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Digital Avionics Systems Conference
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Avionics Systems Panel Tutorial: Application & Certification Challenges for AI/ML Techniques in Safety Critical Avionics Systems

PRESENTERS

Roberto Sabatini, Khalifa University of Science and Technology (UAE)
Erik Blasch, IEEE Aerospace & Electronic Systems Society (USA)
Irfan Majid, Institute of Space Technology, Islamabad (Pakistan)
Alessandro Gardi, Khalifa University of Science and Technology (UAE)
Giancarmine Fasano, University of Naples “Federico II” (Italy)
Kathleen A Kramer, University of San Diego, CA (USA)
Aloke Roy, VisionAR Systems LLC (USA)

https://ieee-aess.org/tech-ops/avionics-systems-panel-asp

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Outline

1. Multidomain Traffic Management and Intelligent Avionics Systems	Rob (8:05)
2. Overview of AI/ML Techniques	Irfan/Erik (8:25)
3. Interactive HMI Systems	Erik (8:45)
4. AI in ATM and UTM Systems	Alex/Rob (9:05)
5. AI in Sense and Avoid Systems	Giancarmine (9:40)
6. Cyber Security Perspective in Intelligent/Autonomous Systems	Kathleen (10:00)
7. Certification Aspects and Industry Perspectives	Aloke/Kathleen (10:20)
8. Wrap Up and Questions	All

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1. MDTM and Intelligent Avionics Systems
2. Overview of AI/ML Techniques
3. Interactive HMI Systems
4. AI in ATM and UTM Systems
5. AI in Sense and Avoid Systems
6. Cyber Security Perspective in Intelligent/Autonomous Systems
7. Certification Aspects and Industry Perspectives
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1. MULTIDOMAIN TRAFFIC MANAGEMENT AND INTELLIGENT AVIONICS SYSTEMS

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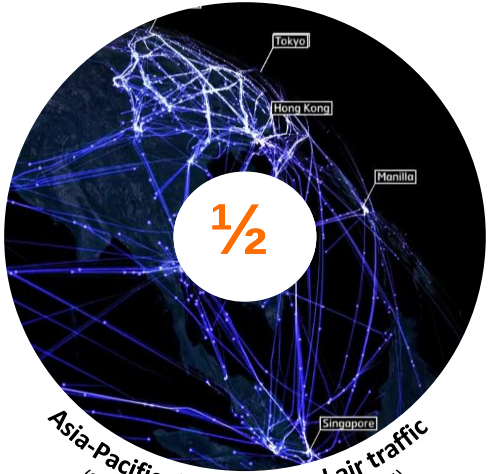
Global Air Transport Challenges (pre-COVID)

FORECAST
2050

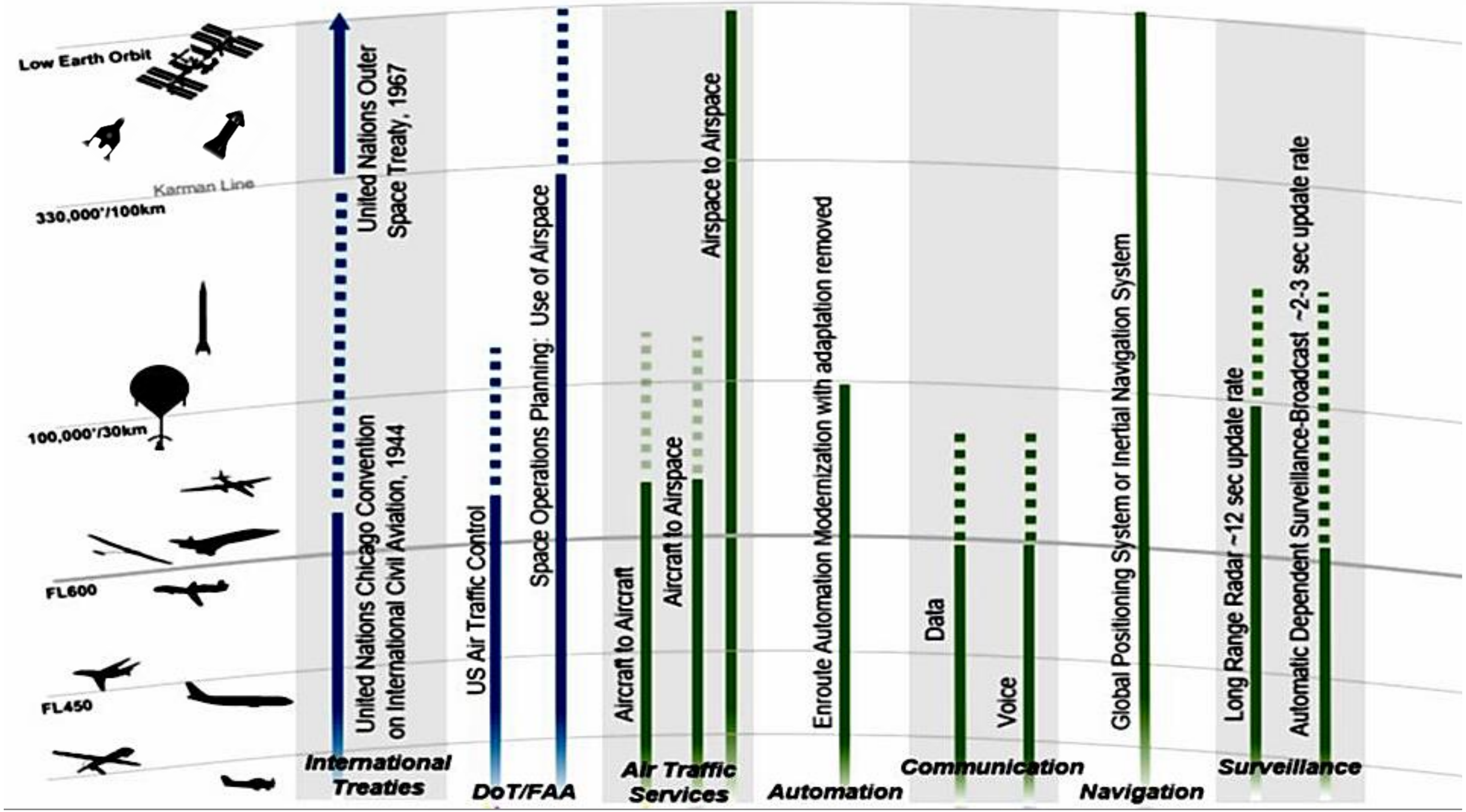
Global Air Traffic

Aviation-induced global warming
(climate change impacts)



Asia-Pacific share of global air traffic
(215 new airports in China alone by 2035)

Evolving Air & Space Transport Ecosystem



Courtesy: FAA

Air Transport Industry Snapshot

- The Aerospace and Aviation (A&A) industries play an important role in the global economy. Before the recent crisis caused by the COVID-19 pandemic, air transport alone contributed US$2.7 trillion to the world GDP (3.6%) and supported 65.5 million jobs globally

- Despite the significant reduction of air transport due to COVID-19 (in the order of 60%), forecasts show that demand for aviation will continue to rise in the period up to 2050. So, its growth must be sustainable – with affected communities supported and the environment protected

- Key drivers post-COVID include Advanced Air Mobility and low-level ATM evolutions (UAS Traffic Management and Urban/Regional Air Mobility), flight above FL600 (stratospheric flight) and sub-orbital space transport

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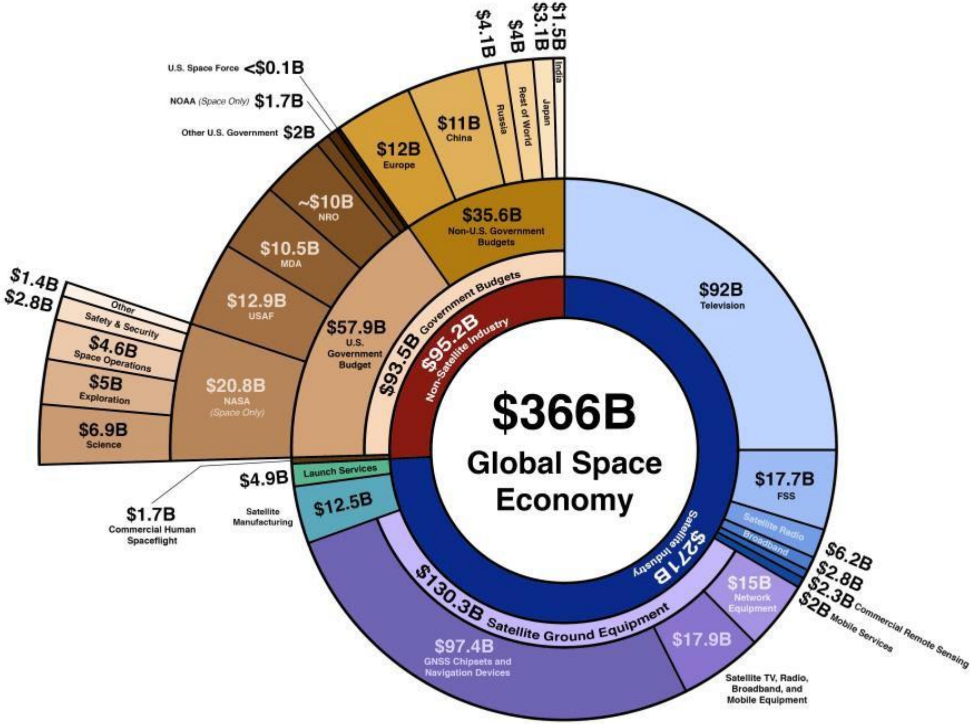
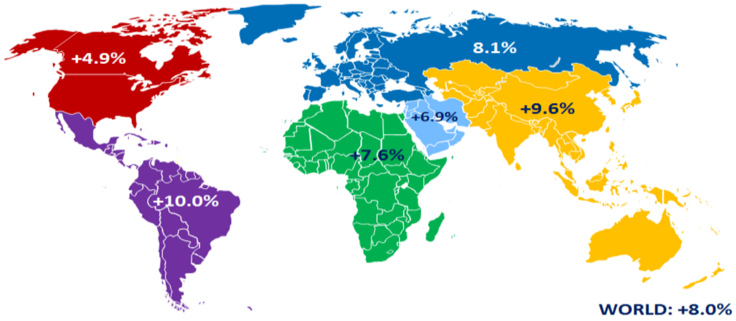
Space Industry Snapshot

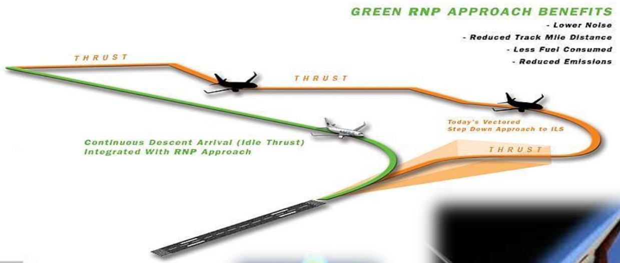
- In 2020, the global space economy was worth 366 billion USD
- One quarter attributed to non-satellite industries (government budgets and a very small portion allocated to commercial human spaceflight) and three quarters to commercial satellite and launch services
- While satellite manufacturing and launch services account for a total of 17.4 billion USD, the satellite systems industry (space, ground and user segments) holds the majority of the market share, with a staggering 253.4 billion USD
- The entire human spaceflight market volume accounts for a mere 1.7B but it is expected to grow significantly

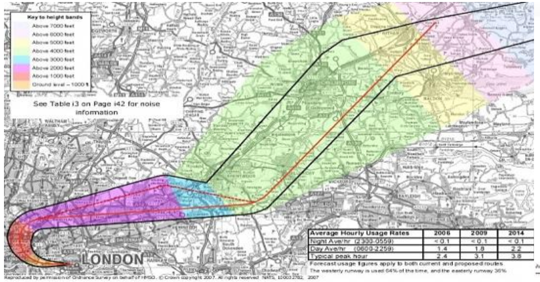


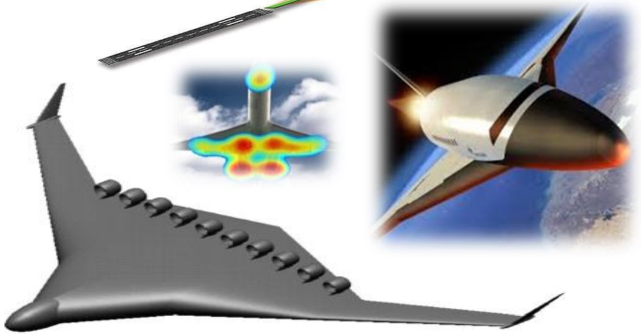
Avionics Challenges and Opportunities

- Enhancing **Safety, Efficiency and Sustainability** of the air and space transport sector to support the anticipated growth post-COVID
- Research and Innovation Areas
  - Next Generation ATM Communications, Navigation, Surveillance (CNS) & Avionics (A) Systems (CNS+A)
  - UAS access to all classes of airspace (trusted autonomy)
  - Improved efficiency/capacity of airports and spaceports (digitalisation/multimodal)
  - Solutions for enhanced safety and security

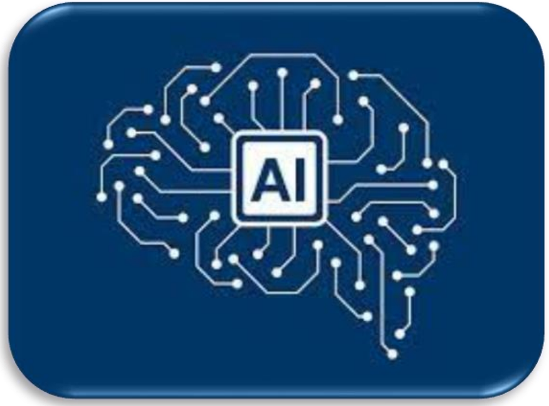






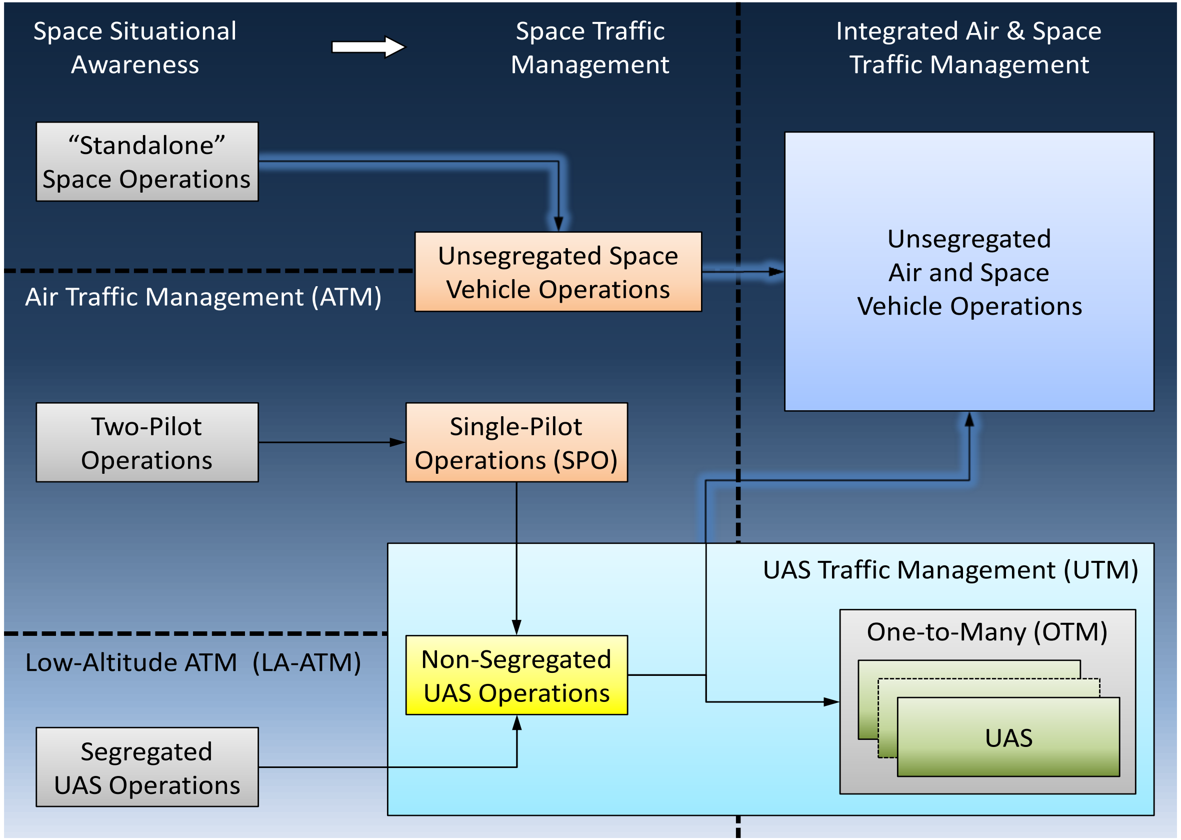


Automation and AI in Avionics Systems



- Integrated and Interoperable CNS+A
- UAS access to all classes of airspace (trusted autonomy)
- Improved efficiency/capacity of airports and spaceports (digitalisation/multimodal)
- Solutions for enhanced safety and security (cyber-physical systems)

MDTM Evolutionary Framework



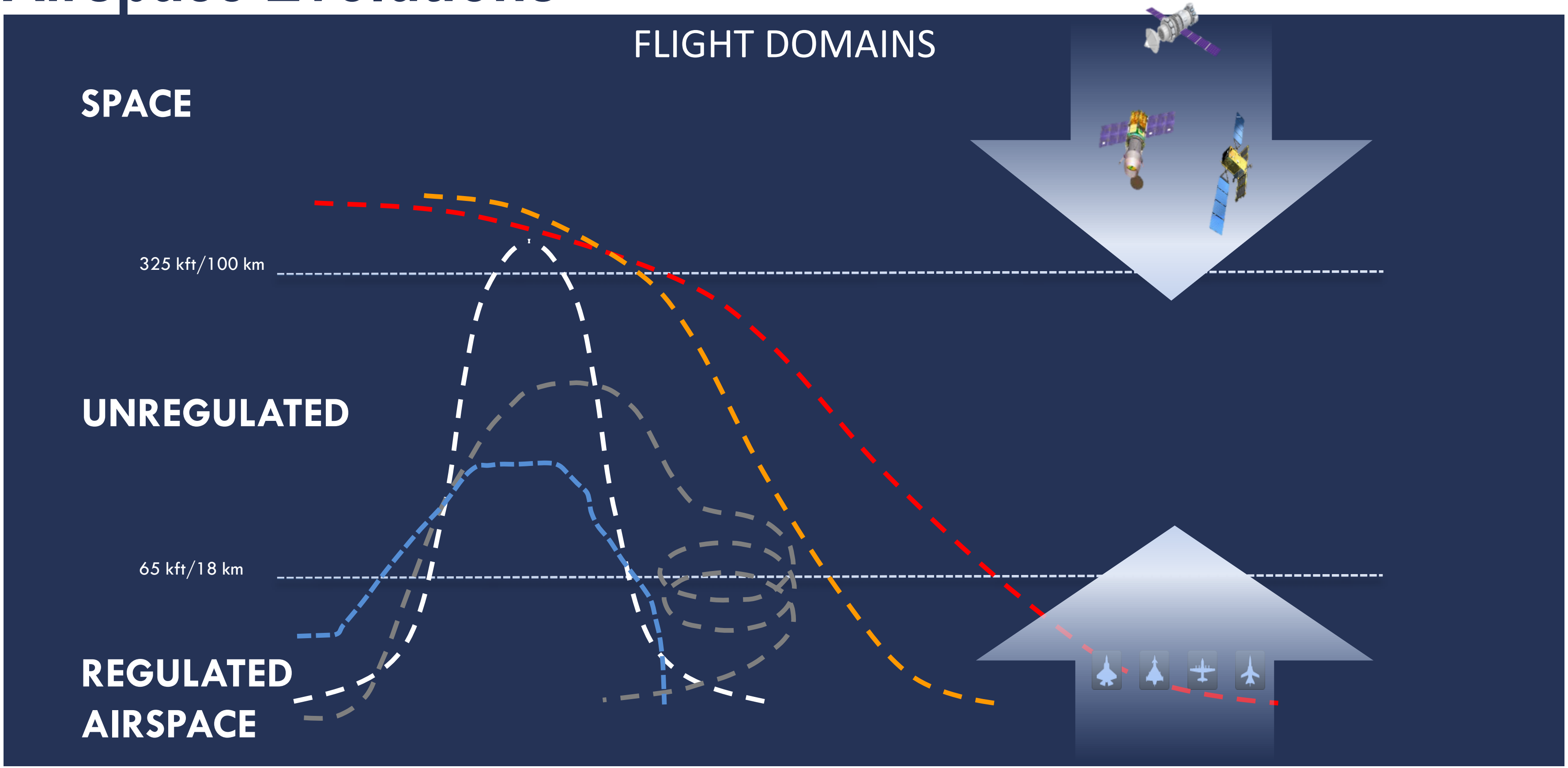
R. Sabatini, A. Roy, E. Blasch, K. A. Kramer, G. Fasano, I. Majid, O. G. Crespillo, D. A. Brown and R. Ogan, "Avionics Systems Panel Research and Innovation Perspectives." IEEE Aerospace and Electronic Systems Magazine, Vol. 35, Issue 12, pp. 58-72, December 2020.

http://dx.doi.org/10.1109/MAES.2020.3033475

AI in Avionics Systems

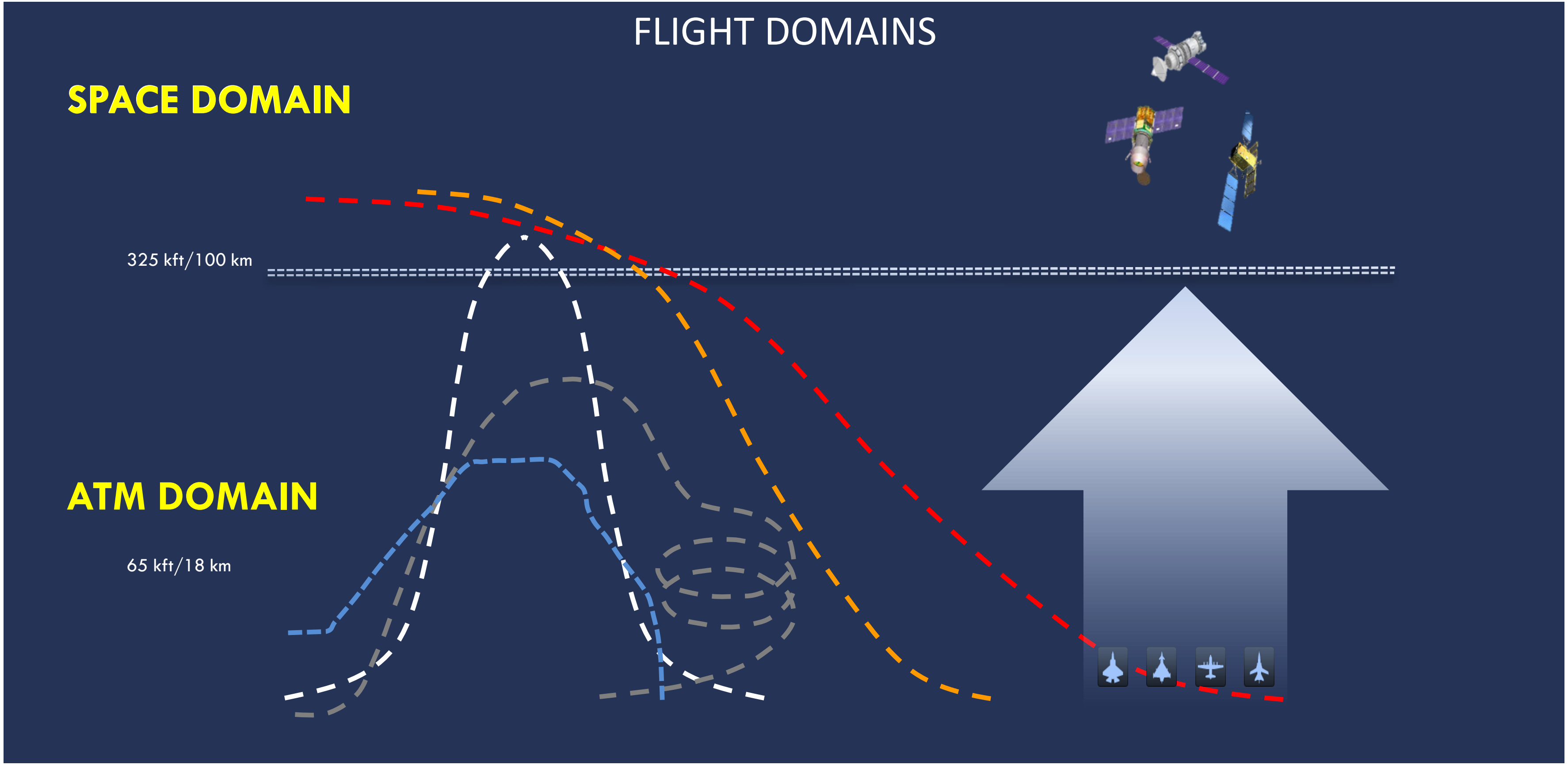
- Application Domains:
  - Advanced Air Mobility (AAM) - Urban and Regional
  - NextGen/SESAR ATM and UAS Traffic Management (UTM)
  - Space domain awareness and Space Traffic Management (STM)
- Practical Examples:
  - Autonomous separation assurance and collision avoidance
  - Aircraft health and mission management systems
  - Vision-based navigation and landing
  - ATM/UTM decision support tools
  - Distributed Space Systems (DSS)

Airspace Evolutions



Ref.: S. Hilton, R. Sabatini, A. Gardi, H. Ogawa, and P. Teofilatto, "Space traffic management: towards safe and unsegregated space transport operations", Progress in Aerospace Sciences, vol. 105, pp. 98-125, Feb 2019. DOI: 10.1016/j.paerosci.2018.10.006

Airspace Evolutions



Ref.: S. Hilton, R. Sabatini, A. Gardi, H. Ogawa, and P. Teofilatto, "Space traffic management: towards safe and unsegregated space transport operations", Progress in Aerospace Sciences, vol. 105, pp. 98-125, Feb 2019. DOI: 10.1016/j.paerosci.2018.10.006

Evolving Space Transport Ecosystem

- Introduction of Commercial Space Industry has accelerated development of Reusable Space Vehicles (Reaction Engines, Virgin Galactic, Sierra Nevada, etc.)
- Space Tourism, Research, Point to Point transport have been identified as commercially and economically viable markets
- The need for integration of space and traditional atmospheric traffic is widely recognized (NextGen, SESAR)
- A global, harmonized Air and Space Traffic Management network will require the implementation of advanced CNS+A technology
- Success of industry will fundamentally depend on the ability to demonstrate an acceptable level of safety
- The Space Shuttle approach is not scalable and unsustainable

Virgin Galactic Space Ship 2
Courtesy: Virgin Galactic

Sierra Nevada Dream Chaser
Courtesy: Sierra Nevada

Reaction Engines Skylon
Courtesy: Reaction Engines

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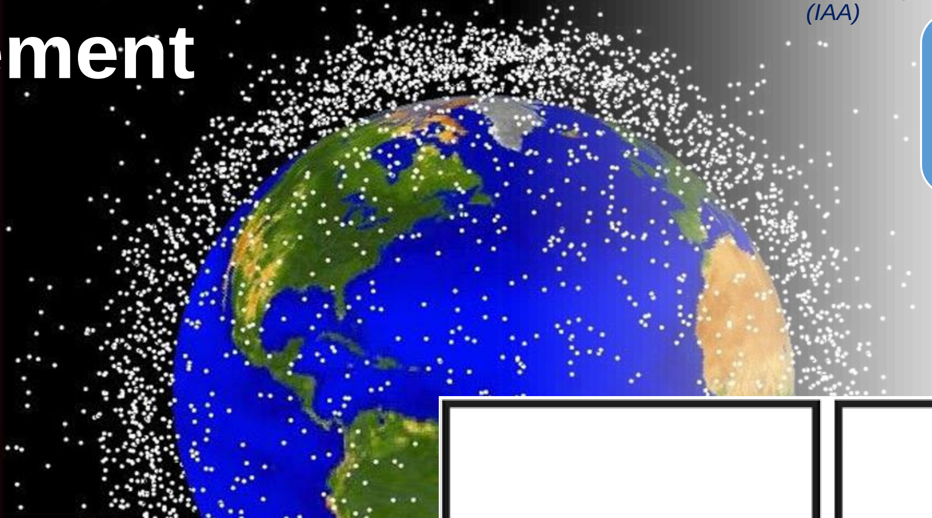
Space Traffic Management

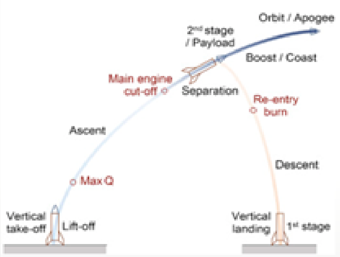


"Space traffic management is the set of technical and regulatory provisions for promoting safe access into outer space, operations in outer space and return from outer space to Earth free from physical or radio-frequency interference." - International Academy of Astronautics (IAA)

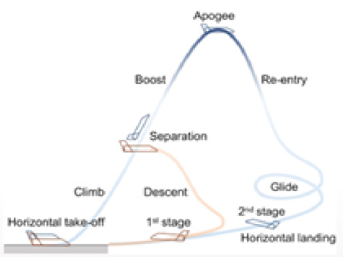
Only a few organisations have the global sensor networks and computational capability to perform this task

- Space Surveillance Network (SSN), USA,
- Space Surveillance and Tracking (SST) system, European Space Agency (ESA) ,
- Space Surveillance System (SSS),Russia,
- Network for Space Objects, Tracking, and Analysis (NETRA), ISRO,
- Canadian Space Surveillance System (CSSS), Canada.

