The Center for Autonomous Air Mobility and Sensing (CAAMS)

Innovation Beyond Integration

Eric Frew

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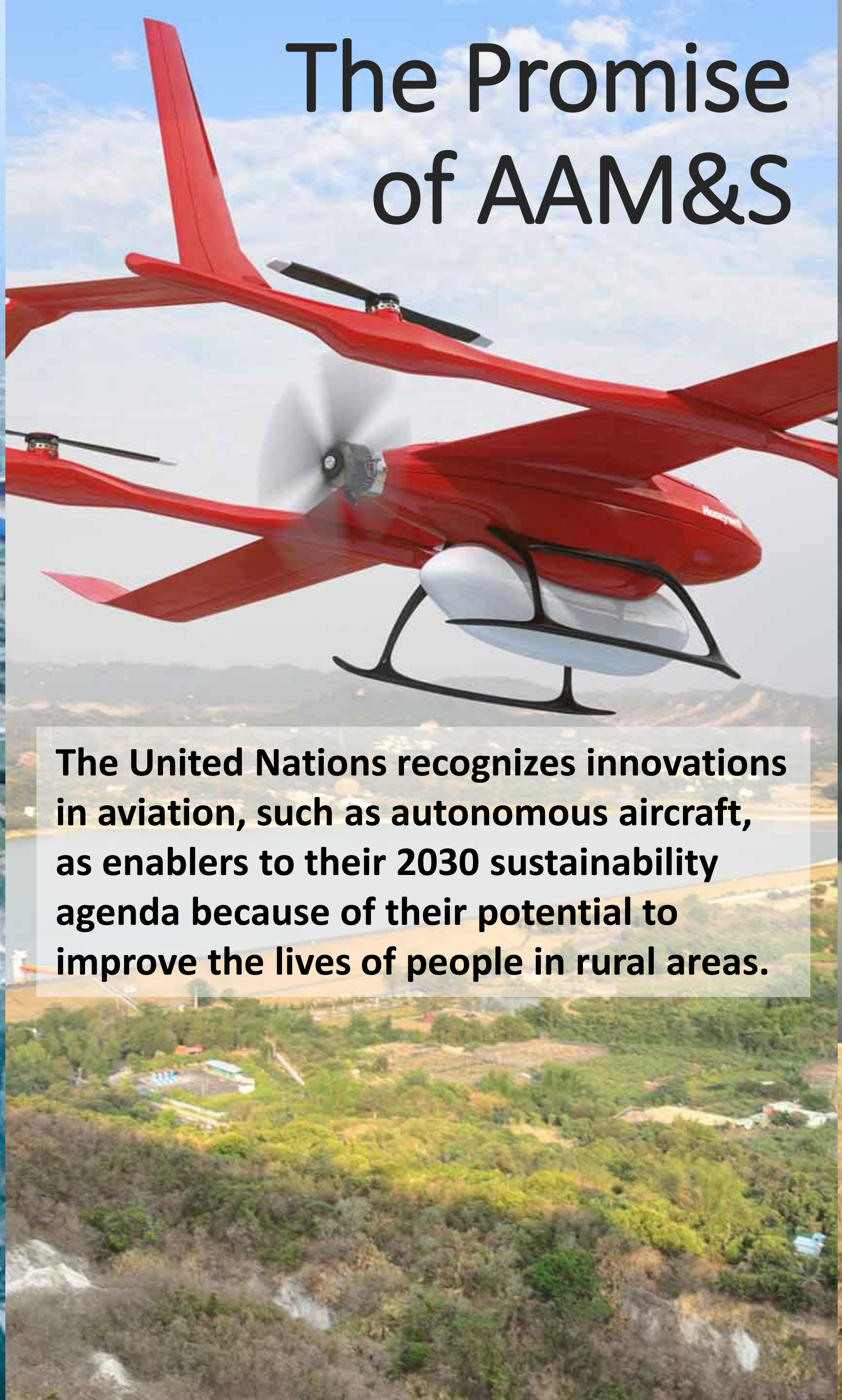
Center web site: **https://caams.center/**

The Promise of AAM&S

The market for autonomous aircraft is projected at $1.5 trillion by 2040, with autonomous aircraft seen as a means to alleviate urban gridlock.



The United Nations recognizes innovations in aviation, such as autonomous aircraft, as enablers to their 2030 sustainability agenda because of their potential to improve the lives of people in rural areas.

