AN INTEGRATED HIGH-PERFORMANCE COMPUTING RELIABILITY PREDICTION FRAMEWORK FOR GROUND VEHICLE DESIGN EVALUATION

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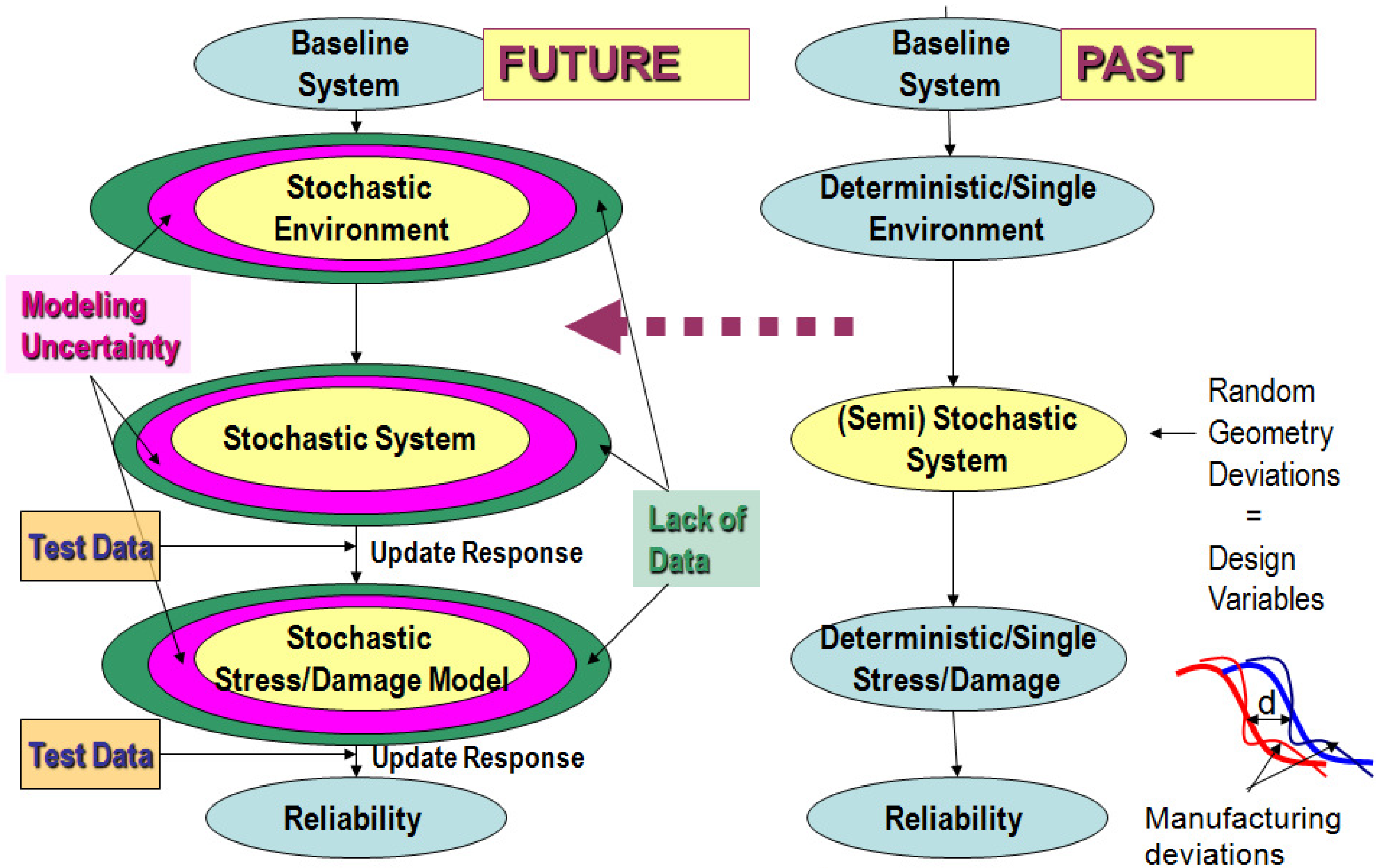
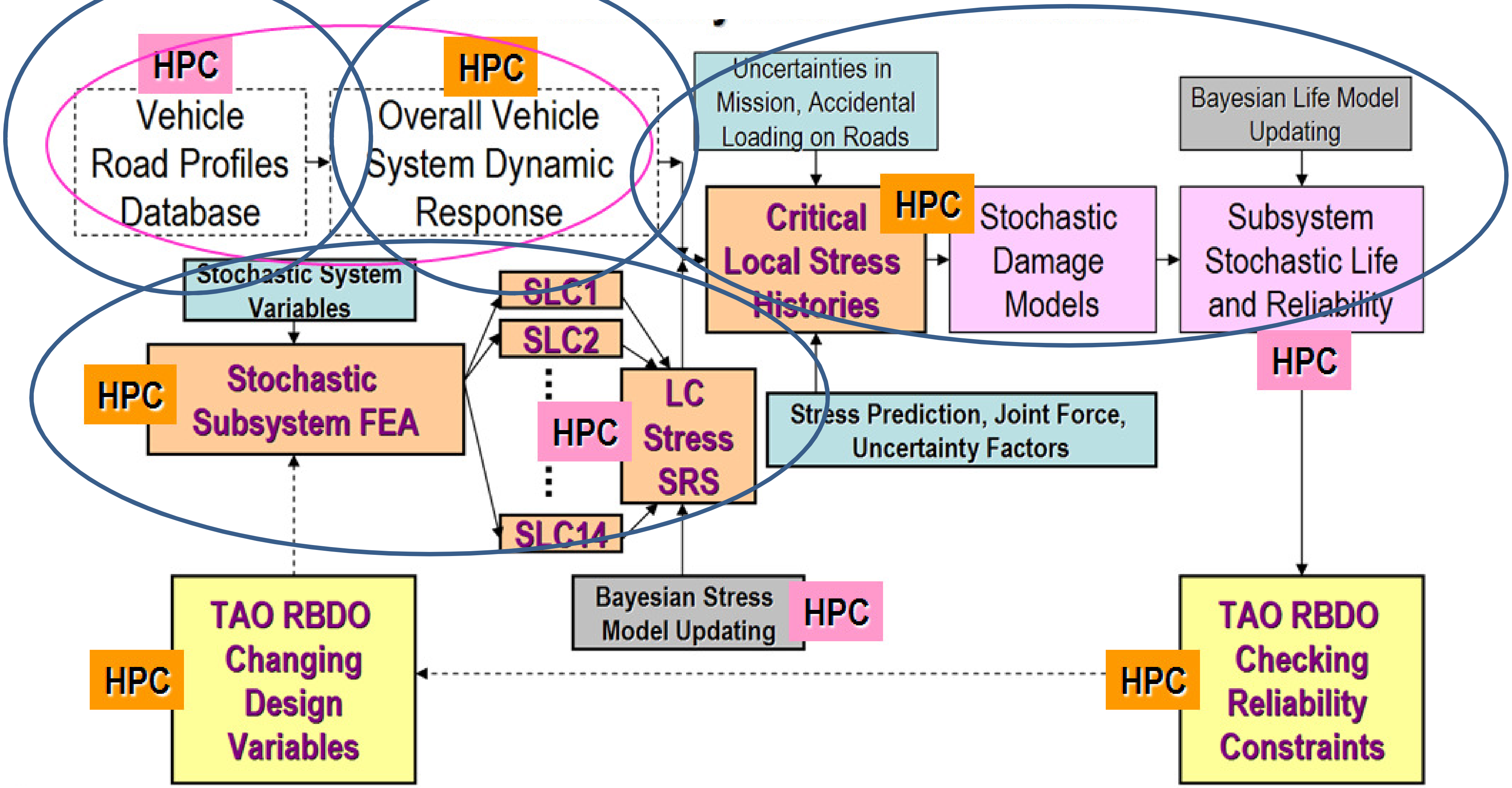
- Presentation Scope:
  - To present on overview of an integrated HPC stochastic physics-based framework that has been developed for vehicle reliability prediction.
  - Illustrative application to the HMMWV military system
  - Focus on:
    - The front-left suspension system (FLSS)
    - Qualitative aspects and methodology, not precise quantitative results

VEHICLE RELIABILITY PREDICTION MULTISTEP PROCESS



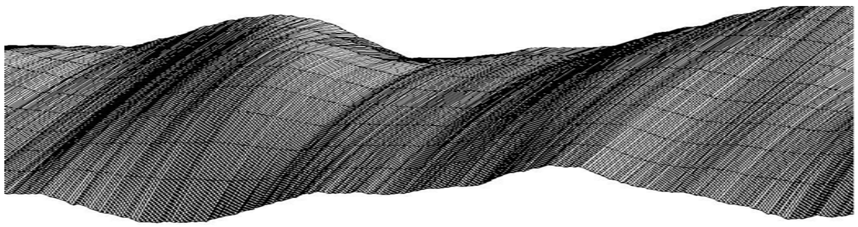
Note: HPC Future Need = 100…1,000 X Present HPC Need!

