Cooperative Communication for Autonomous Hypersonics

Sandia National Laboratories

PRESENTED BY

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Overview

- Future Battlefield Challenges
- Hypersonics of the Future
- Autonomy for Hypersonics (A4H)
- Cooperative Communication for Robust Hypersonics
- A4H Cooperative Communication R&D Highlights

Future Battlefield Challenges

Battlefield of the Future

- Increased Speed of Warfare
- Autonomous Operations
- Shared Situational Awareness

Cooperative Communication between Machines – and Humans – is Essential!

Hypersonics of the Future

SWERVE
1981-1985

PGR Grand Challenge
2003-2005

AHW- FT1A
2011

CPS- FE1
2017

A4H
2017-2025

CPS- FE2
2020

FT-3
FY2021

JFC-1A and JFC-1B
FY2022

Sandia's Hypersonics History

Sandia has a long history in hypersonic systems development

- Leveraging Atomic Energy Commission work in reentry technology
- Development of multiple systems in the 70s/80s leading to SWERVE
- SWERVE culminated with a successful flight test in 1985 and was the first demonstration of a controlled boost-glide system
- AHW- FT1A (partnership with OSD/Army SMDC)- flight test in 2011
- CPS FE-1 (partnership with OSD/Navy/Army) flight test in 2017
- CPS FE-2 (partnership with OSD/Navy/Army) flight test in 2020

DOE has a long history in hypersonics

- Pre-SWERVE, SWERVE, and PGR were all DOE R&D investments
- DOE continues to invest and lead in the future of hypersonics technology development through the A4H Mission Campaign

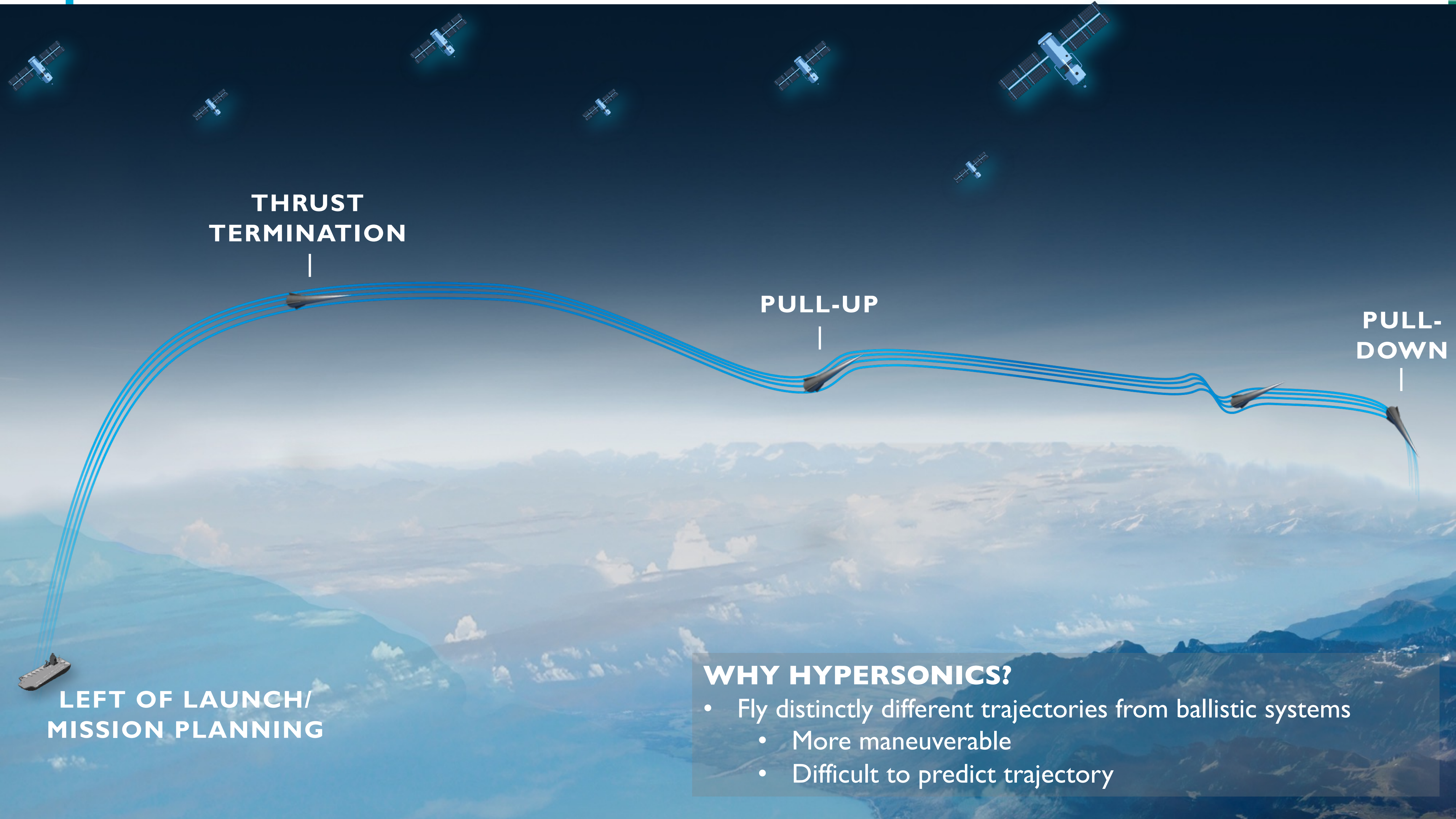
In partnership with the DoD, Sandia has successfully performed multiple flight tests of a hypersonic boost-glide vehicle

