IEEE Advancing Technology for Humanity

DASC 43rd Digital Avionics Systems Conference
San Diego, CA, USA - September 29-October 3, 2024

Digital Avionics for Sustainability

PRESENTERS

Roberto Sabatini, Khalifa University of Science and Technology (UAE)

Giancarmine Fasano, University of Naples "Federico II" (Italy)

Erik Blasch, IEEE Aerospace & Electronic Systems Society (USA)

Alessandro Gardi, Khalifa University of Science and Technology (UAE)

ASP
AESS IEEE Aerospace & Electronic Systems Society

San Diego (CA), 30 September 2024

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

Outline

1. Introduction to the IEEE AESS Avionics Systems Panel	Rob (11:30)
2. Sustainable Aviation Challenges and Opportunities	Rob (11:50)
3. Aviation Noise Impact Assessment and Mitigation	Erik (12:10)
4. Evolving Technologies and R&I Agenda	Rob (12.30)
5. ATM and Flight Management Systems	Alex (12.50)
6. UTM, AAM and Trusted Automation	Alex (13.30)
7. Recent Advances in Surveillance Systems	Giancarmine (13.50)
8. High-Altitude and Sub-Orbital Flight Operations	Rob (14.10)
9. Concluding Remarks	All (14.20)

IEEE Aerospace & Electronic Systems Society

1. Introduction to the IEEE AESS Avionics Systems Panel	Rob (11:30)
2. Sustainable Aviation Challenges and Opportunities	Rob (11:50)
3. Aviation Noise Impact Assessment and Mitigation	Erik (12:10)
4. Evolving Technologies and R&I Agenda	Rob (12.30)
5. ATM and Flight Management Systems	Alex (12.50)
6. UTM, AAM and Trusted Automation	Alex (13.30)
7. Recent Advances in Surveillance Systems	Giancarmine (13.50)
8. High-Altitude and Sub-Orbital Flight Operations	Rob (14.10)
9. Concluding Remarks	All (14.20)

Introduction to the IEEE AESS Avionics Systems Panel

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

ASP Committees and Regular Meetings

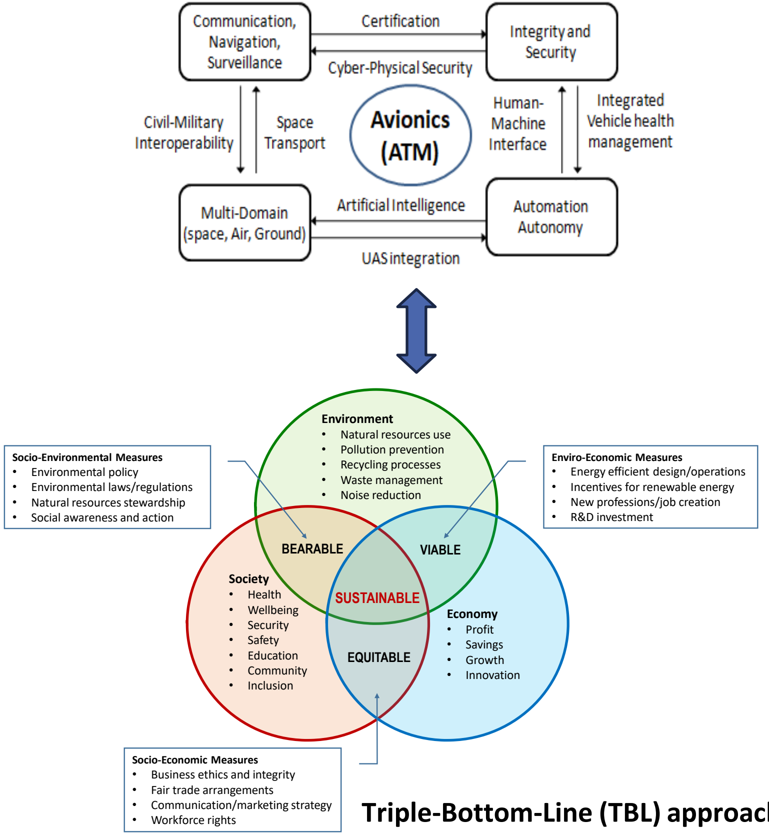
- The ASP relies on a diverse community of experts (currently from US, EU, UK and Asia), contributing to the work of five different committees. The panel holds regular monthly meetings addressing the following topics:
  - **Research and Innovation (R&I).** Participation to NASA UTM and AAM activities;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

Current ASP Activities

- The ASP focuses on avionics systems for commercial, military, and general aviation applications. Relevant avionics functions include: communications; navigation; surveillance; command and control; manned/unmanned air traffic management; and space systems (launch vehicles, satellites, and other space platforms)
- The ASP monitors, analyzes and supports industry and government activities that impact the future of aviation and space operations, such as the ICAO, RTCA/EUROCAE and AEEC standardization initiatives, the FAA NextGen program, the SESAR program, the NASA UTM and Advanced Air Mobility (AAM) initiatives, the JARUS working groups, the UNOOSA and COPUOS activities, and the NOAA-OSC Space Situation Awareness and Space Traffic Management (SSA/STM) policy developments
- The ASP also supports research and education activities related to the social, environmental, and economic impact of aviation and space systems, with specific emphasis on the development and industry uptake of digital technologies. The ongoing transformations of the airspace (both low-altitude and high-altitude operations) and the increasing congestion of the near-Earth space environment are prompting the need to integrate legacy ATM with emerging UTM, AAM and STM systems
- The establishment of a Multi-Domain Traffic Management (MDTM) framework requires significant technological and regulatory advances, especially in the area of autonomous systems, trustworthy/certifiable AI, and cognitive human-machine systems. This next-generation of avionics systems will support safer and more efficient flight operations, offering an array of new services and supporting a more sustainable development of the aerospace sector

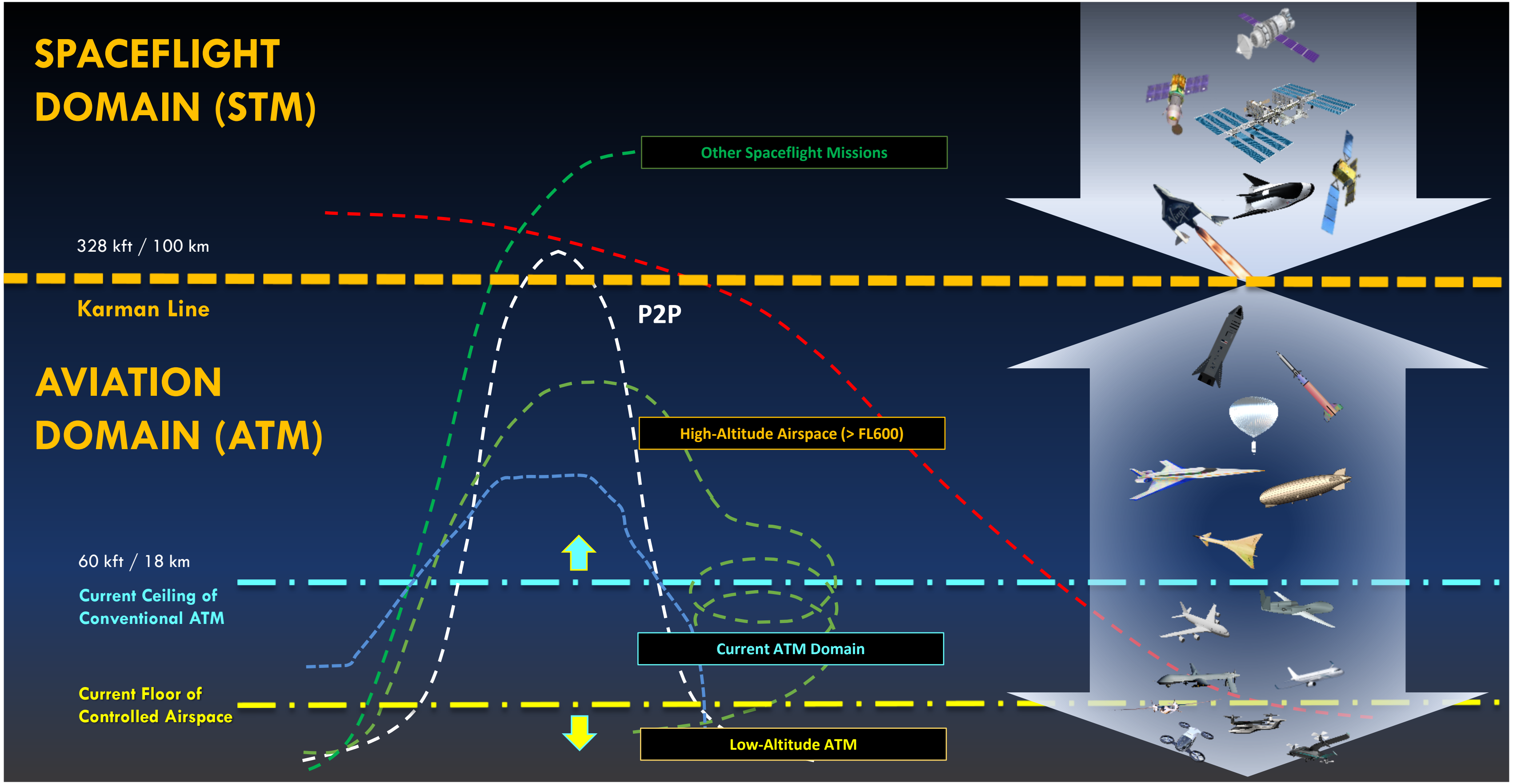
ASP Research and Innovation Areas

1) **Communication, Navigation and Surveillance for Air Traffic Management (CNS/ATM):**
   - Evolution of the certification framework for integrated CNS +Avionics
   - Civil and military airspace integration and CNS+A systems interoperability.
2) **Avionics Systems Integration and Security:**
   - Fault-tolerant avionics design and Integrated Vehicle Health Management (IVHM) systems;
   - Cyber-physical security of avionics and CNS/ATM systems.
3) **Multi-Domain Traffic Management (MDTM):**
   - 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 (HMI²); and
   - Artificial Intelligence (AI)/Machine Learning (ML) in avionics systems design and operations.



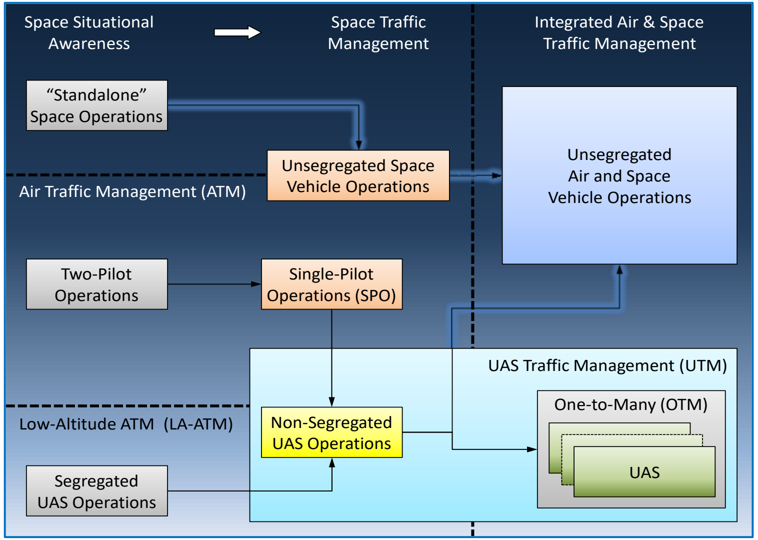
Triple-Bottom-Line (TBL) approach

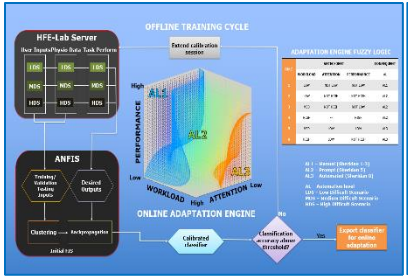
ASP R&I – Evolving Flight Domains

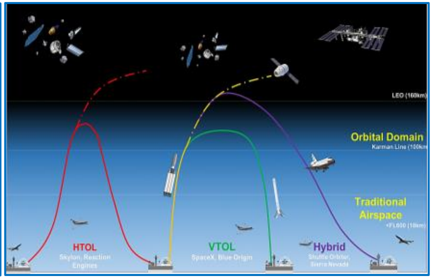


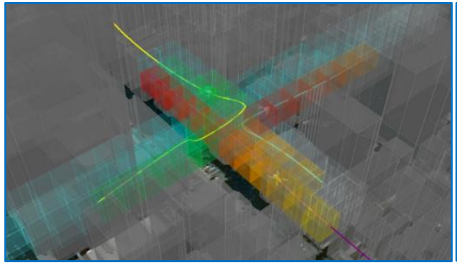
ASP R&I – MDTM Concept

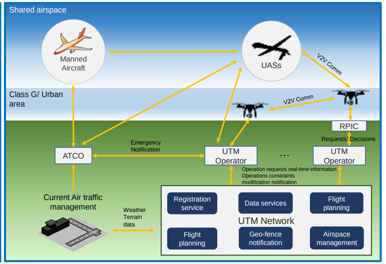
- Multi-Domain Traffic Management (MDTM) research
- AI-based Cyber-Physical System (iCPS) architectures are being studied to support CNS/ATM and Avionics (CNS+A) system evolutions for trusted autonomous air and space transport operations











Recent ASP Publications

[1] G. Fasano, O. G. Crespillo, R. Sabatini, A. Roy, and R. Ogan, "From the Editors of the Special Issue on Urban Air Mobility and UAS Airspace Integration: Vision, Challenges, and Enabling Avionics Technologies." IEEE Aerospace and Electronic Systems Magazine, Vol. 38, No. 5, pp. 4-5, May 2023

[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.

[3] 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

[4] 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, December 2020.

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

Other ASP Publication Initiatives

- Currently working to a new position paper for the AESS Systems Magazine on industry-focused Avionics Research and Innovation (R&I) perspectives, focusing on AI opportunities and challenges
- Discussing a possible update of the paper published in April 2021 on Avionics Systems Education, with stronger focus on "system thinking" and practical avionics systems design (HW/SW) for certification and Test and Evaluation (T&E) skills
- The ASP is developing a book proposal for the IEEE Series on Aeronautics and Astronautics Systems. The goal is to send this new book proposal by the end of 2024. The provisional title is ***"Advances in Digital Avionics and Space Systems."*** Current chapters include:
  - Chapter 1: Avionics Research and Innovation Perspectives
  - Chapter 2: CNS/ATM and Avionics Evolutions to Meet future Air Traffic Requirements
  - Chapter 3: UTM and AAM Implementation Challenges
  - Chapter 4: Avionics Systems for Urban Air Mobility
  - Chapter 5: Avionics Systems for Spacecraft Operations
  - Chapter 6: Cyber Security Aspects in Future Avionics Systems
  - Chapter 7: Avionics Human-Machine Interactive Interfaces
  - Chapter 8: Architectures to Support Future On-Board Avionics
  - Chapter 9: Avionics Hardware and Software Certification Aspects
  - Chapter 10: Certification of AI/ML in Safety-Critical Avionics Systems
  - Chapter 11: Avionics Education and Training to Support Industry Needs and Future Trends

IEEE PRESS

ASP
IEEE Aerospace & Electronic Systems Society

ASP Distinguished Lecturers

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





ASP Industry Engagement and Standards

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

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

Future Standards

- In 2024, the ASP continued supporting the development of DDT&E and certification standards, focusing on CNS, UAS Traffic Management and Advanced Air Mobility

- ASP members contributed to JARUS (Joint Authorities for Rulemaking on Unmanned Systems) Working Group 7 – Automation Concept of Operations, focusing on:
  - ATM and UTM Automation
  - Flight Rules for Autonomous Operations
  - Infrastructure, Aerodromes and Ground Equipment
  - Automation and Trusted Autonomy Use Cases
  - Considerations for Technology Maturity
  - Multiple Simultaneous Operations

JARUS Joint Authorities for Rulemaking on Unmanned Systems

- Documents with ASP contributions:
  - ***Whitepaper on the Automation of the Airspace Environment.*** Joint Authorities for Rulemaking of Unmanned Systems (JARUS), Document No. JARUS- DEL-WG-AUTO-Whitepaper, January 2024
  - ***JARUS Methodology for Evaluation of Automation for UAS Operations.*** Joint Authorities for Rulemaking of Unmanned Systems (JARUS), Document No. JARUS-Doc-AutoMethod.1.0, April 2023.

Future Standards (cont.)

In addition to JARUS Automation/Autonomy, recent ASP contributions have focused on AI/ML certification (SAE G-34/EUROCAE WG-114), which was also a topic of the DASC 2022 and 2023 ASP tutorials:

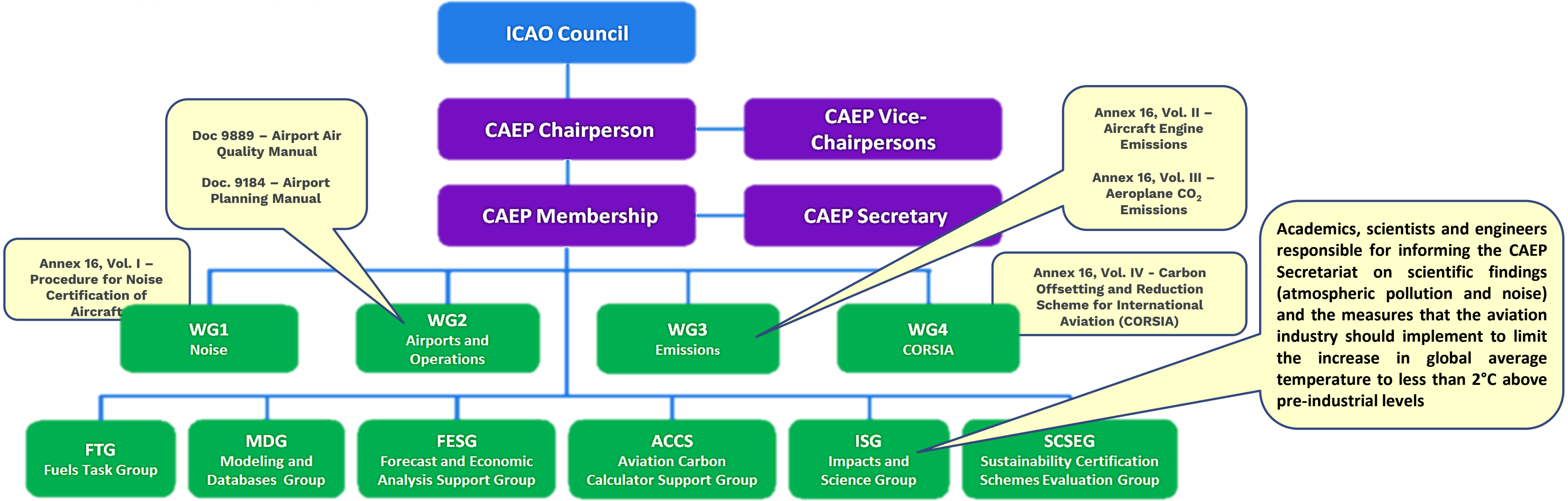
- **SAE G-34/EUROCAE WG-114, Artificial intelligence in Aviation** - Reviews current aerospace software, hardware, and system development standards used in the certification/approval process of safety-critical airborne and ground-based systems, and assesses whether these standards are compatible with a typical Artificial Intelligence (AI) and Machine Learning (ML) development approach.
- Published Standard: AIR6988 / ER-022 Artificial Intelligence in Aeronautical Systems: Statement of Concerns (2021).
- Works In Progress:
  - ARP6983 / ED-324 Process Standard for Development and Certification / Approval of Aeronautical Safety-Related Products Implementing AI;
  - AIR6987 / ER-27 Artificial Intelligence in Aeronautical Systems: Taxonomy;
  - AIR6994 / ER-xxx Artificial Intelligence in Aeronautical Systems: Use Cases Considerations.

ICAO Environmental Policy

ICAO ENVIRONMENT

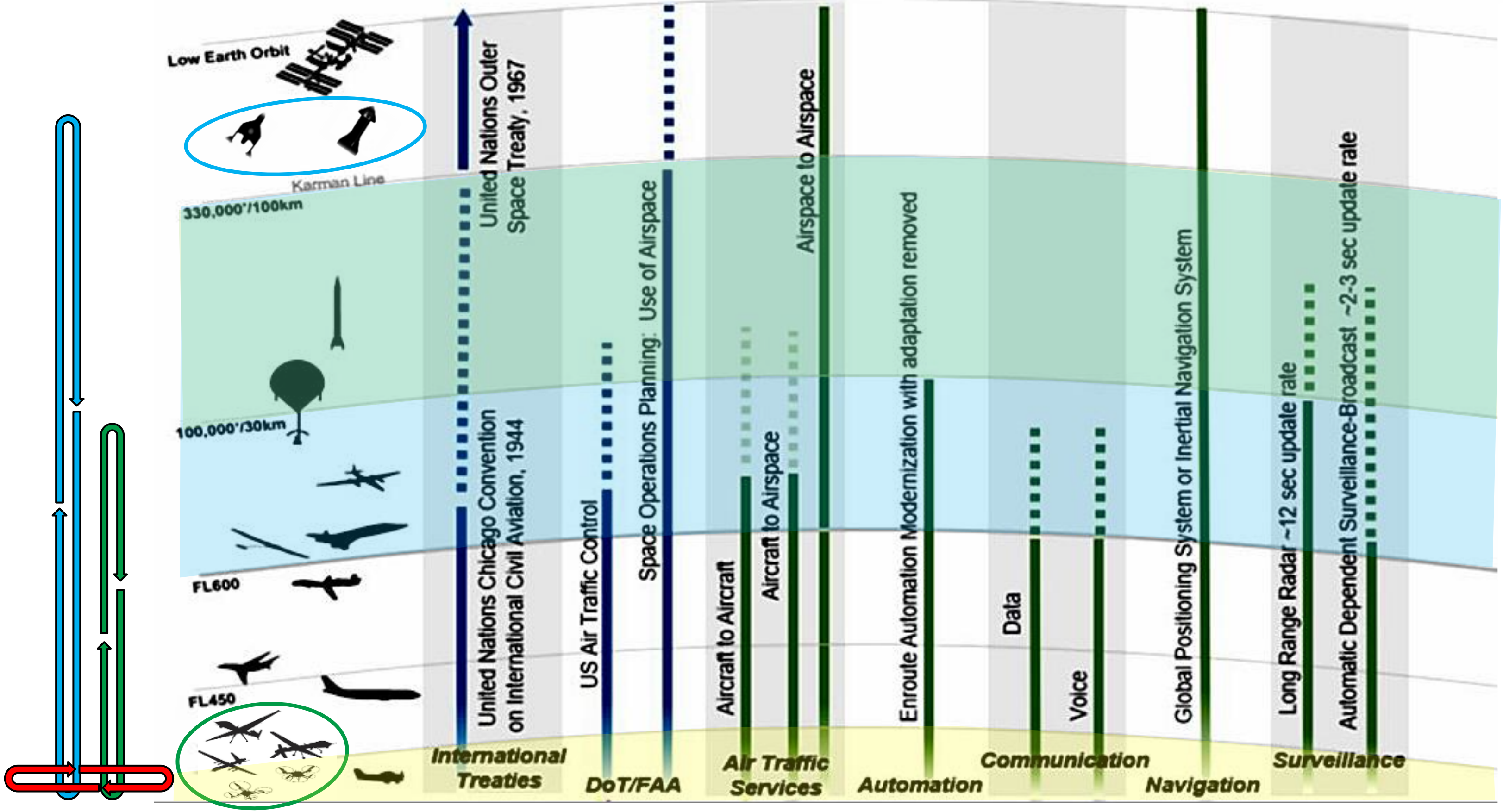
Committee on Aviation Environmental Protection - CAEP

- To limit or reduce the number of people affected by significant aircraft noise
- To limit or reduce the impact of aviation greenhouse gas emissions on the global climate
- To limit or reduce the impact of aviation emissions on local air quality and water/land contamination



Sustainability Challenges and Opportunities

Evolving Flight Domains



Air Transport Industry Snapshot

- The aviation industry plays an important role in the global economy. According to ATAG*, this sector contributed US$3.5 trillion to the world GDP (4.1%) and supports 87.7 million jobs globally
- The aviation market is expected to grow significantly in the coming decades. By 2038, global air transport is forecast to support 143 million jobs and contribute $6.3 trillion to the global economy. So, its growth must be sustainable – with affected communities supported and the environment protected
- Key R&I drivers post-COVID include Advanced Air Mobility and low-level ATM evolutions (UAS Traffic Management and Urban/Regional Air Mobility), flight above FL600 (stratospheric flight) and sub-orbital space transport

(*) Aviation Benefits Beyond Borders Report. URL: https://aviationbenefits.org/economic-growth/

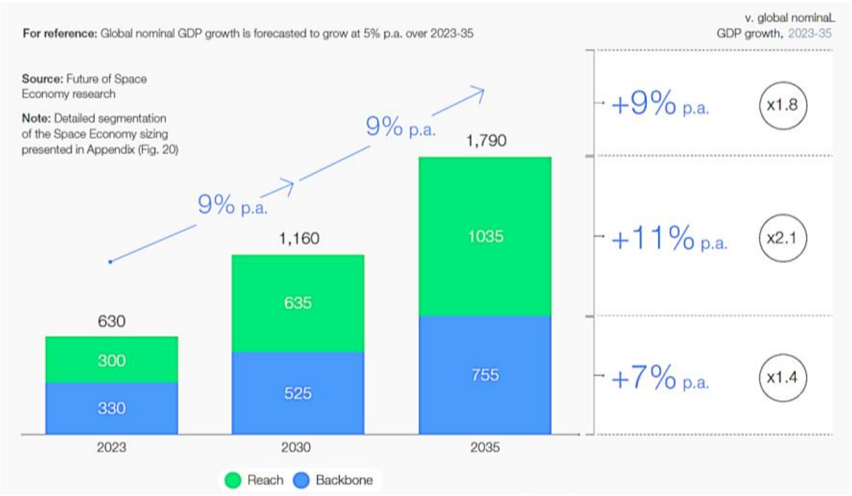
Space Industry Snapshot

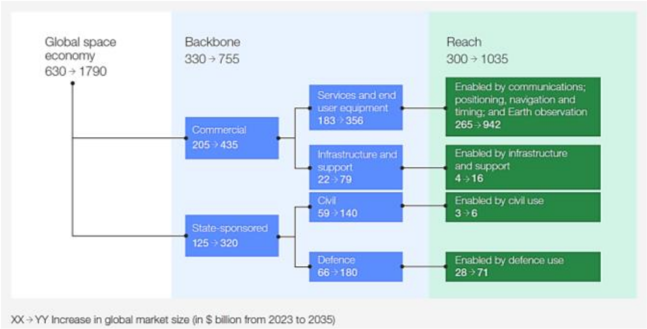
- The global space economy is worth approximately 500 billion USD and, at the current annual growth rate (9%), is set to reach $1.8 trillion by 2035 (*)

- Space-based and/or enabled technologies such communications; positioning, navigation and timing; and Earth observation services are expected to be the key drivers of this growth

- Five sectors – supply chain and transport; food and beverage; state-sponsored defense; retail, consumer and lifestyle; and digital communications – are forecast to generate 60% of the global space economy by 2035, although others will also benefit

- Space will play an increasingly vital role in mitigating world challenges, ranging from disaster warning and climate monitoring, to improved humanitarian response and more widespread prosperity



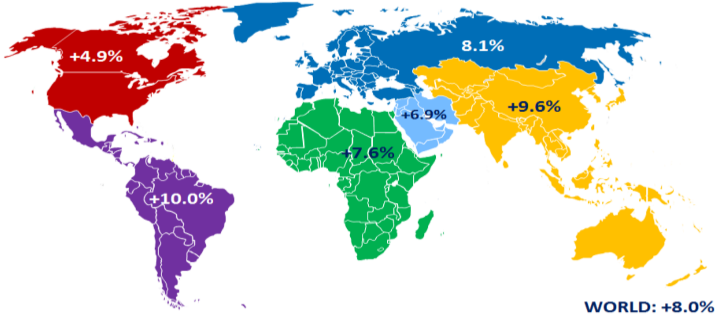


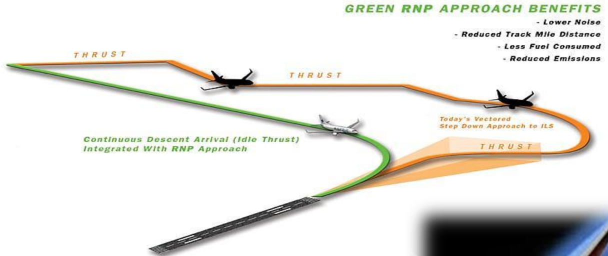
(*) World Economic Forum (2024): https://www.weforum.org/agenda/2024/04/space-economy-technology-invest-rocket-opportunity/

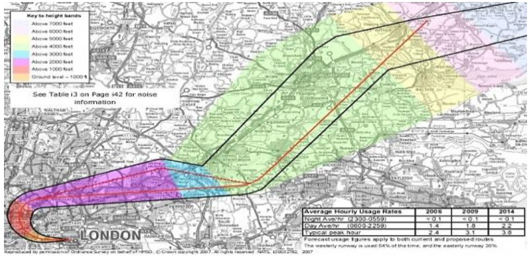
Current Challenges

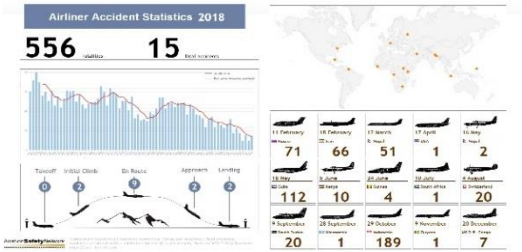
- **Enhancing Safety, Efficiency and Environmental Sustainability of aviation and spaceflight to support the anticipated growth of these sectors**

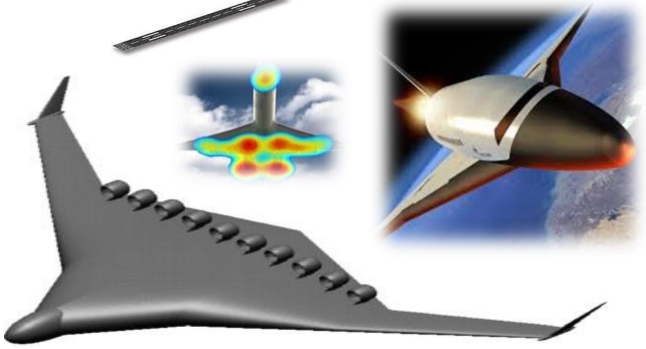
- **Research and Innovation Areas**
  - Next Generation ATM Communications, Navigation, Surveillance (CNS) & Avionics (A) Systems (CNS+A)
  - UAS access to all classes of airspace (trusted autonomy)
  - Development and rapid uptake of low-emission technologies (gaseous and noise emissions)
  - Improved efficiency and capacity of airports and spaceports (digitalisation/multimodal)
  - Solutions for enhanced safety and security











