



Mobility of Military Vehicles at TARDEC

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May 15, 2012



TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

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Presented at SAE Heavy Truck Handling, Dynamics, & Control Symposium, Greenville, SC, May 15-17

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- History and Background
- Modeling and Simulation at TARDEC
- Current Research Efforts
- Future Growth and Trends

Dr. Gregory Bekker

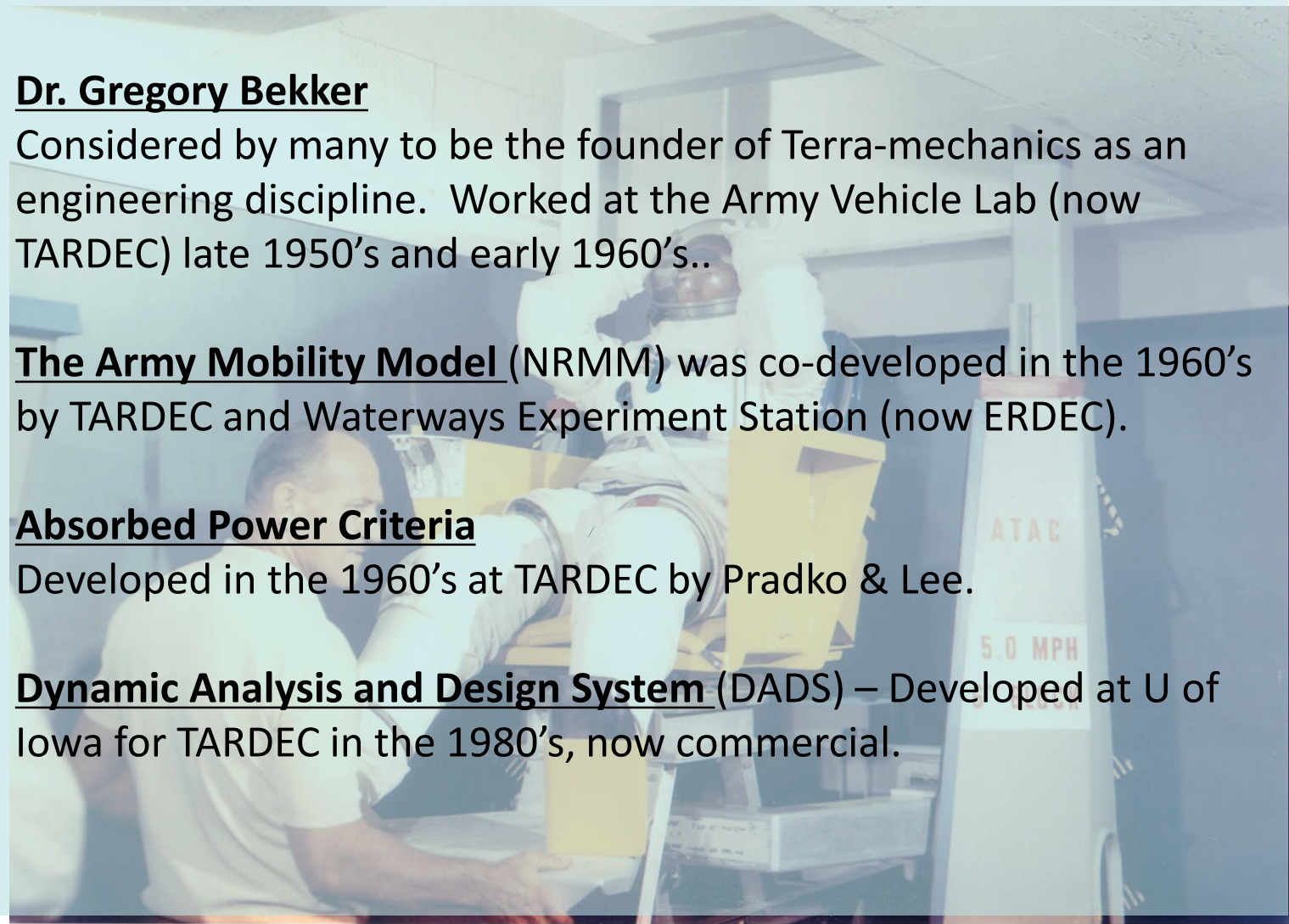
Considered by many to be the founder of Terra-mechanics as an engineering discipline. Worked at the Army Vehicle Lab (now TARDEC) late 1950's and early 1960's..

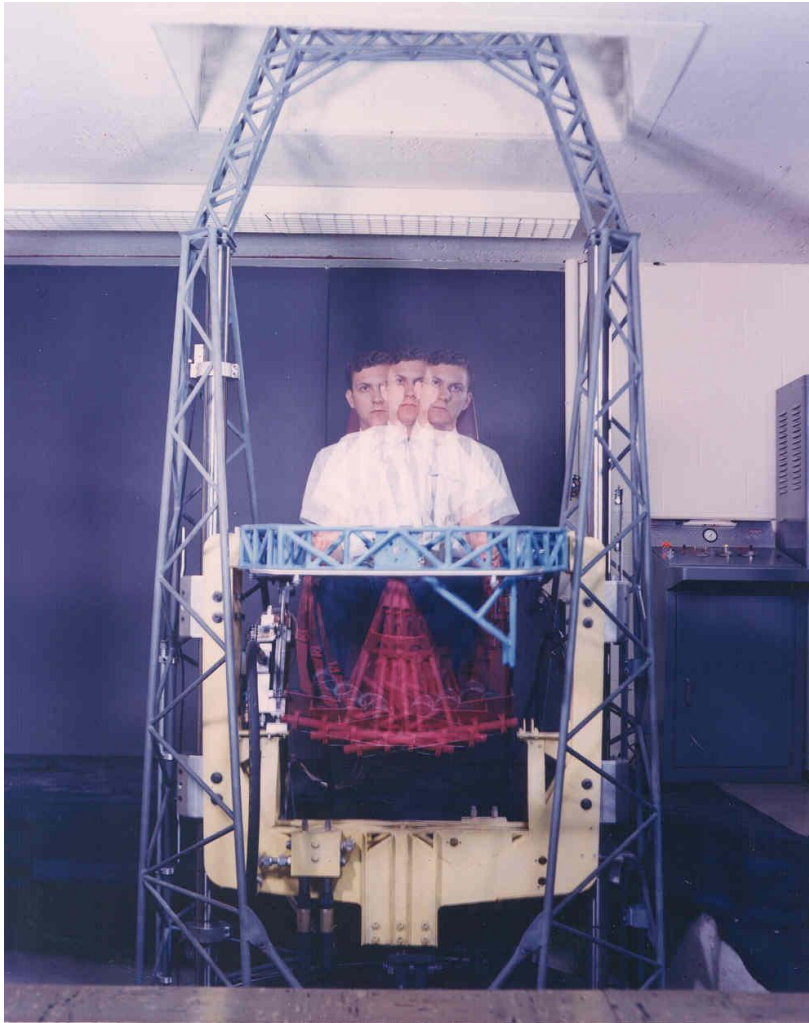
The Army Mobility Model (NRMM) was co-developed in the 1960's by TARDEC and Waterways Experiment Station (now ERDEC).

Absorbed Power Criteria

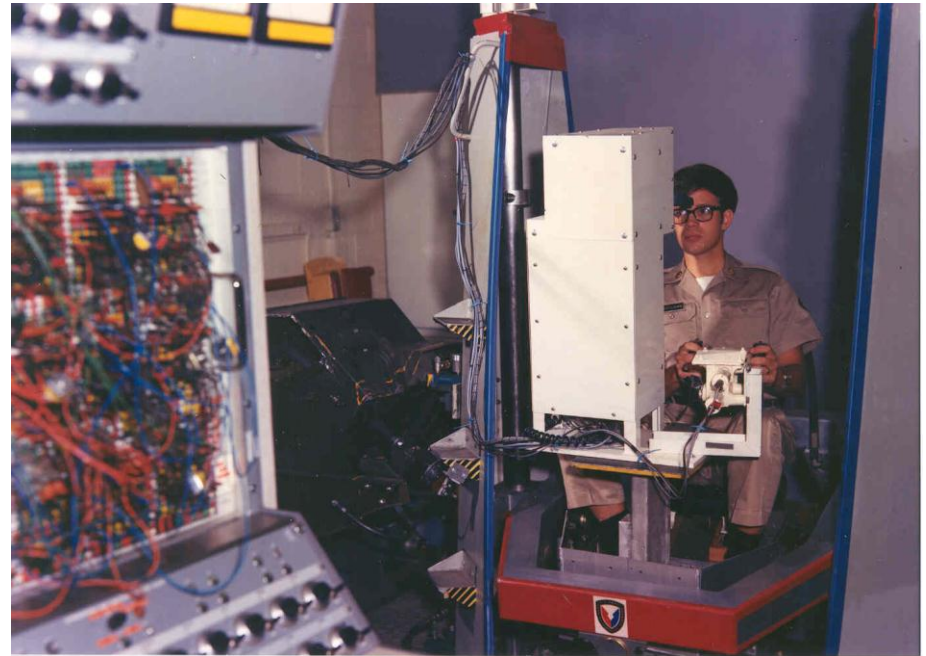
Developed in the 1960's at TARDEC by Pradko & Lee.

Dynamic Analysis and Design System (DADS) – Developed at U of Iowa for TARDEC in the 1980's, now commercial.

