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Sandia National Laboratories

Autonomy for Hypersonics

PRESENTED BY

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Outline

- Hypersonics 101
- Autonomous Systems for National Security
- Autonomy for Hypersonics
- AutonomyNM

Hypersonics 101

Hypersonics 101

- Hypersonic is defined as five times the speed of sound, which is generally considered to be the point at which aerodynamic heating becomes significant.
- The speed of sound is about 750 mph* or about 1000 feet per second*.
- A mile is 5280 feet, so the threshold for hypersonic flight is about a mile per second.
- The speed of sound is the basis for a unit called Mach Number.
- Advanced fighters fly at about Mach 3; the SR-71 flew about Mach 4. The fastest human-piloted aircraft (X-15) achieved Mach 6.7.
- For reference, earth orbital velocity is about 25,000 feet per second and provides an upper limit to the hypersonic flight regime.

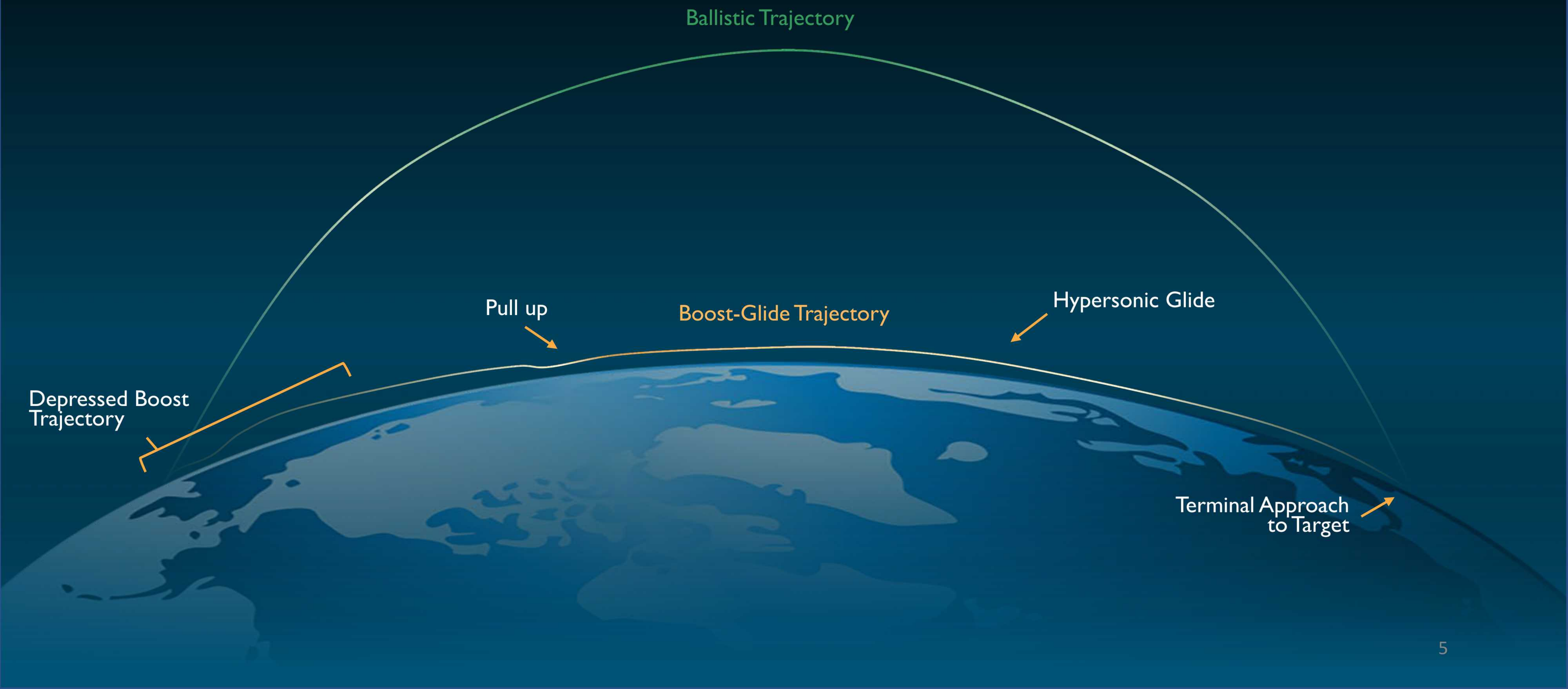
*** At flight altitude**

Engineering Challenges

- Vehicle shape changes in hypersonic flight, creating challenges for flight control
- Difficult to simulate velocity, temperature, and Mach number on the ground
- Difficult to design sensors & actuators that can operate in a hypersonic flight environment
- Calculations are extremely time consuming