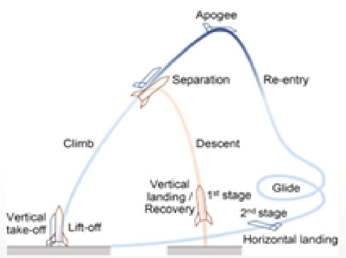
- **Vertical Take-off and Landing** (VTOL) - E.g., SpaceX Falcon 9 - Figure (a)
- **Horizontal Take-off and Landing** (HTOL) - NASP and HOTOL - Figure (b)
- **HYBRID**-Space Shuttle Orbiter and Sierra Nevada Corporation's Dream Chaser platforms - Figure (c)



VTOL platform schematic (a)



HTOL platform schematic (b)



Hybrid platform schematic (c)

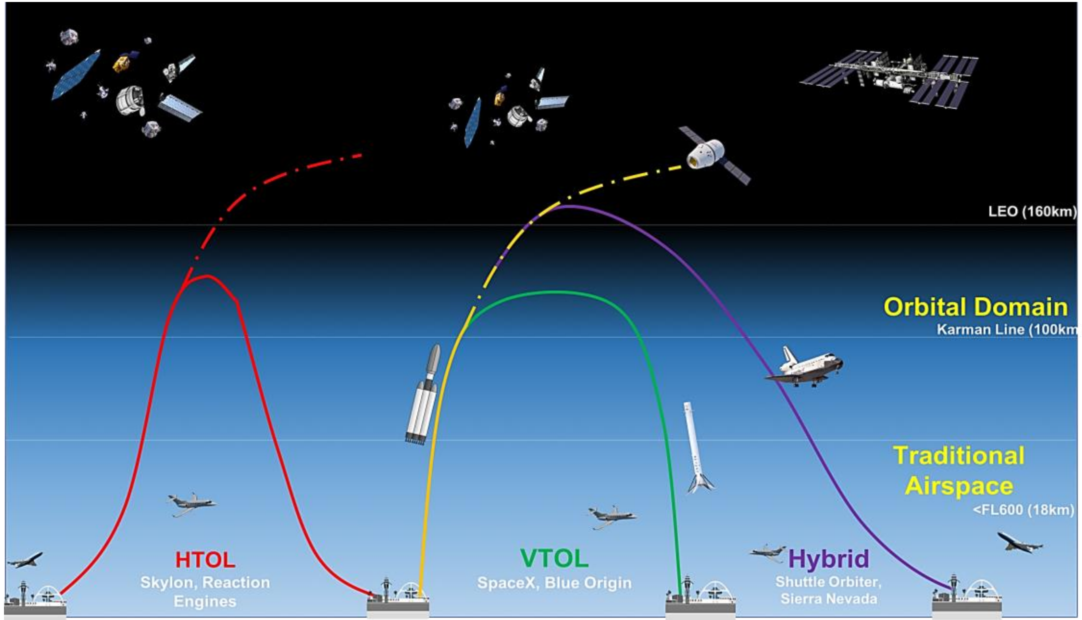
Space Transport Platforms

Vertical Takeoff & Landing

- Traditional approach to access space
- Limited in maneuverability (non-lifting body)
- Vertical landing pioneered by SpaceX reusable vehicle
- Minimized time in atmosphere is primary advantage from ATM perspective

Horizontal Takeoff & Landing

- Ability to perform “tactical” maneuvers like atmospheric aircraft
- More accommodating in their integration with ATM systems (can enact rerouting and tactical deconfliction)
- Promising concept for point-to-point suborbital transportation



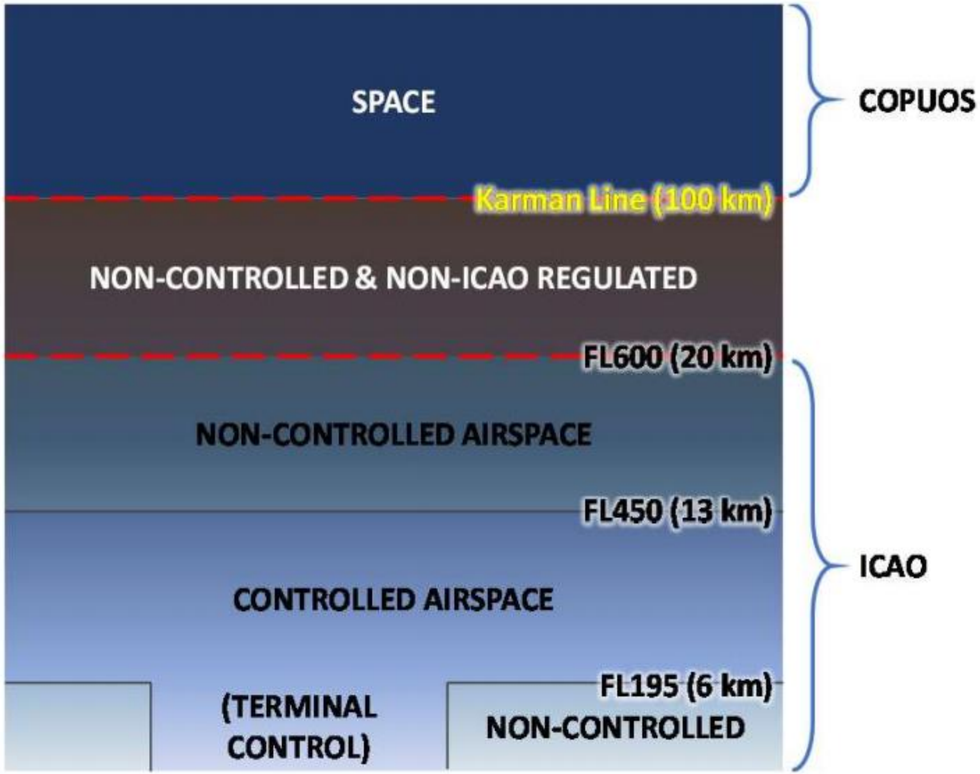
Hybrid

- E.g. carrier aircraft taking space vehicle to launch altitude
- Gliding flight most commonly performed after re-entry
- Currently applied to Space Tourism

Regulatory Framework Evolutions

The lack of regulatory oversight by the United Nations between FL600 (ceiling of ICAO jurisdiction) and the Karman Line (base of the COPUOS jurisdiction) is seen as a growing issue as more and more platforms operate regularly above FL600, while space launch and re-entry operations necessarily transit through this region.

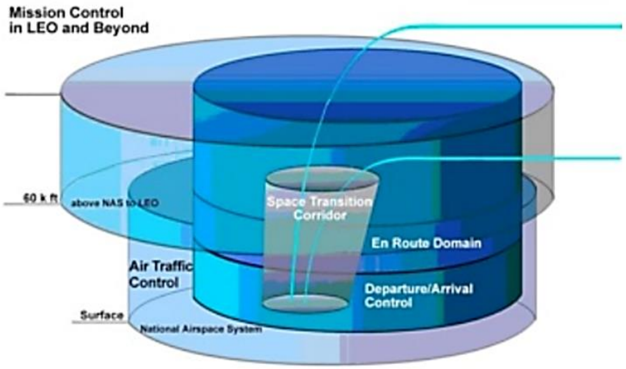
An extension of the ICAO jurisdiction up to 50 km or more has been already proposed by ICCAIA.



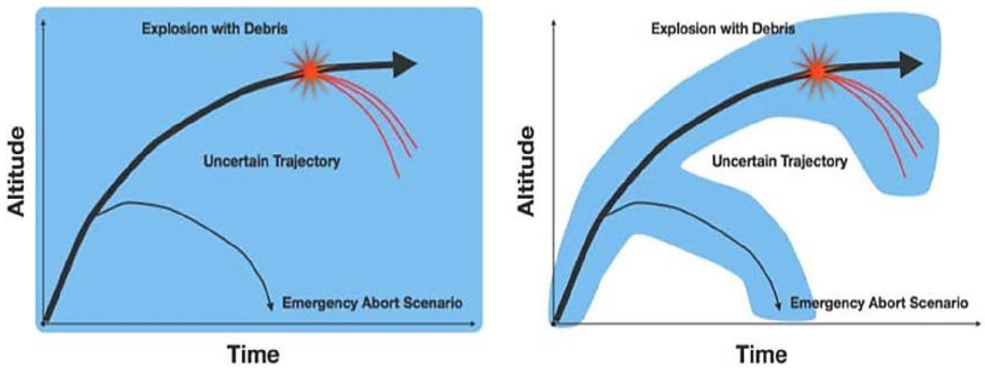
ICAO- International Civil Aviation Organization
COPUOS -Committee on the Peaceful Use of Outer Space
ICCAIA- International Coordinating Council of Aerospace Industries Associations

Ref.: S. Hilton, R. Sabatini, A. Gardi, H. Ogawa, and P. Teofilatto, "Space traffic management: towards safe and unsegregated space transport operations", Progress in Aerospace Sciences, vol. 105, pp. 98-125, Feb 2019. DOI: 10.1016/j.paerosci.2018.10.006

Proposed Concepts



Space Transition Corridor
Courtesy: NextGen US



4 Dimensional Compact Envelopes
Courtesy Stanford University Aerospace Design Lab

Space Transition Corridors

- Employing three spatial (length, width, azimuth) and two temporal parameters (duration and midpoint of corridor)
- Corridor remains static throughout its implementation

Four-Dimensional Compact Envelopes

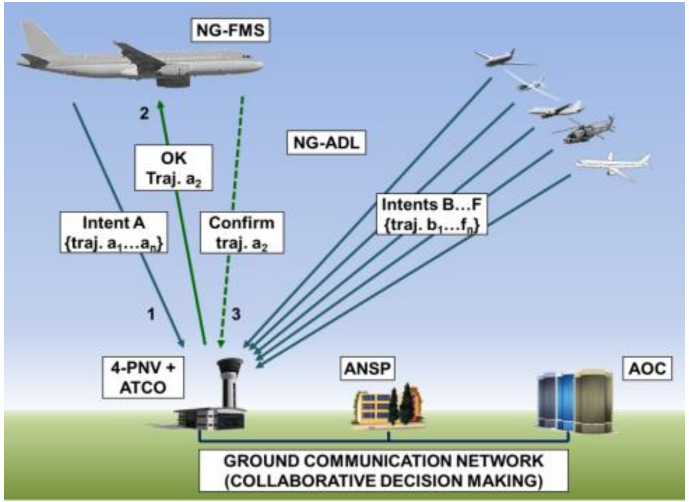
- Based on individual probabilistic off-nominal spacecraft conditions during launch and re-entry phases
- Compact envelopes enforce only the portion of airspace that is at risk
- Elegant solution in safeguarding spacecraft operations compared to STC (but complex practical implementation)

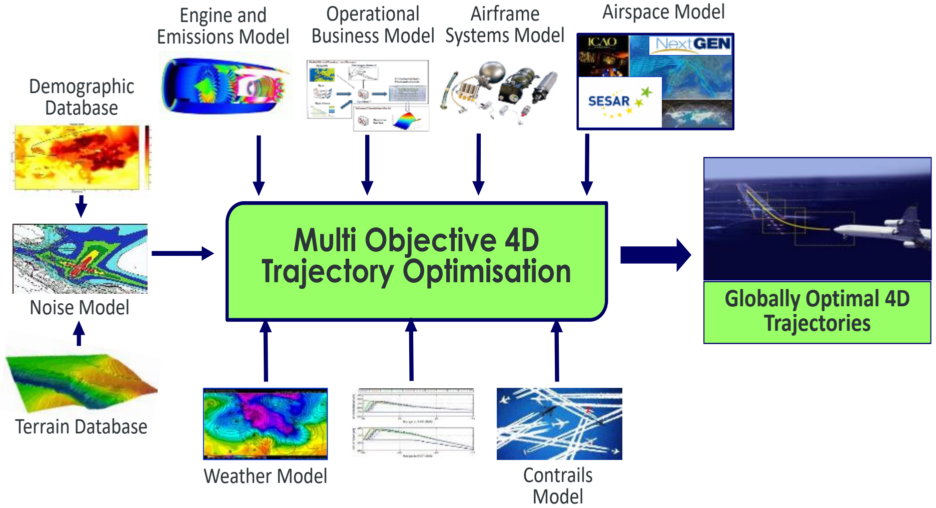
Evolving ATM Technologies

4D Trajectories and Intent-Based Operations

- **Development of innovative ATM Decision Support Systems (DSS)** to enable 4D-Trajectory (4DT) optimization, negotiation and validation in the future ATM context

- **4DT Planning, Negotiation and Validation** (4-PNV) in synergy with Next Generation of Flight Management Systems (NG-FMS)



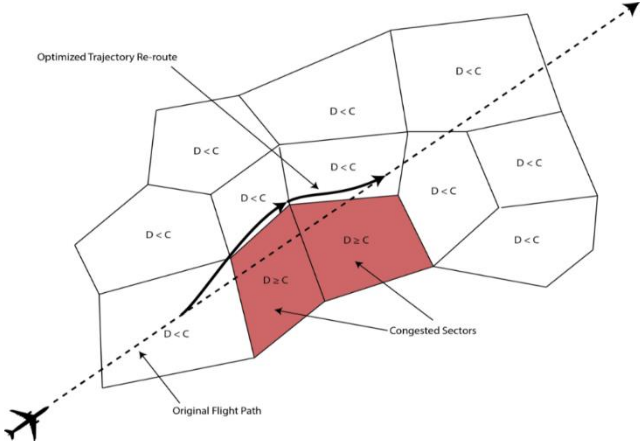


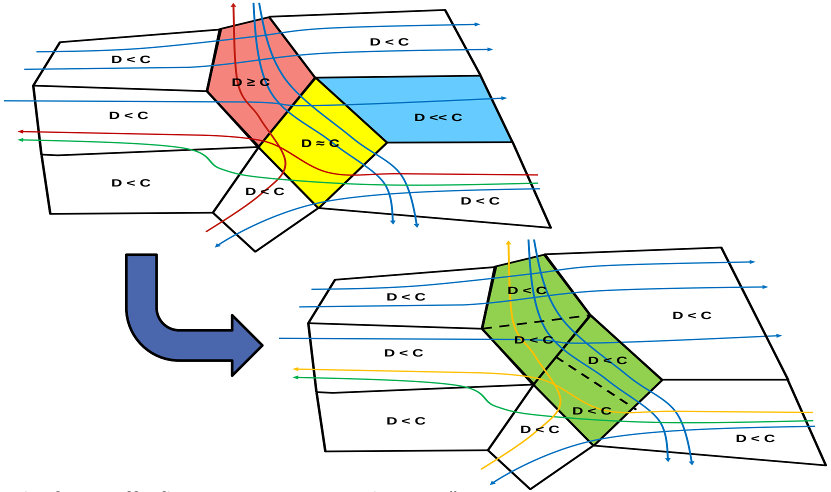
Ref.: A. Gardi, R. Sabatini, and S. Ramasamy, "Multi-objective optimisation of aircraft flight trajectories in the ATM and avionics context", Progress in Aerospace Sciences, vol. 83, pp. 1-36, 2016. DOI: 10.1016/j.paerosci.2015.11.006

Dynamic Airspace Management

- In the near term, ATM systems will automatically validate aircraft intents by implementing **adequate separation assurance and time-based flow optimization methods**

- In the longer term, DSS will evolve to allow **Dynamic Airspace Management** (DAM) with morphing techniques (e.g., dynamic geo-fencing) also supporting UAS Traffic Management (UTM) and Urban Air Mobility (UAM) operations





Ref.: T. Kistan, A. Gardi, R. Sabatini, S. Ramasamy, and E. Batuwangala, "An evolutionary outlook of air traffic flow management techniques", Progress in Aerospace Sciences, vol. 88, pp. 15-42, 2017. DOI: 10.1016/j.paerosci.2016.10.001

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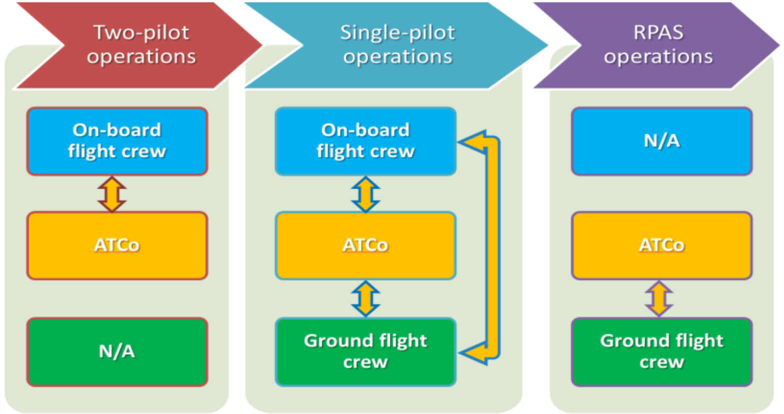
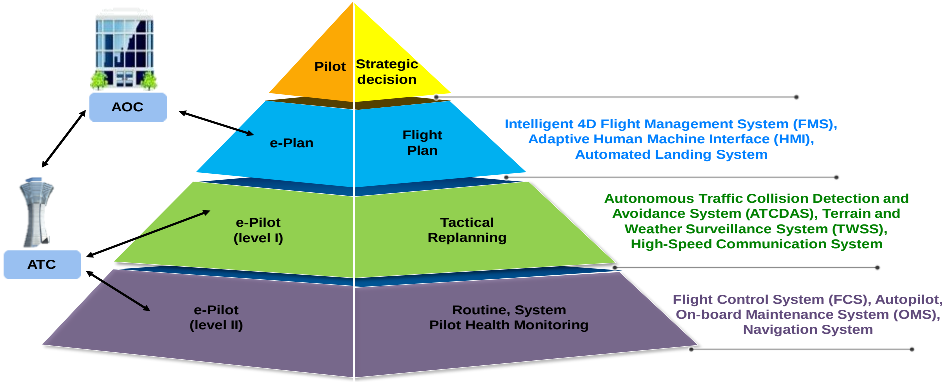
SiPO to RPAS in Conventional Airspace

- Improve the total system performance through highly automated CNS+A systems supporting human-machine teaming
- Adaptive Human-Machine Interfaces and Interactions (HMI2) based on:
  - Real-time avionics systems integrity monitoring
  - Sensing of neuro-physiological parameters and AI-based estimation of cognitive states





Ref.: Y. Lim, V. Bassien-Capsa, S. Ramasamy, J. Liu, and R. Sabatini, "Commercial airline single-pilot operations: System design and pathways to certification", IEEE Aerospace and Electronic Systems Magazine, vol. 32, pp. 4-21, 2017. DOI: 10.1109/MAES.2017.160175

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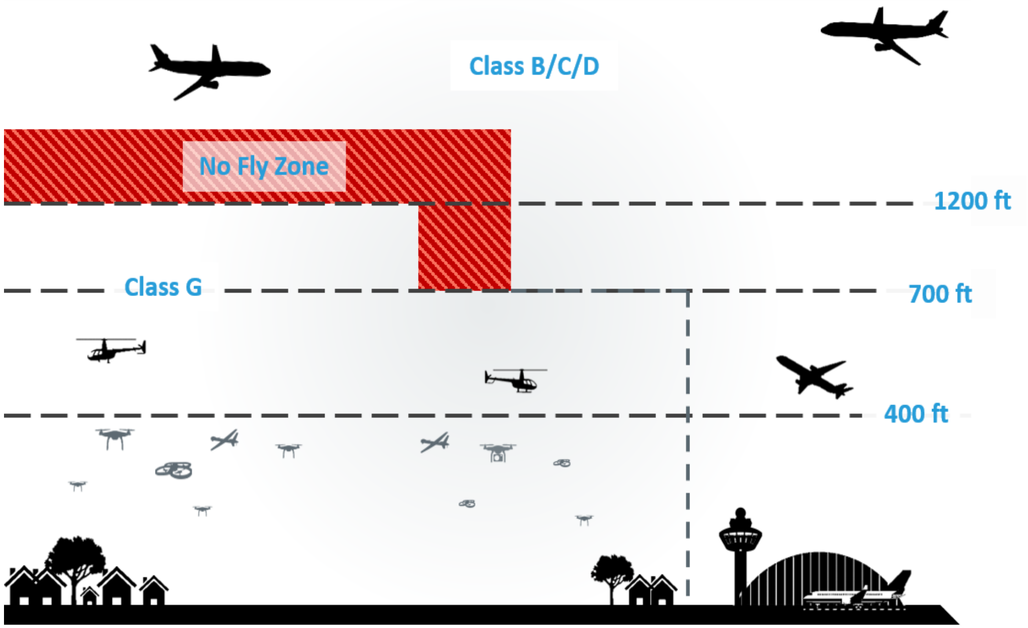
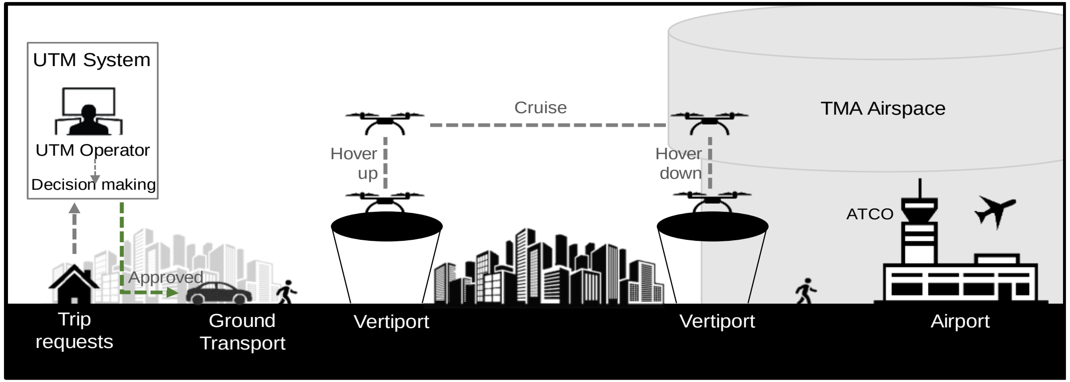
UAS Traffic Management – Key Challenges



- The conventional human-intensive and tactical ATC paradigm cannot fulfil the needs of manned/UAS traffic integration
- A higher degree of automation is necessary in the UTM framework
- The tactical deconfliction approach of traditional ATM cannot be scaled down to apply in UTM
- The tasks and responsibilities of human UTM operators are not fully defined

Ref.: - N. Pongsakornsathien, A. Gardi, R. Sabatini, and T. Kistan, "Evolutionary Human-Machine Interactions for UAS Traffic Management", AIAA Aviation Forum 2021
- N. Pongsakornsathien, A. Gardi, R. Sabatini, T. Kistan, and N. Ezer, "Human-Machine Interactions in Very-Low-Level UAS Operations and Traffic Management", DASC 2020, San Antonio, TX, USA, 2020

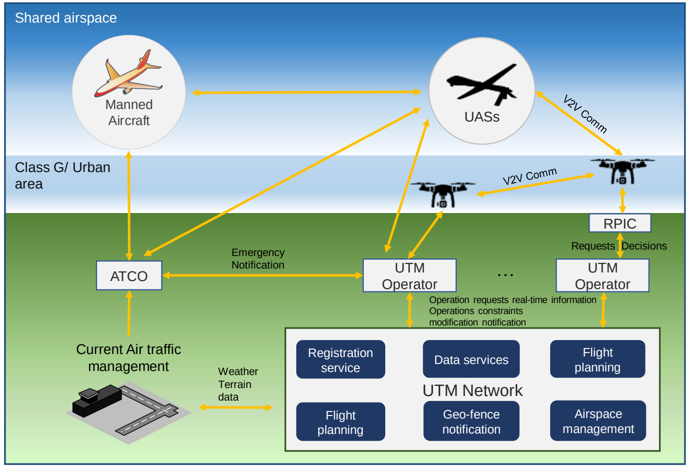
UAS Traffic Management and UAM



Advanced Air Mobility

A safe, automated air transportation system for passengers and cargo in urban and rural locations

- Regional Air Mobility (RAM)
- Urban Air Mobility (UAM)



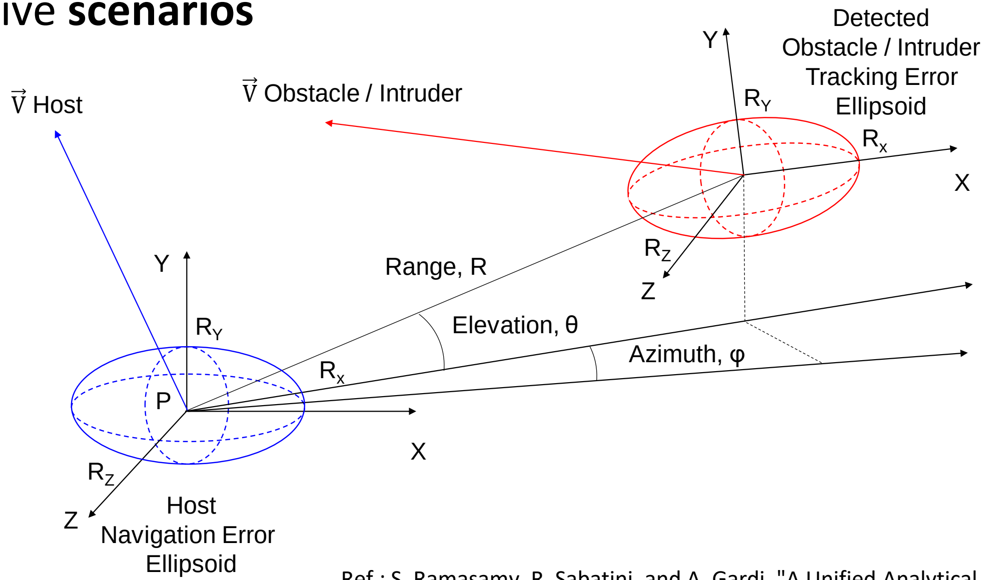
- UTM/AAM are moving towards trusted autonomy
- Highly automated human-in-the-loop operations bring about issues of responsibility allocation and mandates evolutions in the legal and regulatory frameworks (liability concerns)

The tasks and responsibilities of humans and AI agents in UTM/AAM are yet to be defined

Ref.: - N. Pongsakornsathien, A. Gardi, R. Sabatini, and T. Kistan, "Evolutionary Human-Machine Interactions for UAS Traffic Management", AIAA Aviation Forum 2021
- N. Pongsakornsathien, A. Gardi, R. Sabatini, T. Kistan, and N. Ezer, "Human-Machine Interactions in Very-Low-Level UAS Operations and Traffic Management", DASC 2020, San Antonio, TX, USA, 2020

UTM/AAM Separation Assurance and Collision Avoidance

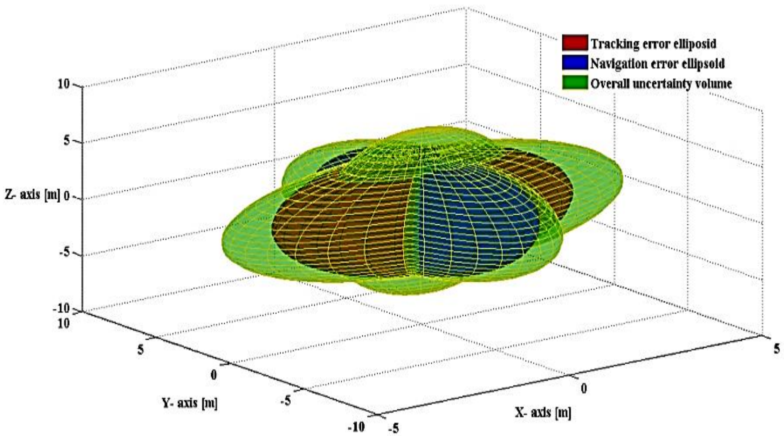
- **Avoidance volume** in the space surrounding each track is determined
- Accomplished by **continuing estimating both navigation and tracking errors** affecting the measurements (plus perturbations) and translating them to **unified range and bearing uncertainty descriptors**, which apply both to cooperative and non-cooperative **scenarios**

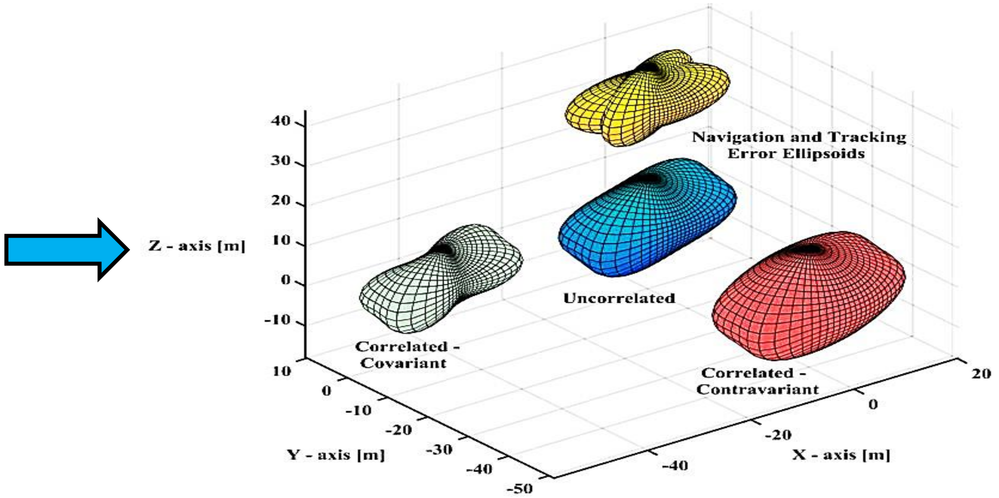


Ref.: S. Ramasamy, R. Sabatini, and A. Gardi, "A Unified Analytical Framework for Aircraft Separation Assurance and UAS Sense-and-Avoid", Journal of Intelligent & Robotic Systems, 91, pp. 735-754, 2018.