VEHICLE RELIABILITY IMPLEMENTATION CHART

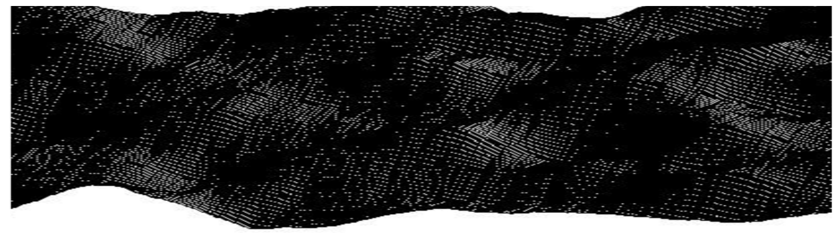


Stochastic Road Surfaces

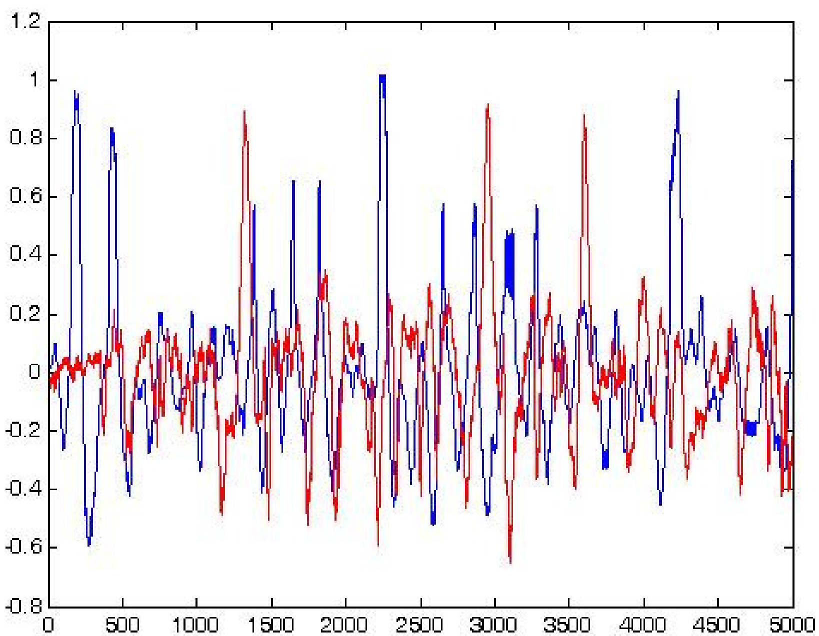
High Spatial Transverse Correlation

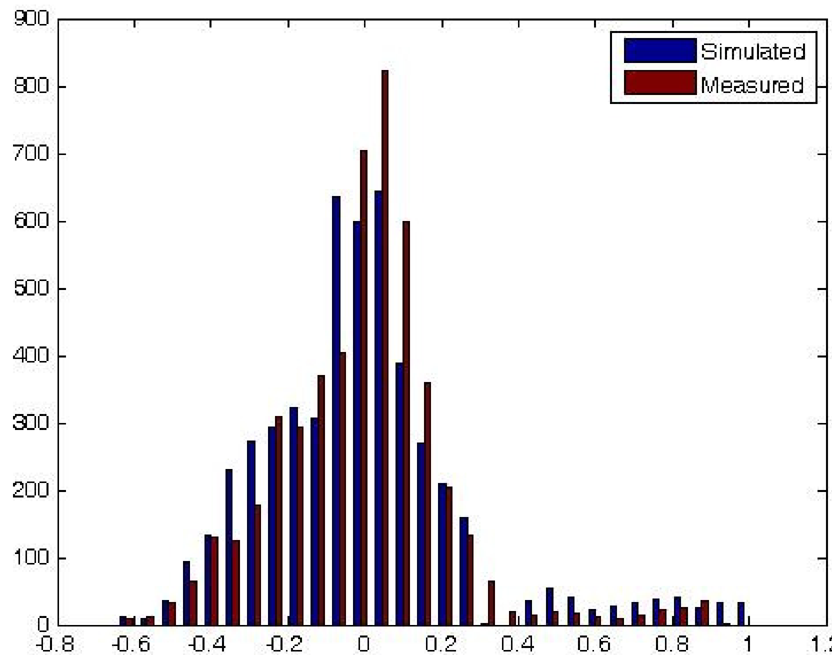


Low Spatial Transverse Correlation



Simulated vs. Measured Road Profiles





Stochastic Road Surfaces

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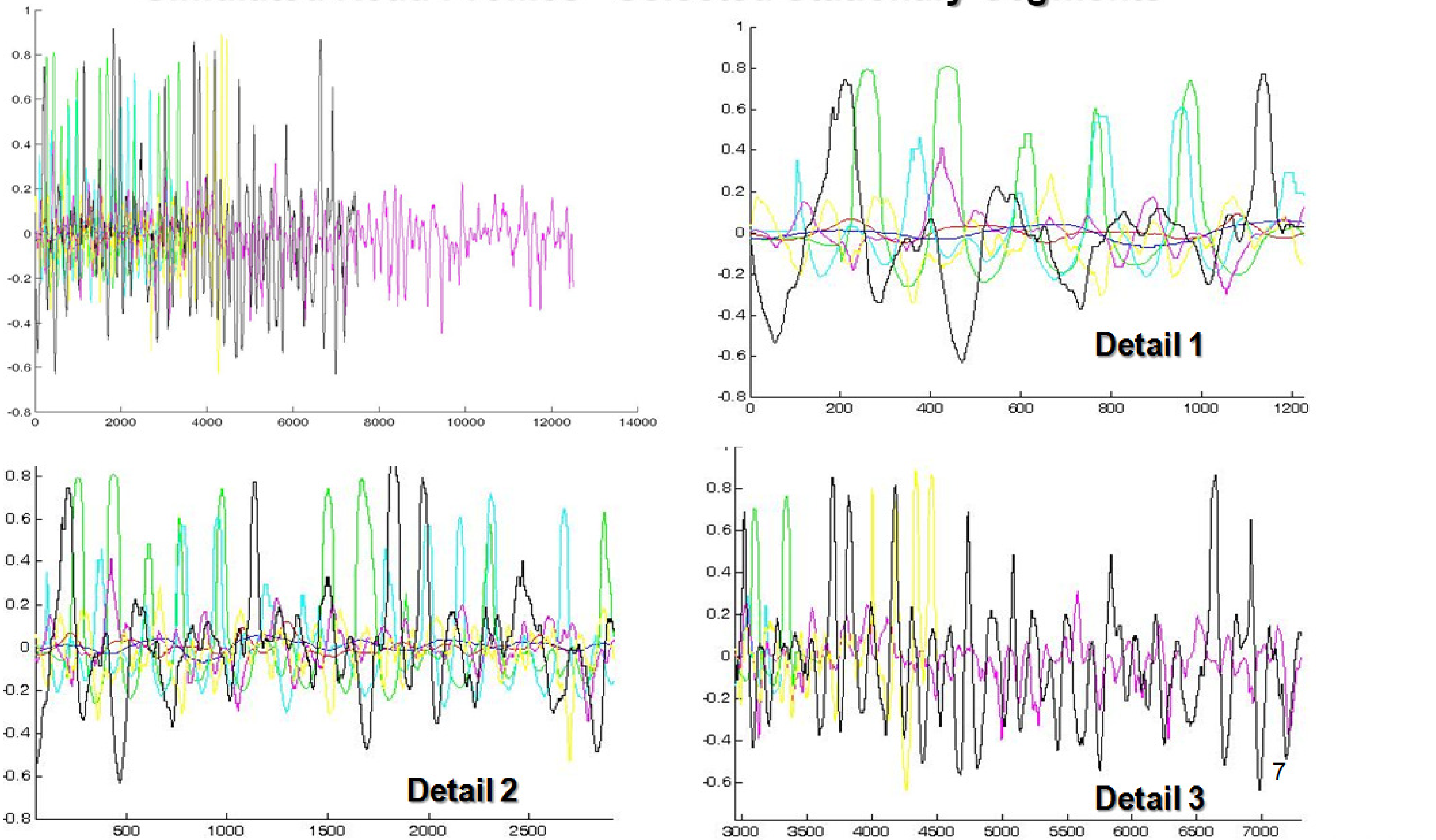
Simulated Road Profiles - Selected Stationary Segments



Vehicle Behavior to Stochastic Road Surfaces

•With topography Effects; Smooth and Rough Stochastic Roads

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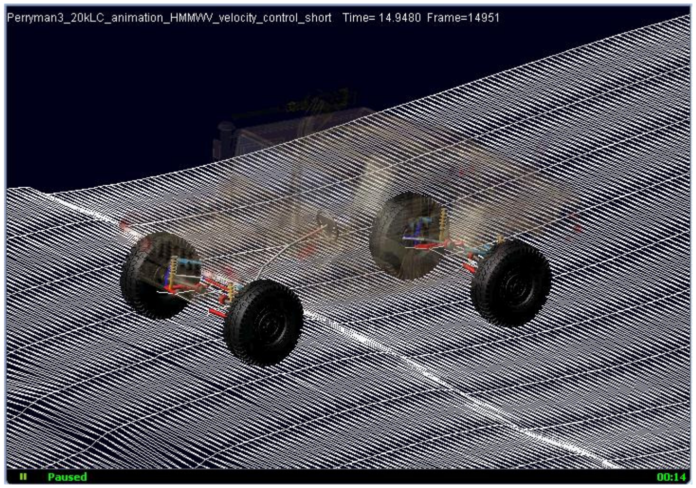
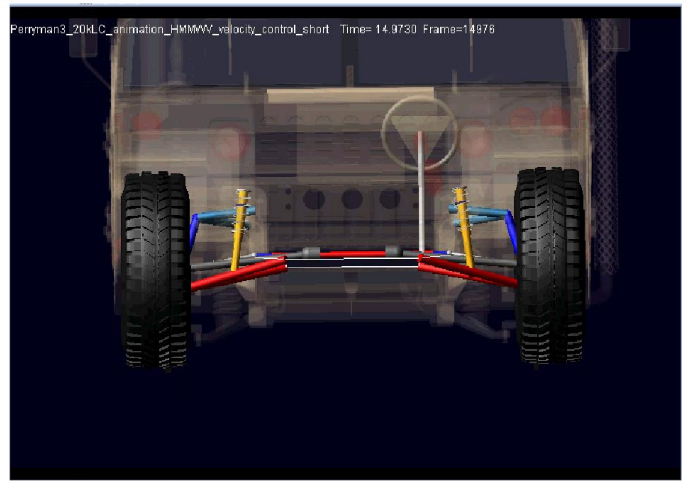
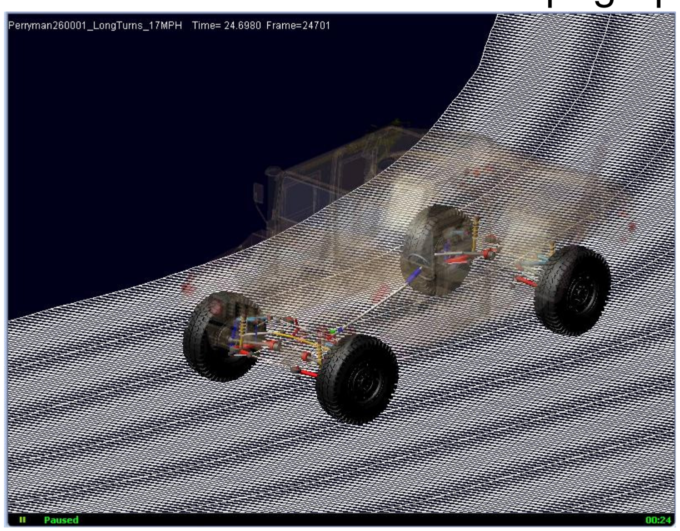
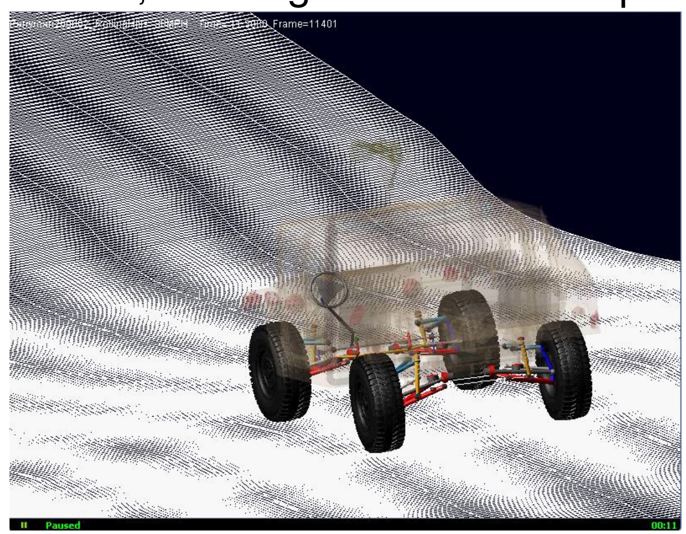