Teams of autonomous sensing aircraft enables new forecasting capabilities to predict the evolution of severe weather or to monitor precision agriculture and improve crop yield.

Center for Autonomous Air Mobility and Sensing

Vision:

To provide innovative solutions to key technical challenges and superb training for future leaders in the industries that create **autonomous air mobility and sensing**.

Motivation:

The aviation industry is moving beyond remotely-piloted aircraft systems toward future autonomous aerial mobility and sensing concepts, from urban air mobility systems that transport goods and people to autonomous aircraft performing adaptive sensing of complex environments. Realizing these concepts requires multidisciplinary integration of traditional aerospace engineering topics such as automatic control, aerodynamics, wireless communication, and energy storage with new disciplines such as artificial intelligence, autonomy, machine learning, and robotics.

University Partner Sites:

University of Colorado Boulder

BYU Brigham Young University

University of Michigan

Texas A&M University

Virginia Tech

PennState

Affiliated Universities:

National UAS Training and Certification Center

Industry Advisory Board (IAB):

- **Raytheon Technologies Research Center**
- Ball Aerospace
- L3 Harris
- AeroVironment
- Lockheed Martin
- Department of Homeland Security
- Sandia
- NASA Langley
- AFRL Munitions
- AFRL Aerospace Systems
- Army BIO
- ARL
- Armaments Center - ARDEC
- Draper
- VectorNav
- Honeywell
- Parallax

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NSF I/UCRC Program Highlights

The National Science Foundation (NSF) Industry / University Cooperative Research Center (I/UCRC) Program

- Established in 1973
- 76 centers, 204 sites (in 2019)
- 1216 industry memberships
- Average of 16 industry members per center
- Largest - $4.8M, Average - 1.2M, Smallest - $240K

https://iucrc.nsf.gov/

Well established, proven, highly successful program

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I/UCRC Model

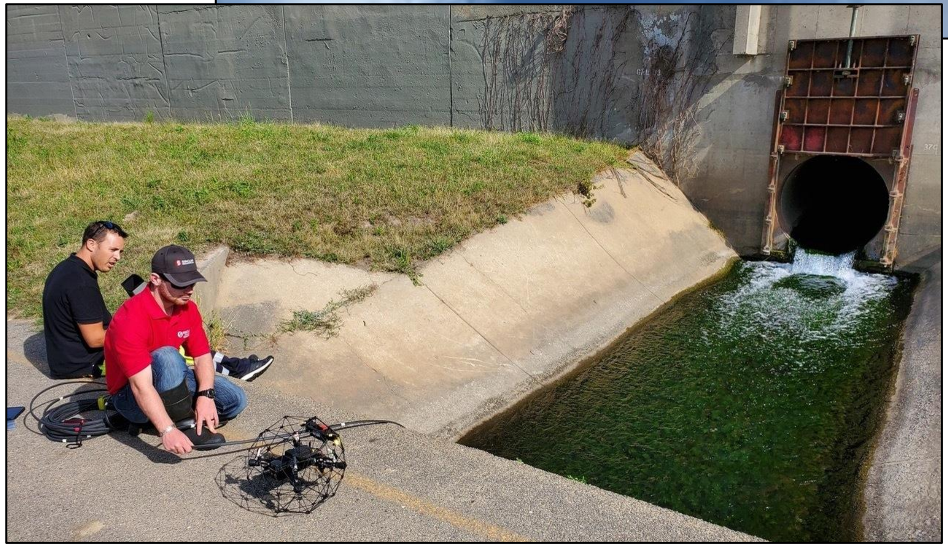
- Center is consortium of organizations with common research interest
- Funding from members is highly leveraged
- **Shared research portfolio** of pre-competitive technologies
- Collective ownership, **collective decision making**
- Research driven by ideas of industry advisory board (IAB)
- Focus shift
  - Problems facing company to problems facing UAS industry
  - Short-term narrow IP to long-term fundamental research
  - Single organization to multiple organization

Leveraging Membership

2022-2023 Research Funding Projections:

- NSF Supplemental Funding = 6 @ $150K = $900K
- Membership funds (20 @ $50K) = $1000K
- University waived overhead = approx. $500K
  - Value of space, aircraft, software tools, hardware tools, facilities, etc.
- $50K membership provides access to $2.4M of research/resources
  - More if administrative resources considered

