Annex D – VIRTUAL AND PHYSICAL DEMONSTRATION PLAN

Note: This Annex appears in its original format.

Virtual and Physical Demonstration Plan

Presented by

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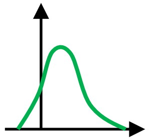
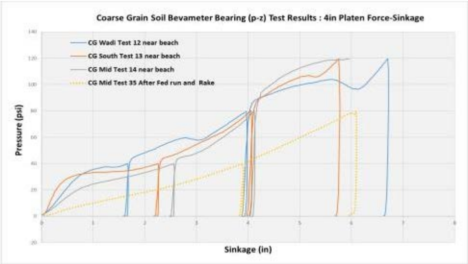
Outline of the Presentation

- **Objective of the coming hour**
  - Introduce the NG-NRMM Spirit: A Standard and Recommendation for 3D Physics based Mobility Prediction
  - Virtual Demonstration Plan (Dr. Ole Balling)
    - Presentation of Virtual Technologies for the NG-NRMM Demonstration
    - Data Environment and Sourcing of Data
    - Modeling and Simulation Technologies
    - Participating Vendors and Collaboration Between Organizations
  - Physical Demonstration Plan (Scott Bradley)
    - Choice and Details of Vehicle Platform and Instrumentation
    - Introduction to the Acquisition of Soil and Terrain Data (topology, soil, vegetation, water etc)
    - Introduction to the Vehicle Behavior (Automotive, Soft Soil and the Mobility Traverse)
  - The Resulting Mobility Prediction based on V&V and demonstrated in the Mobility Traverse (Dr. Ole Balling)

Objective of the Demonstration during the next 3 Days

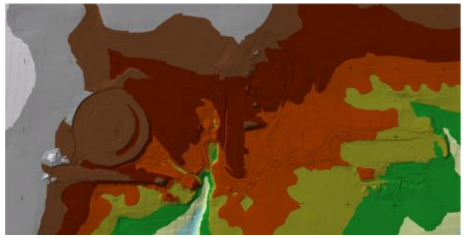
- **Demonstrate the NG-NRMM process through Modeling and Simulation, Vehicle Testing and Demonstration (Illustrated through Ride-along)**





  - ➢ Familiarity with the Capability of the Chosen Vehicle

  - ➢ Understanding of the Challenges of Soil Data Collection and Variability



  - ➢ Insight in the Capture of Soil and Terrain Data in Maps and Data Formats for Modeling and Simulation

  - ➢ Gain insight into Different Software Organizations implementation of Mobility Prediction Solutions

  - ➢ Demonstration of NG-NRMM will be Illustrated through the Mobility Traverses

The Demonstration of Technology and NG-NRMM

- **NG-NRMM: Next generation NATO Reference Mobility Model:**
  - A Standardization and Recommendation: The **StanRec**

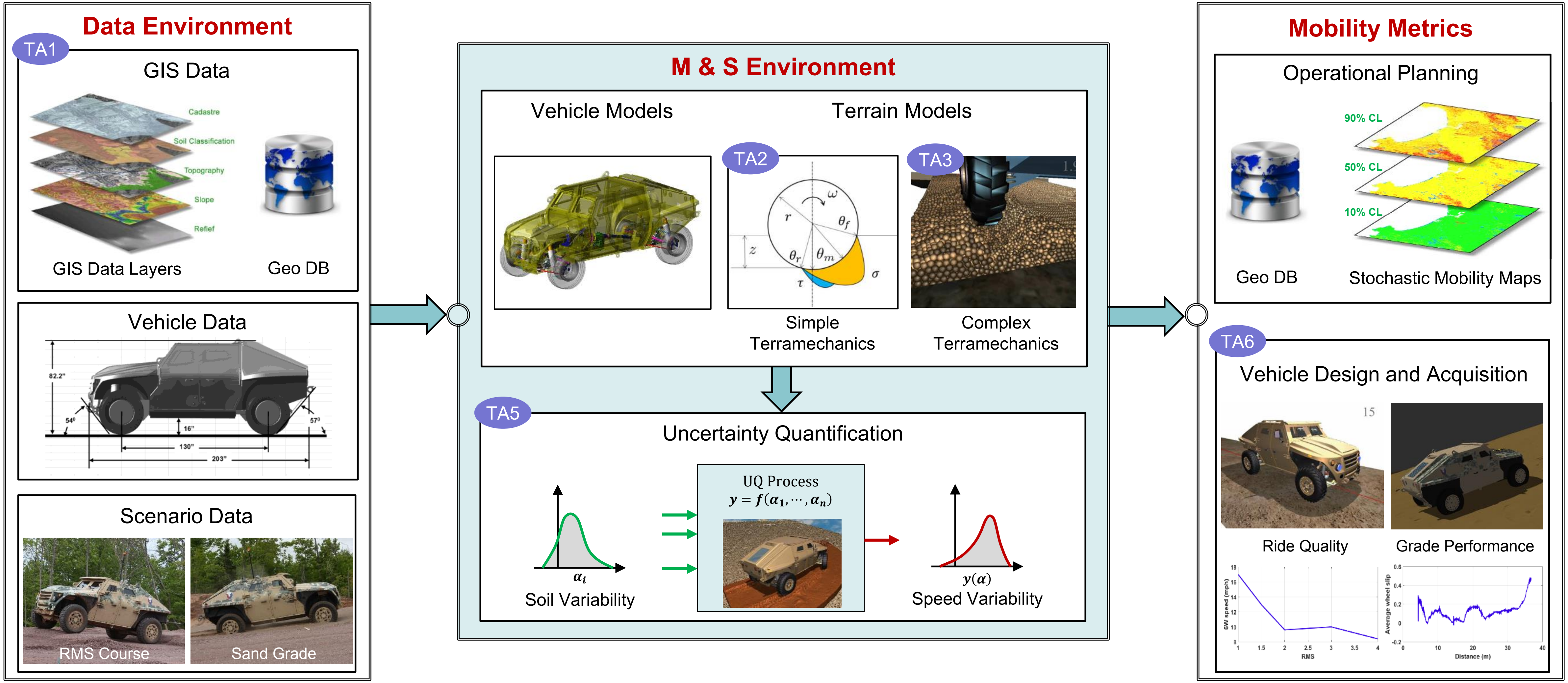
The StanRec

- Standardization and Recommendation that Documents Practices to be Compliant with the intent of the NG-NRMM.
- Provides a Database of Examples Vehicles and Test Data that exemplifies the use of the StanRec

- **Materialized through Vehicle Data, Testing and the Mobility Traverses**
  - Automotive Tests
  - Soft Soil
  - The Mobility Traverse

- (Sample pictures/movies of data, test and traverses)

