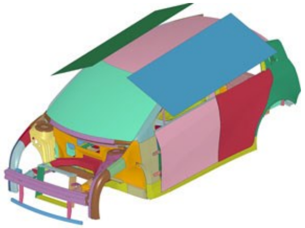
IIHS Side



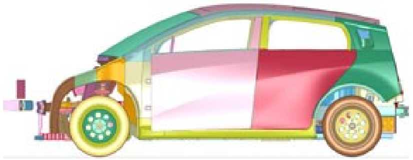
FMVSS 214 Pole



EURO NCAP Pole



FMVSS 216a, IIHS Roof



RCAR/IIHS Low Speed

NVH Assessment

- Lower sound pressure levels, except for an isolated high frequency peak heard at high speeds (3500 Hz)
- This peak is lowered by increased use of acoustic absorbent materials in the motor compartment
- Reshaping the suspension mounts, the rear roof, the front header and the cowl top connection area, each change driving large reductions of noise levels while adding little to no mass

Noise, Vibration and Harshness Analysis

Physical Testing on i-MiEV / i

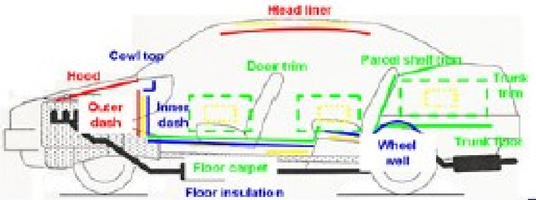
Step 1

- Understanding of EV noise
- Obtain input condition
- NV target setting

Virtual Simulation on FSV

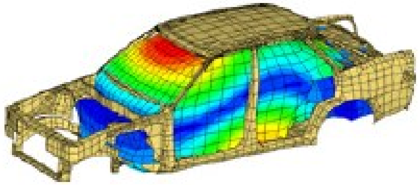
Step 2

High Frequency: Trim Design



Step 4

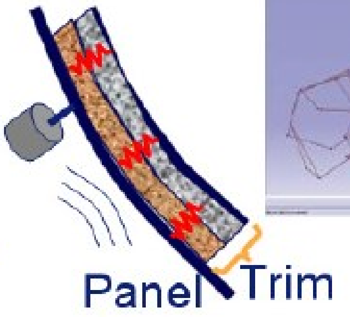
Low Frequency: Body Design



- Motor & suspension mounts