- Sandia's long history and expertise are leveraged to support continued hypersonic technology development in the national interest

Through a multi-service/OSD MOA, Sandia's glide body design has been designated the DoD Common Hypersonic Glide Body (C-HGB)

2017: CPS FE-1 launch

ACRONYMS KEY
- ***SWERVE:*** *Sandia Winged Energetic Reentry Vehicle*
- ***SMDC:*** *Space & Missile Development Center*
- ***PGR Grand Challenge:*** *Prompt Global Response Grand Challenge*
- ***AHW-FT1A:*** *Advanced Hypersonic Weapon Flight Test 1A*
- ***CPS FE-1:*** *Conventional Prompt Strike Flight Experiment 1*
- ***A4H:*** *Autonomy for Hypersonics*
- ***CPS FE-2:*** *Conventional Prompt Strike Flight Experiment 2*



THRUST TERMINATION
PULL-UP
PULL-DOWN
LEFT OF LAUNCH/ MISSION PLANNING
WHY HYPERSONICS?
• Fly distinctly different trajectories from ballistic systems
• More maneuverable
• Difficult to predict trajectory

Different Hypersonic Systems

Boost-Glide Systems

- Rocket boosted to velocity outside the atmosphere
- Reenters and establishes glide across upper atmosphere (near space)
- Cruise is typically between M 5 - 25
- Dives to target

Air-Breathing Systems

- Rocket boosted to into altitude and velocity
- SCRAMJET propulsion cruise across upper atmosphere
- Cruise is typically between M 5 - 6
- Glides to target

Sandia's Hypersonics of the Future Roadmap

PRE-PROGRAMMED

Some autonomy, but entirely rules-based, unable to handle uncertainties/unknowns or adapt the flight plan on the fly

POSITIONALLY AWARE

Coordinate seeking capability that is robust to the GPS contested environment

POSITION ADAPTING

Coordinate seeking capability that is robust In the Non-GPS environment

TARGET HUNTING

Robust capability to address relocatable and mobile targets

SITUATIONALLY AWARE

Autonomous adaptation to maximize strike effectiveness or provide the ability to intercept incoming adversary weapons

Commercial VS Defense

Commercial	Defense
Structured environments	Unstructured, adversarial environments
Large tolerance for error	Low tolerance for error
Large labeled training datasets for accuracy	Lack of training data
Can deal with object classes (car, pedestrian, etc.)	Requires precise object identification
Short-range imaging modalities (e.g. RGB iPhone)	Remote EO/IR/SAR imaging modalities
Can typically rely on GPS and network connectivity, which allows off-board processing and simplifies C2	Operation in potentially GPS-challenged environment with minimal to no network connectivity