NG-NRMM Architecture

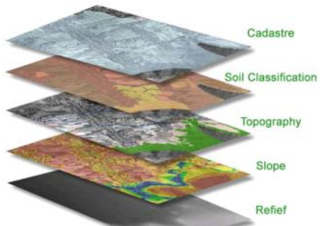


Data Environment Technologies

Data Environment

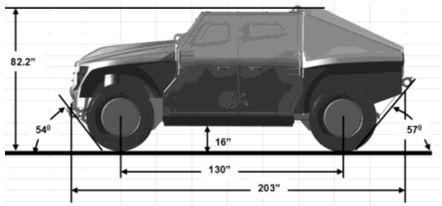
TA1

GIS Data



GIS Data Layers   Geo DB

Vehicle Data

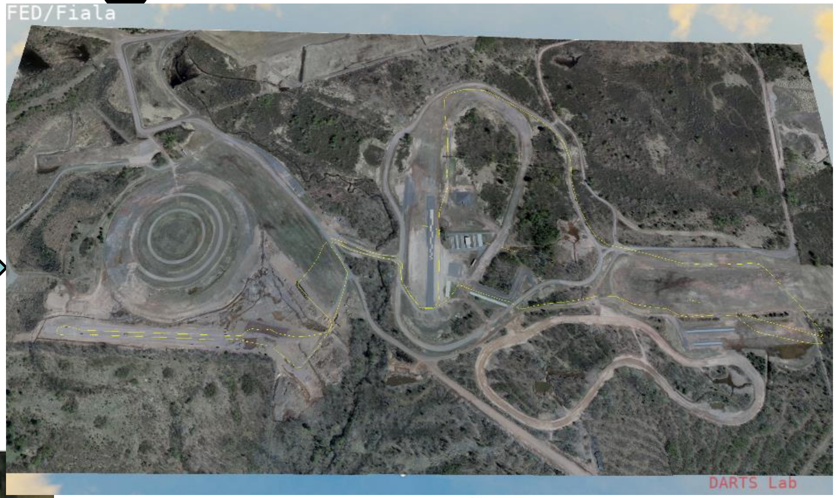


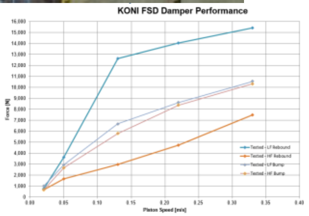
Scenario Data

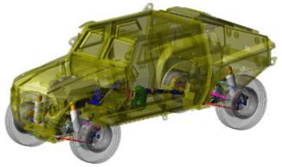

RMS Course

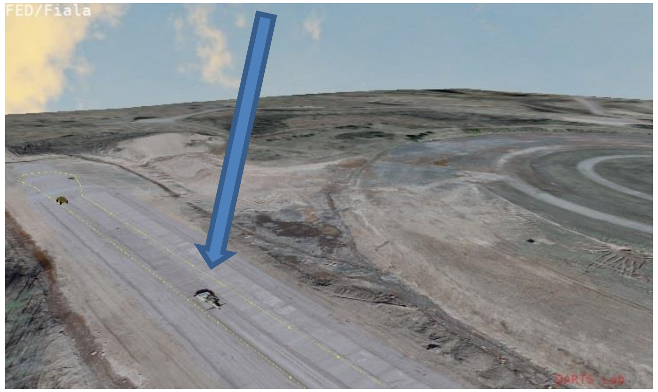

Sand Grade

- **Geographical Information Systems (GIS) Data (TA1)**
  - Data Collection Technologies
  - Several Sources (USGS, FAO, EPA, NPS, ESRI etc)
    - Topography, Slope
    - Soil Classification
    - Moisture Content
- **Vehicle Data**
  - Vehicle Design Data
  - Vehicle Measurements
  - Component Measurements
- **Scenario Data**
  - Test Specifications
  - Course Scans and Data Formats

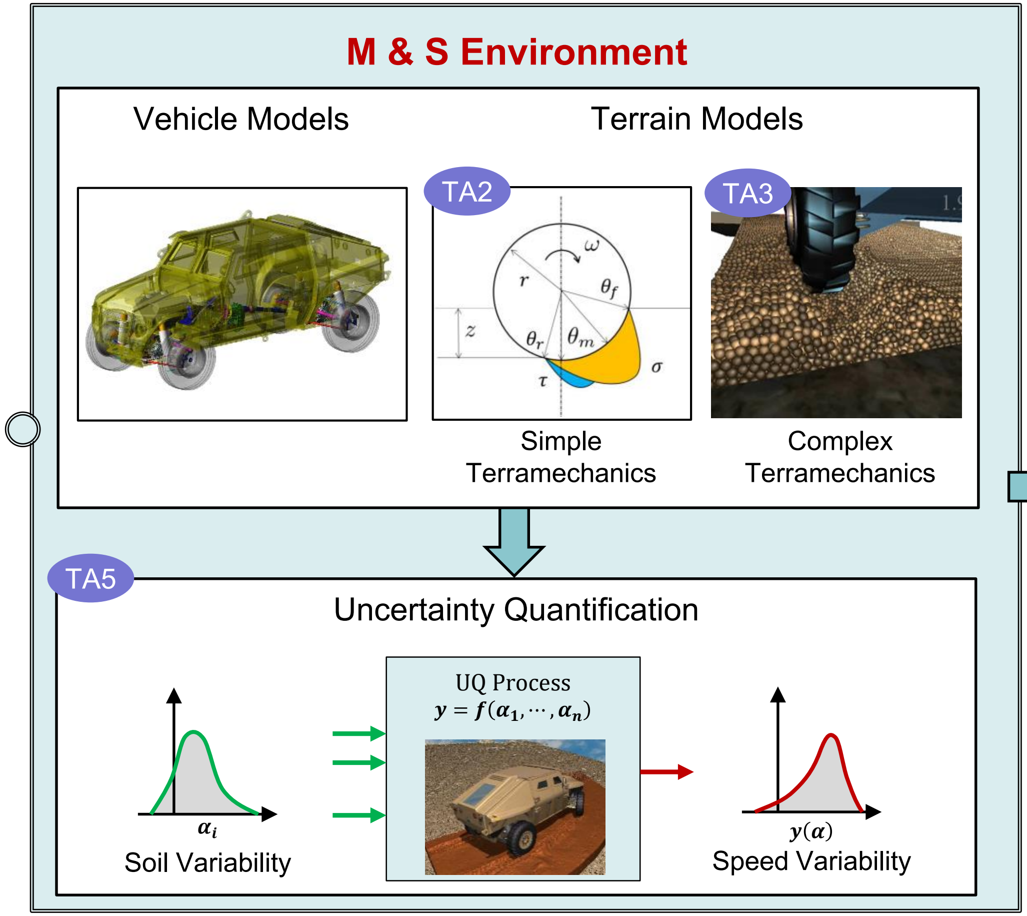








NG-NRMM Modeling and Simulation Technologies

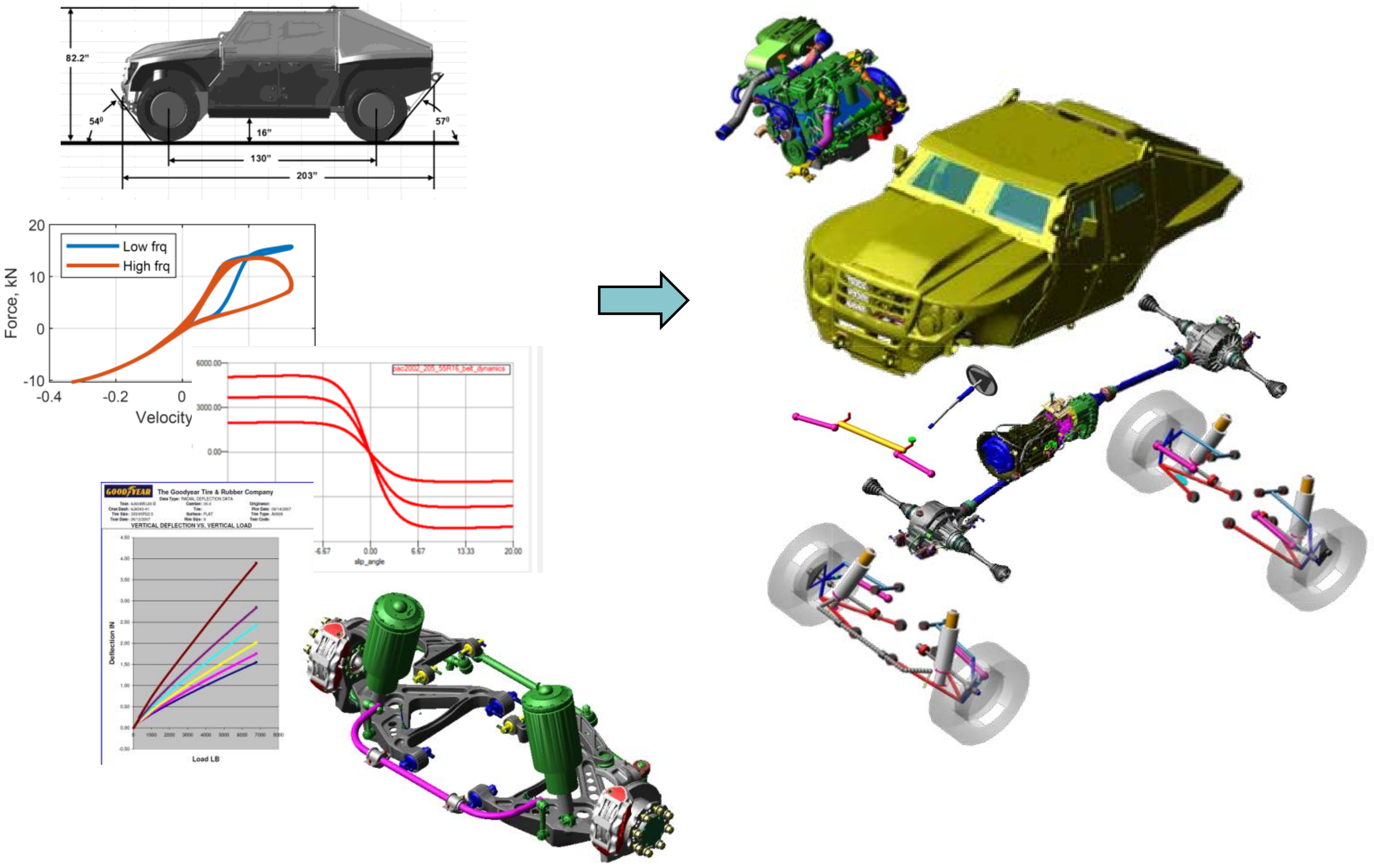


- **NG-NRMM: Vehicle Modeling:**
  - Leverages recent advantages in 3D Multibody Vehicle Modeling
    - Automotive Virtual Testing
  - Brings in Terramechanics
    - TA 2: Simple Terramechanics
      - Bekker-Wong Type Models etc
    - TA 3: Complex Terramechanics
      - Discrete Element Method for Soil Representation
- **NG-NRMM Adds Uncertainty Quantification (TA5)**
  - ➢ Harnesses Variation in Data input to Mobility Performance Metrics

NG-NRMM Modeling and Simulation Technologies

- Vehicle System
  - Based on 3D Multibody Dynamics
- Advancement in Suspension Systems such as
  - Independent Multilink Suspension with Bushings, Coils and Air Springs
  - Mechanical or Hydraulic Roll Stabilizer Technology etc
- Steering Systems
  - Rack and Pinion or 4 Bar Linkage Steering
  - Multi-Axle Steer and Steer-by-Wire Systems
- Engine/Powertrain
  - Throttle Dependent Torque and Fuel Maps
- Tires
  - Fiala, Pacejka, FTire, Swift, Complex Soiletc.

