Testing a Run-Time Assurance Framework Coupled with Integrated Risk Mitigation Capabilities for Autonomous Urban UAS Flights

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System-Wide Safety

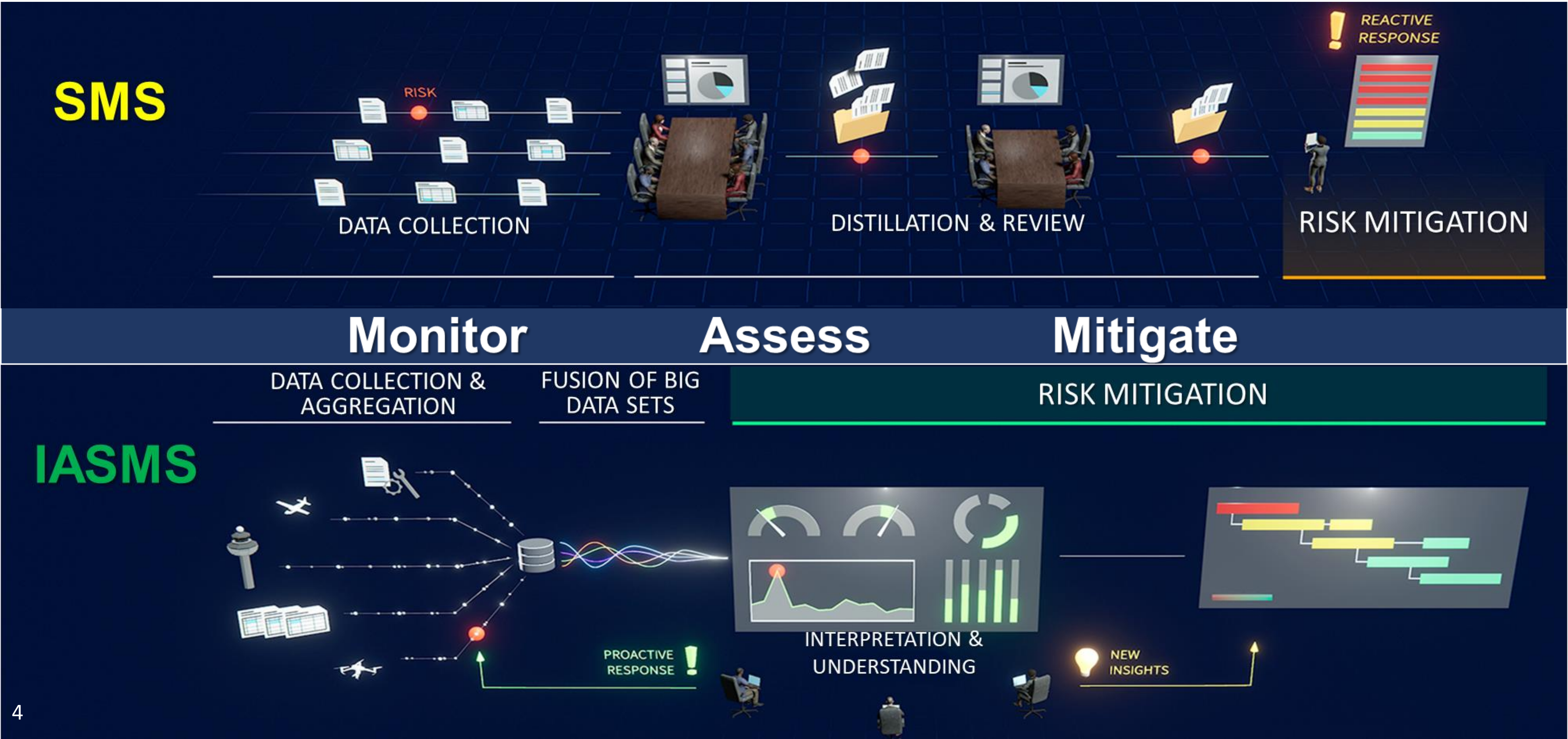
Outline

- Background and In-time Aviation Safety Management System (IASMS)
- Flight System Software Architecture
- Flight Tests
  - Aircraft and Range
  - Phase I and Phase II Testing
  - Flight 097 Results
  - Flight 115 Results
- Next Steps & Concluding Remarks

