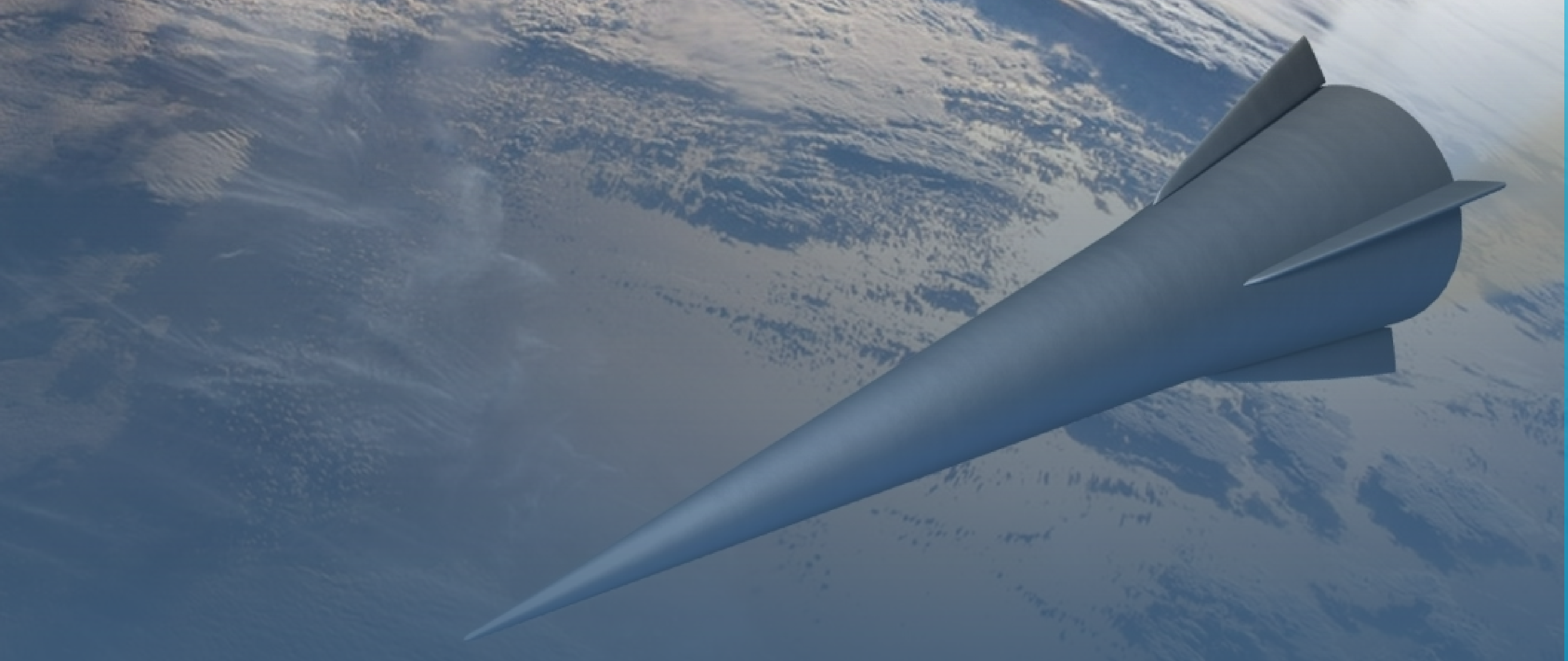
SAND2021-11893C

Sandia National Laboratories



Autonomy for Hypersonics

Hypersonic Weapons Summit | September 29th, 2021

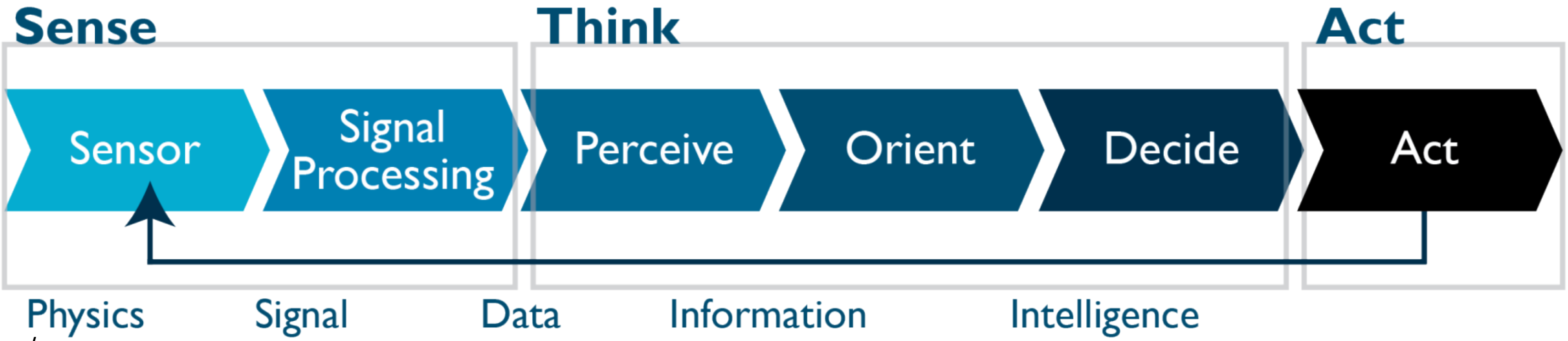
PRESENTED BY

Dr. R. Scott McEntire

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

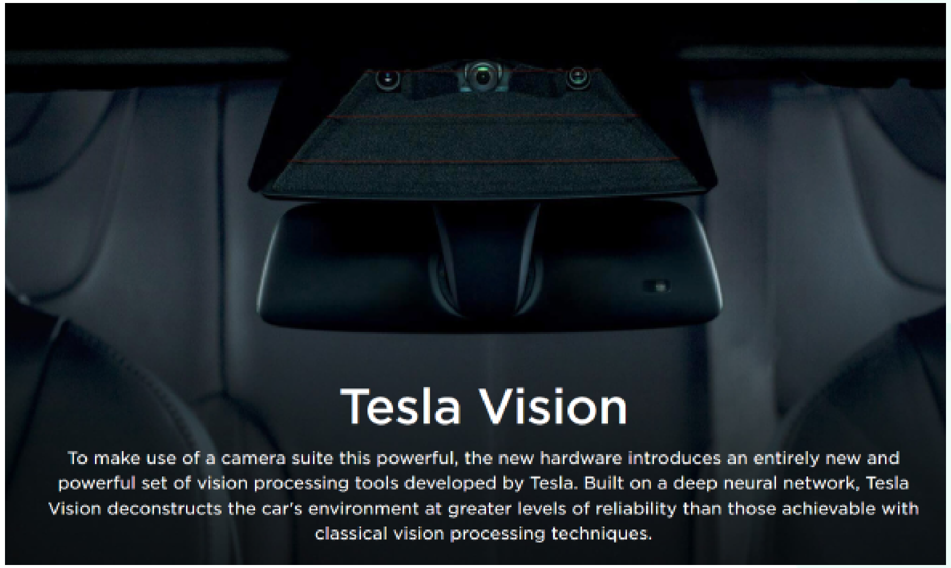
Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