Leverage Factor: 48



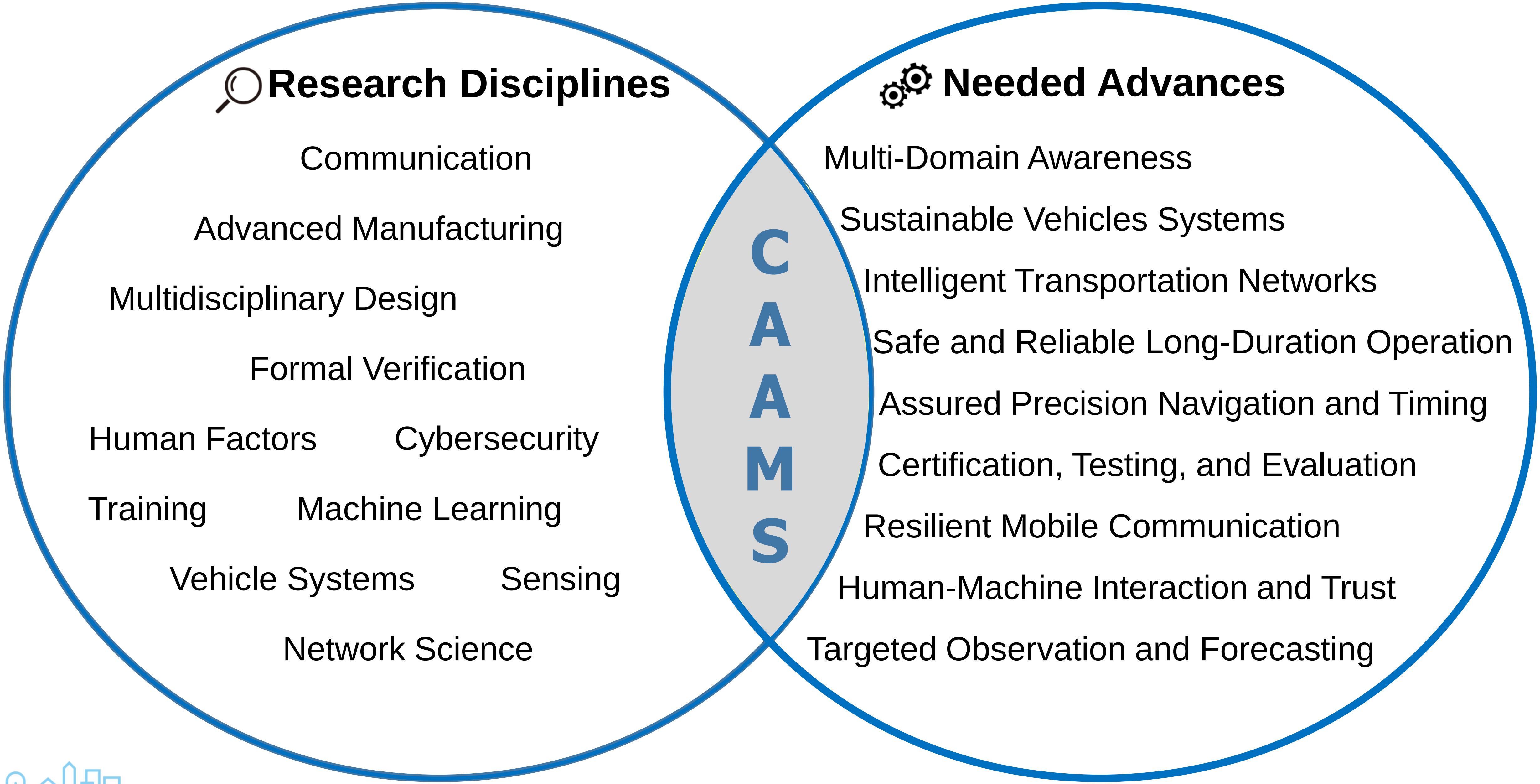
What is the Research?

