# Challenges in sensing small UAVs in low-altitude urban environments

## Insights from experimental tests at NASA Langley

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NASA Langley
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# Presentation Outline

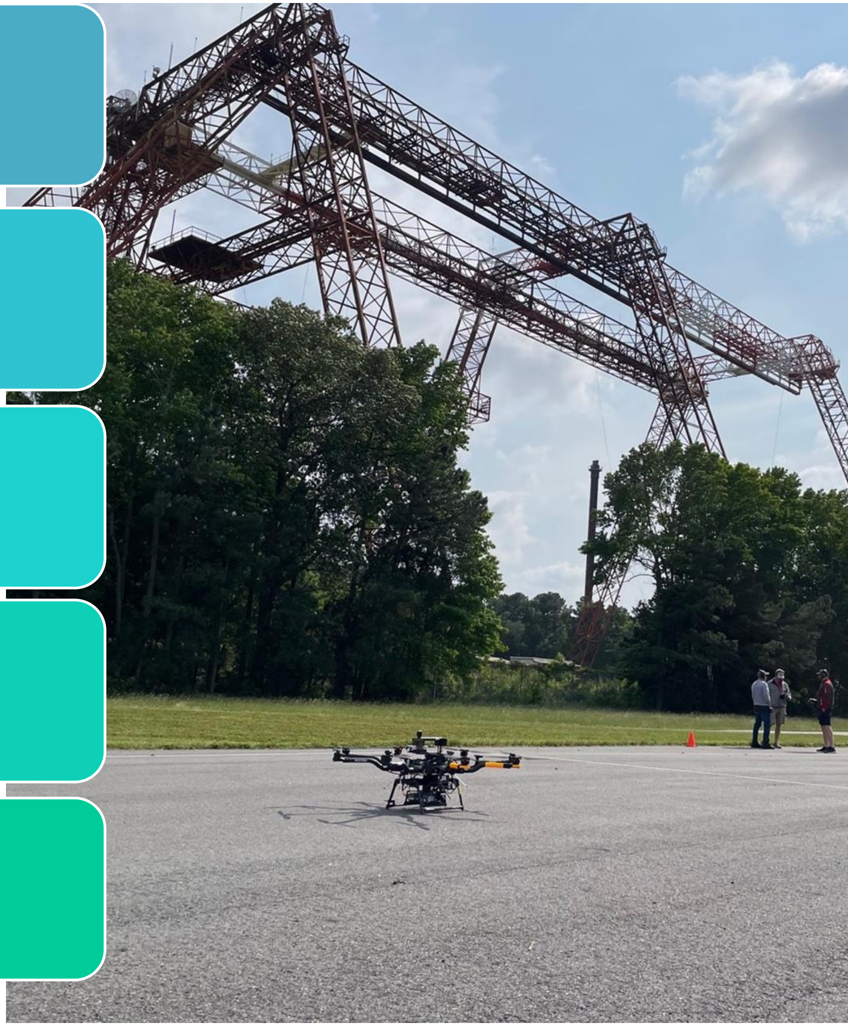
Research Framework

NASA-UNINA Collaboration

2025 Activities

Preliminary Results/Analyses

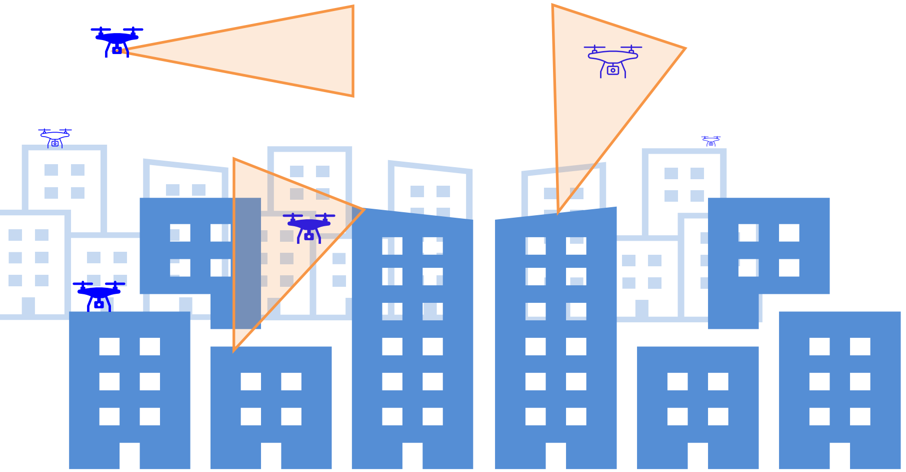
Conclusions



# Research Framework

**Advanced Air Mobility** (**AAM**) and **Urban Air Mobility** (**UAM**) envision high density operations of UAVs in and around urban areas.

**SURVEILLANCE** is essential to ensure airspace safety, traffic management and integration with conventional aviation systems



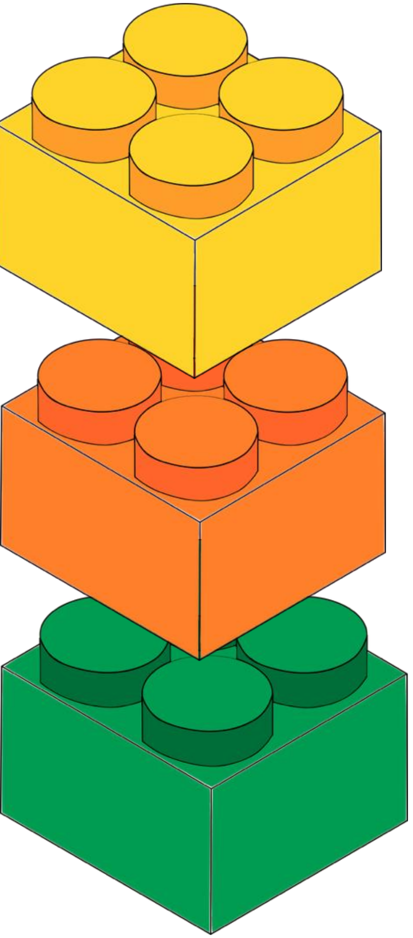
- **Small, low-altitude flying** targets,
- **Weakened or absent GPS** information broadcasting,
- **Non-cooperative** intruders
- **Cluttered** scenarios
- **Coverage limitations** in urban areas

Innovative sensing strategies are required

GNSS – Global Navigation Satellite System
UAV – Uncrewed Aerial Vehicle

# NASA-UNINA Collaboration
## Objective

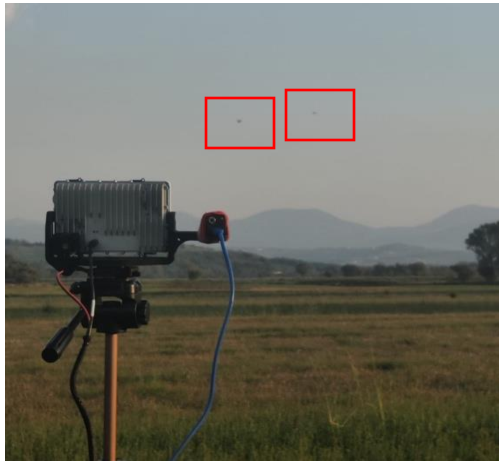
**Development and experimental validation of innovative sensing solutions for AAM/UAM**



Integrate detection and tracking in a **real-time** framework.

Use both **ground-based** and **airborne** experimental data to test the developed sensing strategies.

Collect data with **non-cooperative sensors** in relevant scenarios.
Radars and visual cameras observing the flight of multiple UAV in low altitude conditions.

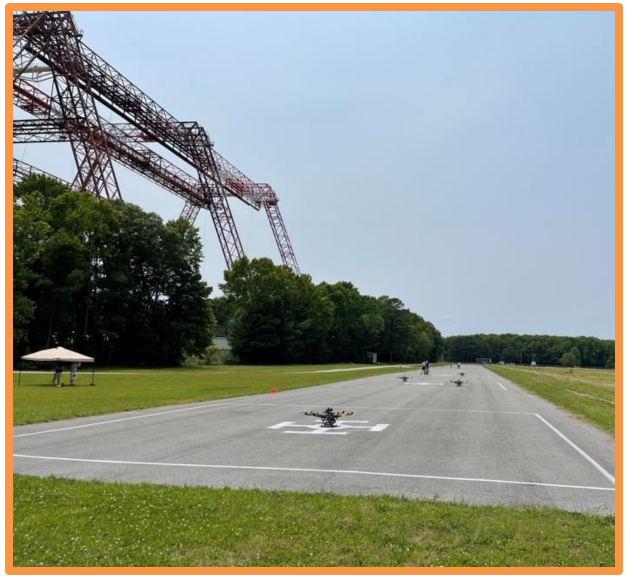


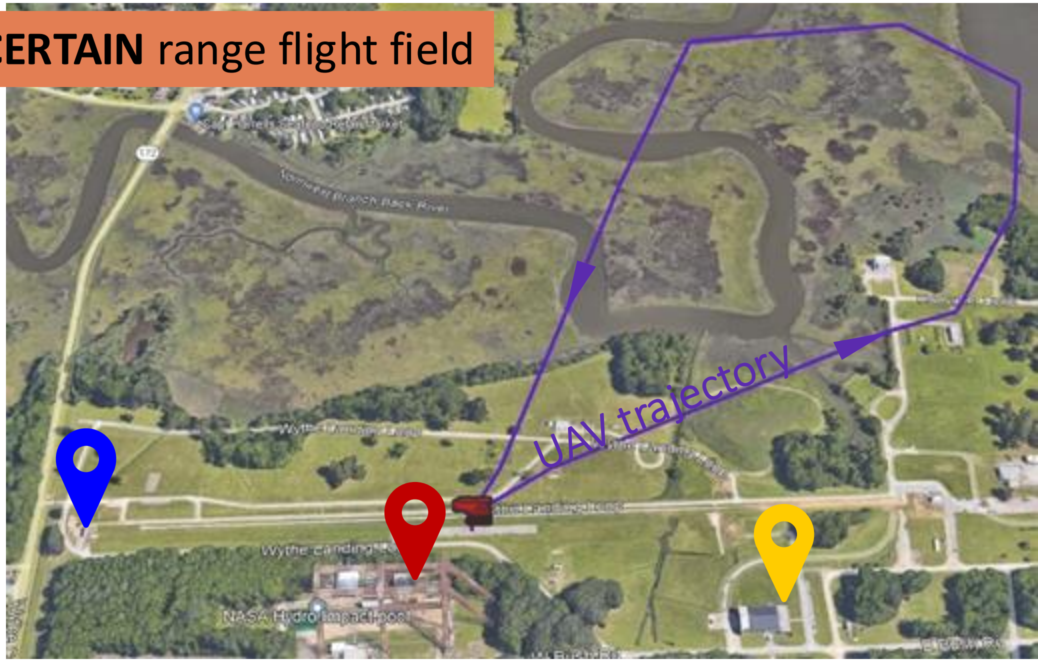
# NASA-UNINA Collaboration
## First activities

Università degli Studi di Napoli Federico II


## Distributed network of sensors experimental campaign

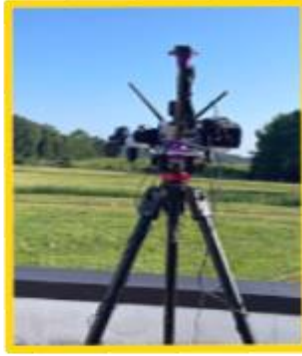
April-July 2023






Dataset built during operations of **High Density Vertiplex** project.