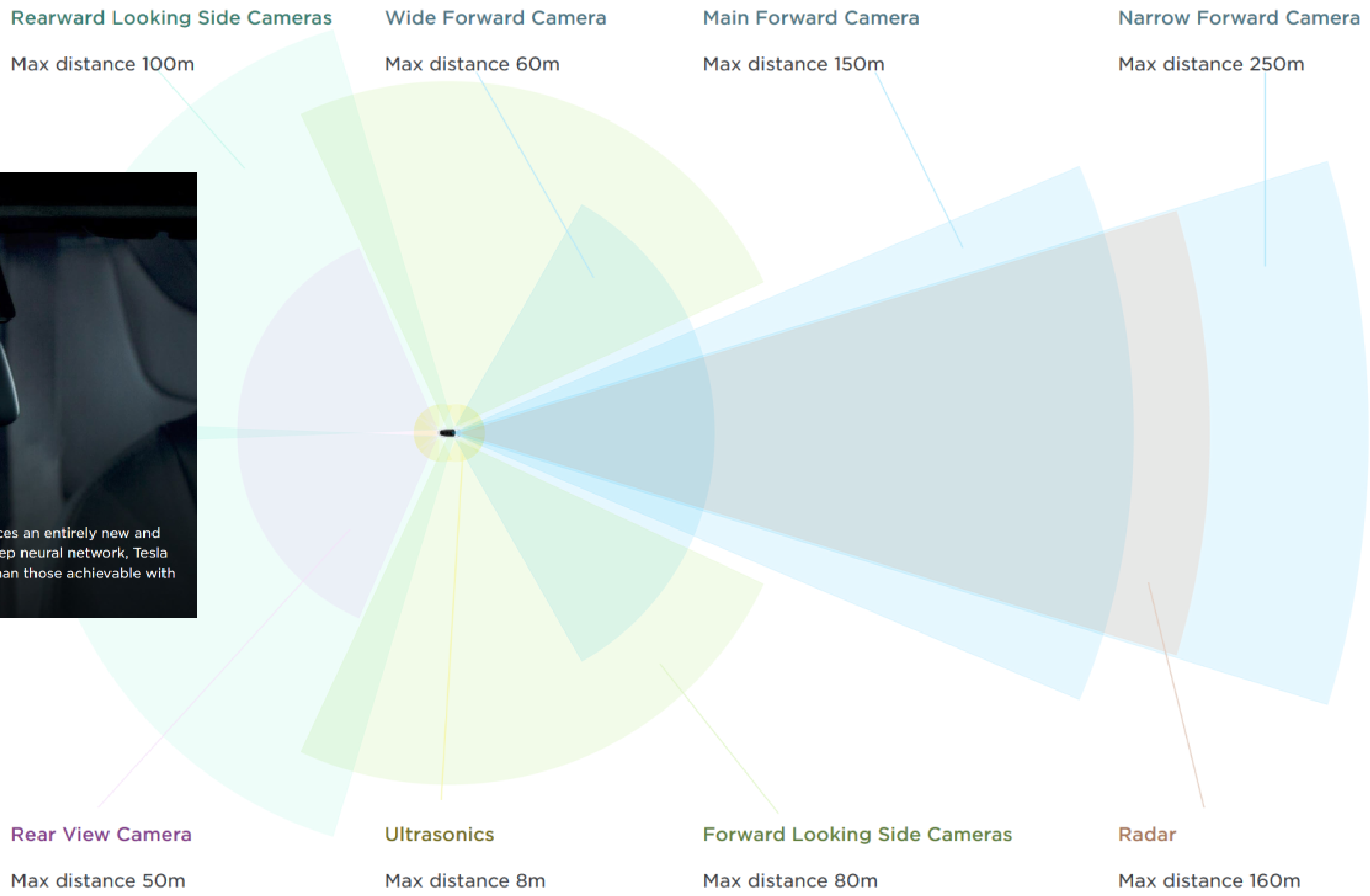
Autonomous Systems – Tesla



Source: https://www.tesla.com/

Autonomous Systems – Tesla - Sensors





Source: https://www.tesla.com/

Commercial

- Structured environments
- Large tolerance for error
- Large labeled training datasets for accuracy
- Can deal with object classes (car, pedestrian, etc.)
- Short-range imaging modalities (e.g. RGB iPhone)
- Can typically rely on GPS and network connectivity, which allows off-board processing and simplifies C2

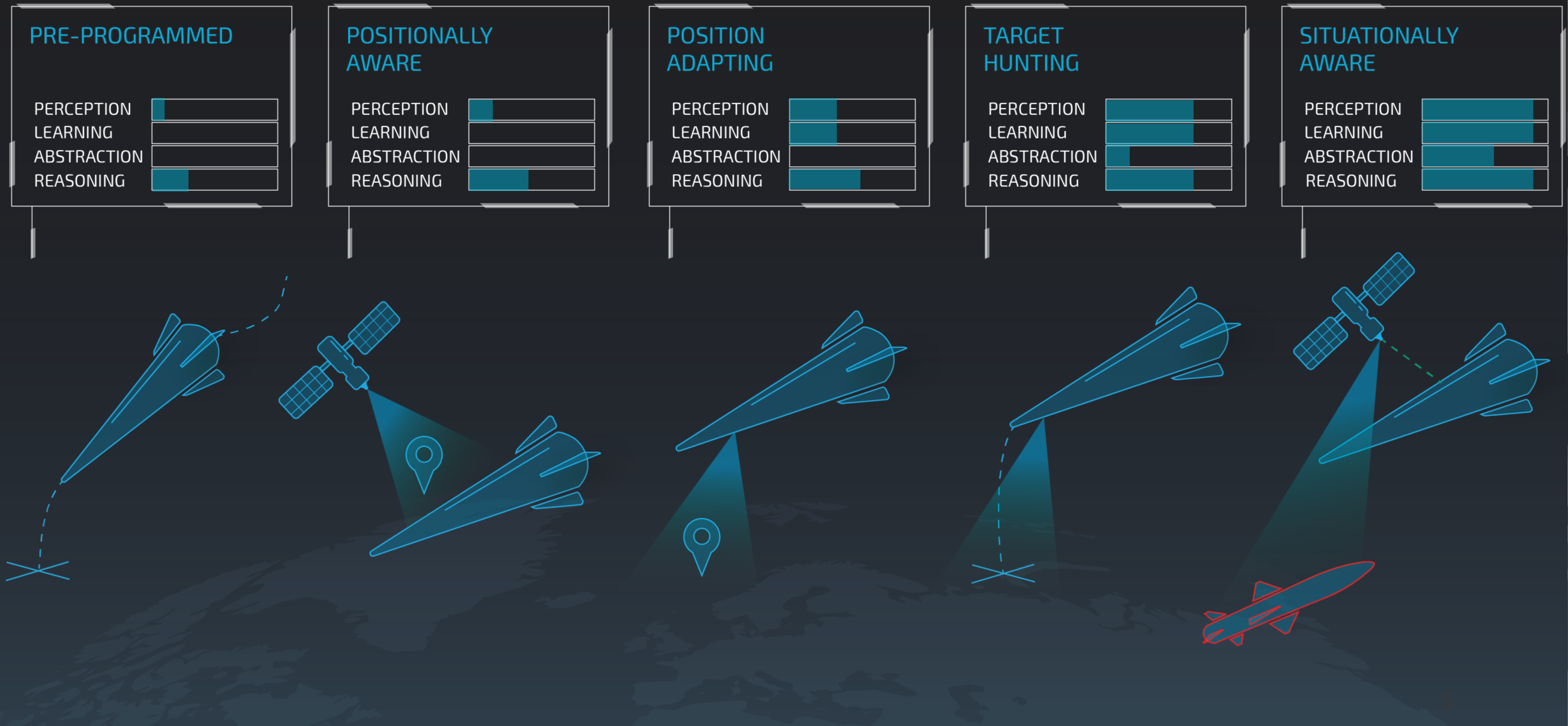
VS

Defense

- Unstructured, adversarial environments
- Low tolerance for error
- Lack of training data
- Requires precise object identification
- Remote EO/IR/SAR imaging modalities
- Operation in potentially contested environment with minimal to no network connectivity

Defense applications require different performance characteristics than their commercial counterparts, while managing SWaP and bandwidth limitations.

