Unmanned Aircraft Systems
Research and Innovation Challenges

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Tutorial Outline

- Introduction
- Unmanned Aircraft Systems (UAS)
- UAS Avionics Research and Development
- UAS Cybersecurity Challenges
- UTM and AAM Research Efforts
- Q&A and Discussion
Introduction
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
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 (Regional and Urban 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
- Multiple Simultaneous Operations
- Avionics CPS and Cyber-security
Evolving Flight Domains

SPACEFLIGHT DOMAIN (STM)

328 kft / 100 km
Karman Line

AVIATION DOMAIN (ATM)

60 kft / 18 km
Current Ceiling of Conventional ATM
Current Floor of Controlled Airspace

Other Spaceflight Missions
High-Altitude Airspace (> FL600)
Current ATM Domain
Low-Altitude ATM

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UAS Research & Innovation Challenges - R. Sabatini
Evolving Airspace and Avionics Systems
Current Industry Challenges

- Enhancing Safety, Efficiency and Sustainability of aviation and space transport operations 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
Avionics Systems Evolution

Space Situational Awareness

“Standalone” Space Operations

Air Traffic Management (ATM)

Two-Pilot Operations

Single-Pilot Operations (SPO)

Low-Altitude ATM (LA-ATM)

Segregated UAS Operations

Non-Segregated UAS Operations

Unsegregated Space Vehicle Operations

UAS Traffic Management (UTM)

1-to-M & N-to-M Multiple Simultaneous Operations

Unsegregated Air and Space Vehicle Operations

Integrated Air & Space Traffic Management

Space Traffic Management

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Unmanned Aircraft Systems
UAS and Cyber-Physical Systems

- UAS are examples of **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.
The Avionics community focuses on two special categories of CPS:

- Autonomous Cyber-Physical (ACP) systems
- Cyber-Physical-Human (CPH) systems

ACP systems operate without the need for human intervention or control. For ACP systems to work, formal reasoning is required as these systems are commonly used to accomplish mission/safety-critical tasks, and any deviation from the intended behavior may have significant implications on human health, well-being, economy, etc.

A sub-class is that of Semi-Autonomous Cyber-Physical (S-ACP) systems, which perform autonomous tasks in a specific set of pre-defined conditions but require a human operator otherwise.
A separate category is that of CPH systems. These are a particular class of CPS where the interaction between the dynamics of the system and the cyber elements of its operation can be influenced by the human operator and the interaction between these three elements is regulated to meet specific objectives.

CPH systems consist of three main components: physical elements sensing and modelling the environment, the systems to be controlled and the human operators; cyber elements including the communication links and software; and human operators who supervise/monitor the operation of the system and can intervene if and when needed.
CPS for Trusted Autonomous Operations

- Current research aims at developing robust and fault-tolerant ACP and CPH system architectures that ensure trusted autonomous operations with the given hardware constraints, despite the uncertainties in physical processes, the limited predictability of environmental conditions, the variability of mission requirements (especially in congested or contested scenarios), and the possibility of both cyber and human errors.

- A key point in these advanced CPS is the control of physical processes from the monitoring of variables and the use of computational intelligence to obtain a deep knowledge of the monitored environment, thus providing timely and more accurate decisions and actions.
UAS Avionics Architecture

Vehicle Data Management System

Navigation Sensors

Flight Control Unit

Autopilot

Flight Controls

Vehicle Dynamics & Performance Subsystem

Trajectory Planning and Optimisation Subsystem

Trajectory Negotiation & Validation

Integrity Management Subsystem

Collision Avoidance

Separation Assurance

Communication System

Line-of-Sight (LoS) & Beyond LoS (BLOS)