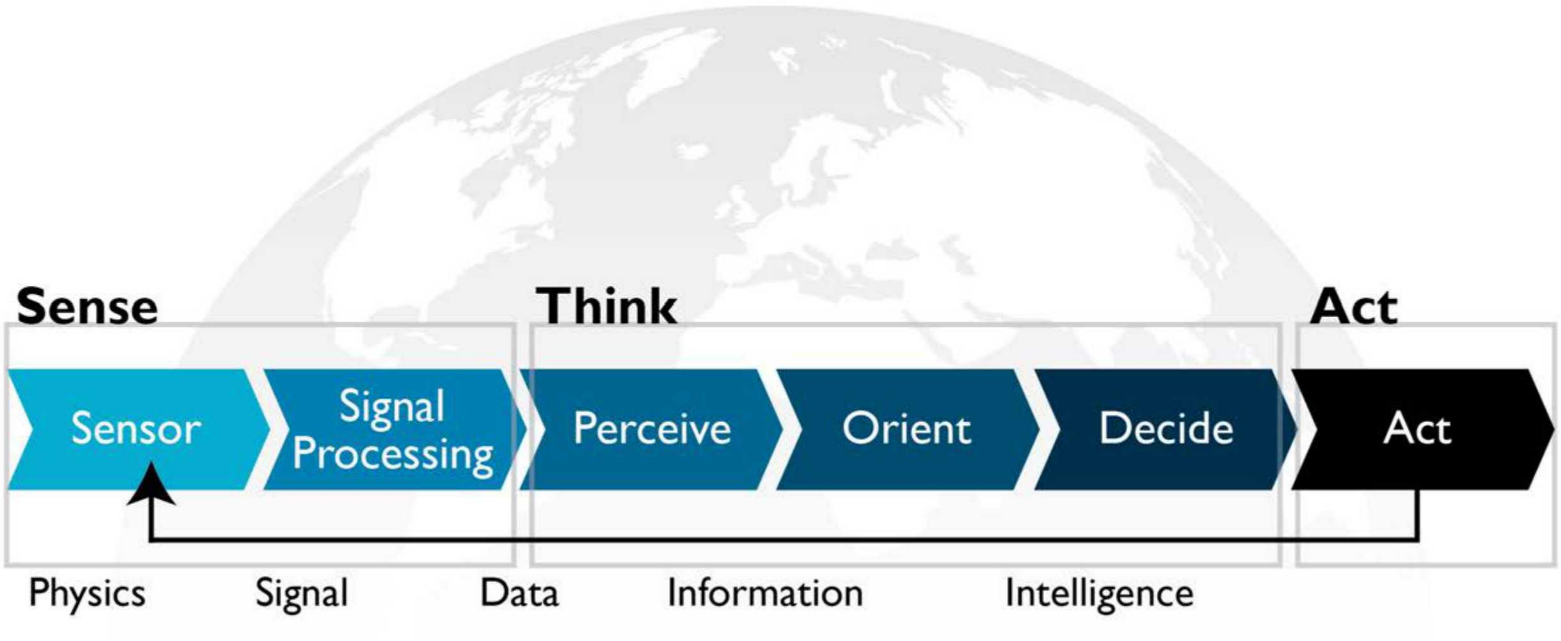
Why Hypersonic Glide?

