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DASC 42nd
Digital Avionics Systems Conference
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Intelligent Cyber-Physical Systems for Integrated Air and Space Transport Operations

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

ASP
AESS IEEE Aerospace & Electronic Systems Society

Avionics Systems Panel

Tutorial Outline

1. Introduction to the IEEE AESS Avionics Systems Panel	Rob (11:30)
2. Air and Space Transport Innovation Ecosystem	Alex (11:50)
3. Autonomous Navigation and Guidance Systems	Irfan (12:10)
4. Advances in Human-Machine Systems	Erik (12:30)
5. Sense-and-Avoid Technologies	Giancarmine (12:50)
6. Ontologies for Space Domain Awareness	Carlos (13:10)
7. Cyber Security Challenges	Kathleen (13:30)
8. Certification Challenges and Industry Perspectives	Aloke (13:50)
9. Wrap Up and Questions	All (14:10)

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Introduction to the IEEE AESS Avionics Systems Panel

About the Avionics Systems Panel

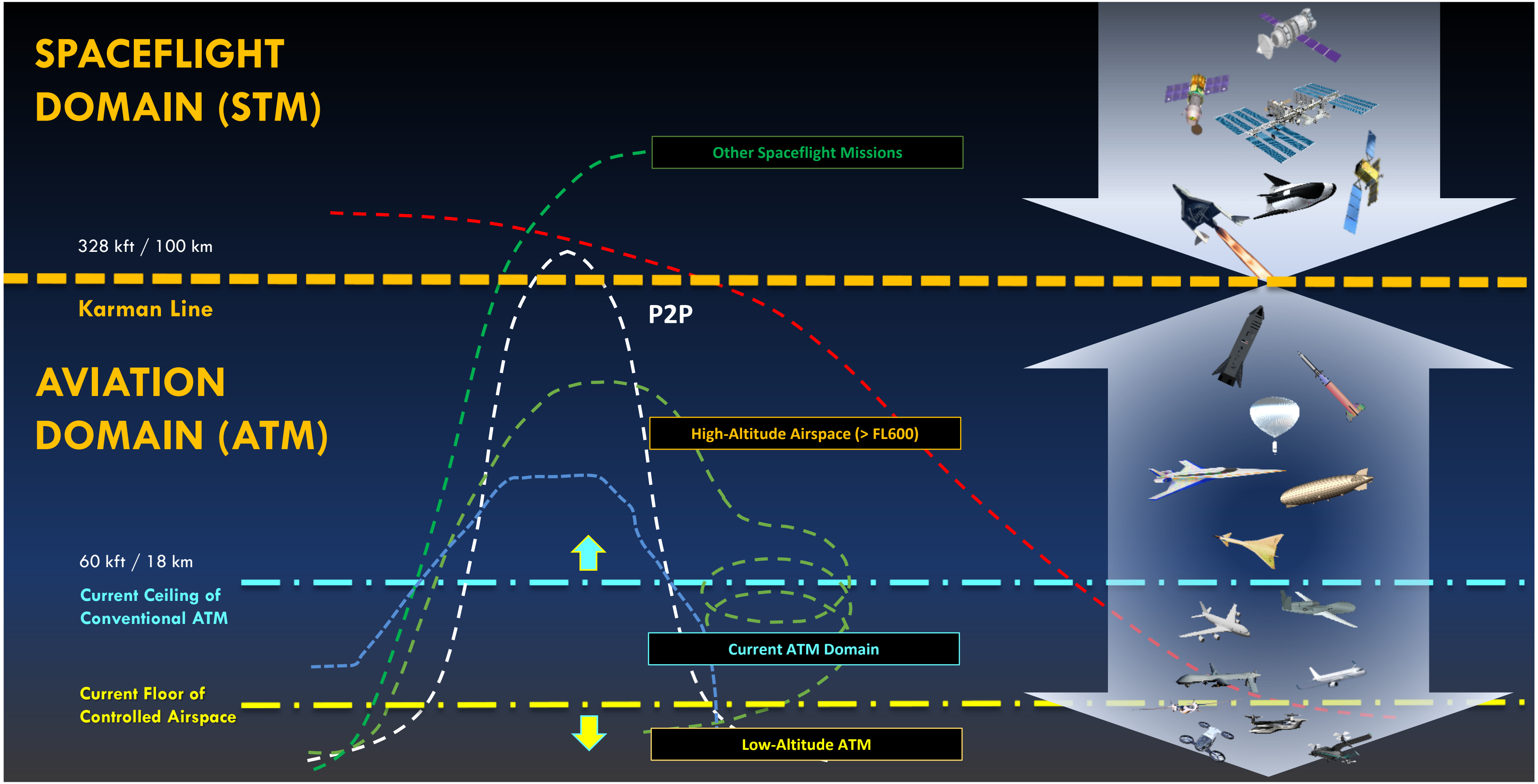
The Avionics Systems Panel (ASP) is composed of IEEE Associate or higher level members who are representatives of industry, government laboratories, educational institutions and professional societies, and who are active in the domain of Avionics. Its main objectives are:

- Promote and support collaborative research initiatives in the domain of Avionics
- Develop and disseminate high-quality IEEE publications in the domain of Avionics
- Promote and support educational activities in the domain of Avionics
- Sustain and oversee the programs of the IEEE/AIAA Digital Avionics Systems Conference (DASC) and the Integrated CNS Conference; and contribute to other conferences and dissemination initiatives
- Manage the nomination and selection of candidates for IEEE Awards in the domain of Avionics
- Encourage submission of nominations for IEEE Fellows and Senior Members in the domain of Avionics
- Recommend and support new IEEE avionics standards or revisions of existing standards

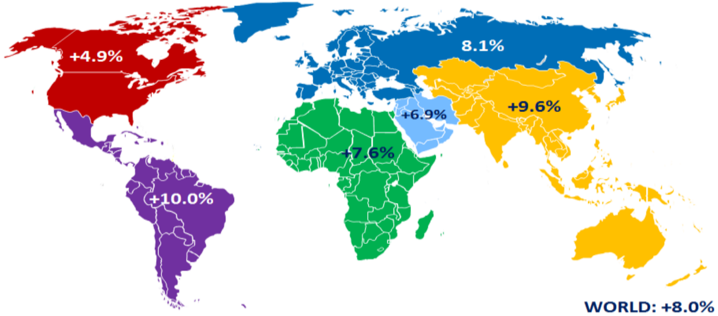
Ongoing Panel Activities

- The ASP relies on a diverse community of experts (currently from US, EU, UK and Asia) and holds regular monthly meetings addressing the following topics:
  - **Research and Innovation (R&I).** Participation to NASA UTM and AAM activities; connections/collaborations with NextGen in the US and SESAR in the EU; other national and international Avionics/ATM/UAS programs; Collaboration with JARUS, ICAO and IFATCA (UAS/UTM)
  - **Publications.** Editorial Committees and Reviewer contributions to the Transactions on Aerospace and Electronic Systems and AESS Systems Magazine; Special Issues on Avionics, UTM/UAM and Space Systems; joint journal publication initiatives (e.g., Avionics Systems for Trusted Autonomy, Multi-Domain Traffic Management, Avionics Education)
  - **Conferences.** IEEE/AIAA Digital Avionics Systems Conference (DASC); IEEE/AIAA Integrated Communications, Navigation and Surveillance Systems (ICNS) Conference; IEEE/AIAA/PHM Aerospace Conference; other conferences
  - **Education Activities.** AESS Distinguished Lecturers/VDL Program updates; Webinars, Tutorials and Short Course initiatives
  - **Industry Engagement and Standards.** UAS/Autonomy, AI, V2X Communications, Cyber Security, etc.
- Joint meetings with the Cyber Security Panel are held on a bi-monthly basis

Evolving Flight Domains

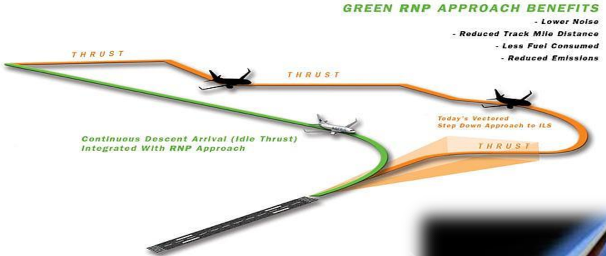


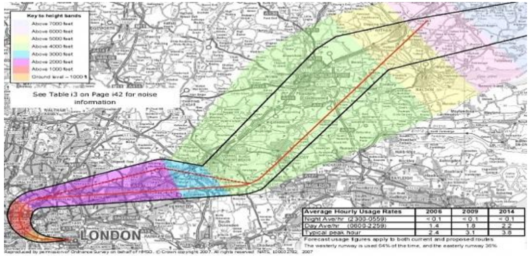
Current Industry Challenges

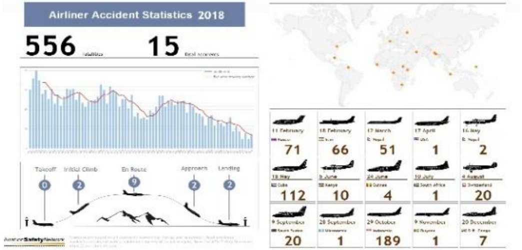


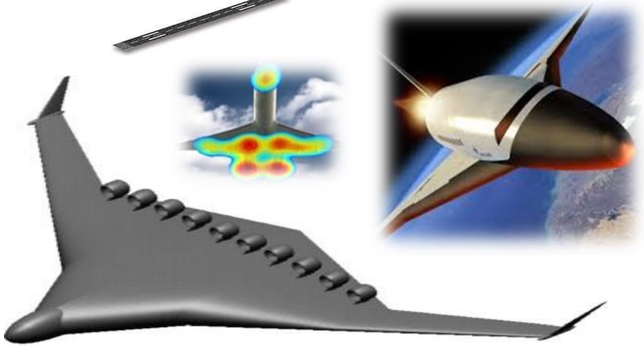
- **Enhancing <u>Safety, Efficiency and Environmental Sustainability</u> of air and space transport to support the anticipated growth of the sector**

- **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)
  - Development and rapid uptake of low-emission technologies (gaseous and noise emissions)
  - Improved efficiency and capacity of airports and spaceports (digitalisation/multimodal)
  - Solutions for enhanced safety and security

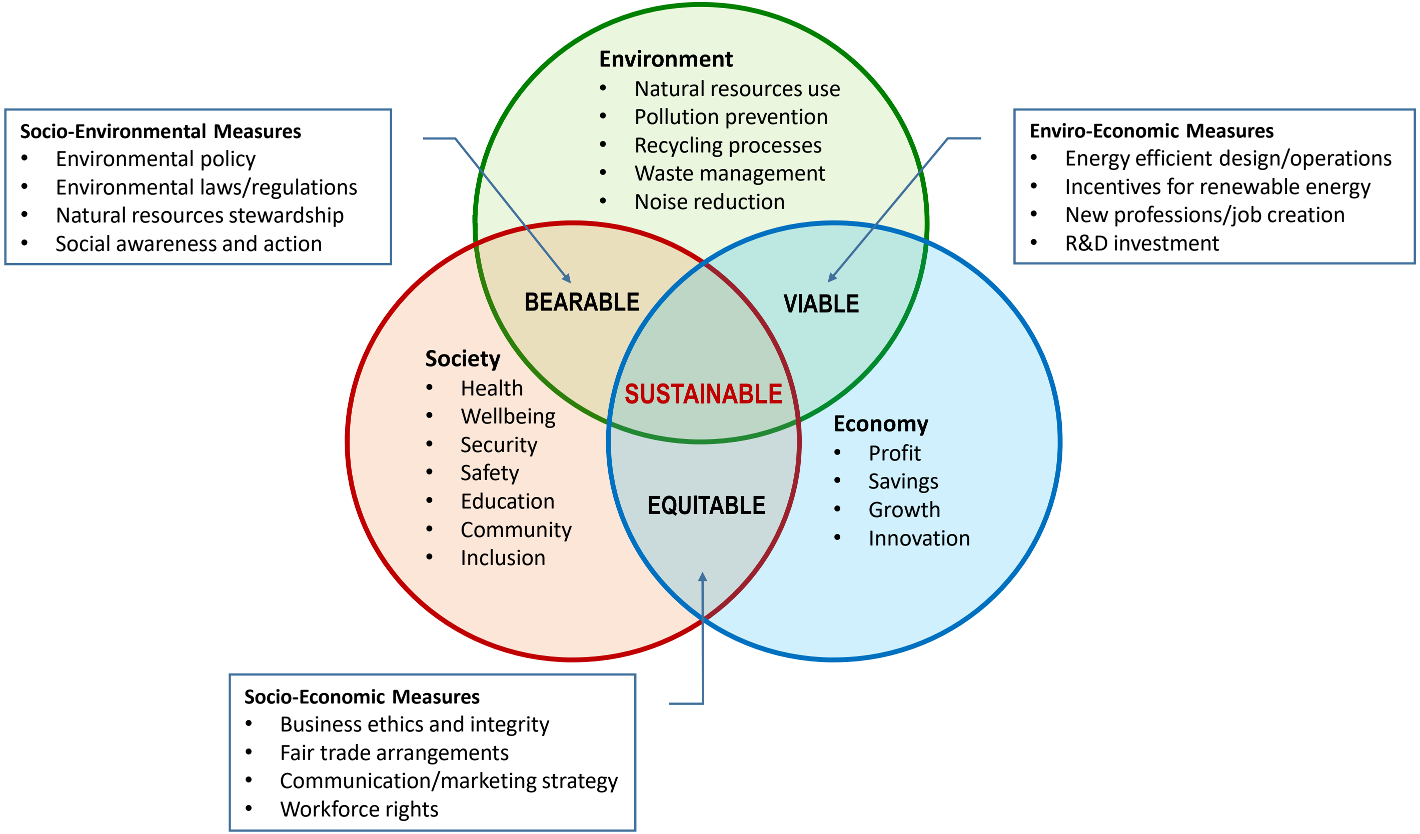






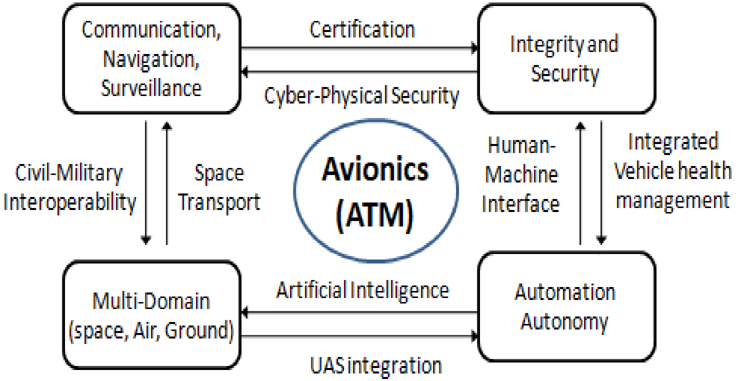


The 3 Spheres of Sustainability

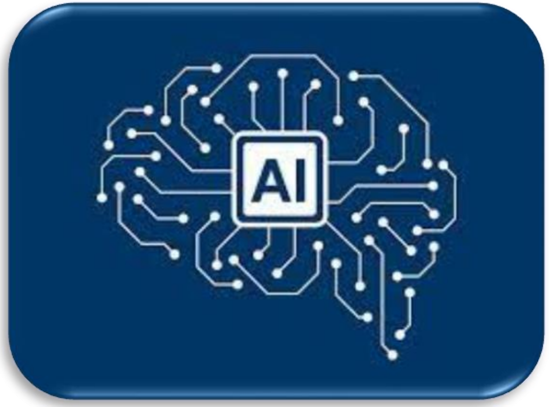


Research and Innovation – Focus Areas

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 Operations**
    - 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)
    - Artificial Intelligence (AI)/Machine Learning (ML) in avionics systems design and operations (including the challenges of certification and the role of explainable AI)



Automation and AI in Aerospace Systems



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

- **Sustainable Automation or Automation for Sustainability?**

Cyber-Physical Avionics Systems

The aerospace community is focusing on two special categories of Cyber-Physical Systems (CPS):

- **Autonomous Cyber-Physical (ACP) systems**
  - Semi-Autonomous Cyber-Physical (S-ACP) systems
- **Cyber-Physical-Human (CPH) systems**

The challenge is to develop robust, fault-tolerant and secure ACP and CPH systems that ensure **trusted autonomous operations** given:

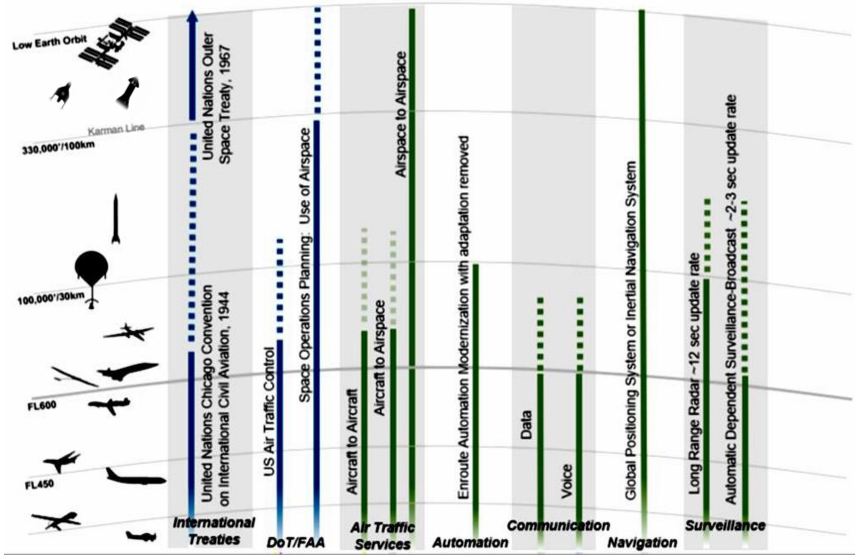
- Specific hardware constraints
- Variability of mission requirements
- Uncertainties in physical processes
- The possibility cyber/physical attacks and human errors

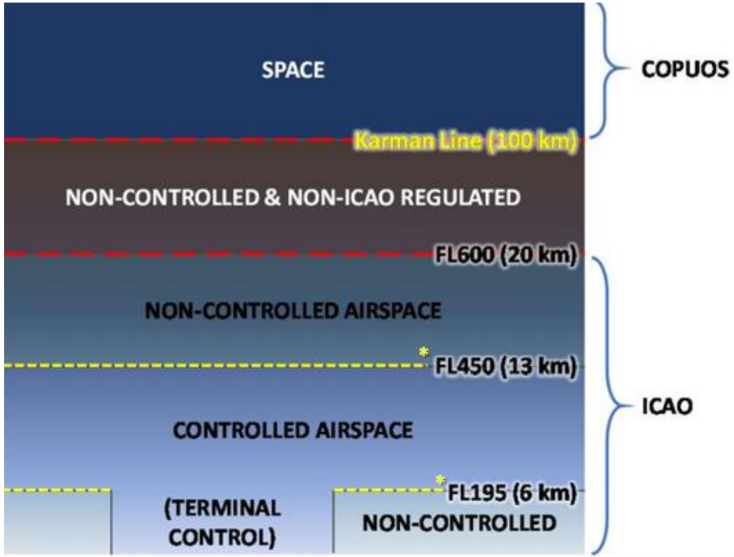
Research and Innovation – Engagement

- The ASP is collaborating with ICAO, IFATCA, EASA, EUROCAE, NASA, JARUS, NextGen and SESAR initiatives to promote avionics research/innovation, education and the evolution of certification standards. Increasing focus on AI, UAS Traffic Management and Advanced Air Mobility
- Current activities focus on:
  - ATM and UTM/AAM Automation
  - Autonomous Navigation and Guidance Systems
  - Advances in Human-Machine Systems
  - Automation and Trusted Autonomy Use Cases
  - Multiple Simultaneous Operations

Research and Innovation – Engagement (cont.)

❖ The ASP is actively working with various industry and government partners to address the future challenges of air-and-space traffic management integration (both technological and regulatory framework evolutions)

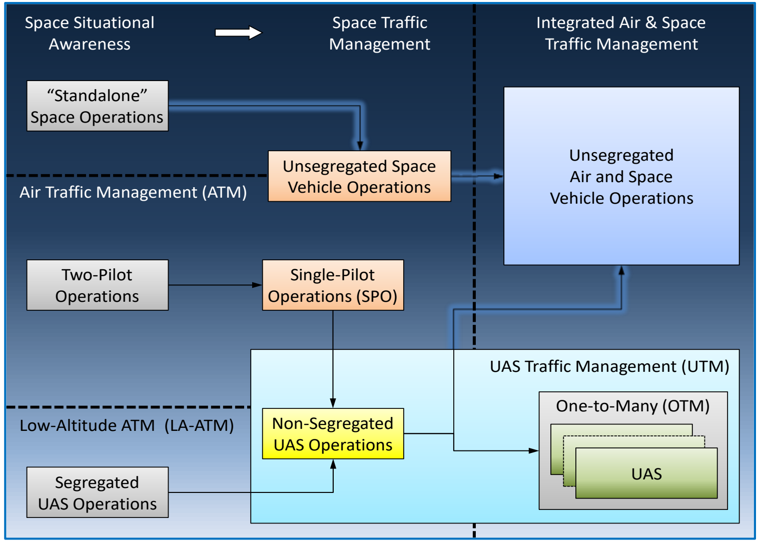


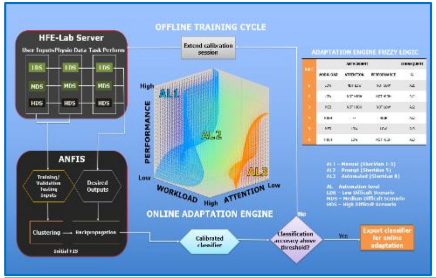


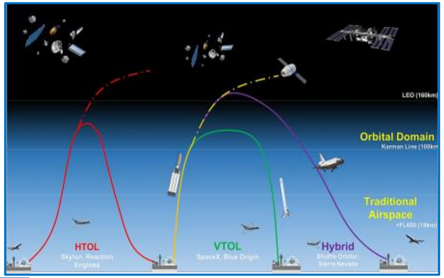
* These boundaries are adopted in many ICAO countries but the actual altitude is subject to national jurisdictions.

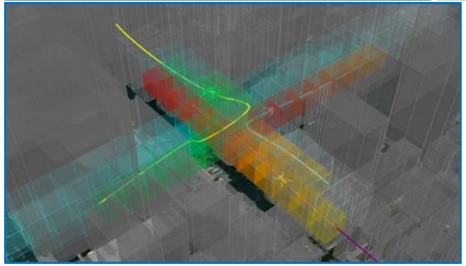
Research and Innovation (cont.)

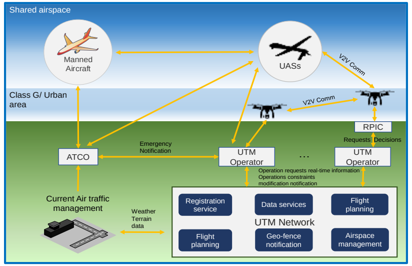
- The concept of Multi-Domain Traffic Management (MDTM) has emerged and various AI-based Cyber-Physical System (iCPS) architectures are being studied to support CNS/ATM and Avionics (CNS+A) system evolutions for <u>trusted autonomous air and space transport operations</u>











Publication Activities

- ❖ The ASP is contributing to the AESS editorial activities in the area of Avionics Systems. These activities include:
  - **IEEE Series – Progress in Aeronautics and Astronautics Systems**
  - **IEEE Transactions on Aerospace and Electronic Systems**
  - **IEEE Aerospace and Electronic Systems Magazine**
- ❖ In 2023, the ASP has led to successful completion an AESS Systems Magazine Special Issues on “UAS Traffic Management and Urban Air Mobility”, focusing on low-level ATM/U-Space
- ❖ An additional Magazine Special Issue is currently under development: “Space Domain Systems”, focusing on Space Domain Awareness

Education Activities

- Various ASP members serve as Distinguished Lecturers (DL) and are actively contributing to the Virtual DL (VDL) Webinar Series:
  - Roberto Sabatini – Aerospace Cyber-Physical Systems and Trusted Autonomy
  - Erik Blasch – Multisensor Systems and Data Fusion
  - Kathleen Kramer – Navigation and Cyber-Security in Avionics
  - Giancarmine Fasano – Unmanned Aerial Vehicles
  - Carlos Insaurralde – Modelling and Decision Making for ATM





Industry Engagement and Standards

- ASP members are contributing to the advancement of ICAO, RTCA, EUROCAE/SAE and AEEC avionics standards.

ICAO

- 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

RTCA / EUROCAE

- 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

AEEC

- 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

Industry Engagement and Standards (cont.)

- ASP members are also contributing to the **Joint Authorities for Rulemaking in Unmanned Systems (JARUS) – Automation WG**
  - The Automation WG has been tasked with defining a framework for assessing the different notions of autonomy and developing a framework for evaluating automation in proposed UAS operations
  - The framework includes definitions, assumptions, levels of automation, methods of assessing and describing operations, and considerations for broad incorporation in aviation standards
  - The roles of the manufacturer, operator, pilot, service providers, and regulators are also assessed for each level of automation

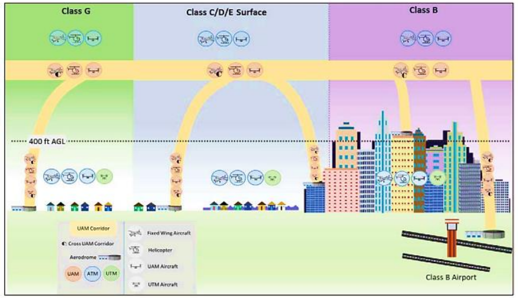
JARUS Joint Authorities for Rulemaking on Unmanned Systems

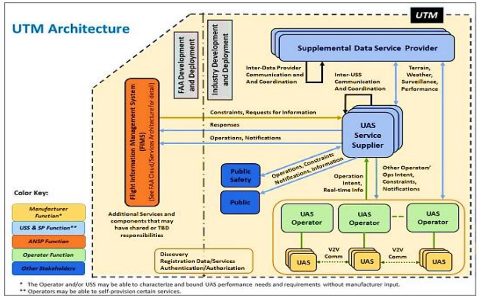
- Previous ASP contributions have been in the area of **Trusted Autonomy** (i.e., human-autonomy teaming) with a focus on integrity metrics definition to support safe and efficient airspace operations
- Current work is focusing on data-centric ATM and associated impacts on CNS/ATM automation, especially in the context of Low-Altitude Airspace Management (LAAM), i.e., addressing both UTM TCL3/4 and AAM requirements

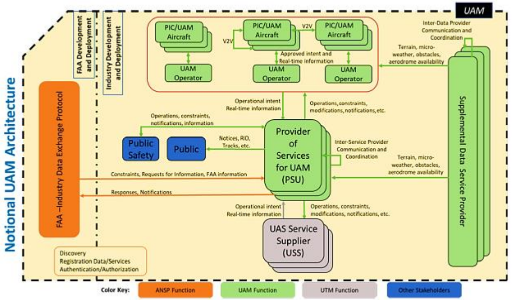
Industry Engagement and Standards (cont.)

Outstanding challenges:

- Develop a CONOPS for Low-Altitude Airspace Management (LAAM) encapsulating UTM and emerging AAM requirements, which clearly specifies the human role for various levels of automation
- Develop new DSS functionalities to enhance human-machine teaming (current focus is on performance-based airspace modelling and dynamic airspace management)
- Develop an integrated approach to Multi-Domain Traffic Management (long-term goal)







Industry Engagement and Standards (cont.)

- In addition to JARUS Automation/Autonomy, recent ASP contributions have focused on AI/ML certification, which was also the topic of DASC 2022 ASP tutorial
- **SAE G-34/EUROCAE WG-114, Artificial intelligence in Aviation** - 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.
- Published Standard: AIR6988 / ER-022 Artificial Intelligence in Aeronautical Systems: Statement of Concerns (2021).
- Works In Progress:
  - AS6983 / ED-xxx Process Standard for Development and Certification / Approval of Aeronautical Safety-Related Products Implementing AI;
  - AIR6987 / ER-xxx Artificial Intelligence in Aeronautical Systems: Taxonomy;
  - AIR6994 / ER-xxx Artificial Intelligence in Aeronautical Systems: Use Cases Considerations.

Recent Panel References

[1] E. Blasch, R. Sabatini, A. Roy, K. Kramer, G. Andrew, G. Schmidt, C. Insaurralde, and G. Fasano, "Cyber Awareness Trends in Avionics," 2019 IEEE/AIAA 38th Digital Avionics Systems Conference (DASC), 1-8, October 2019

[2] R. Sabatini, K. A. Kramer, E. Blasch, A. Roy and G. Fasano, "From the Editors of the Special Issue on Avionics Systems: Future Challenges." IEEE Aerospace and Electronic Systems Magazine, 36(4): 5-6, April 2021

[3] R. Sabatini, A. Roy, E. Blasch, K. A. Kramer, G. Fasano, I. Majid, O. G. Crespillo, D. A. Brown, R. Ogan, "Avionics Systems Panel Research and Innovation Perspectives," *IEEE Aerospace And Electronics Systems Magazine*, 35(12):58-72, Dec. 2020.

[4] I. Majid, R. Sabatini, K. A. Kramer, E. Blasch, G. Fasano, G. Andrews, C. Camargo and A. Roy, "Restructuring Avionics Engineering Curricula to Meet Contemporary Requirements and Future Challenges." IEEE Aerospace and Electronic Systems Magazine, 36(4): 46-58, April 2021.

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).

