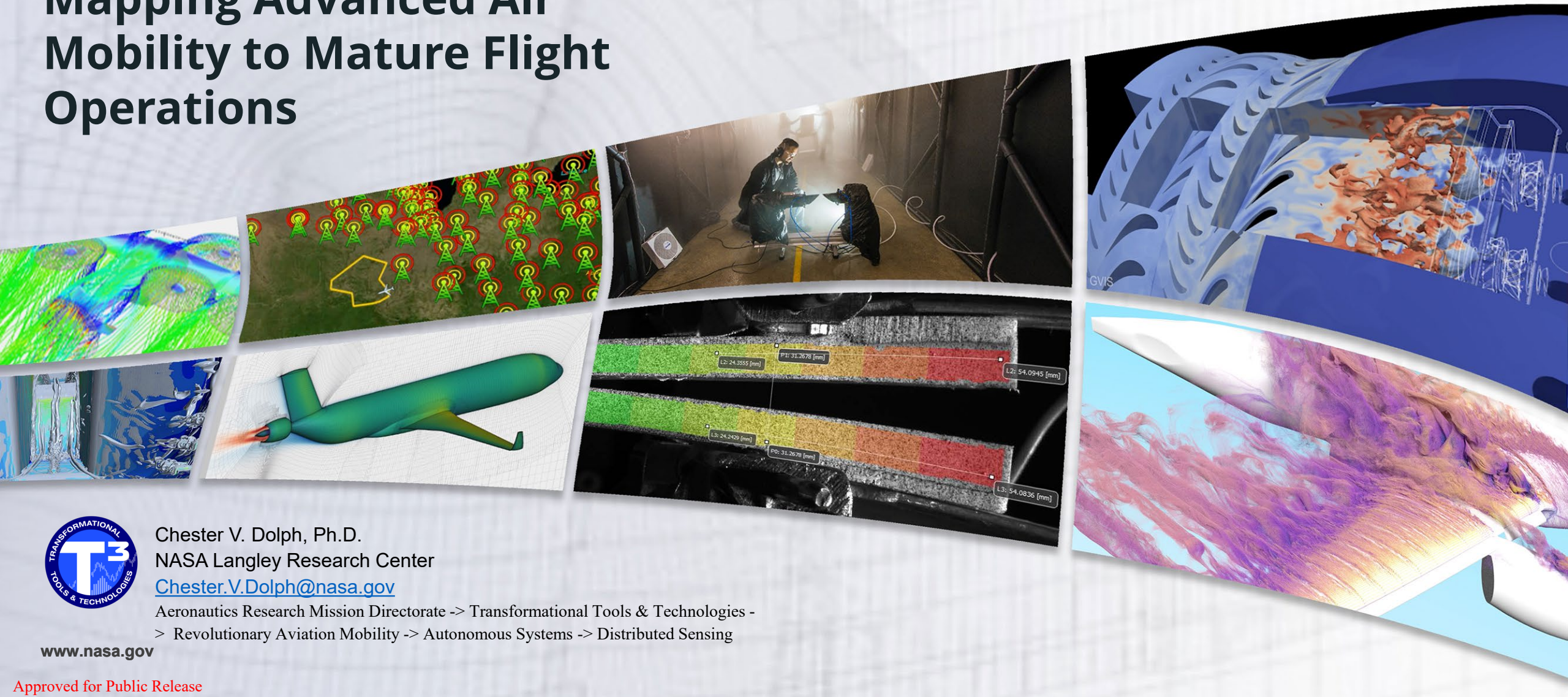
Mapping Advanced Air Mobility to Mature Flight Operations



Chester V. Dolph, Ph.D.
NASA Langley Research Center
Chester.V.Dolph@nasa.gov

Aeronautics Research Mission Directorate -> Transformational Tools & Technologies -> Revolutionary Aviation Mobility -> Autonomous Systems -> Distributed Sensing

Approved for Public Release

Mapping Advanced Air Mobility to Mature Flight Operations

1. **AAM: Vision and Application**
2. **AAM: Partners**
3. **Revolutionary Vertical Lift Technology Project**
4. **Transformational Tools and Technologies**
5. **Distributed Sensing**
    1. Overview
    2. Vision-based Detection and Tracking Algorithm of Aircraft
    3. Deep classifier with adversarial learning of General Aviation, fixed-wing small unmanned aircraft systems (sUAS), multirotor sUAS, and birds
    4. Evaluation of optical-radar detection tracking system prototype in ground-to-air experiment with target multirotor sUAS
    5. Trajectory Classification
    6. Future Testing

Approved for Public Release

Advanced Air Mobility (AAM) Mission

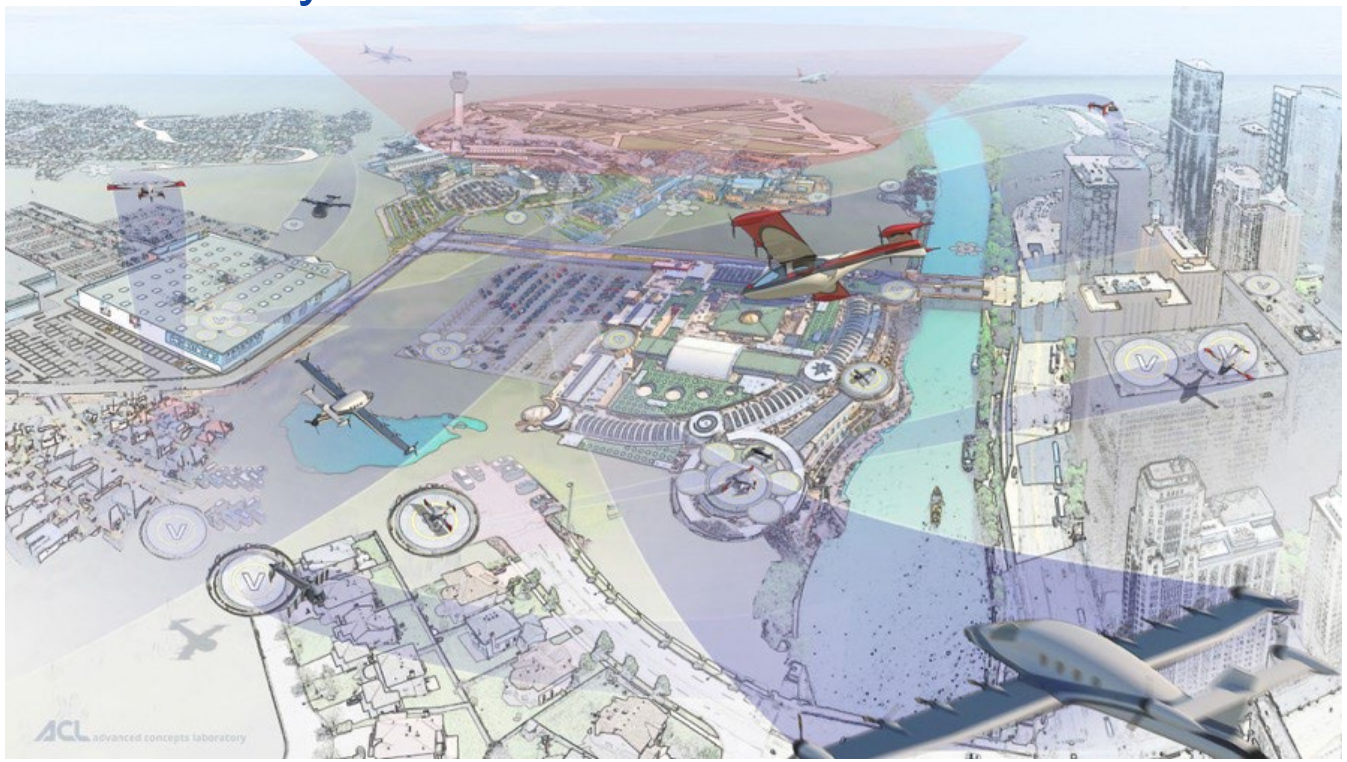


Safe, sustainable, affordable, and accessible aviation for transformational local and intraregional missions

Courtesy of the NASA AAM Mission Integration Office

Advanced Air Mobility (AAM): Bringing Aviation into Daily Life

- Three primary application categories:
  - **Urban Air Mobility (UAM)**
    - **"Local" missions up to ~75 miles around metropolitan areas**
    - Largely novel "**vertiport**" infrastructure
    - Primarily **eVTOL** aircraft
    - 1 to ~6 **passengers** or equivalent **cargo**
  - **Low-Altitude Uncrewed Aircraft Systems**
    - **Local missions for aerial work or (small) cargo delivery (e.g., food, small packages)**
    - Range of required takeoff/landing infrastructure from none to specialized
    - Typically **VTOL-capable aircraft**
  - **Regional Air Mobility (RAM)**
    - **"Intraregional" missions up to ~500 miles**
    - Primarily **existing** (smaller) **airports**
    - Primarily Electric Short Take-Off and Landing (eSTOL) and Conventional Take-Off and Landing (eCTOL) aircraft
    - Up to 19 or 30 passengers or equivalent cargo



- **AAM is generally enabled by electrification & automation**
- Many potential uses, including
  - Passenger transport
  - Cargo/package delivery
  - Emergency services/public good (e.g., air ambulance, EMT transport, etc.)
  - Aerial work (e.g., infrastructure inspection, photography, tourism, etc.)

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

AAM System of Systems

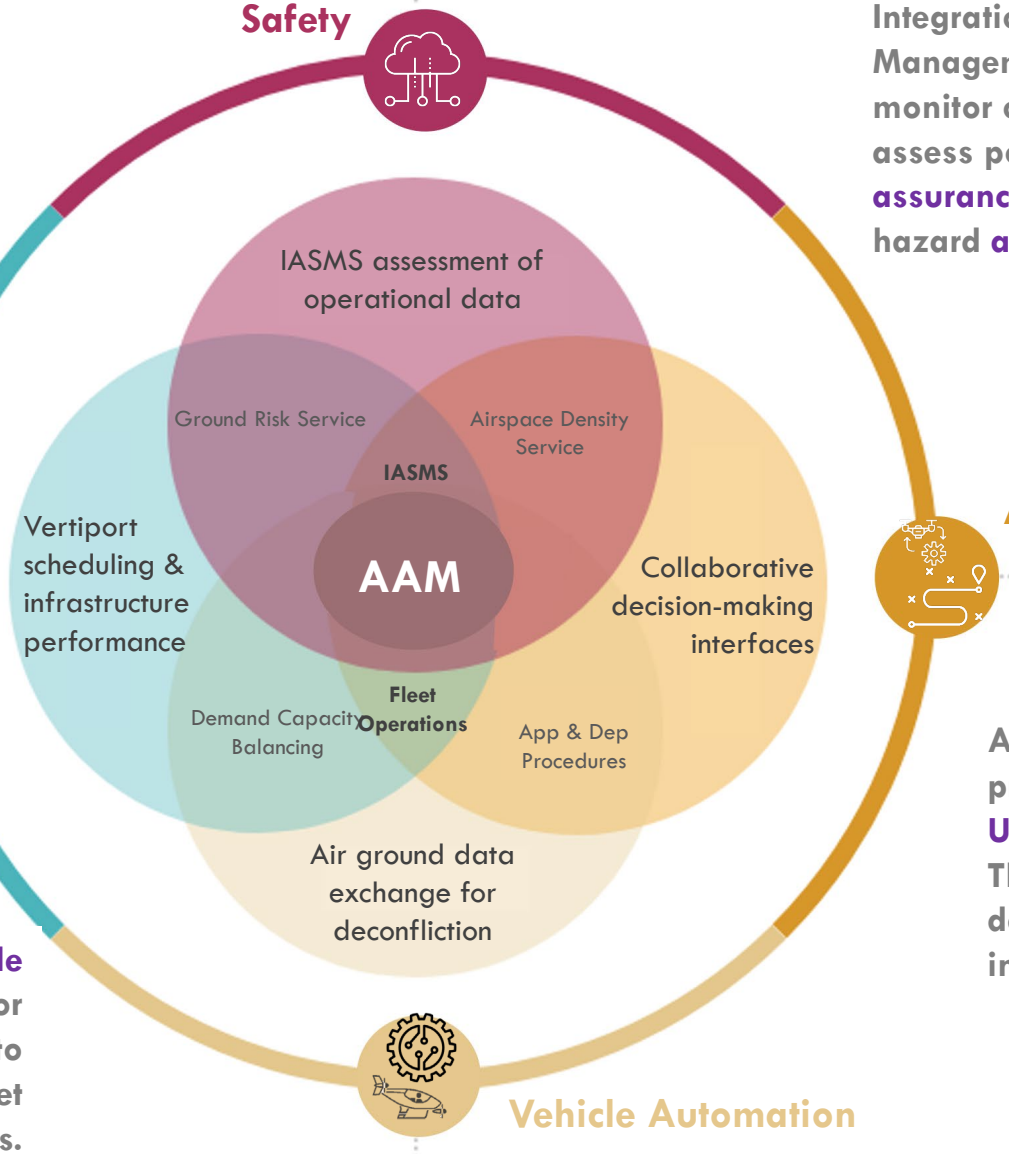
Safety

Integration of In-time Aviation **Safety** Management System (IASMS) services to monitor operational safety data in **real time**, assess potential **hazards** using safety **assurance algorithms** and communicate safety hazard **alerts**.

Vertiport automation to enable resource reservation using **shared data**, extending **fleet** operation capabilities, and assessing **performance** data for critical infrastructure across comms and navigation



Vertiport & Infrastructure



Airspace

Airspace design, procedure development, and prototypes to enable a **Providers of Service to UAM** (PSU) and third party driven ecosystem. This includes **collaborative decision making** for deconfliction and development of interfaces for integration with **safety** and **vertiport functions**.

Development and integration of vehicle automation and its mission suitability for AAM, air ground data exchange protocols to enable deconfliction strategies and fleet operations communications.

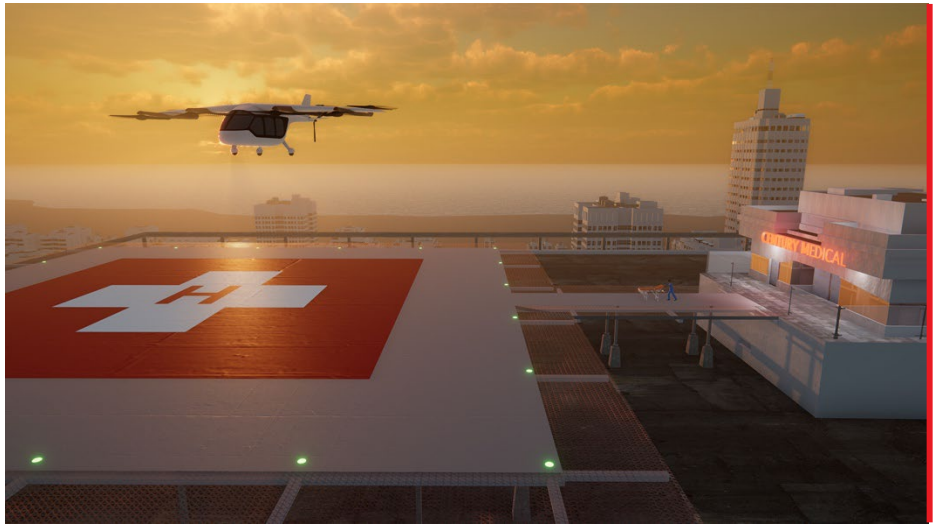
Vehicle Automation

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

Advanced Air Mobility is Emerging

REGIONAL CARGO AND PASSENGER TRANSPORT





PUBLIC GOOD

CONSUMER/ ENTERPRISE GOODS AND SERVICES





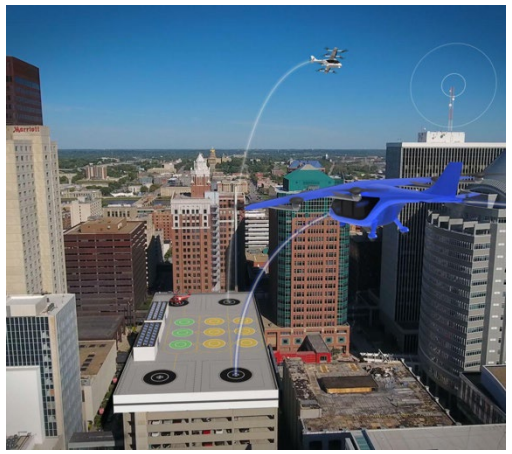
LOCAL PASSENGER TRANSPORT

Courtesy of the NASA AAM Mission Integration Office: Approved for Public release

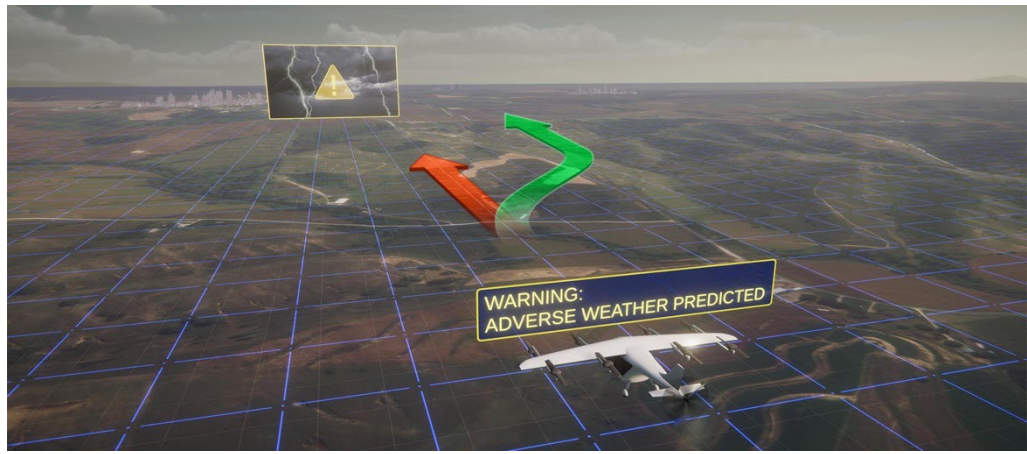
Safe, sustainable, affordable, and accessible aviation for transformational local and intraregional missions

What does Advanced Air Mobility (AAM) look like?

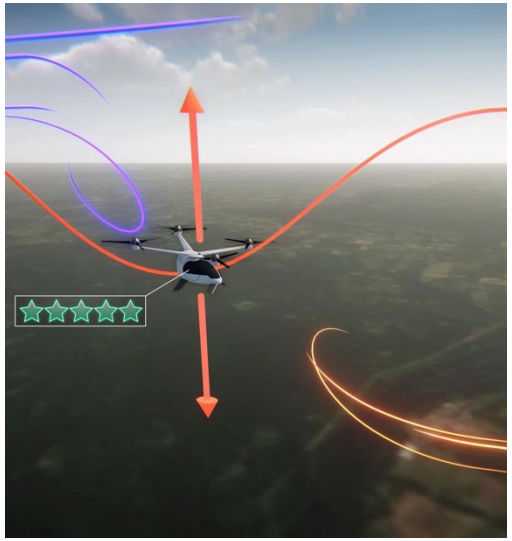
















Air transportation system will include low-altitude passenger transport, cargo delivery, and public service capabilities

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

Emergency Response



https://www.nasa.gov/centers-and-facilities/armstrong/nasa-is-creating-an-advanced-air-mobility-playbook-2/

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

Healthcare Operations



https://www.nasa.gov/centers-and-facilities/armstrong/nasa-is-creating-an-advanced-air-mobility-playbook-2/

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

Autonomous Operations



https://www.nasa.gov/centers-and-facilities/armstrong/nasa-is-creating-an-advanced-air-mobility-playbook-2/

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

Vertiports



https://www.nasa.gov/centers-and-facilities/armstrong/nasa-is-creating-an-advanced-air-mobility-playbook-2/

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

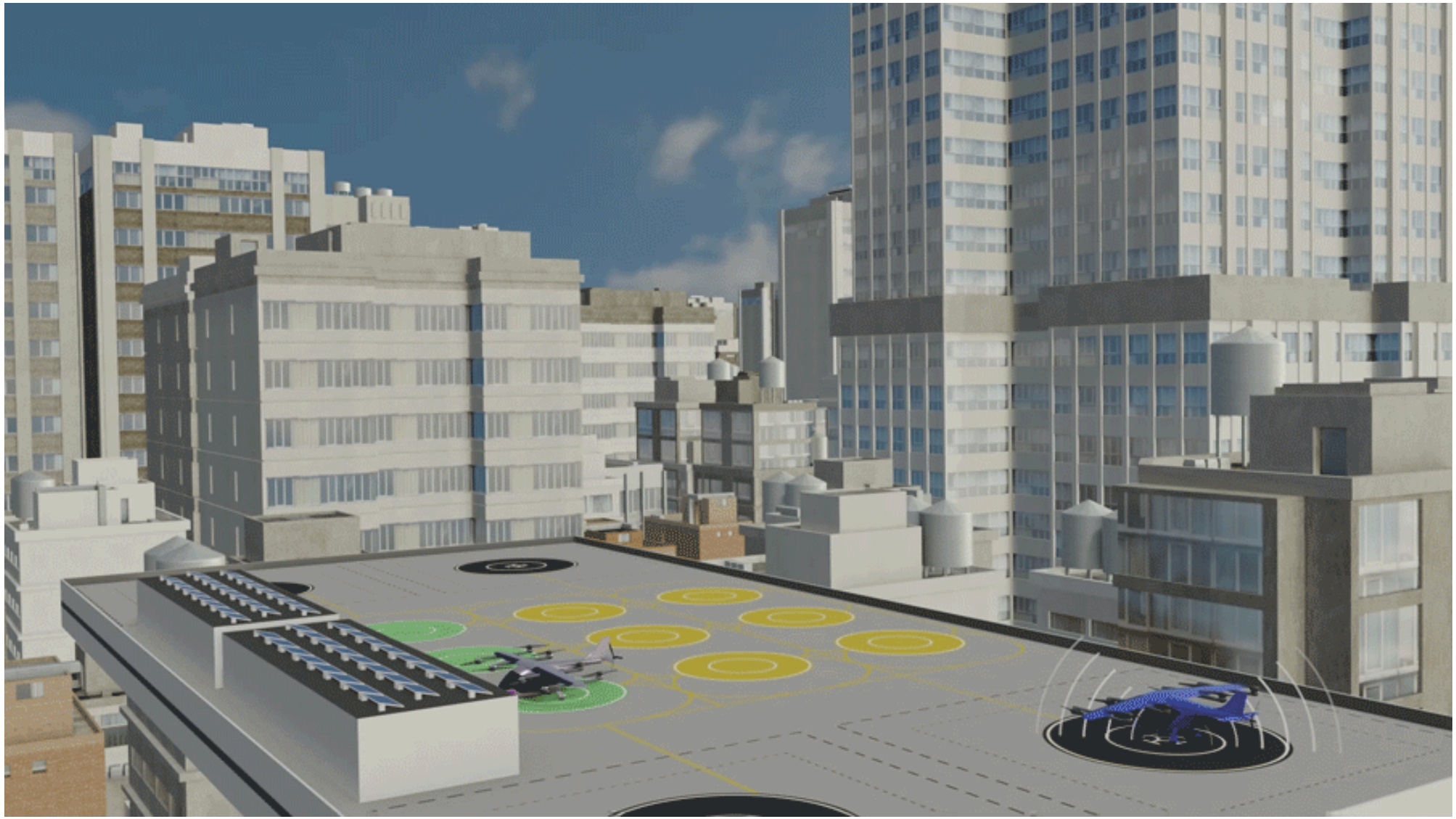
Convenient Travel



https://www.nasa.gov/centers-and-facilities/armstrong/nasa-is-creating-an-advanced-air-mobility-playbook-2/