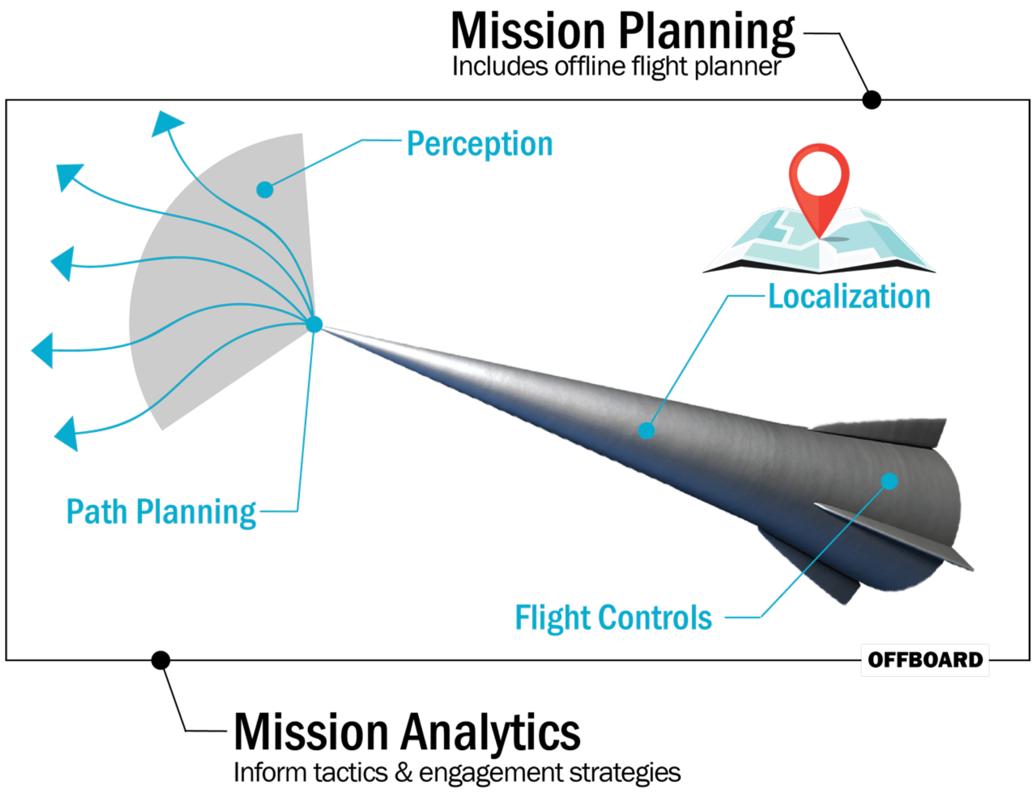
Defense applications require different performance characteristics than their commercial counterparts, while managing SWaP and bandwidth limitations.

Autonomy for Hypersonics

Lab-Directed R&D

National Security Programs Mission Campaign investment

6.5 years



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 a variety of targets in challenged environments
- Provide defense against incoming adversary threats

Autonomy for Hypersonics

Autonomy can enhance the warfighting utility of Hypersonics by enabling:

- Rapid construction of flight plans (enabling speed of action)
- Navigation in challenging environments
- Perception of their environment and ability to adapt (increasing survivability and ability to counter moving targets)
- Tactics and engagement strategies that are highly effective in complex, rapidly evolving environments and heavily defended areas
- Cooperation with other systems

A4H Cooperative Communication Research Efforts

Toward Cooperative Autonomous Systems

Mission-Agile Intelligent Navigation, Guidance, & Control

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.

