Trusted Autonomous Systems

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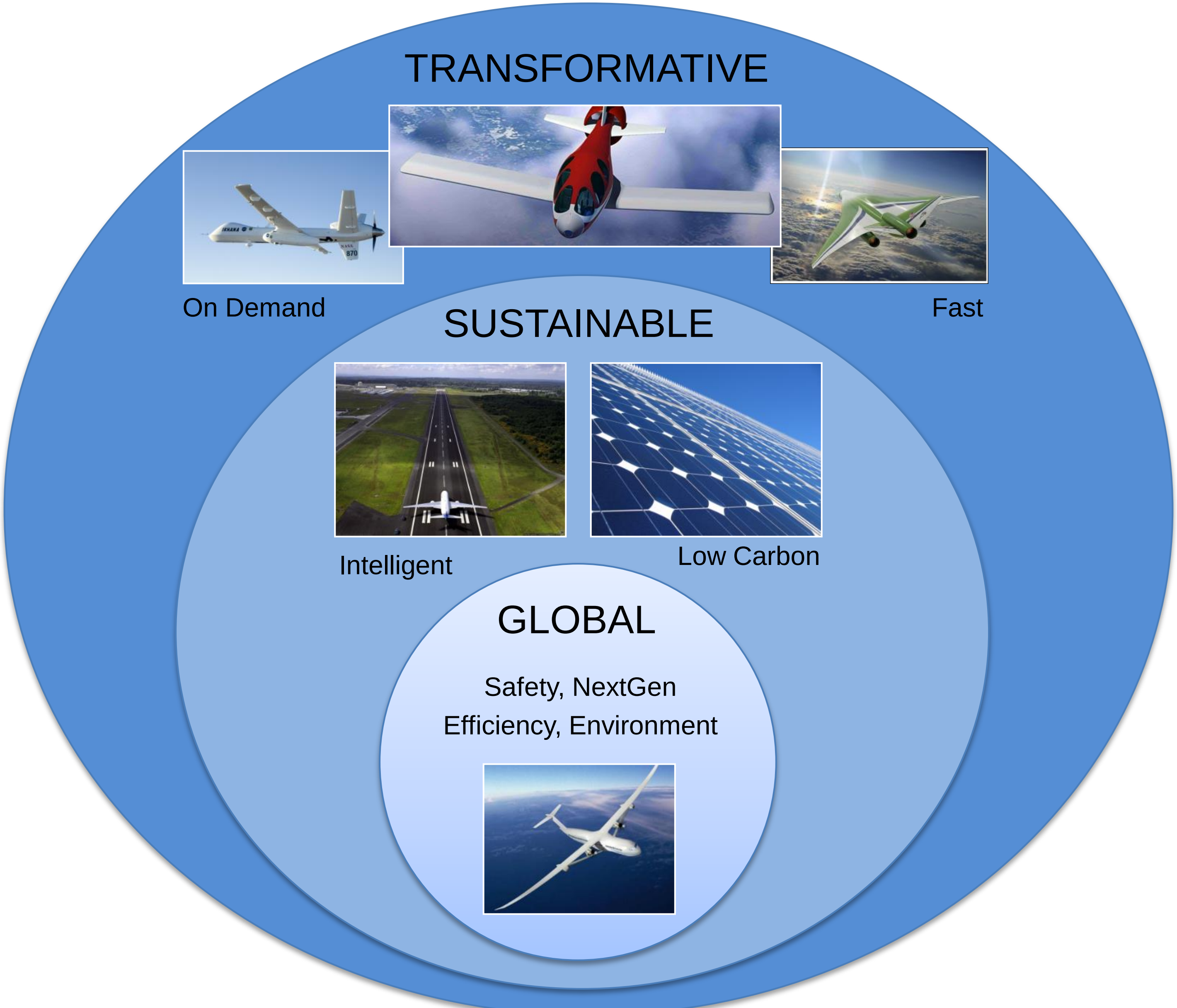
Overview

- NASA's Vision for Civil Aviation
- The Need for Autonomy
- Safety-critical flight systems – Today
- Autonomy in Civil Aviation
- Autonomous systems and Trust
- Framework for design and evaluation of autonomous systems
- Two Test Cases
  - UAS and Autonomy in the NAS
  - Autonomous Airport Management Capability

NASA'S Vision for Civil Aviation



The Need for Autonomy

- *IATA Vision for 2050 is that "Traffic has grown from 2.4 billion to 16 billion passengers in the last 40 years..."* (Ref: International Air Transport Association (IATA))
- *"Civil aviation is on threshold of potentially revolutionary changes in aviation capabilities and operations associated with increasingly autonomous systems."* (Ref: National Research Council's 2014 Autonomy Research for Civil Aviation: Toward a New Era of Flight)

- Belief is that autonomous systems
  - Can **reduce reaction times in safety-critical situations**.
  - Can **improve safety and efficiency** with capability to rapidly cue operators
  - Can substantially **reduce the frequency of those classes of accidents typically ascribed to operator error**.
  - Have the potential to reduce manpower requirements, thereby **increasing the efficiency of operations and reducing operating costs**.