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

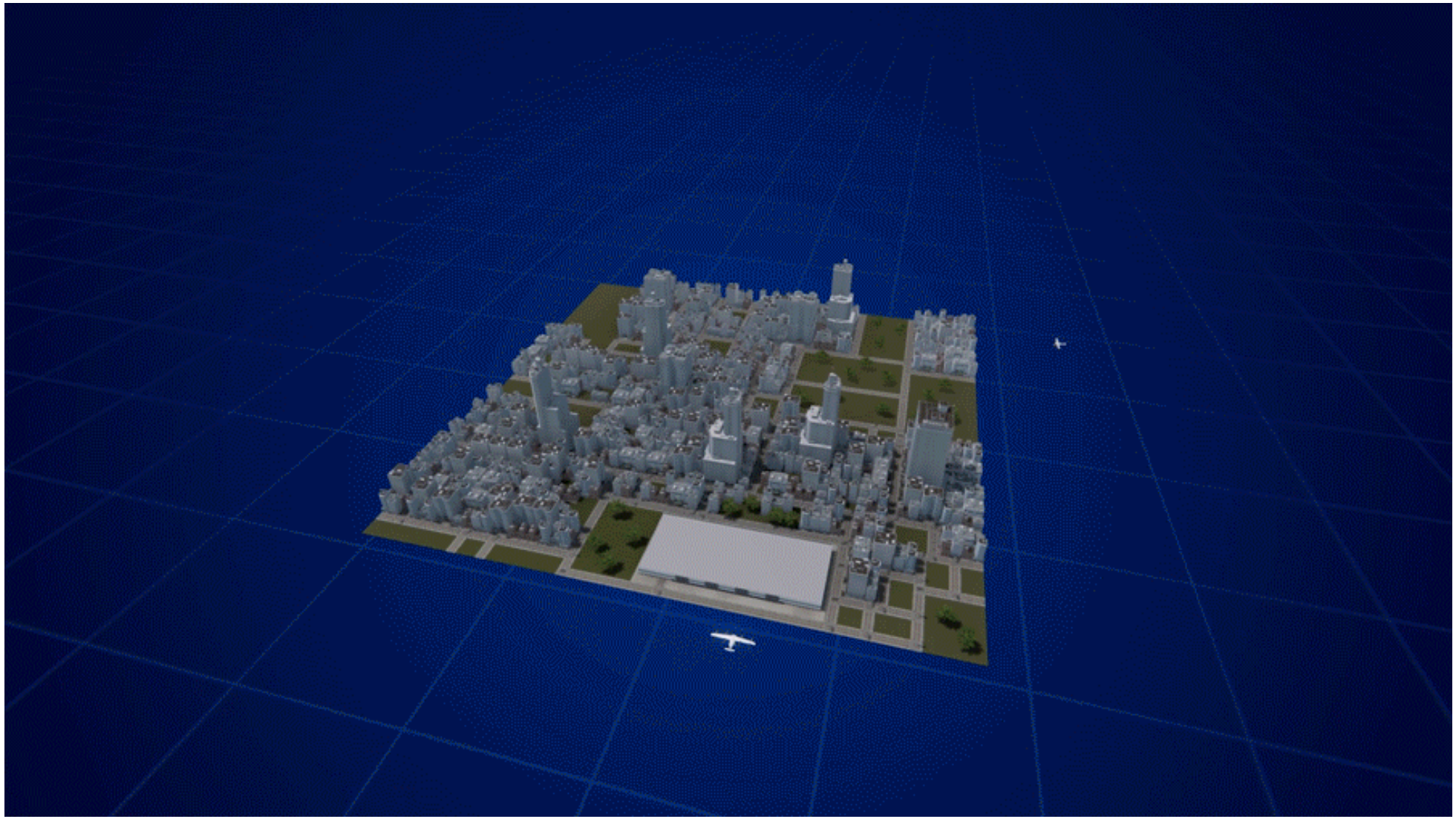
Low sound levels



https://www.nasa.gov/centers-and-facilities/armstrong/nasa-is-creating-an-advanced-air-mobility-playbook-2/

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

Infrastructure/System



https://www.nasa.gov/centers-and-facilities/armstrong/nasa-is-creating-an-advanced-air-mobility-playbook-2/

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

Future Airspace



https://www.nasa.gov/centers-and-facilities/armstrong/nasa-is-creating-an-advanced-air-mobility-playbook-2/

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

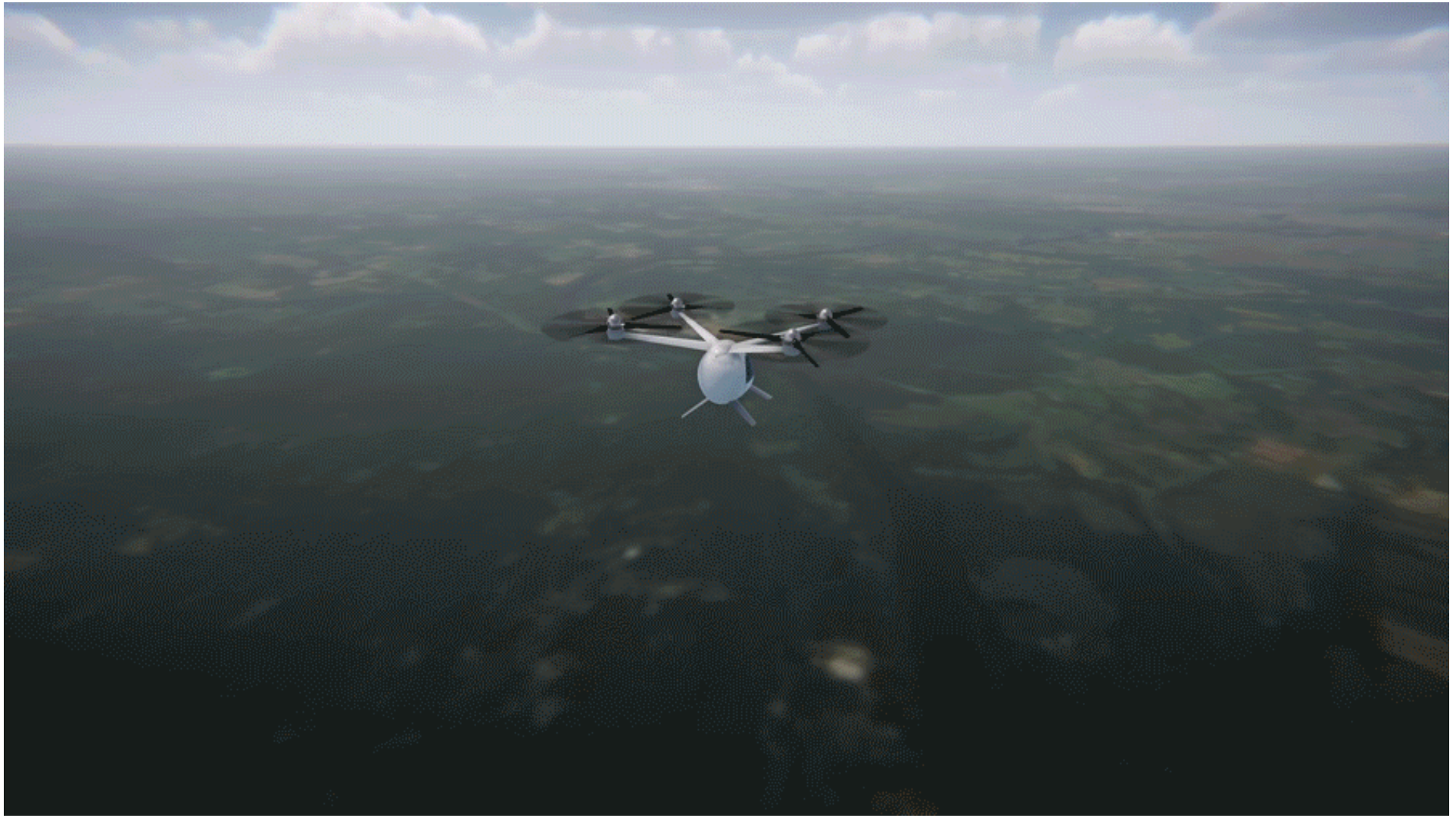
Safety



https://www.nasa.gov/centers-and-facilities/armstrong/nasa-is-creating-an-advanced-air-mobility-playbook-2/

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

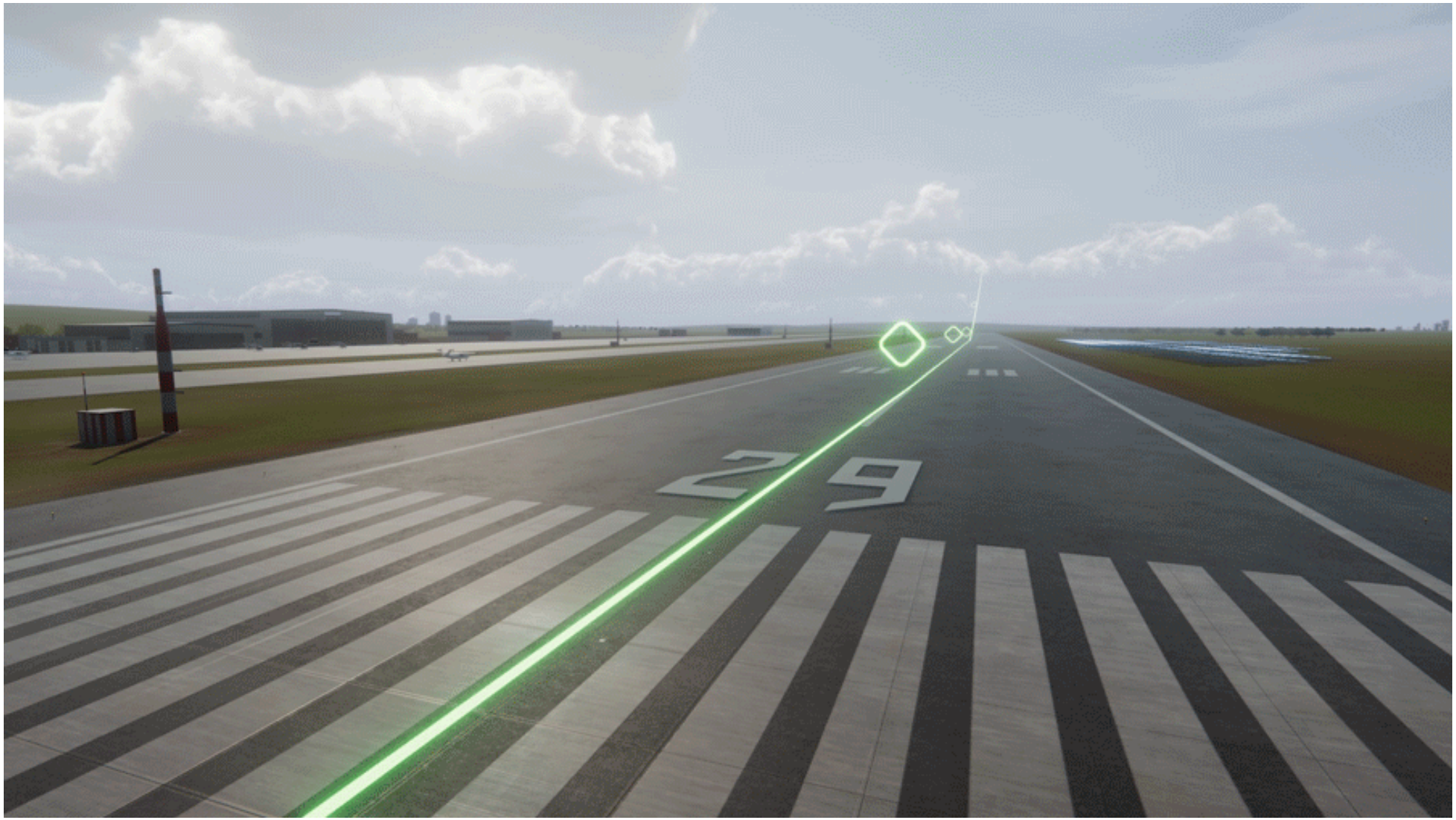
Ride Quality



https://www.nasa.gov/centers-and-facilities/armstrong/nasa-is-creating-an-advanced-air-mobility-playbook-2/

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

Cargo Delivery



https://www.nasa.gov/centers-and-facilities/armstrong/nasa-is-creating-an-advanced-air-mobility-playbook-2/

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

Accessibility



https://www.nasa.gov/centers-and-facilities/armstrong/nasa-is-creating-an-advanced-air-mobility-playbook-2/

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

Example AAM Aircraft Manufactures



- Archer



- Beta



- Bell



- ElectraAero



- Elroy Air



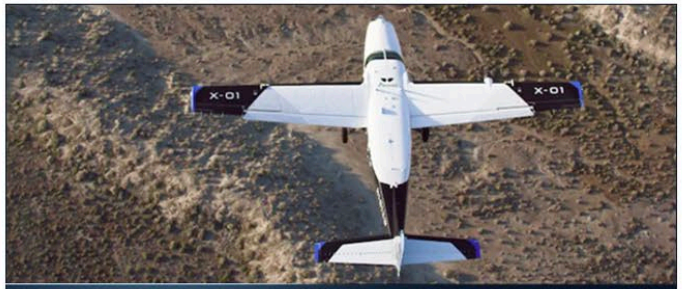
- Joby



- Reliable Robotics



- Wisk



- Xwing

According to a 2021 Deloitte study the U.S. AAM market could reach $115 billion annually, potentially creating 280,000 jobs

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

Note: NASA does not endorse any of the companies shown above. This slide is to show that there is innovation happening within U.S. industry with a few vehicle examples.

What is a Vertiport?

An area of land, or a structure, used or intended to be used, for electric, hydrogen, and hybrid VTOL aircraft landings and takeoffs and includes associated buildings and facilities.

Vertiport



Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

Infrastructure

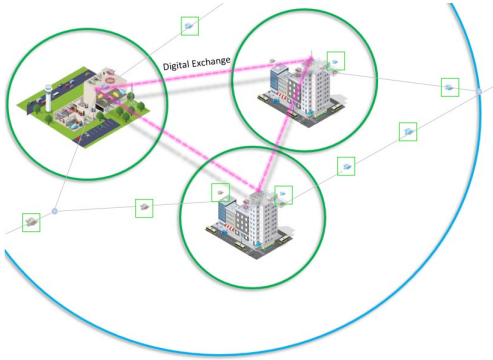
Vertistop



Vertiport



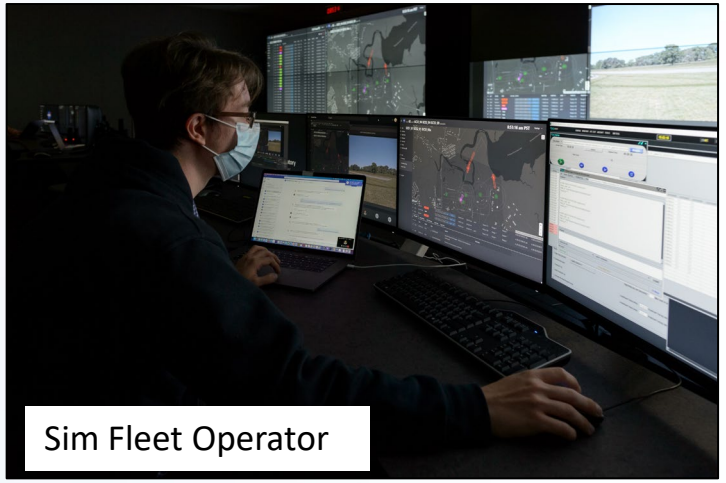
Vertiplex



https://ntrs.nasa.gov/citations/20210016168

HDV Integrated Architecture Elements





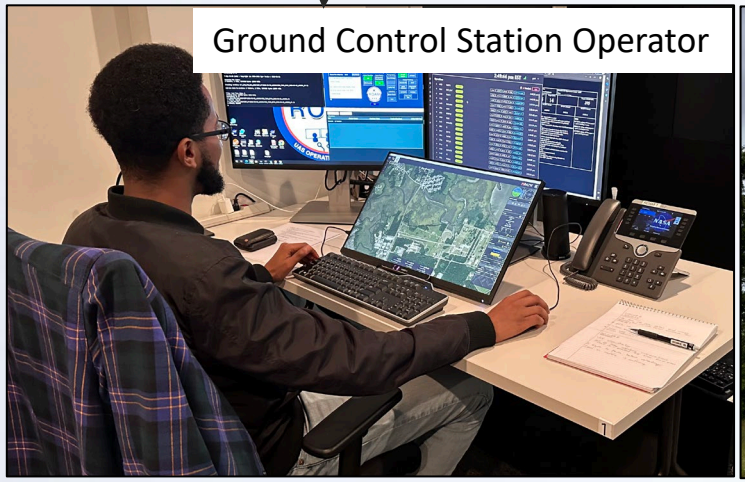
Provider of Services for UAM

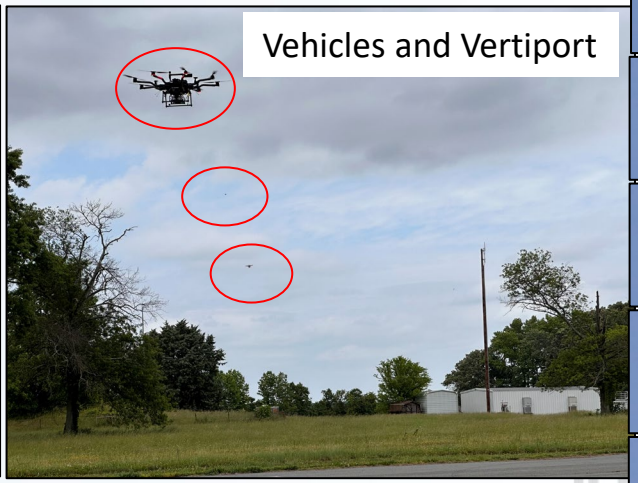
Vertiport Automation System

Fleet Management Service

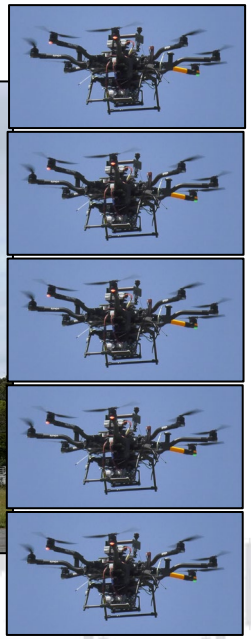
Fleet Operations







5 total



Vehicles and Onboard Automation

National Aeronautics and Space Administration

ARC

LaRC

Courtesy of the UTM BVLOS project: Approved for Public Release

HDV Simulation and Flight Testing

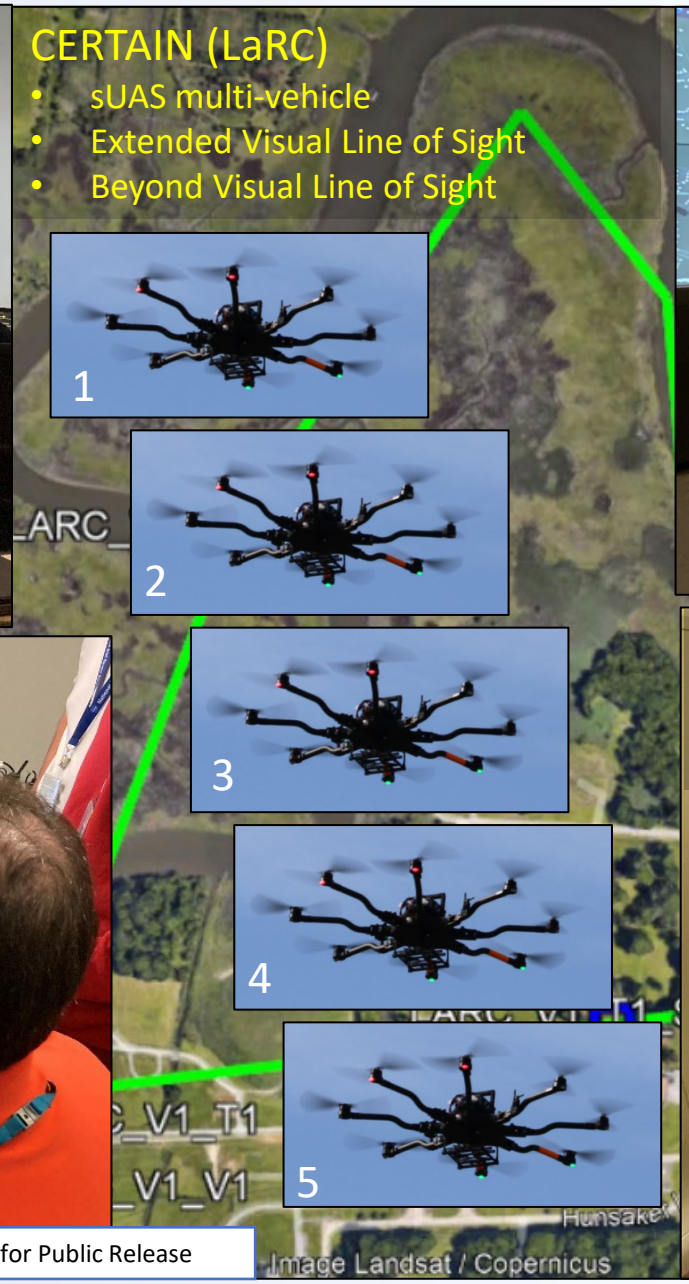


ROAM I/II UAS Ops Center (LaRC)