- ~**10 Tbytes** of data
- **Different weather conditions**
- **Varying number of small UAV** (from 1 to 5)



# NASA-UNINA collaboration
## Achievements so far

### PUBLICATIONS

- F. Vitiello, et al., “Assessing performance of Radar and Visual Sensing Techniques for Ground-to-Air Surveillance in Advanced Air Mobility”, *2023 IEEE/AIAA 42nd Digital Avionics Systems Conference (DASC).*
- F. Vitiello, et al.,“Experimental testing of data fusion in a distributed ground-based sensing network for Advanced Air Mobility”, *2024 AIAA Science and Technology Forum and Exposition (AIAA SciTech Forum).*
- C. Dolph, et al.,“Distributed Sensor Fusion of Ground and Air Nodes using Vision and Radar Modalities for Tracking Multirotor Small Uncrewed Air Systems and Birds”, *2024 AIAA Science and Technology Forum and Exposition (AIAA SciTech Forum).*
- F. Vitiello, et al. "Distributed Visual Sensing and Fusion for Advanced Air Mobility." *2024 AIAA DATC/IEEE 43rd Digital Avionics Systems Conference (DASC)*. IEEE, 2024.
- F. Vitiello, et al. "Sensing Small Uncrewed Aerial Vehicles With Distributed Radars for Advanced Air Mobility Surveillance." *AIAA SCITECH 2025 Forum.* 2025.
- C. Dolph et al., “Distributed Vision Sensing of Small Uncrewed Aircraft Systems in Urban Traffic Corridors.” *AIAA SCITECH 2025 Forum.* 2025.
- F. Vitiello, et al., "Demonstration of Data Processing and Fusion from Distributed Radars for Advanced Air Mobility Surveillance." *Journal of Aerospace Information Systems* 22, no. 6 (2025): 510-522.
- F. Vitiello, et al., ‘’Enhanced AAM Surveillance Using Radar/Visual Distributed Sensing.’’ *2025 AIAA DATC/IEEE 44th Digital Avionics Systems Conference (DASC).* IEEE, 2025. **Best of Track Award**.

### DATASETS

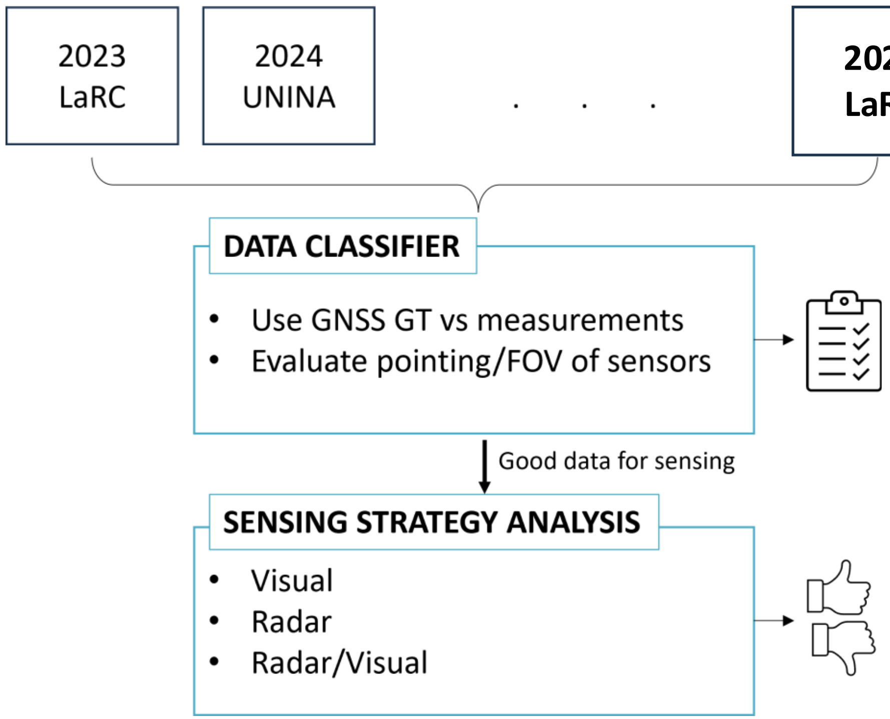
- **2023 LaRC** – flights with up to 4 small UAVs over the CERTAIN range
- **2023 UNINA** – flights with up to 2 small UAVs during ‘collision-like’ scenarios
- **2024 LaRC** – flight with 2 small UAVs flying over Langley boulevard (urban scenario). One airborne sensing node used as ‘chaser’.
- **2025 AFRC** – distributed sensing data collection during Joby flight tests. Extended targets.
- **2025 UNINA** – flights with up to 3 small UAVs.



# 2025 Activities
## Software developments

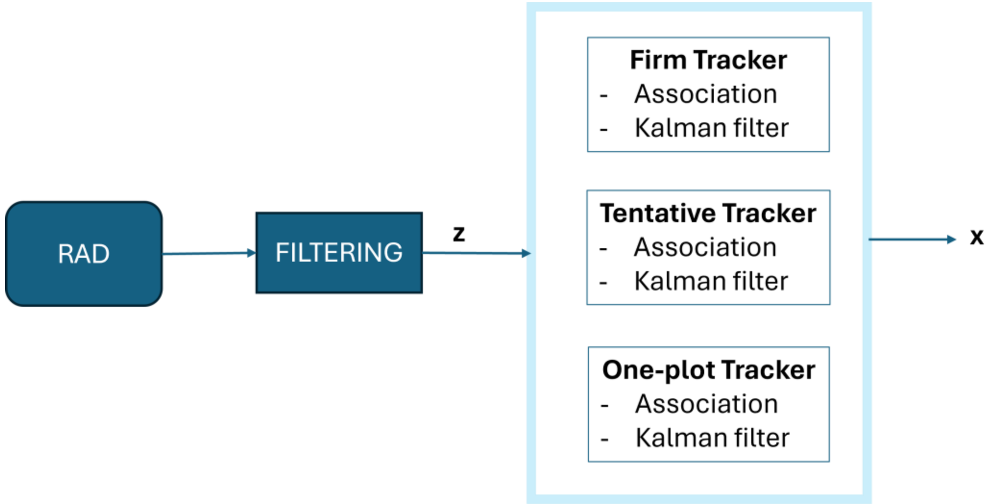
Tool to quickly analyze and classify collected data for both airborne and ground-based sensors.

Targeting enhanced efficiency and automation in handling datasets for future analysis and publication.




Integration of UNINA-developed radar tracking strategy into NASA sensing pipeline.

Targeting fulfillment of agreement milestone.




FOV – Field Of View
GT – Ground Truth

# 2025 Activities
## Software developments

$\mathbf{p}^{W}_{UAV}$, $t_{UAV}$ →
$\mathbf{p}^{W}_{S}$, $t_S$ →
$M^{S}_{W}$ → (QUEST algo)

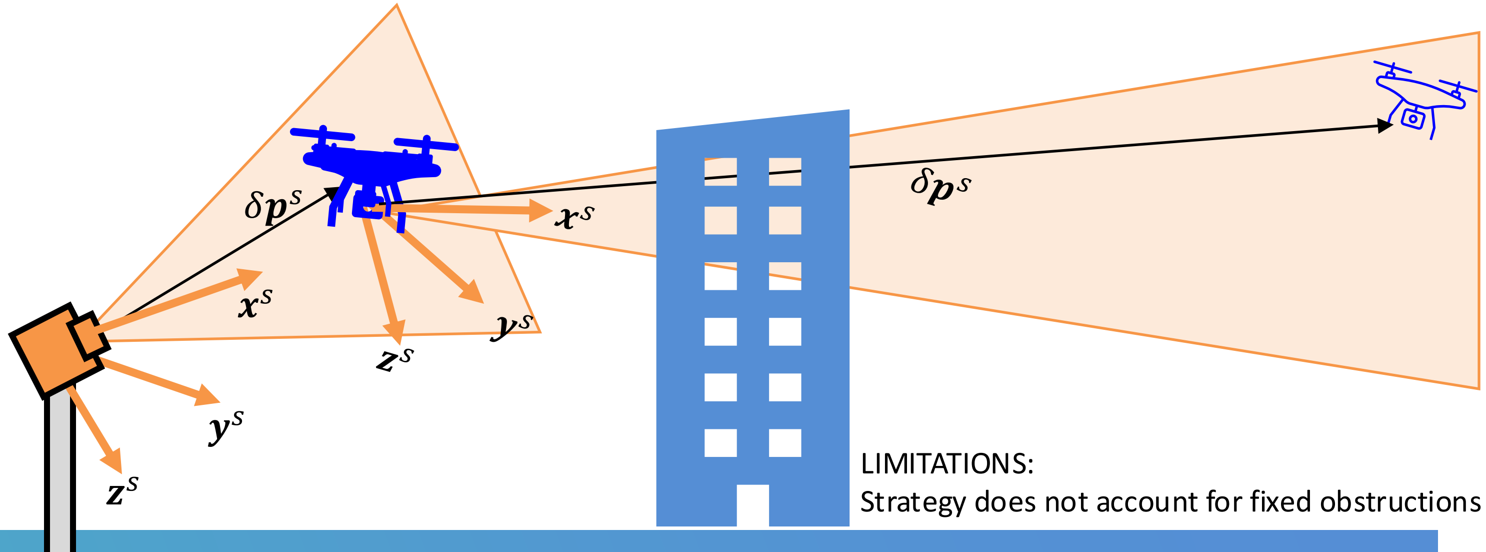
**GROUND**

- Temporal alignment of UAV positioning information with sensor time
- Computation of relative position of UAV with respect to sensor
- Projection of relative position in Sensor Reference Frame
- Sensor FOV vs trajectory analysis

$\mathbf{p}^{W}_{UAV}$, $t_{UAV}$ →
$\mathbf{p}^{W}_{S}$, $t_S$ →
$M^{S}_{W}$ → (NAV. DATA)

**AIR**

- Temporal alignment of UAV positioning information with sensor time
- Computation of relative position of UAV with respect to sensor
- Projection of relative position in Sensor Reference Frame
- Sensor FOV vs trajectory analysis

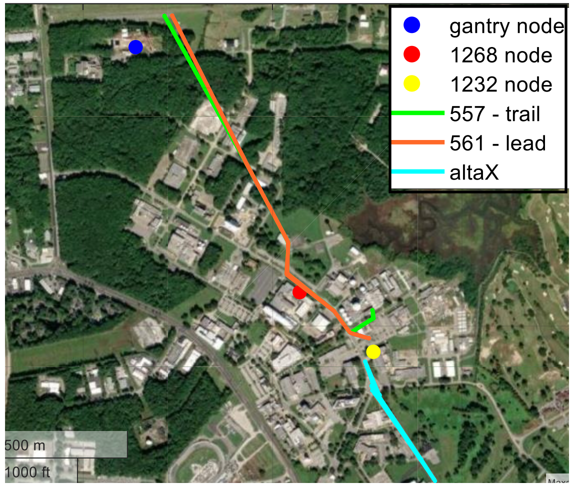


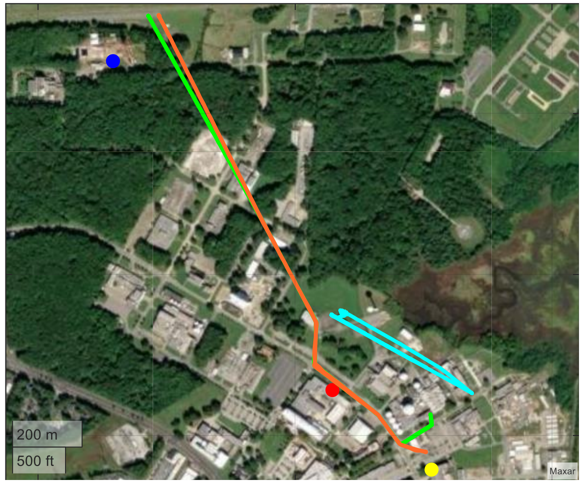

| | |
|---|---|
| S | Sensor Reference Frame |
| W | World Reference Frame |
| $\mathbf{p}^{W}_{UAV}$, | position of UAV in the World reference frame |
| $t_{UAV}$, | time-stamp associated to UAV position |
| $\mathbf{p}^{W}_{S}$, | position of sensor in the World reference frame |
| $t_S$, | time-stamp associated to sensor position |
| $M^{S}_{W}$, | rotation matrix from Sensor to World reference frame |
| $\delta p^s$, | UAV-sensor relative position in Sensor reference frame |
| QUEST | Quaternion ESTimation |

LIMITATIONS:
Strategy does not account for fixed obstructions in the FOV

# 2025 Activities
## Flight Tests

Distributed network of sensors installed to observe flights of small UAVs in low altitude, transiting from ‘rural’ to urban area.