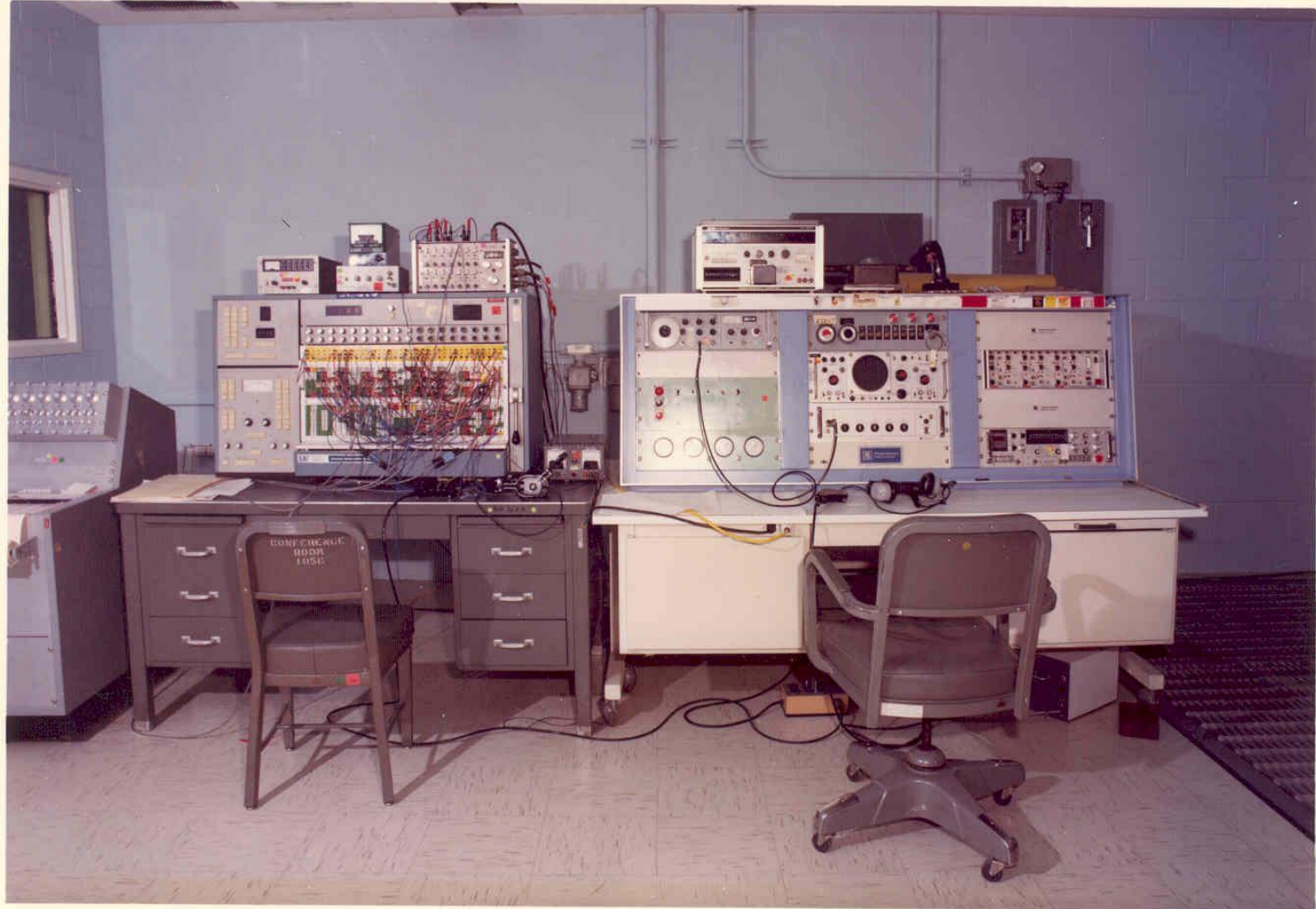


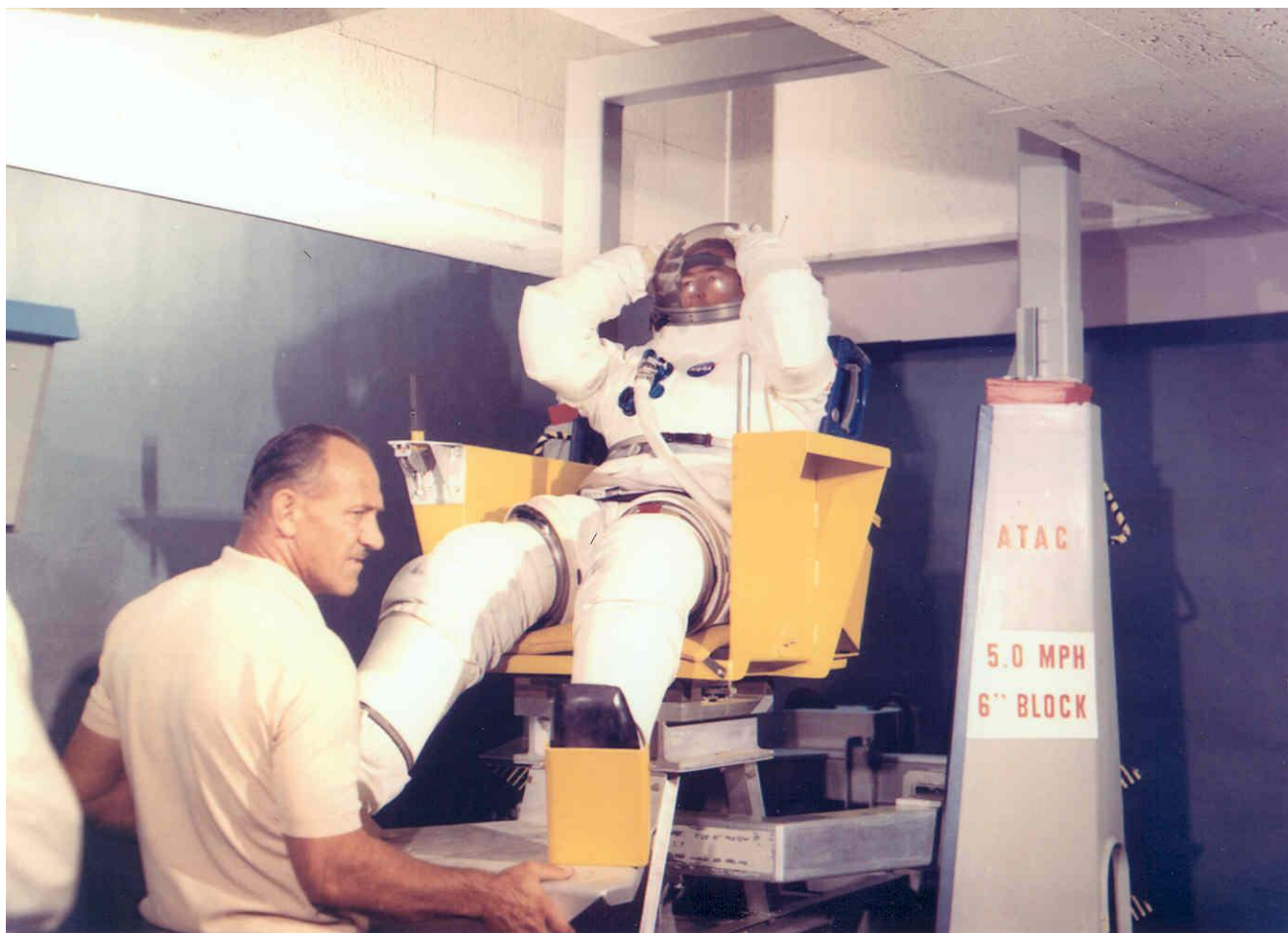


DETROIT ARSENAL **NEG. NO.** C-68218 **DATE** 1 Feb 62
Dynamic Simulations Laboratory Drivers Seat Action Test.



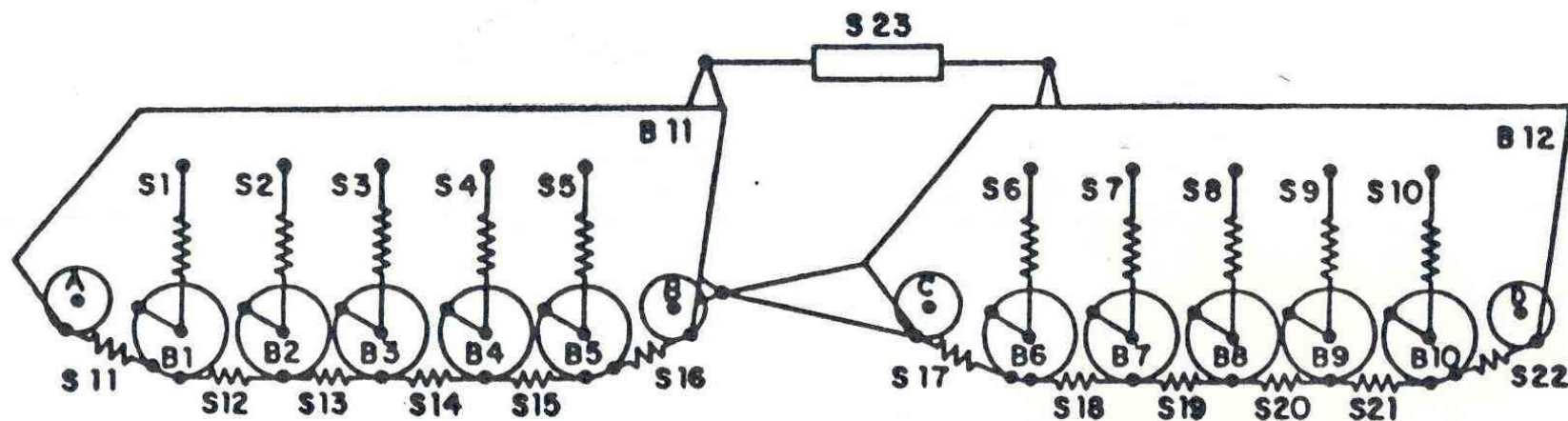
TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.



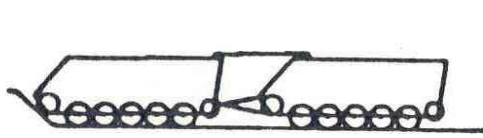


TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

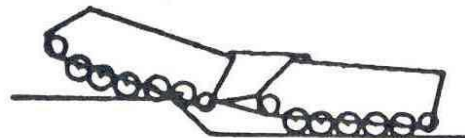
UNCLASSIFIED



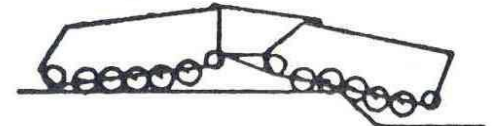
A computer model of the coupled M113's.