- Primary control stations
- Shared Situational Awareness
- Vertiport Management
- Data integration and distribution

CERTAIN (LaRC)

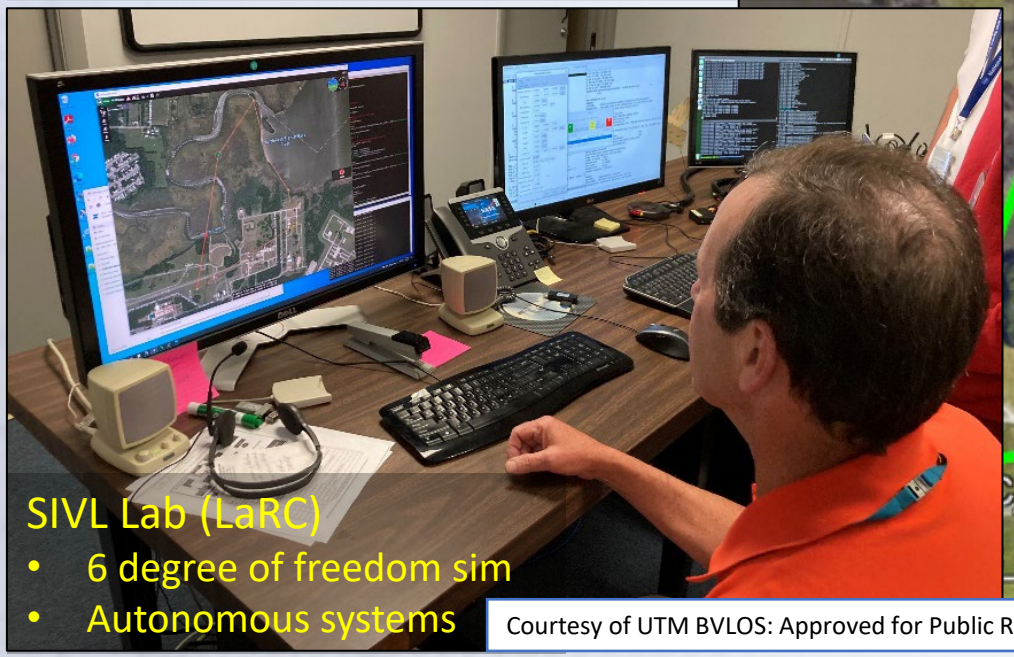
- sUAS multi-vehicle
- Extended Visual Line of Sight
- Beyond Visual Line of Sight





AOL (ARC)

- Fleet management
- Provider of Services UAM interface
- Multi Aircraft Control System Sim

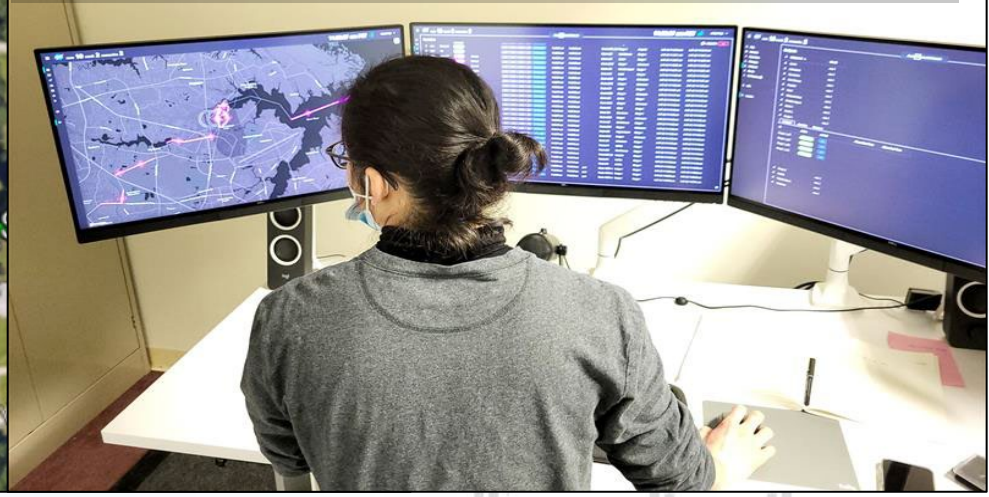


SIVL Lab (LaRC)

- 6 degree of freedom sim
- Autonomous systems

AVAL (ARC)

- Overall test quality monitoring
- Trial planning tool testing and development



Courtesy of UTM BVLOS: Approved for Public Release



NASA's Role

NASA is delivering **data** to guide the industry's development of electric air taxis and UAS/SUAS.

NASA is assisting the Federal Aviation Administration in **safely** integrating these vehicles into the national airspace.

NASA will set the stage for a flourishing industry in the 2030s.

Industry is building new types of low-altitude **aircraft**.

Industry seeks Federal Aviation Administration **certification** of aircraft.

Industry wants to invent a world where air taxis and UAS/SUAS are used routinely for passenger transport, emergency response, and in the delivery of goods.

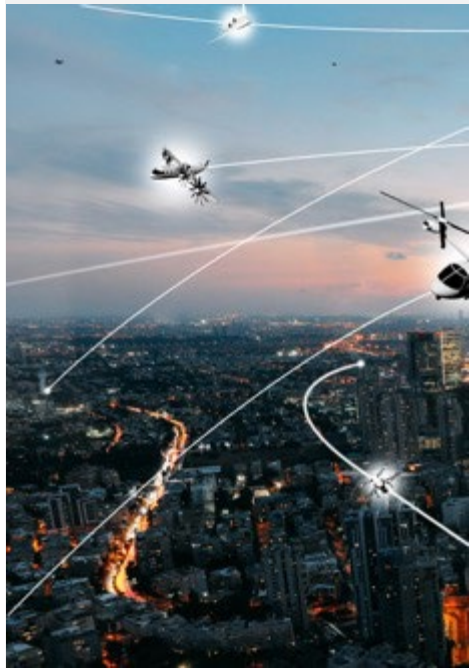


Industry's Role

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

NASA Role to Address AAM Challenges

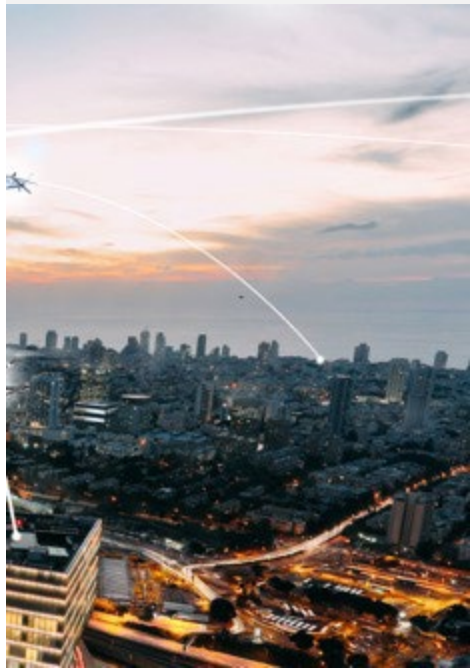
Vehicle Development and Operations



Airspace Design and Operations



Community Integration



NASA and key partners are collectively taking on the most difficult mission challenges to enable industry to flourish

- **Research and Development Portfolio**
- **Robust Ecosystem Partnerships**

NASA will deliver long term technical solutions through concept, requirement, and architecture development for industry and the regulatory community

Courtesy of the NASA AAM Mission Integration Office

NASA's AAM Constellation

Automation

Airspace

Safety

Noise



Courtesy of the NASA AAM Mission Integration Office: Approved for Public Release

Framework for Integrated System Level Architecture

- NASA's role emphasizes an integrated system level approach to deliver requirements for total system performance

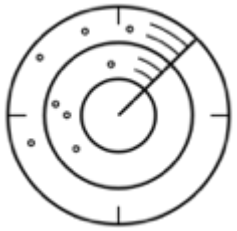
Airspace Management



Fleet Management



FAA Aircraft Network Security Program



In-Time Aviation Safety Management Systems



Integrated System Architecture



Aircraft Technologies and Automation



Infrastructure
Communication, Navigation, Surveillance, SDSP



Vertiport/Airport Management

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

UAM Airspace Research Approach

- Evolving the Airspace Towards Scalable UAM Operational Integration



PC-12 Data Collection Feb 2023

Research to enable digital communication for airspace operations

Collaborative simulations with industry to develop software and community-based rules for cooperative conflict management



Development of a UAM airspace research roadmap, new airspace constructs, and procedures

Development of prototype capabilities and research to inform requirements for operator services

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

NASA's Areas of Research



COMMUNITY INTEGRATION

- How these aircraft will fly routinely in cities and rural areas
- Integration with already established transportation systems, buildings, and city policy



AIRSPACE

- Communication between aircraft and air traffic control
- Location of aircraft in the airspace while flying
- Automation of air traffic control systems for unexpected events



INFRASTRUCTURE

- Vertiport research, where the aircraft will take off and land
- Power research, how the aircraft will be powered
- Digital support for aircraft and operators



AIRCRAFT

- Safety of the aircraft design materials
- Noise of the aircraft, making sure it is quiet
- Ride quality for passengers
- Aircraft automation – software and hardware for self-flying aircraft

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

Collaboration Is Key to Achieving AAM Goals

NASA Research and NC Partnerships

Academia

Airspace Partners



Other Gov't Agencies

State/Local Community Partners

Infrastructure Partners

Vehicle Partners



Standards Development Organizations

NASA's AAM Ecosystem Partnership and Collaboration Approach

AAM Ecosystem Working Groups (AEWG)



Learn more here:

AAM Interagency Working Group



International Forum for Aviation Research (IFAR)



Eco-system wide partnership base designed to accelerate technology development and operationalization

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

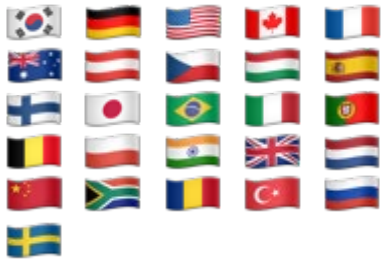
NASA's AAM Partnerships and Collaborations

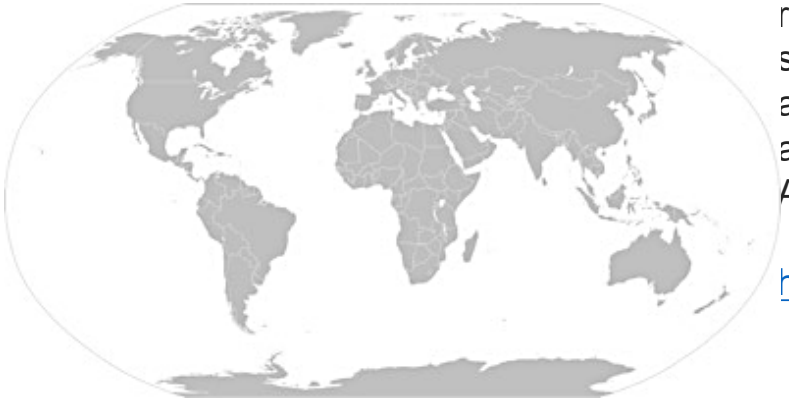
1. Domestic Research Partners

- Academia
- Companies working on AAM aircraft development
- Companies working on AAM airspace
- Companies working on AAM infrastructure
- Other federal government agencies
- City and state local governments
- Standards development organizations

- **Accelerate technology:** NASA is researching the total system through modeling, simulations, and flights to see how the pieces will work together in harmony (airspace, vertiports, aircraft, automation).
- **Accelerate policy and guidance:** NASA is informing standards that need to be met for these aircraft to fly to enable regulators like the FAA to establish the rules.
- **Accelerate aviation leadership:** NASA will help springboard the AAM industry to enable successful domestic industry business models.

2. International Forum for Aviation Research (IFAR)





3. AAM Ecosystem Working Groups



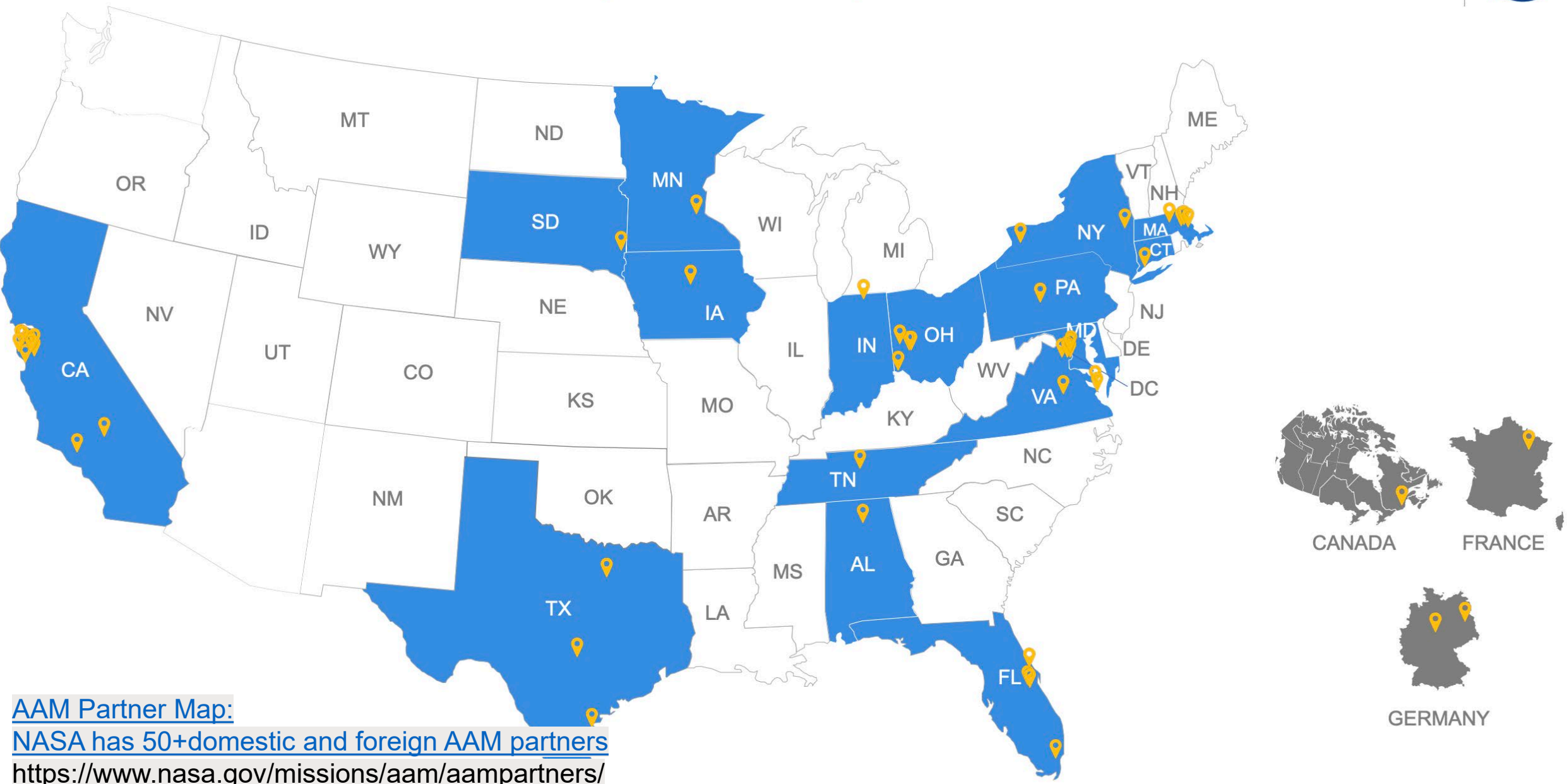
"AEWGs give NASA researchers a front row seat to industry issues needing to be solved, which helps ensure our research and development around AAM is relevant and timely." - Davis Hackenberg, previous AAM mission integration manager

https://nari.arc.nasa.gov/aam-portal/

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

NASA Advanced Air Mobility Partnerships

National Aeronautics and Space Administration



[AAM Partner Map:](https://www.nasa.gov/missions/aam/aampartners/)
[NASA has 50+domestic and foreign AAM partners](https://www.nasa.gov/missions/aam/aampartners/)
https://www.nasa.gov/missions/aam/aampartners/

(Incomplete)

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

IFAR Scientific Assessment on UAM for ICAO



- Industry Assessment
- Technology Priorities
- Operational Priorities
- Societal Acceptance Priorities
- Standards Landscape

- Developed by the IFAR-ICAO UAM Expert Group by consolidating inputs from individual IFAR members and collaborative consensus on final statements.



IFAR-ICAO UAM Expert Group (Subset)

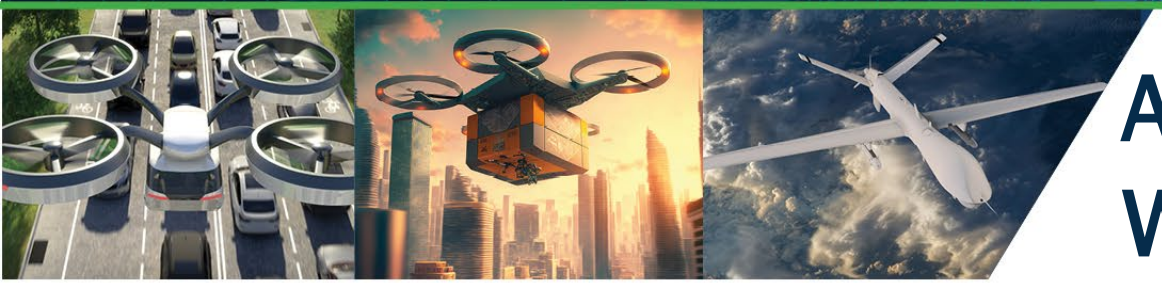


IFAR-ICAO Workshop (April 2022)

Download the Scientific Assessment for UAM at https://ifar.aero/about-us

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

U.S. Department of Transportation



Advanced Air Mobility Interagency Working Group (IWG)

https://www.transportation.gov/aamiwg

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

AAM Interagency Working Group

Organized under the AAM Coordination and Leadership Act Oct '22 and amended in the 2024 FAA Reauthorization

https://www.congress.gov/bill/117th-congress/senate-bill/516/text

Kickoff Meeting in Feb '23 with 22 Federal Agencies

https://www.transportation.gov/aamiwg

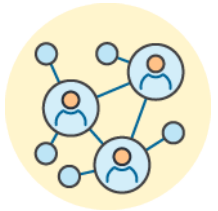
5 Subgroups

Tasked to develop a national strategy that includes:

- Recommendations regarding the safety, operations, security, infrastructure, air traffic concepts, and other Federal investment or actions necessary to support the evolution of early AAM to higher levels of activity and societal benefit; and
- A comprehensive plan detailing the roles and responsibilities of each Federal department and agency, and of State, local, and Tribal governments, necessary to facilitate or implement the recommendations developed.



Automation Strategy



Community Roles



Infrastructure Development

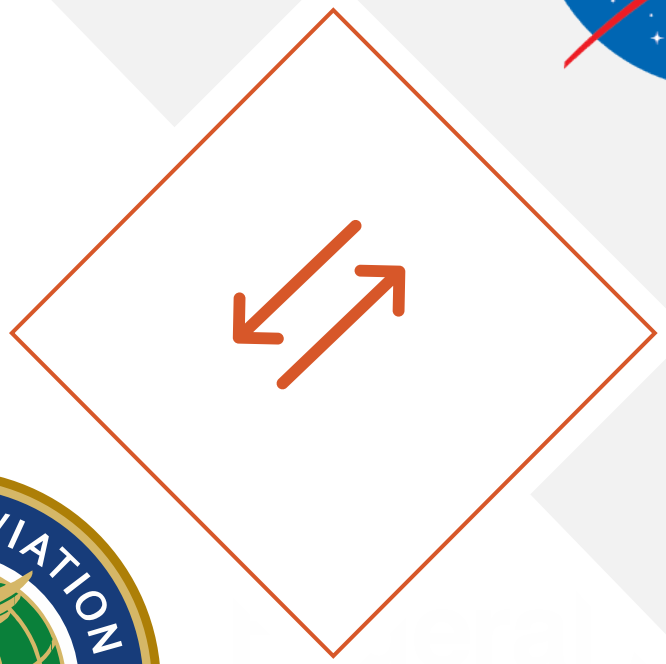


Air Traffic Federation



Security Requirements

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release



Transfer Data to the FAA

Transfer data and results to Federal Aviation Administration to influence future rules and policy.