Sensing nodes equipped with

- Echoflight MESA radar
- FLIR visual cameras
- Ublox F9P GNSS receivers and antennas

NETWORK NODES

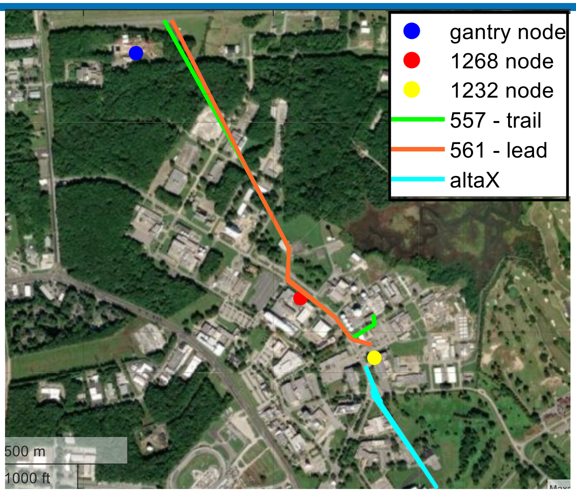


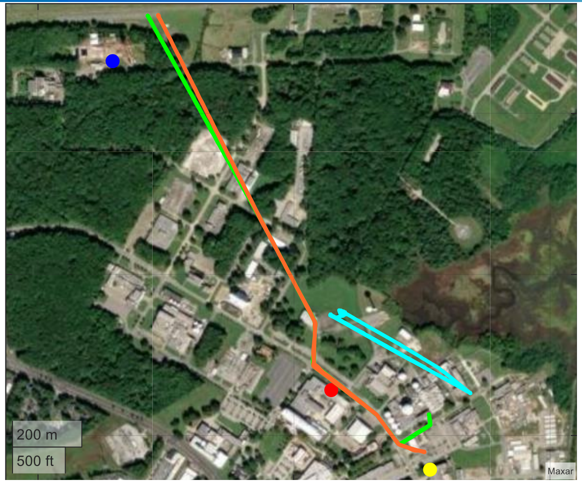
# 2025 Activities
## Flight Tests

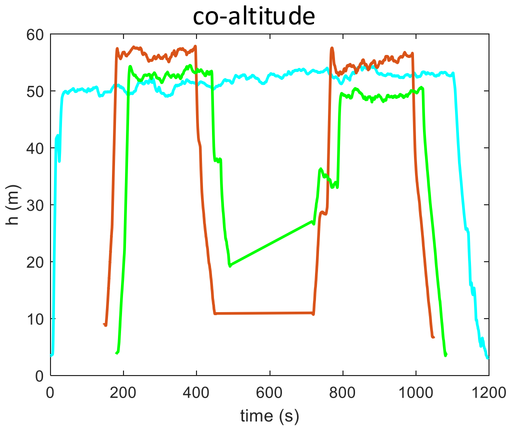
Two small UAVs (Alta8) transiting from rural to urban environments and landing on rooftops – simulating realistic AAM/UAM operations.

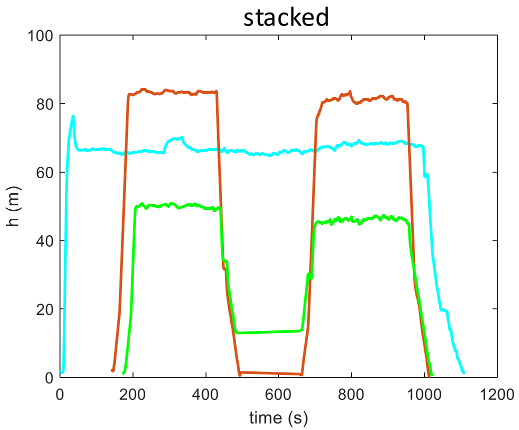
| Day | Alta X route | Total flights * | Data recorded |
|---|---|---|---|
| 7/12 | Frontal | 6 | ≈2.5 TB |
| 7/20 | Lateral | 12 | ≈4 TB |
| 7/26 | Frontal | 10 | ≈4 TB |

*flights refer to single leg of the Alta8 trajectory



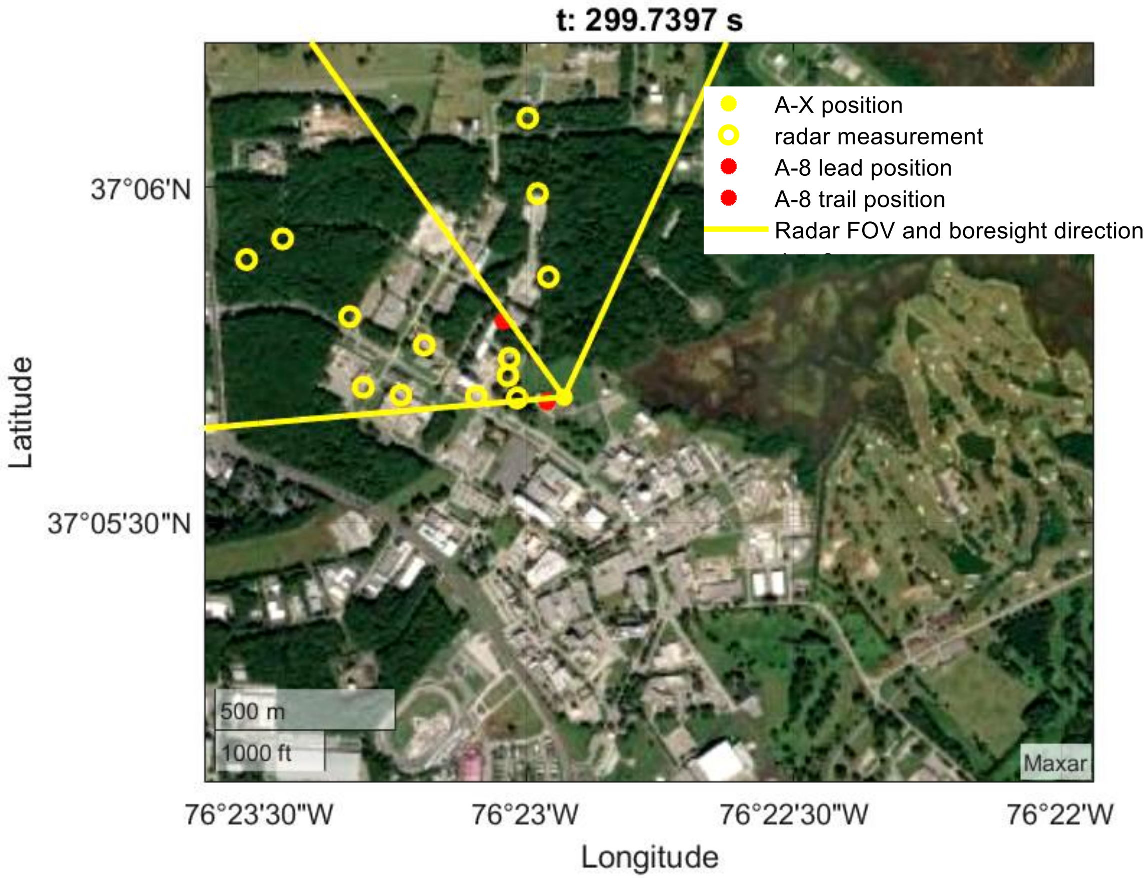



# 2025 Activities
## Flight 3 on 7/20

**AltaX payload data**

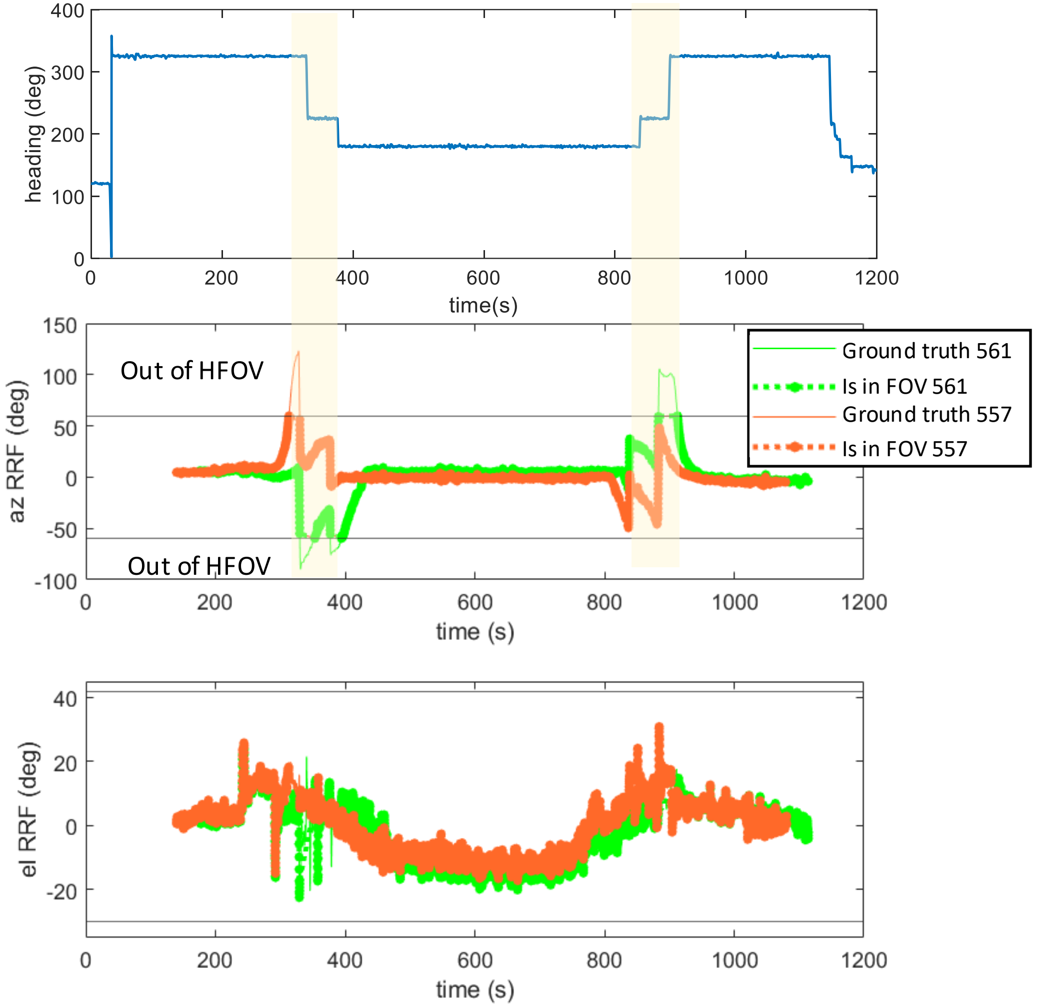



Radar measurements collected by the payload during flight #3. Measurements are converted in latitude and longitude using navigation data.

Camera frames collected by the payload during flight #3.