Innovation Beyond Integration

Fundamental, pre-competitive investigations that complement internal R&D activities of industry members

<u>Determined by industry members</u>

- Combination of researcher expertise, resource access, and industry member needs
- Yearly Industry Advisory Board (IAB) meeting used to allocate research funds to projects based on center member votes


Research Disciplines
Communication
Advanced Manufacturing
Multidisciplinary Design
Formal Verification
Human Factors
Cybersecurity
Training
Machine Learning
Vehicle Systems
Sensing
Network Science
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Needed Advances
Multi-Domain Awareness
Sustainable Vehicles Systems
Intelligent Transportation Networks
Safe and Reliable Long-Duration Operation
Assured Precision Navigation and Timing
Certification, Testing, and Evaluation
Resilient Mobile Communication
Human-Machine Interaction and Trust
Targeted Observation and Forecasting

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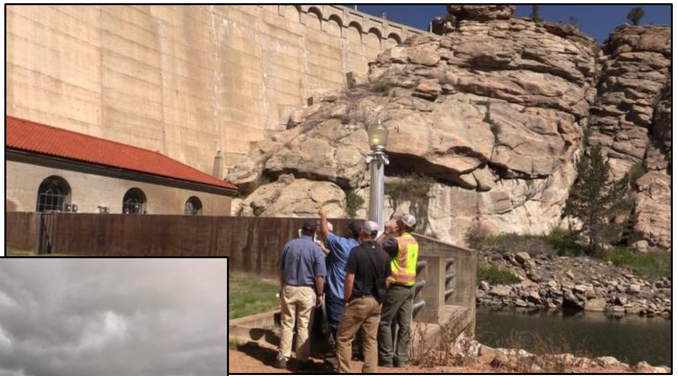
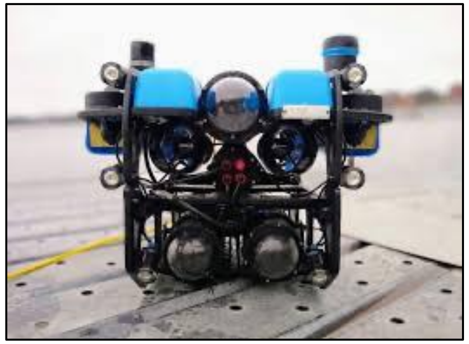
Fundamental Advances

	Advanced Mfg.	Comm.	Cyber-security	Design	Formal V&V	Human Factors	Network Science	Machine Learning	Sensing	Training	Vehicle Systems
CU											
BYU											
PSU											
Sinclair											
TAMU											
UM											
VT											

Application-driven Research





Research can include application-drive projects (e.g. infrastructure monitoring, ecosystem management) and adjacent autonomous system technologies (underwater robotics, legged robots)

What We Are Not

- We are not like an FAA Center of Excellence
  - Research is determined directly by center membership, not the funding agency
  - Focused on more than integration into the NAS
- We are not like an FAA Test Site
  - No need to commercialize our activity
  - We have access to the MAAP test site and other facilities, with full FAA approval for stationary, nomadic, mobile, and swarming concepts of operation

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Year 1 Projects

- Multi-agent localization in GPS-denied environments. Tim McLain and Joshua Mangelson (BYU)
- Fast Path Planner for Unmanned Aerial Mobility. Andrea L'Afflitto (VT)
- Testing UAV-based jammer localization using UWB as surrogate RFI. Mathieu Joerger (VT)
- Opportunistic Sparse Feature-Based Autonomous Navigation in Urban Environments. Manoranjan Majji (TAMU)
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- Effective Alerting. Amy Pritchett (PSU)
- Enhancing Agility of a Tailsitter UAV using a Hybrid Data-Driven Aerodynamic Model. Derrik Yeo (UM)
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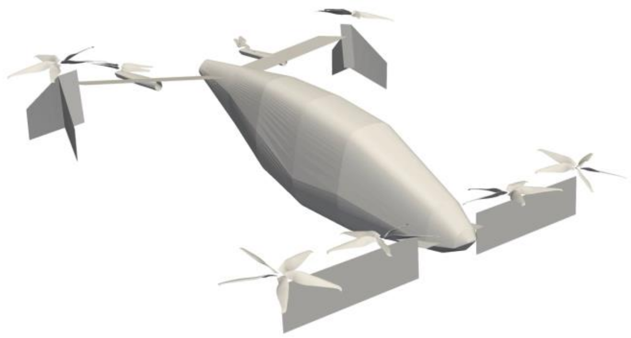
- Human-Informed Planning with Probabilistic Observations (HIPPO). Zachary Sunberg (CU)
- Rescuer Interface for iNtuitive Aircraft Operation (RINAO). Nisar Ahmed (CU)
- Integration of System Theory with Machine Learning Tools for Data Driven System Identification. Puneet Singla (PSU), John Valasek (TAMU), and Randy Beard (BYU)
- Safe and efficient take-off and landing algorithms for winged-VTOL aircraft. Randy Beard(BYU) and Dimitra Panagou (UM)
- Real-time Simulation of Very Flexible Aircraft. Carlos Cesnik (UM)