NASA is answering questions:

- **What are the design requirements for safe and quiet vehicles?**
- **What are the pilot training qualifications to fly these aircraft?**
- **What infrastructure would an airport need to include to support these aircraft?**

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

AAM Ecosystem Working Groups (AEWG)

Share visions for AAM

Learn about NASA's research and planned transition paths

Discuss strategies for engaging the public on AAM



Collectively identify and investigate key hurdles and associated needs

Discuss AAM system and architecture requirements

Identify regulatory and standards development needs

Form a connected stakeholder community

https://nari.arc.nasa.gov/aam-portal/

Accelerate the development of safe and scalable AAM flight operations by bringing together the broad and diverse ecosystem

Courtesy of the NASA AAM Mission Integration Office:
Approved for Public Release

Want to Learn More?

NASA's AAM website: nasa.gov/aam

NASA's Advanced Air Mobility Playbook series: in both English and Spanish. Video series and corresponding web articles. Season one in English is live here: https://www.nasa.gov/feature/nasa-is-creating-an-advanced-air-mobility-playbook/

OSTEM content: Students can engage with the principles of AAM in a variety of ways — including hands-on STEM activities, coding activities, math lessons, and more. https://www.nasa.gov/advanced-air-mobility-aam-stem-toolkit/

Public events: NASA participates in various air shows, conferences, and events each year. Stay tuned to social media to learn more: https://twitter.com/nasaaero



Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

NASA's Advanced Air Mobility Work = Benefits to You



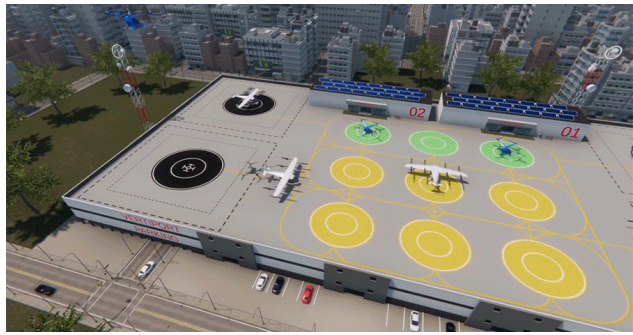
EMERGENCY RESPONSE



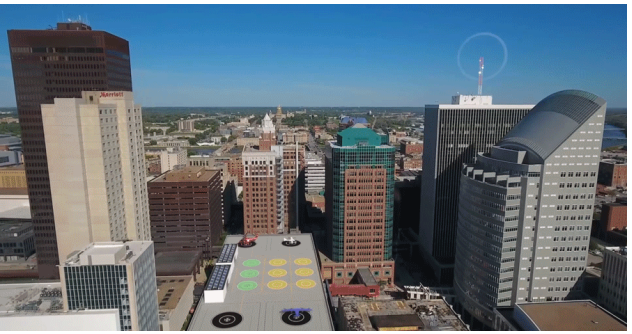
HEALTHCARE



AUTOMATION



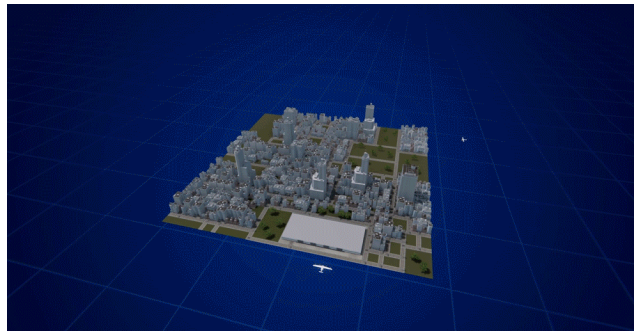
VERTIPORTS



TRAVEL TIME



NOISE



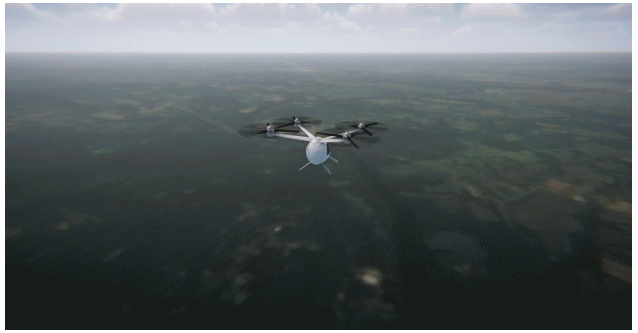
INFRASTRUCTURE



FUTURE AIRSPACE



SAFETY



RIDE QUALITY



CARGO DELIVERY



ACCESSIBILITY



Courtesy of the NASA AAM Mission Integration Office Approved for Public Release









NASA Centers Supporting AAM

Advanced Air Mobility research is happening at all four NASA aeronautics centers located in California, Virginia and Ohio.

- Ames Research Center: Silicon Valley, California
- Armstrong Flight Research Center: Edwards, California
- Glenn Research Center: Cleveland, Ohio
- Langley Research Center: Hampton, Virginia

Courtesy of the NASA AAM Mission Integration Office: Approved for Public Release









NASA Projects Supporting AAM

- Revolutionary Vertical Lift Technology
- Transformational Tools and Technologies
- Convergent Aeronautics Solutions
- System-Wide Safety
- Air Mobility Pathfinders
- Airspace Traffic Management Exploration
- Advanced Capabilities Emergency Response Operations

Courtesy of the NASA AAM Mission Integration Office: Approved for Public Release

ARMD PROGRAMS

Airspace Operations and Safety Program



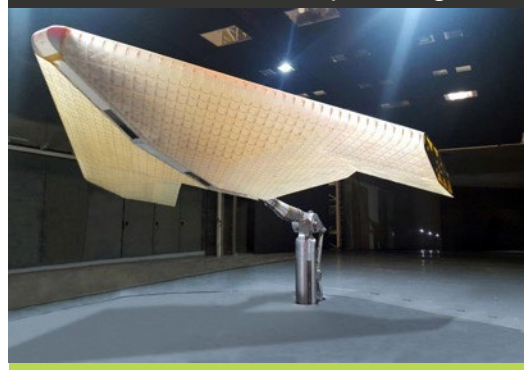
Advanced Air Vehicles Program



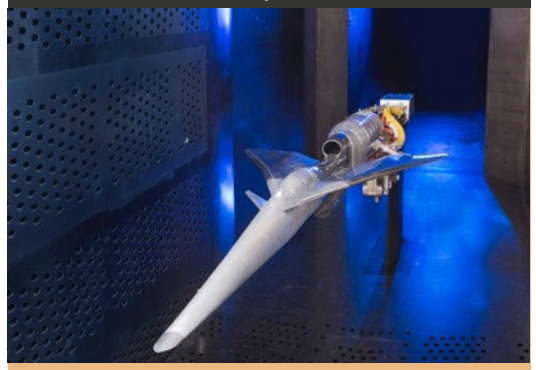
Integrated Aviation Systems Program



Transformative Aeronautics Concepts Program



Aerosciences Evaluation and Test Capabilities Portfolio

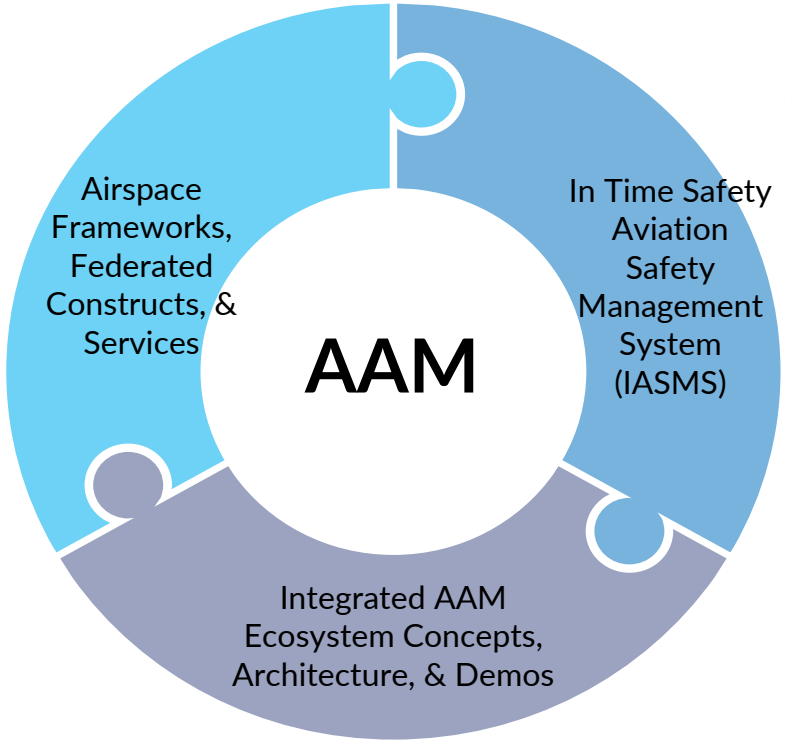


Courtesy of TTT project: Approved for Public Release

Multiple Airspace Operations and Safety Program (AOSP) Projects Support the AAM Mission

Air Traffic Management eXploration (ATM-X)

- Digital information sharing concepts & platforms
- **Airspace frameworks, constructs**, and services to support sUAS, Urban Air Mobility (UAM), remote cargo, and ETM operations



System Wide Safety (SWS)

- Concepts and **requirements** for **safety** services that provide data and information to different participants in AAM
- Development of services & capabilities to assess and potentially mitigate hazards using safety assurance algorithms

Air Mobility Pathfinders (AMP)

- Unified concept, system requirements, and architecture for an integrated AAM ecosystem
- **Automation prototype** capability development for testing and demos with industry partners

Courtesy of the NASA AAM Mission Integration Office Approved for Public Release

Revolutionary Vertical Lift Technology Project



Develop and validate **tools**, **technologies**, and **concepts** to improve future **vertical lift** vehicles with a focus on UAM

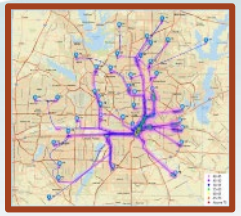
Courtesy of the NASA AAM Mission Integration Office: Approved for Public Release

NASA's RVLT Project Provides Tools and Design Practices for UAM eVTOL Vehicles

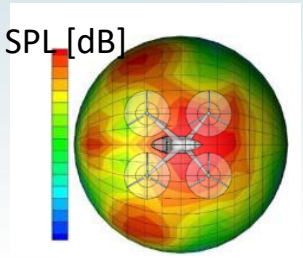
Noise Research



Human Response to UAM Noise



UAM Acoustic Impacts



Predictive Tools for UAM Noise



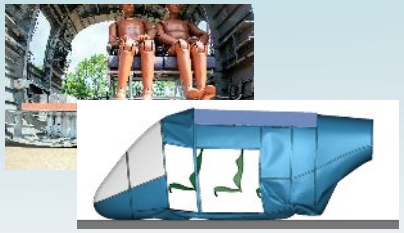
Safety Research



Electric Powertrain Reliability



Handling Qualities



Crashworthiness & Occupant Protection

Share technical insights and lessons learned

INDUSTRY — SDOs — ACADEMIA — FEDERAL AVIATION ADMINISTRATION

Courtesy of the NASA AAM Mission Integration Office: Approved for Public Release

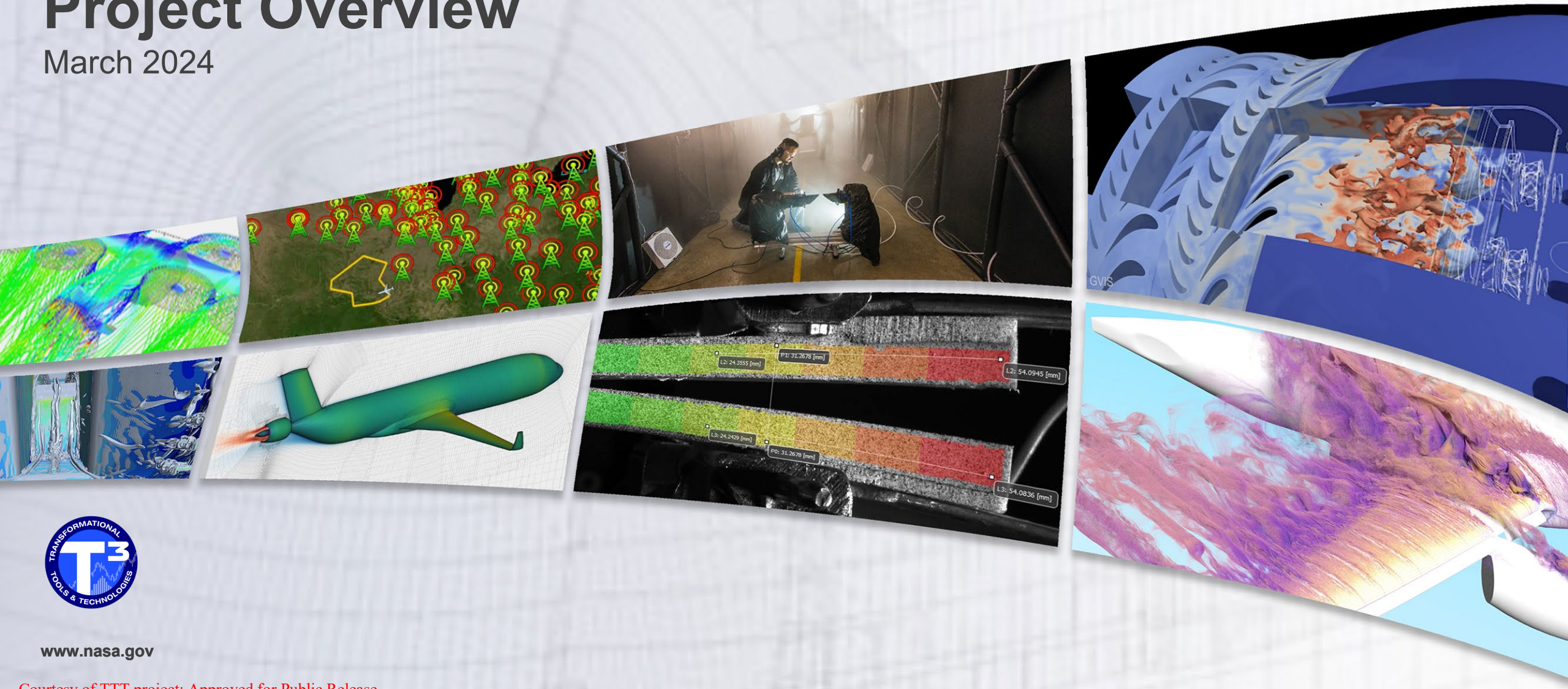
Inform eVTOL Community Regarding Vehicle Technologies

National Aeronautics and Space Administration

Transformational Tools and Technologies (T^3) Project

Project Overview

March 2024



www.nasa.gov

Courtesy of TTT project: Approved for Public Release

Transformational Tools & Technologies (T^3) Project

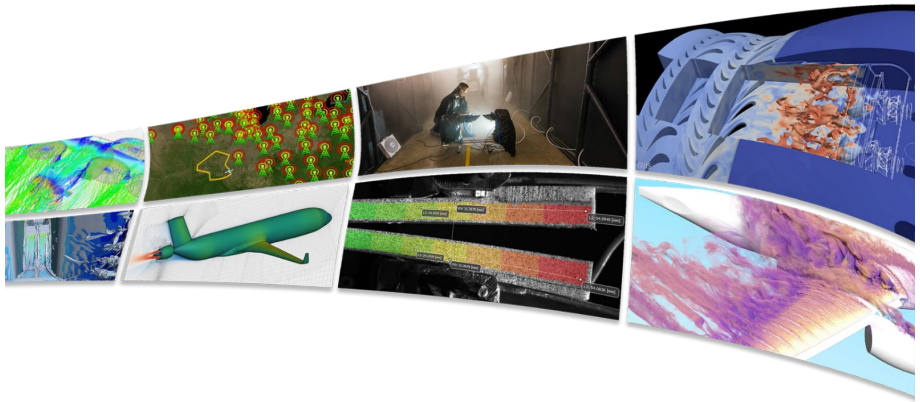
Discover, develop, and transition innovative solutions through foundational research and cross-cutting tools and technologies for the aviation community

T^3 is the home of **enduring research** within the ARMD portfolio, undertaking research that often focuses on **longer-term challenges**.

We sustain critical aeronautics core competencies for the Nation and conduct exploratory research with **breakthrough potential**.

Our tools and technologies provide innovations that impact aeronautics research throughout the community and **revolutionize air transportation**.

Delivering cutting-edge research, leading community vision studies, and providing valuable data and innovations



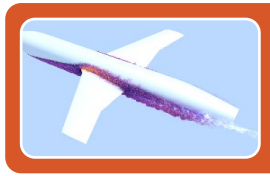
T^3 by the Numbers (FY23)

- 234 Publications
- 222 Presentations
- 100+ Partnerships
- 25 Awards
- 18 Patents/Licenses
- 6 ARMD Strategic Thrusts Supported
- 11 Mission Projects Supported
- 3 Sub-projects
- 8 Enduring Disciplines
- 193.9 FTE

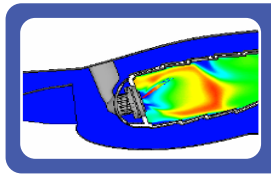
Courtesy of TTT project: Approved for Public Release

Enduring Disciplines

Sustaining Critical Core Competencies for the Nation



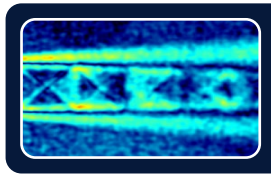
Revolutionary Computational Aerosciences (algorithms, meshing, transition, AI/ML)



Combustion (Modeling & Experiments)



Materials & Structures (EBC/CMC, SMAs, High Temperature Alloys)



Innovative Measurements (Cutting-edge measurement techniques)

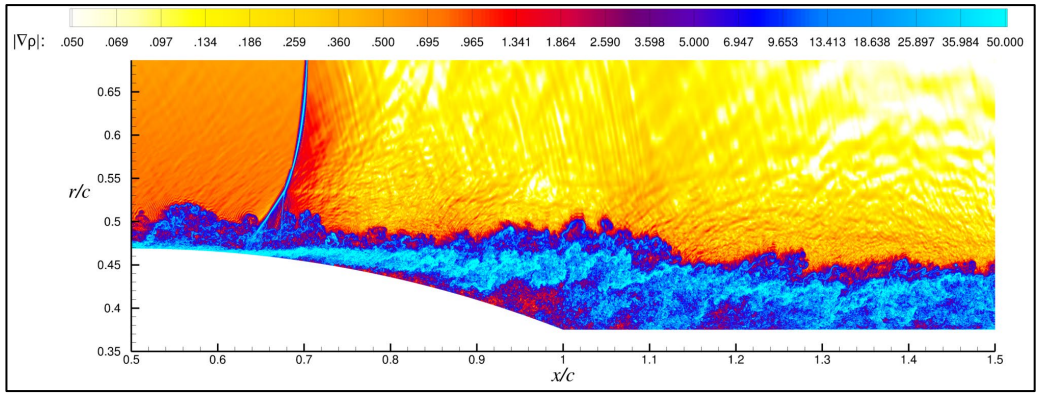


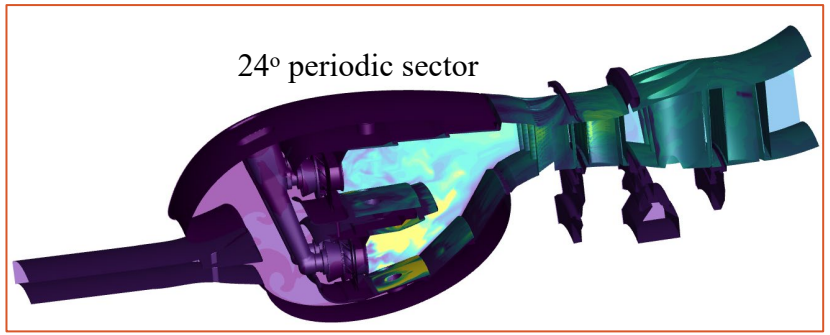
Multidisciplinary Design, Analysis & Optimization (Enduring tools, uncertainty)



Autonomous Systems (Advancing autonomy capabilities in aeronautics)







Courtesy of TTT project: Approved for Public Release

Three Sub-projects Aligned with ARMD Priorities

Executing multidisciplinary projects to apply concepts in a system-level context

Foundational Electrified Aircraft Propulsion

Enable the performance, reliability & durability of electrified propulsion systems by conducting enduring research & developing innovative materials, components, tools & methods

Sub-project Research

- **Battery system** architecture design and testing
- Potential battery materials identification
- Aviary open-source aircraft design tool
- High **voltage power cables** model for electric materials
- **Propulsion controls** – energy management control hardware-in-the-loop

M&S – Propulsion Controls

Reduced Life Cycle Cost

Reduce the life cycle cost of aircraft to enable the U.S. aircraft industry to stay competitive worldwide

Sub-project Research

- **Certification by Analysis** (CbA) with computational fluid dynamics tools
- Community-sourced resources for High Lift Common Research Model (CRM-HL)
- Icing tools to validate simulation
- Computational Materials-informed Qualification and Certification (Q&C) of additive manufacturing (AM) materials
- Researching materials to reduce weight and improve performance

Computational Aerospace – Icing – M&S

Revolutionary Aviation Mobility

Provide leading edge tools, technologies, and research findings to enable increasingly autonomous AAM transportation in the UML-4+ timeframe

Sub-project Research

- **m:N operational roadmap** and critical tool and technique research
- **Human autonomy teaming**
- Intelligent contingency management
- Crowdsourcing aviation sensing data
- Efficient design & testing of AAM vehicles
- **Distributed sensing**
- Communication, navigation & surveillance

AS – Communications, Navigation & Surveillance – Flight Controls

Courtesy of TTT project: Approved for Public Release

Multi-Vehicle (m:N) Operations in the National Airspace

Addressing Barriers to Scaling Emerging Aviation Operations

Enable scalable operations for AAM through development of an m:N operational approval roadmap supported by community coordination and critical tool & technique research



m:N = Small number of humans (m) operates or supervises many autonomous aircraft (N)

m:N operations enables Advanced Air Mobility (AAM)

