Annex X – DIS/GROUNDVEHICLE: COMPLEX TERRAMECHANICS SOFTWARE TOOL FOR PREDICTING VEHICLE MOBILITY

Note: This Annex appears in its original format.

AVT-308 Cooperative Demonstration of Technology on Next-Generation NATO Reference Mobility Model Development

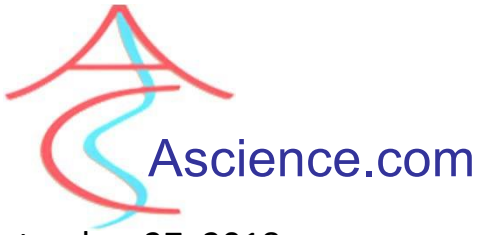
Houghton, Michigan, USA

September 25-27, 2018

DIS/GroundVehicle: Complex Terramechanics Software Tool for Predicting Vehicle Mobility

Tamer M Wasfy

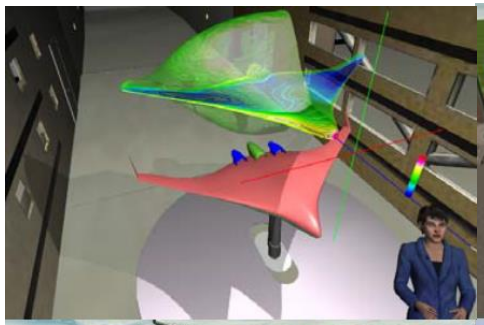
Advanced Science and Automation Corp.

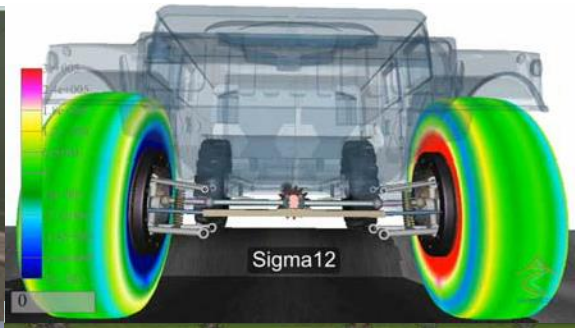


September 27, 2018

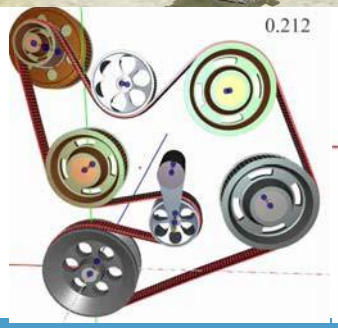
Advanced Science and Automation Corp.

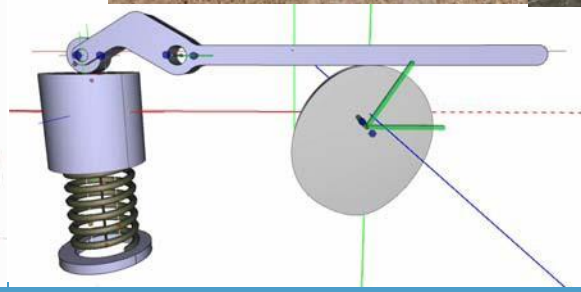
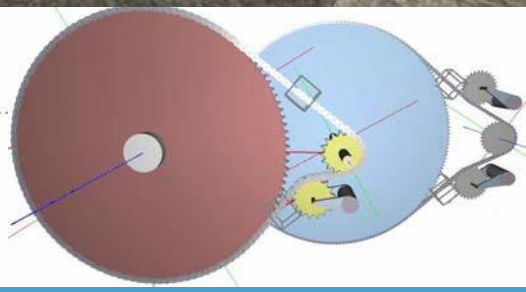
- **Founded in 1998**
- **Small business based in Indianapolis, IN**
- Software Products: **DIS; IVRESS**
- **Customers/industries served:**
  - Automotive
  - Aerospace
  - Shipbuilding and marine
  - Manufacturing
  - Mining
  - Energy
  - Government agencies: DOD, NASA
  - Universities & community colleges
- **Grants:**
  - NSF
  - State of Indiana
  - State of Virginia
- **Academic Partners:**
  - Multibody Dynamics Lab, IUPUI
  - Initiative for Product Lifecycle Innovation (IPLI), IUPUI





Overview of IVRESS/DIS Software

Modeling Capabilities

- **MBD:** Multibody dynamics
  - Rigid bodies
  - Kinematic joints
  - Frictional contact
  - Actuators: linear & rotational
  - Controllers
- **FEM:** Finite element method
  - **Elements**: brick; shell; thick beam; thin beam; truss; spring; torsional spring

Particle methods

- **SPH**: Smoothed particle hydrodynamics
- **DEM**: Discrete element method
- **MD**: Molecular dynamics

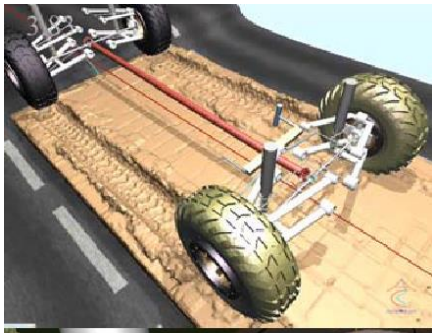
Other Capabilities

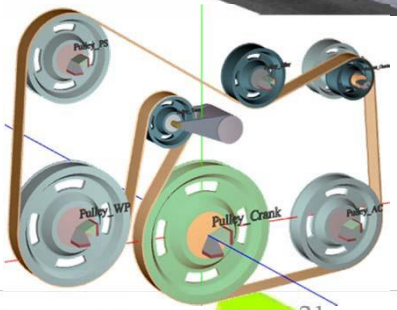
- **RT**: Ray tracing
- **VR**: Virtual-real for scientific visualization

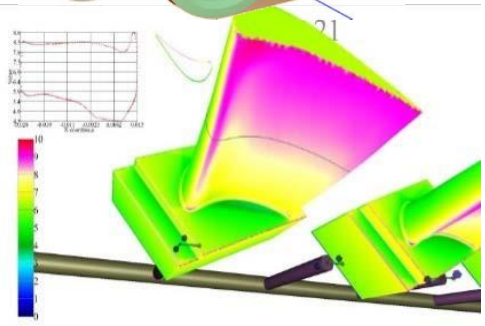
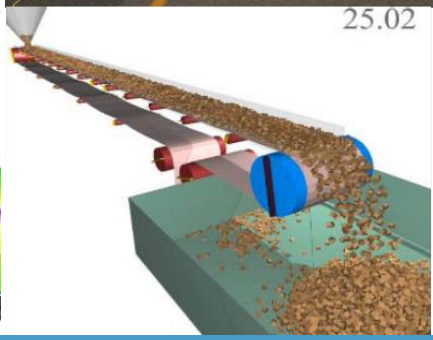
Key Features