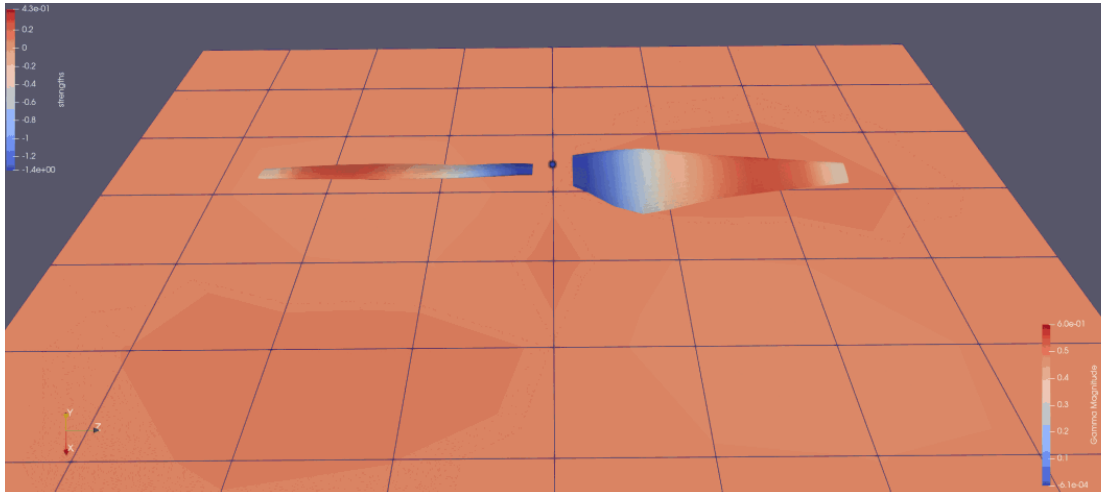
Unsteady aerodynamic analysis with vortex particle methods. Andrew Ning

BYU
BRIGHAM YOUNG
UNIVERSITY

Main Idea: Develop a new fast multipole method for our vortex particle method that will allow simulation of solid bodies, and will greatly simplify installation.



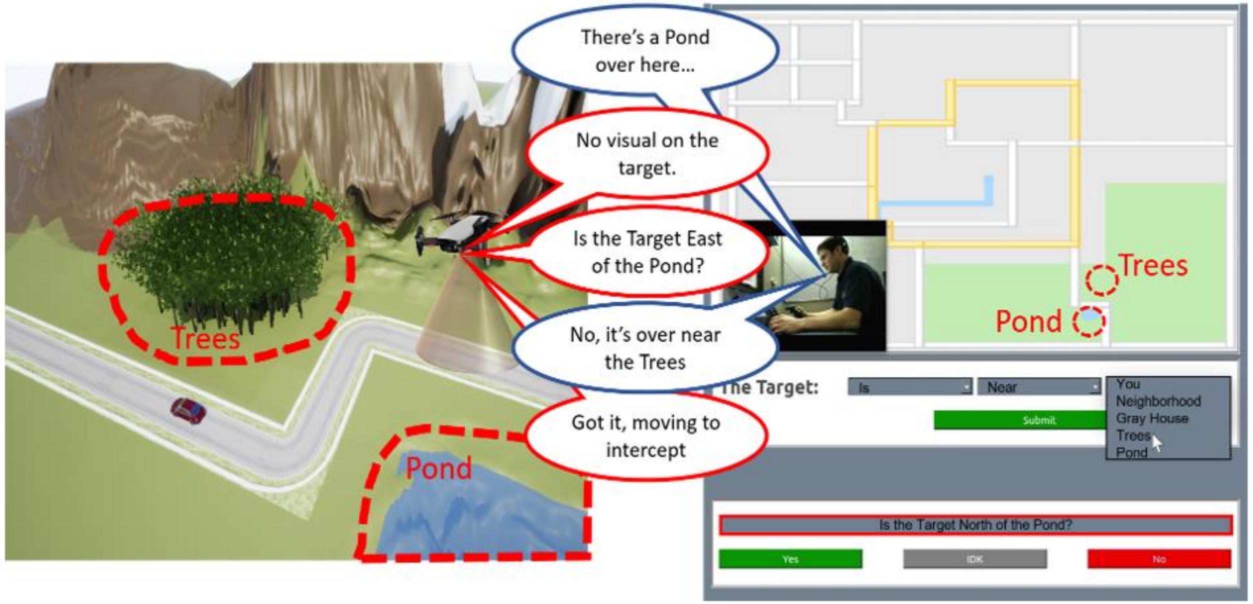
- Strong wake interactions.
- A vortex particle method (VPM) is well suited to these problems.
- Developed the first stable vortex particle method (VPM).
- Can simulate traditionally problematic cases like hover, turbulent mixing, high solidity, high resolution, and transition.