Navigation Sensors

Cooperative Systems/Non-cooperative Sensors

Autopilot

Flight Controls

Mission Management

Surveillance System

Guidance Subsystem

Navigation Subsystem

Unmanned Aircraft

Ground Control Station

UAS Traffic Mana. (UTM) System

Integrated Vehicle Health Management System

Separation Assurance

Vehicle Dynamics

Trajectory Planning

Flight Control Unit

Collision Avoidance

Communication System

Ground Control Station

UAS Traffic Management (UTM) System

Integrated Vehicle Health Management System

Navigation Sensors

Cooperative Systems/Non-cooperative Sensors

Autopilot

Flight Controls

Mission Management

Surveillance System

Guidance Subsystem

Navigation Subsystem

Unmanned Aircraft

Ground Control Station

UAS Traffic Management (UTM) System

Integrated Vehicle Health Management System

Navigation Sensors

Cooperative Systems/Non-cooperative Sensors

Autopilot

Flight Controls

Mission Management

Surveillance System

Guidance Subsystem

Navigation Subsystem

Unmanned Aircraft

Ground Control Station

UAS Traffic Management (UTM) System

Integrated Vehicle Health Management System

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Cooperative Systems/Non-cooperative Sensors

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Unmanned Aircraft
UAS Avionics R&D
## Integration Architecture

<table>
<thead>
<tr>
<th>Data</th>
<th>Position</th>
<th>Velocity</th>
<th>Attitude Angles</th>
<th>Attitude Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMU</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>GNSS</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>ADM</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>VBS</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

![Diagram with sensors and data processing](image)

**PILOT INTERFACE** - Navigation and guidance mode switch

- VIG (Degraded mode of VIGA)
- VIGA (Degraded mode of EVIGA)
- EVIGA

- Global Navigation Satellite System
- Inertial Measurement Unit
- Vision-Based Sensor
- Aircraft Dynamics Model

**Sensors**

**Sensor Processing and data sorting**

**Multi sensor data fusion techniques**

- Extended Kalman Filter
- Unscented Kalman Filter

**Position, Velocity and Attitude (PVA) best estimates**
Vision-Based Navigation

Key Frame (1)
Key Frame (2)
Key Frame (3)
Key Frame (4)
Key Frame (5)

Start of Visual Route

Horizon Detection
Runway Markings Detection
Optical Flow

Extracted Features

Original Image

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Image Processing Module

Current View

Canny Edge Detector and Hough Transform

Optical Flow

Attitude Rates

Pitch/Roll Difference

Relative Position Deviation

Fuzzy - PID controller

Aircraft Dynamics Model

Aileron / Elevator Deflection Angles

Aircraft States

Key Image from Memory

Canny Edge Detector and Hough Transform

Pitch, Roll and Centerline coordinates from current view and key image

+ -
Integration Architectures

- VBN/INS/GNSS (VIG)
- VBN/INS/GNSS/ADM (VIGA)
Integration Architectures (2)

- Unscented Kalman Filter (UKF) based Configuration (UVIGA)
GNSS Augmentation Systems for UAS
GNSS Augmentation Benefits

- GNSS augmentation benefits in aviation include:
  - Precision approach and landing autonomous ops
  - Ops in urban Environments
  - 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. The additional avionics systems operate via separate principles than the GNSS and, therefore, are not subject to the same sources of error or interference

- A system such as this is referred to as an Aircraft (or Avionics) Based Augmentation System (ABAS)
ABIA Architecture

Aircraft Sensors → Aircraft Dynamics Model → Aircraft 3D and Terrain Models

Obscuration Analysis Module → Multipath Analysis Module → DOP Analysis Module

Signal Analysis Module → Doppler Analysis Module → Interference Analysis Module

Flight Path Optimization Module → Caution and Warning Integrity Flags

GNSS → Integrity Flag Generator

Control Surfaces

Flight Control System

Avionics Systems

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ABIA Integrity Flags

Caution Integrity Flag (CIF):
A *predictive annunciation* that the GNSS data delivered to the avionics system is going to exceed the Required Navigation Performance (RNP) thresholds specified for the current and planned flight operational tasks (GNSS alert status)

Warning Integrity Flag (WIF):
A *reactive annunciation* that the GNSS data delivered to the avionics system has exceeded the Required Navigation Performance (RNP) thresholds specified for the current flight operational task (GNSS fault status)

ABIA Time-to-Caution (TTC):
The *minimum time allowed* for the caution flag to be provided to the user before the onset of a GNSS fault resulting in an unsafe condition