Hypersonic systems fly distinctly different trajectories from Ballistic systems



Autonomous Systems for National Security

Autonomous Systems



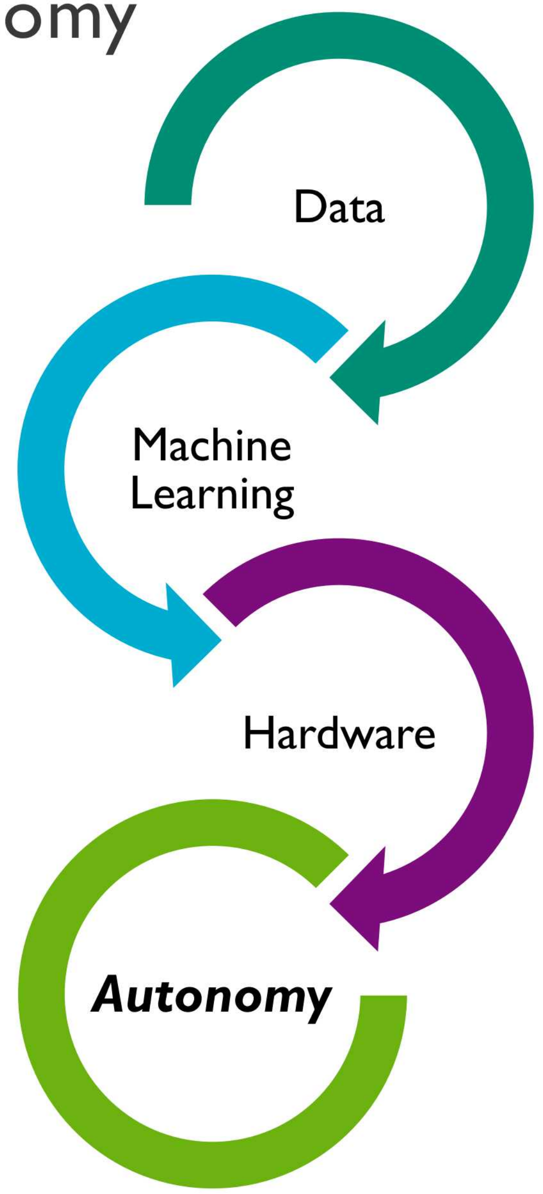
- Follow Sense-Think-Act paradigm
- Sensors provide signals & data
- Machine intelligence starts with data
- Sensor exploitation (target detection, identification, and characterization) provides information and intelligence
- High-level reasoning and dynamic sensor/platform/asset management close the loop with action

AI Underpins Recent Advances in Autonomy

"At least 80 percent of the recent advances in AI can be attributed to the availability of more computer power."

- Dileep George,

MIT Technology Review, 2013



Will AI tech plug-n-play for defense?

- Andrew Ng,
Harvard Business Review

The AI community is remarkably open, with most top researchers publishing and sharing ideas and even open-source code. In this world of open source, the scarce resources are therefore:

Data.

Among leading AI teams, many can likely replicate others' software in, at most, 1–2 years. But it is exceedingly difficult to get access to someone else's data. ***Thus data, rather than software, is the defensible barrier for many businesses.***

Talent.

Simply downloading and "applying" open-source software to your data won't work. ***AI needs to be customized to your business context and data.*** This is why there is currently a war for the scarce AI talent that can do this work.