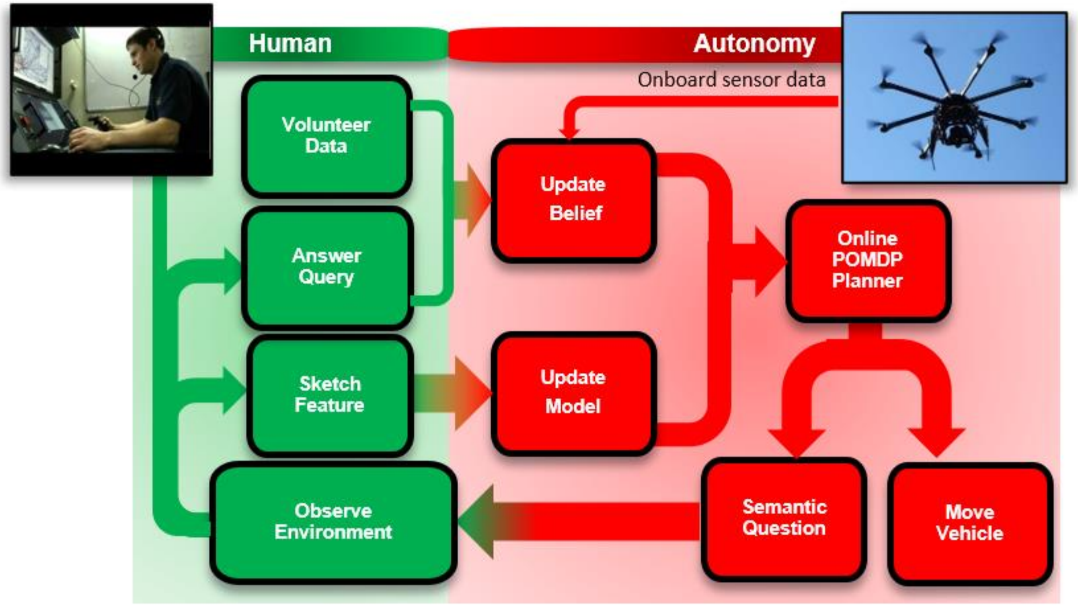


We are developing a new approach to handle both particles (wake) and panels (solid body) in a scalable way.

Rescuer Interface for iNtuitive Aircraft Operation (RINAO). Nisar Ahmed

University of Colorado Boulder





This project will develop and validate novel software tools that let non-expert end users enhance high-level reasoning capabilities of autonomous aircraft (AA), with minimal training and effort. Focus is on public safety applications like search and rescue

Safe and efficient take-off and landing algorithms for winged-VTOL aircraft.

Dimitra Panagou and Randy Beard

- Trajectory planning using B-splines
    - Efficiency, collision avoidance, dynamic constraints
- Flight stability using Lyapunov methods
- Safety guarantees using **control barrier functions**
- **Flight test** with small drones