Flat road with no topography Effects; Passing a Random Bump

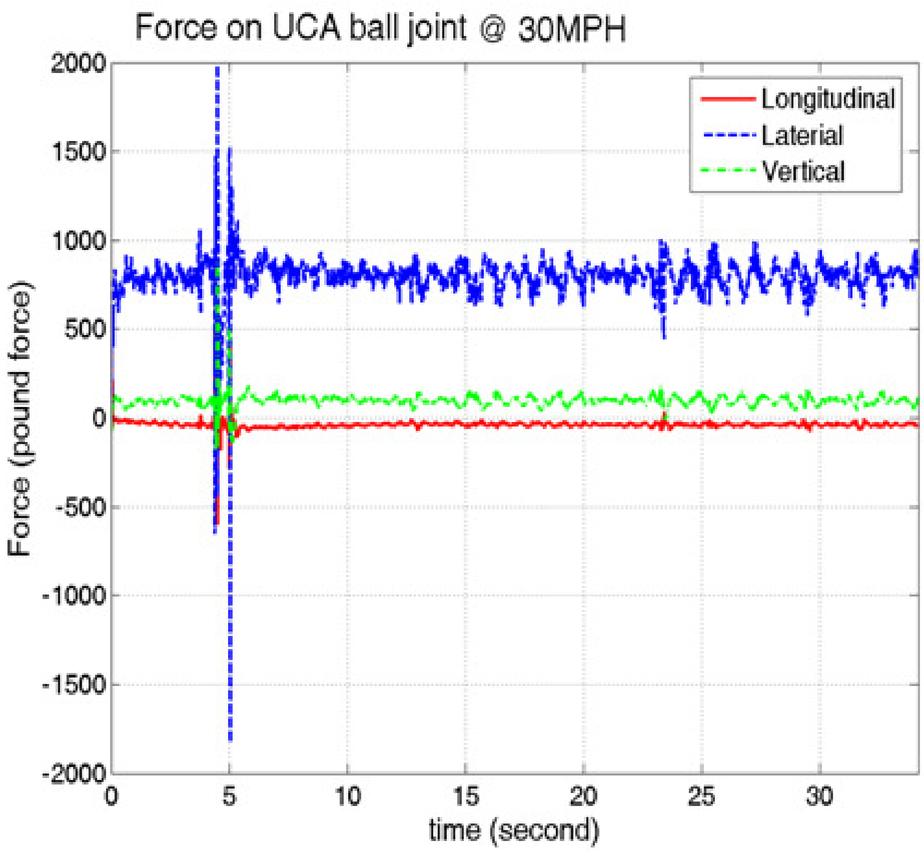




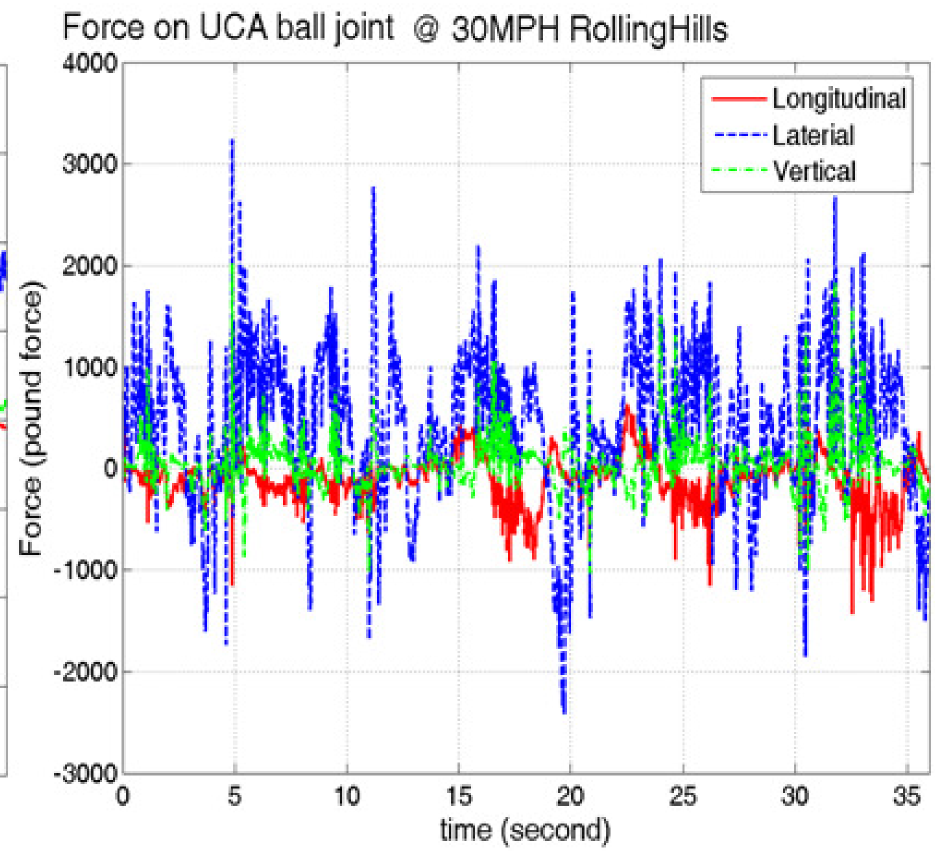
Using HMMWV ADAMS Model

With topography Effects; Smooth and Rough Stochastic Roads

Effects of Road Topography on FLSS UCA Ball Joint Forces



Straight Road Segment



Rolling Hills Segment

- Stochastic Vehicle Suspension Parameters:
  - All four wheel suspensions
  - Only front-wheel suspension

For a wheel suspension, 13 stochastic parameters are considered. For all four wheel suspensions there are 52 stochastic parameters. For each road and speed scenarios, 40 simulations were performed using LHS.

For practicality, we condensed the 52 stochastic parameters in 4 stochastic variation features:

- UCA Bushings (4 variables = 2 stiffness and 2 damping parameters)
- LCA Bushings (4 variables = 2 stiffness and 2 damping parameters)
- Tire (3 variables = lateral, tangential and radial stiffness parameters)
- Spring/Absorber (2 variables = 1 stiffness and 1 damping parameters)

Stochastic Vehicle Behavior

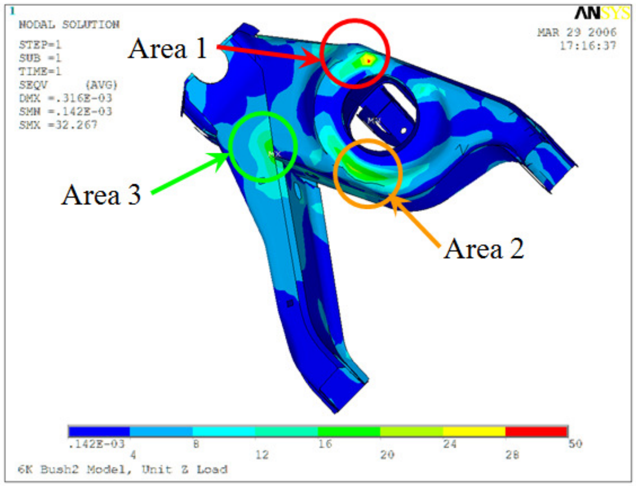
Stochastic Parameters of the ADAMS HMMWV Suspension System (FLSS)

SPRING-SHOCK ABSORBER		TIRE			BUSHING UCA				BUSHING LCA			
STIFF LN(1,0.025)	DAMP LN(1,0.05)	PAR 1 LN(1,0.025)	PAR 2 LN(1,0.05)	PAR 3 LN(1,0.1)	STIFF 1 LN(1,0.025)	STIFF 2 LN(1,0.025)	DAMP 1 LN(1,0.05)	DAMP 2 LN(1,0.05)	STIFF 1 LN(1,0.025)	STIFF 2 LN(1,0.025)	DAMP 1 LN(1,0.05)	DAMP 2 LN(1,0.05)
0.9976	0.9407	1.0357	1.0012	1.0755	0.9016	1.0404	1.0209	1.0045	0.9355	0.9431	0.9465	0.9521
1.0000	1.0047	1.0236	0.9054	0.9975	0.8877	1.0772	1.0671	1.0779	1.0350	1.0314	0.9781	0.8573
0.9921	0.9969	0.9629	0.9171	1.0355	0.9529	1.0299	1.0004	0.9967	0.9800	1.0358	1.0127	0.9054
0.9911	0.9780	1.0711	0.9187	0.9763	0.9560	0.9401	1.1562	0.9853	0.9919	0.9515	0.9387	1.0172
0.9722	1.0008	0.9673	0.9950	1.0029	1.0778	1.1147	0.9273	0.9714	0.9806	1.0154	0.9730	0.9283
1.0231	0.9702	0.9905	0.9823	0.8934	1.0084	1.0501	0.9892	0.9683	0.9536	0.8863	0.9773	1.0970
1.0362	1.0253	0.9304	0.9994	0.9560	1.0677	0.9681	1.0395	1.0646	1.0091	1.0681	1.0766	0.9827
1.0209	0.9917	1.0650	0.9898	1.0016	0.9760	1.0340	1.0686	1.0348	1.1950	0.9364	1.0243	0.9257
0.9810	0.9405	1.0696	1.0506	1.0681	0.9595	0.9632	0.9803	1.0290	1.0055	1.0222	1.0086	1.0530
1.0256	0.9739	0.8864	0.9909	0.9621	1.0090	1.0215	1.0961	1.0269	1.0606	0.9667	1.0385	1.0190

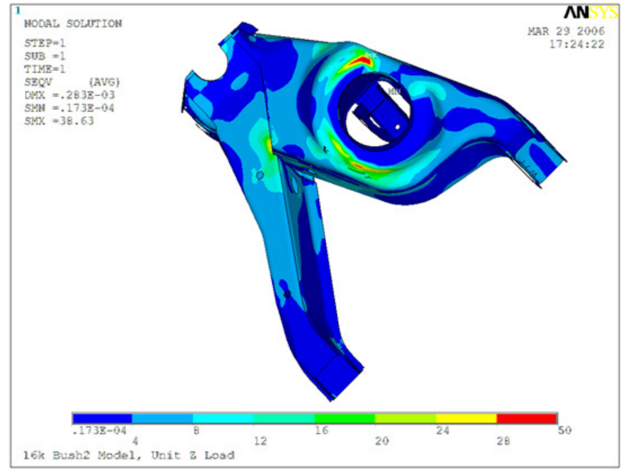
Effects of Stochastic Vehicle Behavior on the FLSS Fatigue Damage

Simulation Sets (Each of 10 Simulations)	**Node=2275 Mean/Std**	**Node=4800 Mean/Std**	**Node=5406 Mean/ Std.**
High_Roughness_Straight_30MPH_set1	1.347724e-003 (3.951257e-005)	1.555955e-005 (7.893527e-007)	6.960761e-005 (1.848916e-006)
High_Roughness_Straight_30MPH_set2	1.331116e-003 (2.192678e-005)	1.643080e-005 (6.492225e-007)	6.597428e-005 (2.088339e-006)
High_Roughness_Straight_30MPH_set3	1.222983e-003 (6.239249e-005)	1.456184e-005 (2.017415e-007)	5.178260e-005 (4.434275e-006)
High_Roughness_Straight_30MPH_set4	1.241959e-003 (3.578063e-005)	1.475359e-005 (3.529030e-007)	6.202625e-005 (3.763194e-006)

