Avionics Systems Panel Tutorial: Research, Opportunities and Education Perspectives

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

DATE: 2021/10/05

Presentation Motivation

- AESS Avionics Systems Panel Research and Education Perspectives
- Part-I: Avionics Systems Research and Innovation Opportunities
- Part-II: Avionics Systems Educational Needs and Curricular Evolution

This tutorial is being organized and presented on behalf of the IEEE Aerospace Electronic Systems Society (AESS) Avionics Systems Panel (ASP). The panel comprises experts in various areas of Avionics Engineering representing industry, academia, and the government around the globe. The tutorial forms part of efforts undertaken by the panel to propagate expertise in Avionics Systems. The tutorial is configured in two distinct segments, which in turn are interconnected as avionics (1) research and (2) education.

[1] 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.

[2] 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.

Avionics Systems Panel

- **Members:** Roberto Sabatini (Chair), Giancarmine Fasano (Vice-Chair), Ron Ogan (Secretary), Aloke Roy, Erik Blasch, Irfan Majid, Kathleen Kramer, Christopher Camargo, George Andrew, Omar Garcia Crespillo, Alessandro Gardi, Carlos Insaurralde
- **Purpose:**
  - To promote and support collaborative research initiatives in the domain of Avionics;
  - To promote and support high-quality IEEE publications in the domain of Avionics;
  - To promote and support educational activities in the domain of Avionics;
  - To sustain and oversee the programs of the IEEE/AIAA Digital Avionics Systems Conference (DASC), the Integrated Communications Navigation and Surveillance Conference (ICNS); and create new conferences or partnerships;
  - To establish a liaison and joint work program with the Cyber Security Panel;
  - To establish a liaison and joint work program with the Unmanned Air Vehicle (UAV) Panel;
  - To encourage members in the domain of Avionics;
  - To recommend and support new IEEE Standards or revisions of existing IEEE standards pertaining to the domain of Avionics

Presentation Outline – Part I – Research

Part-I

1. Introduction
2. Requirements of Future CNS+A Systems
3. UAS Avionics Systems
4. Concept of UTM and STM
5. HMI^2 for Future Aerospace Vehicles
6. Certification of ML/AI in Safety Critical avionics
7. Cyber Security for UAS

Part-II

1. Introduction
2. Overview of Existing Avionics Engineering Programs
3. Keeping pace with Industry Requirements
4. Proposed Undergraduate Curriculum
5. Research and Innovation Areas in Avionics Engineering
6. Proposed Graduate Programs
7. Wrap up

UAS – Unmanned Aerial Systems
UTM – UAV Traffic Management
STM – Space Traffic Management

CNS+A: Communication, Navigation, Surveillance/Avionics
ML/AI – machine learning/artificial intelligence
HMI2 - Human-Machine Interfaces and Interactions

Motivation

[1] 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

[2] 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.

[3] 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).

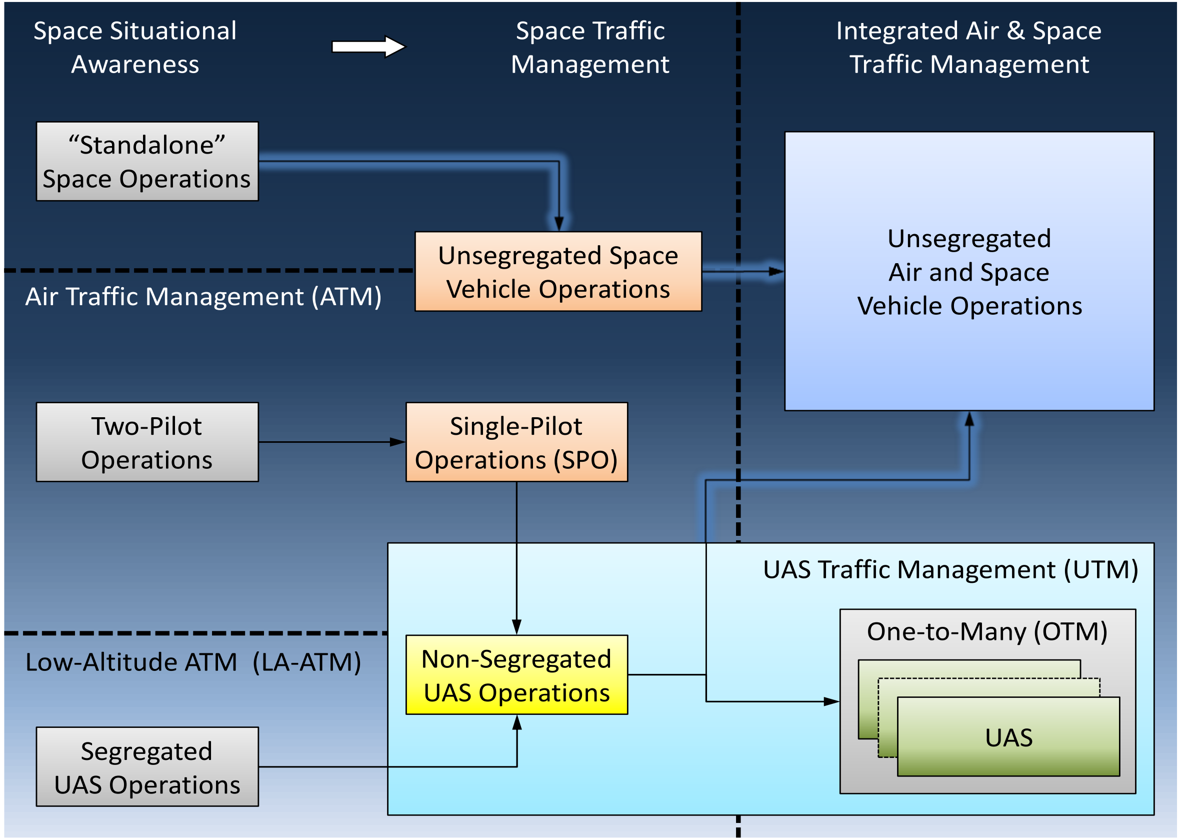
Conceptual evolution of multi-domain traffic management.

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.

Avionics Systems Panel – Future Challenges



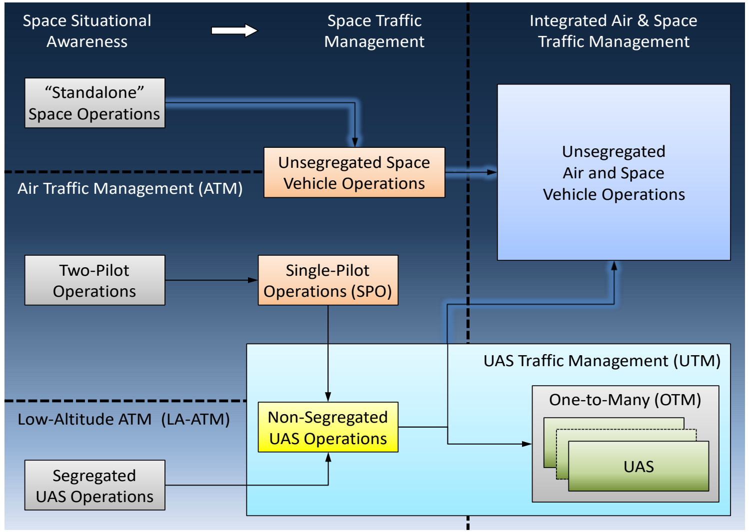
ASP
IEEE Aerospace & Eletronic Systems Society

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

Avionics – Future Challenges

- **Multi-Domain Traffic Management**
  - ATM – Air Traffic Management
  - UTM – UAV Traffic Management
  - STM – Space Traffic Management
- **Urban Air Mobility**
  - UAVs –Unmanned Aerial Vehicles
  - EVTOL – Electric Vertical Takeoff & Landing
  - Autonomous Cars
- **Systems Management**
  - CPS – Cyber-Physical Systems Security
  - HMT – Human Machine Teaming
  - AI/ML – Data-Driven Analytics



IEEE AESS Magazine Call

- **Title:** Urban Air Mobility and UAS Airspace Integration – Vision, Challenges, and Enabling Avionics Technologies
- **Topics:**
  - Evolution of CNS/ATM technologies for UAM/AAM and UAS airspace integration
  - Avionics for autonomous systems and contingency management approaches
  - Innovative sensors and sensor fusion for autonomous flight and UAM/AAM
  - Artificial Intelligence and Machine Learning within the UAM/AAM context
  - Satellite based augmentation of current CNS systems for improved safety
  - Collision avoidance systems for UAS with interface to UTM/UAM/AAM
  - Development of standards for UAM/AAM certification and regulatory framework evolution
  - Methods of interoperable UAM/AAM and autonomous flight operations (e.g., ontologies)
  - Human-robot interactions and human factors engineering in UAM/AAM
  - Flight testing and technology demonstration activities and plans
  - Societal challenges, ethical aspects, and public perception of UAM/AAM and UAS airspace Integration

❖ For more information:

http://ieee-aess.org/sites/ieee-aess.org/files/AESMagazineCfP_SIUAM_finalfinal.pdf

Presentation Outline – Part I: Research

- 1. Introduction
- 2. Requirements of future CNS+A Systems
- 3. Concept of UTM and STM
- 4. Performance Based Operations
- 5. HMI^2 for future aerospace vehicles
- 6. Certification of ML/AI in safety critical Avionics
- 7. Cyber security for UAS

Presentation Outline – Part I: Research

- Determine contemporary and future, industry focused, development and innovation areas in the field of Avionics Engineering.
- The constantly increasing density of air traffic and the growing diversity of aerospace vehicles that will occupy the air space imposes new requirements on Communication, Navigation, Surveillance/Air Traffic Management (CNS/ATM) and Avionics (CNS+A) technologies. Unmanned Aerial Systems (UAS), Urban Air Mobility (UAM), Space Traffic Management (UTM/STM).
- UTM/UAM come further advances in Performance-Based Operations (PBO), which will have profound impacts on aviation equipment mandates and standards.
- Design of Human-Machine Interfaces and Interactions (HMI2) supporting trusted autonomous operations (i.e., human-autonomy teaming).
- Machine Learning & Artificial Intelligence (ML/AI) algorithms to enhance the overall CNS+A systems performance and efficiency. Likewise, certification of ML/AI in aviation and especially safety critical avionics is a major focus of current research.
- Proliferation of cyber-physical systems, especially for UTM/UAM operations makes cyber security a critical requirement.

Presentation Outline – Part II: Education

- 1. Introduction
- 2. Overview of Existing Avionics Engineering Programs
- 3. Keeping pace with Industry Requirements
- 4. Proposed Undergraduate Curriculum
- 5. Research and Innovation Areas in Avionics Engineering
- 6. Proposed Graduate Programs
- 7. Wrap up

Presentation Outline – Part II: Education

- There is a need for practical approaches for the alignment of educational curricula with that of relevant industry needs and technological advances in avionics engineering.
- A review of existing avionics programs, with their current shortcomings vis-a-vis prevailing industry requirements and future trends covered in part one.
- Building on the fact that most curricula have not been updated since the late 1990s, a new and comprehensive **undergraduate curriculum** is proposed, along with a curriculum structure suitable for **graduate avionics** programs focusing on specialist skills aligned with the prevailing research and innovations areas in Avionics Engineering.
- The overall objective of the proposed curricula is to bridge the gaps between higher education, industry practices, government regulators, and public stakeholder needs; towards maximizing educational outcomes and preparedness of the avionics engineering workforce, to prepare students for challenges and opportunities faced by the aerospace sector globally.

Other Opportunities

- **Roberto Sabatini**

  Aerospace Cyber-Physical Systems: Avionics, Spaceflight Systems and Unified Traffic Management

- **Erik Blasch**

  Overview of High-Level Information Fusion Theory, Models, and Representations

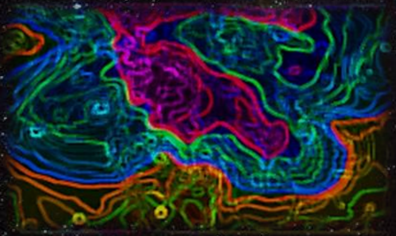
- **Kathleen Kramer**

  Navigation: The Road to GPS and Getting Beyond It



Distinguished Lecturer Program | Aerospace & Electronic Systems Society (ieee-aess.org)

Onward



ASP

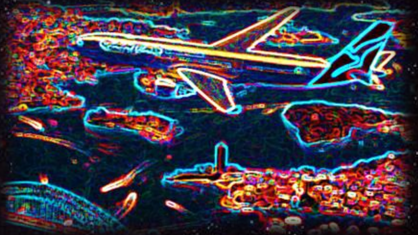
AESS IEEE Aerospace & Eletronic Systems Society

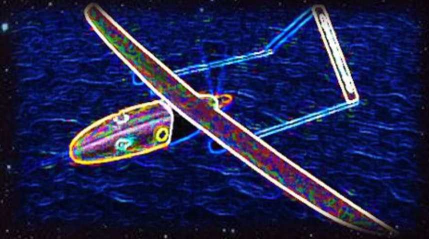
If you wish to discuss how you can contribute to the activities of the AESS Avionics Systems Panel (ASP) please send me an email at: roberto.sabatini@ieee.org

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://2021.dasconline.org/

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





PART 1: Avionics Systems Research and Innovation Opportunities

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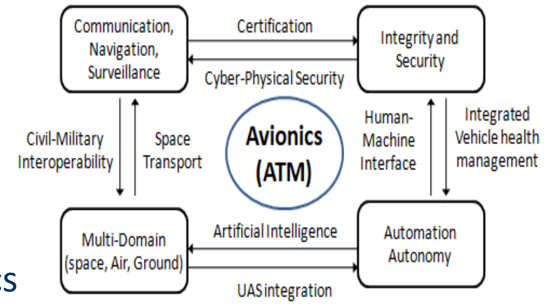
Introduction - Directions



1) Communication, Navigation and Surveillance for Air Traffic Management (CNS/ATM):

- Evolution of the certification framework for integrated CNS+Avionics
- Civil and military airspace integration and CNS+A systems interoperability;

2) Avionics Systems Integration and Security:

- Fault-tolerant avionics design and Integrated Vehicle Health Management (IVHM) systems;
- Cyber-physical security of avionics and CNS/ATM systems;

3) Multi-Domain Avionics (MDA):

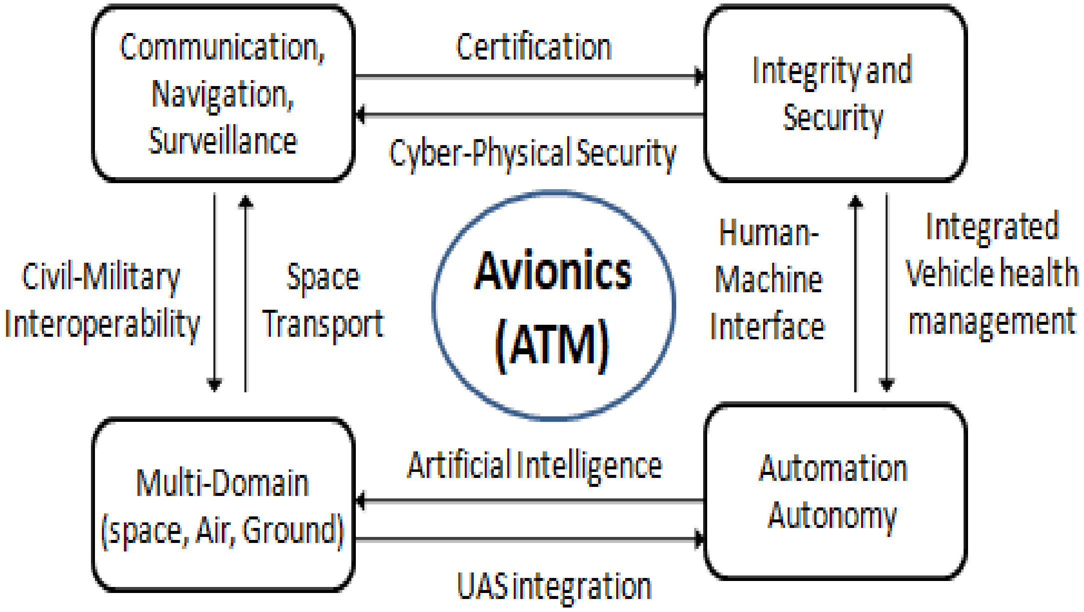
- UAS integration in all classes of airspace and UTM;
- Avionics for space transport, Space Traffic Management (STM) and intelligent satellite systems;

4) Automation and Autonomy:

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

Introduction - Directions

1) **Communication, Navigation and Surveillance for Air Traffic Management (CNS/ATM)**
2) **Avionics Systems Integration and Security**
3) **Multi-Domain Avionics (MDA)**
4) **Automation and Autonomy**



Industry Outlook

Growing – but the pandemic …

Global avionics systems market is projected to exceed USD 94 billion by 2025

Avionics companies are focusing on higher level of automation (e.g., UAVS)

Performance based navigation (PBN), operations (PBO), communications (PBC)

International Civil Aviation Organization (ICAO) - (2016-2030)

Aviation System Block Upgrades (ASBU) rely on a progressive introduction of advanced CNS technologies, including digital data links, satellite services and Automatic Dependent Surveillance–Broadcast (ADS-B), NextGen, SESAR, GNSS, Global Positioning System (GPS),

Global Air Navigation Plan (GANP) – requires certification

Trends: AI/ML, HMT, Cyber-resilient systems

Have not diminished with COVID19 – “Air Package Delivery”

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Global Research Programs

- **Highlights:** NextGen, SESAR, CARATS, ASBU, GANP
  - ATM modernization programs - Terminal Maneuvering Area (TMA) operations
- **Stages for such evolution within SESAR**
  - **Time-based Operations:** Air Traffic Flow Management (ATFM) actions are aimed at optimal traffic synchronization. The time of arrival of traffic at specific points is the fundamental metric being estimated, managed and monitored by all entities.
  - **Trajectory Based Operations (TBO**): Evolution of predictability, flexibility and environmental sustainability of air traffic resulting in additional capacity invovling legacy flight plans into dynamically managed 4DT, which become the continuously updated and negotiated reference plan for the aircraft mission.
  - **Performance-Based Operations (PBO**): CNS established a high-performance, network-centric, collaborative, integrated and seamless ATM system, supporting high-density air traffic. ATM services are customized enabling a further enhanced exploitation of airspace capacity.

Global Research Programs

- **GANP –** Multilayer structure with the following levels:
  - **Global Strategic Level:** providing high-level strategic direction consisting of a common vision, global performance ambitions and a conceptual roadmap.
  - **Global Technical Level**: a Basic Building Blocks (BBB) framework is defined in parallel to the ASBU. The BBB specifies minimum air navigation services for international civil aviation, as opposed to the ASBU that is performance driven [4, 12]. Basic services are aerodrome operations, CNS, air traffic management, meteorology, search and rescue, and aeronautical information. Another technical focus is a performance-based decision making method for defining implementation strategies.
  - **Regional Level:** addressing regional and sub-regional needs aligned with the global objectives.
  - **National Level**: focusing on national plans and Deployment implementation and coordination

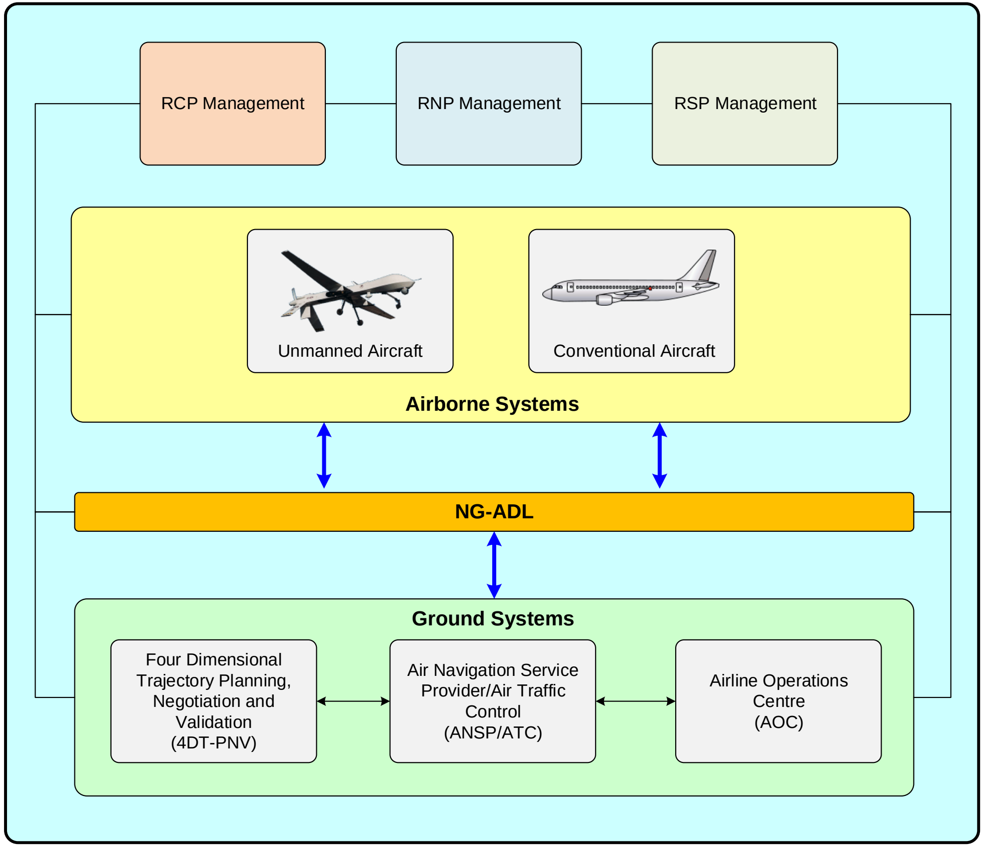
Global Research Programs – CNS+A Operations

❖ Next-Gen

- Air Traffic Management
- Flight Management Systems
- Aeronautical Data Link

❖ Required Management Performance

- RCP - Communication
- RNP - Navigation
- RSP - Surveillance



Global Research Programs – CNS+A Operations

- Four Dimensional Trajectory (4DT) based operations;
  - Higher levels of **Collaborative Decision Making (CDM)** to allow all involved parties to participate in the enhancement of system performance by sharing and accessing more accurate and updated information;
  - **Automation:** Role shifting of ATM from C2 oriented units to a highly **automated,** intelligent and collaborative decision-maker in an interoperable network-centric environment;
  - **Dynamic Airspace Management (DAM)** for an optimized exploitation of airspace capacity;
  - **Human-Machine Teaming (HMT)** with Improved avionics and ATM systems HMI^2 design, interoperability and higher levels of automation; and
  - **Performance-Based CNS**, enabling PBO. ATM digital communication between the airspace controller and the aircraft pilot for improved safety avoiding cockpit overload and misinformation errors.