SA/CA – Error Analysis

- Errors are statistically correlated (e.g., C-SAA) or uncorrelated (e.g., NC-SAA)
- The avoidance (uncertainty) volume for uncorrelated measurements is obtained by inflating the tracking ellipsoid with the navigation error components
- The uncertainty volume for correlated errors is obtained using vector analysis





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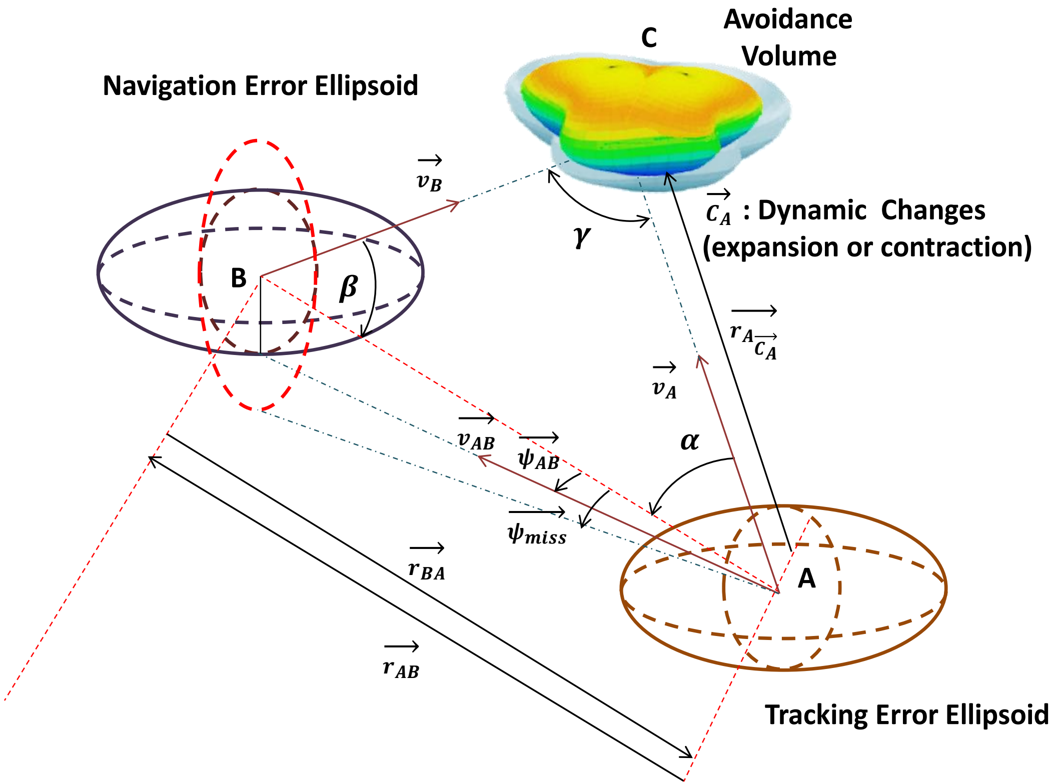
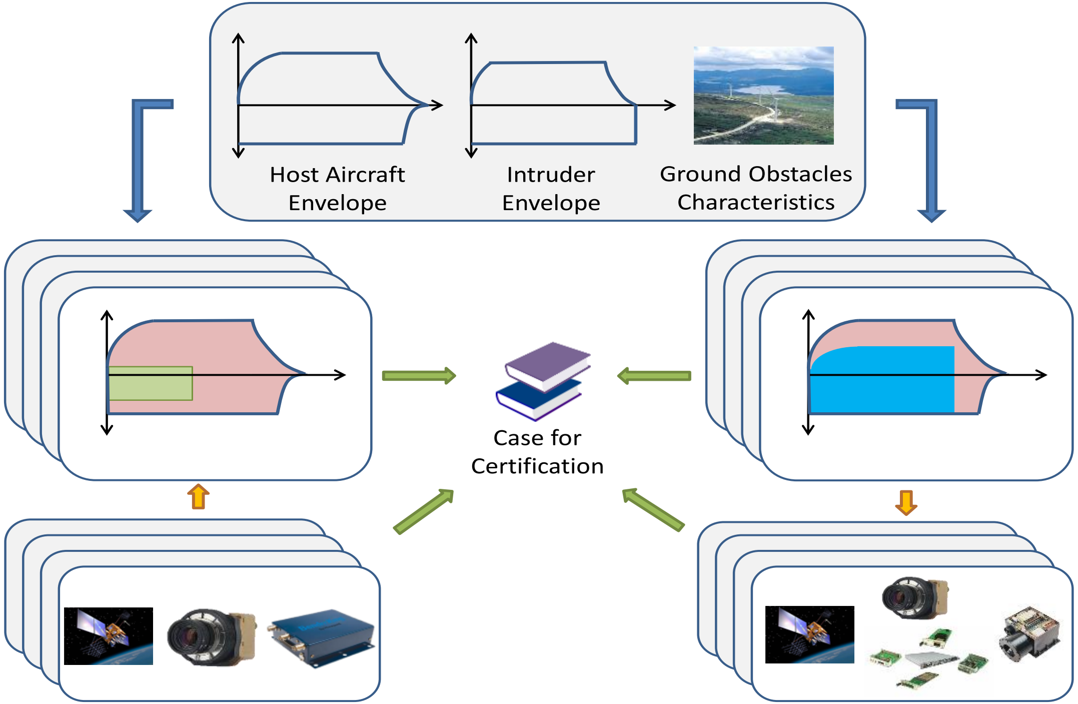
SA/CA – Relative Dynamics and Disturbances



Ref.: S. Ramasamy, R. Sabatini, and A. Gardi, "A Unified Analytical Framework for Aircraft Separation Assurance and UAS Sense-and-Avoid", Journal of Intelligent & Robotic Systems, 91, pp. 735-754, 2018.

SA/CA – Possible Approach to Certification

Distinctive advantage: ability to determine the safe-to-fly UAS envelope based on the on-board sensors/systems and alternatively to identify the required sensors/systems in order to clear a certain predefined safety envelope



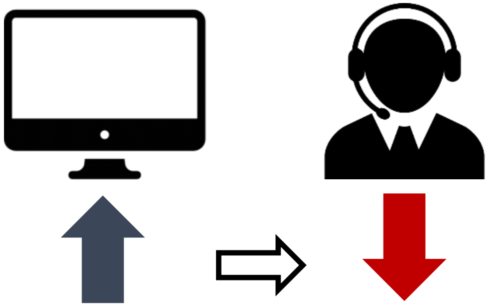
Ref.: S. Ramasamy, R. Sabatini, and A. Gardi, "A Unified Analytical Framework for Aircraft Separation Assurance and UAS Sense-and-Avoid", Journal of Intelligent & Robotic Systems, 91, pp. 735-754, 2018.

HOTL Dynamic Interactions

Challenges

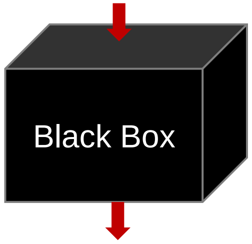
Higher level of automation in an out-of-loop paradigm

- Lower cognitive capability
- Progressive deskilling
- Lower situational awareness

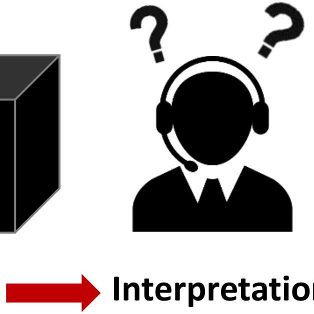


Human Factors

Input



Output



Interpretation

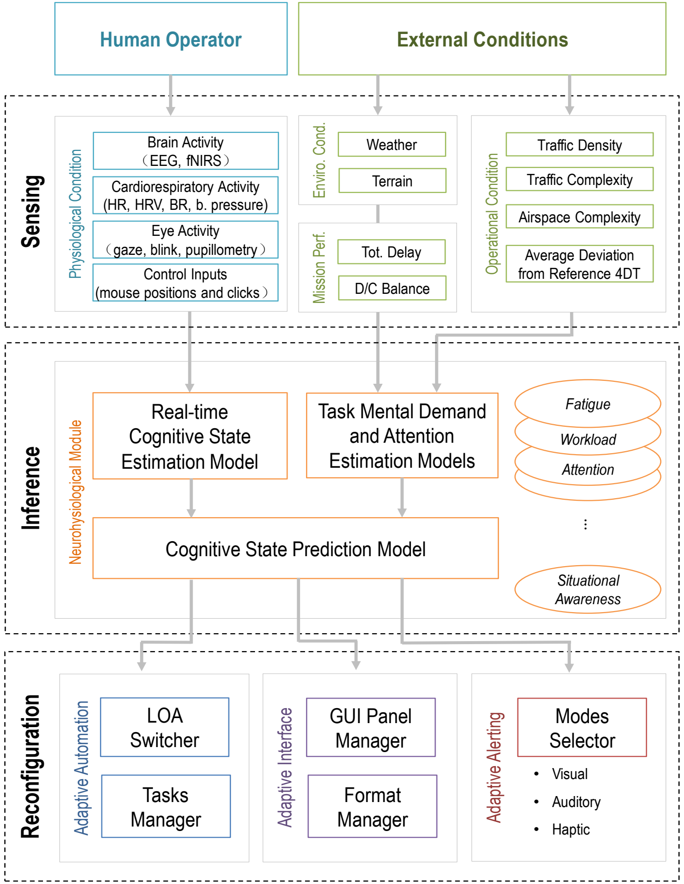
AI Explanation

Solution

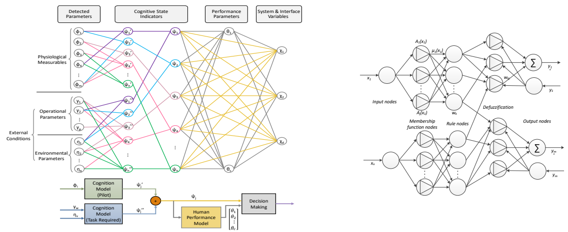
Adaptive HMI based on Explainable and Trusted AI

Cognitive Human-Machine Systems (CHMS)

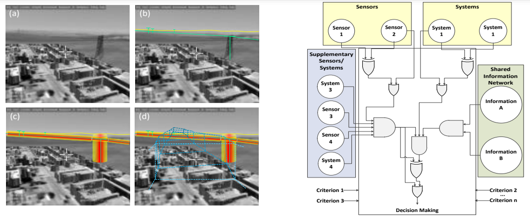
Cognitive HMS Framework



Sensing: uses a suite of sensors to measure neuro-physiological observables in real time, and extracts relevant features from the observables



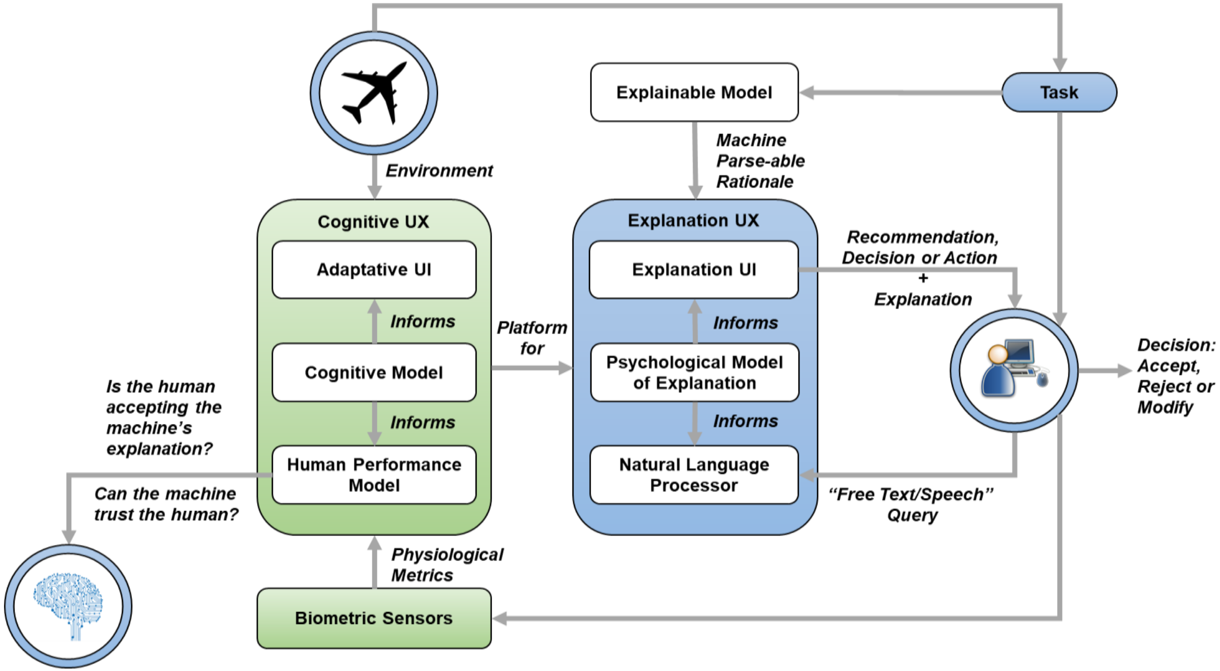
Inference: estimates cognitive states from the features in the sensing layer using various artificial intelligence (and machine learning) techniques



Adaptation: module drives the HMI[2] based on inferred cognitive states and key mission performance metrics

Ref.: J. Liu, A. Gardi, S. Ramasamy, Y. Lim, and R. Sabatini, "Cognitive Pilot-Aircraft Interface for Single-Pilot Operations", Knowledge-Based Systems, 112, pp. 37-53, 2016.

Cognitive HMI and Explanation UX



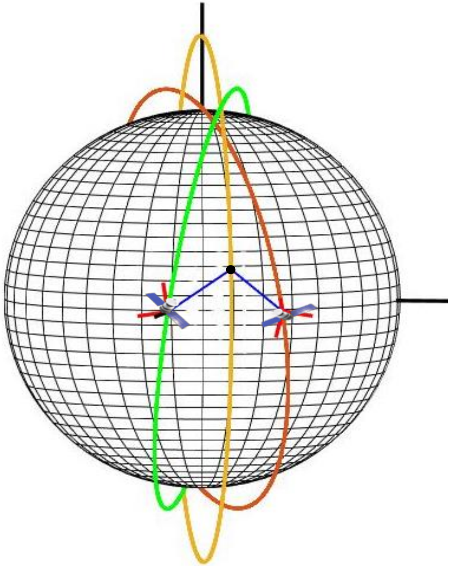
- **Explainable AI**
- **Trusted AI**
- **Certifiable AI**

Ref: T. Kistan, A. Gardi, and R. Sabatini, "Machine Learning and Cognitive Ergonomics in Air Traffic Management: Recent Developments and Considerations for Certification," Aerospace, vol. 5, p. 103, 2018.

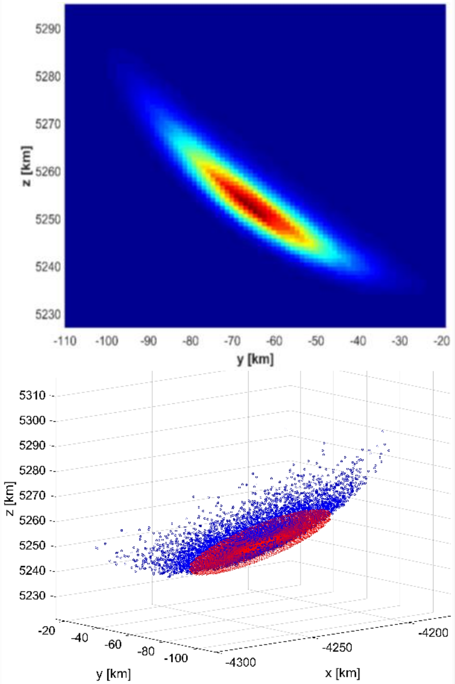
Space Traffic Management

Space Traffic Management

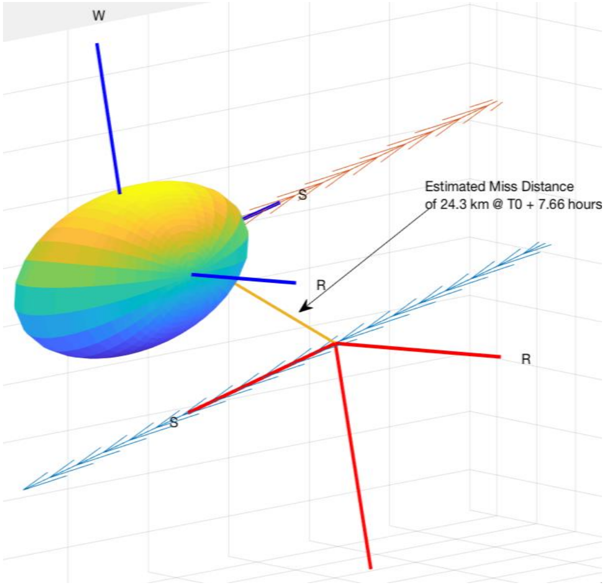
Navigation and Tracking Data Collection and Sharing (Cooperative scenario)



Quantify and Predict Tracked Space Object Uncertainty



Conjunction Analysis and Collision Avoidance



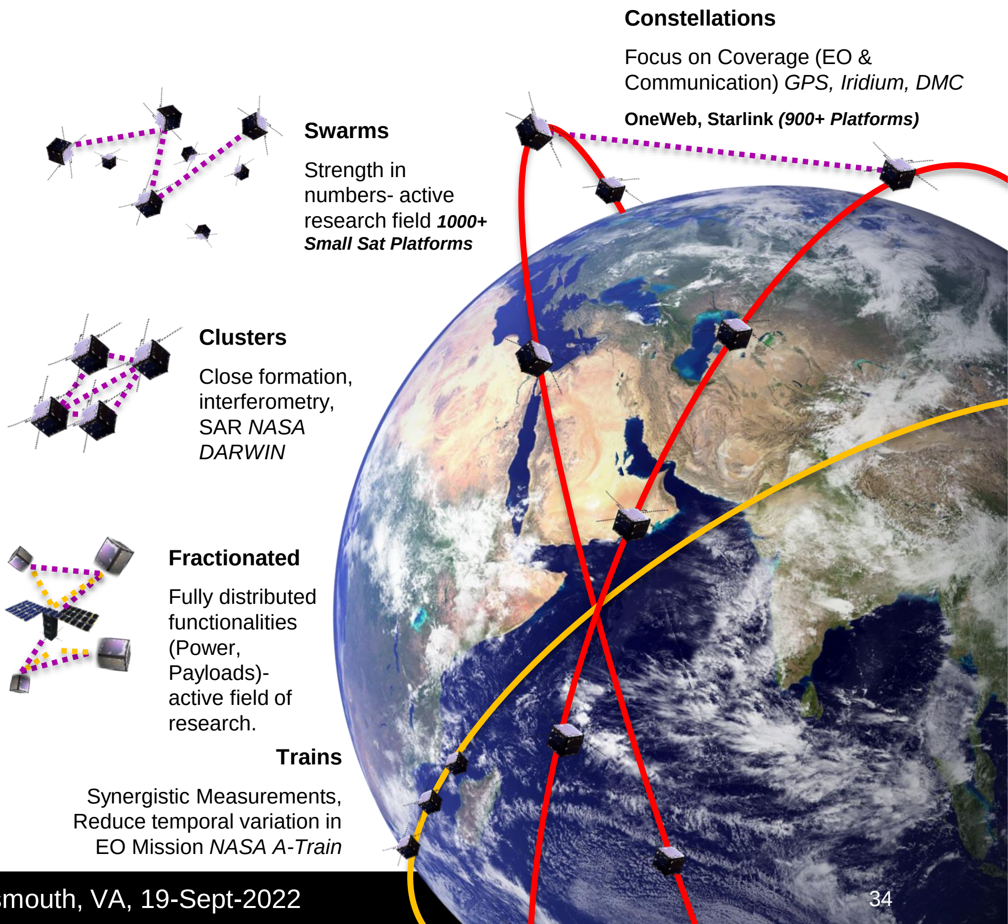
Ref.: - S. Hilton, R. Sabatini, A. Gardi, et al., "Space traffic management: towards safe and unsegregated space transport operations", Progress in Aerospace Sciences, 105, pp. 98-125, 2019.
- S. Hilton, F. Cairola, A. Gardi, R. Sabatini, N. Pongsakornsathien, and N. Ezer, "Uncertainty quantification for space situational awareness and traffic management", Sensors, 19, 2019.

Distributed Space Systems

What Are Distributed Space Systems (DSS)?

*DSS mission architectures move away from the **monolith** system concept to adopt **multiple** elements that **interact**, **cooperate** and **communicate** with each other, resulting in **new systemic properties** and/or **emerging functions***

Architecture	Mission goals	Cooperation	System makeup	Inter-Sat distance	Operational independence
Constellation	Shared - Focus on coverage	Required	Homogeneous	Regional	Independent to co-dependent
Train	Independent to shared	Optional	Heterogeneous	Local	Independent
Cluster	Shared	Required	Homogeneous	Local	Independent to co-dependent
Swarm	Shared	Required	Homogeneous to heterogenous	Local to regional	Independent to co-dependent
Fractionated	Shared	Optional to required	Heterogeneous	Local	Independent to co-dependent
Federated	Independent	Ad-hoc, optional	Heterogeneous	Local to regional	Independent



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AI4SPACE Research Context

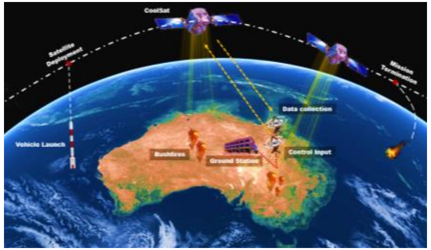
Advanced Satellite Systems, Sensors and Intelligence. Communications, connectivity and IoT technologies. Next Generation Earth Observation Services. Trusted Autonomy and Evolutionary Mission Control Centres

Strengths/Discriminators

- Space-based SDA/STM - Reduction of uncertainty by Tracking of <10cm RSO's elusive to ground infrastructure
- AI-based sensor management and data fusion (autonomous decision making, diagnosis/prognosis and mission management)
- Custom sensors and data analytics products and services for: Mining and Resources, Agriculture/Horticulture/Aquaculture, Transport and Logistics
- Adaptive interfaces and interactions for de-crewing of mission control centres

Research Opportunities

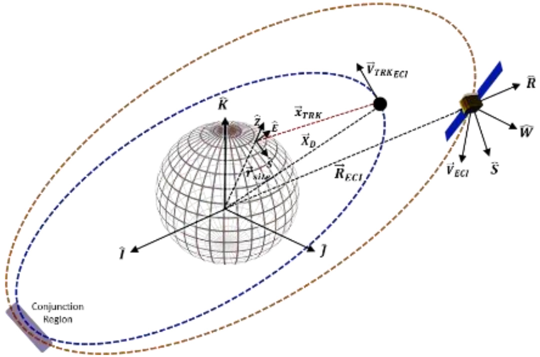
- Artificial Intelligence and Machine Learning (AI/ML) software for trusted autonomous operation
- Fault-tolerant avionics/spaceflight systems research
- Intelligent satellite health management systems
- Passive and active EO/IR sensors and systems

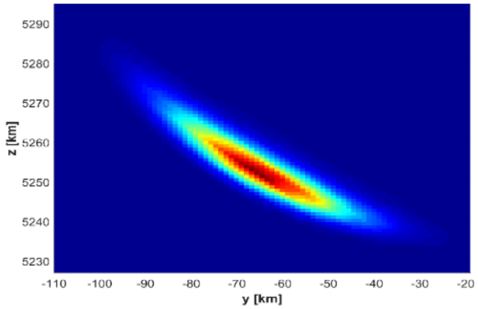


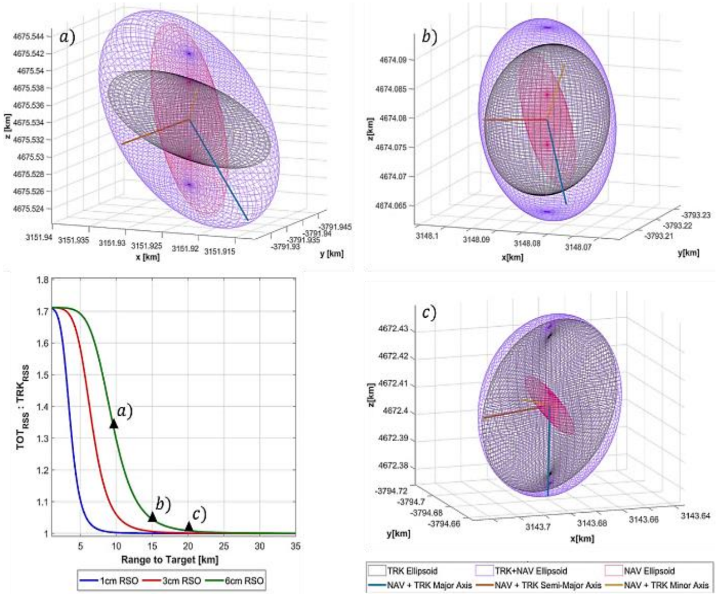
Space Domain Awareness and Traffic Management

Non-cooperative/cooperative tracking, multi-objective trajectory optimisation and goal-based mission planning for time-critical application such as deconfliction of space vehicles

- **Unified mathematical framework** for 4-Dimensional collision uncertainty quantification and mapping
- Considering both space-based and ground-based space surveillance sensors
- Unique software tools employing AI/ML techniques







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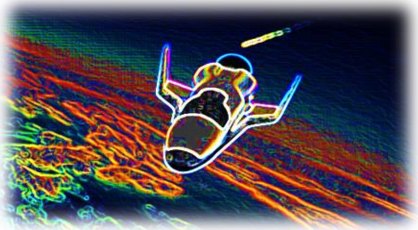
Unified Approach to Air and Space Traffic Management

- Based on a covariance-based formulation (navigation and tracking)
- Expanded to account for relative dynamics and perturbations
- The Gaussian approximation has short-term realism – Need for frequent updates to avoid over-bounding
- Both ground based surveillance and SBSS (cooperative and non-cooperative) are needed for a scalable STM system
- Network-centric STM and MDTM



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2. Overview of AI/ML Techniques
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8. Wrap Up and Questions