FE Modeling Uncertainties



36K dofs model

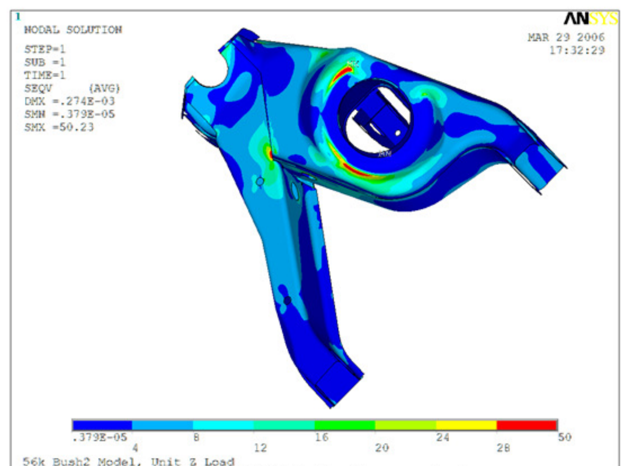


96K dofs model

Load Case – Bushing 2, Z Load

Significant variations (up to 50%) in local stresses due to:

- FE Mesh Refinement
- Shell Element Type



330K dofs model

Stochastic FEA for Stress Computation

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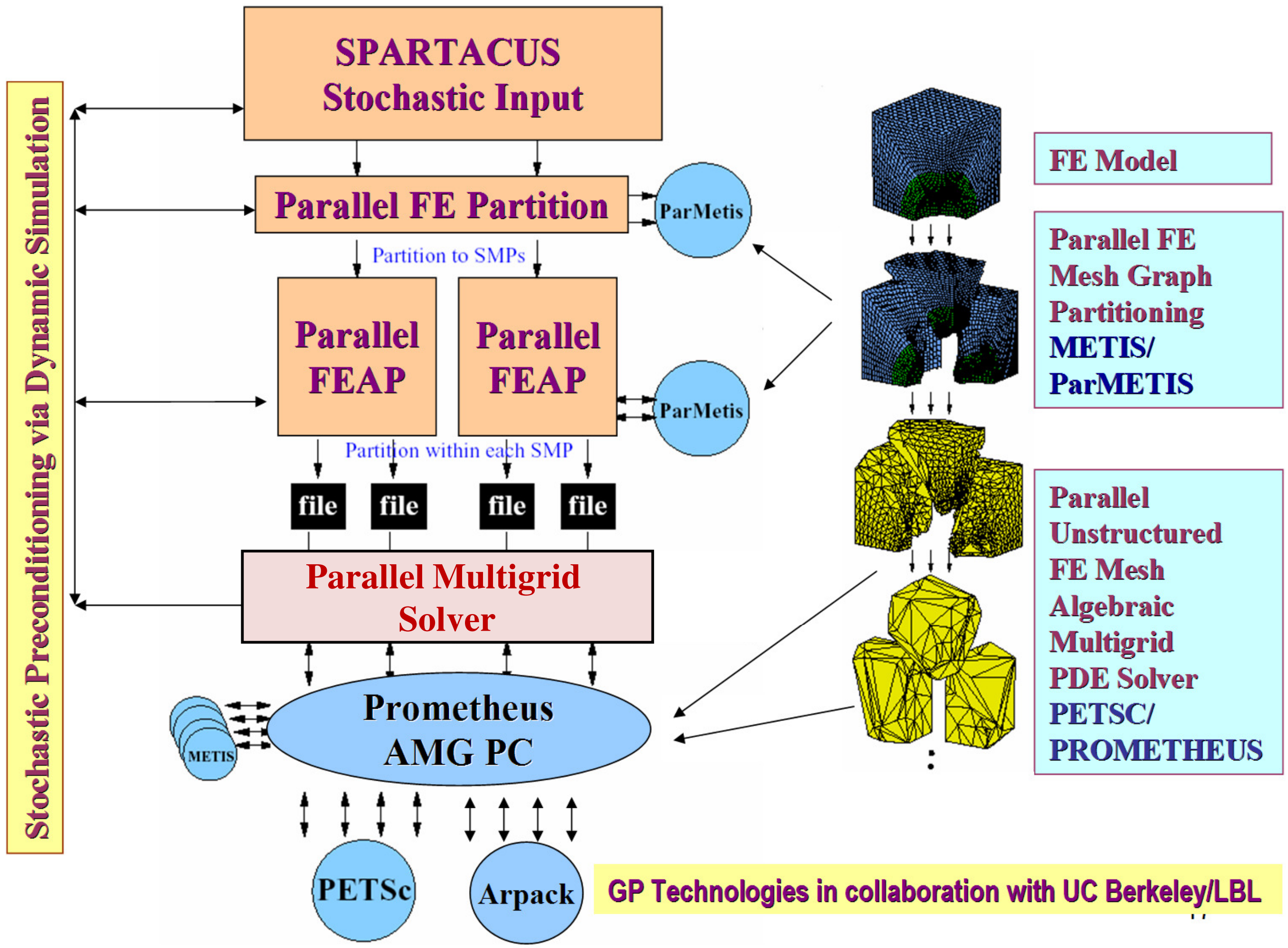
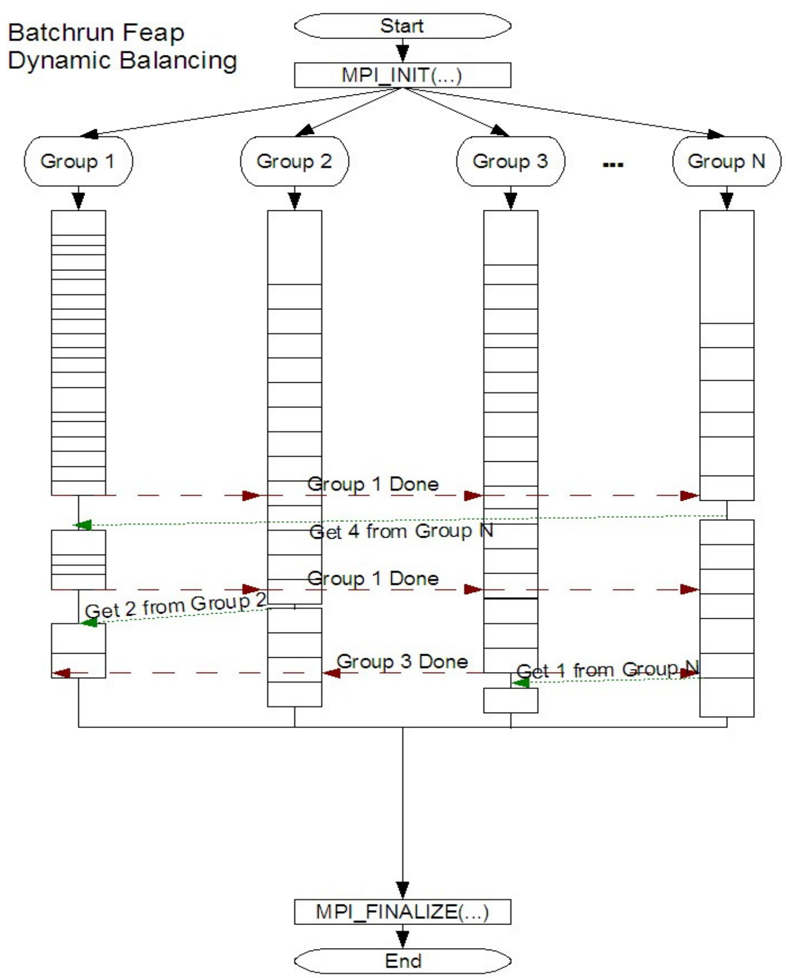
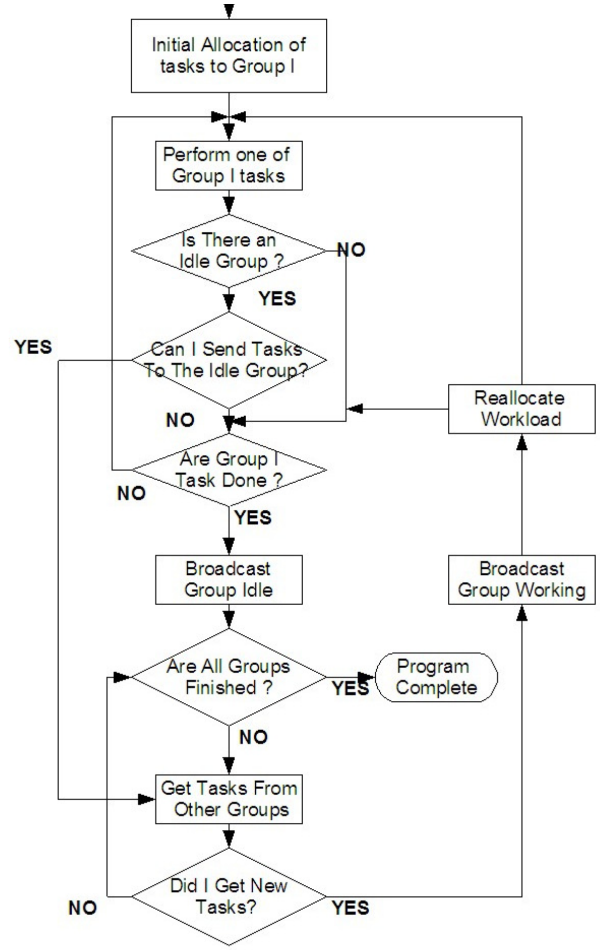
Stochastic PARallel Tool for Analysis of Computational Unstructured-Mesh Solids (SPARTACUS). Applicable to Large-Size FE Models.



