CONNECTING THE DOTS TO INNOVATION

ERDC DAY AT MISSISSIPPI STATE UNIVERSITY

LISTENING SESSION

"VIRTUAL PROVING GROUNDS FOR AUTONOMY DEVELOPMENT: USING SIMULATION TO DRIVE INNOVATION AND RELIABILITY"

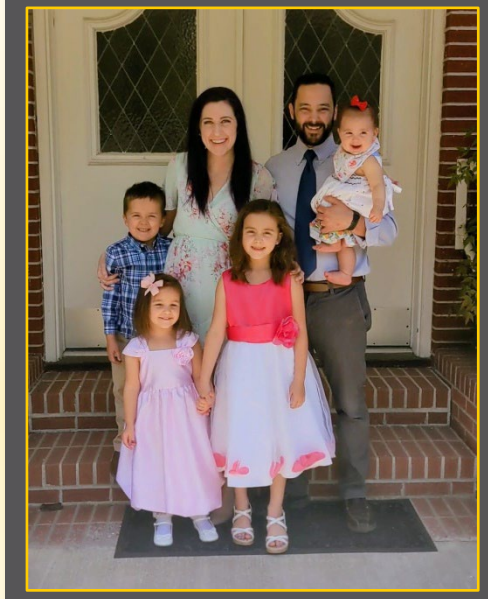
Gabe Monroe, PhD
Geotechnical and Structures Laboratory
US Army Engineer Research and Development Center (ERDC)
30 OCTOBER 2024

U.S. ARMY

US Army Corps of Engineers®

ERDC
ENGINEER RESEARCH & DEVELOPMENT CENTER

WHO AM I AND WHAT DO I DO?



- Name: **Gabe Monroe**
- From: **Meadville, MS**
- Academic Background:
  - B.S. Mechanical Engineering (MSU, 2012)
  - Ph.D. Mechanical Engineering (MSU, 2016)
- Position and Lab: **Research Mechanical Engineer, Geotechnical and Structures Laboratory**
- Career: **Have been with ERDC 8 years. Started 3 days after graduating with PhD**
- Expertise: **Modeling and simulation (M&S) for autonomous vehicle development/experimentation**
  - Vehicle dynamics
  - Sensor physics
  - Thermal modeling
  - 3D modeling
- Real Life: **I'm a husband, dad, woodworker, 3D printing hobbyist, D&D player/DM**

BACKGROUND

DOD REQUIREMENTS FOR MILITARY AUTONOMY

[1]

Human Control

- "Autonomous and semi-autonomous weapon systems will be designed to allow commanders and operators to exercise appropriate levels of human judgment over the use of force."

Compatible with Law

- "Persons who authorize the use of, direct the use of, or operate autonomous and semi- autonomous weapon systems will do so with appropriate care and in accordance with the law of war, applicable treaties, weapon system safety rules, and applicable rules of engagement."

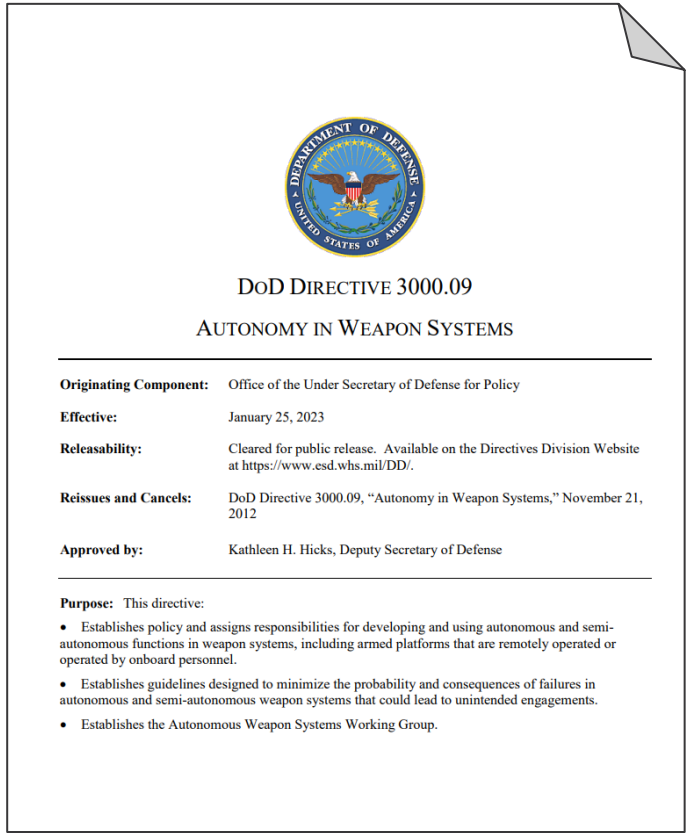
Proven Reliability

- **"The weapon system has demonstrated appropriate performance, capability, reliability, effectiveness, and suitability under realistic conditions."**

Ethically Designed and Implemented

- "The design, development, deployment, and use of systems incorporating AI capabilities is consistent with the DoD AI Ethical Principles and the DoD Responsible AI (RAI) Strategy and Implementation Pathway."

*"Responsible, Equitable, Traceable, **Reliable**, Governable"*



DoD Directive 3000.09

Autonomy in Weapon Systems

Originating Component:	Office of the Under Secretary of Defense for Policy
Effective:	January 25, 2023
Releasability:	Cleared for public release. Available on the Directives Division Website at https://www.esd.whs.mil/DD/.
Reissues and Cancels:	DoD Directive 3000.09, "Autonomy in Weapon Systems," November 21, 2012
Approved by:	Kathleen H. Hicks, Deputy Secretary of Defense

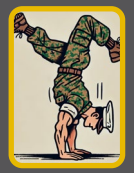
Purpose: This directive:

- Establishes policy and assigns responsibilities for developing and using autonomous and semi-autonomous functions in weapon systems, including armed platforms that are remotely operated or operated by onboard personnel.
- Establishes guidelines designed to minimize the probability and consequences of failures in autonomous and semi-autonomous weapon systems that could lead to unintended engagements.
- Establishes the Autonomous Weapon Systems Working Group.

[1] DoD Press Release: "DoD Announces Update to DoD Directive 3000.09, 'Autonomy In Weapon Systems'", JAN 25, 2023

CASE STUDY: ROBUST AI IS HARD

[2]



Crafty marines: 1
DARPA AI: 0

Crafty marines: 2
DARPA AI: 0

Crafty marines: 3
DARPA AI: 0

"The AI system had been trained to detect humans walking, not humans somersaulting, hiding in a cardboard box, or disguised as a tree. So, these simple tricks, which a human would have easily seen through, were sufficient to break the algorithm."