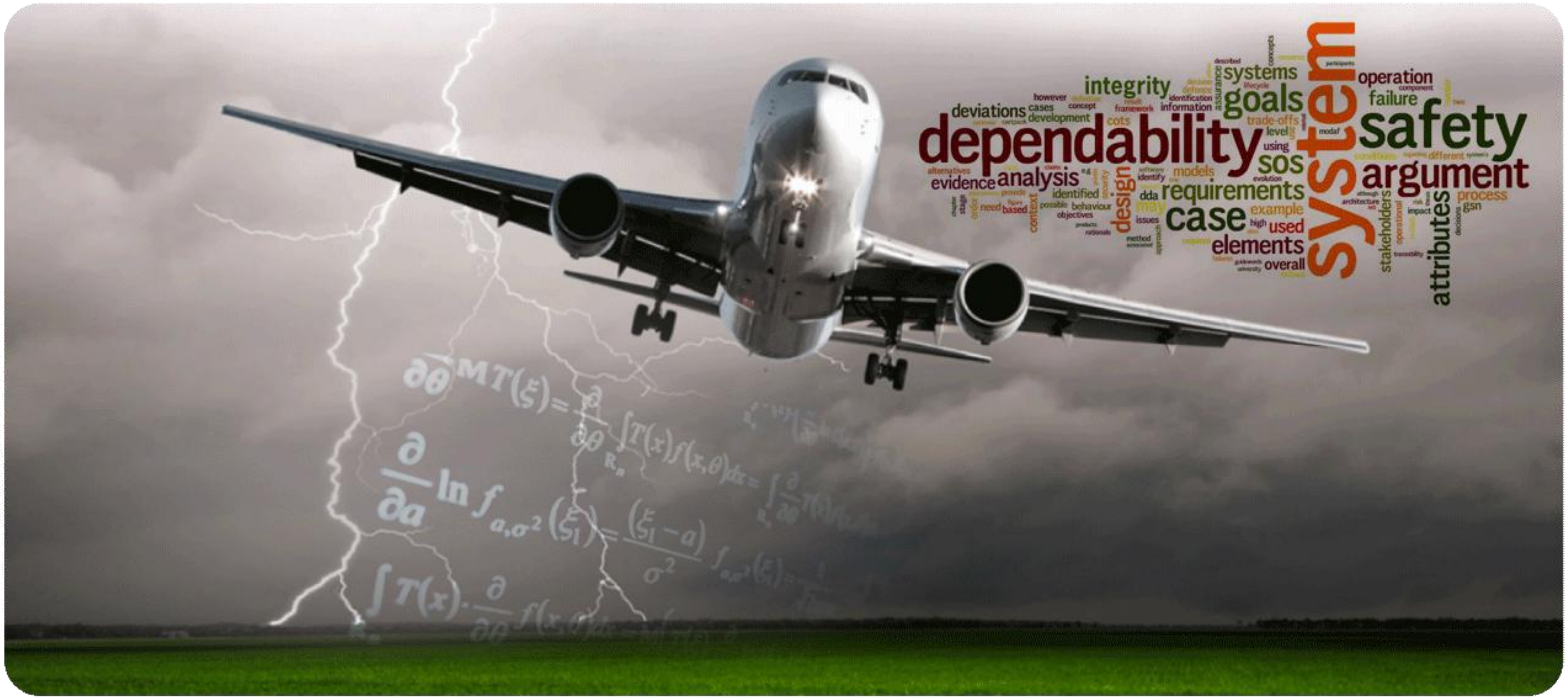
Degrees of Autonomy[1]

Human	Supervisory Control[2]	Fully Automatic	Chasm	Autonomy
• All actions require Pilot intervention • Automation may alert pilot and suggest courses of action	• Automation algorithms determine course of action • Pilot remains informed and can override as needed	• Algorithms respond to input data without human input or possibility of Override • Take predetermined Action • Control Theory - Feedback loops		• <u>Non-deterministic</u> • <u>Judgment</u> • <u>Emergent behavior</u> • <u>Perception & Reasoning</u>

[1]Ref: MITRE, http://sites.nationalacademies.org/DEPS/cs/groups/depssite/documents/webpage/deps_069084.pdf
[2]C. Billings, Aviation Automation: The Search for a Human-Centered Approach

NEED: Harmonious human-machine system integration methods that engender trust and collaboration to ensure safety and increase reliability in the NAS.

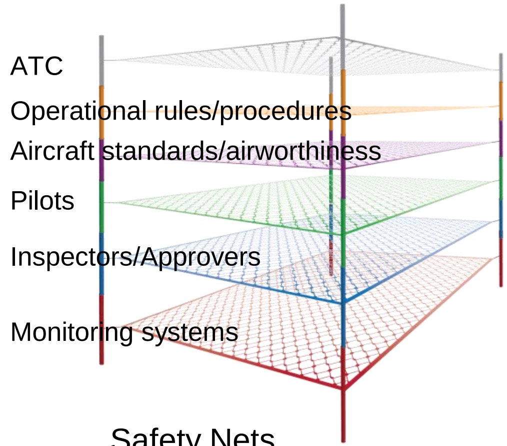
Safety-critical flight systems - Today



Today safety-critical flight systems are trusted because they have met rigorous standards and certification criteria regarding **flightworthiness**, structural **integrity** and **safety-assured** flight controls under nominal conditions.