- All modeling techniques are integrated into one solver and are fully coupled.
- Easily customizable into a specific application using Excel as the user interface/preprocessor



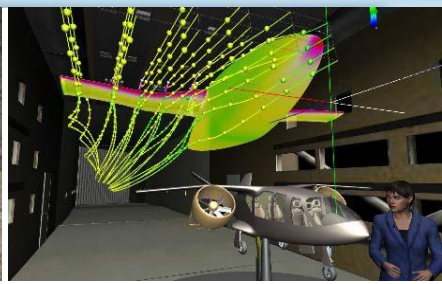
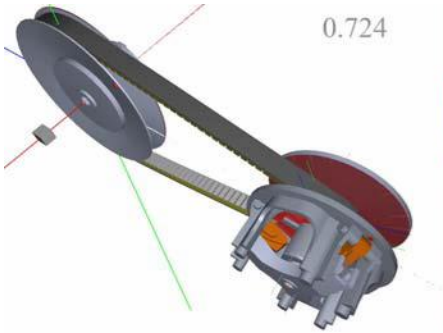


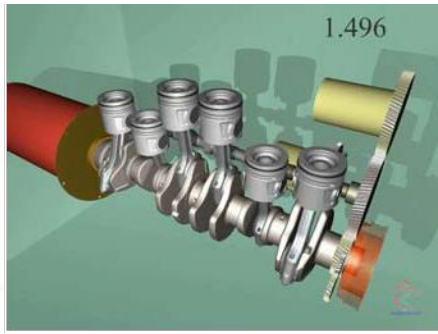



Applications / Customers

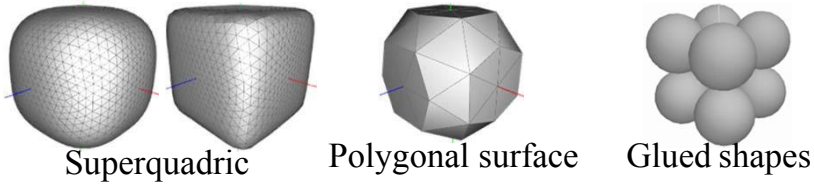
- **IVRESS/DIS** is a general purpose software system for modeling **flexible multibody** systems involving **frictional contact,** coupled with **fluid flow** and **granular material flow.**
- **Sample Applications:**
  - **Automotive vehicles**: Cars; trucks; motorcycles; bicycles.
  - **Automotive sub-systems:** engines; brakes; suspension systems; steering systems; transmission systems.
  - **Aerospace**: landing gears; flaps; rudder; airplanes.
  - **Marine**: ships; submarines; tankers; propellers.
  - **Transportation systems**: Elevators; cable cars.
  - **Manufacturing**: coating; cutting; additive manufacturing; extrusion; forming.
  - **Robotics**: robot arms; autonomous vehicles; legged robots; bipedal robots.
  - **Biodynamic systems**: humans; animals; insects.
  - **Mining**: earth moving; bulk material conveyors; silos.
  - **Construction**: structures; cranes; elevators/hoists; earth moving.
  - **Energy**: mechanical power transmission systems; turbines; energy harvesting.
  - **Agricultural**: earth moving equipment; tillers.
  - **Military**: tracked vehicles; wheeled vehicles; tanker trucks.
  - **Mechanical sub-systems**: gear drives; cams; belt-drives; chain-drives; CVTs.
- **DIS/GroundVehicle** is Specialized version of DIS for modeling on-road and off-road vehicles: mobility, steering/handling, ride, and durability.

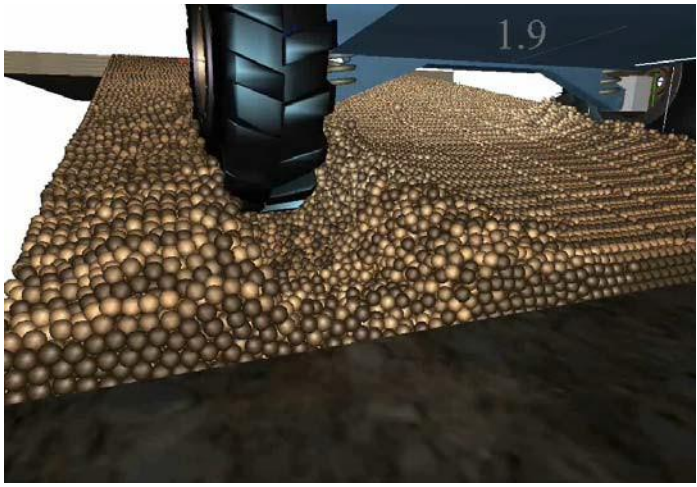






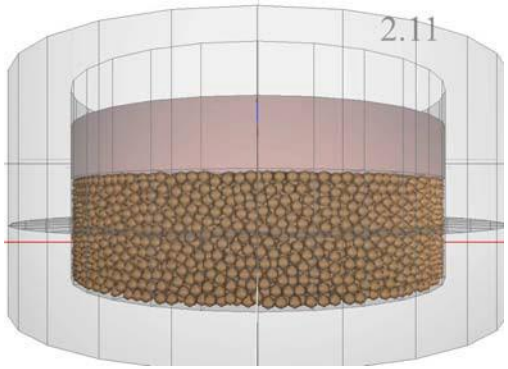

DIS/GroundVehicle - Key Features: **Complex Terramechanics DEM Soil Model**

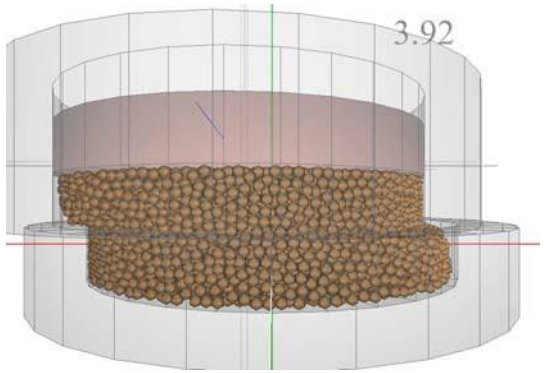
- **The DEM model represent most soil types by include the following effects:**
  - Normal contact forces: **Elastic** forces; **Damping** forces; **cohesive (**adhesion) forces.
  - Tangential contact forces: **Viscous** forces; **Friction** forces.
  - Particle **plastic** deformation as a function of soil compacting normal forces.
  - Increase of cohesion due to soil plastic deformation/compaction.
  - **Soil dilation:** relaxation of soil plastic deformation and cohesion due to tension.
  - Particle shapes.