≠

Proven Reliability

- **"The weapon system has demonstrated appropriate performance, capability, reliability, effectiveness, and suitability under realistic conditions."**

[2] Paul Scharre, "Four Battlegrounds: Power in the Age of Artificial Intelligence," 2023, ISBN 978-1324074779

THE LIMITATIONS OF PHYSICAL AUTONOMY TESTING AND EVALUATION (T&E)

Time

- Many developers may have months with only a handful of prototypes
- Testing centers only have weeks

Money

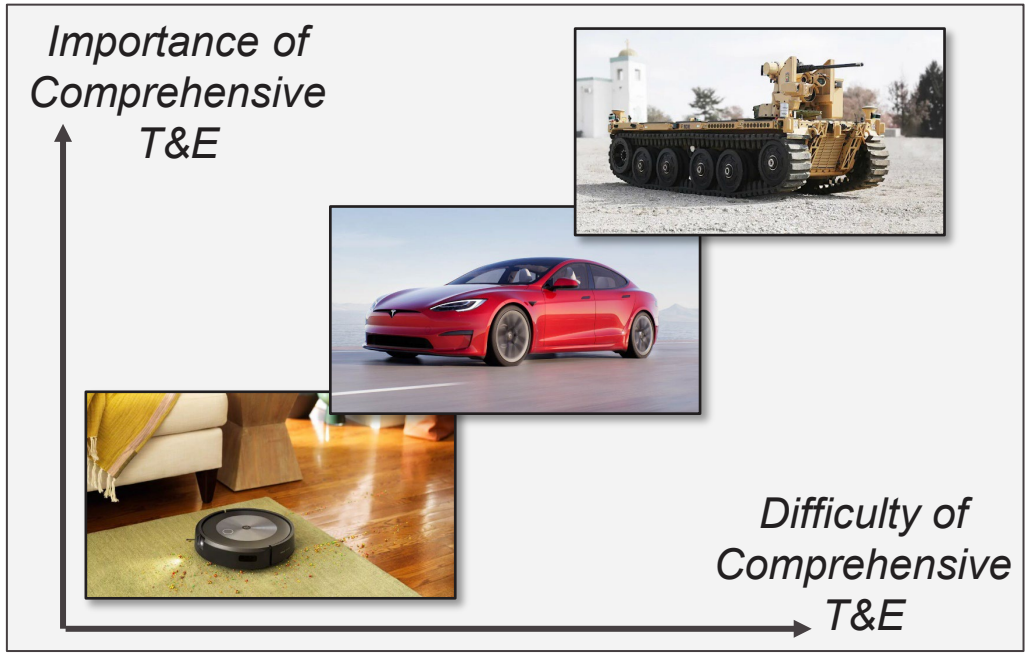
- Traditional T&E regimes can cost millions
- Autonomy requirements still being developed

Control

- Unable to control physical elements
- Tests have limited repeatability and narrow operational applicability

Risk

- Exploring behavior in dynamic environment (e.g. pedestrians, traffic, wildlife) is dangerous
- Damage to exquisite platforms during testing can delay completions



ERDC's Synergy

We Excel at Extending Innovation Across Different Mission Spaces

Watercraft and Ship Simulator: Civil Works

A civilian pilot practices guiding barges down a river

Watercraft and Ship Simulator: Military Engineering

A Warfighter pilot practices nearshore maneuvers

The same Watercraft and Ship Simulator Facility and research team that supports our Navigation mission in Civil Works R&D….

… also supports our Warfighters as they plan logistics-over-the-shore operations overseas.

SIMULATIONS FOR AUTONOMOUS VEHICLES

VIRTUAL AUTONOMOUS NAVIGATION ENVIRONMENT (VANE)

Purpose

- Is a suite of tools that are modular, extensible, and distributable to DoD

Scope

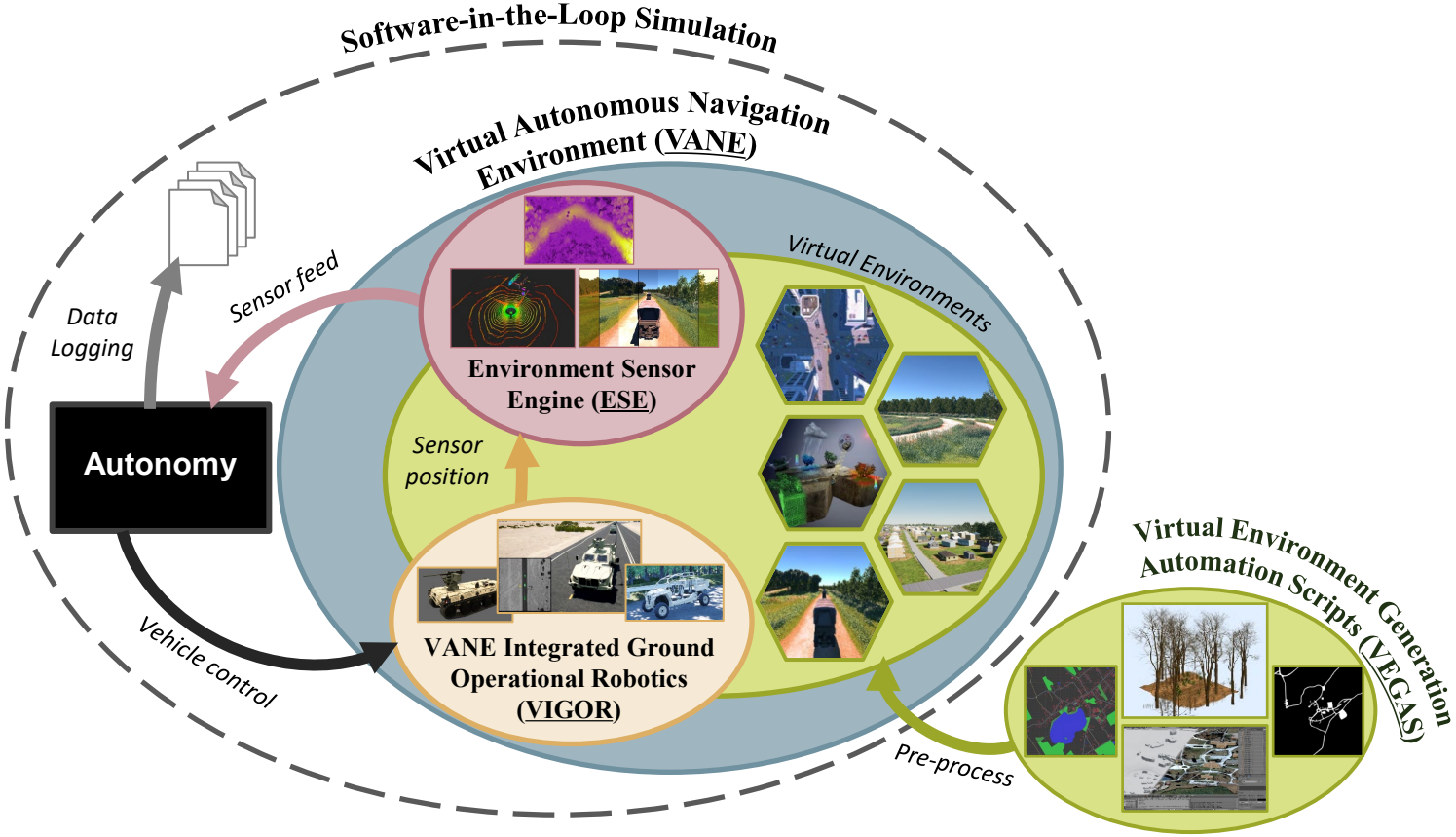
- Provides both real-time and high-fidelity simulation capabilities for ground vehicles (wheeled or tracked) and sensors