Global Research Programs – CNS+A Technologies

- Innovative Concepts
  - **Avionics and ATM Decision Support Systems** (DSS) featuring automation-assisted 4DT planning and negotiation/validation functionalities;
  - **Enhanced Visual Line-of-Sight (VLOS) and Beyond VLOS (BVLOS) communications**, including a substantial exploitation of ground-based and satellite-based aeronautical data-link technology;
  - **Enhanced navigation accuracy and integrity** by means of Ground-, Aircraft- and Satellite-Based Augmentation Systems (GBAS/ABAS/SBAS), promoting Dual-Frequency/Multi-Constellation Global Navigation Satellite Systems (GNSS) as primary means of navigation; as well as Alternative Position Navigation and Timing (APNT) systems as backup for GNSS.
  - **Enhanced ground-based and satellite-based surveillance,** including ADS-B, Multilateration (MLAT) and other self-separation services;
  - **Advanced sensor systems with data fusion**, real-time analytics and learning to enable autonomy; and
  - A **System Wide Information Management** (SWIM) network.

Cyber-Physical Systems Evolutions

Digital – Industry 4.0

ASN (avionics sensor networks) – Larger networks, more data and optimization

HMT – Information overload → autonomy and automation

CPS – sensing, processing, and networking at the edge

…. Environmental concerns

Cyber-Physical-Human (CPH) systems

Multi-Domain: space, air, ground (space domain awareness)

Trends: Intent-Based Operations (IBO)

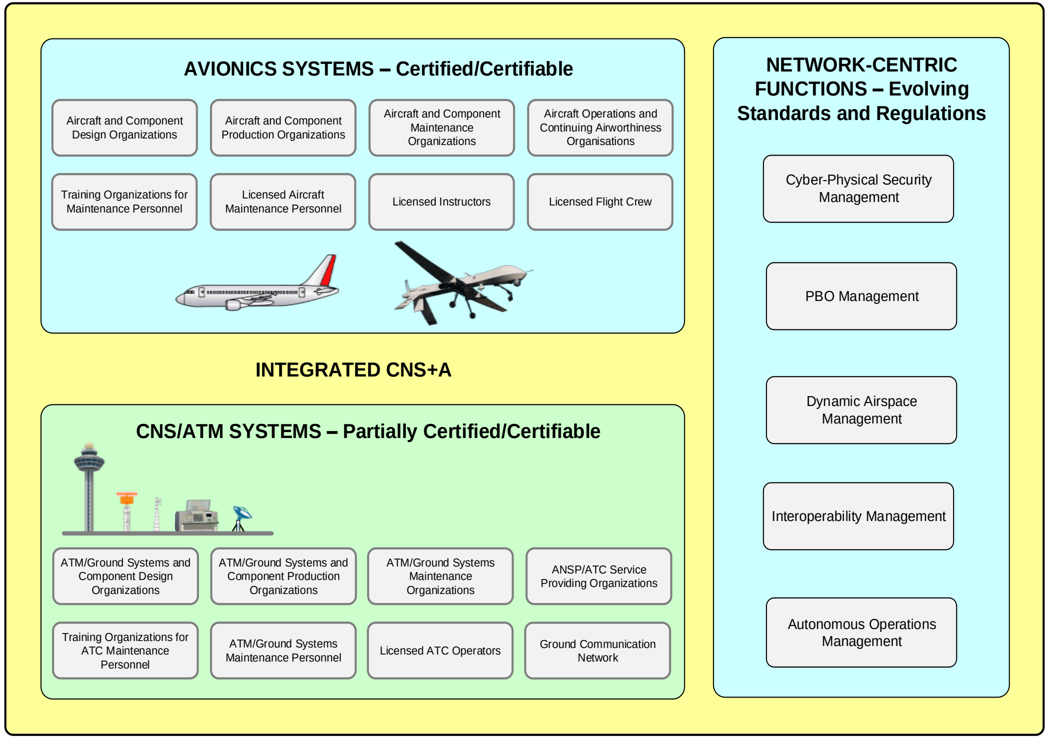
Future Directions – Certifiable

Certifiable

Over

ATM
UTM
STM

Integrated Vehicle Health Management (IVHM) systems are primarily responsible for diagnostics, prognostics, and risk mitigation across both air and space platforms



Future Directions – Integrated Vehicle Health Management

Intelligent IVHM systems include finding suitable methods and techniques for:

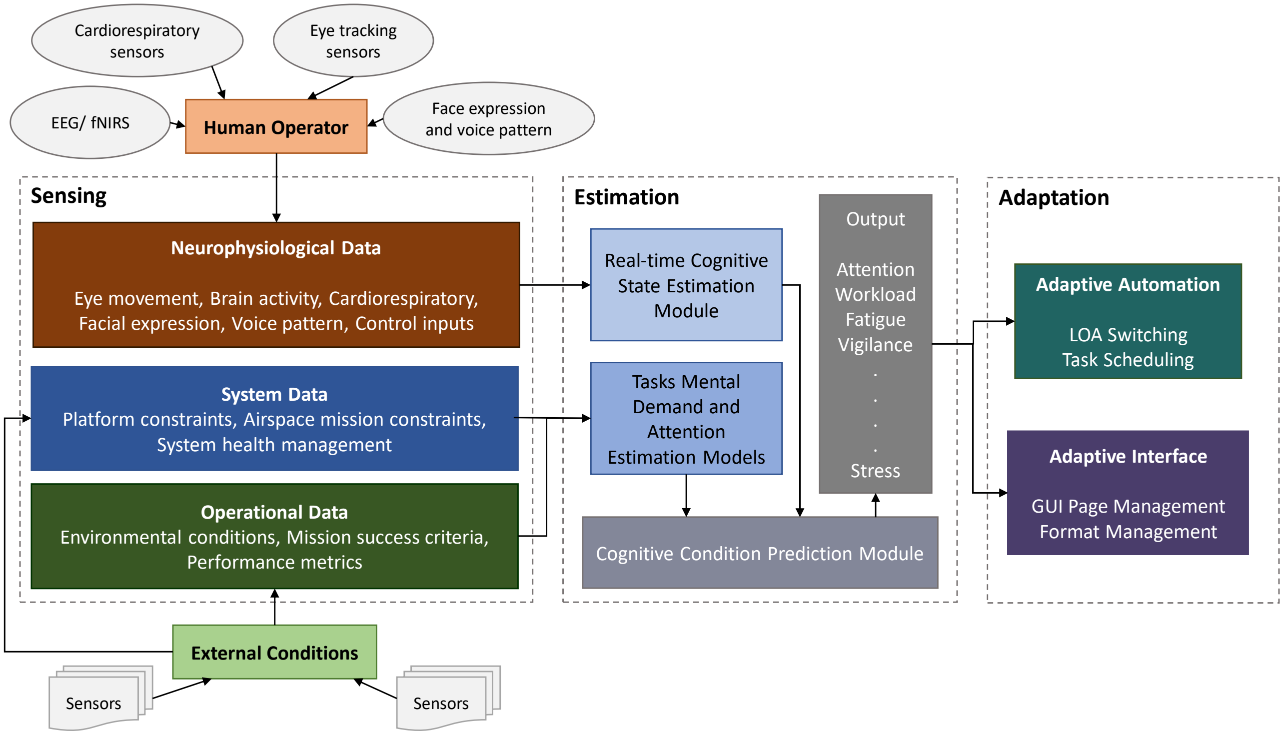
- performing real-time health monitoring functions to support accurate diagnosis of subsystem faults and anomalies;
- providing vital subsystem health and performance information with sufficient time to make real-time decisions in response to detected failures; and
- addressing the complete integration and management of all vehicle functions and subsystems by considering their interactions and fault causal relationships.

Future Directions – HMT

Human
AI/ML

Explainable
Interpretable
Accountable

Situation awareness



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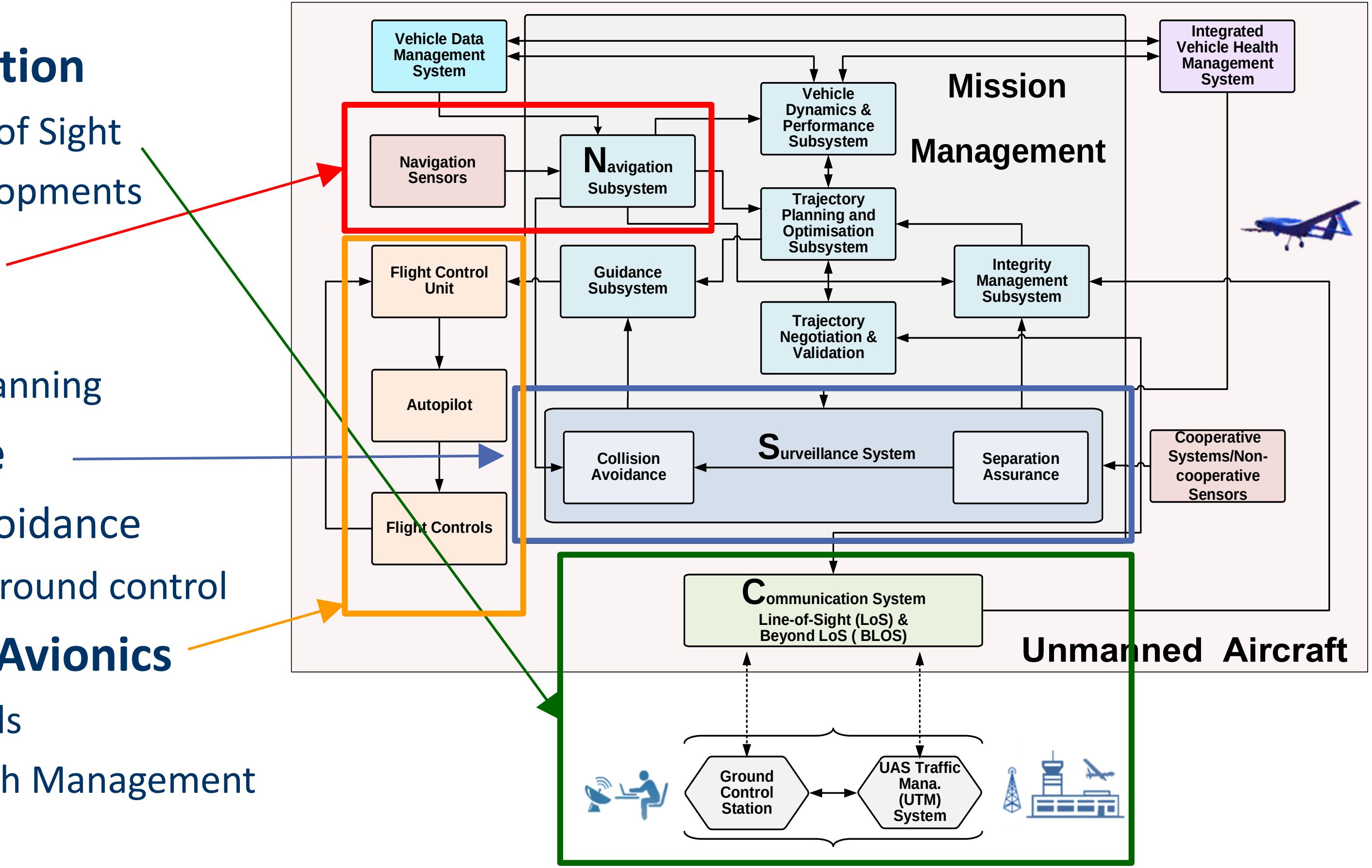
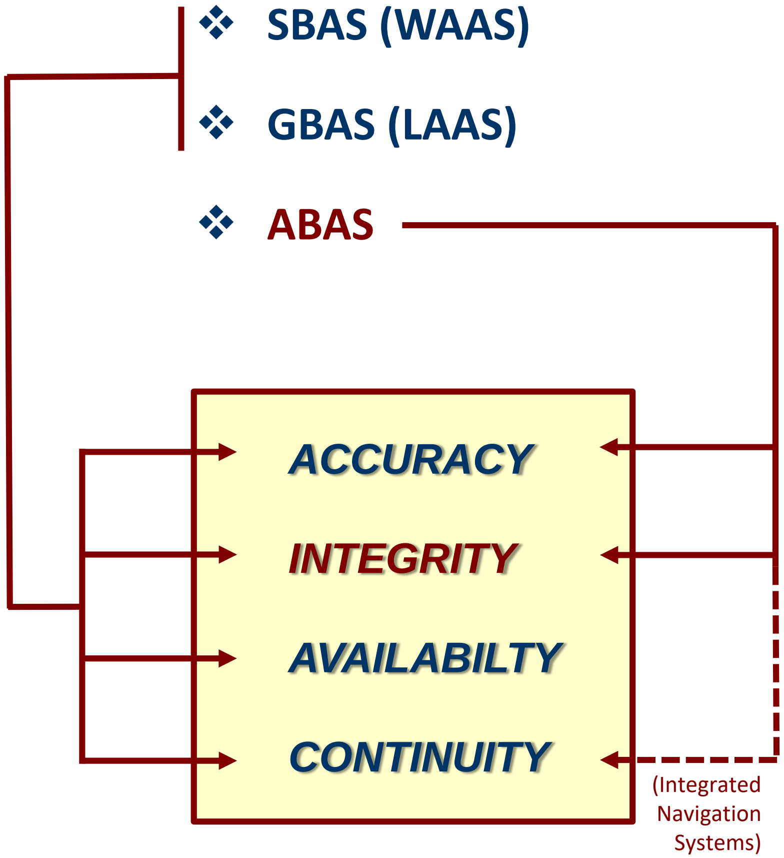
UAS Avionics Systems

- **Communication**
  - Beyond Line of Sight
  - 5G/6G Developments
- **Navigation**
  - Guidance
  - Trajectory Planning
- **Surveillance**
  - Collision avoidance
  - ATC/UTM – ground control
- **Specialized Avionics**
  - Flight Controls
  - Vehicle Health Management



GNSS Augmentation Benefits

- **GNSS augmentation benefits** include:
  - Precision approach and landing autonomous ops
  - Operations in urban environments (e.g., UAM)
  - Interference and jamming resistance/avoidance
  - Reduced and simplified equipment on board aircraft
  - Predictive integrity for optimal AI/ML data fusion
- In addition to SBAS and GBAS, GNSS augmentation may take the form of additional information being provided by **other avionics systems**
- A system such as this is referred to as an **Aircraft** (or Avionics) **Based Augmentation System (ABAS)**

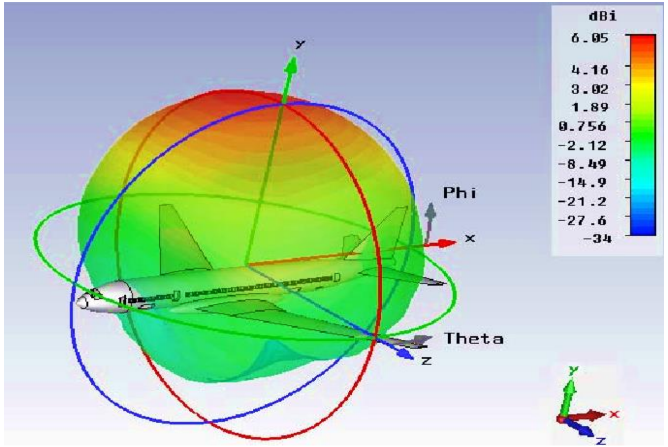


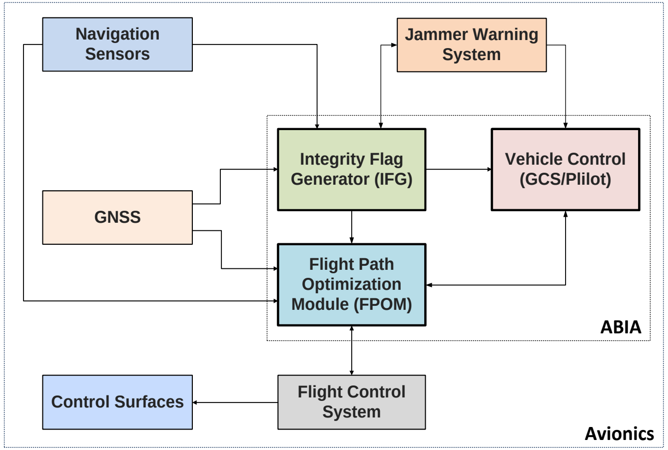
GNSS Integrity Augmentation

❖ **Avionics Based Integrity Augmentation**

- The avionics systems used in ABAS operate via separate principles than the GNSS and, therefore, are **not subject to the same sources of error or interference**
- Focus is on Integrity (in addition to accuracy and continuity) augmentation obtained by system/software redundancy and suitable analytic approaches
- Using suitable data link and data processing technologies, a certified Avionics Based Integrity Augmentation (ABIA) system can be a core element of a future GNSS Space-Ground-Avionics Augmentation Network (SGAAN)

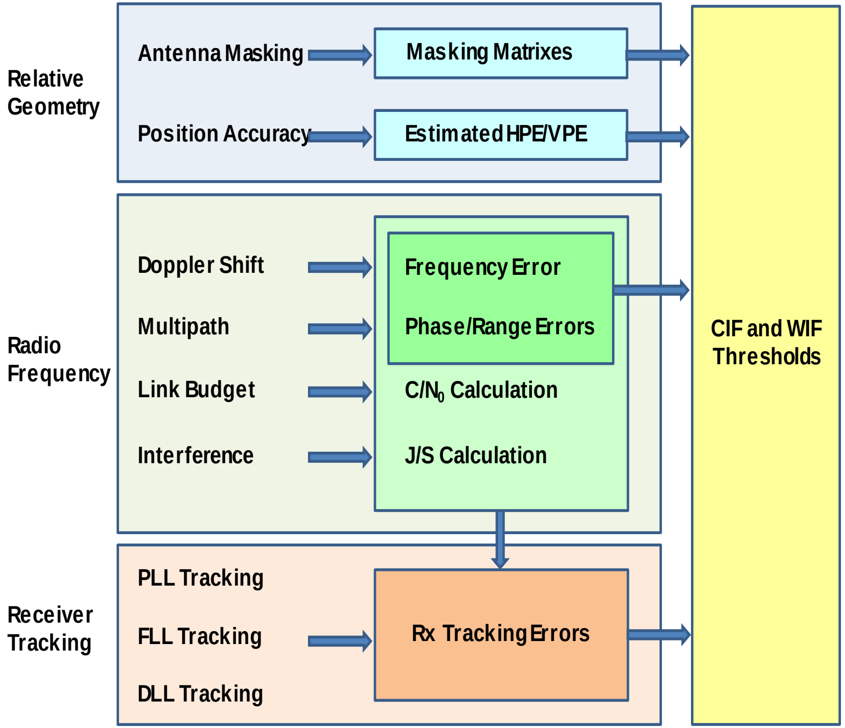
❖ **Developing ABAS for mission-essential and safety-critical GNSS applications (operations with jamming/spoofing, aircraft precision approach/landing, UAS sense-and-avoid, etc.)**



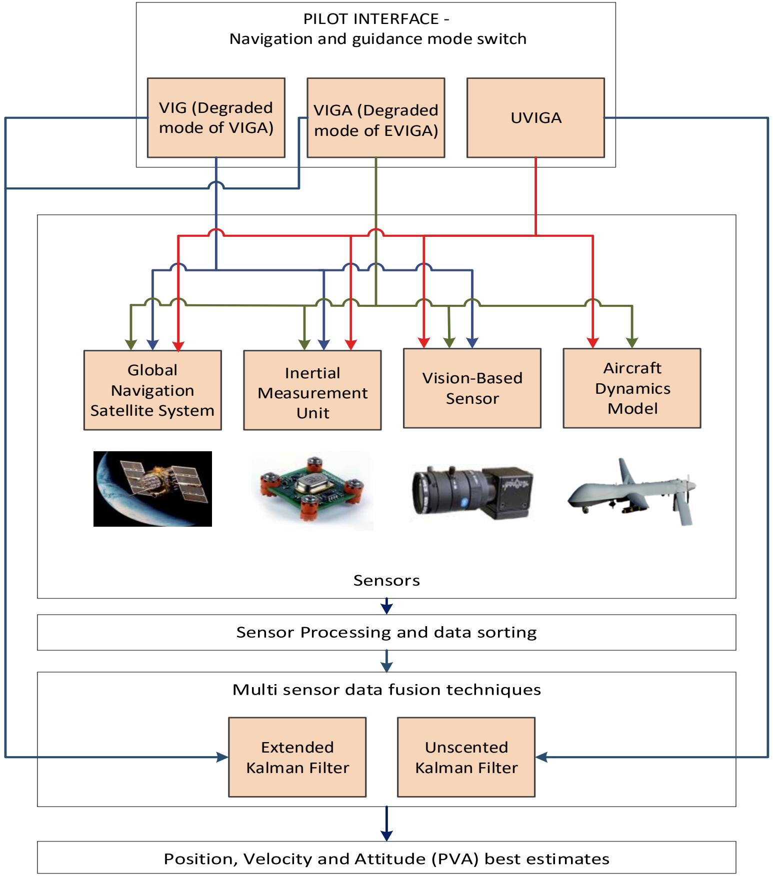


GNSS Performance Threats

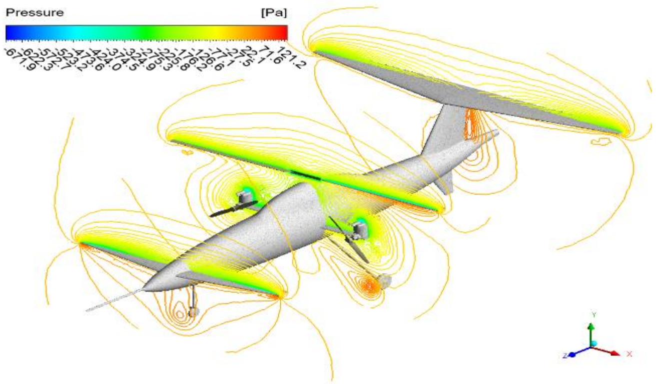
- **Causes of GNSS data degradation or loss:**
  - **Obscuration**
  - **Bad satellite geometry (DOP)**
  - **Fading (low C/N_0)**
  - **Doppler shift (signal tracking, acquisition time)**
  - **Multipath effect (C/N_0, range and phase errors)**
  - **Interference and Jamming**
- GNSS signal outages/degradations models are used in association with suitable integrity thresholds and guidance algorithms
- Using these models, the ABIA system is able to generate integrity caution (predictive) and warning (reactive) flags, as well as steering information to the pilot and electronic commands to the aircraft/UAV flight control system