10^1 – 10^2 degrees of freedom models



NG-NRMM Modeling and Simulation Technologies

- 3D Vehicle Dynamics Mobility Prediction
  - Hard Surface through Coefficient of Friction and Advanced Tire Models
  - Soft Soil through Advancements in Terramechanics Modeling

Add ST and CT figures

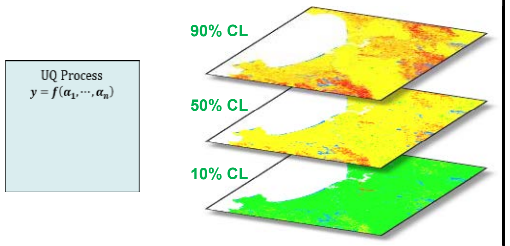
- Simple Terramechanics (TA 2)
  - Bekker-Wong Type Models
  - Bevameter Data and Laboratory Test

- Complex Terramechanics (TA 3)
  - Based primarily on Laboratory Soil Tests
  - Can use:
    - Cone Index
    - Simulated Bevameter

NG-NRMM Mobility Metrics Technologies

Mobility Metrics

Operational Planning Tools

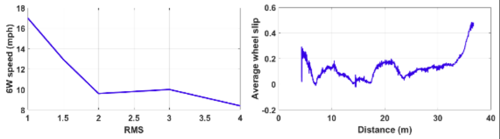


Geo DB

Stochastic Mobility Maps

TA6

Vehicle Design and Acquisition Tools



- **NG-NRMM:**
  - Vast Availability of Simulation Outputs
    - Conventional NRMM Output Metrics Possible (Speed Made Good, Go-NoGo Maps)
    - Additional Metrics such as Output Data from Transient Events.
  - Verification and Validation Possible (TA 6)
    - Depends on Test Data Availability
    - Sample Vehicles and Test Data Available (Wheeled Vehicle Platform and Fed-A)
  - Path Planning with 3D Dynamics

Add map and path figures

CDT Participating Organizations

- **4 Countries, 3 Vehicle Modeling Approaches, 2 Terramechanics Approaches**

Benchmark Participants	Country of Origin	Simulation Software	Terramechanics Approach
Advanced Science and Automation Corporation	USA	IVRESS/DIS (MBS)	Complex
CMLabs	CA	Vortex (MBS)	Simple
MSC Software	USA	ADAMS (MBS)	Simple/Complex
Vehicle Development Systems Corp	CA	NWVPM (Force Balance)	Simple
Aarhus University/JPL	DK/USA	ROAMS (Recursive MBS)	Simple
CSIR (South Africa)	ZAF	MobSim (Force Balance)	Simple

Virtual and Physical Demonstration Plan

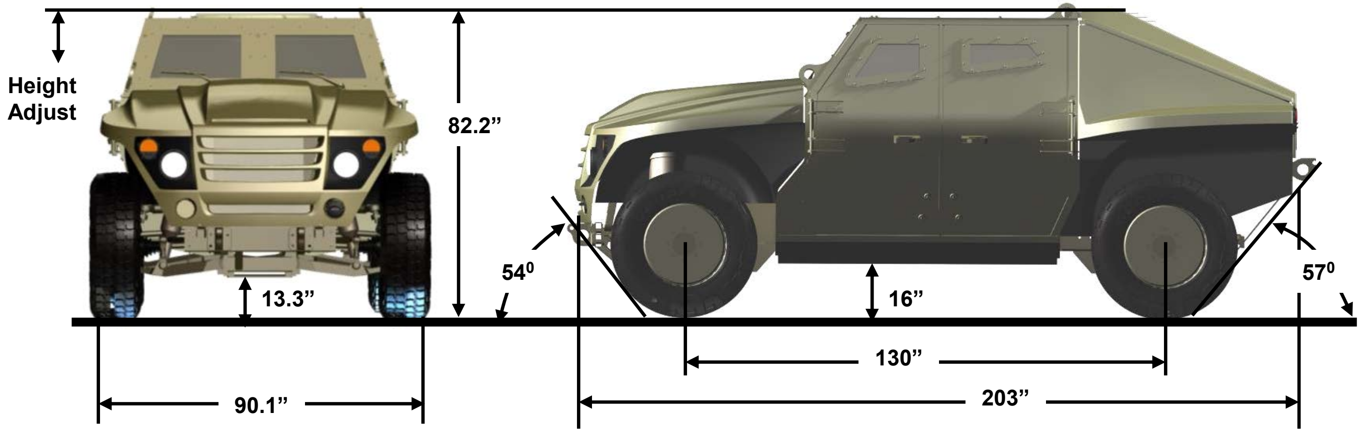
- The Virtual Demonstration Links to the Physical Demonstration by
  - Choice of Vehicle for Demonstrating NG-NRMM Capability
  - Instrumentation
  - Test Plan including Automotive and Soft Soil Tests

Physical Data Collection Plan

- **Vehicle Introduction (Why FED-A?)**
- **Collection Plan for Vehicle Data Set**
  - General Physical Data
  - Ricardo Data Set
  - ATEC Test Report
- **Collection Plan for Terrain Data Set**
  - Details to be Discussed in Today's Thrust Area 1 & Wednesday's Software Presentation
- **Collection Plan for Vehicle Behavior Data Set**
  - Data Acquisition / Instrumentation
  - As Tested Configuration
  - Calibration (General Automotive Tests)
  - Soft Soil Behavior (Sand Grade & Draw Bar)
  - Mobility Traverse (Speed Made Good Estimation)

Introduction to FED-A

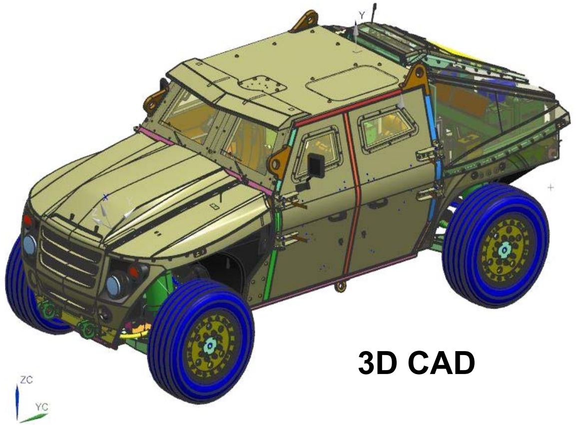
- TARDEC Owned Vehicle
- Fuel Efficiency Demonstrator – Alpha (FED-A)
- Developed by Ricardo
- Full Vehicle Database Already Collected
- Database Open to Public Dissemination
- Subjected to Some US Army Test & Evaluation Command Testing
- Appropriate Size and Weight
- Suitable Off-Road Capability & Durability
- Liberal Use of COTS Components
- Some Spare Part Packages Available



General Vehicle Information

- **Full 3D CAD Package**
- **As Delivered Scanning of Vehicle**
- **VIPER Test Data**
- **As Tested CG Verification**
- **Test Weight 12,333 lbs**

3D Point Cloud of Actual Test Asset



3D CAD

TEST RESULTS

Fuel Efficiency Ground Vehicle Demonstrator (FED) in Low Ride Height

VIPER Test Number: 421
Date of Test Completion: 12 March 2011

Figure 2: FED positioned and restrained on the VIPER.

Test Summary: Fuel Efficiency Ground Vehicle Demonstrator (FED) in Low Ride Height

Vehicle Name:	FED
Fuel Level:	5/8 Full of Fuel
Tire Pressure (Left/Right):	58/59 psi 63/61

Additional Information:

Tire Type:
Goodyear G275 MSA 335/65R22.5

Details of vehicle configuration in Appendix A.
Details of vehicle ride height in Appendix B.

