



# ARMED Transformative Aeronautics Concepts Program Convergent Aeronautics Solutions Execution Project



Autonomy Teaming & TRAjectories for Complex Trusted  
Operational Reliability

# ATTRACTOR

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PI/co-PI: Natalia Alexandrov (LaRC), Danette Allen (LaRC)

Team:

.NASA.gov: LaRC, ARC, AFRC, GRC

.edu: CMU, MIT, NIA, Tufts, UIUC



# ATTRACTOR Team





# The Problem



**UAM – a target environment**



**3D!**

**Unprecedented complexity**



How to achieve **trustworthiness and justified trust** in autonomous cyber-physical-human systems in **safety-critical, time-critical, and certification-dependent** environments?



# Trustworthiness $\Leftrightarrow$ Justified Trust



**Reliable** Multi-agent System for  
Mission Planning and Execution

=

## Trustworthiness:

- Attribute of system
- Assurance that system does what is required and not what is prohibited
- Necessary to deploy system in safety-critical environments

+

## Trust:

- Attribute of the participants/ users/observers/ controllers of system
- Measure of readiness to rely on another system participant for decision/advice/ action

- Trustworthiness should be a prerequisite to trust
- Unjustified mistrust reduces the system's trustworthiness



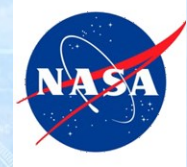
# CPH Trust/Trustworthiness Breakdowns



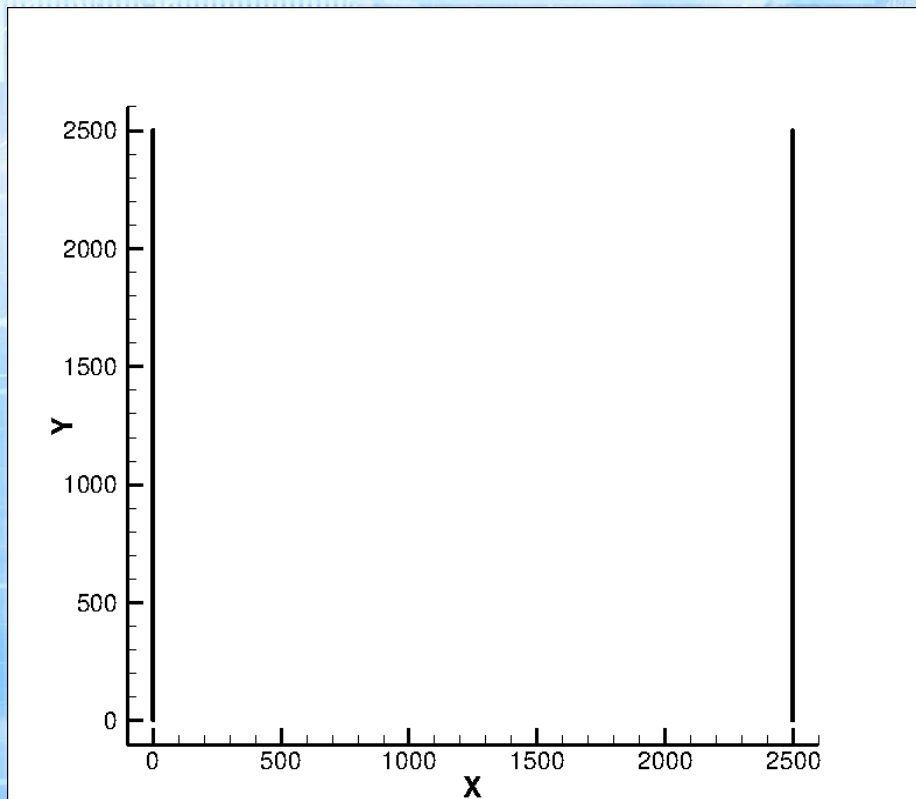


# Trustworthiness of What?

- Every action at every scale in system (moving from point A to point B, taking direction from another agent,...) is a result of a decision-making process / algorithm, regardless of who/what makes the decision.
- When is a decision worthy of trust?



# Trustworthiness, Ideal Case



# Trustworthiness, Really

. B

Single decision:

**Minimize  $\{f_i(x_i, p_i, u_i(x_i, p_i))\}$**

**Subject to  $x_i \in \Gamma, i = 1, \dots, m$**

$\Gamma$  = constraint set

Propagate uncertainties to uncertainty in solution

. A



Uncertainty in vehicle and sensor state, location,  
perception of the environment, obstacle avoidance,

...



# Trustworthiness, Really



. B



Single decision:

**Minimize  $\{f_i(x_i, p_i, u_i(x_i, p_i))\}$**

**Subject to  $x_i \in \Gamma, i = 1, \dots, m$**

$\Gamma$  = constraint set

Propagate uncertainties to uncertainty in solution



. A



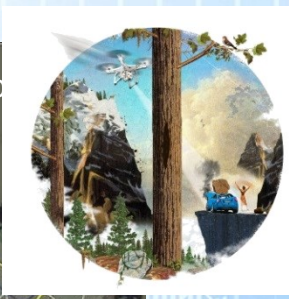
... + Uncertainties about intent of the other vehicles' and its state, mental model, rules, and algorithms...