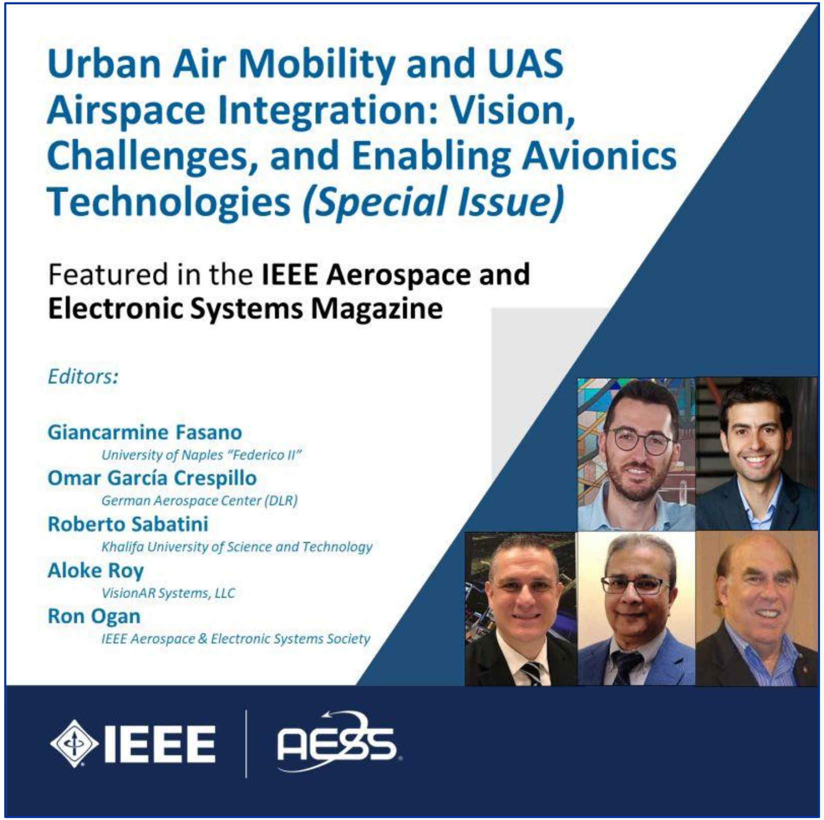
Conceptual evolution of multi-domain traffic management.

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.

Recent Special Issue of the IEEE AES Magazine



Abstract: The integration of unmanned aircraft systems (UAS) in all classes of airspace represents, at the same time, an evolutionary and a revolutionary step in air transport operations. As a result, new concepts have emerged for UAS traffic management to support the anticipated traffic density growth and the need for safe beyond visual line-of-sight operations. Closely linked with these developments, urban/advanced air mobility (UAM/AAM) has appeared as a new and disruptive dimension for aviation, potentially enabling mobility of goods and people at a different scale compared with current operations, while also emphasizing the need of seamless integration with the existing air traffic management (ATM) framework. These UAS capabilities are reshaping the future of aviation, but also challenge traditional paradigms, requiring significant advances both in technologies and regulations, while keeping strong links with public communities and the perception of societal benefits. As an example, a key role is played by the progress of communications, navigation and surveillance technologies, such as sense-and-avoid and global navigation satellite systems-resilient, alternate position, navigation, and timing systems, and by the seamless integration of airborne and ground infrastructure within a cyber-aware context. Similarly, significant restructuring of the existing regulatory framework is needed to ensure that the integrity and safety of the AAM/ATM integrated airspace is maintained while enabling autonomous operations with higher technological flexibility and refresh rates.

Published in: IEEE Aerospace and Electronic Systems Magazine (Volume: 38, Issue: 5, 01 May 2023)

Further ASP Initiatives

- Currently working to a new position paper for the AESS Systems Magazine on industry-focused Avionics Research and Innovation (R&I) perspectives, updating the ASP R&I paper published in 2020
- Discussing a possible update of the paper published in April 2021 on Avionics Systems Education, with stronger focus on "system thinking" and practical avionics systems design (HW/SW) for certification and Test and Evaluation (T&E) skills
- The ASP is developing a book proposal for the IEEE Series on Aeronautics and Astronautics Systems. The provisional title is "Advances in Digital Avionics and Space Systems." Current chapters include:
  - Chapter 1: Avionics Research and Innovation Perspectives
  - Chapter 2: CNS/ATM and Avionics Evolutions to Meet future Air Traffic Requirements
  - Chapter 3: UTM and AAM Implementation Challenges
  - Chapter 4: Avionics Systems for Urban Air Mobility
  - Chapter 5: Avionics Systems for Spacecraft Operations
  - Chapter 6: Cyber Security Aspects in Future Avionics Systems
  - Chapter 7: Avionics Human-Machine Interactive Interfaces
  - Chapter 8: Architectures to Support Future On-Board Avionics
  - Chapter 9: Avionics Hardware and Software Certification Aspects
  - Chapter 10: Certification of AI/ML in Safety-Critical Avionics Systems
  - Chapter 11: Avionics Education and Training to Support Industry Needs and Future Trends

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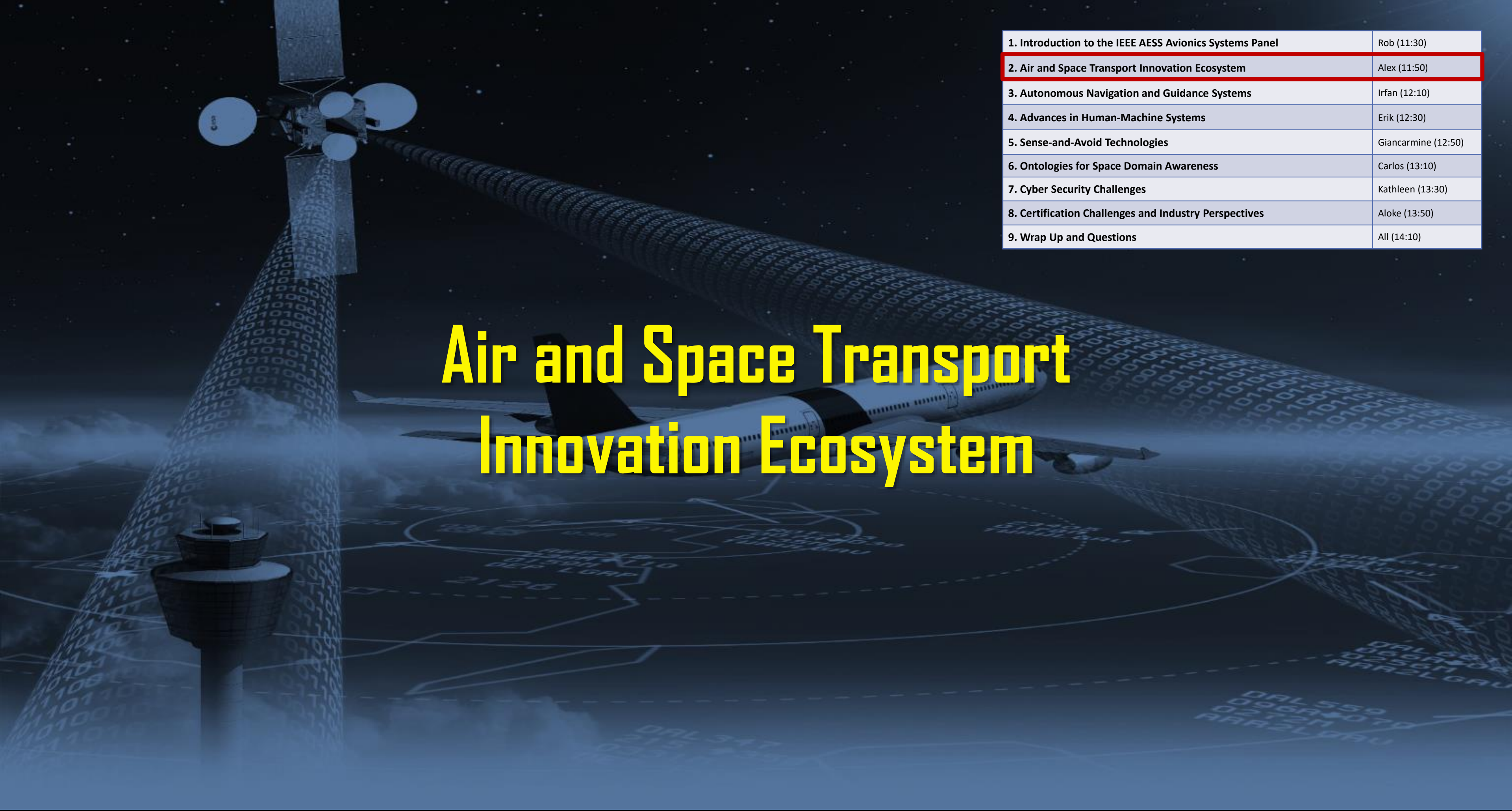
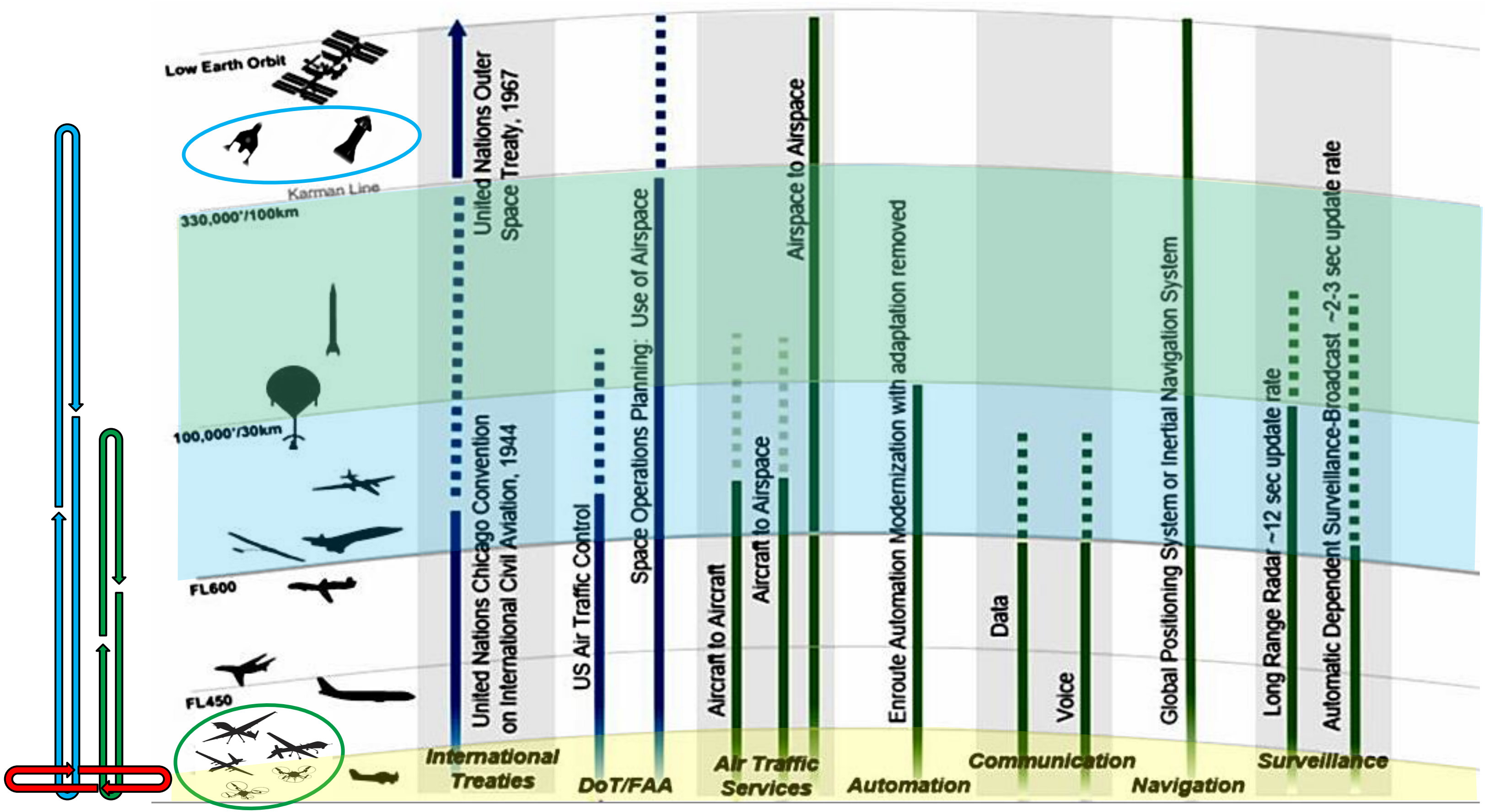


Air and Space Transport Innovation Ecosystem

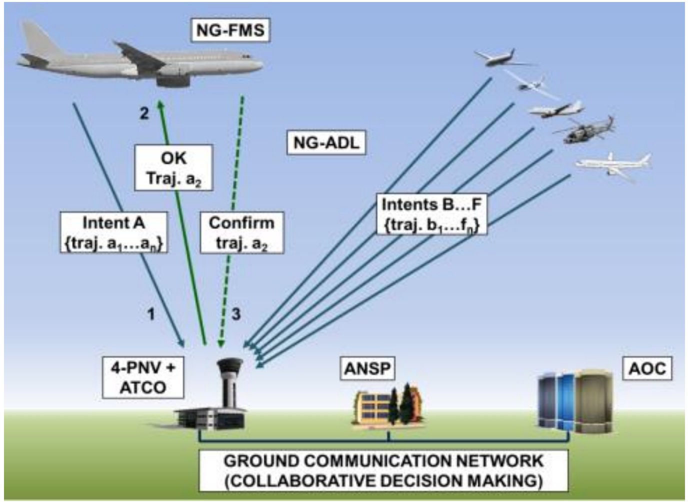
Evolving Airspace and Avionics Systems

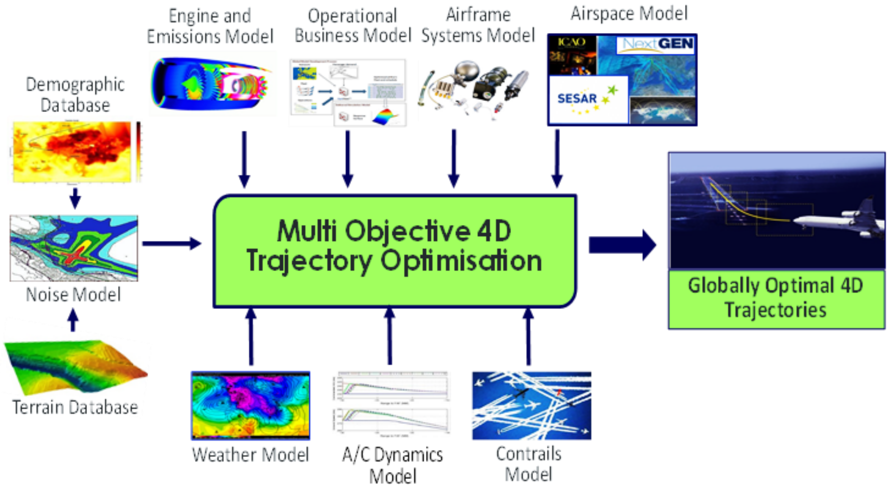


Credit: FAA

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)

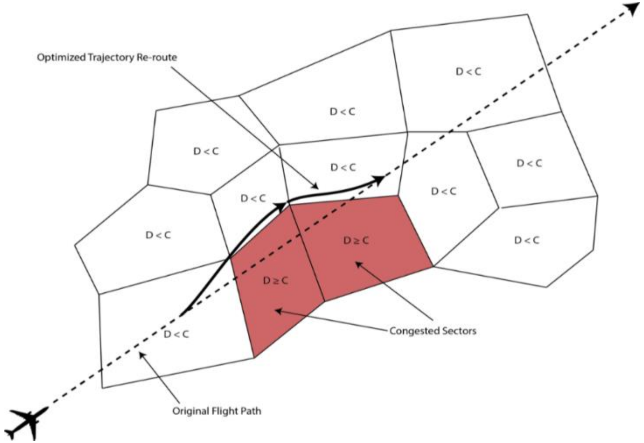


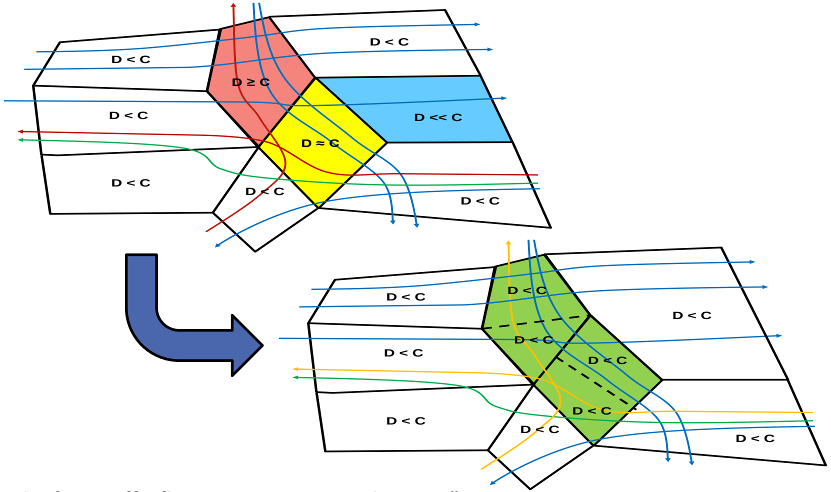


Ref.: A. Gardi, R. Sabatini, and S. Ramasamy, "Multi-objective optimisation of aircraft flight trajectories in the ATM and avionics context", Progress in Aerospace Sciences, vol. 83, pp. 1-36, 2016. DOI: 10.1016/j.paerosci.2015.11.006

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

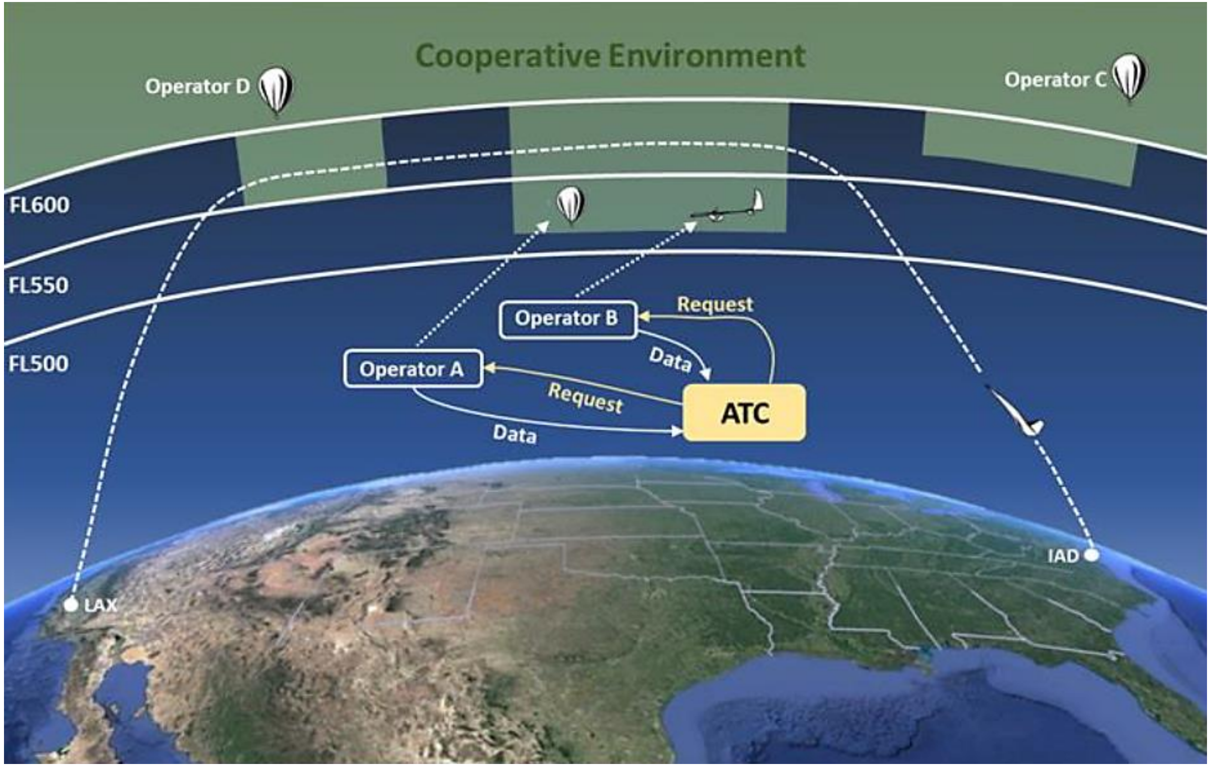




Ref.: T. Kistan, A. Gardi, R. Sabatini, S. Ramasamy, and E. Batuwangala, "An evolutionary outlook of air traffic flow management techniques", Progress in Aerospace Sciences, vol. 88, pp. 15-42, 2017. DOI: 10.1016/j.paerosci.2016.10.001

Flight Above FL 600

- Super/Hypersonic Vehicles, VHALE UAS, Stratospheric Airships, etc.



Credit: FAA

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 accepted (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

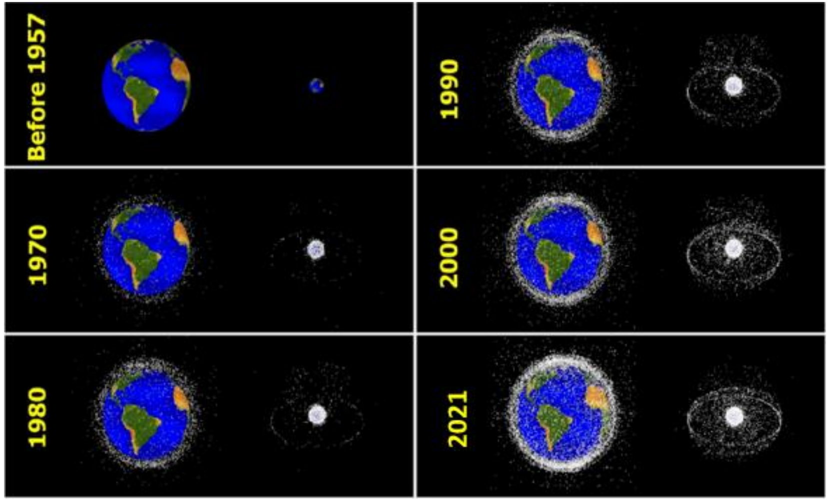
Virgin Galactic Space Ship 2
Credit: Virgin Galactic

Sierra Nevada Dream Chaser
Credit: Sierra Nevada

Reaction Engines Skylon
Credit: Reaction Engines

Orbital Congestion

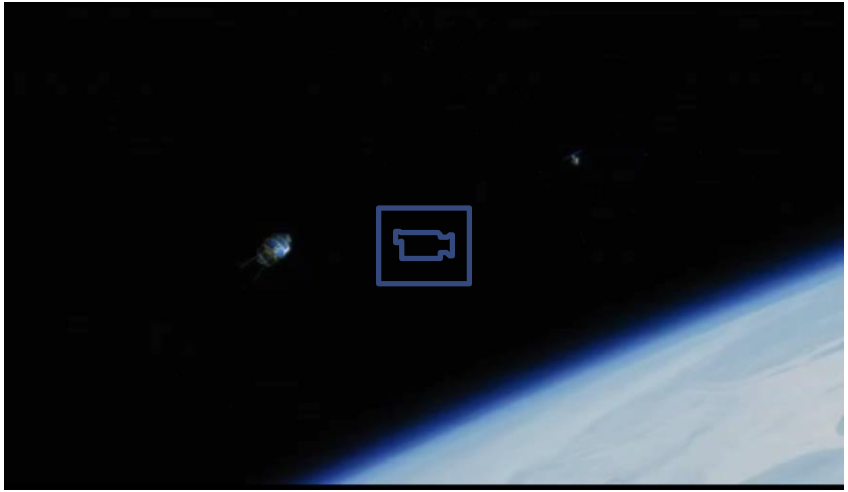
- Resident Space Objects (RSO) > 1mm
- The estimated total number of these RSO is > 170 million
- Any of these RSO can cause harm to an operational spacecraft



Courtesy: ESA

https://www.esa.int/ESA_Multimedia/Images/2019/10/Distribution_of_space_debris_around_Earth

Collision Events



IRIDIUM vs. KOSMOS collision event (2009)

PRC Anti-Satellite Missile Test (2007)

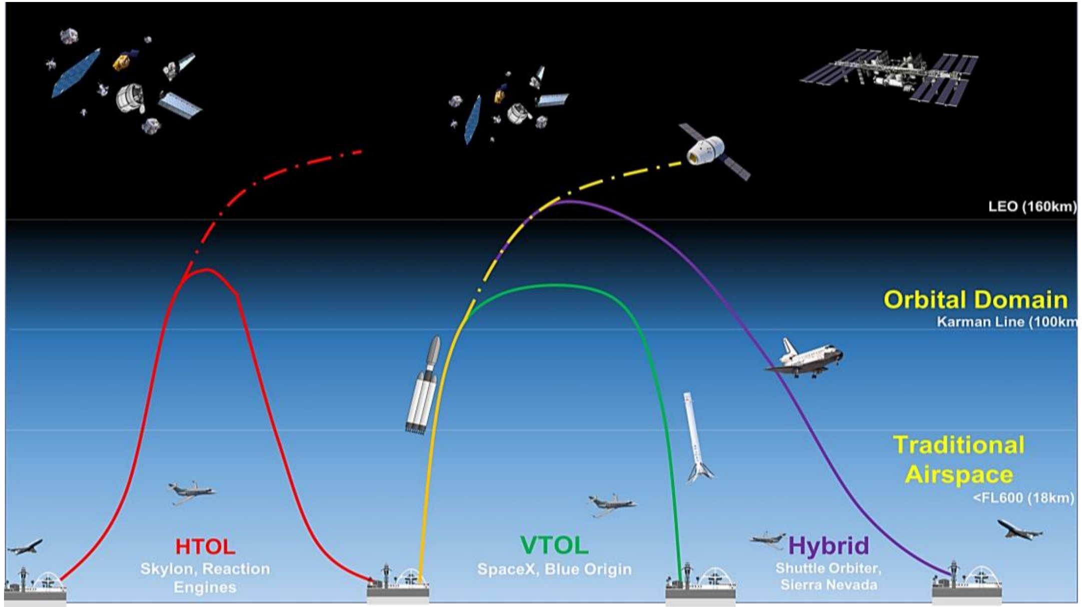
Space Transport Platforms

Vertical Takeoff & Landing

- Traditional approach to access space
- Limited in maneuverability (non-lifting body)
- Vertical landing pioneered by SpaceX reusable vehicle
- <u>Minimized time in atmosphere</u> 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)
- <u>Promising concept for Suborbital Point-To-Point transportation</u>

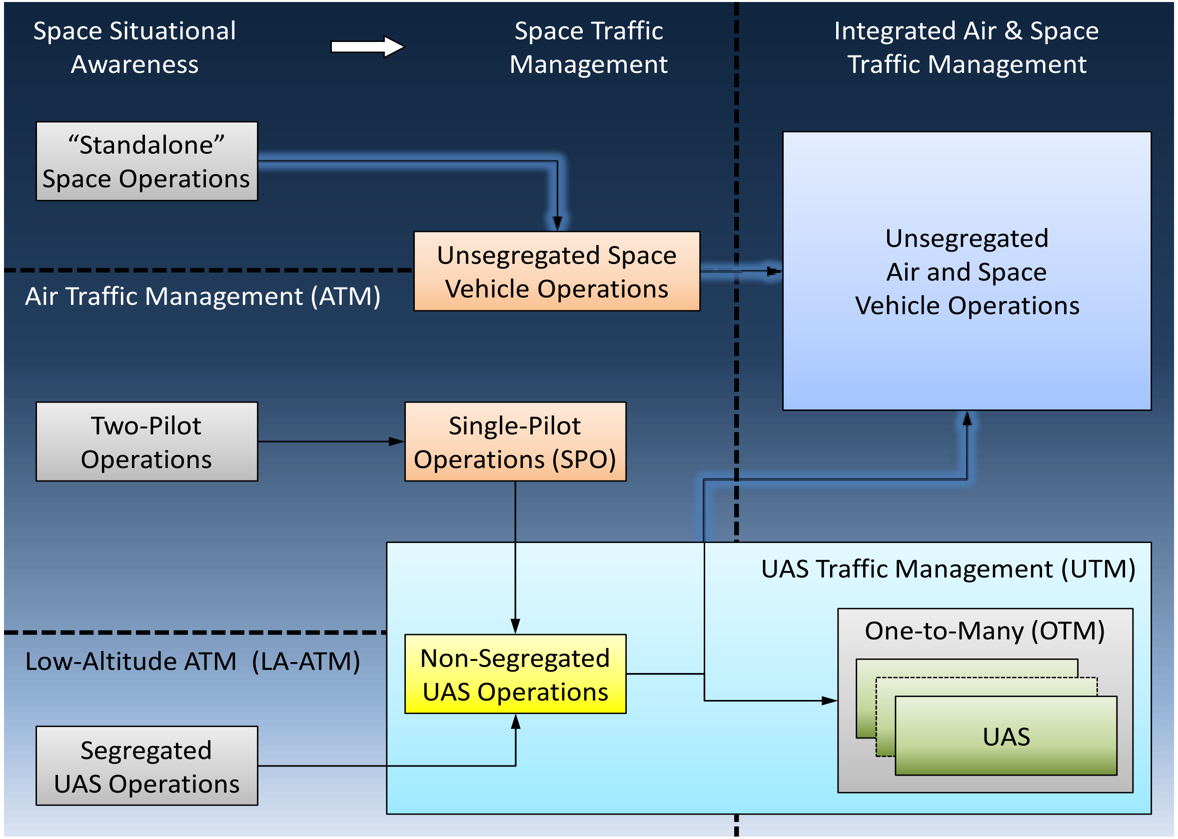


Hybrid

- Typically carrier aircraft taking space vehicle to launch altitude
- Gliding flight most commonly performed after re-entry
- <u>Promising for reduced environmental impact</u>

Emerging Autonomous Vehicle Concepts

Aerospace Systems Evolution



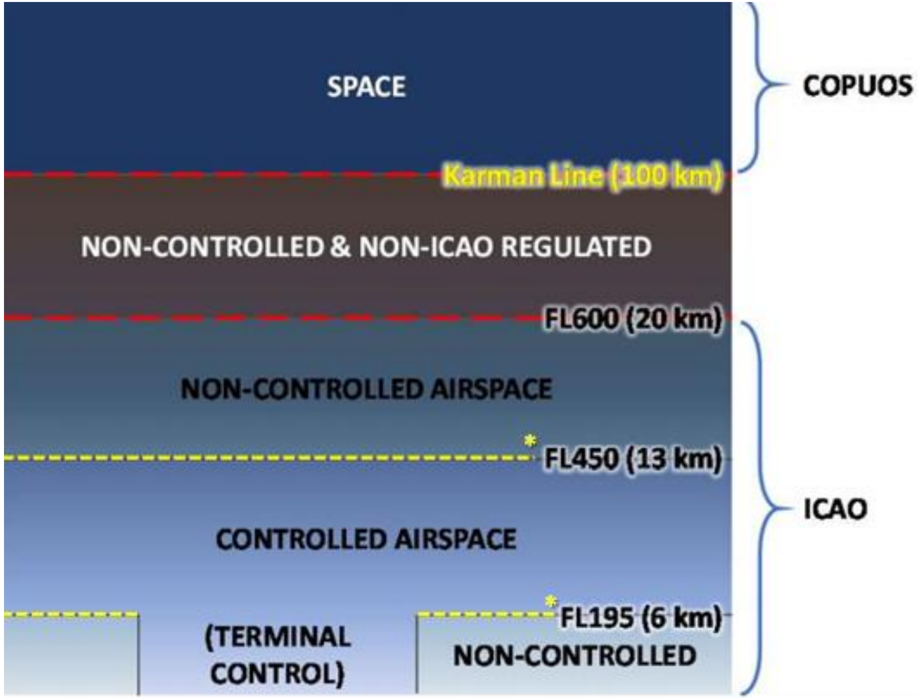
R. Sabatini, A. Roy, E. Blasch, K. A. Kramer, G. Fasano, I. Majid, O. G. Crespillo, D. A. Brown and R. Ogan, "Avionics Systems Panel Research and Innovation Perspectives." IEEE Aerospace and Electronic Systems Magazine, Vol. 35, Issue 12, pp. 58-72, December 2020.