Avionics Cyber-Physical Systems

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

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

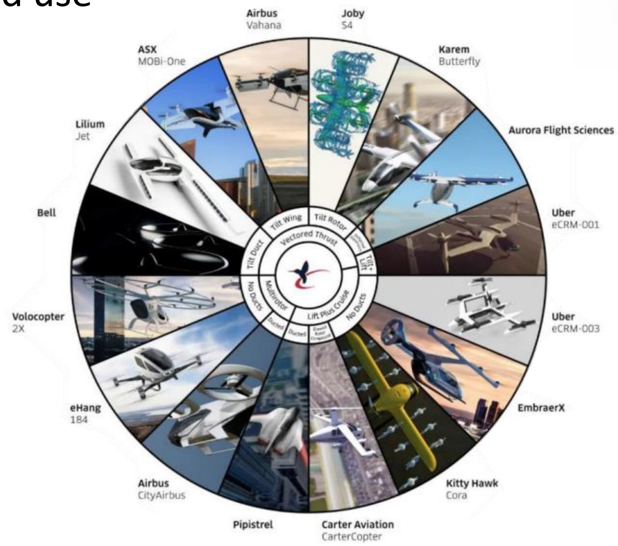
The challenge is to develop robust, fault-tolerant and secure ACP and CPH systems that ensure **trusted autonomous operations** given:

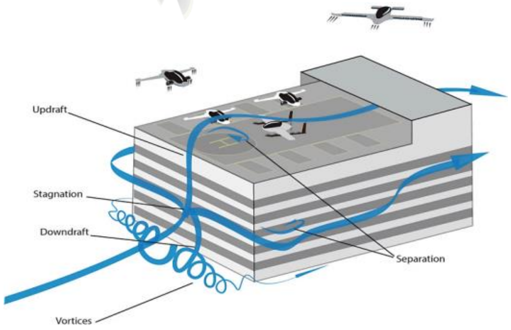
- Specific hardware constraints
- Variability of mission requirements
- Uncertainties in physical processes
- The possibility cyber/physical attacks and human errors

Advanced Air Mobility (AAM)

- AAM integrates innovative aircraft like electric and hybrid-electric VTOLs and UAS technologies into airspace (predominately low-altitude airspace), enhancing transport for people and goods

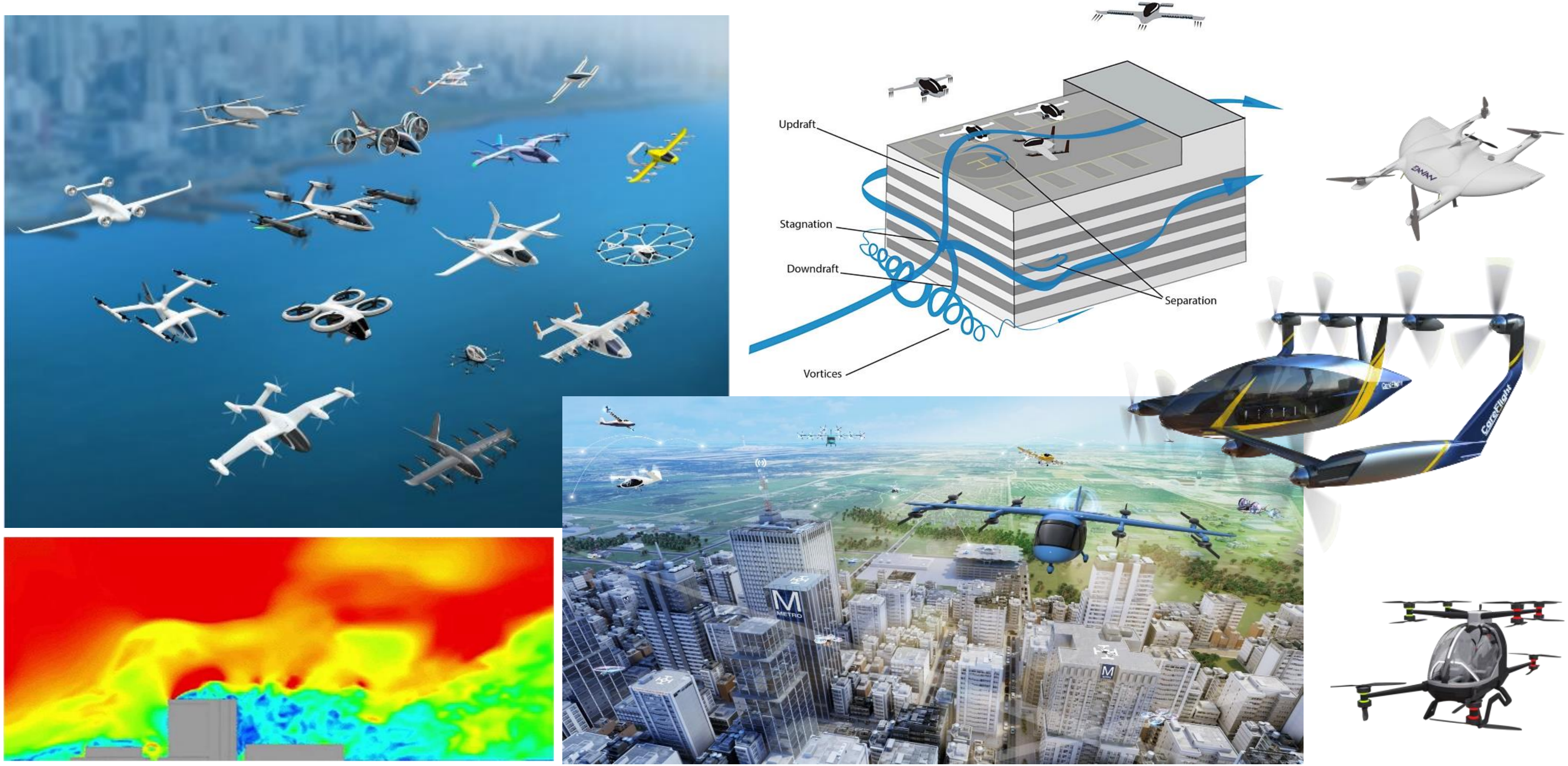
- Set to transform air travel, especially in urban, suburban and rural areas, with diverse applications and use cases (air taxis, regional cargo, transport, aeromedical, etc.)





- The system promises to reduce congestion, improve accessibility, and offer sustainable transportation solutions

AAM VTOL Platforms and Environment



Sustainable Flight Platforms

High-Altitude & High-Speed Flight Platforms


Atlas LTA


Kea Atmos

Stratobus


Proteus


NASA Helios


UAVOS


Lockheed – Mach 1.8


Boeing – Mach 5


NASA X-59 – Mach 1.4

Point-to-Point Suborbital Transport

- Introduction of Commercial Space Industry has accelerated development of <u>manned and unmanned reusable space vehicles</u> (SpaceX, Reaction Engines, Virgin Galactic, Sierra Nevada, etc.)
- Space Tourism, Research, Point to Point transport have been identified as commercially and economically viable markets
- The need for integration of space and traditional atmospheric traffic is widely accepted (NextGen, SESAR)
- A global, harmonized Air and Space Traffic Management network will require the implementation of advanced CNS+A technology for trusted autonomous operations
- Success of industry will fundamentally depend on the ability to demonstrate an acceptable level of safety and sustainability

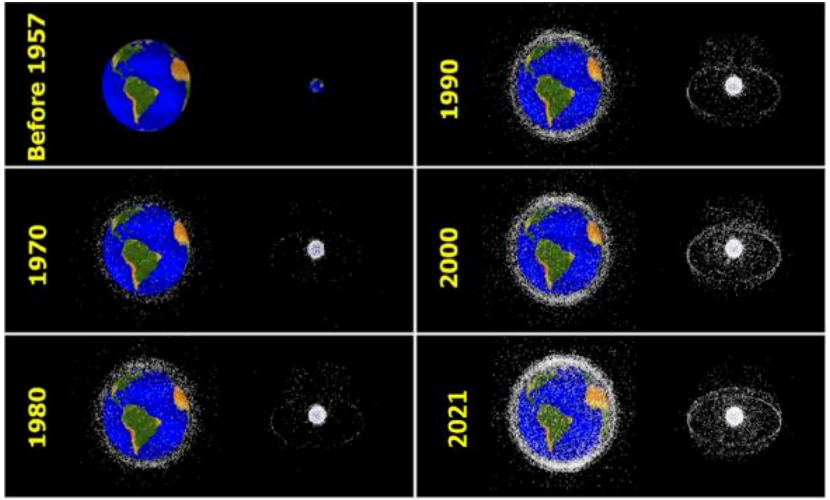
Virgin Galactic Space Ship 2

Sierra Nevada Dream Chaser

Reaction Engines Skylon

Orbital Congestion

- Resident Space Objects (RSO) > 1mm

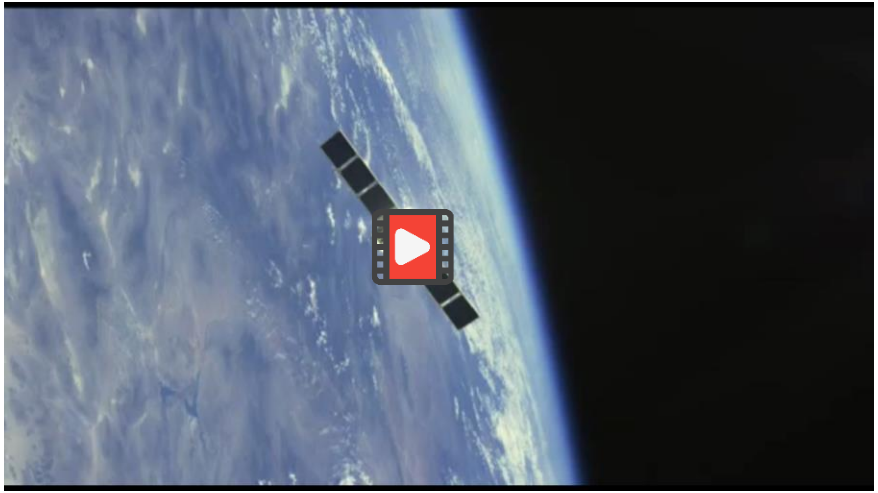


Courtesy: ESA

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

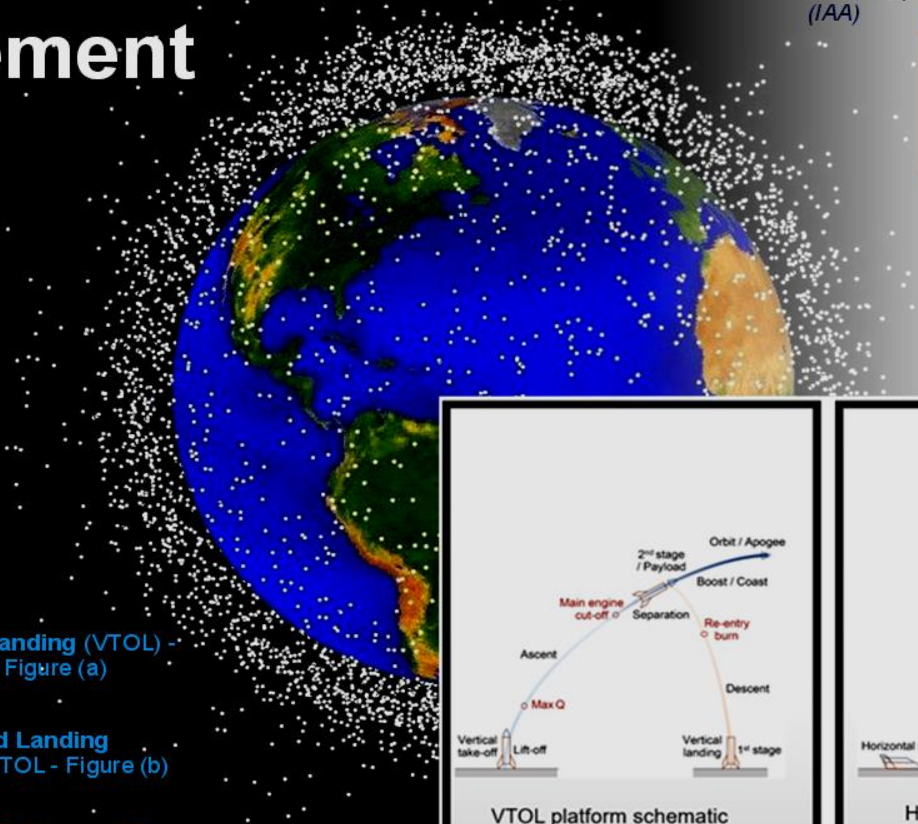
Collision Events

IRIDIUM vs. KOSMOS collision event (2009)



PRC Anti-Satellite Missile Test (2007)

Space Traffic Management

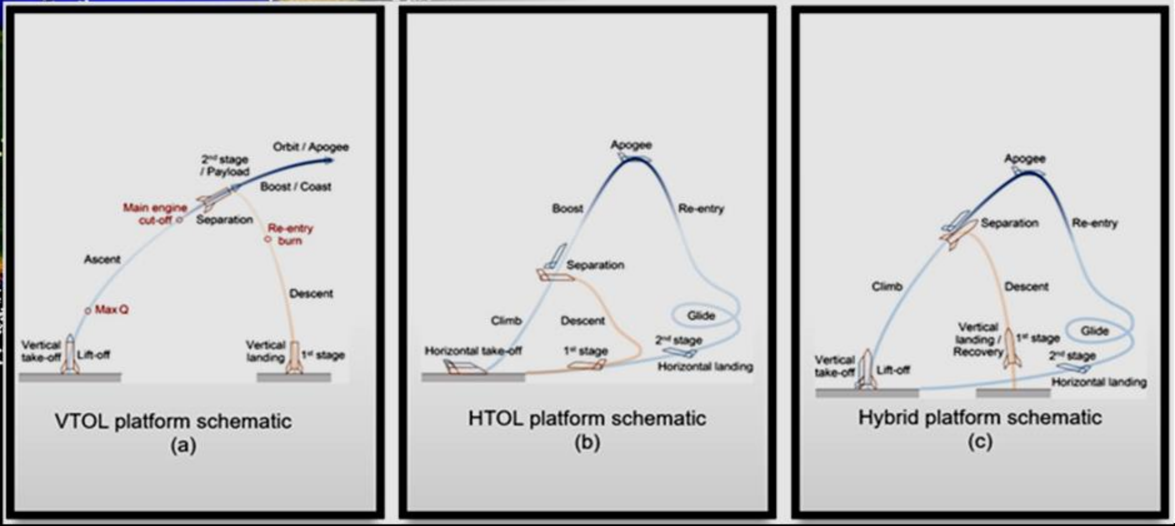


"Space traffic management is the set of technical and regulatory provisions for promoting safe access into outer space, operations in outer space and return from outer space to Earth free from physical or radio-frequency interference." - International Academy of Astronautics (IAA)

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

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

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



VTOL platform schematic (a)

HTOL platform schematic (b)

Hybrid platform schematic (c)

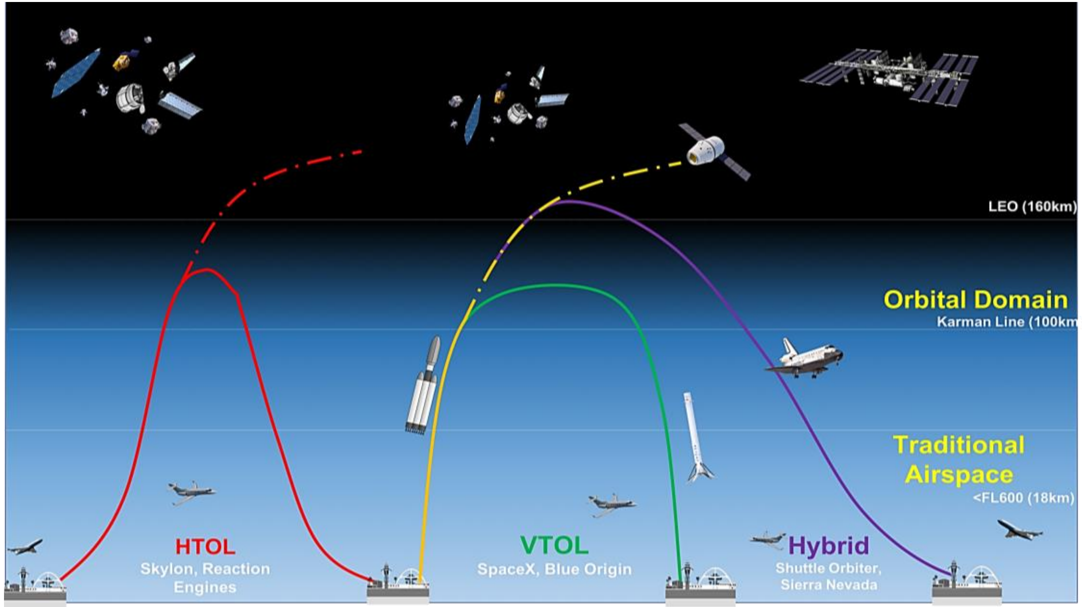
Space Transport Platforms

Vertical Takeoff & Landing

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

Horizontal Takeoff & Landing

- Ability to perform "tactical" maneuvers like atmospheric aircraft
- More accommodating in their integration with ATM systems (can enact rerouting and tactical deconfliction)
- <u>Promising concept for Suborbital Point-To-Point transportation</u>

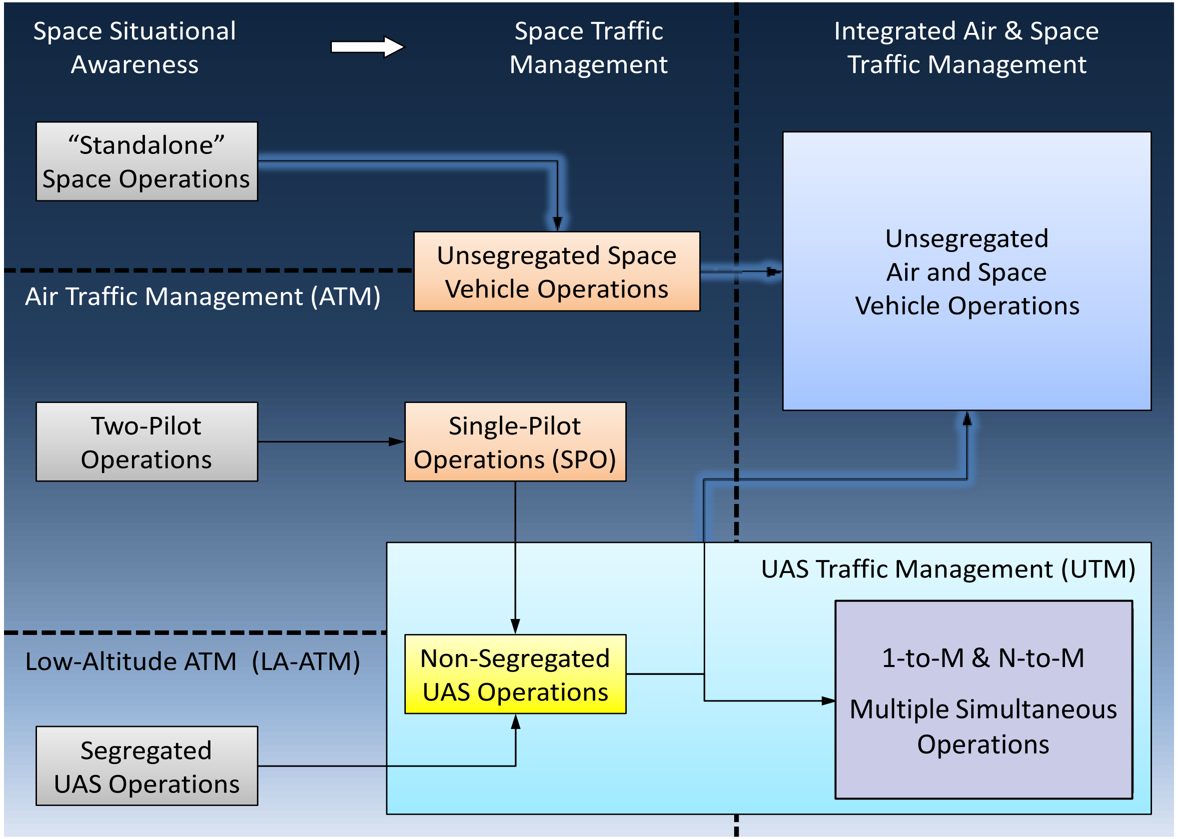


Hybrid

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

Emerging Concepts

Avionics Systems Evolution



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

G. Fasano, O. G. Crespillo, R. Sabatini, A. Roy, and R. Ogan, "From the Editors of the Special Issue on Urban Air Mobility and UAS Airspace Integration: Vision, Challenges, and Enabling Avionics Technologies." IEEE Aerospace and Electronic Systems Magazine, Vol. 38, No. 5, pp. 4-5, May 2023.

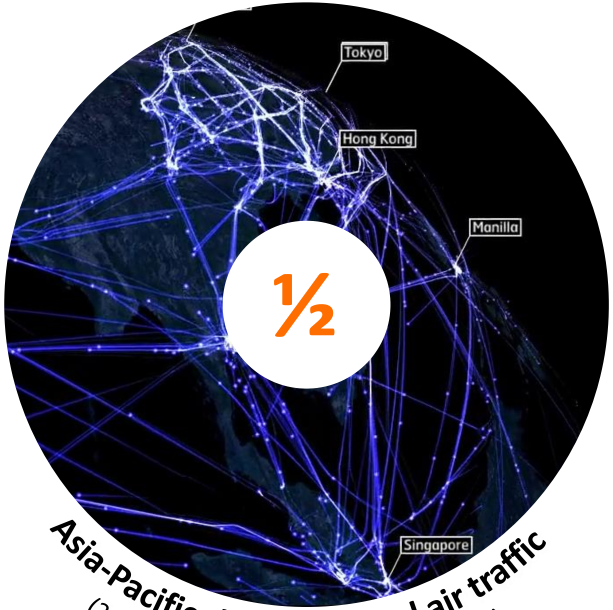
Sustainable Aviation Challenges

Global Aviation Challenges

FORECAST
2050

Global Air Traffic

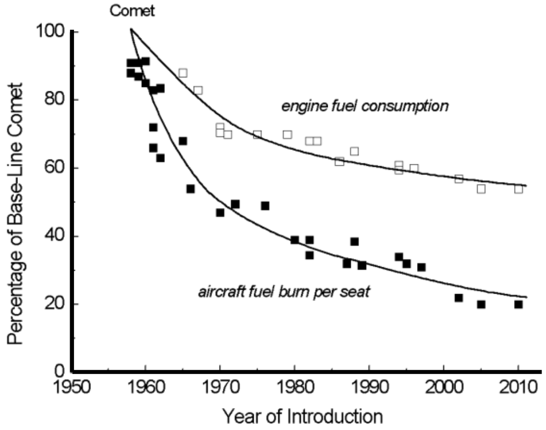
Aviation-induced global warming
(climate change impacts)

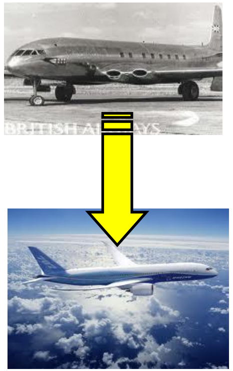


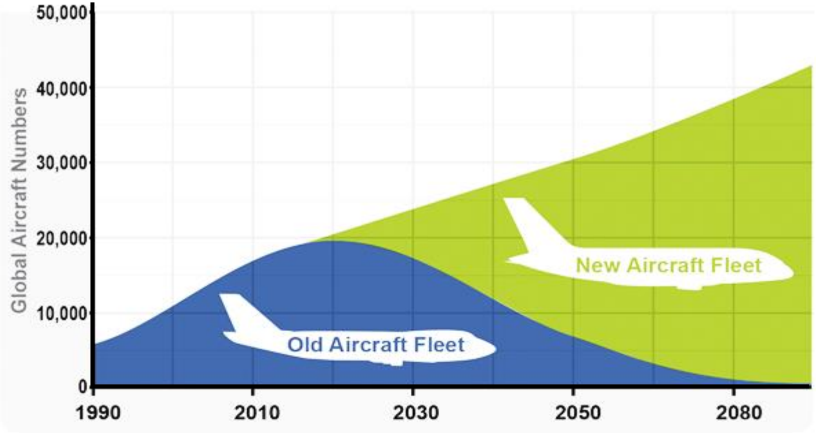
Asia-Pacific share of global air traffic
(215 new airports in China alone by 2035)

Aviation Sustainability Challenges

- Aircraft atmospheric pollution includes **carbon dioxide, nitrogen oxide, unburned hydrocarbons** (and more), **all of which contribute to global warming**
- It is estimated that **aviation industry contribution to global warming is currently about 3%, although it may increase to 5-10% by 2050** due to the anticipated growth of air traffic
- **Air quality is also degrading significantly due to aviation activities**, especially at and around airports
- **Aviation noise also has short and long-term health impacts** both on humans and other animals
- **Technology advances have been successful in reducing atmospheric pollution and noise emissions from aircraft, but these have not been able to offset the impacts of aviation growth**

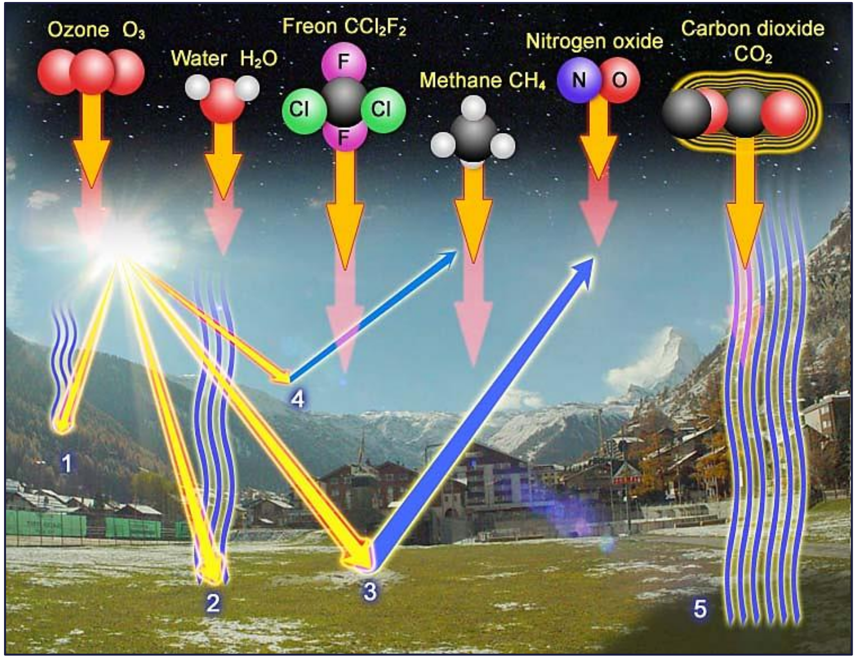


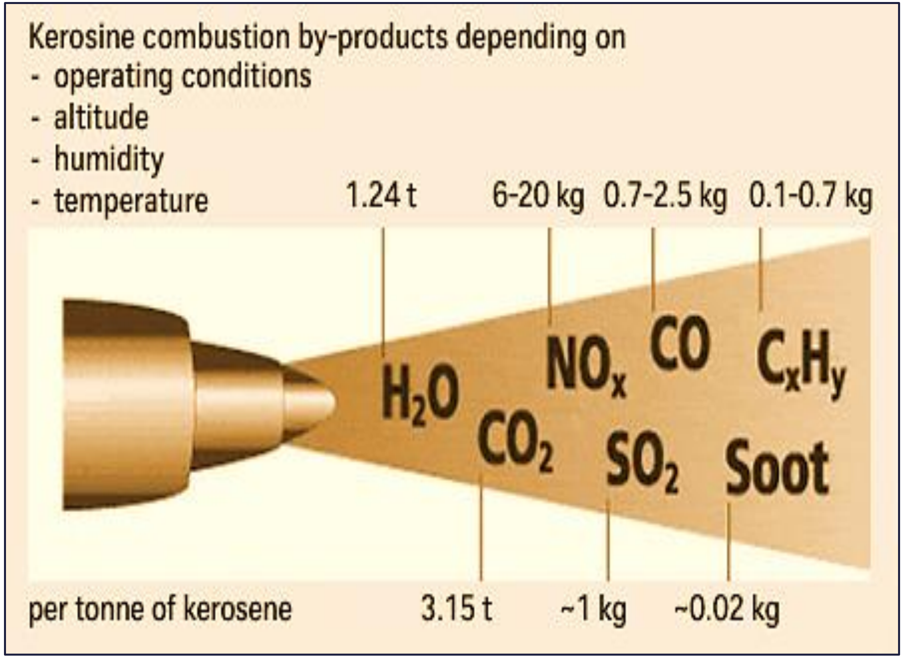




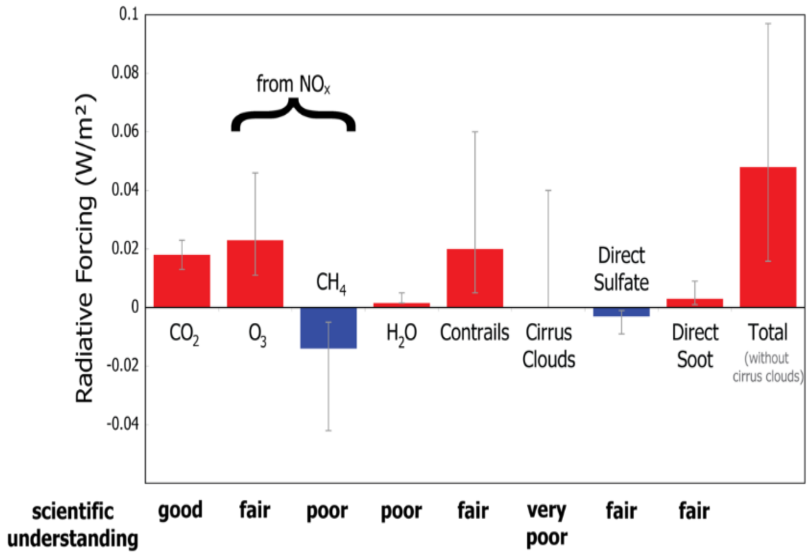
Greenhouse Pollutants and Aircraft Emissions

- Greenhouse effect caused by many types of pollutants. Aviation generates most types