- Enables a viable AAM market
- Makes AAM accessible for the general public and underserved areas
- Provides effective ways to deploy aircraft for public good missions

Perform research to address barriers to m:N operations:

- Developing technologies for increasingly autonomous aircraft
- Capabilities and principles that facilitate humans and machines working and thinking better together

→ Release of publicly available tools and data from NASA research activities to accelerate the maturation of AAM

Lead m:N Working Group with members from NASA, industry, academia, and regulatory organizations
Goal: coalesce around a common operating model and roadmap to operational approval

→
- Deliver m:N operational approval roadmap
- Coordinated relevant research, demos, data, standardized operational schemes & coordinated advocacy

wisk
BOEING
zipline
Sandia National Laboratories
ODU
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN
Georgia Tech
RICE
Università degli Studi di Napoli Federico II
AIAA SHAPING THE FUTURE OF AEROSPACE
RTCA
ASTM INTERNATIONAL

Courtesy of TTT project: Approved for Public Release

Advanced Air Mobility

Tackling fundamental Advanced Air Mobility (AAM) challenges with a multidisciplinary approach

Multi-Vehicle (m:N) Operations

- **Why**: Address barriers to **scaling emerging aviation operations** for AAM
- Performing research to address barriers and enable a system with significantly more vehicles than humans through m:N operations
- Leading an **m:N Working Group** to achieve a common operating model and roadmap to operational approval

60+ WG Participants across government, industry & academia

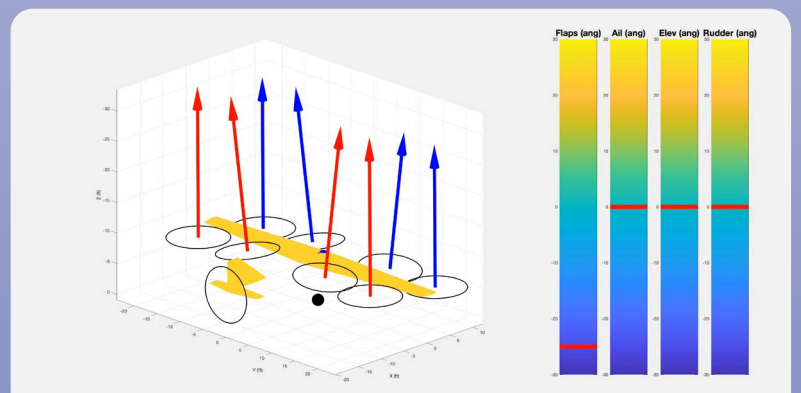


Remote Operations for Autonomous Missions (ROAM) Operations Center at LaRC supports m:N research

Lift + Cruise Vehicle Full Flight Example

Hover => Departure => Cruise => Land

- 2 Moving & 1 Stationary Obstacle
- Aileron Degradation (~103 secs)
- System Identification
- Turbulence



Intelligent Contingency Management Discoveries

- **Why**: Rules-based contingency management (CM) will not cover all possible off-nominal conditions. Smarter systems enable additional safety for complex, unplanned scenarios or unknown unknowns.
- Developed state-of-the-art solutions for scenarios (i.e., 3 intruders, weather) and mitigation decisions based on current and projected vehicle capability
- Released Generic UAM (GUAM) simulation to partners

Exploring next-gen autonomous vehicle technologies to enable smarter, safer AAM ecosystem

Partners

ATM-X/PAAV

Georgia Tech

University of Illinois Urbana-Champaign

Courtesy of TTT project: Approved for Public Release

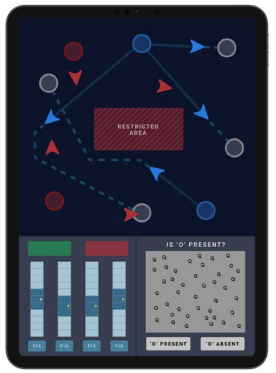
Advanced Air Mobility

Tackling fundamental Advanced Air Mobility (AAM) challenges with a multidisciplinary approach

Human Autonomy Teaming Research

- **Why**: As autonomy increases, need to carefully consider human behavior. It will require humans and machines to work and think together in new and different ways.
- Conducting **Human-in-the-Loop (HITL)** studies to inform safe design of multi-vehicle human-autonomy teaming systems

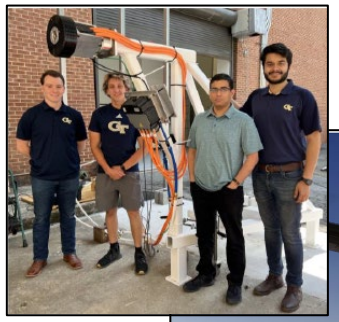
Informing the design of a safe, scalable, profitable AAM future



HATTB UX screen shot

Human Autonomy Teaming Task Battery (HATTB)

HATTB provides general research community with an open-source capability to study human-autonomy teaming factors relevant to supporting scalable m:N ops



Students with Propeller Test Stand at GT



Research Aircraft for eVtol Enabling techNologies (RAVEN)

- **Why**: Lack **of publicly-shareable engineering** and flight data to help address multiple technical barriers related to **novel eVTOL** aircraft
- Collaborating with Georgia Tech to design, build, and fly a mid-scale uncrewed research aircraft at modest cost and in a relevant timeline

Open Access Data for AAM eVTOL Concepts

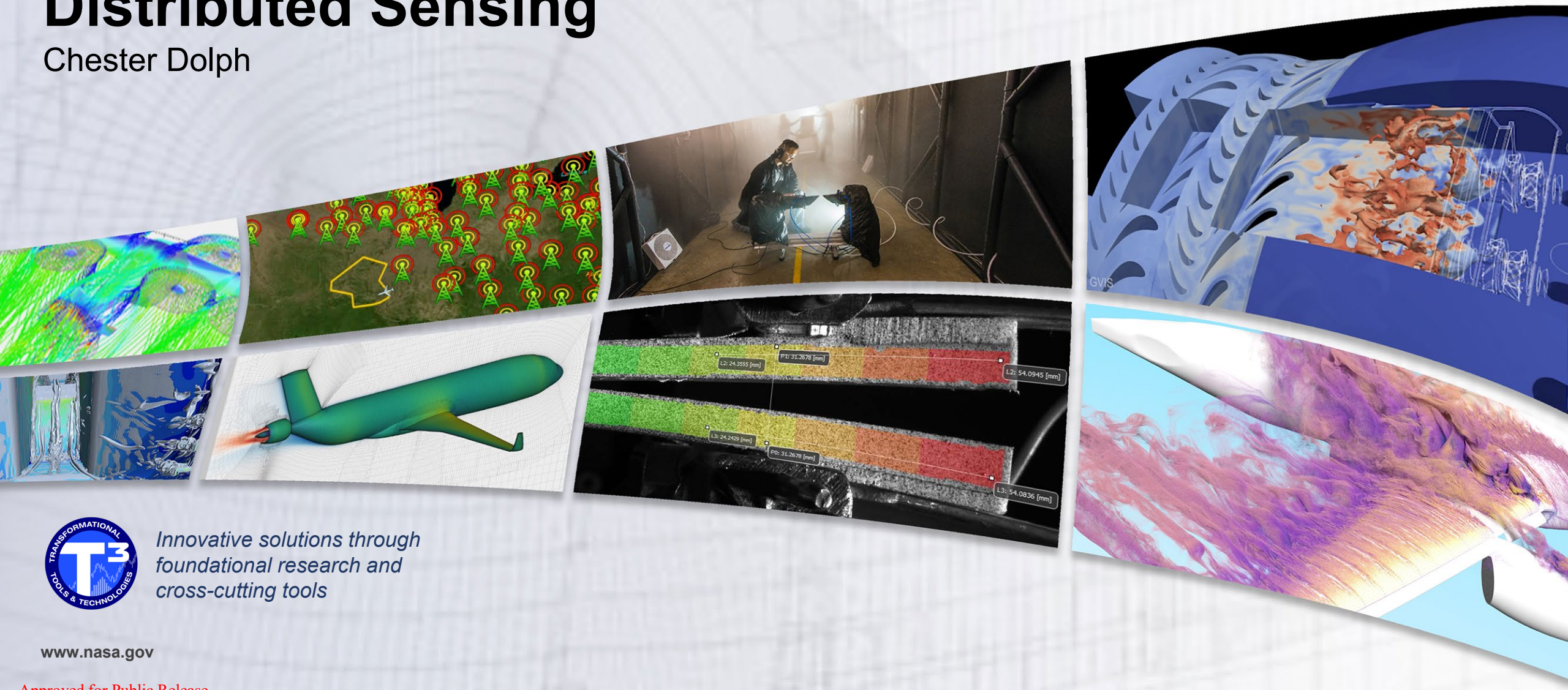
Courtesy of TTT project: Approved for Public Release

National Aeronautics and Space Administration

Transformational Tools and Technologies (T^3) Project

Distributed Sensing

Chester Dolph



Innovative solutions through foundational research and cross-cutting tools

www.nasa.gov

Approved for Public Release

Motivation

Distributed sensing of aircraft in traffic corridors and vertiports for UAS/SUAS is needed for:

- **Onboard collision avoidance**
- **Augment air traffic systems to confirm position information reported over communication links**
- **In event of malfunctioning or interrupted communication links between centralized traffic management system and SUAS/UAS**
- **Detecting non-cooperative SUAS & UAS**
- **Enable precision navigation systems using ground-based sensors for landing**
- **Safety critical nature of UAS and the long-term goal of flying in cities**

Approved for Public Release

Distributed Sensing

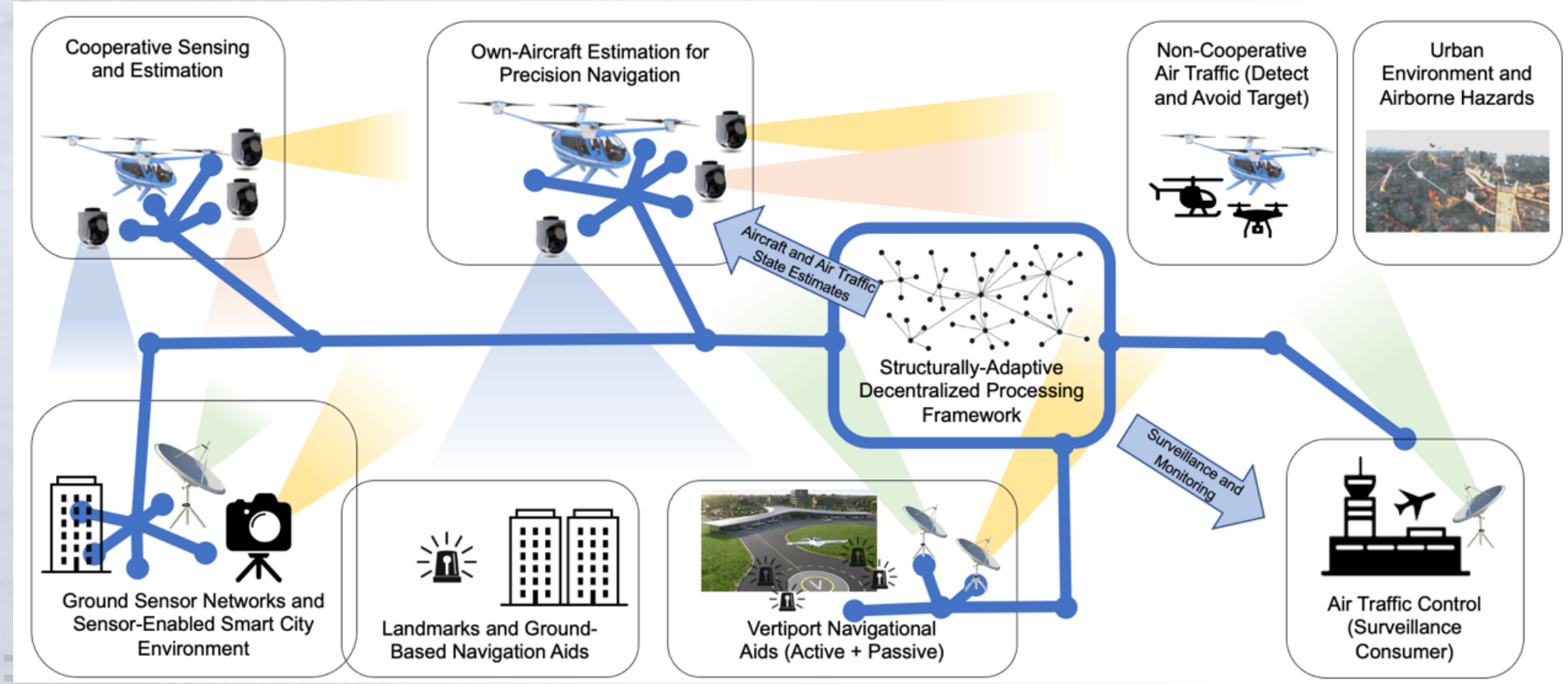
Outline

1. **Overview**
2. **Strategic Plan**
3. **Detect, Track, Classify**
    1. Vision-based Detection and Tracking Algorithm of Aircraft
    2. Deep classifier with adversarial learning of General Aviation, fixed-wing small unmanned aircraft systems (sUAS), multirotor sUAS, and birds
    3. Trajectory Classification
    4. Evaluation of optical-radar detection tracking system prototype in ground-to-air experiment with target multirotor sUAS
4. **Summer 2023 Experiments**
5. **Preliminary Analysis**
6. **Upcoming Experiments**

Approved for Public Release

Overview

Develop distributed sensing architecture



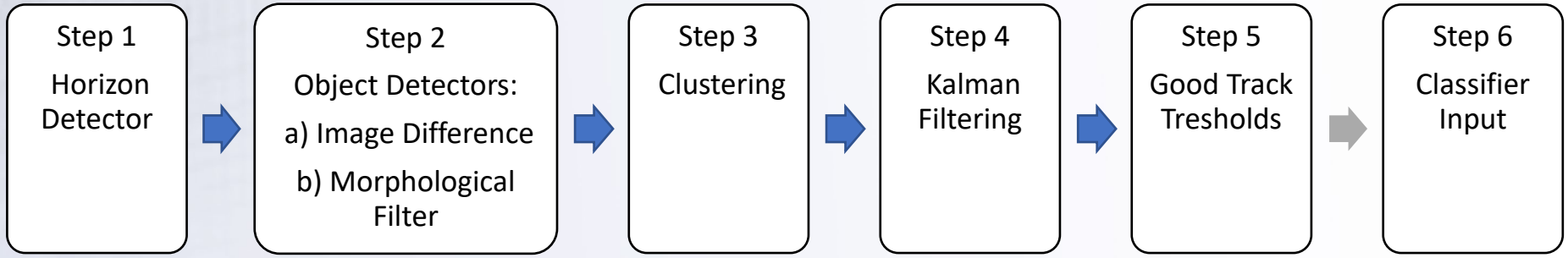
C. Ippolito, E. Kawamura, G. Gorospe, W. Holforty, K. Kannan, V. Stepanyan, T. Lombaerts, N. Brown, A. Jaffe and C. Dolph, "A Structurally-Adaptive Framework for Distributed Airborne Sensing over Real-time Collaborative Information Sharing Networks," in AIAA SciTech, Washington DC, 2023.

Strategic Plan

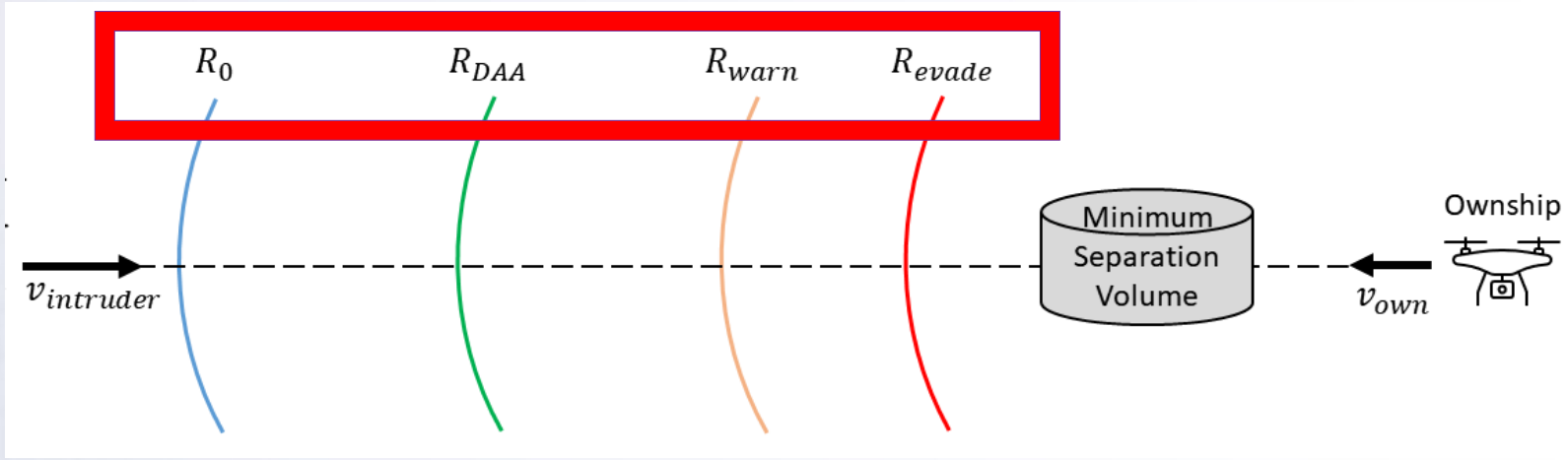
- ✓ <FY21 **Single modality** development for vision/radar detect, track, and classify (UTM)
- ✓ FY22 **fusion with camera and radar**, planning distributed sensor node experiments, and integration of sensors on SUAS
- ✓ FY23 **experiments** to **develop distributed** detect, track, and classify algorithms
- ❑ FY24 **Develop distributed** detect, track, and classify algorithm. Preliminary real-time detect and track system. Flight test DS sensing **urban-like environment**.
- ❑ FY25 Develop **real-time distributed** sensor system and **integrate** with **ROAM** to provide enhanced airspace management needed for AAM/UAM/SUAS

Approved for Public Release

Vision-based detect, track, and classify algorithm







Chester Dolph, Corey Ippolito, Louis Glaab, Michael Logan, Loc Tran, Danette Allen, Mahbubul Alam, Khan Iftekharuddin. Adversarial Learning Improves Vision-Based Perception from Drones with Imbalanced Datasets. *Journal of Aerospace Information Systems*, 2023.

Chester Dolph, Cyrus Minwalla, Louis Glaab, Michael Logan, Danette Allen, Khan Iftekharuddin. Detection and Tracking of Aircraft from Small Unmanned Aerial Systems. *Journal of Aerospace Information Systems*, 2021.

