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CAE and Testing - a hand in hand process for Crash Worthiness

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Ford Motor Company
Global Body Safety

Presentation cadence

- Global Crash Safety Landscape
- Crash Development Process
 - Role of CAE and Test
 - Crash CAE
 - Crash Testing
- History of Radioss at Ford



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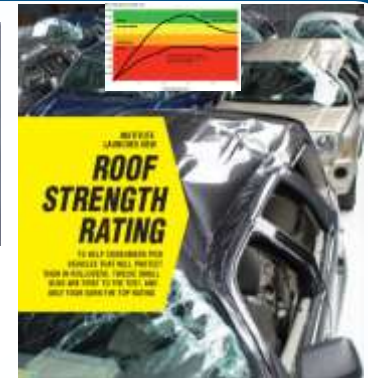
Global Crash Safety Landscape

Crash Safety – Current State

- More Regulations and Regulatory modes
- More Public Domain Rating Organizations and modes
- Global programs
- Reduced cycle time for product development
- Reduced resources while increased program complexity
- Drive toward zero prototypes

- New U.S. Regulations
 - Enhancements to FMVSS208, FMVSS214 & FMVSS216
 - Ejection mitigation
 - Pedestrian Protection (GTR)
 - Kids and Cars (Interlocks, Visibility & Window Regulators)
- More regulations due to CAFÉ (NHTSA)
- Recent NHTSA Studies
 - Continued research in Compatibility
 - Continued elderly occupant research
- Increased rulemaking activity around the world
 - Japan: Rear seat regulation
 - China: Rear seat NCAP
 - South America: European type requirements
 - India: European type requirements

- U.S. Public Domain Tests
 - New U.S. NCAP Star Rating
 - Roof Crush added to IIHS testing
 - Partial pole offset under investigation



- European
 - Changes to EuroNCAP rating system



- Rest of the world
 - ANCAP rating system enhanced to include Pedestrian Protection
 - CNCAP rating system enhancements expected



- Latin NCAP under investigation



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Global Products



Ford Fiesta



Honda Fit/Jazz



Toyota Yaris





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Program complexity

Market ----> Drive (LHD/RHD) ----> Powertrain ---->	China			Australia			South America				India				
	Left			Right			Left				Right				
	1.5L Sigma TiVCT DPS6 A6	1.5L Sigma TiVCT iB5	1.0L Fox GTDI DPS6 A6	1.5L DV5 CRDI iB5	1.5 SIGMA (added)	1.0L Fox GTDI (iB5 / DPS6)	1.6L Sigma PFI FFV iB5	2.0L New I4 PFI FFV DPS6 AT	2.0L New I4 PFI FFV DPS6 AT	2.0L New I4 PFI FFV MMT6	1.5L DV5 iB5	1.5L Sigma Gas iB5	1.5L DV5 CRDI iB5	1.5L DV5 CRDI iB5	1.0L Fox GTDI iB5 (or DPS6)
Test Mode															
FRONT	FF 48kph (ECE12, ECE34, ADR10, NZ32003, AIS96, BG11557)														
	China GB11551-2003 (30mph FF) / China NCAP														
	SDG/Legal - 35mph (56kph)														
	Core SDG / ECE94 / CNCAP / CONTRAN (ODB 35mph)														
	SDG, ANCAP Offset 64kph (40mph)														
SIDE	ECE 95 - Brazil / Chile / CNCAP / India														
	ANCAP (based on ECE95)														
	ANCAP/CNAP 18mph 10" Perp Side Pole														
REAR	SDG / NBR 15241 / ECE34														
	GB 20072/2006 ECE 34														
	SDG/FMVSS 301 (50mph/70%)														
	SDG/FMVSS 301 (50mph)														

Test/CAE

CAE

Global Programs
Around 5 development prototypes and 9 tests
Around 41 verification prototypes and 70 tests



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Program complexity

		TEST MODE	Body Style A	Body Style B			TEST MODE	Body Style A	Body Style B
Front - 5% Female		12/14mph(LOMD)/90/BLT(no bag)			Side Sensor		cart/ no deploy (1st row)		
		17mph(LOMD)/90/BLT(no bag)					cart/ no deploy (2nd row)		
		22mph(HOMD)/90/UNB(stage1)(stage1)					Side Abuse		
		25mph(HOMD)/90/BLT(stage1)(stage1)					Threshold (12mph) pole must deploy (1st row)		
		25mph/40%OFFSET/DOB/BLT(no bag)(no bag)					Threshold (12mph) pole (2nd row)		
		25mph/40%OFFSET/DOB/BLT(stage1)(stage1)					Threshold (12mph) pole (3rd row)		
		25mph/40%OFFSET/DOB/BLT(stage1)(stage2)					Threshold (12mph) pole must deploy (1st row) w/ running boards		
		25mph/90/UNB(stage1)(stage2)					Threshold (12mph) pole (2nd row) w/ running boards		
		30mph/90/BLT(stage1)(stage2) (Canadian)					cart/must deploy (2nd row)		
		35mph/90/BLT(stage1)(stage2)					cart/must deploy (1st row)		
Front - 50% Male		17mph(LOMD)/90/BLT(no bag)			Rear		50mph / CC/ Side forward of rear axle		
		20mph(LOMD)/30LA/UNB(no bag)					50 mph / DMB / Side/ Fuel Filler		
		20mph(LOMD)/30RA/UNB(no bag)					55 mph / DMB / Fuel Side/ 70% Overlap		
		22mph(HOMD)/90/UNB(stage1)(stage1)					55 mph / DMB / Non-Fuel Side/ 70% Overlap		
		25mph(HOMD)/90/BLT(stage1)(stage1)				Side		33.5mph/DMB/SID/ISfrg & ES2re	
		25mph/30LA/UNB(stage1)(stage1)					38.5mph/DMB LINCAP / Fuel Side		
		25mph/30RA/UNB(stage1)(stage1)					38.5mph/DMB LINCAP / Non Fuel Side		
		25mph/30LA/UNB(stage2)(stage2)					38.5mph/DMB LINCAP w/o Curtain		
		25mph/30RA/UNB(stage2)(stage2)					20mph/10° Oblique Pole/ES2re		
		25mph/90/UNB(stage2)(stage2)					20mph/10° Oblique Pole/SID/ISfrg		
		31mph/30LA/UNB(stage1)(stage1)					Threshold/10° Oblique Pole/ES2re		
		31mph/30RA/UNB(stage1)(stage1)					Threshold/10° Oblique Pole/SID/ISfrg		
		35mph/90/BLT/NCAP(stage2)(stage2)					18 mph POLE - 10° 50th SID/HYB II with running boards		
		40mph/40%OFFSET/DOB/BLT(stage1)					18 mph POLE - 10° 50th SID/HYB II without running boards		
		40mph/40%OFFSET/DOB/BLT(stage2)				IIHS Side Impact w/o curtain			
Front Sensor		8mph(LOND)				IIHS Side Impact			
		[TBD]mph(LOND)/VTV(LEFT)/UNB							
		8mph(LOND)/UCH							
		10mph(LOND)/BOR							
		ROUGH ROAD / ABUSE							
		17mph(LOMD)/8° POLE/UNB							
		30mph(HOMD)/8° POLE/BLT							
		[TBD]mph(LOND)/VTV/BLT							
		[TBD]mph(LOND)/VTV/UNB							

Test/CAE

Subsystem test/CAE

North American Programs
 Around 5 development prototypes and 9 tests
 Around 38 verification prototypes and 65 tests

European Programs
 Around 5 development prototypes and 6 tests
 Around 42 verification prototypes and 55 tests