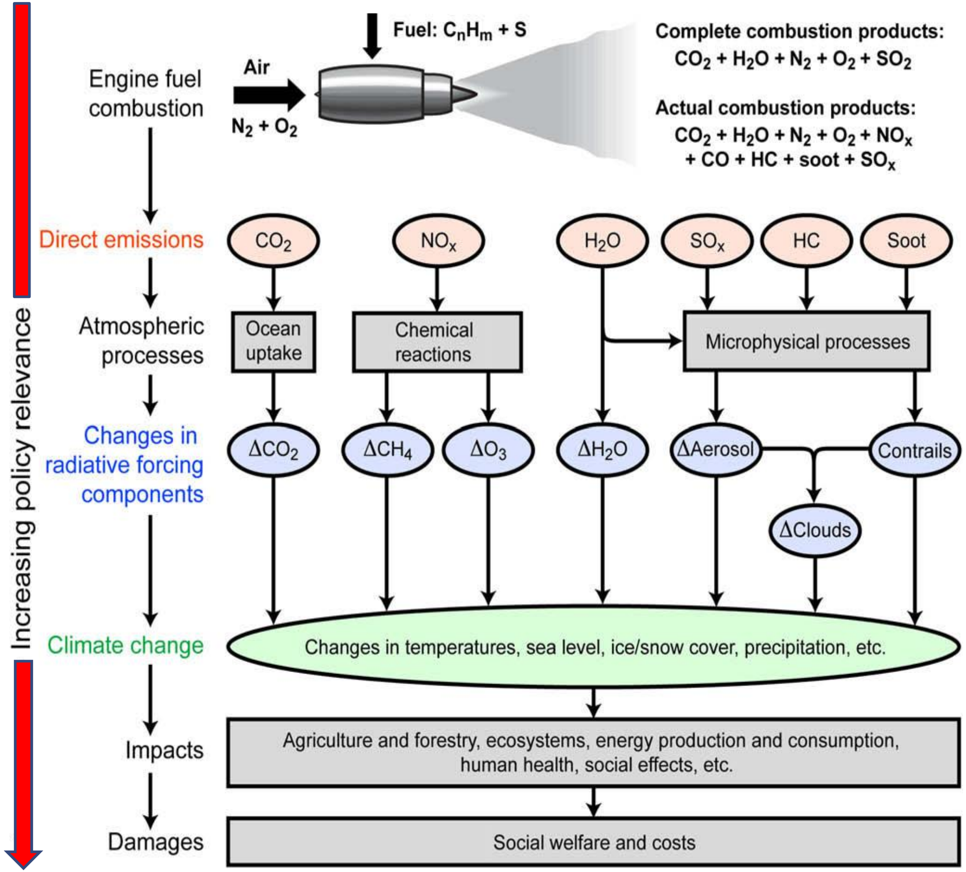




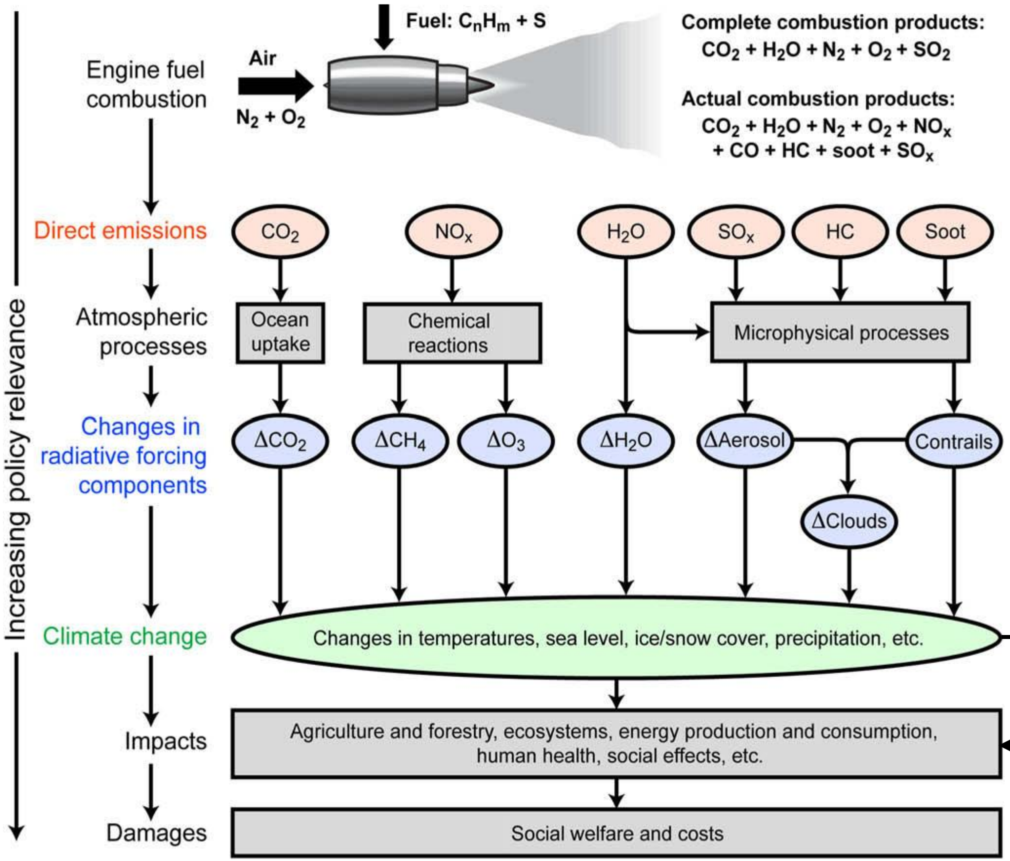
Impacts of Aviation Greenhouse Emissions

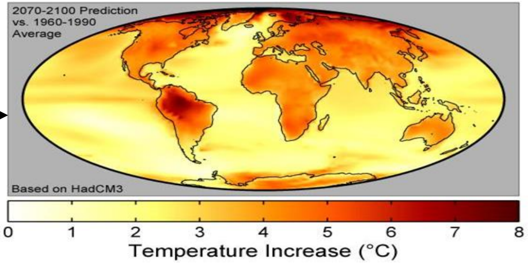


Radiative forcing (RF) is the change in the net vertical irradiance (Wm^{-2}) at the tropopause due to an internal change or a change in the external forcing of the climate system



Impacts of Greenhouse Emissions



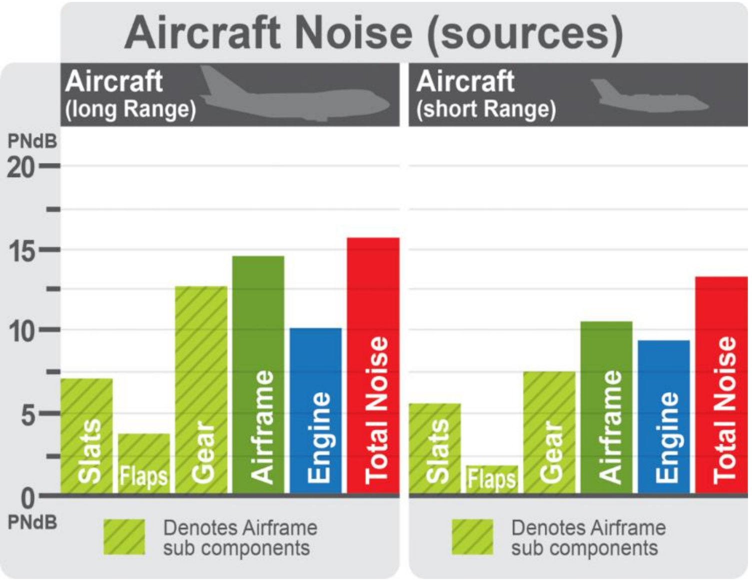


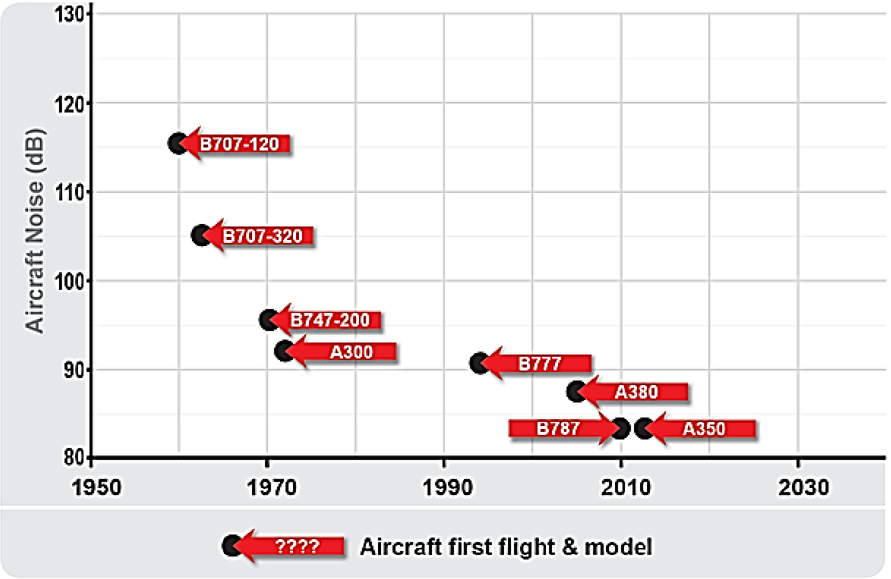
Global Warming Effects on Climate

Phenomenon	Likelihood
Warmer days, less cold days/nights	Virtually certain
More warm spells and heatwaves	Very likely
More heavy rain events	Very likely
More areas hit by drought	Likely
More intense tropical cyclones	Likely
More extreme sea levels (not tsunamis)	Likely

Aircraft Noise Sources and Trends

- Modern aircraft are quieter than their predecessors. However, the steady growth in air traffic increases public exposure to aircraft noise (particularly for people living close to airports)
- Noise can dominate the relationship between airports and local residents, and can lead to restrictions in aircraft operations



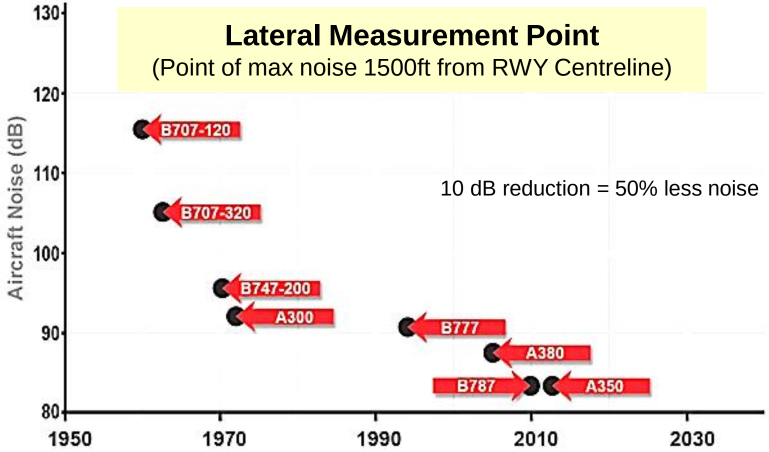


10 dB reduction = 50% less noise

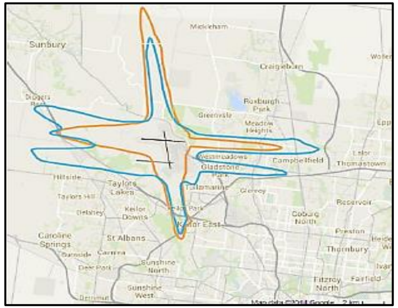
1. Introduction to the IEEE AESS Avionics Systems Panel	Rob (11:30)
2. Sustainable Aviation Challenges and Opportunities	Rob (11:50)
3. Aviation Noise Impact Assessment and Mitigation	Erik (12:10)
4. Evolving Technologies and R&I Agenda	Rob (12.30)
5. ATM and Flight Management Systems	Alex (12.50)
6. UTM, AAM and Trusted Automation	Alex (13.30)
7. Recent Advances in Surveillance Systems	Giancarmine (13.50)
8. High-Altitude and Sub-Orbital Flight Operations	Rob (14.10)
9. Concluding Remarks	All (14.20)

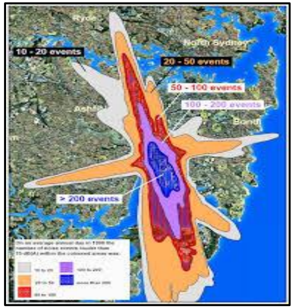
Aviation Noise Impact Assessment and Mitigation

Aircraft Noise Impacts



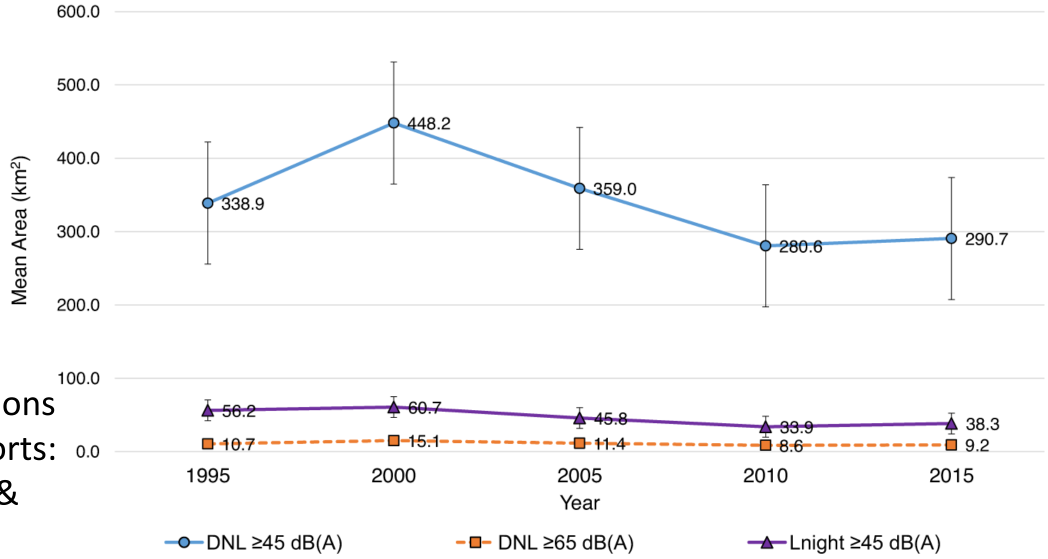
- Engine noise, aerodynamic noise, complex jet-airframe interactions
- **The noise levels experienced by people on the ground** are influenced by:
  - Aircraft type and size (propulsion and aerodynamics)
  - The distance of the aircraft from the ground (trajectory flown)
  - The way the engine and other aircraft systems are operated
  - The rate at which the aircraft climbs/descends
  - Meteorological conditions
- Noise Exposure Forecast (NEF) used for urban planning





Aircraft Noise – Trend Analysis

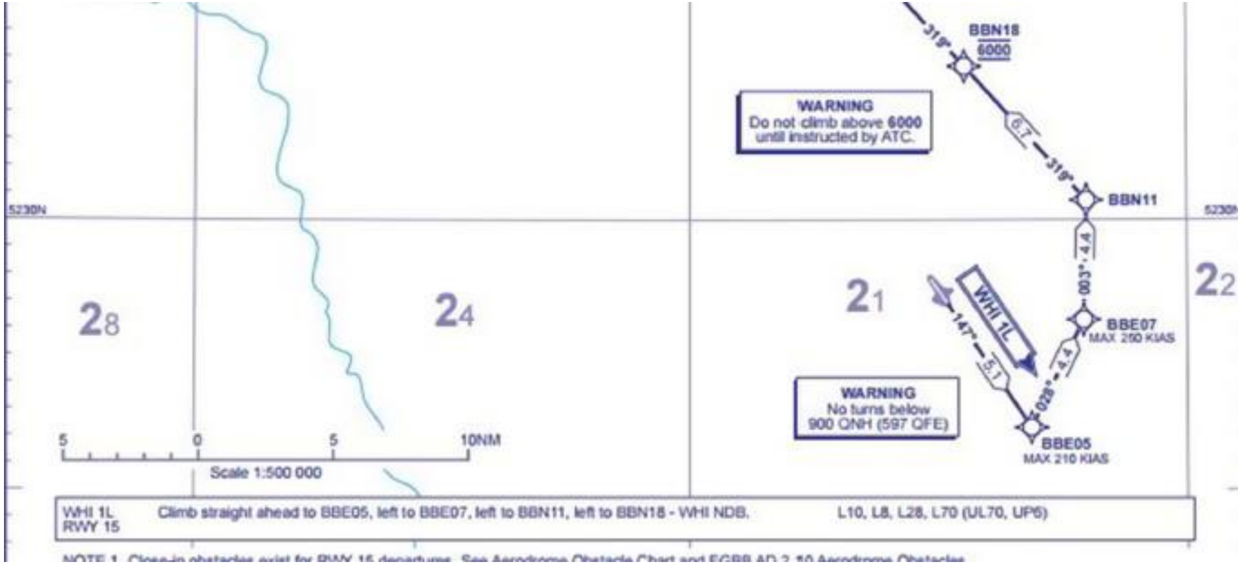
- Analysis of noise levels (Nature study - **Characterizing temporal trends in populations exposed to aircraft noise around U.S. airports: 1995–2015**) influenced by:
  - Types: Passenger versus cargo
  - Region s– South and North America
  - Affects: annoyance, hypertension, child learning
  - 2010 - day-night average sound level (DNL) 55 A-weighted decibels (dB[A])
  - 2015 – levels assessed DNL) 5 dBa and Night 45 dBA
- Assessment and technology helps in the design and analysis for safety



Characterizing temporal trends in populations exposed to aircraft noise around U.S. airports: 1995–2015 | Journal of Exposure Science & Environmental Epidemiology (nature.com)

Aircraft Noise – ex Route Planning to Mitigate

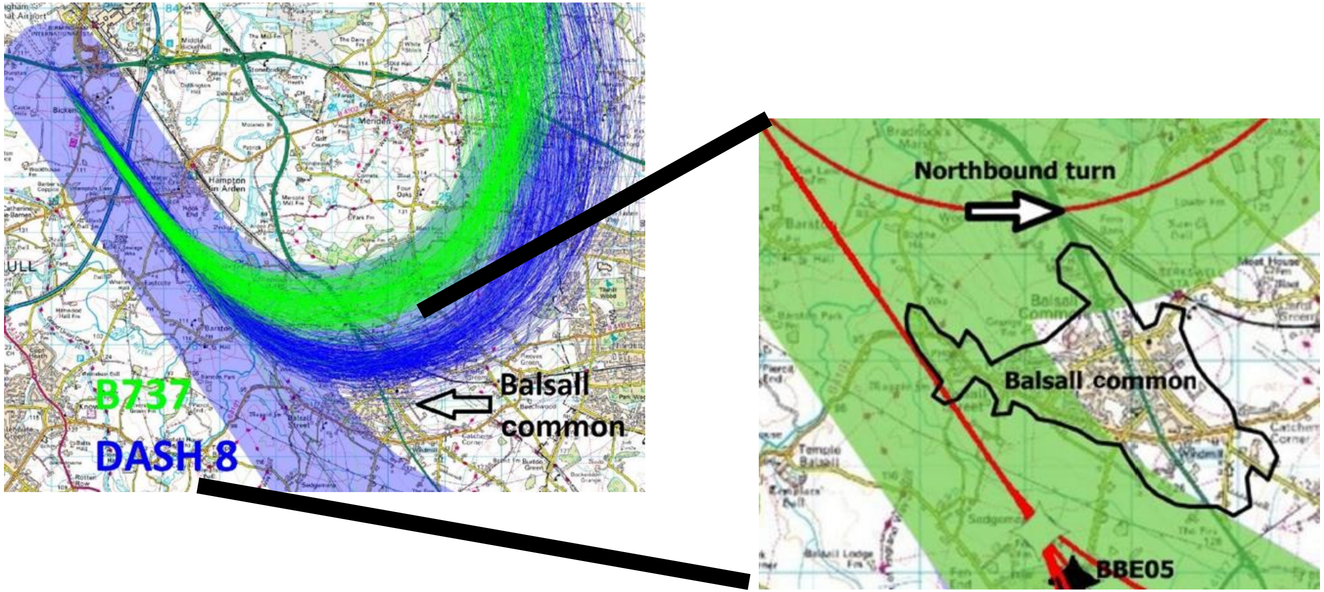
- Parameters for Aircraft aRea Navigation (RNAV)
  - True Airspeed (TAS)
  - Turn Radius
  - Minimum Stabilization distance (MSD)
  - Turning speed
  - Protective zones
  - Waypoint Distance



D. Homola, J. Boril, V. Smrz, J. Leuchter, E. Blasch, "Aviation Noise-Pollution Mitigation through Redesign of Aircraft Departures," *Journal of Aircraft*, 56(5):1-13, Sept: 2019. https://doi.org/10.2514/1.C035001

Aircraft Noise – ex Route Planning to Mitigate

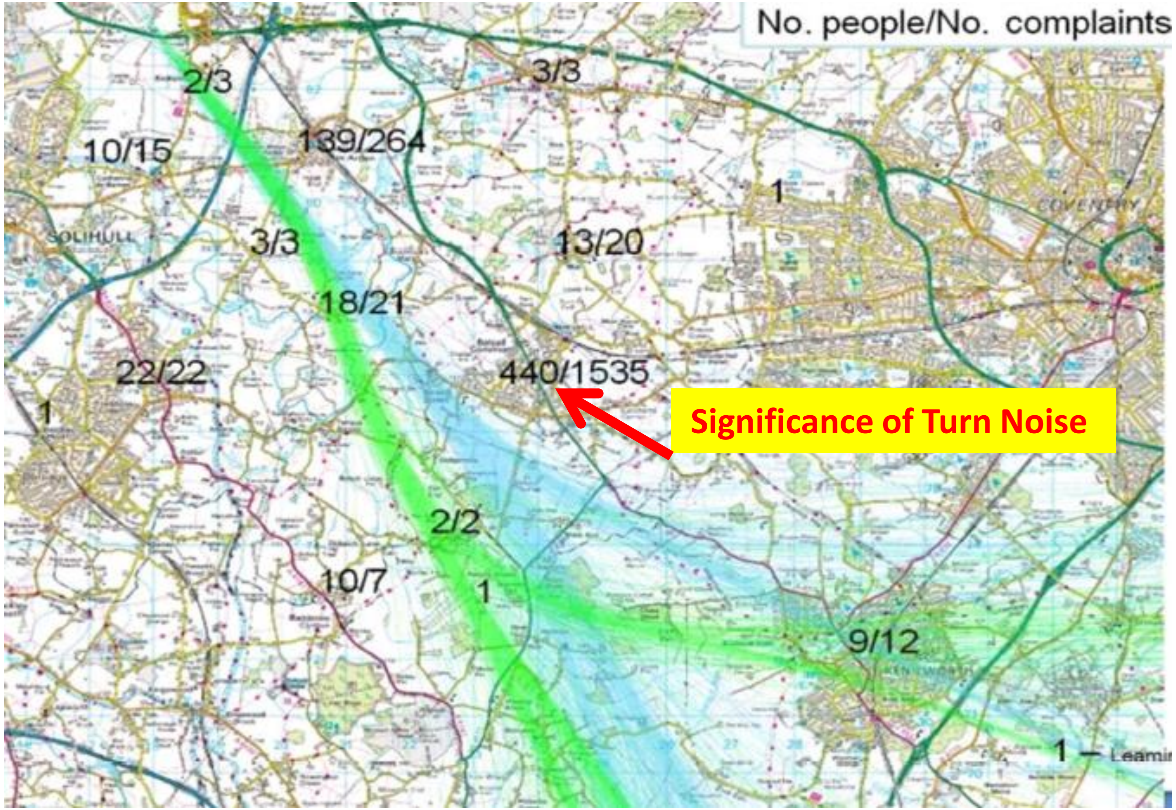
- Routes and Balsall City, UK – data collected from ADS-B information
  - Two routes over city (city sprawl after airport built)



D. Homola, J. Boril, V. Smrz, J. Leuchter, E. Blasch, "Aviation Noise-Pollution Mitigation through Redesign of Aircraft Departures," *Journal of Aircraft*, 56(5):1-13, Sept: 2019. https://doi.org/10.2514/1.C035001

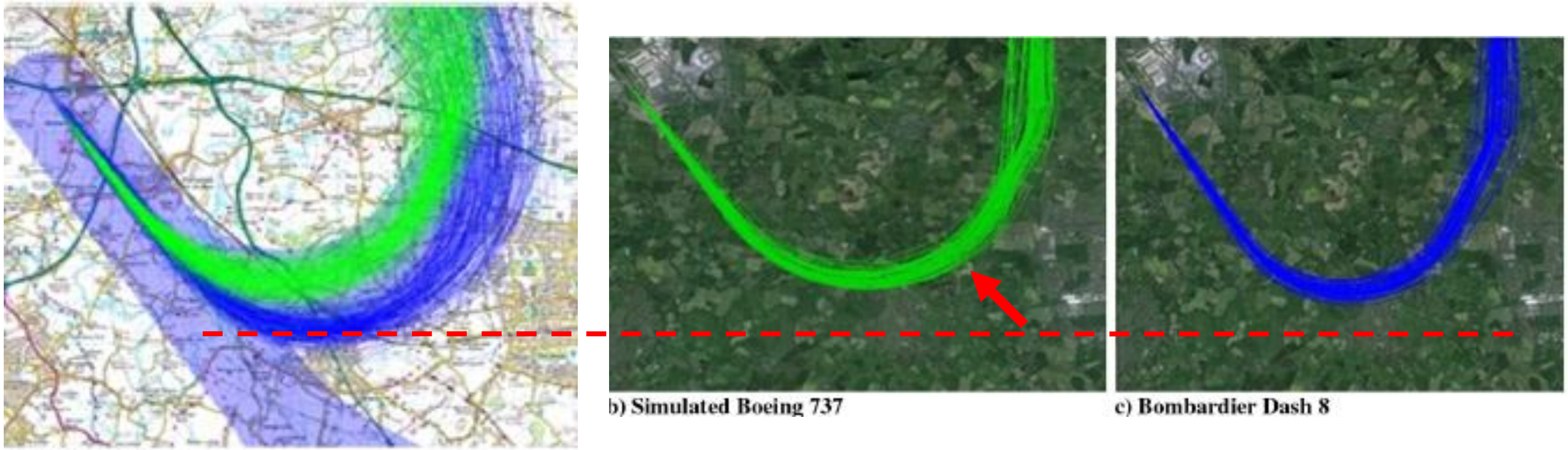
Aircraft Noise – ex Route Planning to Mitigate

- Noise Complaints
- More complaints at the turn when the aircraft is flying up and out



Aircraft Noise – ex Route Planning to Mitigate

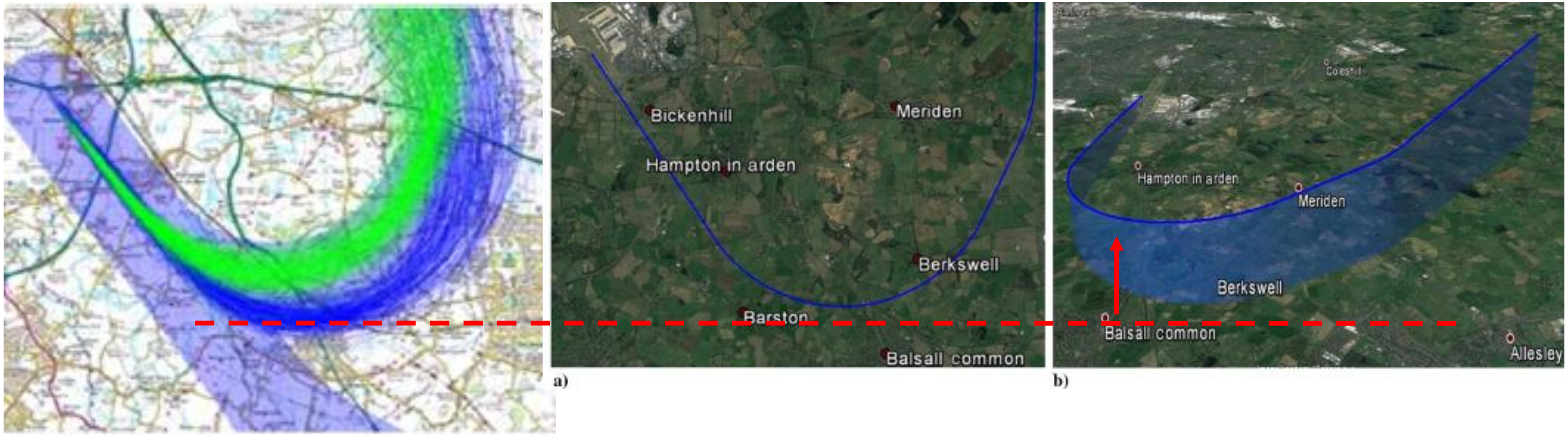
- Replanning the departure – **direction**
- Move the **turning curvature to the north** (away from the complaints in Balsall)



a) Radar data   b) Simulated Boeing 737   c) Bombardier Dash 8

Aircraft Noise – ex Route Planning to Mitigate

- Replanning the departure - **height**
- Move the **turning curvature in altitude** (away from the complaints in Balsall)



a) Radar data

a)

b)

Aircraft Noise – ex Route Planning to Mitigate

- Replanning the departure – RNAV **standard departure route** (SDR) chart – accounting for **wind** speeds, direction and spiral

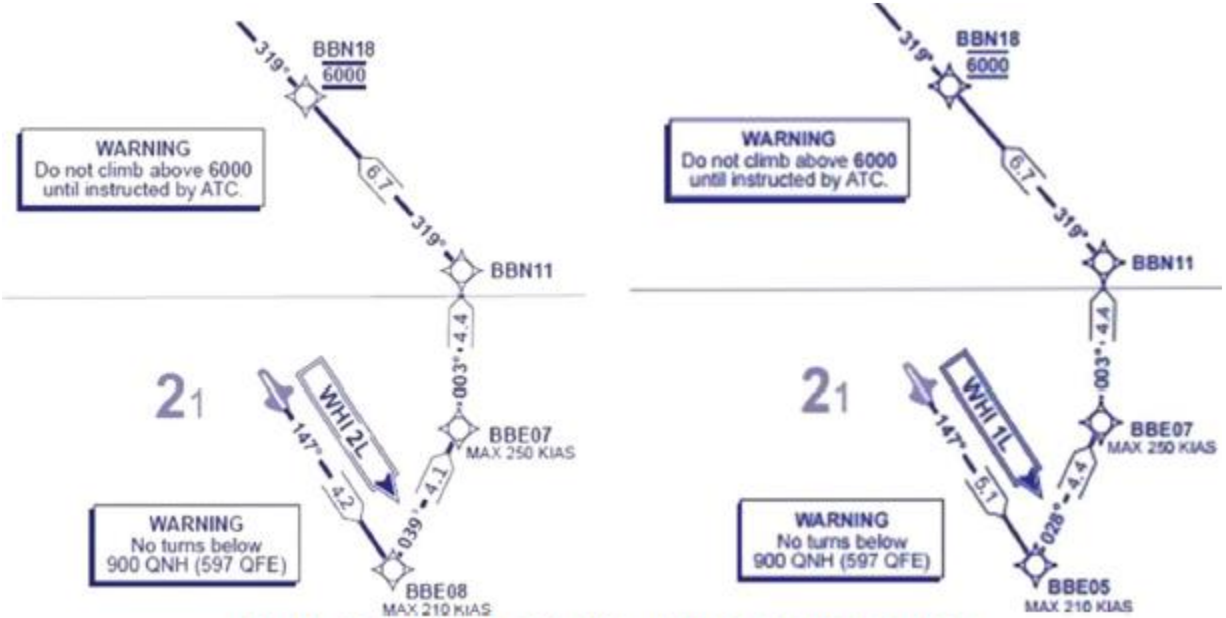


Fig. 13 RNAV 1 SID WHI 2L (left) and RNAV 1 SID WHI 1L (right).