$t = 0$



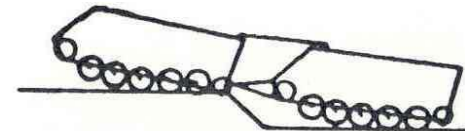
$t = 4$



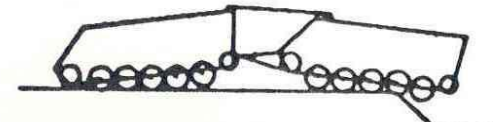
$t = 8$



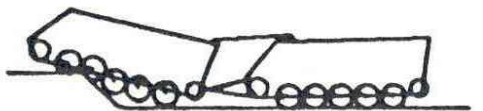
$t = 1$



$t = 5$



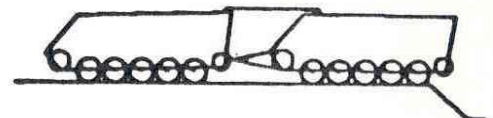
$t = 9$



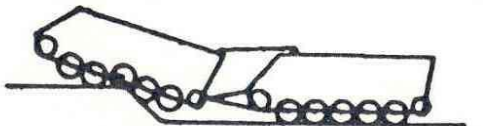
$t = 2$



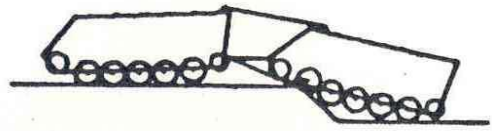
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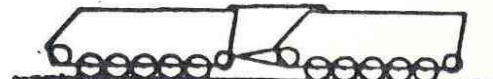
$t = 10$



$t = 3$

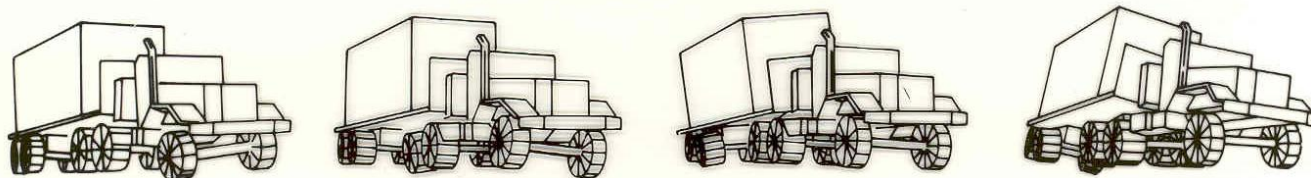


$t = 7$

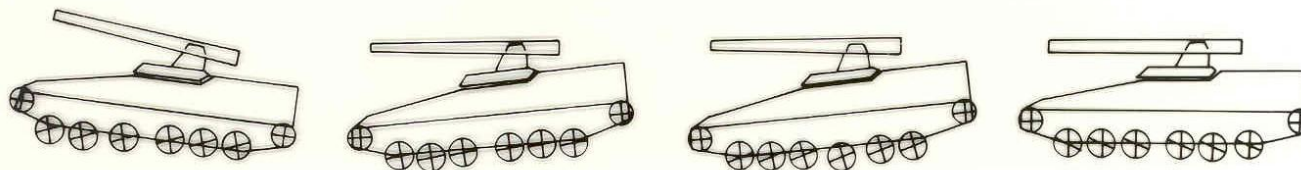


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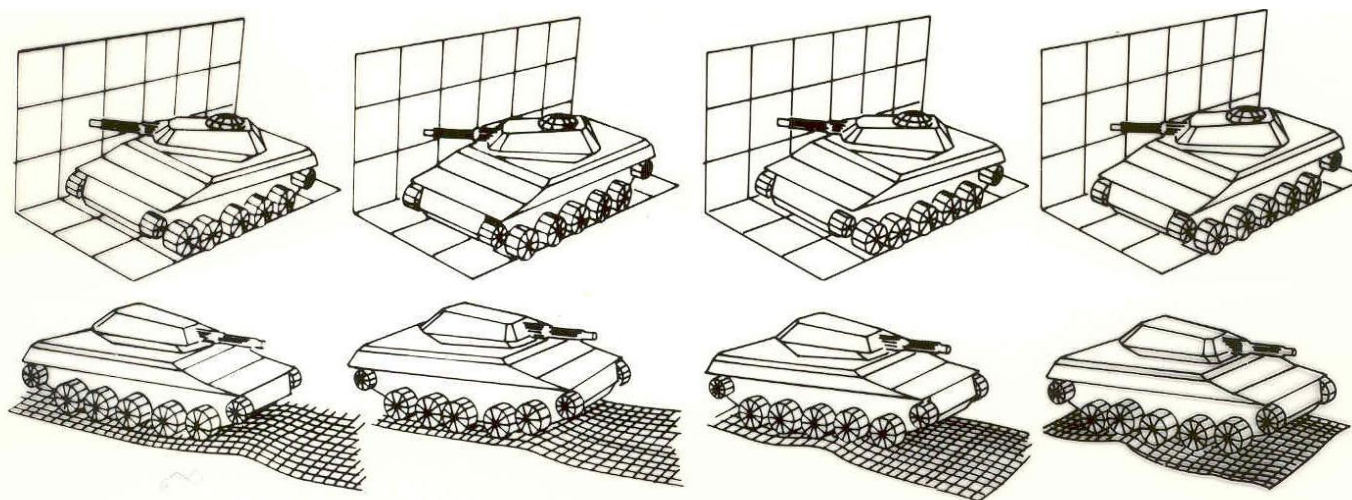
1980



1981

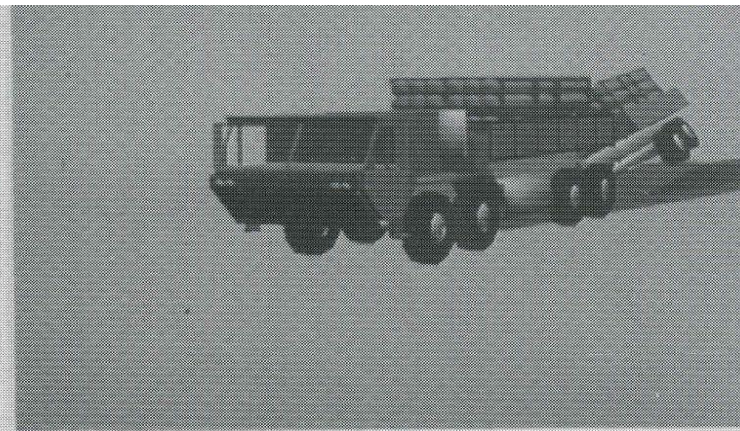
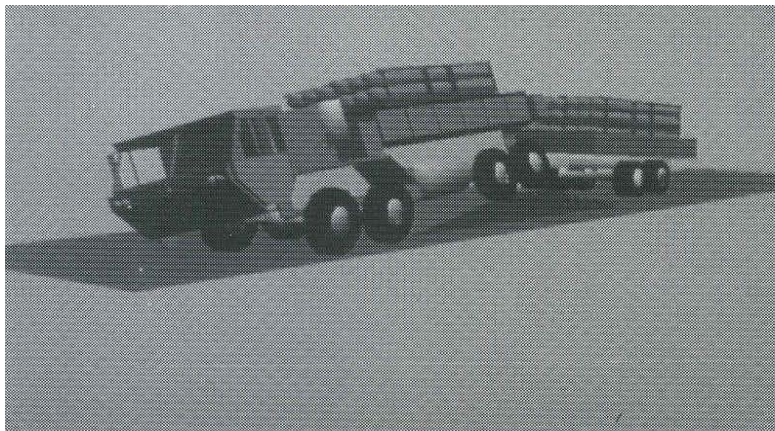


1982

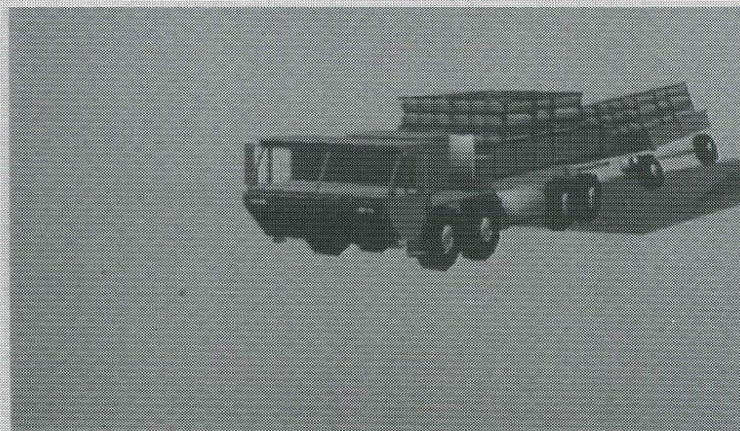
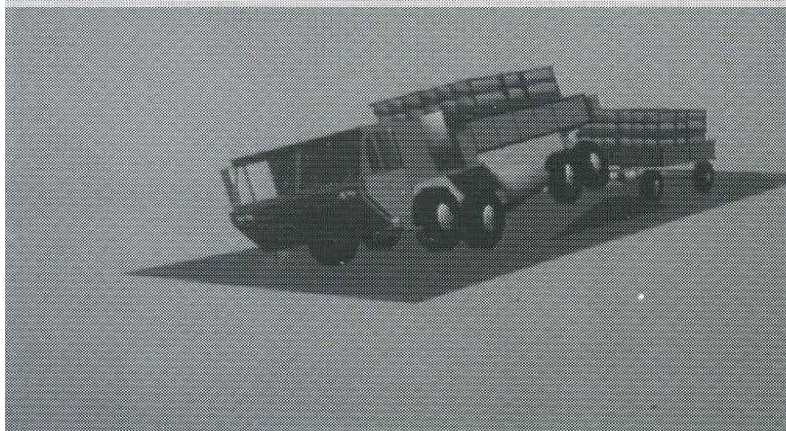


Δ624-83

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10 MILES PER HOUR 24 INCH OBSTACLE



35 MILES PER HOUR 24 INCH OBSTACLE

System-centric, M&S-based Services to integrate and assess the impacts of new concepts/technologies and upgrades to existing systems.