2. OVERVIEW OF AI/ML TECHNIQUES WITH REFERENCE TO AVIONICS SYSTEMS

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AI in Avionics Systems

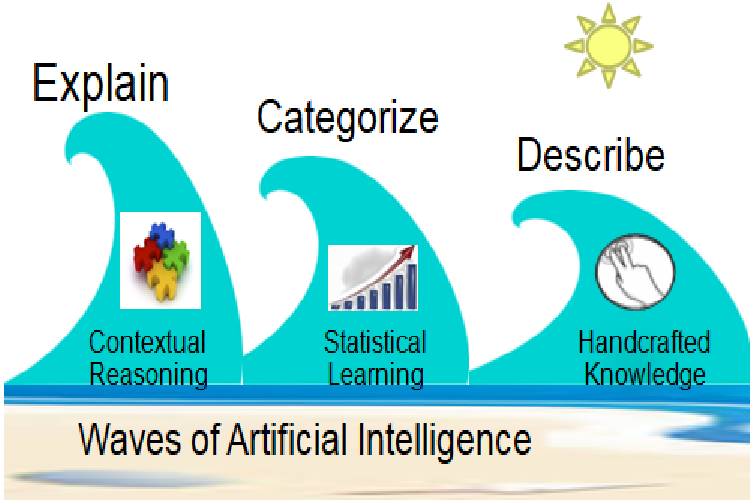
- Significant Advancements in AI (or Deep Learning) since 2012:

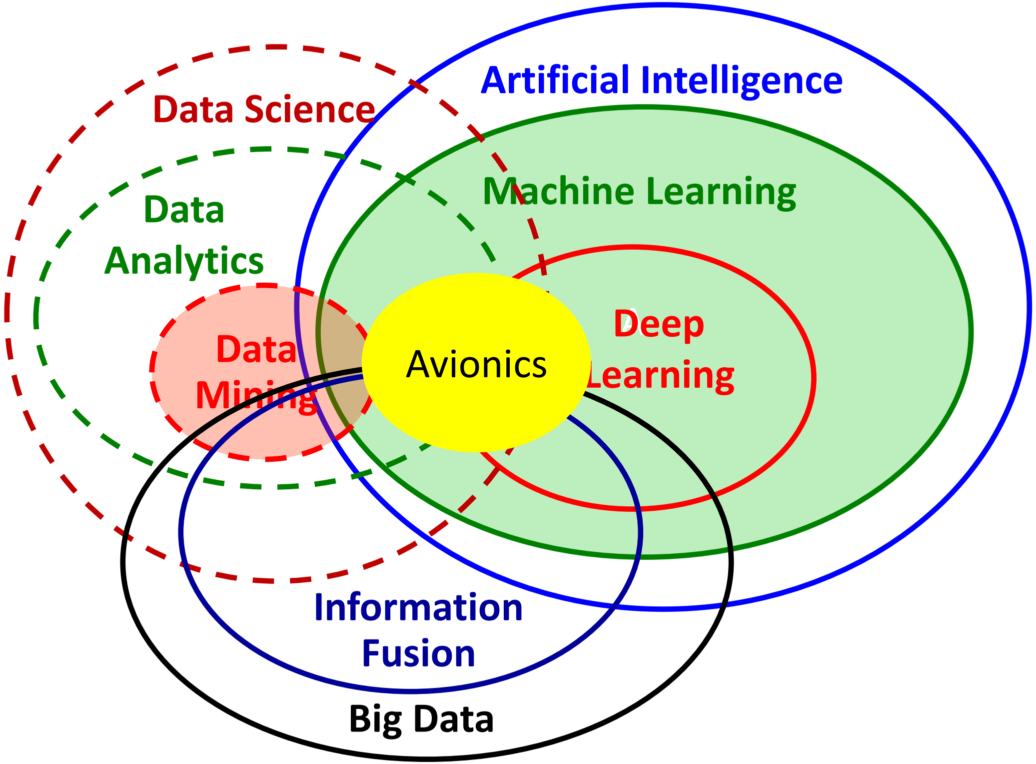
  Data availability, computing power, and methods

- Methods applied to:
  - **Spatial (convolutional neural networks) – imagery/terrain**
  - **Temporal (recurrent neural networks, LSTM) – positioning/navigation**
  - **Frequency (wavelet-based neural networks) – radar/communications**

- Open Challenges:
  - Testing and evaluation of different methods (interpretability, explainability)
  - Certification and logistics analysis (reliability, availability)
  - Performance in the field (Usability, security)

AI in Avionics Systems





R. Cruise, **E. Blasch**, S. Natarajan, A. Raz, "Cyber-physical Command Guided Swarm," *DSIAC Journal*, Vol. 5, No.2, pp. 24-30, Spring 2018.

E. Blasch, T. Pham, C-Y. Chong, W. Koch, H. Leung, D. Braines, T. Abdelzaher, "Machine Learning/Artificial Intelligence for Sensor Data Fusion–Opportunities and Challenges," *IEEE Aerospace and Electronic Systems Magazine* ,36(7):80-93, July 2021.

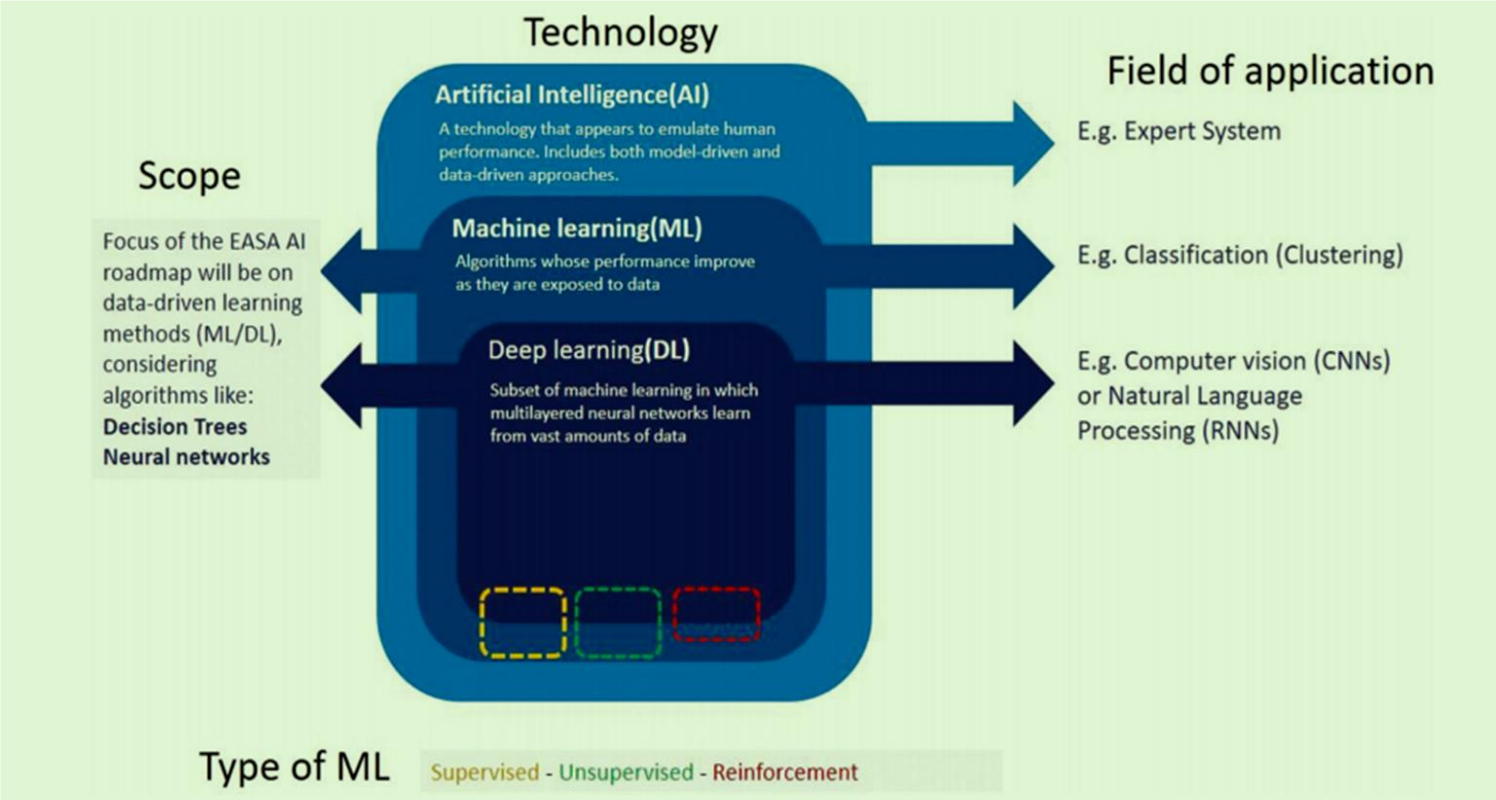
What is Artificial Intelligence

- Computers doing things conventionally performed by humans
- FAA definition: The study of AI is devoted to developing computer programs that will mimic the product of intelligent human problem solving, perception and thought (DOT/FAA/CT-94/41)

How Artificial Intelligence is Transforming the Aviation Industry | Oodles Technologies (wordpress.com)

Baggage screening
Fleet handling
Navigation

Anatomy of AI



Reproduced from EASA AI Roadmap

What Is Machine Learning?

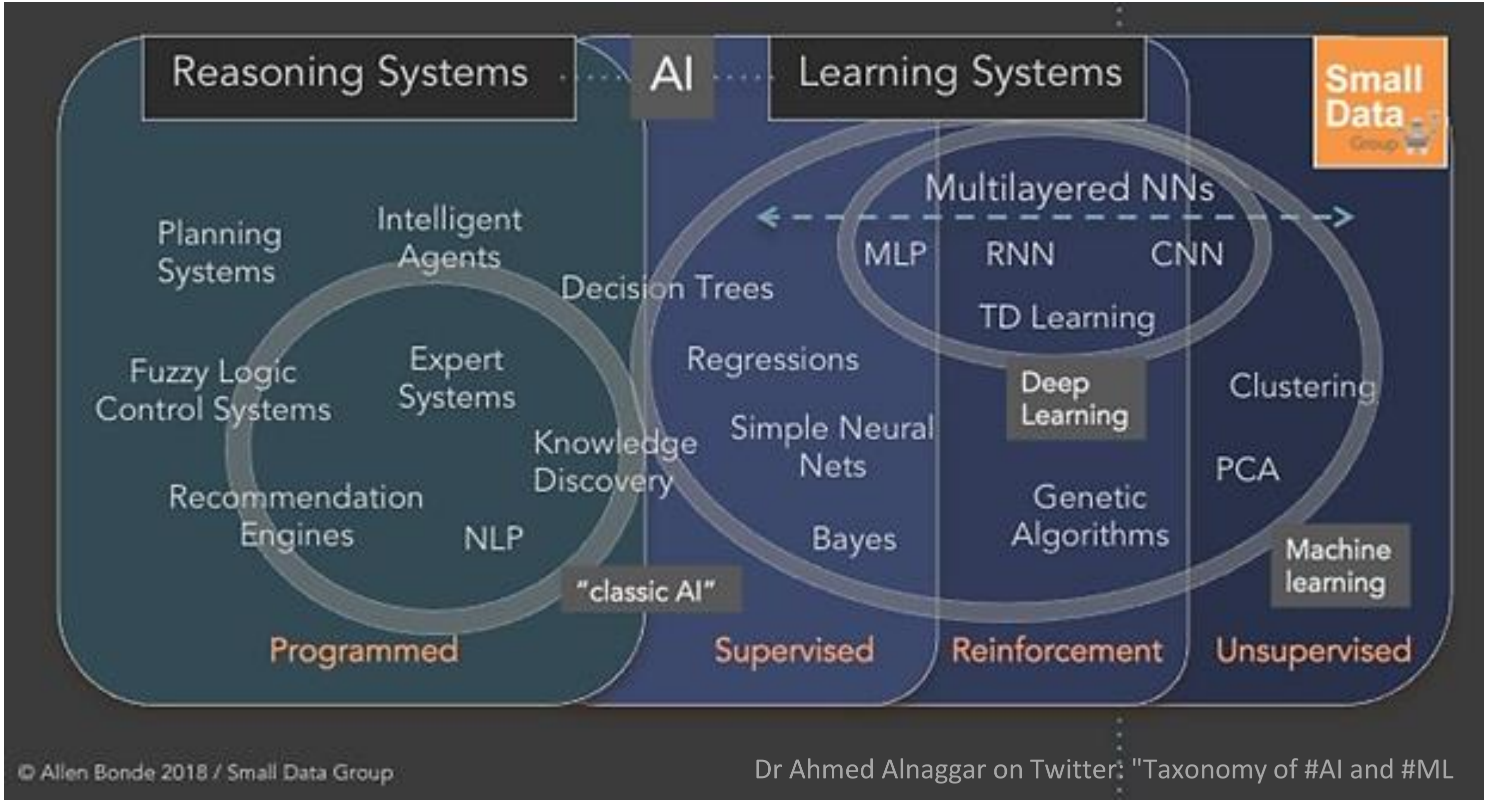
- ❖ An AI technique that teaches computers to learn from experience
- ❖ ML algorithms use computational methods to "learn" information directly from data without relying on a predetermined equation as a model
- ❖ Algorithms adaptively improve their performance as the number of samples available for learning increases
- ❖ Deep learning is a specialized form of machine learning

ML Learning Techniques

- ❖ Supervised learning: which trains a model on known input and output data so that it can predict future outputs
- ❖ Unsupervised learning: which finds hidden patterns or intrinsic structures in input data

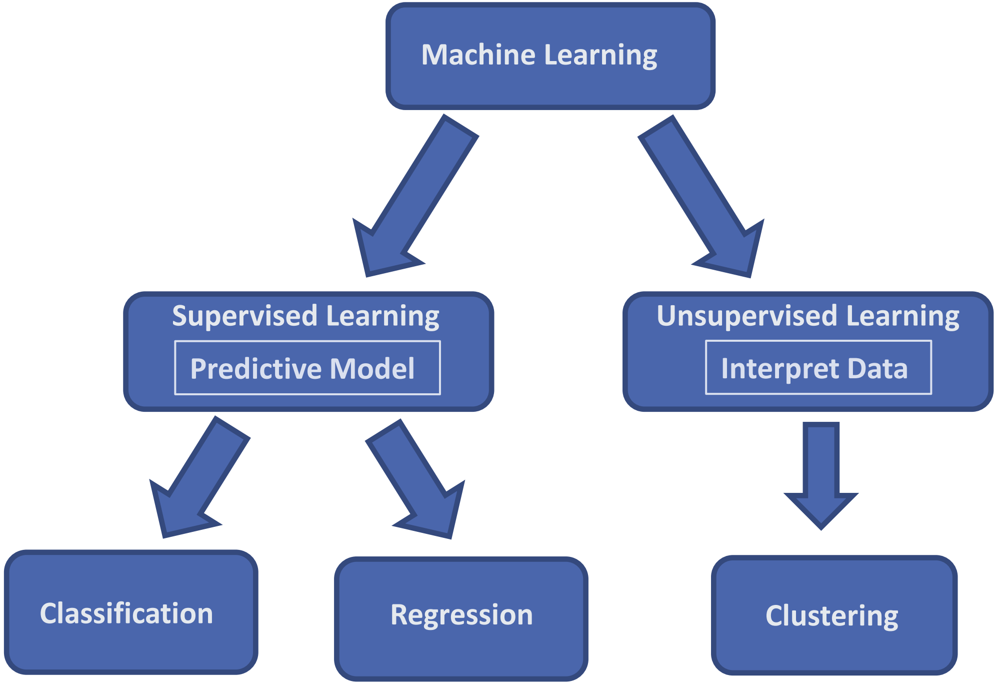
Machine Learning Techniques

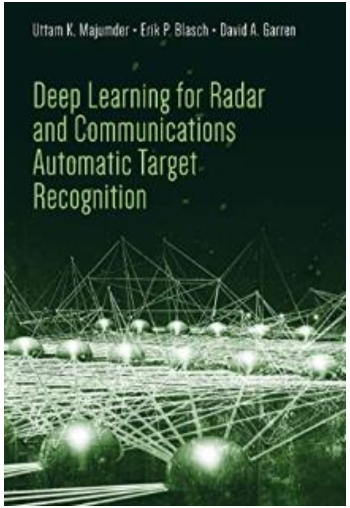
AI: **Machine, Deep, Transfer, Reinforcement Learning**



ML Learning Techniques

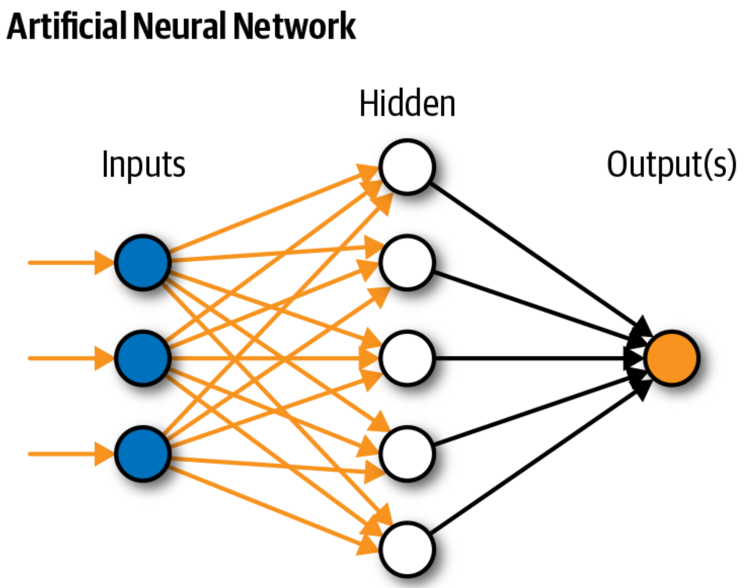
❖ Majumder, Blasch (IEEE Tutorial)





Supervised Learning

- Builds a model that makes predictions based on evidence in the presence of uncertainty
- Use supervised learning if you have known data for the output you are trying to predict
- Supervised learning uses classification and regression techniques to develop machine learning models



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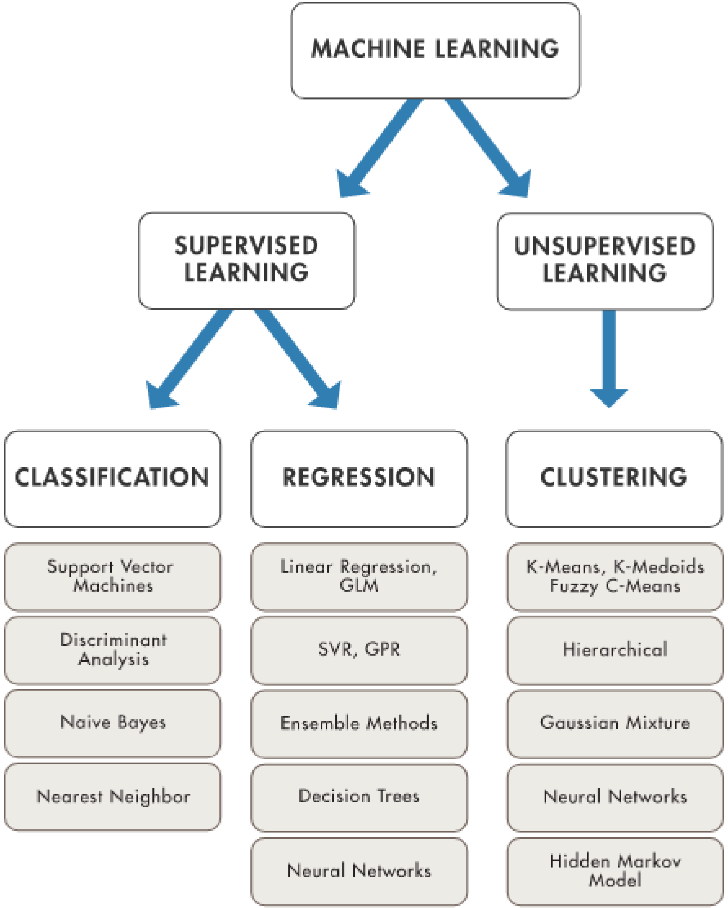
Un-Supervised Learning

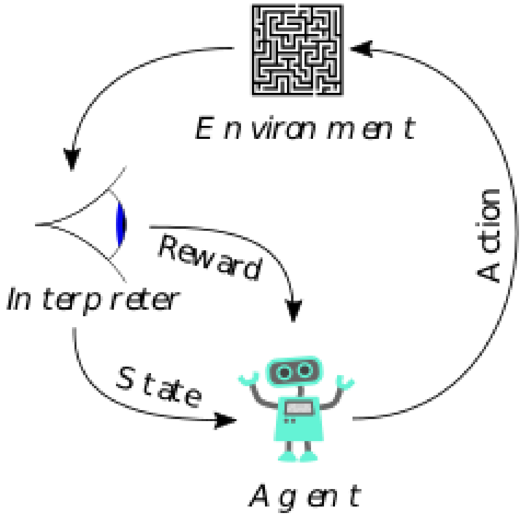
- Finds hidden patterns or intrinsic structures in data
- It is used to draw inferences from datasets consisting of input data without labeled responses
- Most commonly used technique is Clustering. Used for exploratory data analysis to find hidden patterns or groupings in data
- Applications for cluster analysis include gene sequence analysis, market research and object recognition



Reinforcement Learning

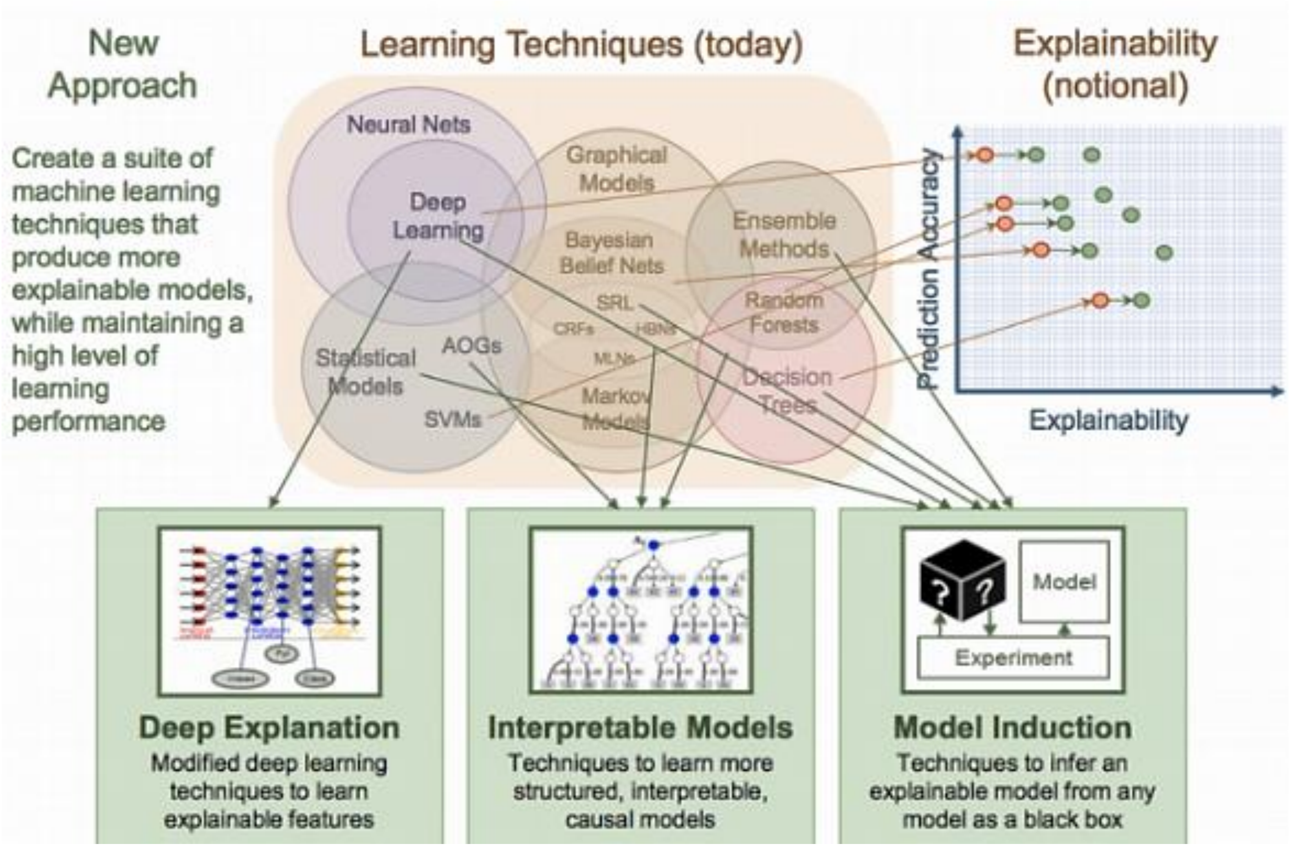
- The training of machine learning models to make a sequence of decisions
- The agent learns to achieve a goal in an uncertain, potentially complex environment
- State (s), action (a), Value (V) or policy (π), discounted (γ) reward (R)

$$\pi : A \times S \rightarrow [0,1]$$
$$\pi(a,s) = \Pr(a_t = a \mid s_t = s)$$
$$V_\pi(s) = \mathrm{E}[R \mid s_0 = s] = \mathrm{E}\left[\sum_{t=0}^{\infty} \gamma^t r_t \mid s_0 = s\right],$$



- Current: Deep Reinforcement Learning

Deep Learning



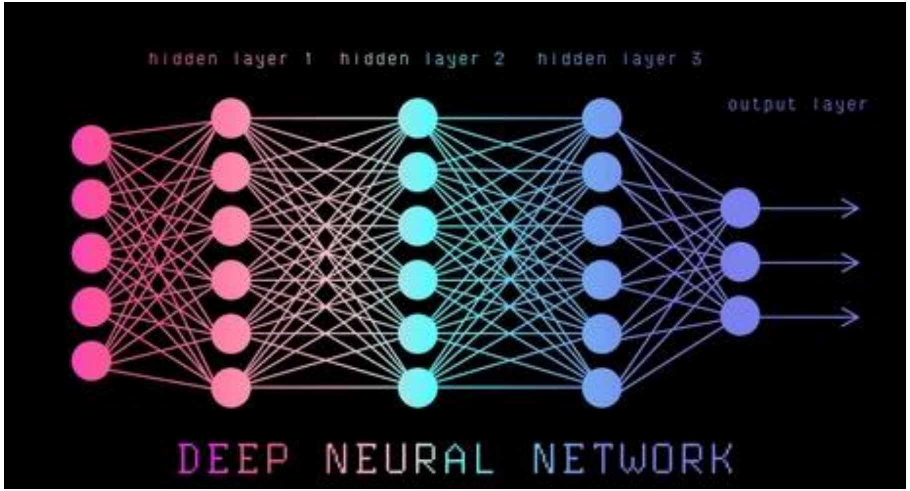
Explainable Artificial Intelligence: Technical Perspective — Part 1 | by Sparsha Devapalli | Medium

Deep Learning

❖ A successful deep learning application requires a very large amount of data (thousands of samples) to train the model, as well as dedicated processing units (e.g., GPU or TPU), to rapidly process data

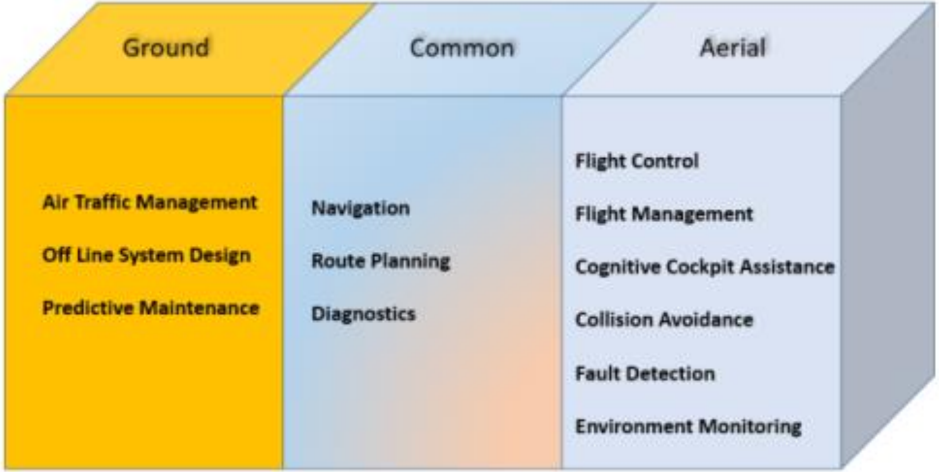
❖ Deep learning requirements:

- High-performance hardware
- Lots of labeled data
- Deep learning is generally more complex