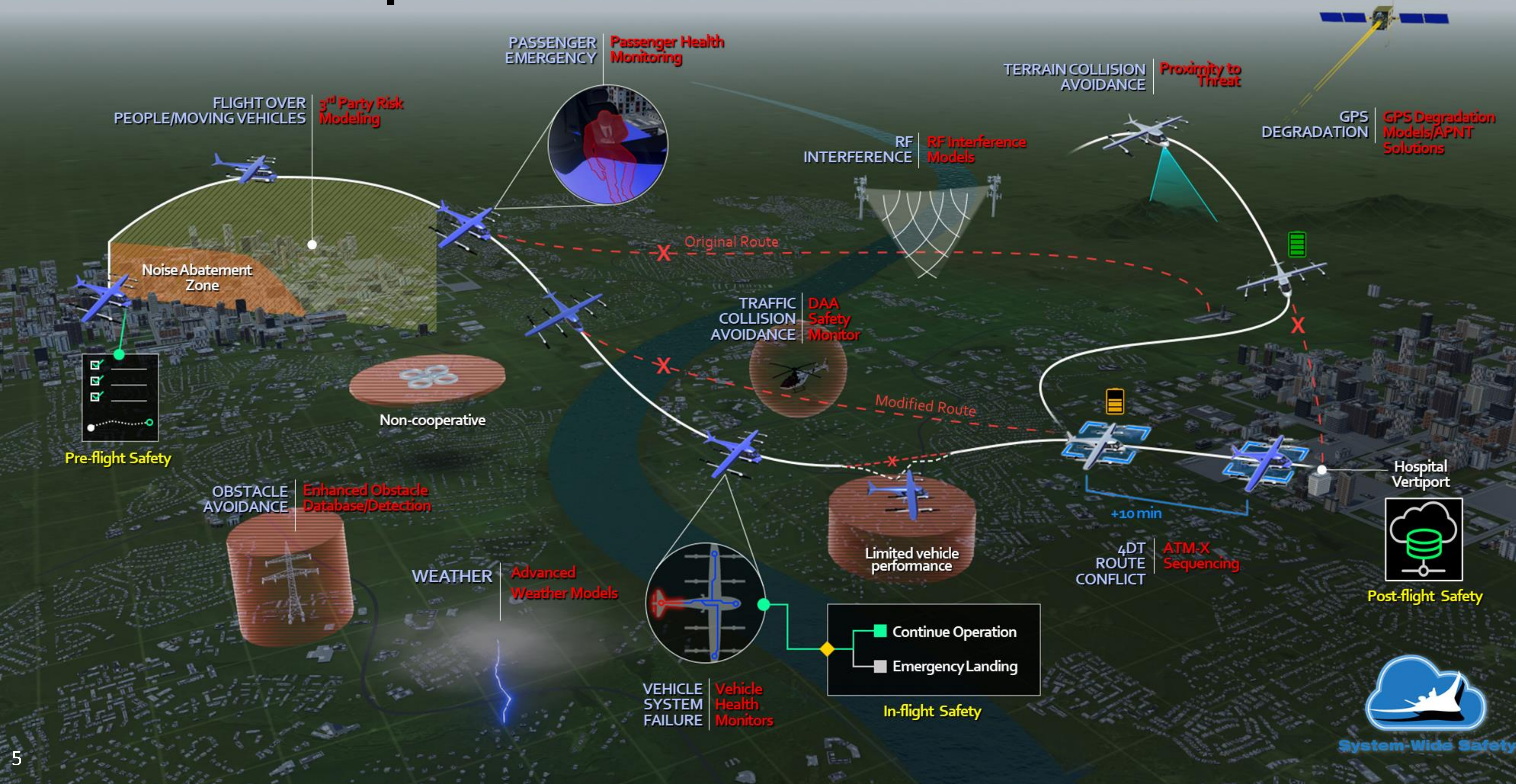
Background and IASMS

- Funded by the System-Wide Safety (SWS) Project
- Informed by the National Academies and NASA Strategic Implementation Plan (SIP)
- Comprised of high-level capabilities (Monitor, Assess, and Mitigate) spanning operational phases (pre-flight, in-flight, and post-flight)
- Decomposed into lower-level Services, Functions, Capabilities (SFCs), residing on board, on the ground, and/or cloud
- Improved real-time detection and automated mitigation of domain-specific hazards by developing predictive capabilities