- Building trust amenable to certification =  
**context + max Justified Trust + thresholds**



SAR Mission



Human or Machine Defines Initial Flight Paths

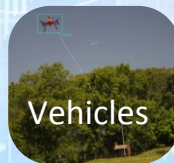


MAKE PRE-MISSION MODIFICATIONS



Natural H-M Interaction Facilitates Trust

Start



Vehicles

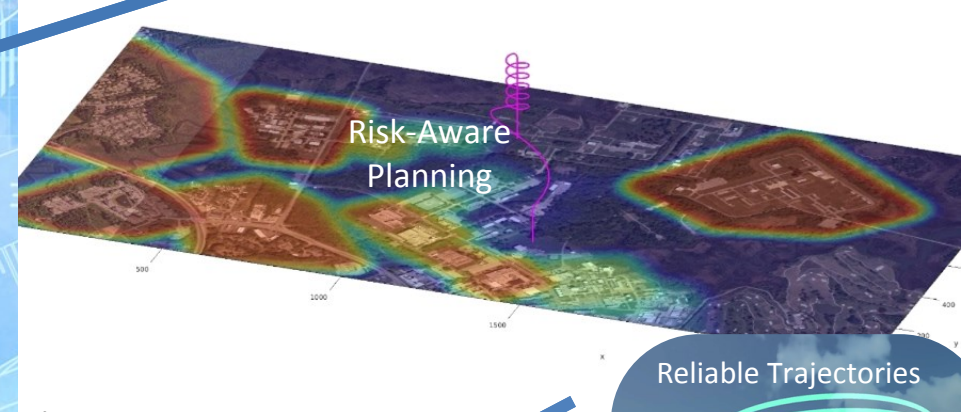


Terrain



People

Manage RT Risks



Risk-Aware Planning

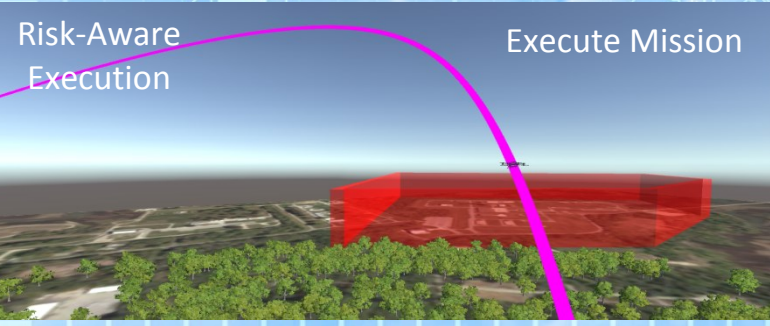


Reliable Trajectories

Adjust and Approve Mission



Simulate Mission

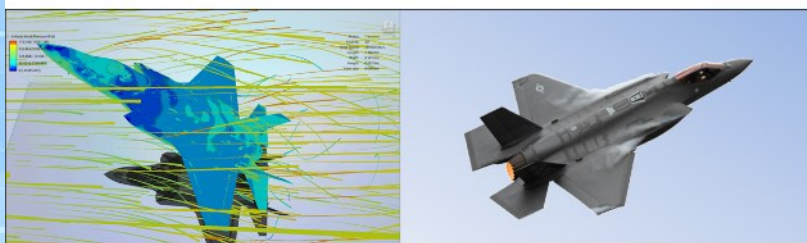


Risk-Aware Execution

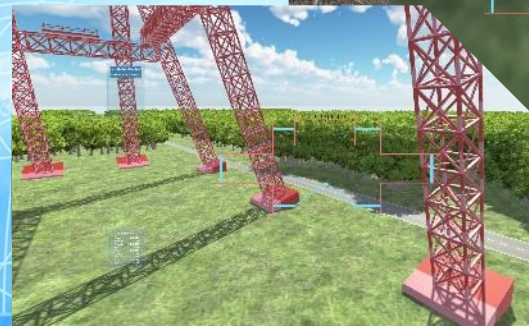
Execute Mission

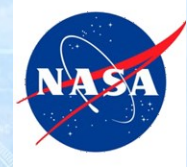
# Persistent “TwinSim”