# 2025 Activities
## Flight 3 on 7/20

### AltaX payload data – radar coverage analysis

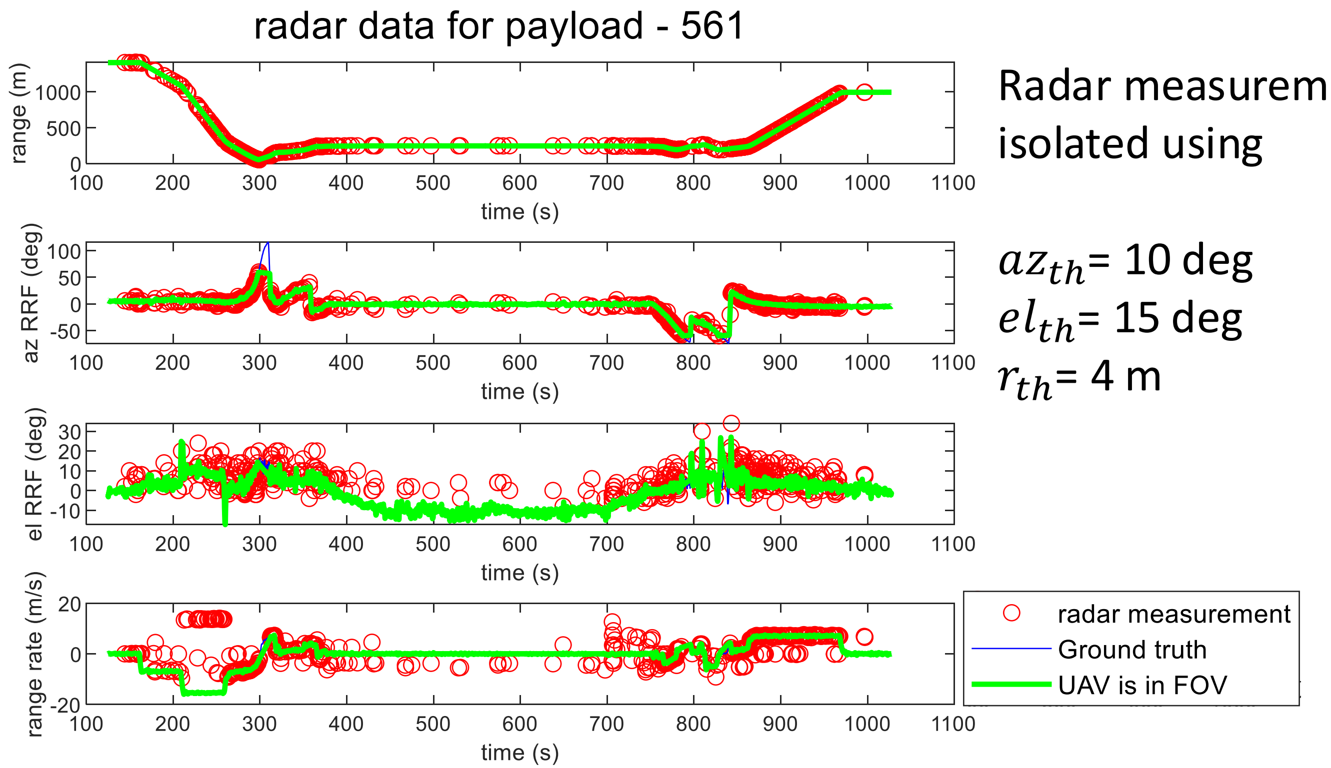



Coverage analysis results show that the two UAVs are always within the limits of the radar VFOV.

UAVs exit the HFOV locally during the altaX heading change maneuvers.

Average coverage for both UAVs is about **95%.**

Camera coverage is slightly lower, about **89%.**




Radar measurements isolated using

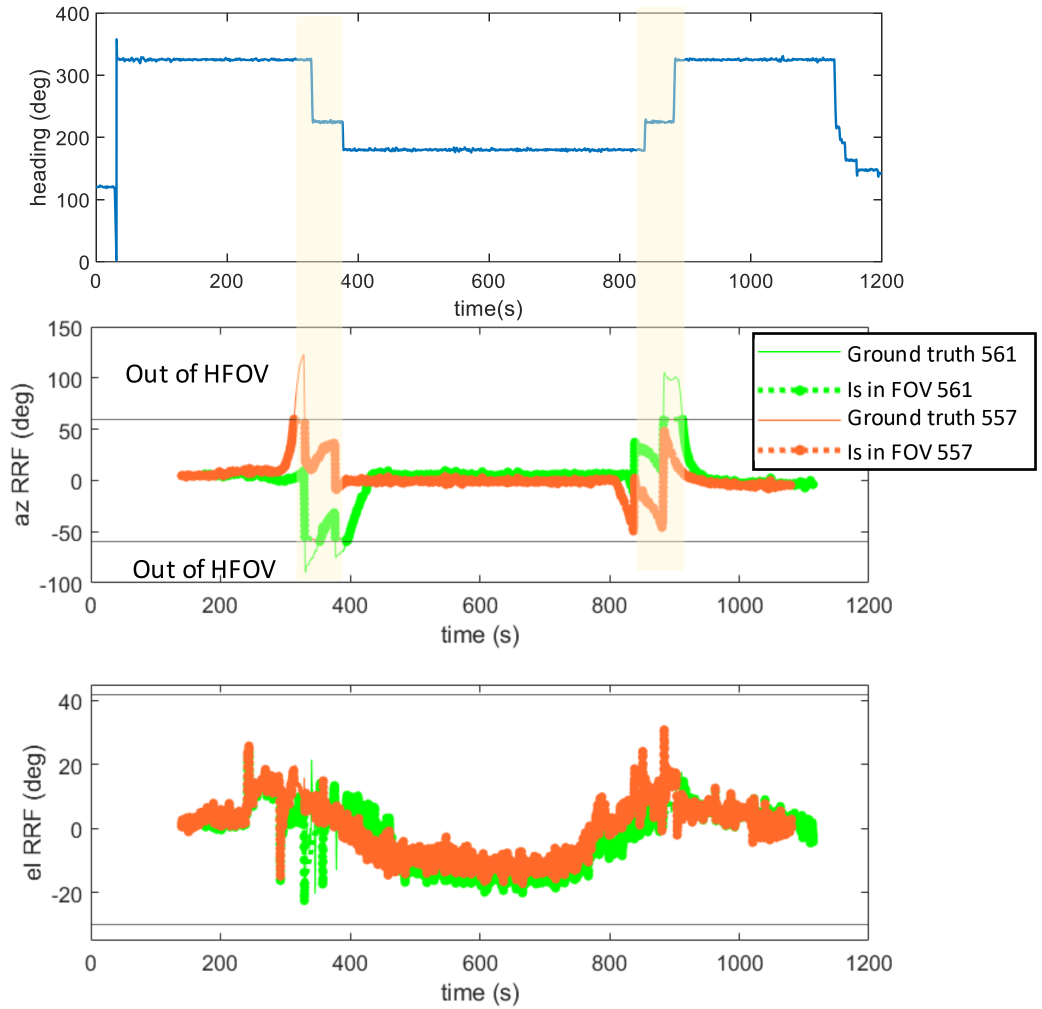
$az_{th}$= 10 deg

$el_{th}$= 15 deg

$r_{th}$= 4 m

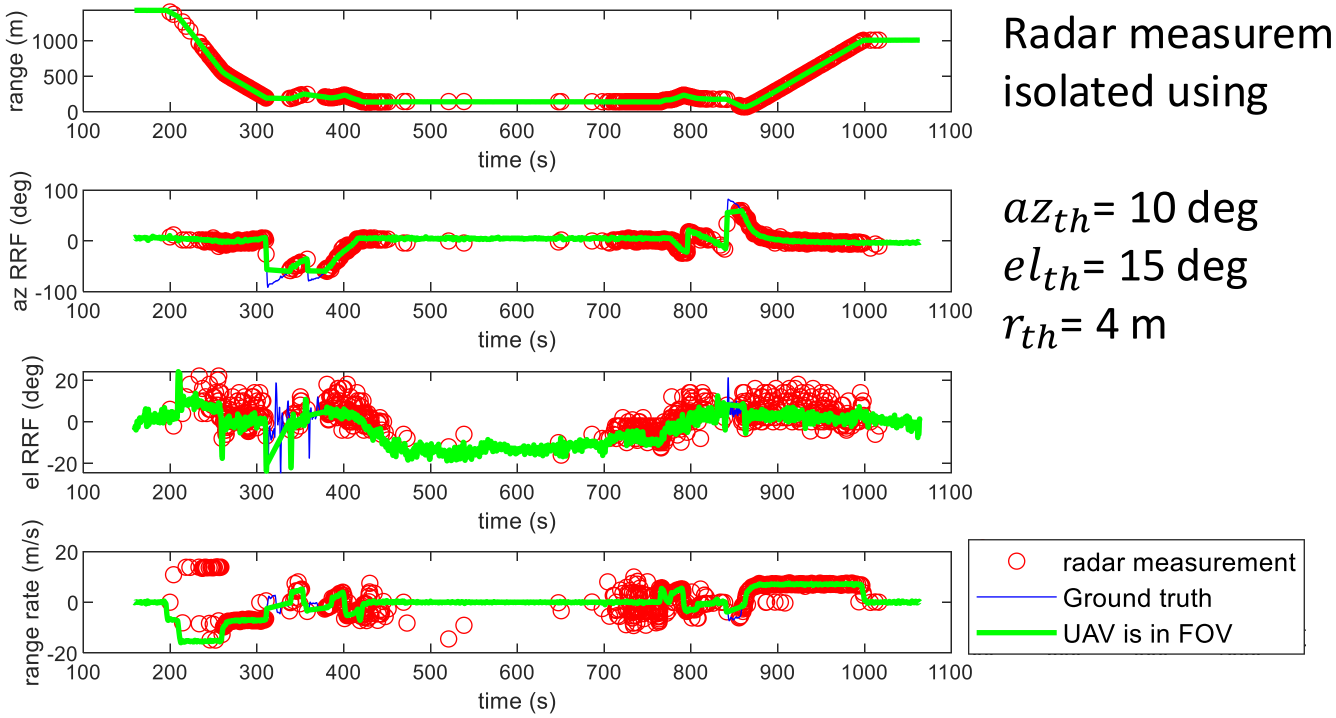
# 2025 Activities
## Flight 3 on 7/20

### AltaX payload data – radar coverage analysis




Coverage analysis results show that the two UAVs are always within the limits of the radar vertical FOV.
UAVs exit the horizontal FOV locally during the altaX heading change maneuvers.
Average coverage for both UAVs is about **95%.**
Camera coverage is slightly lower, about **89%.**

radar data for payload - 557

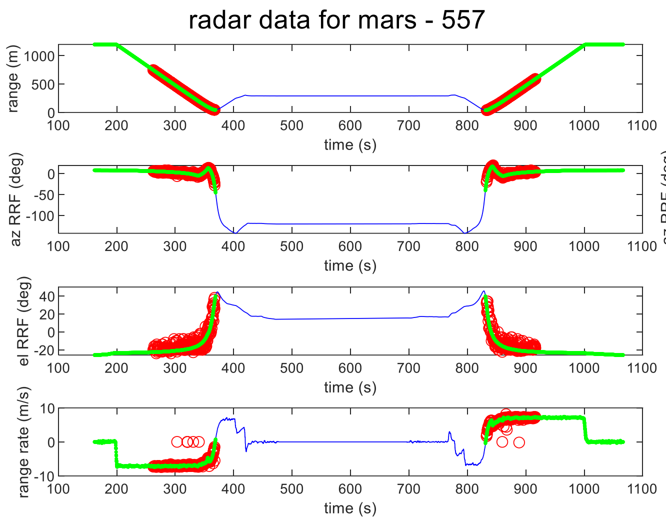


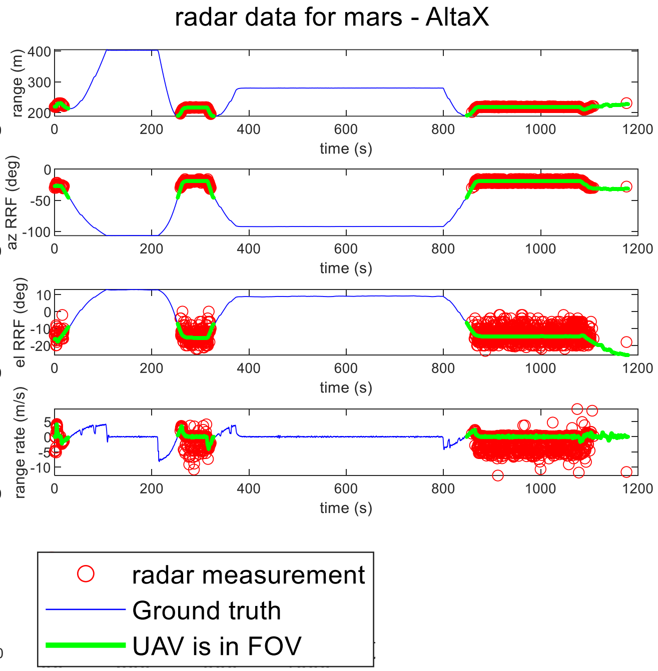

Radar measurements isolated using

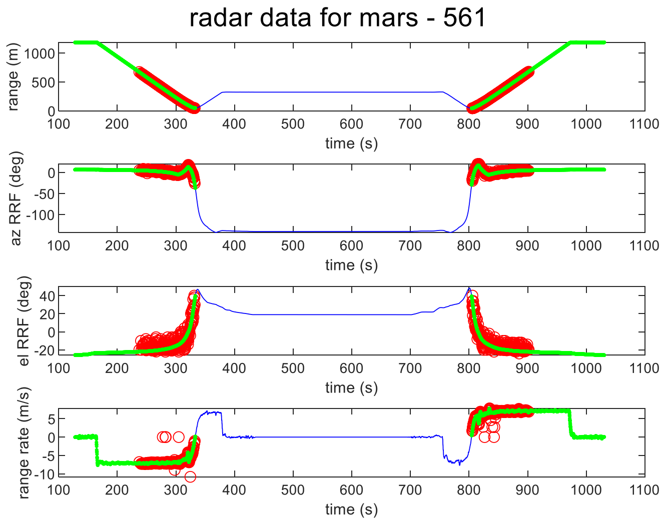
$az_{th}$= 10 deg
$el_{th}$= 15 deg
$r_{th}$= 4 m