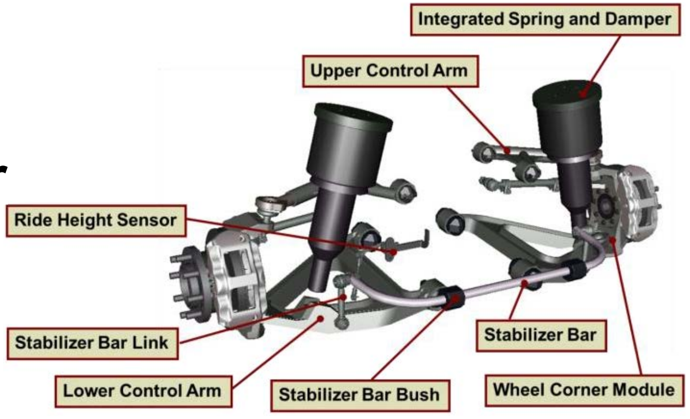
	Pounds	Kilograms
Total Weight	11368	5167

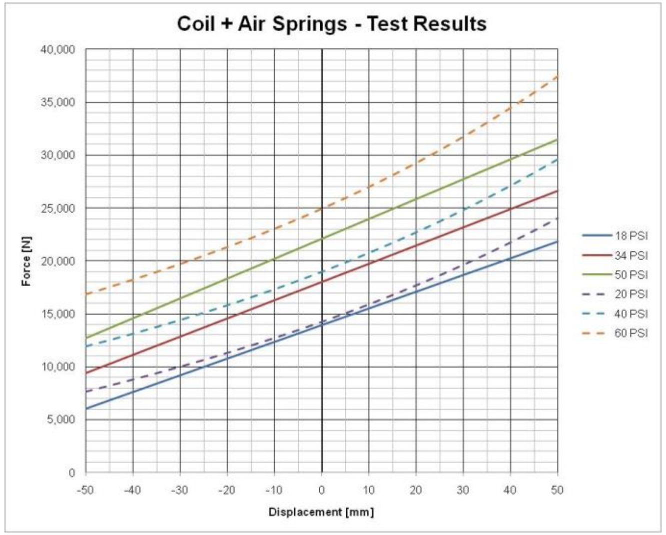
	Inches	Centimeters
Overall Length	203.00	515.62
Overall Width	90.50	229.87
Overall Height	84.88	215.58
Longitudinal CG	61.70	156.72
Lateral CG	-0.20	-0.51
Vertical CG	35.38	89.85

	ft-lb-sec^2	kg-m^2
Roll Inertia (I_{xx})	2405	3259
Pitch Inertia (I_{yy})	7624	10330
Yaw Inertia (I_{zz})	7847	10632
Roll / Yaw Product (I_{xz})	N/A	N/A

Vehicle Data Set (Suspension & Steering)

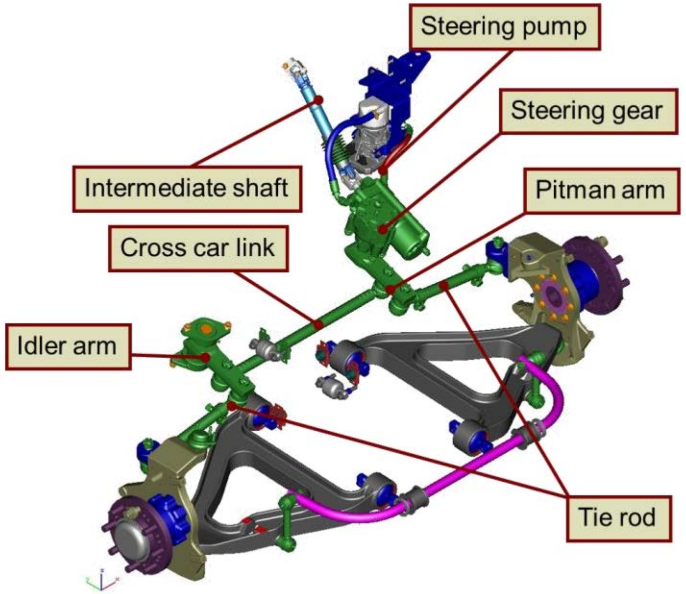
- **Two Wheel Drive "By Wire" Ackerman Steer**
- **Independent Suspension Front & Rear**
- **Coil over Air & Frequency Dependant Damping**
- **Adjustable Ride Height**
- **Advanced & Challenging But Not Hybrid**

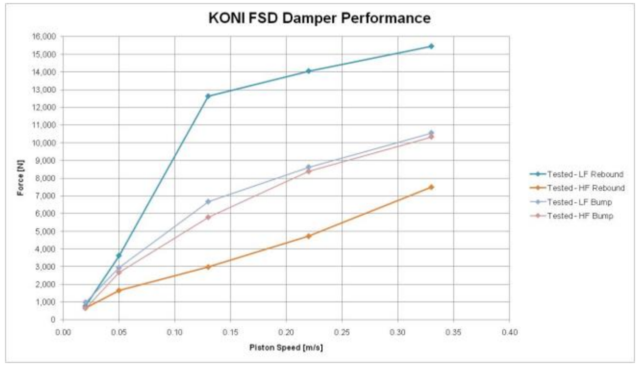




Key Suspension Package Dimensions

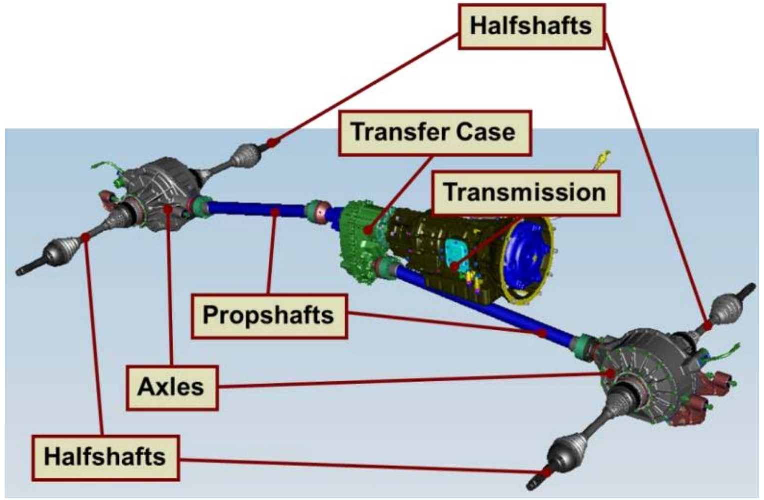
- **Total width (including tires) is 90.1 inches**
- **Track width is 76.9 inches**
- **Wheelbase is 130 inches**
- **Kingpin angle is 11.4°**
- **Ground offset is 57.1mm**
- **Castor angle is 2°**
- **Mechanical trail is 16.2mm**
- **Maximum suspension articulation is +/-180mm**
- **Highway ride height is at 0mm**
- **Obstacle Ride Height is at +70.5mm**
- **Vehicle approach angle at obstacle condition is 60°**
- **Vehicle departure angle at obstacle condition is 63°**
- **Vehicle breakover angle at obstacle condition is 14.3°**

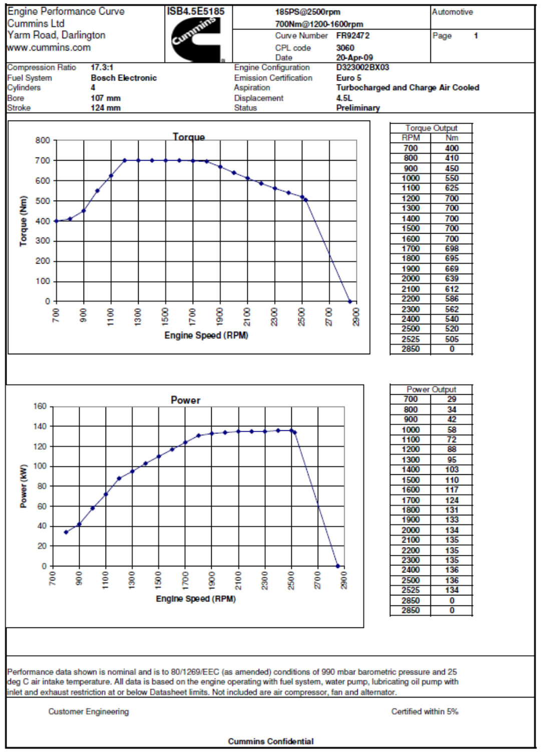




Vehicle Data Set (Power Train)

- Cummins 4 Cylinder 4.6L Engine
- Four Wheel Drive with Low & High Range
- Differential Lock and Traction Control
- Transmission





Engine Performance Curve Cummins Ltd Yarm Road, Darlington www.cummins.com	ISB4.5E5185	185PS@2500rpm 700Nm@1200-1600rpm Curve Number FR92472 CPL code 3060 Date 20-Apr-09	Automotive Page 1