Certification and Safety

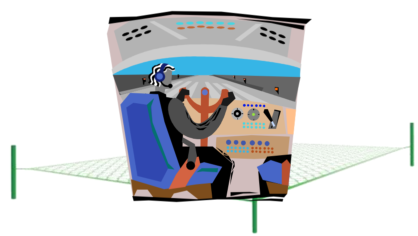
For manned aircraft, there are many safety nets to mitigate hazards and reduce risk



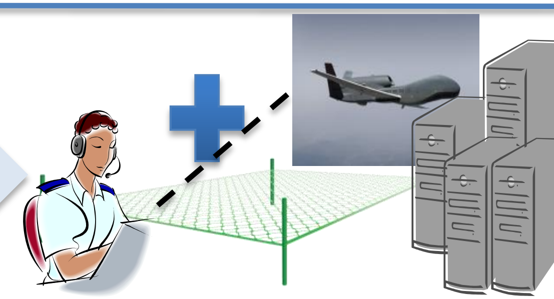
Safety Nets

On-board pilot is one safety net

For unmanned aircraft, how do hazards/risks change when….

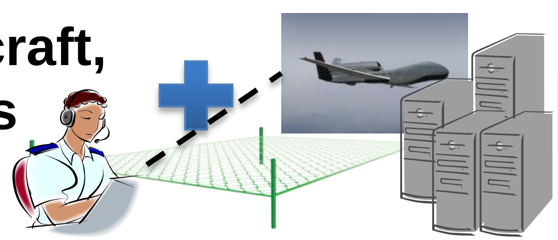


On-board pilot is replaced by…

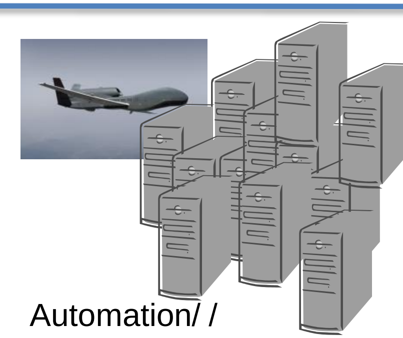


Remote pilot + automation

For autonomous aircraft, how do hazards/risks change when….



Remote pilot + automation is replaced by…



Automation/ / Autonomy

Ref: Safety-Critical Avionics - Certification and Safety, Cooper & Hayhurst, Feb. 19 2014

Autonomy in Civil Aviation[1]

How do we assure that autonomous (adaptive / nondeterministic) systems, that can modify their behavior in response to the external environment, are safe and reliable for Civil Aviation?

(Ref: National Research Council's 2014 Autonomy Research for Civil Aviation: Toward a New Era of Flight)

Barriers

Operation Without Continuous Human Oversight

Technology Barriers

- Human-machine integration
- Nondeterministic decision making
- Sensing, perception & cognition
- System complexity and resilience
- V&V

Regulation and Certification Barriers

- Airspace access for UAS
- Certification
- Equivalent level of safety
- Trust in nondeterministic Increasingly autonomous systems

[1] Autonomy Research for Civil Aviation, NRC Report, 2014

Autonomous Systems and Trust

Trust has been identified as a major challenge in the development and implementation of autonomy in Civil Aviation.

- Innovative **collaborative human-machine system integration methods** are needed that engender human-machine and machine-machine trust and collaboration to maximize performance and be effective.

- **Design, test, evaluation, verification and validation methods** to assure effective and safe operational performance are key challenges facing aviation manufacturers and certifiers today.

- Development of mechanisms for establishing and **maintaining trust in the systems' ability** to perceive relevant environmental circumstances and **to make acceptable decision**s regarding the course or courses of action are needed.

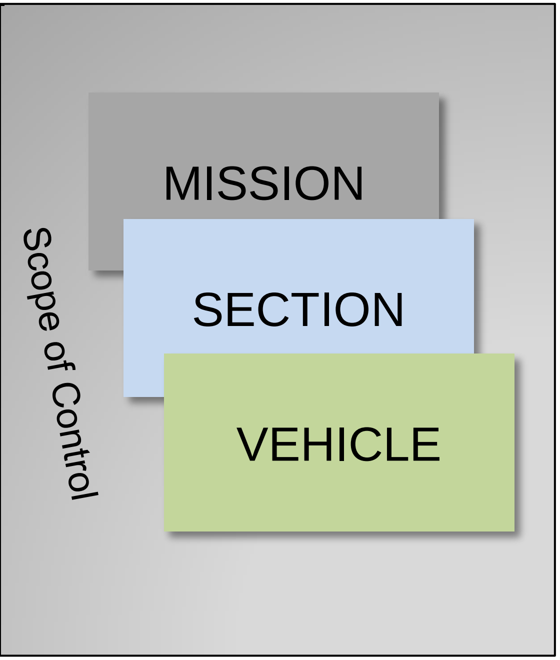
Adaptive / Nondeterministic systems[1]

"Building trust involves the estimation (with associated confidence) of both the ***bounds of performance of the system and the bounds of the control actions that will be performed within and by the system****. This is in contrast to exhaustive testing over given operating conditions, as is typically now the case in verification, validation and certification."*