Autonomy for Hypersonics

Autonomy for Hypersonics

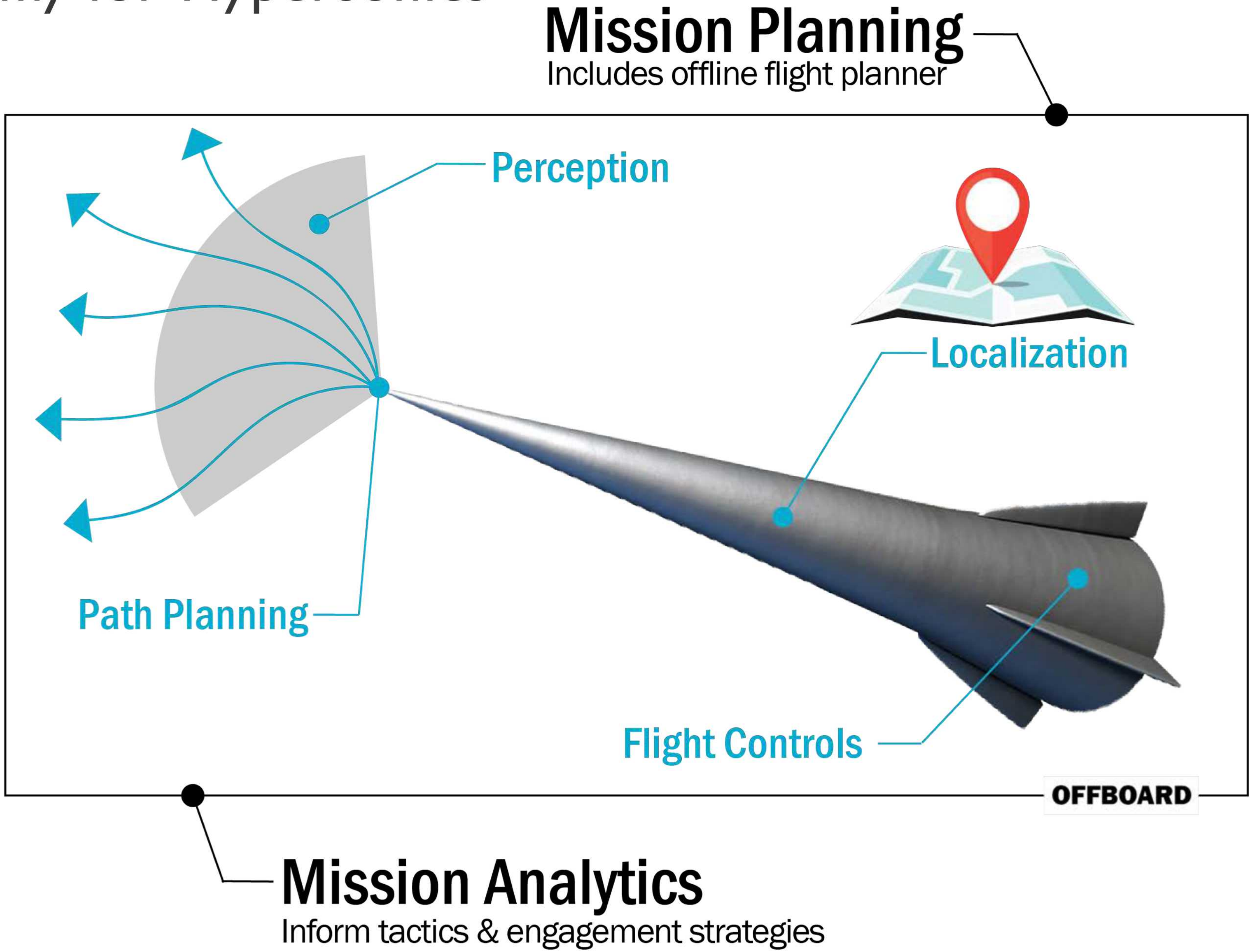
Hypersonics provide a lot of military utility

- Hypersonics offer survivability and utility at long/strategic ranges, since they travel at exceptional speeds and are less susceptible to anti ballistic missile countermeasures and other defensive systems

These systems will offer the most utility if they are able to:

- Utilize rapidly constructed flight plans (enable speed of action)
- Navigate without GPS
- Perceive their environment and adapt to it to increase survivability and to counter moving targets
- Employ tactics and engagement strategies that are highly effective in complex, rapidly evolving environments and heavily defended areas
- Cooperate with other hypersonic systems

Autonomy for Hypersonics



Evolution of Hypersonic Strike Capability

POSITIONALLY AWARE
2-5 YEARS

POSITION ADAPTING
4-7 YEARS

TARGET HUNTING
5-10 YEARS

SITUATIONALLY AWARE
7-15 YEARS


PUBLIC CLASS WINBU
@OVERRIDE
PUBLIC VOID PAINT
SYSTEM.OUT.PRIN

AutonomyNM

External Partnership Plan: AutonomyNM

Autonomy Innovation Hub for Advanced Flight & Space Systems

Creating a mechanism to "spin-in" ideas that provide transformative autonomy solutions, opportunities for commercialization, and a pipeline of AI and autonomy talent

A4H initiated AutonomyNM, with the goal of promoting and attracting collaborative R&D with university partners