Compression Ratio	17.3:1	Engine Configuration	D323002BX03
Fuel System	Bosch Electronic	Emission Certification	Euro 5
Cylinders	4	Aspiration	Turbocharged and Charge Air Cooled
Bore	107 mm	Displacement	4.5L
Stroke	124 mm	Status	Preliminary

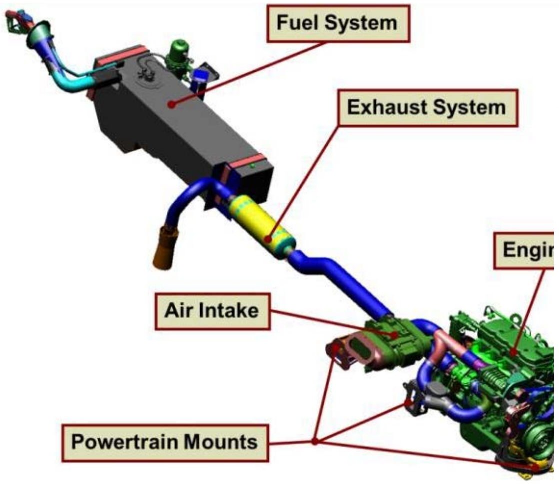
Torque Output	
RPM	Nm
700	400
800	410
900	450
1000	550
1100	625
1200	700
1300	700
1400	700
1500	700
1600	700
1700	698
1800	695
1900	669
2000	639
2100	612
2200	586
2300	562
2400	540
2500	520
2525	505
2850	0

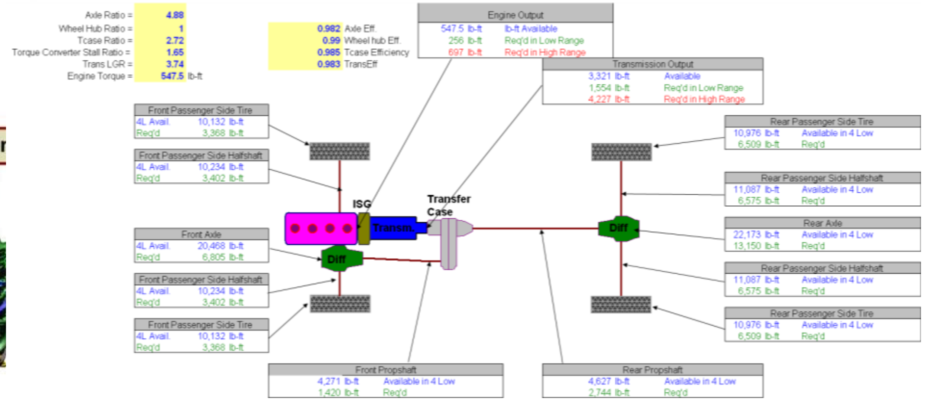
Power Output	
700	29
800	34
900	42
1000	58
1100	72
1200	88
1300	95
1400	103
1500	110
1600	117
1700	124
1800	131
1900	133
2000	134
2100	135
2200	135
2300	135
2400	136
2500	136
2525	134
2850	0
2850	0

Performance data shown is nominal and is to 80/1269/EEC (as amended) conditions of 990 mbar barometric pressure and 25 deg C air intake temperature. All data is based on the engine operating with fuel system, water pump, lubricating oil pump with inlet and exhaust restriction at or below Datasheet limits. Not included are air compressor, fan and alternator.

Customer Engineering Certified within 5%

Cummins Confidential

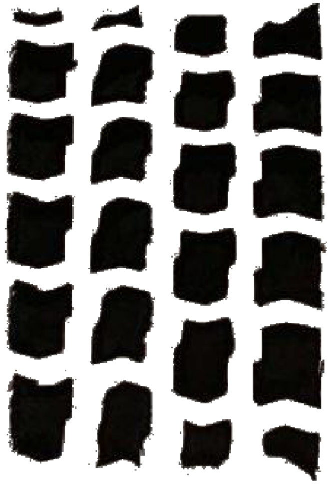




Final Drive Gear Ratio[2]	4.88
Final Drive Efficiency - halfshaft	0.995
Axle Ratios	4.88
Axle Efficiency	0.965
Transmission Spin Losses	
Propshaft	0.992

Vehicle Data Set (Tire)

- Goodyear Fuel Max 335/65R22.5
- ATEC Collected Tire Contact Data For Severa Pressures and Loads
- General Tire Stiffness Measured
- Pacejka Tire Data Available
- Run Flat Rims



GOODYEAR TECHNICAL CENTER - AKRON							
AKRON, OH 44316-0001							
** RADIAL TRUCK - ENGINEERING DATA SHEET **							
TIRE SIZE	335/65R22.5						
LI	147 M						
TIRE DESCRIPTION	G275 MSA						
MAX SPEED - MPH	81						
LOAD RANGE / PLY RATING	G / 14						
KPA	450	480	520	550	590	620	660
KGS							
LOAD CAPACITY: SINGLE	2360	2460	2590	2725	2820	2940	3075
DUAL							
PSI	65	70	75	80	85	90	95
LBS							
LOAD CAPACITY: SINGLE	5205	5430	5700	6005	6220	6475	6780
DUAL							
TIRE WEIGHT	122	LBS					
WIDTHS-MEASURING RIM	9.0	IN					
-NEW TIRE	13.15	IN	334	mm			
-LOADED TIRE	14.10	IN	358	mm			
OVERALL DIAMETER	39.8	IN					
STATIC LOADED RADIUS	18.3	IN	RIM	22.5			
REVOLUTIONS PER MILE	522	RPM					
TREAD-CONTACT WIDTH	9.95	IN	6780 lbs @ 95 psi				
TREAD-CONTACT LENGTH	9.14	IN	6780 lbs @ 95 psi				
-TREAD RADIUS	35.3	IN					
-DEPTH	20/32	or	0.630	IN			
FOOTPRINT AREA (GROSS)	88.3	SQ IN	6780 lbs @ 95 psi				
NET TO GROSS	63.2%						
BELT MATERIAL	3 Ply Steel						
CARCASS MATERIAL	1 Ply Steel						

TABLE 2.3-5. GOODYEAR FUEL MAX 335/65R22.5 GROUND PRESSURE RAW DATA

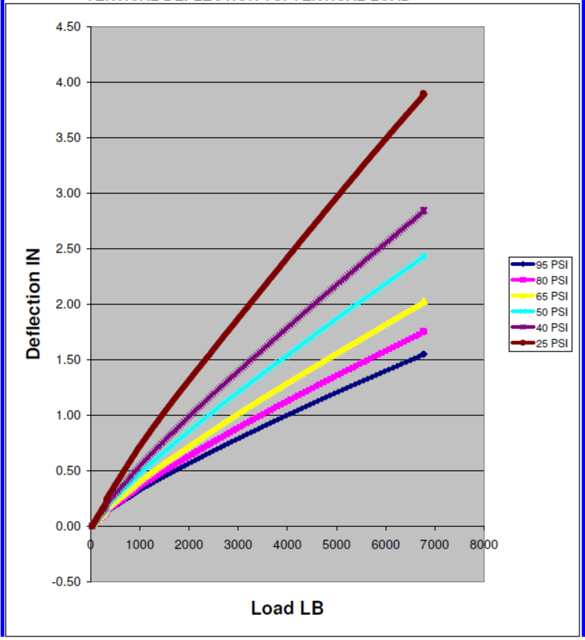
PRESSURE (psi)	LOAD (lb)	NOMINAL AREA (in.^{2})	SPECIFIC AREA (in.^{2})	NOMINAL PRESSURE (psi)	SPECIFIC PRESSURE (psi)	DEFLECTION (in.)
75	1,000	31.6	17.2	31.7	58.2	0.360
75	3,000	61.4	36.2	48.9	82.9	0.924
75	5,000	82.8	50.6	60.4	98.7	1.416
75	7,000	100.8	63.6	69.4	110.0	1.896
60	1,000	33.4	15.9	29.9	62.8	0.396
60	3,000	66.6	39.2	45.1	76.6	1.056
60	5,000	89.8	55.6	55.7	89.9	1.632
60	7,000	110.7	70.3	63.2	99.6	2.196
30	1,000	39.1	19.4	25.6	51.7	0.624
30	3,000	87.2	50.5	34.4	59.4	1.668
30	5,000	125.9	75.7	39.7	66.0	2.652
30	7,000	154.6	93.7	45.3	74.7	3.600
15	1,000	58.7	29.2	17.0	34.2	0.960
15	3,000	128.3	69.6	23.4	43.1	2.628
15	5,000	181.5	99.8	27.6	50.1	4.308
15	7,000	221.9	123.4	31.5	56.7	4.368