Capability

- Supports the full robotics development cycle by performing autonomy-in-the-loop simulations

Advantage

- Allows virtual evaluation of sensors and autonomous vehicles in various environmental conditions



VANE configuration for autonomy SIL use case

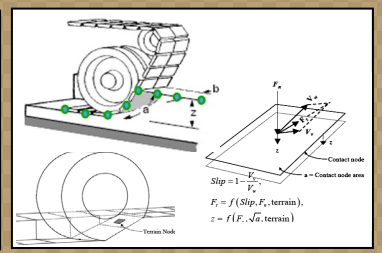
Virtual testing of sensors and autonomous vehicles in various environmental conditions to augment physical testing and ensure a robust system while saving time and money

VIRTUAL ENVIRONMENT REQUIREMENTS FOR AV SIMULATIONS

VANE Autonomy Simulation

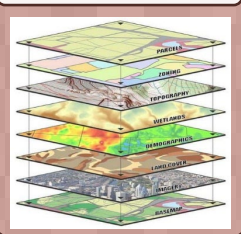
VANE Vehicle Simulation

- Soil properties
- Realistic terrain physics
- Vegetation force response
- Accurate vegetation distributions



GIS Layers

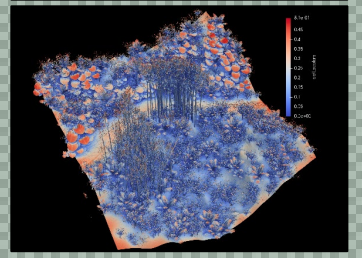
- AOI-scale baseline data



Human-Centric Video Game/Trainer

- Terrain and structure geometry
- Visualization textures
- Artistic scene representation

- Normalized RGB and hyperspectral textures
- Thermal properties attribution
- Transient material states
- Weather effects



High

Data Complexity

Low

VANE VEHICLES-TERRAIN INTERACTION

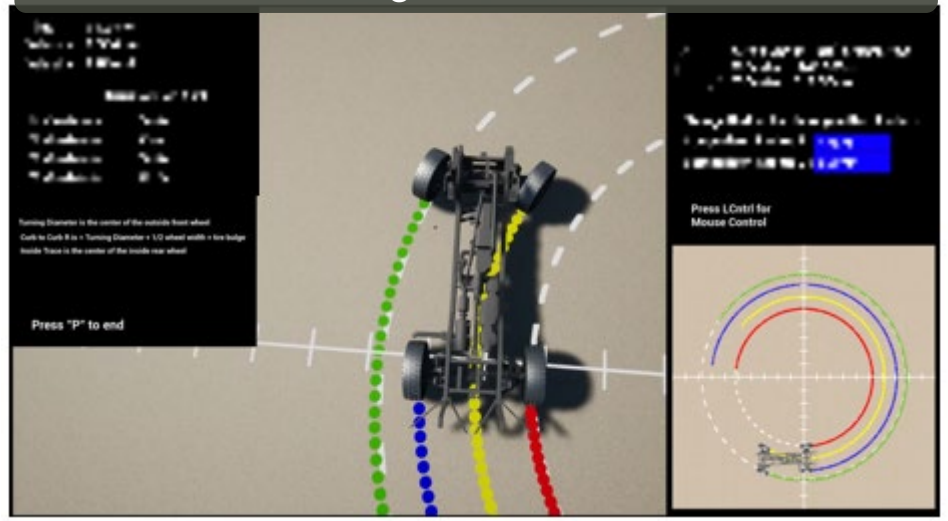
Vehicles-Terrain Interaction Validation

- Virtual vehicle performance metrics determined with VANE implementations of standardized vehicle tests
  - Acceleration, NATO double lane change, braking, steering, ride-shock, etc.
- Vehicle models calibrated by comparing virtual test data with production verification test reports
- Terrain properties based on mobility metrics from ERDC field test data
- Lumped parameter models used for vehicles and terrain for simulation speed

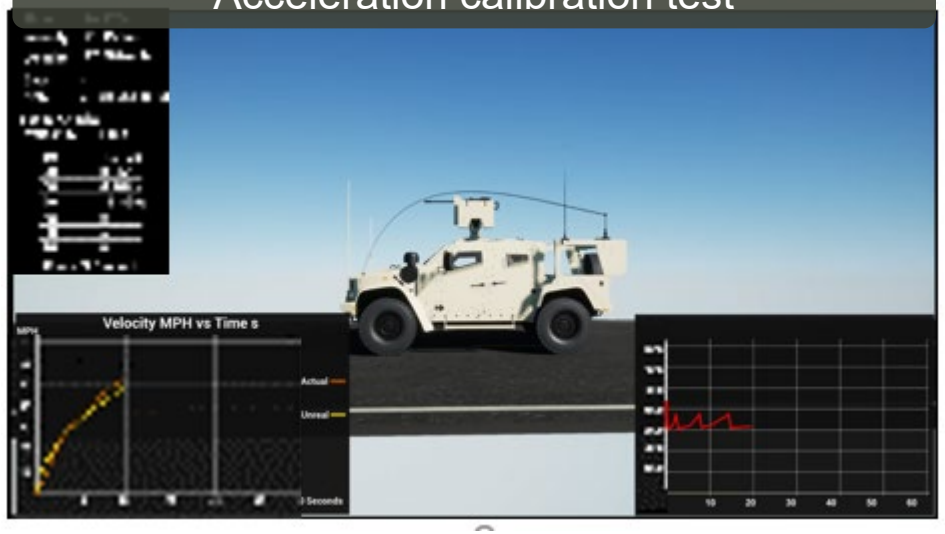
Vehicle	Validation Status
HMMWV	Partially validated
MTVR	Partially validated
MRZR	Validated
PLS	Validated
RCV-L(S)	Partially validated
FMTV	Partially validated
JLTV	Validated