ABIA Time-to-Warning (TTW):
The *maximum time allowed* from the moment a GNSS fault resulting in an unsafe condition is detected to the moment that the ABIA system provides a warning flag to the user
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
AEROSONDE Example

CAD Model

Stereo-Lithography (STL) Format
<table>
<thead>
<tr>
<th>Integrity Event</th>
<th>Integrity Flags Criteria</th>
</tr>
</thead>
</table>
| **Obscuration** | **CIF** – When the current A/C manoeuvre will lead to less than 4 satellite in view, the CIF is generated  
**WIF** – When less than 4 satellites are in view, the WIF is generated |
| **Elevation**   | **CIF** – When one (or more) satellite(s) elevation angle (antenna frame) is less than 10 degrees, the caution integrity flag is generated  
**WIF** – When one (or more) satellite(s) elevation angle is less than 5 degrees, the warning integrity flag is generated |
| **Multipath**   | **CIF** – When the ELP exceeds 0.1 radians, the caution integrity flag is generated  
**WIF** – When the multipath ranging error exceeds 2 metres and the A/C flies in proximity of the ground (below 448.5 metres) the warning integrity flag is generated |
| **Tracking loops** | **CIF** – When either $42.25^\circ \leq 3\sigma_{PLL} \leq 45^\circ$ or $0.2375T \leq 3\sigma_{PLL} \leq 0.25T$ or $0.05d \leq 3\sigma_{DLL} \leq d$, the CIF is generated  
**WIF** – When $3\sigma_{PLL} > 45^\circ$ or $3\sigma_{FLL} > 1/4T$ or $3\sigma_{DLL} > d$ the WIF is generated |
| **C/N₀**        | **CIF** – When the C/N₀ is less than 26 dB-Hz the CIF is generated  
**WIF** – When the C/N₀ is less than 25 dB-Hz the CIF is generated |
| **Jamming**     | **CIF** – When the difference between the received (incident) jammer power (dBw) and the received (incident) signal power (dBw) is 1 dB below the J/S performance of the receiver at its tracking threshold, the CIF is generated  
**WIF** – When the difference between the received (incident) jammer power (dBw) and the received (incident) signal power (dBw) is above the J/S performance of the receiver at its tracking threshold, the WIF is generated |
| **Doppler**     | **CIF** – When the C/N₀ is below 28 dB-Hz and the signal is lost, the caution integrity flag is generated if the estimated acquisition time is less than the application-specific TTA requirements  
**WIF** – When the C/N₀ is below 28 dB-Hz and the signal is lost, the warning integrity flag is generated if the estimated acquisition time exceeds the application-specific TTA requirements |
## FLIGHT LEG

<table>
<thead>
<tr>
<th>FLIGHT LEG</th>
<th>CIF Time</th>
<th>WIF Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight Climb</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Turning Climb</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Straight &amp; Level</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Level Turn</td>
<td>2241 ~ 2311 s, 2413 ~ 2485 s, 2491 ~ 2650 s</td>
<td>2259 ~ 2263 s, 2273 ~ 2283 s, 2432 ~ 2436 s, 2446 ~ 2485 s, 2609 ~ 2612 s, 2621 ~ 2630 s</td>
</tr>
<tr>
<td>Turning Descent</td>
<td>2688 ~ 2752 s, 2811 ~ 2881 s, 2944 ~ 3012 s, 3079 ~ 3100 s</td>
<td>2690 ~ 2739 s, 2814 ~ 2869 s, 2946 ~ 3003 s, 3081 ~ 3100 s</td>
</tr>
<tr>
<td>Straight Descent</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Approach</td>
<td>3301 ~ 3400 s</td>
<td>3303 ~ 3400 s</td>
</tr>
</tbody>
</table>
Online Tactical 4DT Planning Algorithm