GP Technologies in collaboration with UC Berkeley/LBL

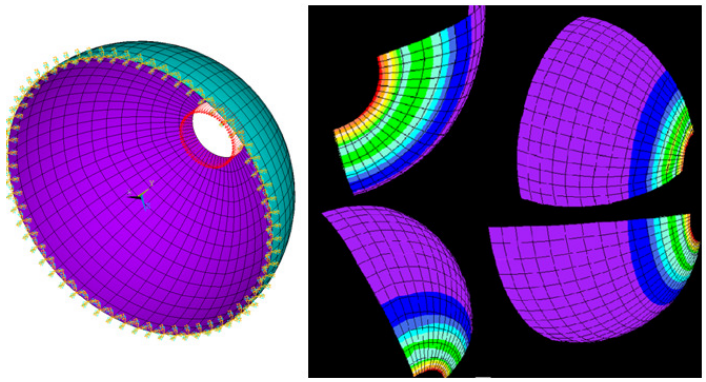
Stochastic FEA HPC Strategy in SPARTACUS

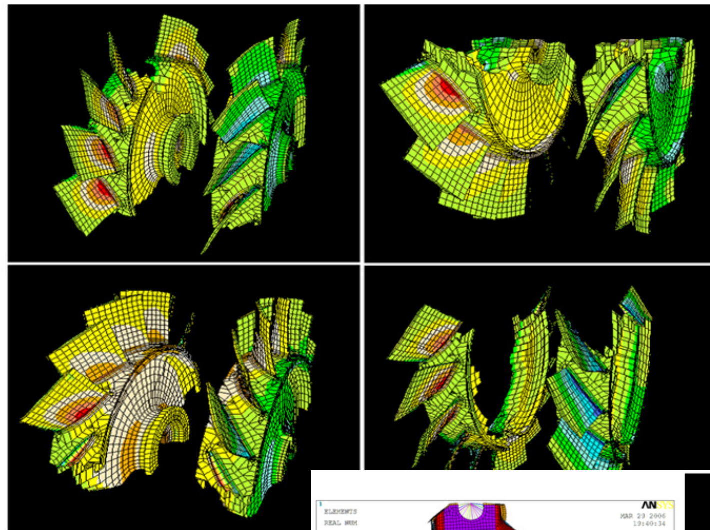




ParMETIS Partitioning for Stochastic Domain Decomposition

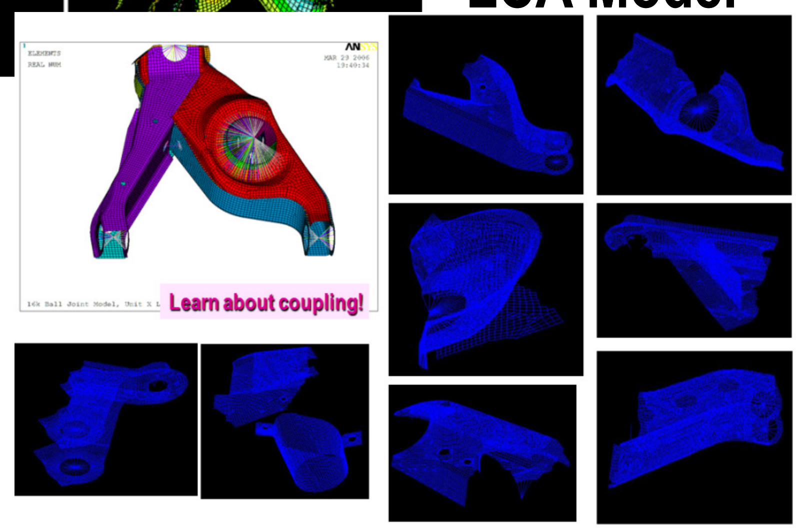
Dome Model



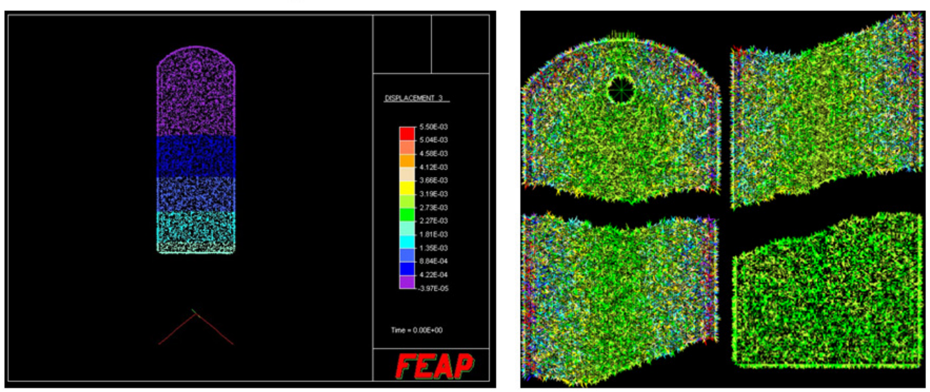


Engine Bladed-Disk Model

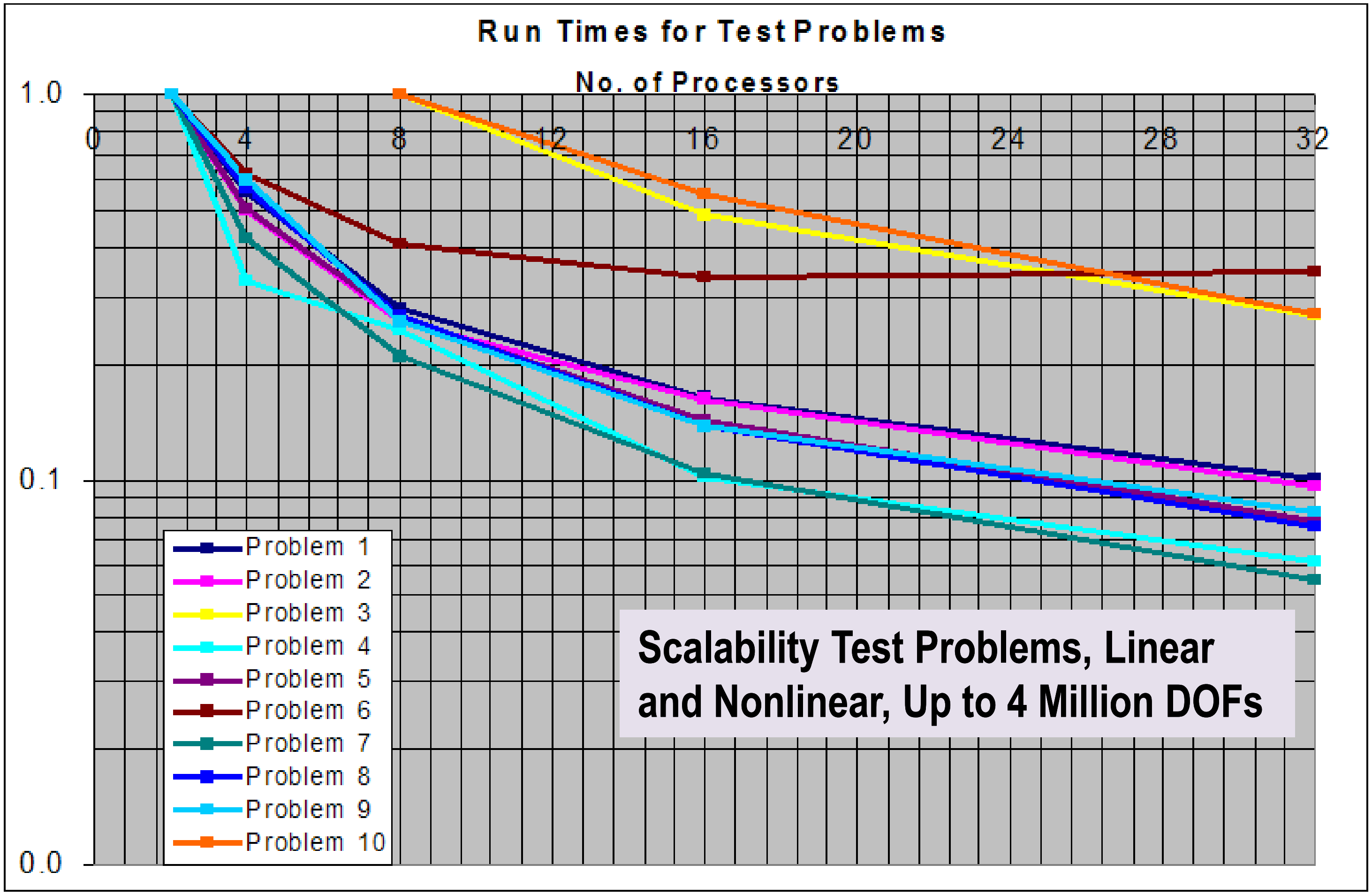
LCA Model



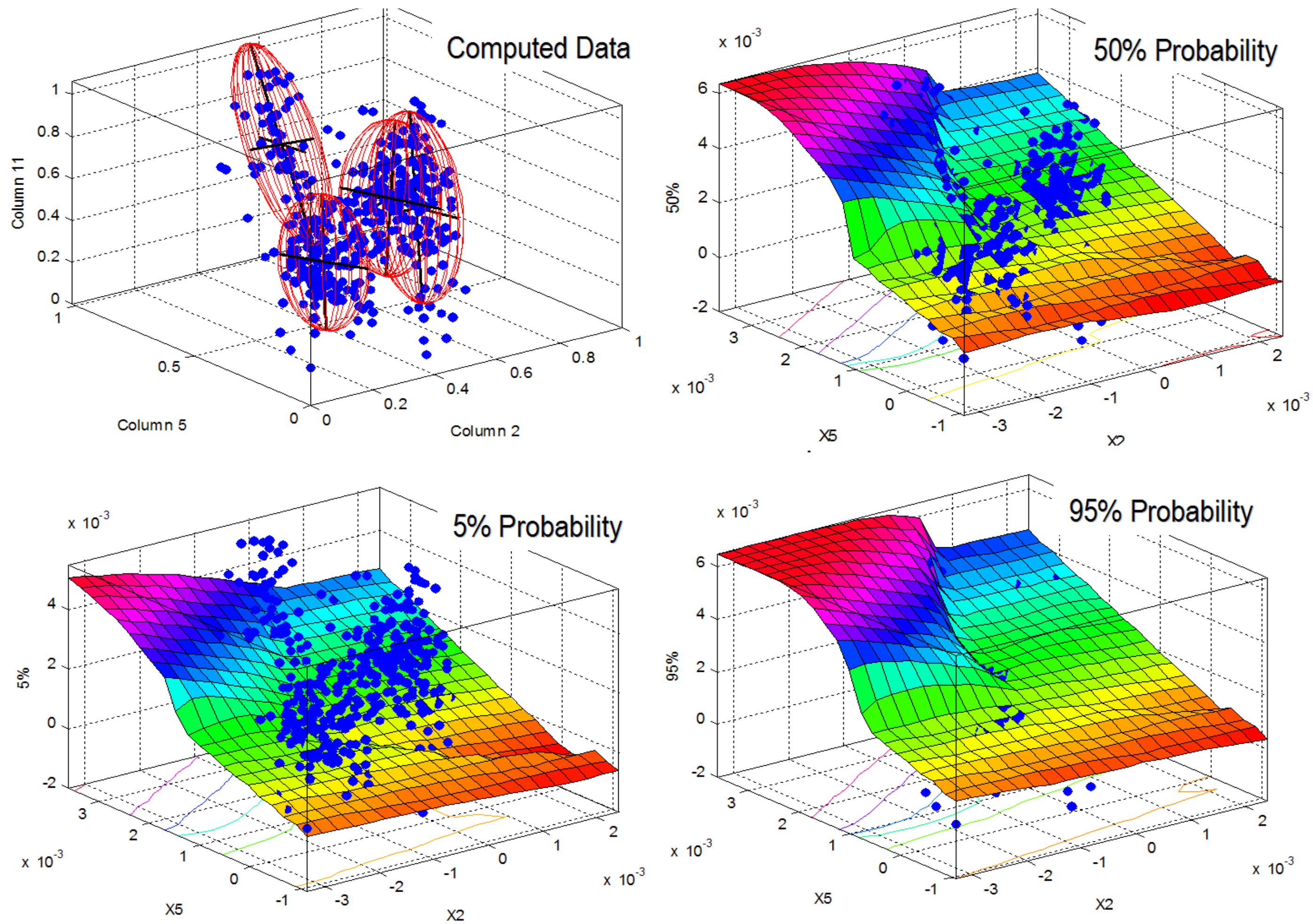
Simple LCA Model



Sizing Partitions: Scalability Studies for Various FEA Problems



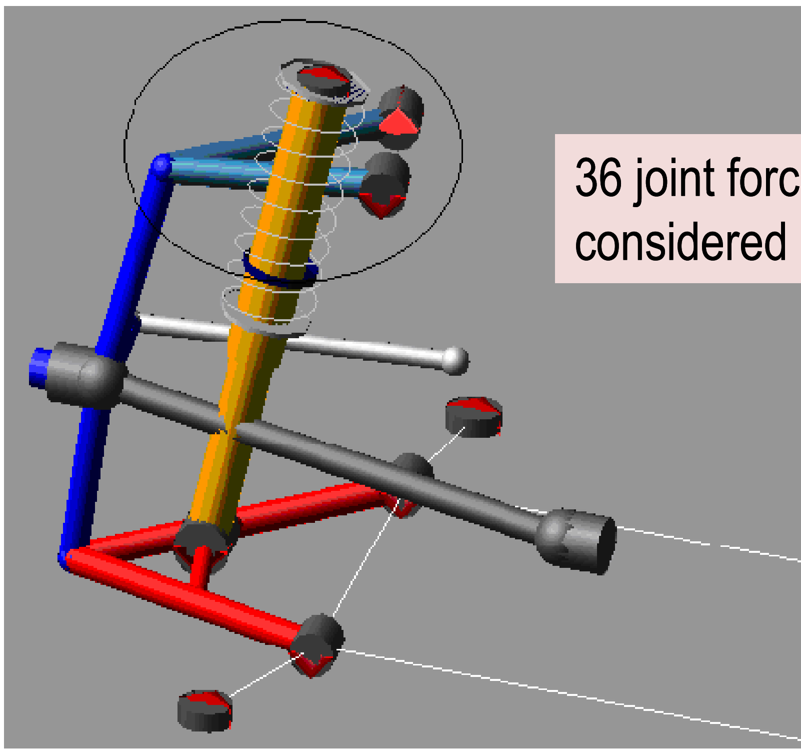