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

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.

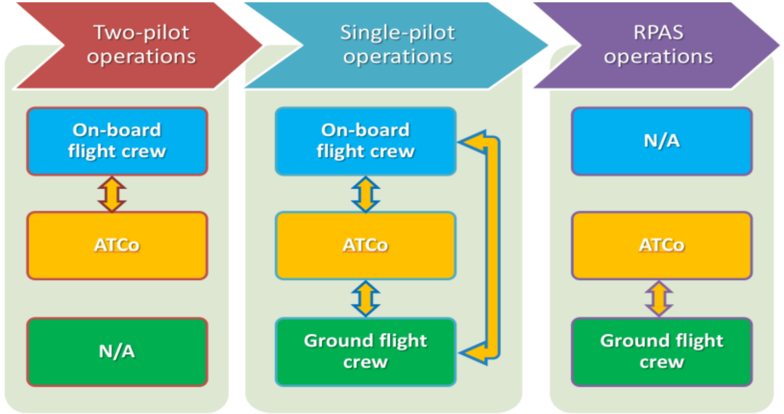


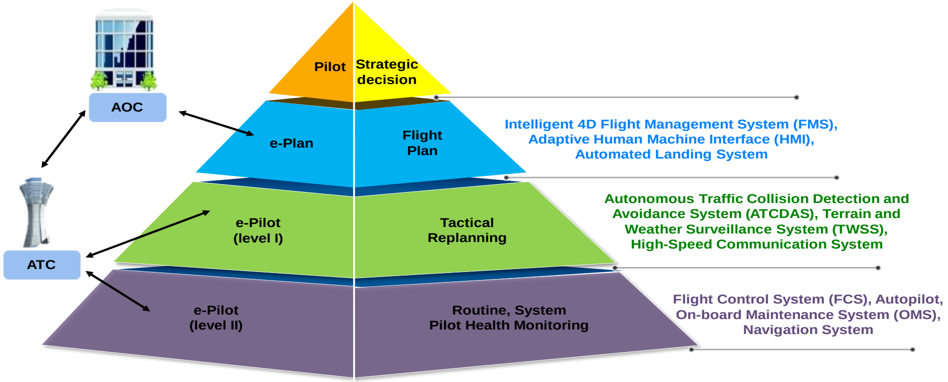
* These boundaries are adopted in many ICAO countries but the actual altitude is subject to national jurisdictions. The current US base and ceiling of controlled airspace are 18,000 ft and 60,000 ft respectively (i.e., there is no uncontrolled airspace up to that FL600).

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

SiPO to RPAS in Conventional Airspace

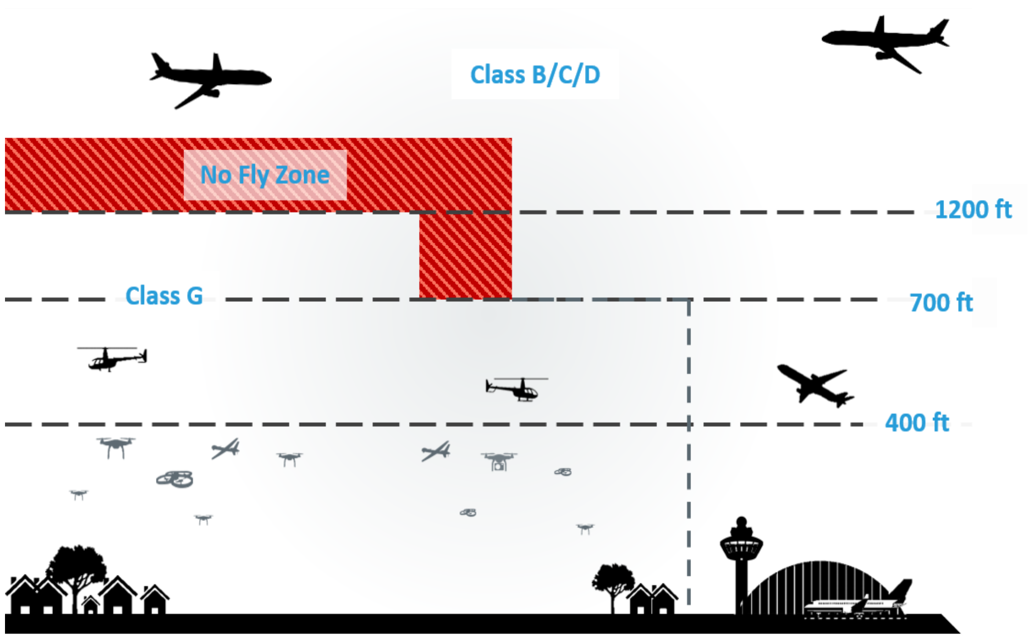
- Improve the total system performance through highly automated CNS+A systems supporting human-machine teaming
- Adaptive Human-Machine Interfaces and Interactions (HMI2) based on:
  - Real-time avionics systems integrity monitoring
  - Sensing of neuro-physiological parameters and AI-based estimation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

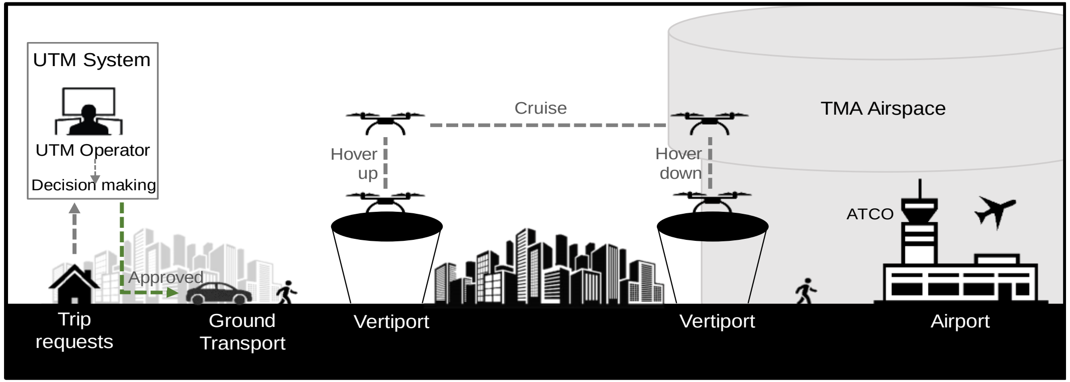
UAS Traffic Management (UTM) – Key Challenges



- 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

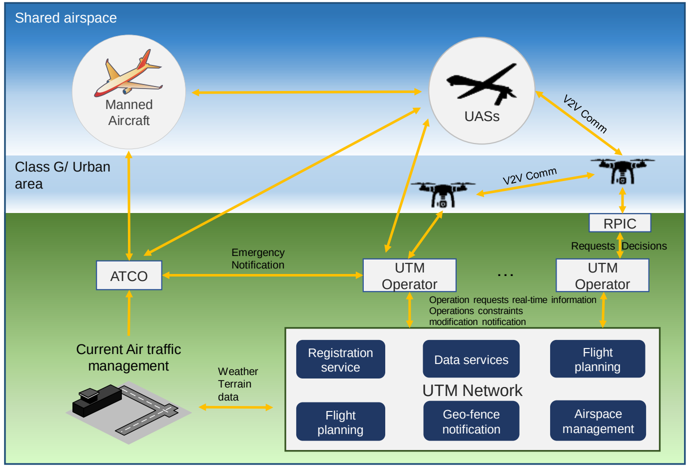
UTM and Advanced Air Mobility (AAM)



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)

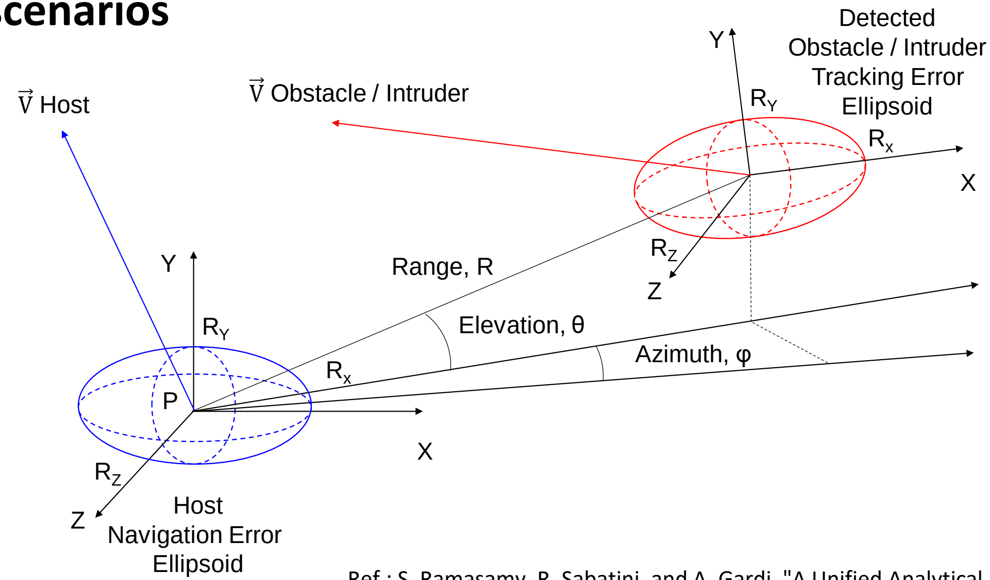
The tasks and responsibilities of humans and AI agents in UTM/AAM are yet to be defined

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.

Separation Assurance and Collision Avoidance

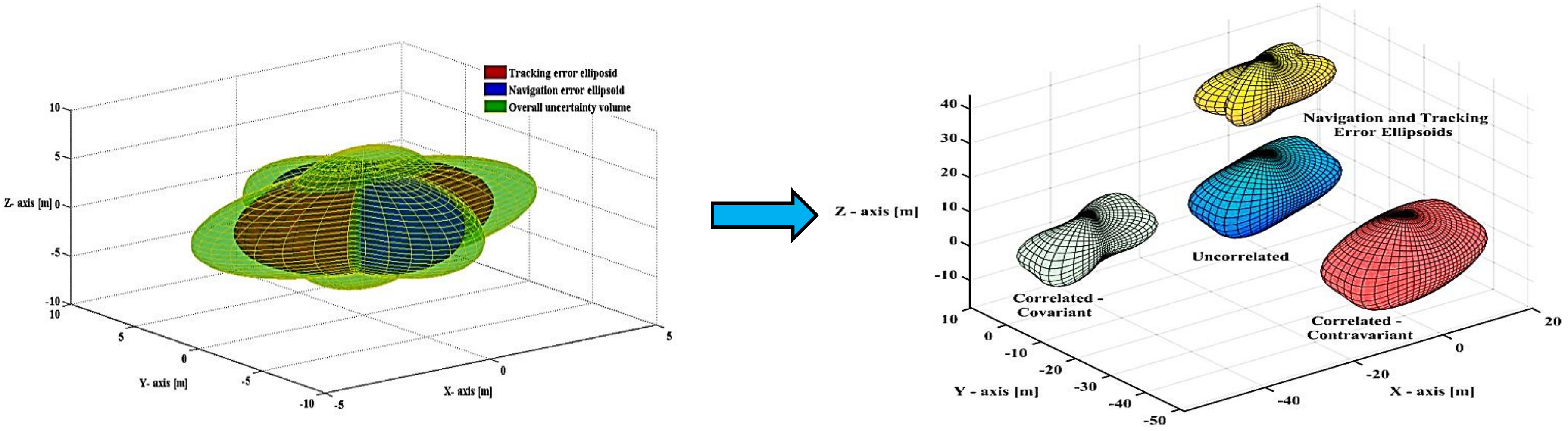
- **Avoidance volume** in the space surrounding each track
- Continuously estimating both **navigation and tracking errors** affecting the measurements (plus perturbations) and translating them to **unified range and bearing uncertainty descriptors**, which apply both to cooperative and non-cooperative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

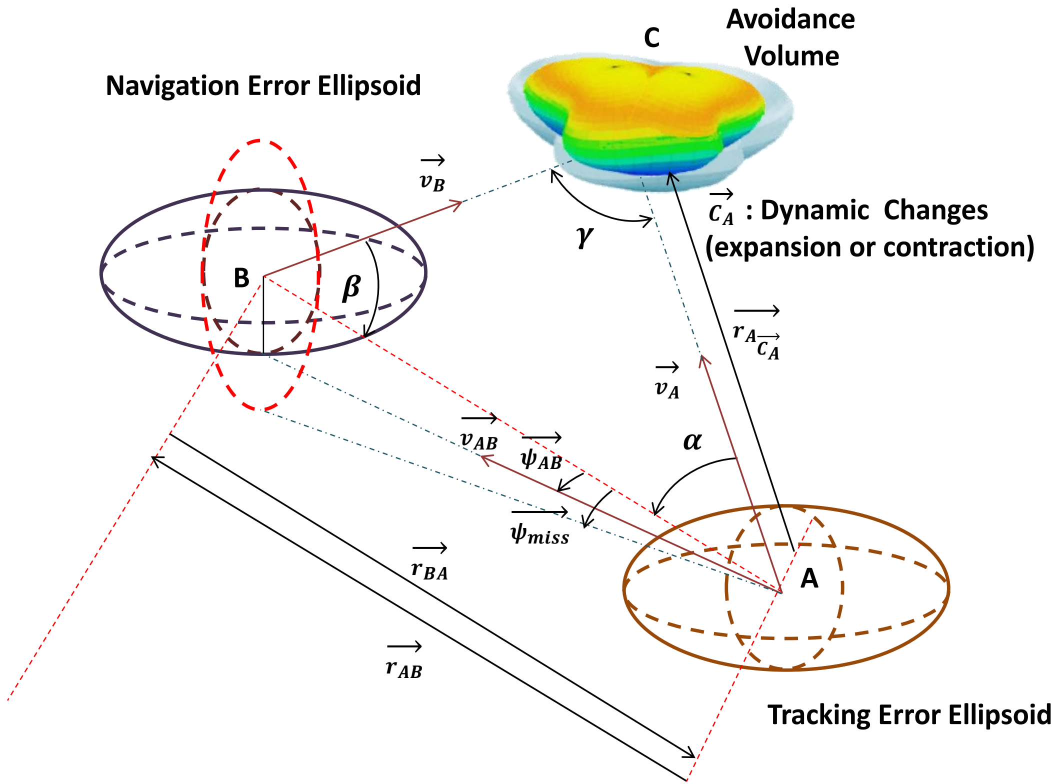
SA/CA – Error Analysis

- 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



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.

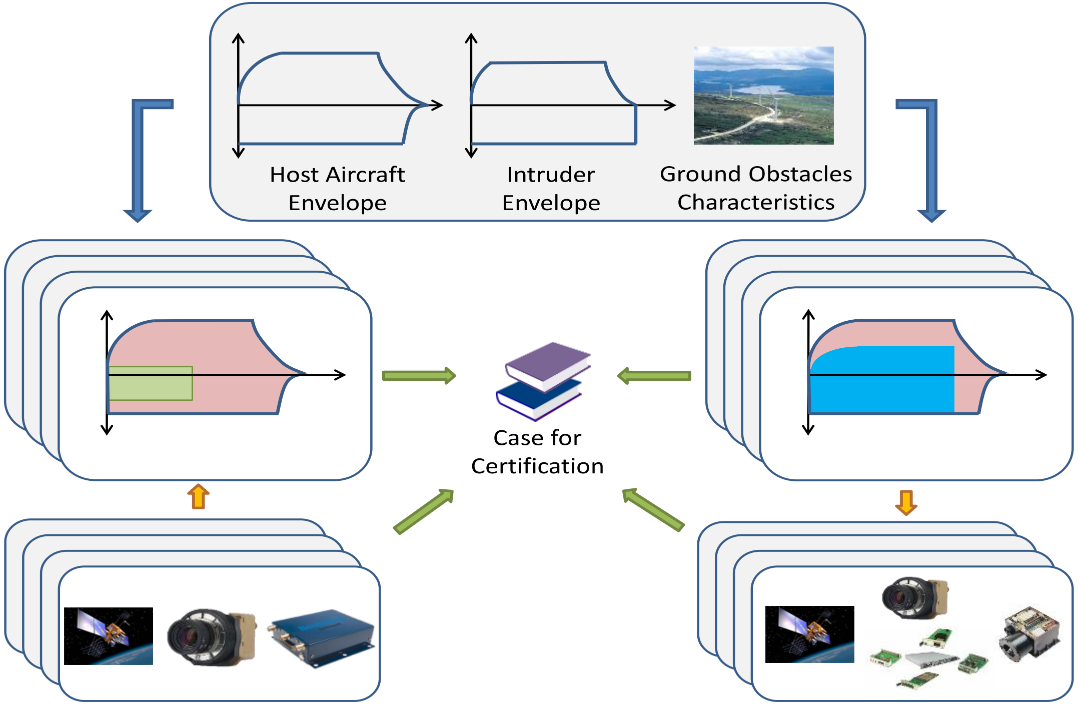
SA/CA – Relative Dynamics and Disturbances



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



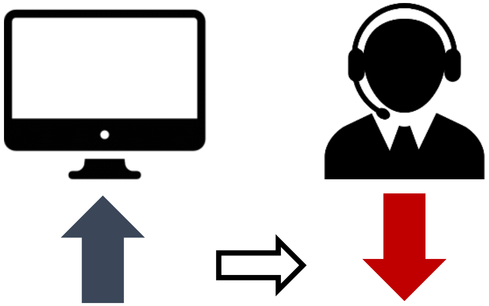
Ref.: S. Ramasamy, R. Sabatini, and A. Gardi, "A Unified Analytical Framework for Aircraft Separation Assurance and UAS Sense-and-Avoid", Journal of Intelligent & Robotic Systems, 91, pp. 735-754, 2018.

HOTL Dynamic Interactions

Challenges

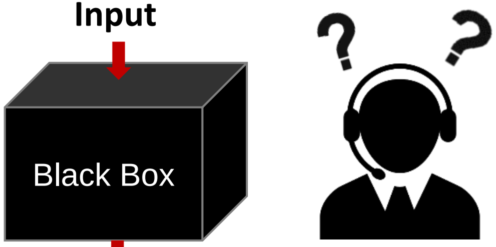
Higher level of automation in an out-of-loop paradigm

- Lower cognitive capability
- Progressive deskilling
- Lower situational awareness



Human Factors

Input



Output → Interpretation

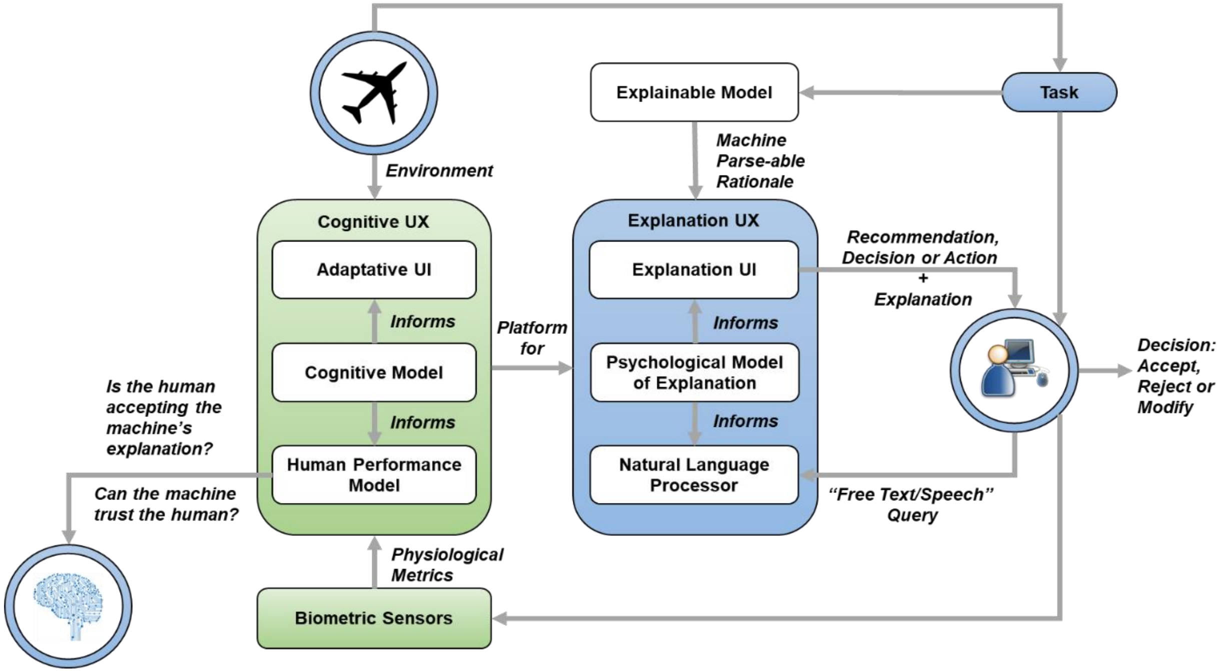
AI Explanation

Solution

Adaptive HMI based on Explainable and Trusted AI

Cognitive Human-Machine Systems (CHMS)

Cognitive HMI and Explanation UX

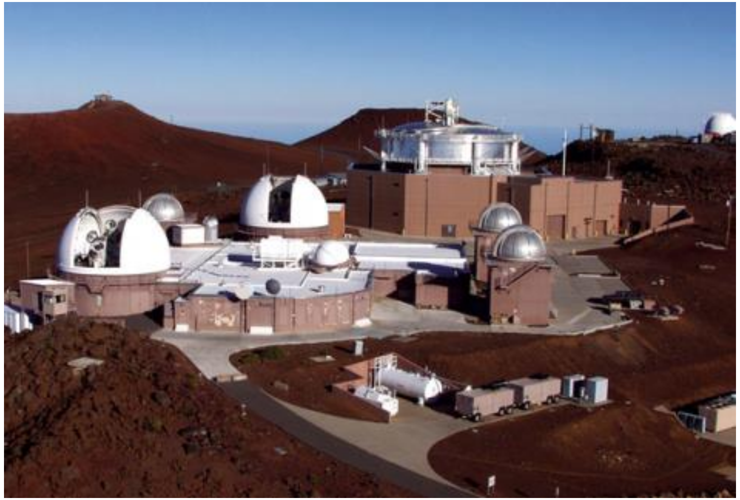


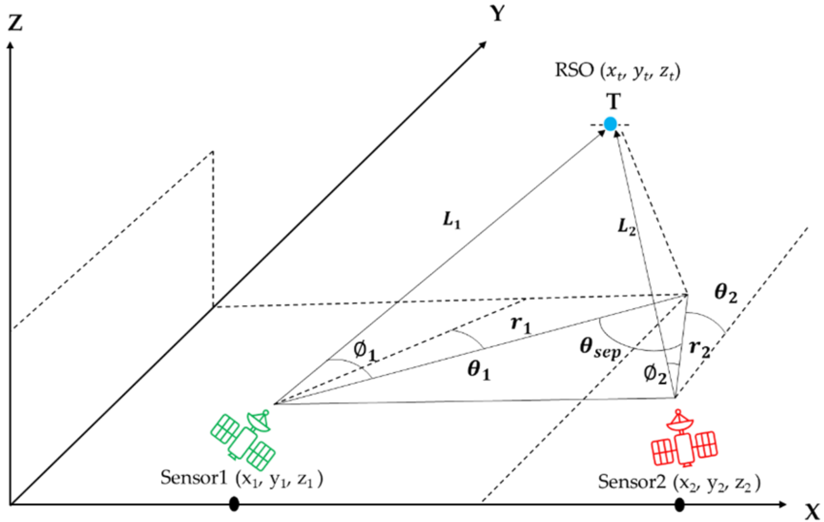
- **Explainable AI**
- **Trusted AI**
- **Certifiable AI**

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.

Multi-Sensor RSO Tracking

- Cooperative and Non-Cooperative Surveillance for SDA and STM
- Ground-Based Surveillance (GBS) and Space-Based Space Surveillance (SBSS)
- Tracking of <10cm RSO elusive to GBS infrastructure – STM Requires SBSS Integration

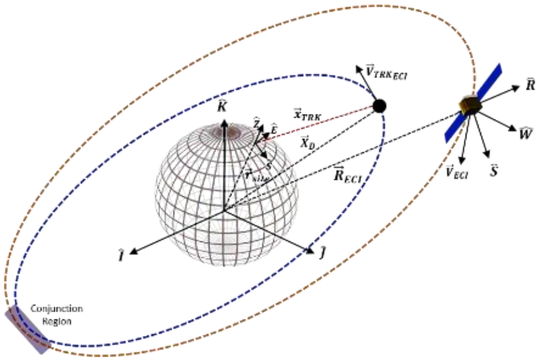


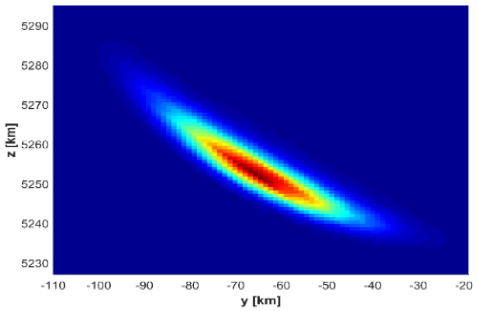


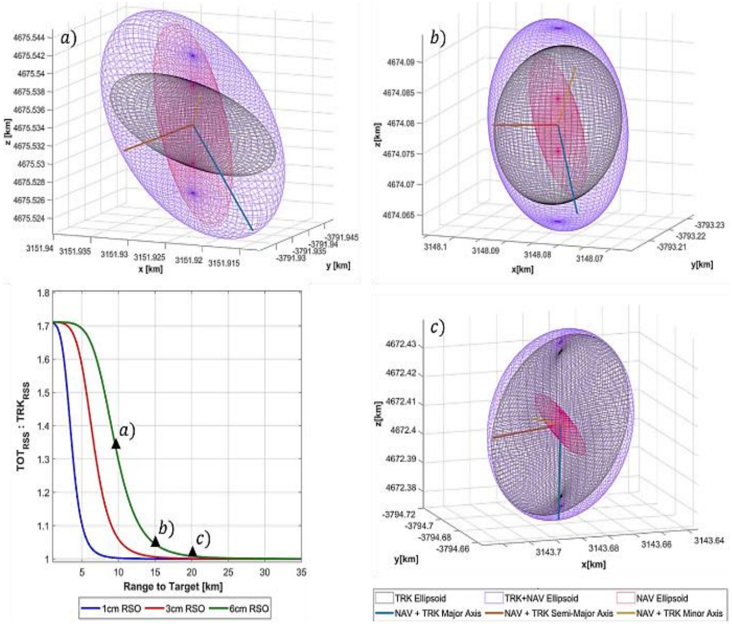
Space Domain Awareness and Traffic Management

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/networks
- Unique software tools employing AI/ML techniques





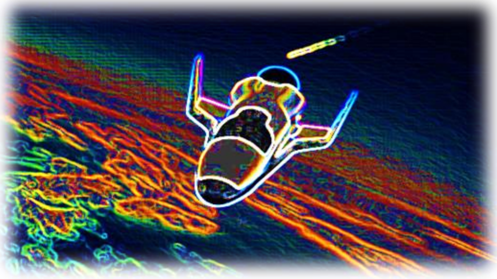


Ref.: - S. Hilton, R. Sabatini, A. Gardi, et al., "Space traffic management: towards safe and unsegregated space transport operations", Progress in Aerospace Sciences, 105, pp. 98-125, 2019.

- 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.