IASMS Concept of Operations



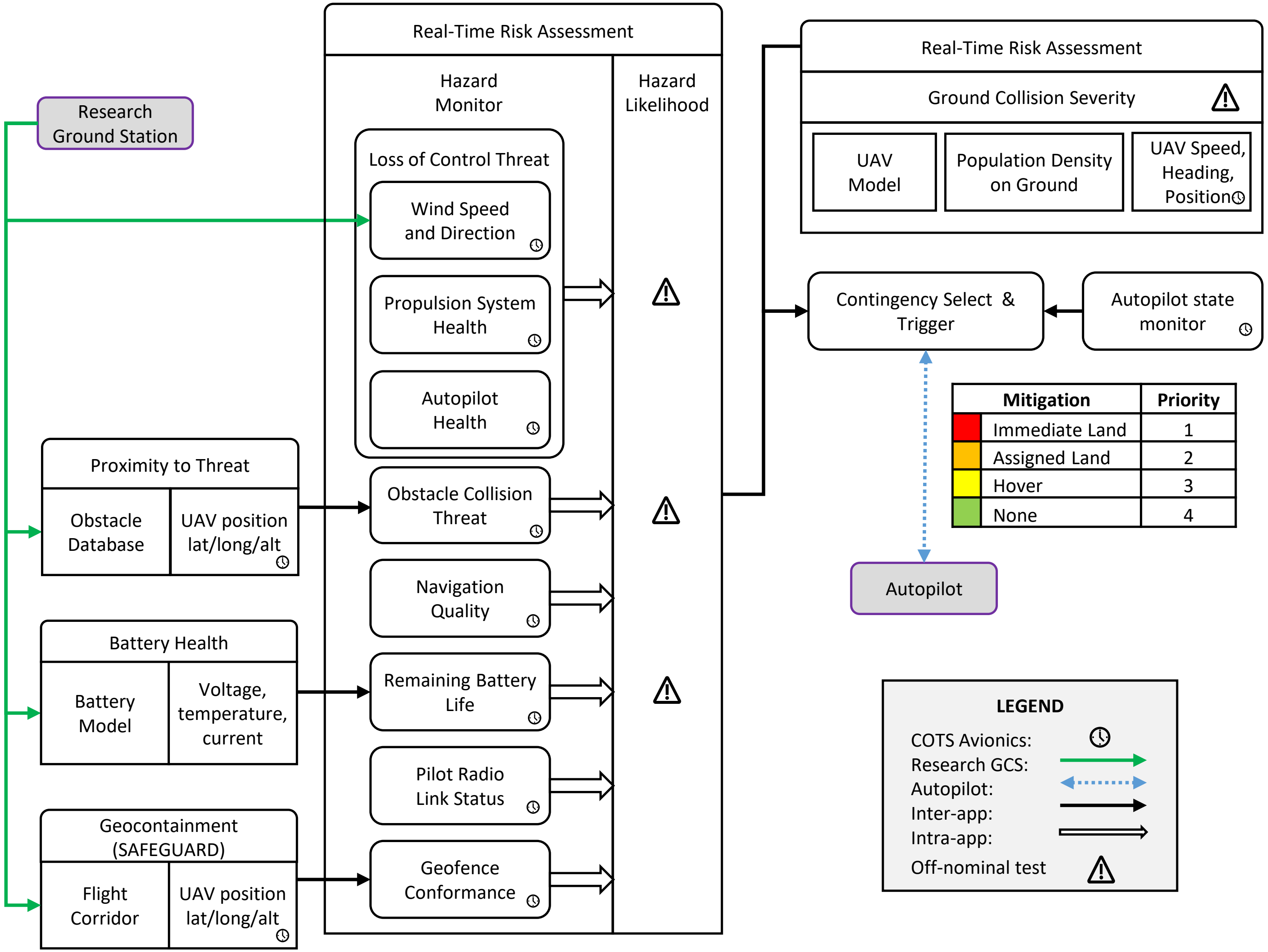
IASMS Implementation



Flight System Software Architecture

- SFCs with Run-time Assurance (RTA) approaches
  - NASA Class C and Class D
  - Execution independent of the unassured autopilot
- In-time risk management with autopilot monitoring, proximity monitoring, and conformance monitoring functions
- Hazards
  - Navigation loss
  - Command & control link loss
  - Unsafe proximity to obstacles
  - Geocontainment
  - Aircraft loss of control
    - Propulsion system
    - Power system
    - Autopilot malfunction
    - Wind presence
- Ground Collision Severity

Onboard Software Architecture



Mitigation	Priority
Immediate Land	1
Assigned Land	2
Hover	3
None	4

LEGEND

COTS Avionics:
Research GCS:
Autopilot:
Inter-app:
Intra-app:
Off-nominal test

Mitigated Actions for Tracked Hazards

- Mitigation actions include Land, Assigned Land (Return-to-Launch), Hover, None
- Based on hazard thresholds, and their priority, research hardware changes the autopilot mode
  - Autopilot is already in Auto mode
  - CST is engaged/enabled