Accurate and real-time vehicle models provide surrogates for autonomy to control during simulations

Steering calibration test



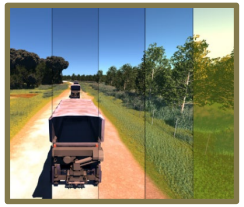
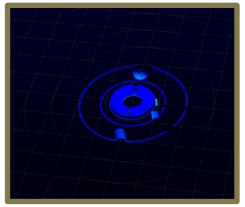
Acceleration calibration test



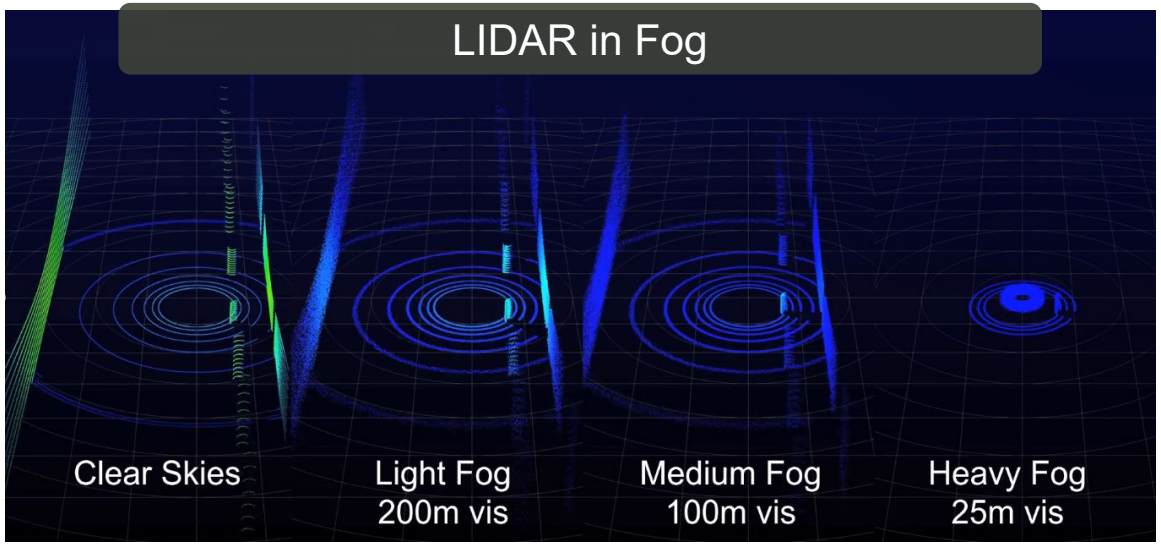
VANE SENSORS AND WEATHER EFFECTS

- High-fidelity sensor models generate realistic synthetic sensor data
  - *Replicates common sensor error found in real world*
- Includes environmental effects that can degrade sensor perception
  - *Weather, lighting, polarization, etc.*
- Can vary fidelity/complexity to balance accuracy and speed of simulations
- Can generate labeled training data for algorithm development

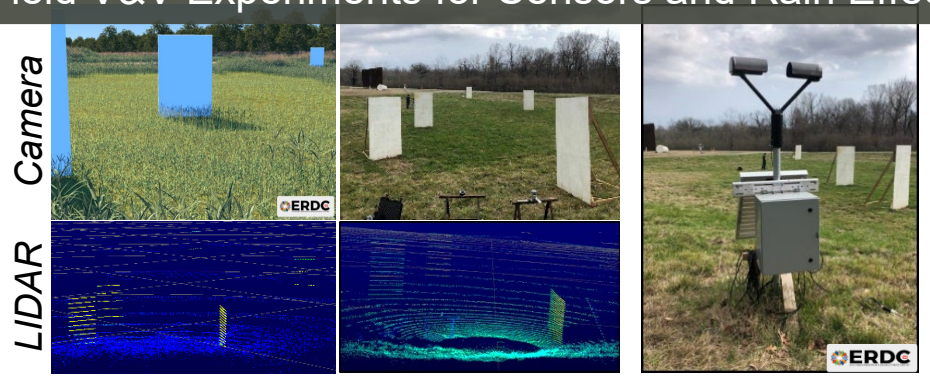
Current Key Environmental Factors in VANE

Lighting	Rain	Dust	Fog
			
• Time-of-day • Shadows • Polarization • Atmosphere haze	• Variable rainfall rate • Wind effects	• Vehicle-generated dust • Wind effects	• Variable fog density • Beam/fog options for fidelity vs. performance

LIDAR in Fog



Field V&V Experiments for Sensors and Rain Effects



Simulated *Real* *Rain Disdrometer*

High-fidelity sensor simulations provide realistic data for a wide variety of environmental conditions at a fraction of the time and cost of physical experiments