Towards a Unified Air and Space Traffic Management

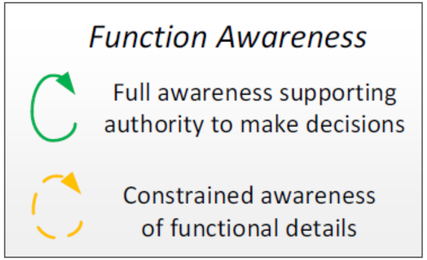
- Unified approach to cooperative and non-cooperative SA/CA is necessary
- Both ground-based surveillance and SBSS are needed for a scalable STM
- Much higher levels of automation and trust in the automation
- Data-centric STM and ATM integration (MDTM)
- Cyber and physical security threats
- AI certification challenges

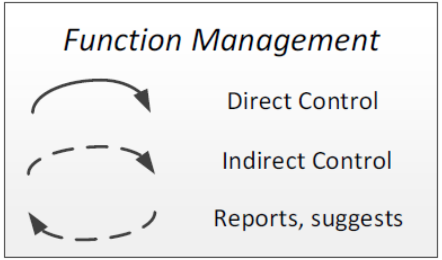


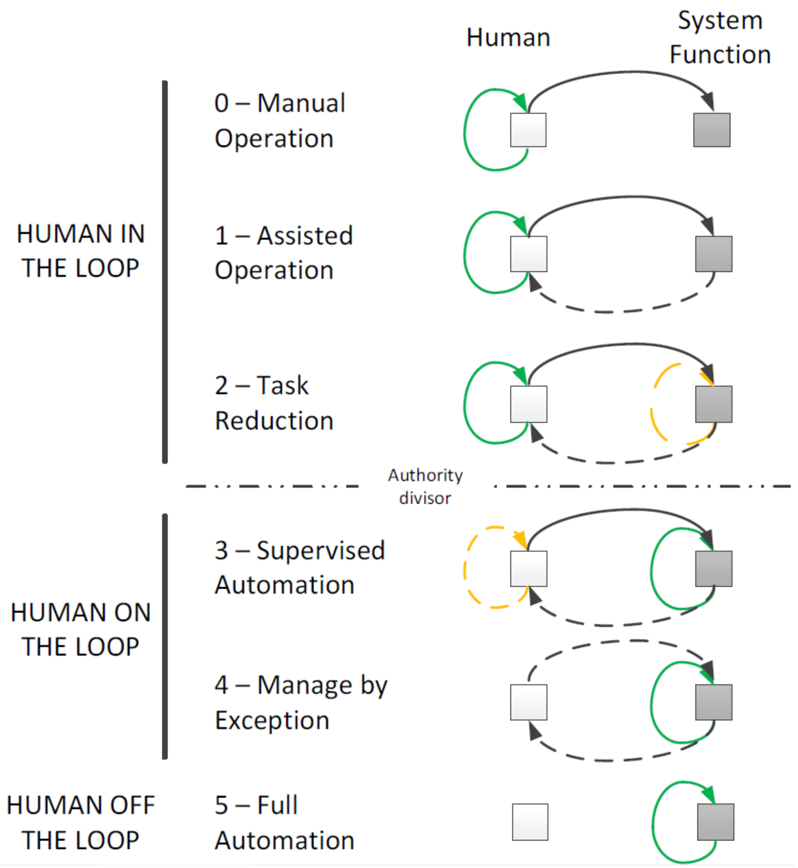
Levels of Automation – Underpinning Concepts

- Supporting a tailored definition of LoA based on the actual allocation of responsibilities in real aerospace platforms

JARUS Joint Authorities for Rulemaking on Unmanned Systems







Levels of Automation – High-Level Definition

- The classification approach proposed builds upon similar work conducted by other aviation groups including the widely publicized SAE international classification for the automotive sector and ASTM International considerations for aircraft automation
- The approach to classification is summarized as follows:
  - **Level 0 – Manual Operation:** The human fully responsible for function execution, with no machine support
  - **Level 1 – Assisted Operation:** The machine operates in an out-of-the-loop supporting role to the human in executing the function, e.g., provision of relevant information
  - **Level 2 – Task Reduction:** The machine operates in an in-the-loop management role in reducing human workload to accomplish the task, e.g., conflict alert and resolution advisory based on predicted flight paths
  - **Level 3 – Supervised Automation:** The machine executes the function under the supervision of the human who is expected to monitor and intervene as required, e.g., an automatic traffic collision and avoidance (TCAS) system tied to an autopilot which can automatically perform a manoeuvre when a Resolution Advisory is alerted
  - **Level 4 – Manage by Exception:** The machine executes the function alerting the human in the event of an issue. The human is not required to monitor the function in real time and is able to intervene at any time after being alerted by the machine to an issue
  - **Level 5 – Full Automation:** The machine is fully responsible for function execution. The human is unable to intervene in real-time either due to practical limitations or deliberate exclusion within the Operational Design Domain (ODD)

Levels of Automation – Tailored Definition

- In aeronautics, the traditional aviate, navigate, communicate and manage tasks are revisited to emphasize more contemporary roles (e.g., self-separation and onboard collision avoidance)
- These updated roles are the baseline upon which the specific allocations are defined
- Integrity thresholds (task dependent) are used to set fallback criteria

Level / Criteria	Level 0 Manual Operation	Level 1 Assisted Operation	Level 2 Task Reduction	Level 3 Supervised Automation	Level 4 Manage by Exception	Level 5 Full Automation
Human-Machine Teaming	Human led	Human-In-the-loop	Human-In/On-the-loop	Human-In/On-the-loop	Human-On-the-loop	Human-Off-the-loop
Fallback (Integrity Thresholds Exceeded)	Human	Human	Human	Human	Fall back Ready Human (Operator/ATS)	Machine (Limited or Segregated Operations)

Level / System Function Examples	Level 0	Level 1	Level 2	Level 3	Level 4	Level 5
Sustained Aircraft Maneuver Control	Human	Human *AND* Machine	Machine (Managed by Human)	Machine (Supervised by Human)	Machine	Machine
Object and Event Detection and Response (OEDR)	Human	Human	Machine (Managed by Human)	Machine (Supervised by Human)	Machine	Machine
Communication with External Systems (Ground and Airspace systems)	Human	Human	Human *OR* Machine (Managed by Human)	Machine (Supervised by Human)	Machine	Machine

Safety Impact Analysis and Trusted Automation

- The impact of automated functions on operations is categorized into 3 general levels:
  - safety independent functions
  - partially safety dependent functions
  - safety dependent functions

  By evaluating the safety criticality of an automated function and understanding the level to which the function is interdependent with other functions, the impact of automated functions on a particular operation can be assessed

- Additionally, in order to fully adopt automated functions across the airspace, trust in the automated systems needs to be built. The application of trust frameworks in the development of autonomous technologies and the training of human operators is a core aspect to achieving fully autonomous system operations. In an operational environment this creates a two-way relationship between the automated machines and their human operators in order to ensure the safest application of automated operations as trusted autonomy

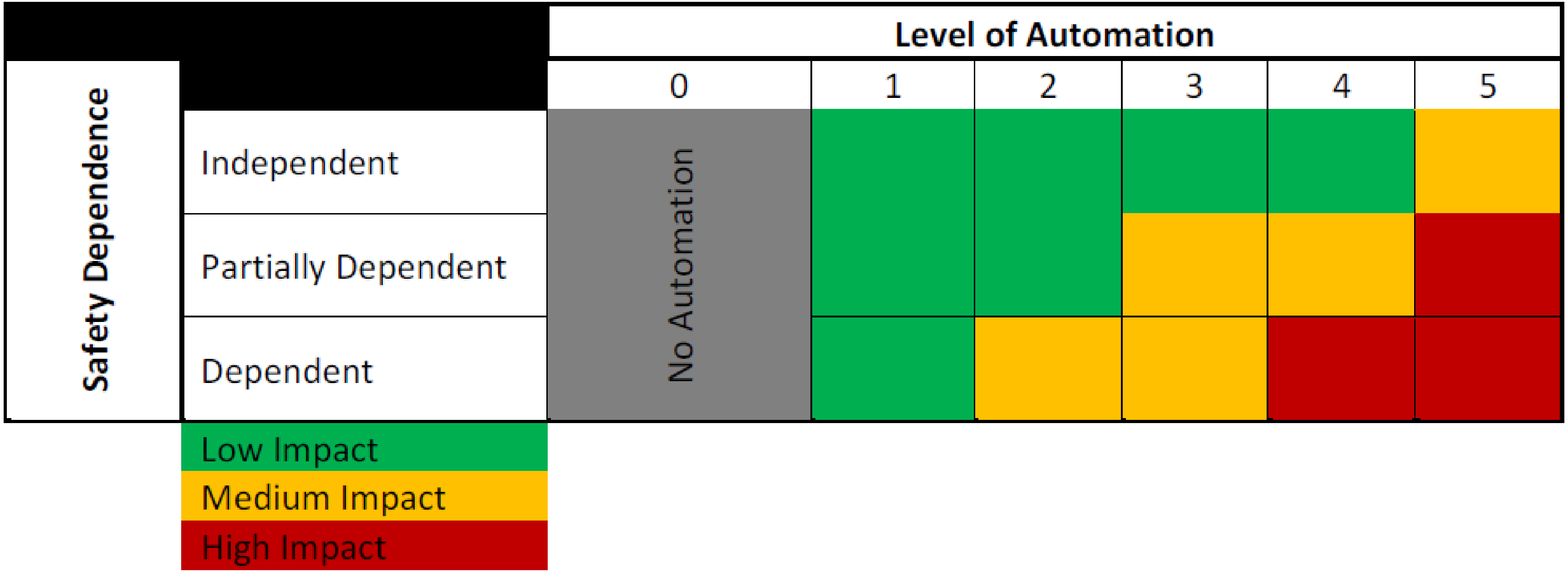
Levels of Automation – Modulation of Authority

- Authority should not be rigidly allocated but instead depend on the current system health and mission integrity characteristics, with suitable Intelligent Health and Mission Management (IHMM) systems supporting safe decision-making for both humans and automation

	Authority		
Level of Automation	*Normal*	*Abnormal*	*Emergency*
Level 0	Human		
Level 1	Human *AND* Machine[1]	Human	Human
Level 2	Human *AND* Machine		Human
Level 3	Machine	Human *AND* Machine[2]	Human[3, 5]
Level 4	Machine		Human *AND* Machine[4, 5]
Level 5	Machine[5]		

Safety Assessment

- A progressive increase in the automation-related operational impacts is propaedeutic to achieving an acceptable and modulated level of safety risk



Automation Technology Maturation

- Progressive mitigation of risks is achieved in line with the technology maturation timeframes

Development Continuum →

Operational Environment	Experimental	Low Risk	Medium Risk	High Risk
Equipment Pedigree	Academic	Commercial-off-the-Shelf	Standardized	Certified
System Chracteristics	Explainable & Capable	Producible & Scalable	Repeatable & Predictable	Reliable & Robust

Autonomous Navigation and Guidance Systems

Outline

What is guidance & navigation

Guidance

- Conventional
- Autonmous
- Example

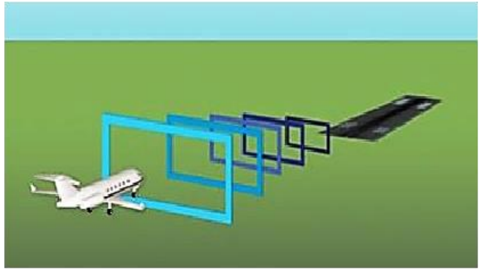
Navigation

- Conventional
- Autonmous
- Example

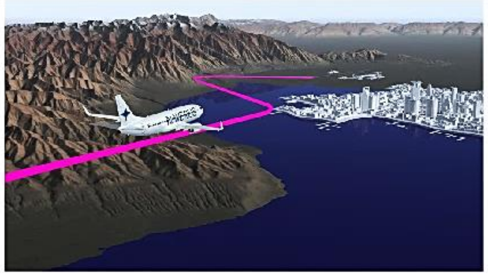
Implementation

What is Guidance and Navigation

Guidance refers to the determination of the desired path of travel (the "trajectory") from the vehicle's current location to a designated target, as well as desired changes in velocity, rotation and acceleration for following that path

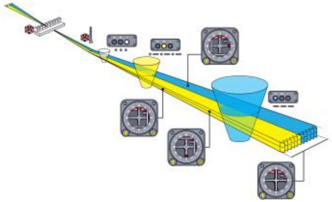


Navigation is the ability to determine the aerospace vehicle location usually in terms of latitude, longitude & altitude and to be able to figure out a path that will take the vehicle from current location to the desired location which will also be defined in earth reference system

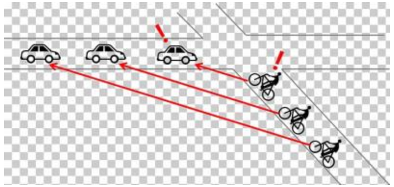


Conventional Guidance Algorithms

- Command Guidance



- Homing Guidance
  - Proportional Navigation



- Optimal Control Theory

Autonomous Guidance

- Path Planning
- Energy Conservation
- Collision Avoidance
- Weather Routing
- Formation Control and Synchronization
- Target/ Destination Identification
- In Flight Reconfiguration

Autonomous Guidance

Real World Example

Airbus Auto'Mate Project

Autonomous and unmanned air-to-air refuelling technologies

- Accurate Relative Navigation to precisely ascertain the relative position, speed and attitudes between the tanker and the receiver
- Intra-Flight Communication between platforms to allow information exchange among the different assets, increasing the autonomy of the system of systems
- Cooperative Control Algorithms to provide guidance, coordination, consensus and collision-avoidance functionalities to the tanker and the receiver/s

Taken from Airbus Website
https://www.airbus.com/en/newsroom/press-releases/2023-03-airbus-achieves-in-flight-autonomous-guidance-and-control-of-a

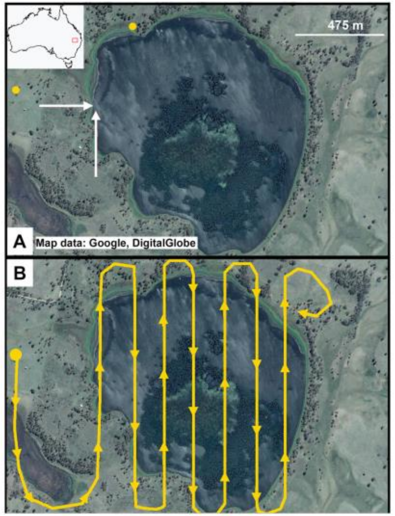
Conventional Navigation Techniques

- Radio Navigation Aids
- Dead Reckoning
- GNSS
- Celestial
- Multisensor

Autonomous Navigation

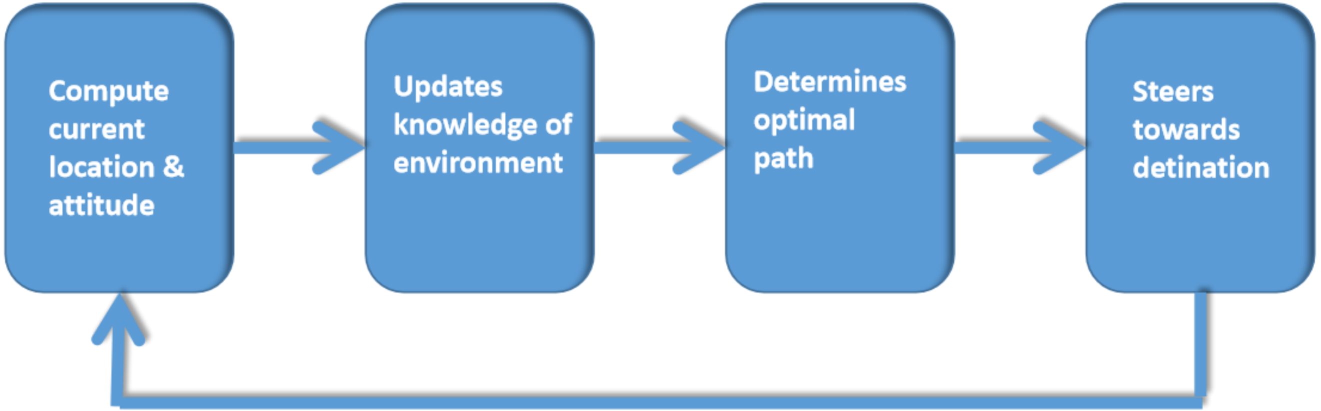
Characteristics

- ❖ Determines current location & orientation using all available sensors
- ❖ Knows its destination location
- ❖ Updates its knowledge of the environment
- ❖ Steers towards the target keeping track of its position
  - ➢ **Avoiding Obstacles**
  - ➢ **Using onboard algorithms**



Autonomous Navigation

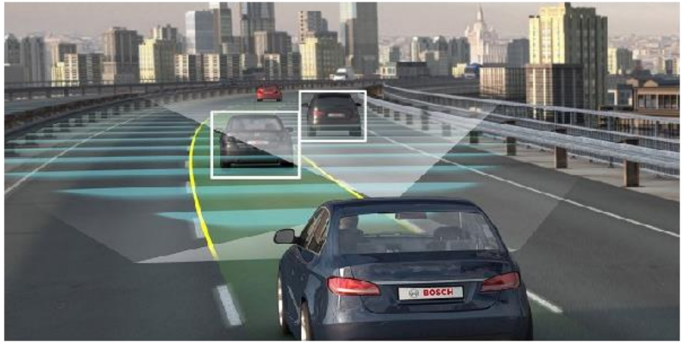
Characteristics

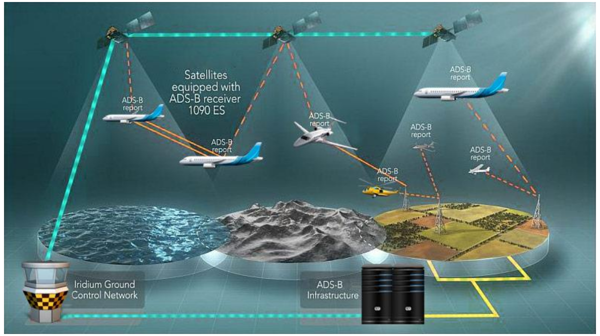


Autonomous Navigation

Types

- ❖ Heuristic or Rule Based
  - ❖ Like a robot cleaning the room with vacuum
- ❖ Algorithm Based Optimal Solution
  - ➢ Self driven cars
    - ☐ Continuously Updates Environment Model
    - ☐ Avoids Obstacles and other cars
    - ☐ Reaches Destination in optimal time

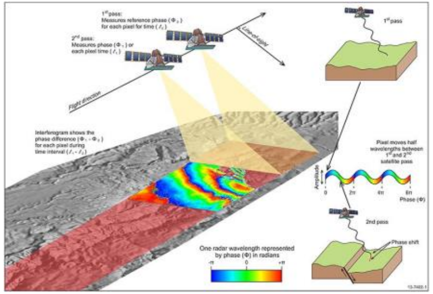


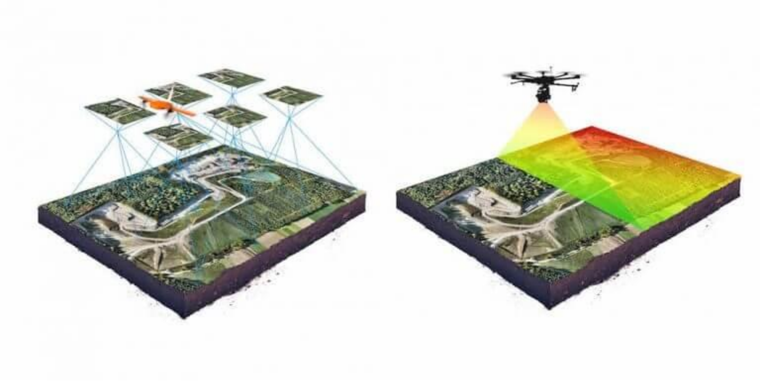


Autonomous Navigation

Algorithms

- Localization (Area Map Known)
  - Multisensor Fusion
    - Kalman Filter
    - Particle Filter
- Simultaneous Location and Mapping (SLAM)
  - Filtering
    - Extended Kalman Filtering
    - Particle Filtering
  - Smoothing
  - Pose Graph Optimization





Autonomous Navigation
Path Planning

- Static Environment Path Planning
  - Search based algorithms
  - Sampling based algorithms

- Dynamic Environment
  - Cooperative
  - Non-Cooperative

Autonomous Navigation

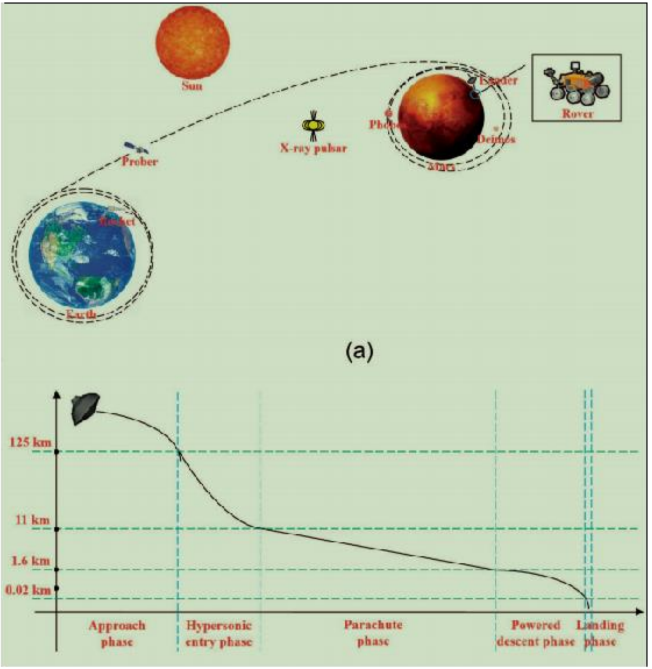
Enabling Technologies

- Inertial Sensors
- GNSS
- Vision Based Systems
- AI/ML
- Filtering Algorithms
- High End Processors

Autonomous Navigation

Real Life Example

- ❖ Entry Descent Landing Phase
  - ➢ Inertial Navigation
  - ➢ Satellite Navigation
  - ➢ Celestial Navigation
- ❖ Mars Rover Deployment
  - ➢ Image Based Navigation
  - ➢ Multisensor Navigation
  - ➢ Localization/SLAM



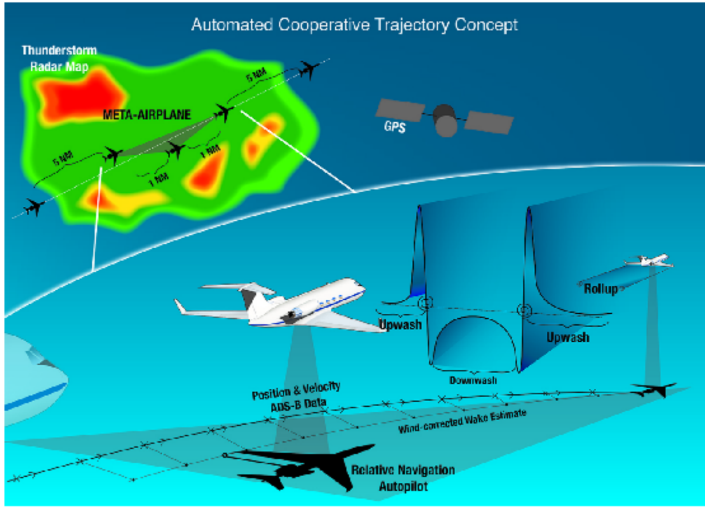
Courtesy book titled Mars Exploration edited by Giuseppe Pezzella and Antonio Viviani

Autonomous Navigation

Implementation

- ❖ A system comprising many elements

- ❖ Key Performance Indicators
  - ➢ Safety
  - ➢ Robustness
  - ➢ Positional Accuracy
  - ➢ Comfort (Vehicles carrying passengers)



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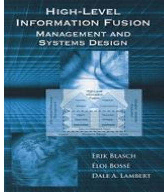
8. Certification Challenges and Industry Perspectives	Aloke (13:50)
9. Wrap Up and Questions	All (14:10)

Advances in Human-Machine Systems

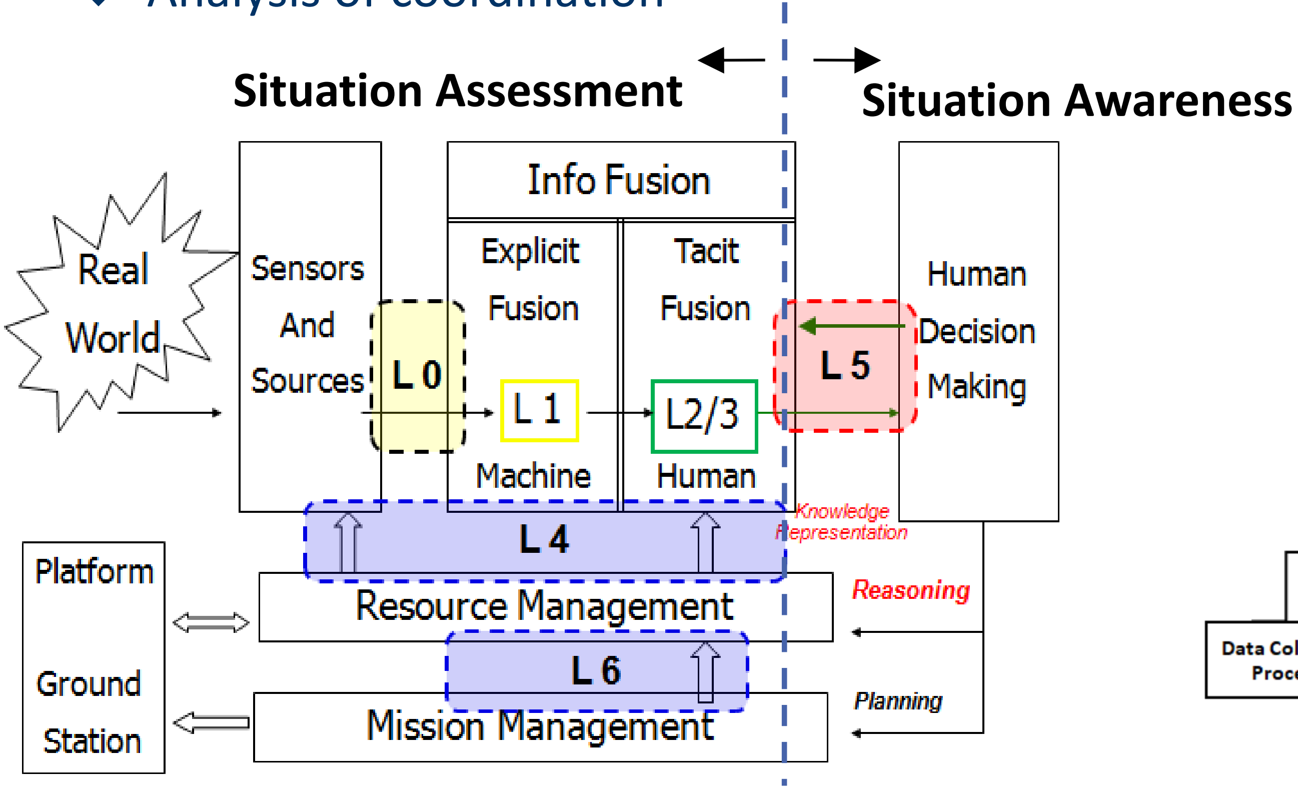
HMI Considerations

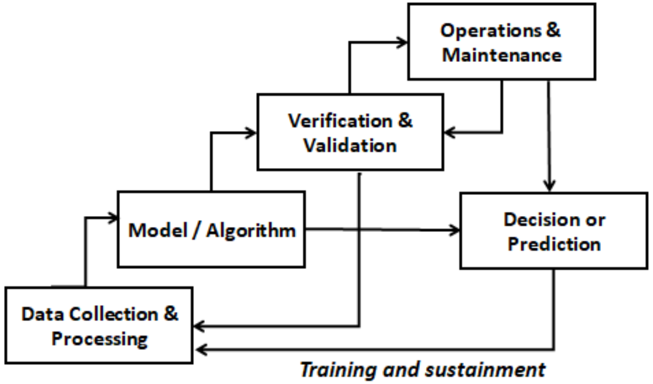
- ❖ Human Interaction (Data Fusion Model)
- ❖ Cognitive reasoning and task coordination
- ❖ Intelligent design through semantic ontologies
- ❖ Autonomy in Use
- ❖ User Defined Operating Picture (display/visualization)
- ❖ Certification issues:
  - No one-on-one certification for UTM (akin to aircraft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

Human Machine Model



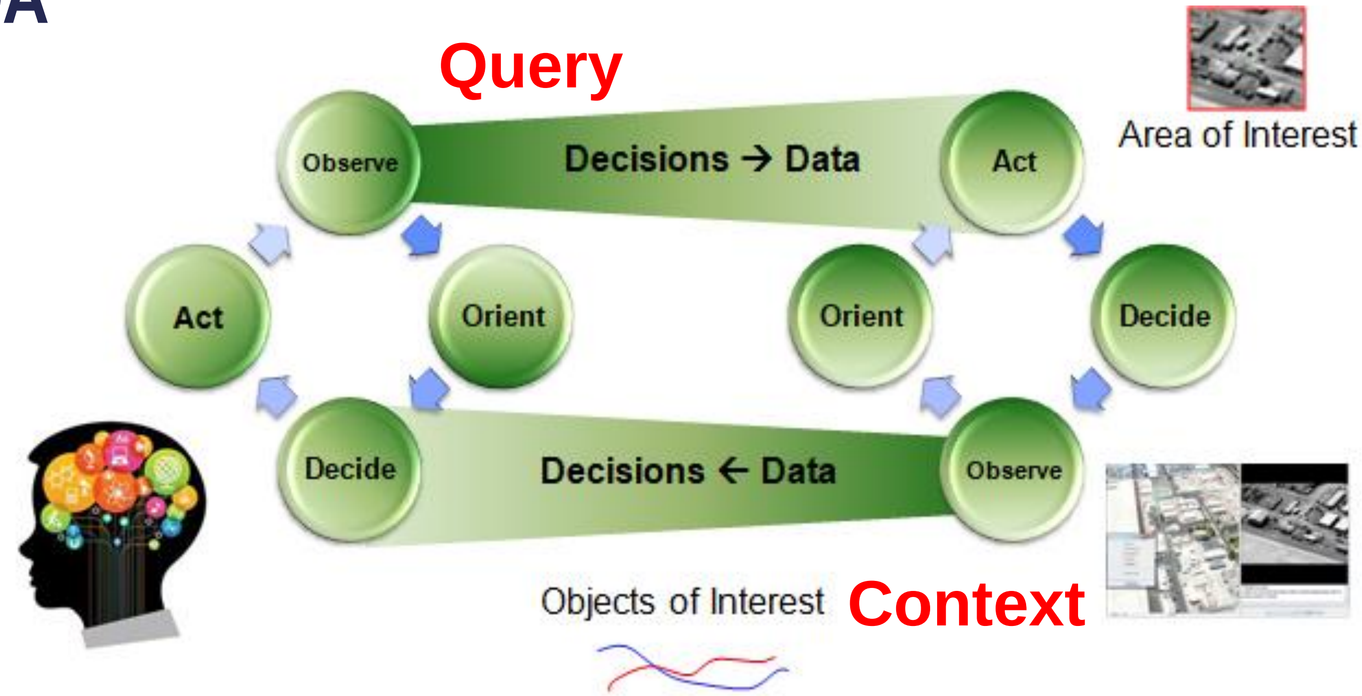
❖ Analysis of coordination





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

OODA

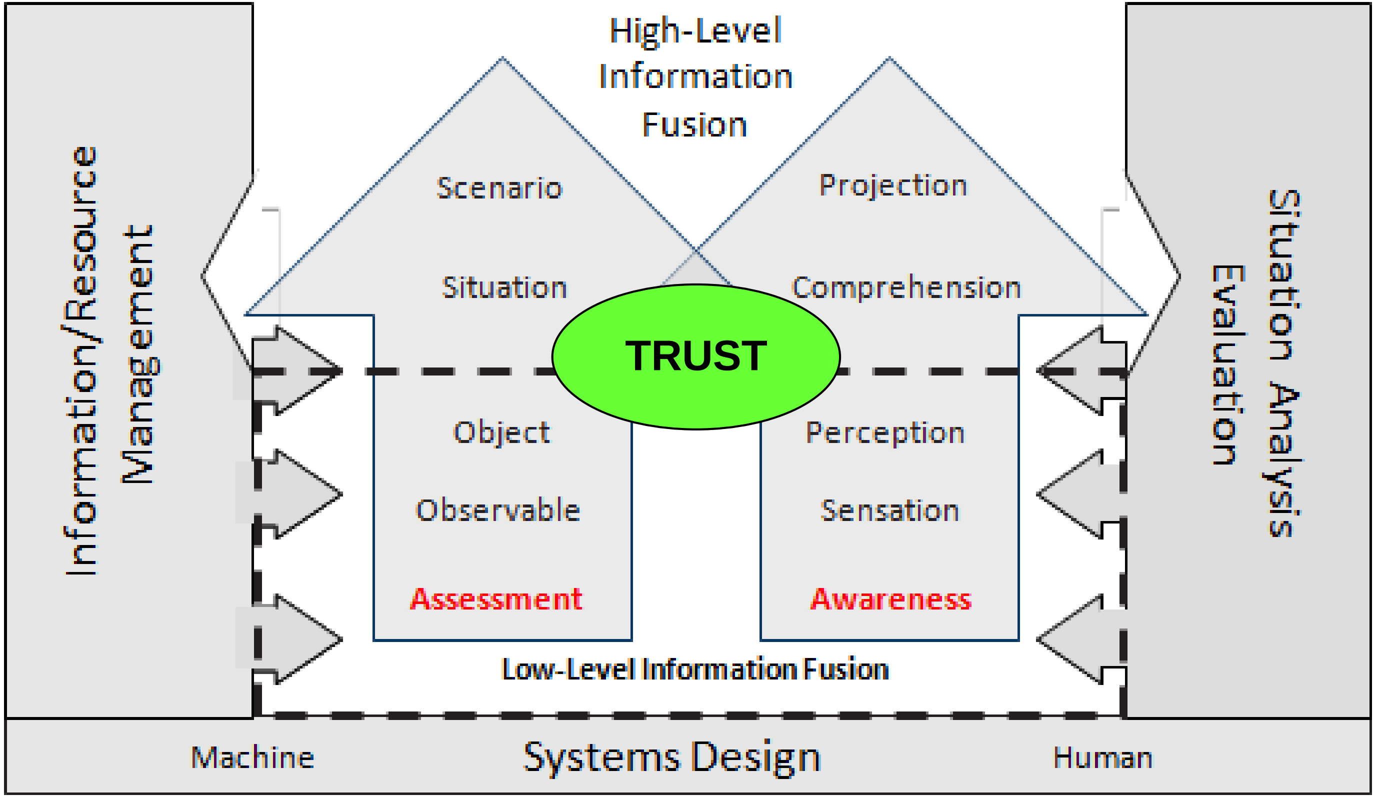


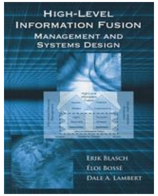
Human-Machine Teaming

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.