Integrated Navigation Architecture

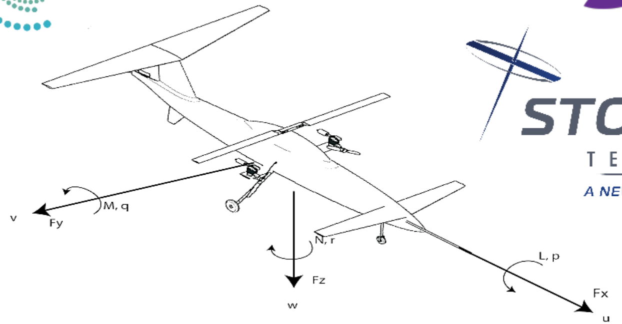


GNC for the StopRotor VTOL UAS



DEFENCE INNOVATION HUB

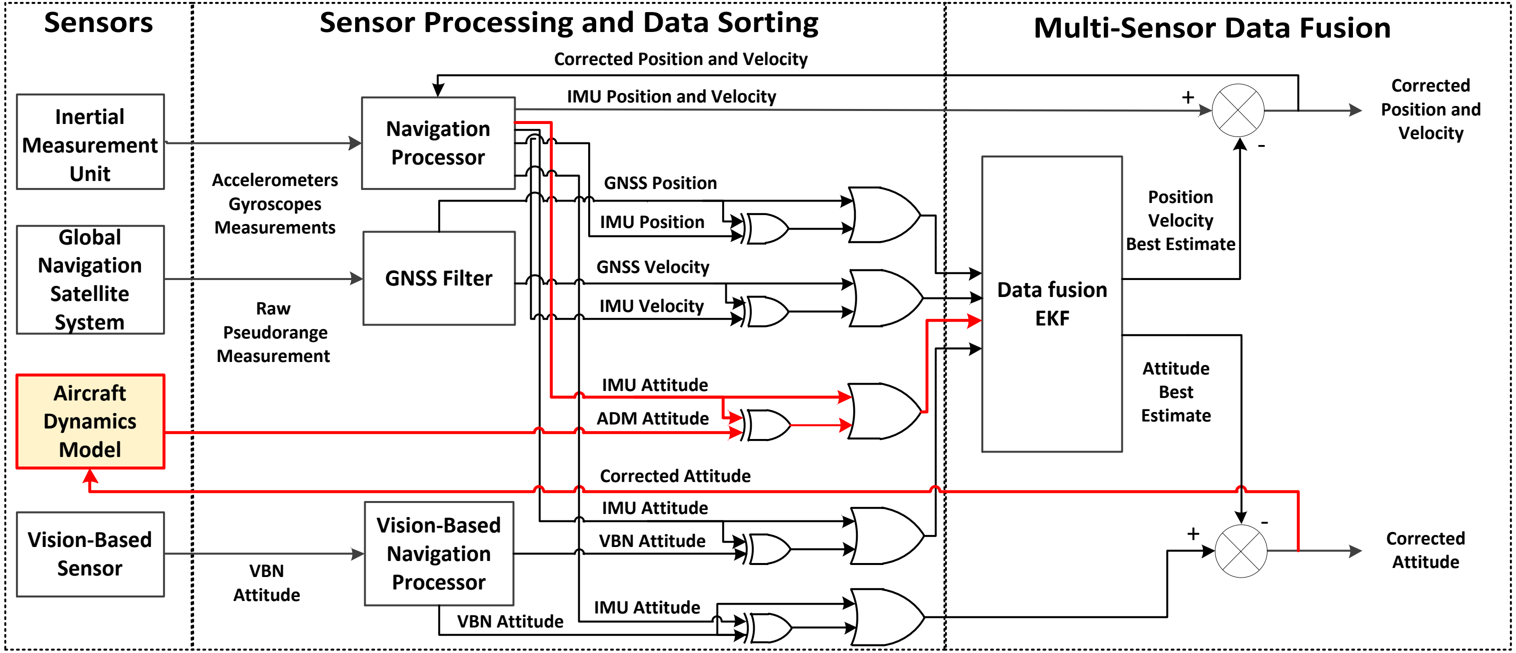
defence science institute
Creating Defence Science Research Networks for Australia



STOPROTOR
TECHNOLOGY
A NEW DIMENSION IN FLIGHT

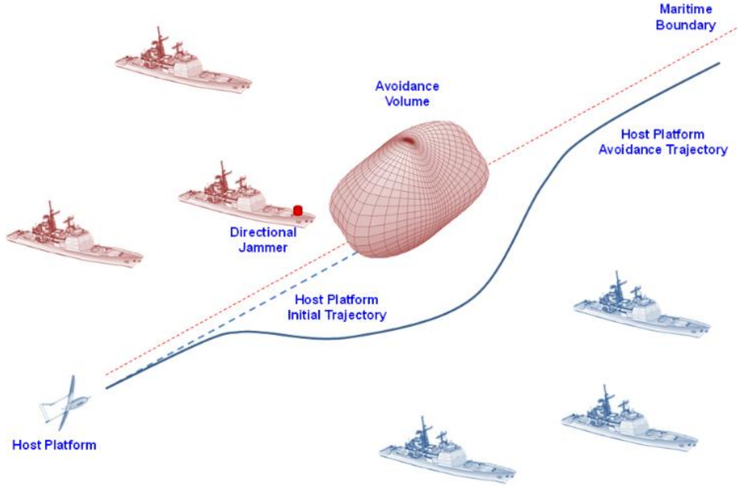
Integration Architectures

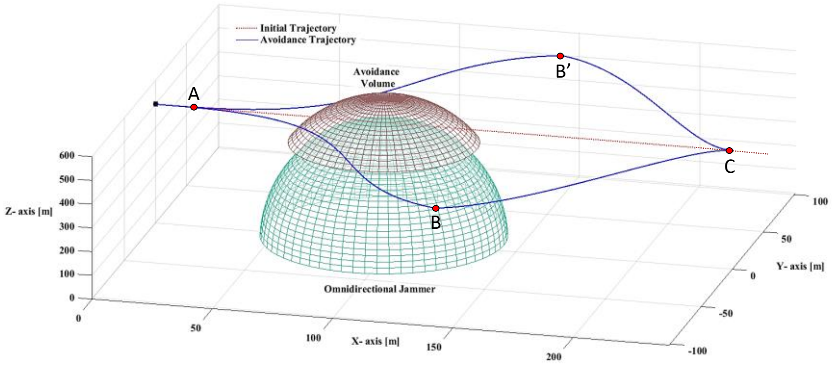
- VBN/INS/GNSS (VIG) Configuration
- VBN/INS/GNSS/ADM (VIGA) Configuration



Autonomous Navigation and Guidance in GNSS-denied Environments

- Jamming radiation pattern estimated based on J/S, C/N_0 and jammer type
- ABAS predictions used to avoid jamming volume
- Simulation of spot, sweep and barrage type jamming
- Generation of optimal avoidance trajectories, preventing degradation or losses of navigation data



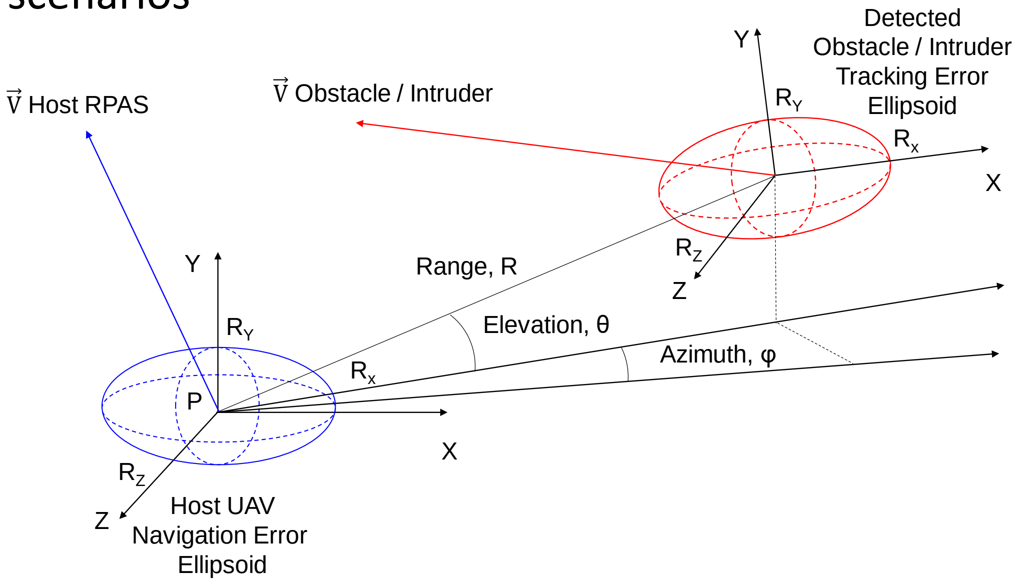


Separation Assurance / Collision Avoidance

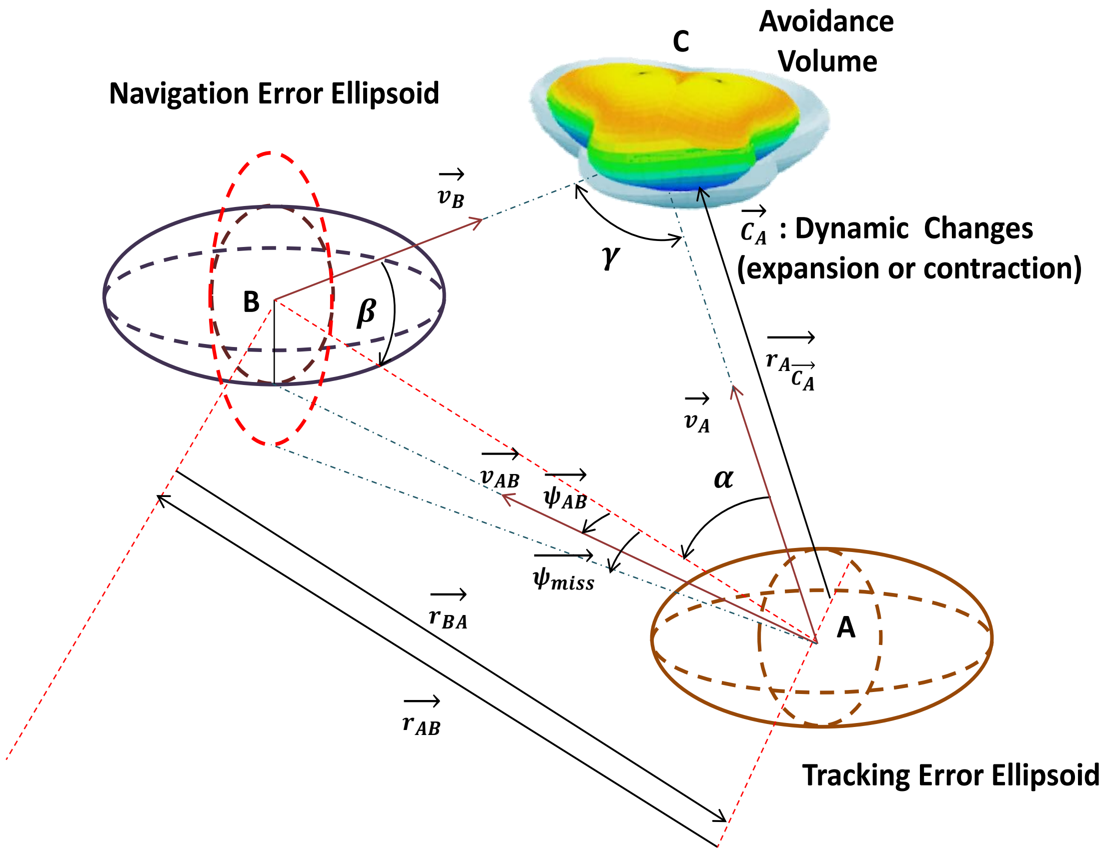
- **Cooperative and Non-Cooperative Separation Assurance** and **UAS Sense-and-Avoid** (SAA) are paramount capability to enable manned and unmanned aircraft to coexist in all classes of airspace
- A new unified framework is required for a seamless integration of UAS in the ATM system (UTM) with no impacts on safety and operational/environmental efficiency
- Autonomous SA and Collision Avoidance (CA) **has to be equivalent or exceed the ATM de-confliction and pilot see-and-avoid capabilities** in current airspace
- SA/CA systems must allow **operations during day and night in all-weather conditions**
- System **response time** and **integrity** must be adequate for platform dynamics and operational environment

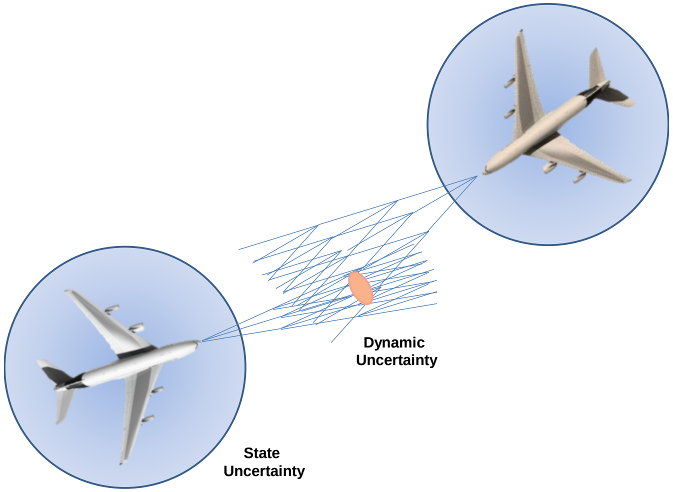
SA/CA – Avoidance Volume

- **Avoidance volume** in the space surrounding each track is determined
- Accomplished by **considering 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



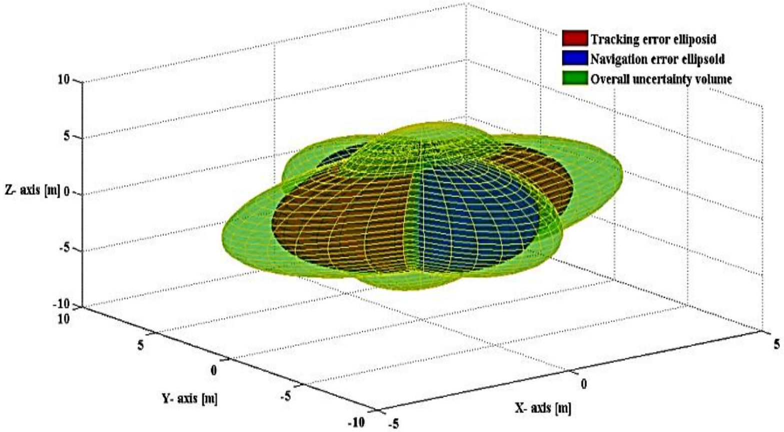
SA/CA – Relative Dynamics

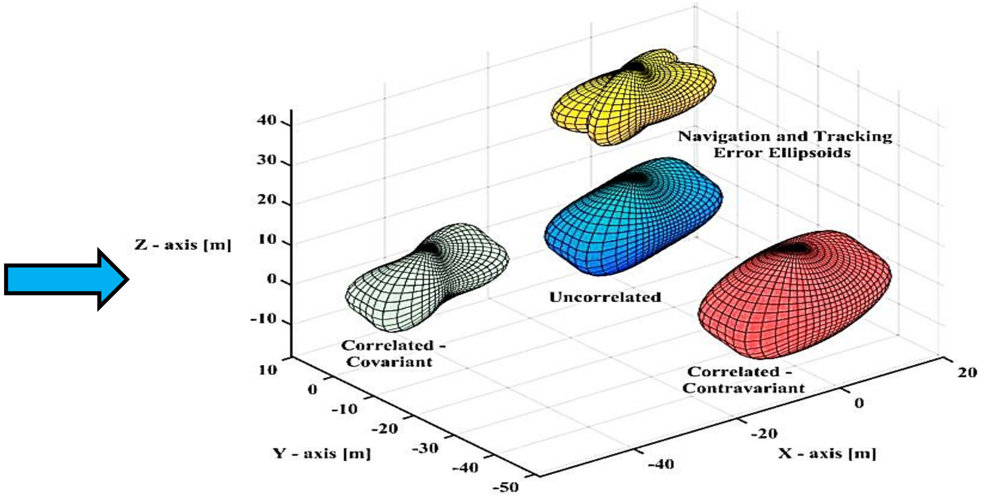




SA/CA – Error Analysis

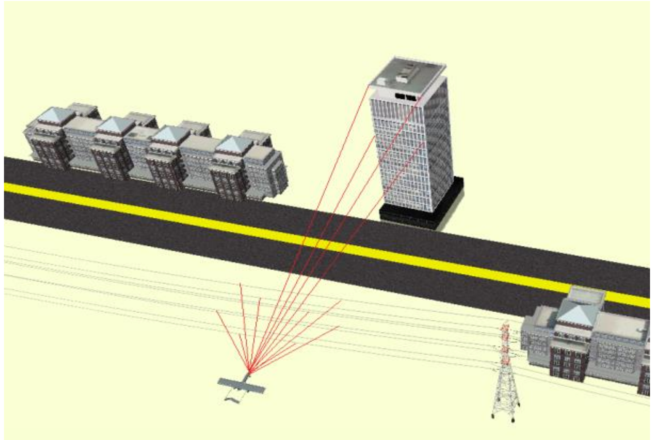
- Errors are statistically correlated (e.g., ADS-B) or uncorrelated (e.g., NC-SAA)
- The avoidance (uncertainty) volume for uncorrelated measurements is obtained by inflating the navigation ellipsoid with the tracking error components
- The uncertainty volume for correlated errors is obtained using vector analysis [14]

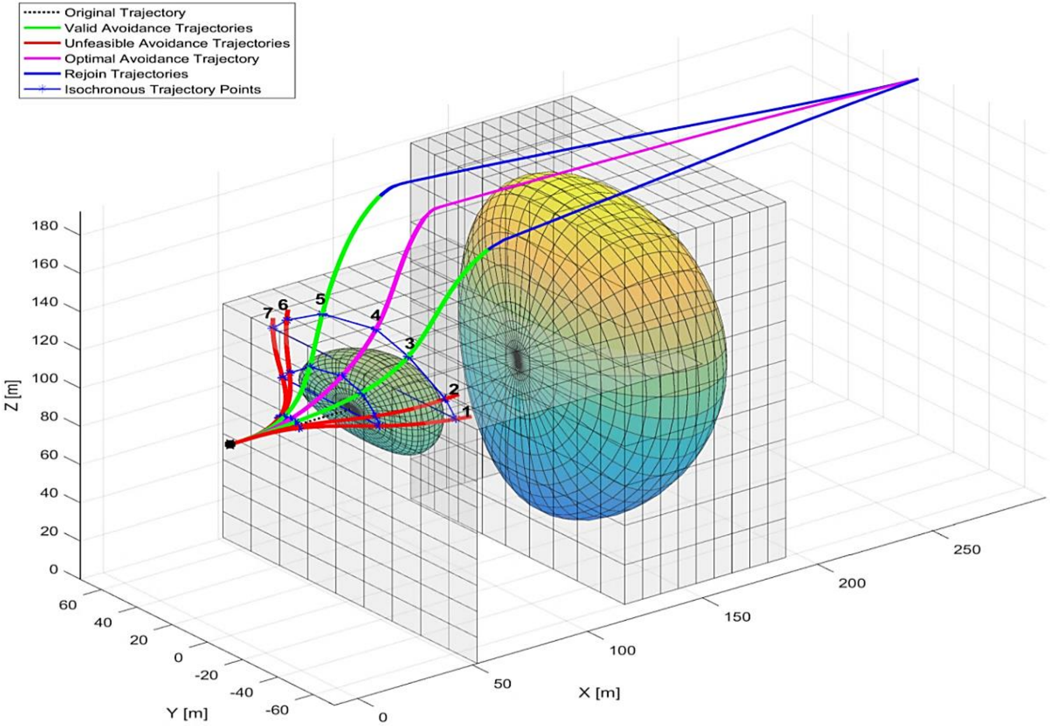




SA/CA – Safety-critical Applications

- Uncertainty volumes for avoidance of ground obstacles
  - A set of feasible avoidance trajectories is generated in real-time





Presentation Outline – Part I: Research

- 1. Introduction
- 2. Requirements of Future CNS+A Systems
- 3. UAS Avionics Systems
- 4. Concept of UTM and STM
- 5. HMI^2 for Future Aerospace Vehicles
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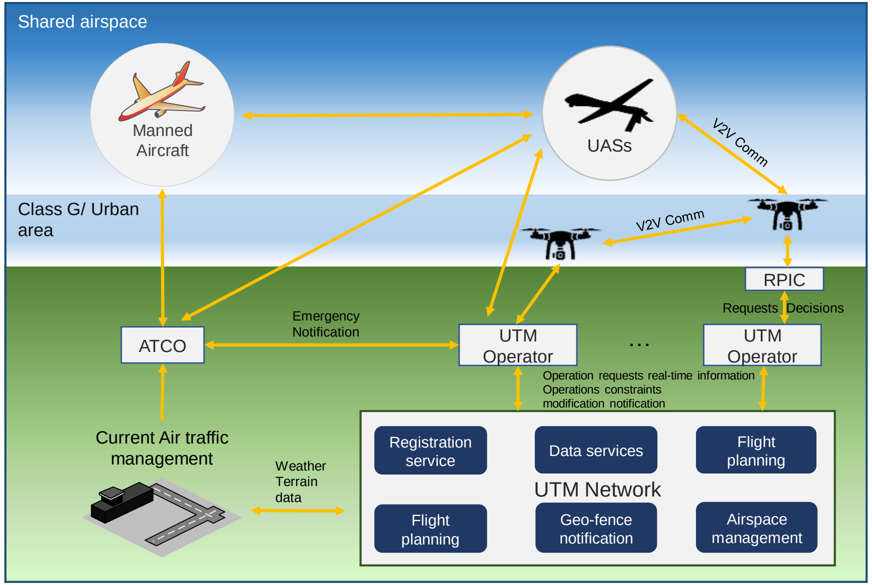
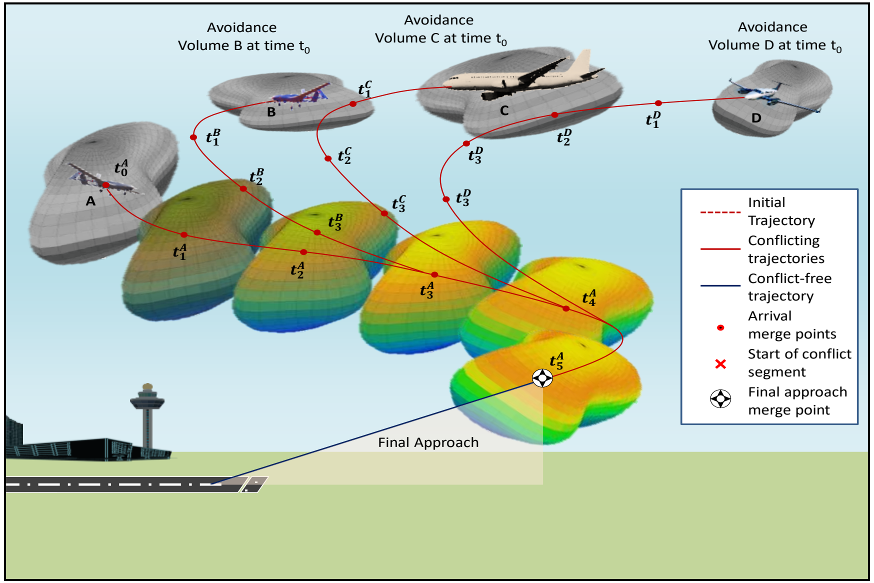
- 7. Cyber Security for UAS