[1]Ref: Autonomy Research for Civil Aviation, NRC Report, 2014, p. 43

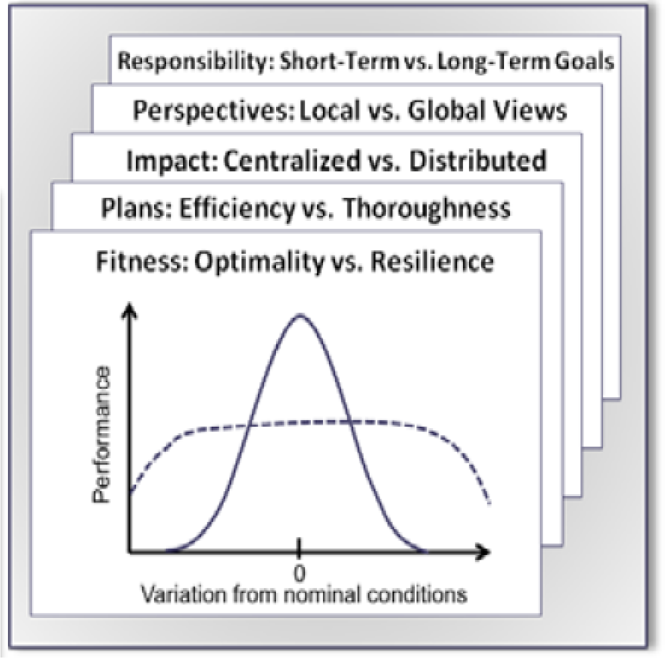
Framework for Design and Evaluation of Autonomous Systems

Cognitive Echelon View



Mission Dynamics View

Complex System Trades Space View



Credit: Defense Science Board Task Force Report "The Role of Autonomy in DoD Systems"

TEST CASE 1: UAS AND AUTONOMY IN THE NAS

Applications for UAS and Autonomy

Many potential UAS civil business models:

- Surveillance (e.g., Border, Oil pipeline)
- Precision Agriculture
- Geological data collection
- Meteorological data collection
- Search and rescue
- Disaster monitoring
- Traffic monitoring
- Telecommunications relay

Challenges to routine UAS usage in the NAS

- **Absence of legislation and regulations** for safe flight in integrated airspace
- Lack of precision technologies to **detect, sense and avoid**
- **Safety assurance under a "lost link"** condition and means to safely prevent aircraft loss of control
- **Systemic trust for information systems and agents** – data must be accurate, or characterized accurately, and the information must be used appropriately
- Trusted autonomy – **assurance that autonomous systems** are safe and operate as specified (**do no harm**)
- Social issues
  - Public's privacy concerns
  - Public's perception of safety