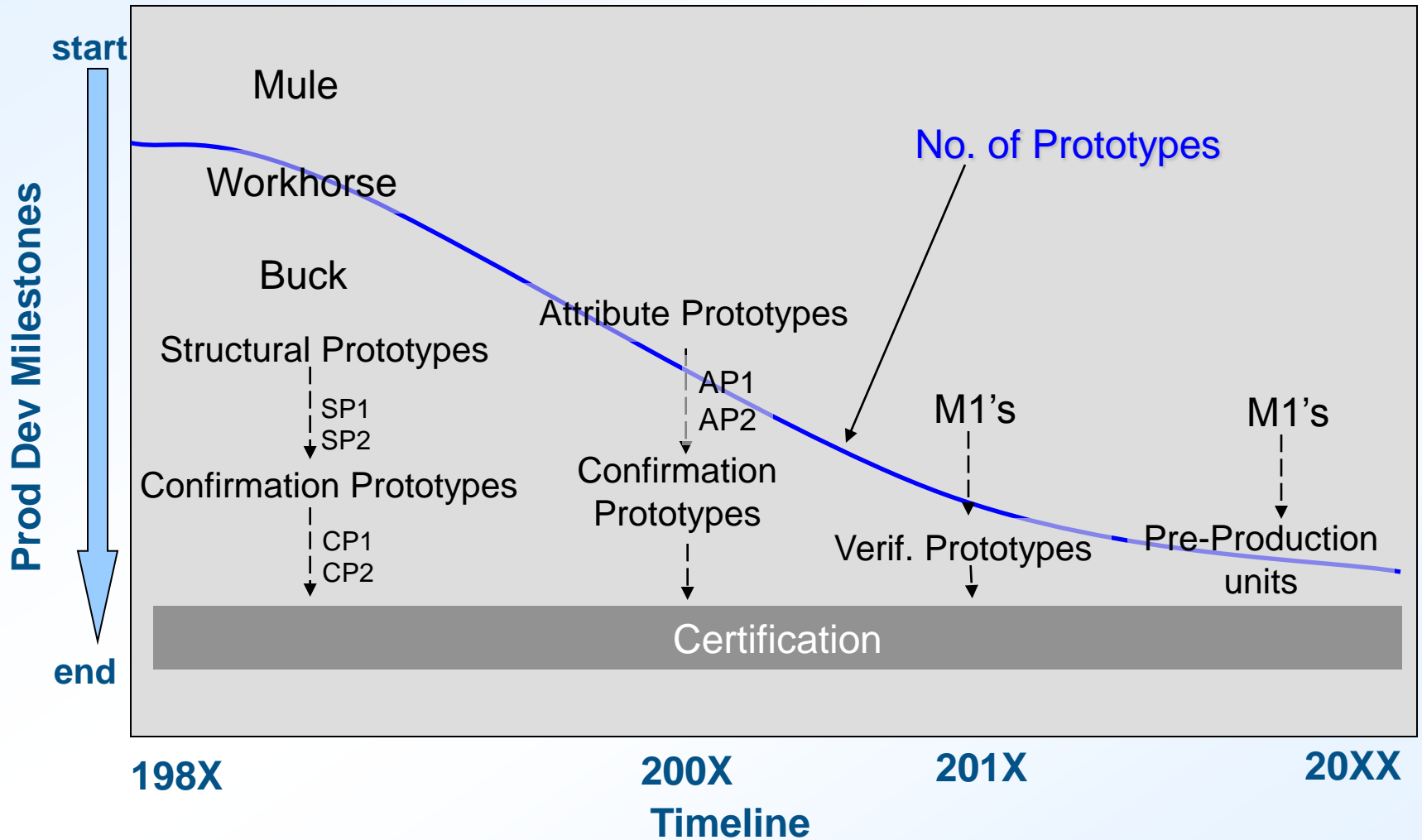


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Drive toward zero prototypes

Crash Safety Prototype Trend



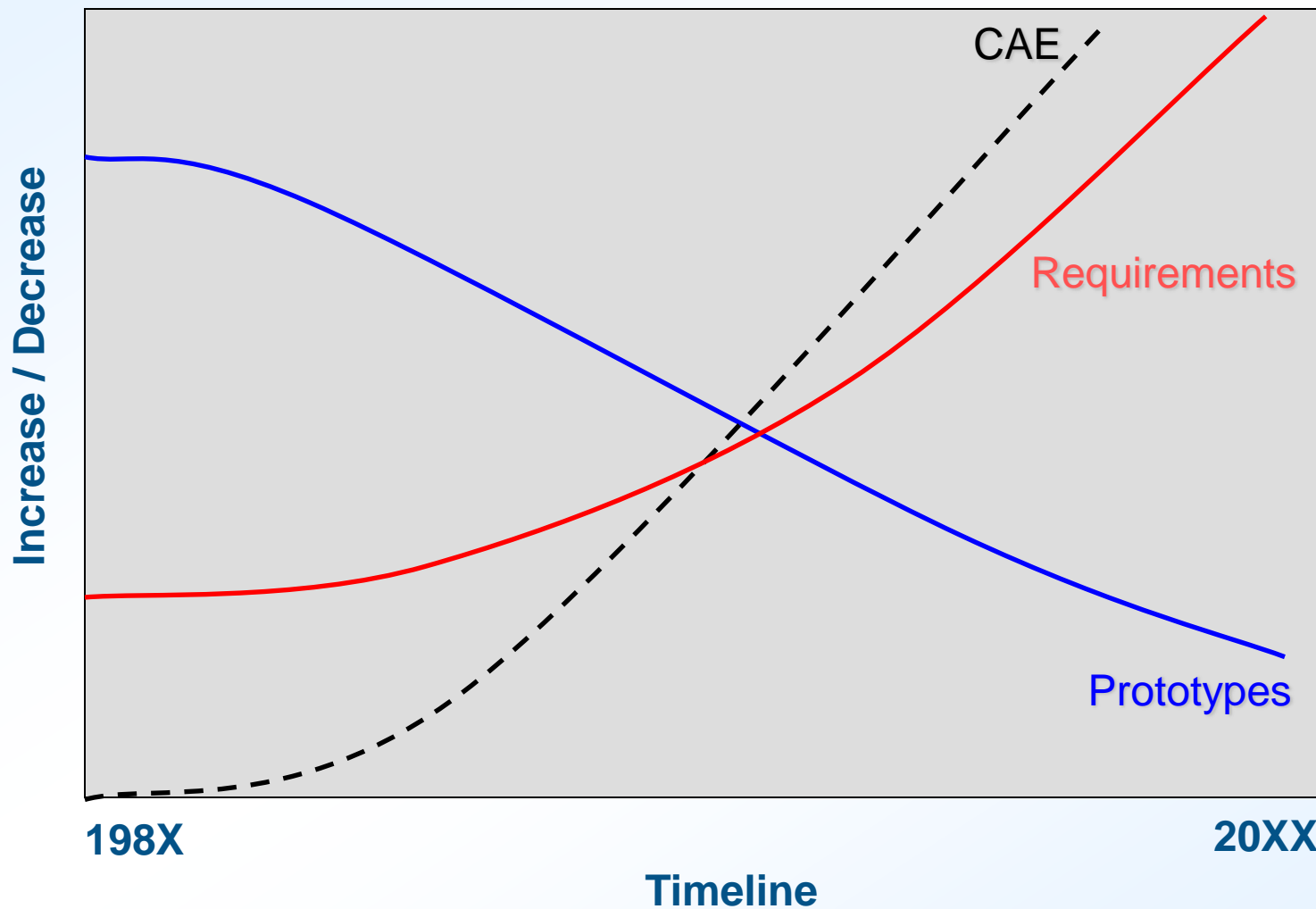


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Crash Prototype Reduction

Crash Safety Landscape





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Crash Development Process



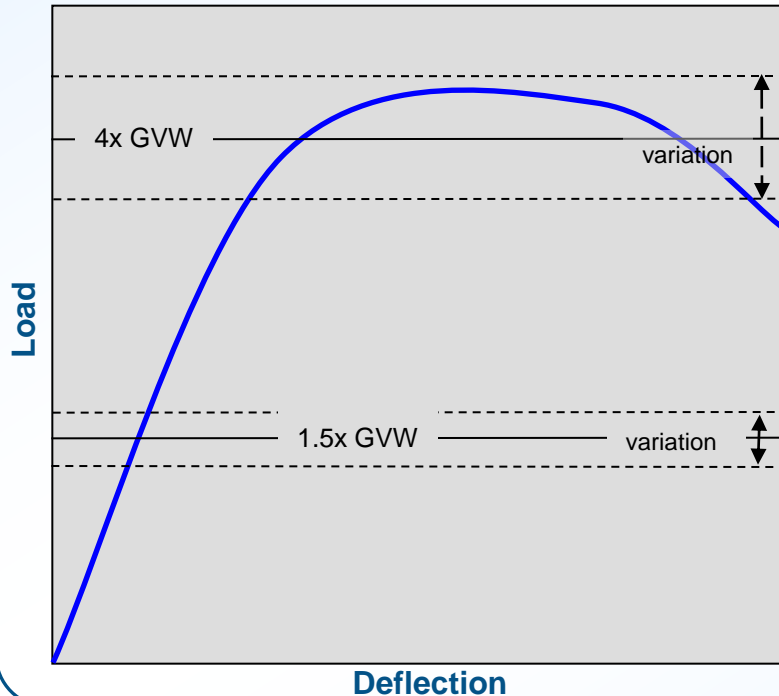
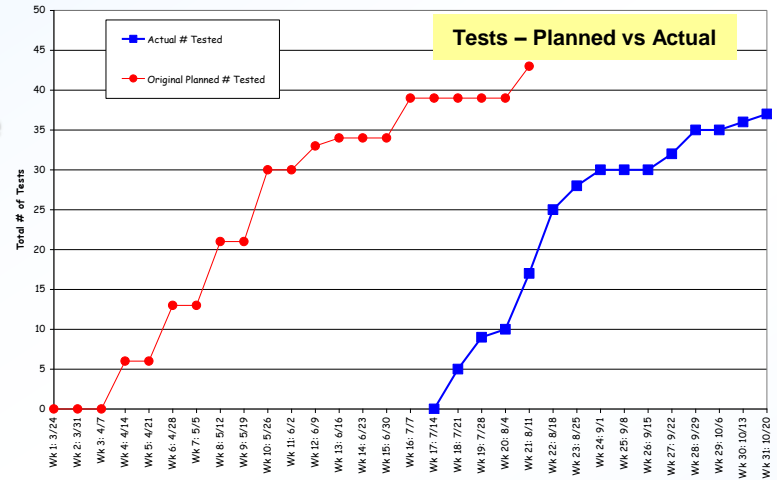
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Product Development Process – CAE vs Test