Situation Assessment (Machine) for Situation Awareness



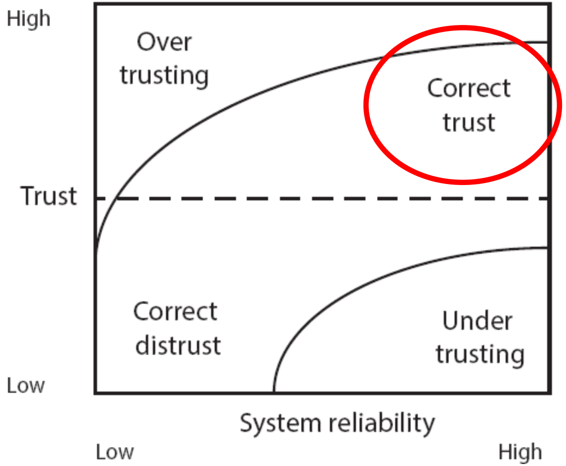


E. P. Blasch, E. Bosse, and D. A. Lambert, *High-Level Information Fusion Management and Systems Design*, Artech House, Norwood, MA, 2012.

Earn Trust

Trust Dimensions, (Muir & Moray, 1996) postulated that Trust = Predictability + Dependability + Faith + Competence + Responsibility + Reliability

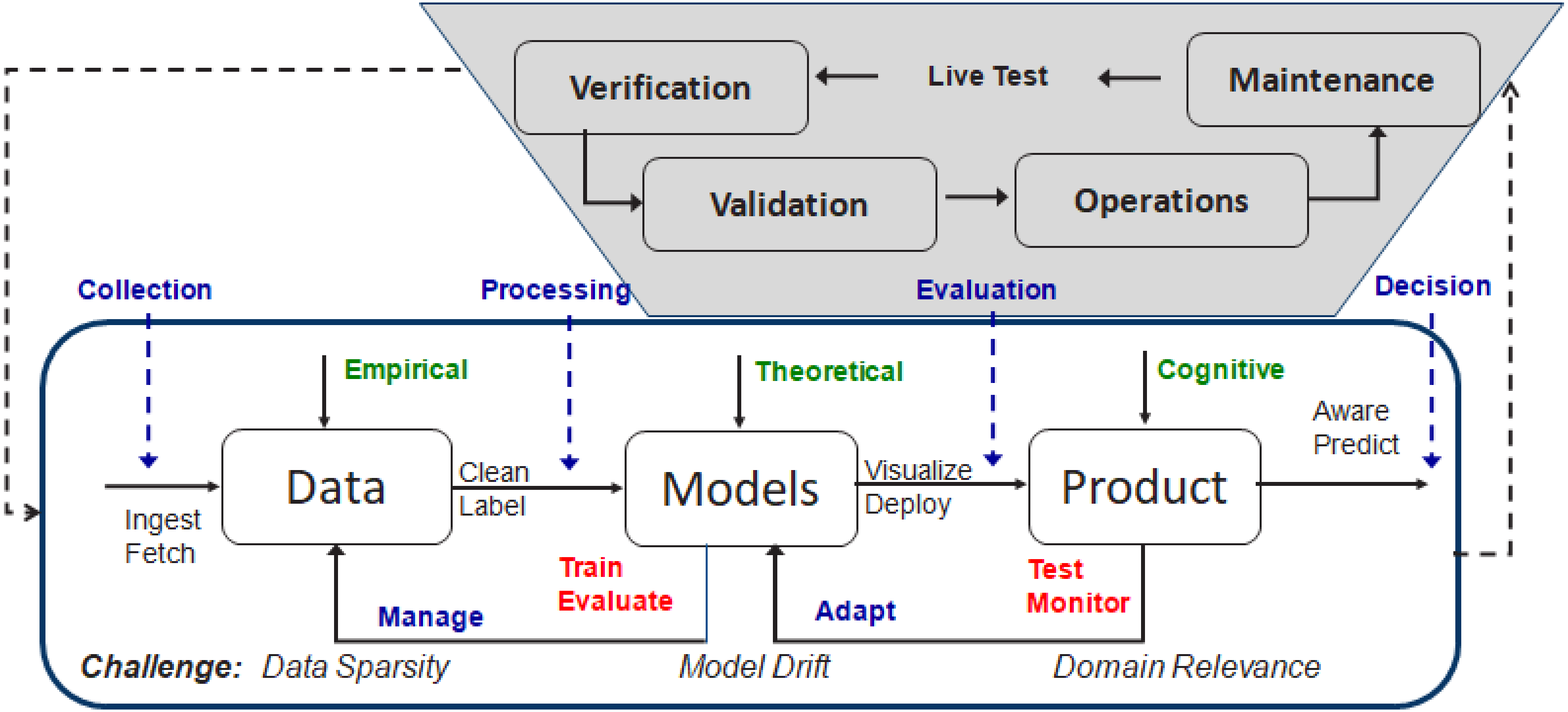
Operator's trust & allocation of function	Quality of the automation 'Good'	'Poor'
Trusts and uses the automation	***Appropriate Trust*** (optimize system performance)	***False Trust*** (risk automated disaster)
Distrusts and rejects the automation	***False Distrust*** (lose benefits of automation, inc. workload)	***Appropriate Distrust*** (optimize system performance)



Helldin, T. "Transparency for Future Semi-Automated Systems: Effects of Transparency on performance, workload, and trust," PhD Dissertation, Univ of Skovde, 2014

Systems Engineering

Consider human cognitive model

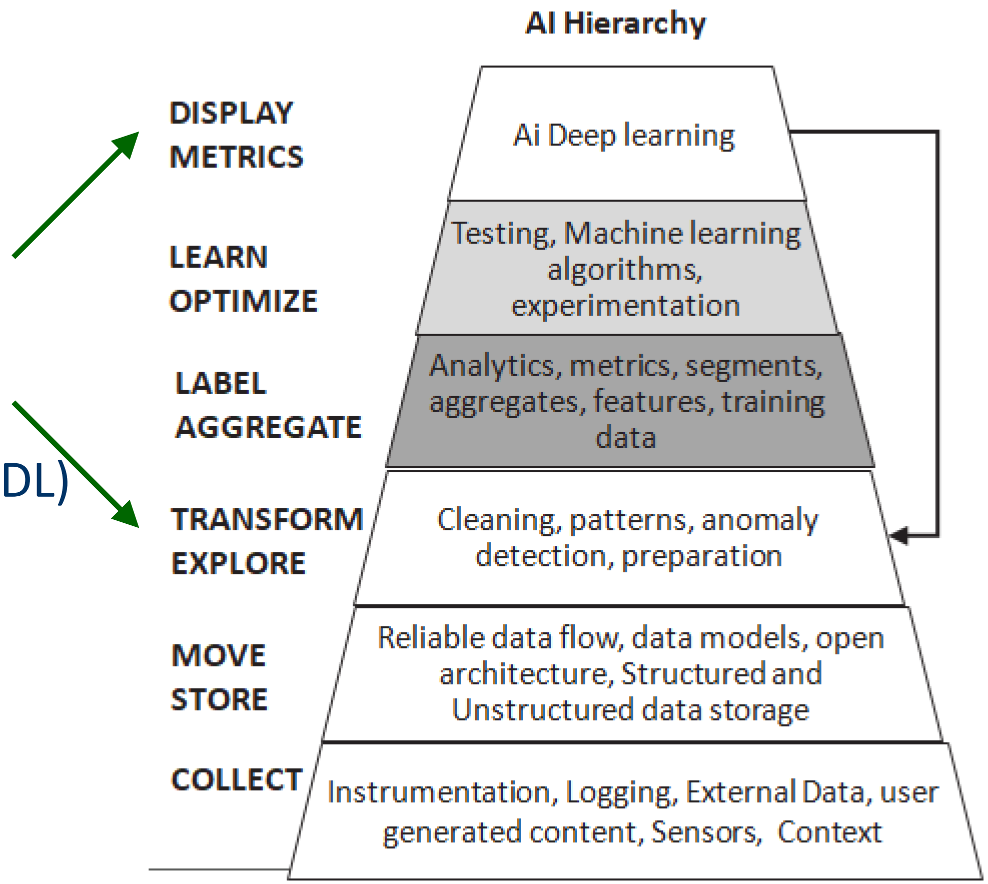


E. Blasch, et al, "Certifiable Artificial Intelligence Through Data Fusion," AAAI FSS-21, 2021. http://arxiv.org/abs/2111.02001

Human Machine Model

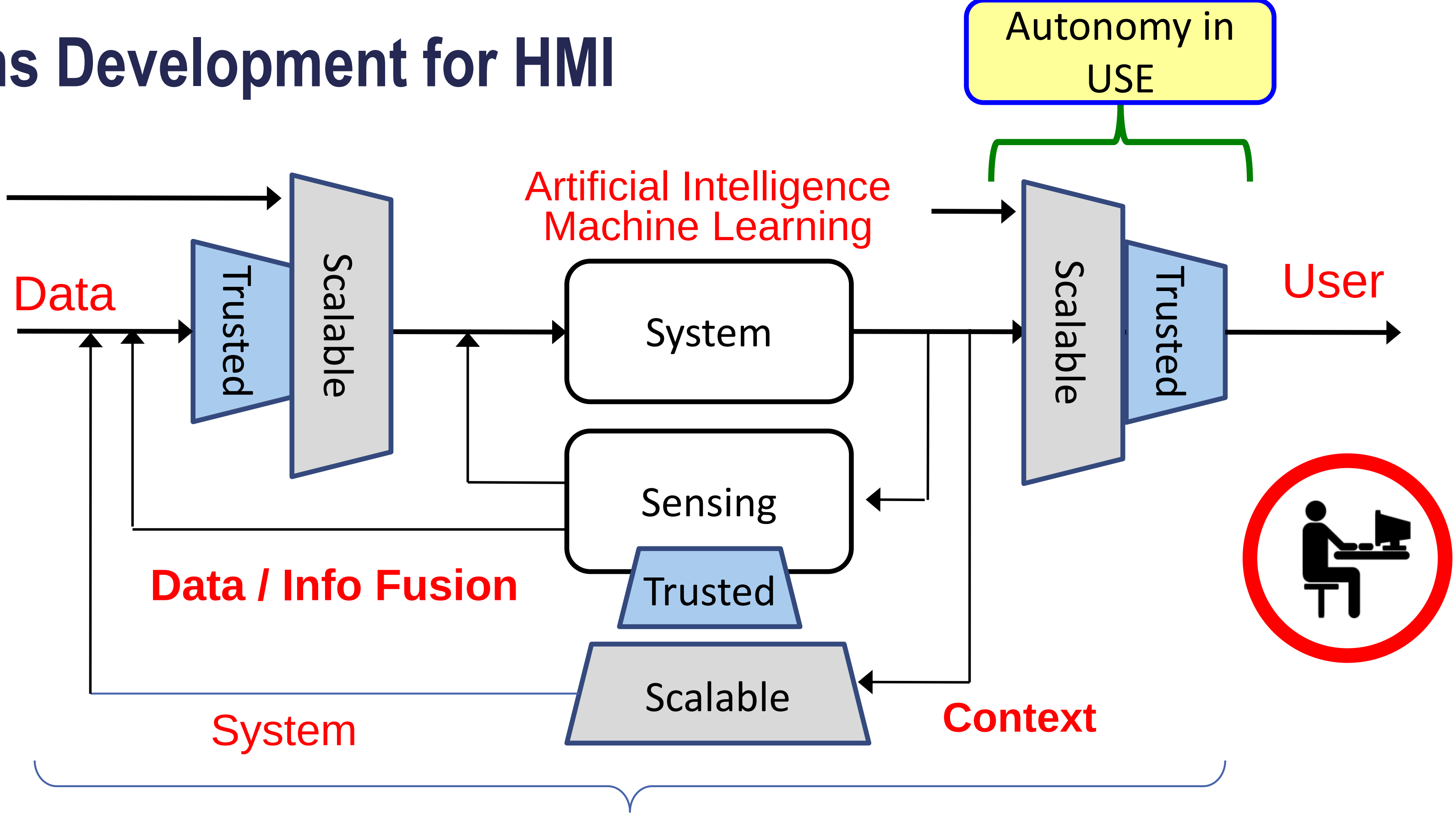
- Analysis of coordination
- Human – Interprets Results
- BUT …………
- Cleans, Labels (semi-supervised DL)
- Approves data movement
- Selects the data to collect

….. 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

Systems Development for HMI

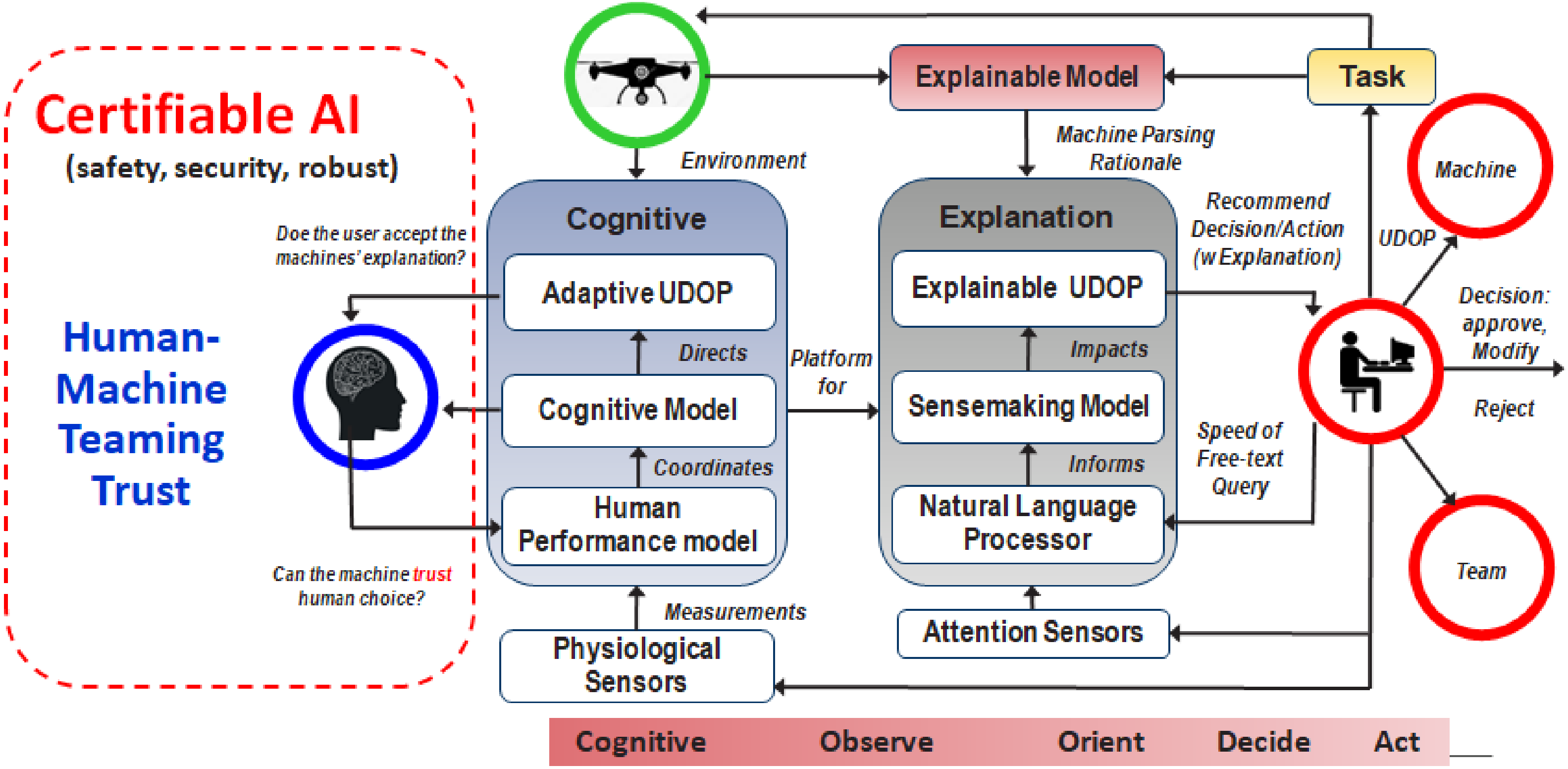


Scalable: f(users, data, software, hardware, network)

Sys Eng

- Performance Evaluation
- Maturity Certification

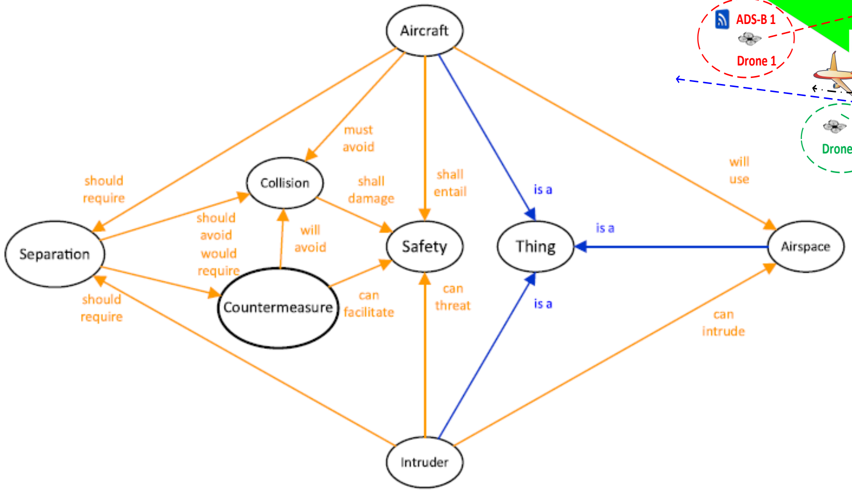
Cognitive reasoning and task coordination

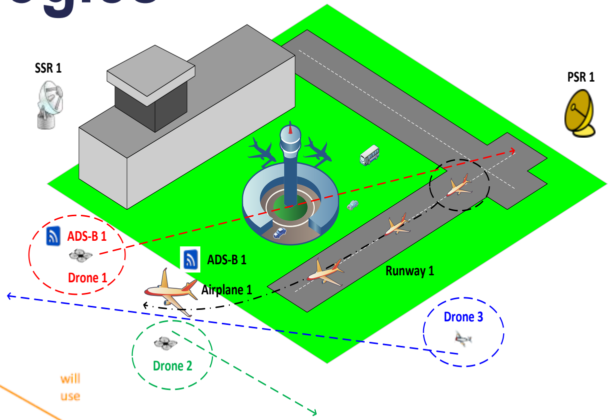


E. Blasch, et al, "Certifiable Artificial Intelligence Through Data Fusion," AAAI FSS-21, 2021. http://arxiv.org/abs/2111.02001

Intelligent design through semantic ontologies

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



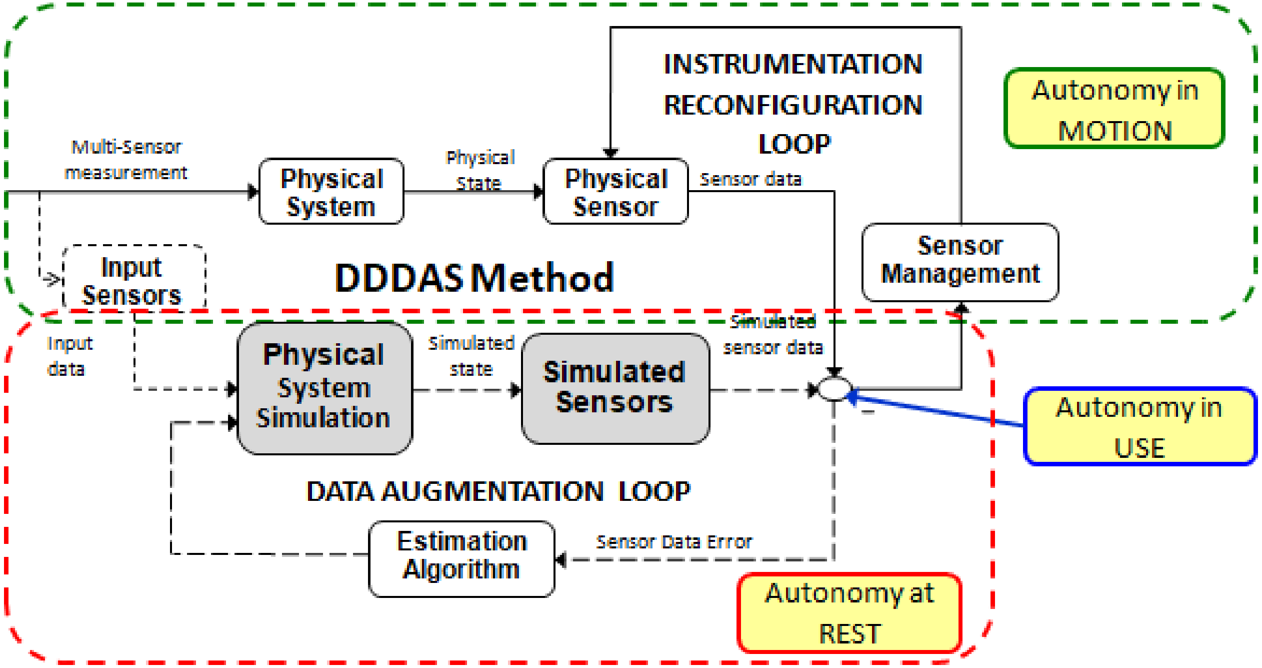


C. Insaurralde, E. Blasch, P. Costa, and K. Sampigethaya, "Uncertainty-Driven Ontology for Decision Support System in Air Transport" *Electronics* 11(3):362, Jan 2022. https://doi.org/10.3390/electronics11030362.

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

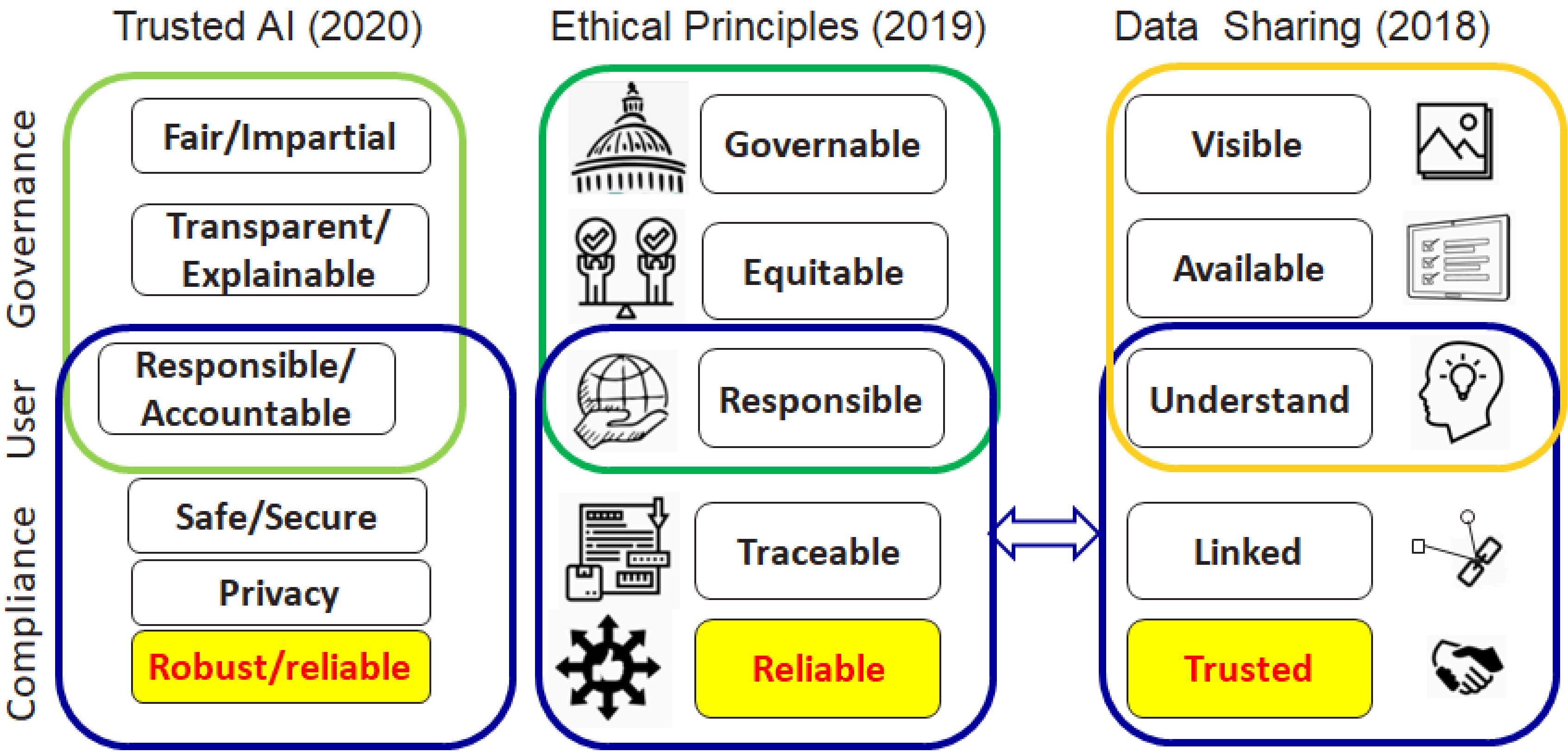
Support Plausible Scenarios



- ❖ 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

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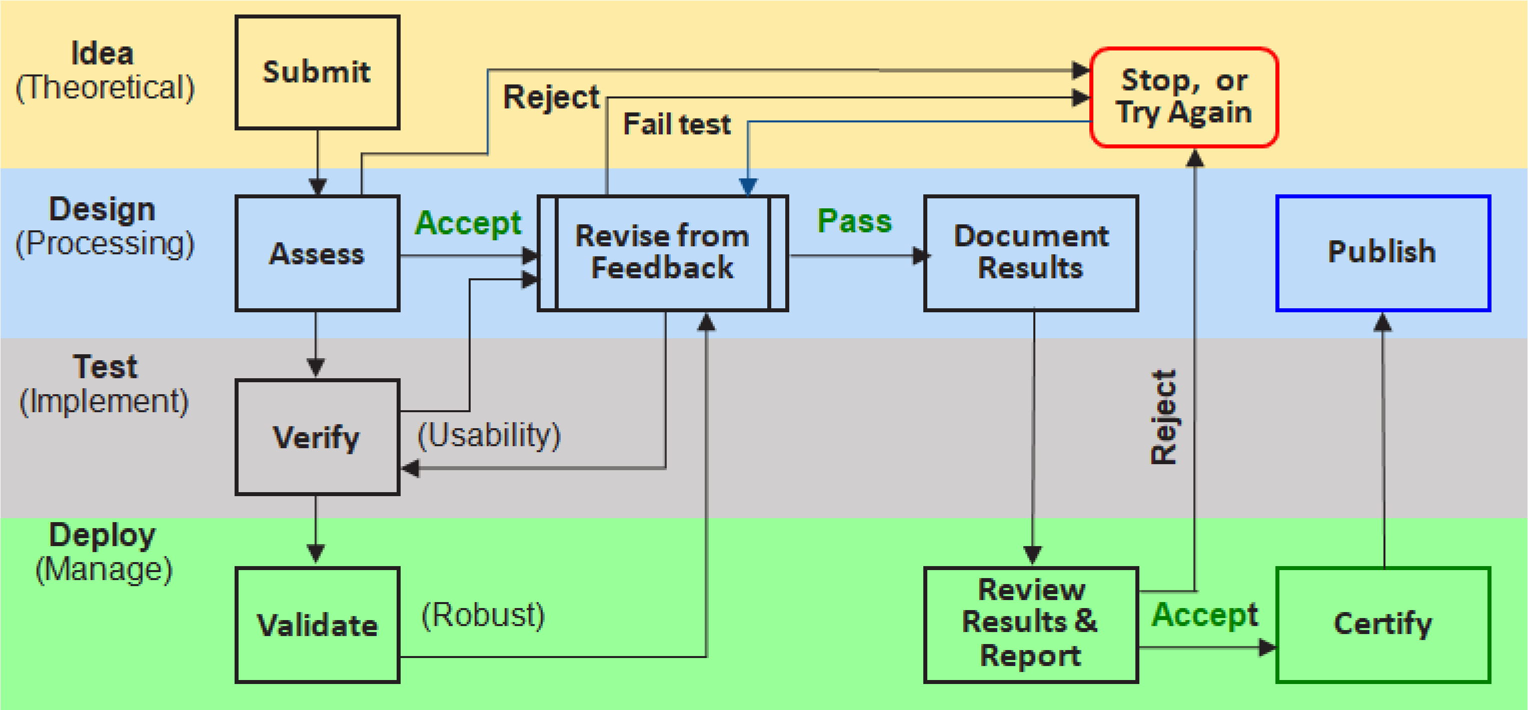
Certification Issues