Aircraft Noise – Regulation

- Monitor from society for future solutions
  - New cargo air routes, density, and aircraft types
- Regulation from ICOA, FAA, etc.
  - US Code of Federal Regulations (CFR) Title 14 Part 36
  - UAVs and **electric aircraft** solutions

ICAO Noise Standards[27]

Chapter	Year	Ch. 3 Margin	Types[28]
none	before	none	Boeing 707, Douglas DC-8
2	1972	~+16 dB	Boeing 727, McDonnell Douglas DC-9
3	1978	baseline	Boeing 737 Classic, MD-80
4 (stage 4)	2006	−10 dB	Airbus A320, Boeing 737NG, Boeing 767, Boeing 747-400
14 (stage 5)	2017–2020	−17 dB	Airbus A320, Airbus A320neo, Airbus A330, Airbus A350, A 757, Boeing 777, Boeing 787

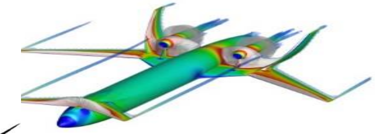
Aircraft noise pollution - Wikipedia

1. Introduction to the IEEE AESS Avionics Systems Panel	Rob (11:30)
2. Sustainable Aviation Challenges and Opportunities	Rob (11:50)
3. Aviation Noise Impact Assessment and Mitigation	Erik (12:10)
4. Evolving Technologies and R&I Agenda	Rob (12.30)
5. ATM and Flight Management Systems	Alex (12.50)
6. UTM, AAM and Trusted Automation	Alex (13.30)
7. Recent Advances in Surveillance Systems	Giancarmine (13.50)
8. High-Altitude and Sub-Orbital Flight Operations	Rob (14.10)
9. Concluding Remarks	All (14.20)

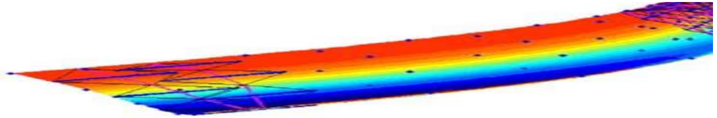
Evolving Technologies and R&I Agenda

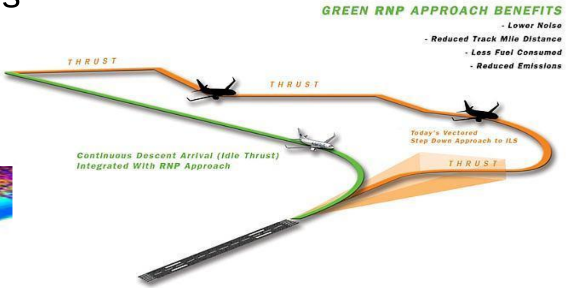
Aircraft Design & Operations

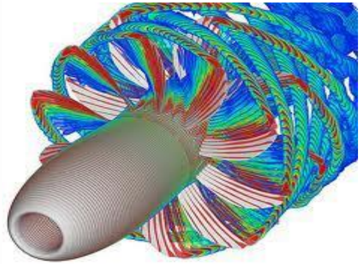
- ❖ **Weight reduction**
  - – Lighter materials and structures
  - – Use of composites and new metals to reduce mass
- ❖ **Aerodynamic gains**
  - – Novel aircraft design configurations and architectures (e.g., blended wing, box-wing, morphing wings, smart high-lift devices, boundary layer control)



- ❖ **Gaseous emissions reduction/offsetting**
  - – Novel propulsion systems (e.g., geared turbofan, open rotor, distributed and hybrid propulsion)
  - – Bio-fuels / Hydrogen / sustainable fuels
- ❖ **Noise mitigation**
  - – Flight paths / engines / aerodynamics







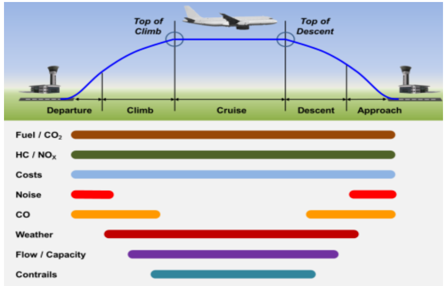
Aircraft Design & Operations

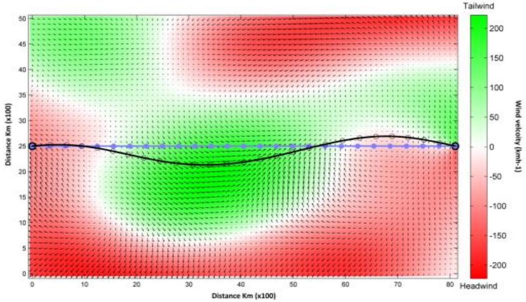
❖ Energy gains

- **Evolution of aircraft systems** to increase fuel economy and reduce off-take from engine
- On-board fuel system control and management of fuel efficiently
- Optimal choice of hydraulic, electrics and bleed-air as a source of power for systems actuation

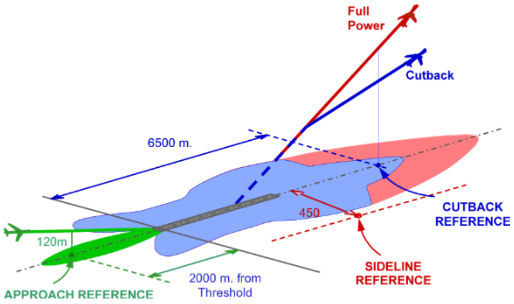
❖ Operational gains

- **Highly automated avionics systems** connected with ground-based CNS/ATM systems (CNS+A)
- **4D trajectory optimisation and flow management.** The future aircraft are “moving nodes” in a network with pilots and air traffic controllers providing high-level decision making
- **Aircraft Health Monitoring Systems** (AHMS), which use real-time data captured through various sensors integrated on aircraft parts to enhance operations/reliability and safety of the aircraft



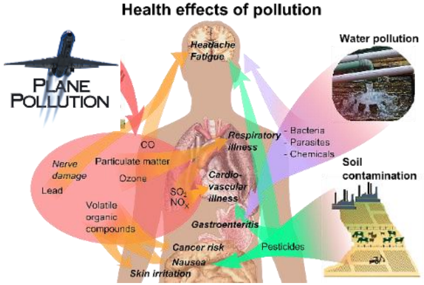


Airport Technologies and Operations



❖ Ongoing Measures

– Airport-level noise mitigations
– Air quality and climate change mitigations
– Water quality and wildlife impact mitigations



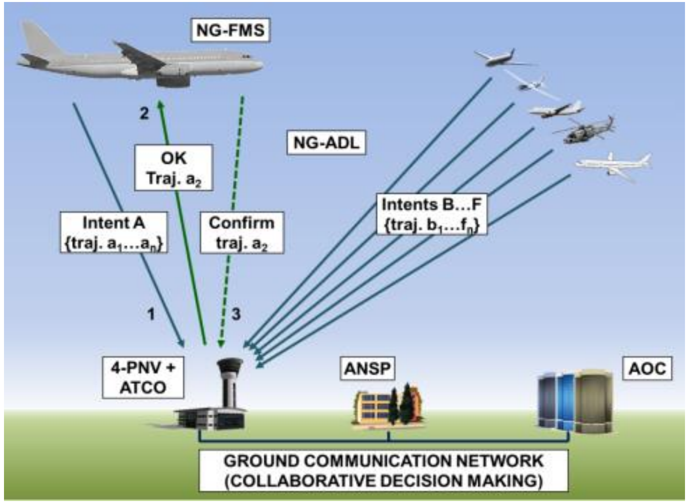
❖ Airport Multi-Modal Transformation

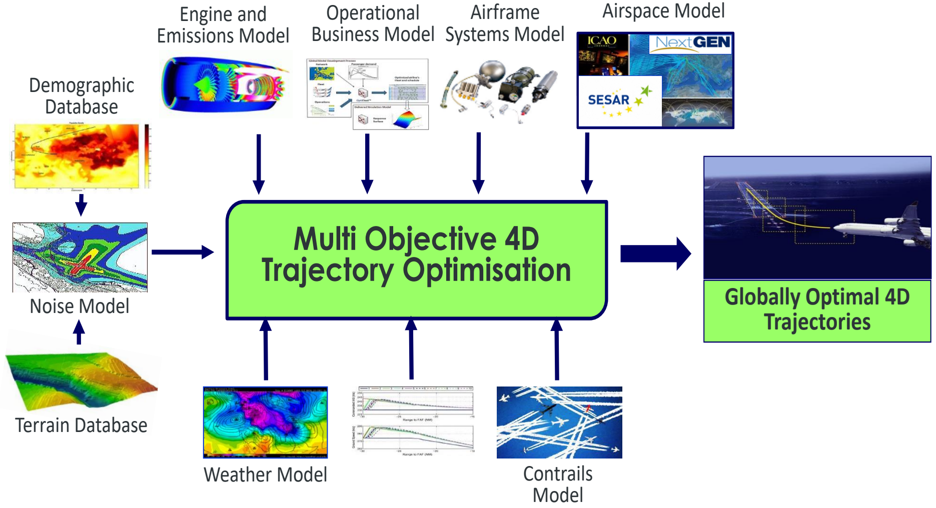
Maximising efficiency and sustainability by employing:

– Digital technology (intelligent automation)
– Interconnectivity with suburban/metropolitan rail
– High Speed Rail (HSR) connecting to farther cities
– Cargo interconnectivity (road, rail and maritime facilities)

ATM Technologies

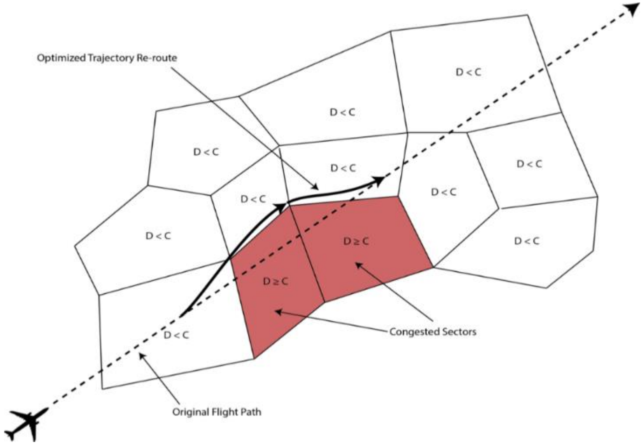
- **Development of innovative ATM Decision Support Systems (DSS)** to enable 4D-Trajectory (4DT) optimisation, negotiation and validation in the future ATM context
- **4DT Planning, Negotiation and Validation** (4-PNV) in synergy with Next Generation of Flight Management Systems (NG-FMS)

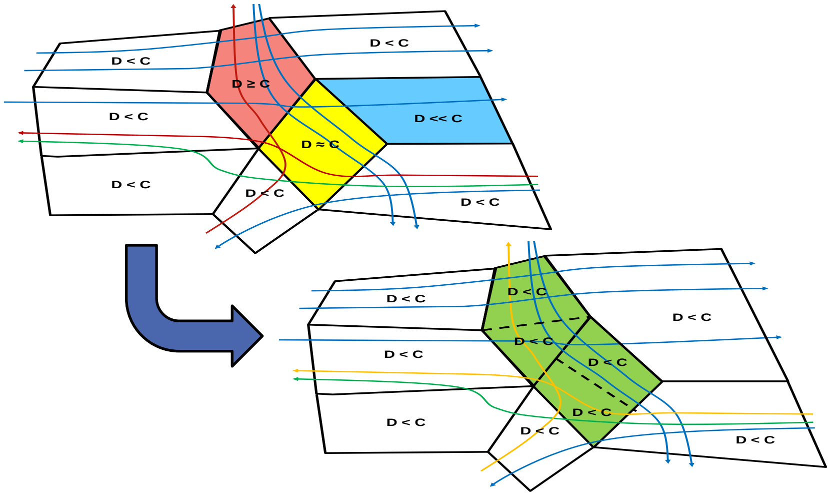




ATM Technologies

- In the near term, ATM systems will automatically validate aircraft intents by implementing **adequate separation assurance and time-based flow optimisation methods**
- In the longer term, DSS will evolve to allow **Dynamic Airspace Management** (DAM) with morphing techniques (e.g., dynamic geo-fencing) also supporting UAS Traffic Management (UTM) and Urban Air Mobility (UAM) operations





Developing a Coherent R&I Agenda

Fuel, Emissions and Noise Reduction Goals

	ACARE – SRA and SRIA (wrt 2000)		**NASA – ERA** (wrt 1998) **and SIP** (wrt 2005)					
Subsonic A/C Emissions	Vision 2020	**FlightPath 2050**	ERA 2015	ERA 2025	ERA 2035	SIP 2015-25	SIP 2025-35	**SIP >2035**
Fuel/CO_2	50% (38% 2015)	**75%**	50%	50%	60%	40-50%	50-60%	**60-80%**
NO_X	80% (----- 2015)	**90%**	75%	75%	80%	70-75% LTO* 60-70% CRZ	80%	**>80%**
Noise	50% (37% 2015)	**65%**	32dB	42dB	71dB	22-32dB**	32-42dB	**42-52dB**

ACARE - Advisory Council for Aviation R&I in Europe, **SRA** - Strategic Research Agenda, **SRIA** - Strategic Research and Innovation Agenda, **ERA** - Environmentally Responsible Aviation, **SIP** - Strategic Implementation Plan

A/C - Aircraft, **LTO** - Landing and Take/Off, **CRZ** - Cruise, ***Below CAEP6, ****Below Chapter 4. All % reductions are in Passenger-km

Fuel, Emissions and Noise Reduction Goals

	ACARE – SRA and SRIA (wrt 2000)		**NASA – ERA** (wrt 1998) **and SIP** (wrt 2005)					
Subsonic A/C Emissions	Vision 2020	**FlightPath 2050**	ERA 2015	ERA 2025	ERA 2035	SIP 2015-25	SIP 2025-35	**SIP >2035**
Fuel/CO_2	50% (38% 2015)	**75%**	50%	50%	60%	40-50%	50-60%	**60-80%**
NO_X	80% (----- 2015)	**90%**	75%	75%	80%	70-75% LTO* 60-70% CRZ	80%	**>80%**
Noise	50% (37% 2015)	**65%**	32dB	42dB	71dB	22-32dB**	32-42dB	**42-52dB**

Cooperation Opportunities

ACARE - Advisory Council for Aviation R&I in Europe, **SRA** - Strategic Research Agenda, **SRIA** - Strategic Research and Innovation Agenda, **ERA** - Environmentally Responsible Aviation, **SIP** - Strategic Implementation Plan

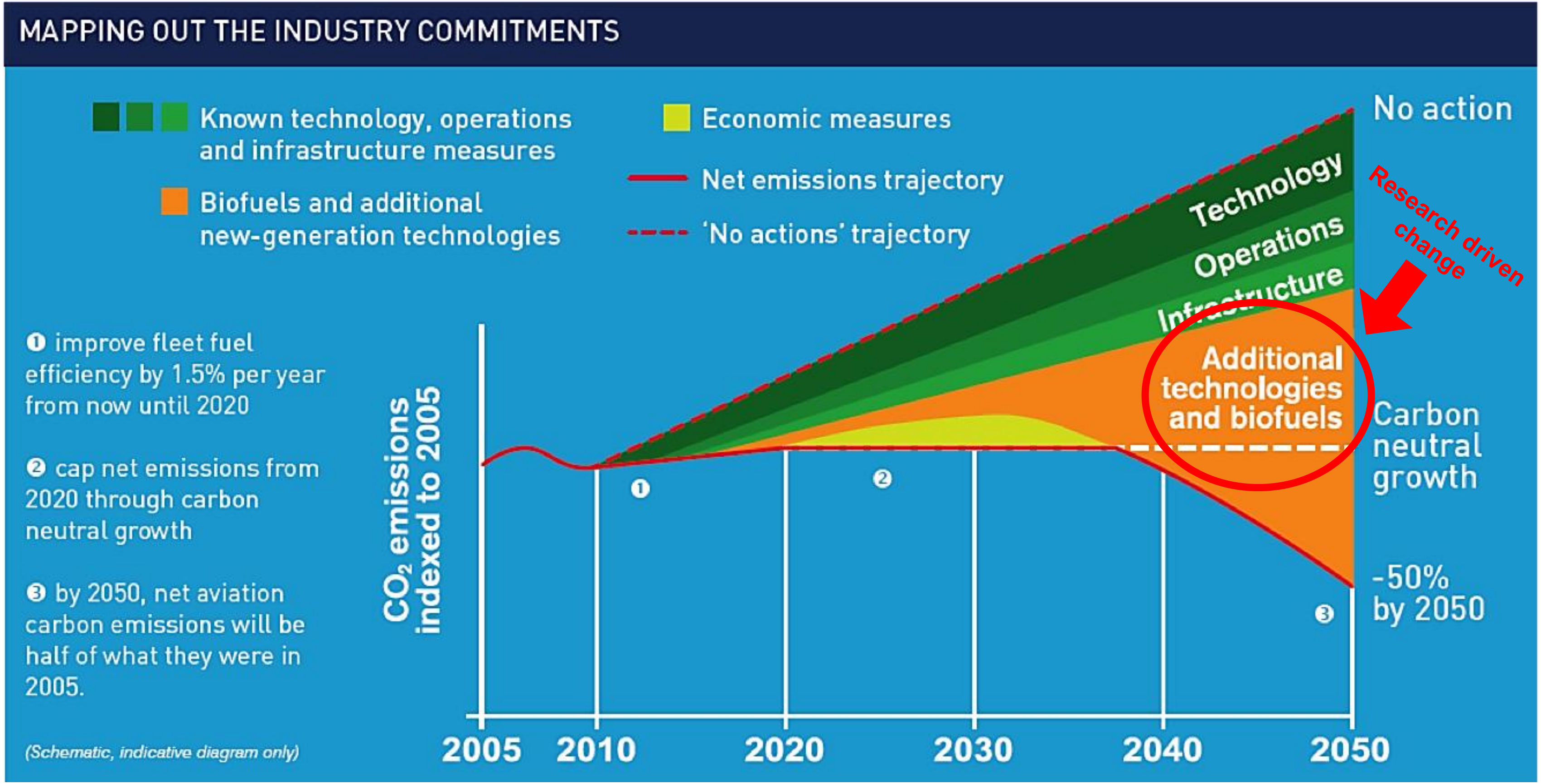
A/C - Aircraft, **LTO** - Landing and Take/Off, **CRZ** - Cruise, *Below CAEP6, **Below Chapter 4. All % reductions are in Passenger-km

Current R&I Priorities

- **Grand Challenge:** Enhancing aviation environmental sustainability (along with efficiency, safety and security) in times of increasing air transport demand

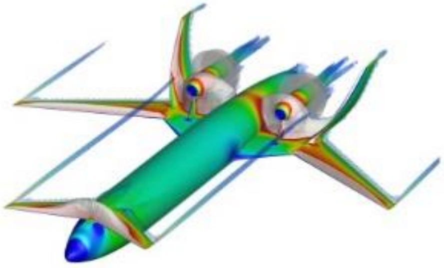
- **Priority Areas**
  - Development and rapid uptake of low emission technologies and alternative aviation fuels
  - ATM Communications, Navigation, Surveillance (CNS) and Avionics (A) Systems (CNS+A)
  - Cost-effective through-life support of new/ageing aircraft
  - Airport efficiency/capacity and multi-modal transformation
  - Automation/autonomy and cyber-physical security

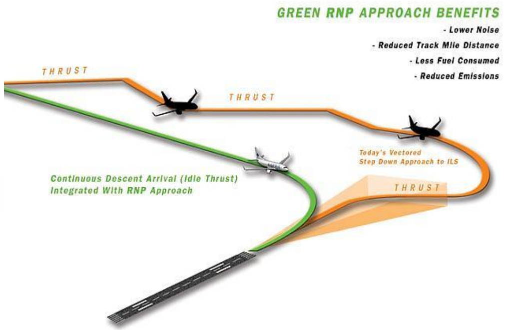
Reverting the CO_2 emission trends



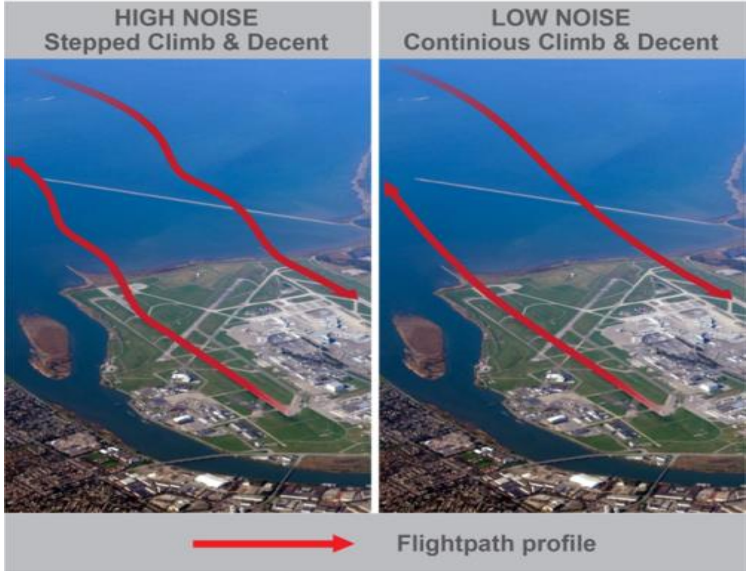
R&I Areas of Focus

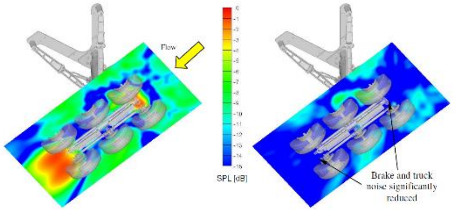
- **Science**
  - Assessing aviation environmental impacts
  - Forecasting, modelling and analysis
- **Technology and Operations**
  - Aerodynamics and propulsive technologies
  - Flight operations, avionics and air traffic management
  - Airport design, upgrade and operations
  - Advanced manufacturing and logistics
- **Policy and Regulations**
  - Sustainability policies for aviation
  - Greenhouse/noise limiting standards
  - Technology uptake and certification

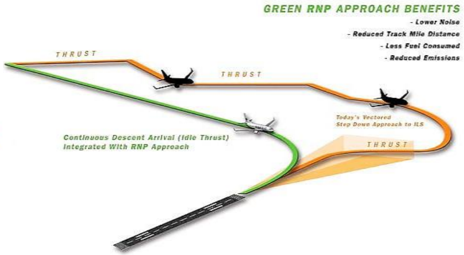


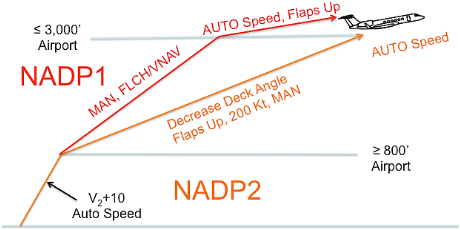


Aircraft Design & Operations

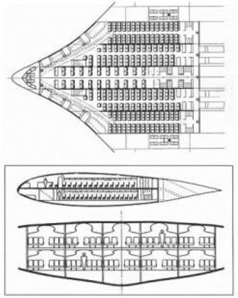






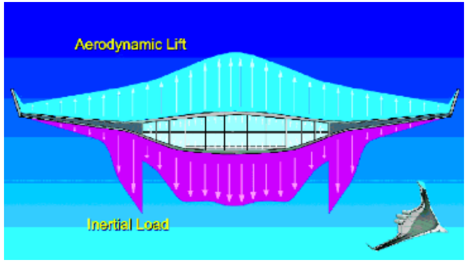


Blended Wing Body Aircraft



- Increased seating capacity
- Up to 800 per flight

- 20% increased L/D ratio
- More uniform lift distribution



- Reduced induced and parasite drag
- 27% reduction in fuel burn
- Various propulsive configurations
- Noise reduction due to fuselage obstruction

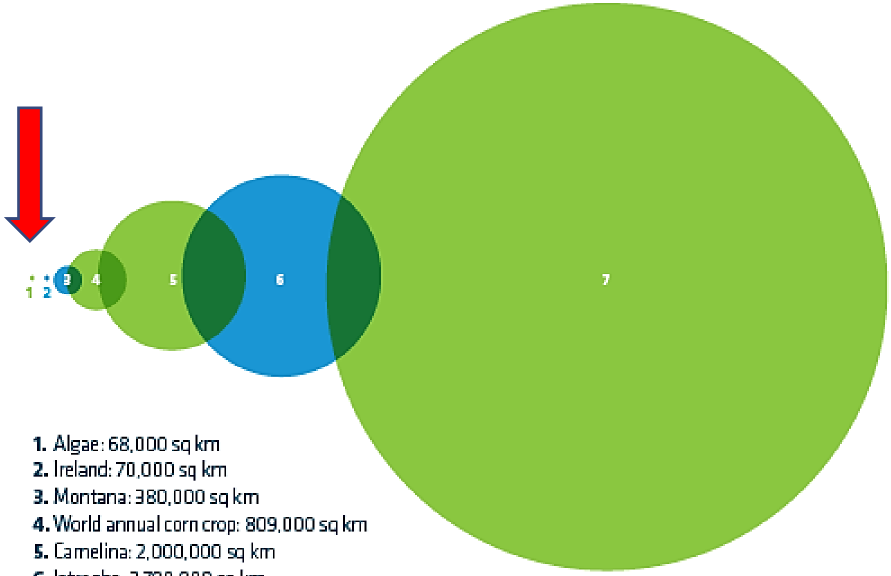
- Lighter structure (15% weight saving compared to current aircraft)
- Greater structural efficiency due to fuselage thickness
- Increase cargo and fuel capacity

Challenges include:

- Latero-directional stability and flight control systems design
- Distributed and hybrid propulsion system management
- Certification and airport compatibility
- Problematic spin characteristics
- Low-speed handling qualities
- Passenger satisfaction

Aviation Bio-Fuels

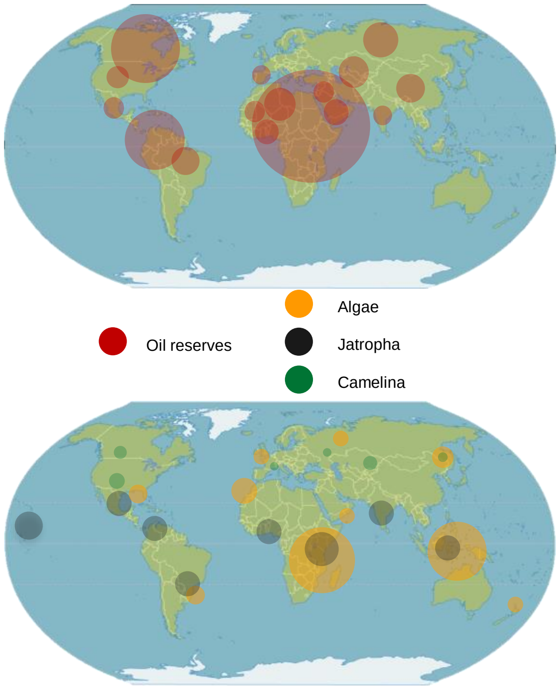
Land area equivalents required to produce enough fuel to completely supply the aviation industry



1. Algae: 68,000 sq km
2. Ireland: 70,000 sq km
3. Montana: 380,000 sq km
4. World annual corn crop: 809,000 sq km
5. Camelina: 2,000,000 sq km
6. Jatropha: 2,700,000 sq km
7. Australia: 7,617,930 sq km

These diagrams represent a conservative estimate of the amount of land that would be needed to completely replace the amount of traditional jet fuel currently used with just one of these sources (as well as a comparison with different land areas).

It is unlikely that aviation will rely on just one type of biofuel, so a combination of these and other sources will be used.