Tests

- Availability of resources
- Availability of representative parts in time
- Delays in testing
- New requirements
- More late Changes



CAE

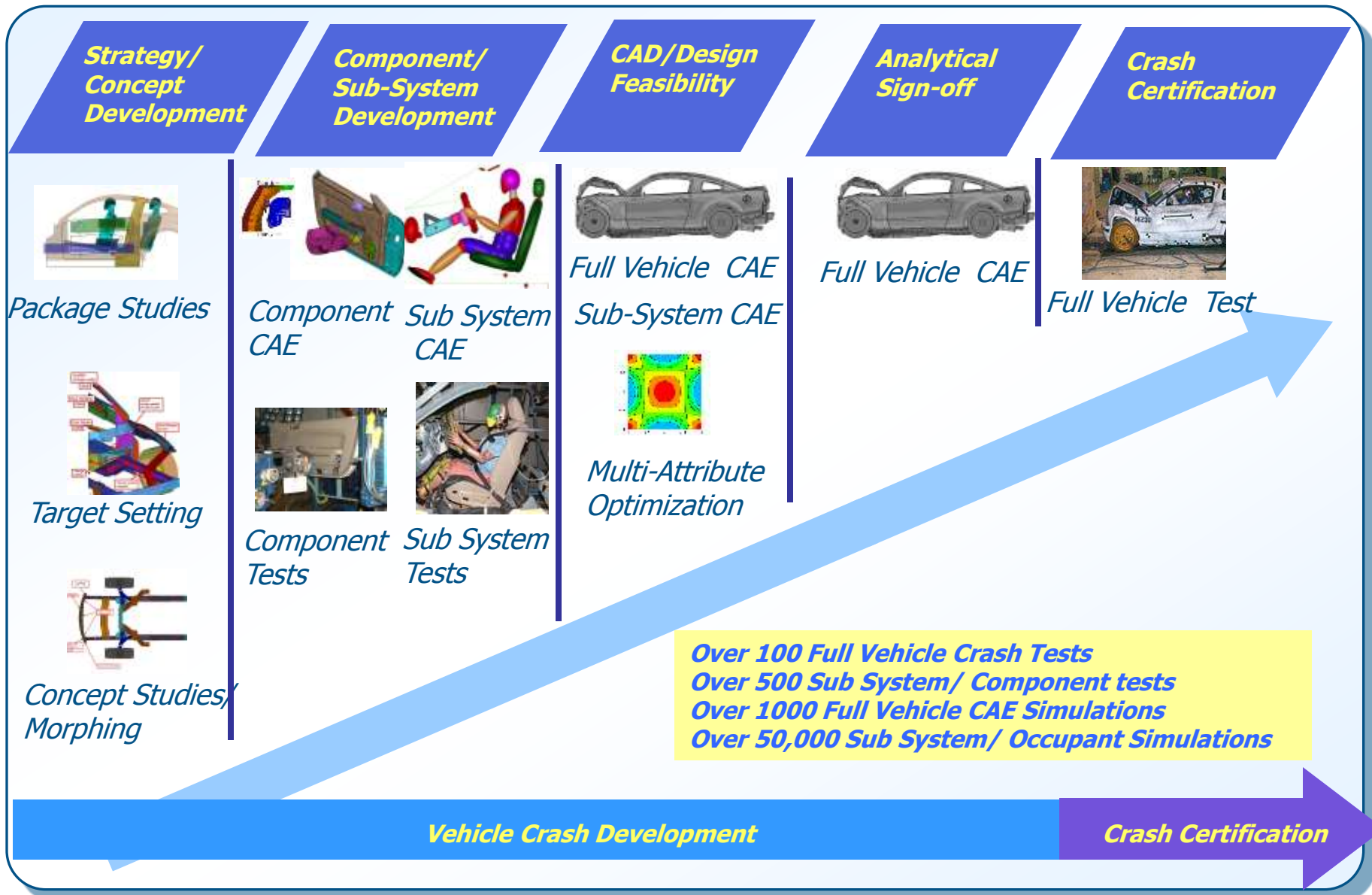
- Ability to sign-off the attribute using CAE
- Predictability of CAE under extreme conditions
- CAE capability
- New requirements



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Product Development Process – CAE and Test





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CAE Enablers

- Morphing and Parametric modeling, Target setting tools
- Synchronous CAE Model build process and tools
- Automated results processing and comparison
- Fully Integrated System models as well as Sub-system 'cut' models
- Material Failure risk and other advanced predictive CAE technologies
- Unique computation speed with accuracy improvements in Radioss

- Global Standardized Dummy and Barrier DB
- Global Standardized Material DB, Spotweld DB
- Design Robustness using CAE
 - Material failure prediction,
 - Weld presence/position, etc
- Test variability using CAE
 - Impact speed/location, Occupant position, Test weight etc

- Established Safety CAE Methods
- Modeling and Analysis Best Practices
- Design Disciplines
- Working Groups
- Program Peer Reviews, Model Quality Reviews
- Lessons Learned, Bookshelving program experience



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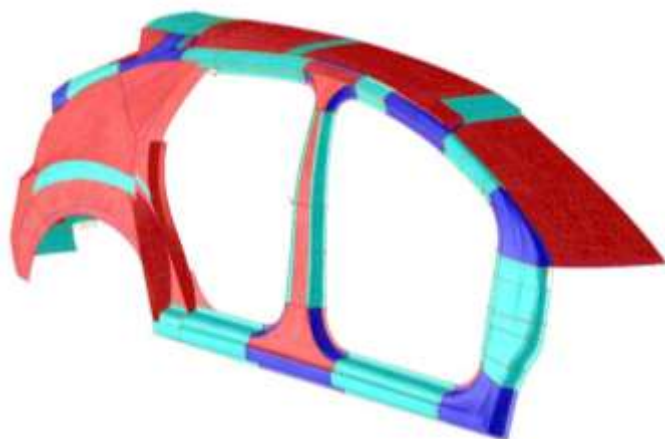
CAE Enablers

Morphing Tools

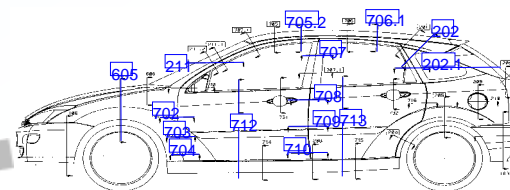
Benefit = Quick/early assessment



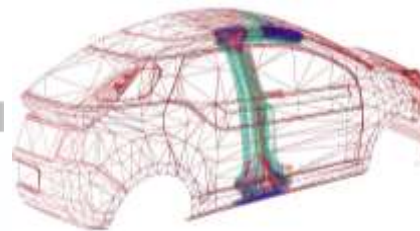
Model creation with different input sources



