Airspace Autonomy

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Agenda

- Airspace Autonomy – Definition and Context
- The Hard Problems
- Towards an Autonomous Future

Definition

Autonomy Definition: Vehicle performing tasks for/ with humans in domains that are sufficiently unstructured, uncertain or complex (U2C) to render automation (rote mechanization) insufficient

External Landscape – Some Examples

Vehicle Autonomy

Aviate – Navigate – Communicate

Skydio
Inspection
ISR

Google Wing
Drone Delivery

Reliable Robotics
Cargo Delivery/
Regional Air Transport

Ehang AAV
Urban Air Mobility

Boeing Wisk
Urban Air Mobility

Joby Xwing
Cargo Delivery

Boeing Caravan
Autonomy Demonstrator

Merlin
Reduced
Crew/Uncrewed Flight

Zipline
Autonomous Logistics

Airbus
Autonomous Taxi, Take-Off and
Landing (ATTOL)

Commercial - Drones, Advanced Air Mobility, …

Mission Autonomy

Find – Fix – Track – Target – Engage – Assess

AeroVironment
Switchblade

Boeing MQ-25
Carrier Based Refuelling

Northrop Grumman
Global Hawk
Persistent ISR

Kratos XQ-58A
Valkyrie
UCAV

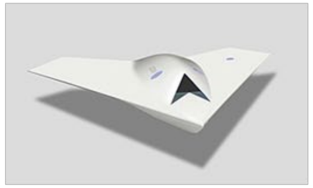
Boeing Skiron-X
ISR

Anduril Fury
UCAV

General Atomics
Reaper
ISR, Hunter Killer

Raytheon Peregrine
Missile

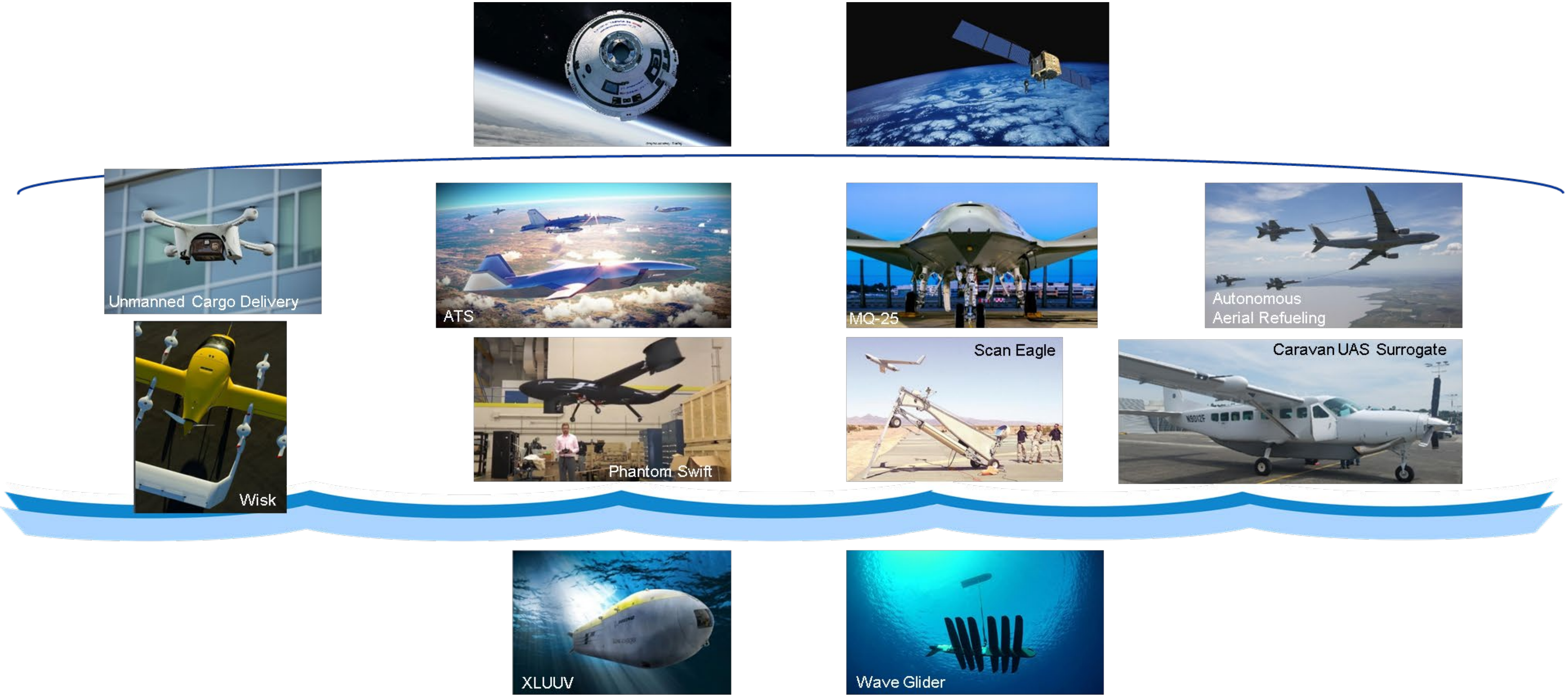
Boeing MQ-28
GhostBat
UCAV



BA E Taranis
UCAV

Military - Group 1 through Group 5 UAS (range/altitude/…)

Boeing Landscape



High-Level CONOPS

Safety

Mission Expansion

Future Flight Deck
Urban Air Mobility
Inspection/Public Safety/Search and Rescue Operations
Intelligence, Surveillance, Reconnaissance and Targeting (ISR&T)
Strike Operations
Air to Air Operations
Maritime Autonomy
Command and Control
Planning & Decision Aiding Systems
…

Efficiency & Performance

Increased Capabilities

CONOPS, Capabilities and Functions

CONOPS

Capabilities

- Pilot Assist and Capability Augmentation
- Human Autonomy Teaming
- Air to Air Conflict Management
- Contingency Management
- Cooperative and Adversarial Autonomy
- Trusted Autonomy