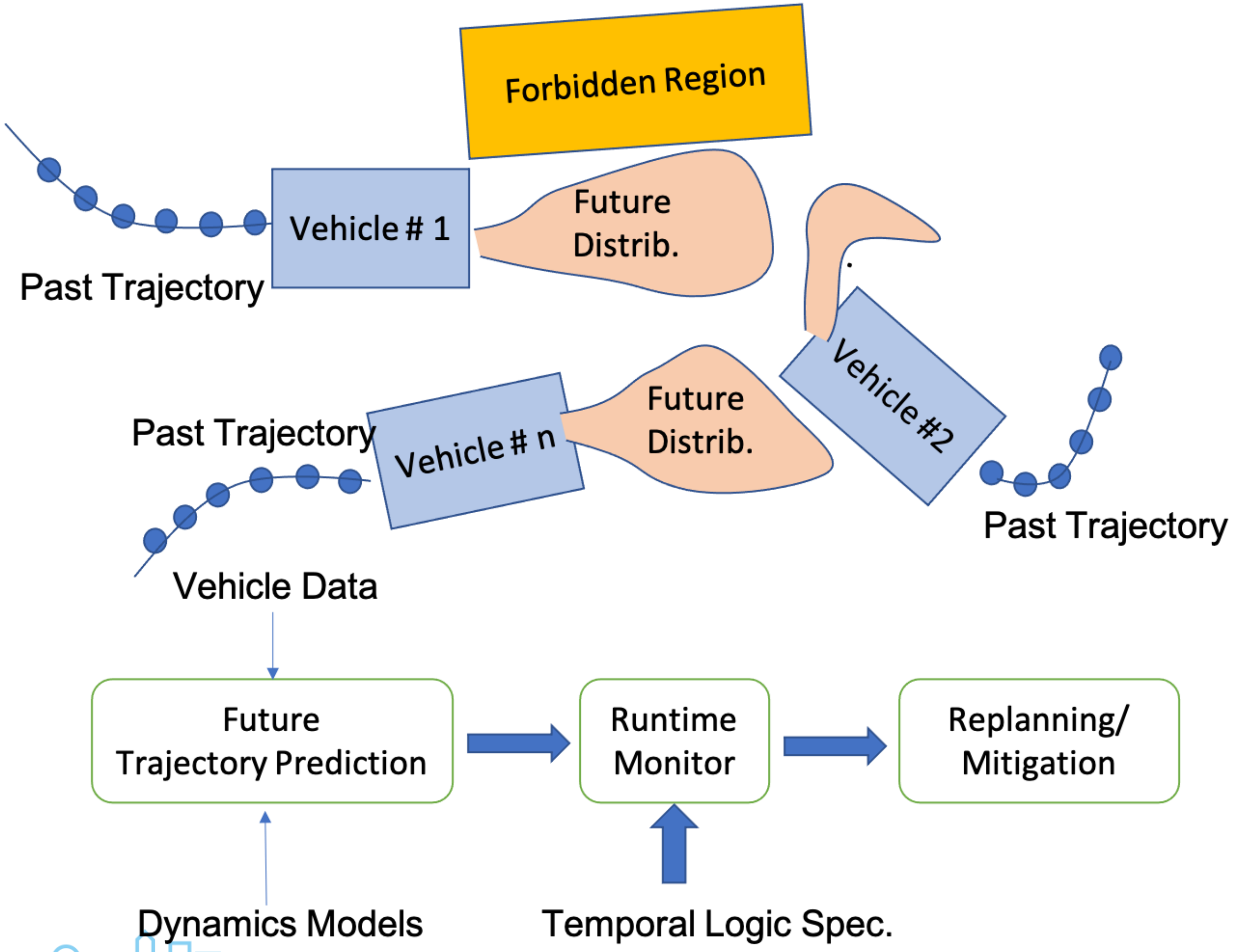
This project aims to combine open-loop planning using B-splines, and closed-loop behavior using control barrier functions to plan safe take-off and landing maneuvers for eVTOL aircraft that optimize for time and fuel efficiency.