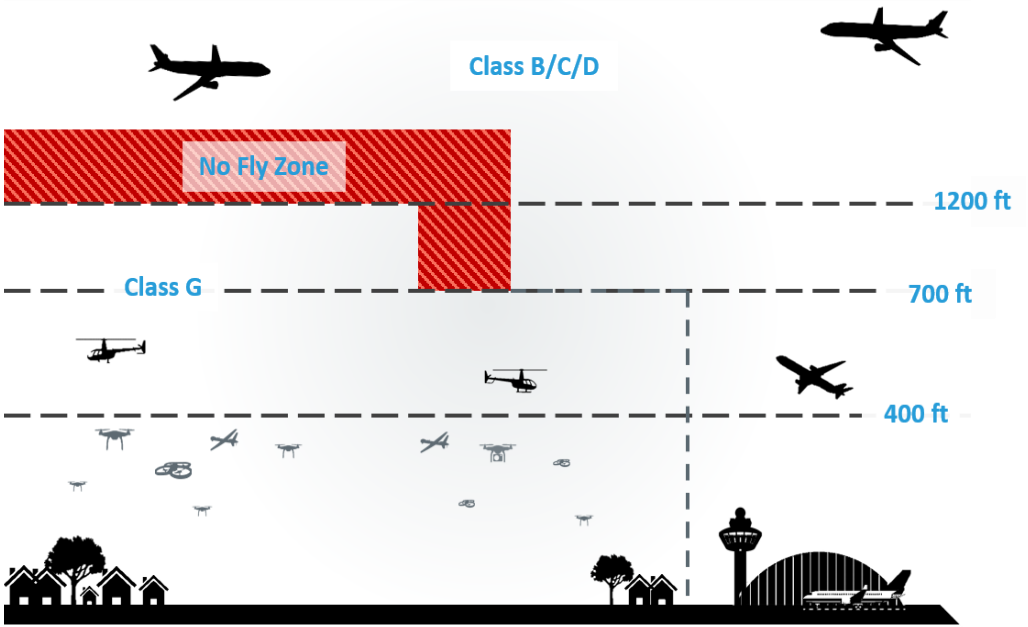
UAS Traffic Management

- The unified approach supports trusted autonomous operations in the UAS Traffic Management (UTM) context
- Avoidance volumes (i.e., dynamic geo-fences) are generated in real-time to allow computation of the optimal avoidance flight trajectories



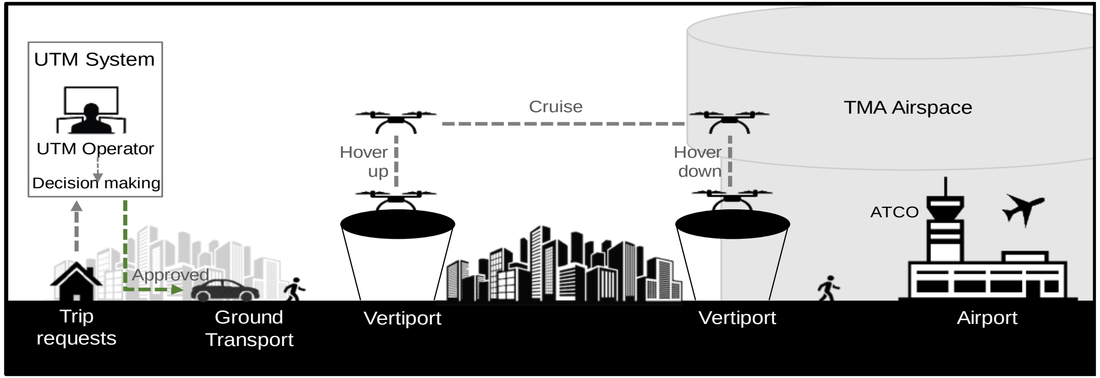


UAS Traffic Management – Key Challenges



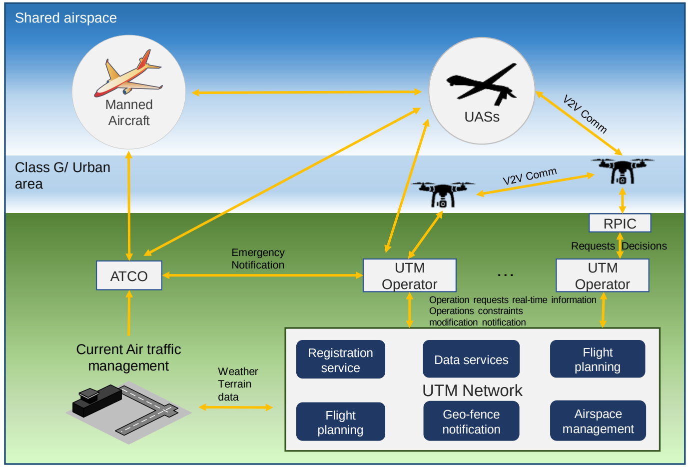
- The conventional tactically focussed and tactical ATC paradigm cannot fulfil the needs of manned/UAS traffic integration
- A higher degree of automation is necessary in the UTM framework
- The tactical deconfliction approach of traditional ATM cannot be scaled down to apply in UTM
- The tasks and responsibilities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

UAS Traffic Management and UAM



Urban Air Mobility

The ability to start/end flight trips essentially anywhere (low predictability of traffic)



- UTM/UAM 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/UAM are yet to be defined

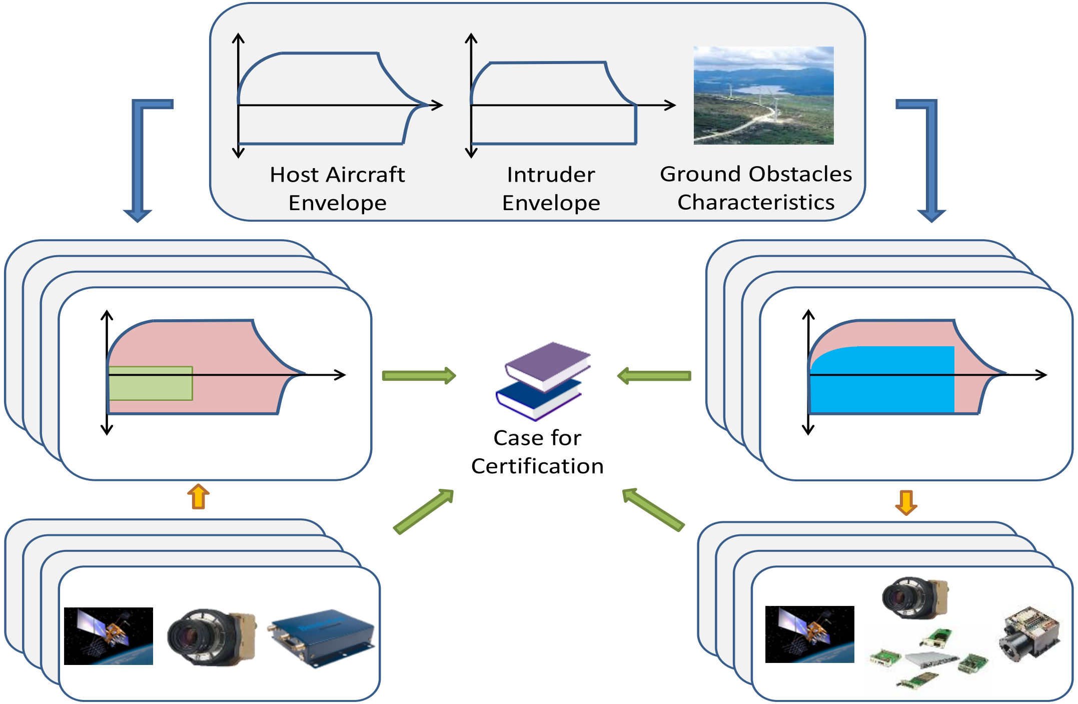
What will be the role of Human Operators?

From Human-IN-the-Loop to Human-ON-the-Loop

- **HOTL is a supervisory control paradigm** where an operator focusses on **high-level strategic tasks**, meaning that the autonomous/intelligent system performs most or all tactical level activities
- The synergy of AI with HOTL architectures is seen as a possible solution to the problem:
  - ❑ AI can prevent/mitigate imminent hazards without requiring the operator's approval as in HITL operations
  - ❑ Human is still informed and consulted, with the possibility of intervening if and when required (based on both predictive and reactive integrity features)
- The introduction of high-performance AI requires a higher and better level of human-machine coordination (machine and human integrity monitoring/augmentation functions)

SA/CA – Pathway to Certification

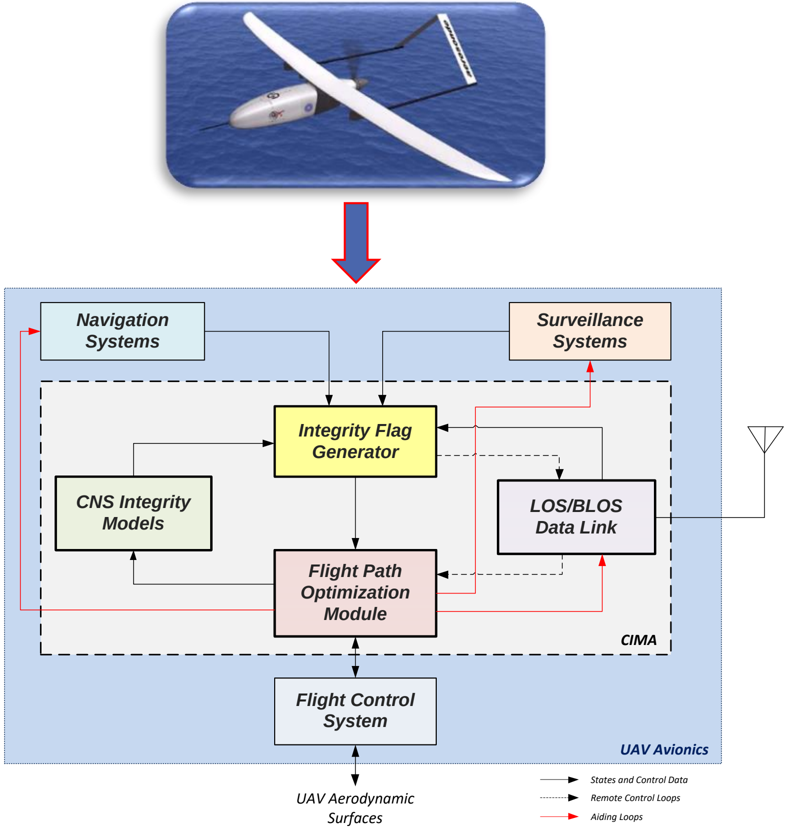
- Distinctive advantage: ability to determine the safe-to-fly UAS envelope based on the on-board sensors and alternatively to identify the required sensors in order to achieve a certain predefined safety envelope

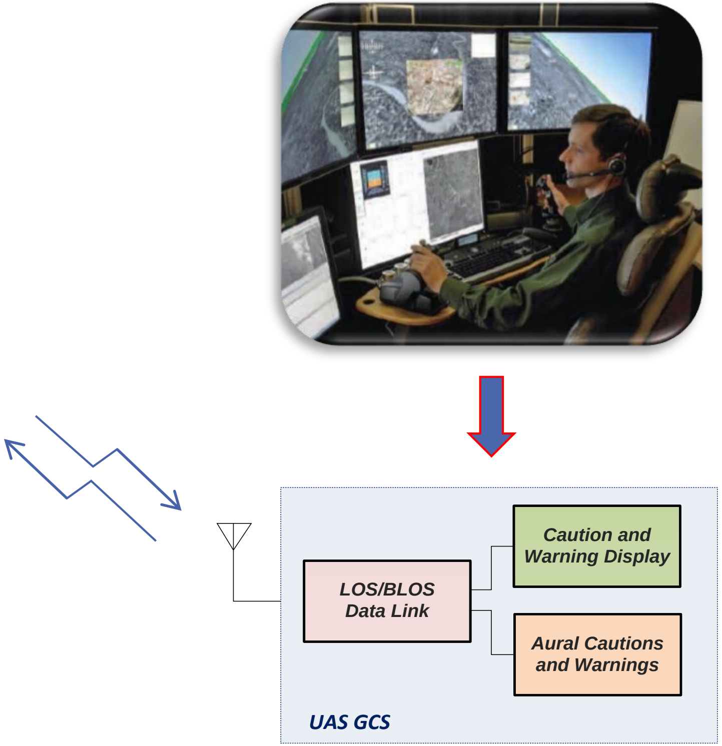


CNS Integrity Monitoring and Augmentation for SAA

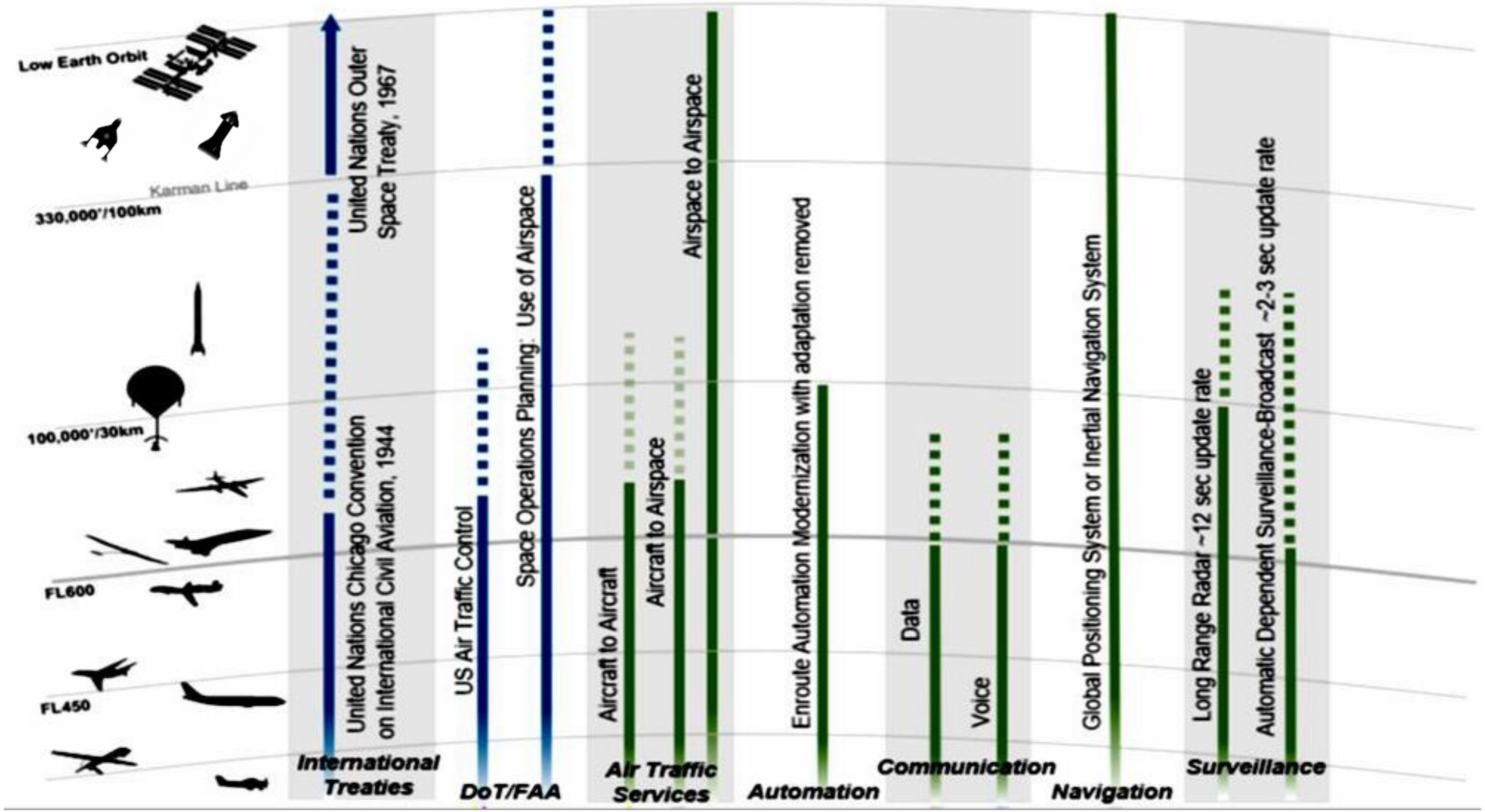
- To allow the high levels of autonomous decision making required in TDA loop, the UAS Communication, Navigation and Surveillance (CNS) systems **must guarantee high levels of integrity**
- Integrity is a measure of the level of trust that can be placed in the performance of a system. For CNS, this means that either a specified level of performance is available (with a specified max probability of failure) or, if not, a usable integrity flag is generated within a max Time-To-Alert (TTA)
- In addition to integrity monitoring (inherently reactive), in UAS applications there is a strong need for Integrity Augmentation including **both predictive and reactive features**
- In UAS the adoption of **Integrity Augmentation for all CNS systems** would allow an extended spectrum of autonomous and safety-critical operations

CNS Integrity Monitoring & Augmentation





Evolving Air and Space Transport Ecosystem

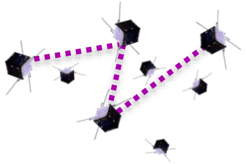


Distributed Satellite Systems

What Are Distributed Satellite Systems (DSS)?

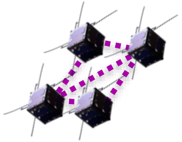
*DSS mission architectures move away from the **monolith** system concept to adopt **multiple** elements that **interact**, **cooperate** and **communicate** with each other, resulting in **new systemic properties** and/or **emerging functions***

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



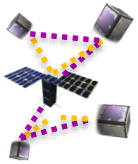
Swarms

Strength in numbers- active research field ***1000+ Small Sat Platforms***



Clusters

Close formation, interferometry, SAR *NASA DARWIN*



Fractionated

Fully distributed functionalities (Power, Payloads)- active field of research.

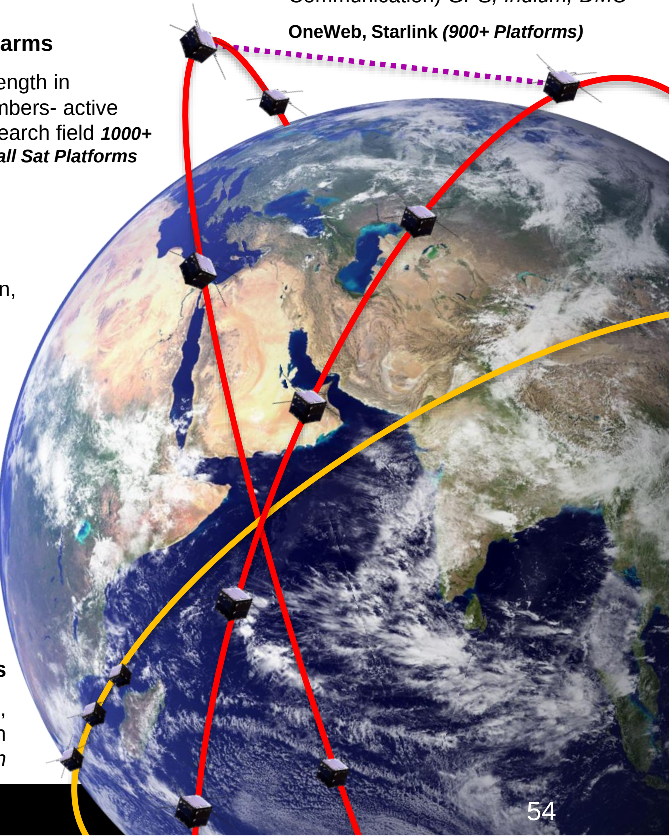
Trains

Synergistic Measurements, Reduce temporal variation in EO Mission *NASA A-Train*

Constellations

Focus on Coverage (EO & Communication) *GPS, Iridium, DMC*

OneWeb, Starlink *(900+ Platforms)*



Distributed Satellite Systems (2)

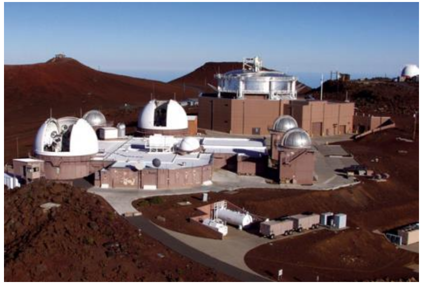
Why do we need *truly* Distributed Satellite Systems?