Hazard Detected	Mitigation		Priority
Navigation Loss		Immediate Land	1
Battery Loss		Immediate Land	1
Command/Control Link Loss		Assigned Land	2
Proximity to Obstacle		Hover	3
Loss of Control		See Below	

	Loss of Control Severity			
Loss of Control Likelihood	Minimal	Minor	Major	Catastrophic
Frequent				
Probable				
Remote				
Improbable				

Key					
	Immediate Land		Assigned Land		None

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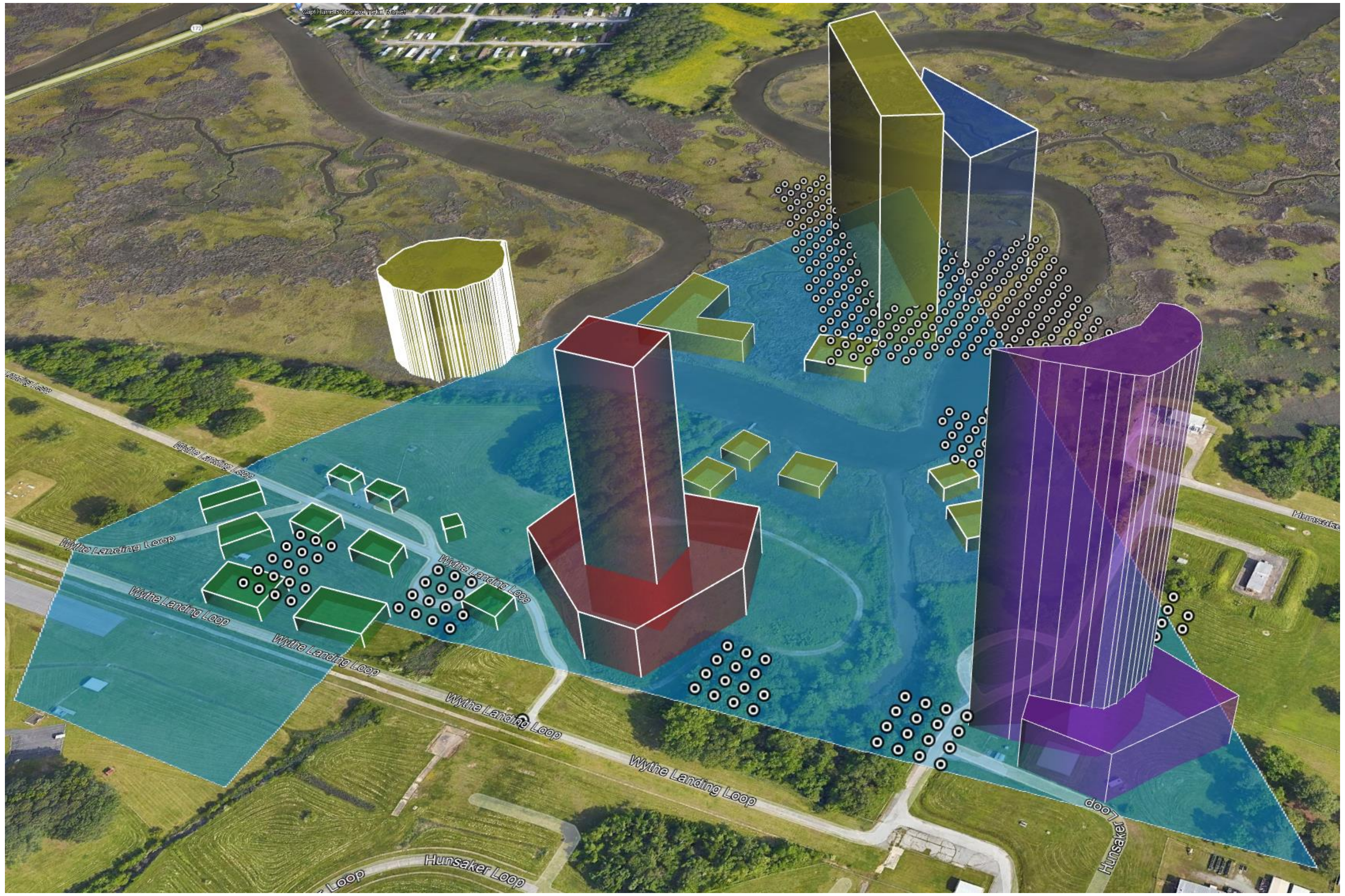
Aircraft