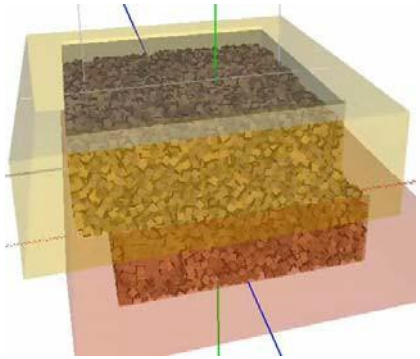


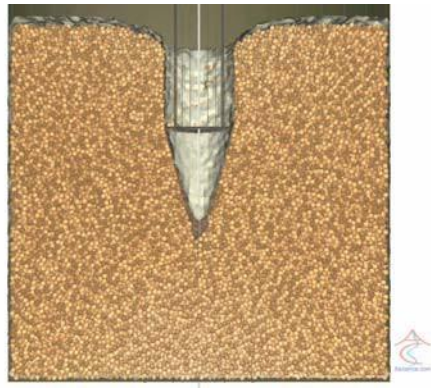


- **The DEM model can be calibrated using terramechanics tests such as:**
  - Hydrostatic compression, Shear cell, Tri-axial cell, Bevameter, Penetroplate, Cone penetrometer.







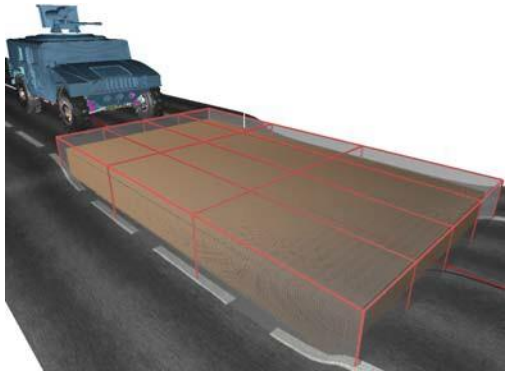


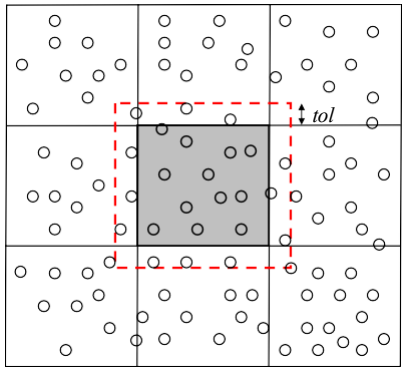
DIS/GroundVehicle - Key Features: **Complex Topography Terrain**

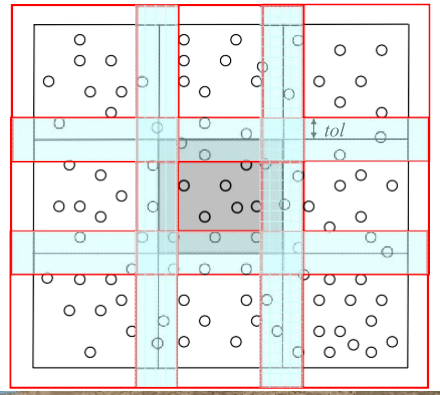
1. DEM soft soil
2. Variable DEM soil properties on terrain
3. Arbitrary terrain length (moving soil patch)
4. Turns
5. Ditches
6. Bumps
7. Long +ve/-ve Slopes
8. Side Slopes
9. Roughness.

DIS/GroundVehicle - Key Features: **Complex Topography Terrain**

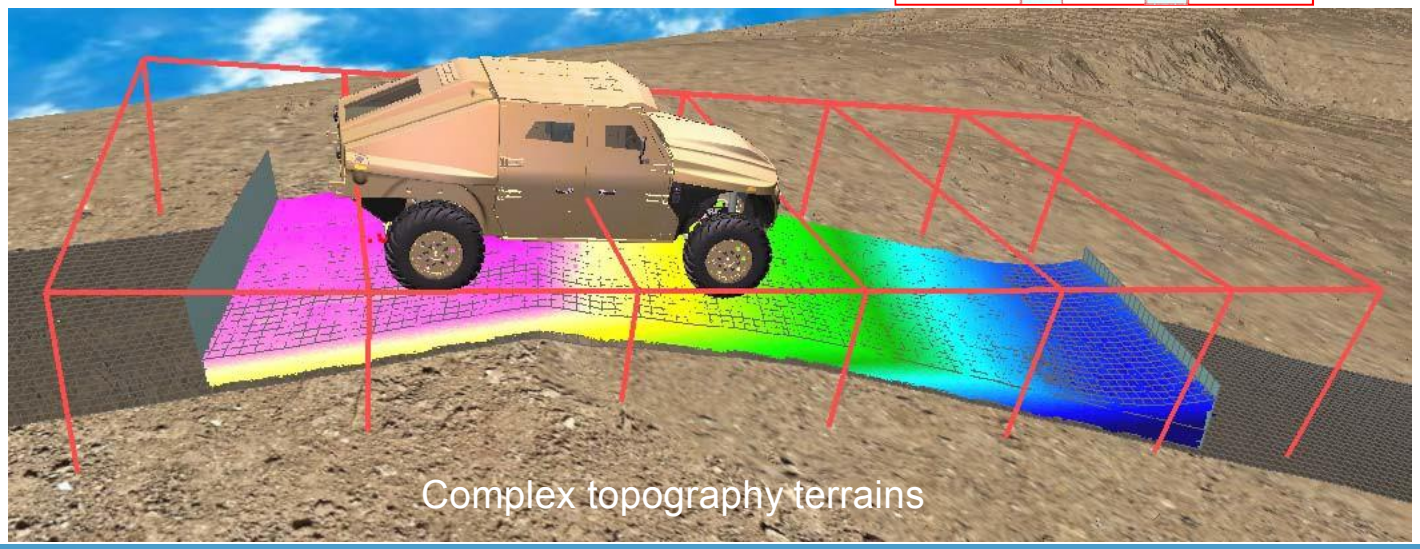
DIS/GroundVehicle - Key Features: **Distributed/Shared Memory Parallel Solver**