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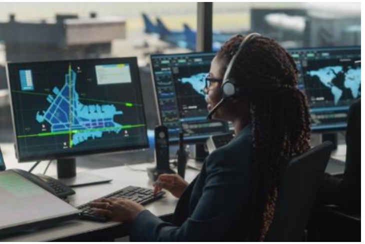
Certification Opportunities

Needs

- Reliable/Resilient
- Cooperative
- Multi-modal
- Secure
- Robust
- Efficient/effective
- Durable

Methods

- ❖ Sensor Data Fusion (SDF)
- ❖ Artificial Intelligence (AI)
- ❖ Machine Learning (ML)
- ❖ Deep learning (DL) (e.g., DNN)
- ❖ Cognitive (e.g., radio, network)
- ❖ Software-defined (e.g., radio, network)



Certifiable AI/ML

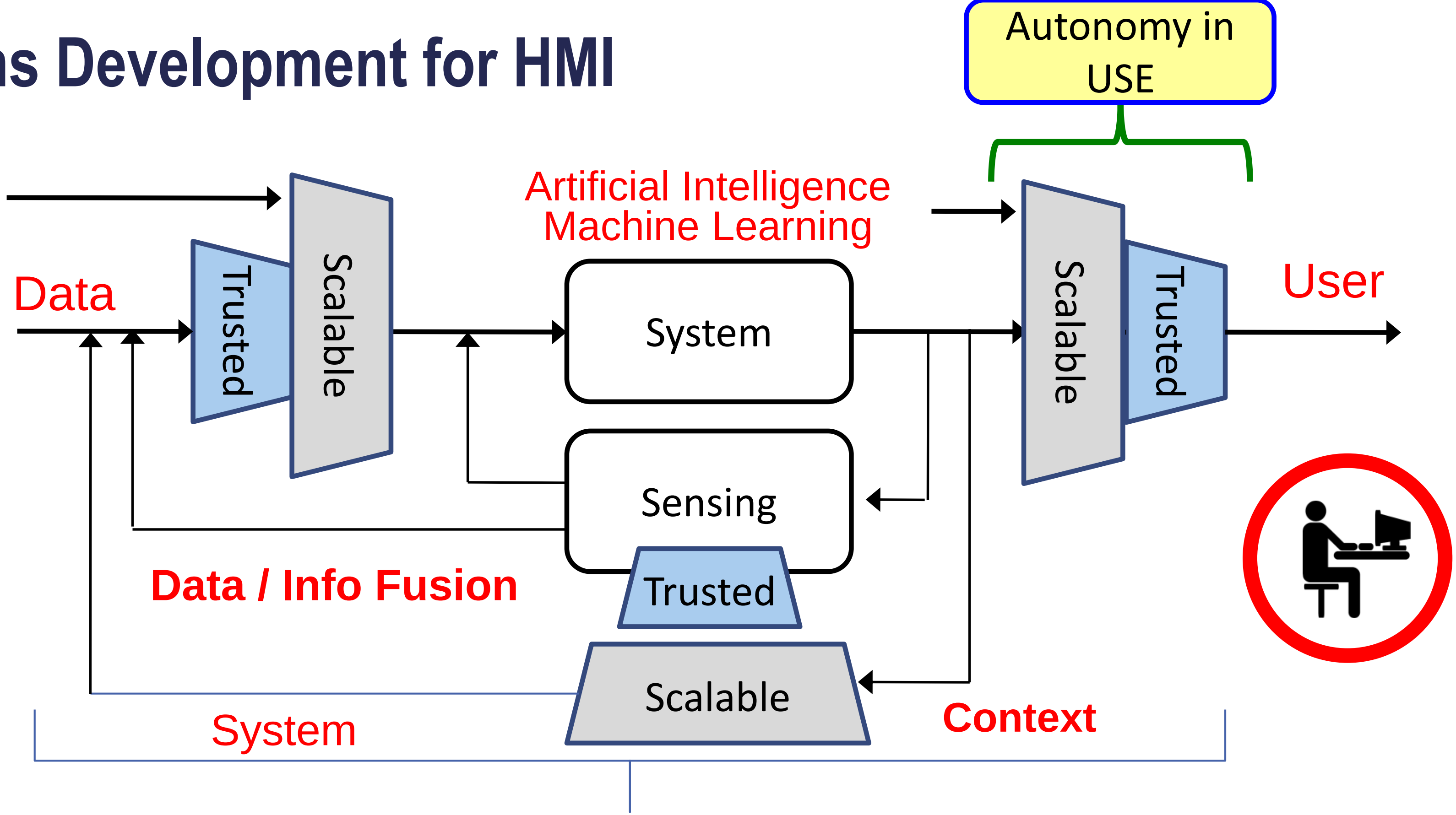
Meet performance bounds

Trusted **Data Fusion** **at Scale**

Air traffic control chaos caused by 'one in a million' occurrence - Travel Gossip

AIAA, 2023

Systems Development for HMI



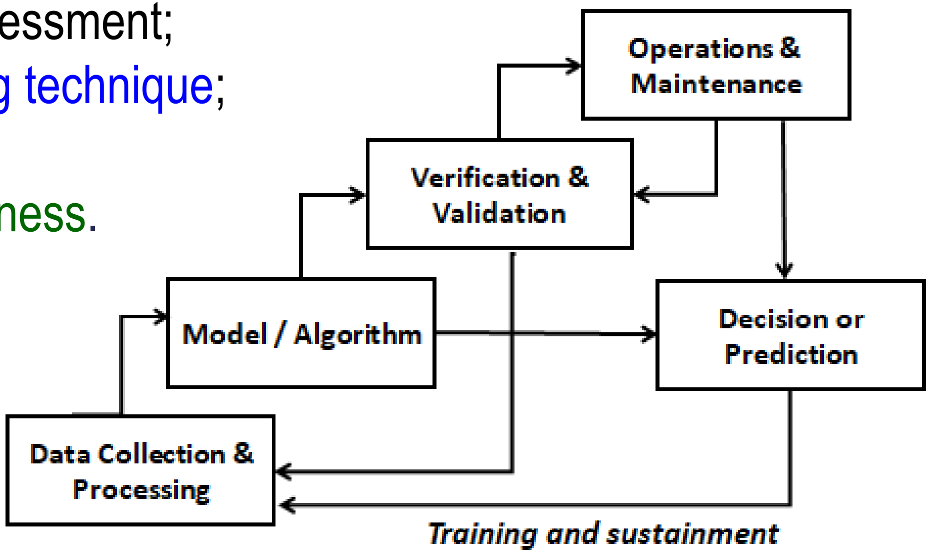
Sys Eng

- Performance Evaluation
- Maturity Certification

Scalable: f(users, data, software, hardware, network)

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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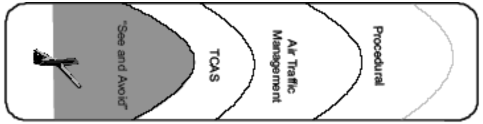
Sense-and-Avoid Technologies

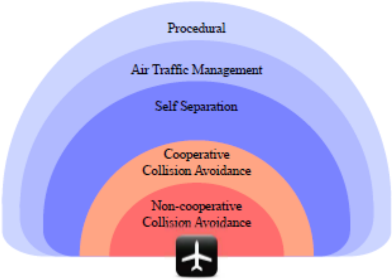
Sense-and-Avoid Technologies

- Definitions and Principles of Sense-and-Avoid
    - Topic addressed in details in a specific DASC Tutorial
- Solutions and Trends
    - Sensing technologies
    - Avoidance
    - AI/ML
- Perspectives

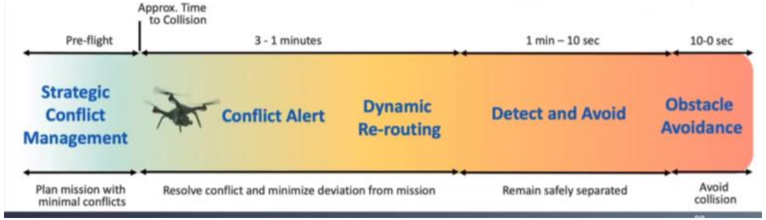
Principles of Sense-and-Avoid

- 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)

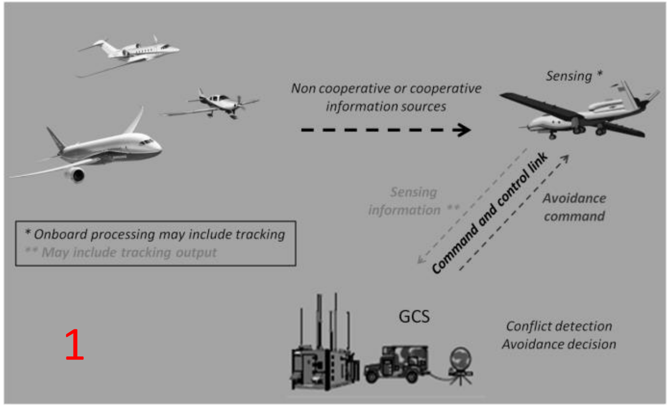
Principles of Sense-and-Avoid: Taxonomy

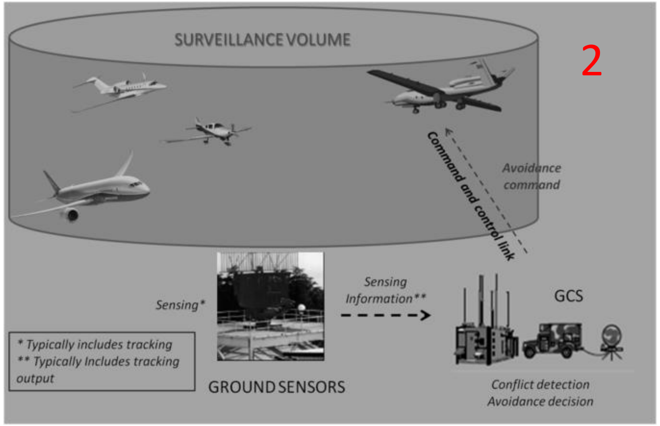
- These three fundamental tasks of an SAA system can be implemented in different ways, giving rise to several architectural and technical solutions. These solutions can then be classified using different taxonomies

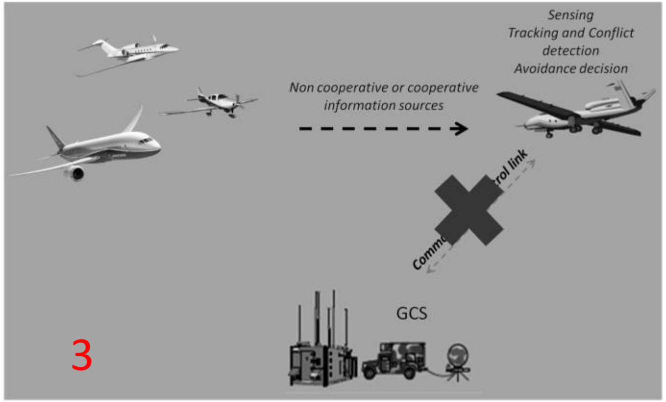
- A general approach for classification that involves all three parts is based on the physical location of information sources and processing/decision making centers

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

Principles of Sense-and-Avoid: Taxonomy

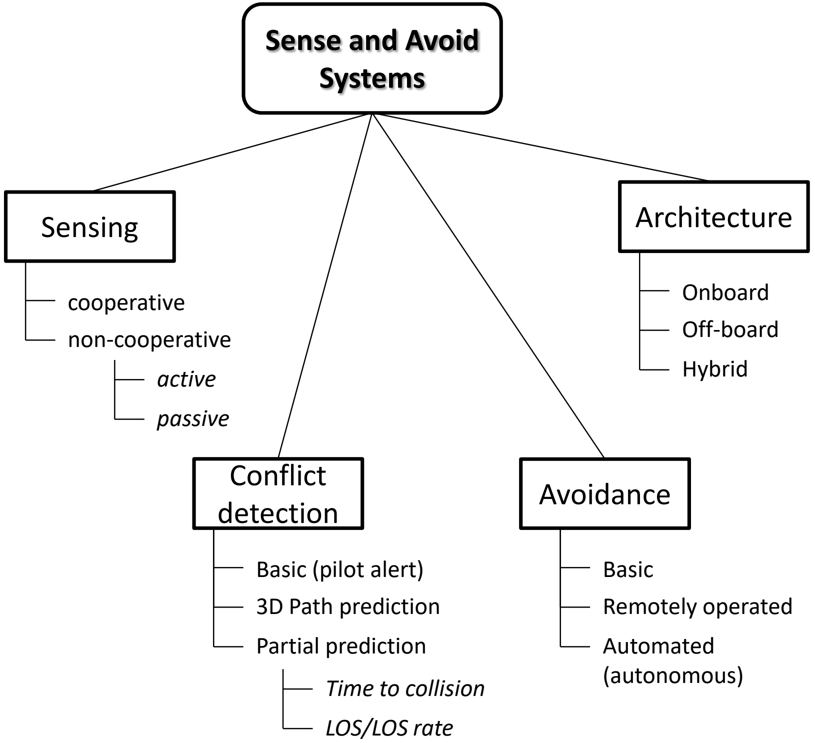






Principles of Sense-and-Avoid: Taxonomy

- General SAA Taxonomy



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

Sense-and-Avoid: Sensing

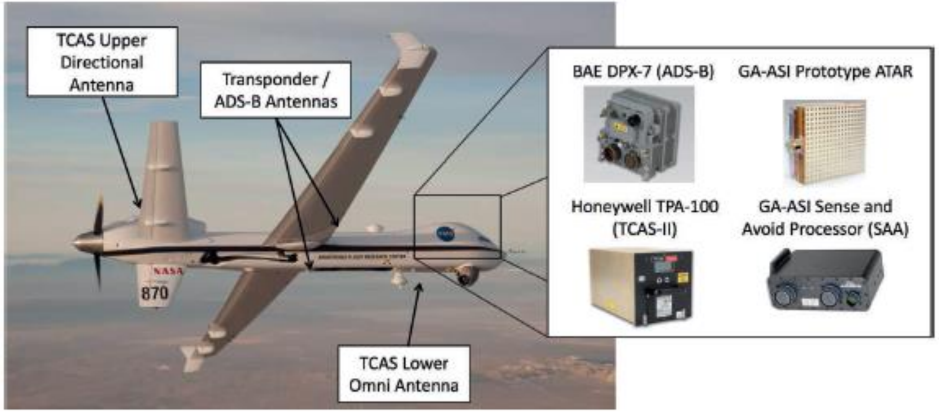
- Monostatic radars and daylight cameras as traditional options for medium/large and small UAS

Method / Energy	ACTIVE (requires electronic interrogation)	PASSIVE (no electronic interrogation)
LIGHT	LIDAR • Direct Energy • Coherent	Optical (camera) • Visible light • Infra-red
RF	Monostatic RADAR Bi/Multi-static RADAR (known signal source)	Bi/Multi-static RADAR (using signals-of-opportunity – cell, FM radio)
SOUND	SONAR	Acoustic (microphone) • Array • Vector

Current Trends: Radar Sensing

❖ Large UAS

- Several companies developing air-to-air radars for large UAS
- C-band and X-band considered, electronic scanning
- Radar as key sensor to enable UAS integration without chase planes and observers
- Software defined architectures and multi-function options being considered

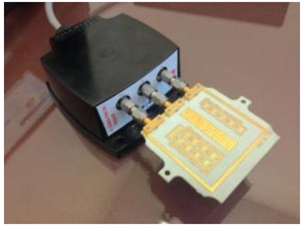


From: T. Kotegawa, "Proof-of-concept airborne Sense-and-Avoid system with ACAS-XU flight test," in *IEEE Aerospace and Electronic Systems Magazine*, vol. 31, no. 9, pp. 53-62, September 2016

Current Trends: Radar Sensing

- Small UAS / UAM / AAM
  - (high frequency) FMCW technology to cope with limited onboard power and size/weight budgets, link with automotive technology
  - Multi-channel techniques and/or innovative beam steering approaches (metamaterial antennas) to combine wide FOV coverage and degree-level angular accuracy
  - Different classes, weight ranging from a few tens of grams to order 1 Kg
  - Low target detectability as an issue for low power / low gain solutions in view of moving traffic avoidance
  - Ground clutter removal as a key issue in very low altitude scenarios

https://echodyne.com/products/echoflight/

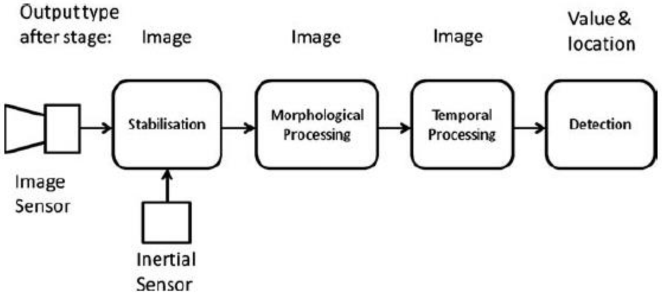


https://shop.imst.de/radar-solutions/

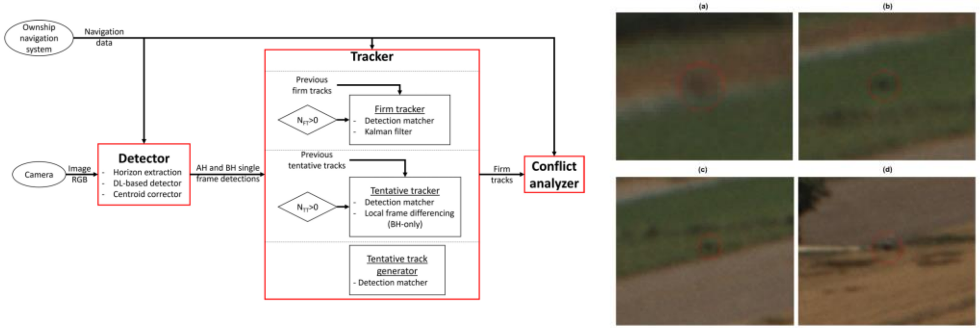
(https://ntrs.nasa.gov/api/citations/20210009973/downloads/NASA-CR-20210009973.pdf)

Current Trends: Visual Sensing

- Main trends of interest concern algorithms (and computational power)
- Sky region vs below-the-horizon sensing
- Several sky region techniques augment morphological filters with multi-temporal techniques to extract slowly moving targets. Morphological filters can be aided or replaced by AI-based detectors
- Below-the-horizon: frame differencing / image registration concepts – challenges, appearance-based techniques using deep learning



(J. Lai et alii, Journal of Field Robotics, 2013)



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

Current Trends: Visual Sensing

- Deep learning also exploited in commercial solutions (airborne and ground-based)
- Emphasis on detection and tracking of manned aircraft
  - Non cooperative traffic 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/)

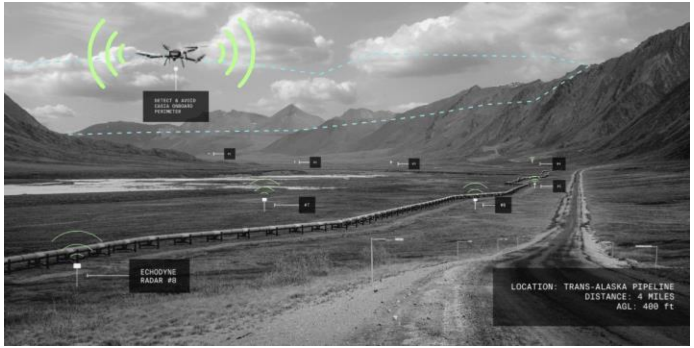
(https://daedalean.ai/products/detection)

Current Trends: Ground-based sensing

- Main Technologies

  - Monostatic or traditional radar: existing, repurposed or new sensors
  - Bi-static or multi-static radar
  - EO cameras
  - Passive Acoustic

- Initially conceived as a near term / geographically limited solution. Development towards distributed sensing networks
- Less SWaP constraints, limited surveillance volumes with variable sensing accuracy. Link with communications requirements and airspace management concepts

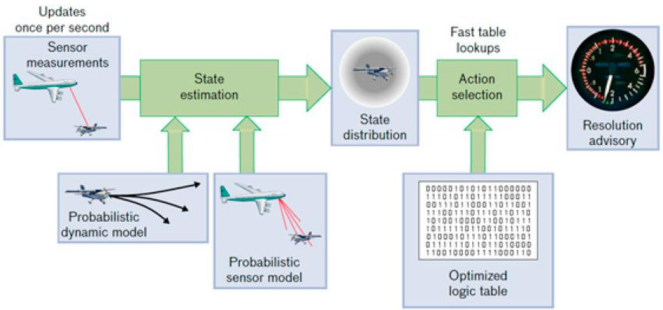


Combination of airborne cameras and ground-based radars (Echodyne Echoguard)
https://dronebelow.com/2019/08/02/first-ever-bvlos-drone-operation-without-visual-observers/

https://www.raytheon.com/capabilities/products/skyler

Avoidance: Solutions and trends

- ❖ Probabilistic and deterministic approaches being considered in standard developments. Main examples: ACAS-Xu and DAIDALUS
- ❖ Other efforts aimed at new scenarios: ACAS-sXu and ACAS-Xr
- ❖ Active research on autonomous avoidance with emphasis on complex environments



Once per second, ACAS X ingests and processes surveillance data and determines the optimal action for every target aircraft.

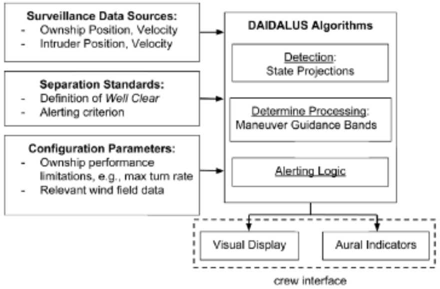


Figure 1. High-Level Architecture of DAIDALUS

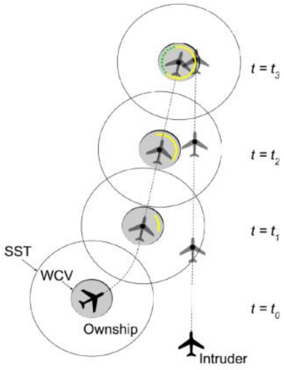


Figure 4. Maneuver Guidance Bands

(Olson, W. A.: Airborne Collision Avoidance System X. , Massachusetts Institute of Technology, Lincoln Laboratory, June 2015. Tech Notes)

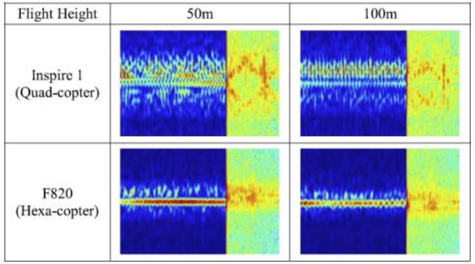
(C. Muñoz et al., “DAIDALUS: Detect and Avoid Alerting Logic for Unmanned Systems,” 2015 IEEE/AIAA 34th Digital Avionics Systems Conference (DASC))

AI in Sense-and-Avoid

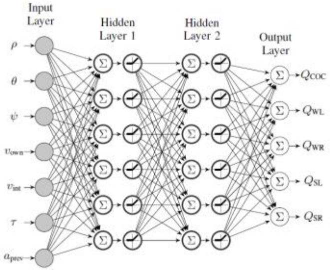
- AI potential is being investigated in the whole SAA pipeline

- Sensing
  - Visual
  - Information extraction by CNNs from raw radar and acoustic data

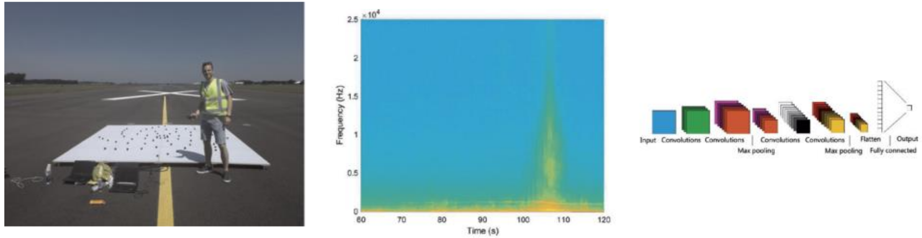
- Decision-making
  - Neural networks to compress look-up tables in ACAX-sXu
  - Reinforcement learning
  - End-to-end AI-based solutions
  - Many recent approaches are relevant to Micro Aerial Vehicles and agile flight in cluttered environments



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



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



(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 – Considerations

- 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
  - Datasets for new operating environments
- Certification
  - dataset characterization
  - stochastic nature of non cooperative sensing
  - multi-stage processing pipelines → system level perspective

Perspectives

- Lots of on-going activities on SAA in ATM (en-route and terminal areas)
  - Link with enhanced safety for manned aviation (sensing subsystem as a pilot assistance tool, contingency management)
  - Interoperability between SAA and manned aircraft collision avoidance

- Evolution of very low altitude SAA closely related to evolving U-Space/UTM concepts
  - Definition of requirements and standards: how much is enough?
  - Need for integrated and «technology aware» approach
  - Different use cases likely to be accounted for

- UAM/AAM as a new entrant – main players addressing SAA
  - Depending on mission profiles, link between SAA in ATM and UTM/U-Space

- SAA as an exciting and evolving framework still presenting a number of open issues

- The diversity of UAS, and the related diversity of issues around SAA have contributed to the fact that there is not one accepted answer for SAA for UAS

1. Introduction to the IEEE AESS Avionics Systems Panel	Rob (11:30)
2. Air and Space Transport Innovation Ecosystem	Alex (11:50)
3. Autonomous Navigation and Guidance Systems	Irfan (12:10)
4. Advances in Human-Machine Systems	Erik (12:30)
5. Sense-and-Avoid Technologies	Giancarmine (12:50)
6. Ontologies for Space Domain Awareness	Carlos (13:10)
7. Cyber Security Challenges	Kathleen (13:30)
8. Certification Challenges and Industry Perspectives	Aloke (13:50)
9. Wrap Up and Questions	All (14:10)

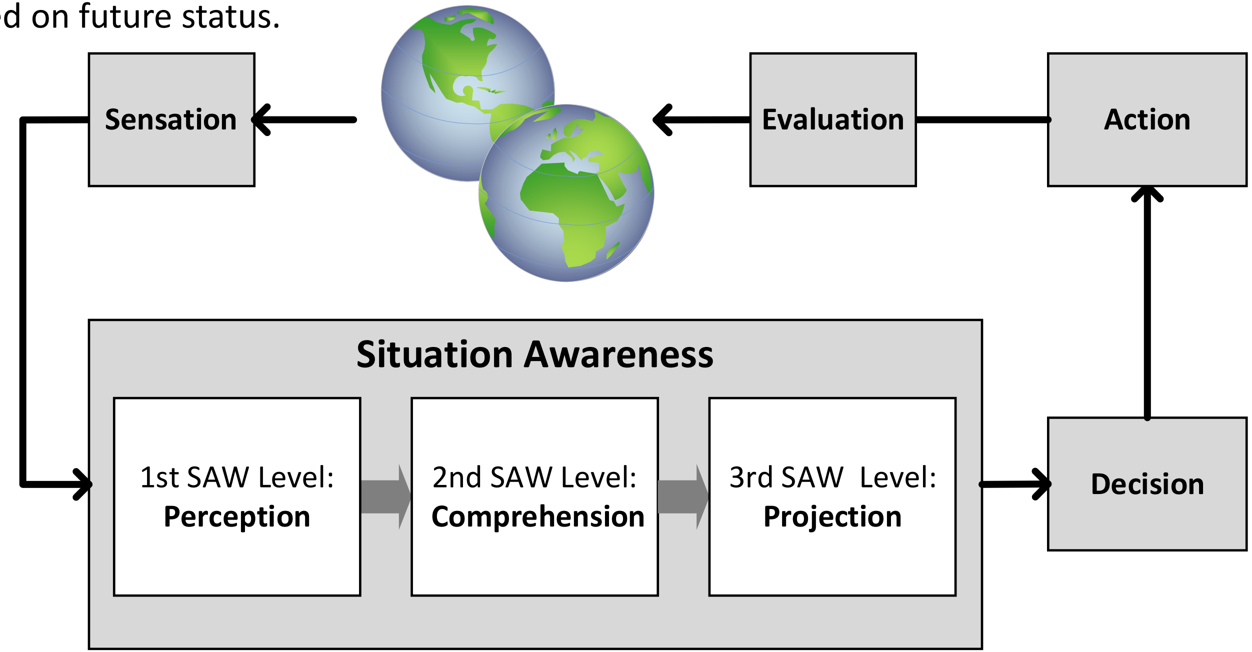
Ontologies for Space Domain Awareness

Initiatives to Use of Ontologies in Airspace and Space

- Airspace
  - The NASA **ATMOnto** is meant to integrate heterogeneous aviation data with a clear propose to be used for aeronautics investigation [1].
  - The BEST project proposes an ontological infrastructure for the Single European Sky ATM Research (SESAR) Joint Undertaking [2]-[4].
  - An **Avionics Analytics Ontology** (AAO) has been developed as a cognitive engine of a Decision Support System (DSS) for avionics analytics for application such as Air Traffic Management (ATM) [5].
- Space
  - A **Space Situational Awareness Ontology** (SSAO) for space debris has been developed by enter for Orbital Debris Education & Research, University of Maryland, USA [6].
  - Modular ontology for space weather research [7].
  - Use of an **Uncertainty Representation and Reasoning Evaluation Framework** (URREF) ontology for Space Object Tracking Uncertainty Analysis [8].