Airport Technologies and Operations

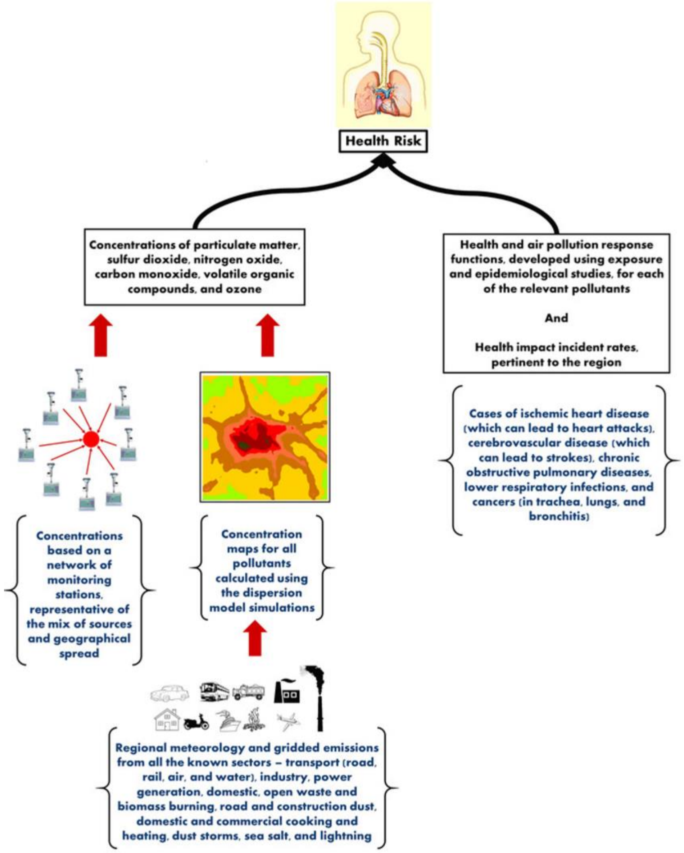
❖ Air quality and climate change mitigations

Measuring air quality and assessing impacts:

- Concentration-Response Functions (CRFs), taking into account concentration levels and exposure times to observe health response (e.g,, epidemiological studies)
- Air pollution sensors (ground/airborne) and emission models
- Computer models for emission and dispersion (e.g., ICAO, FAA, Eurocontrol and UK DoT)

Possible mitigations:

- Operational procedures (e.g., APU use limitations, restrictions on engine run-up for test, restrictions on thrust reverse)
- Airport authority policies (e.g., cleaner ground transportation, high-occupancy, hybrid and electric vehicles)
- Emission charges



Current and Emerging Social Challenges

Industry Growth and Workforce Development

- The global aviation industry is projected to grow at a very fast pace in the coming decade
- Introduction of unmanned aircraft for various roles
- Inception of Urban Air Mobility (UAM) and Regional Air Mobility (RAM)
- Increased activity in the defense context and in the high-speed/suborbital space transport sector
- U-Space 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.)
- Education requirements on avionics systems continue to evolve at an impressive rate

Current Challenges

- **Lack of political consensus on climate change mitigation measures.** Several nations did not ratify the Kyoto Protocol (e.g., USA, Canada, Russia and New Zealand), which is now obsolete

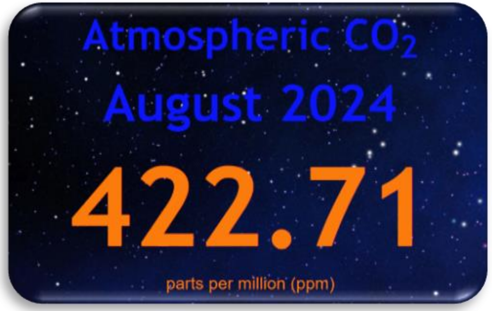
- Most nations ratified the Paris Agreement, but there is debate about the effectiveness of the agreement, and the pledges made seem inadequate to achieve the set goal. The USA withdrew from the agreement in 2020 and rejoined in 2021

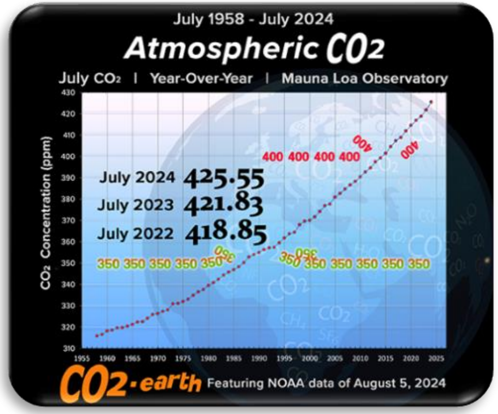
- The *Jevons paradox* is often used to support the argument that novel aviation technologies and operations will not be able to contribute "significantly" to reversing climate change

- In economics, the *Jevons paradox* is the proposition that **technological progress that increases the efficiency by which a resource is used tends to increase (rather than decrease) the rate of consumption of that resource**

- So improvements to engine/fuel efficiency, reflected by lower fares, will eventually produce not less emissions… but more!

- With this approach, most current efforts (from any unsustainable industry) would not be worthwhile. Why should we improve the thermal efficiency of our houses or the fuel consumption of our cars?





http://co2now.org

The Paris Agreement has a long-term temperature goal which is to keep the rise in global surface temperature to well below 2 °C (3.6 °F) above pre-industrial levels.

Emerging Challenges

- ❖ Lack of international cooperation and possible R&D funding reduction
- ❖ Diminishing returns on investment for non-disruptive technology solutions
- ❖ Reduced community engagement and influence of non-government organizations (e.g., “green” lobby groups)
- ❖ Effects of anti-globalization and separatism initiatives (e.g., trade wars)
- ❖ Evolving geopolitical challenges
  - Political instability and terrorism threats
  - Ongoing conflicts in the Middle East and Ukraine
  - South China Sea border disputes (including airspace)

Avionics Education and Training

Avionics System Design

- Design of Safety Critical Aerospace Systems
- Design of CNS/ATM Systems
- Avionics and Payload Integration
- Human Factors Engineering/Mission Systems

CNS/ATM Systems

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

Unmanned Aircraft Systems

- Autonomous Systems Guidance & Control
- UAS Traffic Management
- UAS Airspace Integration Technologies
- Alternative PNT Systems
- UAS Design, Test and Evaluation

Avionics Software and Cyber Security

- Software Design and Certification
- Avionics and CNS/ATM Cyber Security
- Cyber Security for Embedded Systems
- Software for IMA and Multi-Core Systems
- Agile and DevOps for Avionics Systems

ASP

AESS IEEE Aerospace & Electronic Systems Society

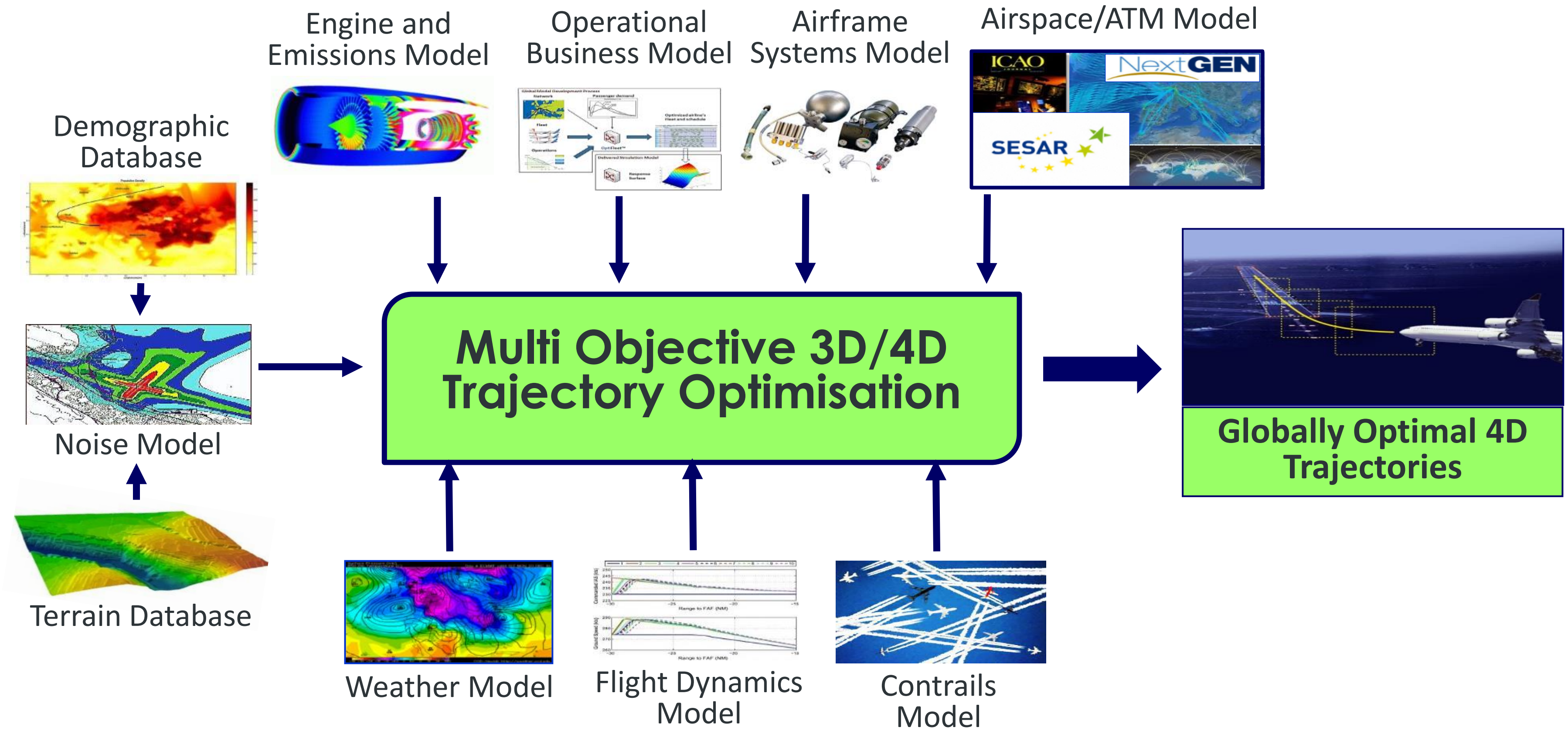
I. Majid, R. Sabatini, K. A. Kramer, E. Blasch, G. Fasano, G. Andrews, C. Camargo, A. Roy, “Restructuring Avionics Engineering Curricula to Meet Contemporary Requirements and Future Challenges.” IEEE Aerospace and Electronic Systems Magazine, Vol. 36, No. 4, pp. 46-58, April 2021.

R. Sabatini and A. Gardi (Editors), “Sustainable Aviation Technology and Operations: Research and Innovation Perspectives.” Aerospace Series, John Wiley & Sons, Chichester, 2023

1. Introduction to the IEEE AESS Avionics Systems Panel	Rob (11:30)
2. Sustainable Aviation Challenges and Opportunities	Rob (11:50)
3. Aviation Noise Impact Assessment and Mitigation	Erik (12:10)
4. Evolving Technologies and R&I Agenda	Rob (12.30)
5. ATM and Flight Management Systems	Alex (12.50)
6. UTM, AAM and Trusted Automation	Alex (13.30)
7. Recent Advances in Surveillance Systems	Giancarmine (13.50)
8. High-Altitude and Sub-Orbital Flight Operations	Rob (14.10)
9. Concluding Remarks	All (14.20)

ATM and Flight Management Systems

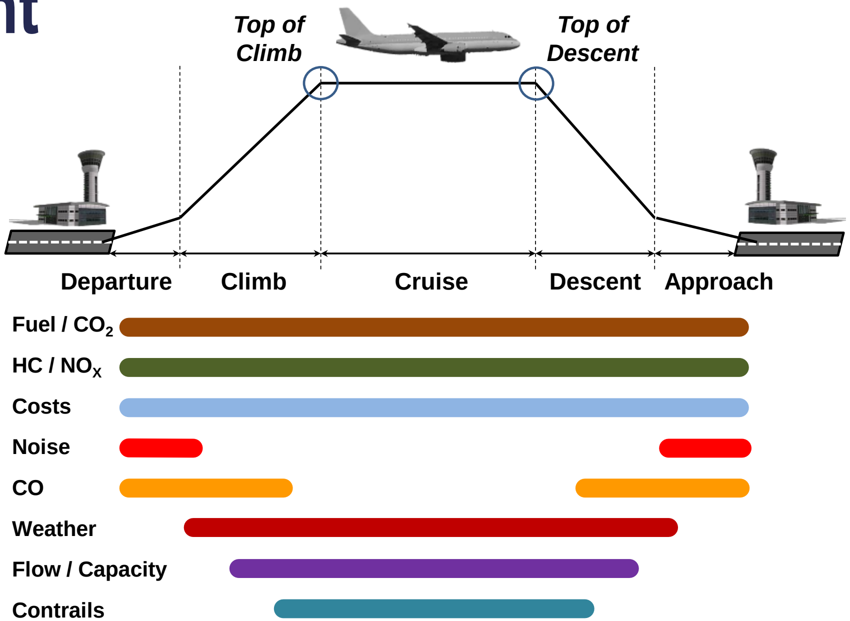
Multi-Objective Trajectory Optimisation Concept



Environmental Impacts in Flight

- Carbon Oxides (CO_X)
- Nitrogen Oxides (NO_X)
- Sulphur Oxides (SO_X)
- Unburned Hydro-Carbons (UHC)
- General Expressions:

  (HBR Turbofan Engines)



$$GP = \int_{t_0}^{t_f} EI_{GP} \cdot FF \, dt \quad [\mathrm{Kg}]$$

$$FF = \max \left[\underbrace{\tau \cdot C_{f1} \cdot \left(1 + \frac{v_{TAS}}{C_{f2}}\right)}_{\text{High throttle}}, \quad \underbrace{C_{f3} \cdot \left(1 - \frac{H_P}{C_{f4}}\right)}_{\text{Idle throttle}} \right]$$

MOTO-4D – ATM DSS/FMS Design Requirements

- Efficient optimisation and negotiation
  - Shared dynamic models
  - Synchronisation of states, constraints, optimality criteria and 4DT predictions

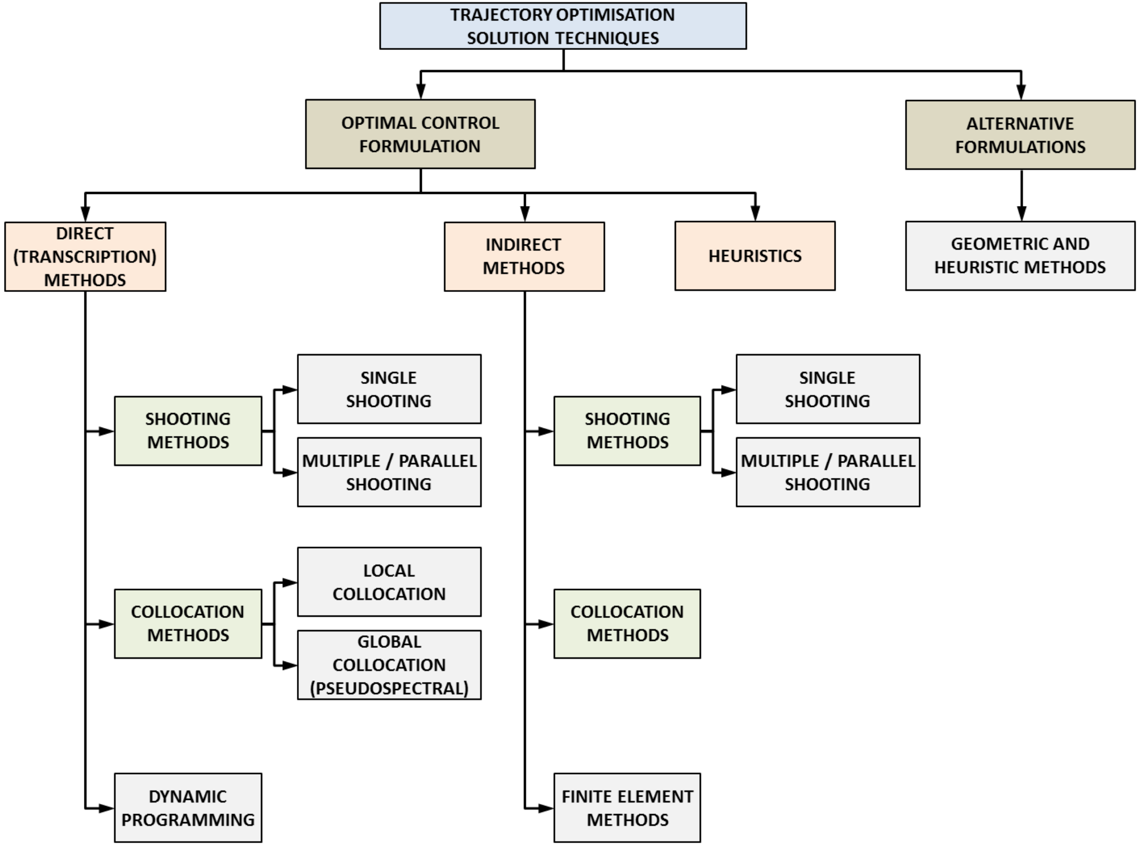
  } mathematical consistency of the 4D-TOP

  - Standardised 4DT descriptors & transmission protocols/formats
  - Intent prioritisation
  - Fair scheduling principle

  } global optimality

- Robust and efficient validation
  - Reliable conflict identification algorithms, assessing mandatory separation minima (vertical, horizontal and longitudinal) for both traffic and obstacles
  - Continuous assessment of path constraints fulfilment

Review of Solution Approaches



Optimal Control Formulation – Theoretical Framework

- Purpose: identify the trajectory that minimises a predefined performance index, subject to dynamics and path constraints, while adhering to boundary conditions
- Optimality criteria (cost function in the Bolza form):

$$J_i = \underbrace{\int_{t_0}^{t_f} \mathcal{L}_i(\boldsymbol{x}(t), \boldsymbol{u}(t), t)}_{\text{Lagrange term}} \, dt + \underbrace{\Phi_i(\boldsymbol{x}(t_f), \boldsymbol{u}(t_f), t_f)}_{\text{Mayer term}}$$

t: time
$\boldsymbol{x}$: states
$\boldsymbol{u}$: controls

- Dynamic constraints:

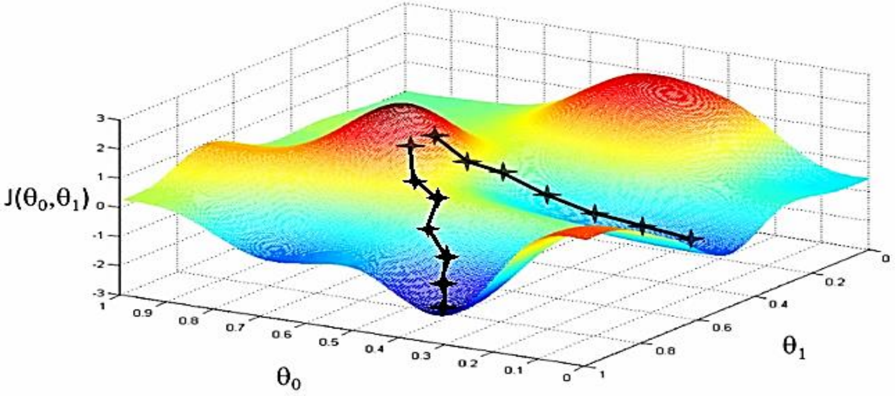
$$\dot{\boldsymbol{x}} = f(\boldsymbol{x}, \boldsymbol{u}, t), t \in [t_0, t_f]$$

- Path constraints:

$$\boldsymbol{C}_{min} \leq \boldsymbol{C}[\boldsymbol{x}(t), \boldsymbol{u}(t), t; \boldsymbol{p}] \leq \boldsymbol{C}_{max}$$

- Boundary conditions:

$$\boldsymbol{\Phi}_{min} \leq \boldsymbol{\Phi}[\boldsymbol{x}(t_0), \boldsymbol{x}(t_f), \boldsymbol{u}(t_0), \boldsymbol{u}(t_f); \boldsymbol{p}] \leq \boldsymbol{\Phi}_{max}$$



MOTO-4D – Aircraft Dynamics Model

- 3 Degrees of Freedom (3DoF) Aircraft Dynamics

$$\boldsymbol{u} = \begin{Bmatrix} \alpha \\ \beta \\ \mu \end{Bmatrix}$$

$$\tau = \begin{cases} \beta & if\ \beta > 0 \\ 0 & otherwise \end{cases}$$

$$\delta = \begin{cases} -\beta & if\ \beta < 0 \\ 0 & otherwise \end{cases}$$

$$\boldsymbol{x} = \begin{Bmatrix} v \\ \gamma \\ \chi \\ \phi \\ \lambda \\ z \\ m \end{Bmatrix} \quad \begin{cases} \dot{v} = \dfrac{g}{W}\,(T\cos\epsilon - D - W\sin\gamma) \\ \dot{\gamma} = \dfrac{g}{v\,W}\cdot[(T\sin\epsilon + N)\cos\mu - W\cos\gamma] \\ \dot{\chi} = \dfrac{g}{v\,W}\cdot\dfrac{(T\sin\epsilon + N)\sin\mu}{\cos\gamma} \\ \dot{\phi} = \dfrac{v\cos\gamma\sin\chi + v_{w_\phi}}{R_E + z} \\ \dot{\lambda} = \dfrac{v\cos\gamma\cos\chi + v_{w_\lambda}}{(R_E + z)\cos\phi} \\ \dot{z} = v\sin\gamma + v_{w_z} \\ \dot{m} = -FF \end{cases}$$

$$N = \frac{q \cdot S \cdot [(\alpha - \alpha_0)\cdot C_{L\alpha} + \alpha_F \cdot C_{LF}]}{m \cdot g}$$

$$C_{L\alpha} = \frac{2\pi}{1 + 2/AR}$$

$$T = \tau \cdot \left[C_{T1}\cdot\left(1 - \frac{z_{ft}}{C_{T2}} + C_{T3}\cdot {z_{ft}}^2\right)\cdot\left(1 - C_{T5}\cdot(\Delta T - C_{T4})\right)\right]$$

$$D = q \cdot S \cdot \left[C_{D0} + \left(C_{D2}\cdot {C_L}^2\right) + \delta \cdot \left(\frac{\partial\, C_{D0splr}}{\partial\,\delta}\right)\right]$$

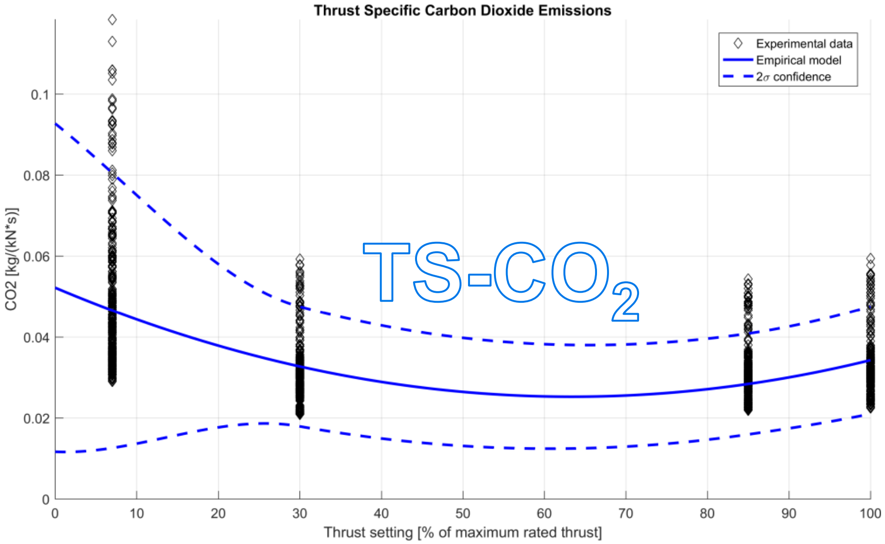
$\boldsymbol{x}(t)$

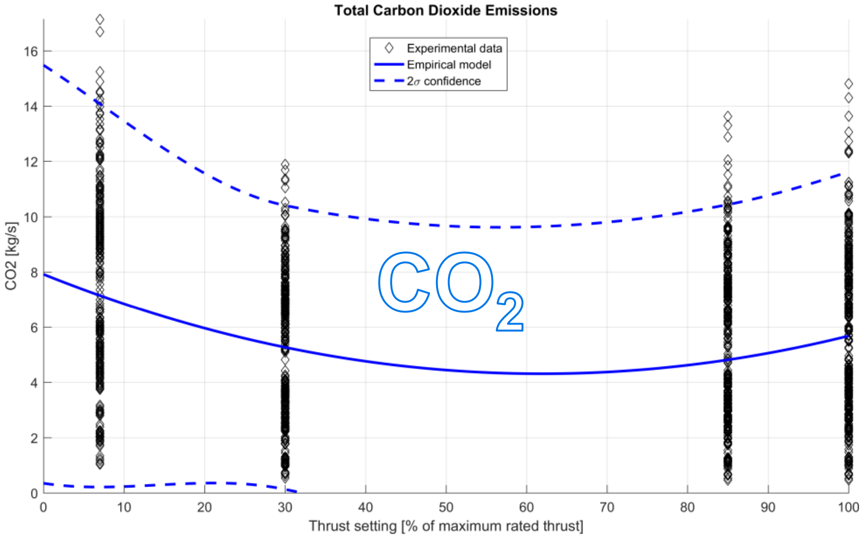
t: time

x: states

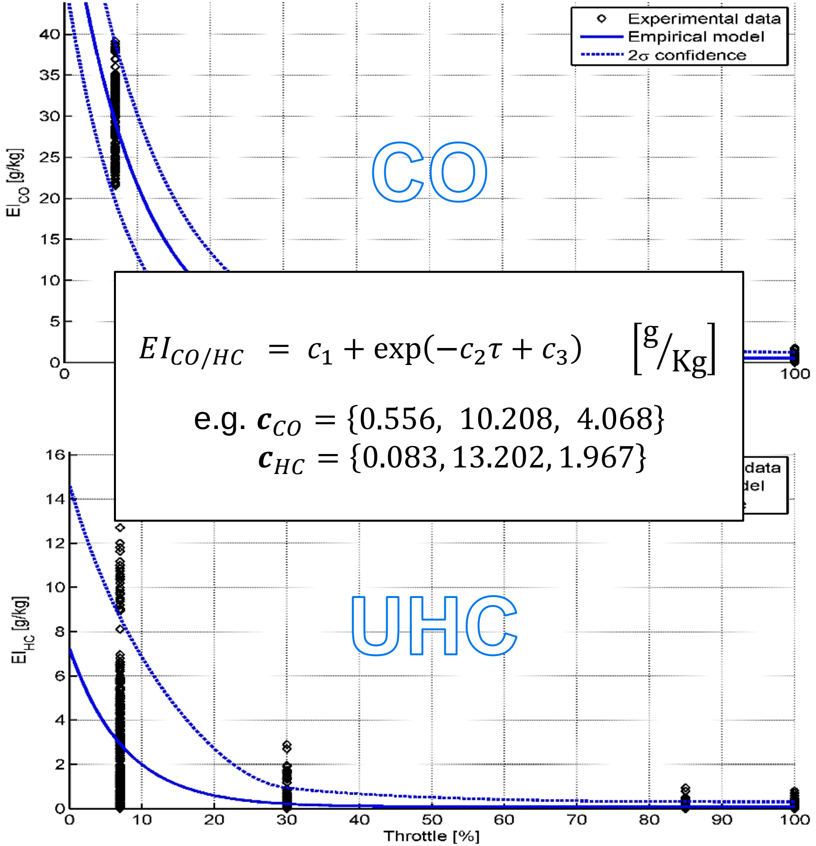
u: controls

MOTO-4D – Greenhouse Emission Models





MOTO-4D – Pollutant Emission Models

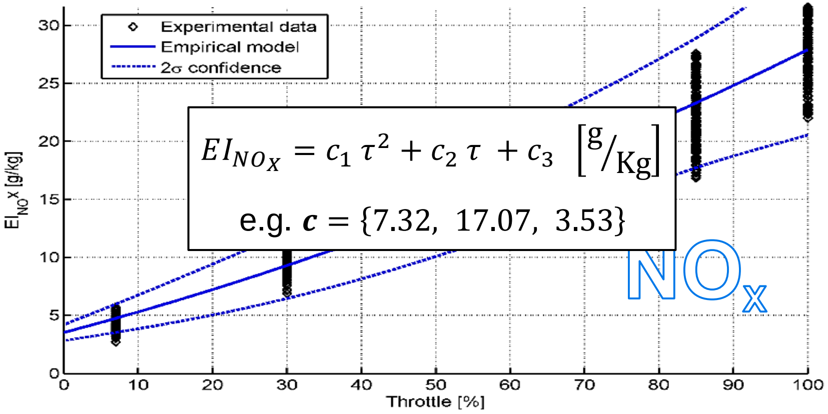


$$EI_{CO/HC} = c_1 + \exp(-c_2\tau + c_3) \quad [^{g}/_{Kg}]$$

e.g. $\boldsymbol{c}_{CO} = \{0.556,\ 10.208,\ 4.068\}$

$\boldsymbol{c}_{HC} = \{0.083, 13.202, 1.967\}$

- Emission models capturing dependence on throttle settings
- Aircraft-specific model coefficients
- 3DOF or 6DOF dynamics needed
- BADA models are adequate
- Can be applied as objective function to reduce emissions profile

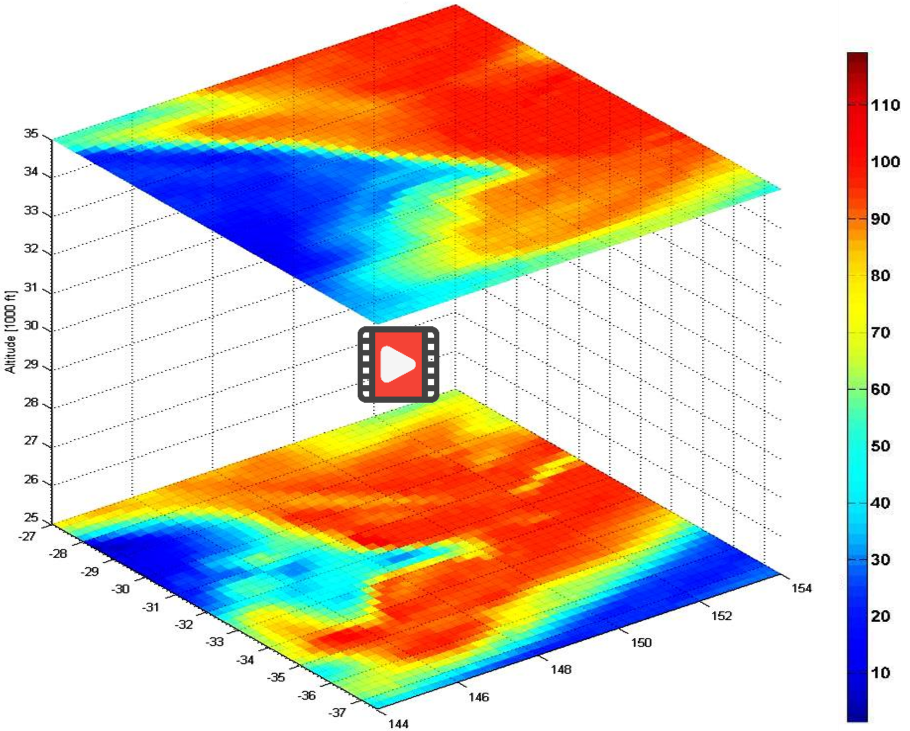


$$EI_{NO_X} = c_1\,\tau^2 + c_2\,\tau + c_3 \quad [^{g}/_{Kg}]$$

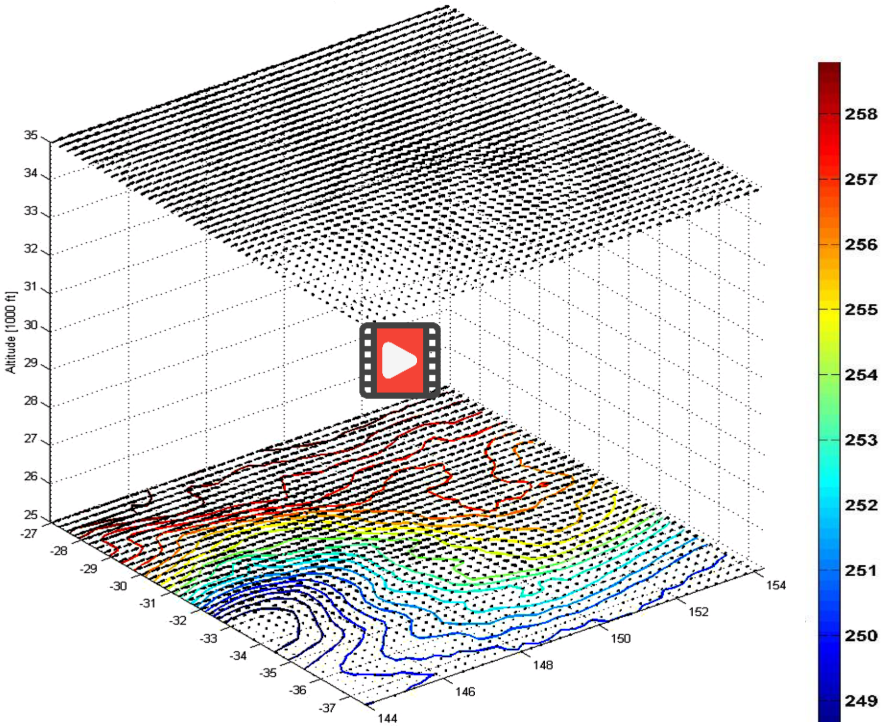
e.g. $\boldsymbol{c} = \{7.32,\ 17.07,\ 3.53\}$

MOTO-4D – Non-Standard Atmosphere and 4D Weather Model

Relative Humidity



Wind Velocity Vector and Temperature

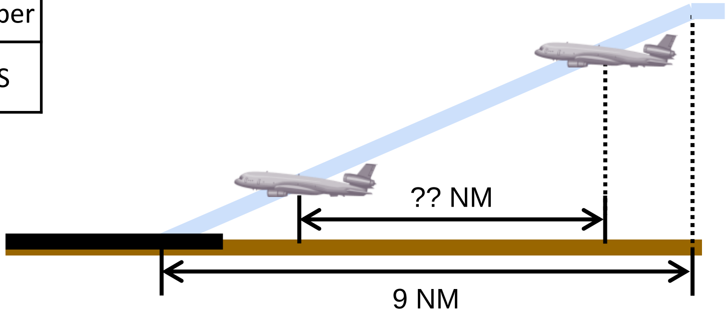


MOTO-4D – ATM Airport Capacity Model – Approach

Runway capacity model - arrivals

	Light	Medium	Heavy/Super
Approach Speed	115 KIAS	140 KIAS	165 KIAS

L \ T	Light	Med	Heavy	Super
Super	8 NM	7 NM	6 NM	3 NM
Heavy	6 NM	5 NM	4 NM	3 NM
Med	5 NM	3 NM	2.5 NM	.
Light	.	.	.	.