Predictive Monitoring through Intent Inference

Sriram Sankaranarayanan, Eric Frew, Mazen Farhood

Virginia Tech

University of Colorado Boulder

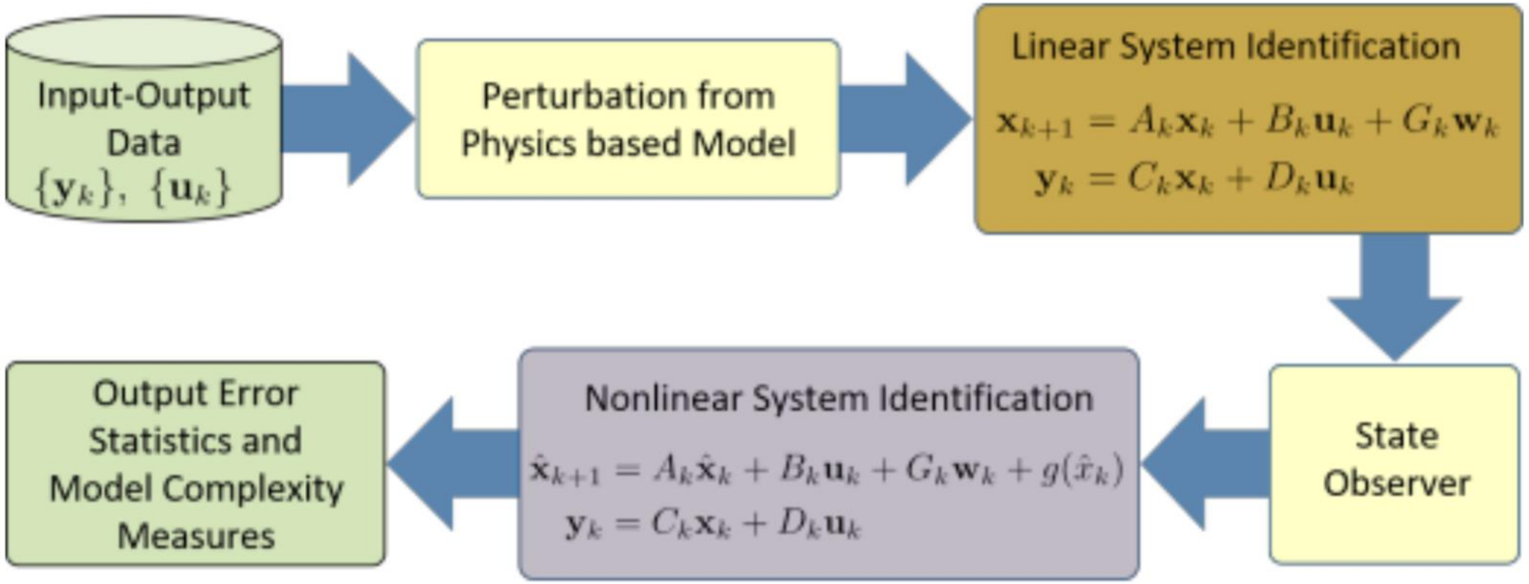


This project will provide runtime assurance for complex multi-agent autonomous systems by predicting impending unsafe events or failures ahead of time in order to allow for timely interventions such as replanning.

Integration of System Theory with Machine Learning Tools for Data Driven System Identification

Puneet Singla (PSU), John Valasek (TAMU), Randal Beard (BYU)

TEXAS A&M UNIVERSITY
BYU BRIGHAM YOUNG UNIVERSITY
PennState



Handshake linear time varying (LTV) model identification with sparse approximation tools to enable generation of highly accurate and robust models of AAMS **onboard** the vehicle, **in real-time**.

Seamlessly integrate emerging machine learning tools with well established dynamic system identification techniques to provide accurate vehicle models

•Very high levels of safety and fault tolerance in multi-obstacle urban environments and potentially crowded low altitude airspaces.

•Facilitates type certification by understanding handling qualities, fault-tolerant control systems, and obstacle and collision avoidance.

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Challenges and Trends

Challenging Problems

- GPS denied navigation
    - Signals of opportunity
    - Identify and localize jammers
    - Cooperative localization
- Fault tolerance
    - System prognostics and status management
    - Contingency management for autonomous flight in complex environments with multi-modal vehicles

Challenging Problems

- Swarming
  - How do we verify the performance of multi-agent teams and swarms?
  - Swarm offensive and defensive tactics
- Security and Counter UAS
  - Identifying the small number of UAS acting nefariously out of a very large number of UAS operating legitimately
  - Planning with dynamic threats
  - How can the technology you are developing be exploited, maliciously tricked, or just plain mess with by an adversary

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Challenging Problems

- Testing and Evaluation
  - To what extent can we extrapolate lessons learned from small UAS to large UAS, e.g. slow platforms to hypersonic ones, single aircraft to fleets of vehicles
  - Measuring trustworthiness of autonomous systems
- Certification
  - Lack of structure in acceptability of AI/ML solutions in the aerospace industry
  - Can we define an autonomy certification process for intelligent/adaptive/non-deterministic systems in a way similar to the way we certify pilots now

Trends

Assured > Trusted

Dispersed > Distributed

Safe >> Secure > Smart

Swarming > Flocking

Operations > Demonstrations

Human-AI Interaction > Human Factors

Data-Driven Learning > Model-Based Design

Applications for AI Assurance

- Cooperative localization and navigation of heterogeneous teams
- Human-AI teaming for search and rescue / seek and destroy
- Learning-enhanced control of novel platforms (eVTOL/STOL)
- Swarms for surveillance and protection
- Weather-aware routing, planning, guidance, and control

Thanks

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https://caams.center/