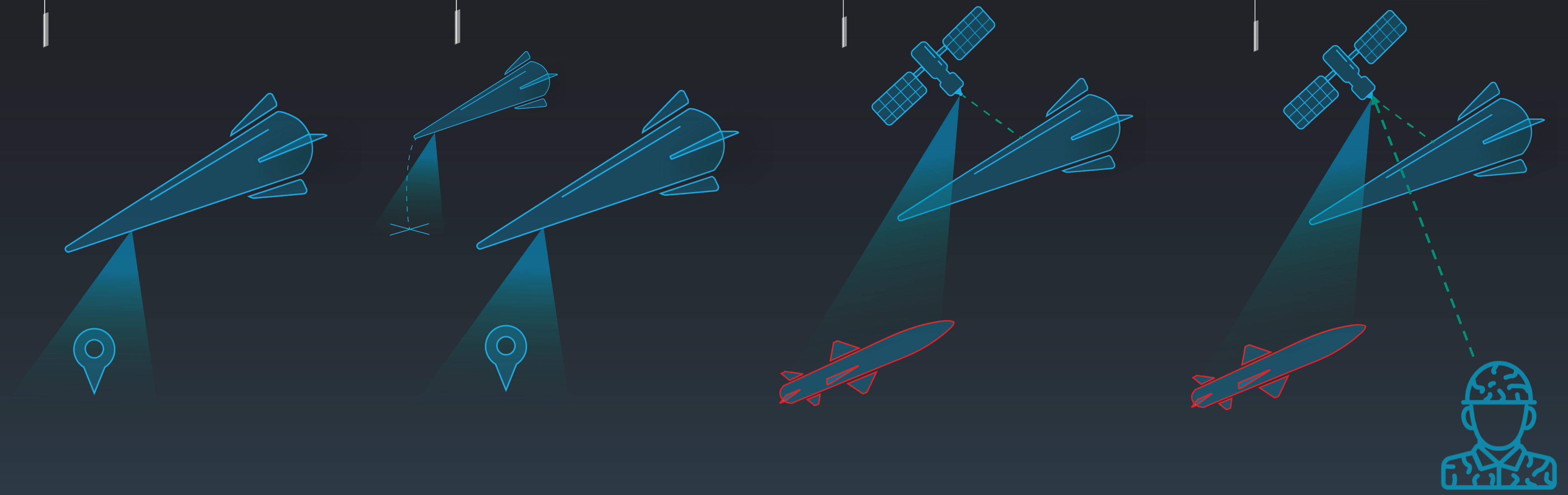
Cooperative Communication for Shared Situational Awareness

What does the vehicle know?

What does the flight team know?

What does the system know?

What does the warfighter know?