- Modified Tarot T18 Octocopter
  - 2x Intel Next Unit Computing (NUC) nodes
  - Various research sensors, switches, upgraded speed controllers, radios, and associated electronics supporting the research payload
  - SAFEGUARD module
  - Radio-controlled cut-off relays to isolate the autopilot per NASA Class C Software requirements

Flight Range and Path

- NASA's City Environment Range Testing for Autonomous Integrated Navigation (CERTAIN) range
- Virtual buildings, simulated population activity in varying densities, and geofence
- Departure and arrival legs of a longer air taxi operation with ~600m legs , up to 104m altitude



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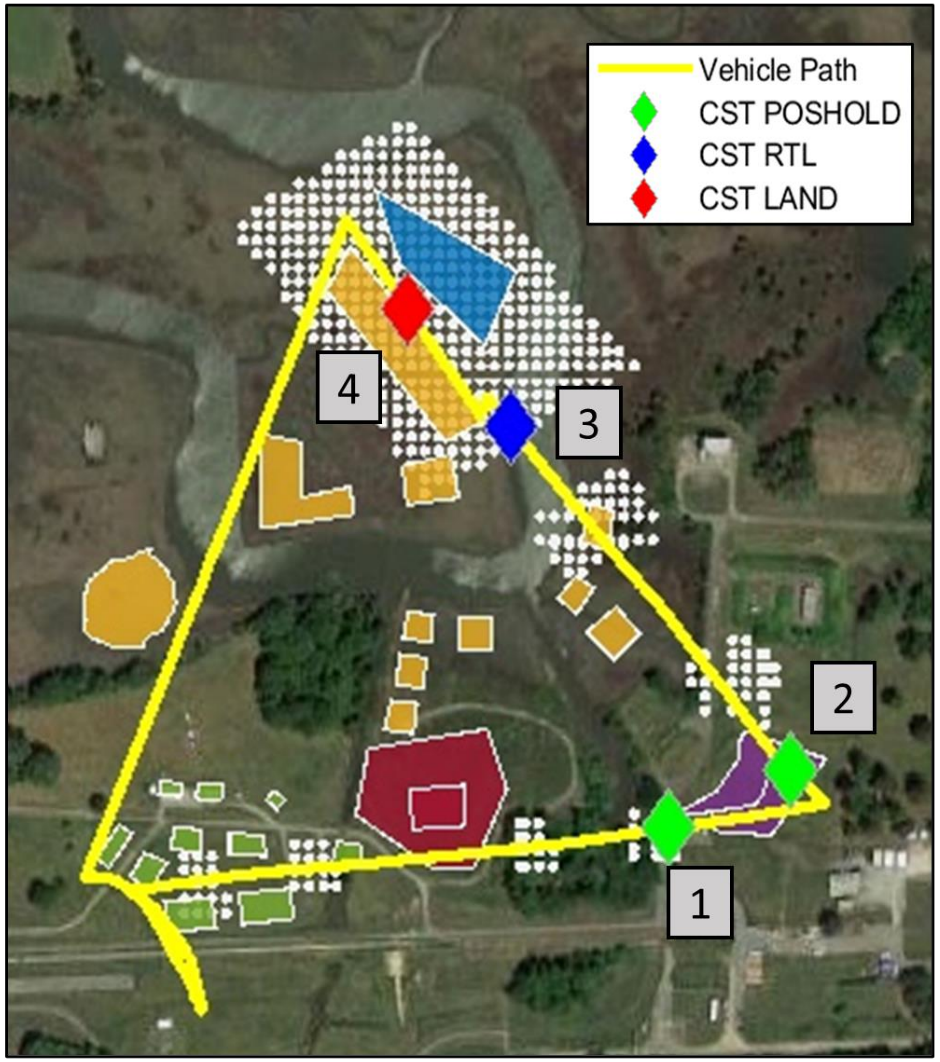
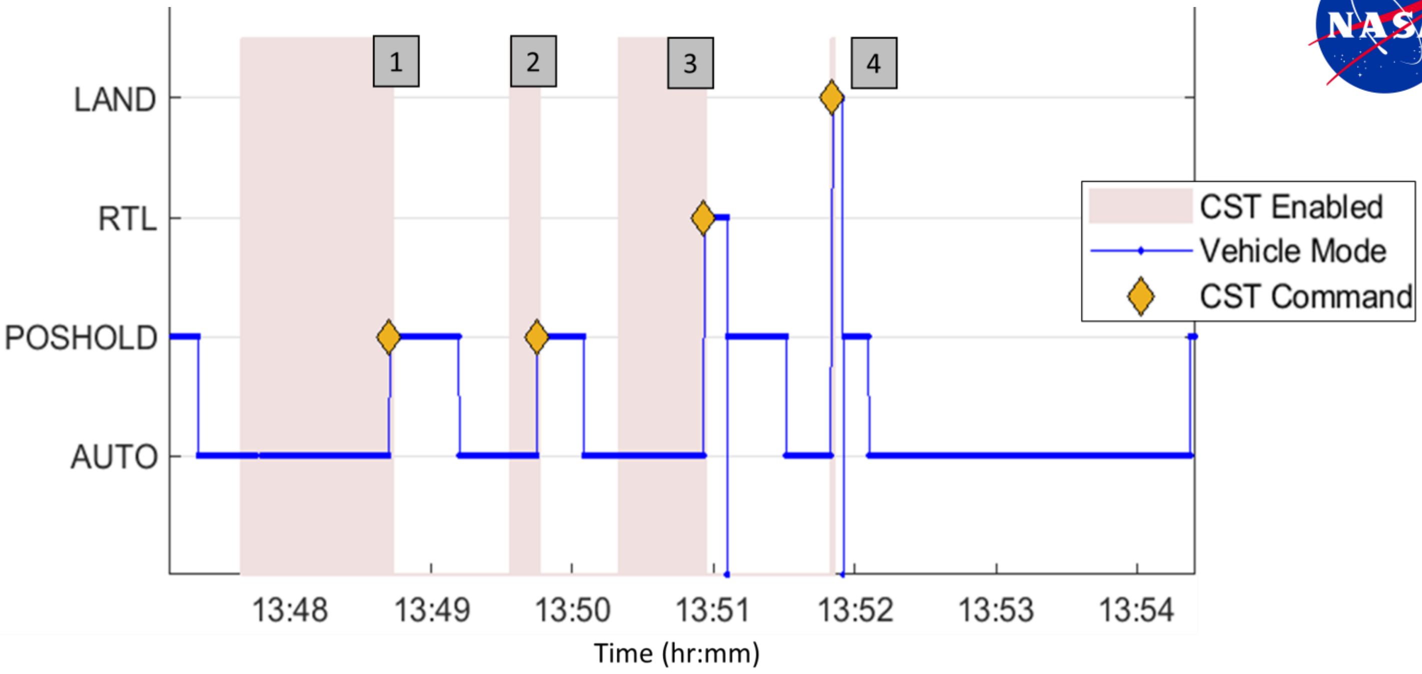
Sample Flight Test Results