Wake turbulence + radar separation; reference: http://www.skybrary.aero/bookshelf/books/1166.pdf

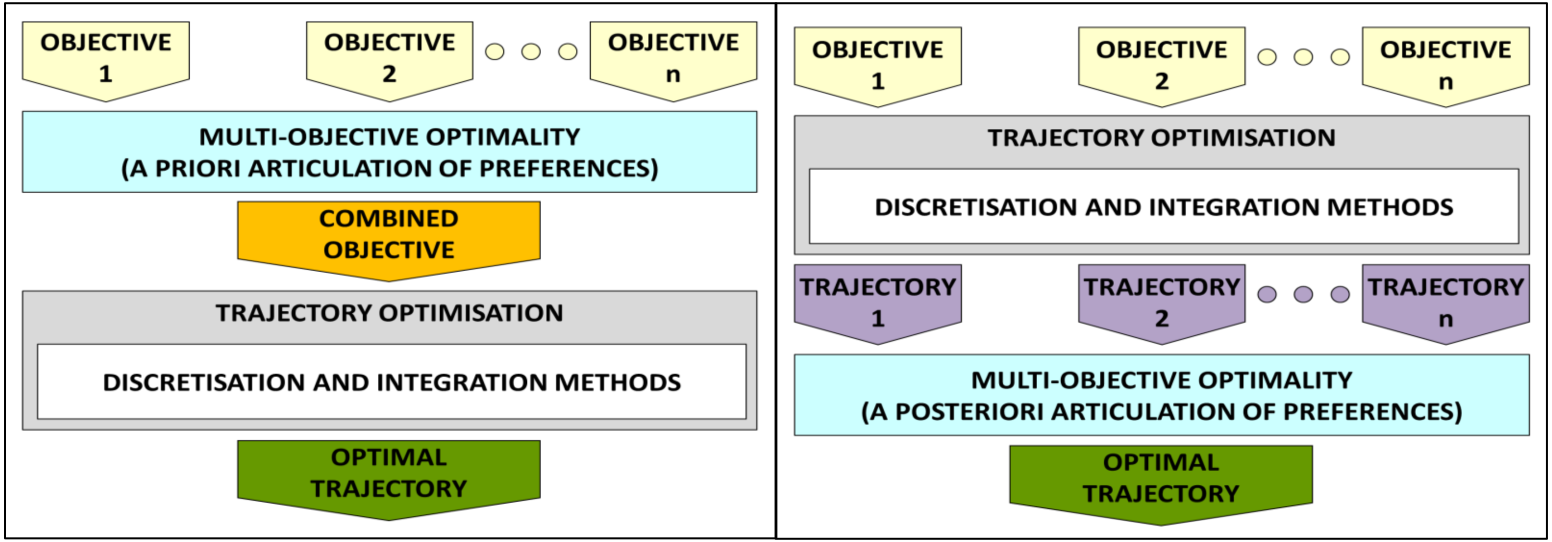
- $T_{i,j} = \max\left[\frac{r+s_{i,j}}{v_j} - \frac{r}{v_i},\ o_i\right]$ when $v_i > v_j$
- $T_{i,j} = \max\left[\frac{s_{i,j}}{v_j},\ o_i\right]$ when $v_i \leq v_j$

L \ T	Light	Med	Heavy	Super
Super	336 s	215 s	131 s	66 s
Heavy	273 s	164 s	87 s	66 s
Med	207 s	77 s	60 s	60 s
Light	78.3 s	60 s	60 s	60 s

Ref. de Neufville & Odoni, *Airport Systems – Planning, Design and Management*, McGraw-Hill

MOTO-4D – Multi-Objective Optimality

- *Articulation of preferences*: "***a priori***" versus "***a posteriori***"



- Other possibilities:
  - ***Progressive articulation of preferences***
  - ***No articulation of preferences***

MOTO-4D – Cost Function (Weighted Product)

$$J = (q_{time} + 1)^{w_{time}} \cdot (q_{fuel})^{w_{fuel}} \cdot (q_{CO})^{w_{CO}} \cdot (q_{NOx})^{w_{NO_X}}$$

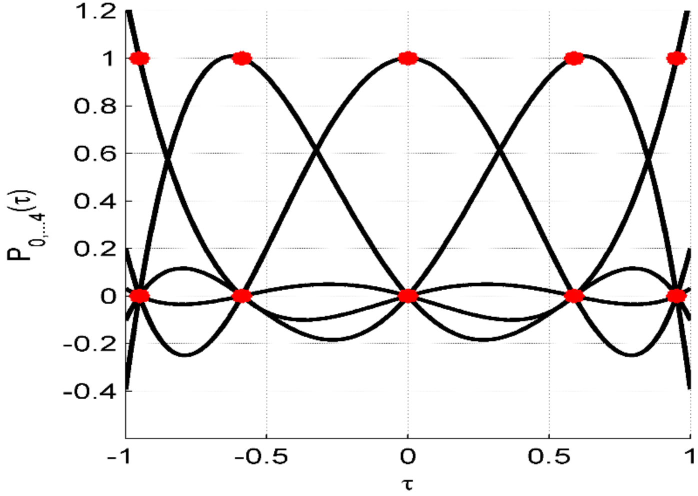
Time deviation → $(q_{time} + 1)$; Fuel usage → (q_{fuel}); CO/UHC → (q_{CO}); NO_x → (q_{NOx})

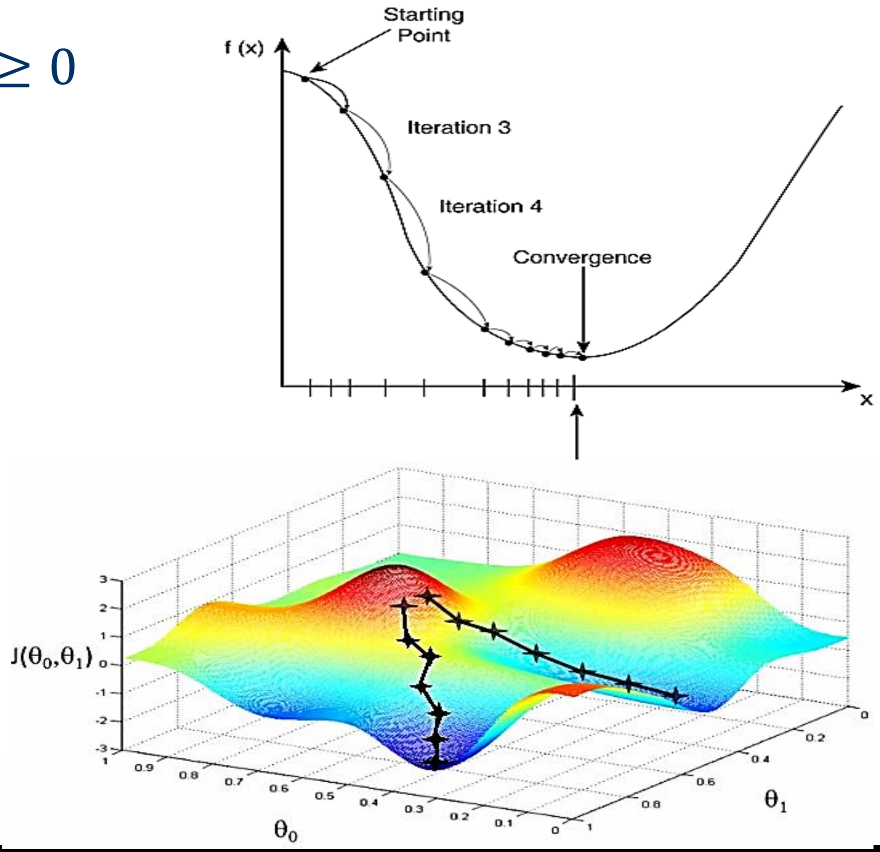
$$w_{time} + w_{fuel} + w_{CO} + w_{NO_X} = 6$$

Case	w_{time}	w_{fuel}	w_{CO}	w_{NOX}
1	6	0	0	0
2	5	1	0	0
…	…	…	…	…
73	0	0	0	6

MOTO-4D – Iterative Solution for Pseudospectral OCP

- Gradient-based methods:
  $$\boldsymbol{x}_{n+1} = \boldsymbol{x}_n - \gamma_n \nabla F(\boldsymbol{x}_n), \forall\, n \geq 0$$
- Pseudospectral transcription (global orthogonal collocation)

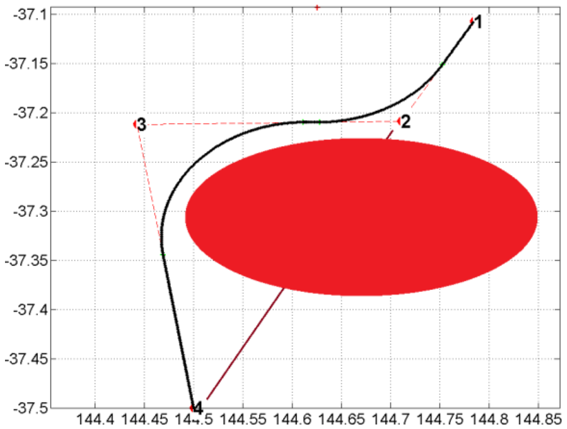


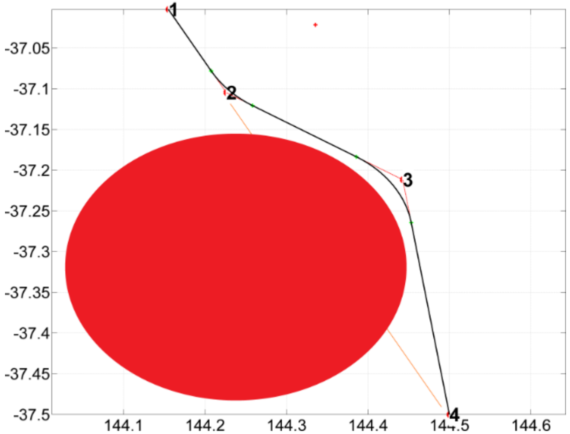


- Non-global convergence

MOTO-4D – Operational 4DT Smoothing

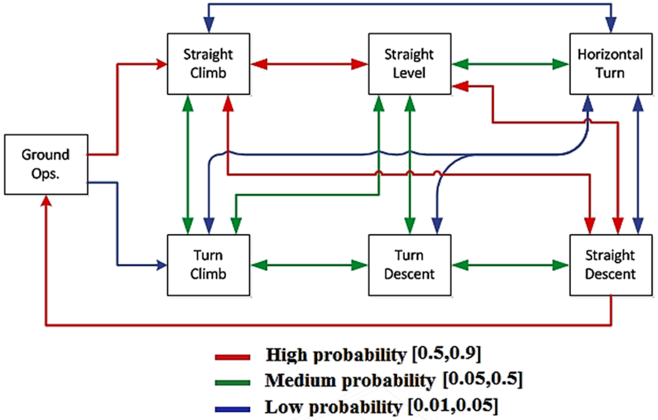
- The mathematically Continuous and Piece-Wise Smooth (CPWS) optimal 4DT generated by the MOTO algorithm must be processed into a sequence of segments that are flyable by human pilots and conventional autopilots
- The set includes straight and level segments, straight climbs and descent segments, level turns, and climbing/descending turns (both with constant radius)
- The result is further processed to be translated in a flight path concisely described by standard 4DT descriptors (using either real or virtual waypoints), **compliant with PBN/RNP standards**

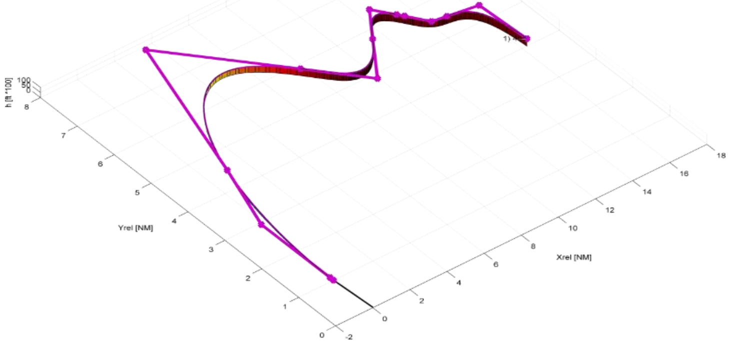




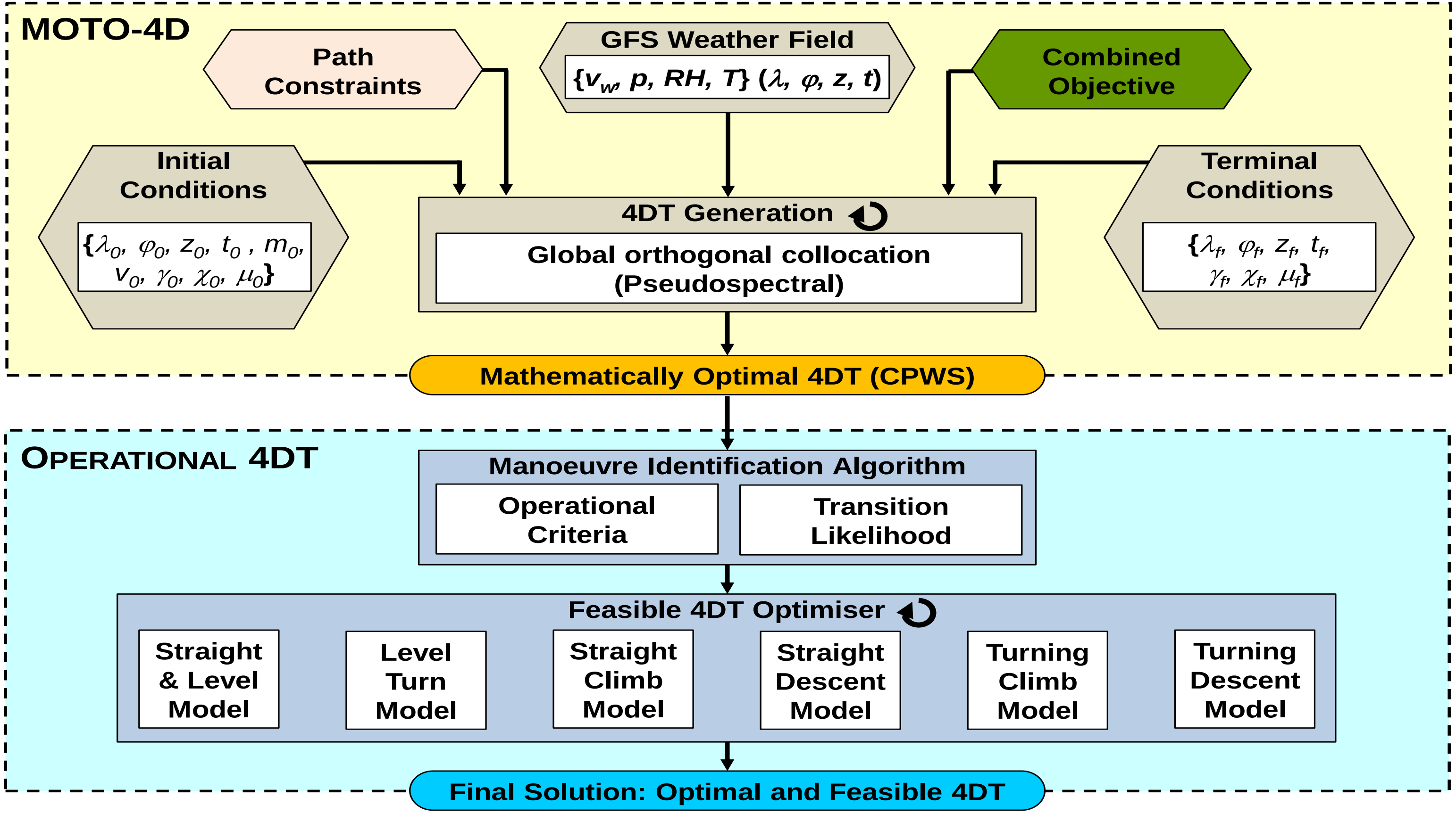
MOTO-4D – Manoeuvre Identification for 4DT Smoothing

Manœuvre Modes		Identification Criteria
GROUND OPERATIONS (GO)		Weight on wheels
STRAIGHT AND LEVEL (SL)		No Pitch/Bank Constant Altitude/Heading
HORIZONTAL TURN (HT)		No Pitch/Bank, Constant Altitude, Heading Variation
TURNING CLIMB (TC)		Pitch up, Altitude increase, Nonzero Bank, Heading Variation
STRAIGHT CLIMB (SC)	TAKE OFF	Positive FPA, No Bank, Flaps and/or Gear Down
	STRAIGHT CLIMB	No Bank, Positive FPA
TURNING DESCENT (TD)	CURVED APPROACH	Negative FPA, Nonzero Bank, Heading Variation, Flaps and/or Gear Down
	TURNING DESCENT	Negative FPA, Nonzero Bank, Heading Variation
STRAIGHT DESCENT (SD)	STRAIGHT APPROACH	No Bank, Constant Negative FPA, Constant Heading, Flaps and/or Landing Gear Down
	STRAIGHT DESCENT	No Bank, Negative FPA, Constant Heading

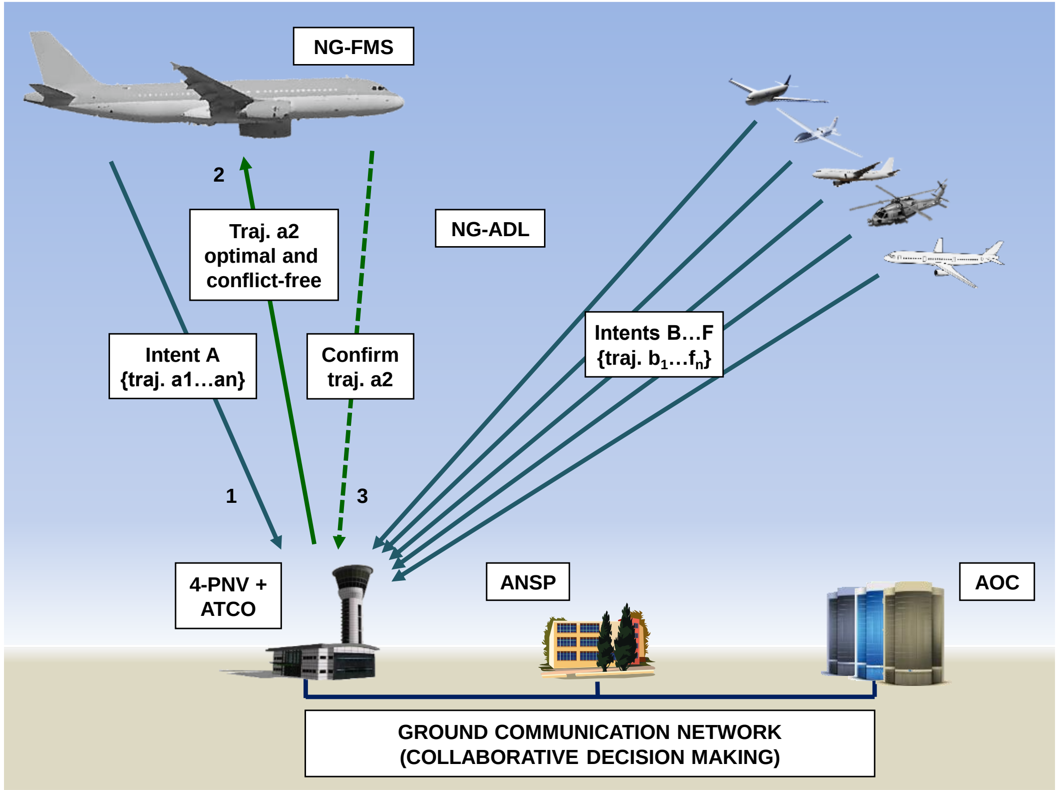




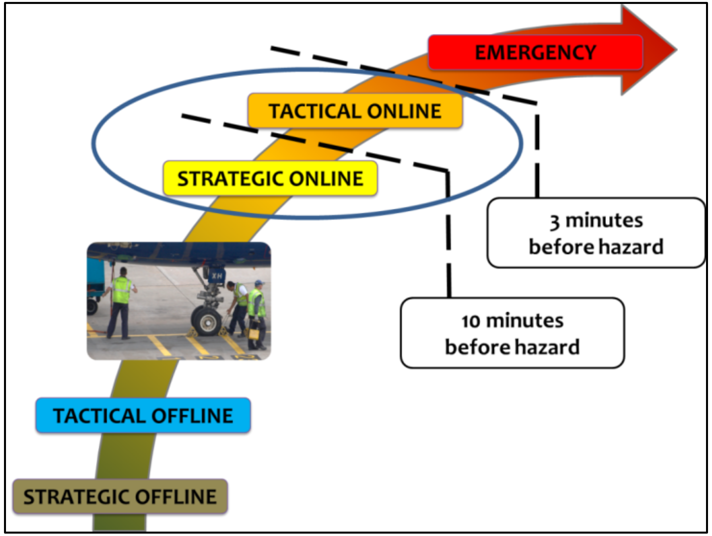
MOTO-4D – Online Tactical 4DT Planning Algorithm



System Implementation – 4-PNV Concept



4-PNV – Operational Timeframes



Strategic Online

- ❖ Suboptimal estimation due to long-term forecast
- ✓ More complex analysis and calculation algorithms due to the longer time available

Tactical Online

- ✓ Uncertainties have a very limited effect
- ❖ Limited time for the identification of a valid solution

4-PNV – Distributed MOTO-4D

The traffic flow optimisation problem:

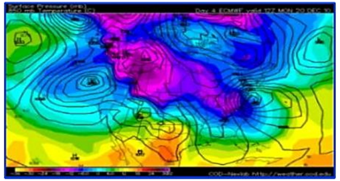
- ❖ Non-deterministic Polynomial Hard (NP-Hard)
- ❖ non-optimal substructure
- ✓ overlapping substructures

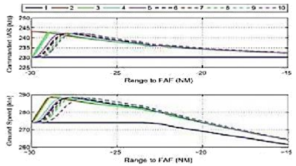
Dynamic Programming Approach

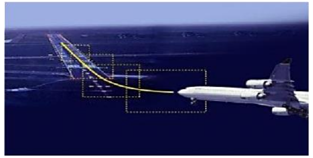
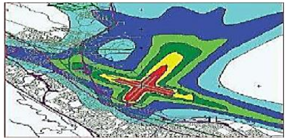
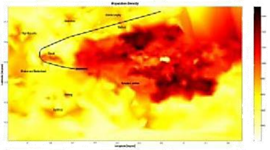
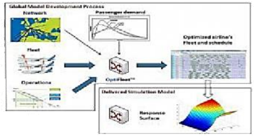
Combinatorial Optimisation

NG-FMS

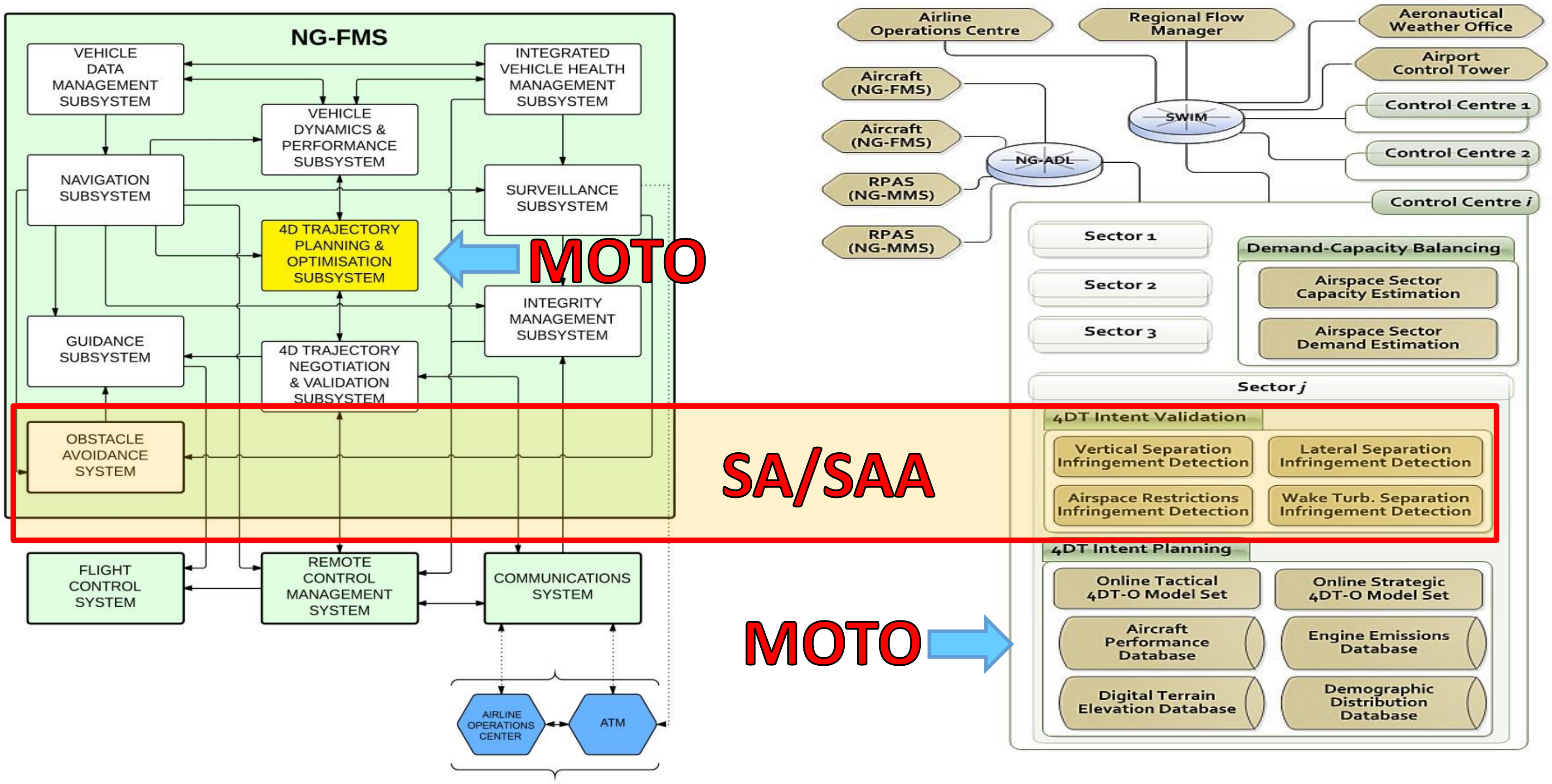
4-PNV





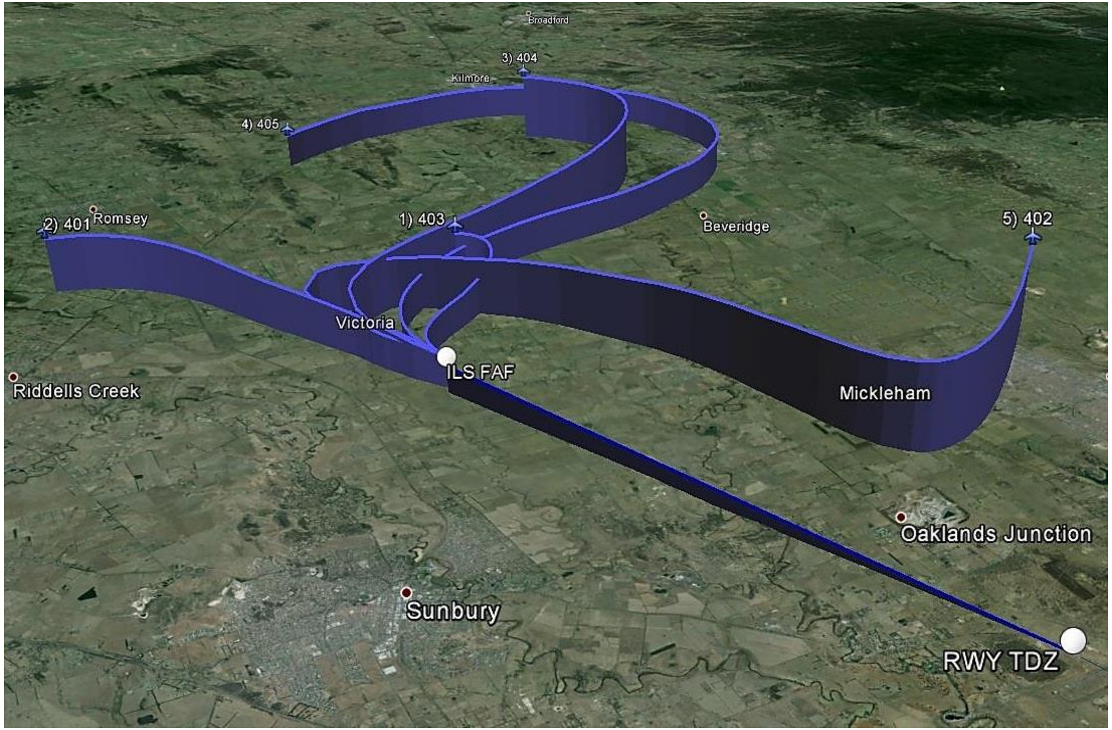

NG-FMS and 4-PNV (ATM DSS) Architecture



MOTO-4D for TMA – Preliminary Verification

Melbourne (RWY 16)