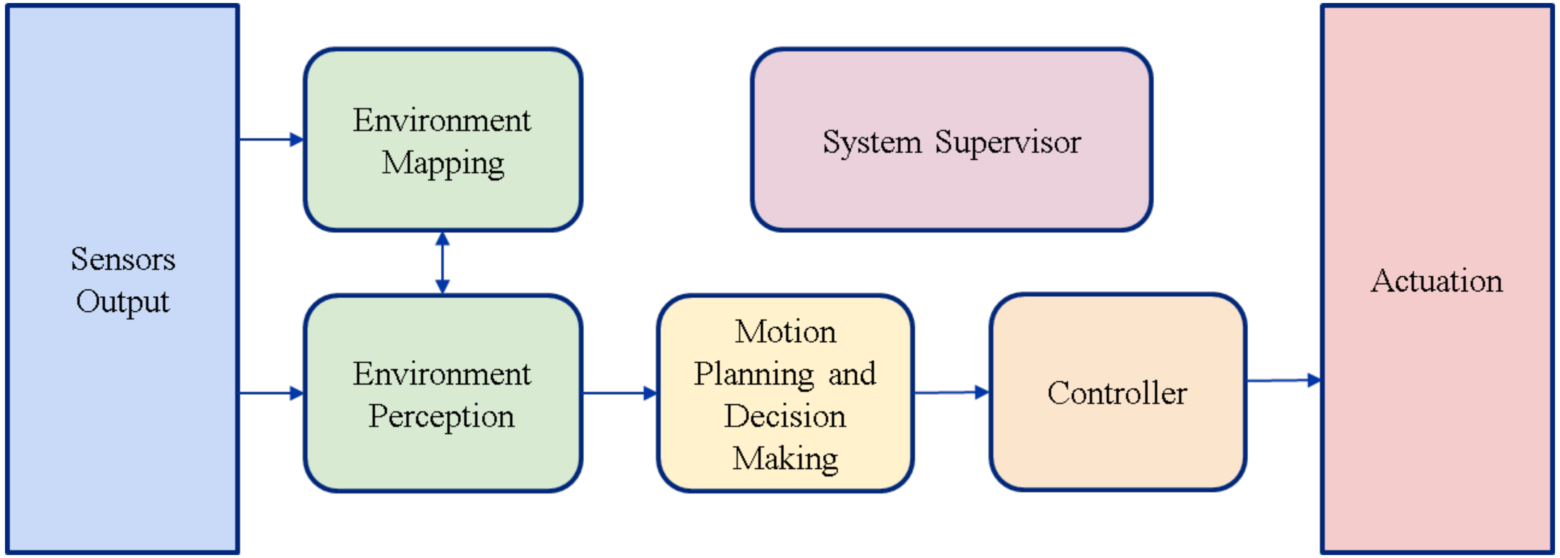
Component Functions

- Perception
- Subsystem Interface
- Communication & HMI
- Planning & Decision Making
- Trust & Safety

Implementation

Infrastructure, Software Framework, Tools

High-Level Functional Architecture*



*: Self Driving Car Specialization, Coursera, Steve Waslander

Aerospace and Automotive Domains

Level 5: Full Automation

Level 4: High Automation

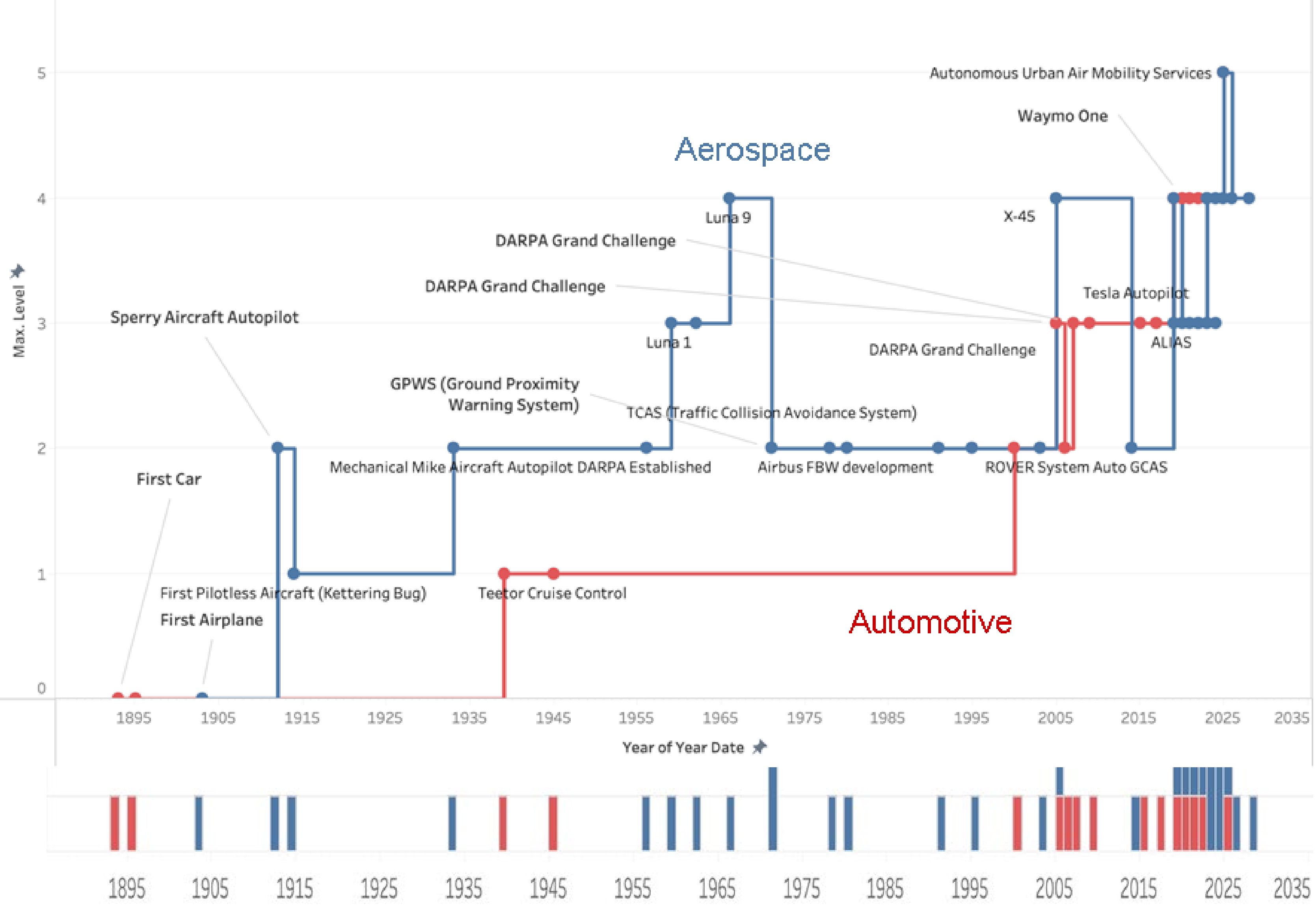
Level 3: Conditional Automation

Level 2: Partial Automation

Level 1: Operator Assistance

Level 0: No Automation

Major Events in each year:



Courtesy – Tim Booher, VP, Autonomy, Boeing

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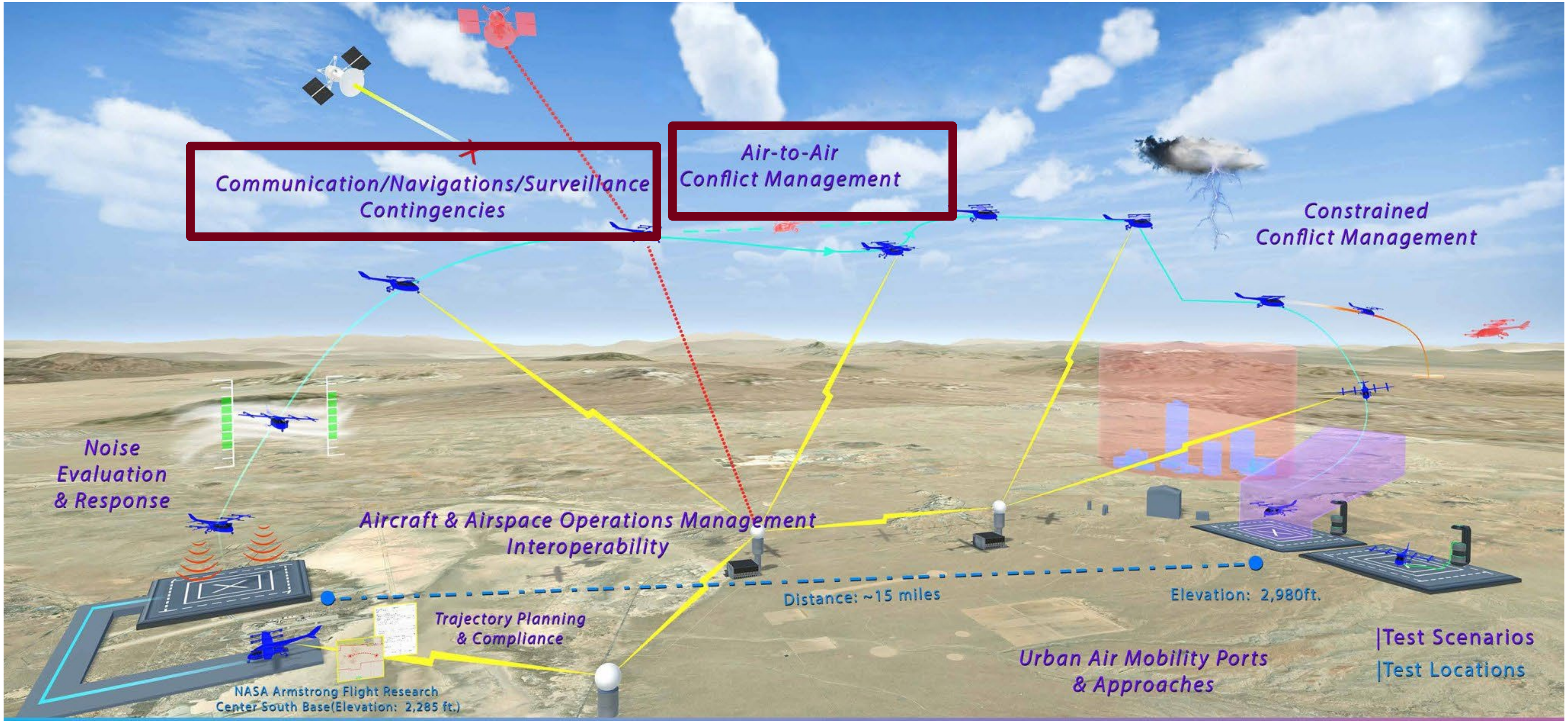
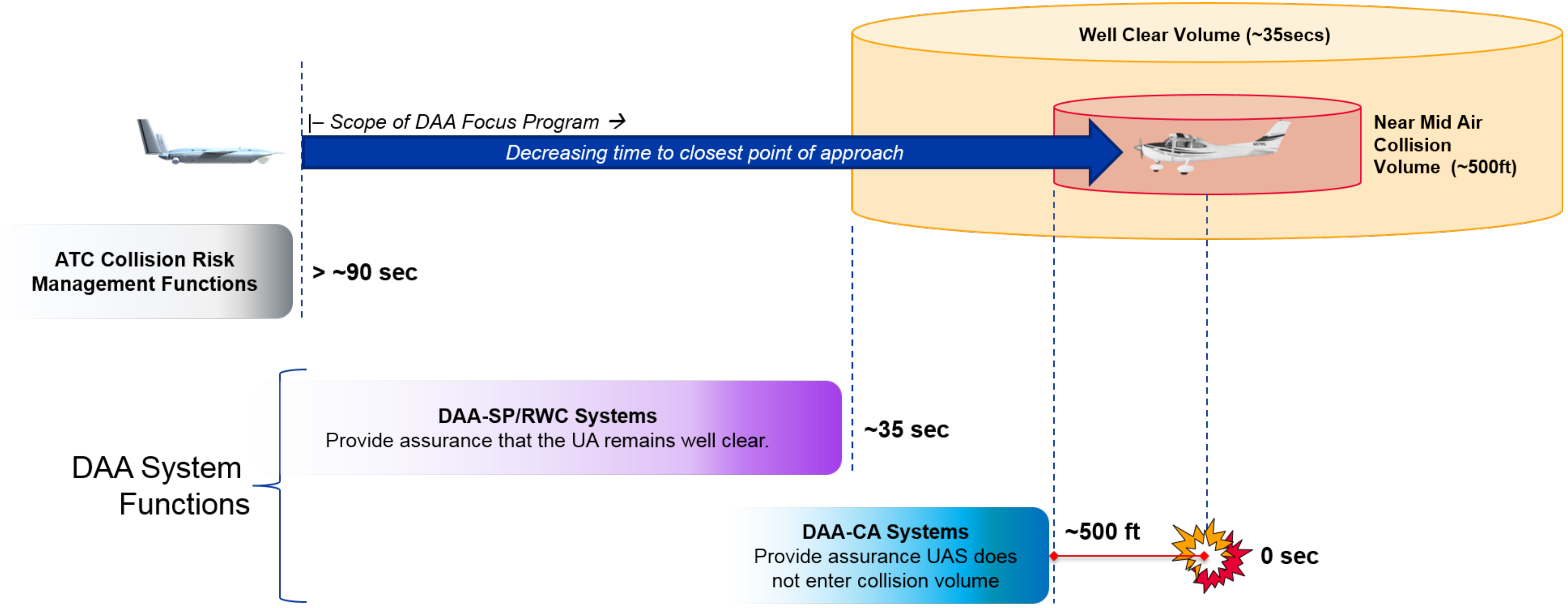
Flight Autonomy – Urban Air Mobility Applications



[NASA Urban Air Mobility – Grand Challenge Problems]