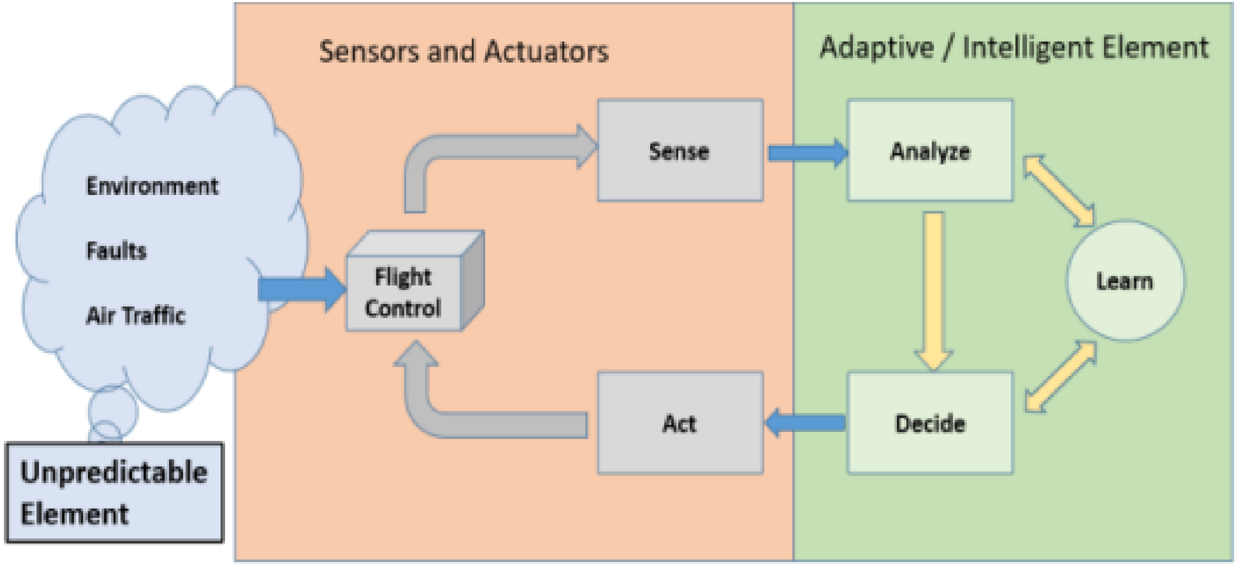
EASA Identified AI Applications

- ❖ Aircraft design and operation
- ❖ Aircraft production and maintenance
- ❖ Air traffic management
- ❖ Drones, urban air mobility & U-space
- ❖ Safety risk management
- ❖ Cybersecurity
- ❖ Environment



Application Example – Adaptive Control

- A system in which the computational element of the active feedback process changes in order to maintain desired performance in response to failures, threats, or a changing environment



Intelligent Adaptive Flight Control

- Recovering from stall is a challenging task for pilots
- Aircraft is nearly unresponsive during stall, then responds abnormally
- Conventional flight control systems provide desired handling qualities and robust control for operational flight envelope but cannot cope with the highly nonlinear dynamics of stall recovery
- Intelligent adaptive control well suited for these applications

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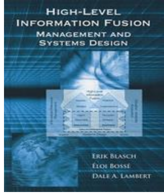
3. INTERACTIVE HMI SYSTEMS

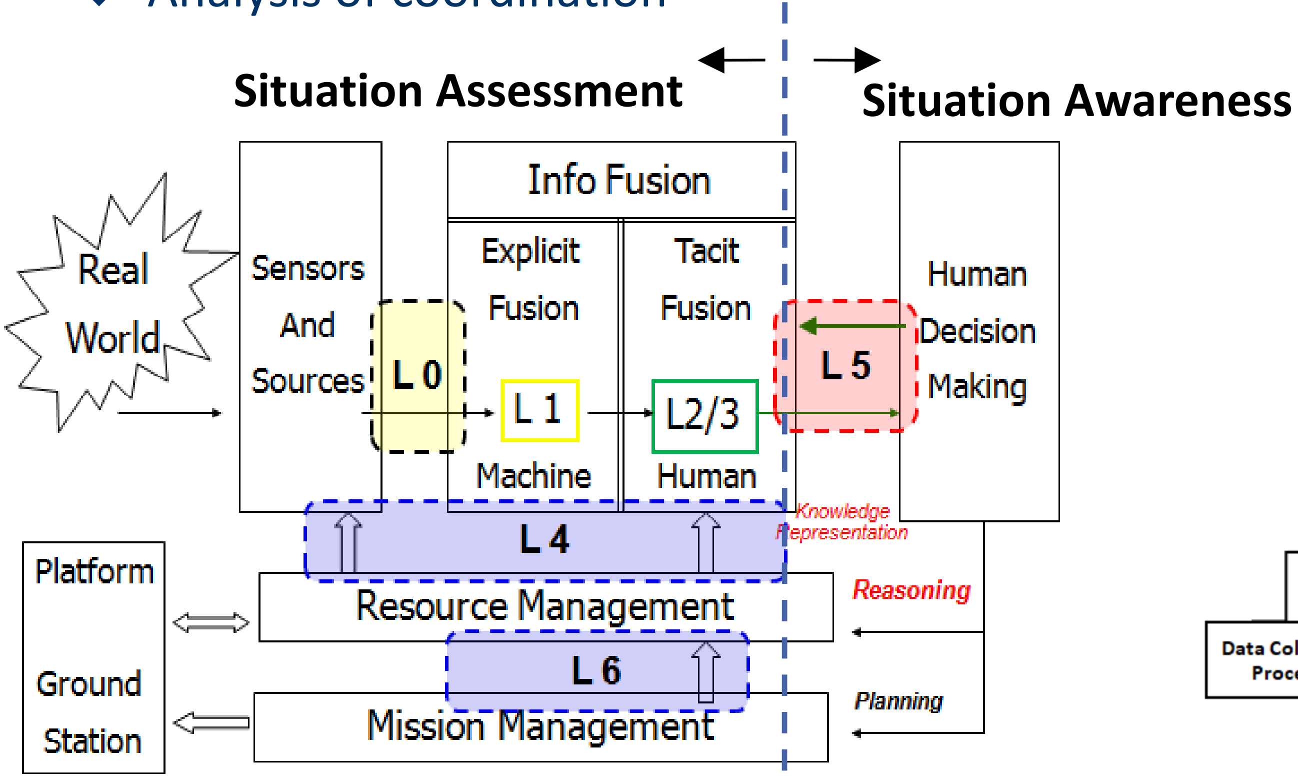
HMI Considerations

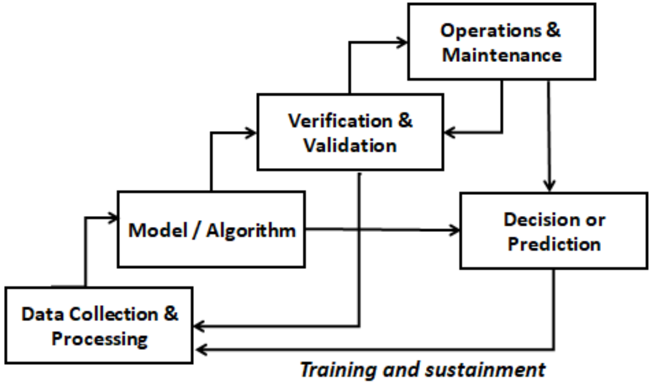
- Human Interaction (Data Fusion Model)
- Cognitive reasoning and task coordination
- Intelligent design through semantic ontologies
- Autonomy in Use
- User Defined Operating Picture (display/visualization)
- Certification issues:
  - No one-on-one certification for UTM (akin to aircraft pilots)
  - No certification of AI/ML methods
  - Do we certify platform, pilot, software (separately or together)?

Human Machine Model

❖ Analysis of coordination

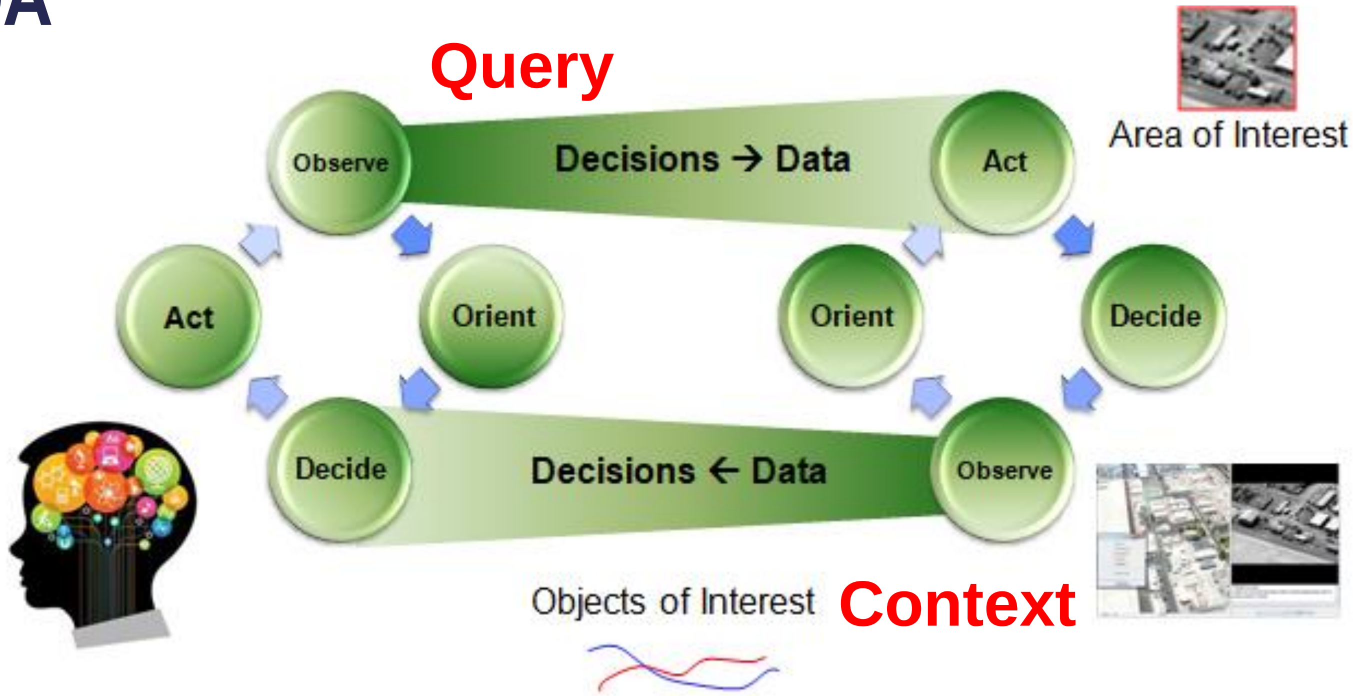






E. P. Blasch, E. Bosse, and D. A. Lambert, *High-Level Information Fusion Management and Systems Design*, Artech House, Norwood, MA, 2012.

OODA



Human-Machine Teaming

Observe-Orient-Decide-Act (OODA) loops

E. Blasch, O. Kessler, **J. Morrison,** J. F. Tangney, and F. E. White, "Information Fusion Management and Enterprise Processing." *IEEE National Aerospace and Electronics Conference (NAECON)*, 2012.

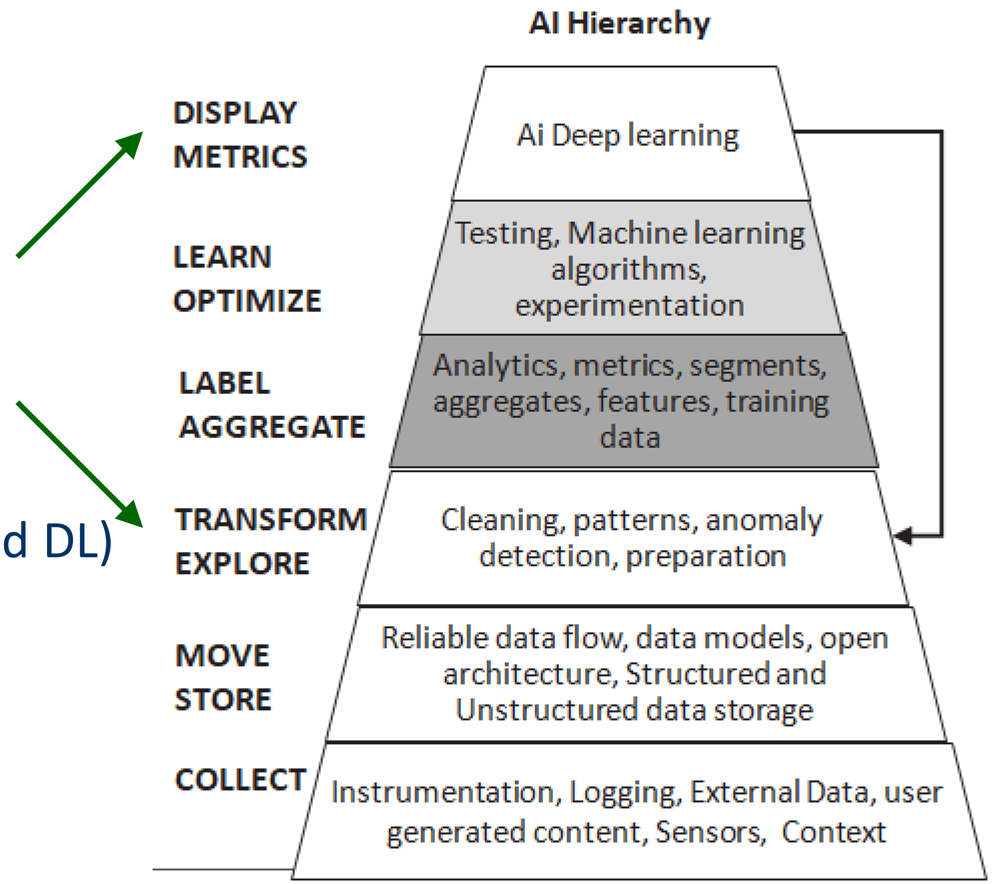
Human Machine Model

- Analysis of coordination
- Human – Interprets Results

- BUT ………..

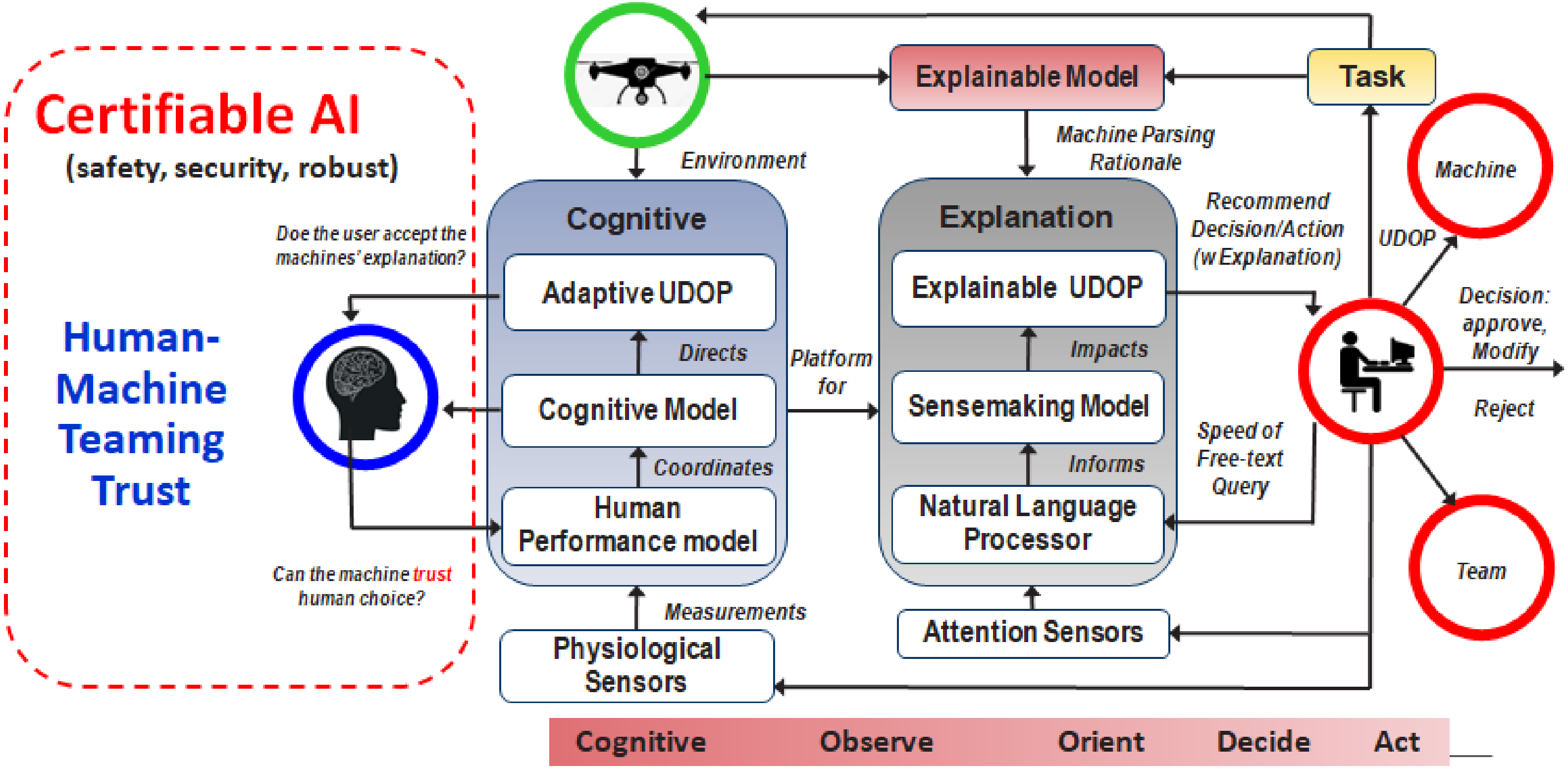
- Cleans, Labels (semi-supervised DL)
- Approves data movement
- Selects the data to collect

….. Certification Issue?



E. Blasch, J. Sung, T. Nguyen, "Multisource AI Scorecard Table for System Evaluation," *AAAI FSS-20: Artificial Intelligence in Government and Public Sector*, Washington, DC, USA, 2020. arXiv:2102.03985

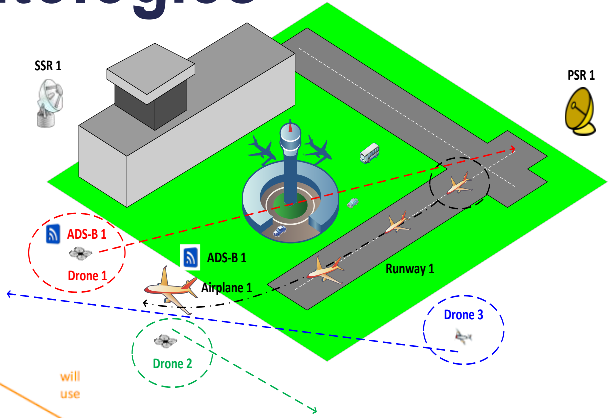
Cognitive reasoning and task coordination

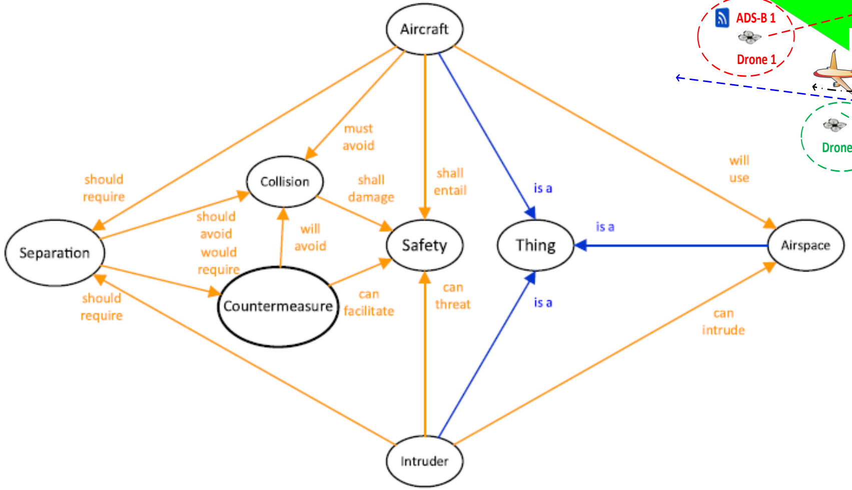


E. Blasch, et al, "Certifiable Artificial Intelligence Through Data Fusion," AAAI FSS-21, 2021. http://arxiv.org/abs/2111.02001

Intelligent design through semantic ontologies

- Map text-to-physics
  - Notice to airman (NOTAM)
  - Tail Number
  - Runway coordination (e.g. F
  - Decisions (e.g., possible)
- Implementation
  - Terminology
  - Assertions
  - Drone *is-a* quadcopter

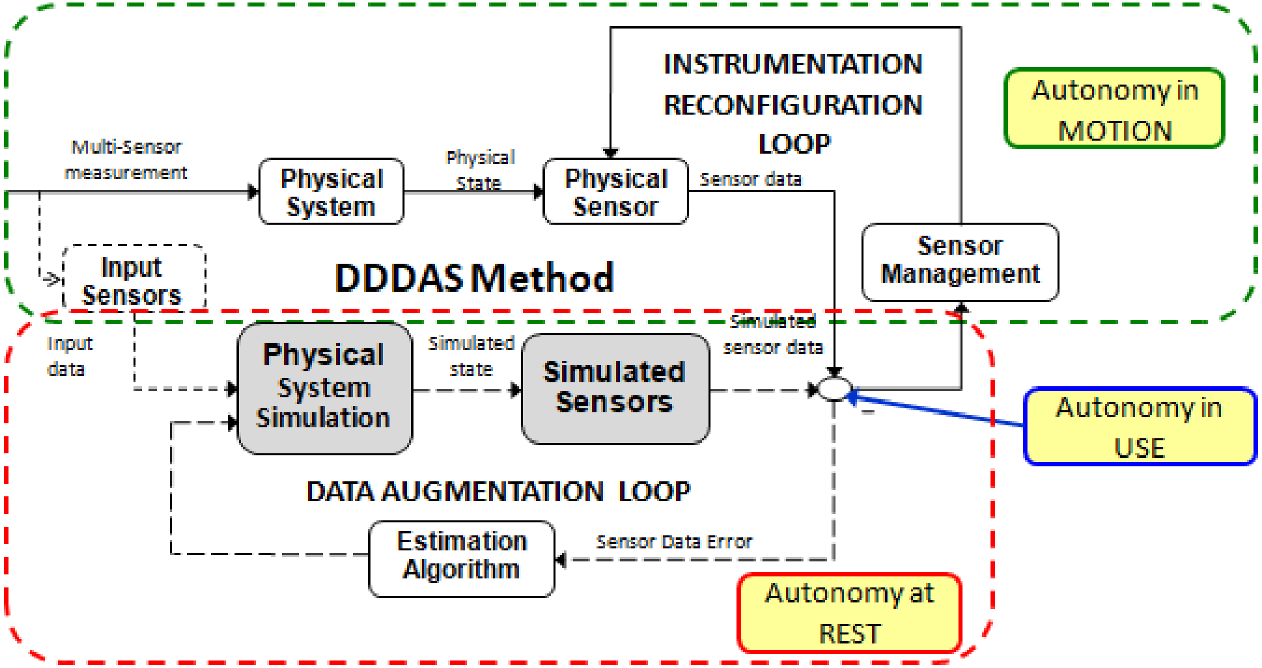




C. Insaurralde, E. Blasch, P. Costa, and K. Sampigethaya, "Uncertainty-Driven Ontology for Decision Support System in Air Transport" *Electronics* 11(3):362, Jan 2022. https://doi.org/10.3390/electronics11030362.

C. Insaurralde, E. Blasch, "Situation Awareness Decision Support System for Air Traffic Management Using Ontological Reasoning," *AIAA Journal of Aerospace Information Systems* 19 (3), 224-245, 2022

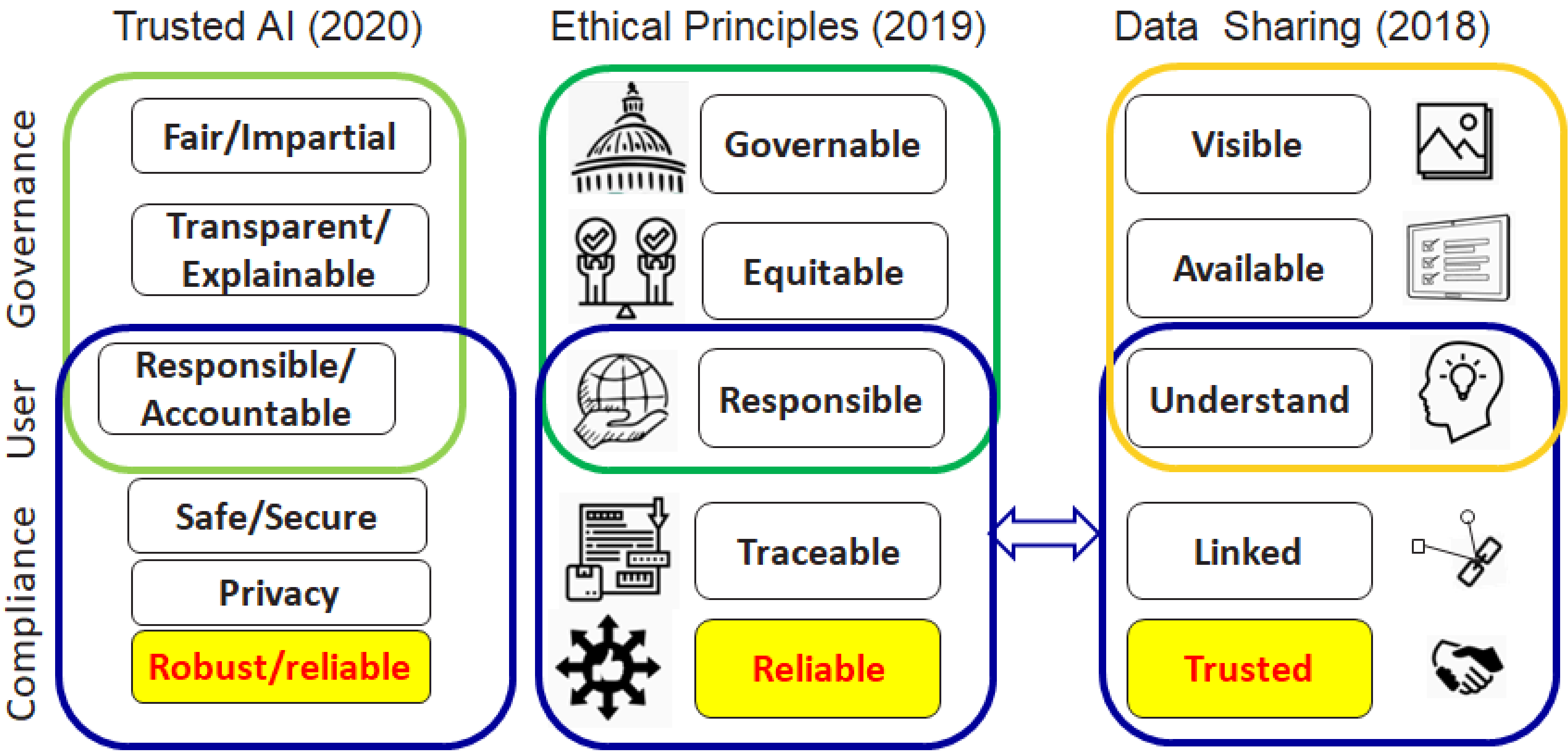
Autonomy in Use



- Traditional
  - Filtering
  - Estimation
  - Analysis
- AI Methods
  - Generative AI
  - Deep Learning

E. P. Blasch, F. Darema, S. Ravela, A. J. Aved (eds.), *Handbook of Dynamic Data Driven Applications Systems*, Vol. 1, 2nd ed., Springer, 2022.

AI/ML Policies



E. Blasch, J. Sung, T. Nguyen, "Multisource AI Scorecard Table for System Evaluation," *AAAI FSS-20:*, 2020. arXiv:2102.03985

Certification Issues

Methods

- Human
- Machine
- Software
- Data

Example	Certification
Hardware - Electronics	Quality Control Rating
Hardware - Platform	Airworthiness
Sensor	Calibration specifications
Software - Routine	Processing time
Software - System	Assurance
Human- Novice	Drivers License
Human- Expert	Medical License
Human-Software	Security Certificate
Human-Data	Data Analytics Certificate
Human-Data Domain	Data Analysis License

Human-Machine Teaming

Observe-Orient-Decide-Act (OODA) loops

R. Cruise, **E. Blasch**, S. Natarajan, A. Raz, "Cyber-physical ... Command Guided Swarm," *DSIAC Journal*, Vol. 5, No. 2, pp. 24-30, Spring 2018.