Sandia's Hypersonics of the Future Roadmap



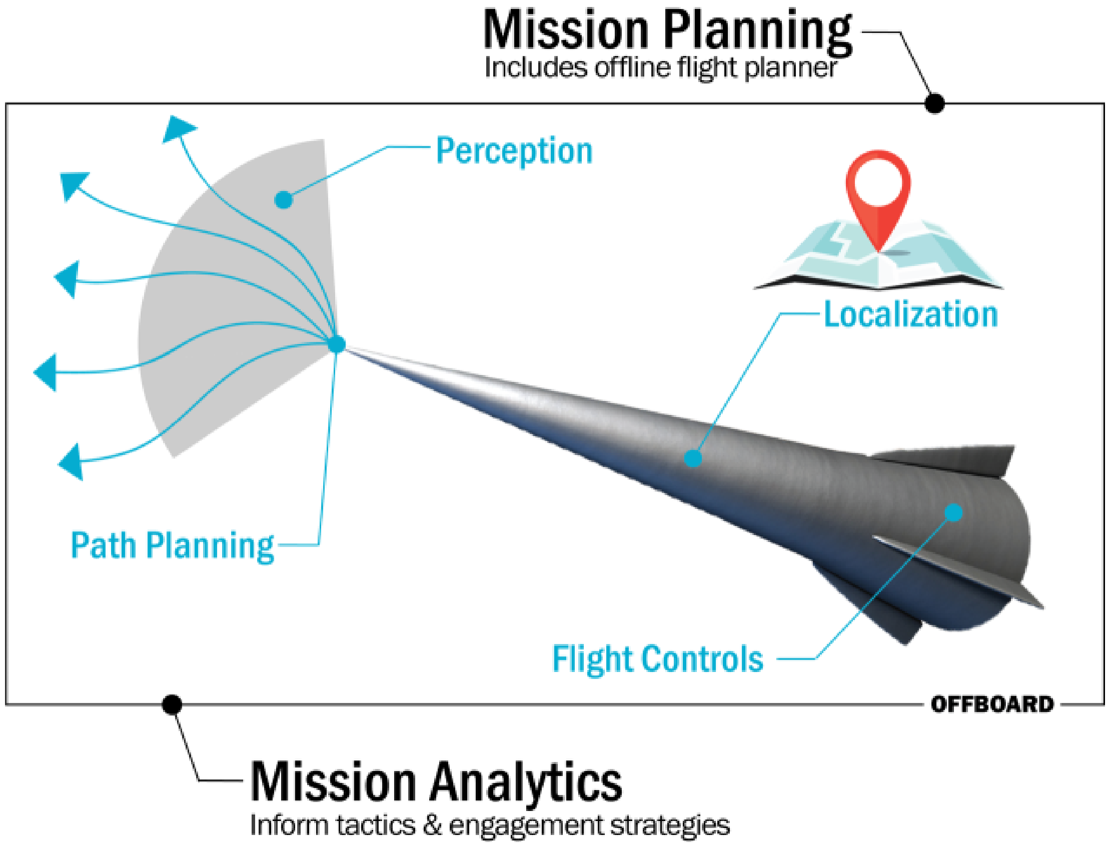
Autonomy for Hypersonics (A4H)

A4H will research and develop autonomous systems technologies that will enhance the warfighting utility of hypersonic flight systems

- Provide autonomous mission planning for rapid response to time-sensitive threats
- Enable adaptive, highly-maneuvering vehicles that intelligently navigate, guide, and control to targets

The developed autonomy solutions will strengthen conventional deterrence by enabling adaptive hypersonic systems that can:

- Prosecute fleeting targets in contested environments
- Provide a defense against adversary hypersonic weapons



Internal Sandia Investment | 6.5 years | 2018- 2023

Collaborating with Universities

ILLINOIS

Naresh Shanbhag
+ Craig Vineyard

Neural-Inspired Approaches and Implementations for Automatic Target Recognition

Zach Putnam
+ Daniel Whitten

Tightly Integrated Navigation and Guidance for Target Acquisition

Girish Chowdhary
+ Bart von Bloemen Waanders

Hyper-Differential Analysis to Mitigate Uncertainties for Control of Hypersonic Vehicles

Roy Dong
+ Kyle Williams

Coordinated Multi-Agent Reinforcement Learning in Continuous Action Spaces

Georgia Tech

Jonathan Rogers
+ Kyle Williams

Real-Time Evasive Maneuvers in Contested, Uncertain Environments

Ani Mazumdar
+ Katya Casper

Hypersonic Wind Tunnel Test Bed for Fault-Tolerant and Adaptive Control

Panos Tsiotras
+ Bart von Bloemen Waanders

Hyper-Differential Analysis to Mitigate Uncertainties for Control of Hypersonic Vehicles

Matthew Gomboley
+ Anirudh Patel

Learning Optimal Communication for Cooperative Sensor Fusion

Ani Mazumdar
+ Michael Sparapany

Eris: Chaotic Trajectories for Hypersonics

Evangelos Theodorou
+ Dave Kozlowski

Optimization & Robust Control Technique for use in Flight Control Design for Hypersonics

Ani Mazumdar
+ Kyle Williams

Real-Time Evasive Maneuvers in Contested, Uncertain Environments

Karen Feigh
+ Paul Schutte

Transparency & Operator Performance in Human Autonomy Teaming (TOPHAT)

The University of Arizona

Roberto Furfaro
+ Bethany Nicholson

Real-Time, Nonlinear, Optimization-Based Control Algorithms for Hypersonics

Texas A&M University

John Valasek
+ Daniel Whitten

Tightly Integrated Navigation and Guidance for Target Acquisition

Johnny Hurtado
+ Lisa Hood

Surrogate-Constrained Vehicle Modeling to Enable Rapid and Real-Time Trajectory Generation

NM State

Hyeongjun Park
+ Bethany Nicholson

Real-Time, Nonlinear, Optimization-Based Control Algorithms for Hypersonics

The University of New Mexico

Don Hush
+ Mary Moya

Improving Model-Based Training of ATR for Rapidly Responding to Evolving Threats

Texas — The University of Texas at Austin

Todd Humphreys
+ Kyle Williams

Coorindated Multi-Agent Reinforcement Learning in Continuous Action Spaces

Maruthi Akella
+ Mike Grant

Autonomous 6DOF RTTG for Highly Constrained Hypersonic Missions

Karen Willcox
+ Patrick Blonigan

Rapid High-Fidelity Aerothermal Responses with UQ via Reduced-Order Modeling

Renato Zanetti
+ Felix Wang

NeuroGrid: Robust Autonomous Localization through Multi-Resolution Grids

Purdue University

Kaushik Roy
+ Craig Vineyard

Neural-Inspired Approaches and Implementations for Automatic Target Recognition

Ali Raz
+ Kyle Williams

Real-Time Evasive Maneuvers in Contested, Uncertain Environments

Tim Pourpoint
+ Katya Casper

Hypersonic Wind Tunnel Test Bed for Fault-Tolerant and Adaptive Control

USC University of Southern California

Roger Ghanem
+ Cosmin Safta

Unsupervised Learning Algorithms for Autonomous Trajectory Analysis

Desired A4H Core Outcomes

Mission-Agile Intelligent NG&C

Advance traditional navigation, guidance, and control techniques beyond rules-based algorithms to more agile and intelligent architectures.

Distributed Execution of Complex Missions

Ability to quickly and collaboratively determine tasking of multiple agents in a dynamically changing mission environment for successful prosecution of targets.

Agent Driven Mission Analysis

Leverage advances in complex gameplay for developing novel maneuvers and strategies for future warfighting scenarios.