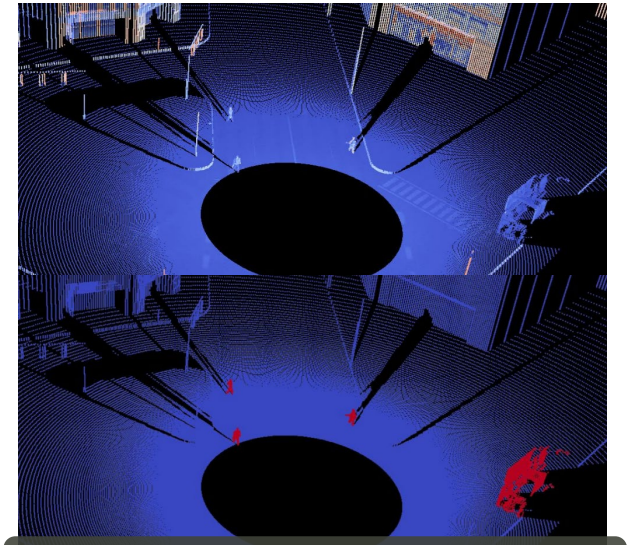
SYNTHETIC TRAINING DATA

Importance

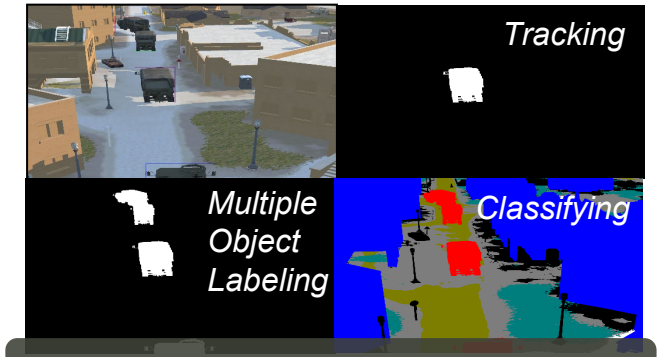
- Machine Learning algorithms are advancing rapidly for UxV navigation and for intelligence analysis
- Detection and classification algorithms are only as robust as their training datasets

Impact of VANE

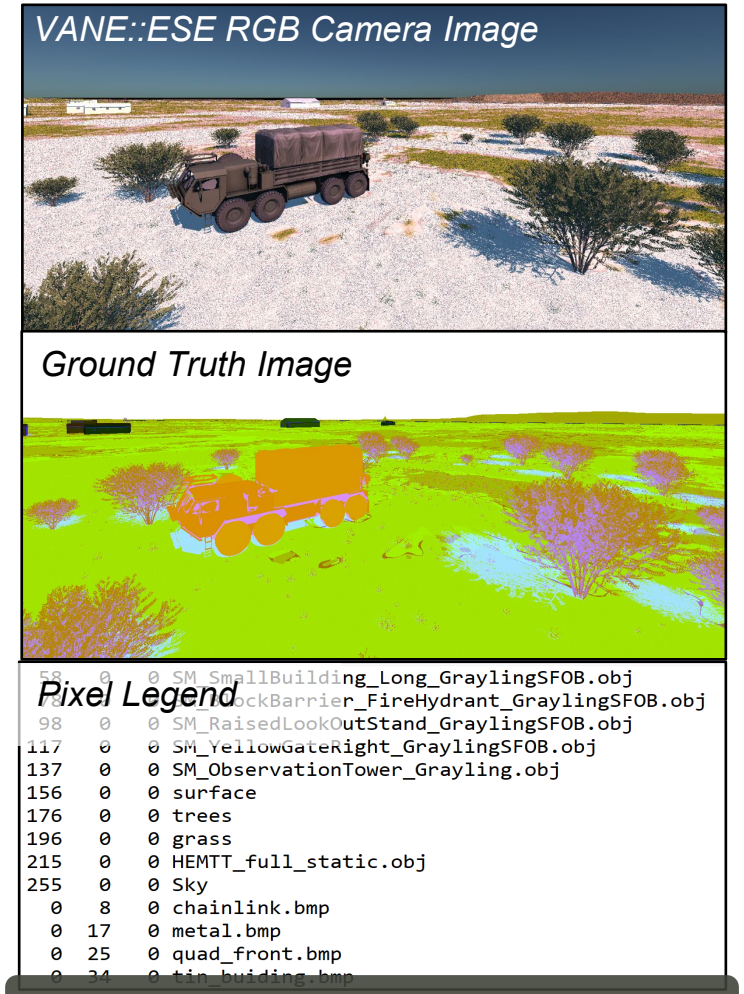
- Effective algorithms require ~1000s of labeled training images (manual labeling takes weeks/months)
- VANE can rapidly generate ~10,000 ground-truth training images (automated in hours/days)



LIDAR points classification



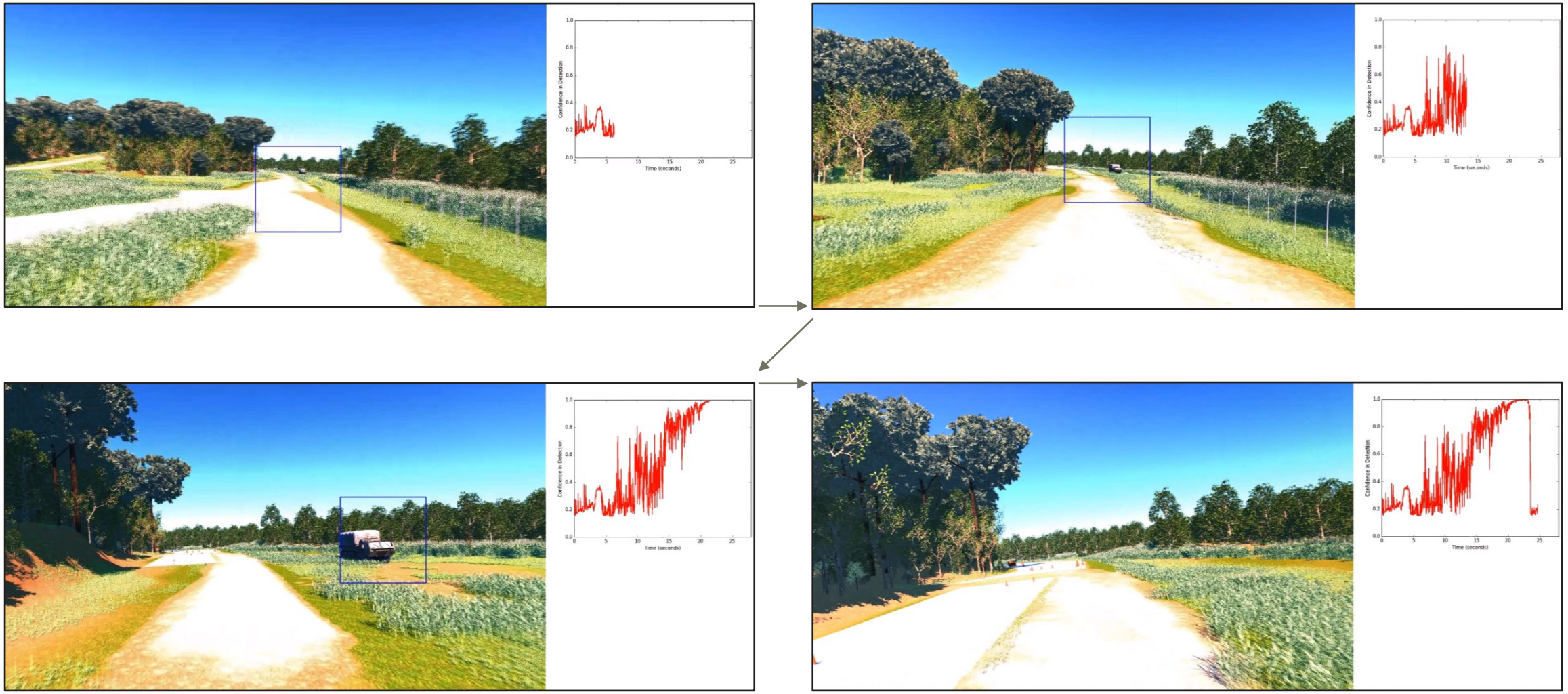
Versatile labeling



Fully labeled ESE image

M&S-enabled machine learning algorithm development by providing synthetic data with sufficient entropy and metadata to fulfil the object detection and classification training needs