Vehicle upper structure

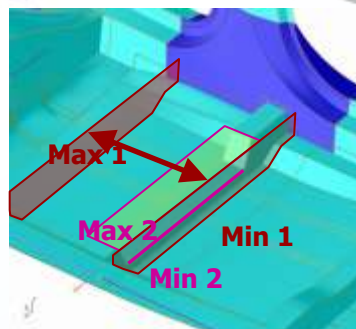


Master Sections



B-Pillar proposal and Design scan

Package boundaries; Hand written sketches; others



Design Variables

- Position of seat x-member
- X-section height of member



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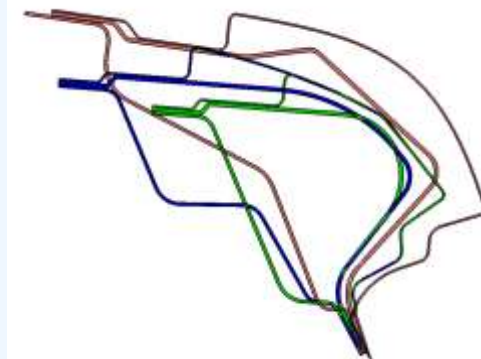
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B.E.A.T. - Ford internal tool

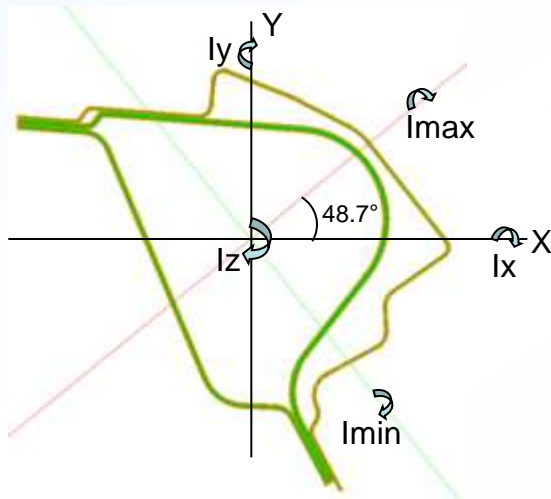
CAE Enablers

Benefit = Target setting

- Section analysis
- Benchmarking
- Proportioning
- Early studies
- Target setting



- IIHS Front Offset
 - Axial (column) Stiffness
 - Bending Stiffness: Ix, Iy
- IIHS Side Impact
 - Torsion: Iz
 - Bending Stiffness: Iy
- Roof Strength
 - Axial Load Capacity
 - Bending: Ix



vs Veh A	Area		104%	93%	76%	89%
	Imin		57%	45%	32%	41%
	Imax		114%	76%	37%	68%
	Jo		139%	96%	51%	67%
vs Veh B	Area	96%		89%	73%	86%
	Ix	175%		70%	56%	67%
	Iy	88%		66%	32%	54%
	Iz	72%		69%	37%	48%



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Safety CAE – Synchronous Model Build

CAE Enablers

Benefit = 3 week Model build w/up to-date design

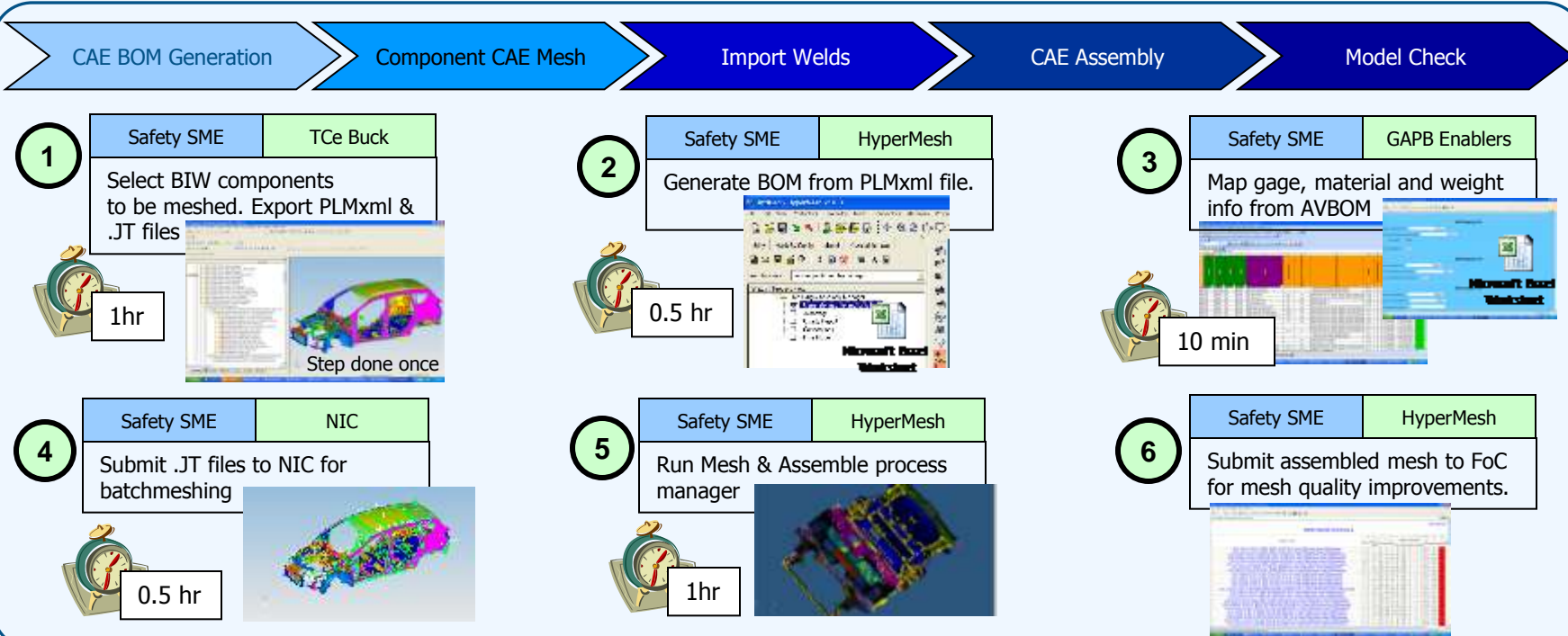
CAE Model Build Process

Previous state

- Start model build @ CAD DRD
- Model content is static while CAD state is dynamic
- Deliver model 4 wks after CAD DRD or 2 wks after milestone gateway
- Model content no longer representative of CAD
- Further model updates = late assessment timing

Current state

- Start model build 2 weeks prior to CAD DRD
- Automatically monitor CAD changes, continuous model updates
- Deliver model 1 wk after CAD DRD or 1 wk **before** milestone gateway
- Model content is relevant to CAD state
- On-time CAE assessment to support milestone gateway





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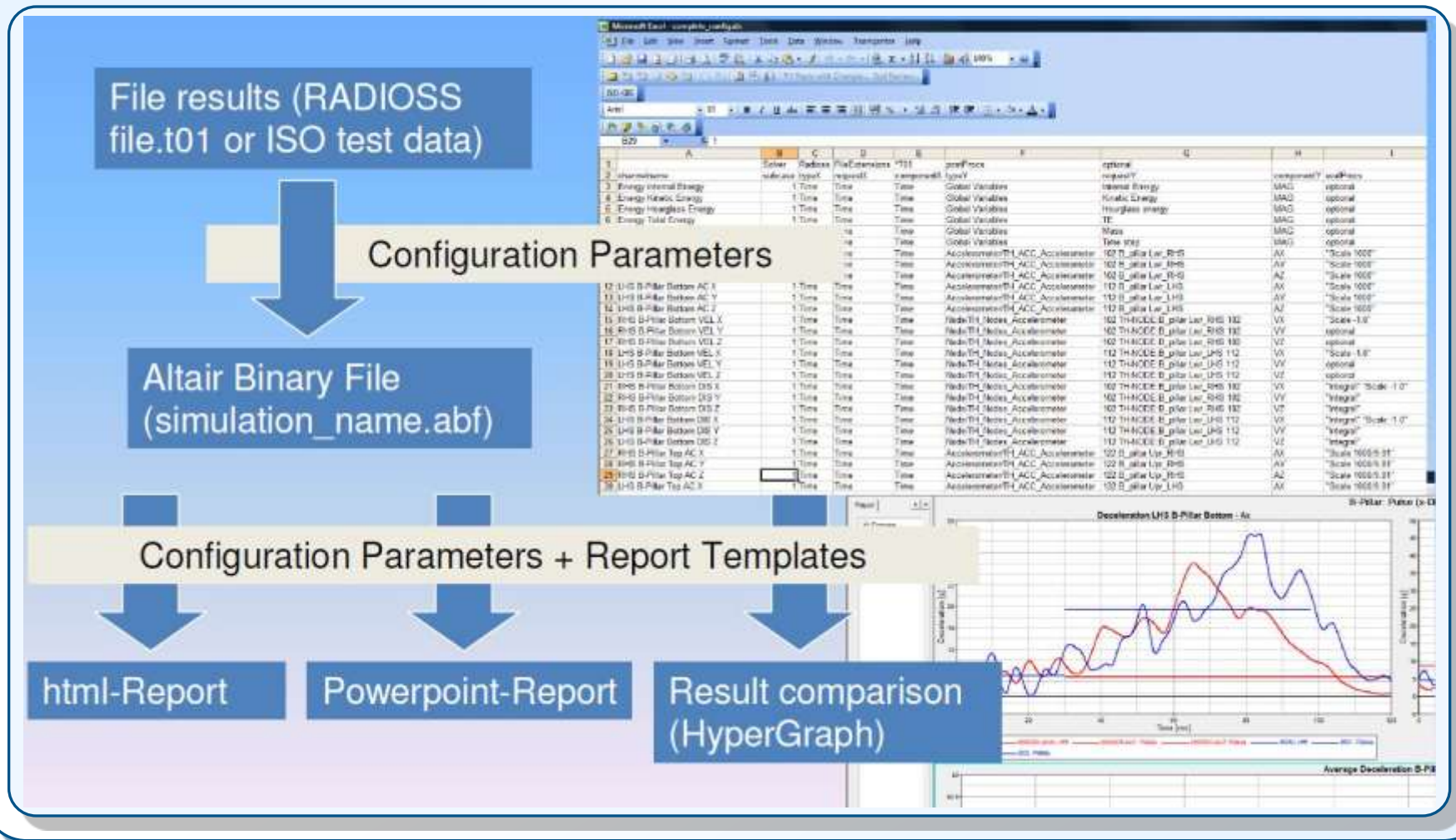
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CAE Enablers