**MOTO-4D**

- **Path Constraints**
- **Initial Conditions**
  \[ \{\lambda_0, \varphi_0, z_0, t_0, m_0, v_0^r, \gamma_0^r, \chi_0, \mu_0\} \]
- **GFS Weather Field**
  \[ \{v_w, p, RH, T\} (\lambda, \varphi, z, t) \]
- **Combined Objective**
- **Terminal Conditions**
  \[ \{\lambda_f, \varphi_f, z_f, t_f, \gamma_f, \chi_f, \mu_f\} \]
- **4DT Generation**
  Global orthogonal collocation (Pseudospectral)
  
  **Mathematically Optimal 4DT (CPWS)**

**Operational 4DT**

- **Manoeuvre Identification Algorithm**
  - **Operational Criteria**
  - **Transition Likelihood**

**Feasible 4DT Optimiser**

- **Straight & Level Model**
- **Level Turn Model**
- **Straight Climb Model**
- **Straight Descent Model**
- **Turning Climb Model**
- **Turning Descent Model**

**Final Solution: Optimal and Feasible 4DT**

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CIF not followed by WIF

- Pseudo-spectral methods produce quasi real-time solutions (acceptable for mission planning and some flight management implementations)
- More efficient (real-time) geometric algorithms are used in other cases
Autonomous Navigation and Guidance in GNSS-denied and Challenged Environments

- Jamming radiation pattern estimated based on J/S, C/N₀ and jammer type
- Development of ABAS-based predictions to avoid jamming volume
- Generation of optimal avoidance trajectories, preventing degradation or losses of navigation data
SBAS and GBAS IFG Architectures

- **Avionics Inputs/Simulators**
  - Aircraft Dynamics Models
  - GNSS/GEO Constellations
- **Databases**
  - Masking Matrixes
- **Satellites in View**
- **Fast and Long Term Error Model**
- **Residual Tropospheric Error Model**
- **Residual Ionospheric Error Model**
- **Airborne Receiver Error Model**

**Total Error Model**

- **Observation Matrix G**
- **Weighted Matrix W**
- **Projection Matrix S**

**VPL**:
- **VPL_{SBAS}**
- **VPL_{HD}**
- **VPL_{L1}**
- **PVPL_{H1}**
- **PVPL_{HD}**
- **PVPL_{L1}**

**HPL**:
- **HPL_{SBAS}**
- **HPL_{HD}**
- **HPL_{L1}**
- **PLPL_{H1}**
- **PLPL_{HD}**
- **PLPL_{L1}**

**SBAS Integrity Flag Generator Module**

- **VAL**
- **HAL**
- **Warning Flags**

**GBAS Integrity Flag Generator Module**

- **LAL**
- **Caution and Warning Flags**

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**VPL**: Vertical Protection Level
**LPL**: Lateral Protection Level
**VAL**: Vertical Alert Limit
**LAL**: Lateral Alert Limit

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VPL: Vertical Protection Level
LPL: Lateral Protection Level
VAL: Vertical Alert Limit
LAL: Lateral Alert Limit
PVPL: Predicted VPL
PLPL: Predicted LPL
Separation Assurance and Collision Avoidance Systems
Separation Assurance and Collision Avoidance

- **Avoidance volume** in the airspace surrounding each track is determined.

- Accomplished by **considering both navigation and tracking errors** affecting the measurements (plus disturbances) and translating them to **unified range and bearing uncertainty descriptors**, which apply both to cooperative and non-cooperative scenarios.
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
SA/CA – Relative Dynamics and Inflations

Avoidance Volume: Dynamic Changes (expansion or contraction)

Navigation Error Ellipsoid

Tracking Error Ellipsoid

SA/CA – Relative Dynamics and Inflations

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SA/CA – Safety-critical Applications

- Uncertainty volumes for avoidance of ground obstacles
  - A set of feasible avoidance trajectories is generated in real-time
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
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.
UAS Human-Machine Interfaces and Interactions
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 **Trusted Autonomous Operations** in both mission-critical and safety-critical applications
CHMİ² Aeronautical Applications

❖ 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
CHMI² Framework

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

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

**Adaptation:** module drives the HMI² based on inferred cognitive states and key mission performance metrics.
Inference Engine
Cognitive Adaptation Methodology (Summary View)
Current Research: Cognitive HMI and Explanation UX