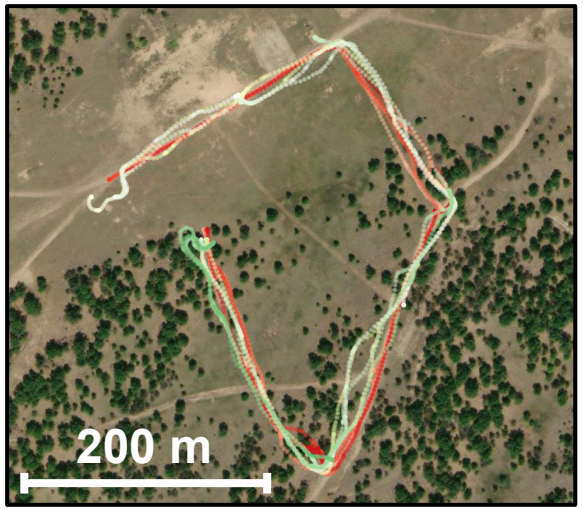
EXAMPLE OF OBJECT DETECTION WITH VANE DATA (VIDEO SCREENSHOTS)



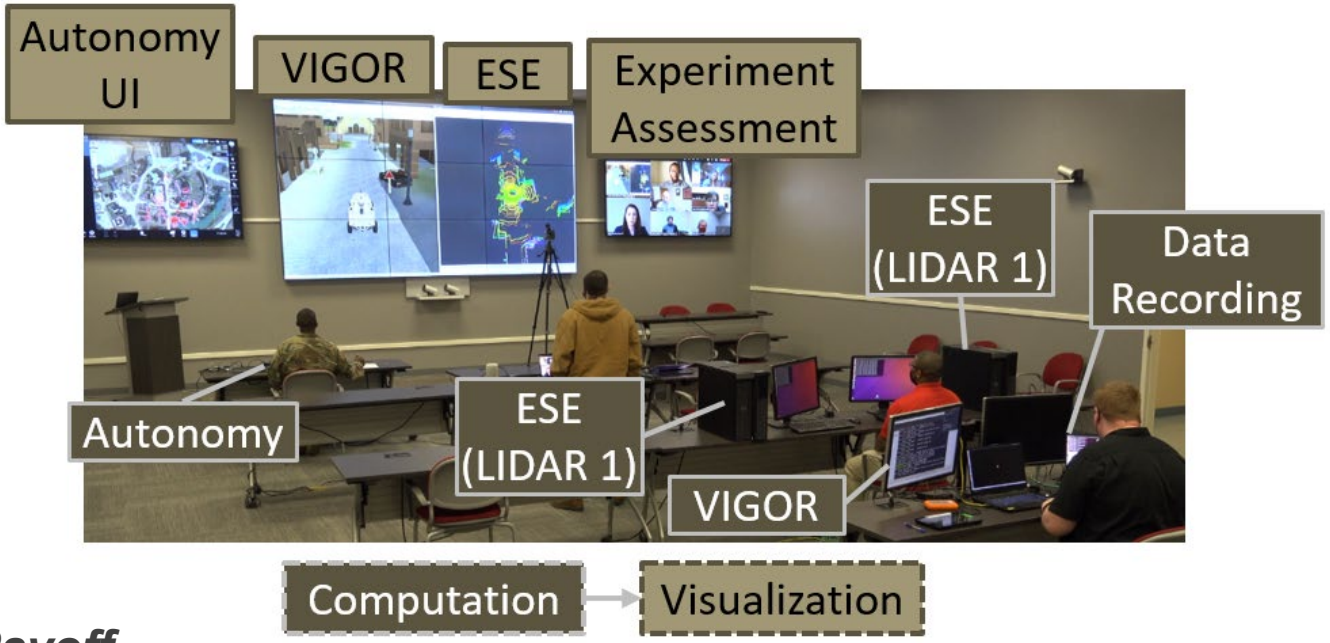
SOFTWARE-IN-THE-LOOP (SIL) SIMULATIONS

Overview

- SIL simulations combine environment, vehicle, and sensor models into comprehensive M&S architecture
- Allows for development or evaluation of autonomy without requiring physical system or test ranges