C

A

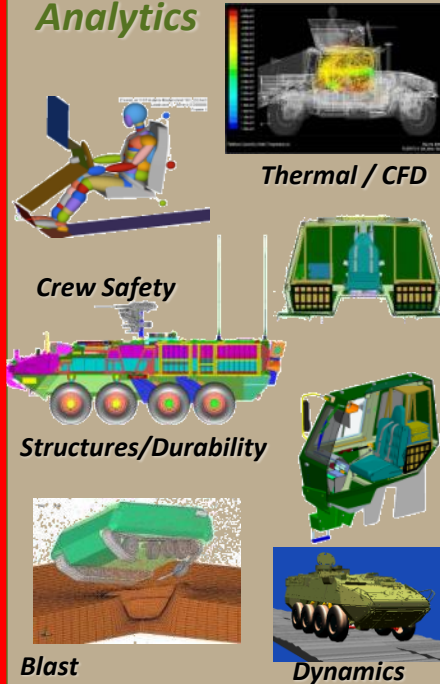
SS

I

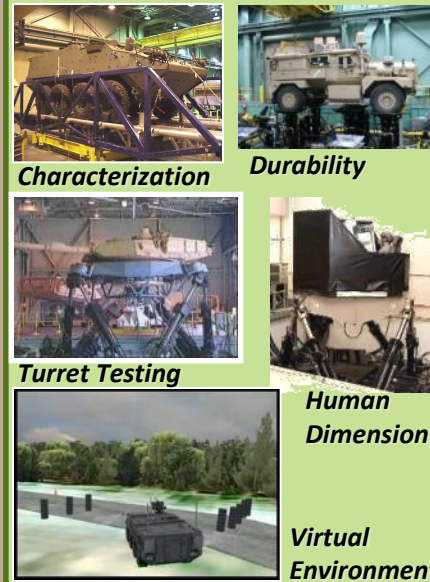
Concepts



Analytics



Hardware & Man-In-The-Loop Simulation



Integration & Demonstrators



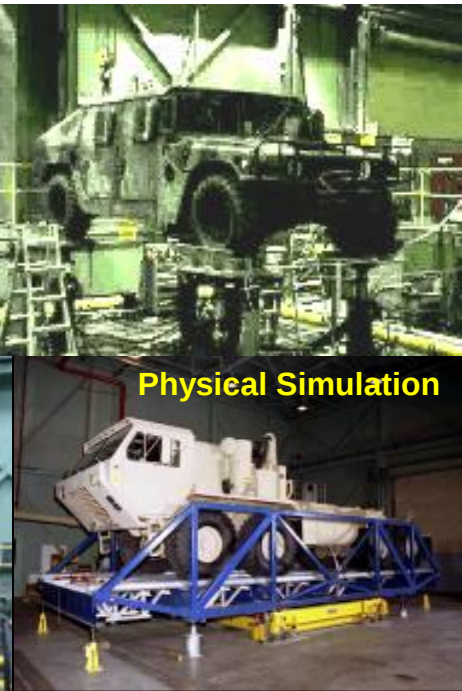
HPC & Data Management



Key Partnerships with TARDEC Technology Groups, other Army RDECs/Labs, PM's, TRADOC - MCOE, TACOM Sys & Cost Analysis, ATEC

- **Vehicle Dynamics**
 - Ride and Shock Quality
 - Lateral Stability
 - Handling (oversteer / understeer)
 - Braking
 - Rollover
 - Soft-soil Mobility
 - Suspension/vehicle Loads
- **Structural Analysis**
 - Reliability Modeling and Analysis
 - Failure analysis
 - Durability degradation
- **Technology Insertion**
 - Semi active/Active suspensions
 - Weight growth issues
 - Others (suspension upgrades, etc)
- **Research and Development**
 - Operational uncertainties and Reliability
 - Accelerated Testing
 - Rollover
 - Track, Tire and Terrain Modeling etc.





Ground Vehicle Simulation Laboratory

- Vehicle Characterization
- System Durability Studies
- Performance Validation
- System "Shakedown" Testing
- Man-In-the-Loop Testing



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- ✓ Suspension vertical stiffness
- ✓ Toe vs. vertical travel
- ✓ Camber vs. vertical travel
- ✓ Roll Center Height
- ✓ Overall Steering Ratio
- ✓ Wheel X,Y,Z motion wrt. travel

Machine Specs:

Vehicle Weight Capacity: up to 100,000 lbs

Suspension Travel: Up to 24 in (total)

Maximum Compressive Force: 60,000 lbs per axle.

Track width: up to 110 in.

Vehicle width up to 150 inches.

Wheel base up to 325 inches.

Vehicle length up to 600 inches.

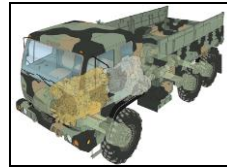


Coming in May!

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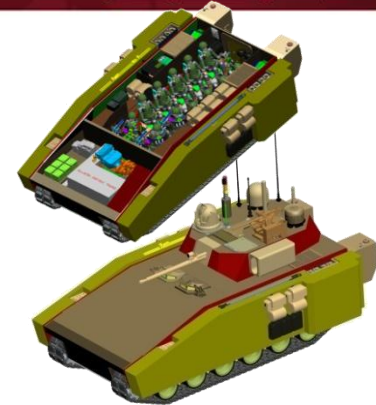
HMMWV FoV



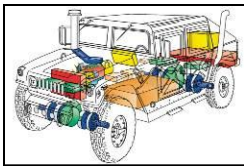
FMTV FoV – Armor
Effects on
Performance



JLTV - SSEB, AoA, TD Phase
Performance Assessments



GCV – Concept Analysis,
Power Pack Sizing, Req't
Definition, CDD Support



XM1124 HE HMMWV - Hybrid
Electric Vehicle Evaluation and
Assessment



HEMTT – Armor Effects on
Performance



M915/NGLH – Armor
Effects on Performance



Abrams – AGT
1500 Testing,
AoA



MRAPs – SSEB, Tech Insertion,
Armor/Power Effects on
Performance



Paladin – PIM
Analysis



Bradley – AoA,
Upgrade
Assessment



Stryker – Belly
Armor/Power
Effects on
Performance



Joint Recovery and Distribution System (JRaDS) Joint Capability Technology Demonstration (JCTD) Program



Armored Security Vehicle (ASV)



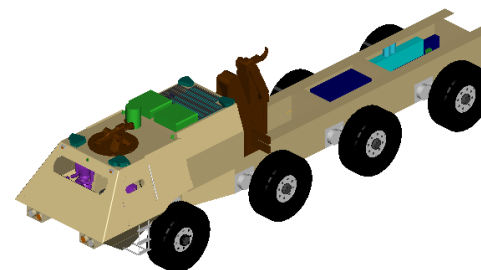
Expanded Capacity Vehicle (ECV)



MRAP All Terrain Vehicle (M-ATV)



Joint Explosive Ordnance Disposal Rapid Response Vehicle (JERRV)



Future Tactical Truck System (FTTS)

Conventionally, tied to operational performance:

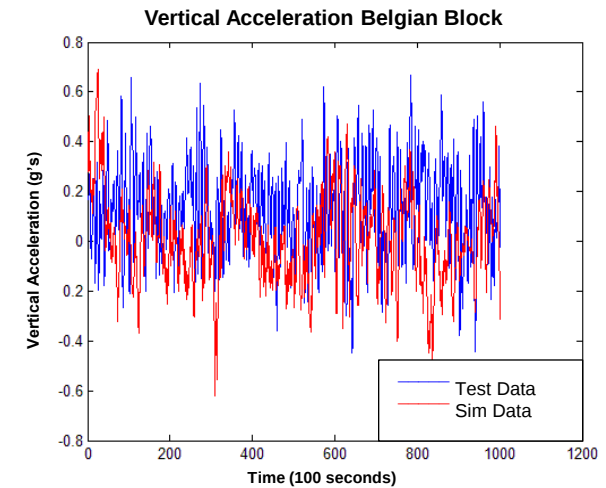
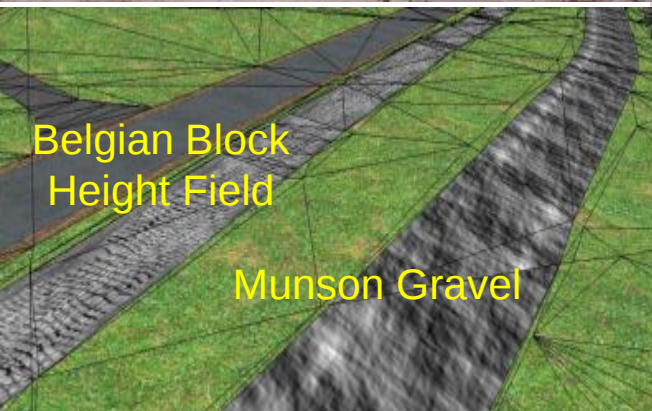
- Ride Quality: 6W Absorbed Power, Half-round Bumps
- NATO Lane Change
- Turning Radius
- Lateral Acceleration Capability in a Steady State Turn
- Soft Soil Mobility, Vehicle Cone Index
- Tilt Table

Open Research Ideas:

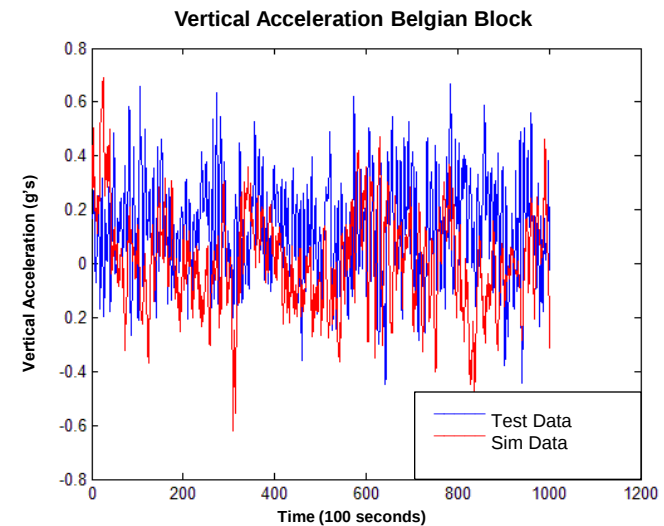
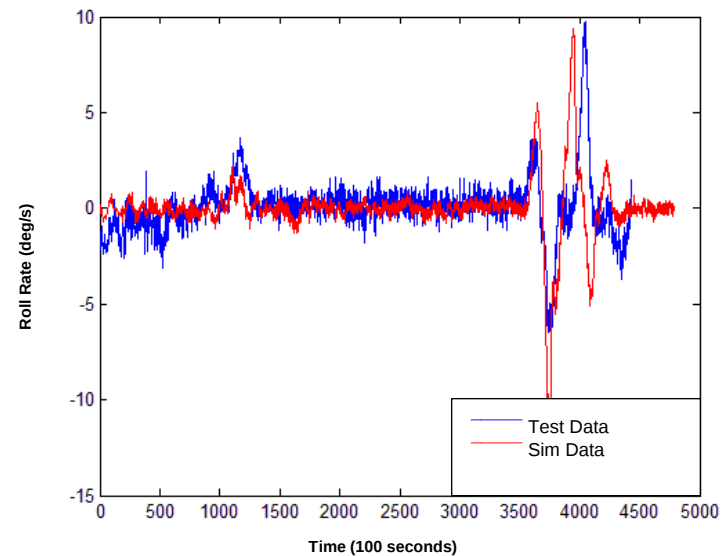
- Requirements based on operational uncertainties
- Off-road rollover
- ESC performance under on-road and off-road conditions
- New soft-soil mobility metrics
- Steering feel for fatigue, driving confidence