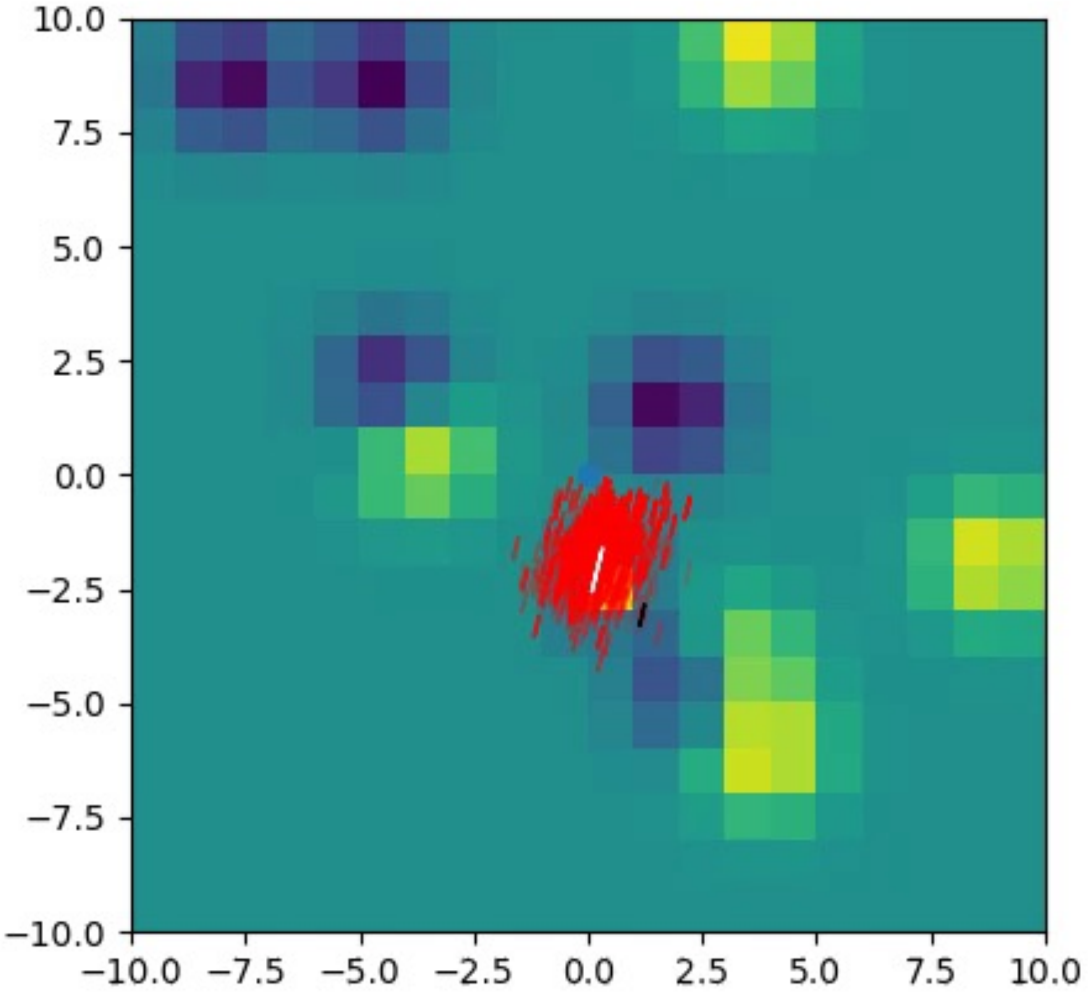


Tightly Integrated Navigation and Guidance

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:

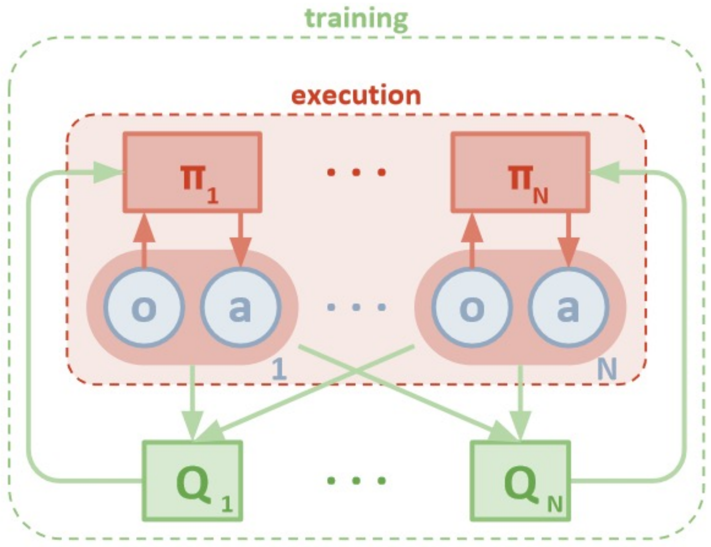
- Black dot is true position
- White dot is position estimate

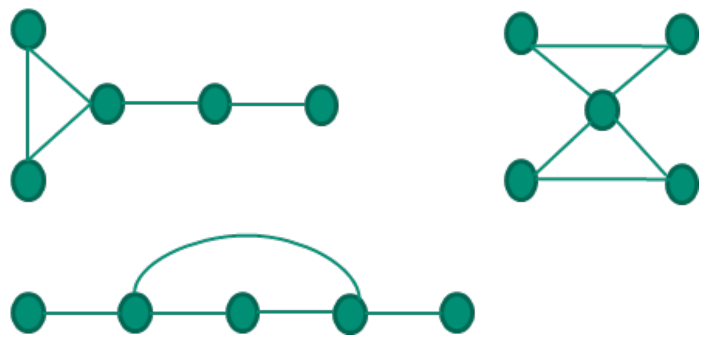
Multi-Agent Reinforcement Learning in Continuous Action Spaces

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

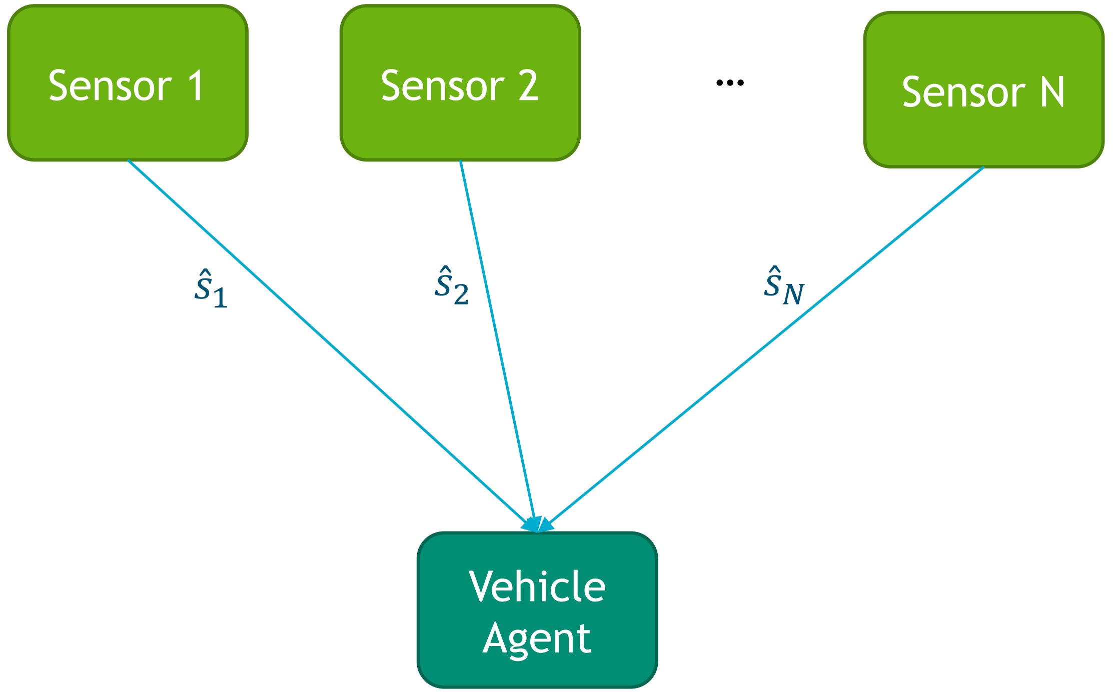
- Devise a strategy for multiple sensor nodes to communicate global state beliefs to a vehicle by combining concepts from Multi-Agent Game Theory with recent advancements in Deep RL