Situation Awareness Process

- The SAW loop include the Endsley model [9]:
  - observed **perception** of the elements in the environment,
  - **comprehension** and understanding of the current situation, and
  - **projection** and action based on future status.

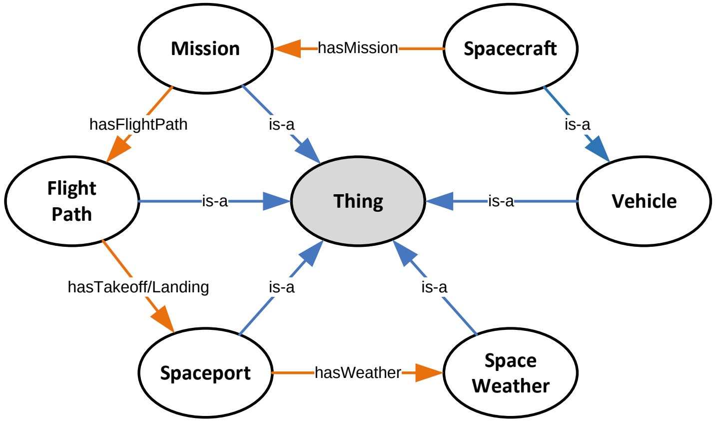


$P \sqcap C_3$

Knowledge Representation by means Ontologies

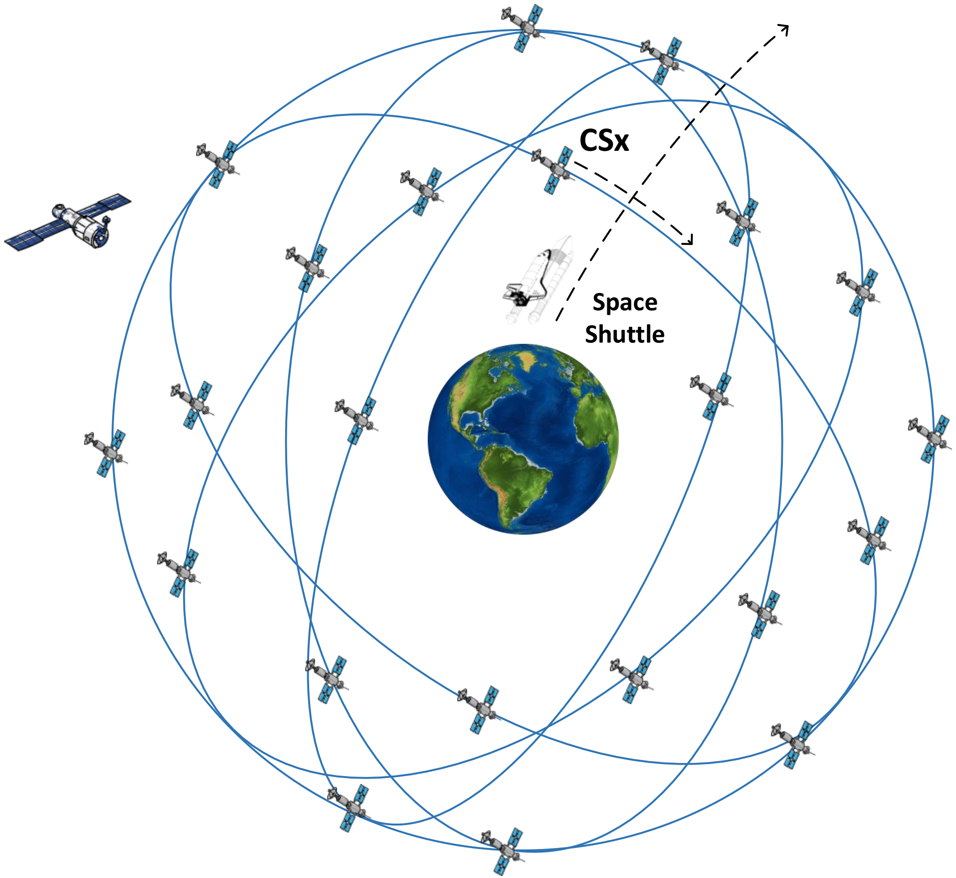
- One of the way to formalize the representation of knowledge is by using Description Logic (DL) [10]:
  - Tedious elaboration; mathematical expressions, e.g., (Airplane ⊔ UAV) ⊑ Aircraft ⊑ Vehicle
  - No easy-to-use tool; difficult to quickly express semantics
- Ontologies based on DL but
  - More friendly for human users with free computer tools such as Protégé [11]
  - Intuitive expressions to describe knowledge that can easily write in Protégé syntax:
    - Aircraft is a Vehicle
    - Airplane is an Aircraft
    - UAV is an Aircraft

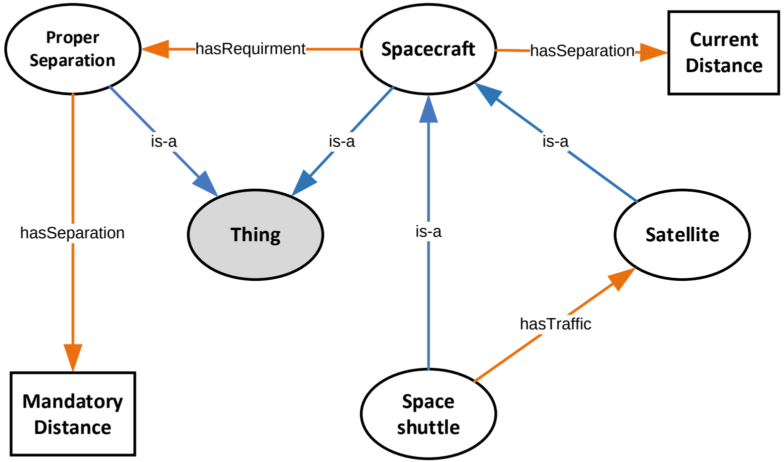
	DL	Protégé Syntax
Concept expressions	$C_1 \sqcup C_2$ $C_1 \sqcap C_2$ $\neg C_1$	C_1 or C_2 (*unionOf*) C_1 and C_2 (*intersectionOf*) C_1 (*complementOf*)
Role expressions	$\exists P.C$ $\forall P.C$ $\forall P.\{i\}$	hasClass toClass hasValue
Schema axioms	$C_1 \sqsubseteq C_2$ $P_1 \equiv P_2^-$ $C_1 \equiv C_2 \sqcap C_3$	C_1 *SubclassOf* C_2 P_1 *DisjointWith* P_2 C_1 *EquivalentTo* *intersectionOf*(C_2, C_3)
Data axioms	$i : C$ $\langle i_1, i_2 \rangle : P$	Type hasClass



Element	OOP	DL	Example
Concept	Class	C	Spaceplane
Role	Property	P	hasRocketPropulsion
Individual	Object	i	DiscoveryShuttle

Application Scenario 1: Space Traffic



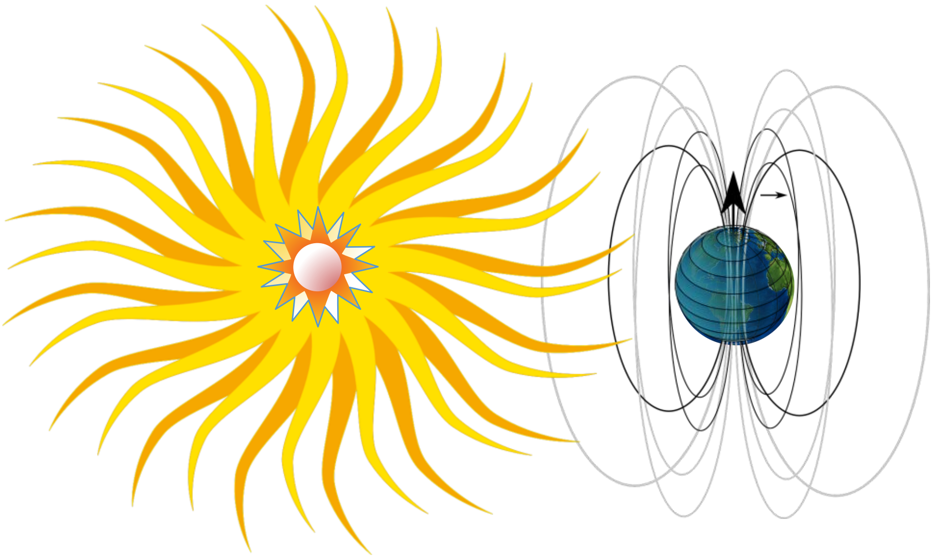


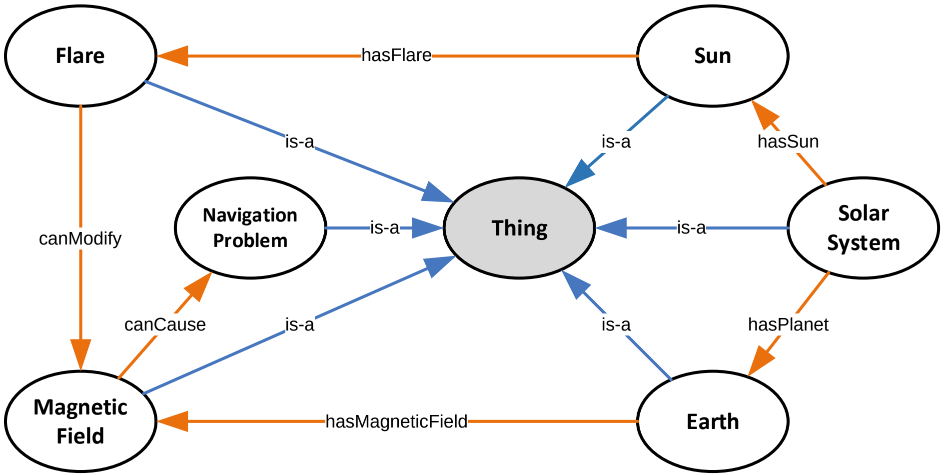
Application Scenario 1: Space Traffic

Description Logic (DL)	Protégé	Human
Satellite ⊑ Spacecraft	Satellite **SubclassOf** Spacecraft	Satellite **is a** Spacecraft
SpaceShuttle ⊑ Spacecraft	SpaceShuttle **SubclassOf** Spacecraft	Space Shuttle **is a** Spacecraft
Spacecraft ⊑ ∃*hasRequirement*.ProperSeparation	Spacecraft **SubclassOf** *hasRequirement* **some** ProperSeparation	Spacecraft **has** Requirement **of** Proper Separation
ProperSeparation ≡ ∃*hasSeparation*.{>mandatorydistance} ⊓ ∃*hasTraffic*.Satellite	ProperSeparation **EquivalentTo** *hasSeparation* **some** xsd:integer[>mandatorydistance] **and** *hasTraffic* Satellite	Proper Separation **means has** separation **larger than** mandatory distance **and has** traffic of satellite
CS_x: Satellite	Satellite **Instances** CSx	CSx **is an instance of** Satellite
Orion: SpaceShuttle	SpaceShuttle **Instances** Orion	Orion **is an instance of** Space Shuttle
⟨Orion, CS_x⟩: *hasTraffic*	Orion *hasTraffic* **value** CSx	Orion **has** Traffic **of** CSx
⟨CS_x, currentdistance⟩: *hasSeparation*	CSx *hasSeparation* **value** currentdistance	CSx **has** Separation **of** current distance
⟨Orion, currentdistance⟩: *hasSeparation*	Orion *hasSeparation* **value** currentdistance	Orion **has** Separation **of** current distance

- CS_x and Orion are spacecraft; CS_x: Satellite, Orion: SpaceShuttle. Satellite and SpaceShuttle are spacecraft. Then, CS_x and Orion are spacecraft.
- CS_x means traffic for Orion (the latter as reference); ⟨Orion, CS_x⟩: *hasTraffic*.
- CS_x and Orion require proper separation from each other as they are spacecraft; Spacecraft ⊑ ∃*hasRequirement*.ProperSeparation. Note: Separation is given by the distance between spacecraft when following their orbital trajectory
- The value 'currentseparation' is the actual separation between spacecraft: ⟨CS_x, currentdistance⟩: *hasSeparation* and ⟨Orion, currentdistance⟩: *hasSeparation*.
- Proper separation (Orion as reference) is possible if and only if the (projected) mandatory distance is shorter than the current distance, and CS_x is part of the traffic for Orion; ProperSeparation ≡ ∃*hasSeparation*.{> mandatorydistance} and ∃*hasTraffic*.Satellite

Application Scenario 2: Space Weather



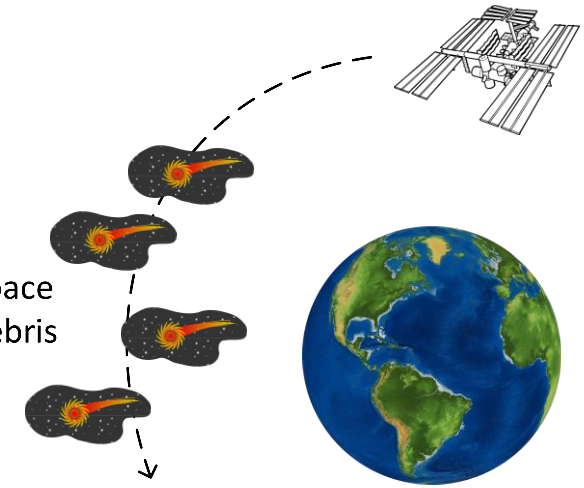


Application Scenario 2: Space Weather

The following DL equations, Protégé expressions, and sentences show the premises for the conclusion that sun flares affect the Earth's magnetic field.

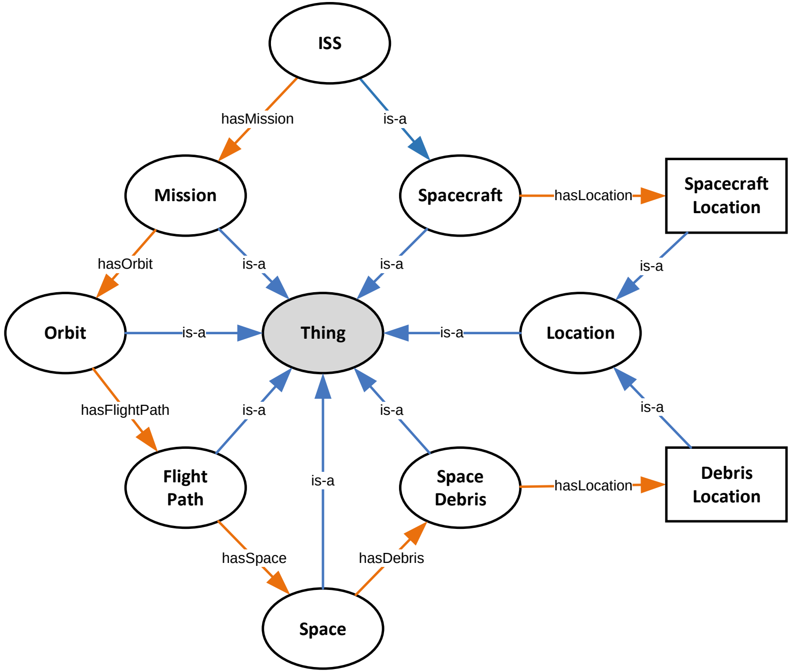
Description Logic (DL)	Protégé	Human
SolarSytem ≡ Sun ⊔ Earth	SolarSytem **EquivalentTo** Sun **or** Earth	Solar System **means** Sun **or** Earth
Sun ⊑ ∃hasFlare.Flare	Sun **SubclassOf** *hasFlare*.Flare	Sun **has** flare given by Flare
Earth ⊑ ∃*hasMagneticField*.MagneticField	Earth **SubclassOf** *hasMagneticField* **some** MagneticField	Sun **has** magnetic field given by Magnetic Field
Flare ⊑ ∃*canModify*.MagneticField	Flare **SubclassOf** *canModifiy* **some** MagneticField	Flare **can** modify Magnetic Field
MagneticField ⊑ ∃*canCause*.NavigationProblem	MagneticField **SubclassOf** *canCause* **some** NavigationProblem	Magnetic Field **can** cause Navigation Problem
NavigationProblem ≡ ∃*canModifiy*.MagneticField ⊓ ∃*hasMagneticField*.MagneticField	NavigationProblem **EquivalentTo** *canModifiy* **some** MagneticField **and** *hasMagneticField* **some** MagneticField	Navigation Problem **means** can modify Magnetic Field **and** has magnetic field given by Magnetic Field

Application Scenario 3: Orbital Network



International Space Station (ISS)

Space Debris



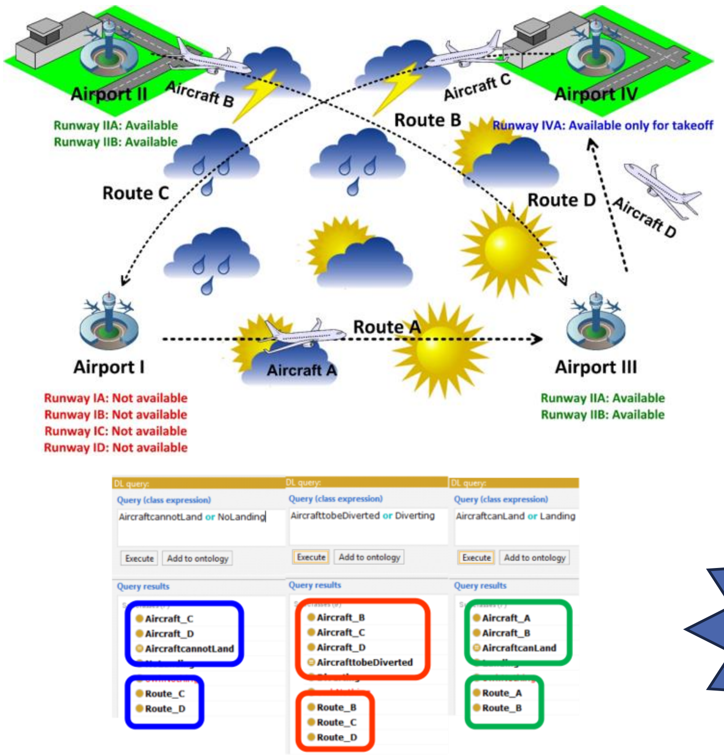
Application Scenario 3: Orbital Network

The following DL equations, Protégé expressions, and sentences are to check if the SAAO satisfies that the debris and the ISS cannot be in the same location. Formally, in DL it is written K **|=** DebrisLocation **≠** ISSLocation.

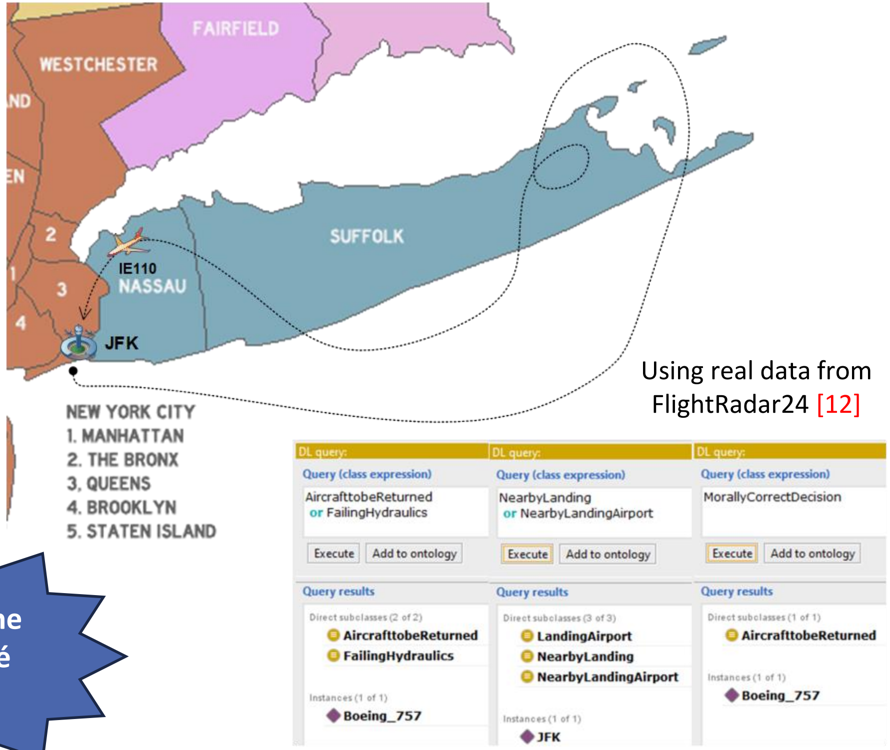
Description Logic (DL)	Protégé	Human
SpaceStation ⊑ Spacescraft	SpaceStation **SubclassOf** Spacecraft	SpaceStation **is a** Spacecraft
SpaceStation ⊑ ∃*hasMission*.Mission	SpaceStation **SubclassOf** *hasMission* **some** Mission	SpaceStation **has** mission given by Mission
Mission ⊑ ∃*hasOrbit*.Orbit	Mission **SubclassOf** *hasOrbit* **some** Orbit	Mission **has** obrit given by Orbit
Orbit ⊑ ∃*hasFlightPath*.FlightPath	Obrit **SubclassOf** *hasFlighPath* **some** FlightPath	Orbit **has** flight path Flight Path
FlightPath ⊑ ∃*hasSpace*.Space	MagneticField **SubclassOf** *canCause* **some** NavigationProblem	Magnetic Field **can** cause Navigation Problem
Space ⊑ ∃*hasSpaceDebris*.SpaceDebris	Space **SubclassOf** *hasSpaceDebris* **some** SpaceDebris	Space **has** space debris SpaceDebris
SpaceDebris ⊑ ∃*hasLocation*.{DebrisLocation}	SpaceDebris **SubclassOf** *hasLocation* **value** DebrisLocation	SpaceDebris **has** location Debris Location
ISS: SpaceStation	ISS **instances** SpaceStation	ISS **is an instance of** Space Station
ISS ⊑ ∃*hasLocation*.{ISSLocation}	ISS **SubclassOf** *hasLocation* **value** ISSLocation	ISS **has** location ISS Location
∃hasLocation.{DebrisLocation} ⊓ ∃hasLocation.{ISSLocation} ≡ ⊥	(*hasLocation* **value** DebrisLocation) **and** (*hasLocation* **value** ISSLocation) **equivalentTo** "0"^^xsd:integer	Debris Locations **and** ISS Locations **are** different

Related Work Done for Airspace (1)

Weather Condition on and nearby an Airport, and Runway Availability



Moral autonomy: emergency landing



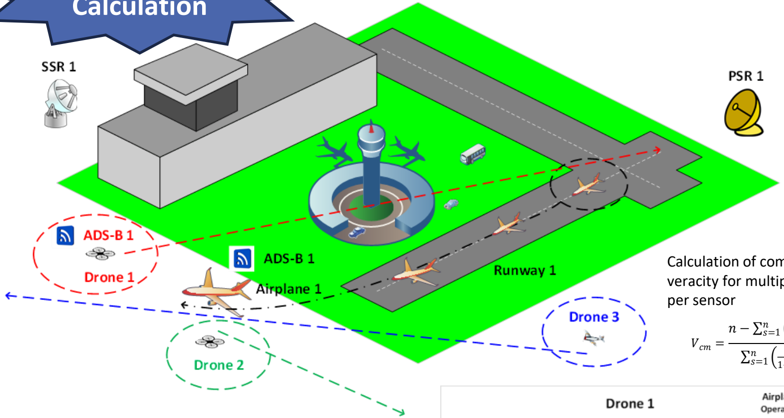
Using real data from FlightRadar24 [12]

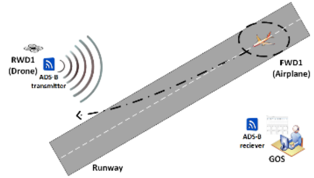
Using the Protégé tool

Related Work Done for Airspace (2)

Analytical Calculation

UAV(s) flying around airplane taking off





Calculation of combined veracity for multiple targets per sensor

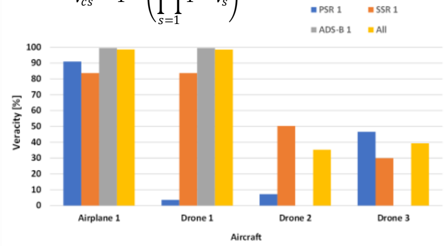
$$V_{cm} = \frac{n - \sum_{s=1}^{n}\left(\frac{1}{1-V_s}\right)}{\sum_{s=1}^{n}\left(\frac{1}{1-V_s}\right)}$$

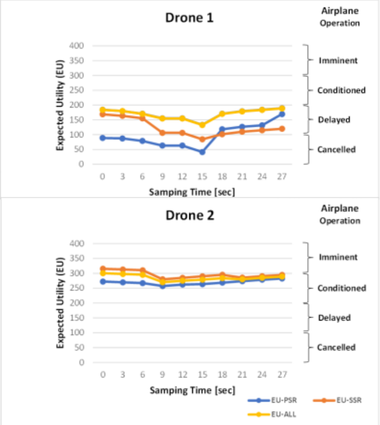
Bayesian Networks for uncertainty (based on sensors' veracity)

$$P_B(X_1, X_2, \ldots X_n) = \prod_{i=1}^{n} \theta_{x_i|\pi_i} = \prod_{i=1}^{n} P_B(x_i|\pi_i)$$

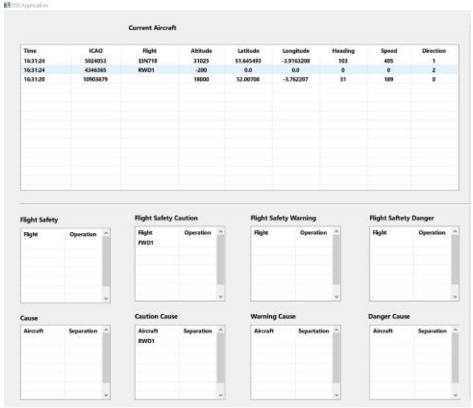
The veracity for combined sensors (that detect the same target)

$$V_{cs} = 1 - \left(\prod_{s=1}^{n} 1 - V_s\right)$$





DSS Software application (user interface)



Physical Prototype

Some Challenges and Opportunities

- Fundamental Research
  - Refinement and enrichment of the DL theory to represent knowledge and reasoning to provide SAW.
  - Main limitations when using ontological analytics to support decision-making processes.
  - Extension of ontological SAW from ATM to CSTM to tackle problems that can be generalized.
  - Unknown situations as well as the lack of understanding of phenomena affecting SAW.
  - Supported and unsupported SAW from specific space situations.
- Applied Research [13]
  - Awareness uncertainty
  - Integration of aerospace-related ontologies
  - Distributed space traffic control
  - Rapidly changing space missions

Topic 6 References

[1] R. M. Keller, The NASA Air Traffic Management Ontology, Technical Documentation, NASA/TM-2017-219526, 2017.

[2] BEST Deliverable D1.1, “Experimental ontology modules formalising concept definition of ATM data”, ver. 01.03.00, 2017.

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Cyber Security Challenges

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?