- Body Noise Transfer Functions

Step 3

Mid Frequency: Panel Design



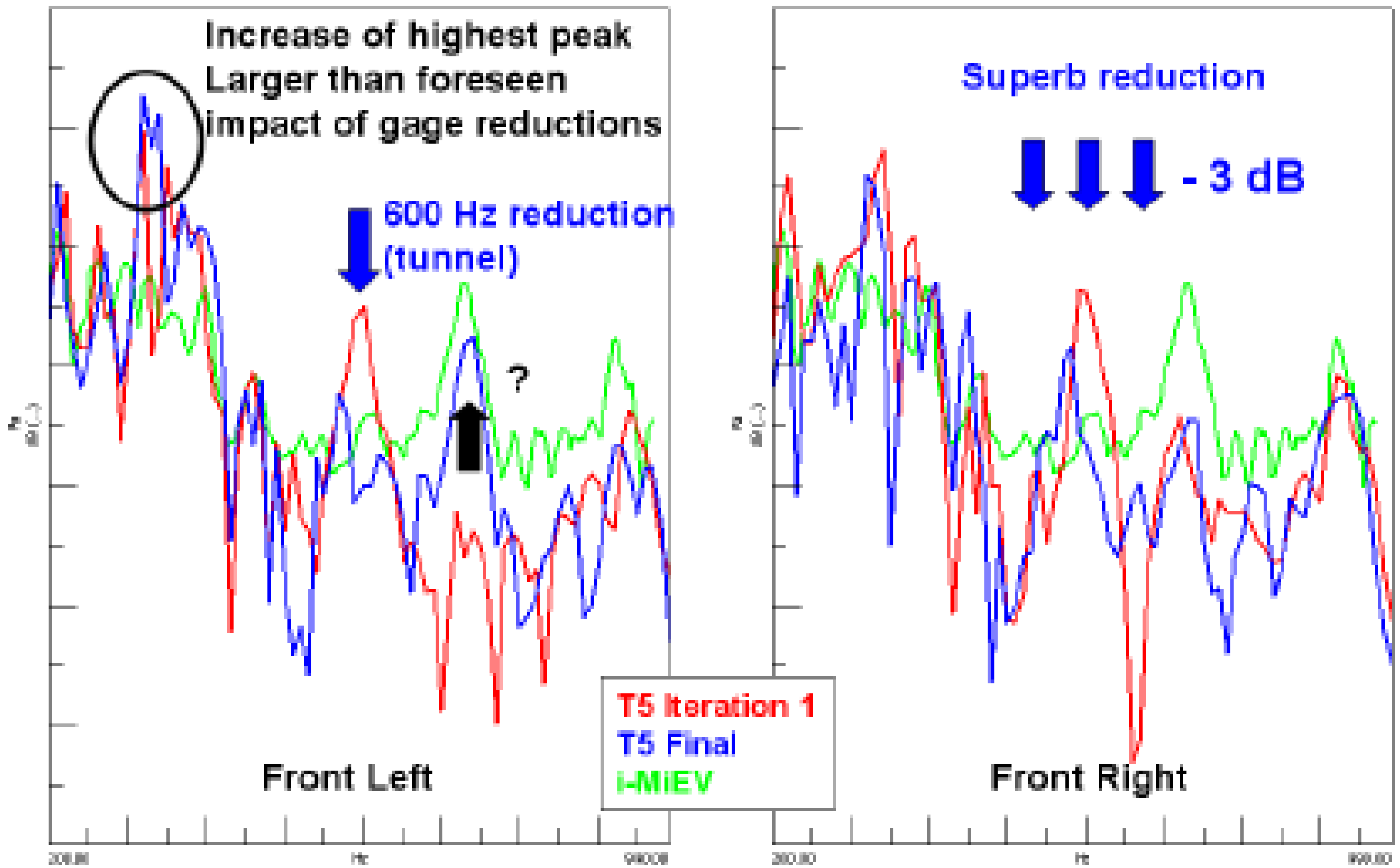
SAE Paper No. 2011-01-1724

Mid-Frequency Comparison

T5 Iteration 1

T5 Final

I-MIEV

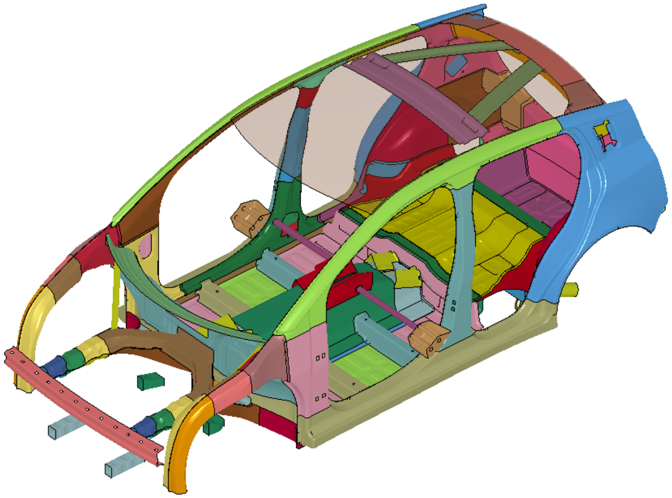


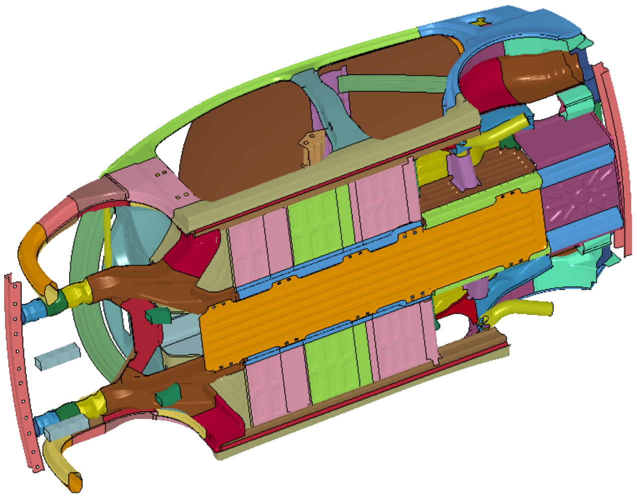
In average: – 0.3 dB and on target

Final Grade & Gauge (2G) Full System Optimization

Final Grade & Gauge (2G) Full System Optimization

Best Design: #336





T4 Baseline BIW Mass	= 203.7 kg
T5 Optimized Design 336 BIW	= 188.0 kg
BIW Mass Savings	= 15.7 kg (8.4%)

Body Structure Manufacturing Cost Breakdown

Manufacturing Technology	Parts Weight (kg)	Unit Cost Per Vehicle ($USD)
Stamping	76.1	$306.10
Stamping – Laser welded blanks	72.0	$270.40
Hot Stamping	4.8	$48.70
Hot Stamping – Laser welded blanks	16.8	$118.50
Open Roll Forming	4.5	$7.70
Closed Roll Forming	13.5	$23.60
Total Manufacturing Cost	187.7	$775.00

Body Structure Parts Costs

Parameter	FSV		ULSAB AVC
Body Structure Weight (kg)	187.7 kg		202 kg