A4H Research Effort Snapshots

Hypersonic Wind Tunnel for Fault-Tolerant & Adaptive Control *PI: Katya Casper (1515)*

Project Goal

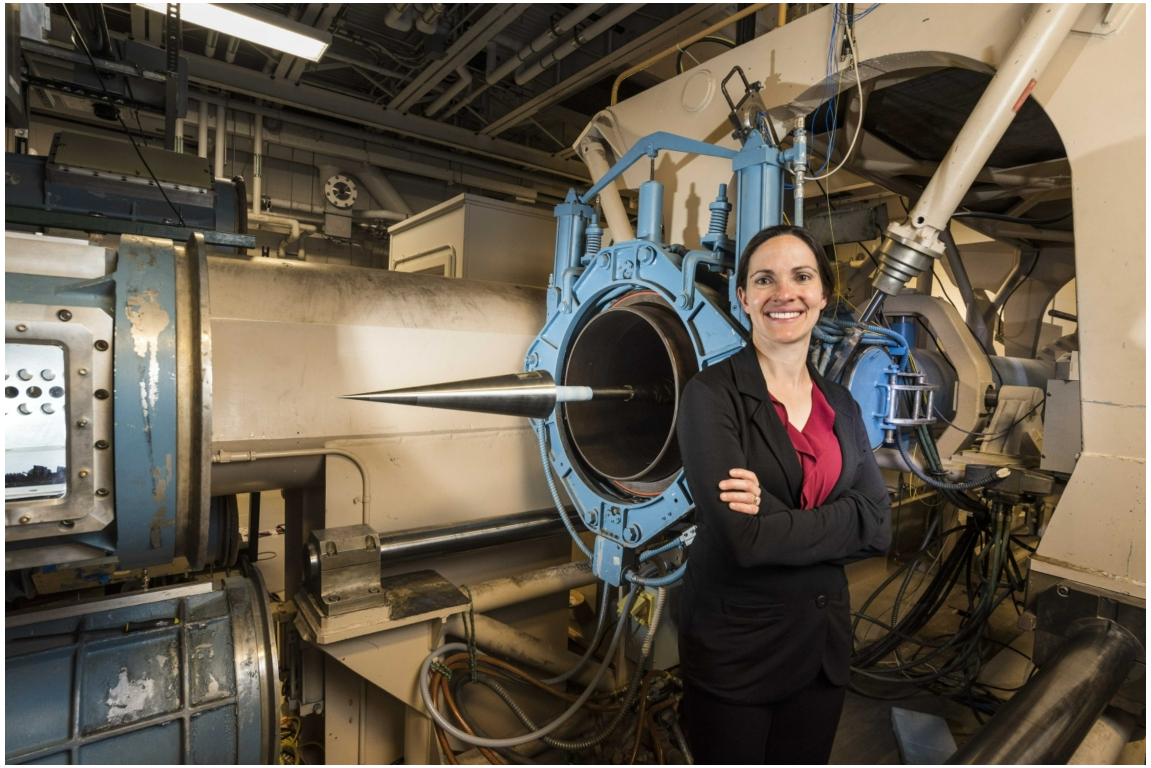
- Create dynamic controls ground-test capability for vehicle performance characterization

Mission Impact

- Provide confidence in and performance of control motion planning algorithms. Working with academic partners to evaluate maneuvers to develop onboard library

New Capability

- Successfully demonstrated control-in-the-loop hypersonic wind tunnel test



Biologically-Inspired Unmanned System Interception

PI: Frances Chance (1421)

Project Goals

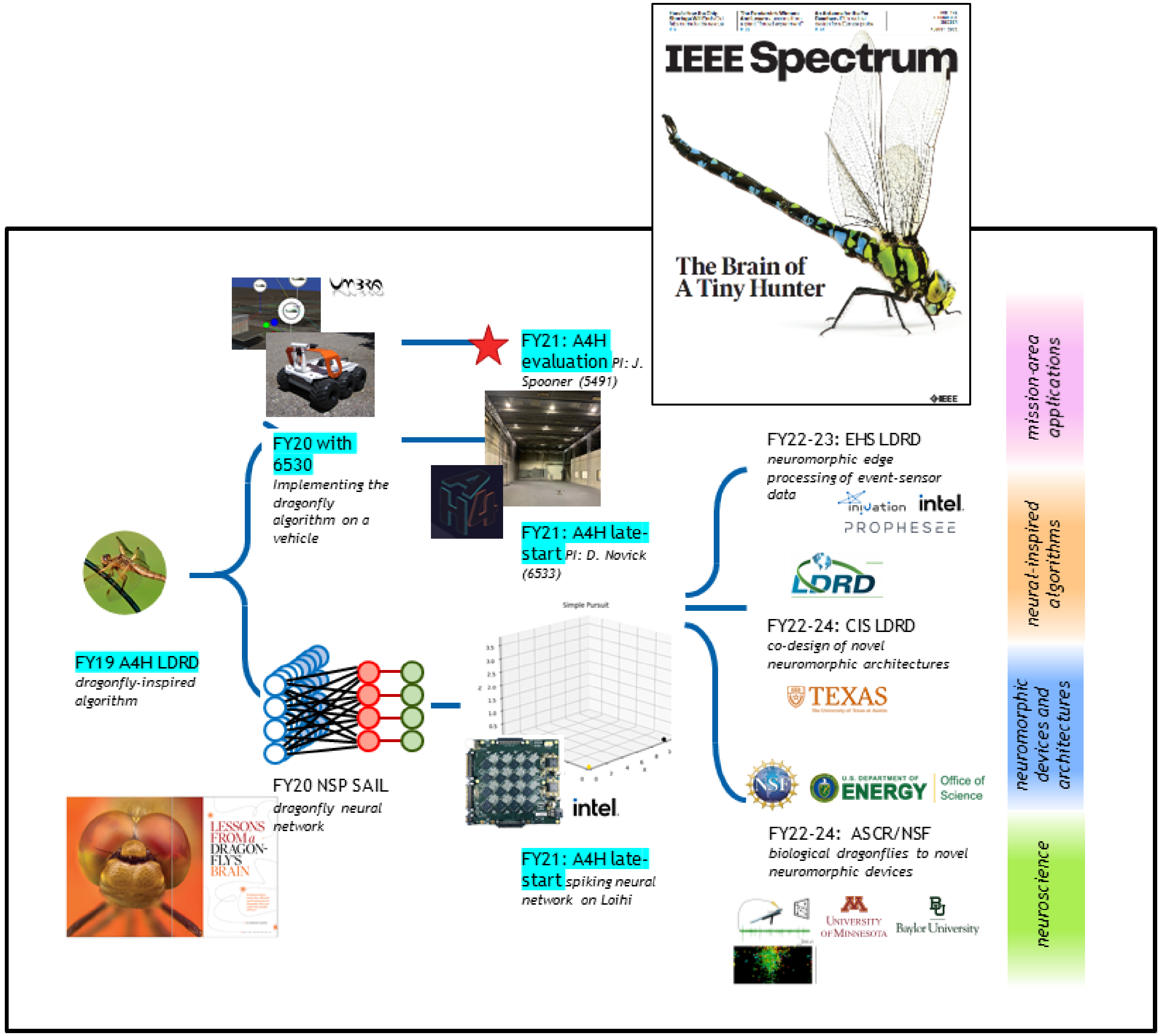
- Demonstrate “dragonfly-inspired” dynamic interception algorithms on actual hardware.

Approach

- Leverage an early A4H seedling project to actual port these neuromorophic algorithm

Impact & Benefit

- Continued investment and connection with other efforts across Sandia has led to research outcomes more attractive to potential government sponsors.