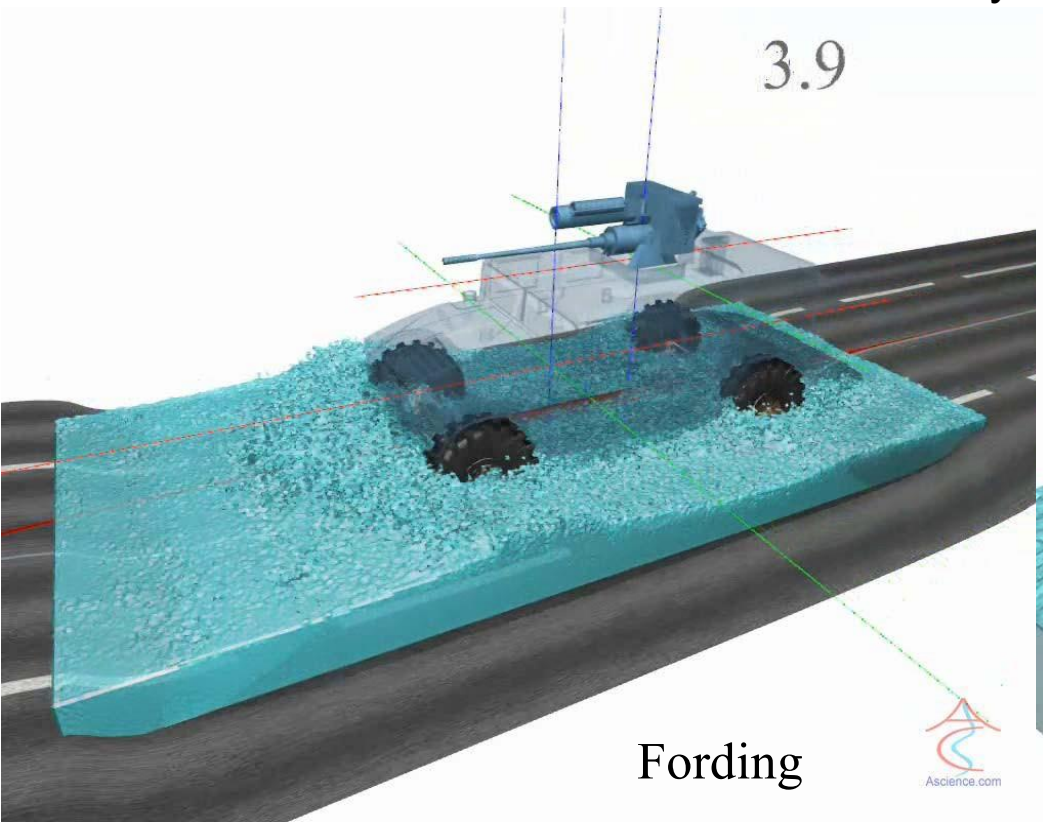




Areas of exchange of particle positions/forces each time step.