*To provide a more **responsive** and **resilient** option to **addressing the growing needs** of the global **scientific community** and **defense sector** by aiding in the **measurement and prediction of:***

Earth Observation (EO)

- Global meteorological events, natural disasters and fauna migration movements as a result of climate change
- Maritime illegal fishing, sea terrorism, illegal immigrations

Space Domain Awareness/STM



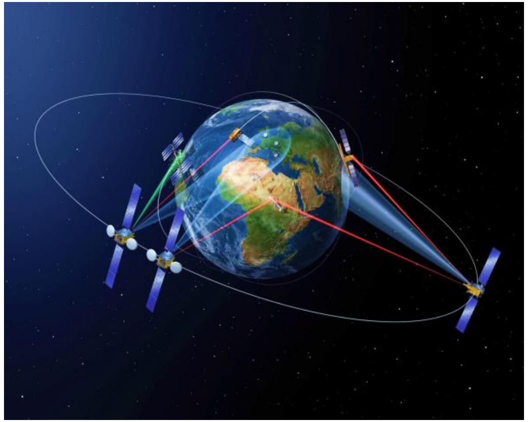
- Increase of Resident Space Objects (RSO) perpetuating hazardous *"Kessler Syndrome"*
- Reduction of uncertainty by Tracking of <10cm RSO's elusive to ground infrastructure

DSS and SmartSat Research Context

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

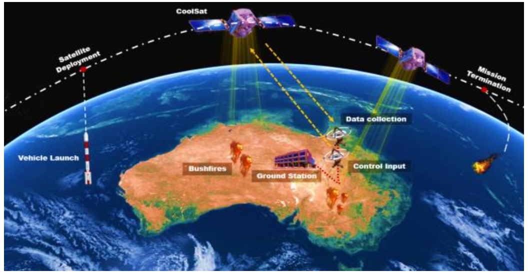
Strengths/Discriminators

- Ground-based and space-based SDA/STM
- AI-based sensor management and data fusion (autonomous decision making, diagnosis/prognosis and mission management)
- Custom sensors and data analytics products and services for: Mining and Resources, Agriculture/Horticulture/Aquaculture, Transport and Logistics
- Adaptive interfaces and interactions for de-crewing of mission control centres



Research Capabilities

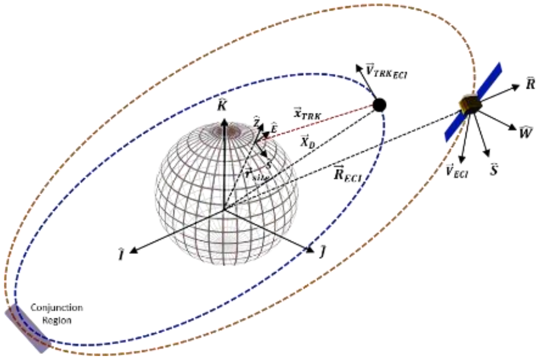
- Artificial Intelligence and Machine Learning (AI/ML) software for trusted autonomous operation
- Fault-tolerant avionics/spaceflight systems research
- Intelligent satellite health management systems
- Passive and active EO/IR sensors and systems

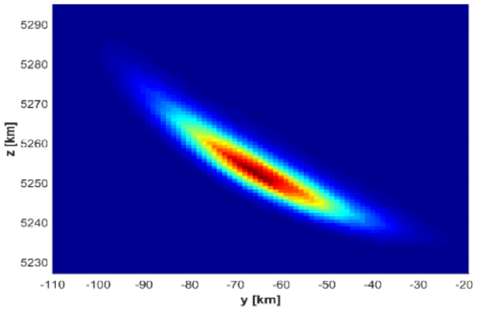


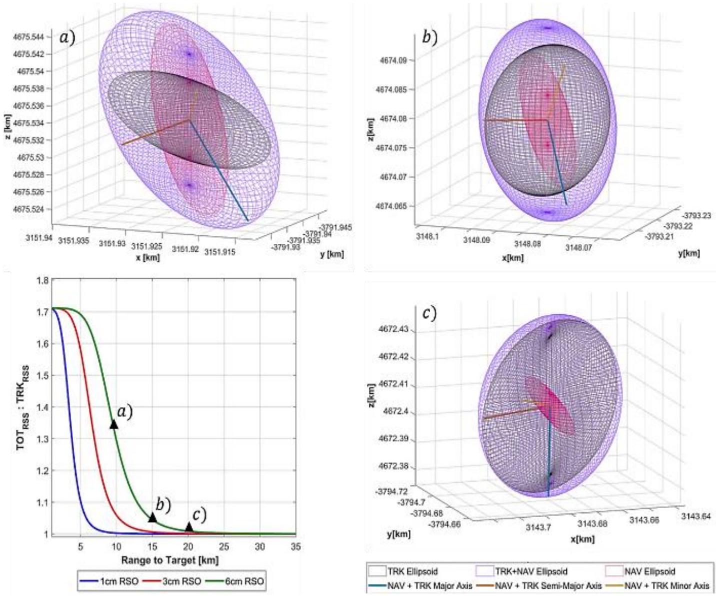
Space Domain Awareness and Traffic Management

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

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







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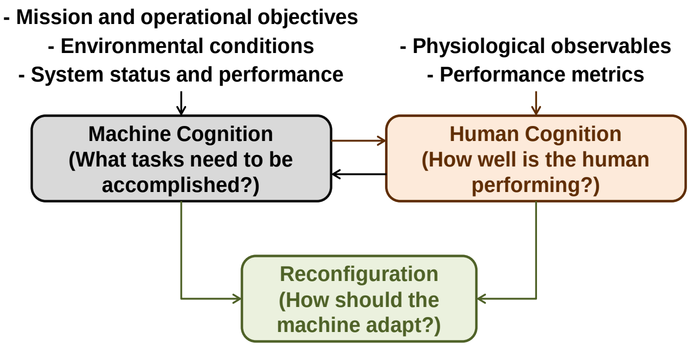
The CHMI² Concept

- This project addresses the development of closed-loop human machine systems implementing Cognitive Human Machine Interfaces and Interactions (CHMI²)
- CHMI² supports human machine teaming whereby a system senses and adapts to the mission environment and the cognitive state of the operator

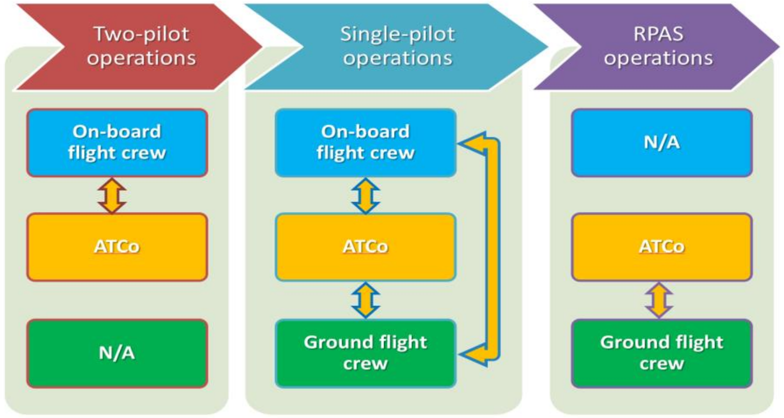


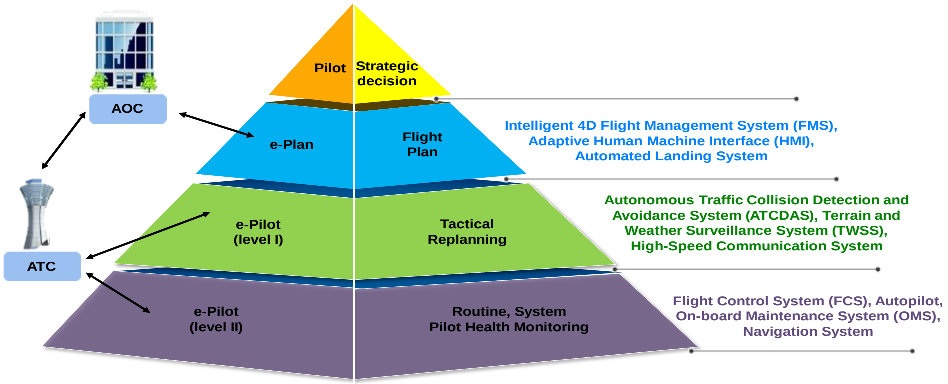
- The CHMI² concept enables **<u>Trusted Autonomous Operations</u>** in both mission-critical and safety-critical applications

CHMI^2 Aeronautical Applications

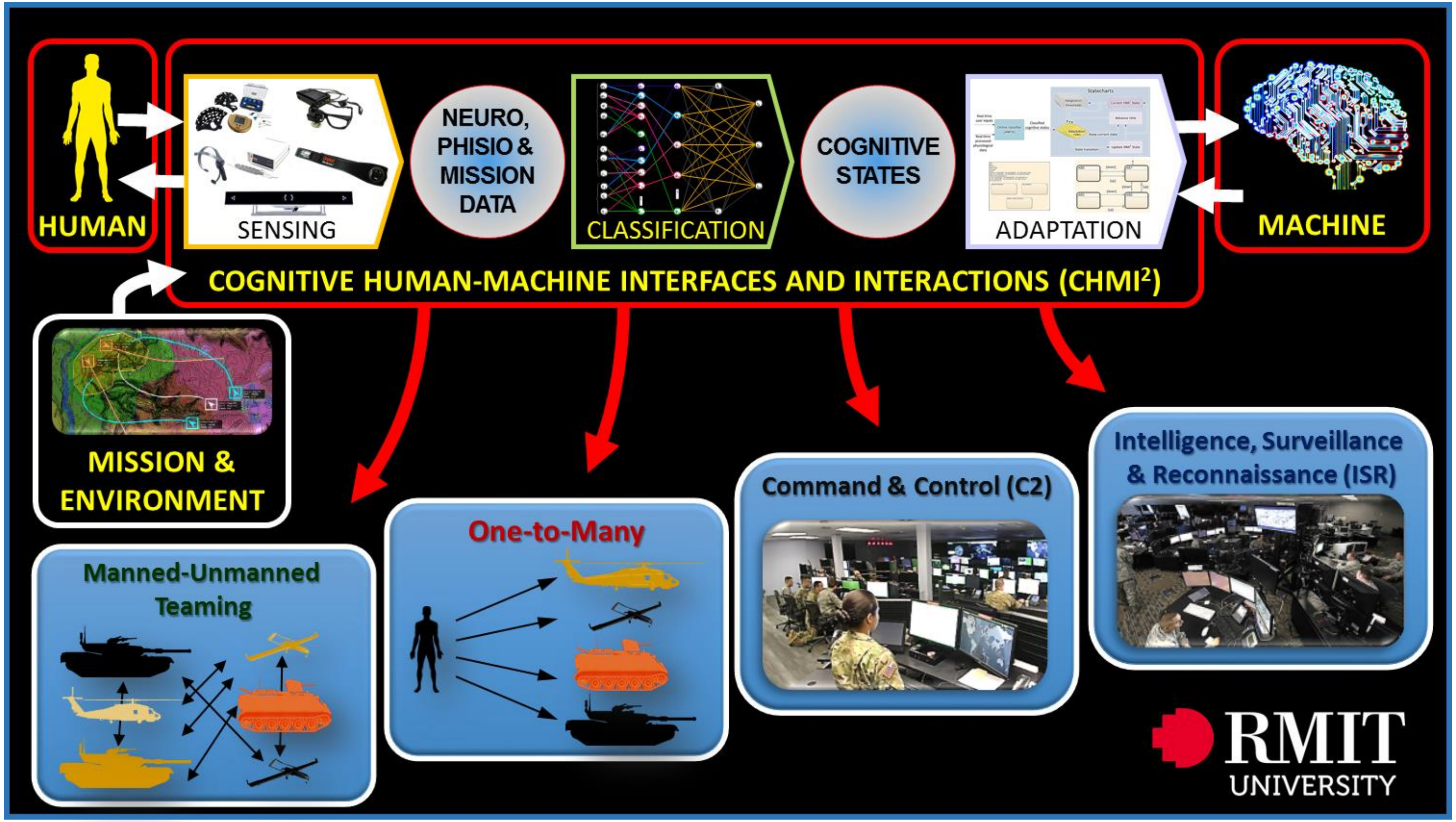
❖ Initial System Requirements

- Increase CNS+A efficiency by dynamically assisting human operators based on real-time detection of physiological and cognitive states
- To improve the total system performance by facilitating human-machine teaming
- To provide clear and unambiguous display formats and functions (system modes, sub-modes and data) based on the operator’s estimated cognitive states

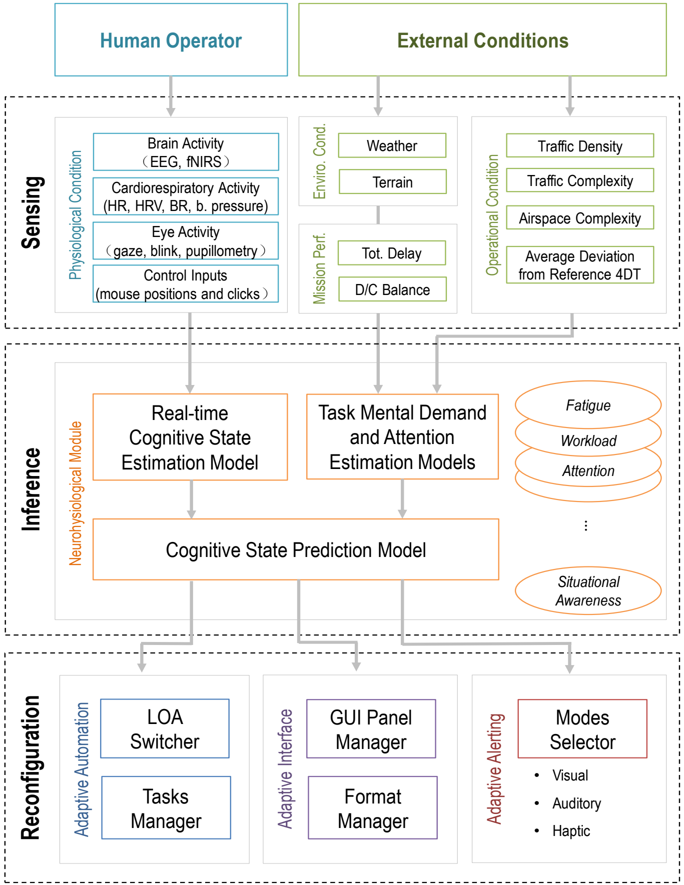


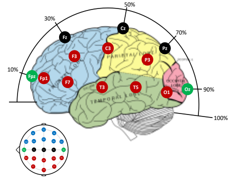


CHMI² Defence Applications

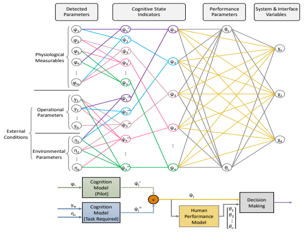


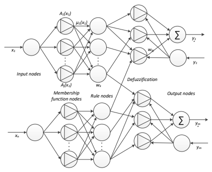
CHMI^2 Framework



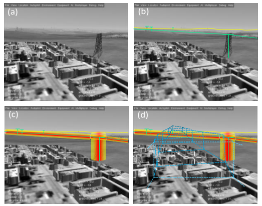


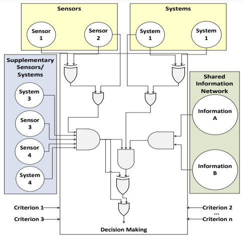
Sensing: uses a suite of sensors to measure neuro-physiological observables in real time, and extracts relevant features from the observables





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





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

CHMI² Mathematical Framework

φ_1 (Heart Rate), φ_2 (Blood Pressure), φ_3 (Blink Rate), φ_4 (Blink Duration), ⋮, φ_m (Respiration Rate)

$$\psi'_{j,t} = f(\varphi_{i,t})$$

$$\psi_{j,ref}' = f(\varphi_{i,ref})$$

$$\psi'_j = \sum_{i=1}^{n} \alpha_i \cdot \frac{\psi_{j,t}' - \psi_{j,ref}'}{\psi_{j,ref}'}$$

ψ_1' (Vigilance), ψ_2' (Arousal), ψ_3' (Workload), ψ_4' (Stress), ⋮, ψ_n' (Fatigue)

ψ_1 (Vigilance), ψ_2 (Arousal), ψ_3 (Workload), ψ_4 (Stress), ⋮, ψ_n (Fatigue)

$$\begin{bmatrix}\theta_1\\ \theta_2\\ \vdots\\ \theta_c\end{bmatrix} = \begin{bmatrix}\beta_{11} & \beta_{12} & \cdots & \beta_{1n}\\ \beta_{21} & \beta_{22} & \cdots & \beta_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ \beta_{c1} & \beta_{l2} & \cdots & \beta_{cn}\end{bmatrix}\begin{bmatrix}\psi_1\\ \psi_2\\ \vdots\\ \psi_n\end{bmatrix} + \begin{bmatrix}\theta_1\\ \theta_2\\ \vdots\\ \theta_c\end{bmatrix}_0$$

Θ_1 (Error Rate), Θ_2 (Reaction Time), Θ_3 (Search Time), Θ_4 (Action Time), ⋮, Θ_c (Time to Complete)

γ_1 (ATM clearance), γ_2 (Airline constraints), ⋮, γ_p (Air traffic complexity)

η_1 (Weather complexity), ⋮, η_q (Terrain complexity)

$$\psi''_j = \sum_{w=1}^{p} \alpha_w \cdot \frac{\gamma_{w,t}}{\gamma_{w,t-1}} + \sum_{v=1}^{q} \alpha_v \cdot \frac{\eta_{v,t}}{\eta_{v,t-1}}$$

ψ_1'' (Vigilance), ψ_2'' (Workload), ψ_3'' (Stress), ψ_4'' (Fatigue), ⋮, ψ_n'' (Arousal)

Linear models

Non-linear models

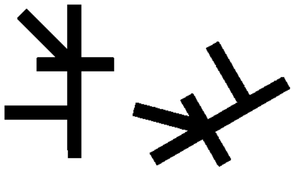
	Fixation time	Glance count	Saccade dispersion	Dwell time	Visual Entropy	Pupil dilation	Heart rate	Resp. Rate	Blink rate
Vigilance	Q-N	L-P	Q-N	Q-N	Q-N	L-P	-	-	L-N
Workload	SPL-P	-	L-N	SPL-P	L-N	L-P	L-P	L-P	L-N
Attention	L-P	SBL-N	L-N	L-P	L-N	L-P	SPL-P	-	L-N

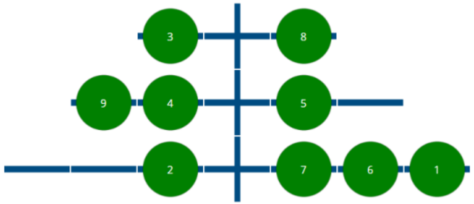
	Vigilance	Workload	Attention
Error rate	L-N	SPL-P	L-N
Reaction time	L-N	Q-P	Q-P
Situational awareness	L-P	Q-N	L-N
Efficiency	L-P	SBL-N	Q-N
Precision	L-P	SBL-N	L-P

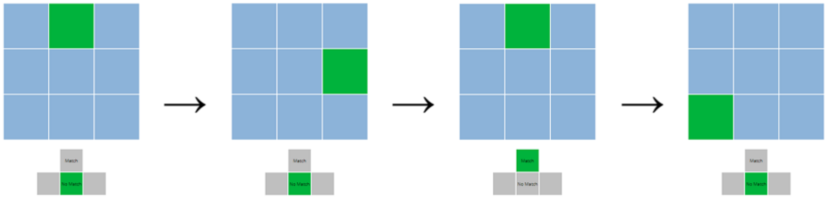
Offline Calibration – Cognitive Test Battery

- A battery of cognitive tests was developed to support the offline calibration of the ANFIS classifier

- The Cognitive Test Battery (CTB) comprises a number of standardized tasks:
  - Mental rotation – spatial processing
  - Hampshire tree – reasoning and planning
  - N-back – working memory





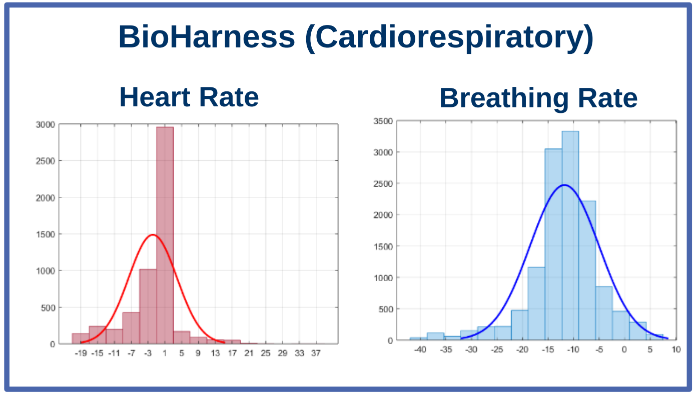


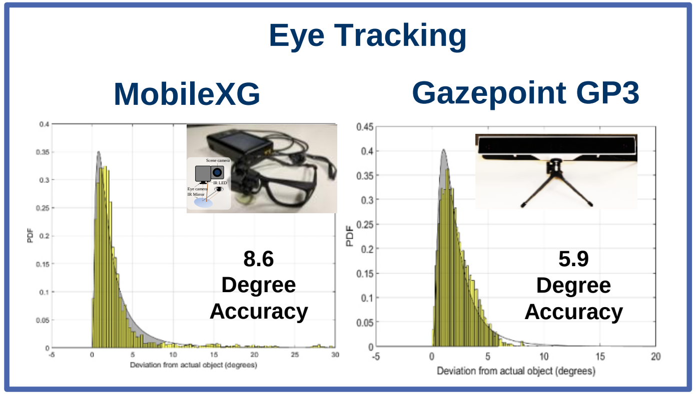
- The CTB is evolving by adopting the NASA Multi-Attribute Test Battery (MATB-II) software