GOODYEAR The Goodyear Tire & Rubber Company

Data Type: RADIAL DEFLECTION DATA

Test:	6J604WL83 B	Camber:	00.0	Originator:	
Cnst/Dash:	6J6043-41	Toe:		Plot Date:	05/14/2007
Tire Size:	335/65R22.5	Surface:	FLAT	Tire Type:	A0608
Test Date:	05/12/2007	Rim Size:	9	Test Code:	

VERTICAL DEFLECTION VS. VERTICAL LOAD



Vehicle Behavior Data Set (Instrumentation)

- **97 Channels Simultaneously Collected @ 1600 Samples per Second**
- **On Board Vehicle Network Monitoring**
- **CG Motion Using Three Different Methods**
- **Axle Torque**
- **No Wheel Force Transducer**

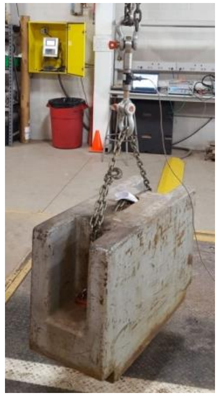
Table 2.2.2-1. Instrumentation of the FED-A

Measurement	EU	MFG	Model	Location/Description
Vehicle Speed	mph	Racelogic	VBox 3i RTK	Doppler-based GPS speed sensor
Pitch Angle	deg	Racelogic	VBox 3i RTK	Vehicle CG, IMU-compensated Dual Antenna GPS
Roll Angle	deg	Racelogic	VBox 3i RTK	Vehicle CG, IMU-compensated Dual Antenna GPS
Heading	deg	Racelogic	VBox 3i RTK	Vehicle CG, IMU-compensated Dual Antenna GPS
GPS Lat/Long	deg	Racelogic	VBox 3i RTK	Vehicle CG, 2cm Accuracy with DGPS correction
GPS Elevation	ft	Racelogic	VBox 3i RTK	Vehicle CG, 2cm Accuracy with DGPS correction
Tri-axial Acceleration	g	PCB	T356A02	LF, RF, LR, RR Wheel Locations
Suspension Travel	mm	Firestone	Intelliride Sensors	LF, RF, LR, RR (Lower A-arms)
Motion Pak accelerometers, x/y/z axes	g	Systron Donner	MP-GDDDQVVV-100	Vehicle CG
Motion Pak rates, roll/pitch/yaw	deg/s	Systron Donner	MP-GDDDQVVV-100	Vehicle CG
SeatPad Tri-axial Accelerometer	g	PCB	356B41	Driver and Passenger Seat 0.5 to 1000Hz, 100mV/g, Conforms to ISO 10326-1
SeatTrack Tri-axial Accelerometer	g	PCB	T356A15	Driver and Passenger Seat 2 to 5000Hz, 100mV/g
Steering-Wheel (Handle) Angle	deg	RLS Renishaw	MR047B040A076B0 LM13IC10BCA10F00	Radial Magnetic Encoder and Reader Head
Pitman Arm Angle	deg	Koyo	TRD-N5000-RZVWD	5000 PPR Incremental (Quadrature) Encoder
Wheel Torque	lb-ft	Vishay	Foil Strain Gages	LF, RF, LR, RR Wheel Locations Half-Shaft Telemetry Units
Brake Pedal Force	lb	Futek	FSH03184	Low Profile Pedal Force Sensor, 300lb Range
Drawbar Force	lb	Sensotec	RI/6020-06	Cable Pull Tension Loadcell

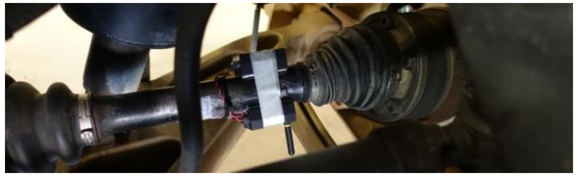
LEGEND:
EU – Engineering Unit
deg – degrees
g – acceleration due to gravity
GPS – Global Positioning Unit
mm - millimeters
MFG – Manufacturer
mph – miles per hour
NA – Not applicable
s – seconds
ft – feet
lb – pound

Table 2.2.2-2. Vehicle Network Monitoring

Source	Parameter	Description	EU	Bus Hz
J1939	Acc_PedPos	Accelerator Pedal Position	%	20
J1939	Eng_Spd	Engine Speed	rpm	50
J1939	Eng_ActTq	Engine Torque	%	50
J1939	Trans_Output_Speed	Transmission Output Speed	rpm	100
J1939	Trans_Current_Gear	Transmission Gear Range Attained	/	10
J1939	TC_Lockup_Engaged	Torque Converter Lock/Unlock	/	100
J1939	Trans_Gear_Ratio	Transmission Actual Gear Ratio	/	10
Aisin	Whl_Spd_Rear_Left	Wheel Speed- Rear L	rpm	50
Aisin	Whl_Spd_Rear_Right	Wheel Speed- Rear R	rpm	50
Aisin	Whl_Spd_Frnt_Left	Wheel Speed- Front L	rpm	50
Aisin	Whl_Spd_Frnt_Right	Wheel Speed- Front R	rpm	50

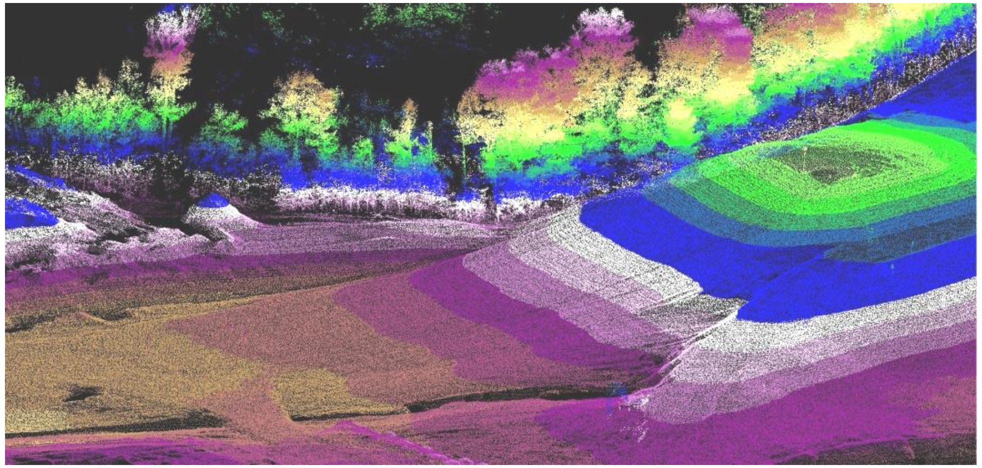


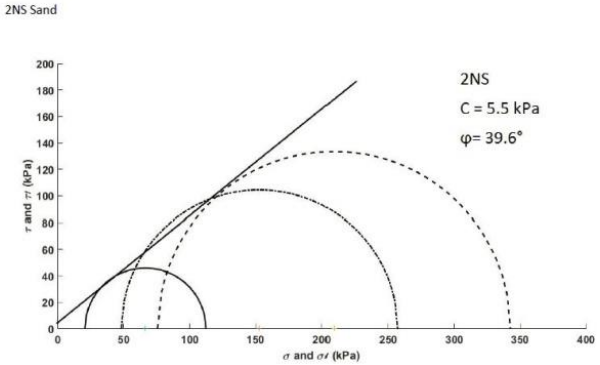


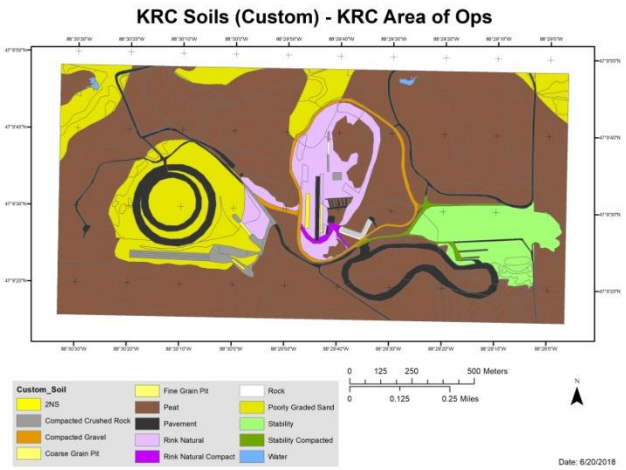



Terrain Data Set

- Terrestrial LIDAR Scanning
- Conversion to Geotiff & TIN
- Laboratory Soil Strength Data
- In Situ Data Set
- Five (5) Soil Types Identified
- Several Formats