Production Volume Scenario	100000/yr	225000/yr	225000/yr
Total Body Structure Parts Costs	$775	$684	$620
Base material Price	$0.73		$0.73
Material	50%	57%	66%
Labor	7%	7%	7%
Equipment	14%	15%	10.5%
Tooling	17%	9%	8%
Energy	3%	3%	2%
Overhead	5%	5%	4%
Building	1%	1%	0.5%
Maintenance	3%	3%	2%
Number Stamped Parts	75		64
Number of Hot Stamped parts	16		0
Number of Tubular parts	10 (Rollformed)		4 (Hydroformed)
Number of LWB Parts	18		11
Total Number of Parts	119		79

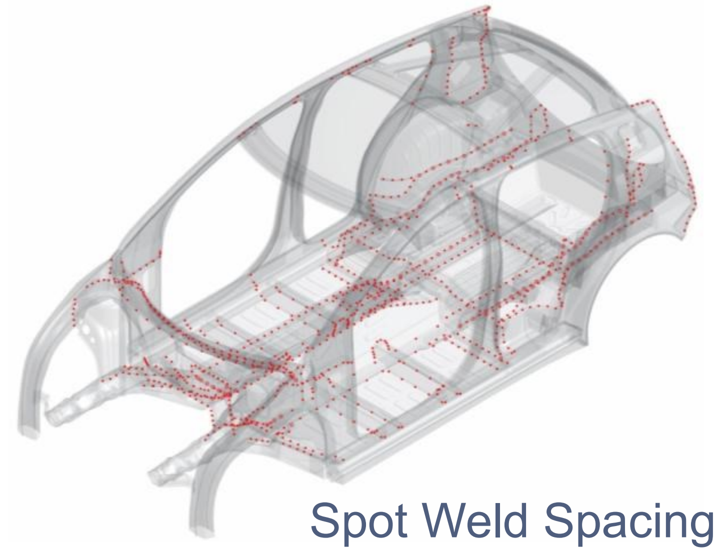
Body Structure Assembly Costs

Assembly Name	Assembly ($ USD) Cost
Body Side Inner Sub Assembly RH	$17.59
Body Side Inner Sub Assembly LH	$17.59
Body Side Outer Sub Assembly RH	$5.29
Body Side Outer Sub Assembly LH	$5.29
Body Side Assembly RH	$24.95
Body Side Assembly LH	$24.95
Front Structure Assembly	$46.53
Front Floor Sub-Assembly	$39.91
Rear Floor Assembly	$89.63
Underbody Assembly	$22.20
Body Structure Assembly	$45.79
Total Cost of Body Structure Assembly	$339.73