- Helps SNL expand its innovation network in this critical technology area
- AutonomyNM Facility: A cutting-edge, modern research environment that will promote scientific exchange and facilitate two-way technology transfer
- Venture track for AA Collaborators: The program will allow SNL and AA researchers to work side-by-side to help university innovators transition their research into end-use applications
- Internship track: AutonomyNM is incorporated under TITANS and provide students an opportunity to research autonomy solutions for advanced flight and space systems

Current University Research Partnerships

Illinois

Naresh Shanbhag + Craig Vineyard
Neural-Inspired Approaches and Implementations for Automatic Target Recognition

Girish Chowdhary + David Kozlowski
Optimal Elevon Control Allocation and Fault Detection/Recovery for Hypersonic Flight Vehicles

Alex Scwing + Josh Coon
Synthetic High Forward Squint SAR Images Using Generative Adversarial Networks

Rakesh Nagi + Keith LeGrand
Autonomous Multi-Platform Sensor Scheduling

Georgia Tech

Jennifer Hasler + Craig Vineyard
Neural-Inspired Approaches and Implementations for Automatic Target Recognition

Ani Mazundar + Mary Rose Sena
Using Generative Models to Generate Hypersonic Boost-Glide Vehicle Trajectories

Evangelos Theodorou + David Kozlowski
An Optimization and Robust Control Technique for use in Flight Control Design for Hypersonic Vehicles

Jonathan Rogers + Julie Parish
Robust, Rapid, Autonomous Mission Planning for Hypersonic Flight Vehicles

UT Austin

Renato Zanetti + Scott Jenkins
SAR Image Formation and Feedback to Navigation Subsystem in GPS Denied and Degraded Environments

Ufuk Topcu + David Kozlowski
An Optimization and Robust Control Technique for use in Flight Control Design for Hypersonic Vehicles

Maruthi Akella + Mike Grant
Autonomy-Enabled, Real-Time, Rapid Trajectory Generation for Highly Dynamic Hypersonic Missions

Karen Willcox + Kevin Carlberg
Rapid High-Fidelity Aerothermal Responses with UQ via Reduced-Order Modeling

Purdue

Kaushik Roy + Craig Vineyard
Neural-Inspired Approaches and Implementations for Automatic Target Recognition

Dan DeLaurentis + Larry Jones
Rapid Estimation for Hypersonic Engagements

Shreyas Sundaram + John Richards
Autonomous Multi-Platform Sensor Scheduling

Kansas State

Bill Hsu + Jason Searcy
Magnetometer-Aided GPS-Denied Navigation

Texas A&M

John Hurtado + Julie Parish
Robust, Rapid, Autonomous Mission Planning for Hypersonic Flight Vehicles

John Hurtado + Jason Searcy
Magnetometer-Aided GPS-Denied Navigation

UNM

Meeko Oishi + John Richards
Autonomous Multi-Platform Sensor Scheduling

Utah State

Randall Christensen + Scott Jenkins
SAR Image Formation and Feedback to Navigation Subsystem in GPS Denied and Degraded Environments

The University of Arizona

NM State University

AutonomyNM Gauntlet

- A state-of-the-art research testbed that incorporates Design Reference Missions (DRMs) and low-cost COTS technology to enable scientific exchange with academia and industry
  - Will allow users to characterize performance of AI/autonomy algorithms – ultimately demonstrating utility for spin-in and spin-out of autonomous flight and space system technologies
  - Visiting researchers can use the testbed to support their research, and the testbed will help support a "semester at the Labs" program with interested schools

Commercial Applications

AGRICULTURE & CLIMATE

AIRINOV
DEVERON UAS
droneseed
University of Nevada, Reno

DELIVERY

amazon
Google
Flirtey
anything anytime anywhere

FILMMAKING, PHOTOGRAPHY & NEWS

aerodyne
THE SKY GUYS
VERGE AERO

INFRASTRUCTURE INSPECTION

HUVR
Honeywell
airsight
Avitas Systems
a GE venture

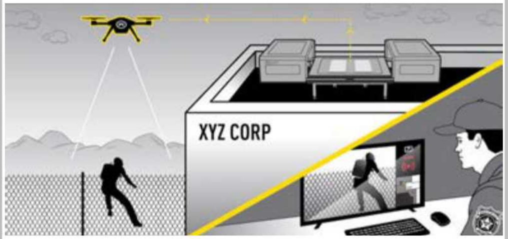
INSURANCE

kespry
Airware
PRECISIONHAWK

MINING & UNDERGROUND

exyn technologies
SKYLARK DRONES

SECURITY & SURVEILLANCE



sunflower LABS
NIGHTINGALE SECURITY
APTONOMY

SEARCH/RESCUE & EMERGENCY RESP.