- Explainable AI
- Trusted AI
- Certifiable AI
Cybersecurity Challenges
Evolving ATM Cyber-Landscape

- Over the last three decades, the “cyber-landscape” in ATM has evolved significantly, particularly in conjunction with:
  - a continuing migration from dedicated to general-purpose hardware, including PCs, rack servers, tablets, laptops and even personal mobile devices, to which a growing number of COTS wireless devices are connected (incl. headsets, input devices, printers etc.)
  - a continuing migration from a dedicated and largely domestic-only Aeronautical Fixed Telecommunication Networks (AFTN) towards global IP-based connectivity
  - the ongoing implementation of new SESAR and NextGen technologies, most of which are data-link-based or terrestrial IP-based technologies (incl. SWIM, VDL, 4D-TRAD, AeroMACS, A-CDM etc.)

- The future of ATM (and especially UTM) involves substantially greater amounts of data exchanged in real-time across an increasing number of stakeholders

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

Cybersecurity

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

Physical Security

- Often, a lack of physical security facilitates cyber attacks. Physical safeguards can reduce vulnerability

Cyber-Physical Systems

- Significant in the context of UAS avionics
- Trustworthy AI?
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
STRIDE is an abbreviation for various known attack paths, one standard approach to assess vulnerabilities:

- **Spoofing Identity**
- **Tampering with Data**
- **Repudiation**
- **Information Disclosure**
- **Denial of Service**
- **Elevation of Privilege**
## UAS Attack Surface and Cybersecurity Framework

<table>
<thead>
<tr>
<th>Segment</th>
<th>Vulnerability</th>
<th>Threats</th>
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<tbody>
<tr>
<td>Unmanned Aircraft</td>
<td>Payload Vulnerabilities</td>
<td>• Denial of Service</td>
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<td>• Hardware Backdoor</td>
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<td>• Bespoke Malware</td>
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<td>• Privilege Escalation</td>
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<td>• Hijacking</td>
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<td>• Sensor Injection</td>
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<td>Comms/C2 Link</td>
<td>Signal Vulnerabilities</td>
<td>• Jamming</td>
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<td>• Eavesdropping</td>
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<td>• Spoofing</td>
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<td>• Metadata-Analysis</td>
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<td>• Command Injection</td>
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<td>• Replay Attacks</td>
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<td>• Signal Injection</td>
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<tr>
<td>Ground Control (GCS and UTM)</td>
<td>GCS/UTM Vulnerabilities</td>
<td>• Bespoke Malware</td>
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<td>• Generic Malware</td>
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<td>• Social Engineering</td>
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<td>• Physical Access</td>
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<td>• Data Corruption</td>
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<td>• Hardware Backdoor</td>
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</table>

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UAS Research & Innovation Challenges - R. Sabatini
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
UTM and AAM Research Efforts
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
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 mandate 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
**AAM Research Framework**

**UAM Vision**: Revolutionise mobility around metropolitan areas by enabling a safe, efficient, convenient, affordable, and accessible air transportation system

- **Design, development, and implementation of infrastructure to enable safe and efficient multi-vehicle UAM operations**
- **Community Integration**
- **Societal integration and acceptance of UAM operations**
- **Operations and management of multiple vehicles within a UAM system that enable safe and efficient sharing of airspace and other system resources**
- **Vehicle Development & Production**
- **Individual Vehicle Management & Operations**
- **Airspace System Design & Implementation**
- **Airspace & Fleet Operations Management**

**Vehicle Barriers**

**Airspace Barriers**

**Community Integration Barriers**
AAM/UAM Missions

- Includes rural and urban applications
  - Cargo transport, aerial work, etc.
  - eVTOL, sUAS, hybrid-electric etc.
  - UAM as a challenging use-case
- Enabled by electrification and scaled through automation
- Does not include:
  - Supersonic or hypersonic
  - Existing hub-and-spoke

Advanced Air Mobility (AAM) Mission

Develop validated AAM System Architectures that define a safe, certifiable, and scalable system
# NASA UAM Maturity Levels (UML)