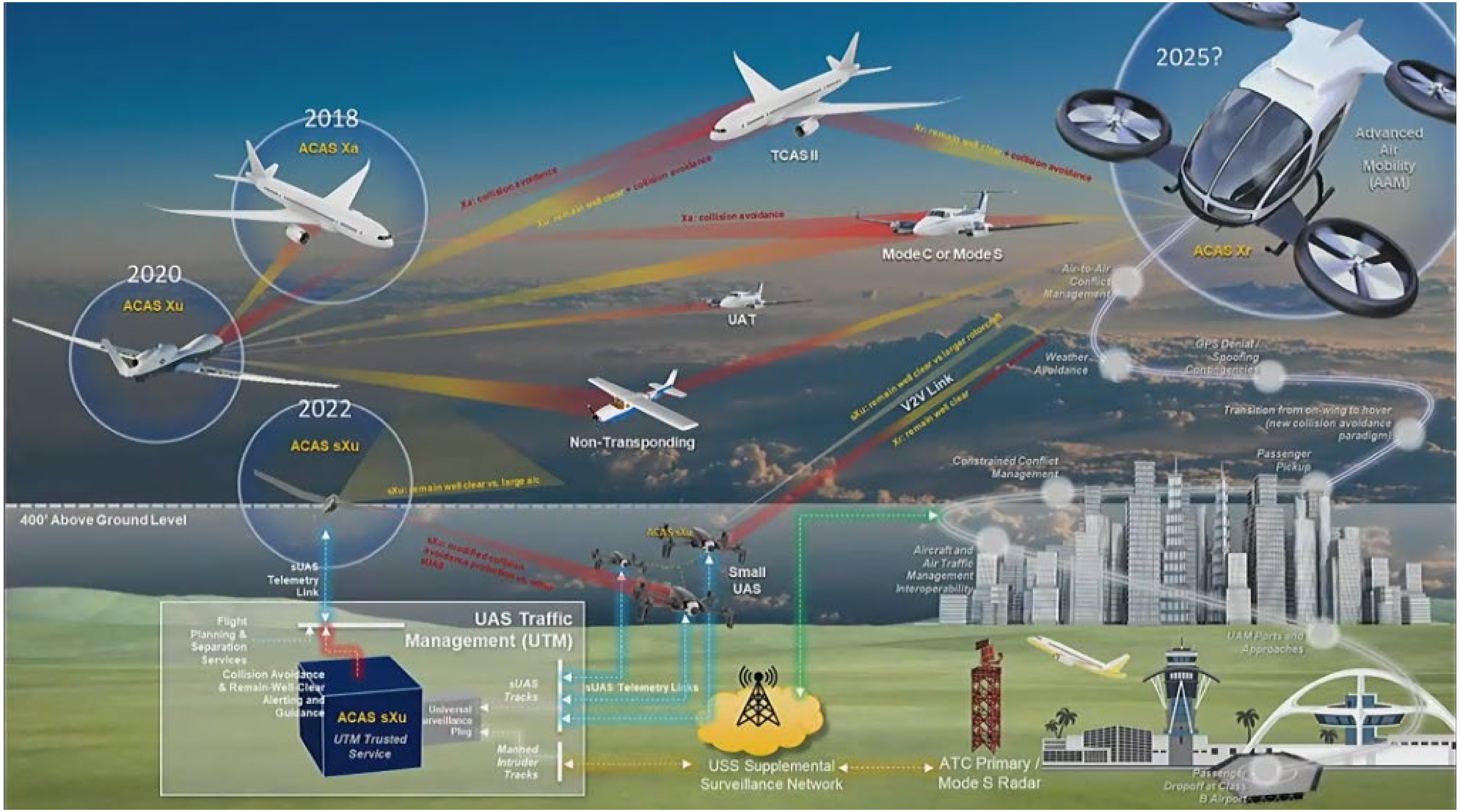
Air to Air Conflict Management*

Air to Air Conflict Management/Collison Avoidance enable UAVs and other autonomous aircraft to **detect potential obstacles and avoid collisions** by taking appropriate actions. The RTCA has developed a set of standards to enable Air to Air Conflict Management/Collison Avoidance

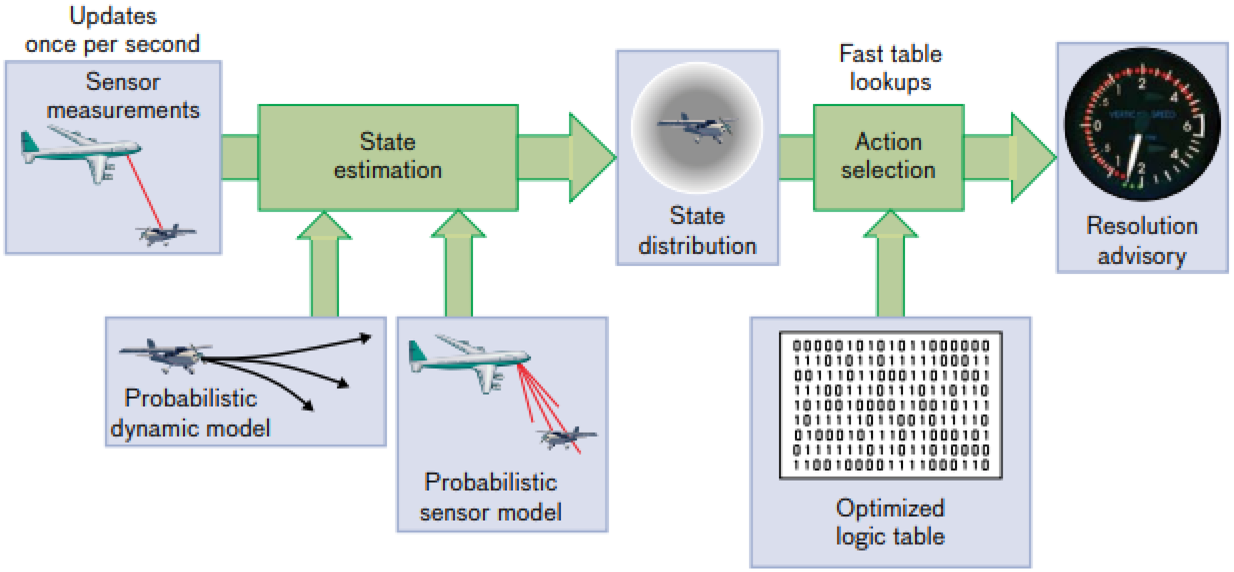


*: Also referred to as Detect and Avoid (DAA)