UGV path comparison of multiple real and virtual experiments

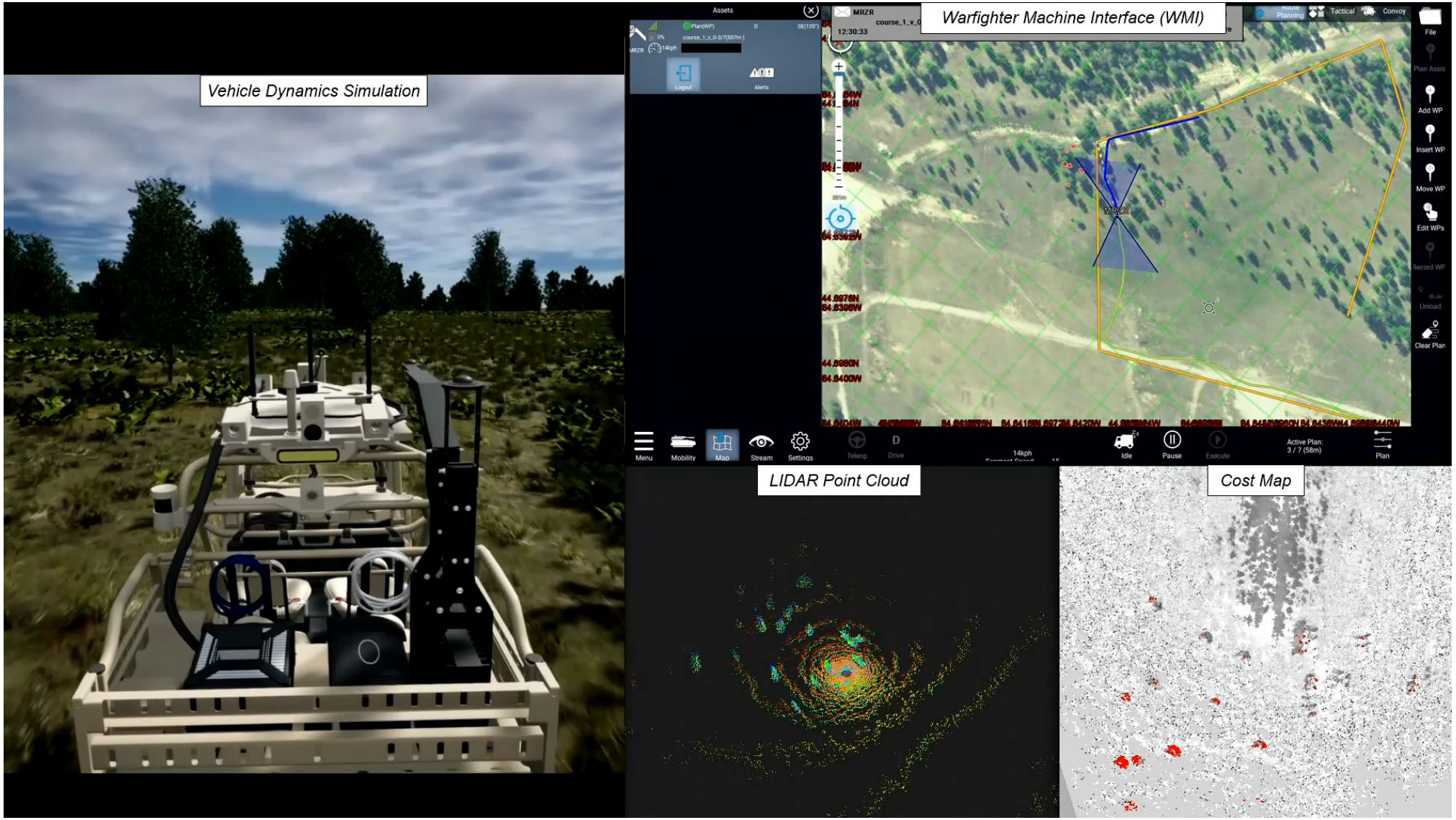


VANE Payoff

- Same communication protocols (e.g. ROS) as physical systems
- High-fidelity sensor-feed for autonomy to process
- Validated vehicle models for Autonomy to control
- Realistic virtual world impact autonomy behavior and performance
- Parameterized testing in low-cost, zero-risk virtual environment

Augment physical experiments with virtual evaluation of AGVs in diverse conditions

VANE SIL SIMULATIONS



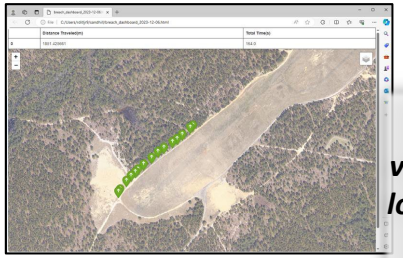
OTHER USE CASES

ERDC M&S SUPPORT TO SANDHILLS REMOTE BREACHING EXPERIMENT

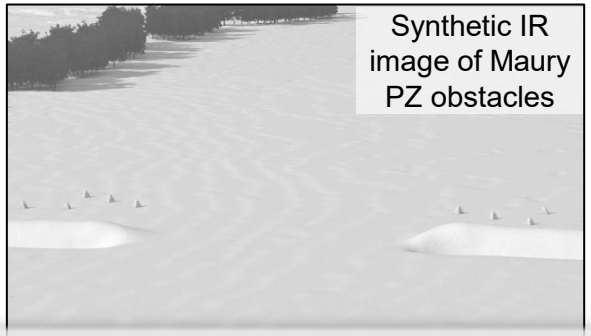
***Project Objective*: Rapidly develop a simulation tool for virtual teleoperation of multiple current and near-future platforms in digital twins of Ft Liberty test ranges to augment the limited time combat engineers have with physical platforms**

VANE-RBS: Remote Breaching Simulator

- Leveraged on-going work being done in support of Army robotics to expedite development
- Constructed multi-user architecture to enable virtual breaching operations in a shared simulation environment
- Coordinated with combat engineers to replicate physical Sandhills Project vignettes
- Enables units to develop TTPs and gain experience related to remote breaching operations



Logging and playback of vehicle positions and obstacle locations enables robust AARs and data analysis



On-going work to integrate ERDC's high-fidelity thermal simulations into VANE-RBS UAV model

State-of-the-art simulation with realistic vehicle models in complex virtual environments decreases cost, time, and risk