Project Goals

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

Key Challenges

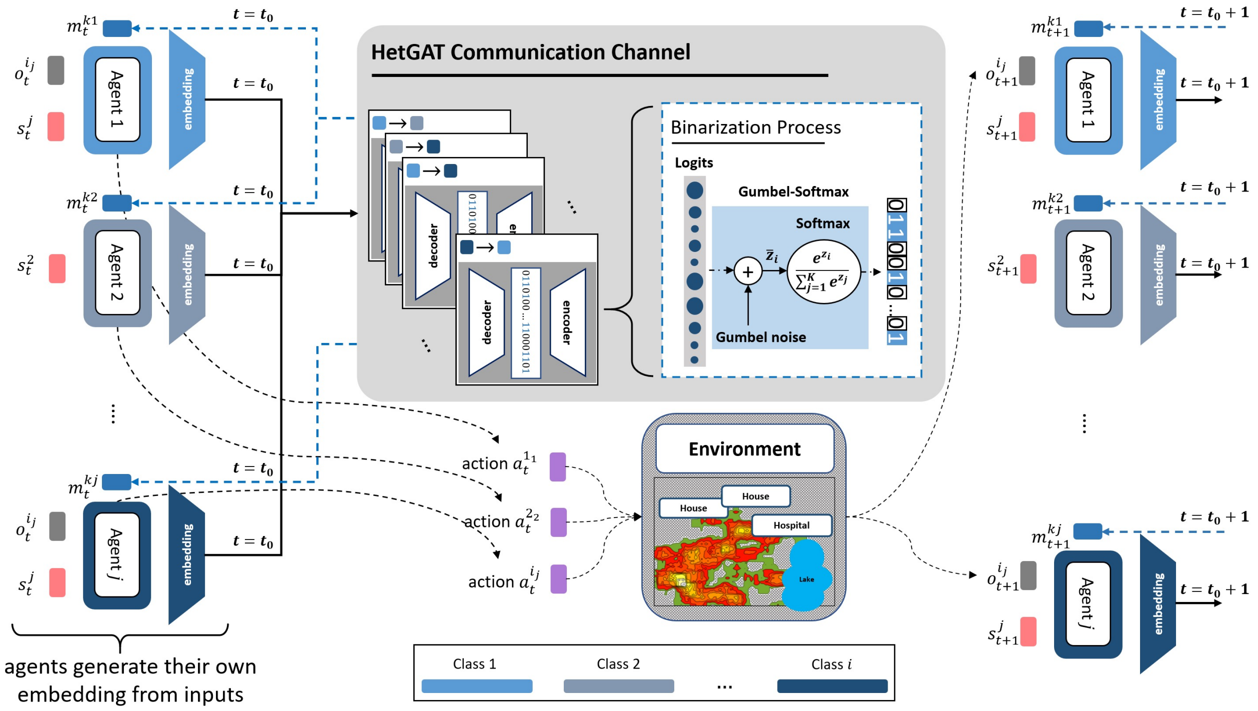
- Loss of algorithm convergence guarantees from single-agent Reinforcement Learning problems
- Non-singleton information states
- Many-to-one communication scenarios