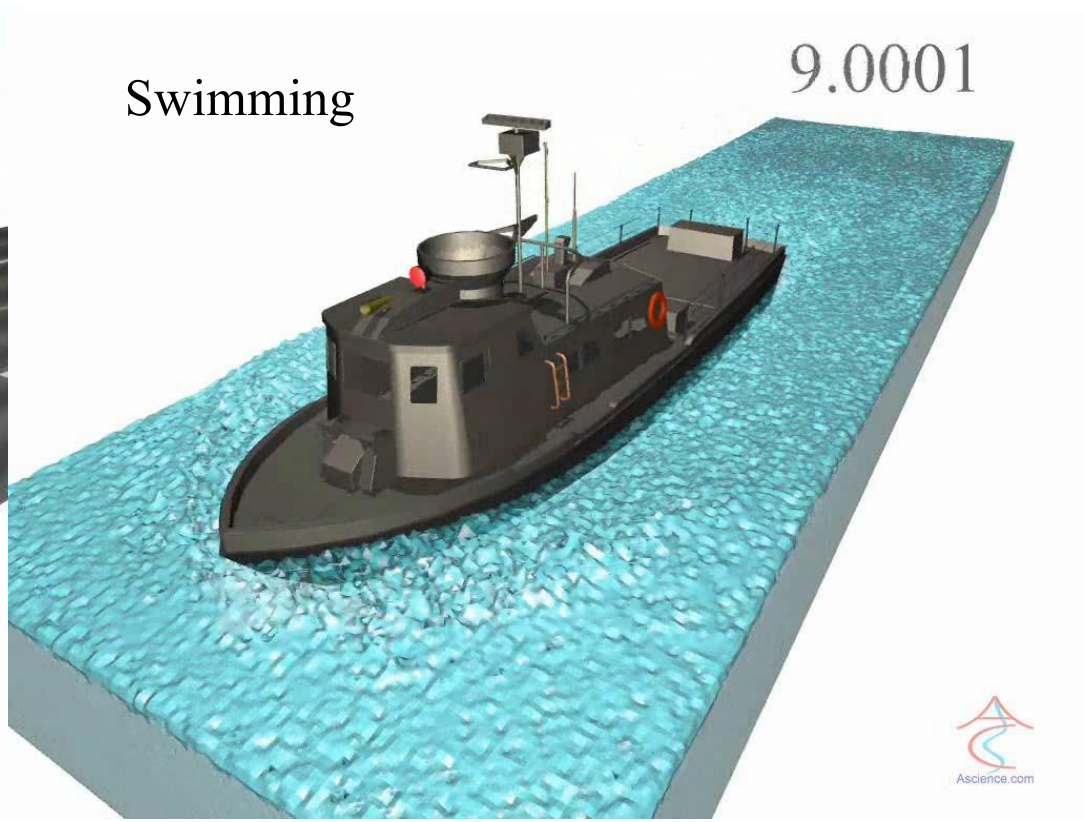


DIS/GroundVehicle - Key Features: **SPH Fluid Model**



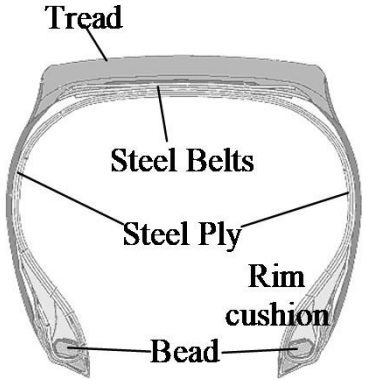
Fording

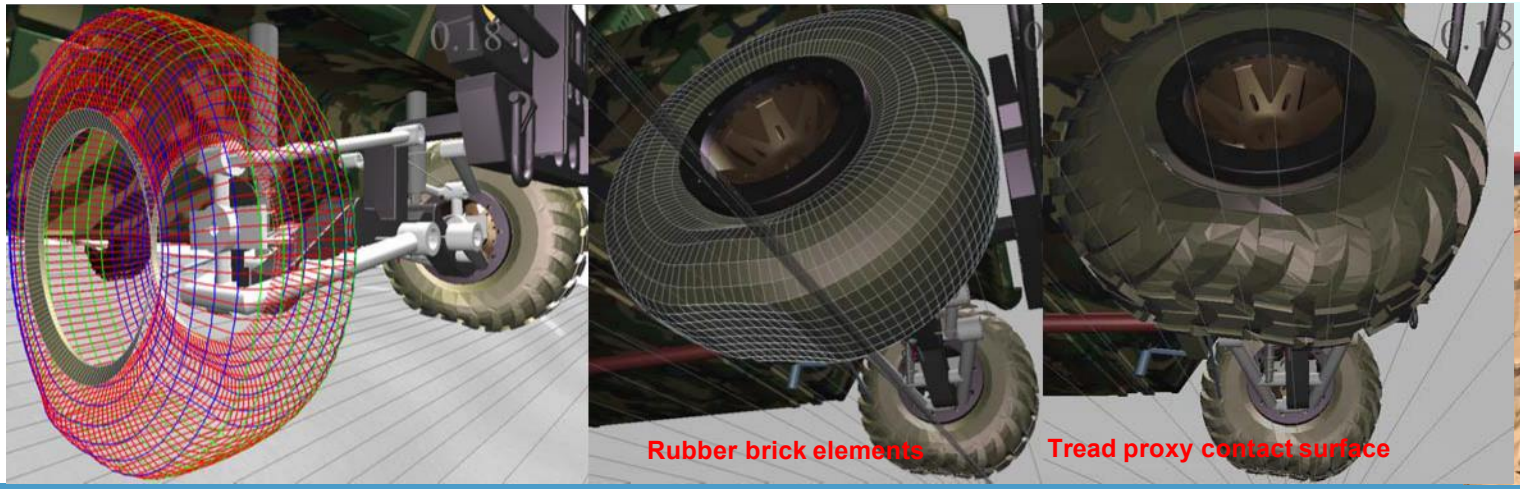
Swimming



DIS/GroundVehicle - Key Features: **High-Fidelity Finite Element Tire**

- Tire rubber matrix modeled using brick elements.
- Tire reinforcements (ply, belt, and bead) modeled using thin beam elements.
- **Any polygonal tread pattern can be used as a proxy contact surface.**
- Tire inflation pressure applied as a normal distributed force to inner surface.
- One explicit time-integration solver approach for: vehicle, tire, and soil.
- Can be used with DEM/SPH terrains

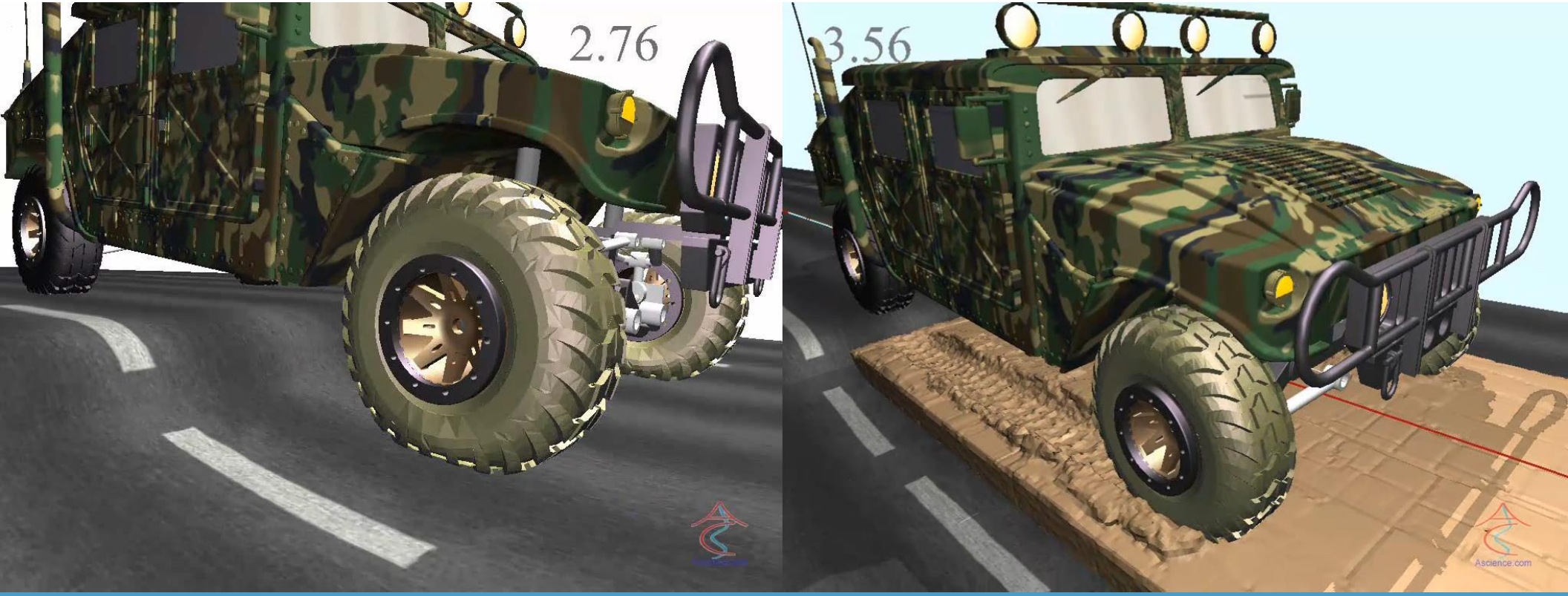




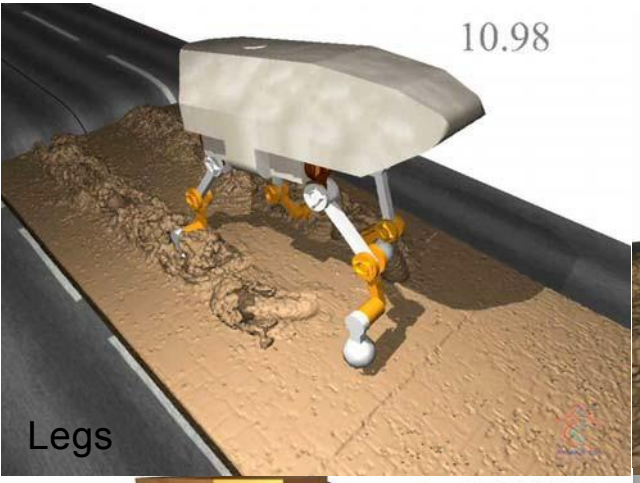
DIS/GroundVehicle - Key Features: **High-Fidelity Finite Element Tire**

FE tire model can be used in vehicle mobility simulations.