Altair AutoPost Post-processing Tool

Benefit = Increased productivity

Automatic Results Processing, Report Creation and Results Comparison





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Fully Integrated System Model

CAE Enablers

Benefit = Prototype and Test reduction

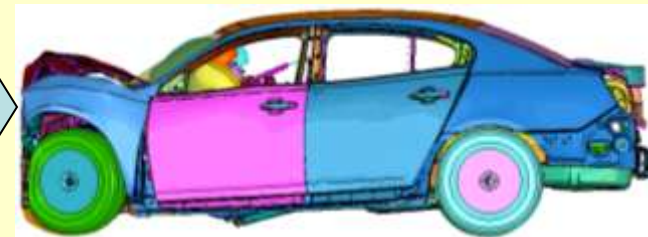
RBD - Madymo



Madymo-FE Coupled

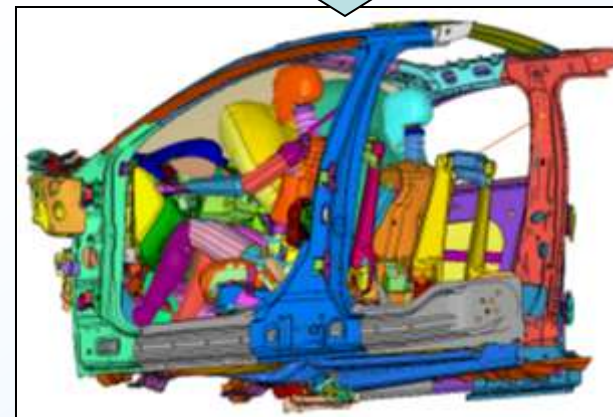


Full Vehicle integrated FEA



Objective: To have a robust CAE Tool that can:

- Predict vehicle kinematics, intrusions & deformations
- Predict occupant kinematics
- Take into account interaction of occupant(s) with
 - Restraint systems & Vehicle Interior environment
- Predict occupant injury responses
- Evaluate effectiveness of countermeasures



Simplified Model

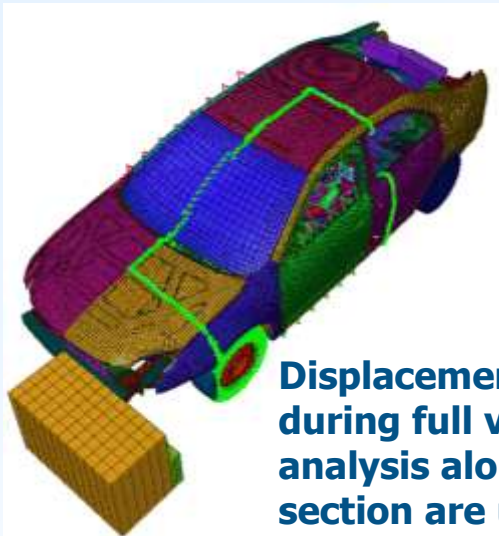
- Using RADIOSS Cut-methodology
 - Full model is reduced to area of interest
 - Boundary Conditions from full model are applied
 - Faster iterations for evaluating Countermeasures



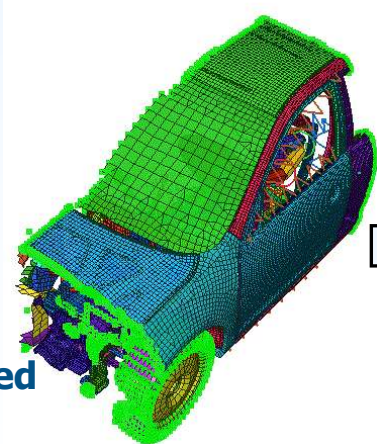
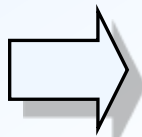
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Radioss Sub Modeling

CAE Enablers



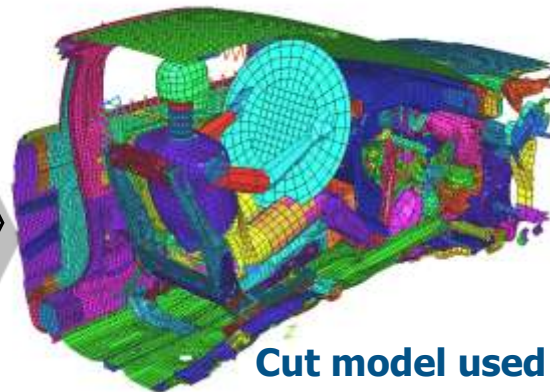
Displacements computed during full vehicle analysis along a defined section are used as an input in the cut model.



Easy definition since fully supported by HyperCrash

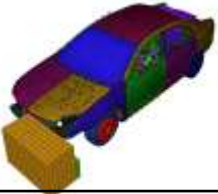
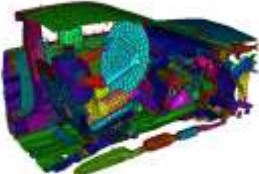


Benefit = Speed and Productivity



Cut model used for design iterations

**Industry first
production
application**

	Number of elements	CPU Time (42t, SPMD 12 procs)
	355.000 elements	6.6 hours
	150.000 elements	2.6 hours