Neuro-Physiological Sensor Network

Sensor Performance Characterization

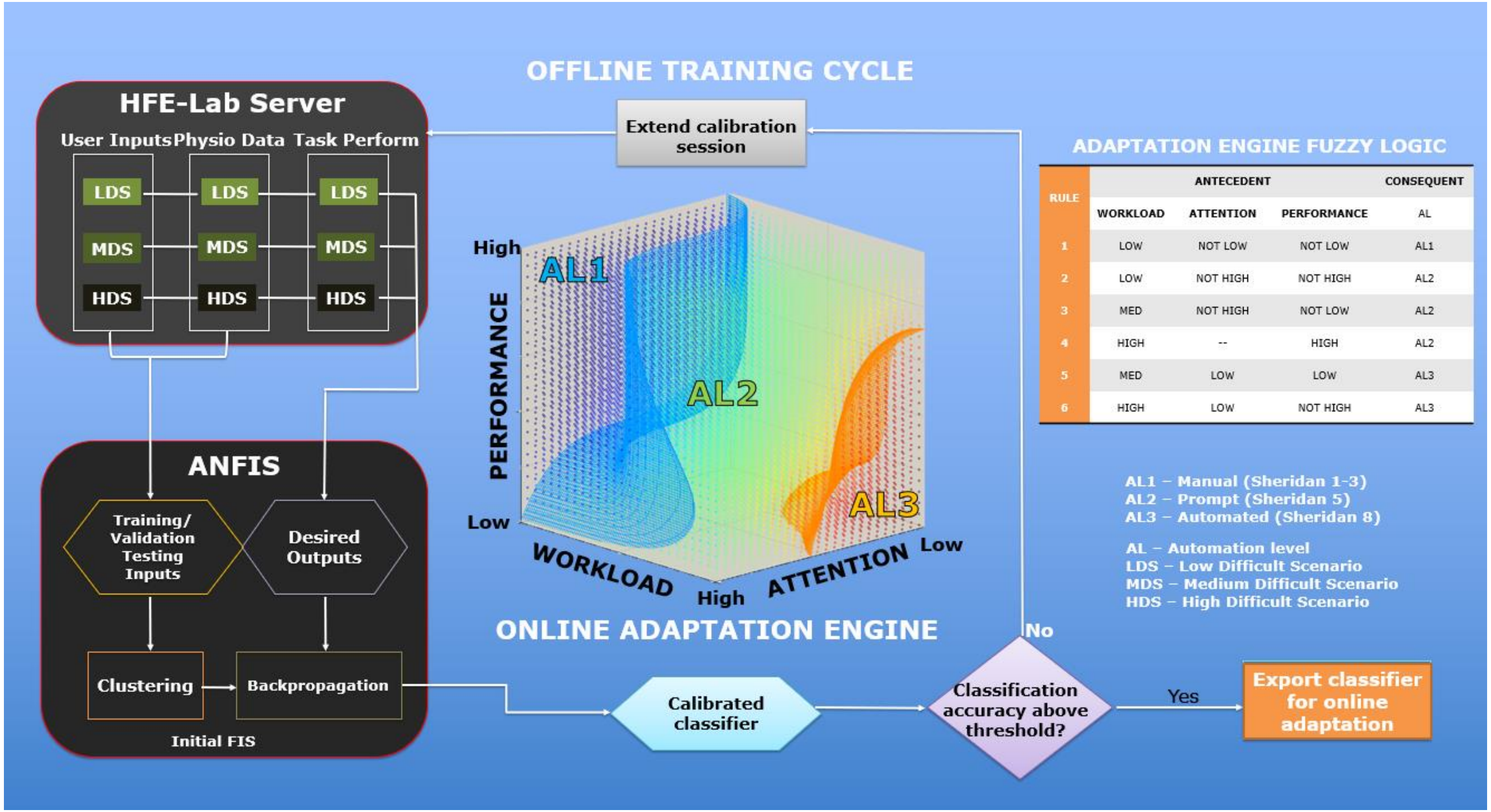
- Characterisation activities of Neuro-Physiological Sensors (NPS) used for the operator cognitive inference
- The uncertainty associated with the neuro-physiological observations is quantified and propagating through the classifier to obtain uncertainty in inferred cognitive states



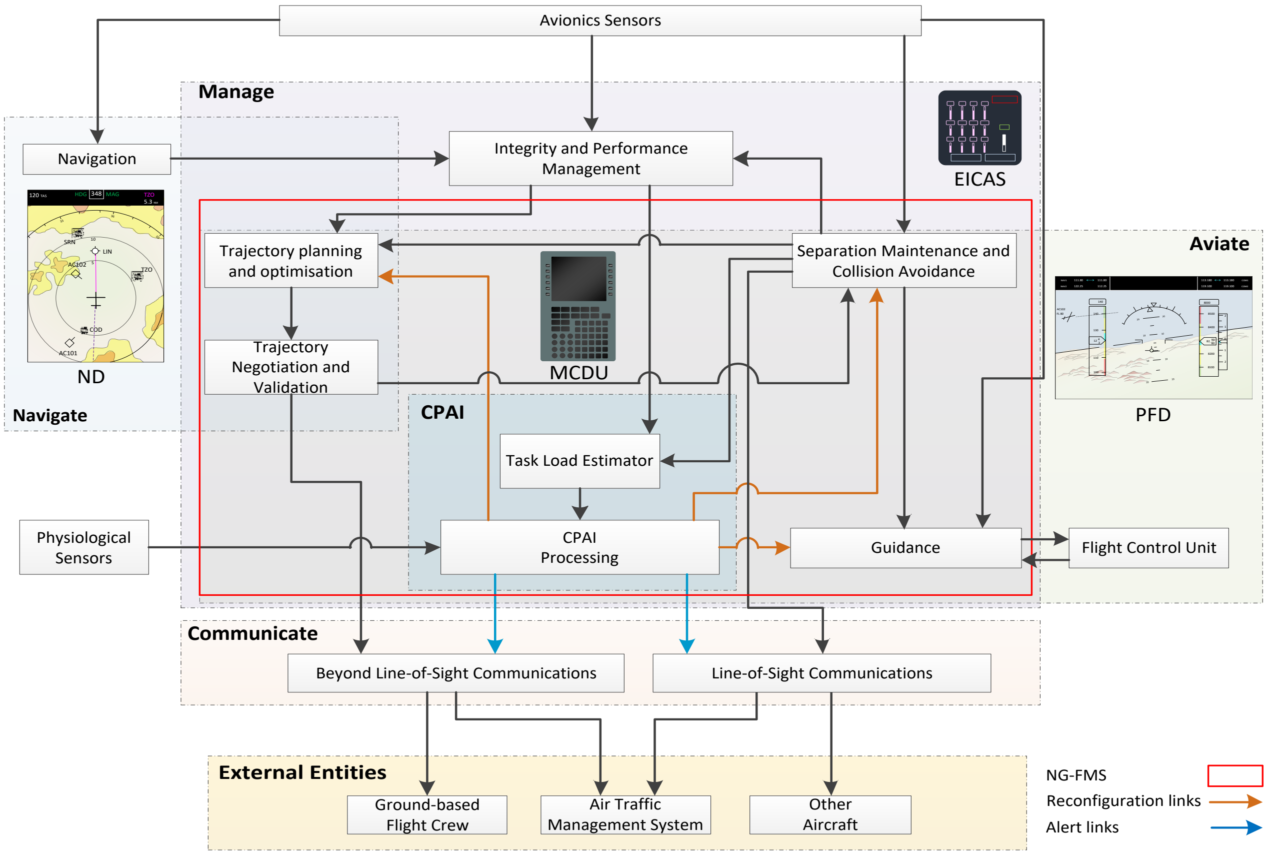


Inference Engine

Cognitive Adaptation Methodology (Summary View)

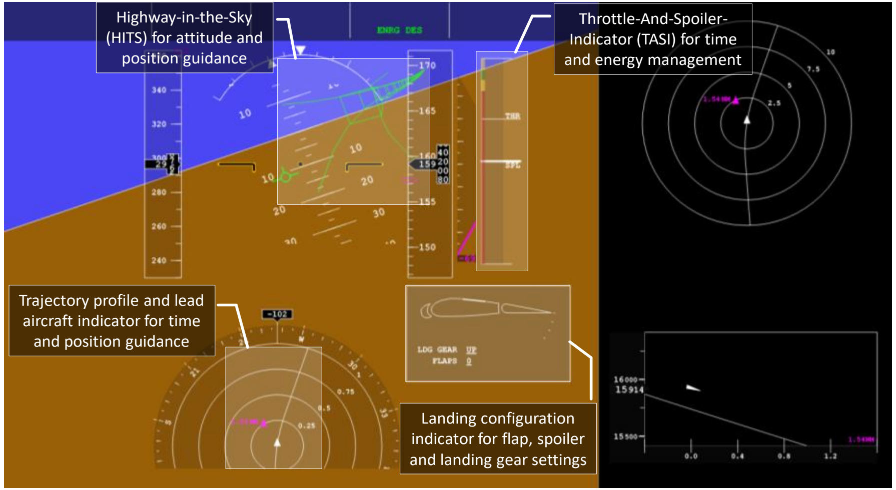


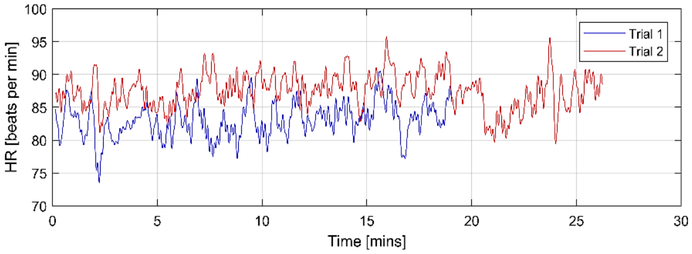
CHMI² SiPO Case Study

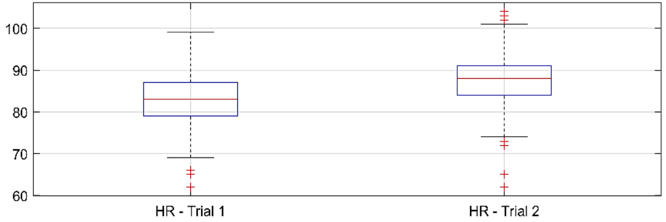


CHMI² SiPO Case Study (2)

- Simulated **A320 SYD-MEL flight** in adverse weather conditions
- Development of **novel formats and functions** to generate and follow a **time-and energy optimal descent trajectory** (MEL)
- **Human-in-the-loop experiments** were carried out, with a pilot manually flying the aircraft under different weather conditions
- **Eye tracking data (dispersion and fixation) show correlation with high workload phases**
- **Correlation found between mental workload and HR (positive) and HRV (negative)**

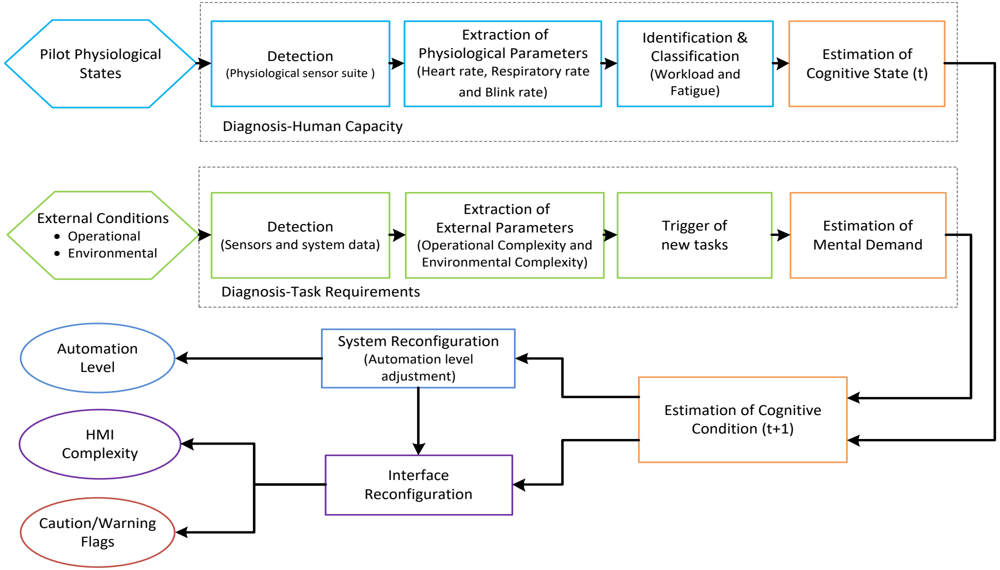


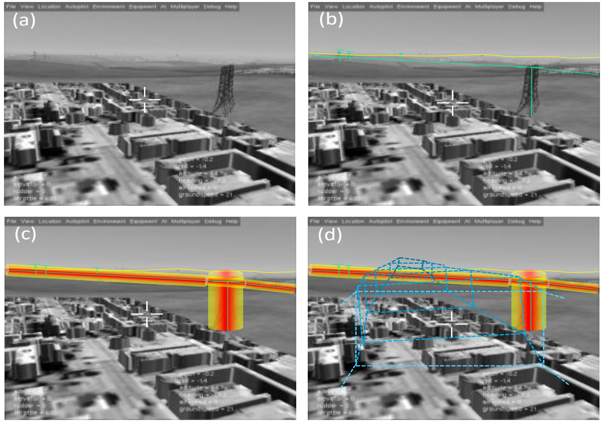


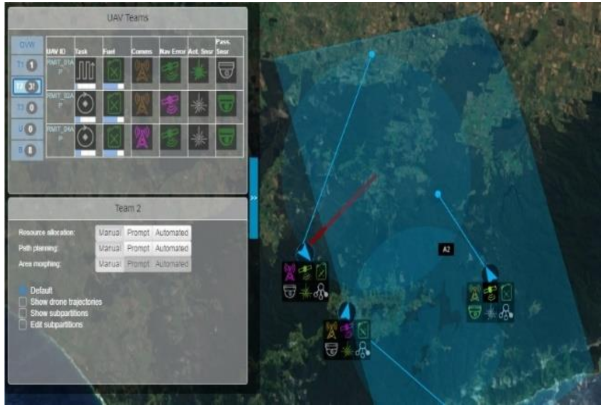


CHMI² UAS Case Studies

- Low-level flying UAS and **One-to-Many** UAS missions
- Sensing, estimation and reconfiguration tested in real-world environemnts
- **Dynamic HMI transitions and AL adaptation** meet requirements for real-time operations (further work on EEG required)







Current Evolutions – Sensor Network

Wearable sensors

Electroencephalography (EEG)

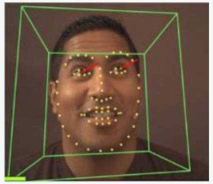
Cardiorespiratory Sensor [P4]

Functional near-infrared spectroscopy (fNIRS)

Remote sensors

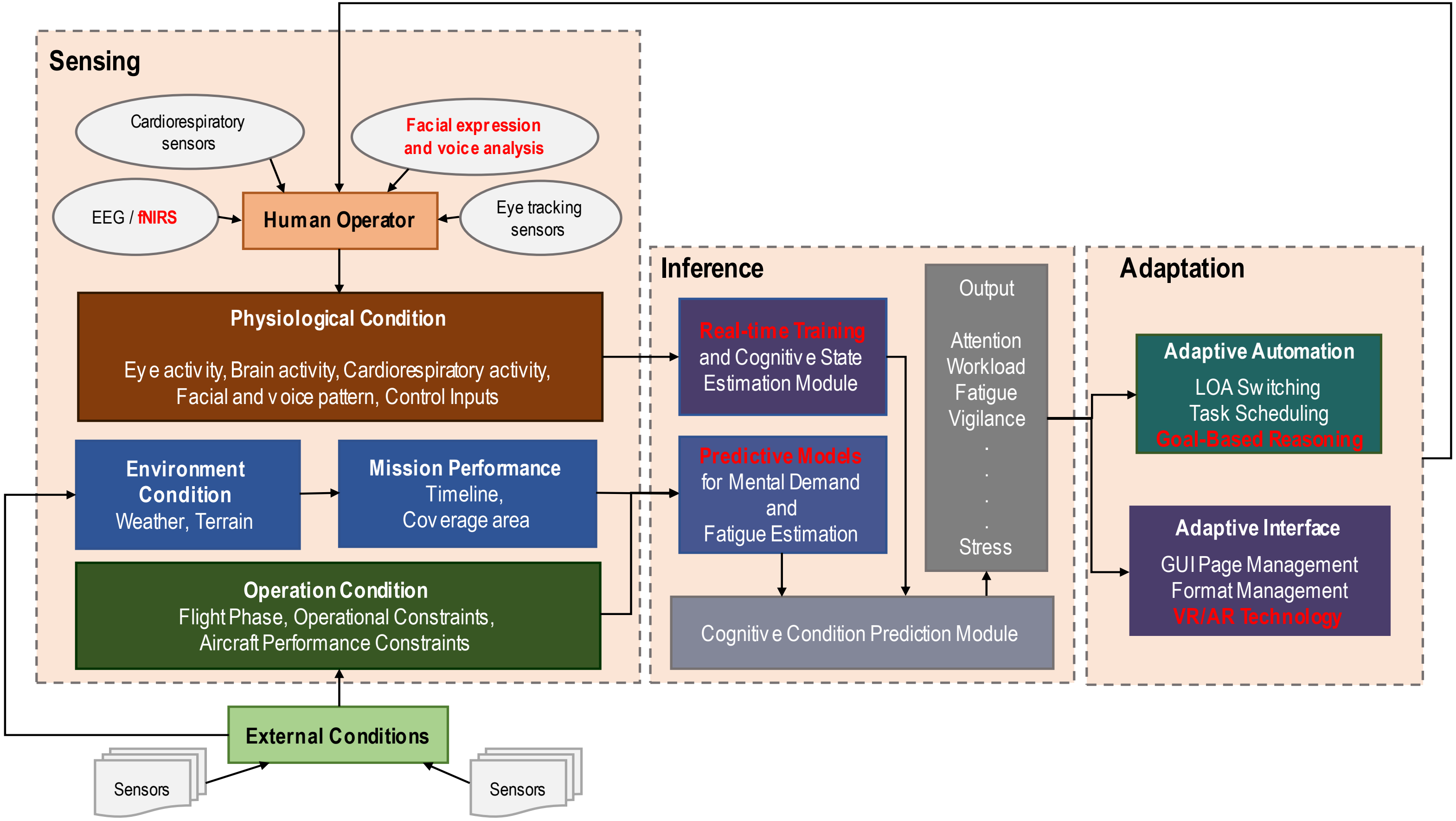
- ✓ Eye tracking sensors

Facial Expression



Voice pattern analysis

CHMI² Current Evolutions – Data Fusion



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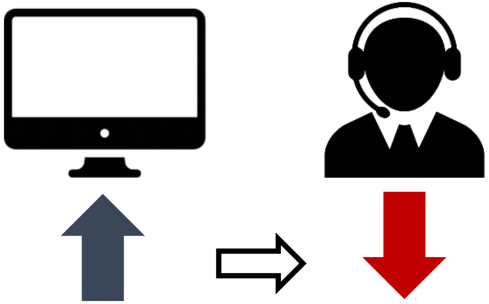
Human On the Look Dynamic Interactions

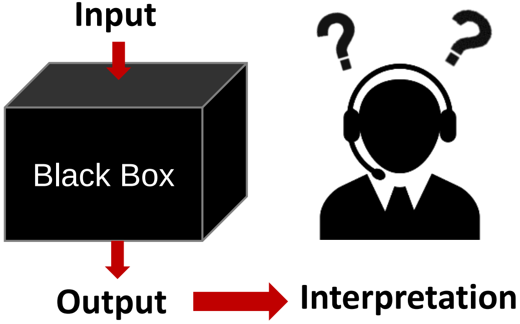
Challenges

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

- Lower cognitive capability
- Progressive deskilling
- Lower situational awareness



Human Factors



AI Explanation

Solution

Adaptive and Interpretable HMI

Cognitive Human-Machine System (CHMS)

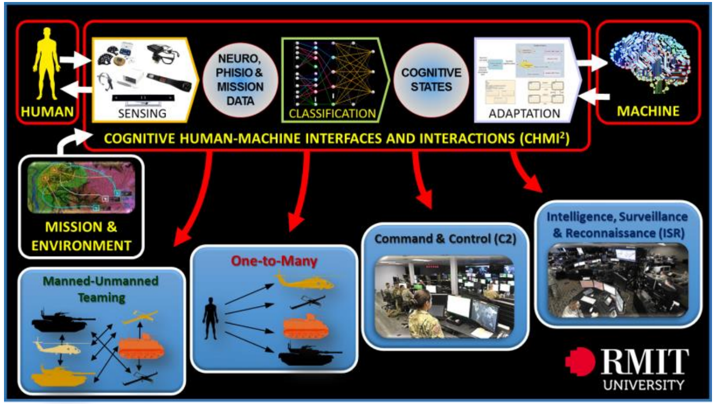
Towards Trusted Autonomous UTM Operations

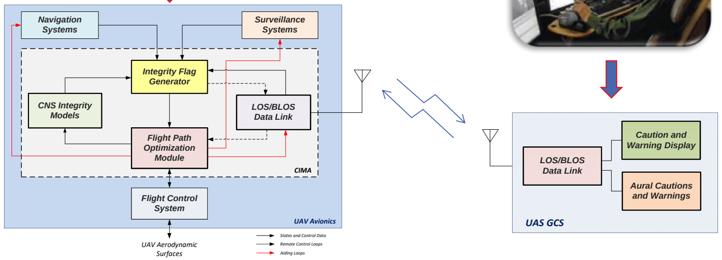
Ongoing verification during operations is not a new concept in ATM. The significance of this development is related to (reciprocal) trust in human–machine teaming:

- **Cognitive Human-Machine Interfaces and interactions (CHMI2)**: machine trust in the human

- **Integrity Monitoring & Augmentation (IM&A)**: human trust in today's machine (not just CNS but all safety-critical and mission-essential onboard/ground systems)

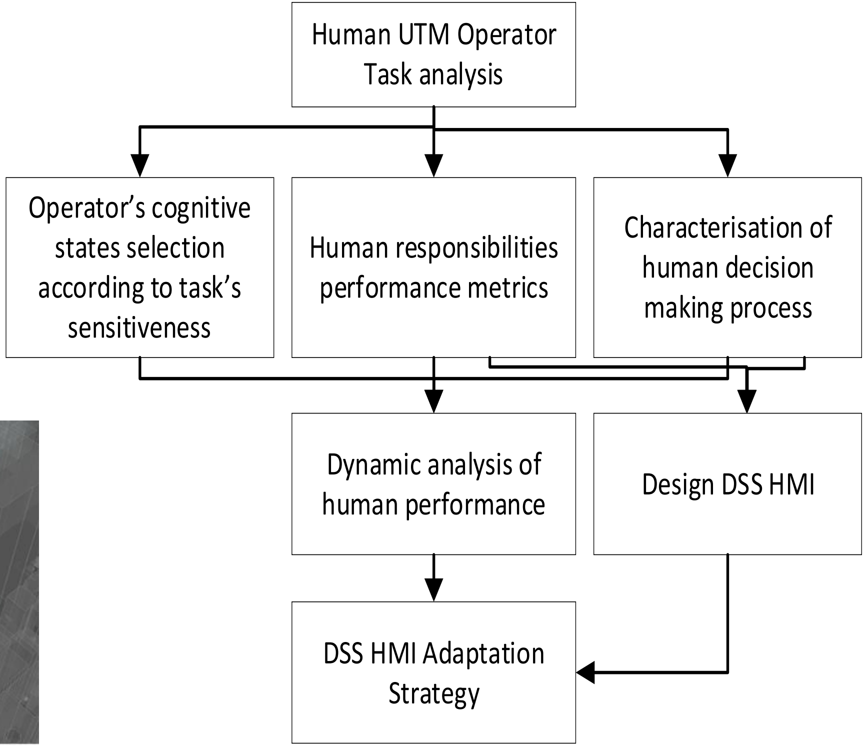
- **Explainable AI**: human trust in emerging iCPS