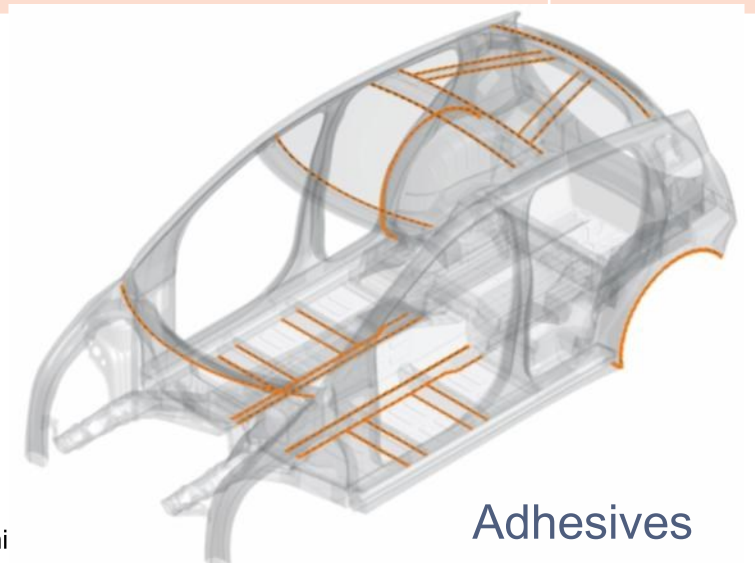
Parameter	FSV		ULSAB AVC	
Body Structure Assembly Cost	$339.73	$294.60	$283.81	$310.01
Number of parts	119		79	
Number of sub-assemblies	54		28	
Production Volume	100000/yr	225000/yr	225000/yr	100000/yr
Number of spot welds:	1023		723	
Length of laser welds	77 m		114 m	
Length of adhesive	18 m		2 m	
Length of hem	2 m		-	

Joining Specification

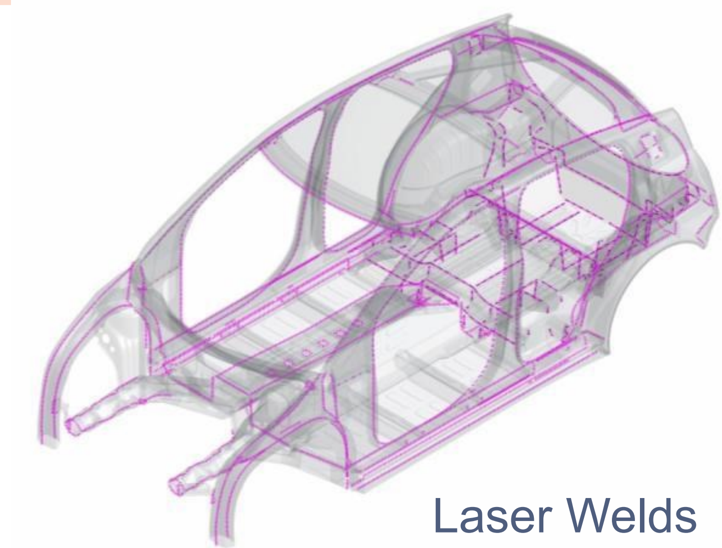
Joining Technology	
Number of spot welds	1023
Length of laser welds	83.6 m
Length of laser braze	3.4m
Length of hem flange	2 m
Length of hem adhesive	2 m
Length of structural adhesive	9.8 m
Length of anti-flutter adhesive	6.5 m