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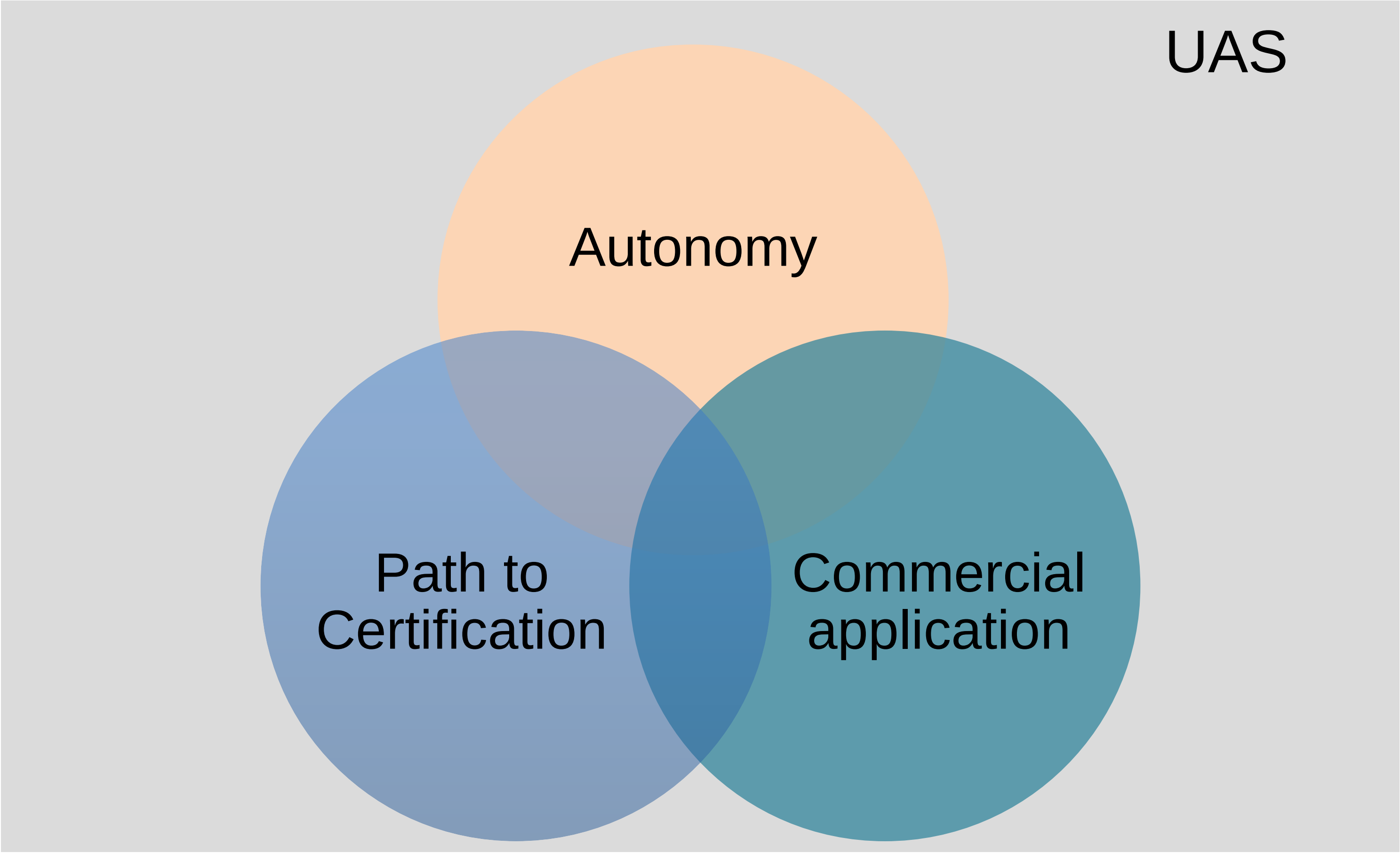
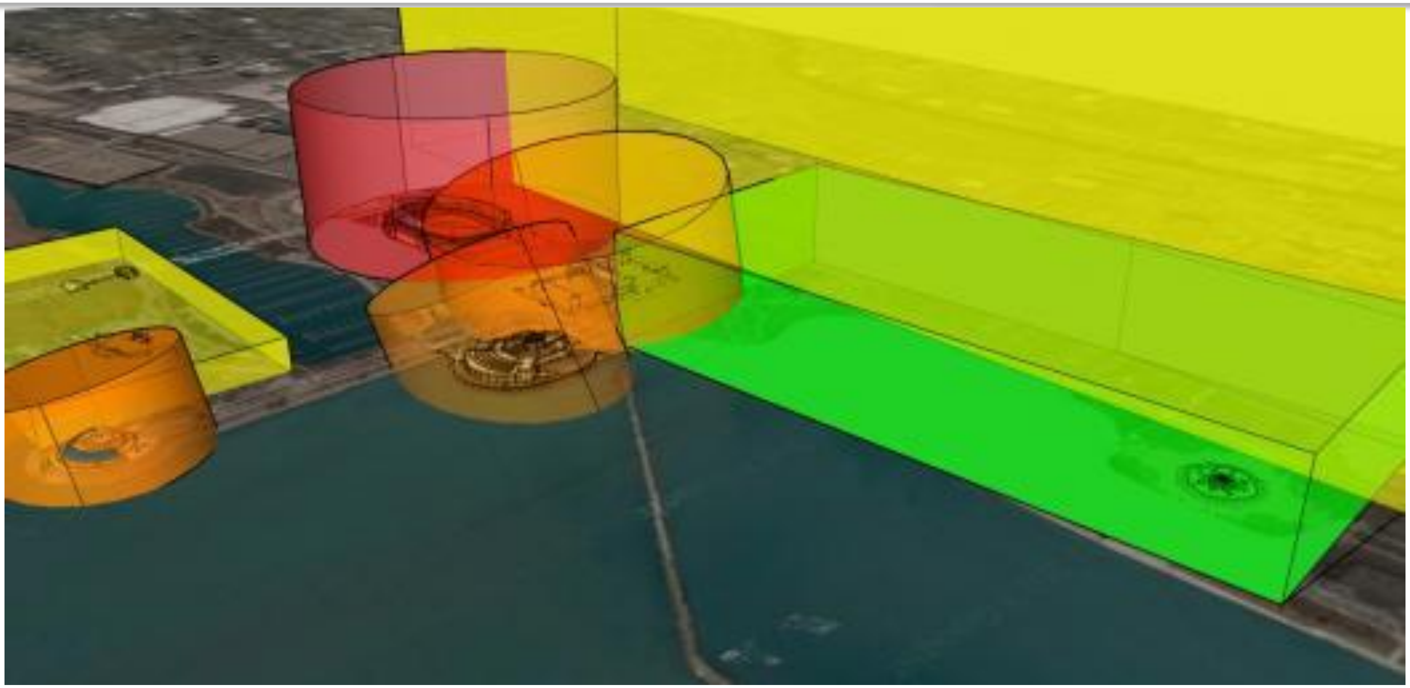
Trusted Autonomy Research Strategy

Use UAS as a developmental platform for developing the technologies to enable trusted autonomy.



Consider UAS geo-spatially contained environments



Source: Zones for Drones Along the Chicago waterfront, Permission from Mitchell Sipus; http://www.popsci.com/article/technology/future-urban-planning-zoning-drones