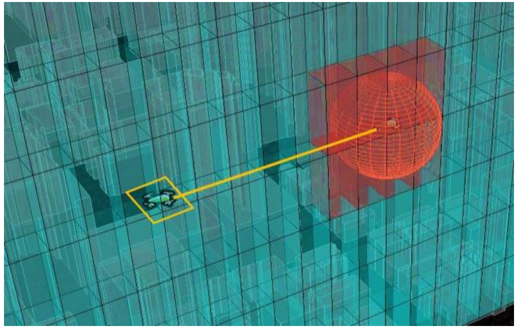


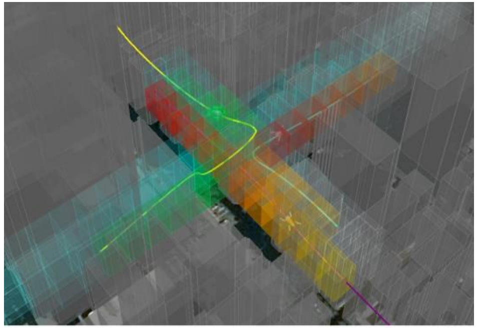


UTM HMI and Decision Support Systems

- To maximize effectiveness and AI interpretability, the HMI design shall be based on task analysis
- System and human operator integrity metrics allow to determine the optimal level of autonomy and a dynamic allocation of tasks to the HMT



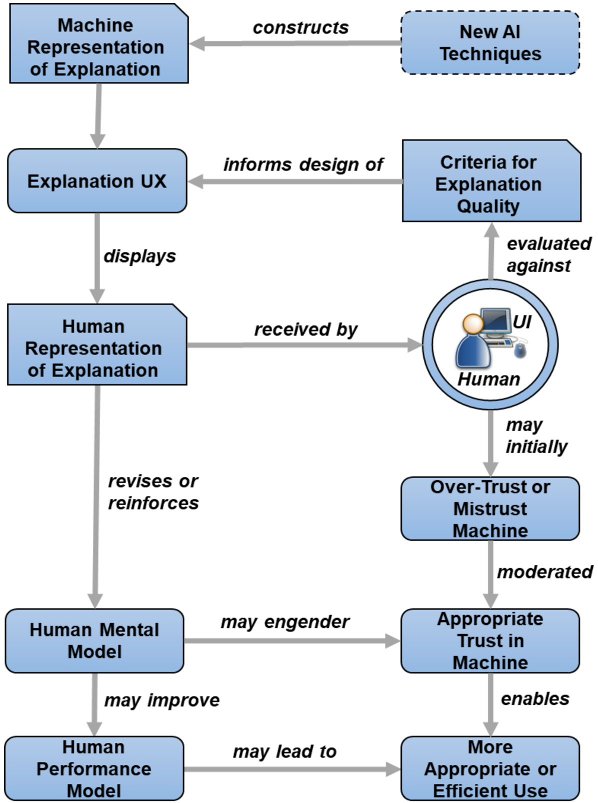




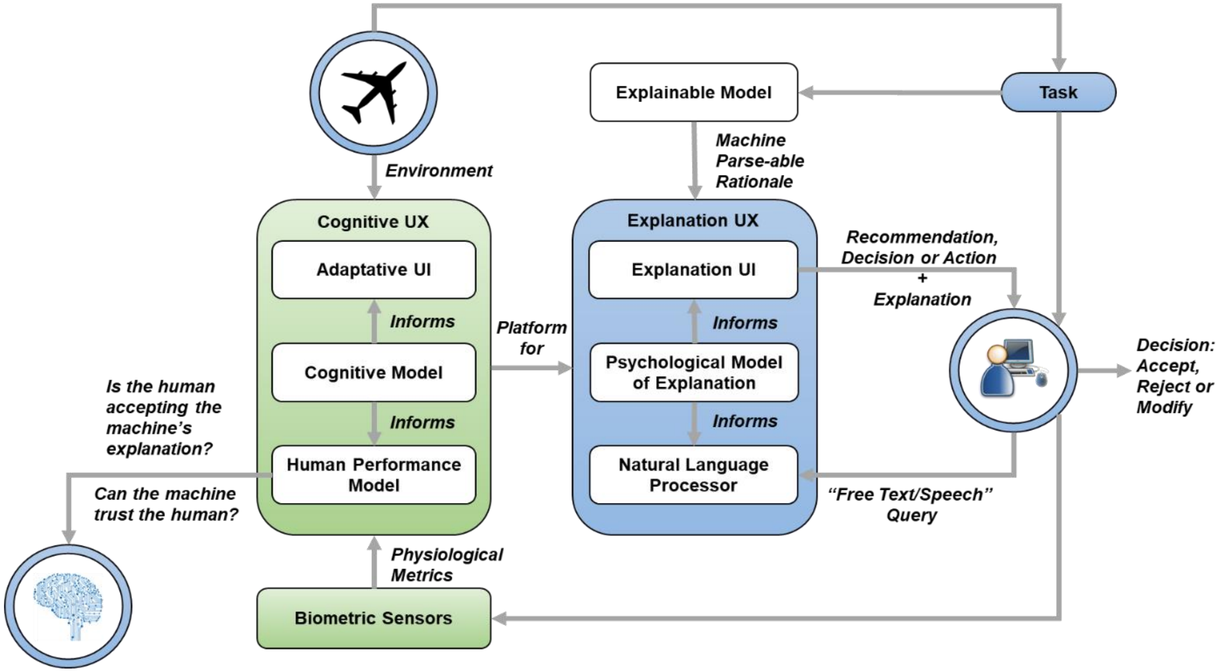
Explainable AI and User Interface Design

- Explainable AI requires both new machine learning processes and an explanation framework comprising both a **psychological model of explanation** and an **explanation HMI**

- Each XAI explanation UX technique will be informed by the same psychological model of explanation, to be developed mainly by the Human and Machine Cognition



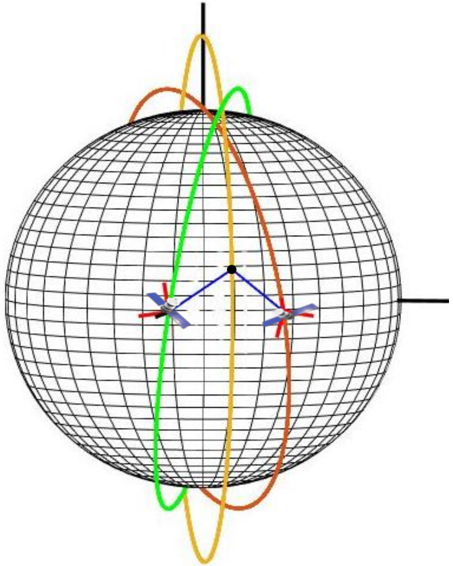
Cognitive HMI and Explanation UX



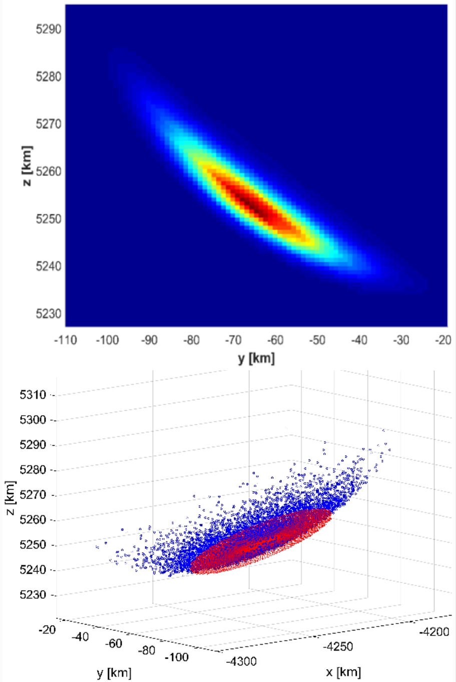
- Explainable AI
- Trusted AI
- Certifiable AI

AI-Based STM Decision Support Systems

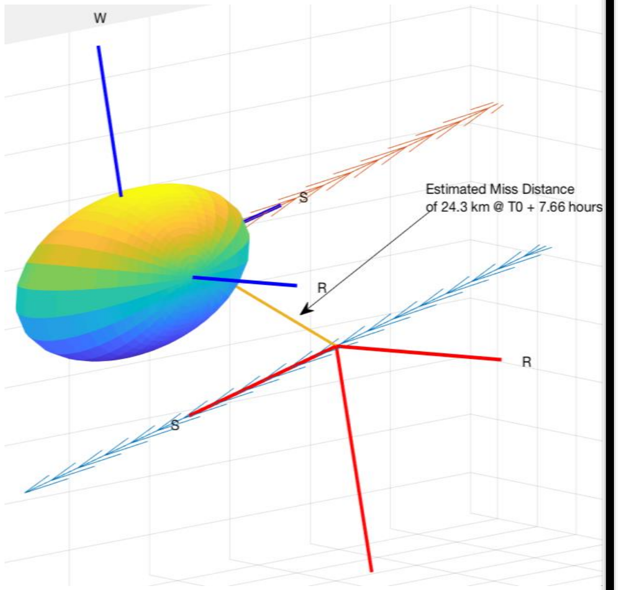
Online Mission Planning and Optimisation



Quantify and Predict Resident Space Object Uncertainty



Assess ROC and Implement Corrective Actions



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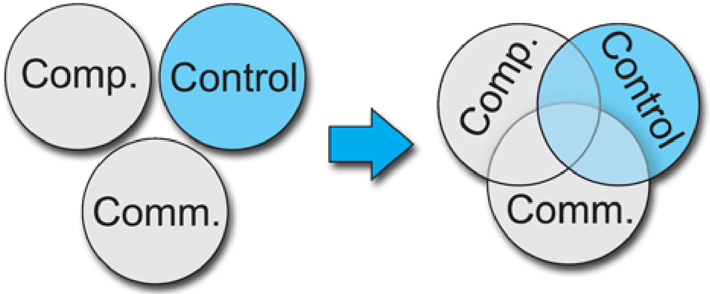
Avionics Systems Evolutions – CPS

- **From Digital Avionics Systems to Aerospace Cyber-Physical Systems (CPS)**
- **CPS are engineered through the seamless integration of digital and physical components, with the possibility of including human interactions**
- This requires **three fundamental functions** to be present: **Control, Computation and Communication (C^3)**
- Practical CPS typically combine sensor networks and embedded computing to monitor and control physical processes, with feedback loops that allow physical processes to affect computations and vice-versa



Avionics CPS and Trusted Autonomy

The avionics R&I systems community is focusing on two special categories of 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

Intelligent CPS (iCPS)

Industry 4.0 focuses on new technologies to deeply connect the digital world with the physical world. Current trends with clear avionics applications include:

- Advances in automation and autonomy
- Enhanced human-machine and machine-machine communications
- Widespread adoption of artificial intelligence and machine learning

Four key technology drivers enable these trends:

- Big data and Internet of Things (IoT)
- Advances in sensor networking and data analytics;
- Improvements in transferring digital instructions to the physical world; and
- New forms of human-machine interaction, such as cognitive, augmented and virtual reality systems.

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Trends: All-Domain Effective Global Intelligent Management (AEGIM)

PART II: Restructuring Avionics Engineering Curricula to Meet Contemporary Requirements and Future Challenges

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DATE: 2021/10/05

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

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Presentation Outline

- Introduction
- Overview of Existing Avionics Engineering Programs
- Keeping pace with Industry Requirements
- Proposed Undergraduate Curriculum
- Research and Innovation Areas in Avionics Engineering
- Proposed Graduate Programs
- Wrap up
- Questions and Discussion

Introduction

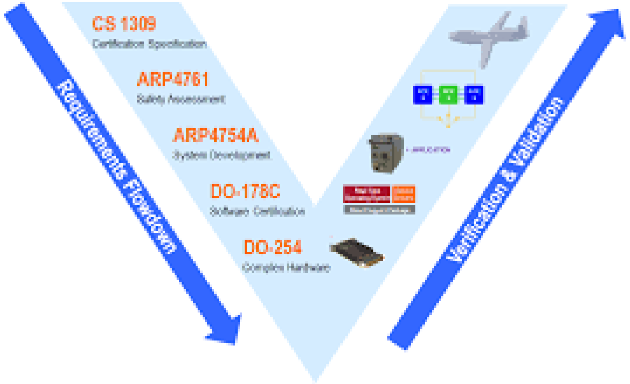
- Scope of Avionics
  - Aviation Electronics
    - Onboard & CNS+A
- Cost of avionics system in aircraft ranges from one third to two thirds
- Avionics is a multi-billion dollar industry world wide
- Avionics is a rapidly evolving applied field

Domains of Avionics

Air Traffic Management	Surface / Runway Mgmt, Arrivals / Departures, Airspace / Trajectory analysis & optimization, ATM
Flight Critical Systems	Flight Control, Engine Mgmt, Architectures, HMI
Comm, Nav and Surveillance	DACS, ACAS, TCAS, ADS-B, Non Cooperative Surveillance
Avionics Hardware and Software Design	Safety Analysis, Complex System Design Processes, Certifiable Hardware & Software Dev, V&V
Autonomous Systems	UAS, UAM, UTM, Human-Autonomy Teaming
Space Systems	Satellite Avionics, Space transport avionics, Space mission systems
System Engineering Support	Design Flow Process, SIl, HIL, System Level V&V
Operational Support	Life Cycle Support, Vehicle Health Mgmt, Weather Info

Unique Features of Avionics Engineering

- ❖ Size, Weight, Power and Cost (SWaP-C)
- ❖ Hardware and Software Safety Certification
- ❖ Product and Service Life Cycle Management
- ❖ Operational Environment (CNS+A)



Career Pathways

- Aerospace Systems Products and Manufacturing
- Aerospace Systems Research and Development
- Government Agencies and Regulators
- Defense Forces
- Avionics Equipment
- Airlines (Maintenance)

Future Growth

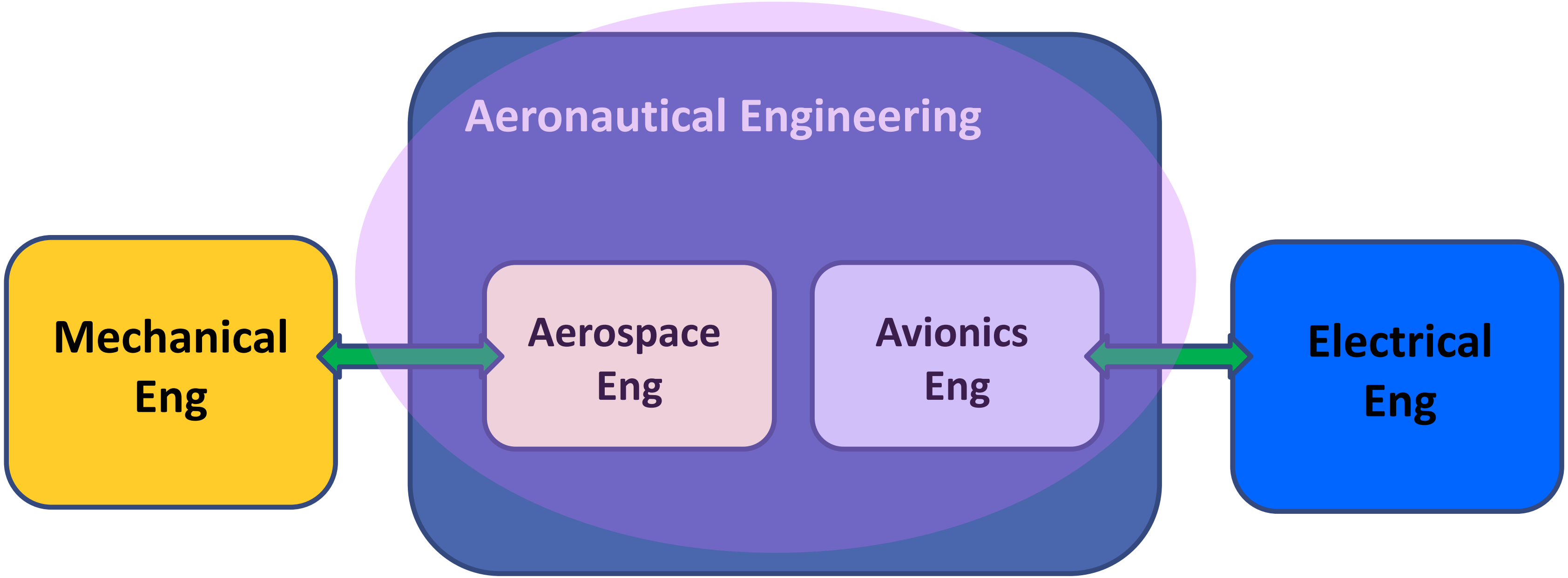
- Aviation industry is projected to grow at a fast pace in the coming decade
- Induction of UAS for various roles
- Inception of Urban Air Mobility (UAM)
- Increased activity in the space sector

- UAS/UTM RDT&E and safe/effective regulations
- New operating environments, such as very low altitude airspace
- Integrated multi-sensor systems for autonomous vehicles (vision-based, RADAR, LiDAR, etc.)
- knowledge requirements on avionics engineers continue to evolve at an impressive rate

Shortcomings of Current Avionics Curricula

- In many universities Avionics Engineering programs exist under the wings of Aerospace or Electrical/Computer Eng. Departments
- Engineers from Electrical/Computer Science/Aerospace degrees take much longer to become useful in Industry
- Scope of many avionics programs narrowed down to aircraft electronics
- Focus on technology oriented avionics programs but lack of CNS+A integration and practical hands-on skills
- Persistent lack of coordination between industry and academia in many areas
- Fail to meet contemporary requirements and future challenges

Avionics Engineering Scope



Under-Graduate Curricula Guidelines

Disciplines	Topics
Aeronautics	Avionics Hardware & Software Design, Testing & Certification (Initial and Continuing Airworthiness), Flight, Control Systems, Aerodynamics & Flight Mechanics, Guidance and Navigation, Aerospace Computing & Data Networks, Aerospace Communications & Networking Systems, Cooperative & Non-Cooperative Surveillance, Systems, Electromagnetic Compatibility for Avionics Systems, UAS Avionics, Air Traffic Management Systems, Aerospace Remote Sensing and Mission Systems, Multi sensor Data Fusion, Spaceflight Systems
Electrical & Electronics	Analog Electronics, Digital Electronics, Applied Electromagnetics, Instrumentation and Measurement, Electronic Communications, Digital Communications, Control Systems, Microwave & Antenna Engineering, Motors and Generators
Interdisciplinary Courses	Statics, Dynamics, Thermodynamics, Manufacturing Systems, Operations Research & Engineering Management
Computing & Systems	Programming and Hardware Languages, Modeling & Simulation, Artificial Intelligence
Humanities & Sciences	Mathematics, Physics, Communication Skills

Lab Contents

- ❖ Avionics Architectures
- ❖ Avionics System Design
- ❖ Radar Systems
- ❖ Sensor Fusion
- ❖ Flight Controls and Navigation Systems
- ❖ Air Traffic Management Systems

Intricacies of Independent Avionics Programs

- Applied breadth oriented field with systems engineering approach
  - Restriction on maximum number of credit hours
- Nomenclatures and Conventions
  - ABET relates to Aviation Electronics
  - Also be considered as complex Cyber Physical Systems
- Safety Critical Autonomous Systems

Requisite knowledge of Avionics Engineering can best be imparted through independent Avionics Engineering programs

Post Graduate Studies

Post Graduate Studies

- Strong link with research and development and with industry needs
- A few universities currently offer master programs in Avionics
- Some universities include avionics studies and courses in master curricula in Aerospace Engineering, or in new programmes aimed at Autonomous Vehicles / Systems
- Education + Research: Opportunity to keep pace with modern needs and to take advantage from the wealth of new research opportunities
- Need of close liaison with industry

Post Graduate Studies

Challenges and opportunities for education and research involve many areas

- Integrated CNS/ATM and Avionics (CNS+A) Systems
- Urban Air mobility and Urban Traffic Management
- Cyber-physical security of avionics and CNS/ATM systems
- Fault-tolerant avionics and intelligent Health and Usage Management Systems (HUMS)
- Artificial Intelligence (AI) in avionics systems design and operations
- Evolution of Avionics Human-Machine Interfaces and Interactions (HMI^2)
- Space Avionics

Post Graduate Curricula

- The hypothesis of a graduate Avionics Engineering program is formulated

- It can focus on six specialization domains

Post Graduate Curricula

Avionics System Design

- Design of Safety Critical Avionics
- Design of CNS/ATM Systems
- Advanced Avionics Architectures and CNS+A Integration
- Avionics Human Factors Engineering

CNS Systems

- Advanced Navigation Systems
- Aircraft Communications and Networking
- Surveillance Systems and Tracking
- Filtering and Estimation Theory

Avionics Software & Cyber Security

- Avionics Software Design & Certification
- Avionics Cyber Security
- Cyber Security for Embedded Systems

Awareness of challenges and aspects relevant to the incorporation of new technologies in avionics systems (e.g., AI)

Post Graduate Curricula

Cont'd

Avionics Microwave Systems

- Integrated RF Front Ends
- Aircraft Antennas
- Advance Radar Systems
- Satellite communications

Unmanned Aircraft Systems

- Autonomous Systems Guidance & Control
- UAS Traffic Management
- UAS Airspace Integration Technologies
- APNT

Spacecraft Avionics Systems

- Space Flight Dynamics and Control
- Space navigation and Mission Planning
- Space Avionics Deign
- Multispectral imaging systems for spacecraft

Electives

- Synthetic Vision
- Adaptive Control for Avionics Systems
- Aircraft Navigation and Trajectory Prediction
- Microwave Circuit Design
- Real Time Operating Systems
- Airborne and Space borne Communication Systems
- Aircraft Electromagnetic Compatibility
- Advanced Engineering Mathematics
- Machine Learning with Avionics Applications
- Multimode data fusion
- Graphical rendering for display technology
- Component manufacturing
- Rotorcraft engineering
- Avionics Design Project
  - Collaboration with industry
  - project linked to specialization area
- AI in Avionics Systems

Wrap Up

- Avionics Engineering education curricula require a major overhaul at all levels
- Engineers from Electrical/Computer Science/Aerospace degrees take much longer to become useful in Industry
- Complete scope of onboard and ground-based systems (CNS+A) must be covered
- Guidelines have been provided for UG and PG curricular evolutions that overcome existing deficiencies, meets industry expectations and embrace RDT&E contemporary challenges

Wrap Up

- Differences in rules and education systems at international level, and constraints relevant to different academic entities, may hinder the full adoption of the proposed curricula
- However, they can represent guidelines for the evolution of avionics education within different curricular frameworks
- Multidisciplinarity, contamination beyond traditional academic boundaries, collaboration with industry, modern practices (challenge-based education, on-the-job training) as directions to train the new avionics workforce

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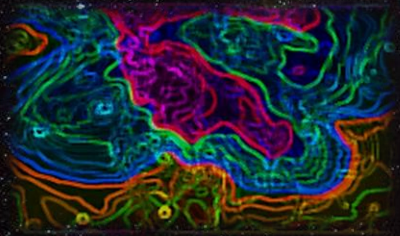
Questions and Discussion



Thank you!