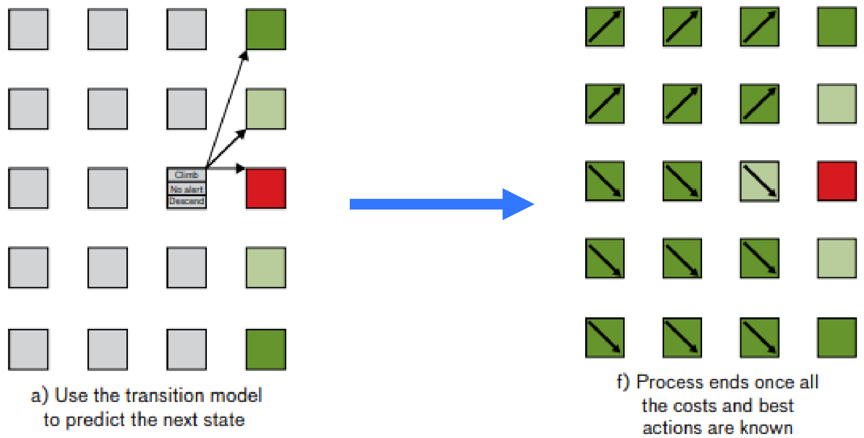
The Evolution of Air to Air Conflict Management



Closed-Loop Analysis – A Deployed System



Airborne Collision Avoidance (ACAS-X)



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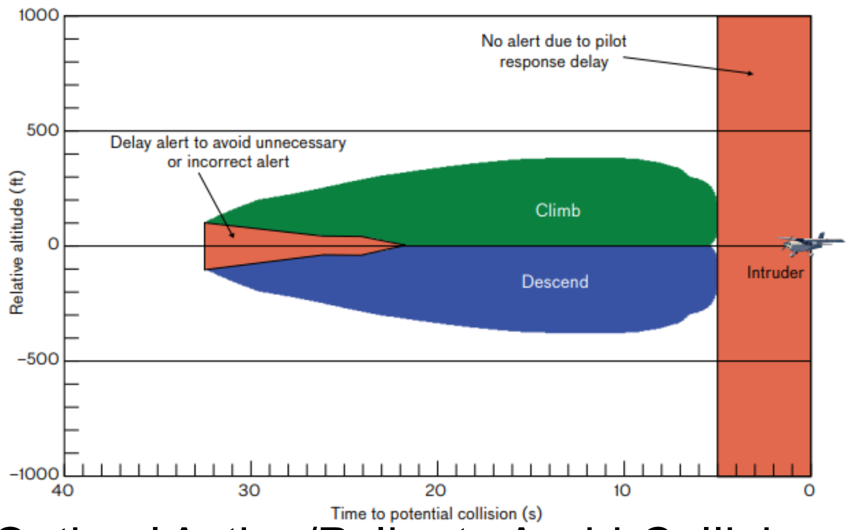


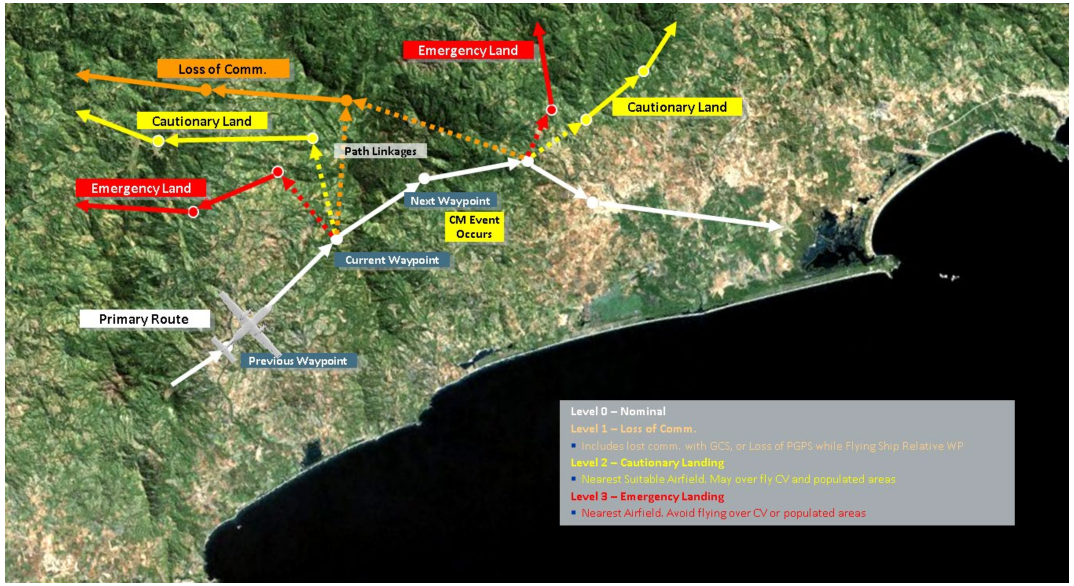
Optimal Action/Policy to Avoid Collisions

Contingency Management

Contingency & Redundancy Management encompasses the architecture, design, and software algorithms that determine the **control and safe operation** of the Air Vehicle in the **presence of failures**, or other factors, that impact the system's ability to complete its desired flight plan

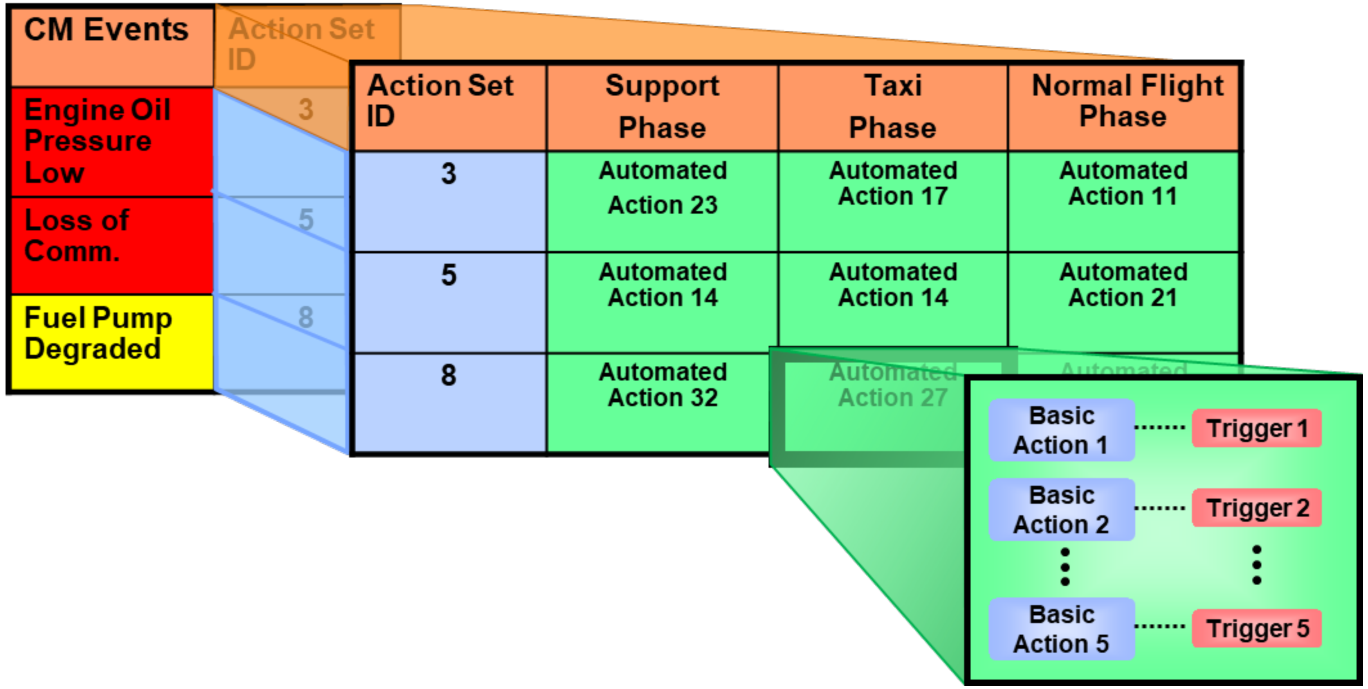
Redundancy Management – Encompasses the architecture, design and software algorithms that monitor, isolate and accommodate system failures or other concerns