Neural-Inspired Approaches & Implementation for ATR

PI: Craig Vineyard (1421)

Project Goal

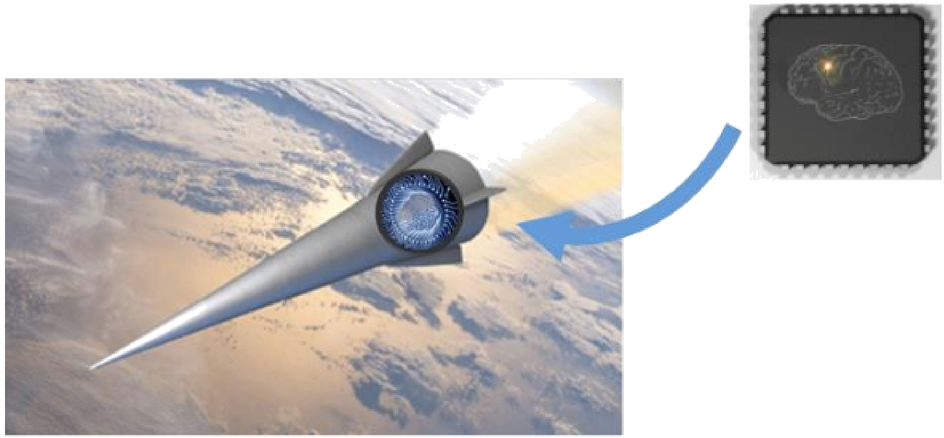
- Advance onboard computing capabilities by evaluating neural networks and associated hardware for Automatic Target Recognition (ATR)

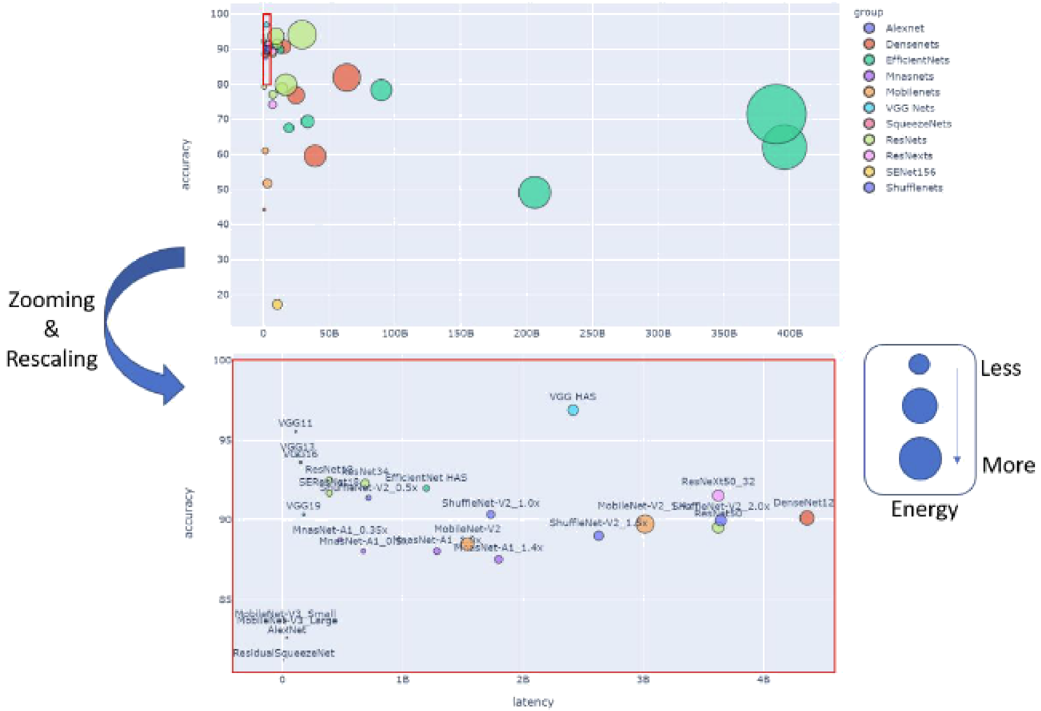
Mission Impact

- Ability to maintain high accuracy while using synthetic data to train neural networks & explore computational costs for swap constrained deployment

Key Outcomes

- State-of-the-art accuracy while offering extensive exploration of neural network approaches



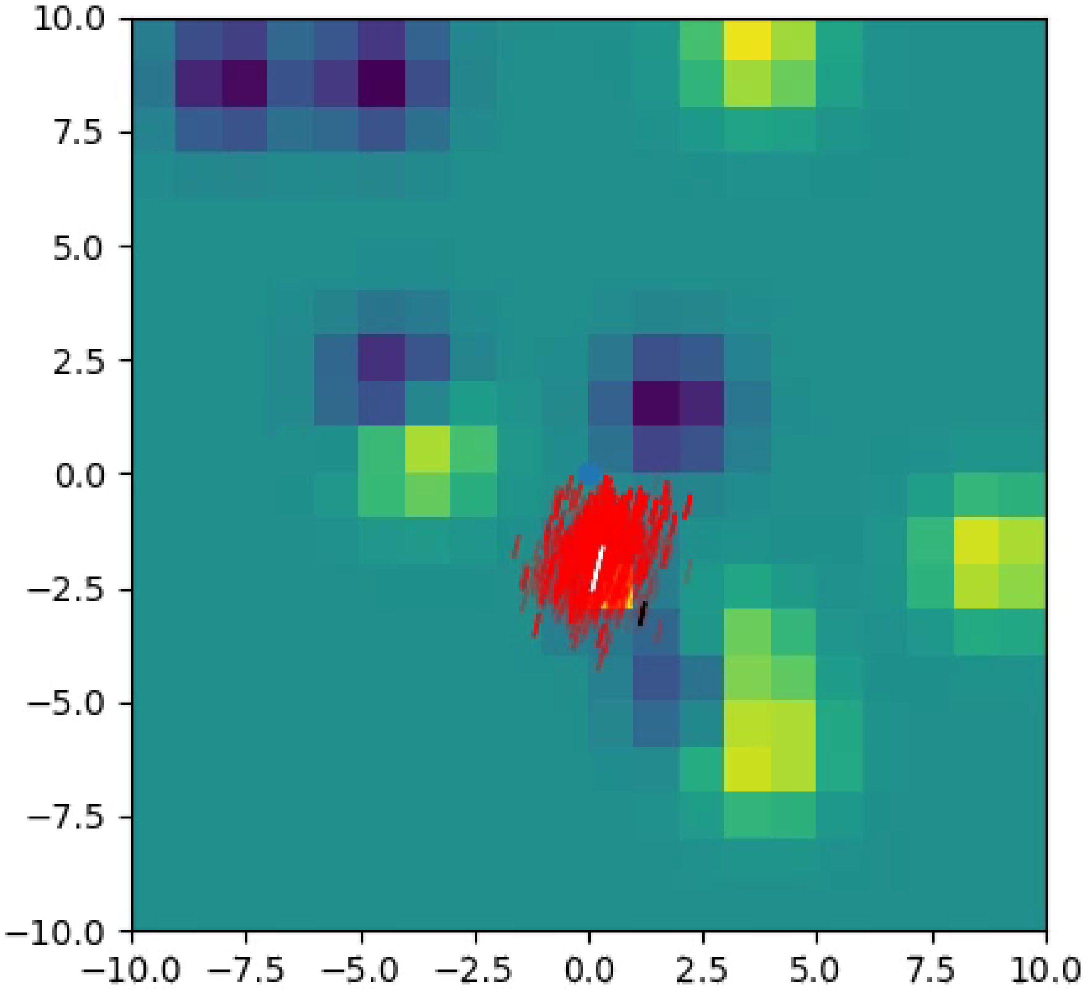


Tightly Integrated Navigation and Guidance

PI: Daniel Whitten

Project Snapshot

- Nontraditional perspective on guidance
- Reduce reliance on traditional data streams for navigation
- Minimize navigation uncertainty by traveling over “high intensity” measurement areas
- Novel application of Reinforcement Learning through integration with navigation particle filter for real-time guidance



Each red dot is a particle in the navigation system:

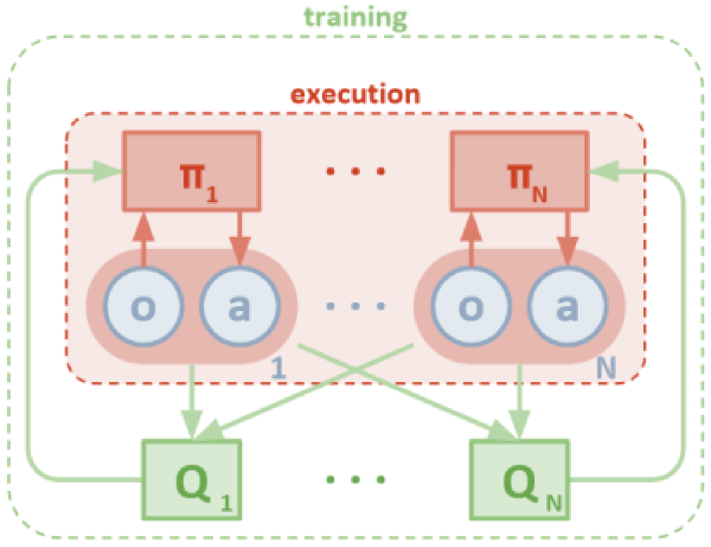
- Black dot is true position
- White dot is position estimate

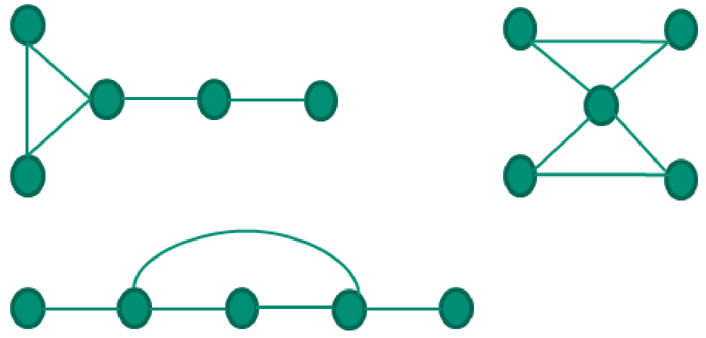
Multi-Agent Reinforcement Learning in Continuous Action Spaces

PI(s): Kyle Williams, Anirudh Patel

Project Snapshot

- Utilize a combination of game theory, RL, and Deep Learning to address the problem of defending against a hypersonic attacker with a sub-hypersonic multi-agent team
- Demonstrate robustness to partial communication loss
- Demonstrate robustness to loss of teammates
- Be trainable and executable in a fully decentralized manner (no central intelligence)





Learning Optimal Communication for Cooperative Sensor Fusion

PI: Anirudh Patel

Project Overview

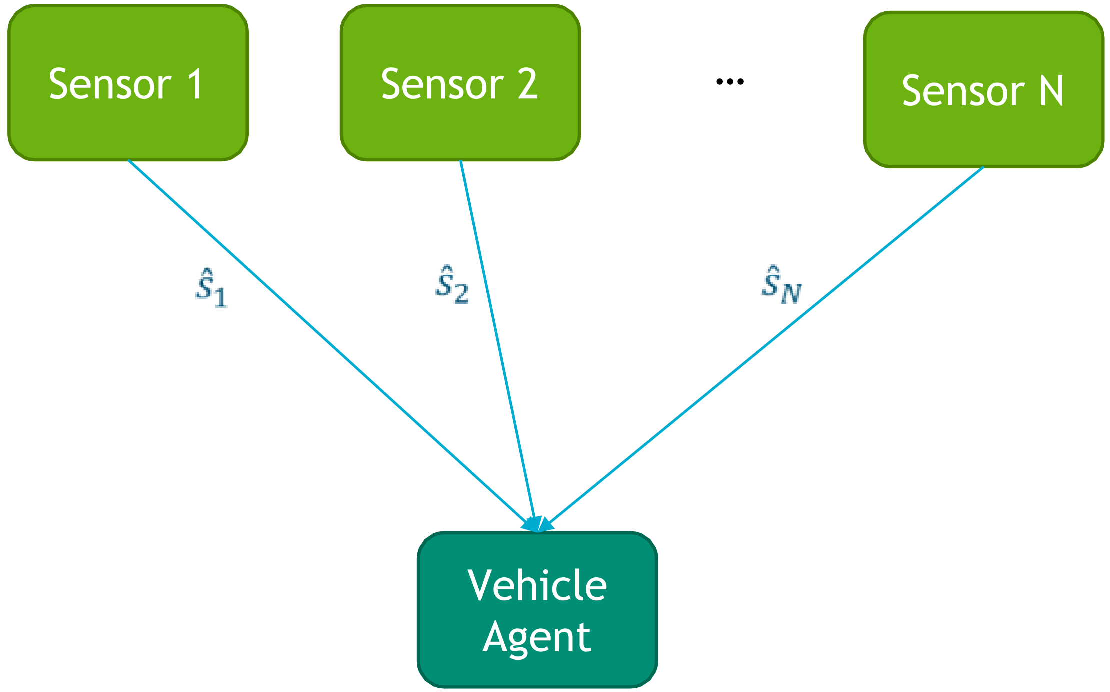
- Devise a strategy for multiple sensor nodes to communicate global state beliefs to a vehicle by combining concepts from Multi-Agent Game Theory with recent advancements in Deep RL

Project Goals

- Minimize power usage by finding a strategy to discourage passing ‘useless’ information
- Learn an efficient sensor fusion technique

Key Challenges

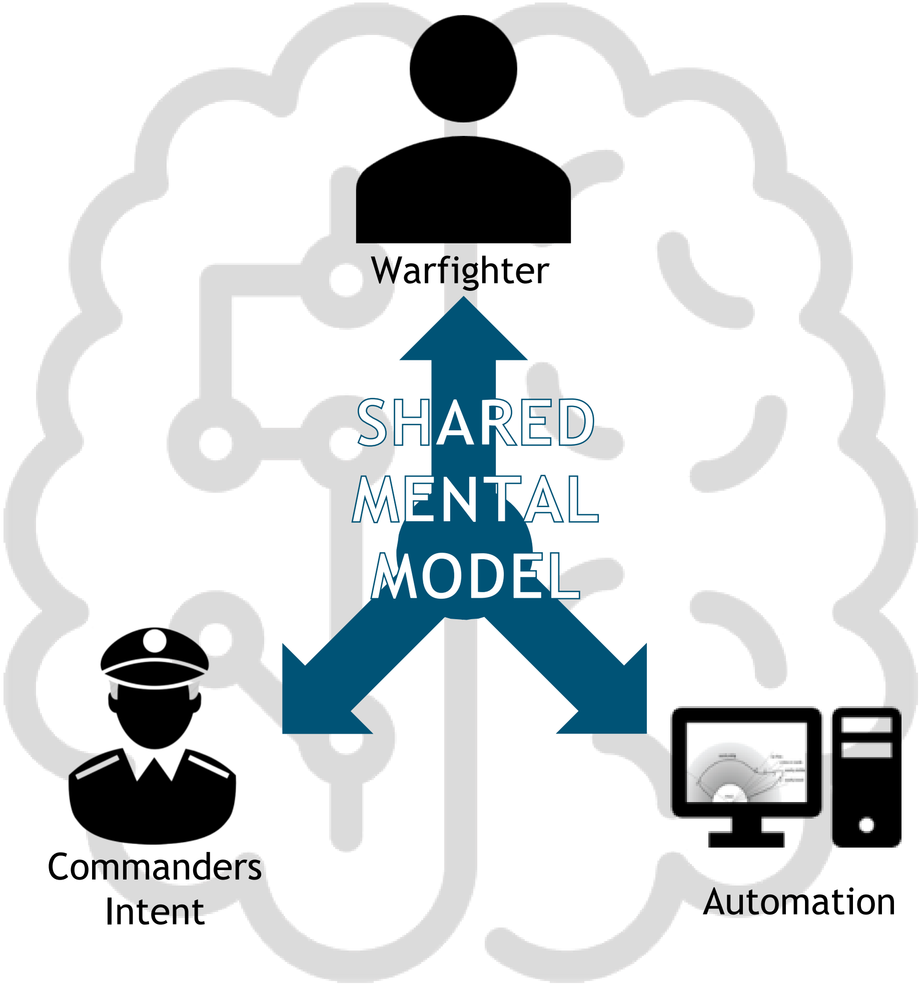
- Loss of algorithm convergence guarantees from single-agent Reinforcement Learning problems
- Non-singleton information states
- Many-to-one communication scenarios