# 2025 Activities
## Flight 3 on 7/20

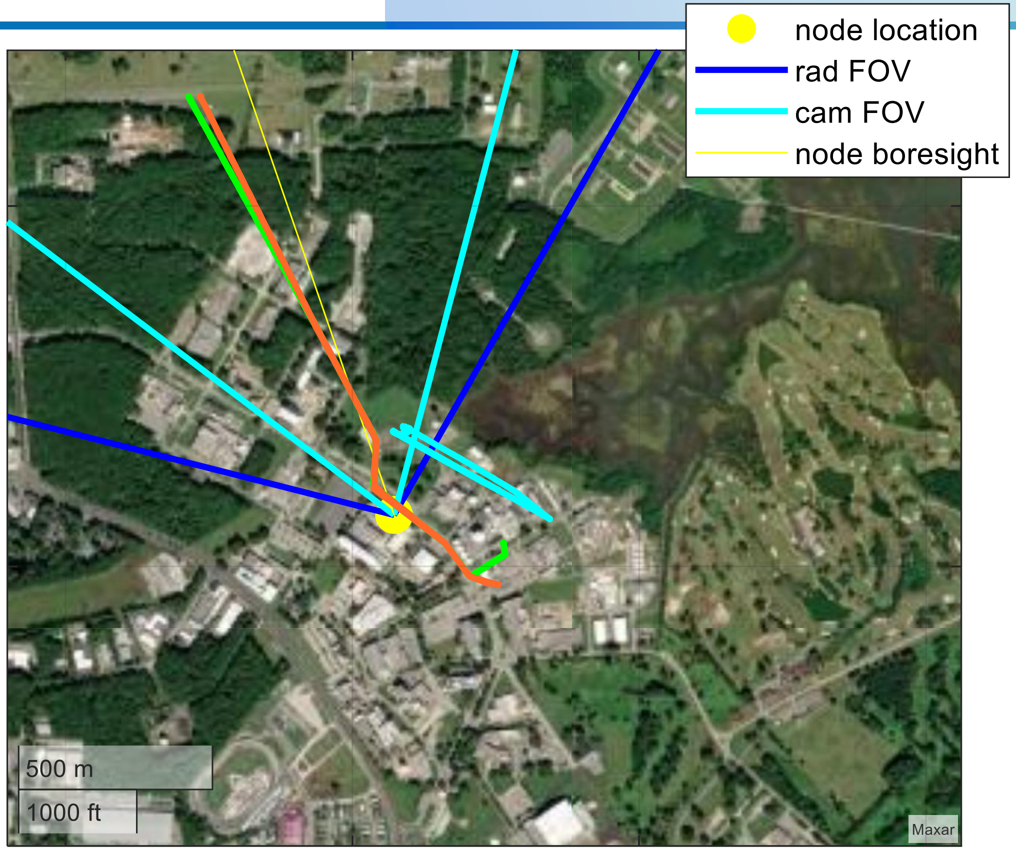
### Mars data - 1268



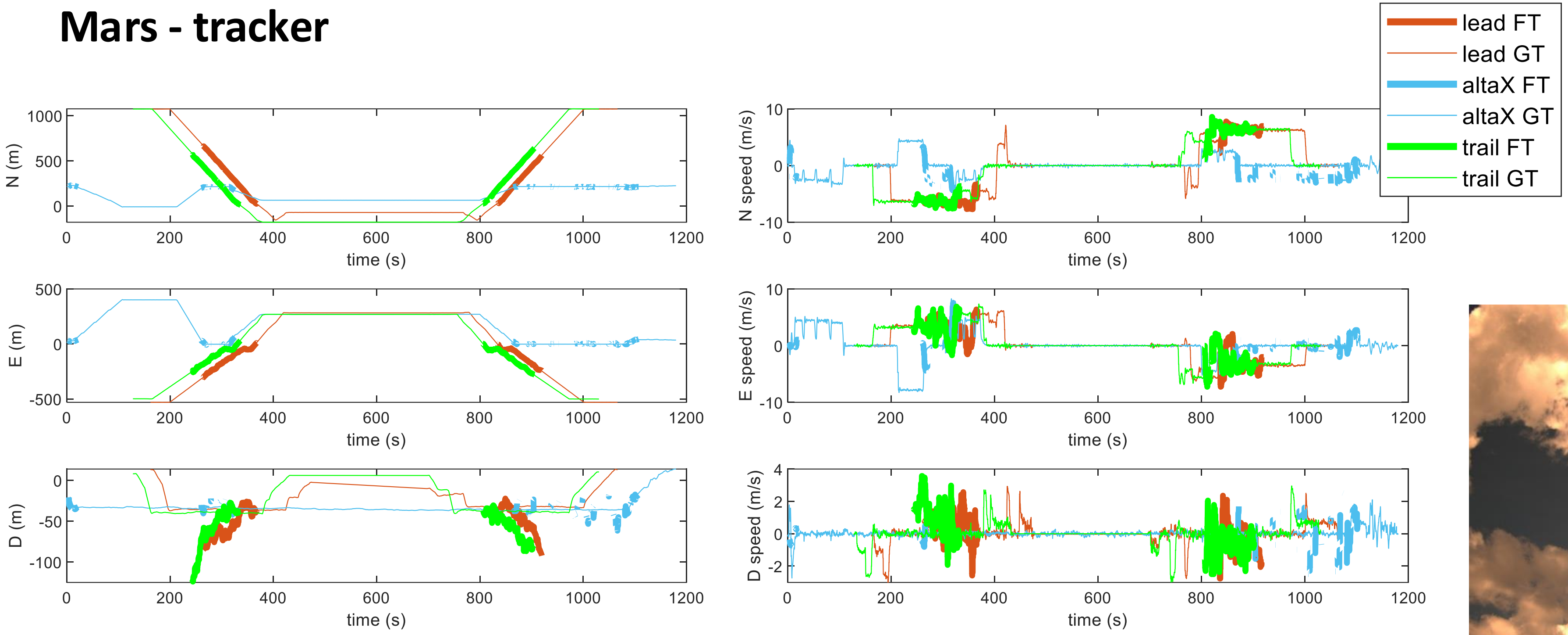




| Predicted Coverage % | 557 | 561 | AltaX |
|---|---|---|---|
| Radar | 49 | 48 | 37 |
| Camera | 38 | 38 | 29 |

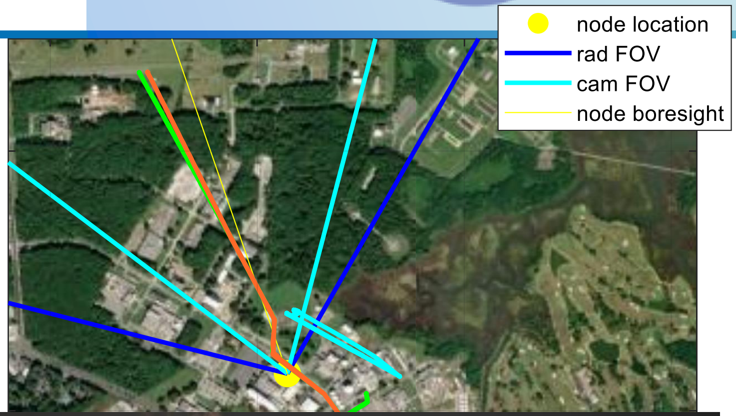


# 2025 Activities
## Flight 3 on 7/20

### Mars - tracker




| | Predicted Coverage % | | | Tracking Coverage % | | |
|---|---|---|---|---|---|---|
| | 557 | 561 | AltaX | 557 | 561 | AltaX |
| Radar | 49 | 48 | 37 | 43 | 45 | 19 |

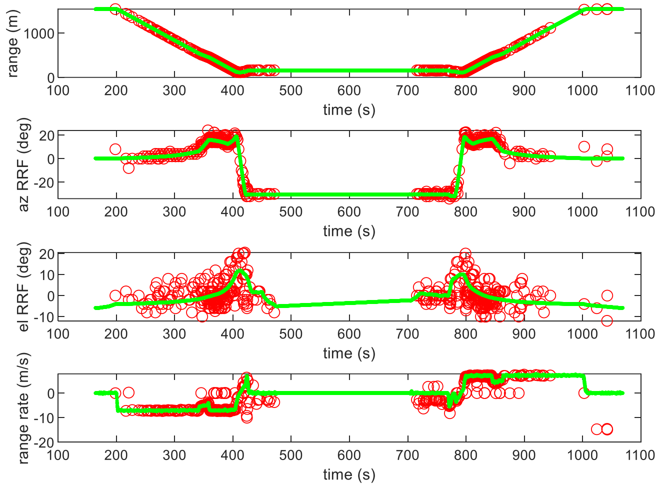



Reduction of coverage for AltaX is due to radar measurements filtering through Doppler.