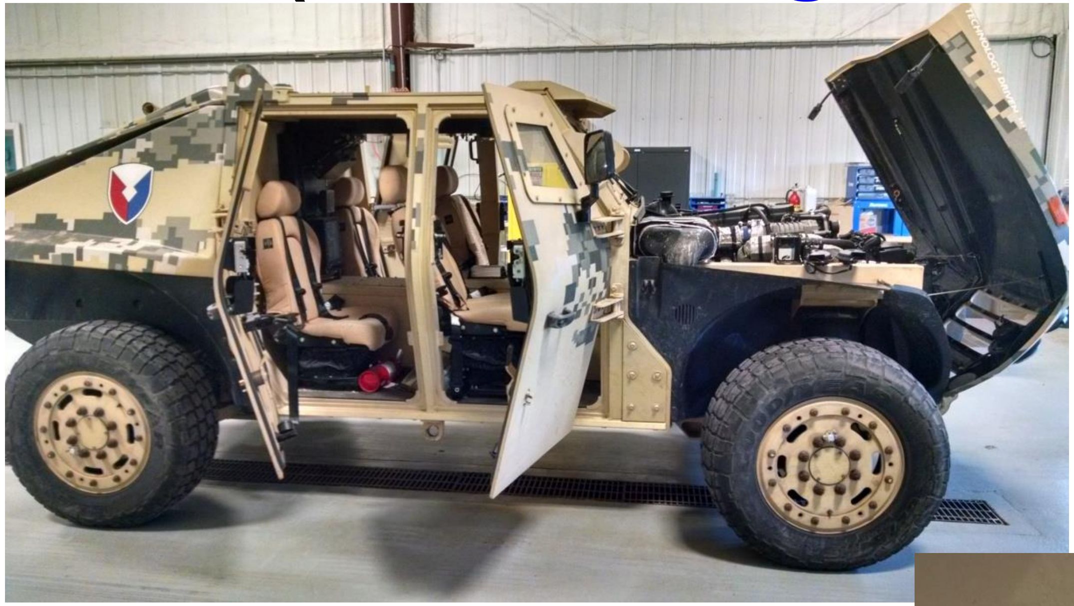






Vehicle Behavior Data Set (Test Configuration)

- Load Case – Lightly Laden Close to VIPER Test Weight
- Ride Height Set @ High
- Front & Rear Differentials Locked for Soft Soil and
- Central Tire Inflation System OFF
- Tire Pressure @ 35 psi & 60 psi to Mathc Available Pacejka Data
- ABS and Traction Control OFF



Vehicle Behavior Data Set (General Automotive Tests)

- **Paved Tests**
  - Wall to Wall Turning
  - Constant Cornering
  - Acceleration
  - Braking
  - Double Lane Change (Paved & Gravel)
- **Obstacles**
  - V-Ditch
  - Vertical Steps
  - Longitudinal Gradability (Paved @ 60%)
  - Obstacle Avoidance on 30% Side Slope
- **Ride Quality**
  - RMS 1.0, 1.5, 2.0, 3.0, 4.0
  - Half Rounds – 4”, 8”, 10”, 12”

Specific Maneuvers Used to Calibrate Simulation Models

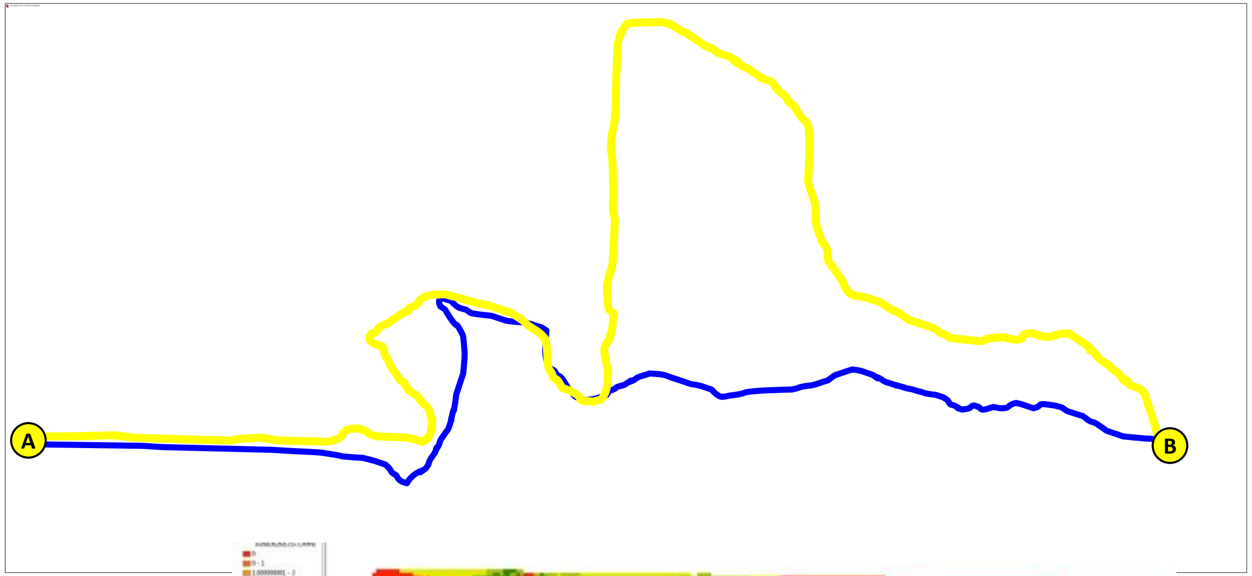
Vehicle Behavior Data Set (Soft Soil)

- **Longitudinal Gradability**
  - 2NS Sand up to 30%
- **Drawbar Pull**
  - Fine Grain Dry
  - Fine Grain Wet
  - Coarse Grain Dry

Used to Judge the Predictive Capability of the Simulation Models

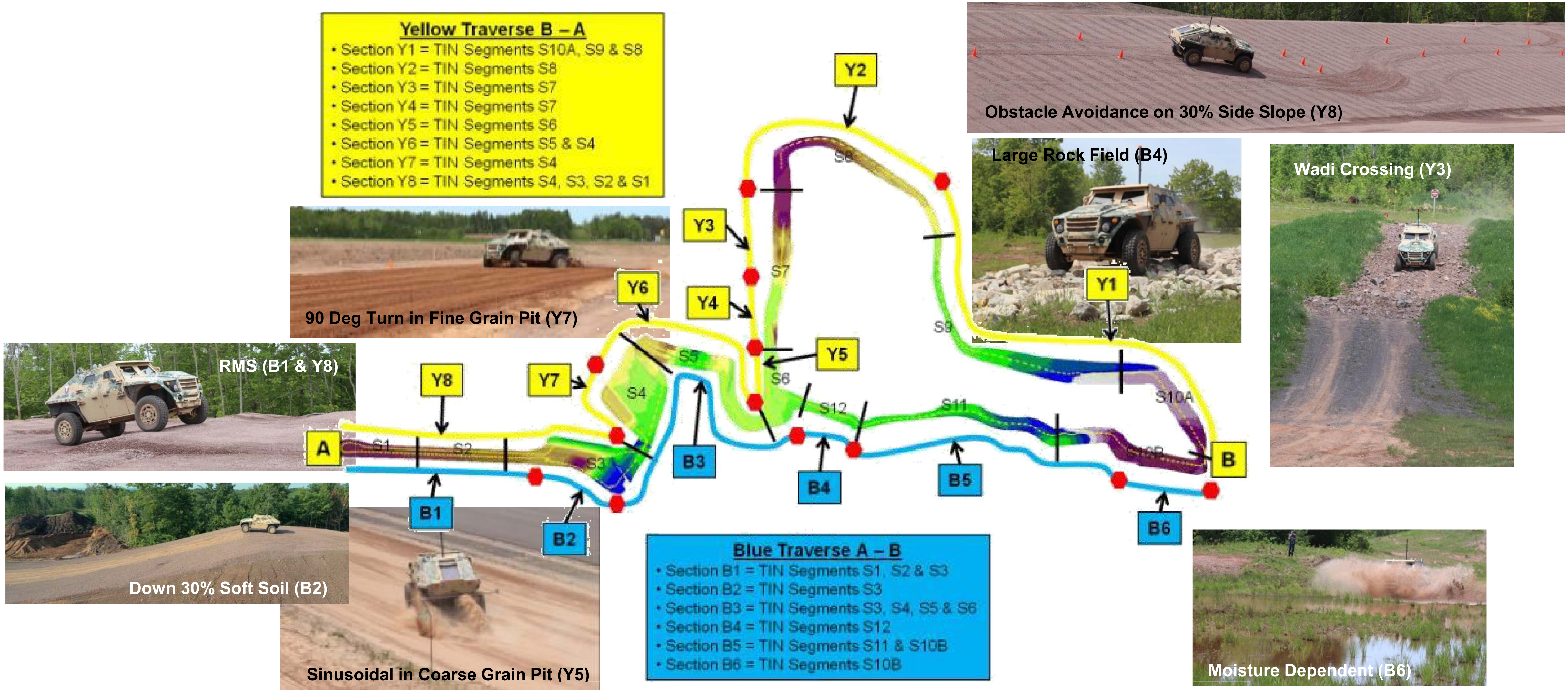
Vehicle Behavior Data Set (Mobility Traverse)