Tread pattern design | Tire construction | Tire material properties | Inflation pressure

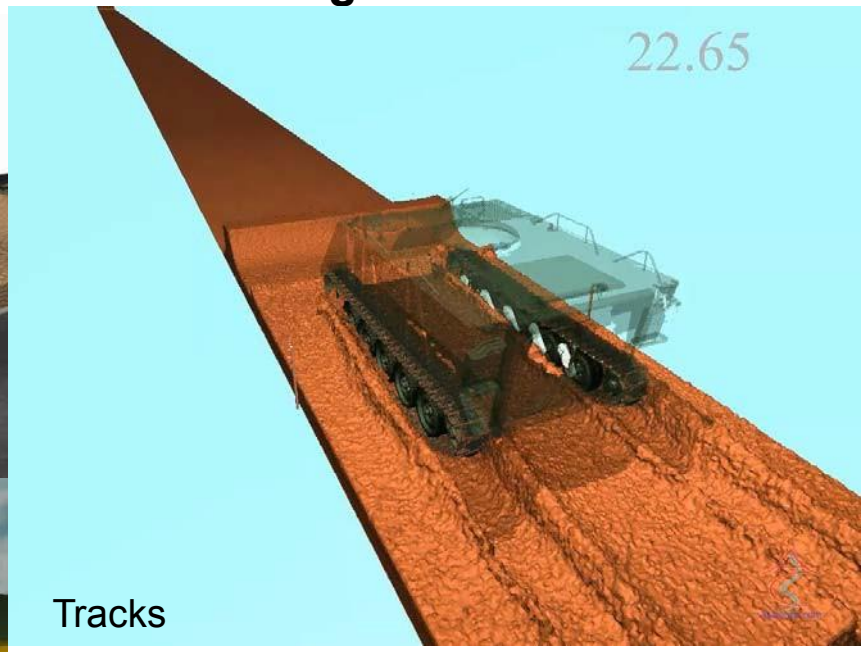


DIS/GroundVehicle - Key Features: **Any Type of Vehicle Running Gear/Surface**

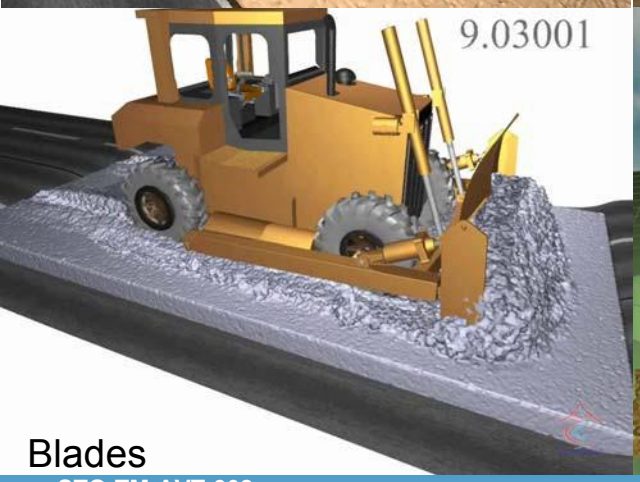


Legs

Buckets



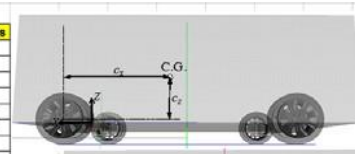
Tracks

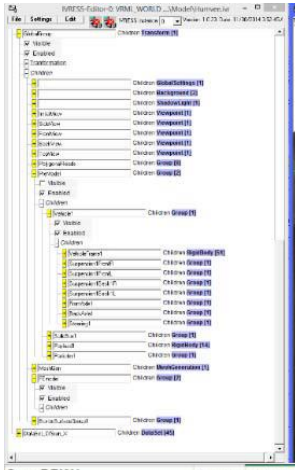


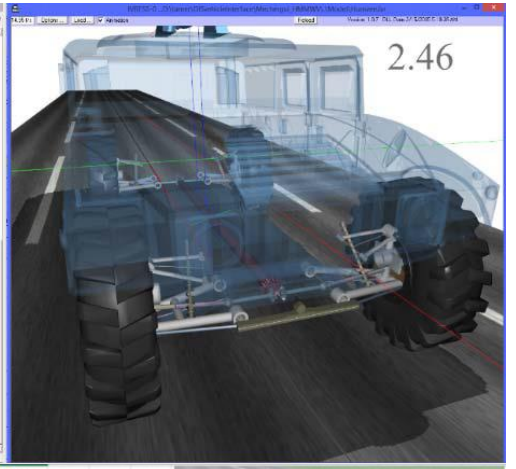
Blades

DIS/GroundVehicle - Key Features: **User-Friendly Template-Based Preprocessor**

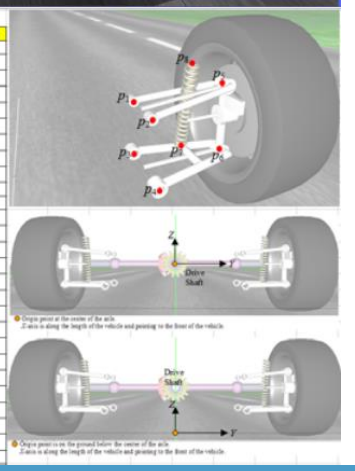
Vehicle1	Comment:	This is a comment			
Parameter Description	**Symbol**	**Value1**	**Value2**	**Value3**	**Units**
Enable vehicle	*Enabled*	Yes			
Vehicle global position (ground point at center of front axle)	*GlobalPos*	0	0	0	
CG position (X, Y, Z) relative to center of front axle	*CG*	-1.2	0	0.5	m
Mass of frame/body	*M*	4000			kg
Inertia of frame/body around (length, width, height) direction	*I*	2160	8640	10000	kg.m^2
Off-diagonal Inertia of frame/body around (Ixy, Ixz, Iyz)	*Ioff*	0	0	0	kg.m^2
Frame icon file name	*File*	hummer_prt.wrl			
Frame icon translation (X, Y, Z)	*Trans*	-1.94	0	0.1	m
Frame icon scale (X, Y, Z)	*Scale*	1	1	1	
Euler Angles	*Angles*	90	90	0	degree
Initial icon visibility	*IconVisible*	No			
Front Axle	*FrontAxle*	Axle1			
Back Axle 1	*BackAxle1*	Axle2			
Back Axle 2	*BackAxle2*	None			
Steering	*Steering*	SteeringRackPinion1			
Motor	*Motor*	Motor1			
Vehicle Steering and Speed	*SteerAndSpeed*	SteeringAndSpeed1			
Air density	Ro_{Air}	1.225			kg/m^3
Vehicle frontal area	$Area_{Front}$	2			m^2
Vehicle side area	$Area_{Side}$	3.5			m^2
Vehicle top area	$Area_{Top}$	5			m^2
Characteristic lift length	L_{Lift}	2.8			m
Aerodynamic frontal drag coefficient	$C_{DragFront}$	0			
Aerodynamic side drag coefficient	$C_{DragSide}$	0			
Aerodynamic top drag coefficient	$C_{DragTop}$	0			