- Investigating state of the art active suspension technologies (such as MR damper) using **driving simulators**
- Developing active/semi-active suspension for off-road **rollover mitigation and ride quality.**
- Considering probabilistic approach for operational uncertainties, reliability, and lifecycle cost.
- Developing accelerated testing techniques to improve reliability and mobility.
- Utilizing multi-disciplinary approach to maximize survivability while meeting land mobility requirements (and water mobility for amphibious).
- Terrain, track, and tire modeling, etc.
- ...

Examine the effectiveness of MR dampers against passive dampers on a Stryker Vehicle



- Driver in the loop
- Max lateral acceleration on skidpad
 - 0.4G max lateral acceleration at 40 mph
- NATO lane change
 - Roll Rate
- Ride on simulated Belgian Block course
 - Vertical Acceleration

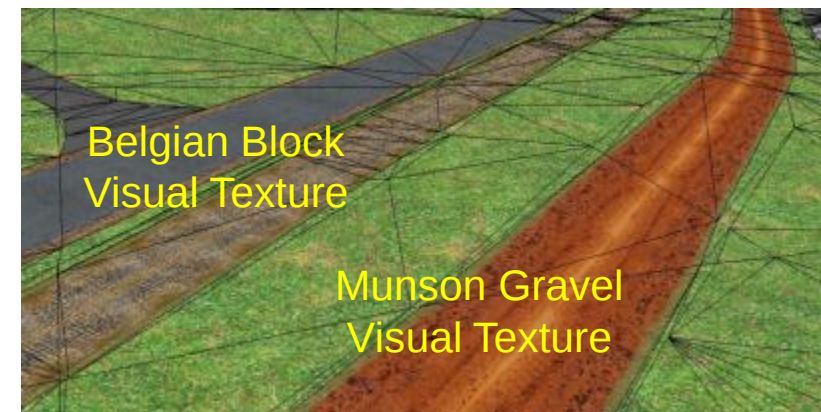
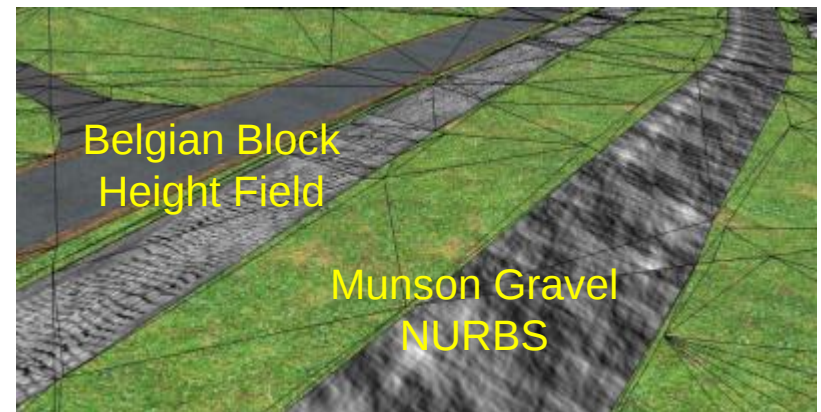


Challenges

Suspension performance requires enough resolution to capture suspension modes

Very dense terrain degrades real-time performance

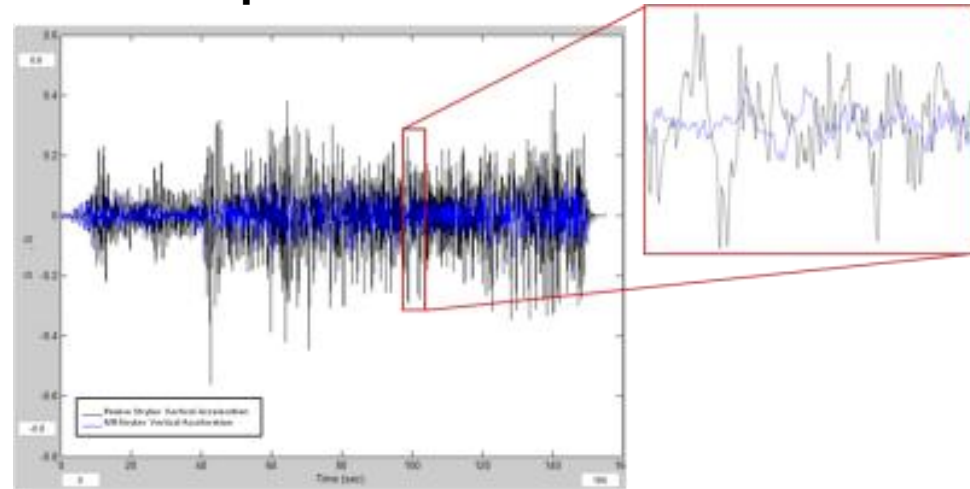
- NURBS
 - Used the Munson Gravel courses based on RMS values of Munson Gravel.
- Height Field
 - Uses texture and RMS of Belgian Block created from photographs of Belgian Block Course
 - Driven and reworked to produce representative response based on test data.



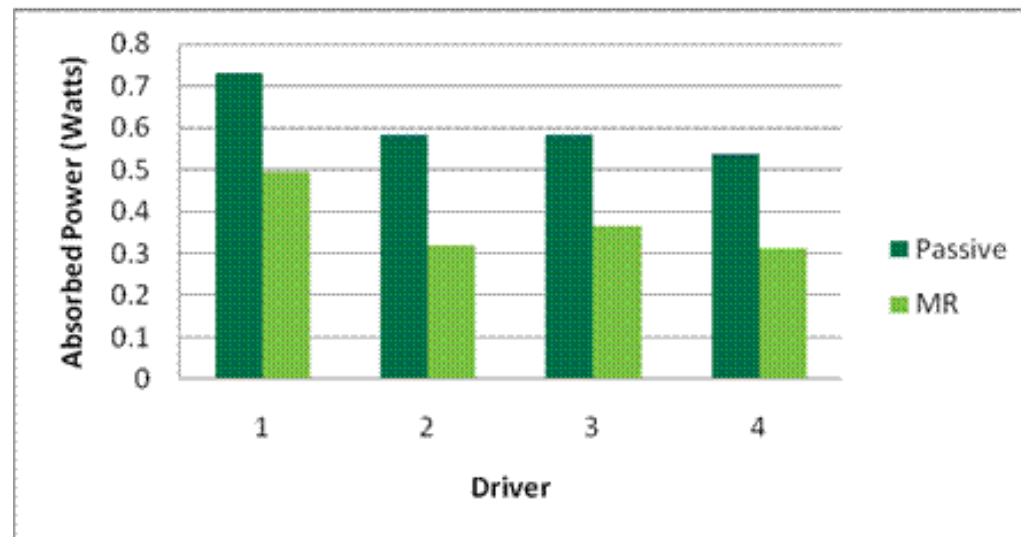
Demonstrated Benefits:

- ✓ Lower Vertical Acceleration
- ✓ Reduced absorbed power
- ✓ Improved subjective experience

Sample Vertical Acceleration



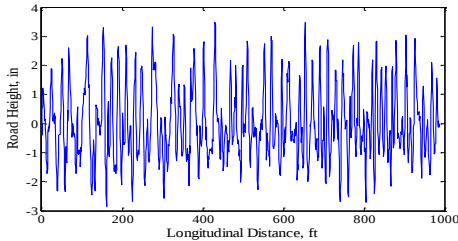
Sample Absorbed Power



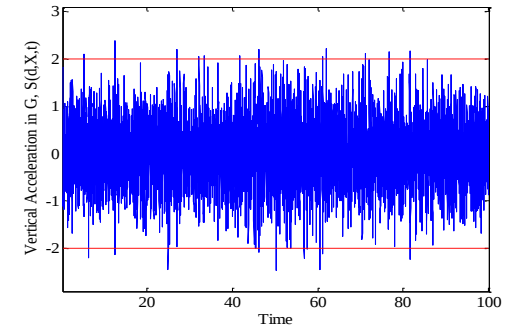
Random Variables



Vertical Accel. (G)



Terrain



Stochastic Input

Stochastic Output

Requires Probabilistic Approach

Constant design parameters:

$m_s = 1000 \text{ kg}$

$m_u = 100 \text{ kg}$

Vehicle speed = 20 mph

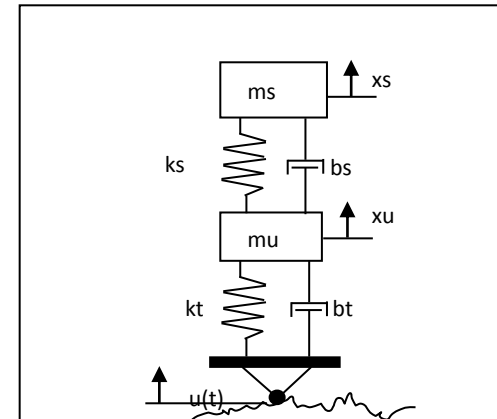
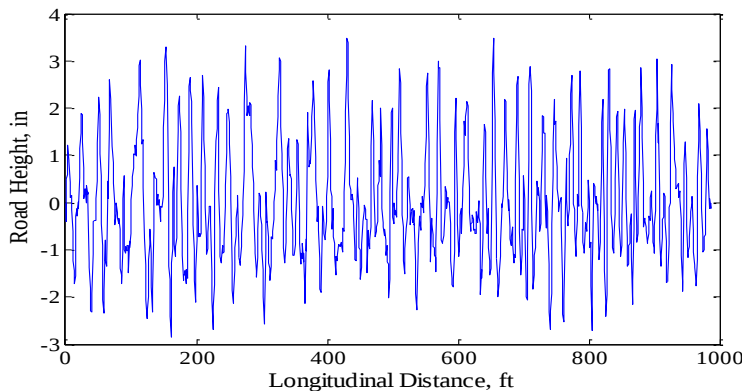


Random Input variables

Damping, $b_s \sim N(7000, 1400^2)$

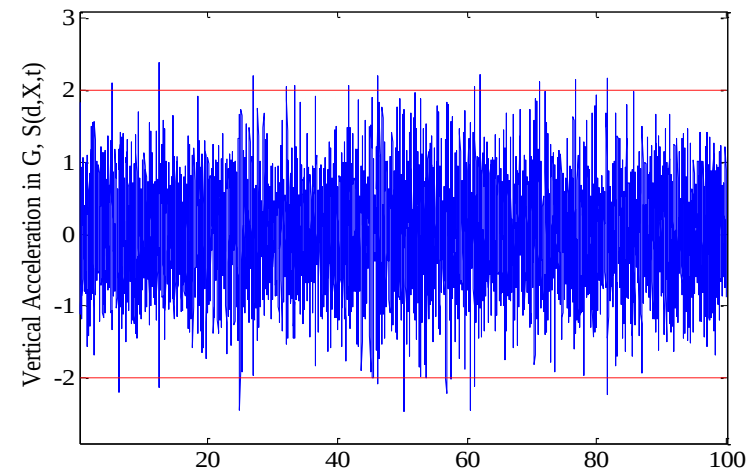
Stiffness, $k_s \sim N(40 \times 10^3, (4 \times 10^3)^2)$

Random Input Process: Experimental Stochastic Terrain from Yuma Proving Grounds.



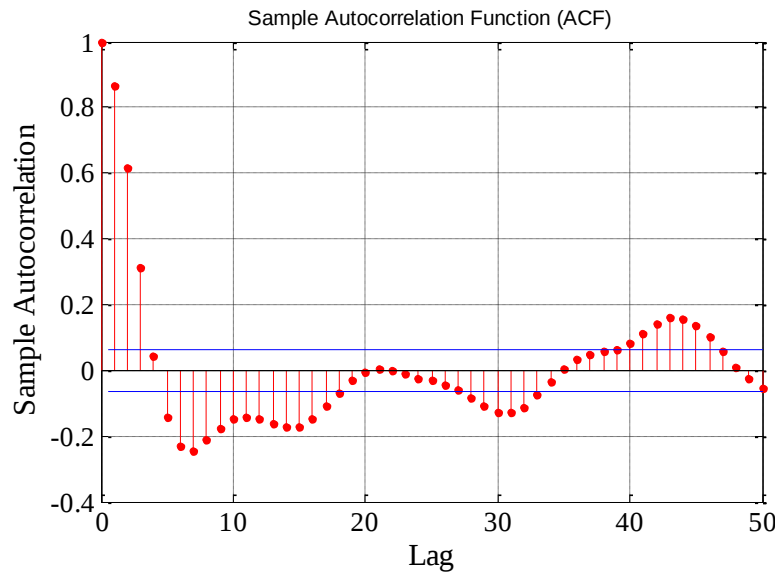
Random Output Process
(Vertical Acceleration, G')

Threshold = 2G

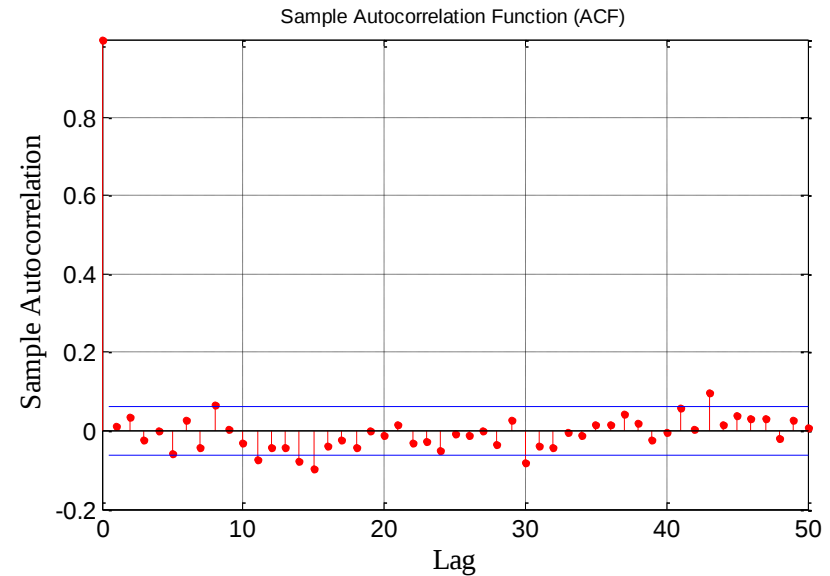


AR(3) model was identified based on:

**Autocorrelation
Function**

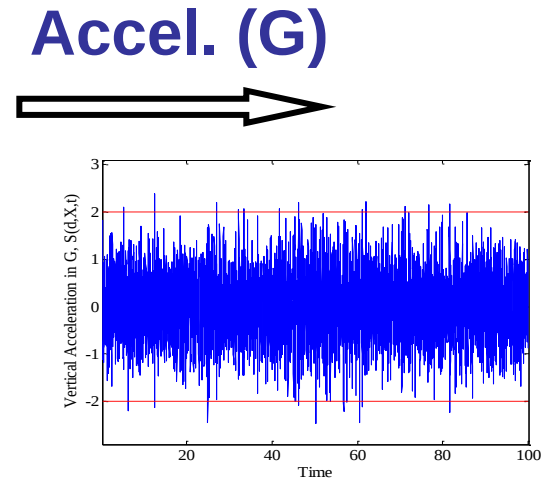
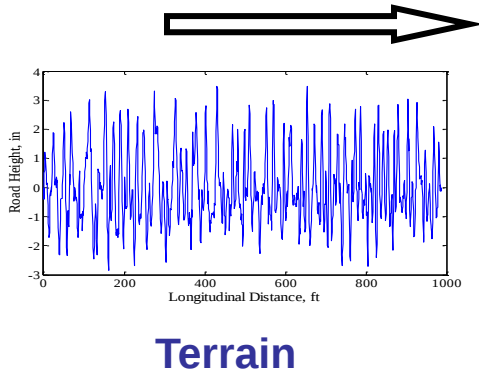


**Autocorrelation of
Residual process**



$$u_i = 1.2456 \quad u_{i-1} - 0.2976 \quad u_{i-2} - 0.1954 \quad u_{i-3} + \varepsilon_i(0, \quad 0.5132^2)$$

Statistical tests were performed to verify the model



Stationary
input random
process

+

Linear
system

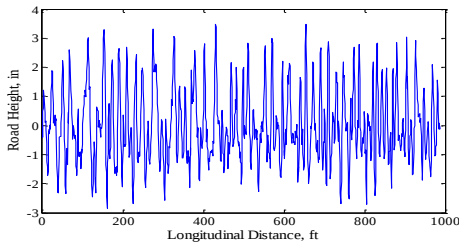


Stationary
output random
process



Constant (**time-independent**) failure
rate

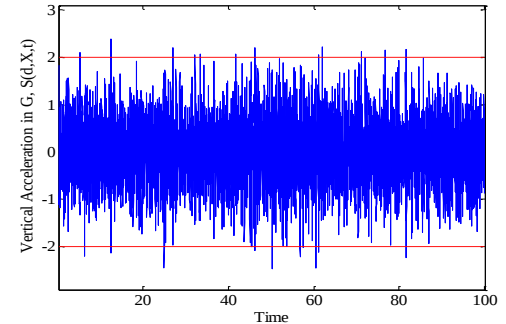
Random Variables



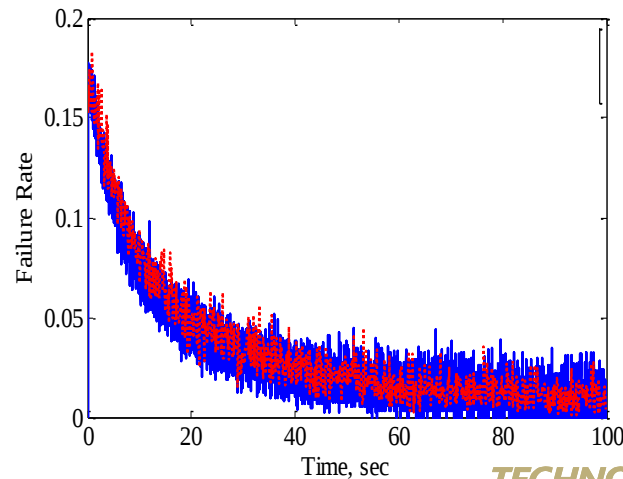
Terrain



Accel. (G)