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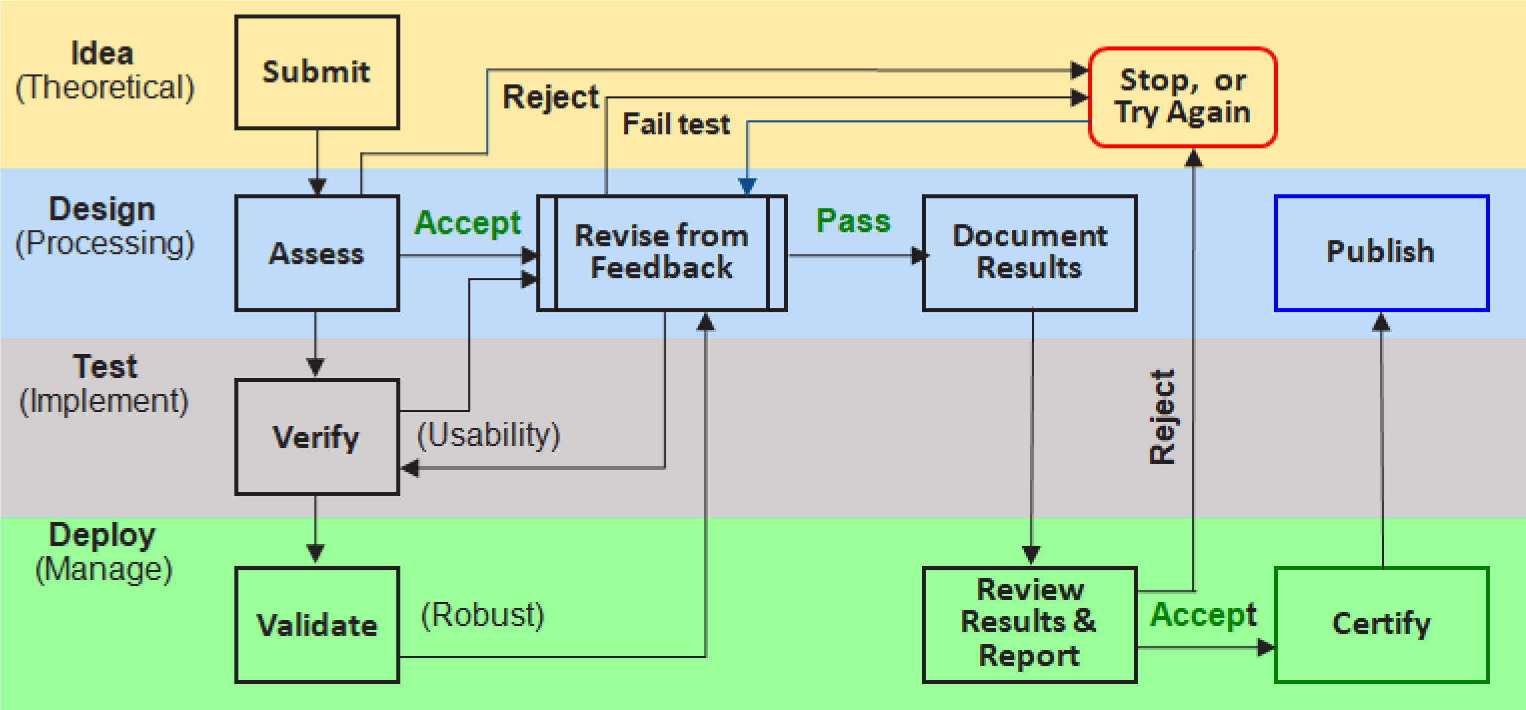
C. Insaurralde, E. Blasch, "Situation Awareness Decision Support System for Air Traffic Management Using Ontological Reasoning," *AIAA Journal of Aerospace* ...

... Springer, 2022.

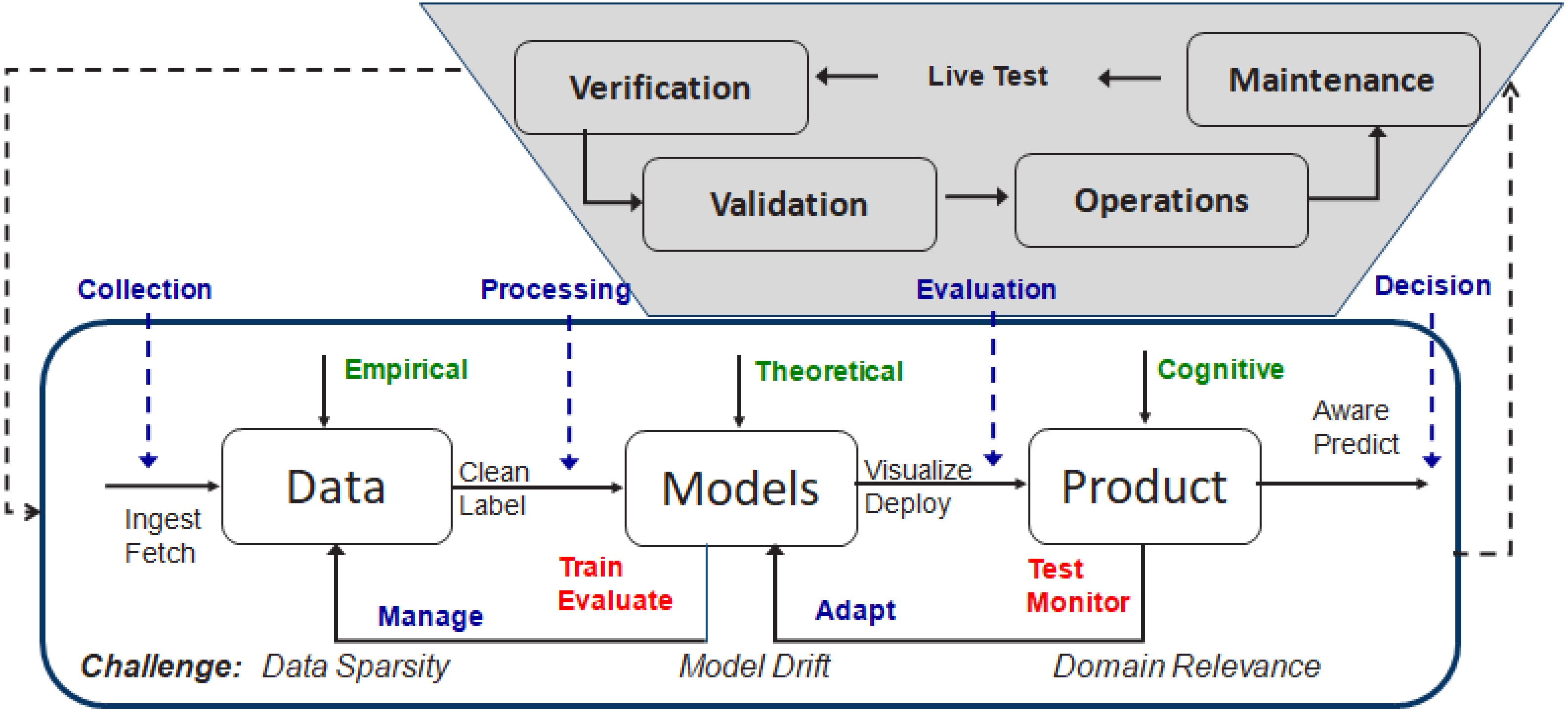
... House, Norwood, MA, 2012.

Certification Issues



E. Blasch, et al, "Certifiable Artificial Intelligence Through Data Fusion," AAAI FSS-21, 2021. http://arxiv.org/abs/2111.02001

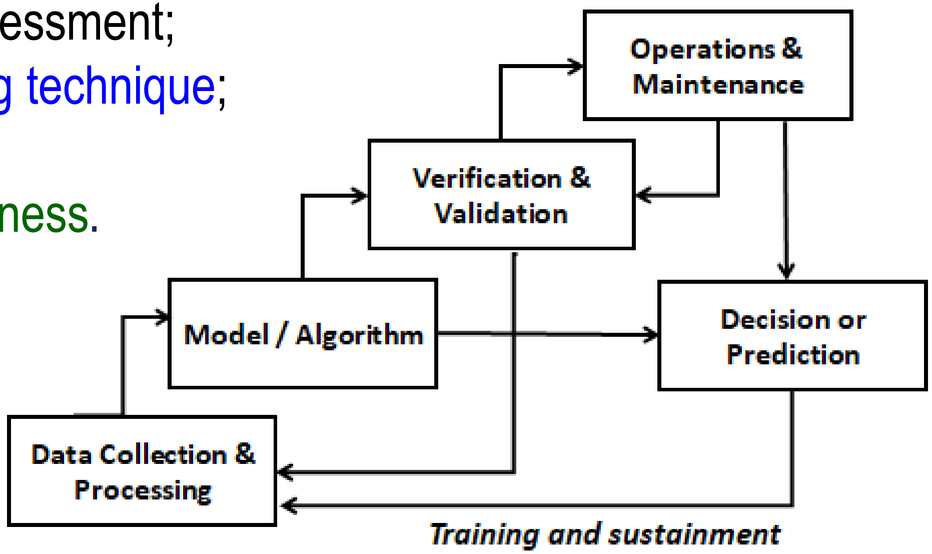
Certification Opportunities



E. Blasch, et al, "Certifiable Artificial Intelligence Through Data Fusion," AAAI FSS-21, 2021. http://arxiv.org/abs/2111.02001

Summary

1) What – type of **data** as the input;
2) Where –certification location such as in a lab or field;
3) When - static certification or dynamic run-time analysis;
4) Who - require user involvement for assessment;
5) Which – system or an AI/ML processing technique;
and
6) How – metrics used to determine readiness.
…
7) How Long ?
8) Training ?
Life Cycle Assessment



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4. AI IN ATM AND UTM SYSTEMS

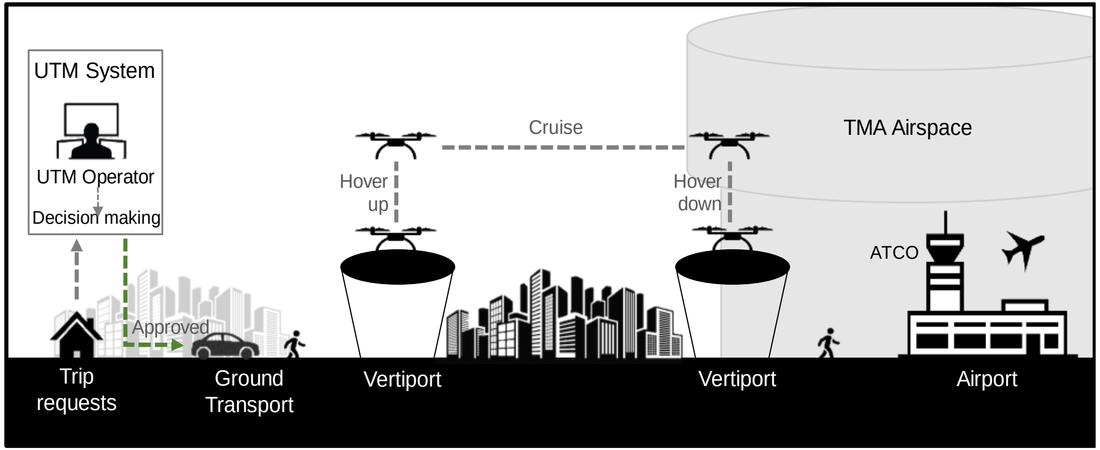
The UTM (ATM 2.0) Challenges

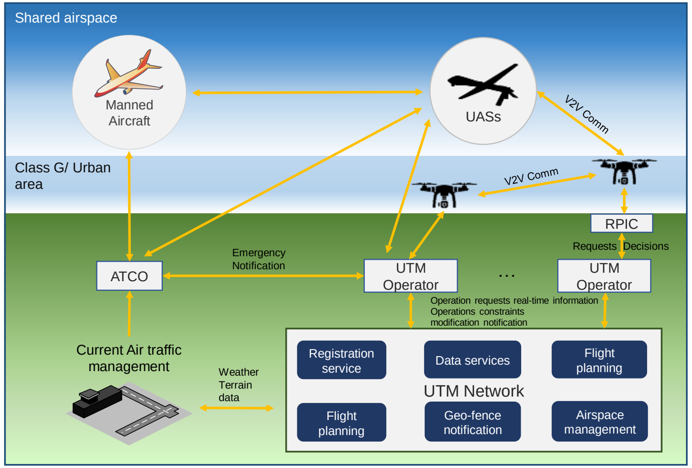
- Advanced Air Mobility (AAM): ability to start/end trips essentially anywhere, with low predictability
- The mostly tactical and human-intensive deconfliction approach of traditional ATM cannot be scaled down to fulfil UTM

Low altitude airspace needs restructuring of air traffic services

A high degree of autonomy is necessary in UTM systems

UTM still requires human in/on the loop for accountability, reliability of the system



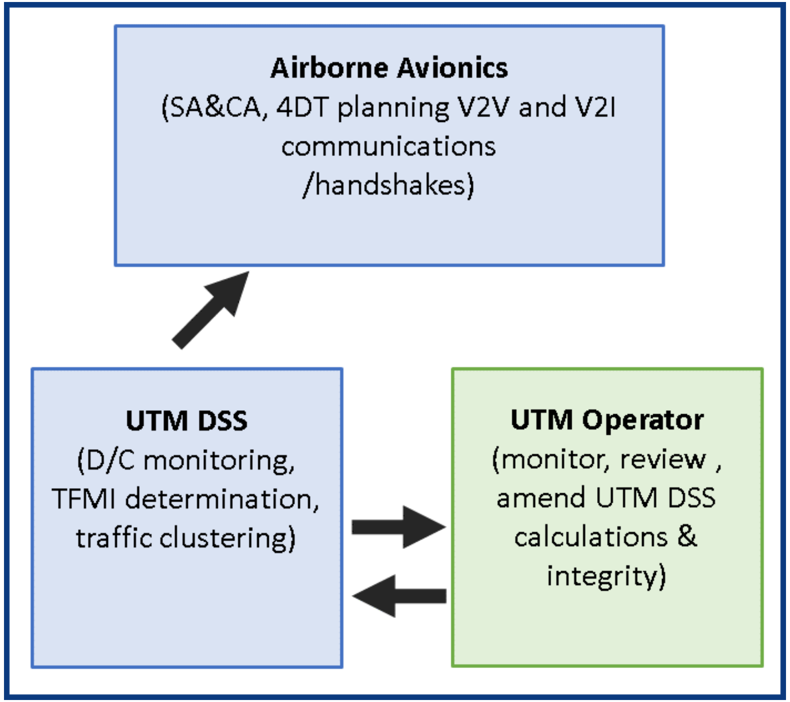


Ref.: - N. Pongsakornsathien, A. Gardi, R. Sabatini, and T. Kistan, "Evolutionary Human-Machine Interactions for UAS Traffic Management", AIAA Aviation Forum 2021

- N. Pongsakornsathien, A. Gardi, R. Sabatini, T. Kistan, and N. Ezer, "Human-Machine Interactions in Very-Low-Level UAS Operations and Traffic Management", DASC 2020, San Antonio, TX, USA, 2020

The Role of UTM Systems and Operators in UAM/AAM

- Ground-based UTM is foreseen to become a highly-automated Air Traffic Flow Management (ATFM) service (e.g., SESAR's DACUS concept)
- Shifting away from human-in-the-loop to a supervisory control of highly automated UTM DSS: human-on-the-loop
- UTM System responsible for:
    1. visualizing the overall situation
    2. determining Demand/Capacity imbalances
    3. generating possible solutions



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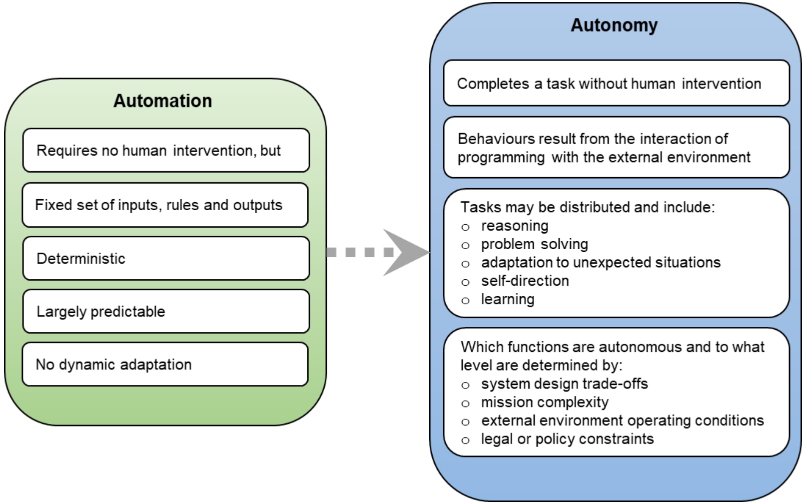
Automation and Autonomy in Air Traffic Management



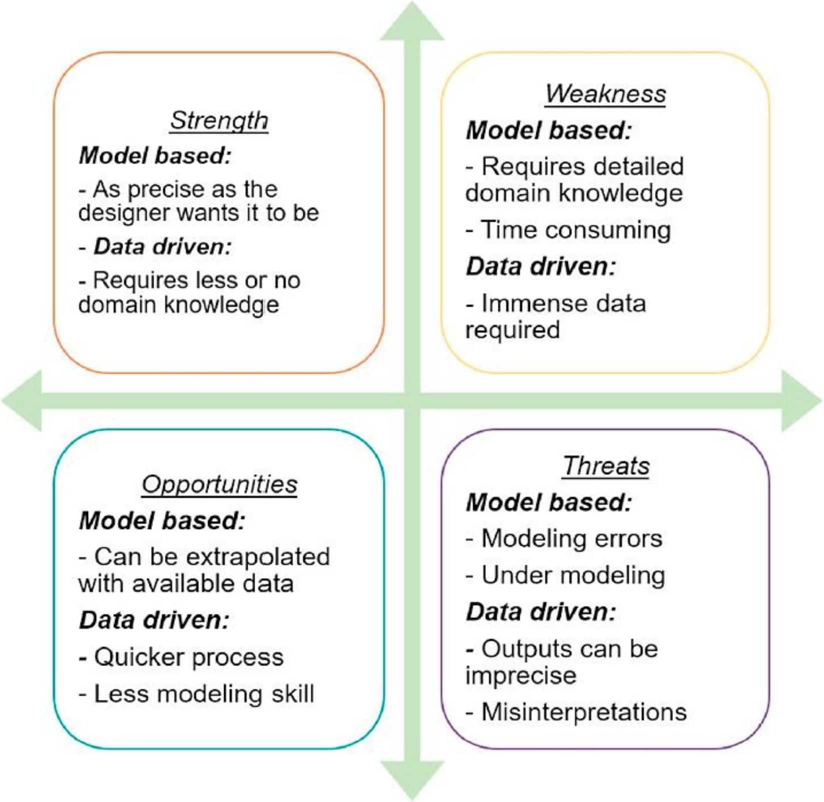
Characteristic	Automation	Autonomy
Augments human decision-making	Usually	Usually
Proxy for human actions or decisions	Usually	Usually
Reacts at cyber speed	Usually	Usually
Reacts to the environment	Usually	Usually
Reduces tedious tasks	Usually	Usually
Robust to incomplete or missing data	Usually	Usually
Adapts behaviour to feedback (learns)	Sometimes	Usually
Exhibits emergent behaviour	Sometimes	Usually
Reduces cognitive workload for humans	Sometimes	Usually
Responds differently to identical inputs (non-deterministic)	Sometimes	Usually
Addresses situations beyond the routine	Rarely	Usually
Replaces human decision-makers	Rarely	Potentially
Robust to unanticipated situations	Limited	Usually
Adapts behaviour to unforeseen environmental changes	Rarely	Potentially
Behaviour is determined by experience rather than by design	Never	Usually
Makes value judgments (weighted decisions)	Never	Usually
Makes mistakes in perception and judgment	N/A	Potentially

Ref: T. Kistan, A. Gardi, and R. Sabatini, "Machine Learning and Cognitive Ergonomics in Air Traffic Management: Recent Developments and Considerations for Certification," Aerospace, vol. 5, p. 103, 2018.

Model-Based VS Data-Driven Reasoning

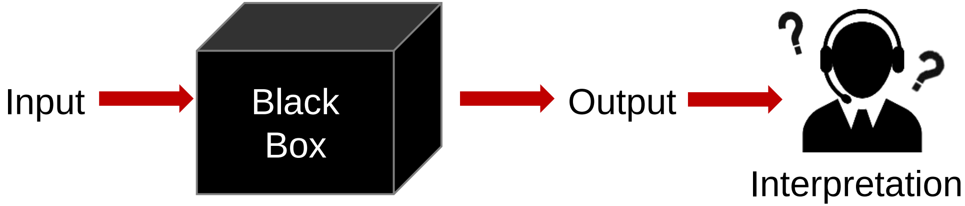
- ❖ Physics/Model-based algorithms and Data-Driven methods have clear complementary SWOT
- ❖ Hybrid approaches that combine model-based and data-driven methods can greatly improve robustness, flexibility and computational efficiency

	Dynamic Systems (Time Trends)	Aggregated Data
Physics Model-Based	• Fourier/Modal Analysis • Kalman Filters • Markov Models	• Taylor/Linearization • Regression
Data-Driven (Model-agnostic)	• Particle Filter • RNN/LSTM	• Clustering • SVM, PCA, NN, Neuro-Fuzzy

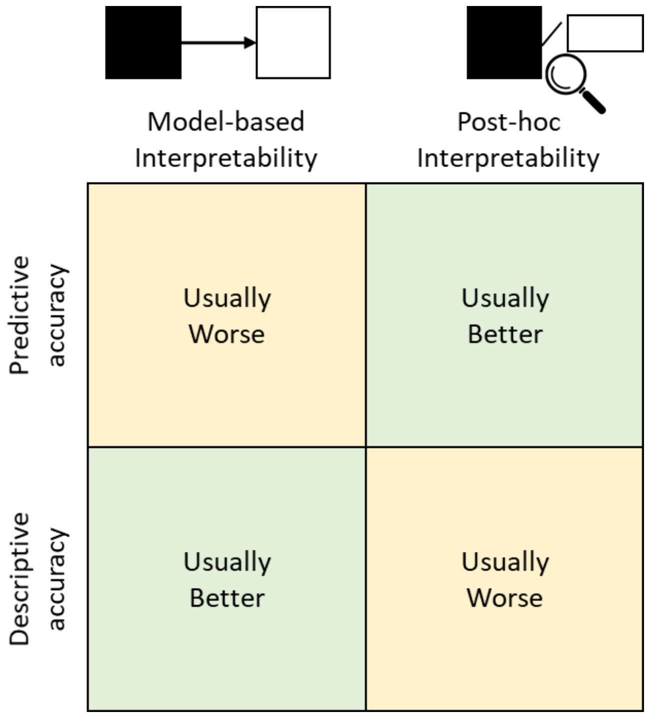


Ref.: - K. Ranasinghe, R. Sabatini, A. Gardi, et al., "Advances in Integrated System Health Management for mission-essential and safety-critical aerospace applications", Progress in Aerospace Sciences, 128, 2022.
- K. Ranasinghe, S. Bijjahalli, A. Gardi, and R. Sabatini, "Intelligent Health and Mission Management for Multicopter UAS Integrity Assurance", IEEE/AIAA 40th DASC 2021, San Antonio, TX, USA, 2021

Explainable AI



- Model-based and post-hoc explainability are key approaches to increase interpretability and explorability of the model solutions
- Model-based interpretability tends to have a limited predictive accuracy but increased descriptive accuracy because a simpler model is derived
- Post-hoc interpretability does not rely on the specific model structure but adopt methods to generate descriptive accuracy



W. J. Murdoch, C. Singh, K. Kumbier, R. Abbasi-Asl, and B. Yu, "Definitions, Methods, and Applications in Interpretable Machine Learning," *Proceedings of the National Academy of Sciences*, 2019, pp. 22071–22080

Explanation Methodologies

Contrastive Explanation

"Why" questions are contrastive—they take the form "why P instead of Q"

Social Attribution

Similar to the "belief–desire–intention" model, we need a different explanation framework for fail and success actions

Causal Connection

"what if" of what would have happened differently

Explanation Selection

Allowing users to construct a preferred explanation

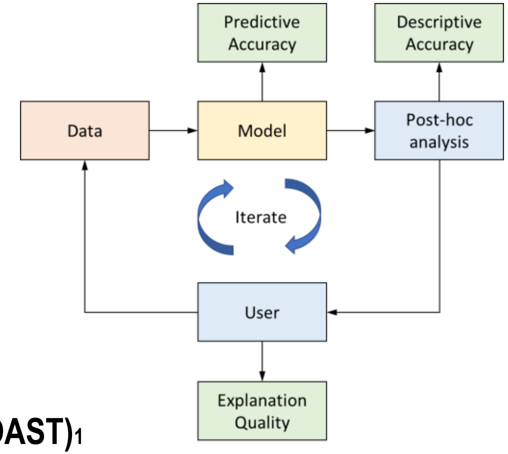
Explanation Evaluation

Simplicity and generality are the most important criterion people use to judge explanations

Explanation as Conversation

Based on interactive conversations. For time-constrained situation, minimise interactions and ensure visual explanations

Explanation Quality and Trust



Explanation Quality Factors

Measure	Note
User Satisfaction	- Clarity of the explanation - Utility of the explanation
Mental Model	- Understanding individual decisions - Understanding the overall model - Strength/weakness assessment - “What will it do” prediction - “How do I intervene” prediction
Task Performance	- Does the explanation improve the user’s decision, task performance? - Artificial decision tasks introduced to diagnose the user’s understanding
Trust Assessment	- Appropriate future use and trust
Correctability	- Identifying errors - Correcting errors - Continuous training

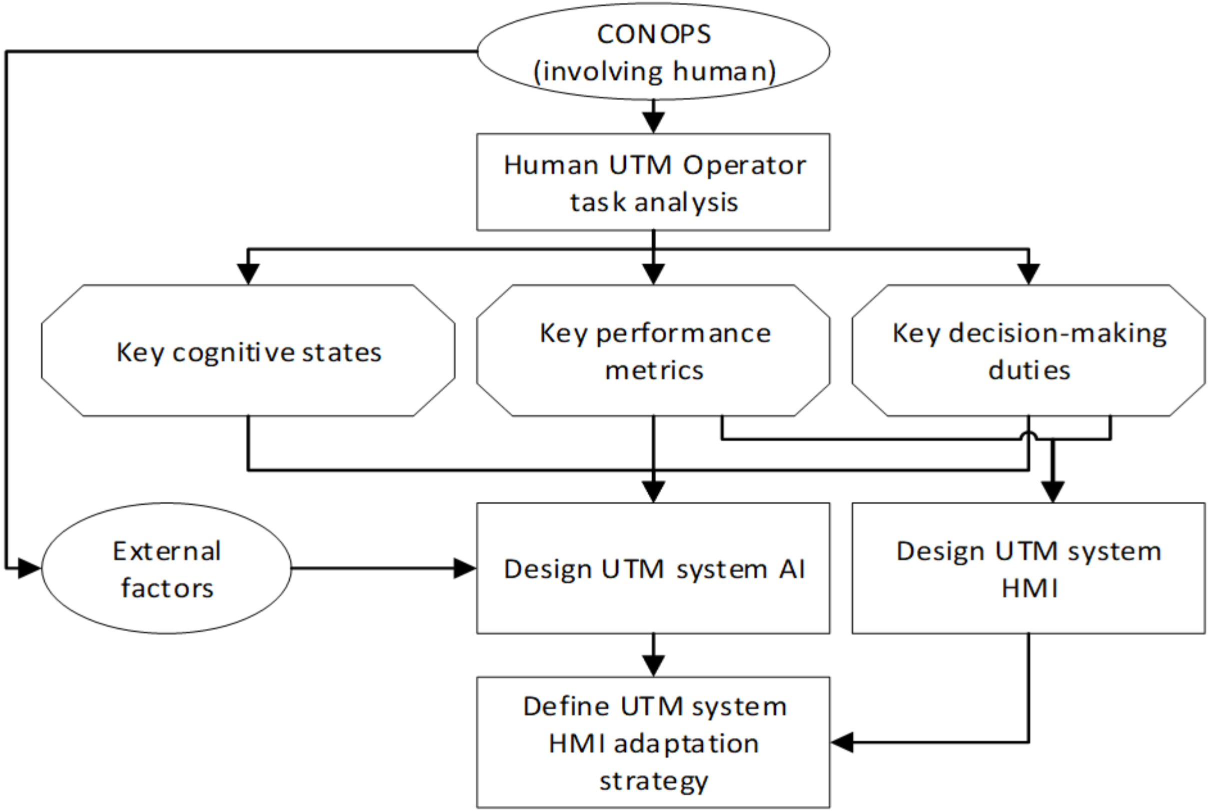
Trust of Automated Systems Test (TOAST)[1]

Trust	
System Understanding	**System Performance**
-I understand what the system should do -I understand the limitations of the system -I understand the capabilities of the system -I understand how the system executes tasks	-The system helps me achieve my goals -The system performs consistently -The system performs the way it should -I am rarely surprised by how the system responds -I feel comfortable relying on the information provided by the system
Reliance Intentions	
-I would recommend others to such system -If placed in a similar situation in real life, I would rely on such system	

1. H. M. Wojton, D. Porter, et al., "Initial validation of the trust of automated systems test (TOAST)," Journal of social psychology, vol. 160, pp. 735-750, 2020.