10 D Stochastic Surface Using High-Order Stochastic Field Models



FLSS ADAMS RBD Model and SPARTACUS FE Model

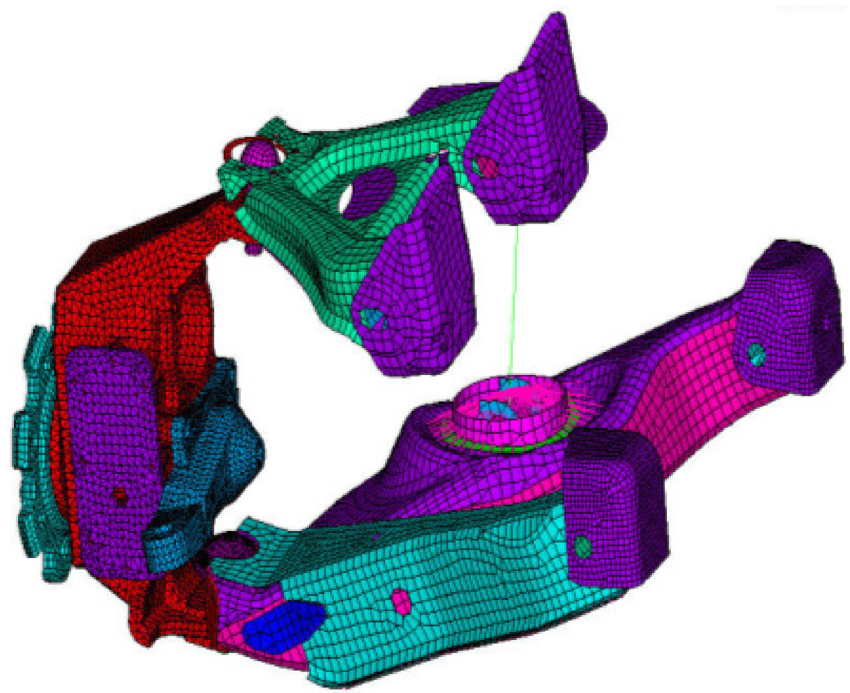
(36 Joint Component Forces/Moments Considered for FLSS)

ADAMS Model



36 joint forces considered

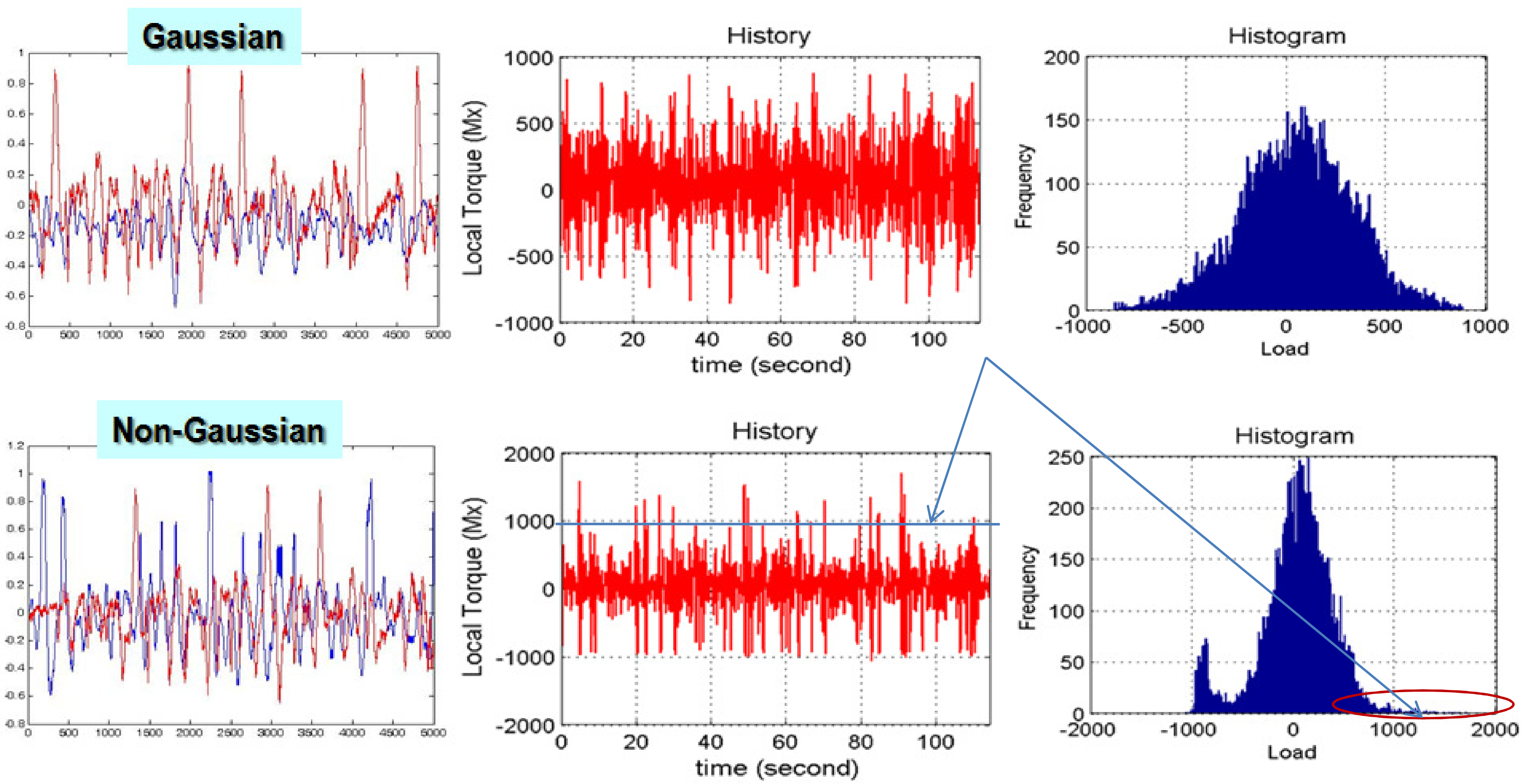
SPARTACUS Model



Sensitivity Studies: Effects of Road Surface Variation Non-Gaussianity

High roughness segment, with given PSD, for an average vehicle speed 30mph

Simulated Road Profiles | **LCA Busing Moment History** | **LCA Bushing Moment PDF**



Sensitivity Studies: Effects of Road Topography on FLLS Joint Forces and Stresses