AERONES
DRAPER
UASTRAKKER

SURVEYING

CYBERHAWK
FALCON EYE DRONES
TEXO Drone
Survey & Inspection Ltd

WAREHOUSING & INVENTORY

exyn technologies
vtrus
DRONE SCAN

WIRELESS COVERAGE

AT&T
verizon
Google
Facebook

Technical Challenges

REAL-TIME MAPPING & NAVIGATION

The ability to autonomously navigate between target locations quickly (i.e., at fairly high speed) and reliably while avoiding obstacles in its path, and with little to no a-priori knowledge of the operating environment.

ENERGY MANAGEMENT

Reliable, continuous, & smart energy management in the network layer, data link layer, physical layer, & cross-layer protocols to extend missions without adding capacity for larger batteries. Enables robust sensing, navigation, etc.

COOPERATIVE SENSING

Ability of autonomously functioning vehicles to be reliably deployed in the form of a "swarm" or combine into a system to carry out a prescribed mission and to respond as a group to high-level management commands.

MOVING OBSTACLE AVOIDANCE

The ability to avoid collisions with moving obstacles (including those that are on a given path such as another UAV or those that are persistent such as an angry dog) and still arrive at the desired location or complete a mission.

VERSATILE NAVIGATION

The ability to use alternate (non-GPS) navigation including terrain-aided navigation and imagery analysis; and to switch between navigation capabilities (e.g., flying with GPS and using LIDAR to "visualize" the landing zone).

CHALLENGING ENVIRONMENTS

Mostly related to weather (but can also include emergency response, fire fighting, etc.), the ability to autonomously modify route planning to circumvent identified hazards or navigate in visually-altered environments (flood zones).

AIR TRAFFIC MANAGEMENT

The ability to support the orchestration of a huge number of drone operations by many users (e.g., first responders, Amazon, etc.) in urban environments without air traffic controllers monitoring each and every vehicle in the air

Commercial Application Challenges

REAL-TIME MAPPING & NAVIGATION

APPLICATIONS IN URBAN ENVIRONMENTS: situational awareness in crowded, unknown, or changing environments
MINING & UNDERGOUND: navigation in GPS-denied areas
SEARCH/RESCUE & EMERGENCY RESP.: navigation and hazard identification
INFRASTRUCTURE INSPECTION: indoor operations

ENERGY MANAGEMENT

INFRASTRUCTURE INSPECTION, PACKAGE DELIVERY, SEARCH & RESCUE, SECURITY/SURVEILLANCE: ability to go long distances

All applications that require more robust sensing and processing power

COOPERATIVE SENSING

SECURITY/SURVEILLANCE: site/asset protection
EMERGENCY RESPONSE: fire fighting
DELIVERY: combining to transport larger payloads
AGRICULTURE: wide-area crop treatment
CLIMATE: cloud seeding
Broad Application Space

MOVING OBSTACLE AVOIDANCE

PACKAGE DELIVERY: avoiding the dog or bird of prey
DYNAMIC FILMOGRAPHY: close-up filming in high-speed, unpredictable environments
SEARCH & RESCUE & EMERGENCY RESP.: avoiding falling objects after earthquake, avoiding bad guys

VERSATILE NAVIGATION

PACKAGE DELIVERY: landing in unknown areas
SECURITY/SURVEILLANCE, PACKAGE DELIVERY, SEARCH & RESCUE, INFRASTRUCTURE INSPECTION: operating in urban and other obstructed environments (e.g., canyons, tunnels, etc.)

CHALLENGING ENVIRONMENTS

EMERGENCY RESPONSE, SEARCH & RESCUE: navigating in visually altered environments (e.g., post-tsunami)

AIR TRAFFIC MANAGEMENT

SECURITY/SURVEILLANCE, PACKAGE DELIVERY, WIRELESS COVERAGE: operating in high traffic urban environments