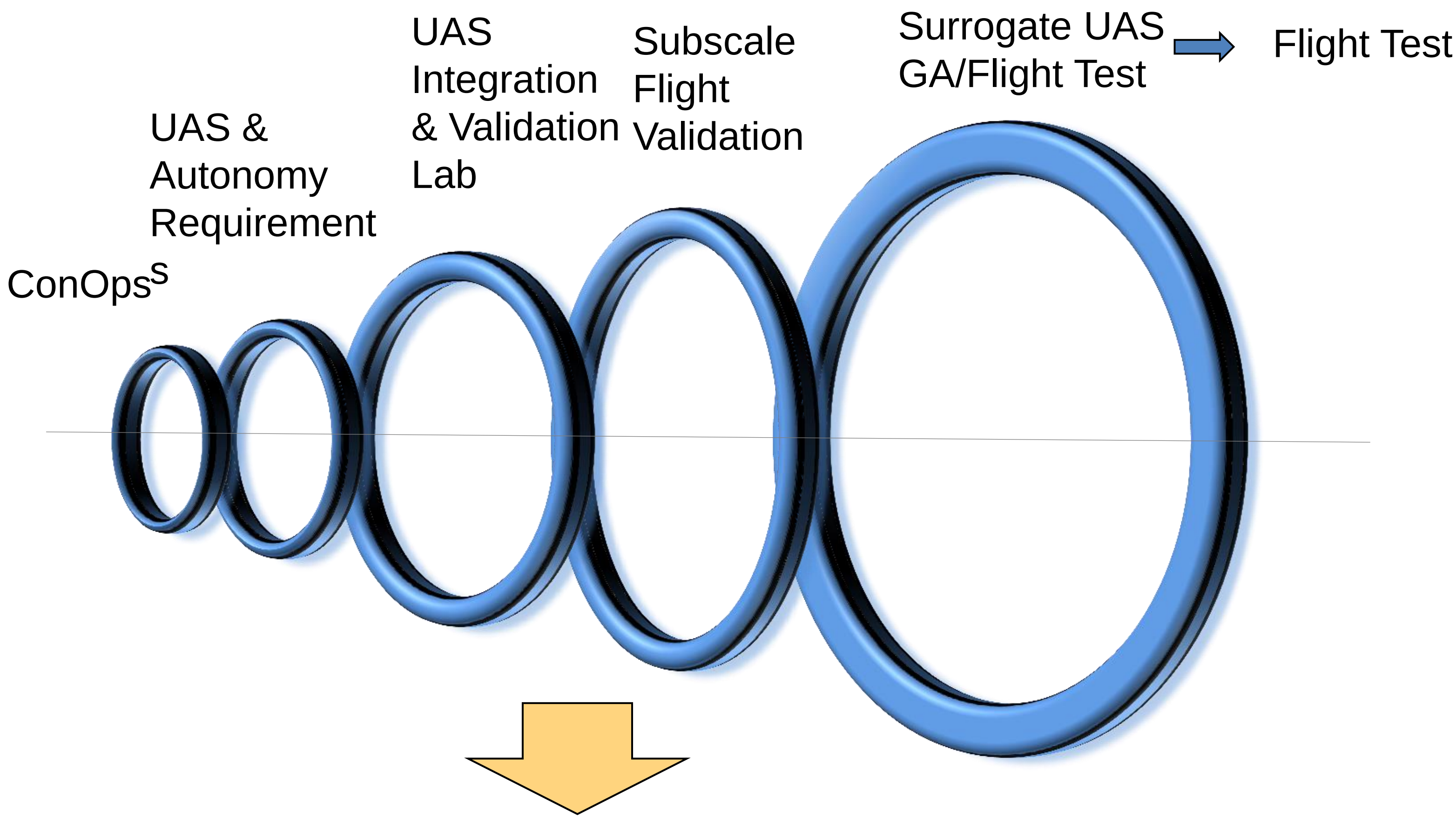
The green area covers an open space near a park and a fountain, where people are likely not too crowded together, and where there's a body of water.

Orange and yellow spaces represent buildings where it would be okay to fly drones some of the time but not all the time. The yellow covers a large block of housing, which could restrict drones during the day but allow them above a certain altitude at night. One of the buildings in orange is an observatory, where daytime flights might be fine but nighttime droning could obstruct the telescope.

The red area in the example is a stadium. Here, personal drones with cameras would be explicitly banned for privacy and licensing concerns, unless explicitly authorized by the stadium and the NFL.