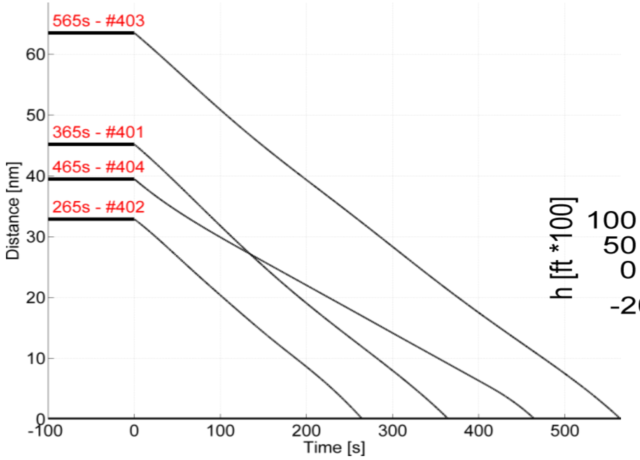
Initial position	Allocated arrival
S 38° 33' 15" E 144° 57' 30" 6851 ft	(1) 152 s
S 38° 33' 53" E 144° 58' 19" 5125 ft	(2) 242 s
S 38° 36' 37" E 144° 36' 58" 8511 ft	(3) 332 s
S 38° 30' 59" E 144° 33' 22" 8328 ft	(4) 422 s
S 38° 43' 8" E 144° 51' 2" 8916 ft	(5) 512 s

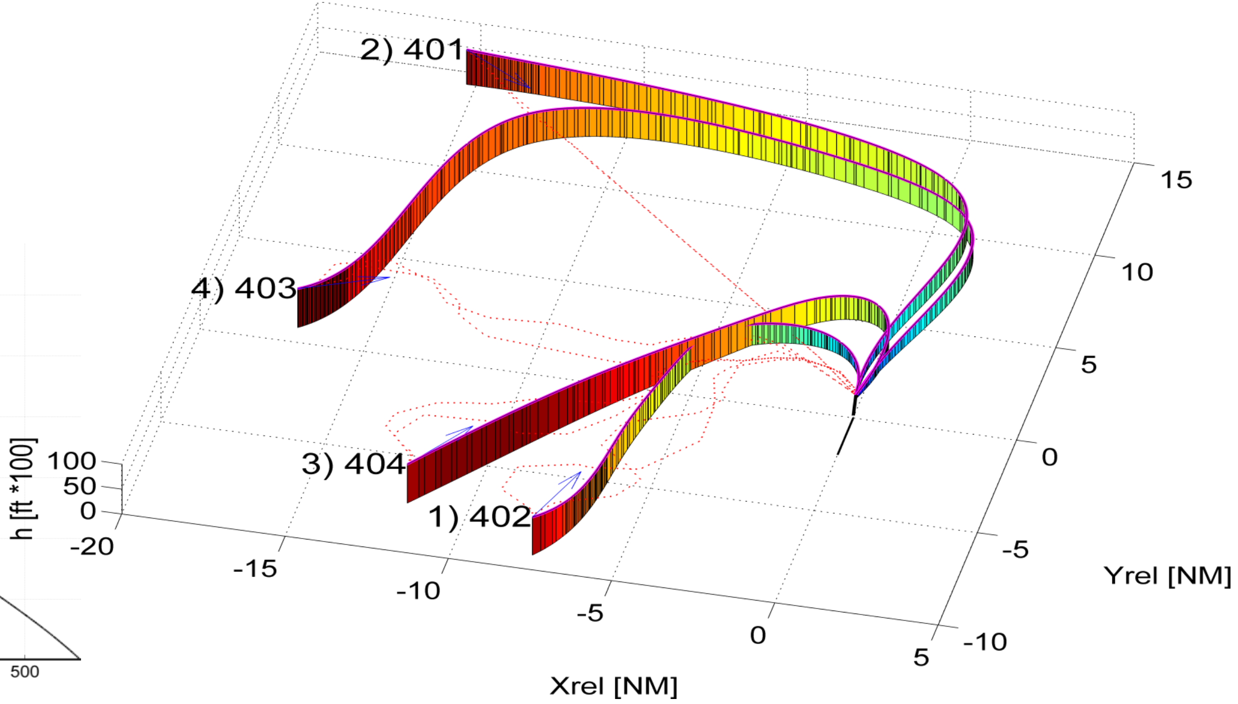


- Negotiation/Validation of all intents in less than 180 sec (167 sec)

MOTO-4D for TMA – Verification (Without 4DT Smoothing)

- Optimal Sequencing of 4 arrivals using GNSS



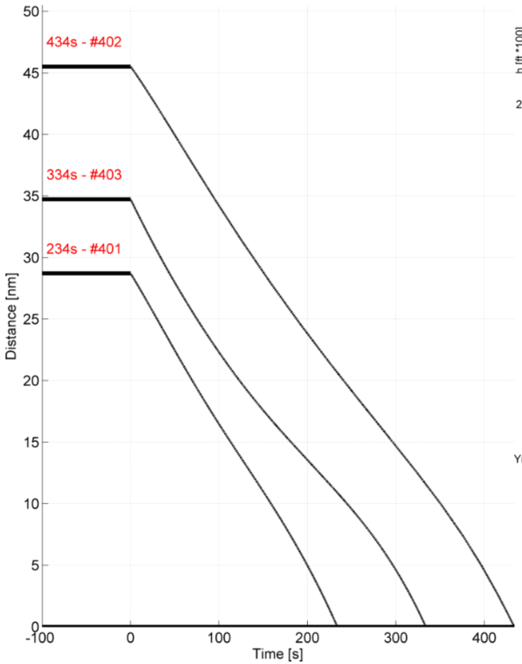


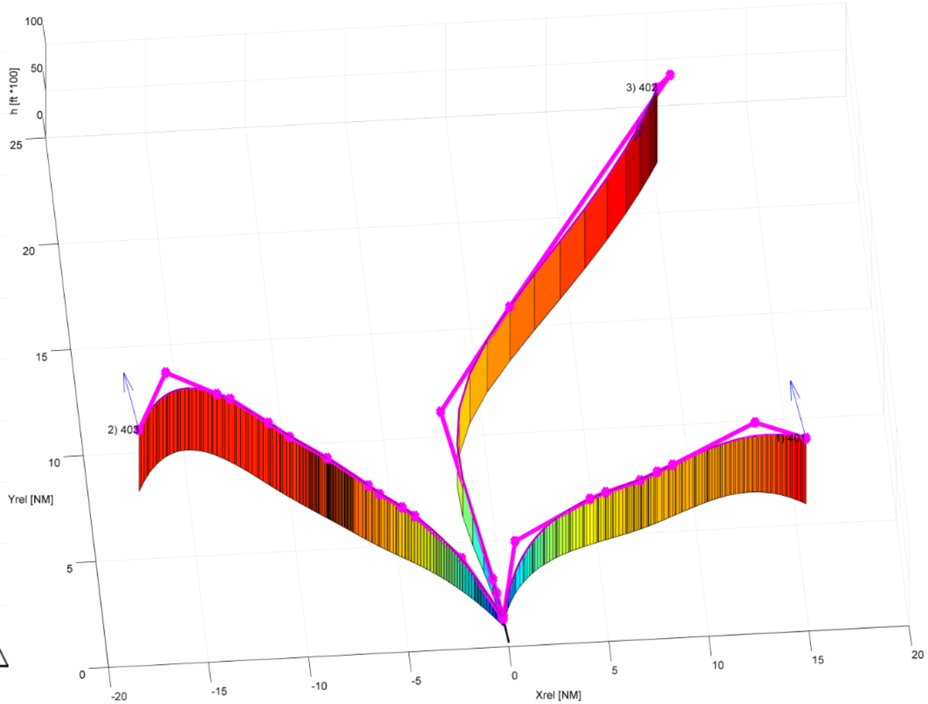
- 4 A/C TMA Negotiation/Validation Loops (<100 sec)

MOTO-4D for TMA – Verification (with 4DT Smoothing)

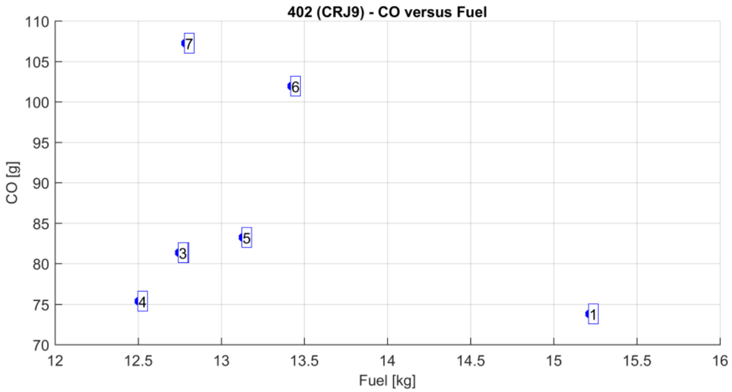
- Intents generated and assessed in 41 s (on average)
- Smoothing:

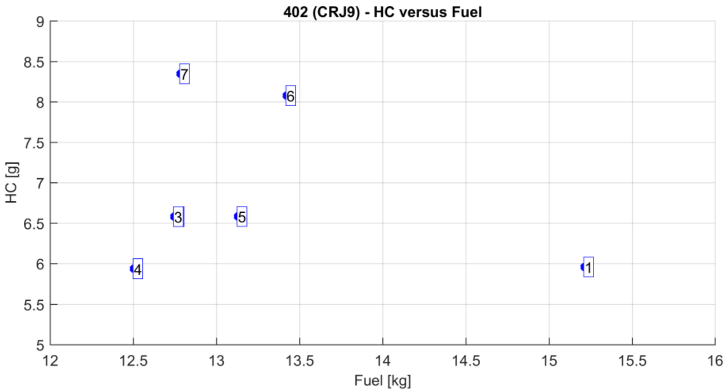
401: 145 → 10
402: 21 → 8
403: 208 → 14

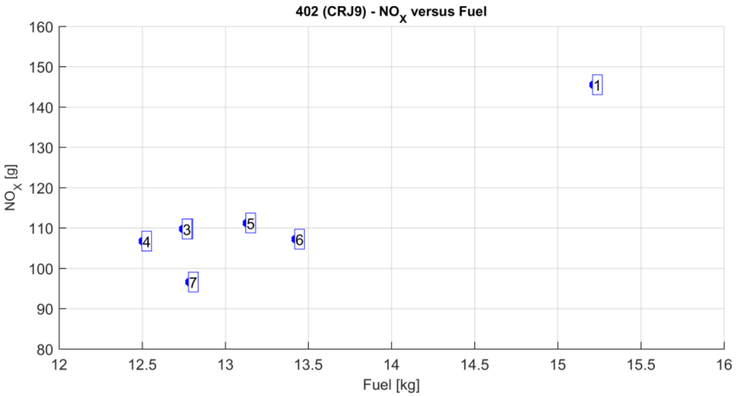


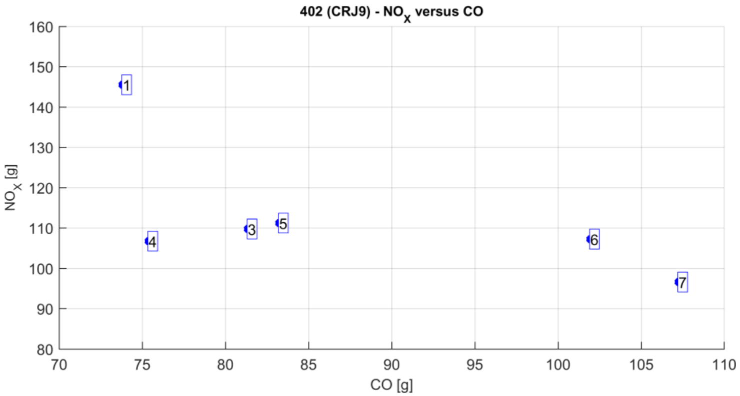


Environmental Optimality – Flight 402

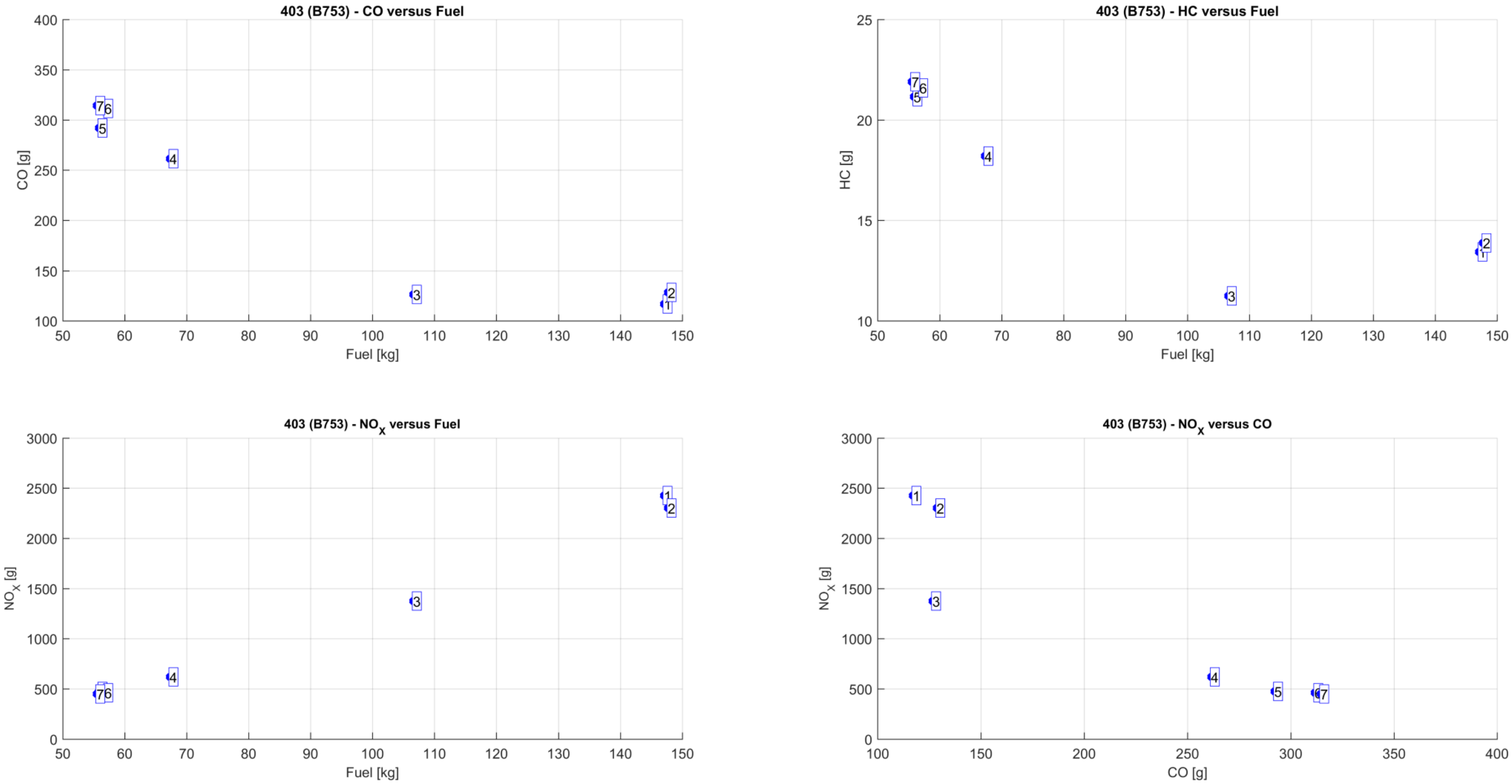




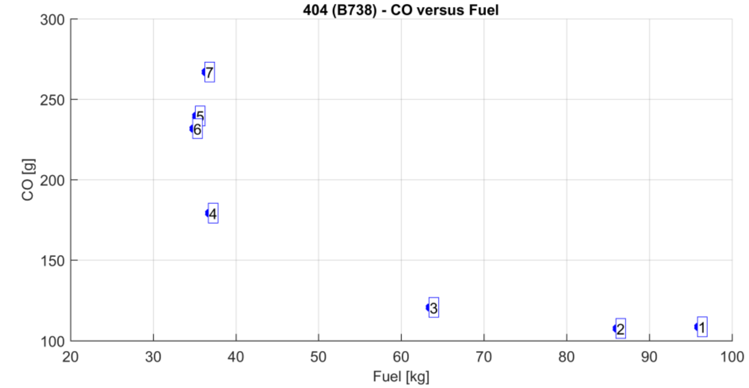


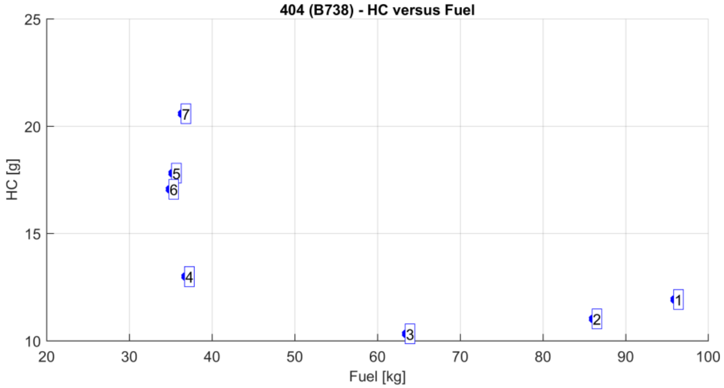


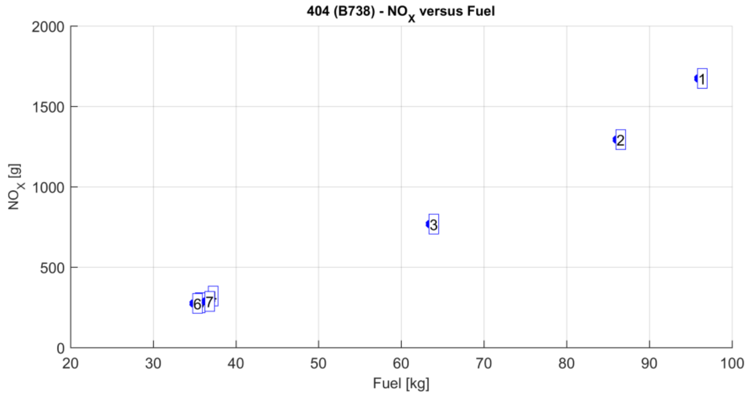
Environmental Optimality – Flight 403

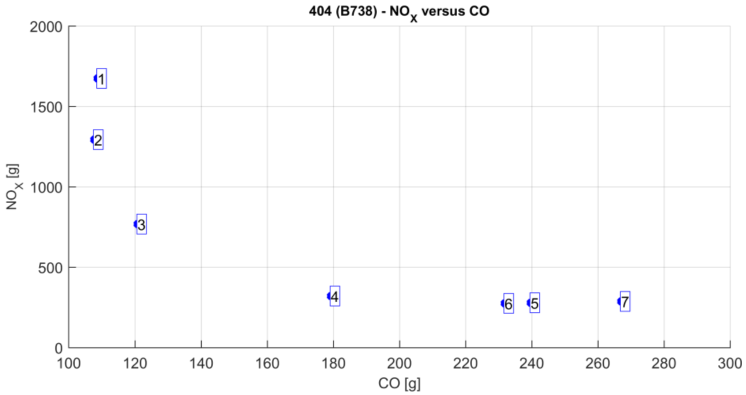


Environmental Optimality – Flight 404





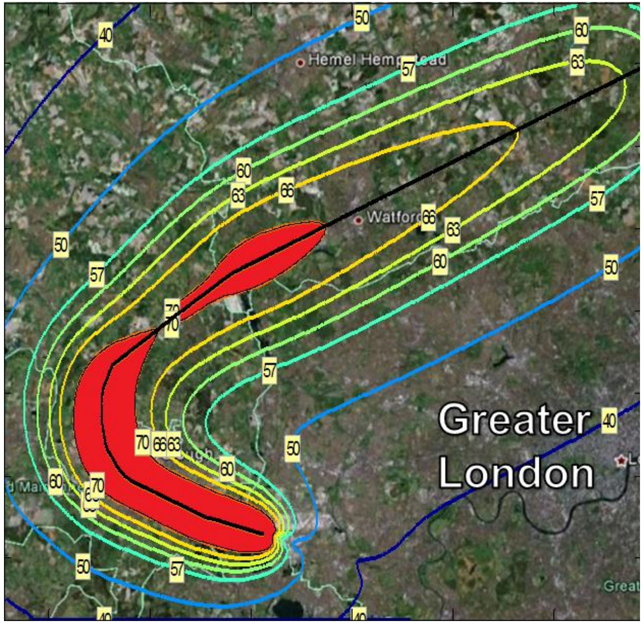


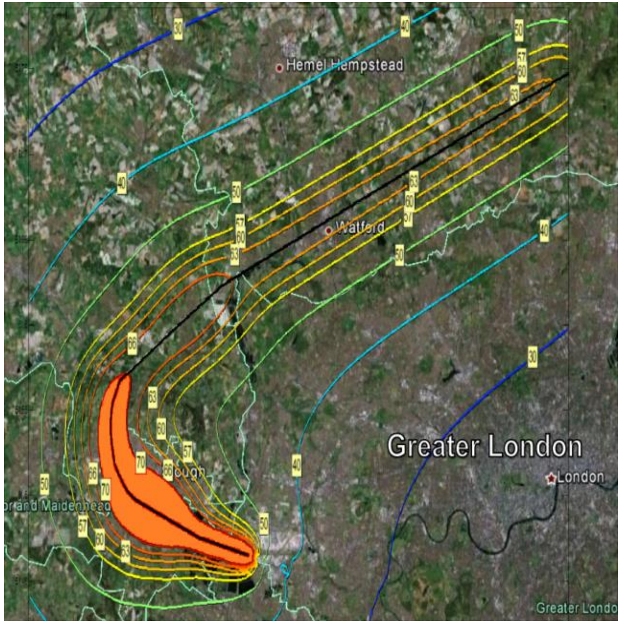


MOTO-4D for TMA – Departure Case Study

Real commercial flight profile used as benchmark

- Departed at 19:27 GMT (night flight)
- Optimisation: Min Fuel and Noise (SEL 70dBA)

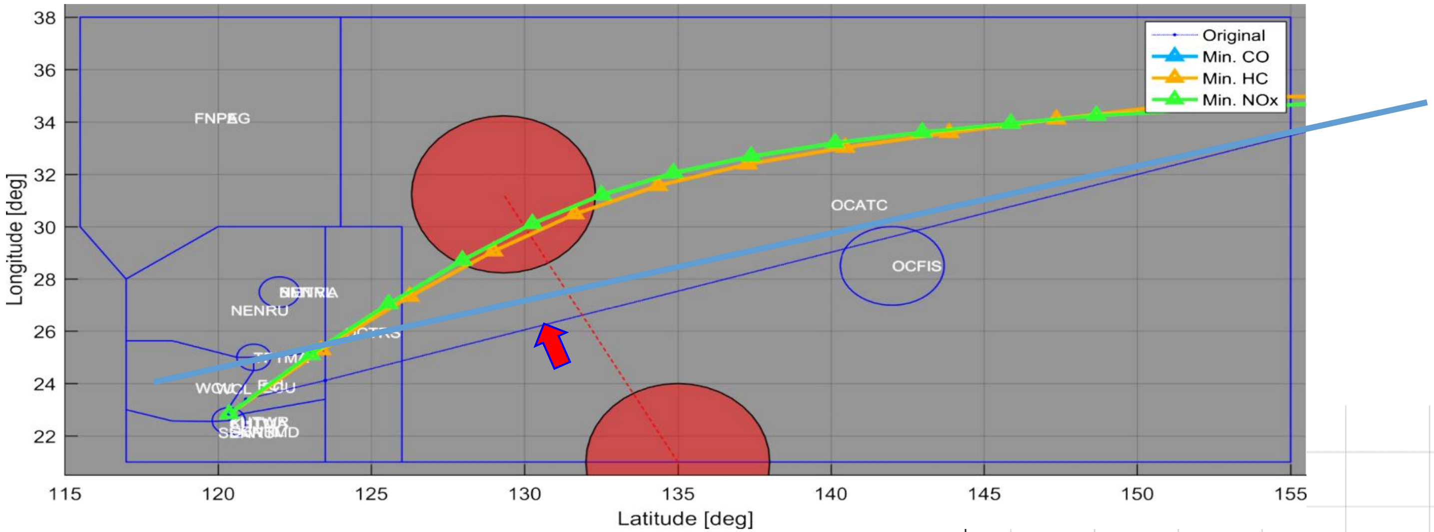


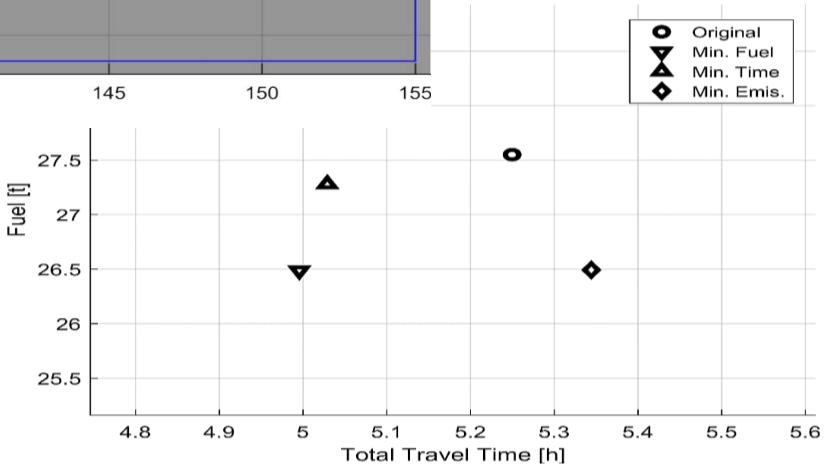


Optimised route for minimum noise indicates approx. **47%** smaller area of SEL 70 dBA (52.3 vs 100.5 km^2)

- ➢ Real Flight: 635 kg fuel
- ➢ MOTO: 469 kg fuel

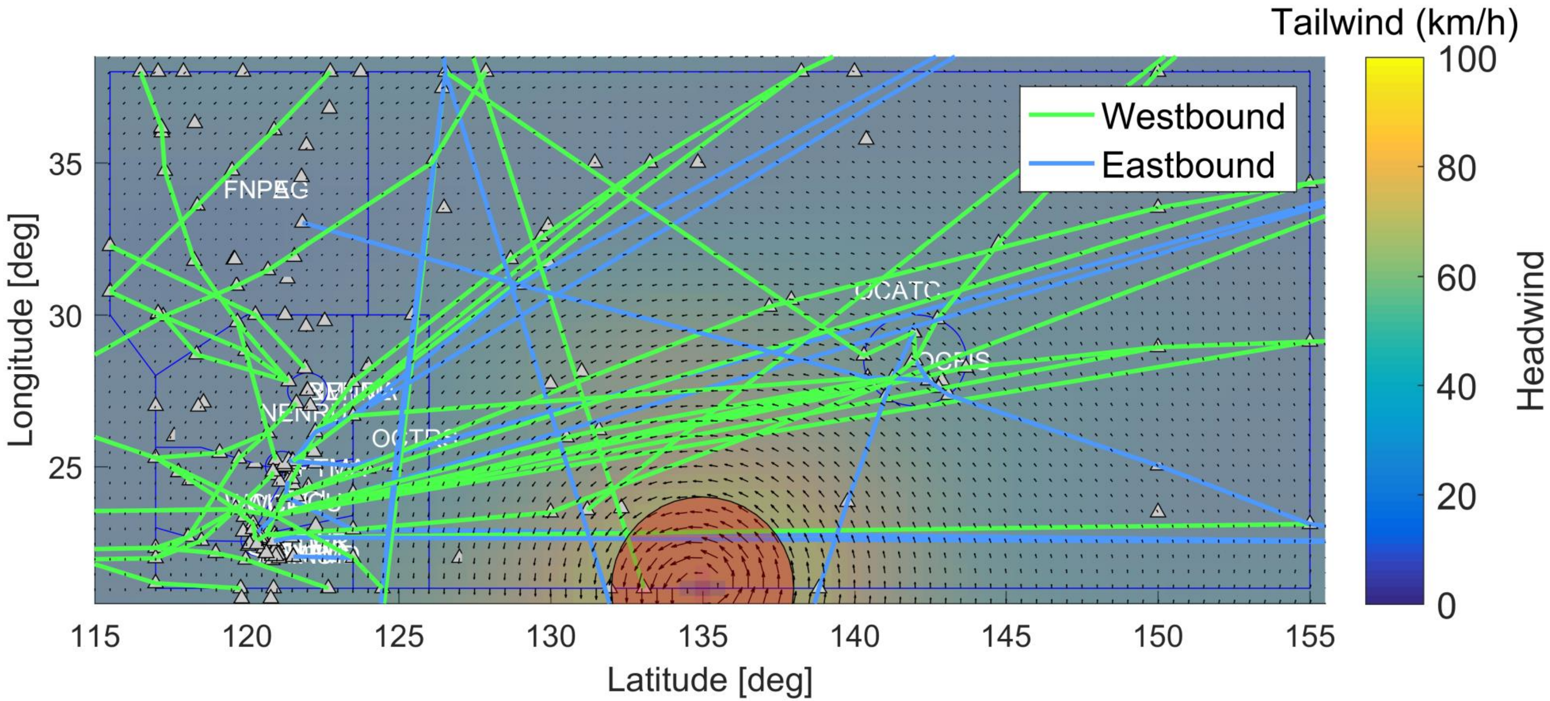
MOTO-4D – Enroute Context



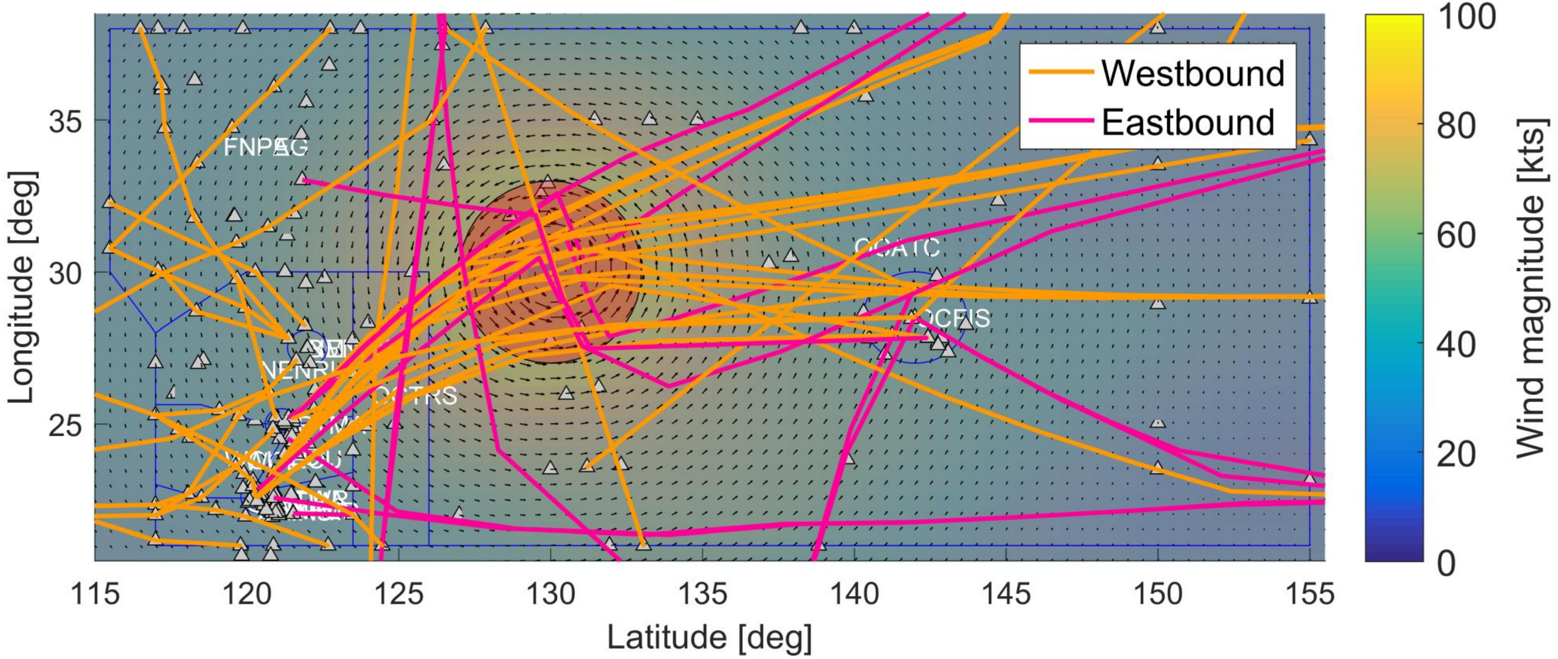


- Optimisation of enroute flights in terms of fuel, time and emissions, considering the 4D wind field and the avoidance of a tropical revolving storm