Intelligent ATM/UTM Human-Machine System Design Methodology

Intelligent ATM/UTM System Design Flow-Chart



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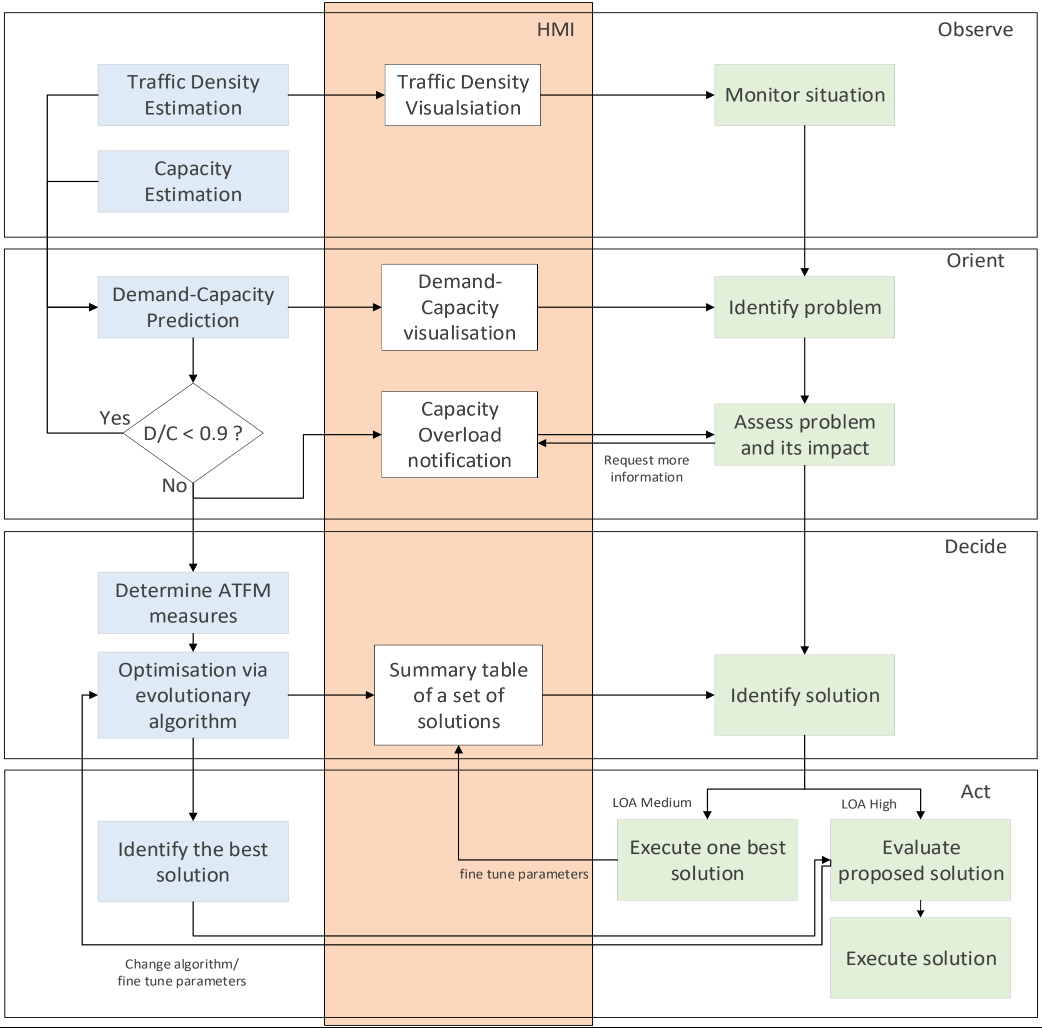
HMI Workflow

❖ Example human-machine workflow for airspace demand-capacity balancing:

- Blue blocks (left-hand side) represent the machine's tasks and sub-tasks
- Green blocks (right-hand side) represent the human's tasks and sub-tasks
- White blocks represent the HMI



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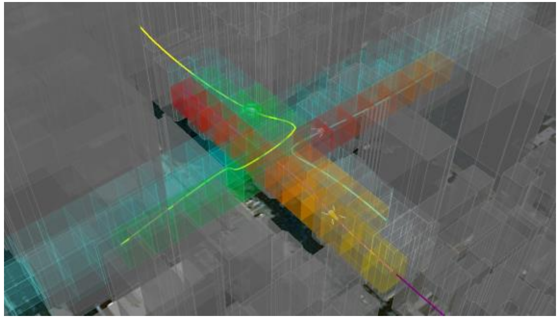
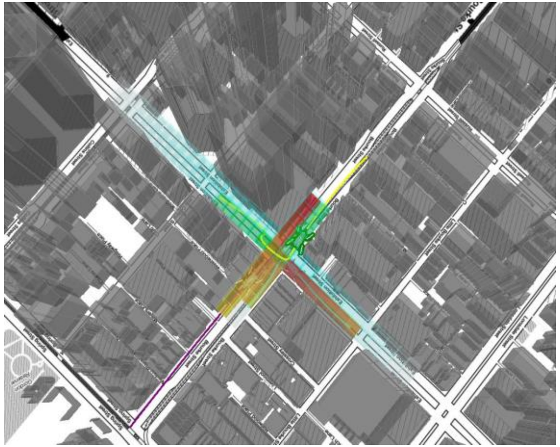
UTM HMI^2 Formats and Functions Components

	Medium support (Sheridan Level 5)	High support (Sheridan Level 7)
Information Visualisation	• Highlights information requiring users attention: current airspace capacity and demand • Notifies/Alerts user when a problem is identified: poor performance aircraft, airspace imbalance • Solution alternatives are presented	• Information and overlays (coloured airspace cell for capacity visualisation) are automatically filtered by level of importance • Notification/Alert and System's decisions are shown where users are able to veto
Airspace planning	• Automatically calculates airspace demand and CNS-based capacity for each sector • Automatically monitors aircraft CNS performance • Automatically calculates airspace cell dimension • Automatically calculates optimal airspace sector trade-off • Suggested set of solutions with recalculated demand-capacity and workload are prompted to users. Users are required to select the solution by themselves. Tuneable parameters can be adjusted by users • Automatically prompts users when there is a need for airspace re-sectorisation	• Automatically calculates airspace demand and capacity • Automatically checks aircraft CNS performance and suggests the most appropriate level of performance • Automatically calculates airspace cell dimension • Automatically calculates airspace sector optimization solutions • Only one solution with recalculated demand-capacity and workload is prompted to users. The parameters are automatically adjusted but users can request to do a manual adjustment • When required, automatically re-sectorises airspace sector while informs users for this change where users can veto





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IEEE Aerospace & Electronic Systems Society

1. MDTM and Intelligent Avionics Systems
2. Overview of AI/ML Techniques
3. Interactive HMI Systems
4. AI in ATM and UTM Systems
5. **AI in Sense and Avoid Systems**
6. Cyber Security Perspective in Intelligent/Autonomous Systems
7. Certification Aspects and Industry Perspectives
8. Wrap Up and Questions

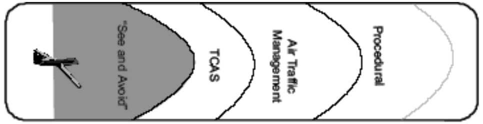
5. AI IN SENSE AND AVOID SYSTEMS

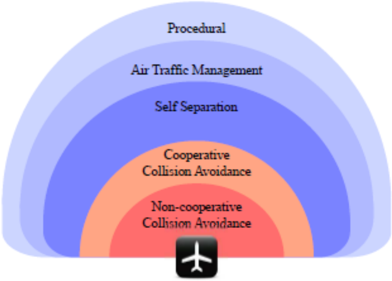
AI/ML in Sense and Avoid

- Definitions and Principles of Sense and Avoid
  - Topic addressed in a specific DASC Tutorial
- Overview of (some) recent AI/ML-based techniques and systems
  - Sensing
    - Optical, radar, acoustic
  - Decision making
- Perspectives and challenges

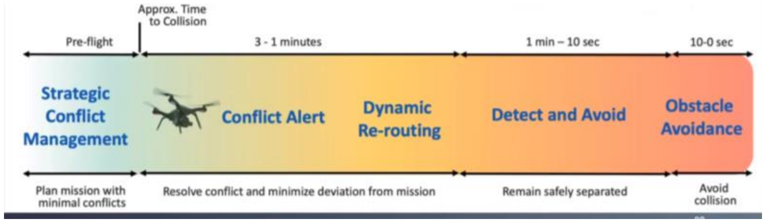
Principles of Sense and Avoid

- Sense and Avoid / Detect and Avoid: one of the major roadblocks that have hindered civil operations, and thus as a key point for UAS integration
- Starting from the need of “equivalent level of safety” with respect to manned aircraft, a significant evolution has been experimented… actually leading to different DAA “frameworks”
- Useful distinction in SAA analyses
  - SAA for “large” UAS in controlled airspace (“traditional” ATM environment)
  - SAA at very low-altitudes in minimally or un-controlled airspace (“small” UAS, U-Space, UTM, UAM)





(From: P. Angelov (Ed), *Sense and Avoid in UAS Research and Applications, 2012)*



(NASA UTM Technical Interchange Meeting, 2021)

Principles of Sense and Avoid - Tasks

- Main SAA tasks:
  - Sense - methods for surveilling the environment around the aircraft
  - Detect - analysis to determine if there are aircraft or obstacles in that environment, and to evaluate if they are, or will be, a threat to the UA
  - Avoid - evaluation of the actions that the UA should take to reduce or remove the threat of the detected aircraft or obstacle.

(Note: while there is a general agreement on the tasks to be carried out, terminology may vary)

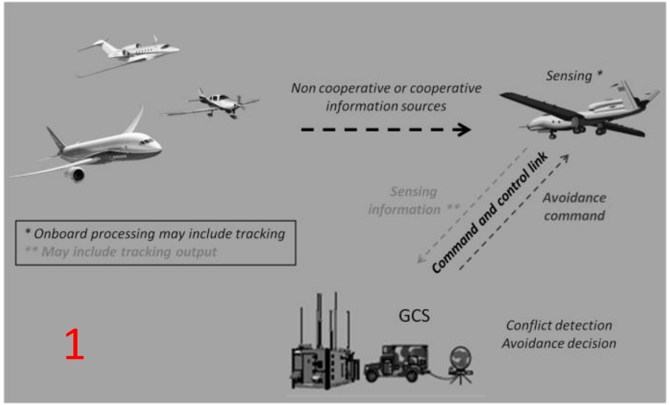
Principles of Sense and Avoid - Taxonomy

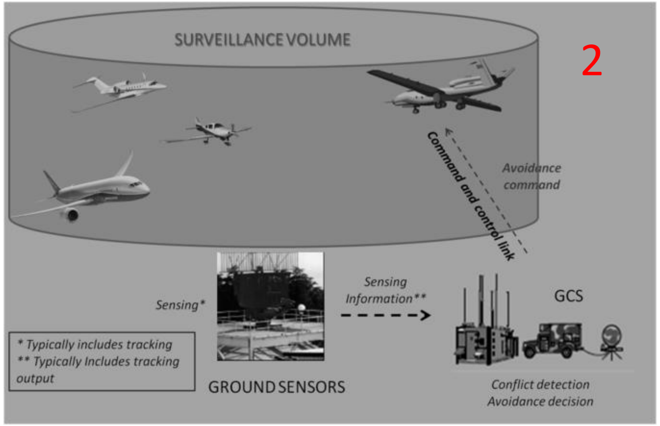
- These three fundamental tasks of an SAA system can be implemented in different ways, giving rise to several architectural and technical solutions. These solutions can then be classified using different taxonomies

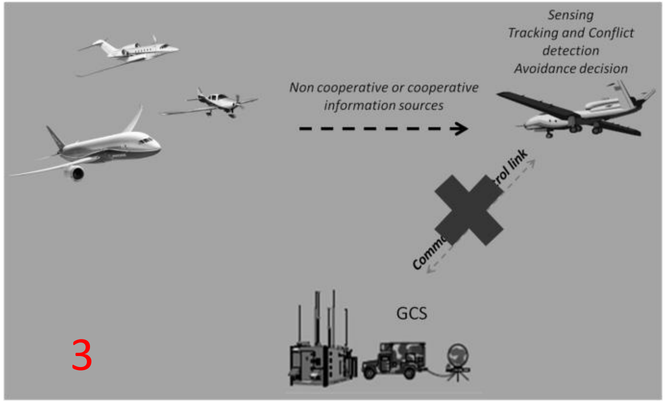
- A general approach for classification that involves all three parts is based on the physical location of information sources and processing/decision making centers

- These elements can be based onboard the UA, or be located on the ground

Principles of Sense and Avoid - Taxonomy

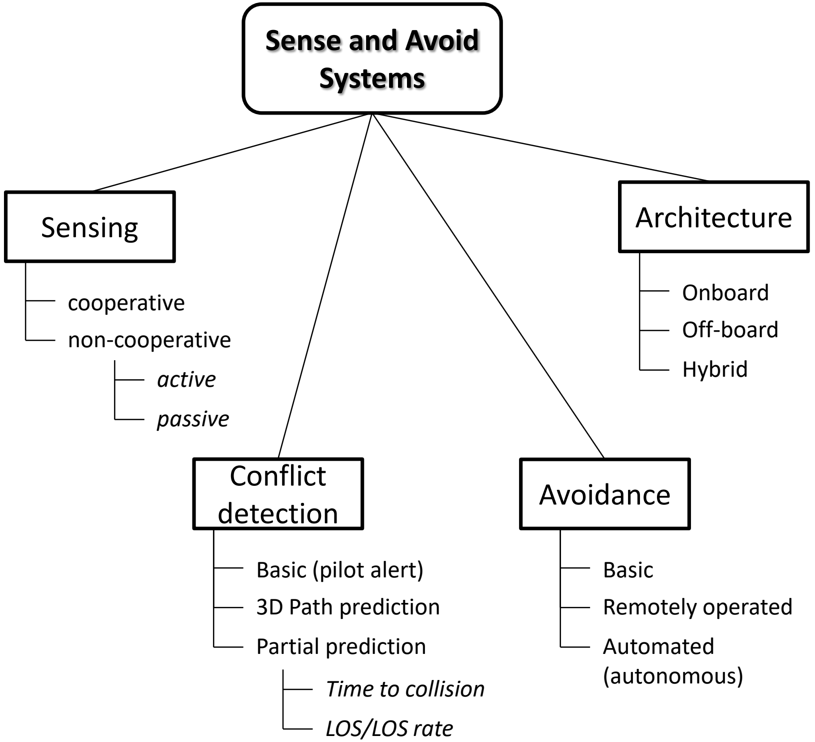






Principles of Sense and Avoid - Taxonomy

❖ General SAA Taxonomy



(Fasano et al., IEEE AES Magazine, 2016)

AI/ML in SAA

- Sensing and decision making solutions based on conventional approaches have been developed in the last years for the different SAA tasks

- Recently, AI/ML-based approaches have been introduced which are having a significant impact
  - Sensing
  - Decision making

- Solutions have been developed by the research community and are available at industrial level

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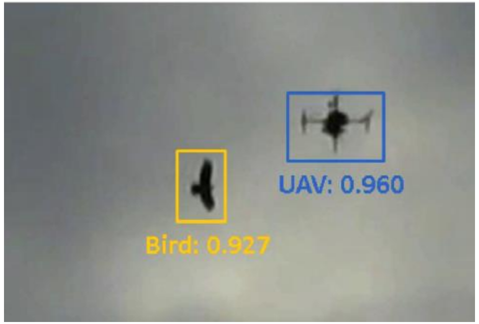
AI/ML in SAA – Sensing

- Most applications related to sensing concern the adoption of AI techniques within visual architectures
  - Detection and/or classification
    - Tight link with counter UAS applications
    - Classification can be used to confirm detection
  - Ad hoc or customized convolutional neural networks
    - Trained on synthetic and/or experimental data
  - Detection outputs in terms of object angles, and range when the number of pixels allows it
  - Hybrid approaches combining conventional and AI-based detection concepts
  - Some examples are described in the next slides



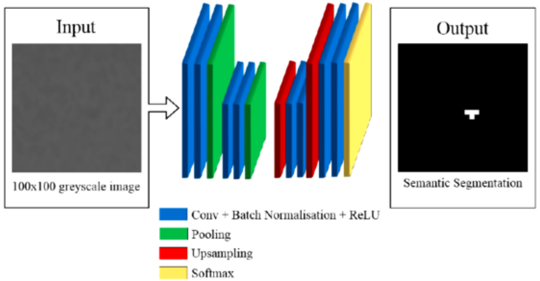
(*)

*Schuman et al., Deep Cross-Domain Flying Object Classification for Robust UAV Detection, IEEE AVSS 2017

AI/ML in SAA – Visual Sensing

- Popular deep learning-based detectors (such as YOLO – You Only Look Once) widely adopted in the visual SAA literature. Recent examples:
  - Lombaerts et al. (*) exploit a YOLO v3 detector trained with synthetic images to provide visual detection within a multi-sensor-based SAA solution
  - CNN-based solutions are often integrated within a multi-stage detection pipeline as in the work by James et al. (**), where long range experimental data are exploited
  - Images from flight tests are also used to train YOLO detectors in (***), where different networks are trained for different image regions (above and below the horizon)

(*)



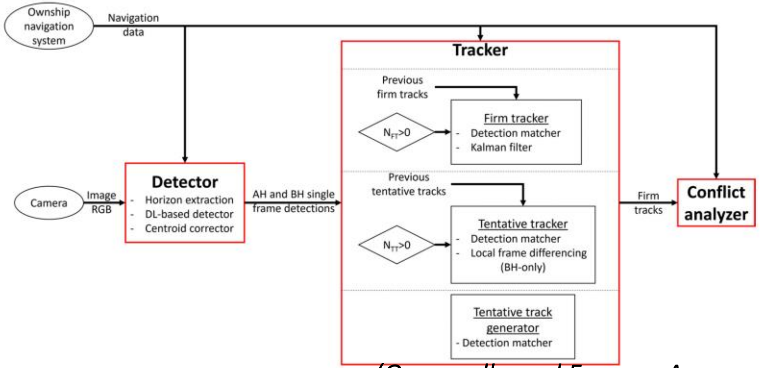
* Lombaerts et al. Adaptive Multi-Sensor Fusion Based Object Tracking for Autonomous Urban Air Mobility Operations, AIAA Scitech 2022

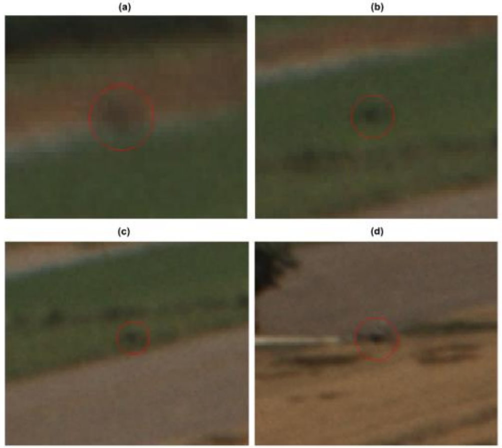
** James et al., Learning to detect aircraft for long range, vision-based sense and avoid systems, IEEE Robotics and Automation Letters, 2018

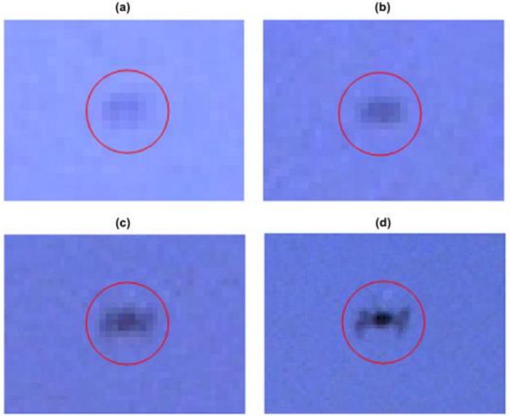
*** Opromolla and Fasano, Visual-based obstacle detection and tracking, and conflict detection for small UAS sense and avoid, Aerospace Science and Technology 2021

AI/ML in SAA – Visual Sensing

- AI/ML has demonstrated a significant potential as an appearance-based technique which can be tailored to different scenarios (known issues of motion-based detection)
- AI/ML techniques are typically integrated in a multi-stage processing architecture
  - Need to improve the missed detection / false alarm trade off
  - Obstacle tracking and kinematics estimation
- Multi-stage processing can combine traditional and ML-based algorithms
- Many choices are available, e.g. concerning the detection logic, the neural network architecture and characteristics, the training dataset, etc.







(Opromolla and Fasano, Aerospace Science and Technology, 2021)

AI/ML in SAA – Example Commercial Solutions

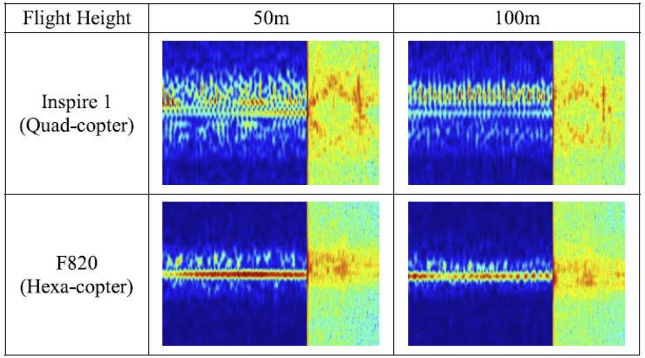
- ❖ Emphasis on detection and tracking of manned aircraft
  - Interest in visual obstacle detection to improve safety figures of general aviation
- ❖ Very large datasets for training, based on synthetic and flight data
- ❖ Airborne visual detection and tracking as test case in EASA – Daedalean project “Concepts of Design Assurance for Neural Networks II” (CoDANN II) aimed at examining the challenges posed by the use of neural networks in aviation
  - https://www.easa.europa.eu/newsroom-and-events/news/easa-publishes-second-joint-report-learning-assurance-neural-networks

(https://www.irisonboard.com/casia/)

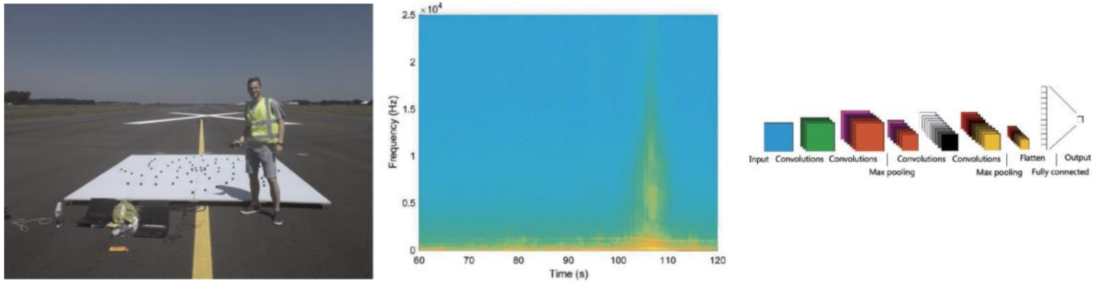
(https://daedalean.ai/products/detection)

AI/ML in SAA – Radar and Acoustic Sensing

- Detection and classification based on raw sensing data
  - E.g., classification exploiting Doppler data
- CNNs investigated as technique for object detection based on microphone array data



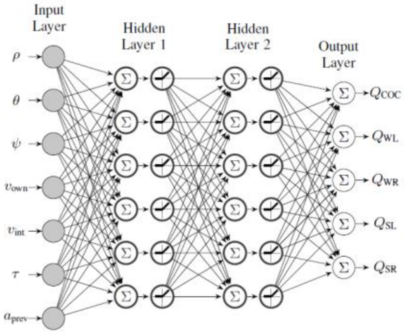
(Kim et al., Drone Classification Using Convolutional Neural Networks With Merged Doppler Images, IEEE GRSL 2016)



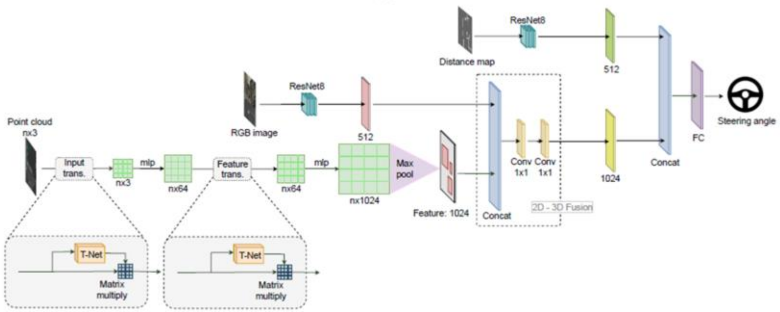
(Wijnker et al., Hear-and-avoid for unmanned air vehicles using convolutional neural networks, Int. J. of Micro Aerial Vehicles, 2021)

AI/ML in SAA – Decision Making

- ❖ Deterministic and stochastic approaches for conflict detection and definition of avoidance maneuvers, e.g. DAIDALUS, ACAS-Xu
- ❖ Recent flurry of research on AI-based decision-making
  - Neural networks to compress look-up tables in ACAX-sXu
  - Reinforcement learning
  - End-to-end AI-based solutions
  - Many recent approaches are relevant to Micro Aerial Vehicles and agile flight in cluttered environments



(Julian et al., Deep neural network compression for aircraft collision avoidance systems, JGCD 2019)



(Nguyen et al., Autonomous navigation in complex environments with deep multimodal fusion network, IEEE IROS 2020)

AI/ML in SAA – Perspectives and Challenges

- AI/ML approaches represent well assessed techniques, especially considering visual sensing
- Research perspectives and upgrades concern the entire SAA pipeline
- Dataset availability
  - Experimental tests in relevant environments
  - Challenges
- Combination of real and synthetic data
  - Generalization, performance/computational trade-offs
  - Dataset for new operating environments
- Certification
  - dataset characterization
  - stochastic nature of non cooperative sensing
  - multi-stage processing pipelines

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6. CYBER SECURITY PERSPECTIVE IN INTELLIGENT/AUTONOMOUS SYSTEMS

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Security - *Protecting Operations/Applications, Protecting Communications, Protecting Data*

Cybersecurity

- **Privacy** – preventing eavesdropping
- **Authentication** – proof that a person or message is what it purports to be
- **Authorization** – allowing only certain access or behaviors

[Physical] Security

- Often a lack of physical security is the easiest place to attack the system. Physical safeguards can allow vulnerability by access.

Cyber Physical Systems

- Significant for avionics.
- Trustworthy AI?