Investigation of Critical Attributes for Transparency and Operator Performance in Human Autonomy Teaming (TOPHAT) *PI: Paul Schutte*

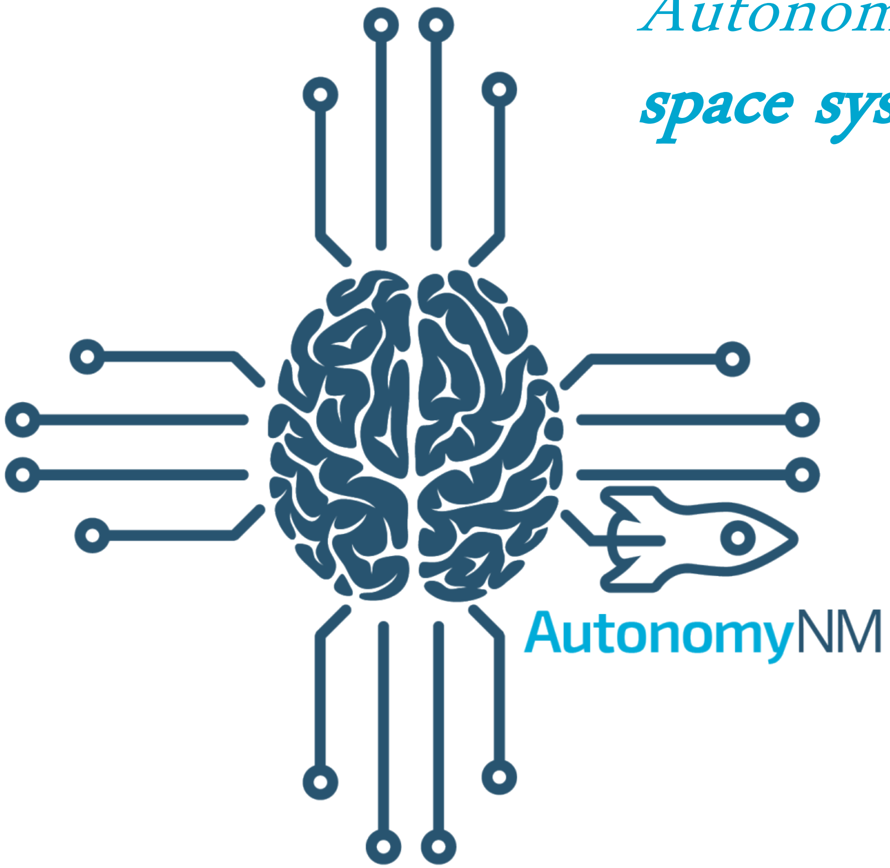
Project Snapshot

- Develop Human-Machine Teaming Strategies to enable the warfighter to use advanced software to effectively create, evaluate, and modify hypersonic missile trajectory plans
- Explore and identify methods for creating and maintaining a shared mental model/situation awareness between AMP, Warfighter, and Command
- Common situational awareness among warfighter, commander, and automation




AutonomyNM

AutonomyNM Overview



Autonomy Innovation hub for advanced ***flight*** *and* ***space systems***

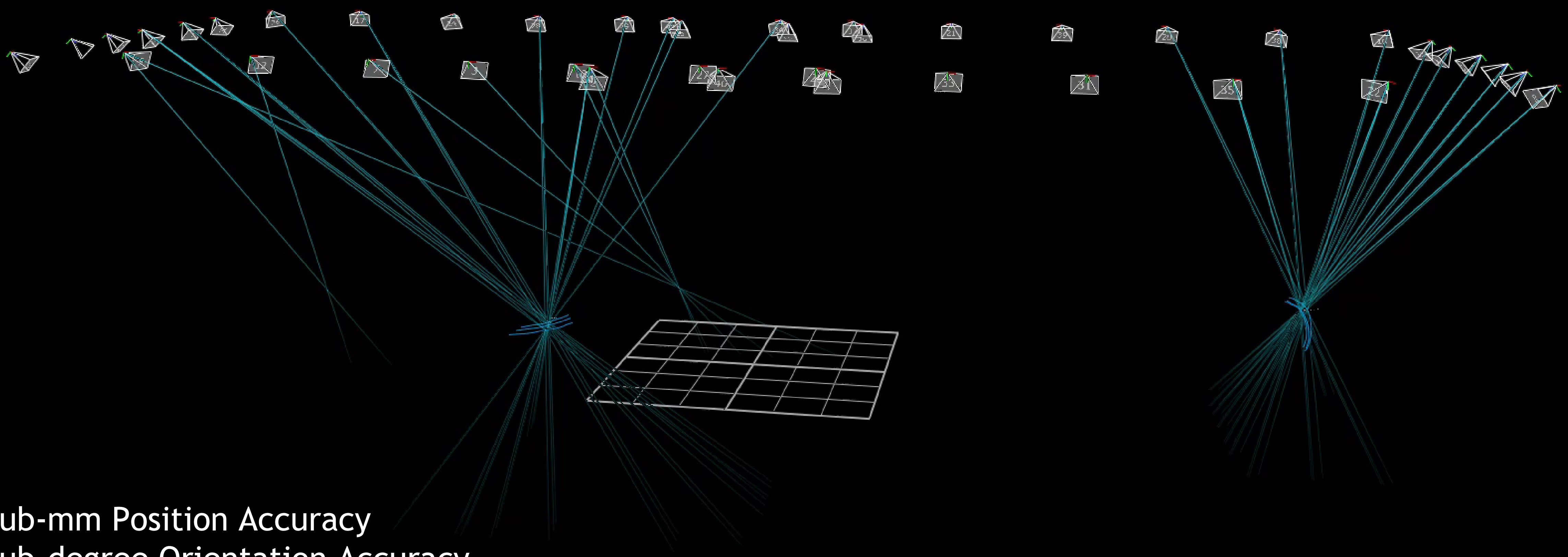
- AutonomyNM's goal is to promote and attract collaborative research and education programs with Academic Alliance schools and additional university partners

- Originally initiated in conjunction with A4H, AutonomyNM is now supporting R&D across Sandia

AutonomyNM Testbed

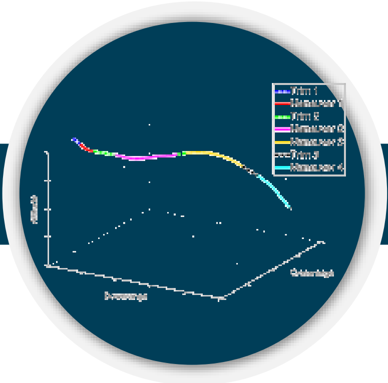
1. Lab Initialization
2. First Flight
3. Autonomy Infrastructure
4. Advanced Sensing & Guidance