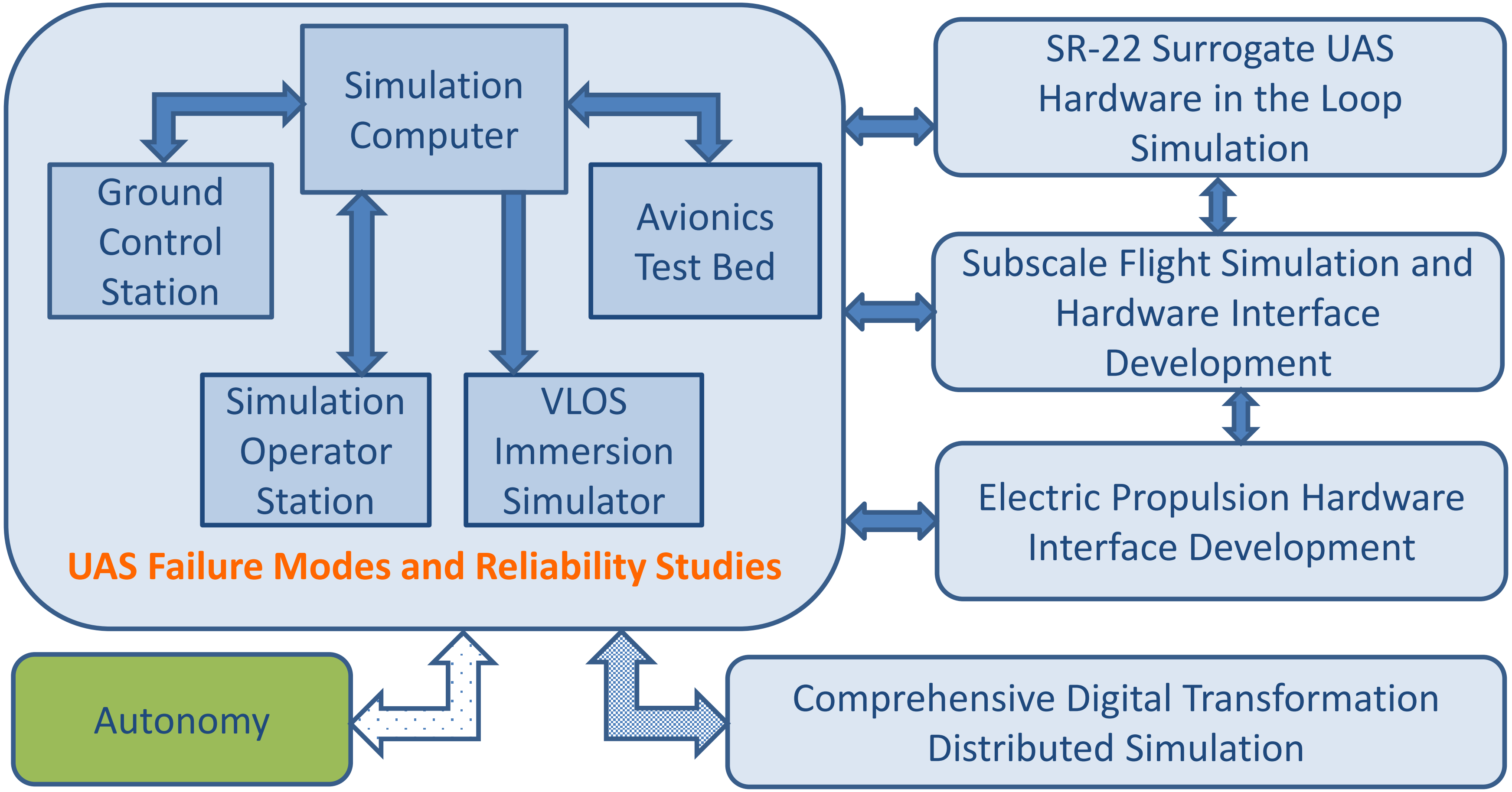
Building Path to Certification for UAS

Representative Spiral Development System Builds



Provide Evidence for Safety Assurance Case

UAS Systems Integration and Validation Laboratory



CREDIT: Buttrill, Cathy; Unisys Corporation 2014

TEST CASE 2: AUTONOMOUS AIRPORT SERVICES MANAGEMENT

Airport Services Management

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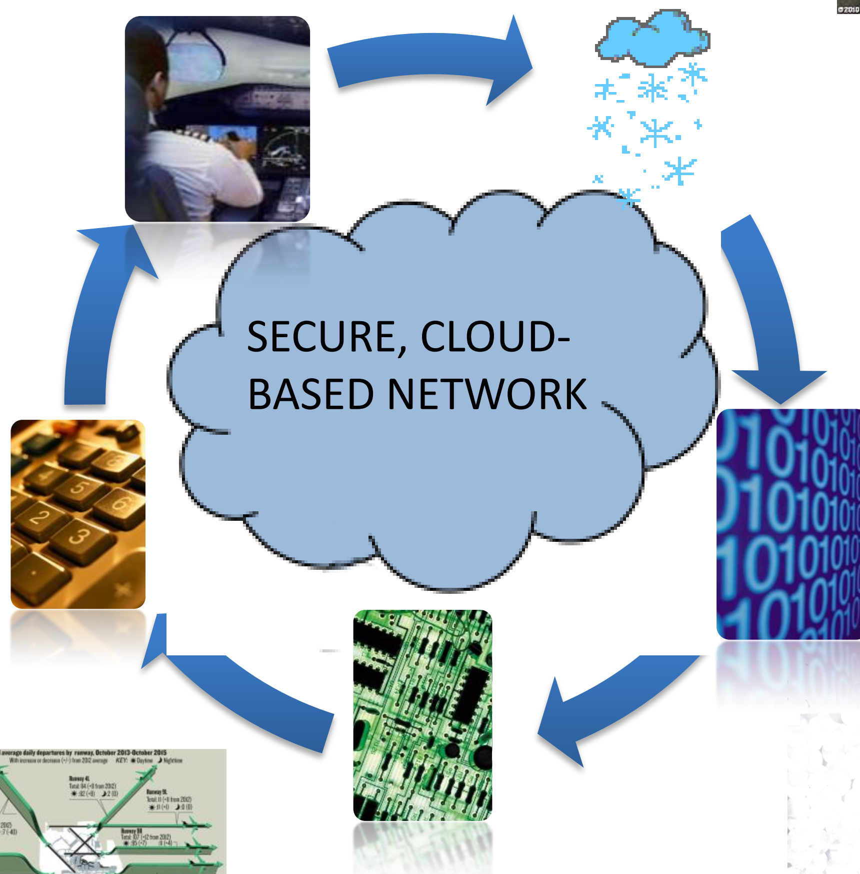
Autonomous Airport Management Capability

TRUSTED FLOW OF INFORMATION

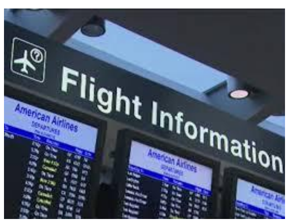
Cooperation and foresight of airlines (suspended operations, cleared runways, flight cancellations)

Weather-related information: Analysis of snow: severity; wind, rate of snowfall, water content in snow



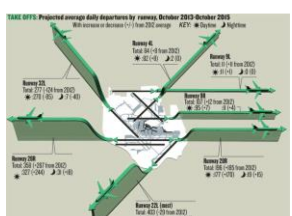
Machine-based algorithms and data analysis