<table>
<thead>
<tr>
<th>Vehicles</th>
<th>Airspace</th>
<th>Community</th>
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<tbody>
<tr>
<td><strong>UML-1</strong></td>
<td>Late-Stage Certification Testing and Operational Demonstrations in Limited Environments&lt;br&gt;Aircraft certification testing and operational evaluations with conforming prototypes; procedural and technology innovation supporting future airspace operations (e.g., UTM-inspired); community/market demonstrations and data collection</td>
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<td><strong>UML-2</strong></td>
<td>Low Density and Complexity Commercial Operations with Assistive Automation&lt;br&gt;Type certified aircraft; initial Part 135 operation approvals; limited markets with favorable weather and regulation; small UAM network serving urban periphery; UTM Construct and UAM routes supporting self-managed operations through controlled airspace</td>
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<td><strong>UML-3</strong></td>
<td>Low Density, Medium Complexity Operations with Comprehensive Safety Assurance Automation&lt;br&gt;Operations include urban core; operational validation of advanced airspace operations and management including UTM inspired ATM, CNSI, C², and automation for scalable, weather-tolerant operations; few high-capacity vertiports; noise compatible with urban soundscape; model-local regulations</td>
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<td><strong>UML-4</strong></td>
<td>Medium Density and Complexity Operations with Collaborative and Responsible Automated Systems&lt;br&gt;100s of simultaneous operations; expanded networks including closely-spaced high throughput vertiports; many UTM inspired ATM services available; simplified vehicle operations for credit; low-visibility operations</td>
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<td><strong>UML-5</strong></td>
<td>High Density and Complexity Operations with Highly-Integrated Automated Networks&lt;br&gt;1,000s of simultaneous operations; large-scale, highly-distributed networks; high-density UTM inspired ATM; autonomous aircraft and remote, M:N fleet management; high-weather tolerance including icing; high-volume manufacturing</td>
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<td><strong>UML-6</strong></td>
<td>Ubiquitous UAM Operations with System-Wide Automated Optimization&lt;br&gt;10,000s of simultaneous operations (capacity limited by physical infrastructure); ad hoc landing sites; noise compatible with suburban/rural operations; private ownership &amp; operation models enabled; societal expectation</td>
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AAM/UAM Missions

UNLOCKING UML-4 HELPS ENABLE OTHER UAM MISSIONS

UML-3
Limited inter-city eVTOL networks. Limited "feeder networks" between rural areas to nearest city. Public service missions.

UML-4
Wide-scale on-demand, regional air transportation network

UML-2
Cargo delivery to/from warehouses & distribution centers in non-urban areas. Increased utility & safety of General Aviation.

UML-1
No new commercial rural missions enabled.

“Rural” Missions

UML-4
Increasing network of eVTOL operations to smaller vertiports in IMC. Increase in previous missions. (e.g., early on-demand urban air taxi network, wide-scale, distributed small package delivery)

UML-3
Initial eVTOL fleet operations from urban vertiports. (e.g., airport transfer, cargo delivery, initial urban air metro); Public service missions (e.g., air ambulance, disaster relief)

UML-2
Initial, commercial UAM flights using eVTOL, eSTOL, and eCTOL aircraft. (e.g., ex-urban airport transfers, medical transport, cross-metro transfers)

UML-1
No new commercial urban missions enabled.

Define Stability, Control and Performance standards that guarantee ability to safely fly IFR approaches to zero altitude/zero airspeed above the Touchdown Point (TDP)
Evolutionary systems for UTM and AAM

- Integrated CNS (ICNS) for the large amount of data/information that needs to be exchanged
- On-board vehicle situational awareness and sensors required
- Vertiport infrastructure
- Automation relationship to scalability
- Time-Based Flow Management
  - PBN and TBO
  - Sequencing and Spacing
  - Congestion Management
- Moving towards PBO
- Health/performance monitoring systems (safety-critical)
- Microclimate sensor requirements
Present R&D 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 modeling and dynamic airspace management

- Develop an integrated approach to Multi-Domain Traffic Management (long-term)
Thank you!

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