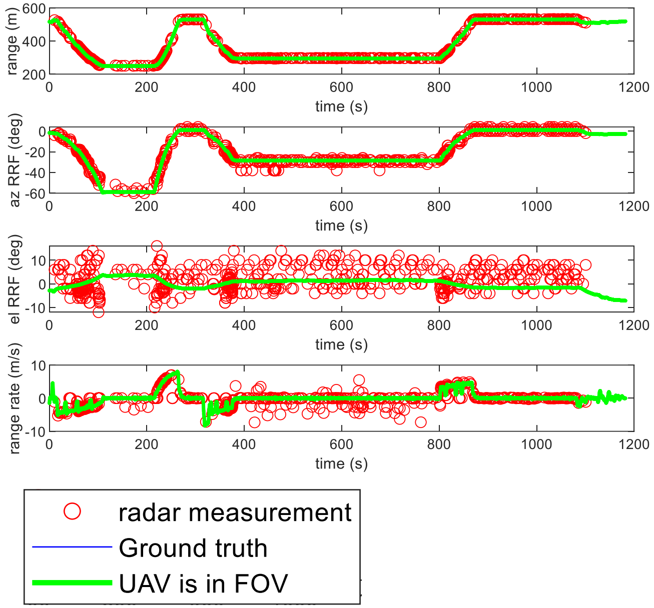
# 2025 Activities
## Flight 3 on 7/20

### Mercury data - 1232

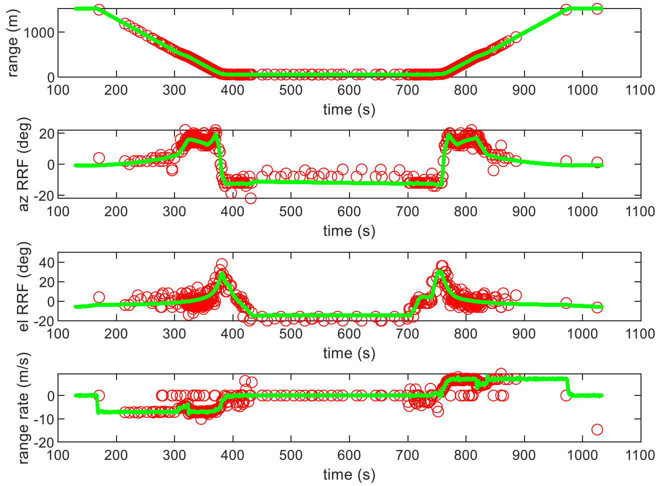
radar data for mercury - 557

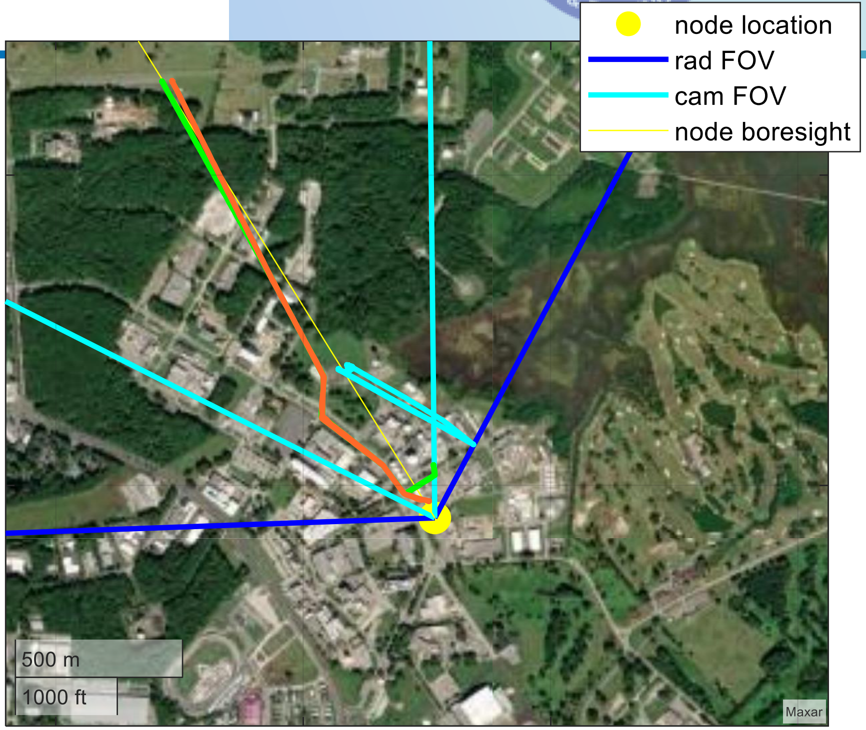



radar data for mercury - AltaX




radar data for mercury - 561

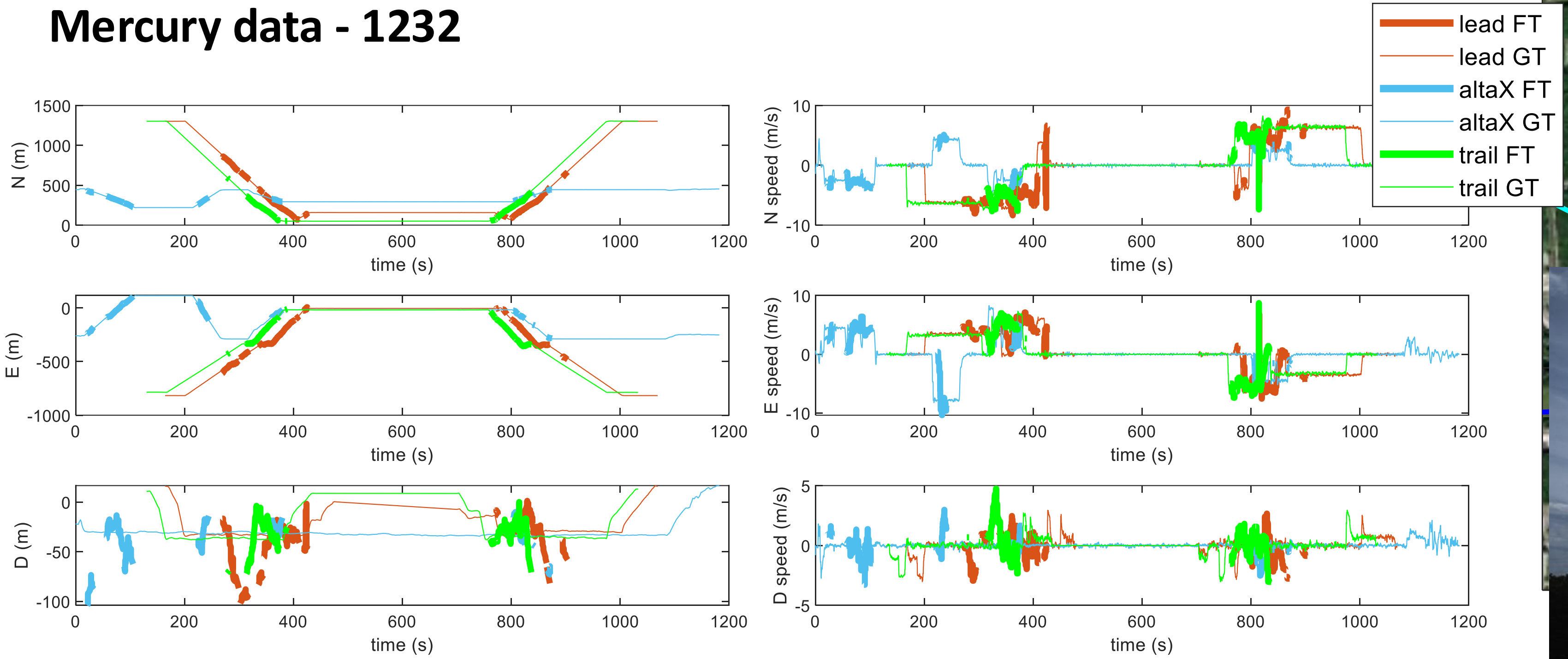


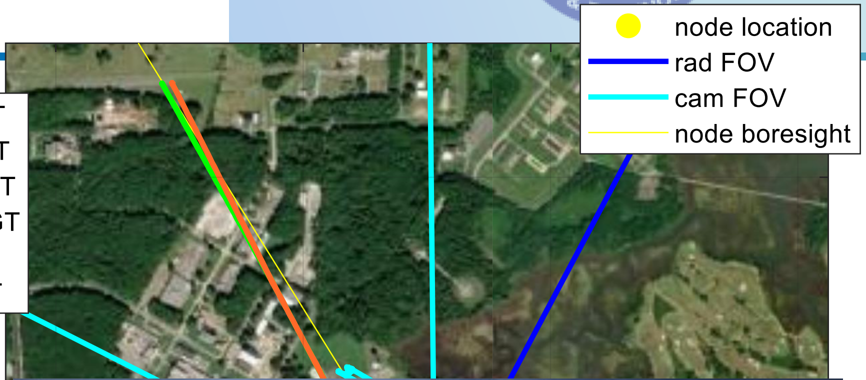



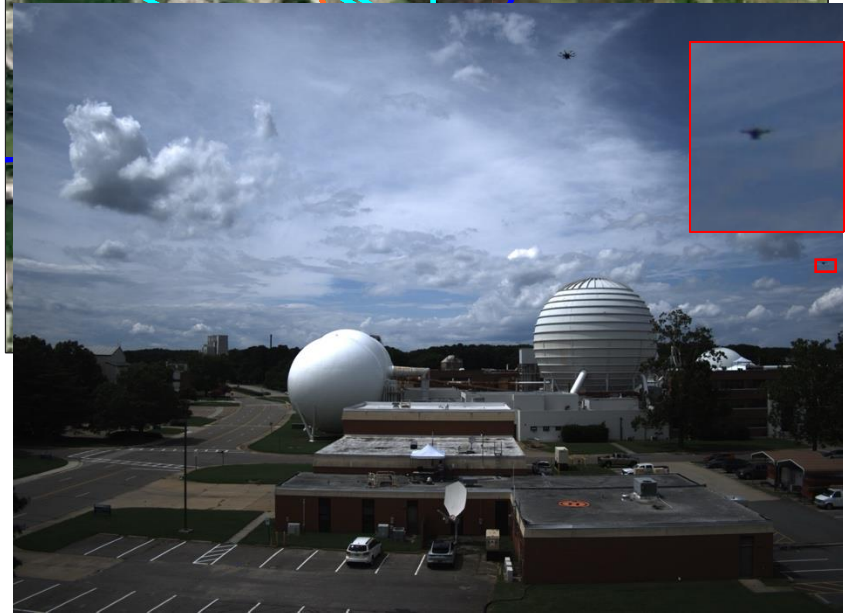

| Predicted Coverage % | | | |
|---|---|---|---|
| | 557 | 561 | AltaX |
| Radar | 100 | 100 | 98 |
| Camera | 99 | 98 | 87 |

# 2025 Activities
## Flight 3 on 7/20

### Mercury data - 1232



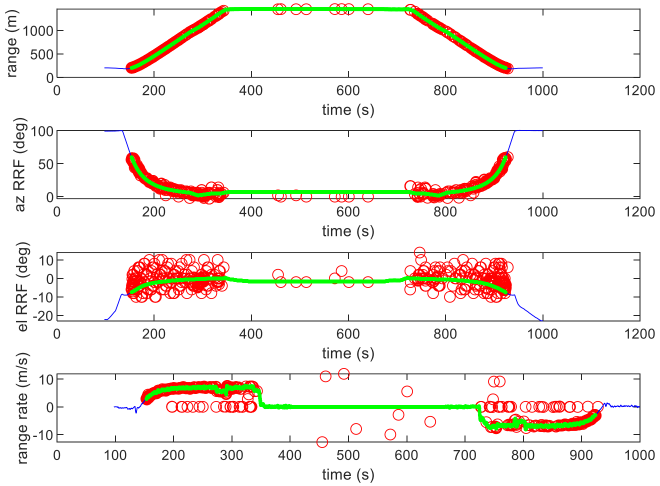
| | Predicted Coverage % | | | Tracking Coverage % | | |
|---|---|---|---|---|---|---|
| | **557** | **561** | **AltaX** | **557** | **561** | **AltaX** |
| Radar | 100 | 100 | 98 | 24 | 16 | 11 |

Reduction of coverage for AltaX is due to radar measurements filtering through Doppler and to fixed obstacles in the FOV.