BIG DATA ANALYTICS



REMOTE AND CENTRALIZED DATA VISUALIZATION

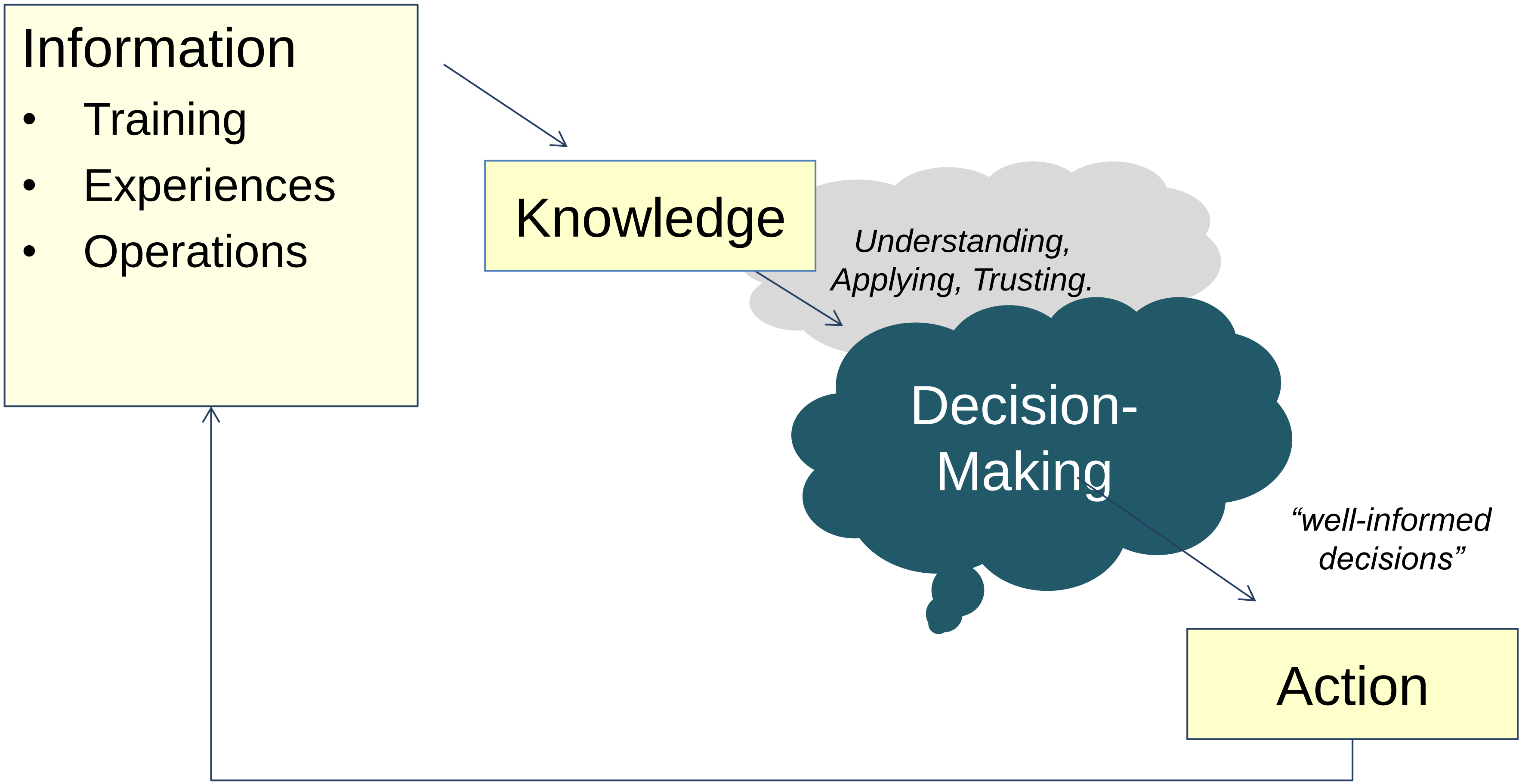
Runway Conditions



Snow Removal Fleet

Information is the Key to Integrity

…but only if the information is “good”



Integrity - the Analog of Trust

Data Processing Integrity	Degree of **assurance that data has not** been altered or **corrupted** in some way during processing	Often bounded using CRC checks and/or error correcting codes (std: ICAO, RTCA)
Data Integrity (a.k.a. Software Design Integrity)	Degree of **assurance that data errors**, or software failures that result in data errors, **do not lead to system failures** that result in unsafe conditions	Difficult to bound or quantify; Current methods based on rigorous design process and meeting Assurance Levels (std: ICAO, RTCA)
System Integrity	Degree of **assurance that the system will not provide misleading information** (or, will provide timely warnings when it should not be used for its intended function)	Very much context specific; very difficult to quantify a priori due to infinite number of contexts that may be encountered during flight (std: None)

Enabling Partnerships / Collaborations

Determine community needs
Define Roles & Responsibilities

Academia
FAA
Industry
NASA
DoD
National Science Foundation
DARPA
Others?

Concluding Remarks

- NASA Trusted Autonomous Systems research seeks to:
  - Identify and develop methods for engendering trust between humans and autonomous machines, to consider the static and dynamic aspects of trust, and to propose metrics for measuring trust.
  - Instantiate trusted integrated systems frameworks for hazards-based resiliency testing of autonomous system operations using a variety of test use cases.
  - Partner/collaborate to address the challenges associated with Trusted Autonomous Systems in Civil Aviation.

Thank you!

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