CPU time decreased by 60%



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Material Failure Prediction

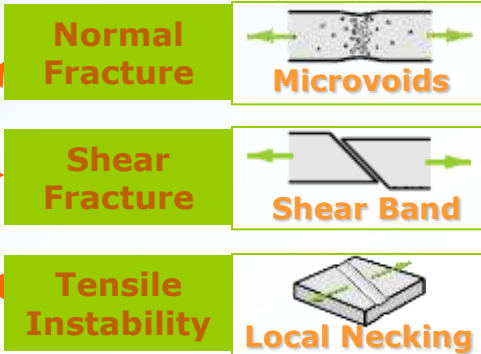
CAE Enablers

Benefit = Design Robustness & increased CAE prediction capability

RADIOSS+CrachFEM Coupling

Industry first production application

Material Failure



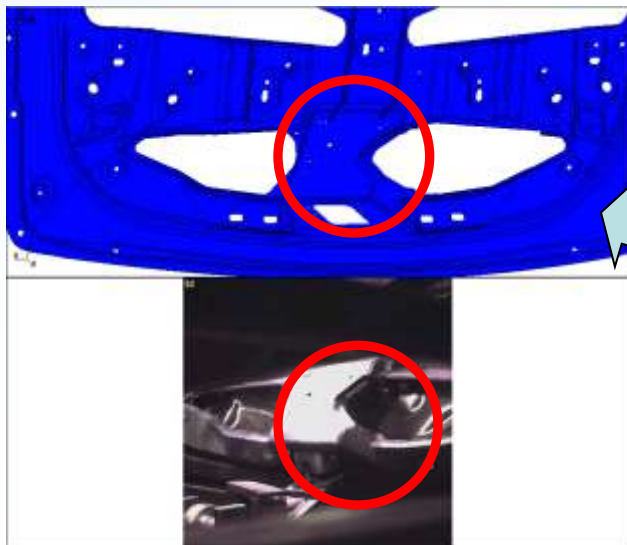
Radioss Law29-user defined

Magnesium Liftgate



Industry First

component CAE



Zero Prototypes



vehicle CAE

Direct to Certification ✓



Sled Test



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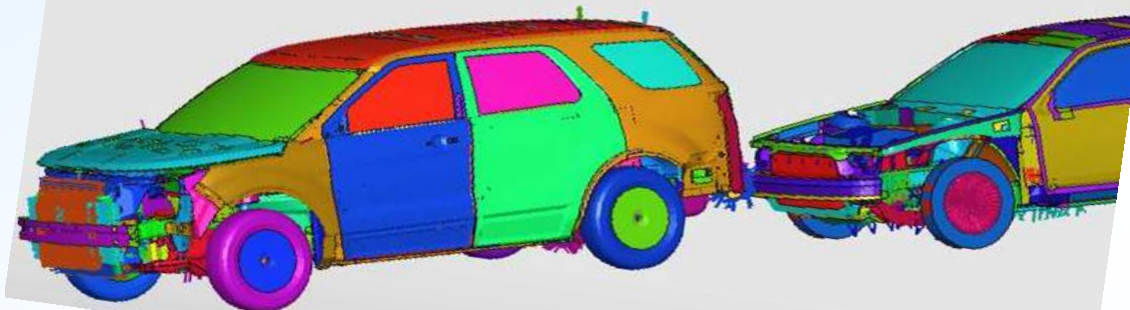
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Fuel Tank Sloshing

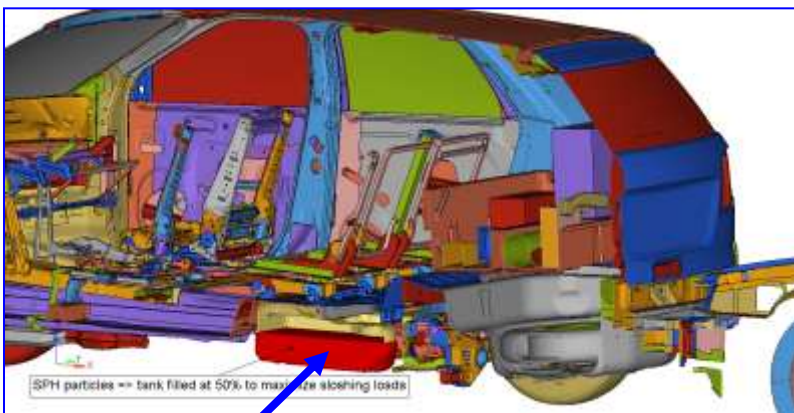
CAE Enablers

Benefit = Increased CAE prediction capability

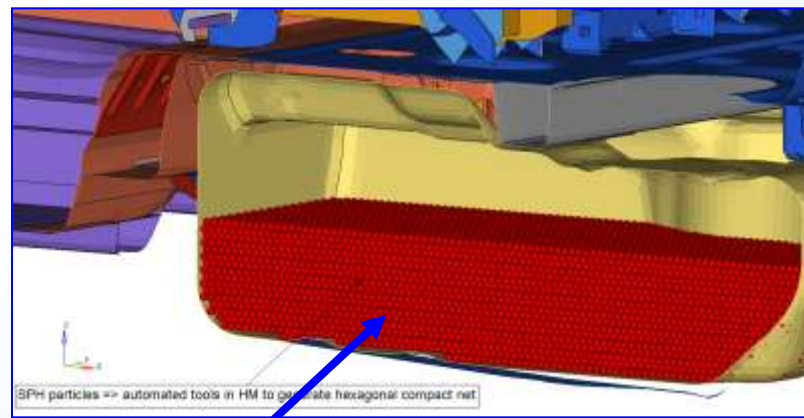
Prediction of Pressure Loads and Deformation



SPH is the optimum solution among ALE, CEL and SPH methods



SPH particles > tank filled at 50% to maximize sloshing loads



SPH particles > automated tools in HM to generate hexagonal compact net



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Implicit-Explicit FE methods

CAE Enablers

Pre-crash quasi-static loading

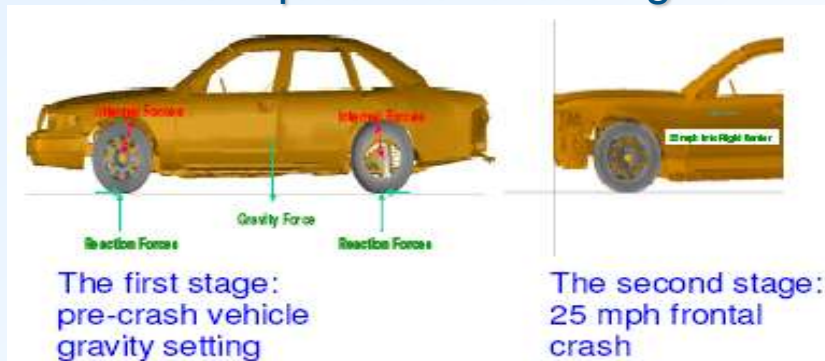
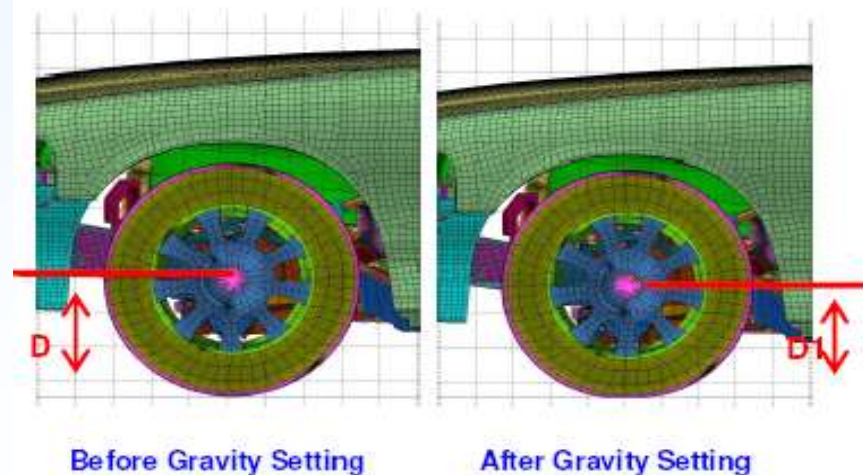


Figure 1. Illustration of two-stage CAE simulation



$$\text{Tire Deformation} = D - D1$$

Figure 5. Illustration of tire deformation for explicit and implicit pre-crash vehicle gravity setting simulations

Benefit = Increased CAE prediction capability

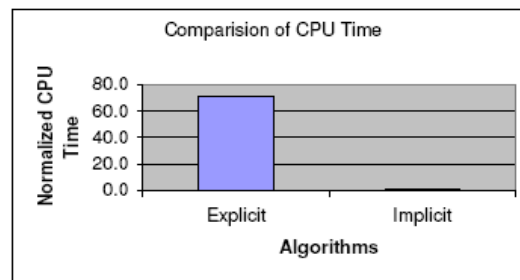


Figure 2. Pre-crash vehicle gravity setting simulation

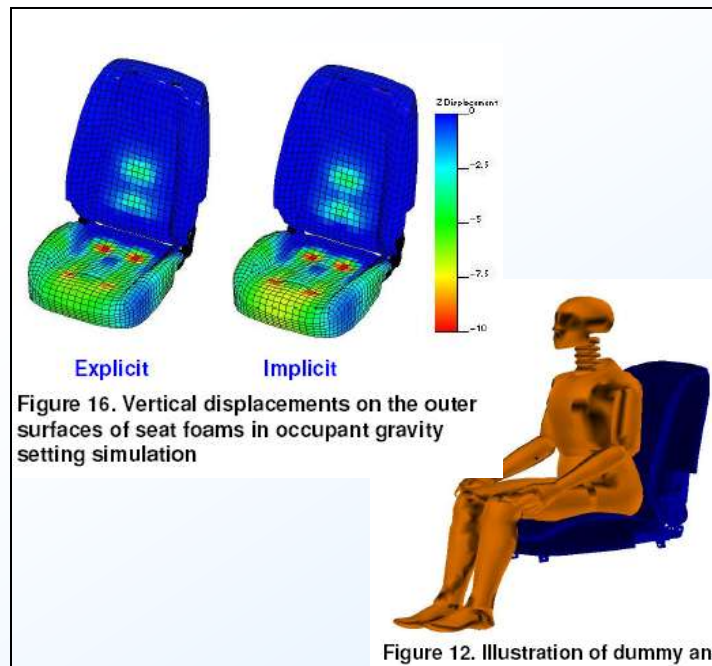


Figure 16. Vertical displacements on the outer surfaces of seat foams in occupant gravity setting simulation