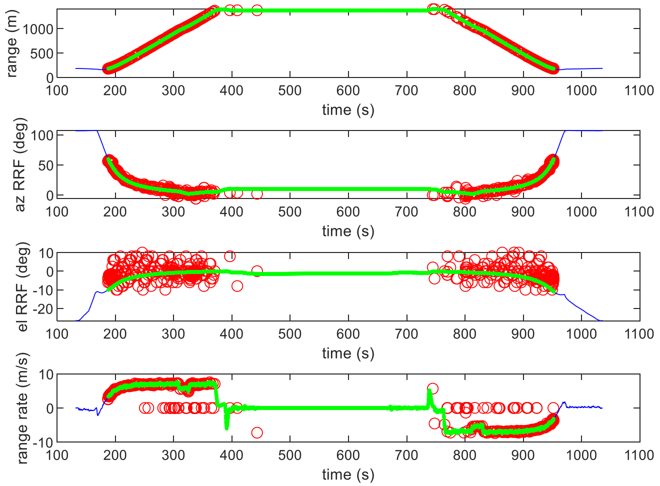
# 2025 Activities
## Flight 3 on 7/20

### Gantry data

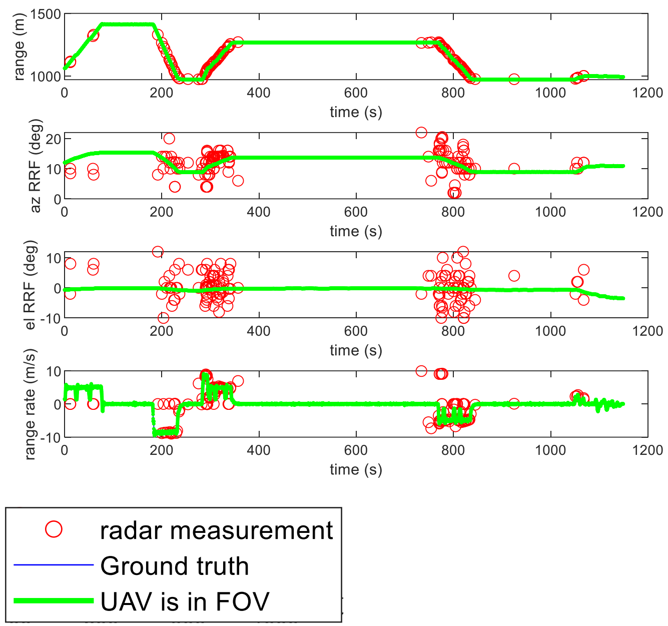
radar data for gantry-venus - 561

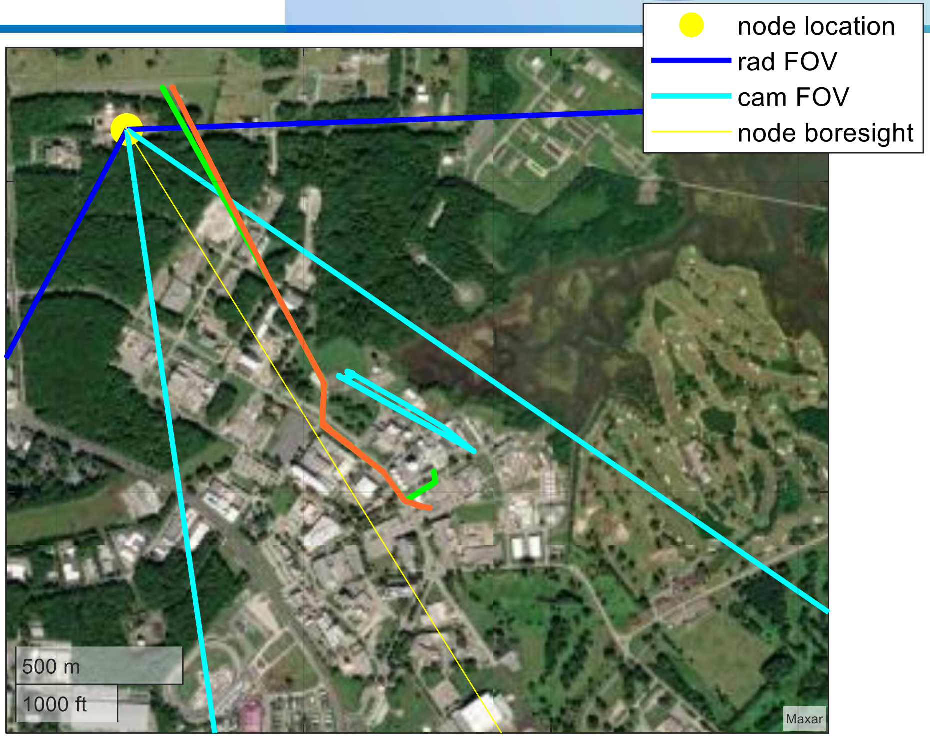



radar data for gantry-venus - 557




radar data for gantry-venus - AltaX

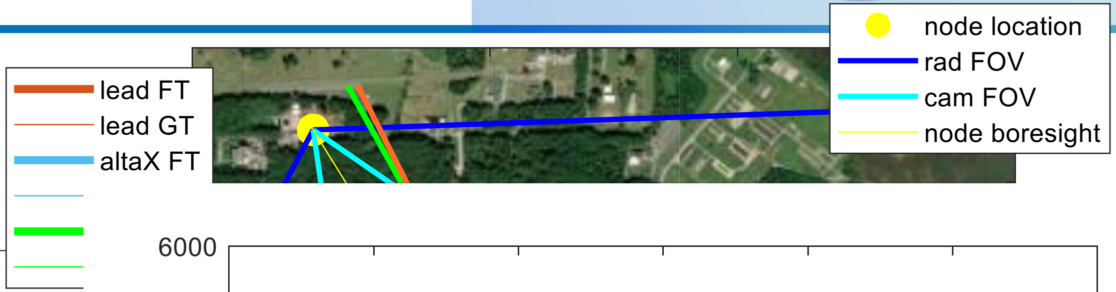


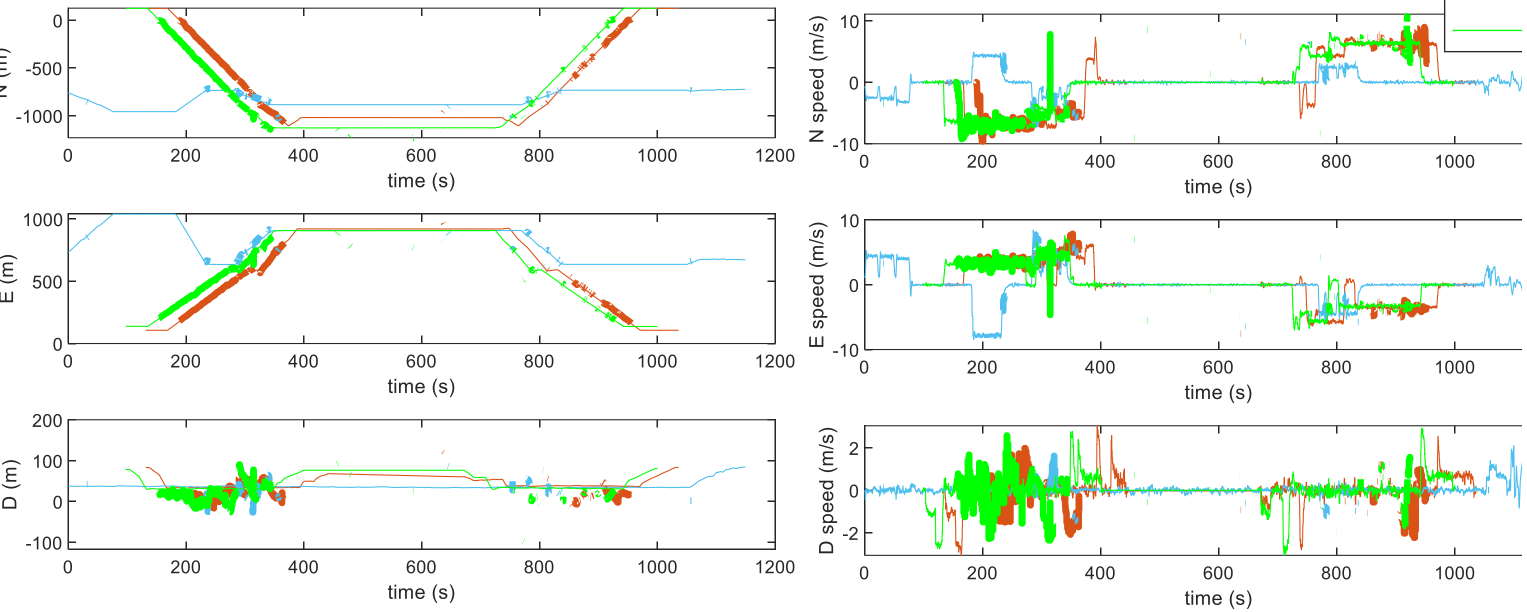



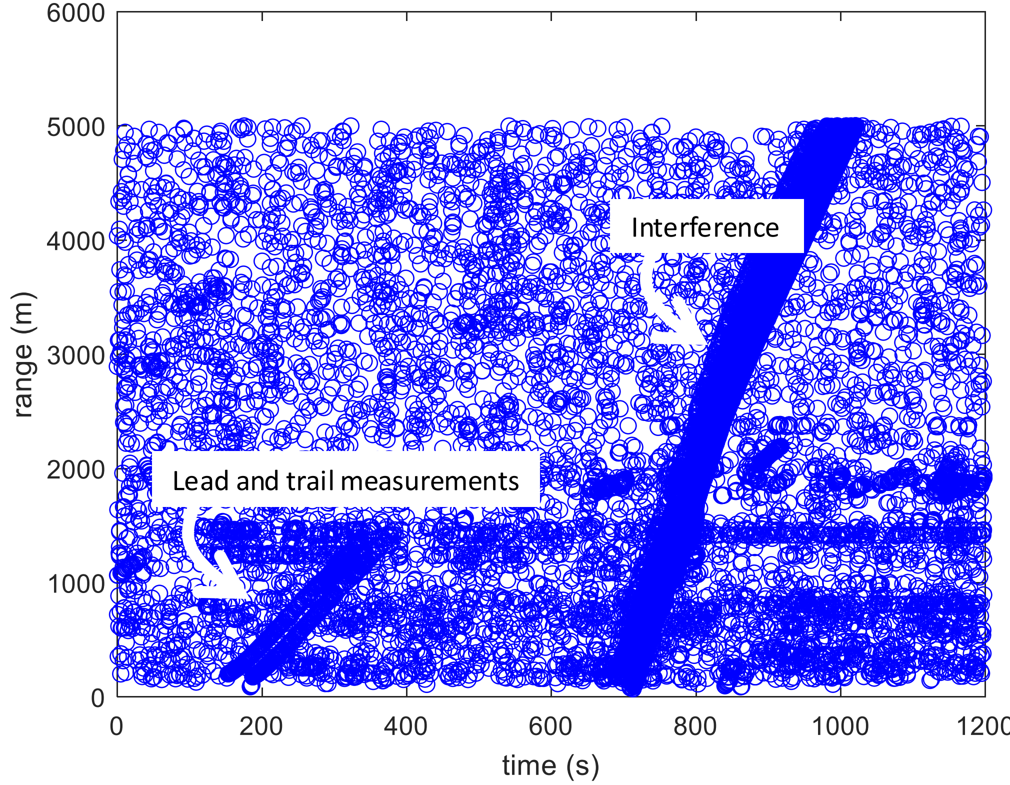

| Predicted Coverage % | | | |
|---|---|---|---|
| | 557 | 561 | AltaX |
| Radar | 85 | 85 | 100 |
| Camera | 80 | 80 | 100 |