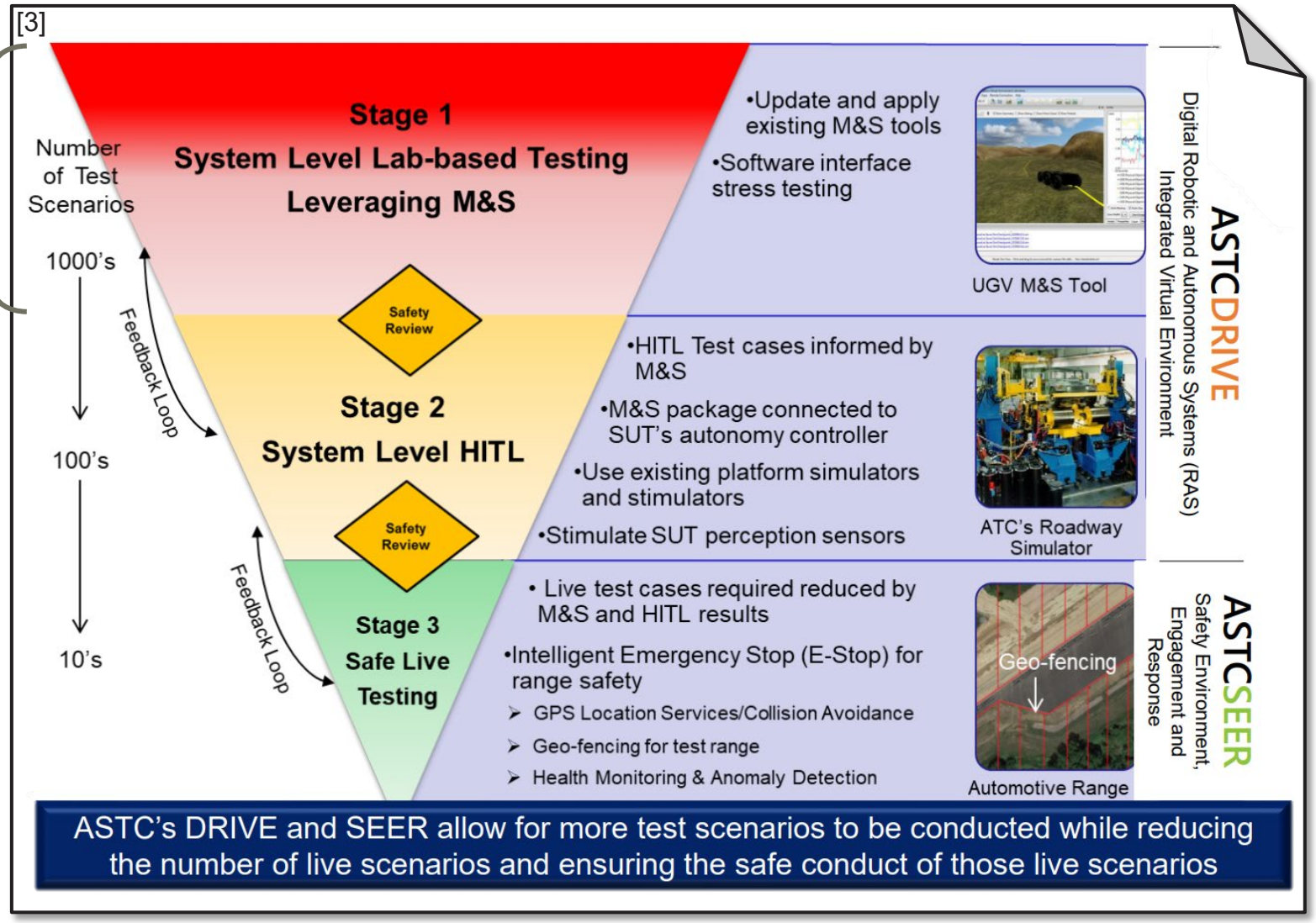
Virtual experimentation of novel operational concepts augments physical training and accelerates human machine integration for combat engineering

Digital twins of Ft. Liberty ranges enhance training by allowing virtual parameterization of obstacles and scenarios

AUTONOMY T&E GOAL: M&S INFORMED PHYSICAL TESTING

Existing Case Study

- Aberdeen Test Center (ATC) is leading the Autonomous System Test Capability (ASTC) program to address autonomous safety testing
  - *Leveraging VANE::ESE for sensor simulation*
- Reduces the vehicles' required time on the test courses while accrediting the safety of the autonomy
- Enables ATC to do more with the time and money available
  - E.g. Current system can "run a typical Leader Follower test phase in 2.5 hours collecting 192 GB of test data, reducing the cost by 98%, and the carbon foot print by 3,200 gallons of fuel" [3]



[3] J. Whitt, P Bounker, "The Use and Benefits of Modeling and Simulation with Autonomous Vehicle Testing", U.S. Army Aberdeen Test Center

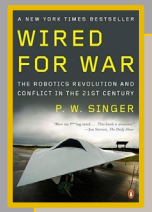
ADDITIONAL RESOURCES

Power of ERDC Podcast Ep. #8: Modeling and Simulation for Unmanned Ground Vehicles
(ERDC, Audio, 2021)

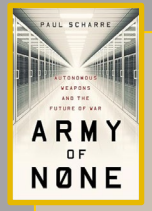
ERDC Modeling and Simulation in Support of Unmanned Ground Vehicles
(ERDC, Video, 2022)

The Sandhills Project: 1.0
(20th EN BDE, Video, 2023)

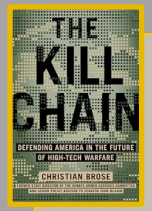
Personal Recommendations



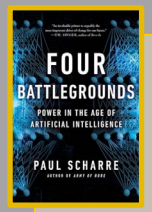
Wired for War: The Robotics Revolution and Conflict in the 21st, P. W. Singer, 2009



Army of None: Autonomous Weapons and the Future of War, Paul Scharre, 2018



The Kill Chain: Defending America in the Future of High-Tech Warfare, Christian Brose, 2020



Four Battlegrounds: Power in the Age of Artificial Intelligence, Paul Scharre, 2023

THANK YOU!

Gabe Monroe, PhD

Research Mechanical Engineer
Geotechnical and Structures Laboratory
U.S. Army Engineer Research and Development Center
U.S. Army Corps of Engineers

john.g.monroe@usace.army.mil
601-634-4015

Scan the QR code with your phone for instant access to ERDC websites and social media

ERDC
ENGINEER RESEARCH & DEVELOPMENT CENTER

COME WORK WITH US!

Scan the QR code to register with us and upload your resume

Scan the QR code or use the link below to download a copy of the **Power of R&D Newsletters**

https://www.dvidshub.net/publication/1366/power-of-rd-newsletter

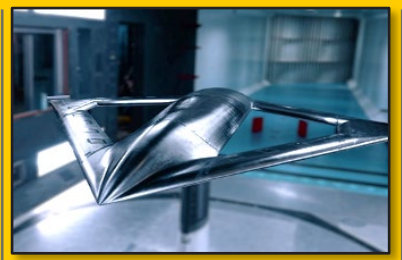
Delivering Innovation

ERDC's Research and Development Areas (RDAs)

RESEARCH & DEVELOPMENT AREAS

CIVIL WORKS

MILITARY ENGINEERING



ENGINEERED RESILIENT SYSTEMS

INSTALLATIONS & OPERATIONAL ENVIRONMENTS

GEOSPATIAL RESEARCH & ENGINEERING

INTEGRATIVE COLD SCIENCE & ENGINEERING

CORE COMPETENCIES

SPECIALIZED ERDC KNOWLEDGE THAT ENABLES OUR RESEARCH AND DEVELOPMENT AREAS

BATTLESPACE
TERRAIN MAPPING AND CHARACTERIZATION

BLAST AND WEAPONS EFFECTS
ON STRUCTURES AND GEO-MATERIALS

CIVIL AND MILITARY ENGINEERING

COLD REGIONS SCIENCE AND ENGINEERING

COASTAL, RIVER AND ENVIRONMENTAL ENGINEERING

COMPUTATIONAL PROTOTYPING OF MILITARY PLATFORMS

MILITARY INSTALLATIONS AND INFRASTRUCTURE