Intelligent Virtual Assistant for Supporting Syndicates in Converting Commander's Guidance into COAs *PI: Matthew Gombolay (Georgia Tech)*

Project Snapshot

- Leverage UAV technology for wildfire surveillance and mitigation under bandwidth-limited and sparse connectivity conditions.
- Develop new methods in distributed control of multi-agent, perception-action agents
- Enable the team to automatically learn communication strategies that balance the goals of maximizing team performance and minimize communication bandwidth
- Formulate both interpretable and non-interpretable, neural message passing protocols showing that the agents can communicate using messages that can be understood by a human



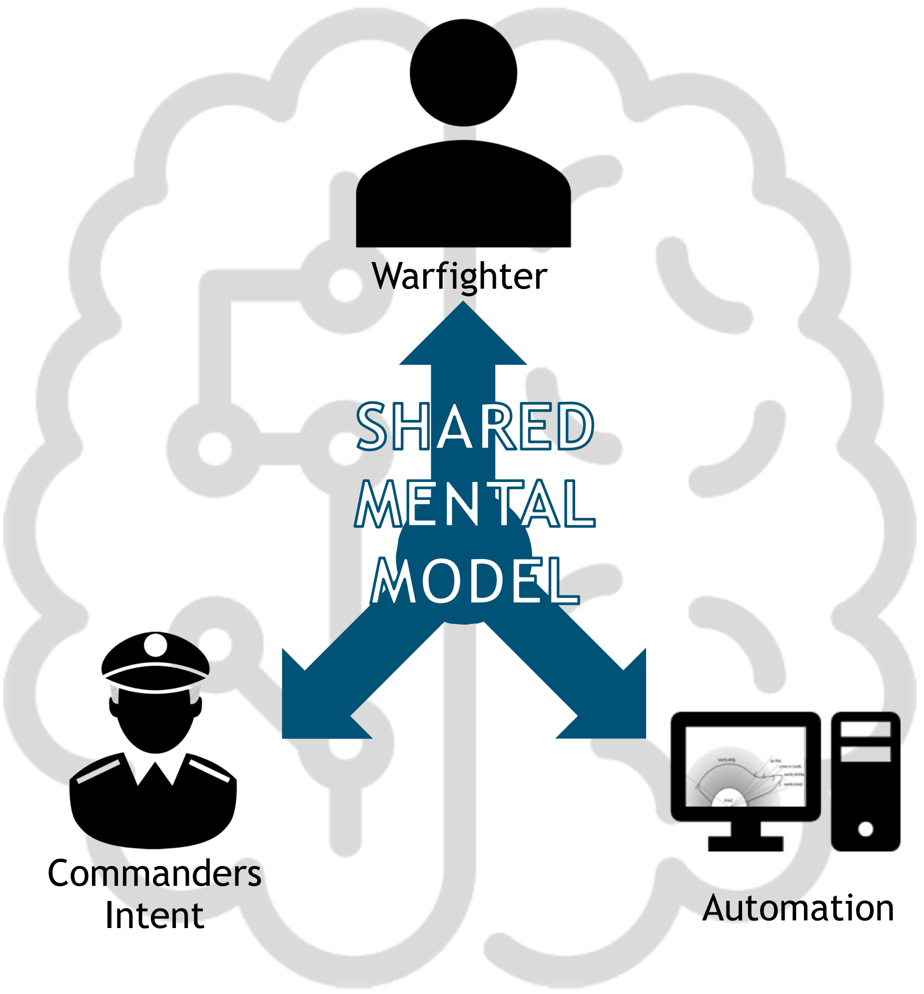
Investigation of Critical Attributes for Transparency and Operator Performance in Human Autonomy Teaming (TOPHAT) *PI: Paul Schutte*

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

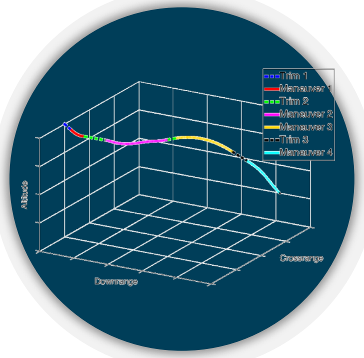
- Common situational awareness among warfighter, commander, and automation



AutonomyNM Testbed

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

Preparing Autonomous Technologies for 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

Questions?

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