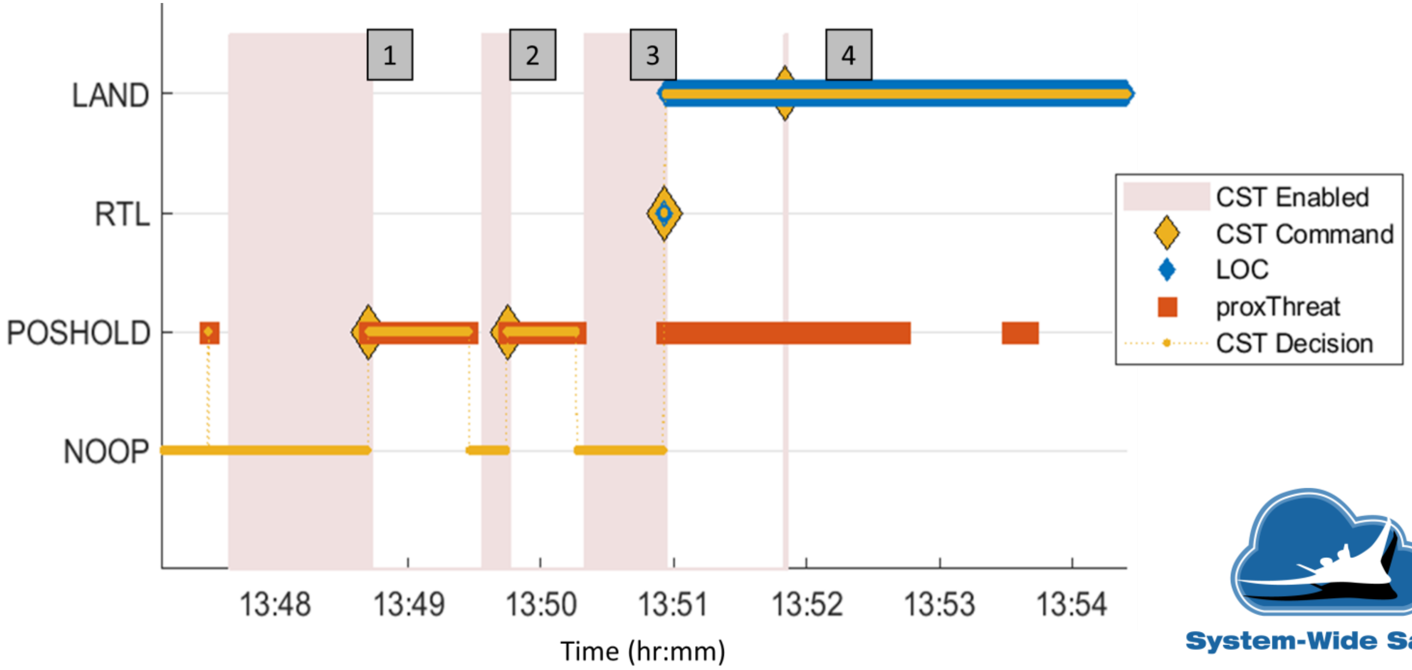
- Phase I Testing
  - Experiments conducted in the secondary computing system with no control over the autopilot mitigation actions
  - 61 Flights between August 2021 and July 2022*
- Phase II Testing
  - Experiments conducted in the primary NUC computer capable of controlling the vehicle autopilot
  - 54 flights between July 2022 and October 2023
- Flight 097
- Flight 115