Spot Weld Spacing

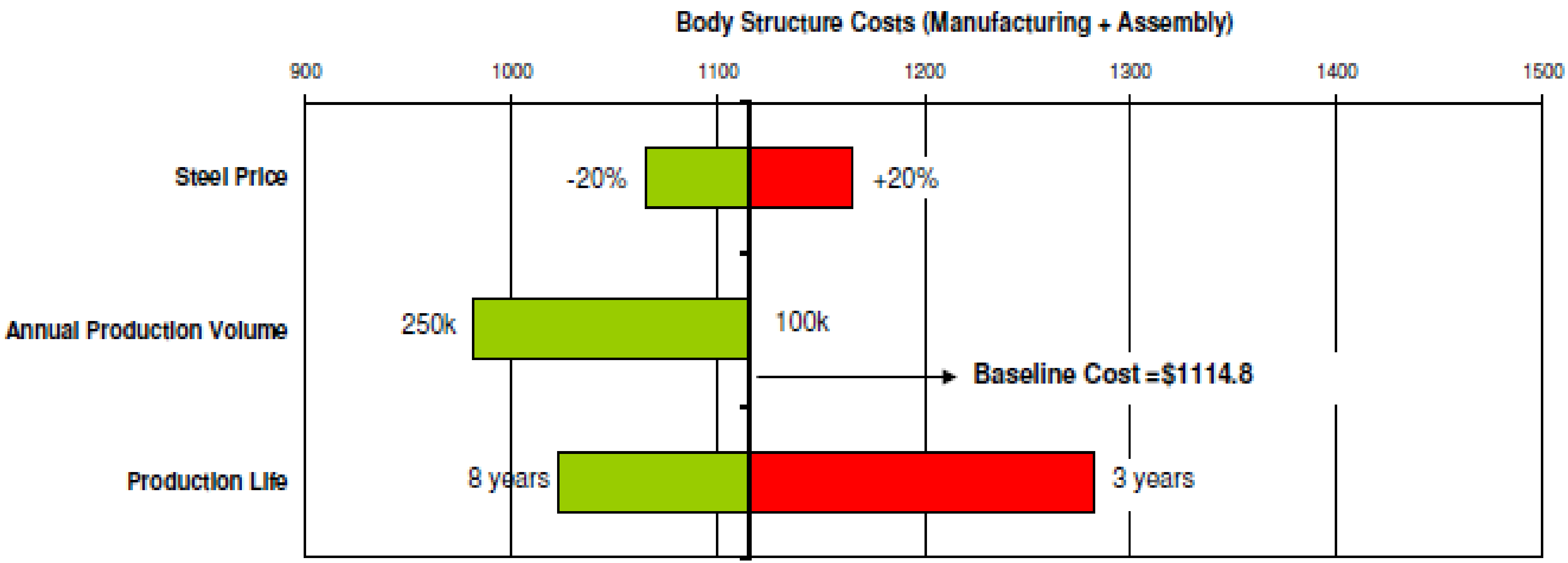


Adhesives



Laser Welds

Sensitivity Analysis

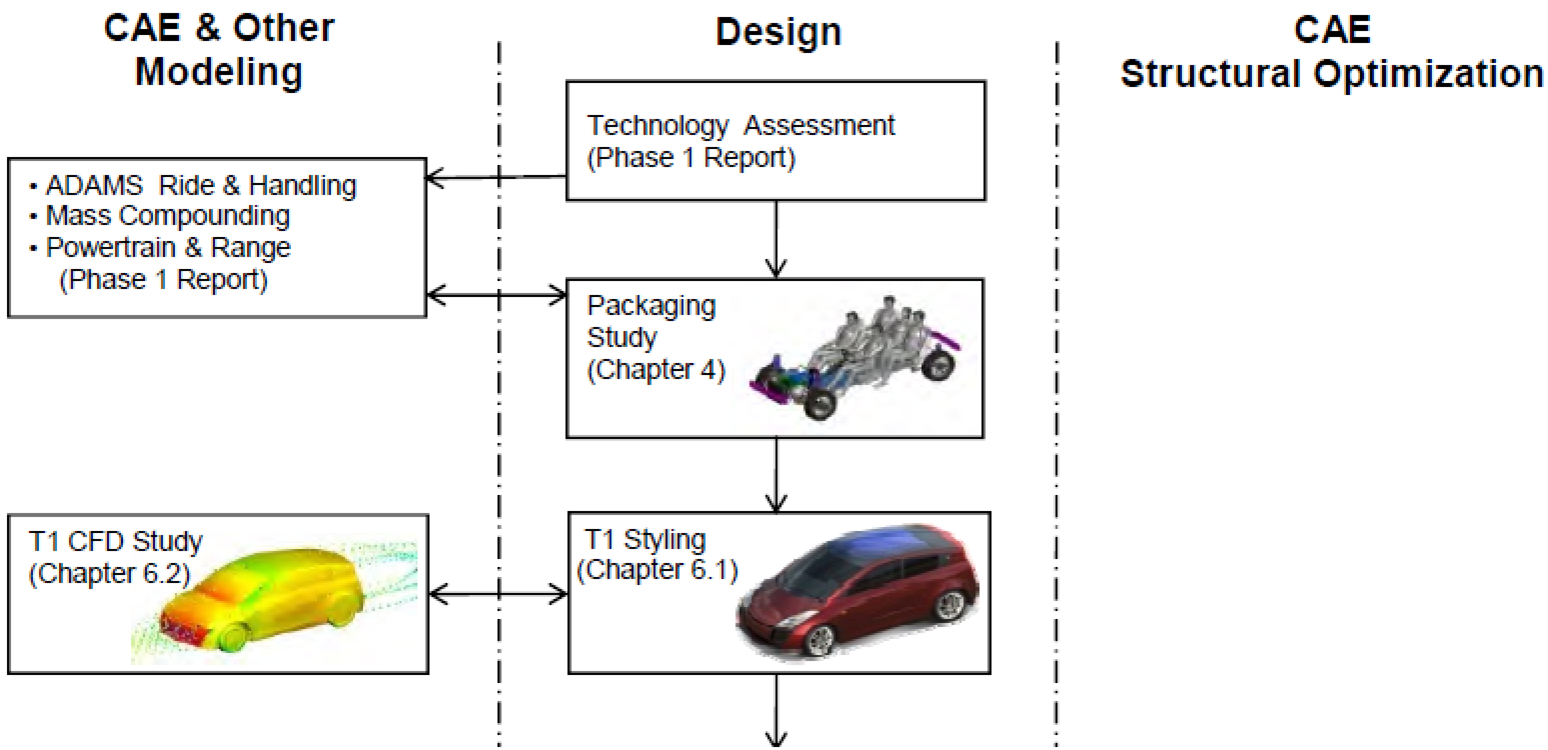


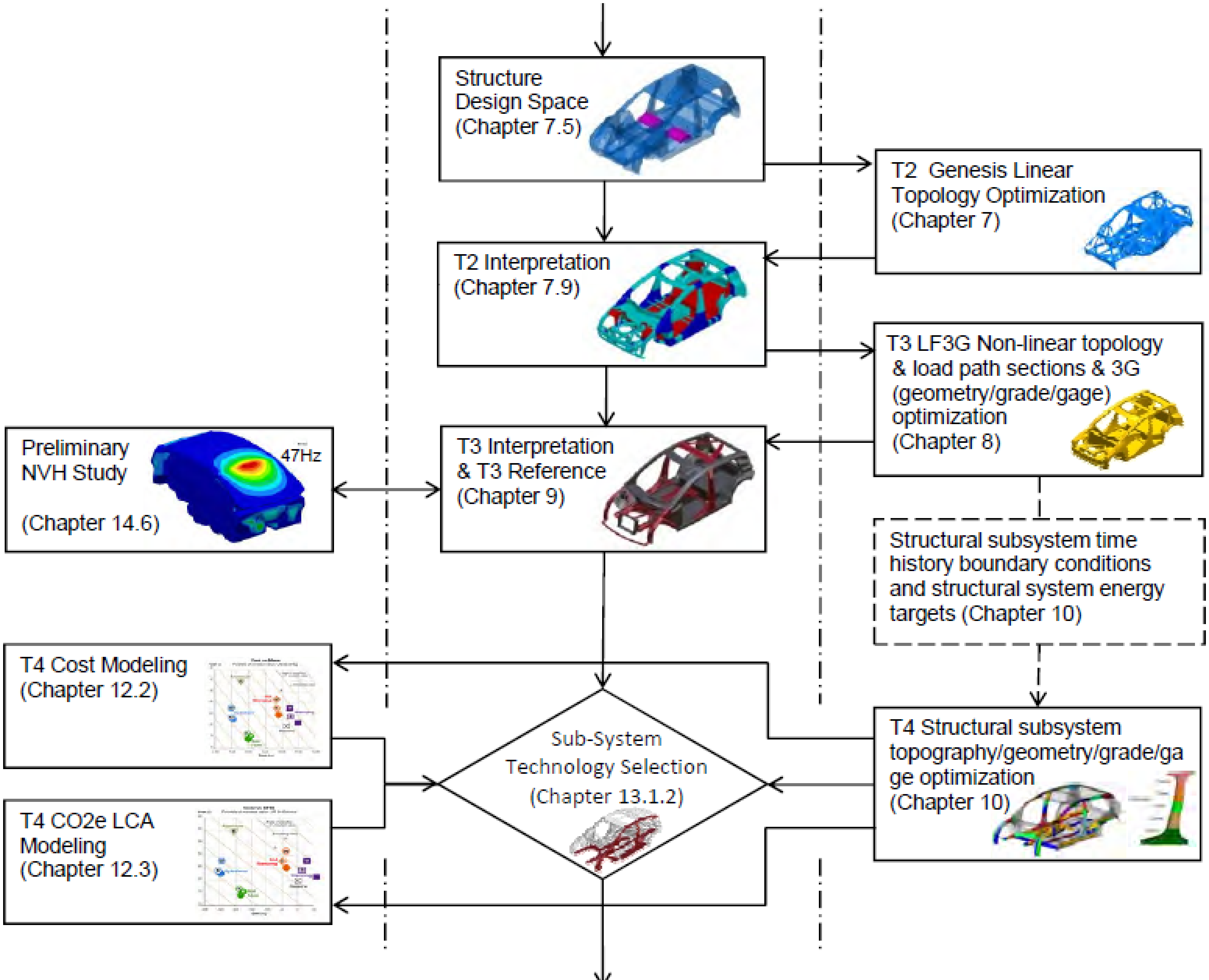
Life Cycle Assessment

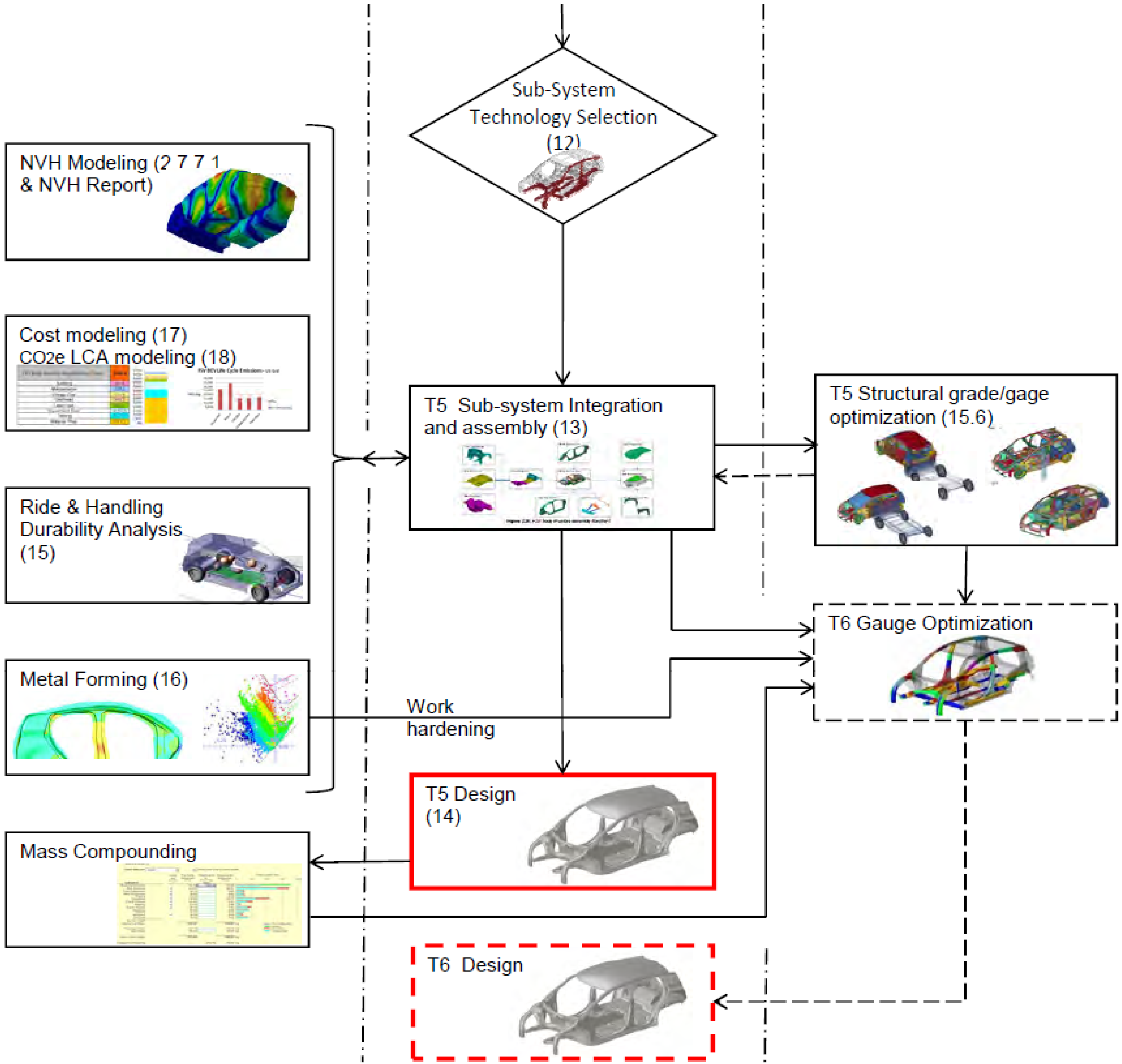
- Key Model Parameters:
  - Powertrain and energy consumption factors, Vehicle size, Geographic power grid emissions, Driving cycle, Vehicle life span, Material production, Recycling