Approved for Public Release

Experimental Methodology: Flight Patterns
Head-On Patterns

Worst Case Scenarios



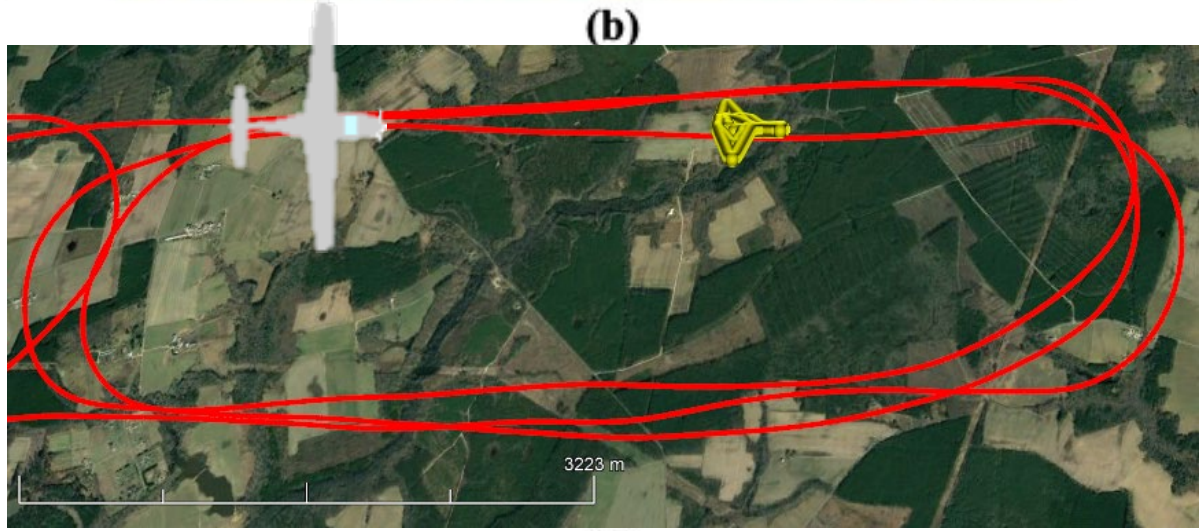
(a)



(b)



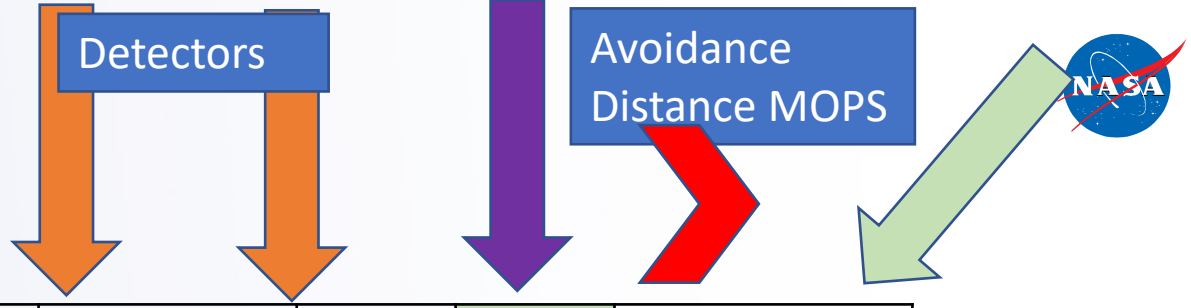
(c)



(d)

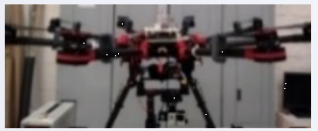
GT=Ground Truth (hand-labeled image)
POT= Pixels On Target

DAA Analysis



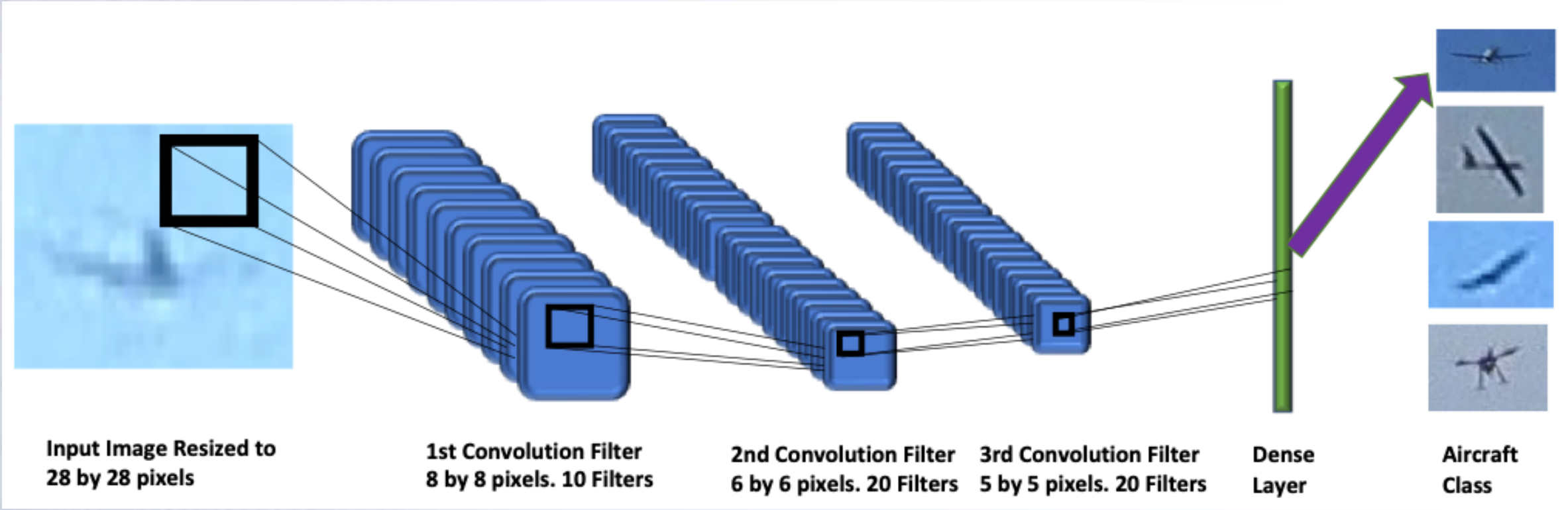
Sortie Number and Description	GT [m]	POT for GT w x h	Diff first detection [m]	Morph first detection [m]	KF R_{det} [m]	R_{evade} [m]	KF t_{detect} [sec]
1 Tempest Head-on	1136	4x3	1136	1136	1022	840	36.5
2 Tempest Head-on	1107	3x3	1093	1107	1078	840	38.5
3 Tempest Head-on	1006	3x4	999	999	980	840	35.0
4 GA Head-on	3406	3x1	3406	3406	3247	1890	51.5
5 GA Head-on, near miss*	858	608x161	812	858	721	1890	11.4
6 Tempest Departing Collision Volume	1067	8x10	1067	1067	987	840	35.3
7 Tempest Departing Collision Volume	1168	4x10	1166	1166	1150	840	41.1
8 GA Head-on	2401	4x3	2401	2401	2297	1890	36.5
9 GA Head-on	2514	3x3	2514	2514	2404	1890	38.2
10 GA Head-on	3053	3x2	2994	2994	2936	1890	46.6
Avg GA	2446	NA	2425	2435	2321	1890	37.3
Avg. sUAS	1097	NA	1092	1095	1043	840	36.8

Approved for Public Release

Aircraft	Type	Image	Dimensions w x l x h (m)	Manufacture	Ground Speed (m/s)	Max Takeoff Weight (kg)
Tempest (intruder)	fixed wing sUAS		3.2 x 1 x 0.3	UASUSA	18	20
MigLH (ownship), cameras mounted on wingtips	sUAS multirotor					
SR22 (intruder)	GA		11.68 x 7.92 x 2.72	Cirrus	53	1,633
Tarot 1 & 2 (intruder/ownship)	sUAS multirotor		0.96 x 0.960 x 0.96	Tarot		
ISAAC (ownship), Camera mounted on gimbal on bottom	sUAS multirotor		1 x 1 x 0.3	DJI	10	11

Approved for Public Release

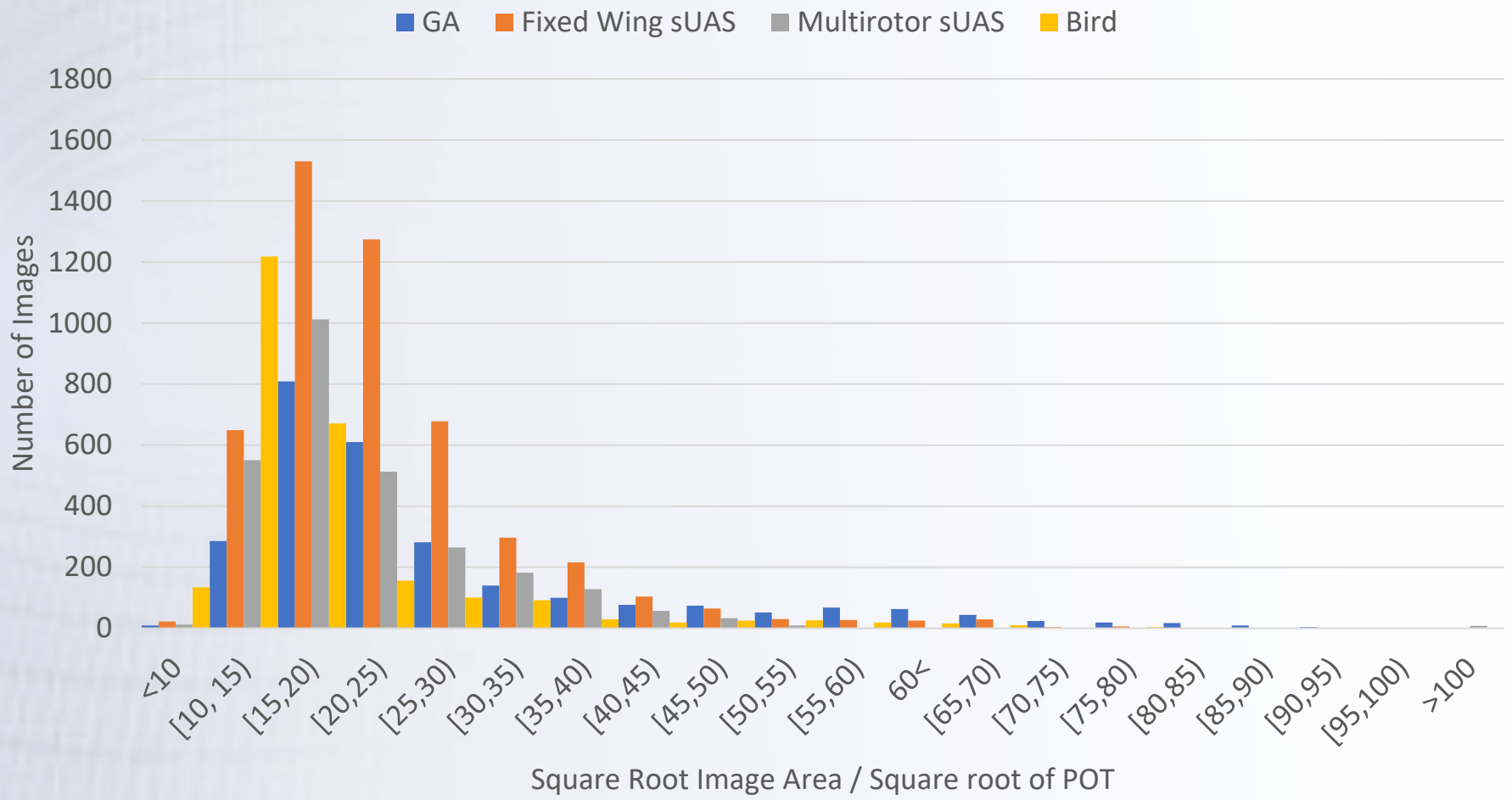
CNN Classifier



Approved for Public Release

Dataset

Low resolution, small object detection



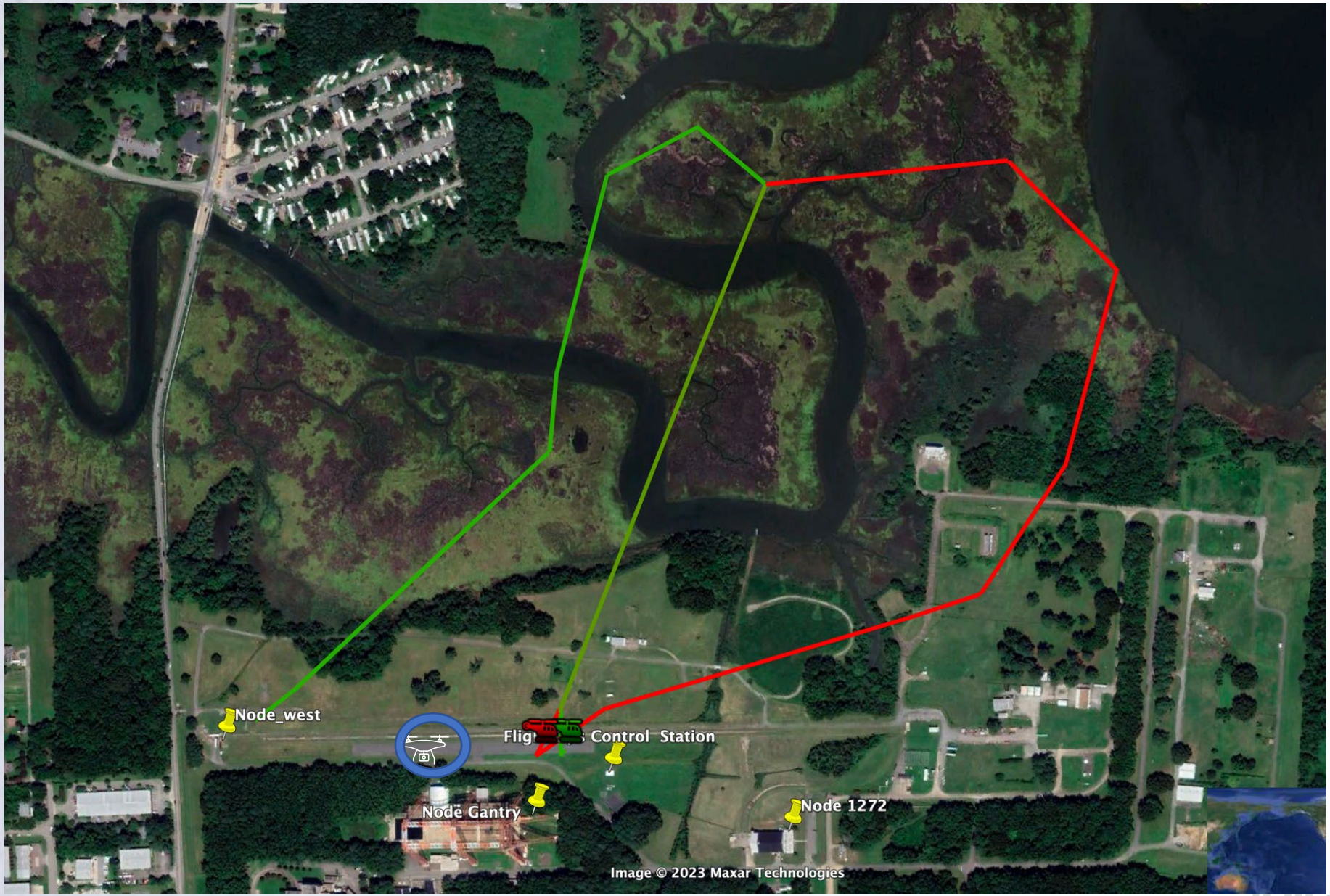
Approved for Public Release

Results: Avoidance Analysis

10 fold Cross Validation Testing

		Model	No. Aircraft	No. fixed	No. GA	No. multi	Overall Acc.
Balanced Training	$R_{evade} > R_{Image}$	CNN	7787	3338	2279	2170	77.2
		CNN+AdvL	7787	3338	2279	2170	59.7
		YOLOv4 Aircraft	4113	1775	1207	1130	63.0
	$R_{evade} <= R_{Image}$	CNN	2631	1619	409	603	84.3
		CNN+AdvL	2631	1619	409	603	63.0
		YOLOv4 Aircraft	697	271	140	285	80.1
Imbalanced Training	$R_{evade} > R_{Image}$	CNN	7787	3338	2279	2170	51.8
		CNN+AdvL	**7787**	**3338**	**2279**	**2170**	**76.0**
		YOLOv4 Aircraft	4113	1775	1207	1130	70.9
	$R_{evade} <= R_{Image}$	CNN	2631	1619	409	603	70.0
		CNN+AdvL	**2631**	**1619**	**409**	**603**	**87.7**
		YOLOv4 Aircraft	697	271	140	285	79.8

Approved for Public Release



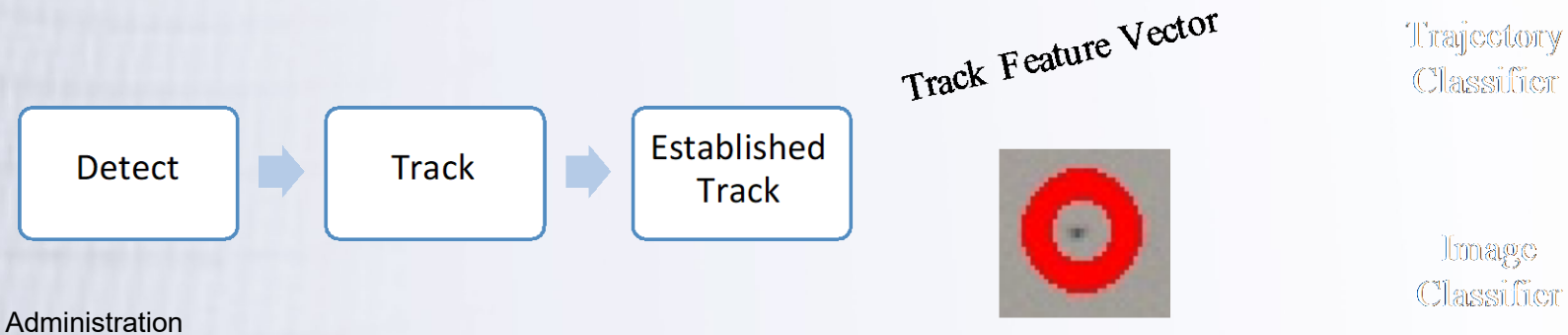
Approved for Public Release

Distributed Computer Vision and Machine Learning for Sensing SUAS and UAS

Chester Dolph

Develop novel perception strategies for detecting, tracking, and classifying aircraft and birds from ground and onboard systems using radar and camera sensor

- Vision tracking of aircraft
- Deep neural network development for classifying aircraft using vision and radar
- Develop trajectory classification strategies for single and multiple modalities
- SUAS flight testing: payload design with consideration toward operational environment of sensors and algorithm capabilities



Approved for Public Release

Instrumentation



Gantry



Rooftop 1262



Wythe Creek



Alta X



Certain Range

Approved for Public Release

Instrumentation

Node Description	Camera Model	Camera Resolution (pixels)	Horizontal and vertical Lens FOV (degrees)	Radar model	RADAR FOV (degree)
Building 3 Camera	123S6C-C	4096 × 3000 Each camera	47.3 × 36.1 Each lens	Echoflight	120 × 80
Ground Tripod	123S6C-C	4096 × 3000	62.5 × 47.8	Echoflight	120 × 50
Rooftop Tripod	122S6C-C	4096 × 3000	62.5 × 47.8	Echoflight	120 × 50
Onboard Payload	123S6C-C	4096 × 3000	62.5 × 47.8	Echoflight	120 × 60

Node	GPS Receiver	Data Logging Computer	Cellular Modem
3 Camera	GPS-RTK-SMA ZED-F9P (Ublox)	3 Xaviers with Contech Rogue breakout Board	RUTX11
Ground	GPS-RTK-SMA ZED-F9P (Ublox)	Xaviers with Contech Rogue breakout Board	RUTX11
Rooftop	GPS-RTK-SMA ZED-F9P (Ublox)	NUC 11 Performance Mini Desktop Computer,	RUTX11
Onboard Payload	GPS-RTK-SMA ZED-F9P (Ublox)	Xaviers with Contech Rogue breakout Board	RUTX11

Approved for Public Release

FY23 TTT+HDV Dataset

10 TTT lead flights partnered HDV, 19 HDV lead flights

			Node Location					
Acquisition Number	Date	Time	Wythe	Roof	Gantry	Payload	# HDV SUAS	Note
1	5/17/23	15:16	Y	Y	Y	N	3	Preliminary Checkout
2	5/23/23	15:05	N	2	N	N	2	DASC
3	5/23/23	16:30	N	2	N	N	2	DASC
4	5/25/23	13:23	2	N	N	N	2	DASC
5	5/25/23	14:45	2	N	N	N	2	DASC
6	5/25/23	16:02	2	N	N	N	2	DASC
7	6/6/23	14:00	2	1	1	G	4	DASC
8	6/6/23	15:46	2	1	1	G	4	DASC
9	6/8/23	12:10	1	1	N	N	5	DS-HDV
10	6/9/23	11:00	1	1	1	G	5	DS-HDV
11	6/9/23	13:37	1	1	1	G	5	DS-HDV
12	6/9/23	15:00	1	1	1	G	4	DS-HDV
13	6/9/23	16:10	1	1	1	G	4	DS-HDV
14	6/13/23	13:15	1	1	1	Y	2	DS-HDV

Approved for Public Release

FY23 TTT+HDV Dataset

			Node Location					
Acquisition Number	Date	Time	Wythe	Roof	Gantry	Payload	# HDV SUAS	Note
15	6/13/23	14:36	1	1	1	Y	2	DS-HDV
16	6/13/23	15:36	1	1	1	Y	2	DS-HDV
17	6/14/23	11:53	1	1	1	N	1	DS-HDV
18	7/11/23	10:54	1	1	1	Y	2	DS-TTT-SAA
19	7/11/23	11:51	1	1	1	Y	2	DS-TTT-SAA
20	7/11/23	14:59	1	1	1	Y	2	DS-TTT-SAA
21	7/11/23	15:10	1	1	1	Y	2	DS-TTT-SAA
22	7/14/23	13:47	1	1	1	N	4	DS-HDV
23	7/14/23	14:45	1	1	1	N	4	DS-HDV
24	7/26/23	10:40	1	1	1	Y	2	DS-TTT-SAA
25	7/26/23	11:32	1	1	1	Y	2	DS-TTT-SAA
26	7/26/23	13:35	1	1	1	Y	2	DS-TTT-SAA
27	7/26/23	14:17	1	1	1	Y	2	DS-TTT-SAA
28	7/26/23	14:53	1	1	1	Y	2	DS-TTT-SAA
29	7/26/23	15:30	1	1	1	Y	2	DS-TTT-SAA