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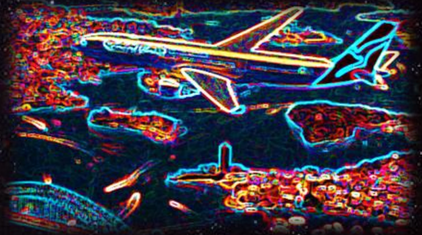
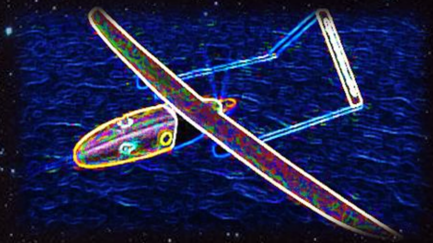
If you wish to discuss possible collaborations with the AESS Avionics Systems Panel (ASP) please send an email to:
roberto.sabatini@ieee.org

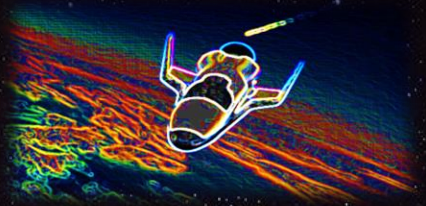
You can find additional information about the ASP at:
https://ieee-aess.org/tech-ops/avionics-systems-panel-asp

IEEE/AIAA Digital Avionics Systems Conference:
https://2021.dasconline.org/

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







References

[1] K. Ranasinghe, R. Sabatini, A. Gardi, S. Bijjahalli, R. Kapoor, T. Fahey and K. Thangavel, "Advances in Integrated System Health Management for Safety-Critical and Mission-Critical Aerospace Applications." Progress in Aerospace Sciences (in press).

[2] Y. Xie, N. Pongsakornsathien, A. Gardi and R. Sabatini, "Explanation of Machine Learning Solutions in Air Traffic Management." Aerospace, Vol. 8, No. 224, August 2021. DOI: 10.3390/aerospace8080224

[3] L. J. Planke, A. Gardi, R. Sabatini and T. Kistan, "Online Multimodal Inference of Mental Workload for Cognitive Human Machine Systems." Computers, Vol. 10, Issue 6, No. 81, June 2021. DOI: 10.3390/computers10060081

[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, Vol. 36, No. 4, pp. 46-58, April 2021.

[5] 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, Vol. 36, No. 4, pp. 5-6, April 2021

[6] Y. Lim, N. Ponsarkornsathien, A. Gardi, R. Sabatini, T. Kistan, N. Ezer and D. Bursch, "Adaptive Human-Robot Interactions for Multi-Unmanned Aircraft Systems Operations." Robotics, Vol. 10(1), 12, January 2021

[7] S. Bijjahalli and R. Sabatini, "A High-Integrity and Low-Cost Navigation System for Autonomous Vehicles." IEEE Transactions on Intelligent Transportation Systems, Vol. 22, Issue 1, pp. 356-369, January 2021

[8] Y. Lim, N. Ponsarkornsathien, A. Gardi, R. Sabatini, T. Kistan, N. Ezer and J. Bursch, "Adaptive Human-Robot Interactions for Multi-Unmanned Aircraft Systems Operations." Robotics (in press).

[9] R. Sabatini, A. Roy, E. Blasch, K. A. Kramer, G. Fasano, I. Majid, O. G. Crespillo, D. A. Brown and R. Ogan, "IEEE Avionics Systems Panel Research and Innovation Perspectives." IEEE Aerospace and Electronic Systems Magazine, Vol. 35, Issue 12, December 2020 (in press).

[10] K. Ranasinghe, R. Kapoor, A. Gardi, R. Sabatini, V. Wickramanayake and D. Ludovici, "Vehicular Sensor Network and Data Analytics for a Health and Usage Management System." Sensors, Vol. 20(20), 5892, October 2020.

[11] FAA, "NextGen Implementation Plan." Federal Aviation Administration (FAA), Washington DC, USA, 2013.

[12] SESAR, "European ATM Master Plan - The Roadmap for Delivering High Performing Aviation for Europe." Single European Sky ATM Research (SESAR) Joint Undertaking, Belgium, 2015.

References

[13] Y. Lim, N. Premlal, A. Gardi, and R. Sabatini, "Eulerian optimal control formulation for dynamic morphing of airspace sectors." 31st Congress of the International Council of the Aeronautical Sciences (ICAS 2018), Belo Horizonte, Brazil, 2018.

[14] N. Pongsakornsathien, S. Bijjahalli, A. Gardi, A. Symons, Y. Xi, R. Sabatini and T. Kistan, “A Performance-based Airspace Model for Unmanned Aircraft Systems Traffic Management.” Aerospace – Special Issue on Advances in Aerospace Sciences and Technology, Vol. 7, 154, October 2020.

[15] S. Bijjahalli, A. Gardi and R. Sabatini, “Advances in Intelligent and Autonomous Navigation Systems for small UAS.” Progress in Aerospace Sciences. Vol. 115, May 2020.

[16] Y. Lim, A. Gardi, R. Sabatini, K. Ranasinghe, N. Ezer, K. Rodgers and D. Salluce, “Optimal Energy-based 4D Guidance and Control for Terminal Descent Operations.” Aerospace Science and Technology. Vol. 95, 105436, December 2019.

[17] S. Hilton, F. Cairola, A. Gardi, R. Sabatini, N. Pongsakornsathien and N. Ezer, “On-Orbit Surveillance Uncertainty Analysis for Space Traffic Management Operations.” Sensors – Special Issue on Aerospace Sensors and Multisensor Systems, Vol. 19(29), 4361. October 2019.

[18] S. Bijjahalli, R. Sabatini and A. Gardi, “GNSS Performance Modelling and Augmentation for Urban Air Mobility.” Sensors – Special Issue on Aerospace Sensors and Multisensor Systems, Vol. 19(19), 4209. September 2019.

[19] S. Hilton, R. Sabatini, A. Gardi, H. Ogawa and P. Teofilatto, “Space Traffic Management: Towards Safe and Unsegregated Space Transport Operations.” Progress in Aerospace Sciences, Vol. 105, pp. 98-125. February 2019.

[20] ICAO, "Global Air Navigation Plan.” Doc. 9750 – 6th Edition. International Civil Aviation Organization (ICAO), Montreal, Canada, 2019.

[21] S. Bijjahalli and R. Sabatini, “A High-Integrity and Low-Cost Navigation System for Autonomous Vehicles." IEEE Transactions on Intelligent Transportation Systems (in press). Publication expected in 2020.

[22] A. Tabassum, R. Sabatini and A. Gardi, “Probabilistic Safety Assessment for UAS Separation Assurance and Collision Avoidance Systems.” Aerospace – Special Issue on Civil and Military Airworthiness, Vol. 6(2). February 2019.

[23] A. Gardi, S. Ramasamy, R. Sabatini and T.Kistan, “CNS+A Capabilities for the Integration of Unmanned Aircraft in Controlled Airspace.” Proceedings of IEEE International Conference on Unmanned Aircraft Systems (ICUAS 2016). Arlington, VA (USA), June 2016.

[24] O. Brown and P. Eremenko, "The Value Proposition for Fractionated Space Architectures.“ In proceedings of 2006 AIAA Space, San Jose, CA (USA), 2006.

[25] A. Golkar and I. L. I. Cruz, "The Federated Satellite Systems paradigm: Concept and business case evaluation." Acta Astronautica, vol. 111, pp. 230- 248, 2015.

References

[26] M. T. Burston, R. Sabatini, R. Clothier, A. Gardi and S. Ramasamy, “Reverse Engineering of a Fixed Wing Unmanned Aircraft 6-DoF Model for Navigation and Guidance Applications.” Applied Mechanics and Materials, Vol. 629, pp. 164-169, October 2014.

[27] S. Ramasamy, R. Sabatini, and A. Gardi, "A Novel Approach to Cooperative and Non-Cooperative RPAS Detect-and-Avoid.“ SAE Technical Paper 2015-01-2470, September, 2015.

[28] S. Ramasamy and R. Sabatini, "A Unified Approach to Cooperative and Non-Cooperative Sense-and-Avoid.“ In proceedings of 2015 International Conference on Unmanned Aircraft Systems (ICUAS '15), Denver, CO (USA), June 2015.

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

[30] M. Marino, J. Ambani, R. Watkins, and R. Sabatini, "StopRotor - A New VTOL Aircraft Configuration." In proceedings of the 17th Australian International Aerospace Congress: AIAC 2017, pp. 157-168, February 2017.

[31] Lim, Y., Gardi, A., Sabatini, R., Ramasamy, S., Kistan, T., Ezer, N., Vince, J., Bolia, R., “Avionics Human-Machine Interfaces and Interactions for Manned and Unmanned Aircraft.” Progress in Aerospace Sciences, vol. 102, pp. 1-46, 2018.

[32] Manchester Z.R., "Centimeter-Scale Spacecraft: Design, Fabrication, and Deployment." PhD Dissertation, Cornell University, 2015.

[33] Liu, J., Gardi, A., Ramasamy, S., Lim, Y., and Sabatini, R., “Cognitive Pilot-Aircraft Interface for Single-Pilot Operations.” Knowledge-Based Systems, 112, pp. 37-53, 2016.

[34] Lim, Y., Ramasamy, S., Gardi, A., Kistan, T., and Sabatini, R., “Cognitive Human-Machine Interfaces and Interactions for Unmanned Aircraft.” Journal of Intelligent & Robotic Systems, 91(3-4), pp. 755-774, 2018.

[35] N. Pongsakornsathien, Y. Lim, A. Gardi, S. Hilton, L. Planke, R. Sabatini, T. Kistan and N. Ezer, “Sensor Networks for Aerospace Human-Machine Systems.” Sensors, vol. 19, no. 16, 3465, 2019.

[36] N. Pongsakornsathien, A. Gardi, Y.Lim, R. Sabatini, T. Kistan, and N. Ezer, "Performance Characterisation of Wearable Cardiac Monitoring Devices for Aerospace Applications.“ In proceedings of the 2019 IEEE International Workshop on Metrology for Aerospace (MetroAeroSpace), Torino, Italy, 2019.

[37] Y. Lim, A. Gardi, N. Pongsakornsathien, R. Sabatini, N. Ezer, and T. Kistan, "Experimental Characterisation of Eye-Tracking Sensors for Adaptive Human-Machine Systems." Measurement, vol. 140, pp. 151-160, 2019.

References

[38] Y. Lim, T. Samreeloy, C. Chantaraviwat, N. Ezer, A. Gardi, and R. Sabatini, "Cognitive Human-Machine Interfaces and Interactions for Multi-UAV Operations.“ In proceedings of the 18th Australian International Aerospace Congress, AIAC18, Melbourne, Australia, 2019.

[39] A. Gardi, R. Sabatini and T. Kistan, "Multi-Objective 4D Trajectory Optimization for Integrated Avionics and Air Traffic Management Systems.” IEEE Transactions on Aerospace and Electronic Systems, Vol. 55, Issue 1, pp. 170-181. February 2019.

[40] A. Gardi, R. Sabatini and S. Ramasamy, "Real-time UAS Guidance for Continuous Curved GNSS Approaches.” Journal of Intelligent and Robotic Systems. Vol. 93, Issue 1, pp. 151-162. February 2019.

[41] V. Sharma, R. Sabatini, S. Ramasamy, K. Srinivasan and R. Kumar, “EFF-FAS: Enhanced Fruit Fly Optimization Based Search and Tracking by Flying Ad-Hoc Swarm.” International Journal of Ad Hoc and Ubiquitous Computing, Vol. 30, No. 3, pp. 161-172. January 2019.

[42] E. Batuwangala, T. Kistan, A. Gardi and R. Sabatini, "Certification Challenges for Next Generation Avionics and Air Traffic Management Systems.” IEEE Aerospace and Electronic Systems Magazine, Vol. 33, Issue 9, pp. 44-53, September 2018.

[43] A. C. Kelly and E. J. Macie, "The A-Train: NASA's Earth Observing System (EOS) Satellites and other Earth Observation Satellites.“ In proceesings of the 4th IAA Symposium on Small Satellites for Earth Observation, vol. IAA-B4-1507P, 2003.

[44] ICAO, “Global Navigation Satellite System (GNSS) Manual”, Doc. 9849 AN/457 – 5th Edition. The International Civil Aviation Organization (ICAO), Montreal, Canada, 2005.

[45] R. Sabatini, T. Moore, C. Hill and S. Ramasamy, "Evaluating GNSS Integrity Augmentation Techniques for UAS Sense-and-Avoid.“ In proceedings of 2015 International Workshop on Metrology for Aerospace (MetroAeroSpace 2015), Benevento (Italy), June 2015.

[46] T. Kistan, A. Gardi and R. Sabatini, "Machine Learning and Cognitive Ergonomics in Air Traffic Management: Recent Developments and Considerations for Certification," Aerospace – Special Issue on Multiagent Systems and Artificial Intelligence Techniques in Aviation, Vol. 5, Issue 4. October 2018.

[47] F. Cappello, S. Bijjahalli, S. Ramasamy and R. Sabatini, “Aircraft Dynamics Model Augmentation for RPAS Navigation and Guidance.” Journal of Intelligent and Robotic Systems, Vol. 91, Issue 3–4, pp 709–723. September 2018.

[48] R. Kapoor, S. Ramasamy, A. Gardi, R. Van Schyndel and R. Sabatini, “Acoustic Sensors for Air and Surface Navigation Applications.” Sensors, Vol. 18, Issue 2. February 2018.

[49] C. Keryk, R. Sabatini, K. Kourousis, A. Gardi and J. M. Silva, "An Innovative Structural Fatigue Monitoring Solution for General Aviation Aircraft." Journal of Aerospace Technology and Management, Vol. 10, e0518, February 2018.

[50] J. Sliwinski, A. Gardi, M. Marino and R. Sabatini, "Hybrid-Electric Propulsion Integration in Unmanned Aircraft.” Energy, Vol. 140, pp. 1407–1416. December 2017.

References

[51] R. Sabatini, T. Moore and S. Ramasamy, "Global Navigation Satellite Systems Performance Analysis and Augmentation Strategies in Aviation." Progress in Aerospace Sciences, Vol. 95, pp. 45-98. November 2017.

[52] H.A. Muller, "The rise of intelligent cyber-physical systems", Computers, vol. 50, pp. 4837-4869, 2017.

[53] S. Bijjahalli, S. Ramasamy and R. Sabatini, "A Novel Vehicle-Based GNSS Integrity Augmentation System for Autonomous Airport Surface Operations." Journal of Intelligent and Robotic Systems, Vol. 87, Issue 2, pp. 379–403. August 2017.

[54] J. Muhammad, J. Silva and R. Sabatini, "A Holistic Approach to Evaluating the Effect of Safety Barriers on the Performance of Safety Reporting Systems in Aviation Organisations." Journal of Air Transport Management, Vol. 63, pp. 95-107. August 2017.

[55] Y. Lim, V. Bassien-Capsa, J. Liu, S. Ramasamy and R. Sabatini, "Commercial Airline Single Pilot Operations: System Design and Pathways to Certification." IEEE Aerospace and Electronic Systems Magazine. Vol. 32, Issue 7, pp. 4-12. July 2017.

[56] R. Sabatini, "Future Aviation Research in Australia: Addressing Air Transport Safety, Efficiency and Environmental Sustainability." International Journal of Sustainable Aviation, Vol. 3, No. 2, pp. 87 - 99, June 2017.

[57] S. Bijjahalli, S. Ramasamy and R. Sabatini, "A GNSS Integrity Augmentation System for Airport Ground Vehicle Operations." Energy Procedia, Volume 110, March 2017, pp. 149-155.

[58] Y. Lim, A. Gardi and R. Sabatini, "Optimal Aircraft Trajectories to Minimize the Radiative Impact of Contrails and CO2." Energy Procedia, Volume 110, March 2017, pp. 446–452.

[59] R. Kapoor, S. Ramasamy, A. Gardi and R. Sabatini, "UAV Navigation Using Signals of Opportunity in Urban Environments: A Review." Energy Procedia, Volume 110, March 2017, pp. 377-383.

[60] R. Sabatini, F. Cappello, S. Ramasamy, A. Gardi and R. Clothier, "An Innovative Navigation and Guidance System for Small Unmanned Aircraft using Low-Cost Sensors." Aircraft Engineering and Aerospace Technology, Vol. 87, Issue 6, pp. 540-545. October 2015.

[61] K. Chircop, A. Gardi, D. Zammit-Mangion and R. Sabatini, "A New Computational Technique for the Generation of Optimised Aircraft Trajectories." Nonlinear Engineering, Vol. 6, Issue 2. June 2017.

[62] 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. January 2017.

References

[63] N. Cai, R. Sabatini, X. Dong, M. J. Khan and Y. Yu, “Decentralized Modeling, Analysis, Control, and Application of Distributed Dynamic Systems.” Journal of Control Science and Engineering, Vol. 2016-1. December 2016.

[64] A. Zanetti, Alessandro Gardi and R. Sabatini, “Introducing Green Life Cycle Management in the Civil Aviation Industry: the State-of-the-Art and the Future.” International Journal of Sustainable Aviation, Vol. 2, Issue 4, pp. 348-380. December 2016.

[65] F. Cappello, S. Ramasamy and R. Sabatini, “A Low-Cost and High Performance Navigation System for Small RPAS Applications.” Aerospace Science and Technology, Vol. 58, pp. 529–545. November 2016.

[66] J. Liu, A. Gardi, S. Ramasamy, Y. Lim and R. Sabatini, "Cognitive Pilot-Aircraft Interface for Single-Pilot Operations.” Knowledge-Based Systems, Vol. 112, pp. 37–53. R. Kapoor, S. Ramasamy 1, A. Gardi, C. Bieber, L. Silverberg and R. Sabatini, “A Novel 3D Multilateration Sensor Using Distributed Ultrasonic Beacons for Indoor Navigation.” Sensors, Vol. 16, No. 10, pp. 1637-1649. October 2016.

[67] V. Sharma, R. Sabatini and S. Ramasamy, “UAVs Assisted Delay Optimization in Heterogeneous Wireless Networks.” IEEE Communications Letters, Vol. 20, Issue 12, pp. 2526-2529. September 2016.

[68] S. Ramasamy, R. Sabatini, A. Gardi, J. Liu, “LIDAR Obstacle Warning and Avoidance System for Unmanned Aerial Vehicle Sense-and-Avoid.” Aerospace Science and Technology, Vol. 55, pp. 344–358, August 2016.

[69] Gardi, R. Sabatini, S. Ramasamy, “Multi-Objective Optimisation of Aircraft Flight Trajectories in the ATM and Avionics Context.” Progress in Aerospace Sciences, Vol. 83, pp. 1-36. May 2016.

[70] R. Sabatini, M.A. Richardson, A. Gardi and S. Ramasamy, “Airborne Laser Sensors and Integrated Systems.” Progress in Aerospace Sciences, Vol. 79, pp. 15-63, November 2015.

[71] Mohamed, S. Watkins, R. Clothier, M. Abdulrahim, K. Massey and R. Sabatini, “Fixed-wing MAV attitude stability in atmospheric turbulence—Part 2: Investigating biologically-inspired sensor.” Progress in Aerospace Sciences, Vol. 71, pp. 1-13, November 2014.

[72] S. Ramasamy, M. Sangam, R. Sabatini and A. Gardi, “Flight Management System for Unmanned Reusable Space Vehicle Atmospheric and Re-entry Trajectory Optimisation.” Applied Mechanics and Materials, Vol. 629, pp. 304-309, October 2014.

[73] L. Planke, Y. Lim, A. Gardi, R. Sabatini, T. Kistan and N. Ezer, “A Cyber-Physical-Human System for One-to-Many UAS Operations: Cognitive Load Analysis.” Sensors, Vol. 20(19), 5467, September 2020.

References

[74] A. Mohamed, R. Clothier, S. Watkins, R. Sabatini and M. Abdulrahim, “Fixed-Wing MAV Attitude Stability in Atmospheric Turbulence PART 1: Suitability of Conventional Sensors.” Progress in Aerospace Sciences. Vol. 70, pp. 69-82. July 2014.

[75] ICAO, "Human Factors training manual", ed. Montreal, Canada, 1998.

[76] PGAM. Jorna, "ATM Human Factors and human resources considerations", Air & Space Europe, vol. 2, pp. 58-64, 2000/09/01/ 2000.

[77] V. Vijayakumar, V. Subramaniyaswamy, J. Abawajy, and L. Yang, "Intelligent, smart and scalable cyber-physical systems", Journal of Intelligent Fuzzy Systems, vol. 36, pp. 3935-3943, 2019.

[78] J. Zhu, A. Liapis, S. Risi, R. Bidarra, and G. M. Youngblood, "Explainable AI for Designers: A Human-Centered Perspective on Mixed-Initiative Co-Creation," 2018 IEEE Conference on Computational Intelligence and Games (CIG), 2018, pp. 1-8.

[79] DARPA, Explainable Artificial Intelligence (XAI) Program Update, DARPA/I2O. November 2017. Available online: https://www.darpa.mil/attachments/XAIProgramUpdate.pdf (accessed on 19 May 2018).

[80] B. Kirwan, A. Evans, L. Donohoe, A. Kilner, T. Lamoureux, T. Atkinson, et al., "Human factors in the ATM system design life cycle", FAA/Eurocontrol ATM R&D Seminar, 1997, pp. 16-20.

[81] T. Prevot, J. Mercer, L. Martin, J. Homola, C. Cabrall, and C. Brasil, "Evaluation of high density air traffic operations with automation for separation assurance, weather avoidance and schedule conformance", 11th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, including the AIAA Balloon Systems Conference and 19th AIAA Lighter-Than, 2011, p. 6890.

[82] E. Sunil, J. Hoekstra, J. Ellerbroek, F. Bussink, D. Nieuwenhuisen, A. Vidosavljevic, et al., "Metropolis: Relating airspace structure and capacity for extreme traffic densities", ATM seminar 2015, 11th USA/EUROPE Air Traffic Management R&D Seminar, 2015.

[83] T.B. Sheridan and R. Parasuraman, "Human-Automation Interaction", Reviews of Human Factors and Ergonomics, vol. 1, pp. 89-129, 06/01 2005.

[84] "CPS Principles, Foundations, System Characteristics, and Complementary Skills", in In A 21st Century Cyber-Physical Systems Education, ed. National Academies Press: National Academies of Sciences Engineering and Medicine, 2016.