# 2025 Activities
## Flight 3 on 7/20

### Gantry tracker



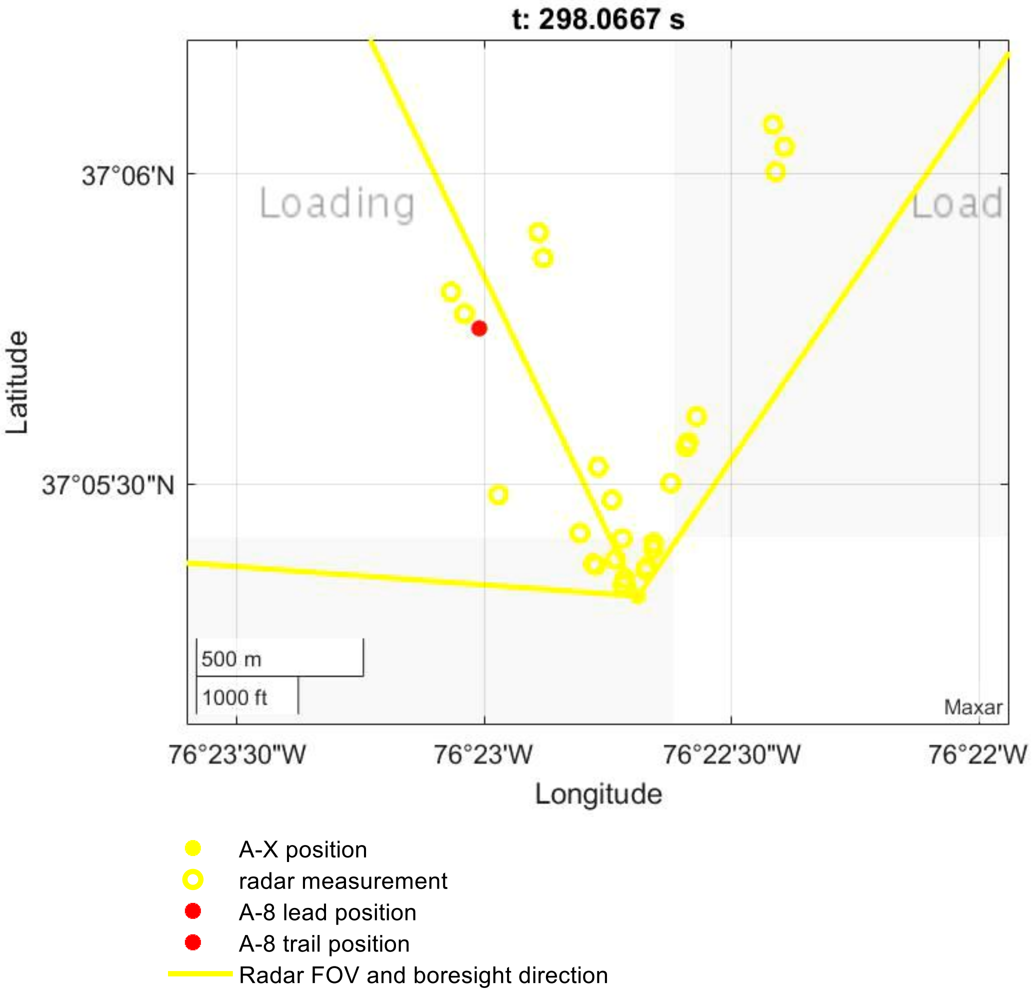



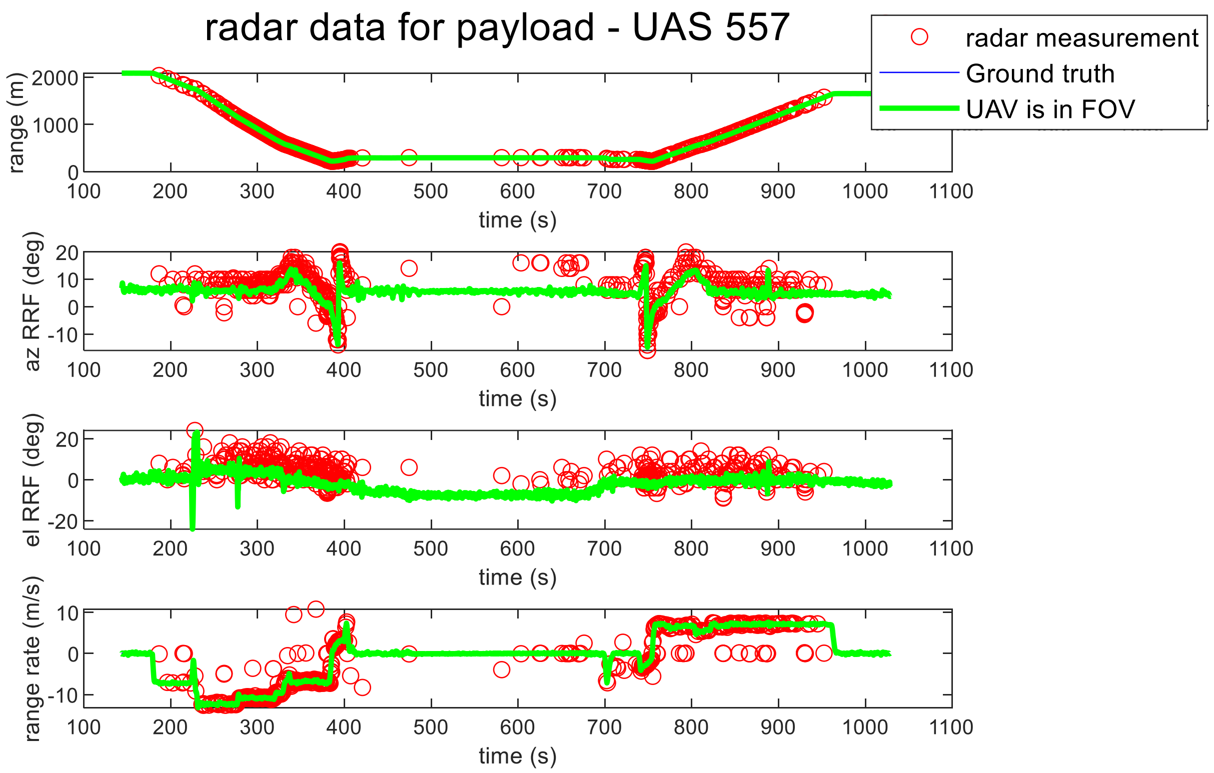

| | Predicted Coverage % | | | Tracking Coverage % | | |
|---|---|---|---|---|---|---|
| | 557 | 561 | AltaX | 557 | 561 | AltaX |
| Radar | 85 | 85 | 100 | 30 | 26 | 5 |

Reduction of coverage for lead and trail UAS is caused by radar interference.

# 2025 Activities
## Flight 3 on 7/26

### AltaX payload data

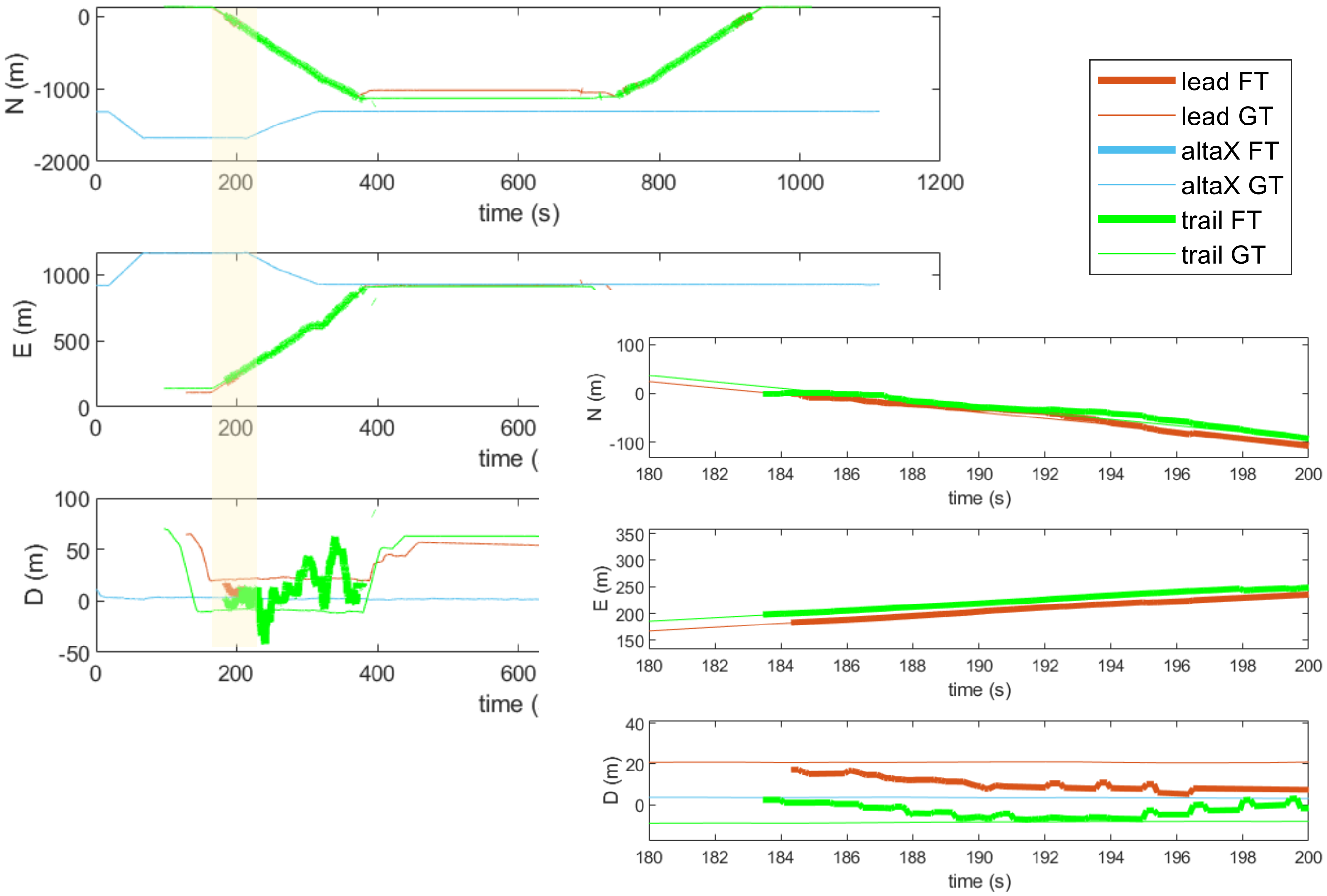



Classifier declares that both UAVs are always in the airborne sensors' FOV. Predicted coverage is **100%** for radar and camera.

# 2025 Activities
## Flight 3 on 7/26

**Gantry tracker**




The 'stacked' configuration challenges the radar sensing performance.

The vertical separation between UAVs (about 30 meters) falls within the elevation resolution limit of the sensor.

When the UAVs are closer to the radar, below 250 meters in range, they become distinguishable.

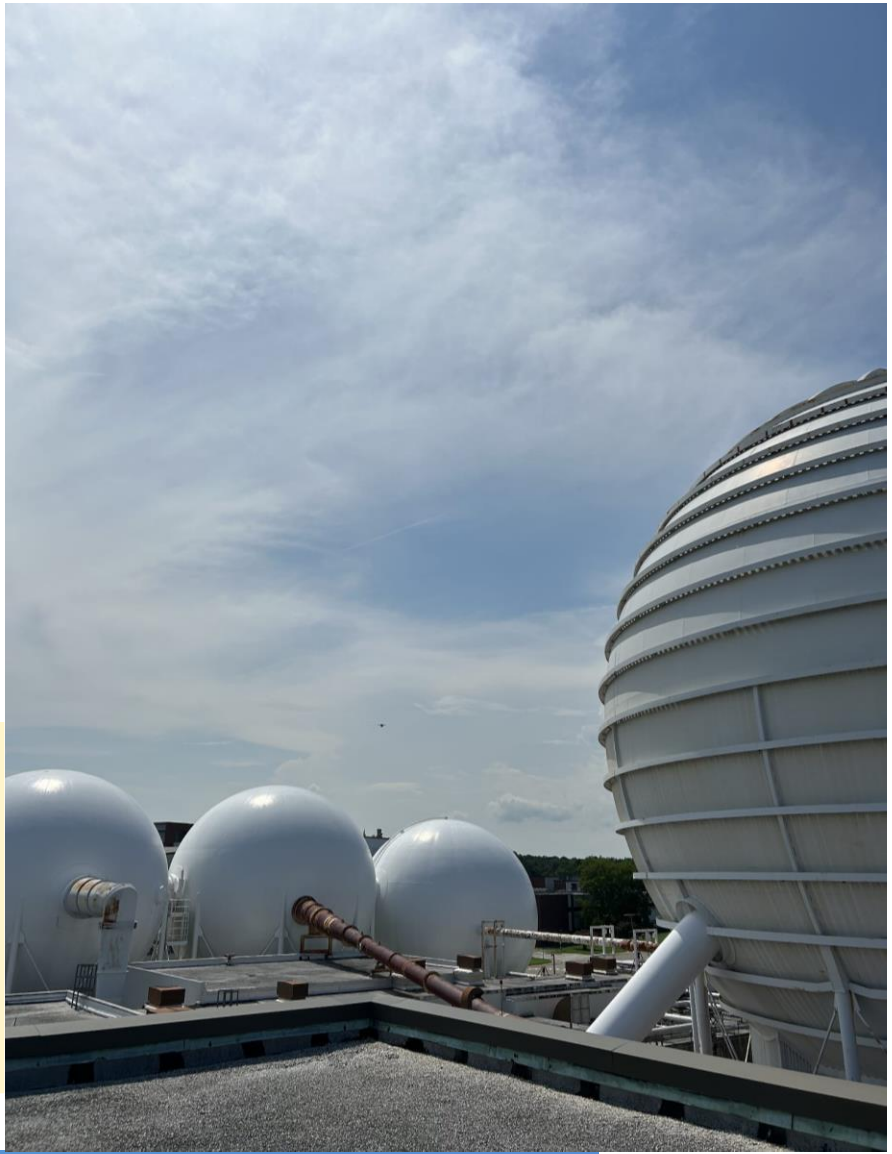
# Conclusions

Experiments and initial results on radar data analysis, classification and tracking highlight the complexity of sensing small UAVs flying in low altitude in urban environments.

In these scenarios, sensing performance are impacted by:

- Occlusions, interference and multipath (clutter),
- Complex geometries.

These preliminary findings **underline the importance of research in distributed sensing to develop robust** surveillance architectures.



**FUTURE WORKS**

Major focus will be given to the following aspects:

- Data fusion for improved accuracy and coverage,
- Sensor scheduling for interference mitigation,
- Airborne tracker and its fusion with ground-based trackers
- Real-time implementation.


# THANK YOU!

**Contacts**

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