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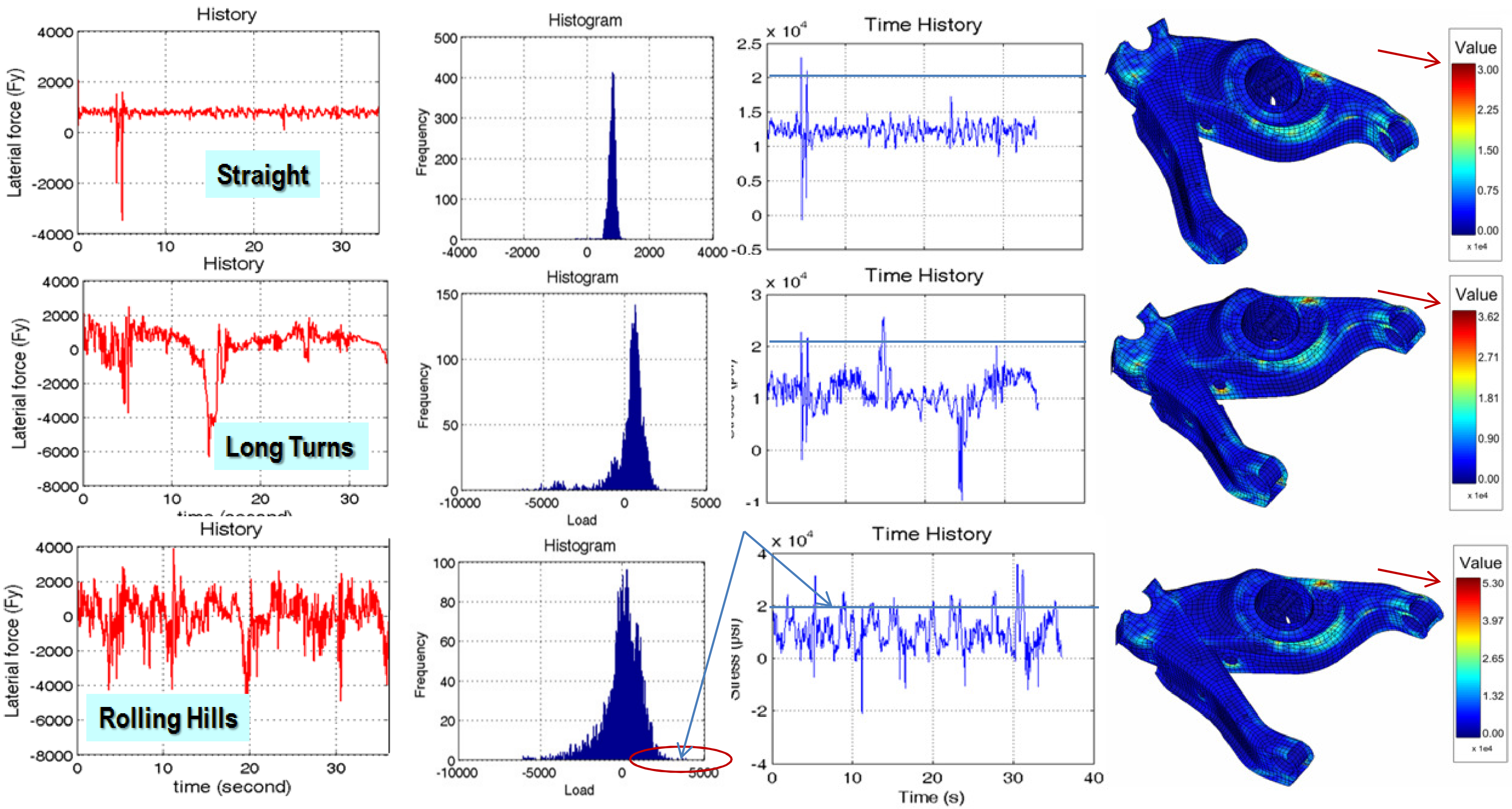
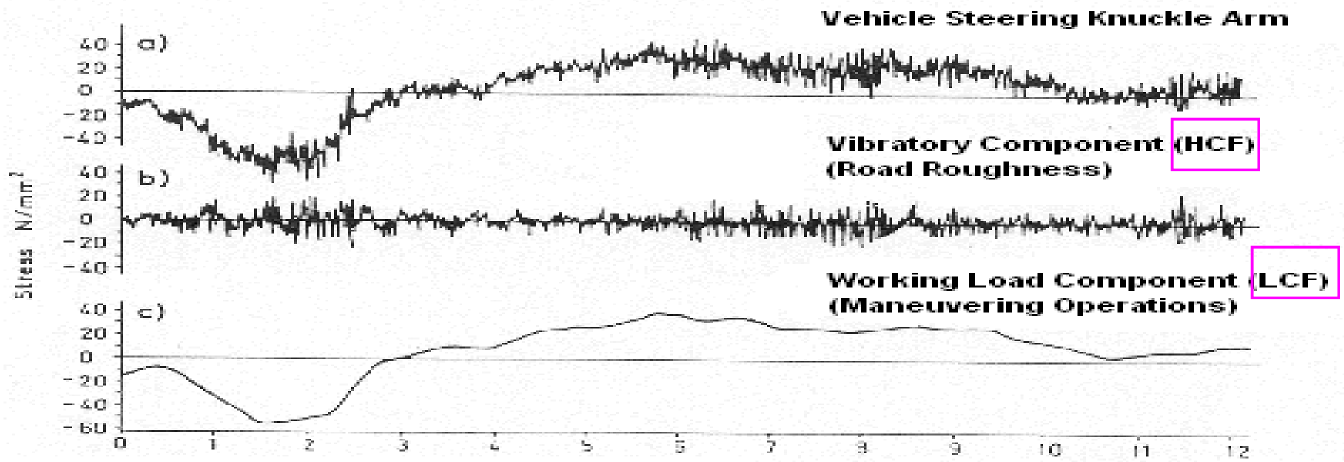
Moderate Roughness Road at 30 mph: Straight, Long Turns, Rolling Hills

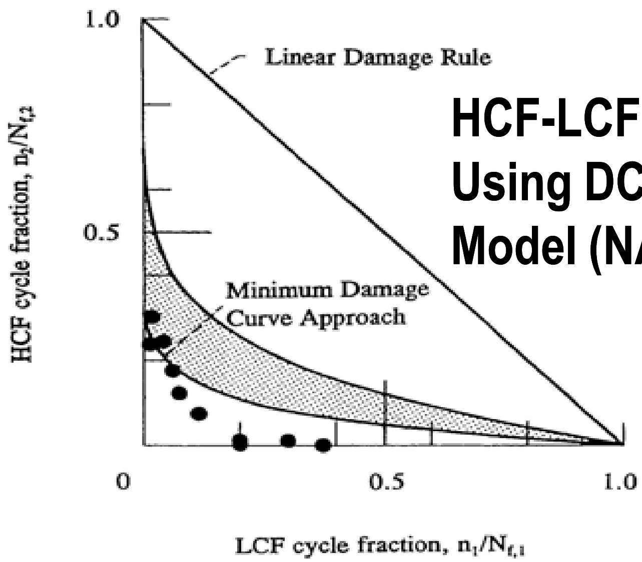
LCA Ball Joint Force

Critical Location Von-Mises Stress Variations

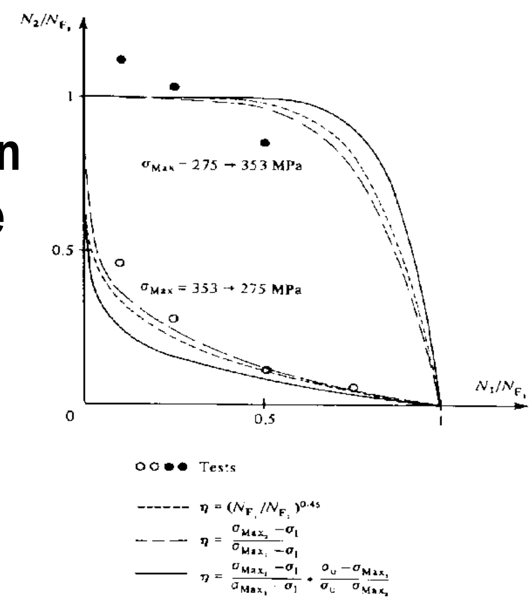


Interactive Fatigue Damage Mechanisms for Vehicle on Rough Terrain

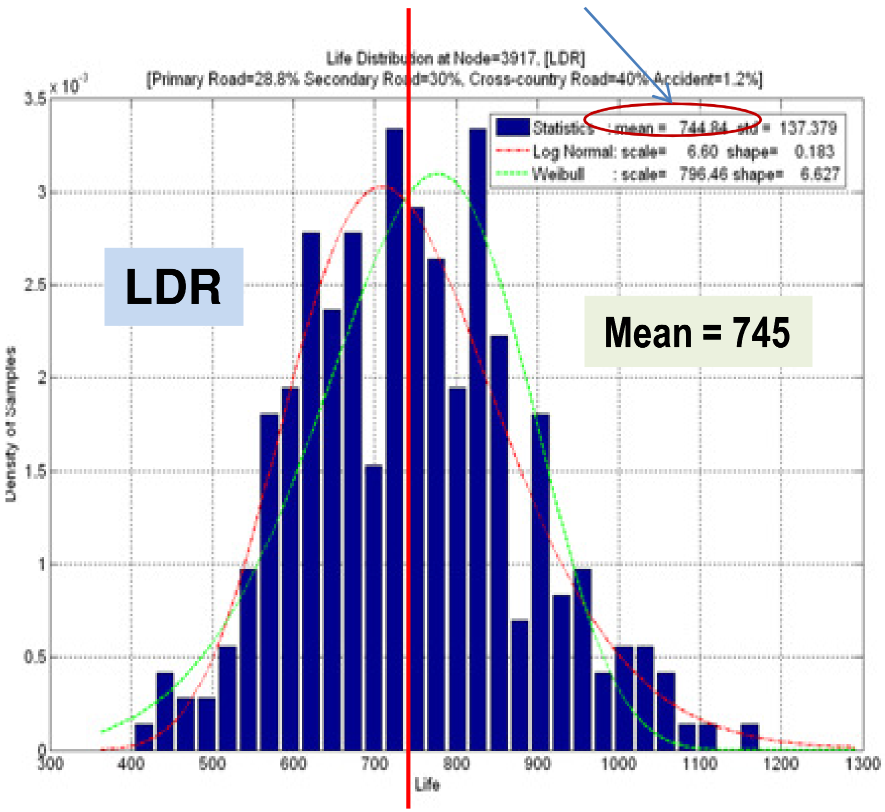


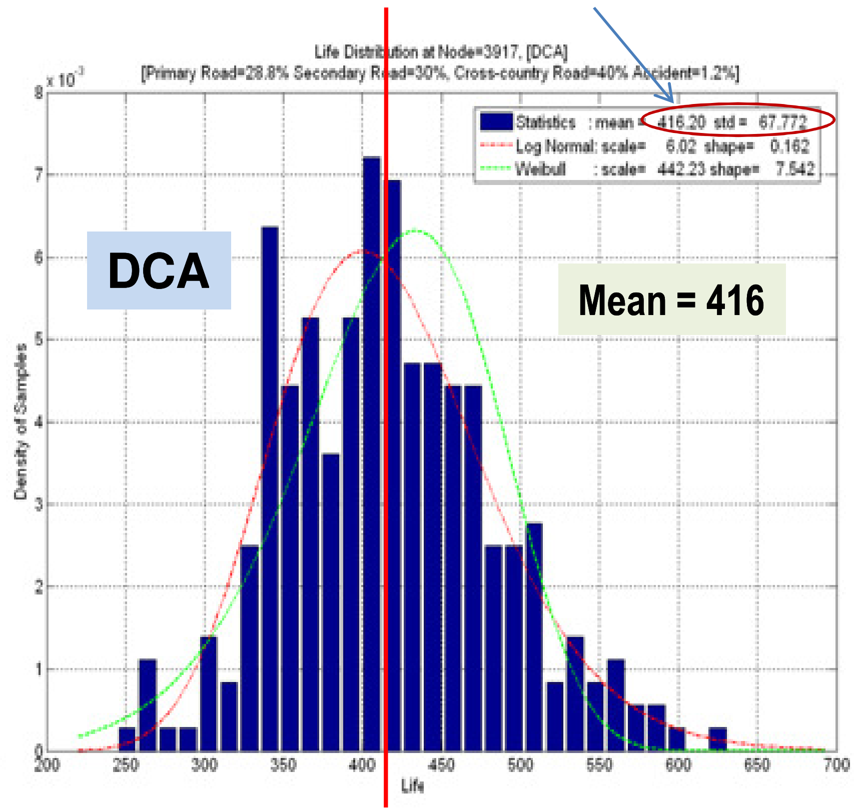


HCF-LCF Interaction Using DCA Damage Model (NASA GRC)