Time-dependent failure rate



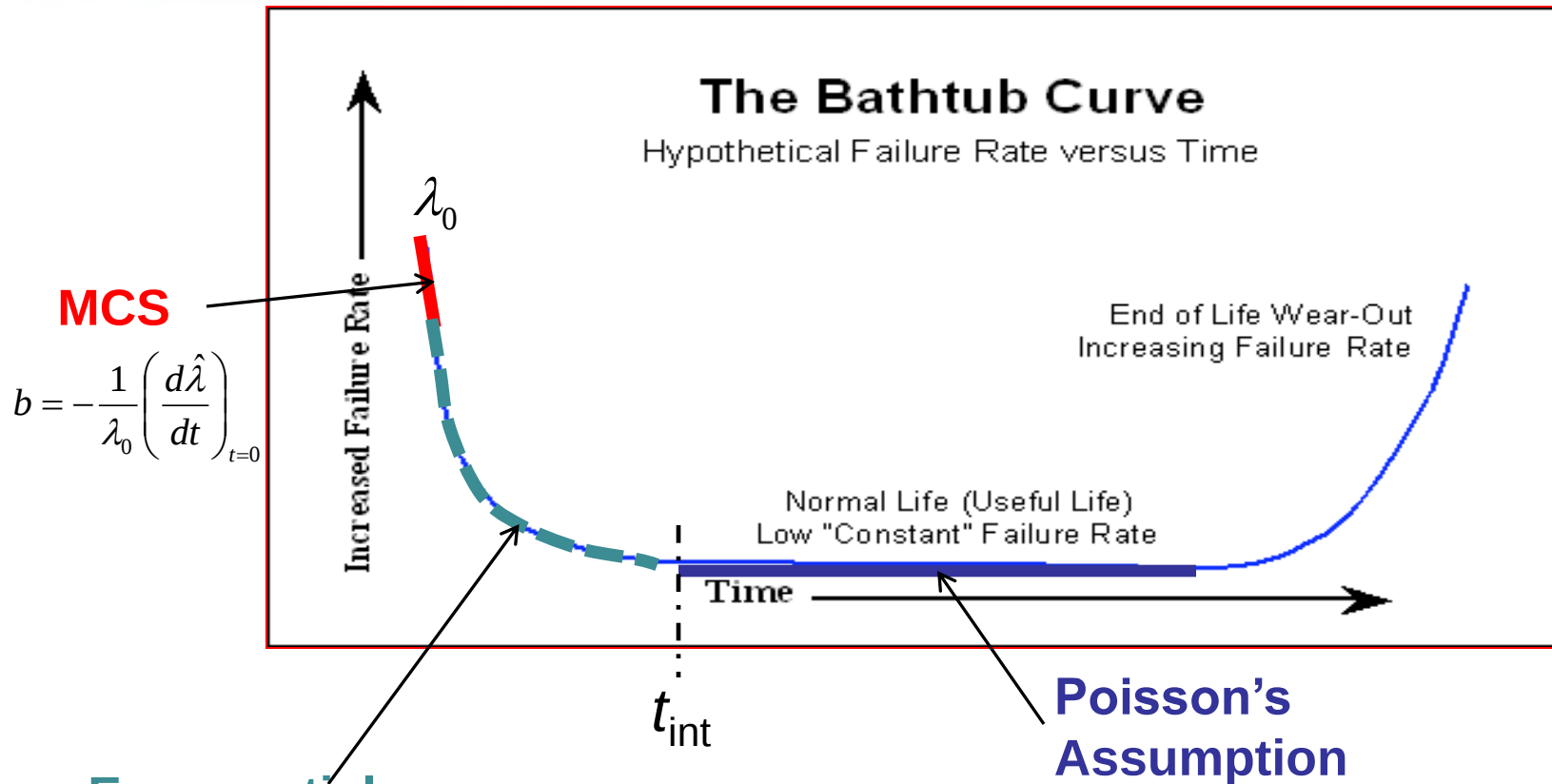
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Vehicle speed : 20 mph; **Mission distance** : 100 miles

Simulation can be practically performed for a **short-duration** time

A novel MC-based method to calculate failure rate based on :

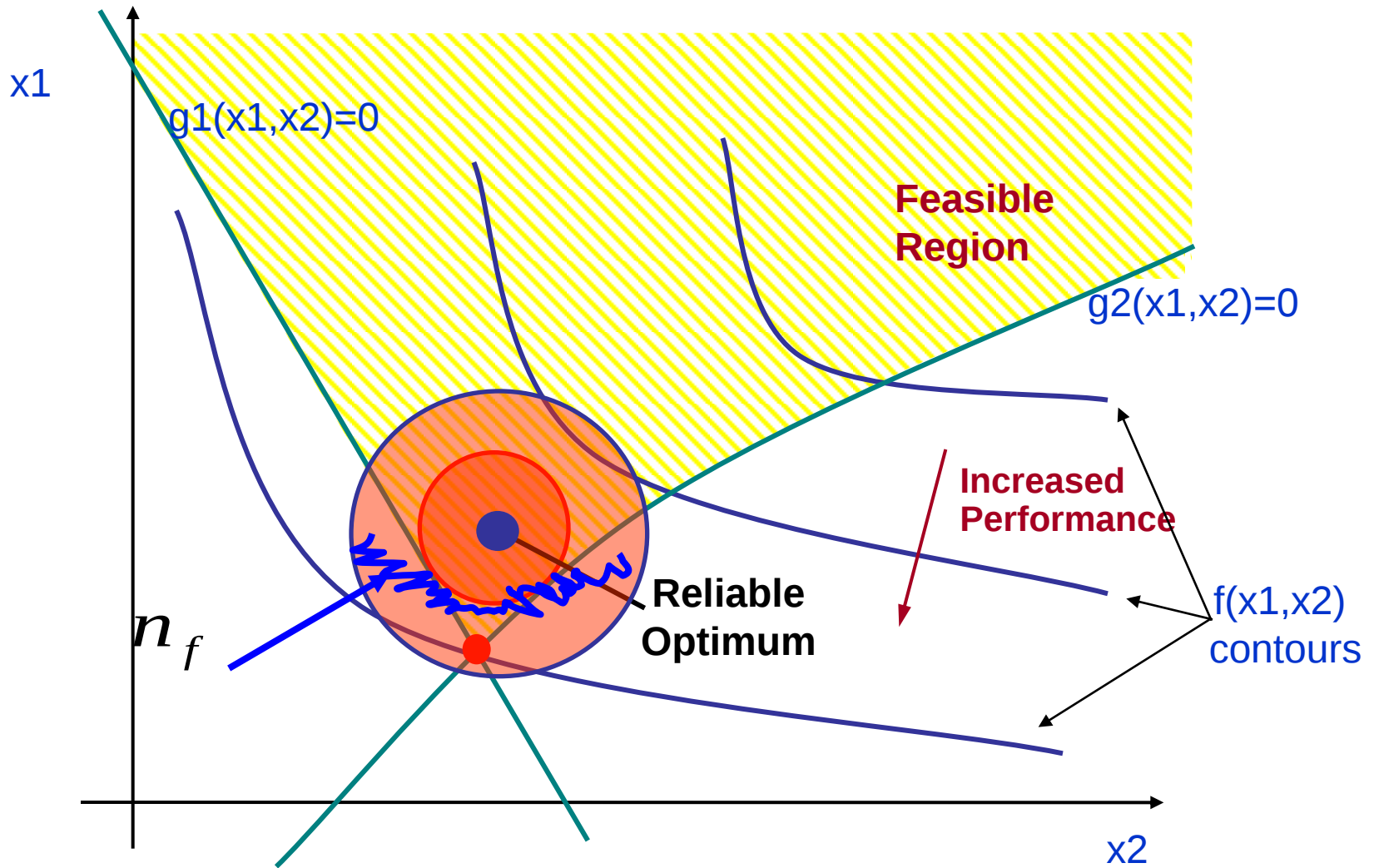
- **Short-duration** data and an **exponential** extrapolation using MCS or Importance Sampling or Subset Simulation (Infant Mortality)
- Poisson's assumption (Useful Life)



Exponential Extrapolation

$$\hat{\lambda}(t) \approx \lambda_0 e^{-bt}$$

$$F_T^c(t) = \begin{cases} 1 - e^{-\int_0^t \hat{\lambda}(t) dt} & , t \in [0, t_{int}] \\ 1 - (1 - F_T^c(t_{int})) e^{-\nu_m(t-t_{int})} & , t \in [t_{int}, t_f] \end{cases}$$



$$\lambda(t_i) = \lim_{\Delta t \rightarrow 0} \frac{\sum_{n=1}^{N_f(t_i)} \omega(\mathbf{x}, t_i)}{\Delta t \cdot N_S(t_{i-1})}$$

where:

$$\omega(\mathbf{x}, t_i) = \frac{f_{\mathbf{x}}(\mathbf{x}; t_i)}{f_{\mathbf{x}^s}(\mathbf{x}; t_i)} \quad \begin{array}{l} \text{: Likelihood ratio} \\ \text{at} \end{array} \quad t_i$$

$N_S(t_{i-1})$: Safe sample points t_{i-1}
at

$N_f(t_i)$: Number of failures in $\Delta t = t_i - t_{i-1}$

Constant design parameters:

$m_s = 1000 \text{ kg}$

$m_u = 100 \text{ kg}$

Vehicle speed = 20 mph

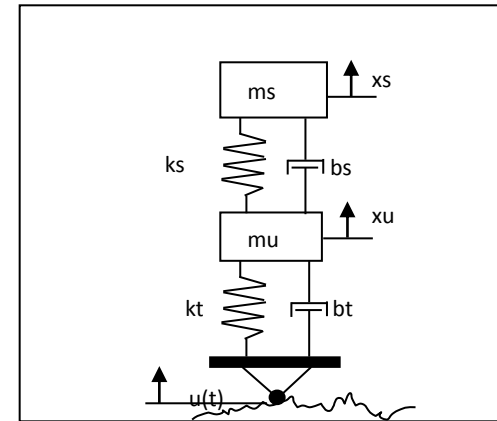
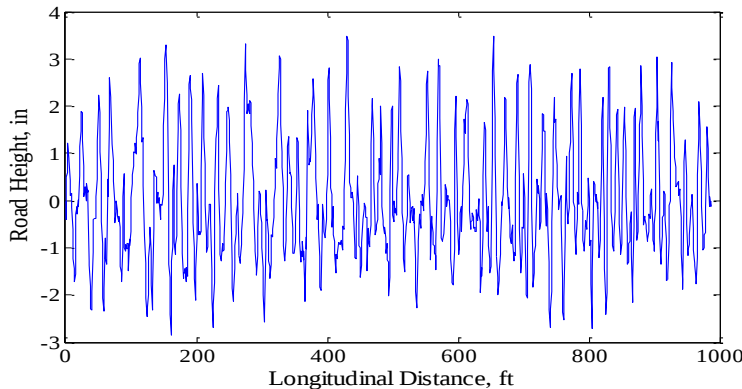


Random Input variables

Damping, $b_s \sim N(7000, 1400^2)$

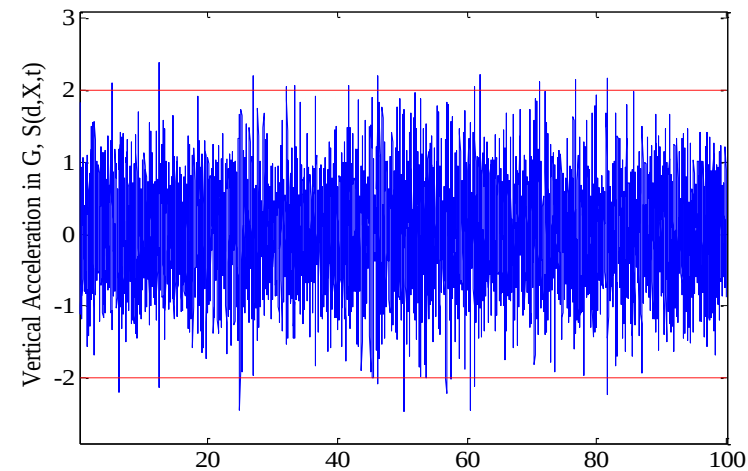
Stiffness, $k_s \sim N(40 \times 10^3, (4 \times 10^3)^2)$

Random Input Process: Experimental Stochastic Terrain from Yuma Proving Grounds.