Contingency Management – Encompasses the architecture and software algorithms that invoke pre-defined actions in the presence of failures detected by Redundancy management



Contingency Management – Under the Hood

- CM events are populated in the CM database
- Each CM event is assigned an action set
- Each action set is assigned 1 autonomous action per phase of flight
- Each autonomous action consists of basic actions
- Key challenge is complexity – mapping events to actions, and verifying the mappings
- How do we deal with unknown unknowns?



Contingency Management Database

AI/ML as an Enabler for Mission Autonomy*

AI/ML offers enhanced capabilities across vehicle and mission autonomy, and across the autonomy functions, but the Verification/Validation remains a significant challenge.

Aviate – Navigate – Communicate   Find – Fix – Track – Target – Engage – Assess

Perception	Planning and Decision Making	Control

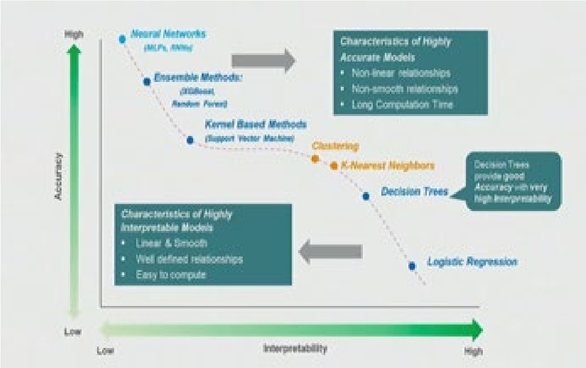
• Object detection
  • Bounding box methods
  • Segmentation
• Change detection
• Scene understanding
• Image preprocessing
• Image augmentation
• Transfer learning
• …
	• Mission planning
	  • Scenario analysis
	  • Optimal resource allocation
	  • Target prioritization
	• Routing
	  • Pathfinding
	  • Dynamic routing
	  • Swarm intelligence
	• Logistics
	• Resource allocation
	• Decision making
	  • Decision support systems
	  • Game theory
		• Collaborative
		• Adversarial
		• Human machine teaming

Case study – Project Maven aimed to develop AI that could categorize and identify vast amount of surveillance footage taken by combat surveillance equipment	Case study – DARPA's Blackjack program focuses on multi-theater mission autonomy – each satellite can self-task, process and distribute tactically relevant information	Case study – DARPA Alpha Dogfight trials where teams competed in a series of simulated air-to-air combat engagements against each other and a human pilot who controlled a virtual fighter through a sim

*: AI for Defense and Intelligence

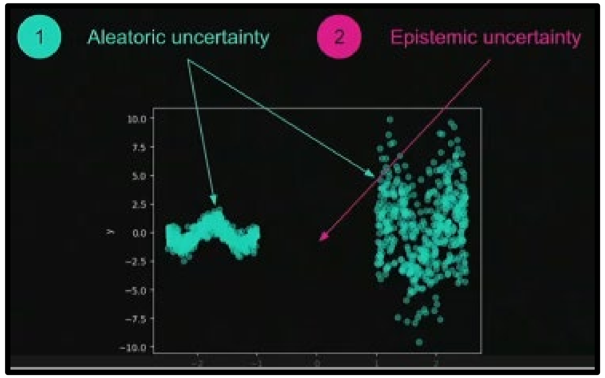
Robust AI/ML

- Robust Machine Learning
  - Distribution shifts degrades model performance
  - Lack of robustness due to the learning of spurious relationships
  - Potential solutions include data augmentation, architectural changes, etc.



- Model Explainability and Verification
  - Assurances beyond test-set accuracy in required in safety-critical apps
  - Potential solutions include saliency maps, formal methods/reachability analysis
  - Model can provide decision support to a human in the loop

- Uncertainty quantification
  - It isn't possible to design/test against all possible scenarios
  - Uncertainty quantification becomes critical in safety-critical apps
  - Potential solutions include out-of-model scope predictions, etc.



- Closed Loop Analysis
  - It is important to set specs on the closed loop system
  - The approach involves defining specs, modeling the system/env, and analyzing safety

*: Designing Reliable and Robust AI Systems – Stanford Short Course. Anthony Corso

Robust AI/ML applied to Advanced Autonomous Capabilities

Runway clear

Perception autoland

Intelligent landing

“Follow-Me” taxi behaviors

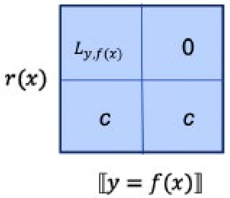
Taxi collision avoidance

Mid-air collision avoidance

Caravan – Boeing’s Autonomy Demonstrator

DARPA Assured Autonomy Program

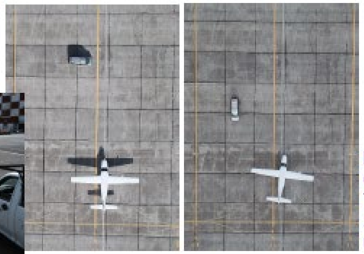
CARAVAN OPEN CATEGORY TESTING AND EXPERIMENTATION



Air Domain Testbed

Testbed Rack Operator

TA1-3 Team Ride-Along



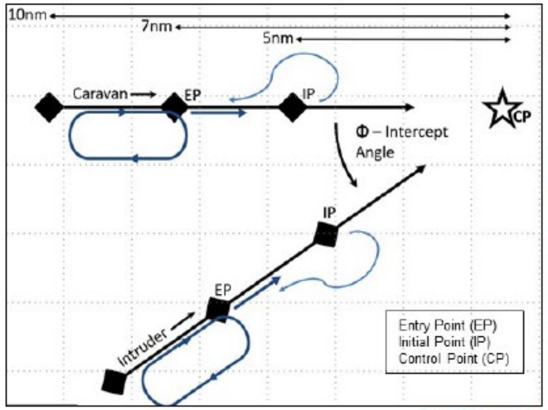
Multiple Test Conditions with Taxiing Airplane, Static Obstacles – unknown class