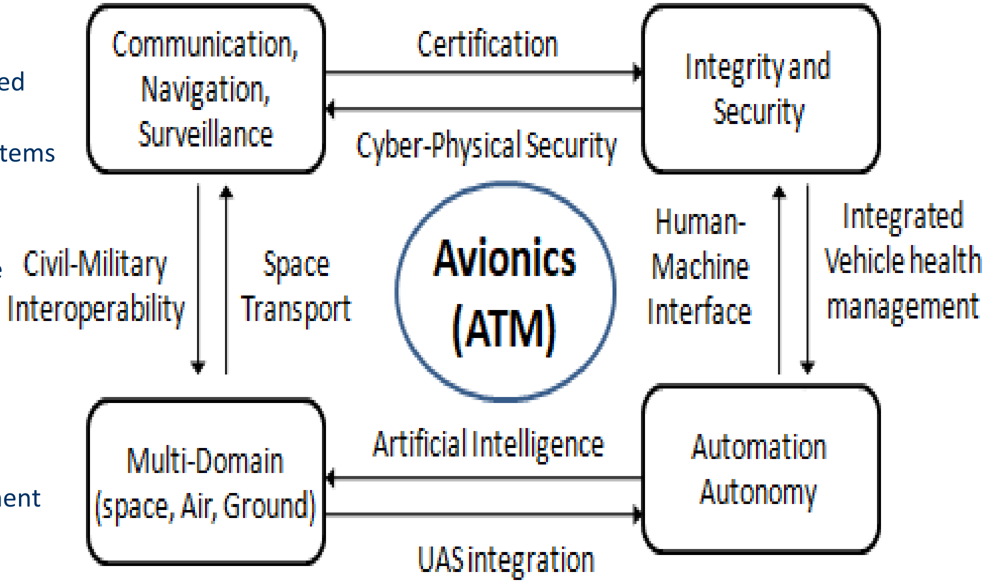
Avionics Framework

1) **Communication, Navigation and Surveillance for Air Traffic Management (CNS/ATM):**
   - Evolution of the certification framework for integrated CNS +Avionics
   - Civil and military airspace integration and CNS+A systems interoperability;

2) **Avionics Systems Integration and Security:**
   - Fault-tolerant avionics design and Integrated Vehicle Health Management (IVHM) systems;
   - **Cyber-physical security of avionics and CNS/ATM systems;**

3) **Multi-Domain Avionics (MDA):**
   - UAS integration in all classes of airspace and UTM;
   - Avionics for space transport, Space Traffic Management (STM) and intelligent satellite systems;

4) **Automation and Autonomy:**
   - Development of Avionics Human-Machine Interfaces and Interactions (HMI^2); and
   - Artificial Intelligence (AI)/Machine Learning (ML) in avionics systems design and operations (including the challenges of certification and the role of explainable AI).



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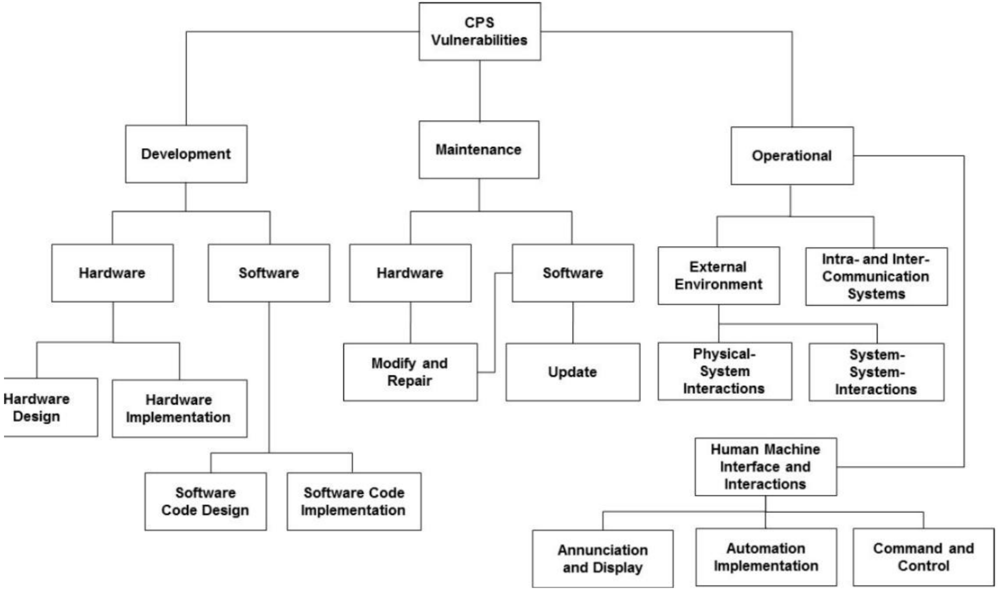
Cyber Awareness for Avionics

- Networks – The various fixed and wireless ground and air constructs that enable the delivery of information to and from the aircraft, ground, and space . Examples include air traffic management (ATM) with the Internet Protocol addresses.
- Electronics – The on-board avionics is subject to internal and external performance requirements against size, weight, and power requirements. Examples include the battery power and sensors supporting engine control.
- Software – As modern systems are operating with large data, the control and run-time operations require sophisticated methods for efficiency. Examples include integrated modular avionics (IMA)
- Analytics – Availability, confidence, and processing of systems is determined by the various standards in development and deployment designs that meet effectiveness criteria. Examples include the compliance and mandates for GPS and ADS-B.
- Communication – A key aspect of cyber is the coordination of the signals that are transferred. For air operations, the wireless signals from the space and air pathways need to operate reliably. Examples include performance-based navigation signals for coordinating flight.
- Data–On the physical networks and communication pathways, the data and protocols should provide information with integrity and consistency. Examples include System Wide Information Management (SWIM) capability for real-time support for collision avoidance.

Vulnerabilities

❖ STRIDE is an abbreviation for various known attack paths, one standard approach to assess vulnerabilities (MSN):

- Spoofing Identity
- Tampering with Data
- Repudiation
- Information Disclosure
- Denial of Service
- Elevation of Privilege



Key Standards

- ARINC 429 – Predominant (two wire) data bus and protocol supporting avionics 100 kbps LAN on commercial and transport aircraft originating in late 1970s (also MIL-STD 1553)
- ARINC 664 part 7 (also AFDX). Airbus patented full duplex extended ethernet (aka 802.3) for safety critical apps with deterministic QoS for datalink layer and higher. 10 Mbps and up. (~ year 2000)
  - Cyber physical vulnerabilities – IFE, access above passengers' level (avionics bay)
- DO-178C - Software Considerations in Airborne Systems and Equipment Certification, is the standard that directs software certification for airborne systems for the commercial segment.
  - Needs to evolve
- RTCA DO-326A, Radio Technical Commission for Aeronautics airworthiness security process certification (also ED202A)
- RTCA DO-356, Airworthiness security methods and considerations
  - No groundworthiness and no culture of applying certifications/regulatory there

AI in Aeronautical Systems

- SAE WG 34 reviews current aerospace software, hardware, and system development standards used in the certification/approval process of safety-critical airborne and ground-based systems, and assesses whether these standards are compatible with a typical Artificial Intelligence (AI) and Machine Learning (ML) development approach.

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From the Editors of the Special Issue on Avionics Systems: Future Challenges

Roberto Sabatini, Kathleen Kramer, Aloke Roy, Erik Blasch, Giancarmine Fasano

Roberto Sabatini

Kathleen Kramer

Aloke Roy

Erik Blasch

Giancarmine Fasano

Avionics systems are experiencing a rapid evolution fuelled by advances in Communication, Navigation and Surveillance (CNS) technologies, and the widespread adoption of Artificial Intelligence/Machine Learning (AI/ML) both on board aerospace vehicles and in ground-based decision support systems. These technologies have the potential to transform the future of aviation and spaceflight, but their successful development and deployment need to simultaneously address safety, efficiency, security and sustainability requirements.

Technological advances of Unmanned Aircraft Systems (UAS) and the maturation of UAS Traffic Management (UTM) and Urban Air Mobility (UAM) concepts offer new promising business opportunities, but also present unique technical and operational challenges, with the need to assess and properly manage the emerging social, economic and environmental impacts. The increasing dependency on connectivity, automation and autonomy exposes avionics and Air Traffic Management (ATM) systems to new vulnerabilities, and requires an integrated cyber-aware approach to achieve cyber-resilience. On the other hand, the new exciting perspectives offered by the space economy have enormous potentials, but require new multi-disciplinary approaches to space mission design and new cyber-physical architectures supporting space domain awareness and Space Traffic Management (STM).

Conceptual evolution of multi-domain traffic management.

While large-scale research and innovation initiatives are reshaping the future of the aerospace sector, it is now clear that avionics systems are becoming cyber-physical and progressively evolving into a variety of autonomous, intelligent and adaptive human-machine systems. Cognizant of the challenges that future avionics systems must overcome, this special issue was developed to span a wide range of topics and tackle, more specifically, the key technical challenges and solutions emerging in the low-level ATM context, including the evolution of CNS systems (and associated performance metrics), and the need for efficient AI solutions in next generation avionics systems. It also aims to illustrate the current state-of-research and educational best practices by bringing together the different viewpoints of experts in the relevant domains and includes discussion on the challenges that must be addressed to support further advances in industry-focused research and innovation.

The papers published in this Special Issue discuss aspects relevant to communications and navigation (Maurer et al.: *Flight Trial Demonstration of Secure GBAS via the L-band Digital Aeronautical Communication System*), augmented human pilot awareness (Ernst et al.: *Virtual Cockpit Instruments - How Head-Worn Displays Can Enhance the Obstacle Awareness of Helicopter Pilots*), impact of approach technologies on regional airports (Dautermann et al.: *Benefits for Greek Regional Airports Through Innovative Approach Technology using an LPV to GLS Converter*), and the perspectives and challenges of avionics education (Majid et al.: *Restructuring Avionics Engineering Curricula to Meet Contemporary Requirements and Future Challenges*).

This special issue would not have been possible without the collective effort of the AESS Avionics Systems Panel (ASP) members, and the high-quality submissions produced by the international avionics research community. The ASP addresses all areas of avionics research and innovation supporting commercial, military and general aviation operations. In particular, the ASP works to identify industry-focused research opportunities, and seeks to create new stimulating forums for discussion, education and dissemination. Despite the challenges caused by COVID-19, the completion of this special issue has shown the success of the panel in working together and coordinating our efforts. It has provided an opportunity for the ASP to contribute significantly to the development, dissemination and rapid uptake of these technologies, as well as informing the evolution of avionics industry standards and educational best practices. So, we would like to thank each and every author and reviewer for their important contributions and encourage your participation and contributions to future special issues.

1. MDTM and Intelligent Avionics Systems
2. Overview of AI/ML Techniques
3. Interactive HMI Systems
4. AI in ATM and UTM Systems
5. AI in Sense and Avoid Systems
6. Cyber Security Perspective in Intelligent/Autonomous Systems
7. Certification Aspects and Industry Perspectives
8. Wrap Up and Questions

7. CERTIFICATION ASPECTS AND INDUSTRY PERSPECTIVES

Objectives of the Aviation Standards

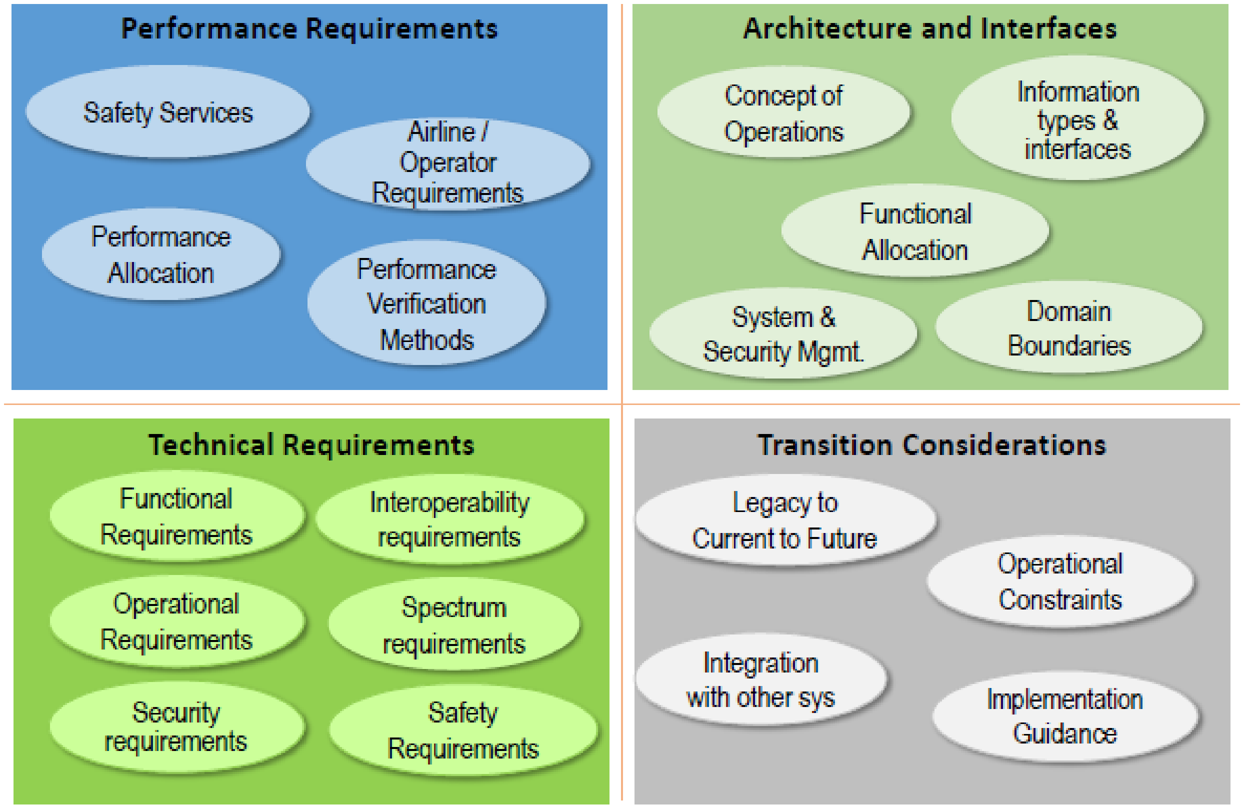
- Ensure safety of life and safety of operations
- Provide globally uniform, equitable services to the aircraft while assuring sovereignty of the airspace
- Enable collaborative surveillance, navigation and communication for efficient airspace management
- Ensure minimum acceptable performance, quality of information, reliability and predictable (deterministic) behavior of systems and components
- Ensure availability of interoperable and line-replaceable parts and services for improved operational costs over long, life-cycle of systems
- Guarantee airworthiness and dispatchability of aircraft for safety

Aviation Standard Bodies

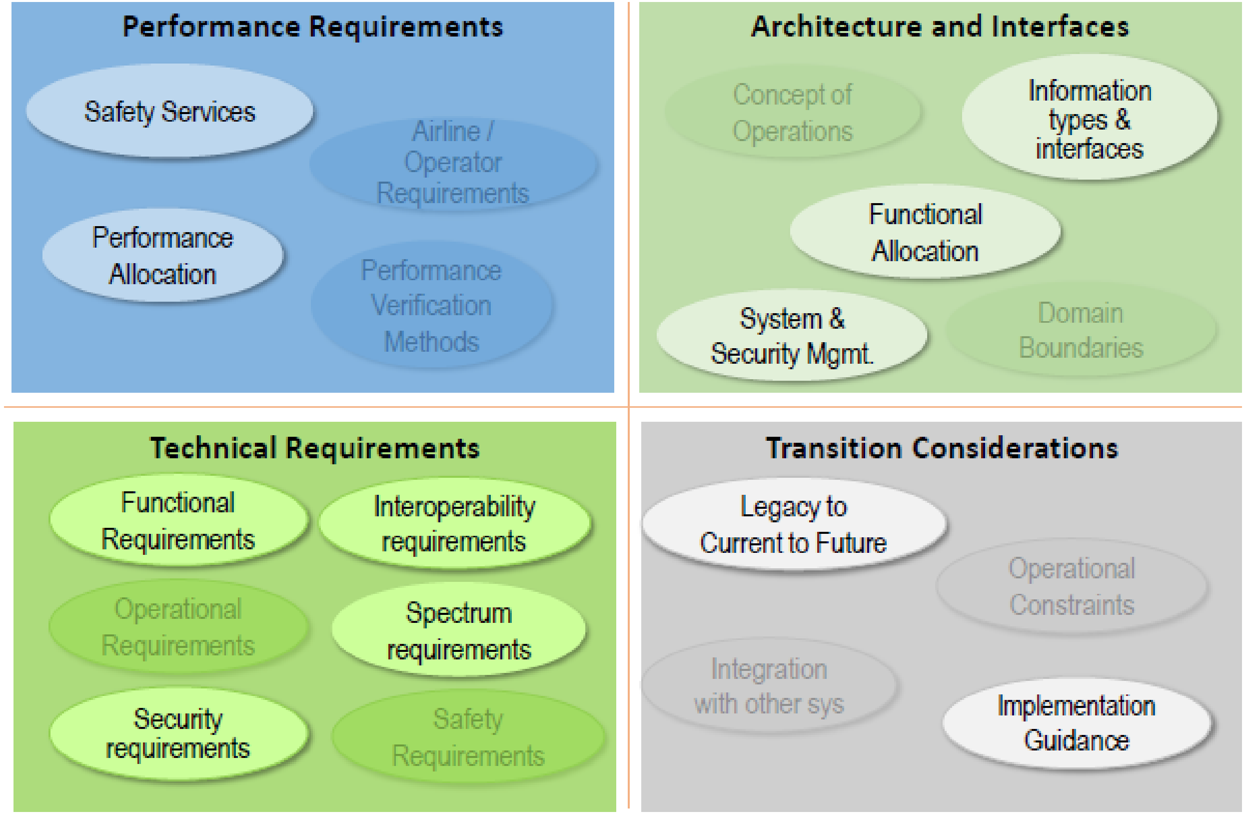
ICAO	RTCA / EUROCAE	AEEC
• Established by the 1944 treaty at Chicago Convention • Operates as a United nations constituency • Caters to prime objectives of global interoperability, uniformity & equitable service of aircraft over all UN countries • Defines system functional and interoperability requirements	• Specifies services, system & avionics concept of operations, safety and performance requirements • Specifies methods for requirements verification • FAA uses RTCA standards for US airworthiness certification • EASA/Europe uses EUROCAE standards for the same purpose • Other countries mostly follows either RTCA or EUROCAE standards	• Established by aircraft operators to specify avionics form, fit and functions supporting airline operations • Primary goal is for avionics vendors and aircraft manufacturer to have uniform equipment standards for line replacement

Three levels of organizations governing different aspects of aviation standards to achieve the overall objectives

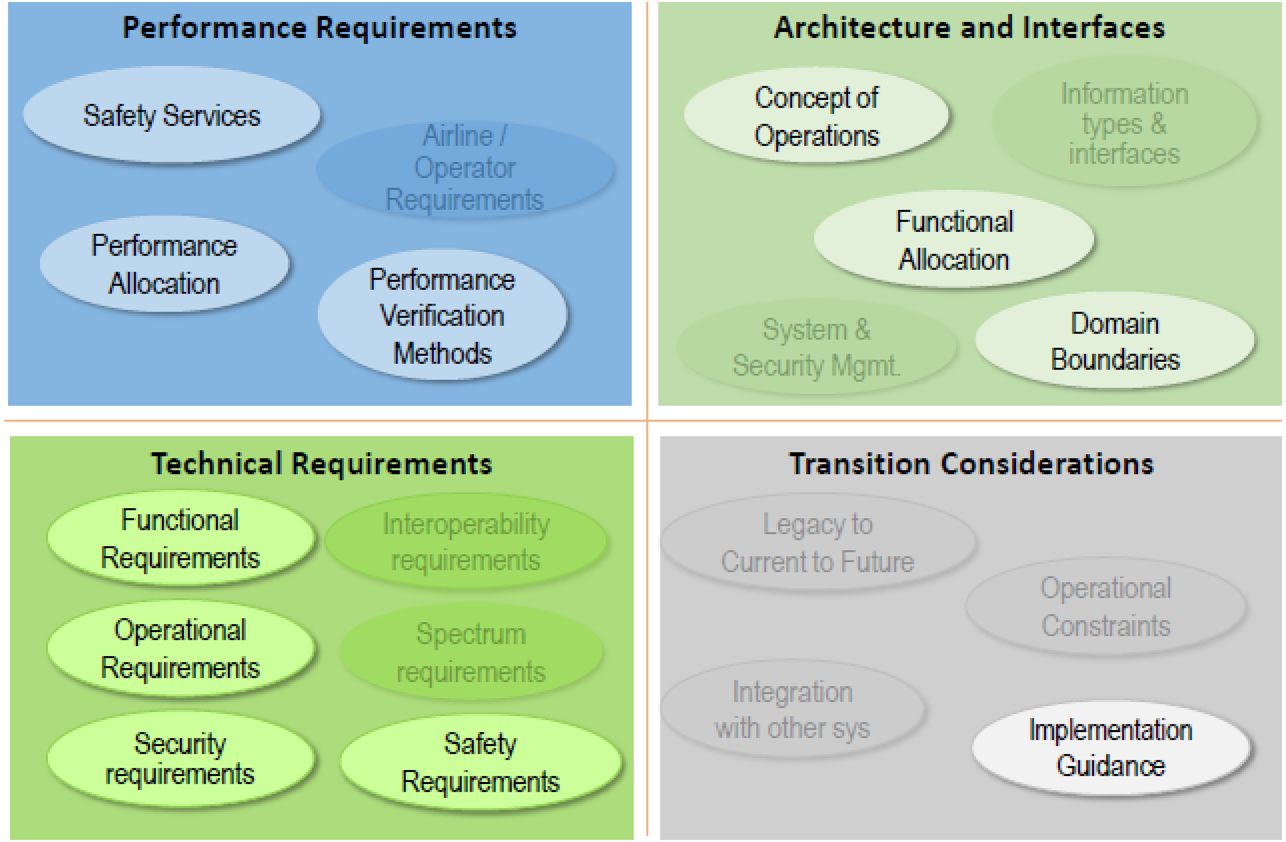
Illustration of Areas Covered by Standards Organizations



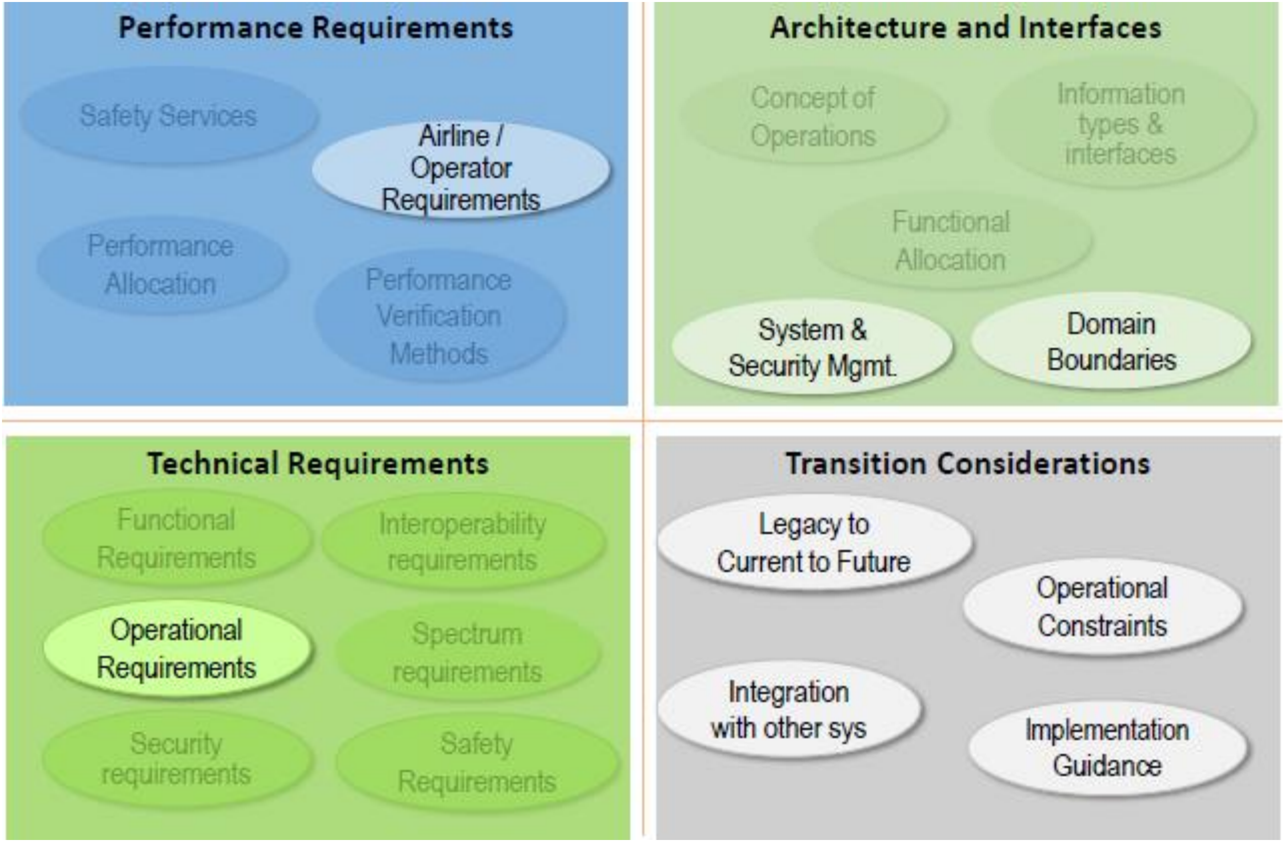
Elements Covered by ICAO Standards



Elements Covered by RTCA/EUROCAE Standards



Elements Covered by AEEC Standards



Relationship to Other Standards

- Aviation industry typically developed their own standards, until recently
  - Systems and capabilities required for aviation were not used in the commercial or consumer world
  - Areas where capabilities overlapped between aviation & commercial, aviation requirements were lot more stringent due to safety of life considerations
  - Operational requirements & constraints for aviation are much tighter than commercial / consumer systems
  - Aviation systems has 20+ years of operating life cycle and aviation systems take a long time to upgrade/replace. This is contrary to consumer systems where business needs & innovations drive obsolescence in couple of years
- Technology maturity for commercial autonomy (UAS, self-driving cars, etc.); analytics; and high-volume information exchange, storage and computation has increased the prospect of leveraging commercial standards for aviation:
  - Several recent aviation standards have been based on IEEE, SAE, NIST and ISO specifications
  - A current ICAO goal is to leverage commercial standards
    - Where feasible, use commercial standards directly by reference

Challenges for AI Standardization in Aviation

- A core premise of AI is learning where the system learns and adapts its behavior to achieve the optimum, desired outcome
  - The AI system response for a given set of excitations in a given environment are not necessarily the same (i.e., deterministic, unique and predictive)
    - In AI System response, there is always a delta error from the target response
    - An AI System learns from every encounter to reduce & optimize the error delta
- For aviation systems, the regulator expectation is that for every scenario, i.e., a set of excitations in a given environment, the expected system response MUST be the same
  - The safety of life risks and liabilities associated with an uncertain outcome is too large for aviation
- An approach for AI standards and certification could be to provide an acceptable error tolerance for each expected system response
  - Need to have high confidence (10-6to10-9) or lower probability that response will be outside the tolerance)
  - Standards MUST also define a fail-safe option, to mitigate unexpected AI system behavior

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8. WRAP UP AND QUESTIONS

Wrap Up

- ❖ AI is a key enabler of MDTM and associated avionics systems evolutions
- ❖ The ongoing transformation embraces:
  - Low-level ATM for AAM (regional and urban air mobility)
  - UAS access to all classes of airspace (supported by UTM)
  - Atmospheric flight above FL600
  - Orbital and suborbital spaceflight
  - DSS for Comms, Nav and Surveillance/EO Services

Wrap Up

- Higher levels of automation and AI are essential to cope with the increased traffic complexity (trusted autonomous operations)
- Trusted autonomy must address predictability and integrity challenges (both in AI-based avionics systems and in closed-loop human-machine systems)
- Fully integrated and interoperable CNS+A systems require an evolution of present day certification standards, specifically addressing safety and security of AI-based cyber-physical systems

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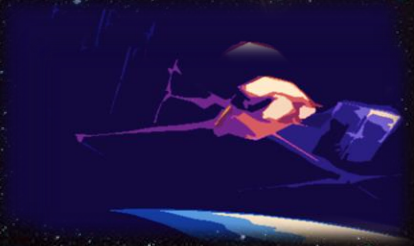
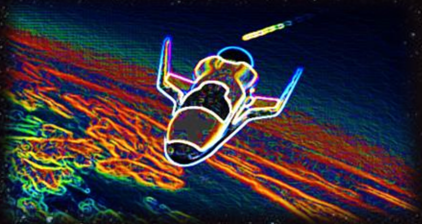
Questions and Discussion





Thank you!

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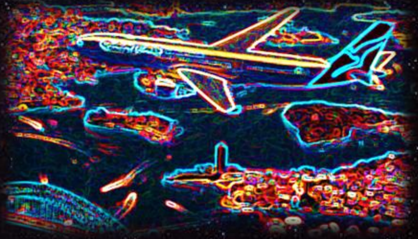
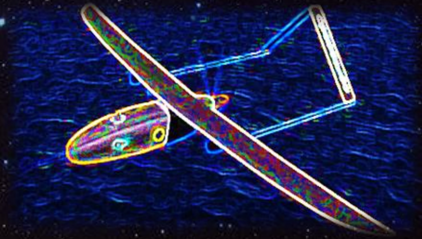
If you wish to discuss how you can contribute to the ASP activities please send me an email at: roberto.sabatini@ku.ac.ae

You can find additional information about the ASP at: https://ieee-aess.org/tech-ops/avionics-systems-panel-asp





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