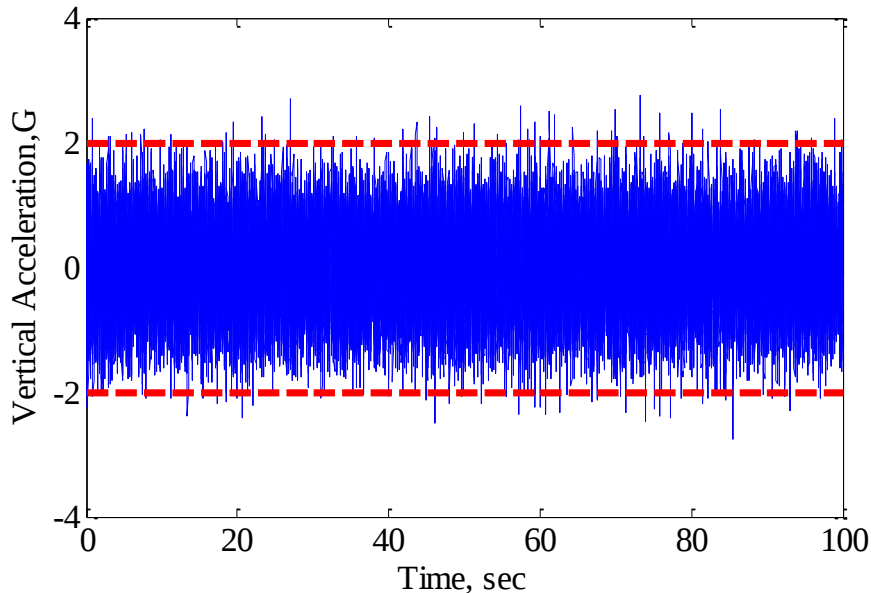
Random Output Process
(Vertical Acceleration, G')

Threshold = 2G

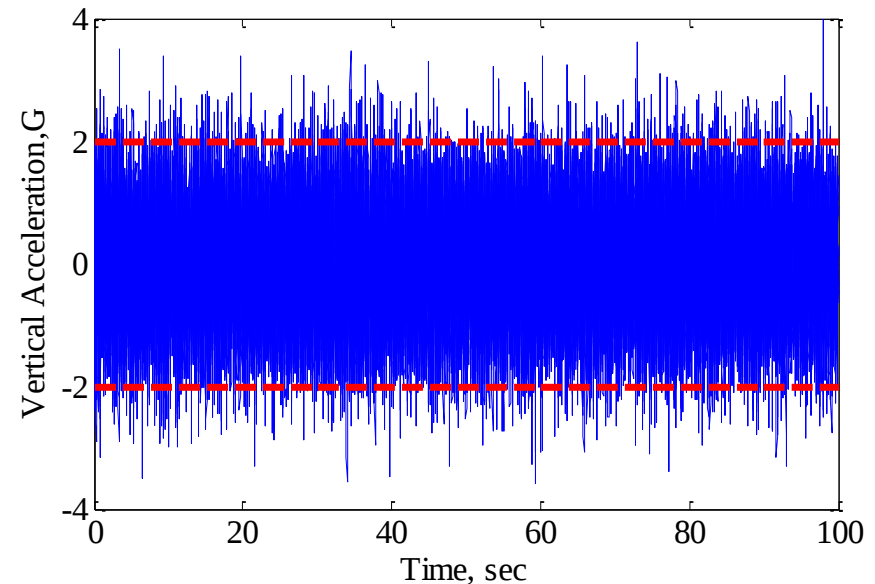


$$u_i = 1.2456u_{i-1} - 0.2976u_{i-2} - 0.1954u_{i-3} + \varepsilon_i(0, 0.5132^2)$$

Original PDF $\sigma_e = 0.51$



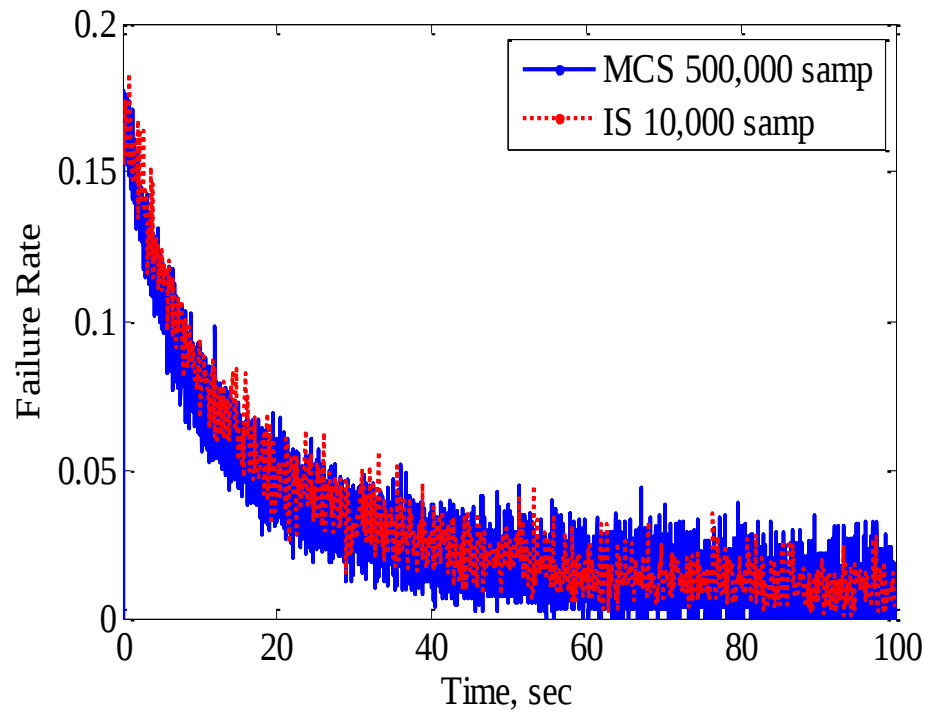
Sampling PDF $\sigma_s = 0.7$



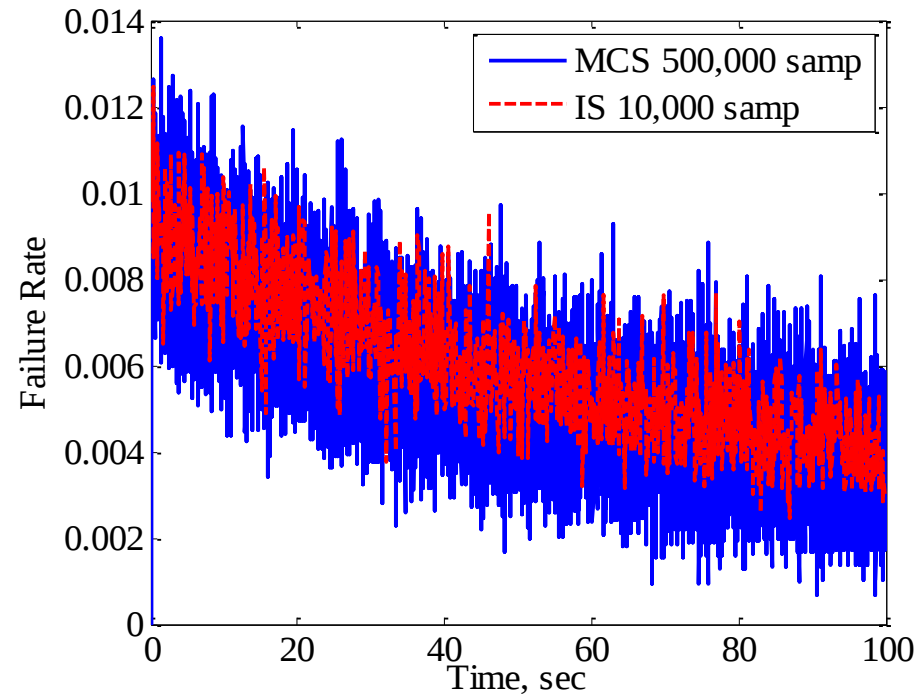
The sampling PDF results in more failures

Non-Stationary Case

Threshold = 2 g



Threshold = 2.65 g





Actuator Capabilities

- Force rating 190 KN
- Dynamic stroke 355 mm
- Velocity 9.1 m/sec
- Force rating of load cell transducer 55 Kip

Analysis Capabilities

- Fatigue Damage Estimate
- Statistical Time History Editing
- Cycle Counting Analysis

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.

- SBIR- Small Business Innovative Research
- Automotive Research Center (ARC)- Alliance between US Army and academia (University of Michigan- Ann Arbor, Clemson University, Oakland University, Virginia Tech, and others). <http://arc.engin.umich.edu/>.
- Simulation Based Reliability and Safety (SimBRS)
- Cooperative Research and Development Agreement (CRADA).
- Innovation Grants

Thank You!

Q&A