REMAIN WELL CLEAR (RWC) FLIGHT TESTING AND EXPERIMENTATION

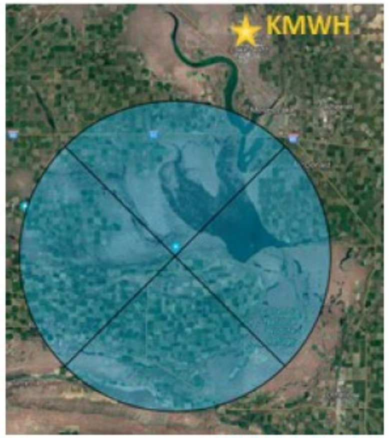
Boeing Cessna Caravan Autonomy Demonstrator Testbed carrying Safety Pilot, Flight Test Director, Caravan Rack Operator, for Remain Well Clear (RWC) Flight Test

Boeing Cessna 206 Stationair Piloted Intruder Aircraft (Note – we have other candidate Intruder aircraft to ensure availability of a test asset)

Grant County Int'l Airport (KMWH) at Moses Lake, WA



Test Trajectories



RWC Flight Test Area

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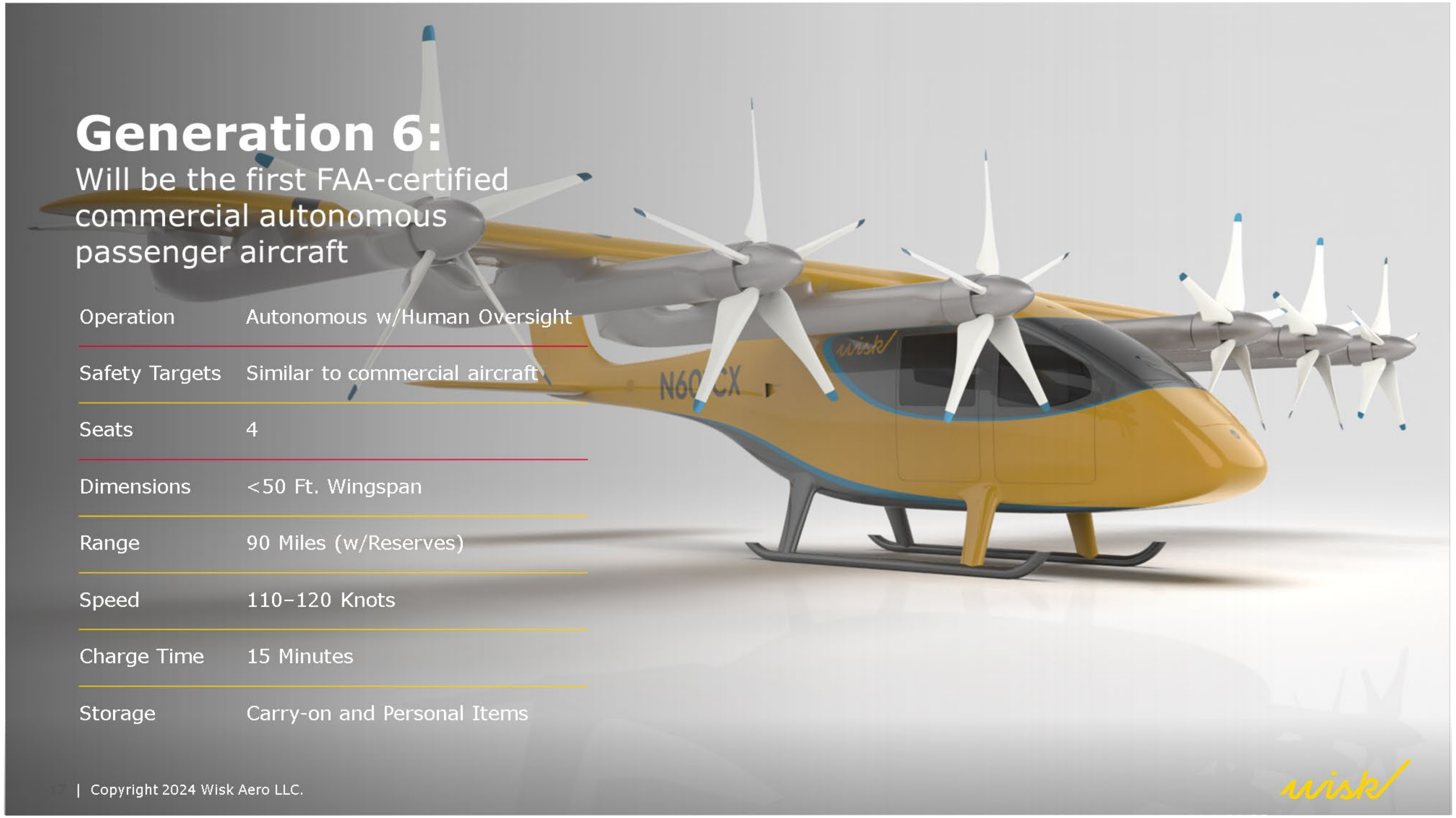
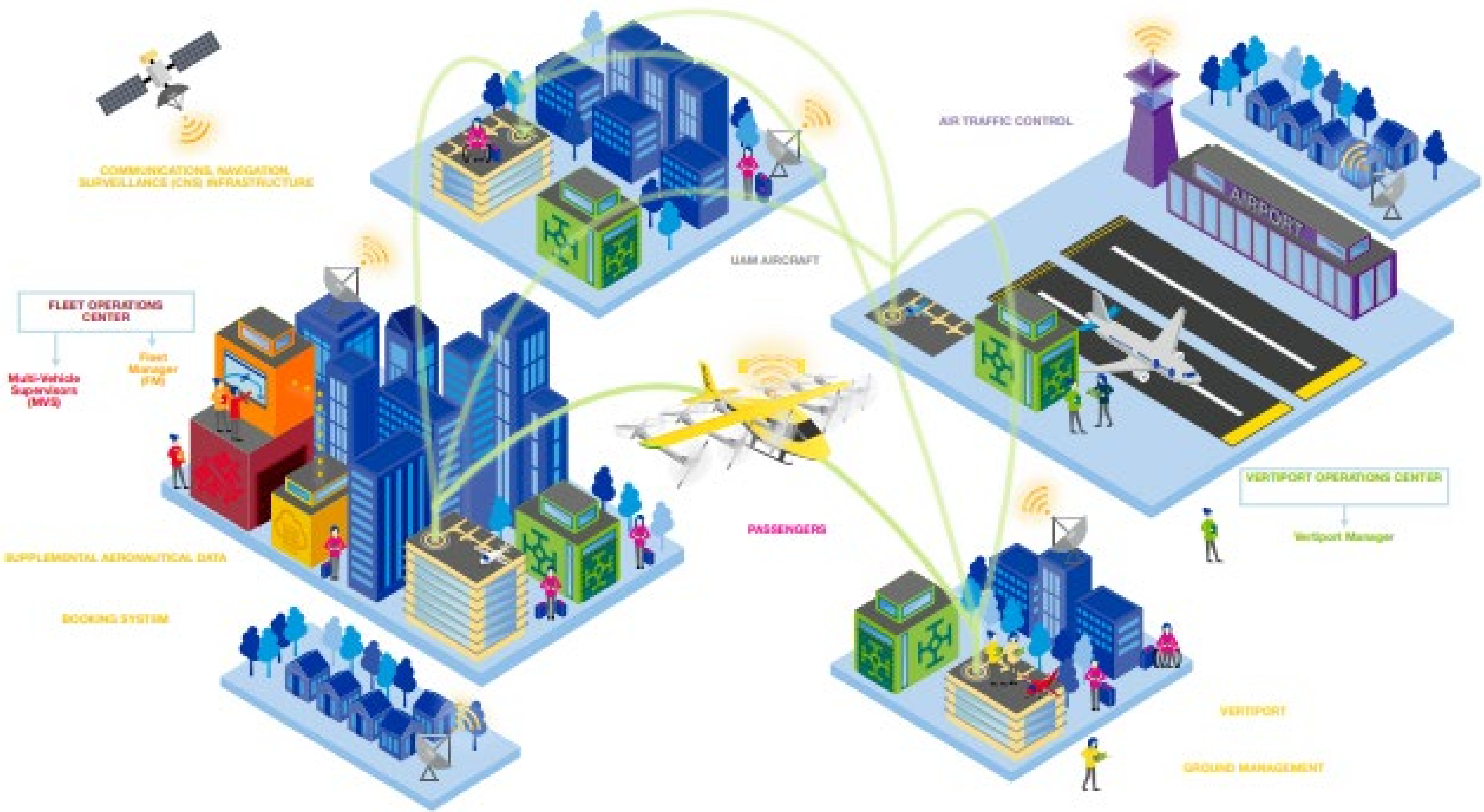
Boeing’s Wisk Platform for Urban Air Mobility