Approved for Public Release

AAM HDV +TTT

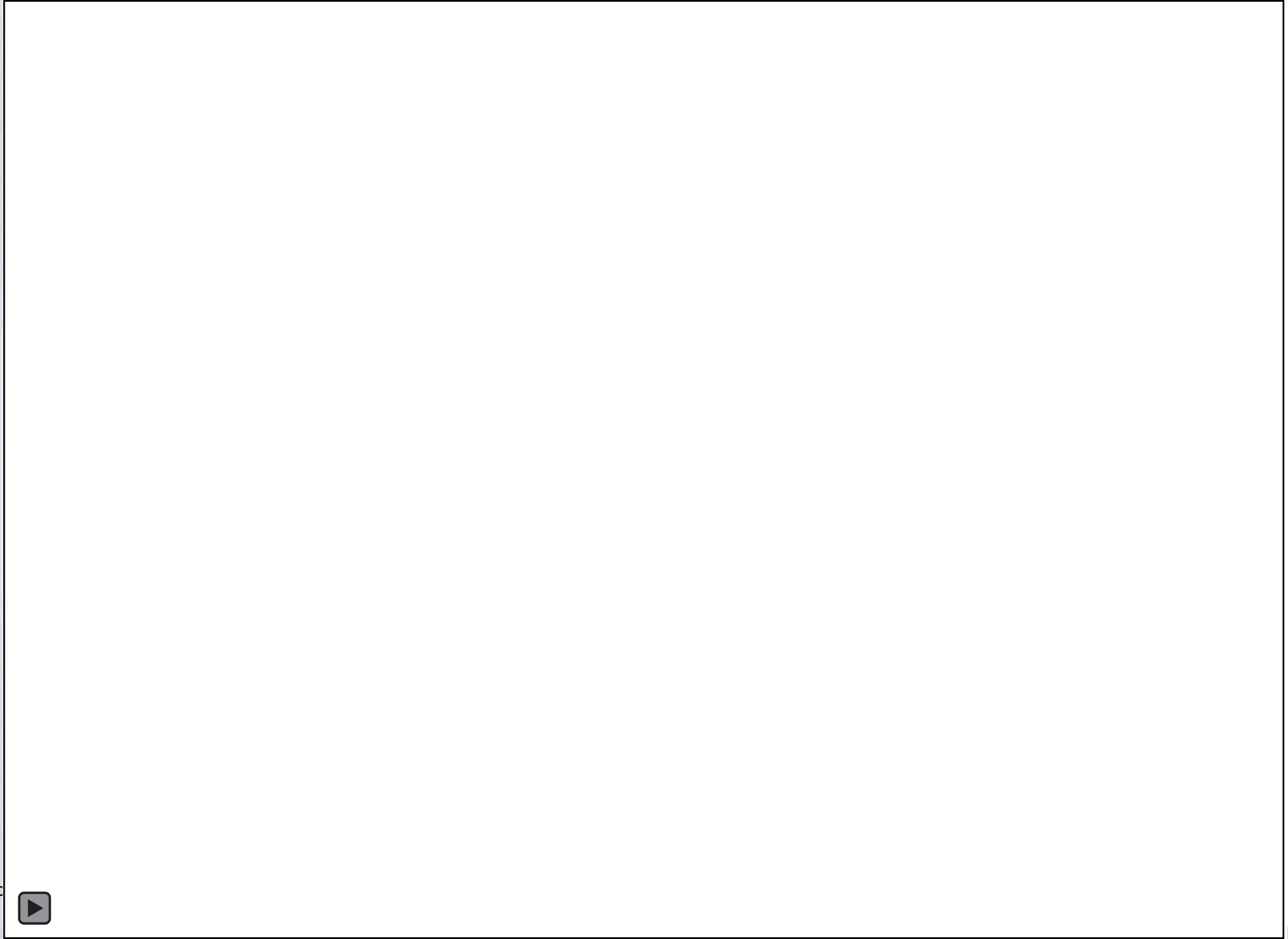


TTT+ HDV Joint Experiments



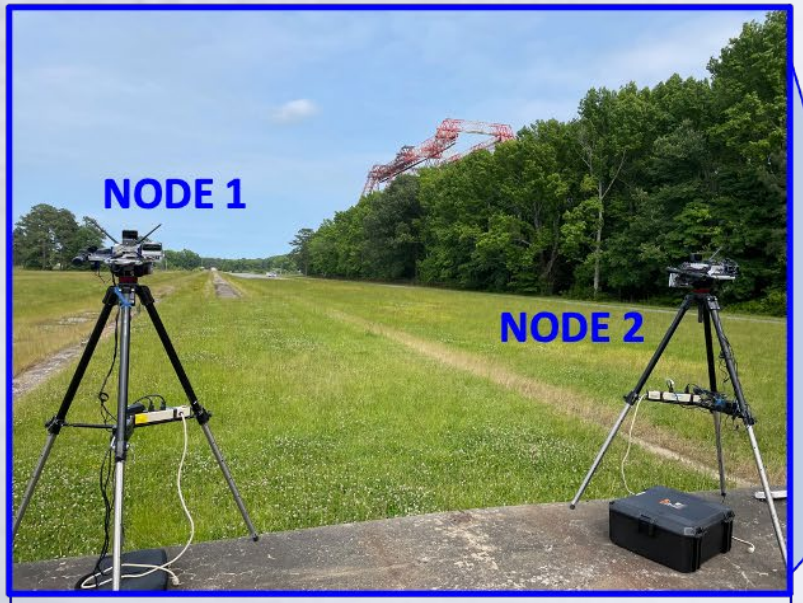
Approved for Public Release

2023_7_11_11_54_60

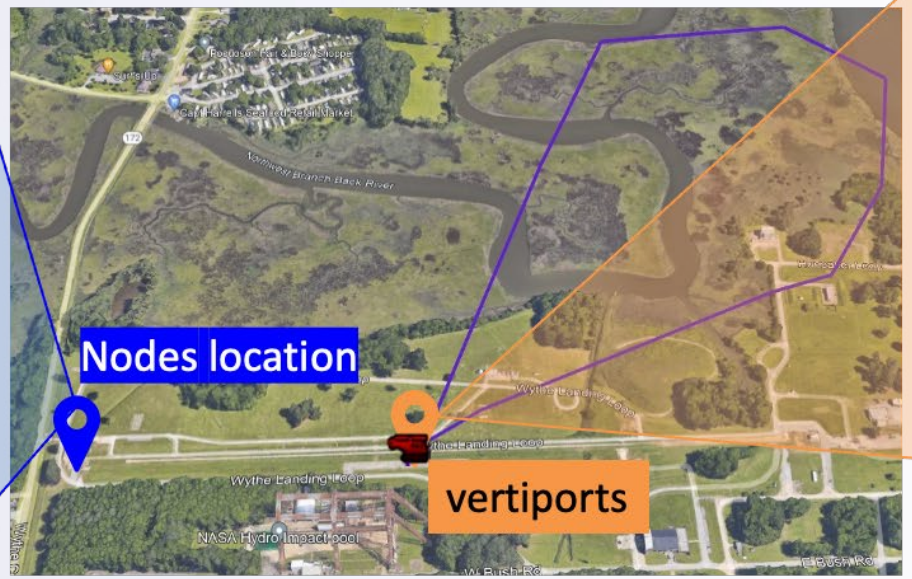


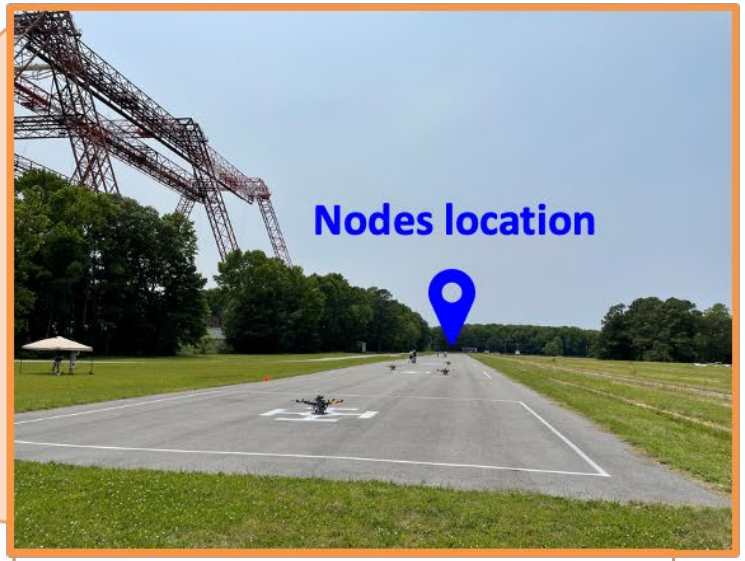
Approved for Public Release

NASA+ UNINA Benchmark



Nodes are pointed towards the runway to independently collect data during the UAV operations





Four small UAVs, flying along repeated pattern, are used as targets of the sensing application

Federica Vitiello, Flavia Causa, Roberto Opromolla, Giancarmine Fasano, Chester Dolph, Thomas Lombaerts, Corey Ippolito. Assessing Performance of Radar/Visual Fusion Techniques for Ground-to-Air Surveillance in Advanced Air Mobility: an Experimental Approach. *IEEE/DASC 2023*. (**International Conference**)

Approved for Public Release

NASA+ UNINA Vision Benchmark

UNINA

Vision TRACKING PERFORMANCE	Averaged over all NUs		
	Coverage (%)	az rms (°)	el rms (°)
Departure	99.92	0.381	0.177
Return	97.29	0.371	0.683

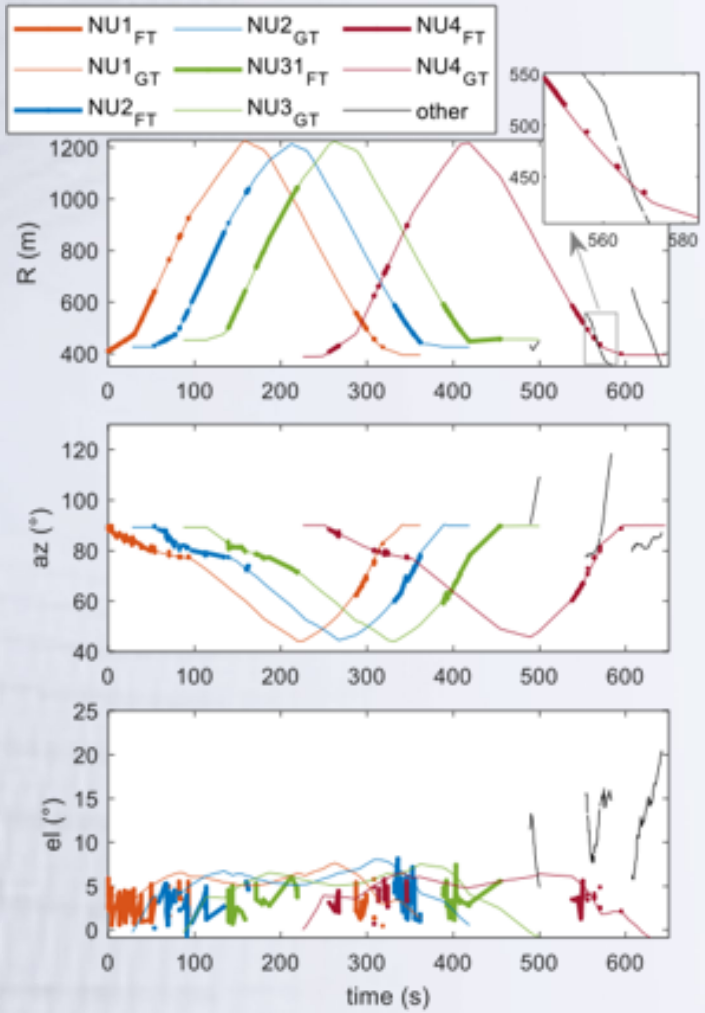
NASA

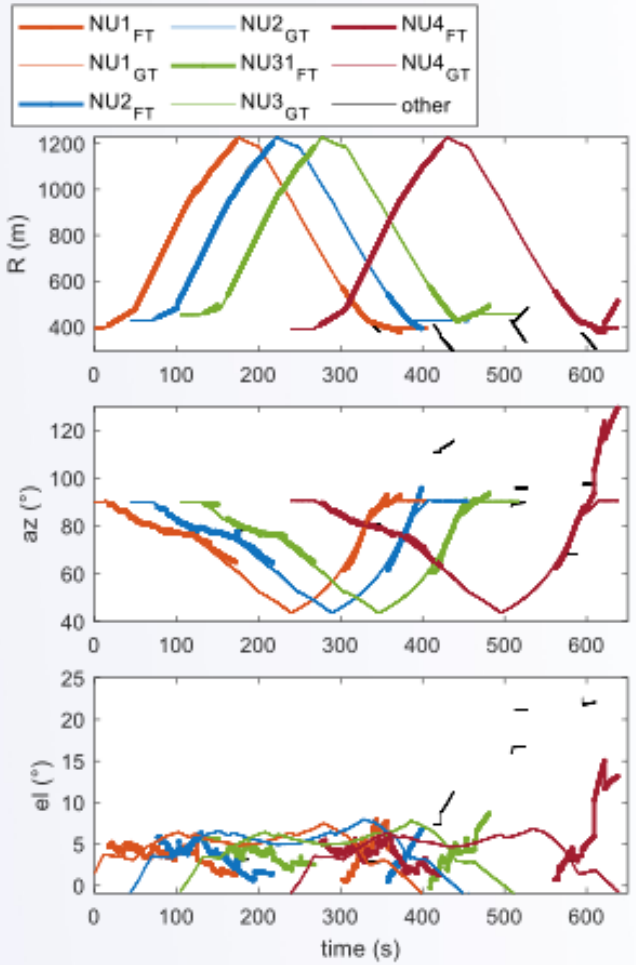
Vision TRACKING PERFORMANCE	Averaged over all NUs		
	Coverage (%)	az rms (°)	el rms (°)
Departure	96.10	0.159	0.479
Return		0.407	1.250

Federica Vitiello, Flavia Causa, Roberto Opromolla, Giancarmine Fasano, Chester Dolph, Thomas Lombaerts, Corey Ippolito. Assessing Performance of Radar/Visual Fusion Techniques for Ground-to-Air Surveillance in Advanced Air Mobility: an Experimental Approach. *IEEE/DASC 2023*.

Approved for Public Release

Manufacture vs UNINA Radar Benchmark





Federica Vitiello, Flavia Causa, Roberto Opromolla, Giancarmine Fasano, Chester Dolph, Thomas Lombaerts, Corey Ippolito. Assessing Performance of Radar/Visual Fusion Techniques for Ground-to-Air Surveillance in Advanced Air Mobility: an Experimental Approach. *IEEE/DASC 2023.*

Approved for Public Release

FY2024

Wythe Creek



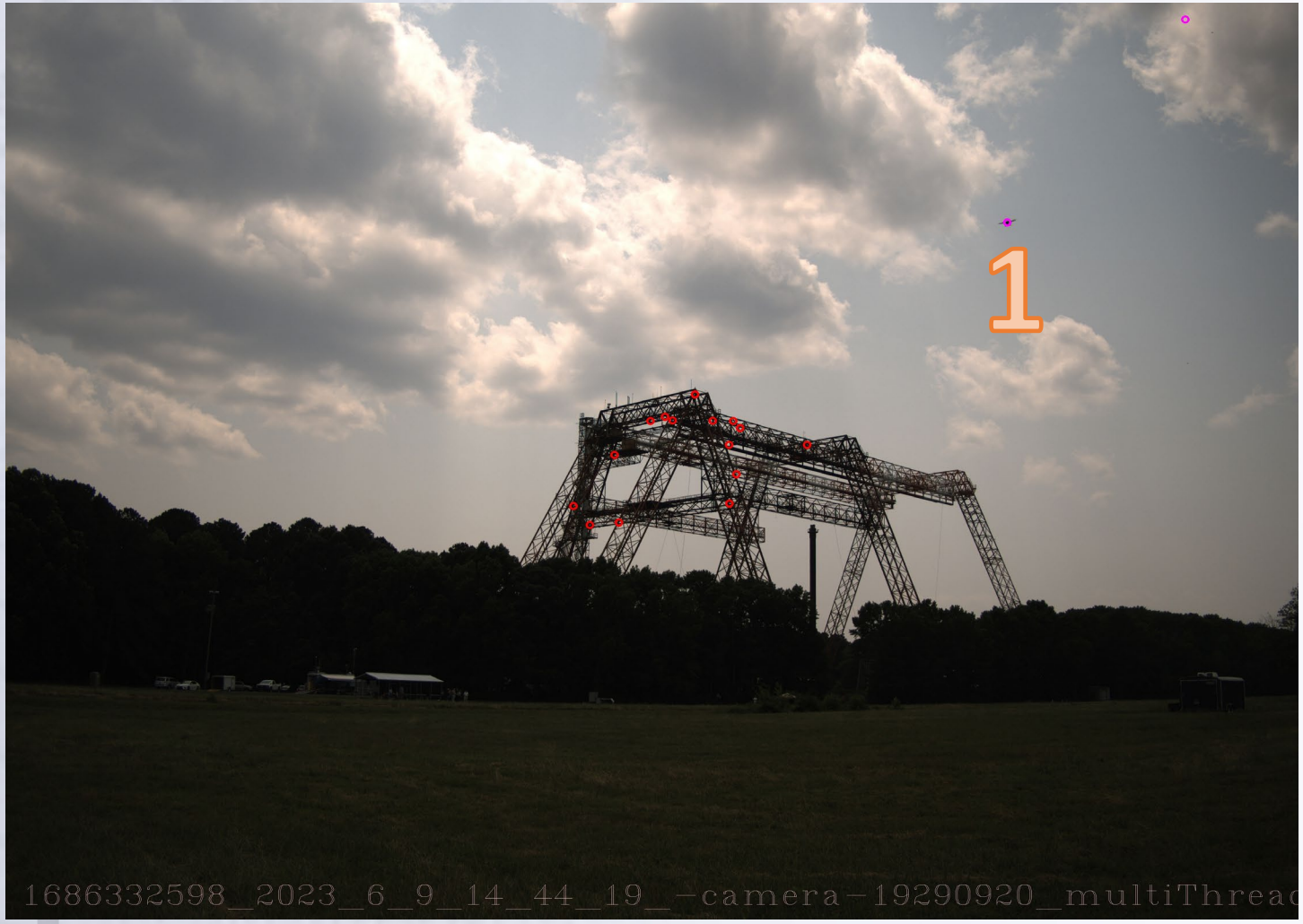
All SUAS visible to human eye detected by Algorithm

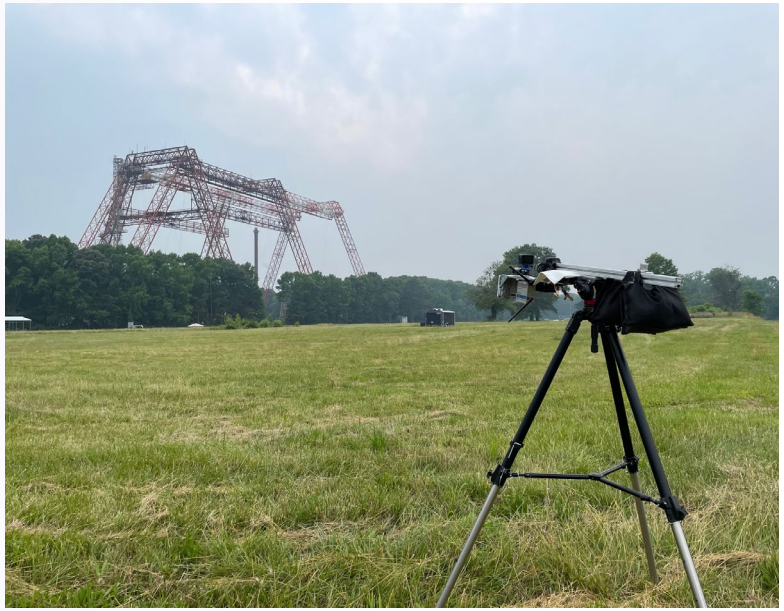


Approved for Public Release

FY2024

Payload on tripod





- All SUAS visible to human eye detected by Algorithm
- This is the payload version of the sensor attached to tripod

Approved for Public Release

FY2024

Gantry Left



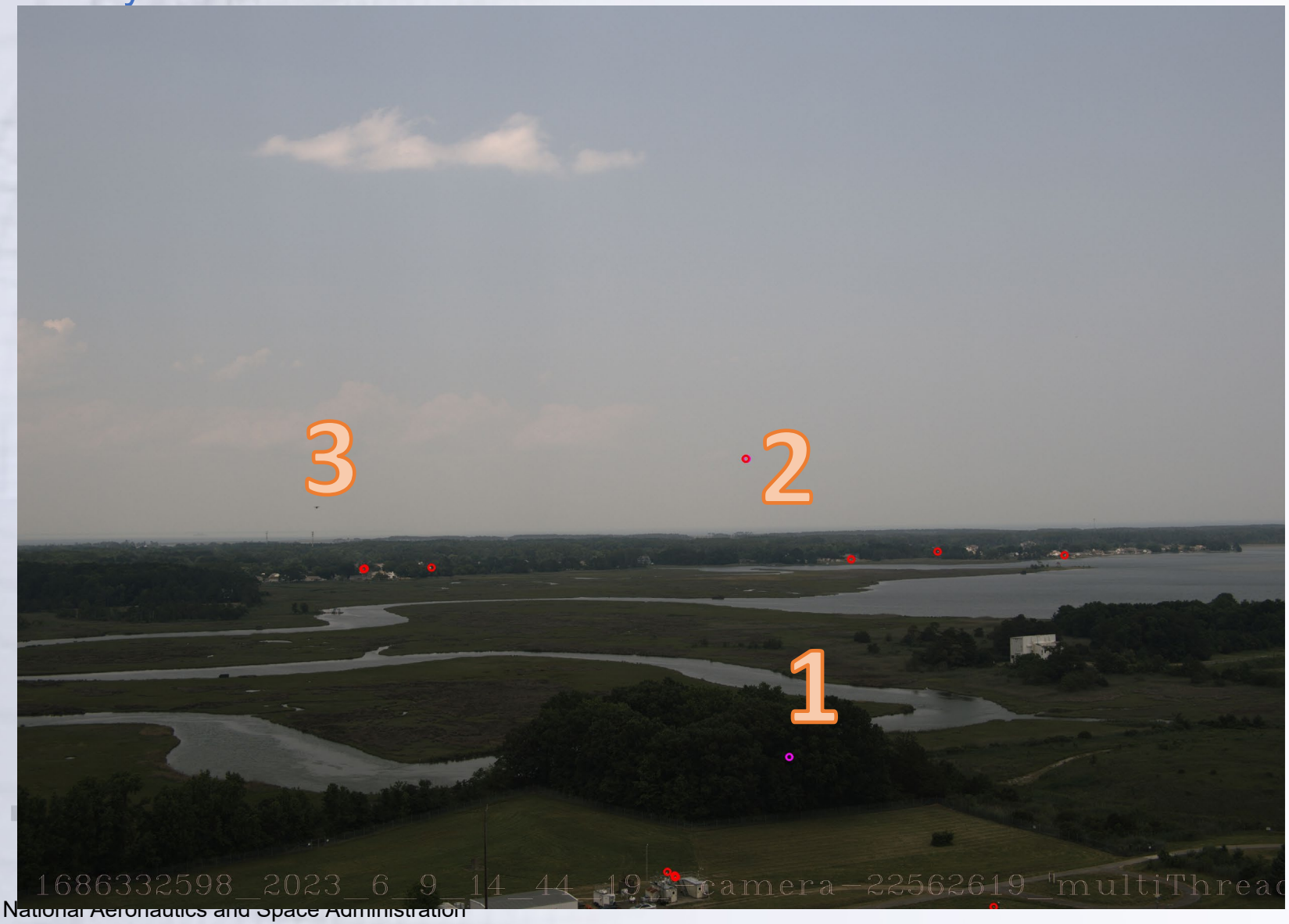


- All SUAS visible to human eye detected by Algorithm
- Successful below the horizon detection