Vehicle/Powertrain	Material Production (kg CO_2e)	Use Phase (kg CO_2e)	Recycling (kg CO_2e)	Total Life Cycle (kg CO_2e)
FSV BEV	2,337	13,844	(1,009)	15,172
ULSAB-AVC*	2,009	25,208	(841)	26,376
Polo V ICEg*	2,603	32,655	(1,124)	34,134
ULSAB-AVC BEV**	2,520	14,271	(1,088)	15,703
Polo V BEV**	2,847	15,044	(1,229)	16,662
* With internal combustion gasoline engine ** Modified to battery electric vehicle (BEV)				

Design and Engineering Process




Structure
Design Space
(Chapter 7.5)
T2 Genesis Linear
Topology Optimization
(Chapter 7)
T2 Interpretation
(Chapter 7.9)
T3 LF3G Non-linear topology
& load path sections & 3G
(geometry/grade/gage)
optimization
(Chapter 8)
Preliminary
NVH Study
(Chapter 14.6)
47Hz
T3 Interpretation
& T3 Reference
(Chapter 9)
Structural subsystem time
history boundary conditions
and structural system energy
targets (Chapter 10)
T4 Cost Modeling
(Chapter 12.2)
Sub-System
Technology Selection
(Chapter 13.1.2)
T4 Structural subsystem
topography/geometry/grade/ga
ge optimization
(Chapter 10)
T4 CO2e LCA
Modeling
(Chapter 12.3)


Sub-System Technology Selection (12)
NVH Modeling (2 7 7 1 & NVH Report)
Cost modeling (17)
CO2e LCA modeling (18)
Ride & Handling Durability Analysis (15)
Metal Forming (16)
Mass Compounding
T5 Sub-system Integration and assembly (13)
T5 Structural grade/gage optimization (15.6)
T6 Gauge Optimization
Work hardening
T5 Design (14)
T6 Design