Aerodynamic lift coefficient	C_{Lift}	0			
Aerodynamic lift moment coefficient	$C_{MomLift}$	0			
Wind velocity	v_{wind}	0	0	0	m/s
Slave contact geometry file	*SlaveContFile*				
Slave contact geometry translation (X, Y, Z)	*TransSlave*	0	0	0	m



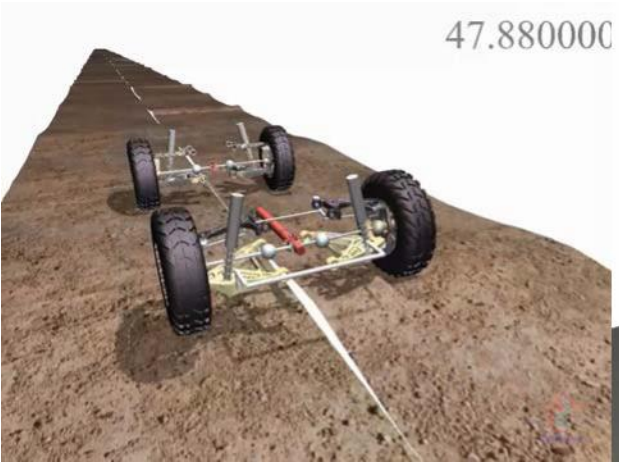




SuspDBW1	Comment:	This is a comment			
Parameter Description	**Symbol**	**Value1**	**Value2**	**Value3**	**Units**
Hard points reference frame origin	*Origin*	*Axle Center*			
Upper control arm point P_1 (X, Y, Z)	p_1	0.15	0.43	0.068	m
Upper control arm point P_2 (X, Y, Z)	p_2	-0.15	0.43	0.068	m
Lower control arm point P_3 (X, Y, Z)	p_3	0.15	0.428	-0.137	m
Lower control arm point P_4 (X, Y, Z)	p_4	-0.15	0.428	-0.137	m
Upper knuckle point P_5 (X, Y, Z)	p_5	0	0.718	0.103	m
Lower knuckle point P_6 (X, Y, Z)	p_6	0	0.718	-0.137	m
Lower suspension strut point P_7 (X, Y, Z)	p_7	0.06	0.573	-0.11	m
Upper suspension strut point P_8 (X, Y, Z)	p_8	0.03	0.573	0.063	m
Lower Suspension Strut P_7 is connected to:	*StrutConn*	*Lower control arm*			
Strut Data	*Strut*	*Spring1*			
Mass of upper control arm	M_U	3			kg
Mass of lower control arm	M_L	3			kg
Mass of knuckle	M_K	3			kg
Moment of inertia of upper control arm	I_U	0.03	0.03	0.03	kg.m^2
Moment of inertia of lower control arm	I_L	0.03	0.03	0.03	kg.m^2
Moment of inertia of knuckle	I_K	0.03	0.03	0.03	kg.m^2
Upper control arm icon	$File_U$				
Upper control arm icon translation (X, Y, Z)	$Trans_U$	0	0	0	m
Upper control arm icon scale (X, Y, Z)	$Scale_U$	1	1	1	
Lower control arm icon	$File_L$				
Lower control arm icon translation (X, Y, Z)	$Trans_L$	0	0	0	m
Lower control arm icon scale (X, Y, Z)	$Scale_L$	1	1	1	
Knuckle icon	$File_K$				
Knuckle icon translation (X, Y, Z)	$Trans_K$	0	0	0	m
Knuckle icon scale (X, Y, Z)	$Scale_K$	1	1	1	
Automatically set joint stiffnees and damping	*AutoStiff*	*AutoStiff*			