Digital Twin Artifacts/Environments

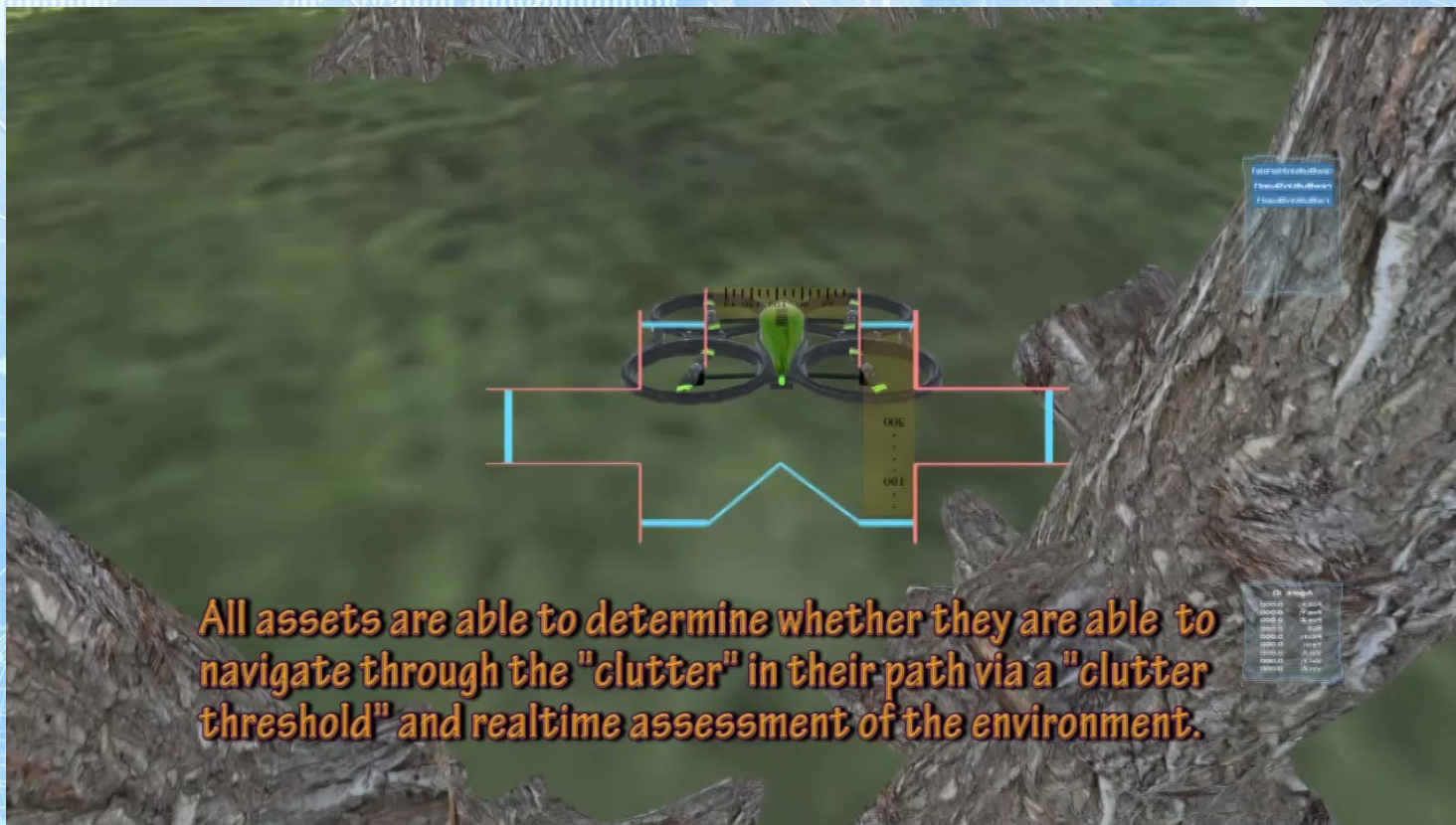


“Digital Twin” Ecosystem





# Multi-Asset Mission



**All assets are able to determine whether they are able to navigate through the "clutter" in their path via a "clutter threshold" and realtime assessment of the environment.**



# Concluding Remarks

- Building a basis of measurable trustworthiness and trust, toward certification of safety-critical autonomous systems paves a way for autonomous systems into aviation and answers cross-cutting questions in autonomous systems safety
- The problem has not been solved elsewhere; often not recognized elsewhere

NASA-MIT team won the AUVSI Xcellence Humanitarian award at AUVSI Xponential (April 2019)





- Check out our blog [autonomyincubator.blogspot.com](http://autonomyincubator.blogspot.com)
- Join us on Twitter @AutonomyIncub8r
- MIT: [acl.mit.edu/projects/search-rescue-forest-canopy-multiple-uas](http://acl.mit.edu/projects/search-rescue-forest-canopy-multiple-uas)



# Developing Trust via Explanation

**APPROVE THE MISSION**







# Developing Trust via Explanation

- M: I must change a planned portion of trajectory
- H: Why?
- M: I detect children in the area. Risk rises from X to Y.
- H: Are you sure?
- M: Yes, here is the image of children.
- H: What is your new trajectory?
- M: Here is the image and associated risk.
- H: Are there alternative trajectories?
- M: Yes, but their associated risks are higher and the associated rewards are small.
- ...
  - Explanations implied that the goals and risk assessment are shared
  - Q: Who has the final decision authority?
  - N.B. Representation of risk and uncertainty to a human is a big problem (e.g., Monty Hall problem)