Figure 12. Illustration of dummy and



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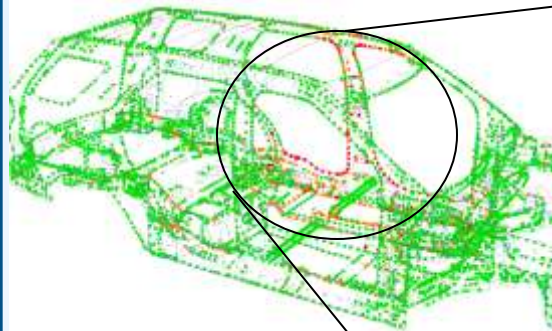
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CAE Enablers

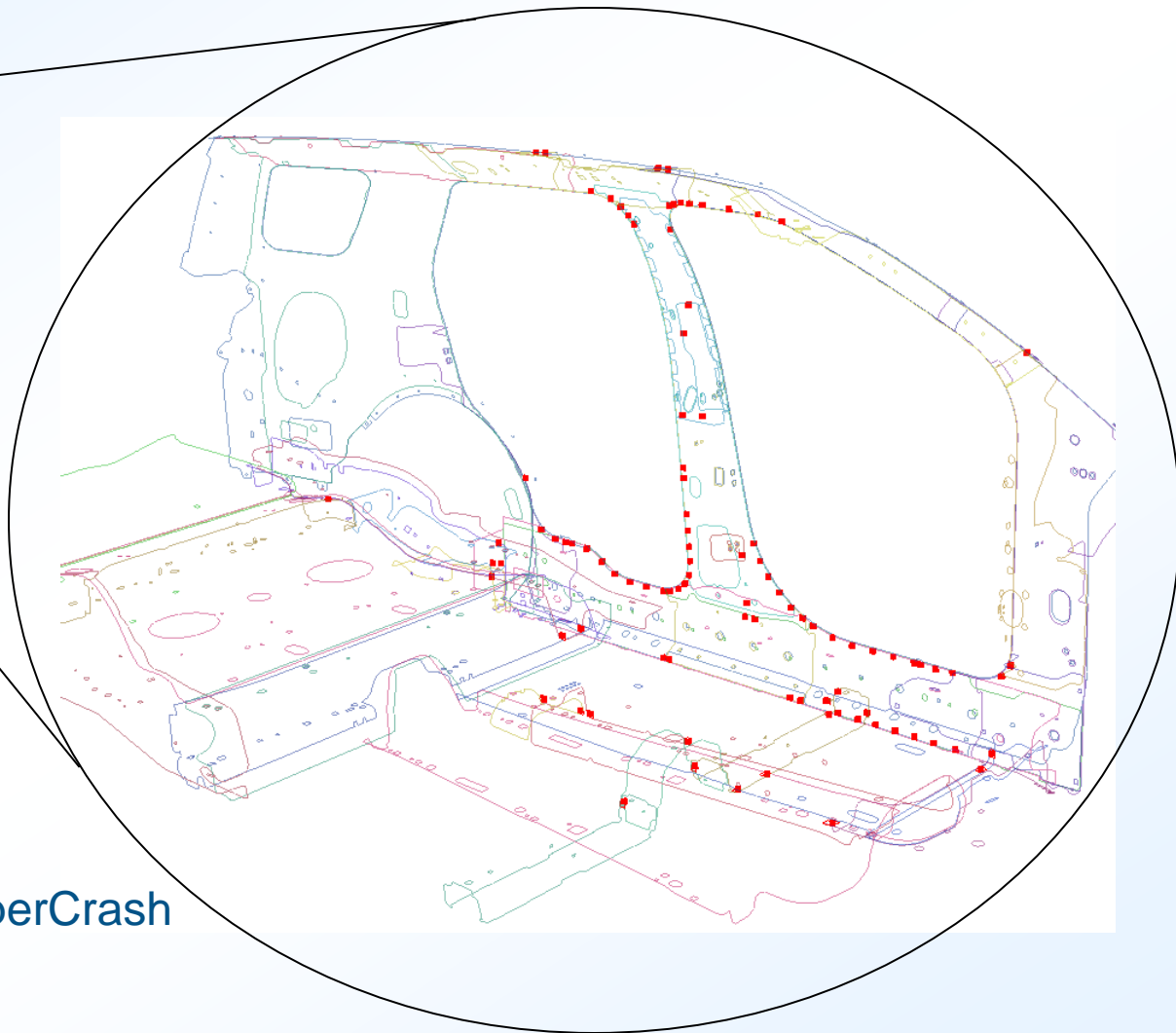
Spotweld Failure/Force Contour

Enabler in determining the number of welds and placement

Benefit = Design Robustness



No Force
Loaded
Failure Limit



- Welds selected for TH
- Post-processing with HyperCrash



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Radioss Multi-Domain

CAE Enablers

Benefit = Computation speed, Productivity

Mg Liftgate with Radioss - CrachFEM coupling

- Crach-FEM accuracy improves with finer mesh
- Vehicle model is split into two domains, one for the Liftgate, one for the rest of the vehicle
- Each domain is computed as an independent Radioss run
- Each run communicates to a managing process (Rad2rad) to ensure the common node and contact coupling
- Time step is different on each domain
- Results are same
- CPU time factor of 2

Elapsed time : Single Domain Multi-domains
 3 days 1.5 days

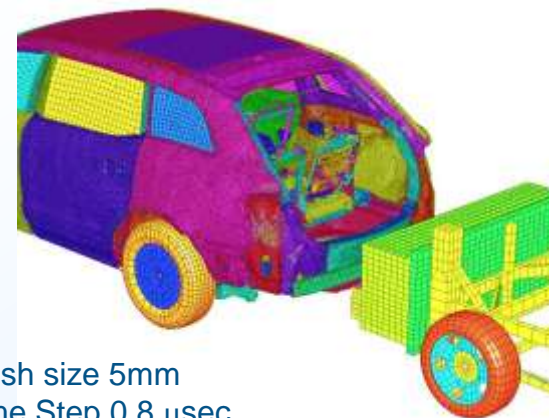
Domain 1

Mesh size 1.5mm
Time Step 0.2 μ sec



Domain 2

Mesh size 5mm
Time Step 0.8 μ sec





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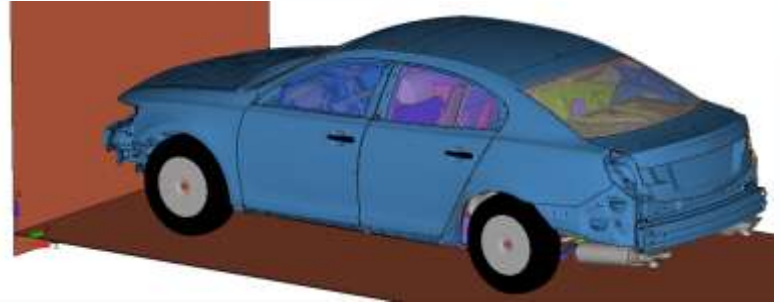
Radioss Advanced Mass Scaling

CAE Enablers

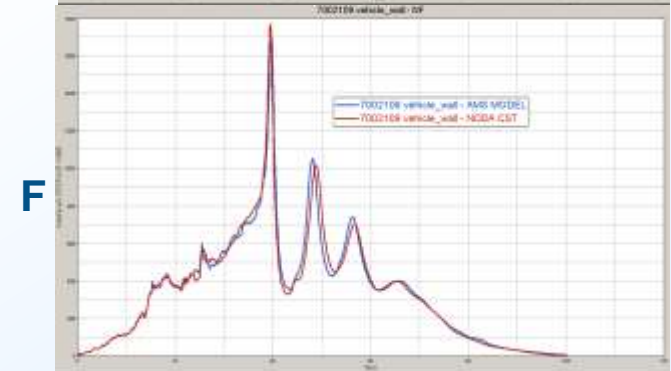
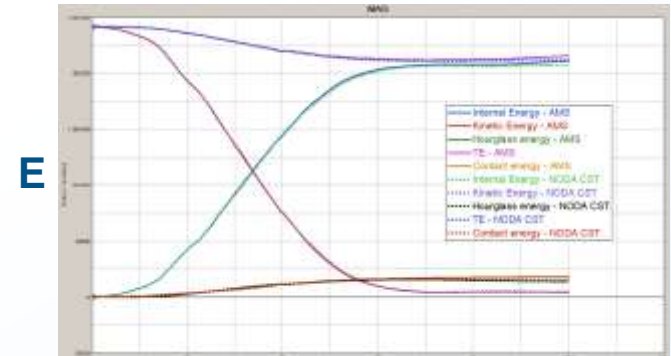
AMS on a Fully Integrated Vehicle System Model 1.3M elements