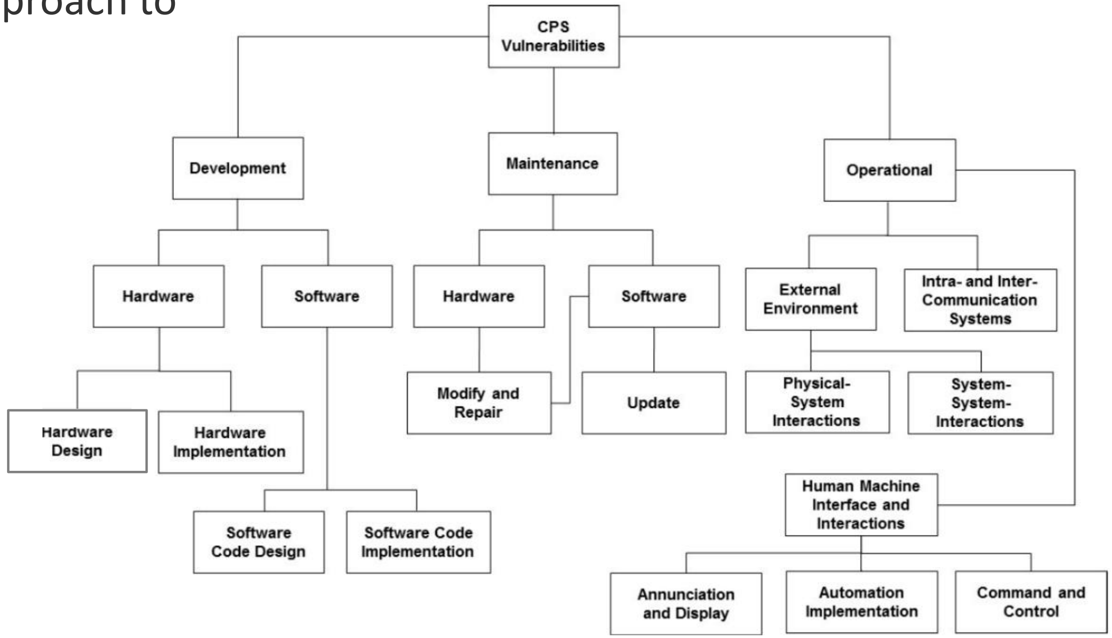
Cyber Awareness for Avionics

- **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

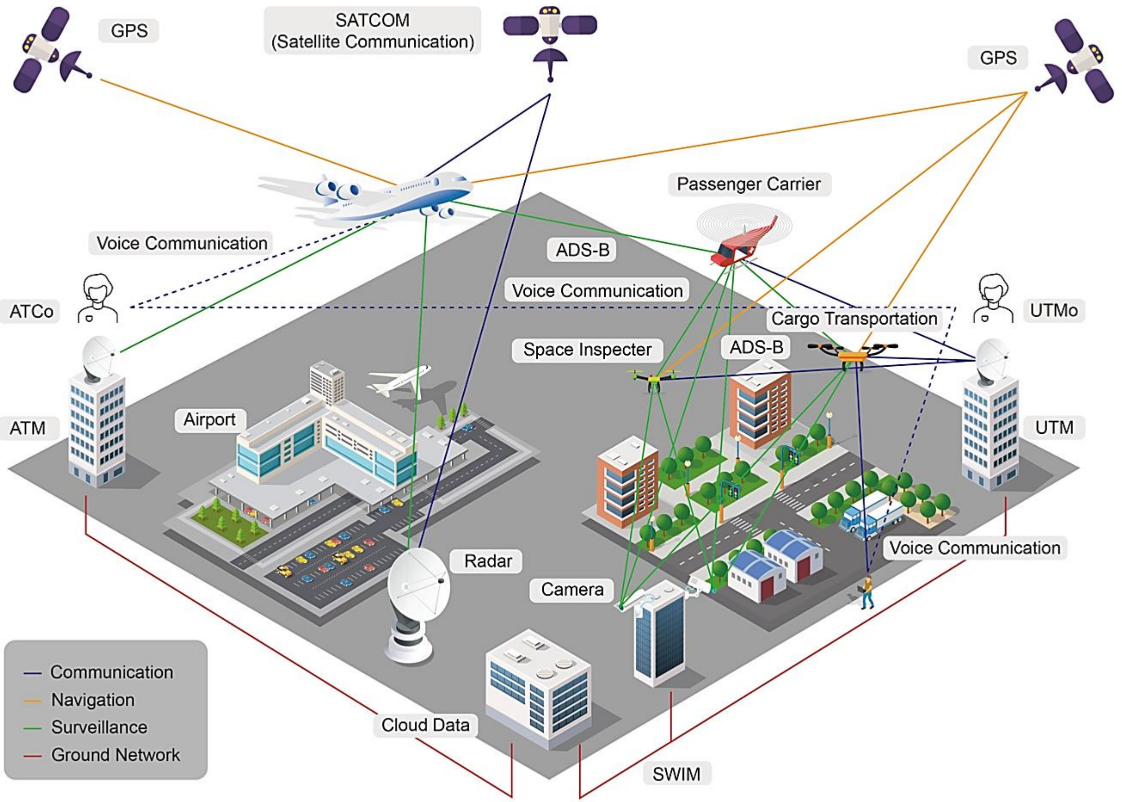
❖ STRIDE is an abbreviation for various known attack paths, one standard approach to assess vulnerabilities (MSN):

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



Cybersecurity Vulnerabilities in ATM and UTM

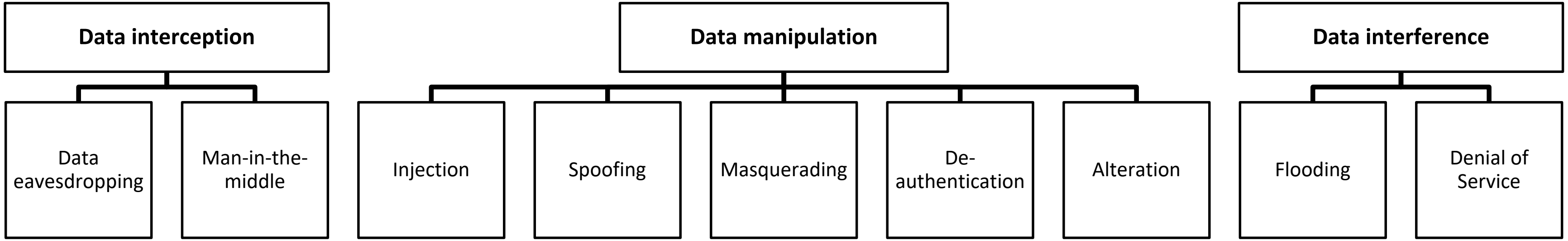
- Communication
  - HF/VHF voice, CPDLC, L-DACS, ACARS, SATCOM, Wireless communication networks
- Navigation
  - TRNAs, GNSS
- Surveillance
  - PSR, SSR, WAM, TACS, ADS-B
- Ground Network
  - SWIM



Y. Xie, A. Gardi, and R. Sabatini, "Cybersecurity Trends in Low-Altitude Air Traffic Management", AIAA/IEEE Digital Avionics Systems Conference, DASC 2022.

Cyber Attack Methods

❖ Cyber-attack can pose threats to both software systems and physical hardware

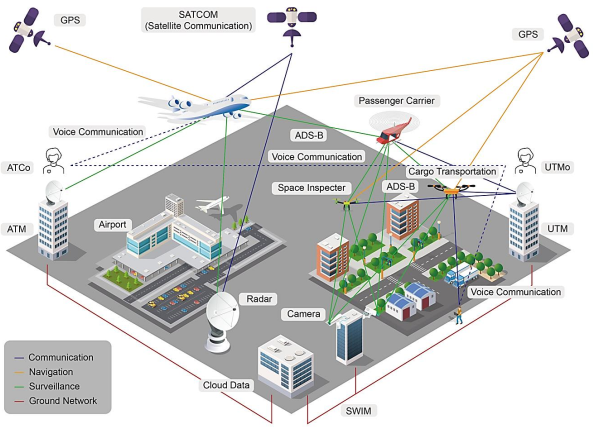


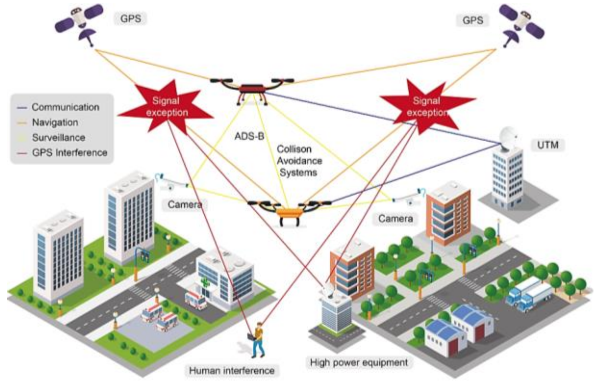
At present, most UAS cannot be effectively defended against network attacks

Y. Xie, A. Gardi, and R. Sabatini, "Cybersecurity Trends in Low-Altitude Air Traffic Management", AIAA/IEEE Digital Avionics Systems Conference, DASC 2022.

Key Challenges

- Evolving ATM & UTM architectures based on big data and AI plus increased interdependence of CNS/ATM and avionics systems result in an increasing attack surface
- AI-based offensive technologies are bound to become very common, requiring AI-based cyber-defenses
- Need for a new generation of security management systems and more efficient attack detection techniques





Y. Xie, A. Gardi, and R. Sabatini, "Cybersecurity Trends in Low-Altitude Air Traffic Management", AIAA/IEEE Digital Avionics Systems Conference, DASC 2022.

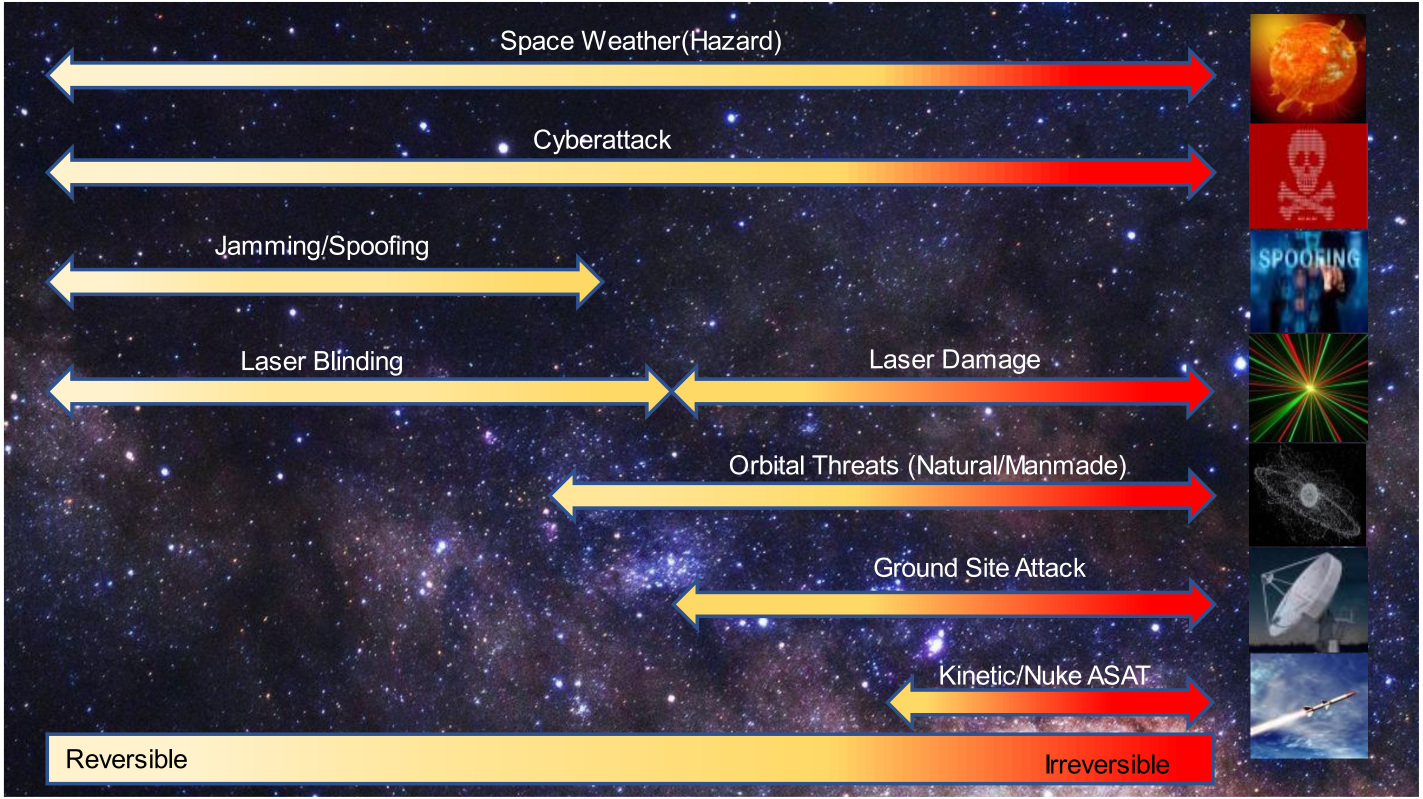
Key Standards

- 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 G-34/EUROCAE WG-114, Artificial intelligence in Aviation** - 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
- Published Standard: AIR6988 / ER-022 Artificial Intelligence in Aeronautical Systems: Statement of Concerns (2021)
- Works In Progress:
  - AS6983 / ED-xxx Process Standard for Development and Certification / Approval of Aeronautical Safety-Related Products Implementing AI;
  - AIR6987 / ER-xxx Artificial Intelligence in Aeronautical Systems: Taxonomy;
  - AIR6994 / ER-xxx Artificial Intelligence in Aeronautical Systems: Use Cases Considerations.

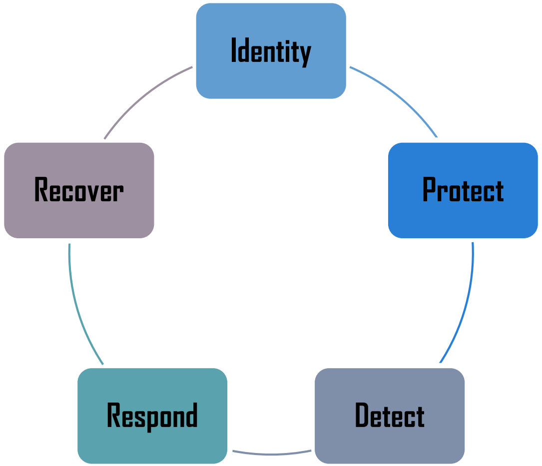
Space Cyber-Physical Threats



K. Thangavel, J.J. Plotnek, A. Gardi, R. Sabatini, "Understanding and Investigating Adversary Threats and Countermeasures in the Context of Space Cybersecurity", IEEE/AIAA 41st Digital Avionics Systems Conference, DASC 2022, Portsmouth, VA, USA, September 2022.

Attack Surfaces and Cybersecurity Framework

Segment	Vulnerability	Threats
Space Segment	Payload Vulnerabilities	• Denial of Service • Hardware Backdoor • Bespoke Malware • Privilege Escalation • Hijacking • Sensor Injection
Link Segment	Signal Vulnerabilities	• Jamming • Eavesdropping • Spoofing • Metadata-Analysis • Command Injection • Replay Attacks • Signal Injection
Ground Segment	Ground station Vulnerabilities	• Bespoke Malware • Generic Malware • Social Engineering • Physical Access • Data Corruption • Hardware Backdoor



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Certification Challenges and Industry Perspectives

Objectives of the Aviation Standards

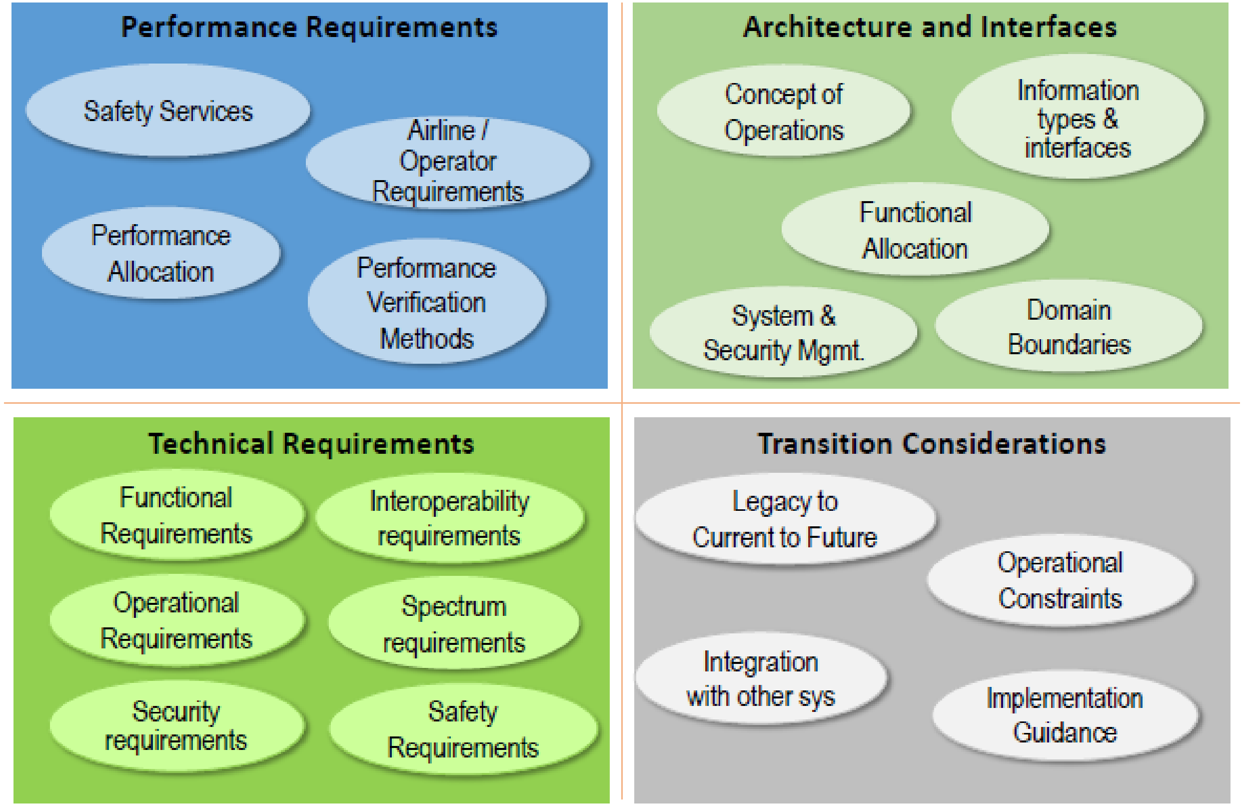
- Ensure safety of life and safety of operations
- Provide globally uniform, equitable services to the aircraft while assuring sovereignty of the airspace
- Enable collaborative surveillance, navigation and communication for efficient airspace management
- Ensure minimum acceptable performance, quality 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

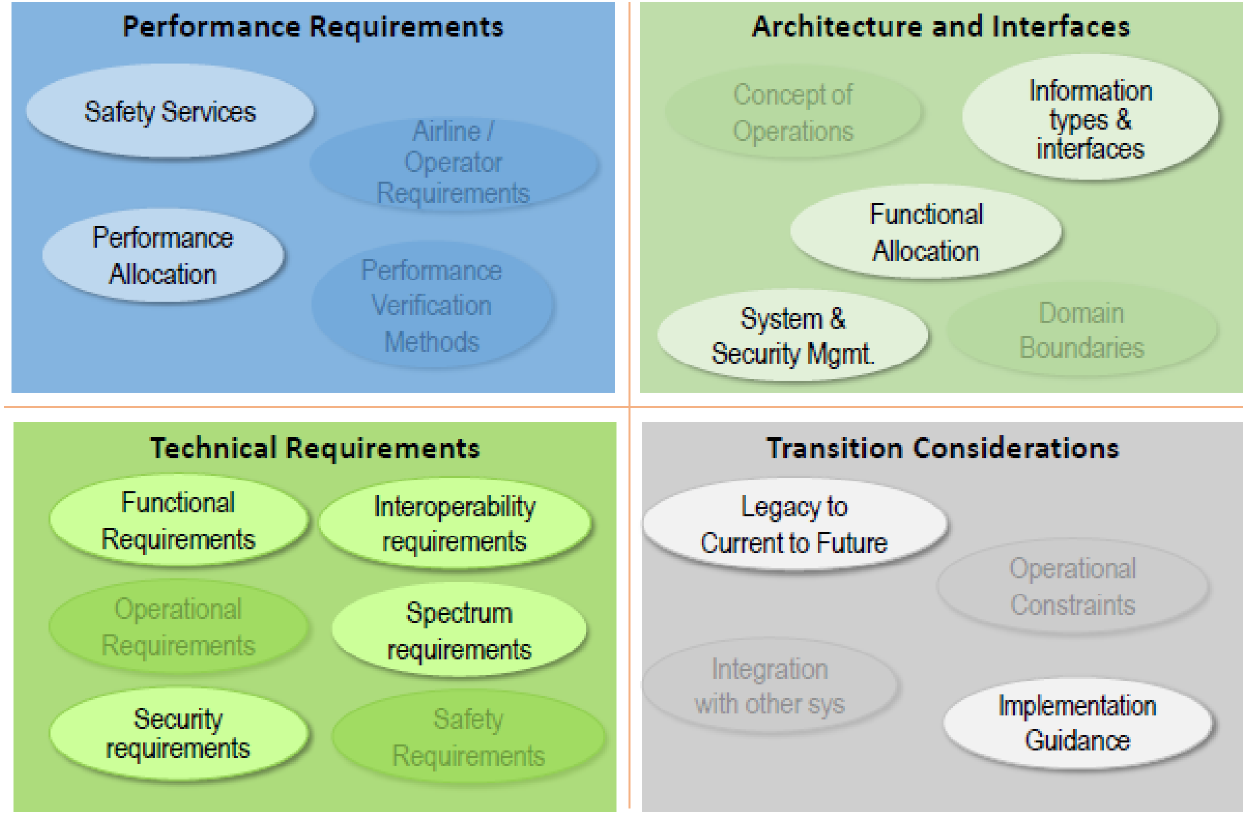
ICAO	RTCA / EUROCAE	AEEC
• Established by the 1944 treaty at Chicago Convention • Operates as a United nations constituency • Caters to prime objectives of global interoperability, uniformity & equitable service of aircraft over all UN countries • Defines system functional and interoperability requirements	• 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

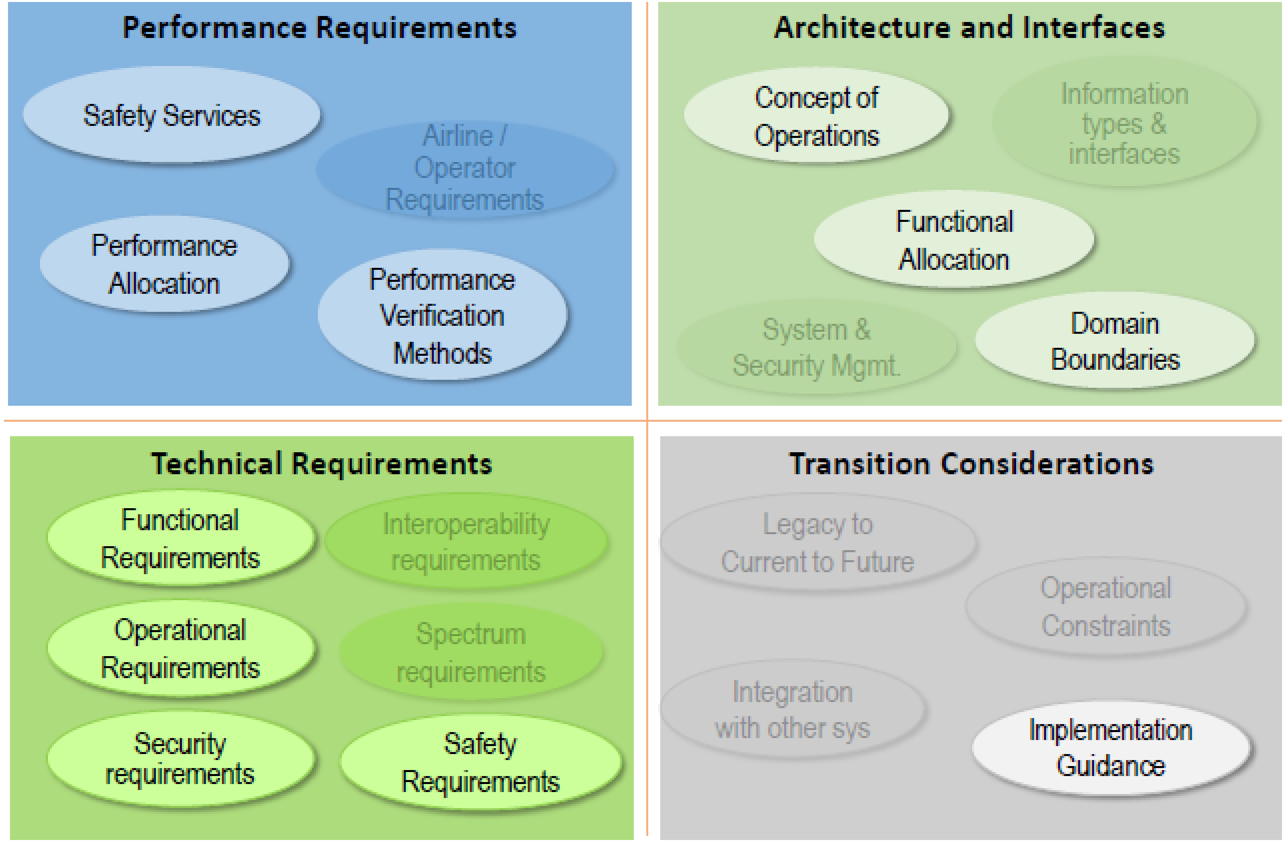
Illustration of Areas Covered by Standards Organizations



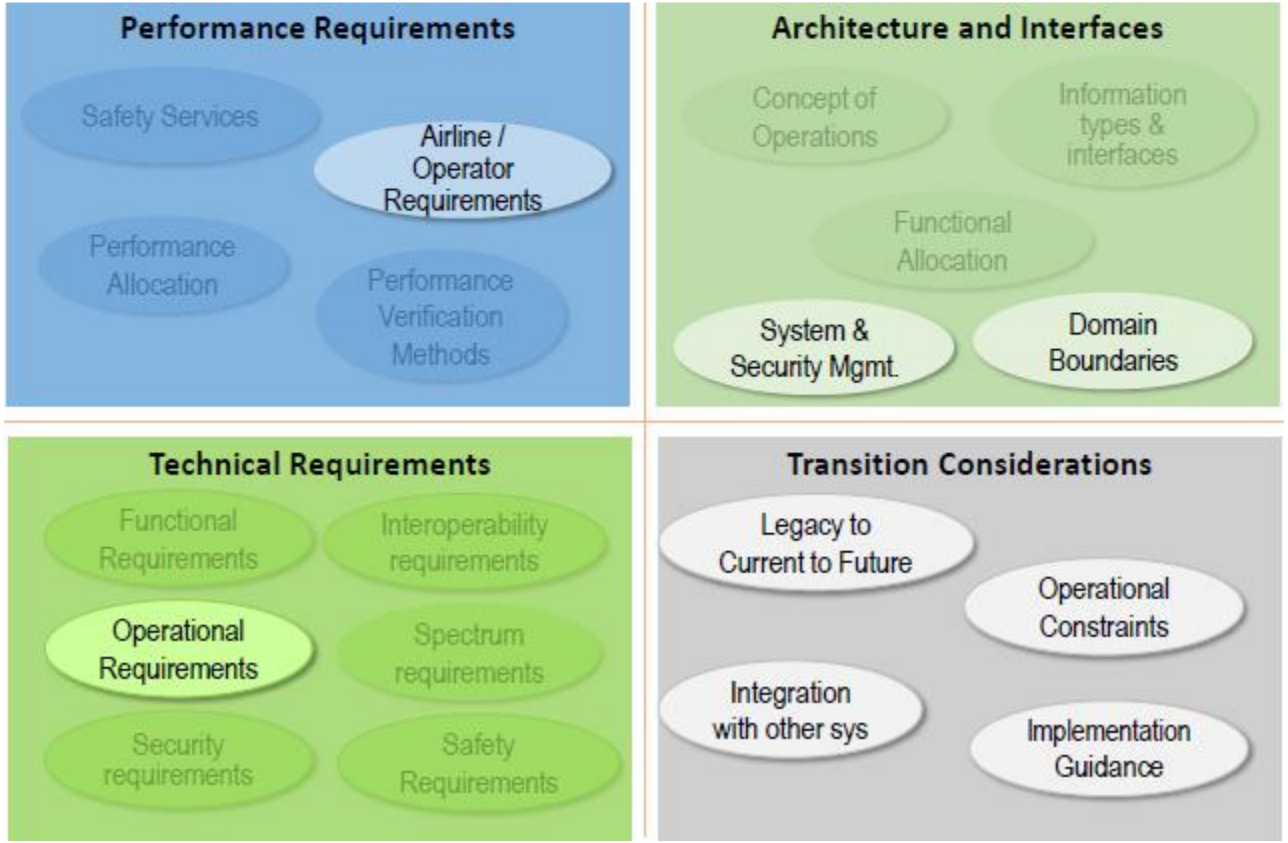
Elements Covered by ICAO Standards



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 Certification 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^{-6} to 10^{-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

1. Introduction to the IEEE AESS Avionics Systems Panel	Rob (11:30)
2. Air and Space Transport Innovation Ecosystem	Alex (11:50)
3. Autonomous Navigation and Guidance Systems	Irfan (12:10)
4. Advances in Human-Machine Systems	Erik (12:30)
5. Sense-and-Avoid Technologies	Giancarmine (12:50)
6. Ontologies for Space Domain Awareness	Carlos (13:10)
7. Cyber Security Challenges	Kathleen (13:30)
8. Certification Challenges and Industry Perspectives	Aloke (13:50)
9. Wrap Up and Questions	All (14:10)

Wrap Up and Questions

Wrap Up

- ❖ The airspace is evolving rapidly with increasingly automated and autonomous platforms in atmospheric and suborbital flight
- ❖ The conventional ATM domain is expanding to include low-altitude operations (AAM/UTM) and flight above FL600
- ❖ The integration of STM with conventional ATM is becoming essential to support the sustainable growth of the sector
- ❖ The forthcoming MDTM system should embrace:
  - An array of new services for highly automated/autonomous platforms
  - New operational paradigms for conventional ATM
  - Evolutionary CNS/ATM and Avionics (CNS+A) systems
  - Adequate airspace and ground risk management provisions

Wrap Up (cont.)

- Higher levels of automation and AI are essential to enable MDTM (trusted autonomous operations)
- Trusted autonomy must address predictability, integrity, and cyber-physical security challenges
- Fully integrated and interoperable CNS+A systems require an evolution of present day certification standards
- Significant research efforts are needed to address safety and security of Autonomous Cyber-Physical Systems (ACPS) and Cyber-Physical-Human Systems (CPHS)

IEEE Advancing Technology for Humanity

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Barcelona, Spain - October 1-5, 2023

Thank you!

ASP

AESS IEEE Aerospace & Electronic Systems Society

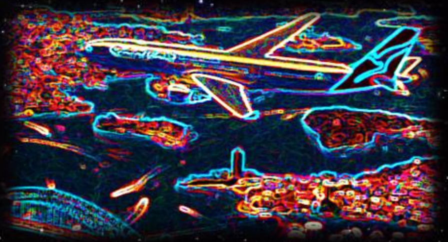
If you wish to discuss how you can contribute to the activities of the Avionics Systems Panel (ASP), please send an email to: roberto.sabatini@ku.ac.ae

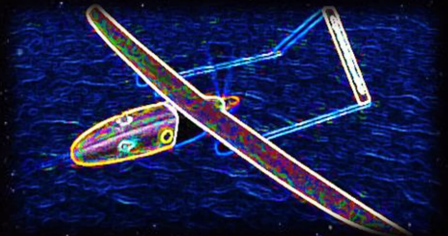
You can find additional information about the ASP at: https://ieee-aess.org/tech-ops/avionics-systems-panel-asp

IEEE/AIAA Digital Avionics Systems Conference: https://2023.dasconline.org/

IEEE/AIAA Integrated Communication, Navigation and Surveillance Conference: https://i-cns.org/about/

IEEE/AIAA Aerospace Conference: https://www.aeroconf.org/





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