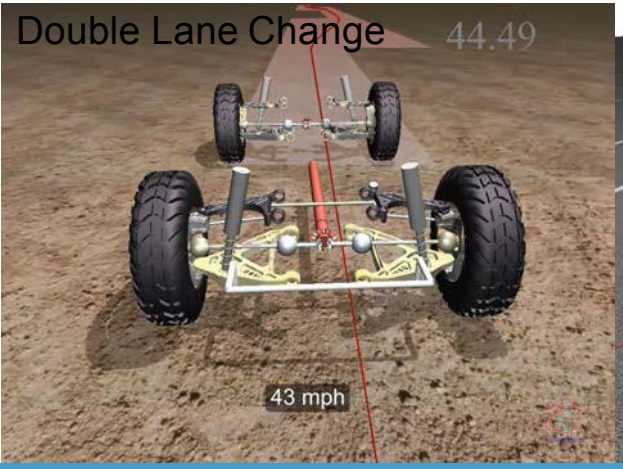
DIS/GroundVehicle – CDT events



V-Ditch

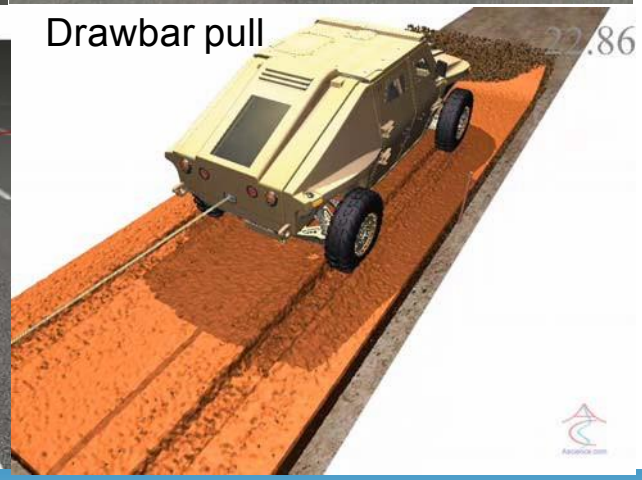
Wall-to-wall turn

Double Lane Change



Cornering

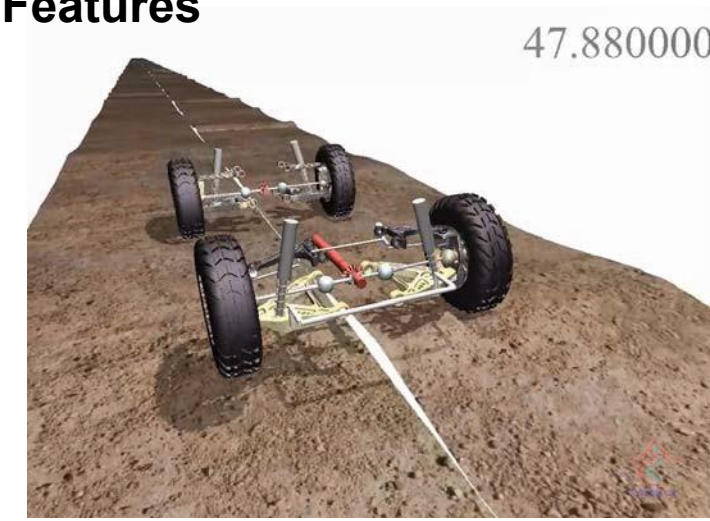
Drawbar pull

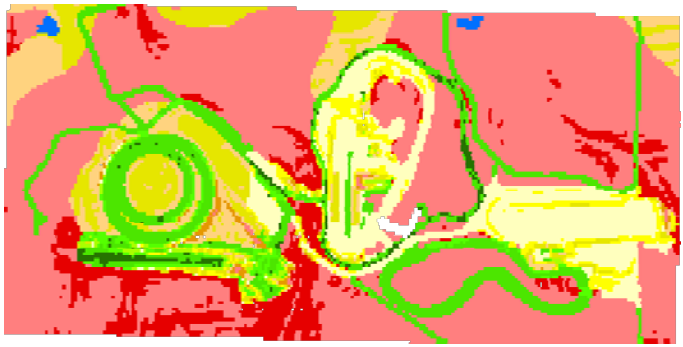


- Acceleration
- Braking
- Half-rounds
- Grade climb
- Side slope
- Step climb
- Grade climb
- Traverse

DIS/GroundVehicle - Key Features: **Other Features**

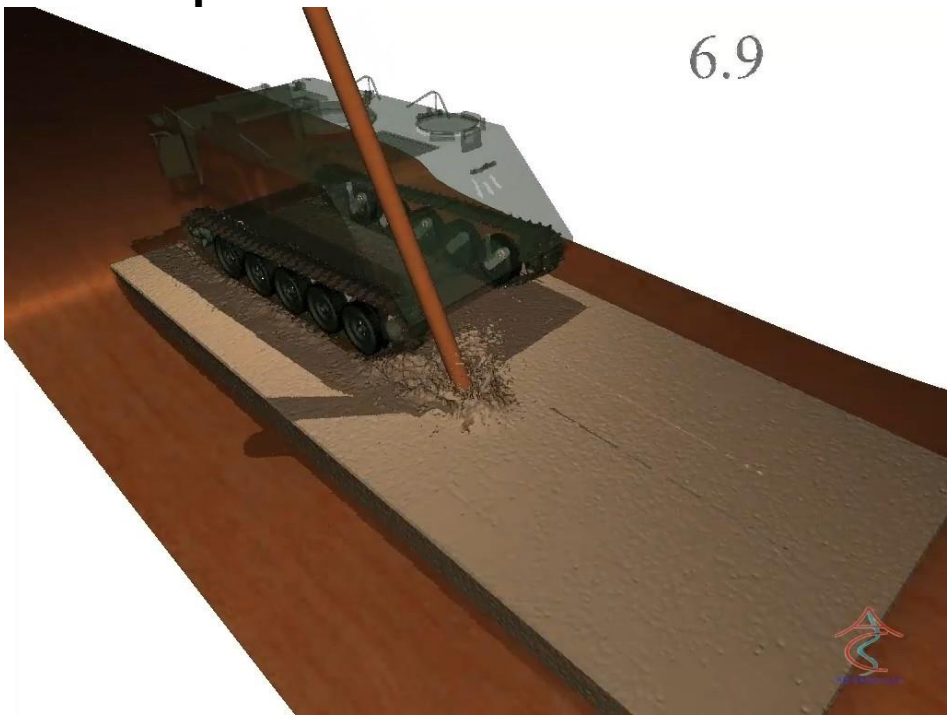
- **Library of vehicle sub-systems** including: suspension, steering, axle, and drive-line.
- Modeling various vehicle **maneuvers** on a moving complex topography soft soil terrain patch and hard surfaces such as: Gradeability, steering, lane-change, cornering, obstacle avoidance, obstacle crossing, ride, braking.
- Integrated JAVA-script and Python interpreters for writing **scripts** to model custom vehicle control systems.
- **Network socket interface** for co-simulation.
- Automated way-point following **driver model**.
- **Real-time virtual vehicle** for driver training and vehicle testing.
- **Advanced VR visualization** of the vehicle and soil/terrain simulations.
- Integrated with **GIS** for inputting the terrain data and outputting vehicle mobility maps.
- Integrated with **DOE**, **response surface surrogate models**, and **UQ** tools for fast generation of vehicle **mobility maps**.





Go/NoGo & Speed-made good Maps

DIS/GroundVehicle – **Future Developments**



- Develop/demonstrate models for:
  - Multi soil layer terrains
  - Water covered soft soil terrains
    - Shallow water fording
    - Deep water swimming
  - Heterogeneous terrain:
    Soil embedded rocks/stones/gravel
  - Vegetation: **trees; bushes; grass; leaves; roots.**
  - Urban obstacles: **structures, buildings, walls, fences, poles, vehicles**
  - Adhesion of soil to running gear
- Validation/calibration of finite Element tire – soil model
- Integrate DIS/GroundVehicle into an NG-NRMM mobility expert system to generate stochastic mobility maps that take into account all mobility constraints.