*Flight Testing In-Time Safety Assurance Technologies for UAS Operations - AIAA 2022-3458
Design and Testing of an Approach to Automated In-Flight Safety Risk Management for sUAS Operations - AIAA 2022-3459

F097 Overview







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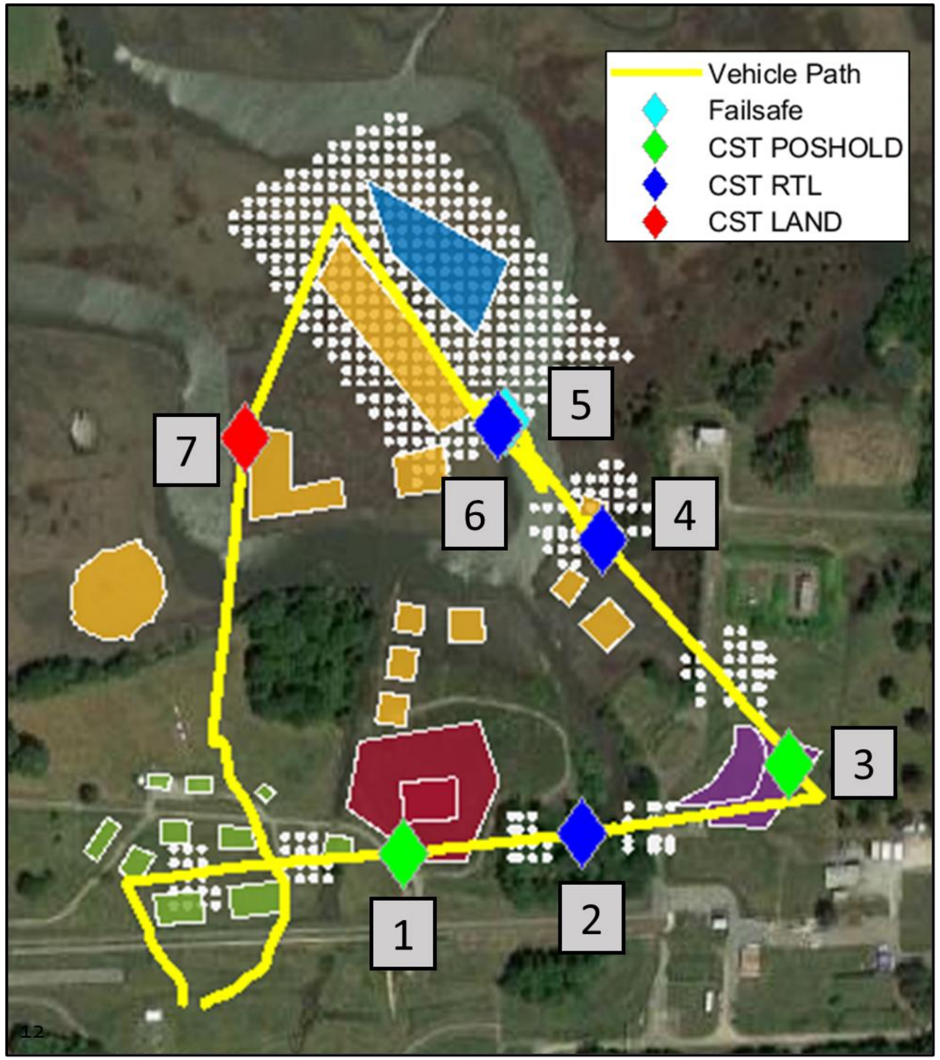
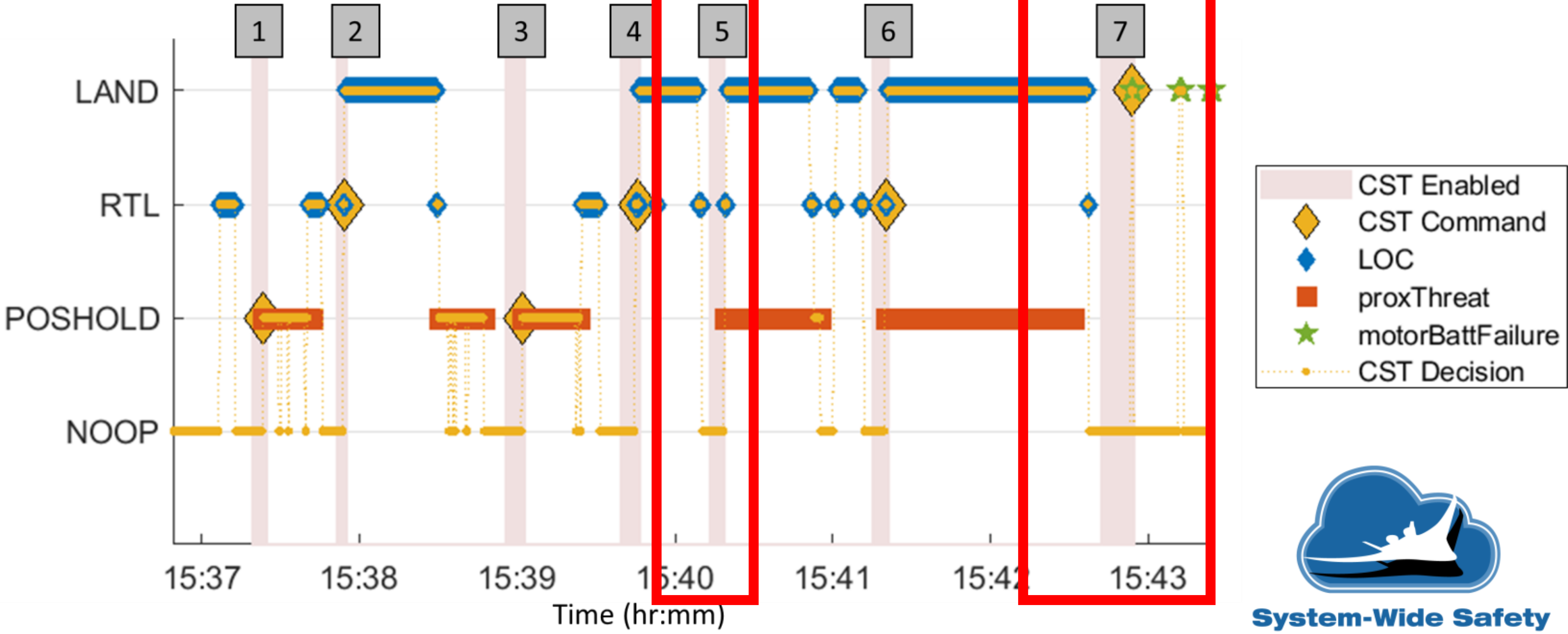
F115 Overview





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Next Steps & Concluding Remarks

- Extensive development and flight testing of more than 20 airborne, ground, and cloud-based SFCs were used to evaluate the IASMS concept and inform the capabilities of future highly-autonomous aircraft
- Second phase of an automated decision-making capability was demonstrated in flight using a virtual city and softcoded threshold values to simulate failures and observe automated decision making
- Flight testing including automated decision making with self-separating aircraft (Detect and Avoid – DAA) is currently underway
- Parallel subproject within SWS will demonstrate these capabilities in increasingly complex flight scenarios/use cases

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Thank you!

Questions?

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