AutonomyNM: Motion Capture System in Action



- Sub-mm Position Accuracy
- Sub-degree Orientation Accuracy

Autonomous Technologies toward System Insertion



Develop New Ideas in Simulation

Demonstrate in Virtual Environment

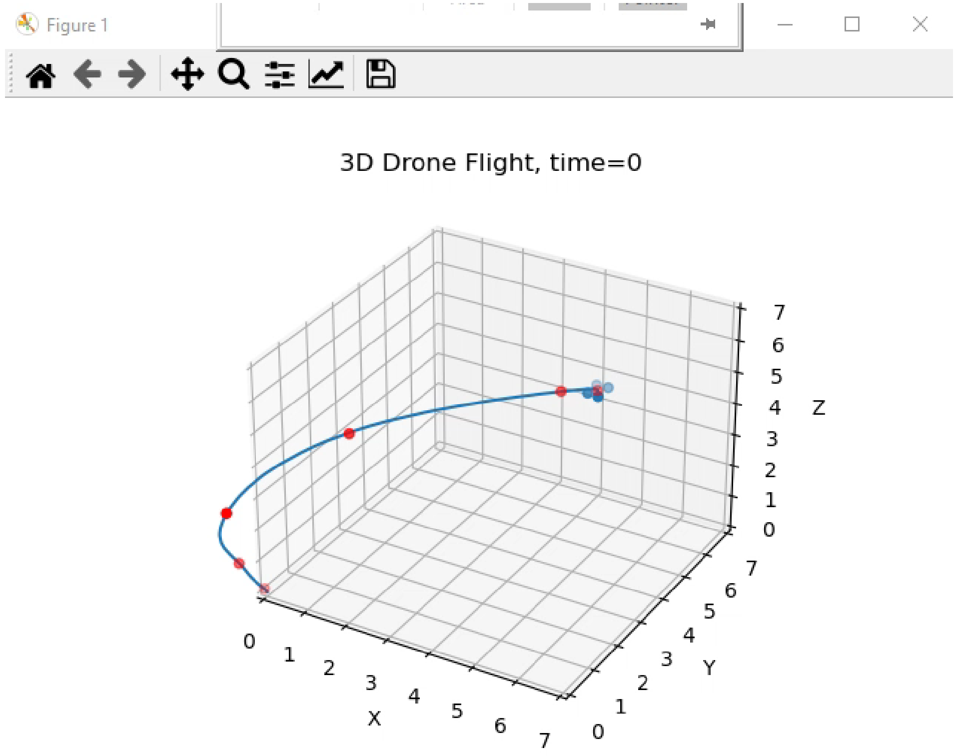
Fly in Slow Airborne Demonstrator

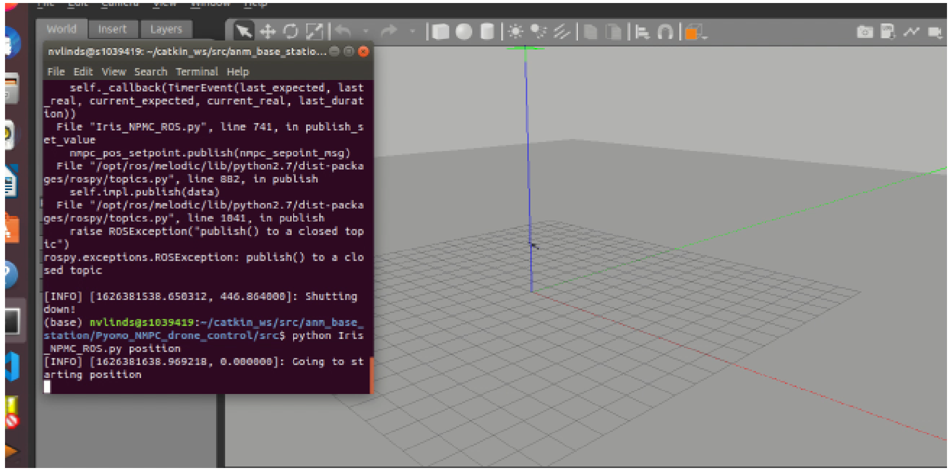
Demonstrate in Hypersonic Virtual Flight Environment

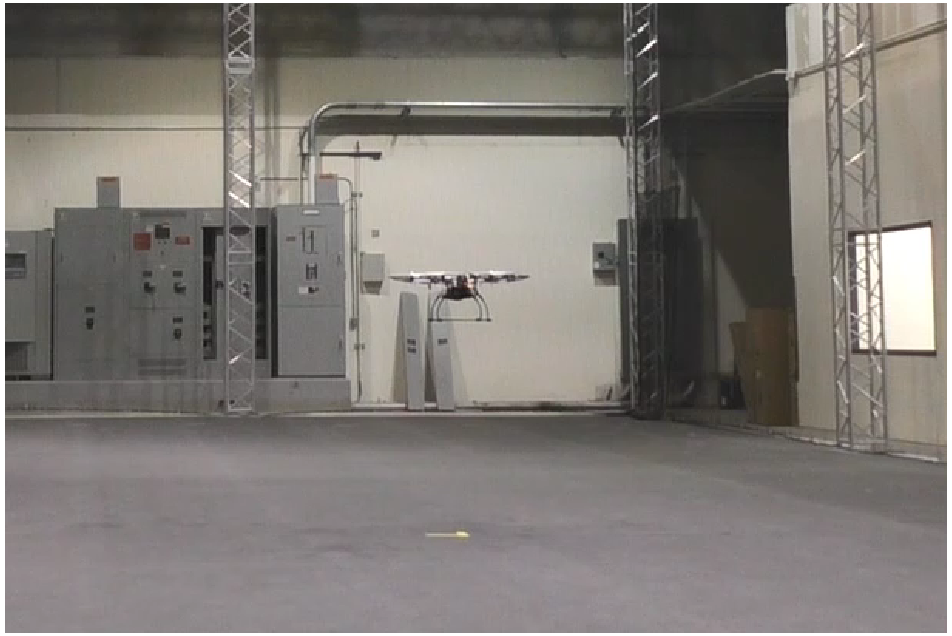
Fly in Hypersonic Sounding Rocket Experiment

AutonomyNM

A4H DEMO: Nonlinear Model Predictive Control







Building a Talent Pipeline

2018
6 total interns
3 year-round interns

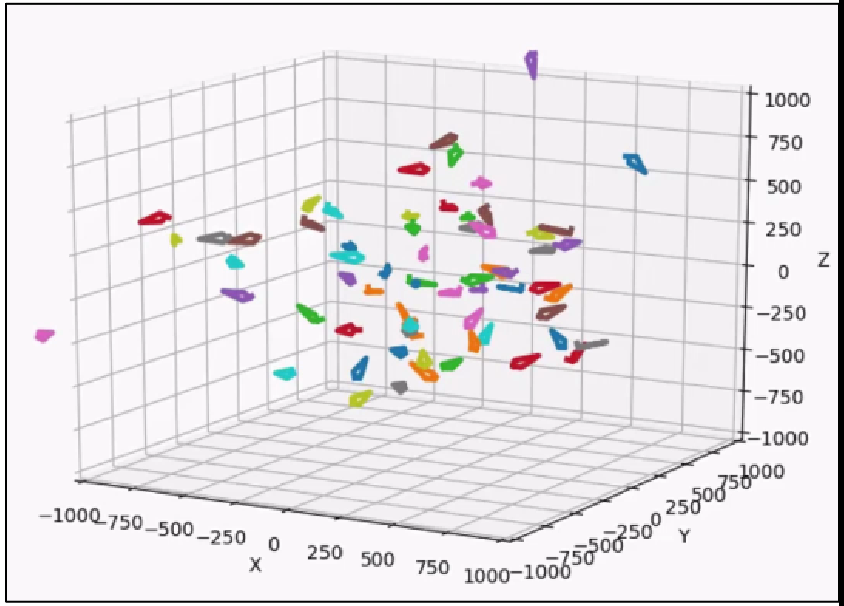
2019
24 total interns
10 year-round interns

2020
500+ applicants
42 total interns
21 converted to year-round

2021
800+ applicants
37 total interns

AutonomyNM’s internship program has seen consistent growth in the level of interest since it was created.
The goal is to expose students to autonomous systems for Sandia’s impactful national security missions.

Preliminary Forward Fixed-Wing RL Hardware Tests



Some final thoughts….

National Power → Software Defined

Data → Currency of Warfare

Agility → Drives Dominance

Algorithms → Trained by Agents

Questions? Interested in learning more?
Contact Dr. Scott McEntire:
rmcenti@sandia.gov