Benefit = Computation speed, Productivity

- Alternative to conventional Mass Scaling
- Adds mass to the non-diagonal mass matrix
- Results match well



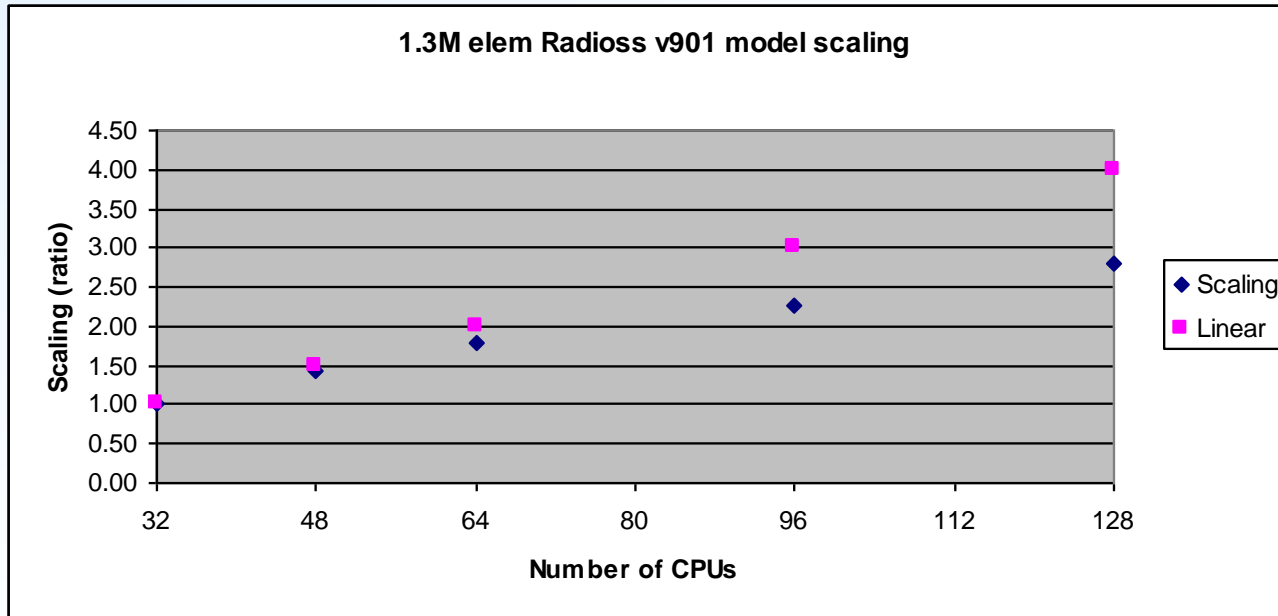
	NODA CST	AMS	AMS
Time step (s)	4e-4 (Stfac 0.67)	1.6e-3 (Stfac 0.67)	2.4e-3 (Stfac 0.67)
Energy error	-12.3%	-10.8%	-9.6%
Added mass	0.2839%	0.2552%	0.2552%
Number of cycle	251500	75100	54666
Cpu time (s)	80574	60732	49973



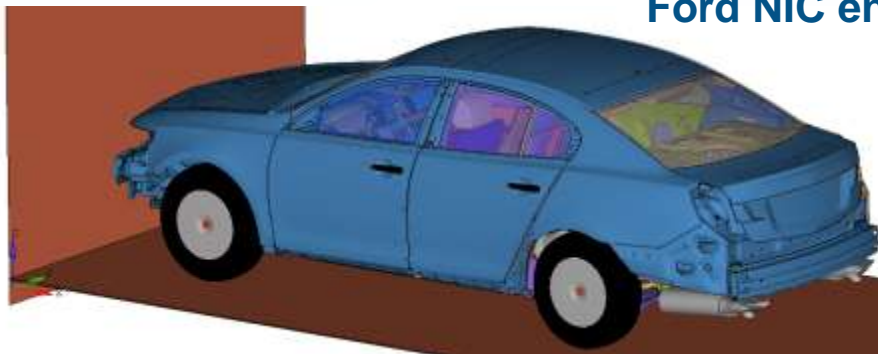
Radioss Scalability

CAE Enablers

Benefit = Computation speed, Productivity



Fully Integrated Vehicle System Model 1.3M elements
Ford NIC environment ECS51 AMD Opteron cluster





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Crash CAE future direction

- Advancing Safety Methods
 - Close CAE gaps
- Digital Design Process
 - Fully Integrated CAD/CAE
- Single CAE tool across functional attributes
 - Enable Concurrent Design/MDO
- Occupant analysis w/Semi-rigid dummies
- Further CAE efficiencies
 - process and tools

- Vehicle testing is trending from a development tool to a verification tool
- Component and sub-system testing during development phase
- Platform verification through minimal vehicle level testing
- Vehicle sign-off using tests in combination with CAE
- Vehicle tests are primary source of data for sensor calibration
- Test efficiencies maximized through use of CAE, sub-system testing and re-hit strategy

Crash testing future direction

- Increased upfront testing to verify platform, validate the hard points and correlate CAE models
- Continue component and sub-system testing during development phase
- Verification testing with production tooled parts
- Continue to pursue test efficiencies through reduction of tests and re-use of vehicles and parts

CAE & Testing a hand in hand process in Crash Worthiness

- Testing leads for new hardware and crash modes
 - New dummies, new Barriers
 - New crash modes
 - New vehicle types like BEV's & HEV's
- Testing leads the certification & homologization process
- CAE leads in well known and developed areas
 - Dummies, Barriers, crash modes, vehicle types
- CAE leads the entire development process of the vehicle
- A well integrated Test/CAE plan is required to manage the current and future challenges in Crash Safety



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History of Radios at Ford

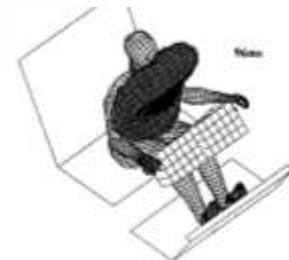


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Crash CAE history at Ford

- 1986: First usage of Radioss
- 1987: First Full Vehicle FEA Model - NCAP
- 1989: Sensor System Development For Airbags
- 1989: First Side Impact FEA Vehicle Model
- 1990: Industry First Rigid Body SID, H-III Dummies
- 1990: First Concept/Interior System FE/Hybrid Modeling
- 1991: First Roof Strength FEA
- 1992: First Offset Deformable Barrier
- 1992: Industry First Detailed SID, H-III FE Dummies
- 1993: Industry First Fully Integrated FE Vehicle System Model
- 1994: First Multi-chambered FE Side Airbag
- 1994: First Interior Head Impact FEA
- 1995: EEC PLASCORE deformable FE Barrier
- 2002: Fuel Tank sloshing using SPH
- 2008: Industry First Mg Liftgate - Failure Prediction CAE



History of Radioss at Ford

- Radioss used beginning ~1986
- Used exclusively for Crash from ~1992
- Used for FE Occupant Development
- Used for Safety Methods Development
- Part of Safety Best Practices ~1996
- Many Radioss Developments/Firsts at Ford
- Driving Advanced Crash Features / Applications
- Crash Safety papers/presentations/publications at SAE/Stapp/ASME/NASA etc.

Radioss Key Benefits and Features

- Radioss Expertise through Experience
 - 20+ years of Safety CAE Methods Devt & Crash Engineering using CAE
 - Deep understanding of tool, maximizing capabilities
 - Enhancements and advances
- Reliable and robust
 - Accurate
 - Fault tolerant
 - Repeatable
- Suitable for Industry environment
 - Focus on Crash Simulation
 - Simple and uncomplicated to use, Easy to debug, Flexible
 - Powerful options when and where needed
- Cost effective
 - Submodeling
 - Multidomain, AMS
 - Scalable
 - Productivity enhancers
 - HyperCrash
- Dedicated on-site support team



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Thank You