Approved for Public Release

FY2024

Gantry Center





- 2 SUAS detected by Algorithm, 1 SUAS missed… detected from another camera vantage point
- Successful below the horizon detection

Approved for Public Release

FY2024

Gantry Right



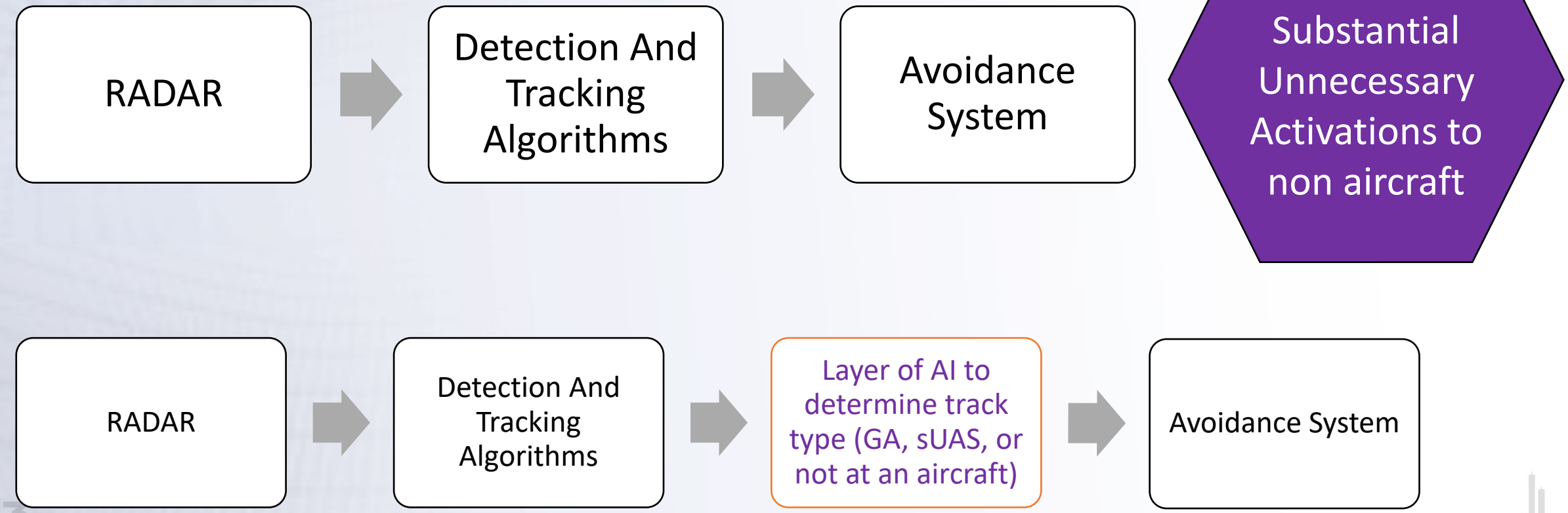


- 2 SUAS detected by Algorithm, 1 SUAS missed… detected from another camera vantage point
- Successful below the horizon detection

Approved for Public Release

Trajectory Classification

UTM Project: ownship SUAS, intruder fixed-wing SUAS or GA

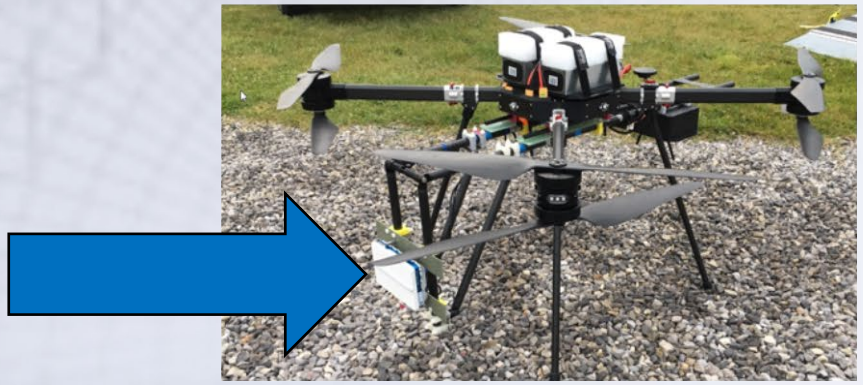


Chester Dolph, George Szatkowski, **Henry Holbrook**, Chris Morris, Larry Ticatch, Mahyar R Malekpour, Robert McSwain. Aircraft Classification Using RADAR from small Unmanned Aerial Systems for Scalable Traffic Management Emergency Response Operations. *AIAA Aviation,* 2021.

Approved for Public Release

Aircraft, RADAR, and Field Testing Results

BFD 1400



C172



Tempest



Intruder aircraft	Scenario	Number of Runs	Number of times ICAROUS Activates on intruder Aircraft	Number of times ICAROUS Activates on non intruder aircraft
Tempest	Head On	6	4	2
Tempest	Intersecting	4	3	0
C172	Head On	6	4	4
C172	Intersecting	9	5	5
Total	>	25	16	11

83

Approved for Public Release

UAS Testing Objective 1A. Near-Target Sensing Configuration



- Preliminary/notional sensor locations are identified.
- Key
  - C : Visual Camera
  - R : Radar
  - I : Infrared
  - M : Multispectral
  - A : Infrasonic
- Assumptions
  - Hover flights over takeoff/landing point within operations area
  - Assuming hover flights are low altitude, less than 20 feet AGL

Approved for Public Release

UAS Testing Objective 1B. Far-Target Sensing Configuration



- Preliminary/notional sensor locations are identified.
- Key
  - C : Visual Camera
  - R : Radar
  - I : Infrared
  - M : Multispectral
  - A : Infrasonic
- Assumptions
  - Hover flights over takeoff/landing point within operations area
  - Assuming hover flights are low altitude, less than 20 feet AGL

Approved for Public Release

Related Publications

1. Chester Dolph, Corey Ippolito, Louis Glaab, Michael Logan, Loc Tran, Danette Allen, Mahbubul Alam, Khan Iftekharuddin. Adversarial Learning Improves Vision-Based Perception from Drones with Imbalanced Datasets. *Journal of Aerospace Information Systems*, 2023.
2. Chester Dolph, Cyrus Minwalla, Louis Glaab, Michael Logan, Danette Allen, Khan Iftekharuddin. Detection and Tracking of Aircraft from Small Unmanned Aerial Systems. *Journal of Aerospace Information Systems*, 2021. Thomas Lombaerts, Keerthana Kannan, Evan Kawamura, Chester Dolph, Vahram Stepanyan, George Gorospe, Corey Ippolito. Distributed Wireless Sensor Fusion Based Object Tracking for Autonomous Advanced Air Mobility Operations. *AIAA SciTech 2024.*
3. Vahram Stepanyan, Corey Ippolito, Keerthana Kannan, Evan Kawamura, Thomas Lombaerts. Wendy Holforty, Chester Dolph. Flight Test Design and Implementation for Independent Surveillance of an Airspace Through a Distributed Ground Sensing Network. *AIAA SciTech 2024.*
4. Evan Kawamura, Keerthana Kannan, Thomas Lombaerts, Vahram Stepanyan, Chester Dolph, Corey Ippolito. Ground-Based Vision Tracker for Advanced Air Mobility and Urban Air Mobility. *AIAA SciTech 2024.*
5. Evan Kawamura, Thomas Lombaerts, Vahram Stepanyan, Keerthana Kannan, Chester Dolph, Corey Ippolito. Hierarchical Mixture of Experts for Advanced Air Mobility Flight Phase Classification. *AIAA SciTech 2024.*
6. Corey Ippolito, Evan Kawamura, George Gorospe, Wendy Holforty, Keerthana Kannan, Vahram Stepanyan, Nelson Brown, Chester Dolph. Distributed Sensing for Monitoring and Independent Surveillance of Urban Airspaces and Corridors. *AIAA SciTech 2024.*
7. **Federica Vitiello**, Flavia Causa, Roberto Opromolla, Giancarmine Fasano, Chester Dolph, Thomas Lombaerts, Corey Ippolito. Experimental testing of data fusion in a distributed ground-based sensing network for Advanced Air Mobility. *AIAA SciTech 2024.*
8. Chester Dolph, Thomas Lombaerts, Corey Ippolito, Vahram Stepanyan, Evan Kawamura, Keerthana Kannan, George Szatkowski, Todd Ferante, Christopher Morris, **Federica Vitiello**, Flavia Causa, Roberto Opromolla, Giancarmine Fasano. Distributed Sensor Fusion of Ground and Air Nodes using Vision and Radar Modalities for Tracking Multirotor Small Uncrewed Air Systems and Birds. *AIAA SciTech 2024.*
9. Chester Dolph, Louis Glaab, Michael Logan, Corey Ippolito, Kelley Hashemi. Position Correlated Vision Dataset from Multirtor and fixed-wing sUAS of General Aviation, fixed-wing sUAS, multirotor sUAS, and Bird. *IEEE/DASC 2023.* (**International Conference**)
10. **Federica Vitiello**, Flavia Causa, Roberto Opromolla, Giancarmine Fasano, Chester Dolph, Thomas Lombaerts, Corey Ippolito. Assessing Performance of Radar/Visual Fusion Techniques for Ground-to-Air Surveillance in Advanced Air Mobility: an Experimental Approach. *IEEE/DASC 2023.* (**International Conference**)
11. **Logan Dihel**, Chester Dolph, **Henry Holbrook**, Sandip Roy. Classification of Aerial Objects Using Likelihood Ratio Tests. *AIAA SciTech 2023.*
12. Evan Kawamura, Chester Dolph, Keerthana Kannan, Nelson Brown, Thomas Lombaerts, Corey Ippolito. VSLAM and Coplanar POSIT for Advanced Air Mobility Approach and Landing. *AIAA SciTech 2023.*
13. Evan Kawamura, Chester Dolph, Keerthana Kannan, Thomas Lombaerts, Corey Ippolito. Distributed Sensing and Computer Vision Methods for Advanced Air Mobility Approach and Landing. *AIAA SciTech 2023.*
14. Corey Ippolito, Kelley Hashemi, Evan Kawamura, George Gorospe, Wendy Holforty, Keerthana Kannan, Vahram Stepanyan, Thomas Lombaerts, Nelson Brown, A.J. Jaffe, Chester Dolph. Distributed Sensing and Advanced Perception Technologies to Enable Advanced Air Mobility. *AIAA SciTech 2023.*
15. Thomas Lombaerts, Keerthana Kannan, Evan Kawamura, Chester Dolph, Vahram Stepanyan, George Gorospe, Corey Ippolito. Distributed Ground Sensor Fusion Based Object Tracking for Autonomous Advanced Air Mobility Operations. *AIAA SciTech 2023.*
16. Keerthana Kannan, Joshua Baculi, Thomas Lombaerts, Evan Kawamura, George Gorospe, Wendy Holforty, Vahram Stepanyan, Chester Dolph, Nelson Brown. A Simulation Architecture for Air Traffic Over Urban Environments Supporting Autonomy Research in Advanced Air Mobility. *AIAA SciTech 2023.*
17. Sandip Roy, David N Petrizze, Mengran Xue, Chester Dolph, **Henry Holbrook**. Using Trajectory Smoothness Metrics to Identify Drones in Radar Track Data. *AIAA Aviation,* 2022.
18. Chester Dolph, Thomas Lombaerts, Evan Kawamura, Corey A Ippolito, Vahram Stepanyan, Khan Iftekharuddin, George Szatkowski, Robert McSwain, Chris Morris, Mahyar R Malekpour, Cyrus Minwalla. Ground to air testing of a fused optical-radar aircraft detection and tracking system. *AIAA SciTech,* 2022.
19. Vahram Stepanyan, Thomas Lombaerts, Chester Dolph, Nick B Cramer, Corey A Ippolito. Estimation With Range Depended Sensor Model. *AIAA SciTech,* 2022.
20. **Henry Holbrook**, **Paris Garrett**, **Nikhil Behari**, Chester Dolph, Christopher Morris, George Szatkowski. Aerial Object Trajectory Classification by Training on Flight Controller Data and Testing on RADAR Generated Tracks. *AIAA SciTech,* 2022.

Approved for Public Release

Links

https://www.faa.gov/sites/faa.gov/files/2022-08/UTM_ConOps_v2.pdf

https://www.faa.gov/sites/faa.gov/files/Urban%20Air%20Mobility%20%28UAM%29%20Concept%20of%20Operations%202.0_0.pdf

https://ntrs.nasa.gov/api/citations/20205011091/downloads/UAM%20Vision%20Concept%20of%20Operations%20UML-4%20v1.0.pdf

https://ntrs.nasa.gov/api/citations/20210016168/downloads/20210016168_MJohnson_VertiportAtmtnConOpsRprt_final_corrected.pdf

https://www.transportation.gov/sites/dot.gov/files/2023-07/Updated_Fact_Sheet_2023_on_State_and_Local_Regulation_of_Unmanned_Aircraft_Systems.pdf

https://sacd.larc.nasa.gov/uam-refs/

https://ntrs.nasa.gov/api/citations/20205007433/downloads/NASA-TP-2020-5007433.pdf

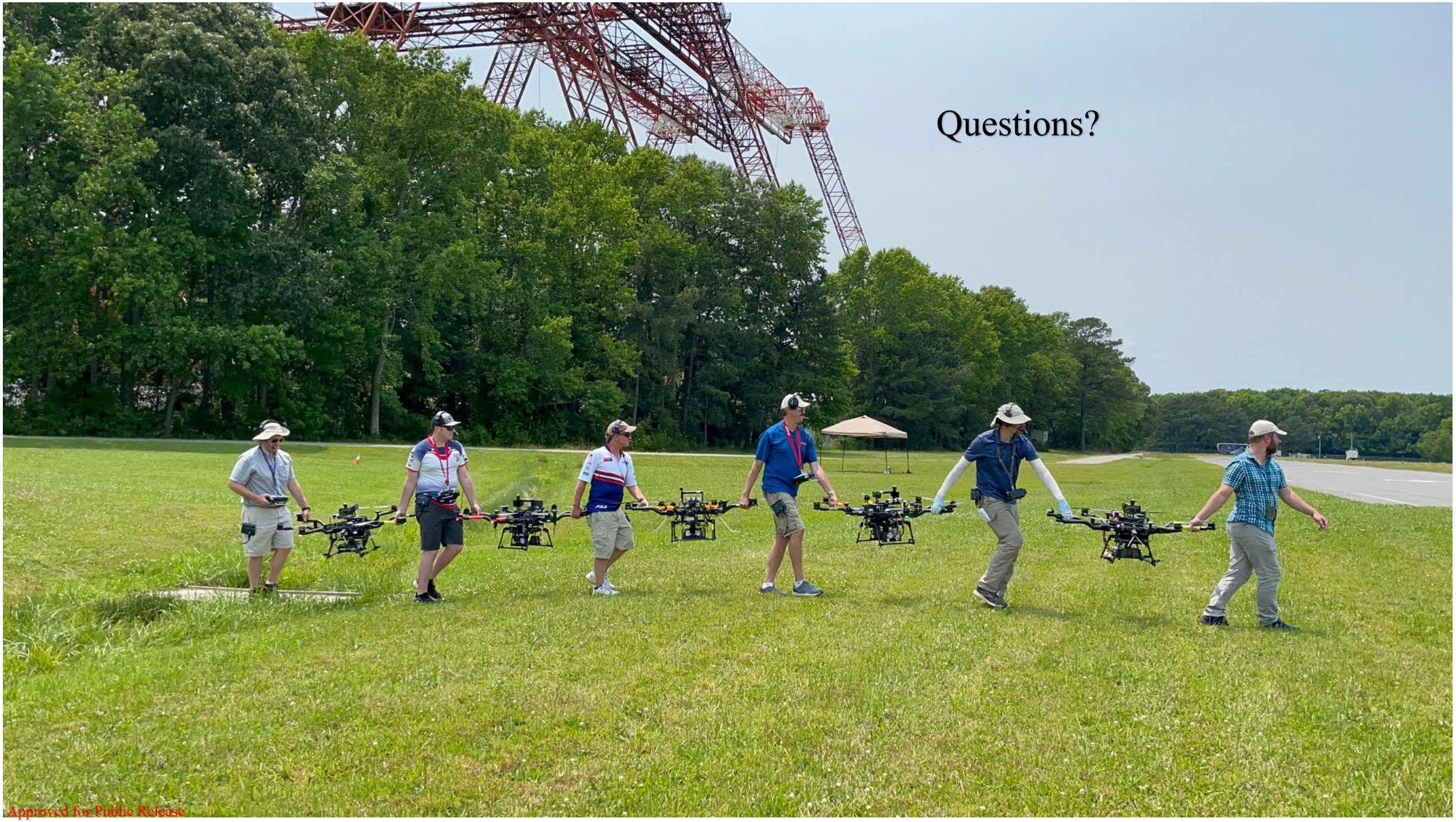
https://ntrs.nasa.gov/api/citations/20230002647/downloads/NASA-TM-20230002647_Final.pdf

Approved for Public Release

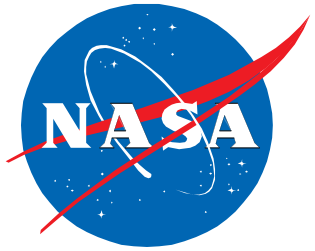
Acknowledgements

- Michael Patterson, Systems Analysis & ConOps Lead, AAM Mission Integration Office
- Nancy Mendonca, Deputy AAM Mission Integration Manager
- Bob Pearce, Associate Administrator for ARMD
- Jeffrey Homola, High Density Vertiport Project Lead
- Corey Ippolito, Distributed Sensing Team Lead
- Bryan Petty, High Density Vertiport Operations Lead
- Susan Gorton, Revolutionary Vertical Lift Technology Project Manager (retired)
- Mike Rogers, Transformational Tools and Technologies Project Manager

Approved for Public Release



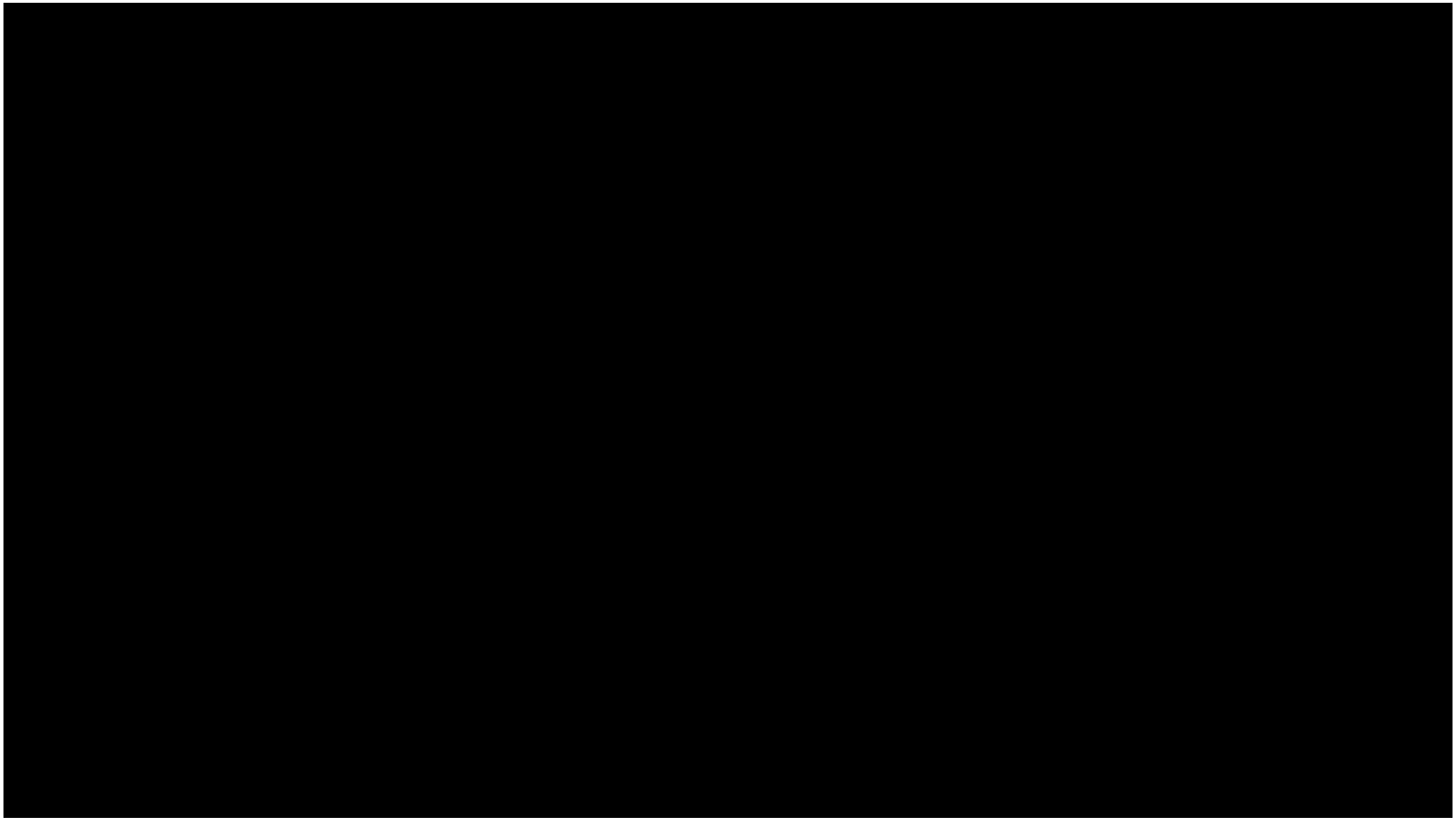
Approved for Public Release



Approved for Public Release



Approved for Public Release



Approved for Public Release