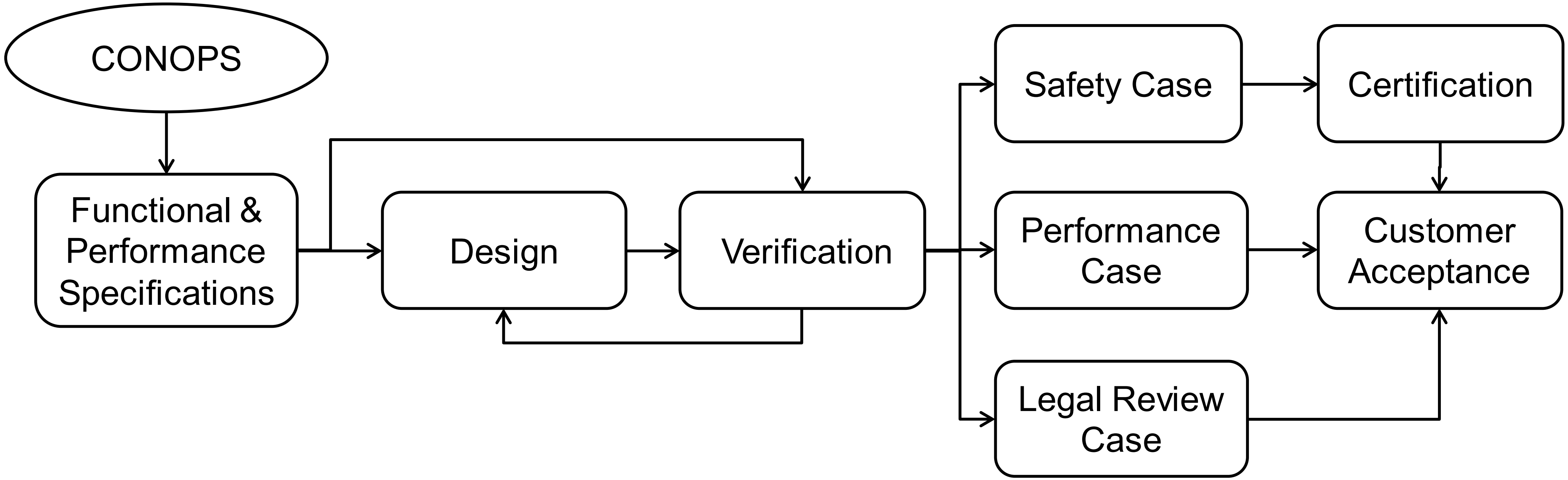


Concept for Advanced Air Mobility in Urban Environments*



*: [Wisk CONOPS]

Development Cycle



Path to Certification

- **Certification** - Establishes that a system meets all **regulatory requirements;** also provides a credible prediction of a future service experience for new systems
  - Type Certificate, Production Certificate, Operations Certificate
- **Regulatory basis for certification** – Subset of Federal Aviation Regulations (FAR_ that apply to a given aircraft development effort
  - Part 21 – Certification Procedures for Products and Parts
  - Part 25 – Airworthiness Standard: Transport Category Aircraft (large commercial airplane)
  - Part 78 - Production
  - Part 135 – Air Carrier and Operations
- **Certification of Urban Air Mobility vehicles–** New vehicle Type that doesn't easily fit into the regulatory basis
  - " Powered-lift" vehicles will be certified under a "special class" defined in Part 21
- **Avionics Equipment Approval (TSO)** – Regulatory instruments that recognize the broad use of certain classes of parts in systems
  - Often refers to third-part guidance material such as RTCA and the SAE, e.g. , DO-365B (Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems)
- **Autonomy Certification** – Compliance comes down to safety assessments, environment qualification, and software/hardware assurance

Towards an Autonomous Future …