- **Test Comparison to Speed Made Good Map Challenging**
- **Mobility Traverse Introduced as Subsitute**
- **Compilation of Mobility Events to Exercise NG Simulation and to Highlight Issues with Legacy**
- **Conducted as a Continuous Circuit with Stops to Engage Low Range & Differential Lock**
- **Driver Instruction to Go Fast But Be Safe & Protect Vehicle**



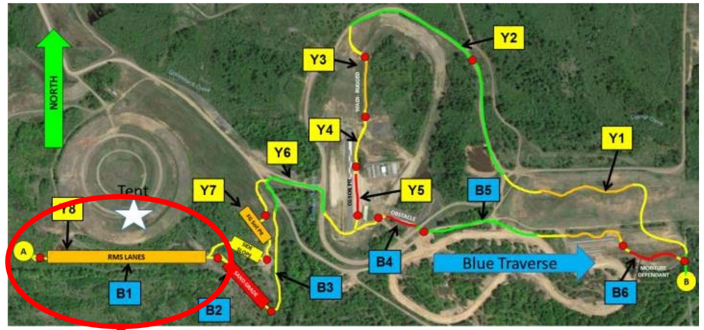
Typical Go / No Go Map

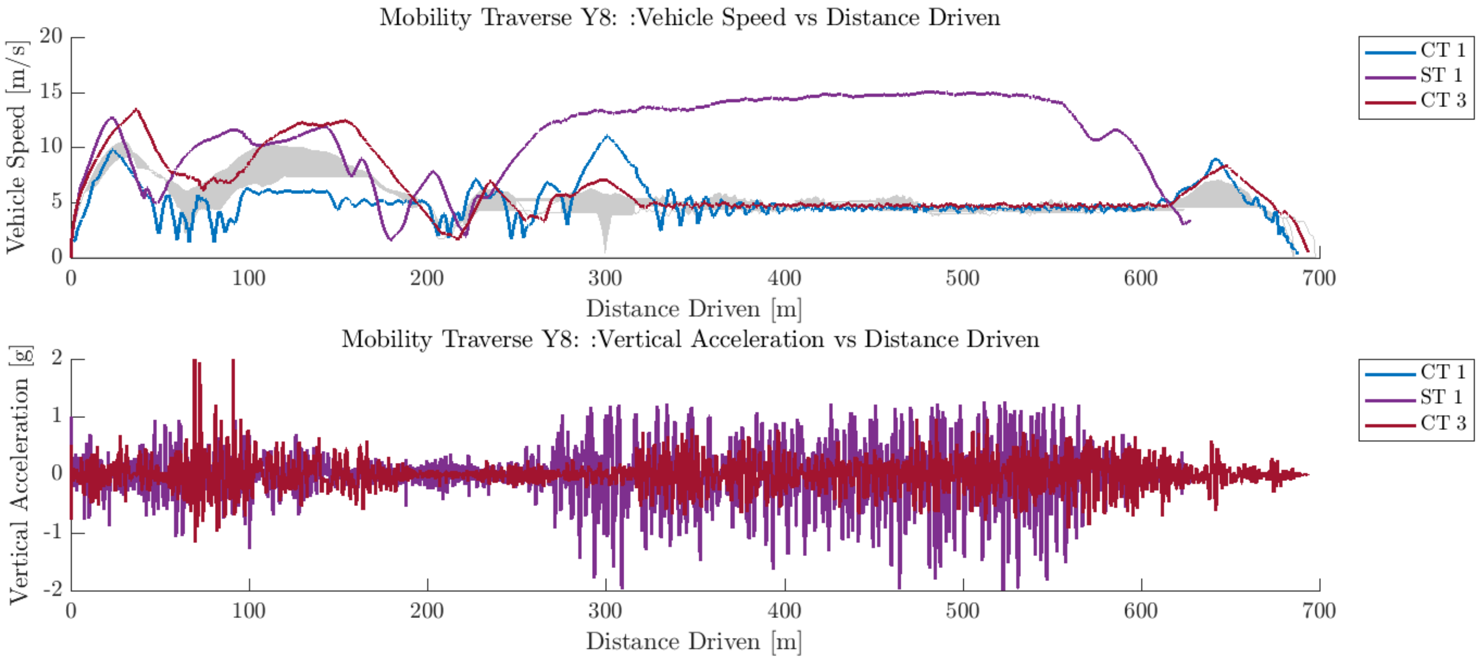
Vehicle Behavior Data Set (Mobility Traverse)



Show a Sample Set of Mobility Traverse (Ole)

Mobility Traverse





Backup Slides

Vehicle Modeling Fidelity

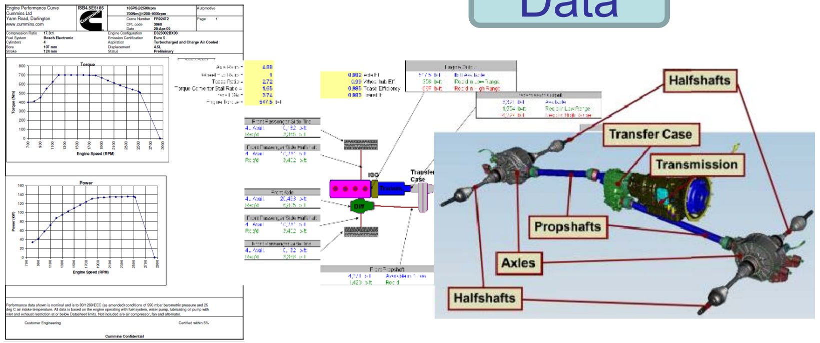
- **Which Fidelity is required for NG-NRMM compliance?**
  - Depends on the end user:

Operations | Acquisition | Design

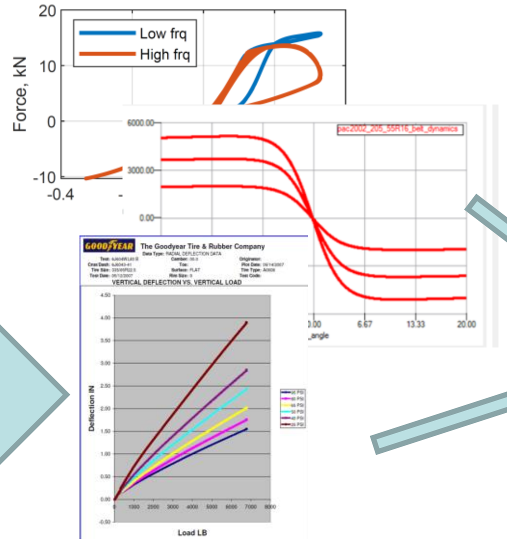
Increased Fidelity/Accuracy →

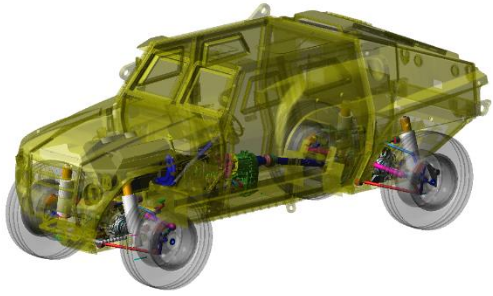
  - The standard does not dictate this, however, Vehicle Data and Test Data is available to demonstrate level of accuracy
  - Same Data Available, Different Implementations

Data



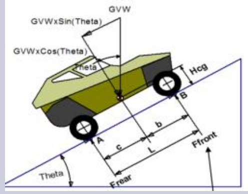
Model Implementations





Vendor Model

Vehicle Simulation Models – Pros and Cons

	Modeling technique		Pros	Cons
Vehicle	Few Body Model (chassis, axles) Lookup tables for Composite Suspension Forces, Camber, Toe versus Deflection.		Easy to set up model. Fewer Input Data Fast computation – Real or Near Real-Time.	Less Accurate
	Detailed MBS: Individual Suspension Components, Bushings, Drive Shafts, steering mechanism etc.		Can Predict Internal Vehicle Metrics of Interest, Forces in Joints and Bushings, Structural Loading of Flex Members. etc	Requires Large Input Data Set Computational Expensive High Accuracy with Good Input Data
Terramechanics	Cone Index, VCI		Few Input Data, Existing Data Available. Fast Computation	Limited by the conditions of testing. Less accuracy on Sloped Terrain
	BW		Some Data Available Fast Computation Good Correlation with Most Soil on Flat	Limited by the Extensive Testing Less accurate on Large Slopes
	DEM		Indicate Good Correlation with Test Results For All Soft Soil	Requires Calibration. Very Long Computation time.

Accuracy

Computation Time

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