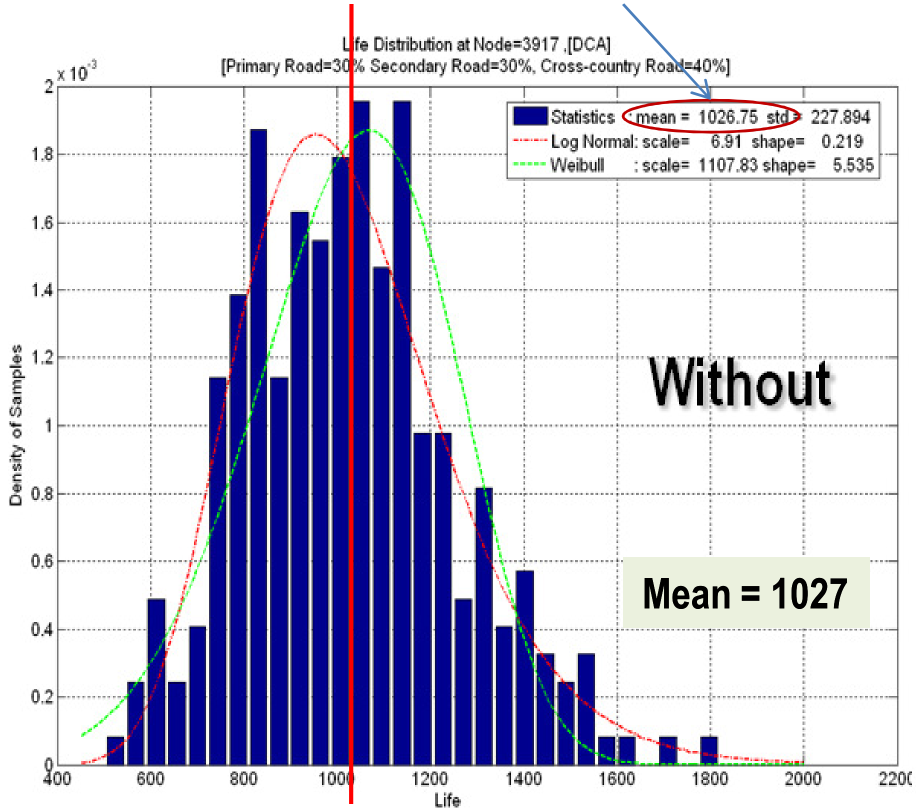


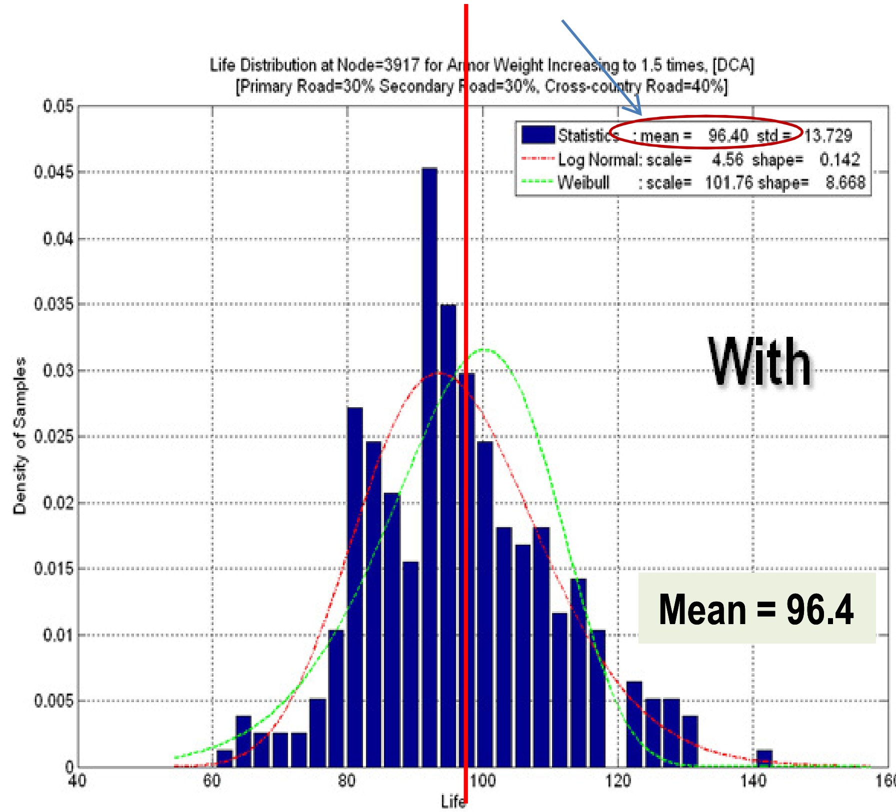
Predicted FLSS Life Using LDR and DCA Damage Models





Predicted FLSS LCA Life Without and With Armour Weight Increase (50% of total vehicle weight)





Effects of Limited FEA Simulations on Life Predictions. Weibull vs. Lognormal Models.

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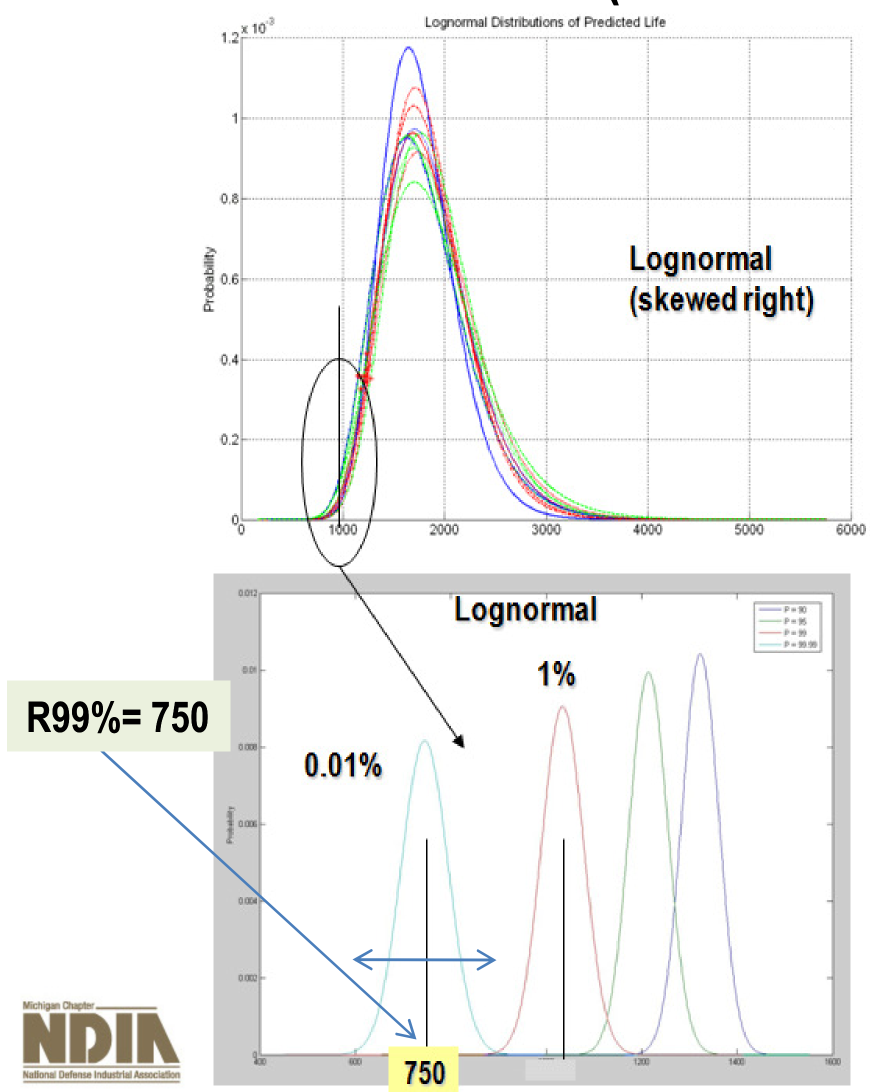
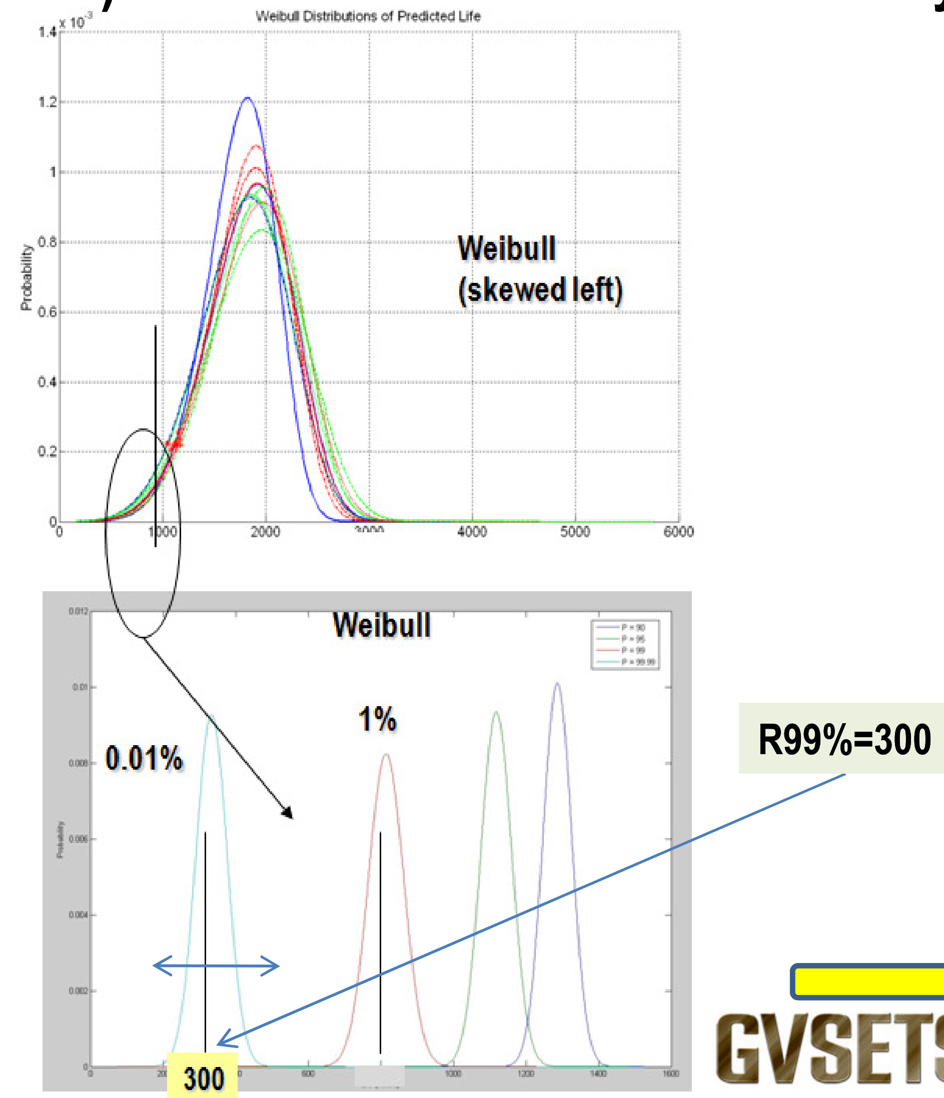
Effect of Lack of Data (280 Simulations) on FLSS Life for Given Reliability





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Summary/Concluding Remarks

An integrated HPC stochastic simulation framework has been implemented and demonstrated.

The integrated HPC reliability prediction framework incorporates the following constitutive parts:

i) simulation of the stochastic operational environment,
ii) stochastic vehicle multi-body dynamics analysis,
iii) stress prediction in subsystems and components,
iv) stochastic progressive damage analysis, and
v) component life prediction including uncertainty from maintenance
vi) reliability prediction at the component and the system levels.

Note:
Accurate stochastic modeling of road surface and topography is an important aspect of an overall vehicle reliability analysis. The non-Gaussian variations of the road profiles have a significant impact on the predicted vehicle fatigue reliability. These non-Gaussian variation aspects are often ignored.