MOTO-4D – En-route Context

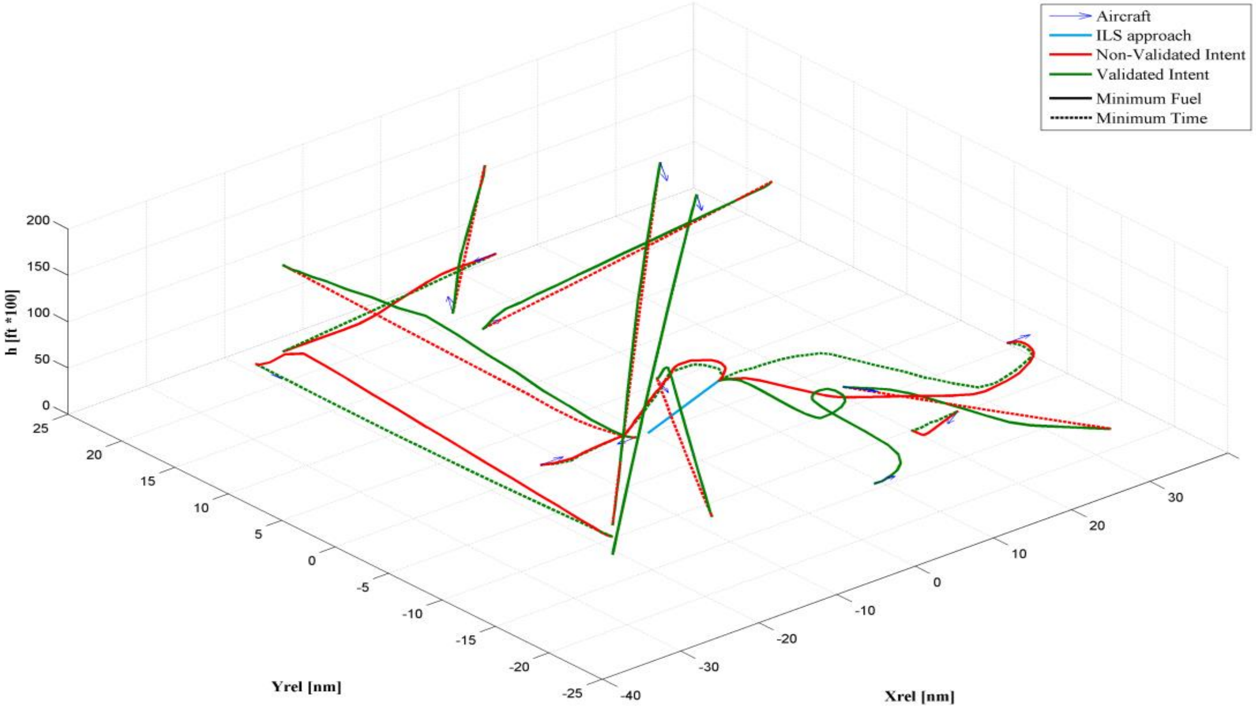


MOTO-4D – En-route Context

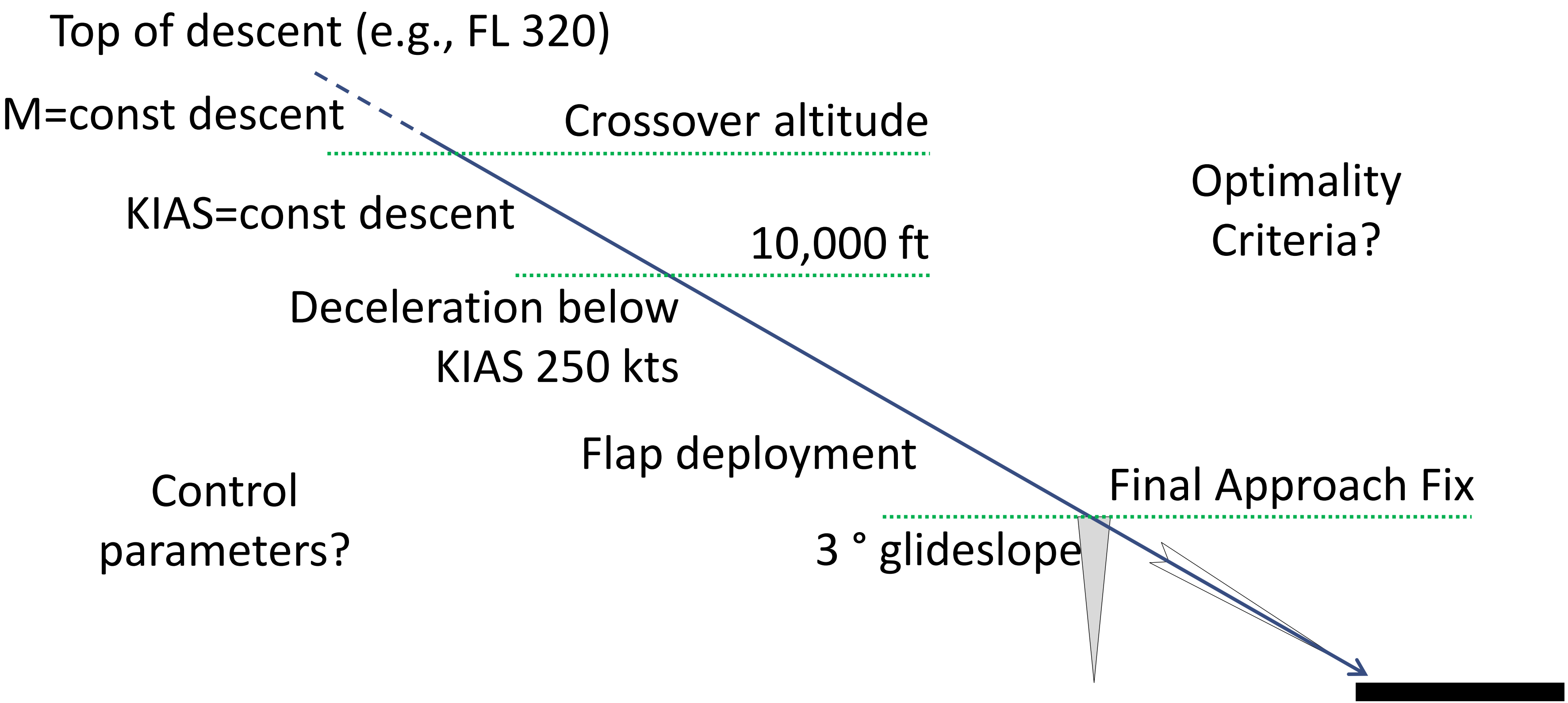


MOTO-4D for TMA – More Complex Scenarios

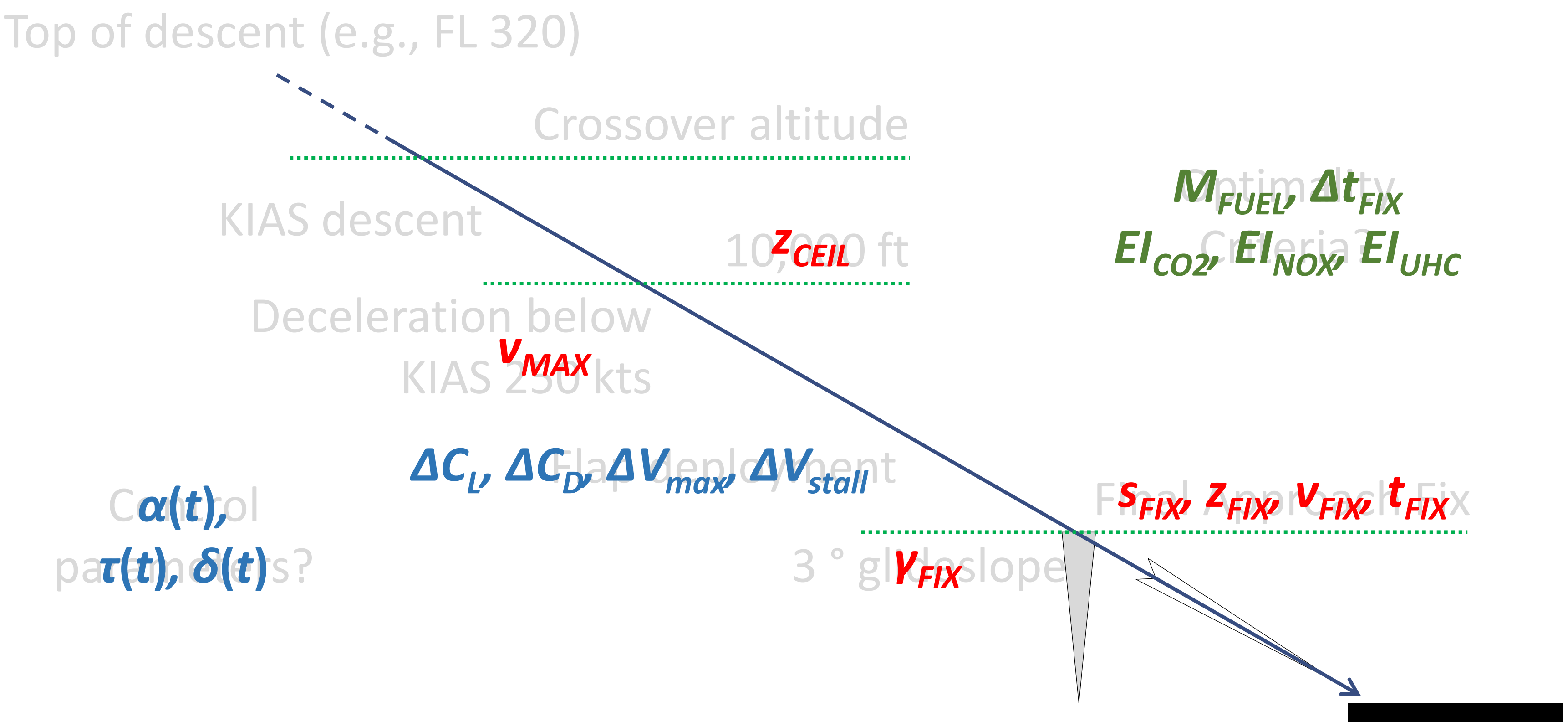
- Curved and Continuous Descent Approach Procedures
- 20 A/C TMA Negotiation/Validation Loops (<300 sec)



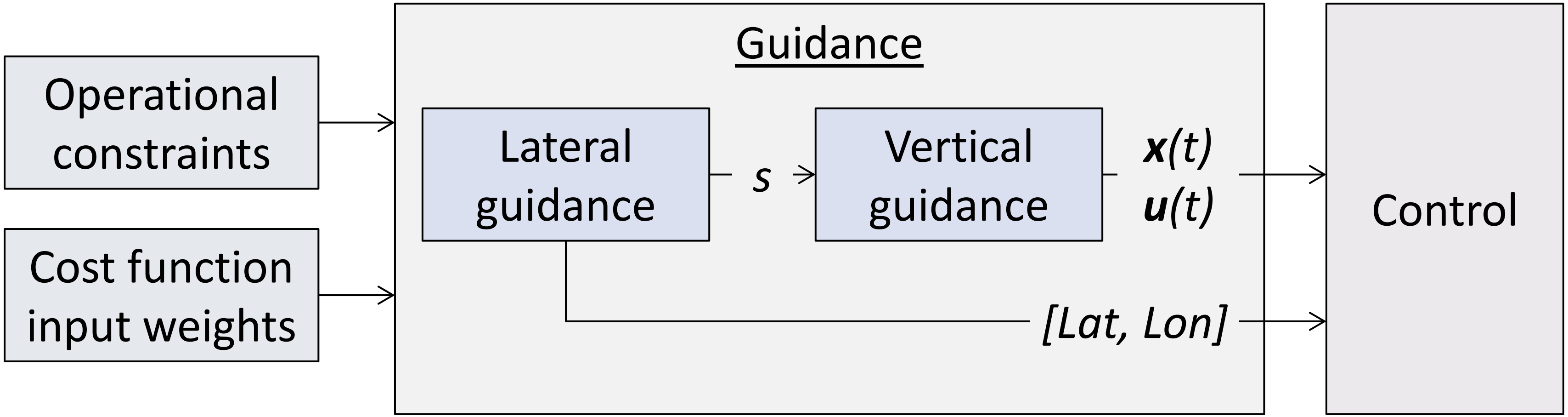
Time and Energy Management (TEMO) in Continuous Descent



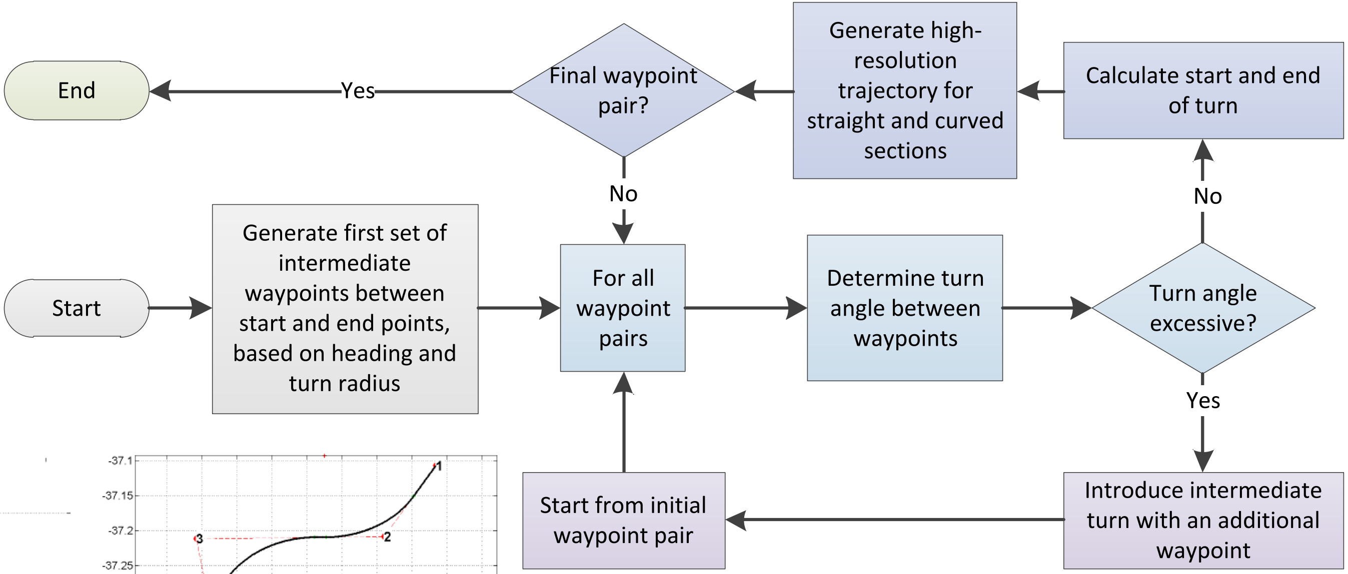
TEMO – Flight Guidance and Control Problem Formulation

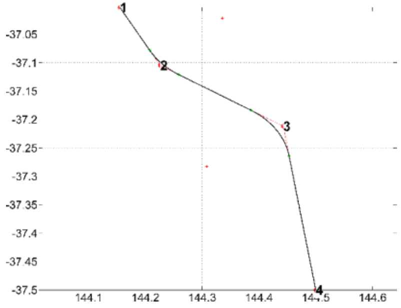


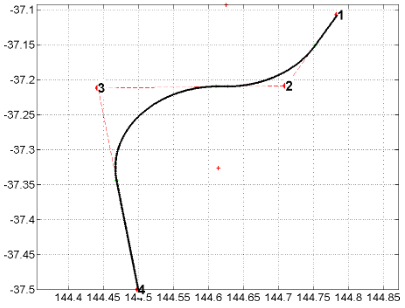
TEMO – Flight Guidance Implementation



TEMO – Lateral Guidance Implementation

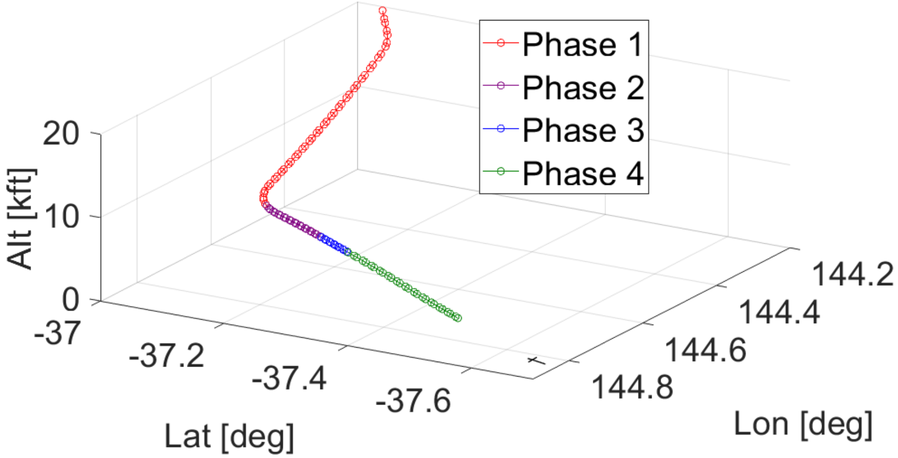




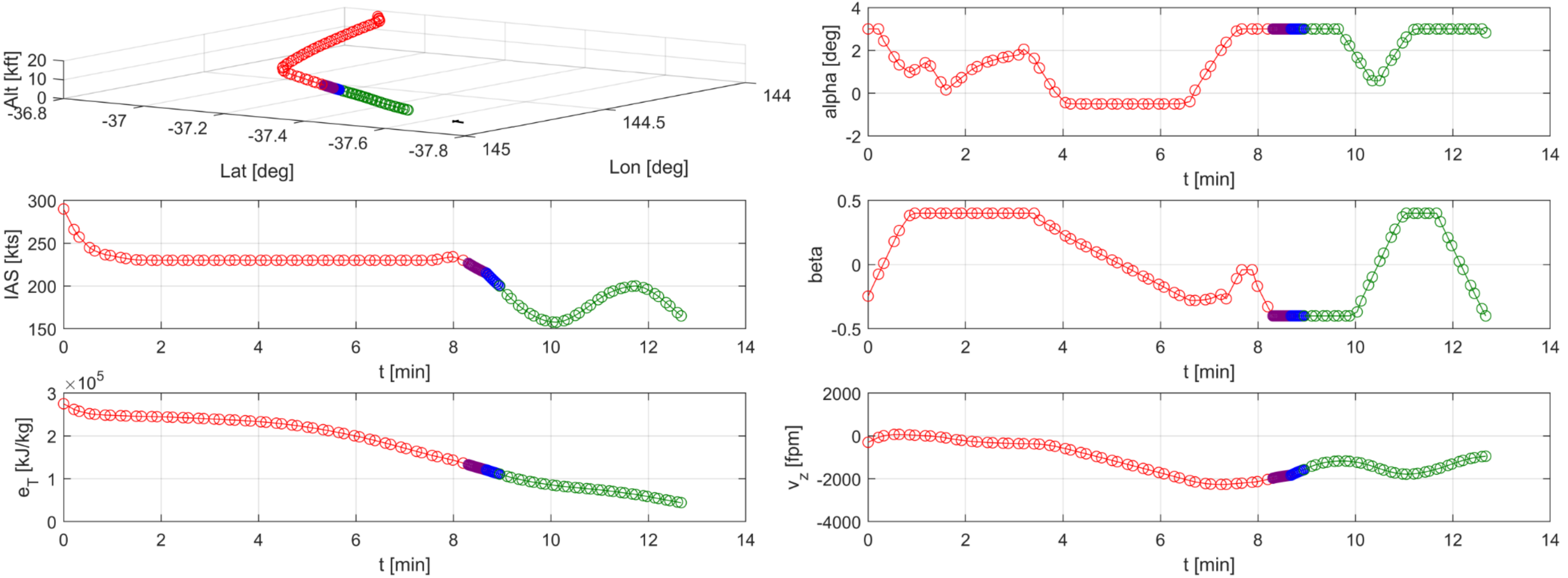


TEMO in CDA – Verification Case Study

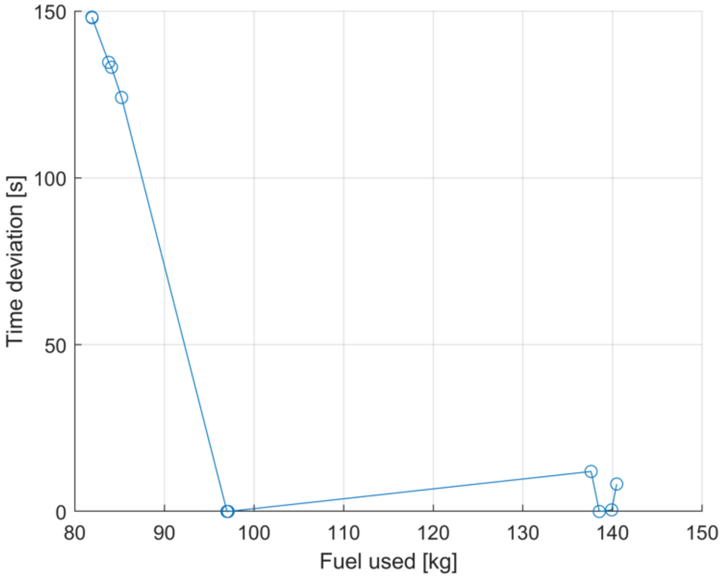
- Descent from 20,000 ft to Final Approach Fix (FAF) at Runway 16 of Tullamarine Airport (~57 NM; 12.5 minutes)
- 4 phases:
  1) Descent to 10,000 ft without regulatory airspeed constraints
  2) Descent below 10,000 ft at a maximum speed of 250 KIAS
  3) Further descent with flap configuration one
  4) Final descent up to FAF with flap configuration two

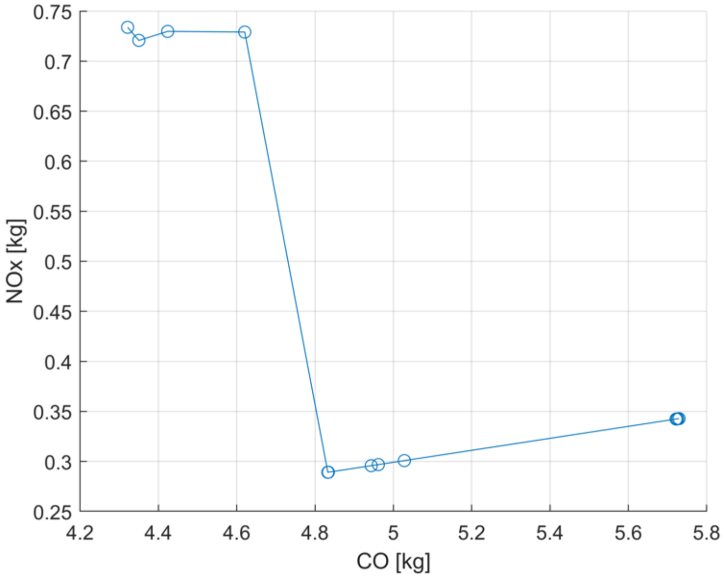


TEMO in CDA – Verification Results



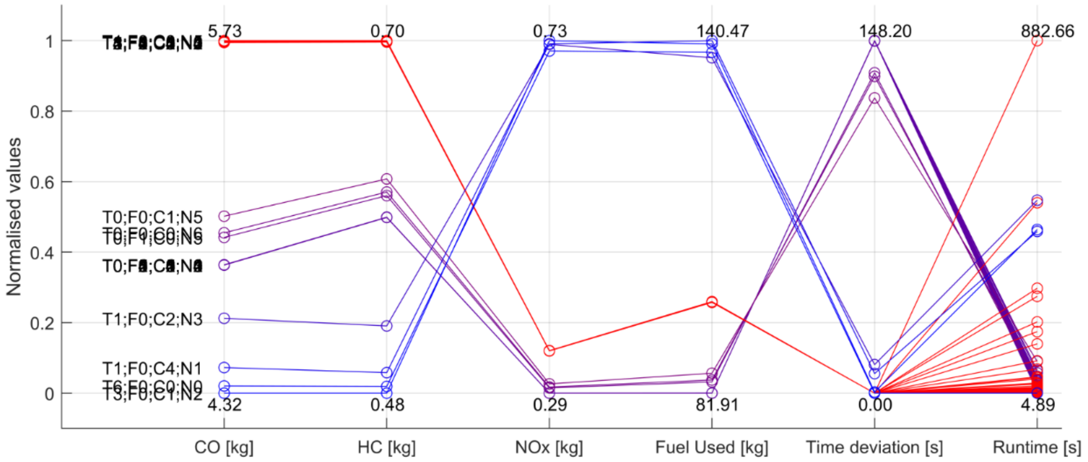
TEMO in CDA – Environmental Impacts





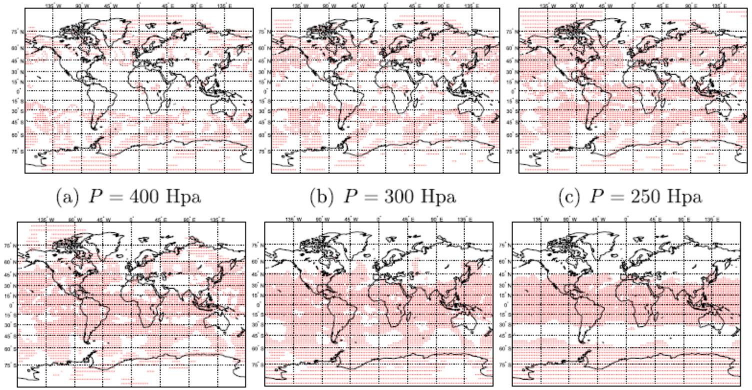
TEMO in CDA – Results

- CO: [4.32 kg – 5.73 kg]; HC: [483 g – 702 g]; NO_X: [289 g – 734 g]
- Fuel: [81.2 kg – 140.47 kg]; Time deviation: [0 s – 148 s]
- Runtime: [4.90 s to 882.66s]
- CO and HC are inversely correlated with fuel use, while NO_X directly correlated
- Most cases converged to two solutions – “Min Fuel” and “Min Time Deviation”
- “Min Fuel” cases tend to reach the FAF in minimum time – idling the throttle appears to consume more fuel



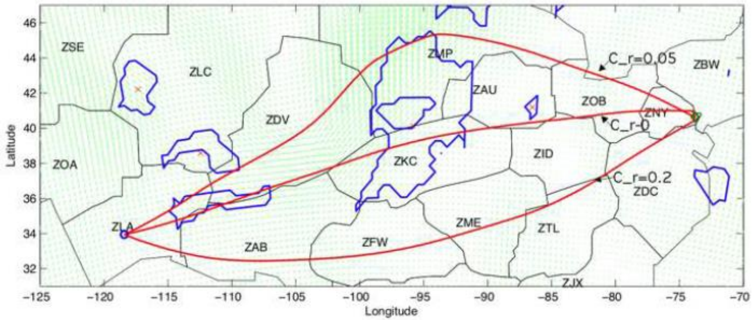
MOTO for Contrail Mitigation – Motivation

- Most of existing literature tackled the **complete avoidance** of large airspace regions entailing suitable conditions for **contrail formation**
- Limited evaluation of **contrail persistence (lifetime – LT)**
- Very limited evaluation of the estimated **Radiative Forcing (RF)**
- Very limited assessment of the **trade-off between contrail-related RF and fuel burn related RF**



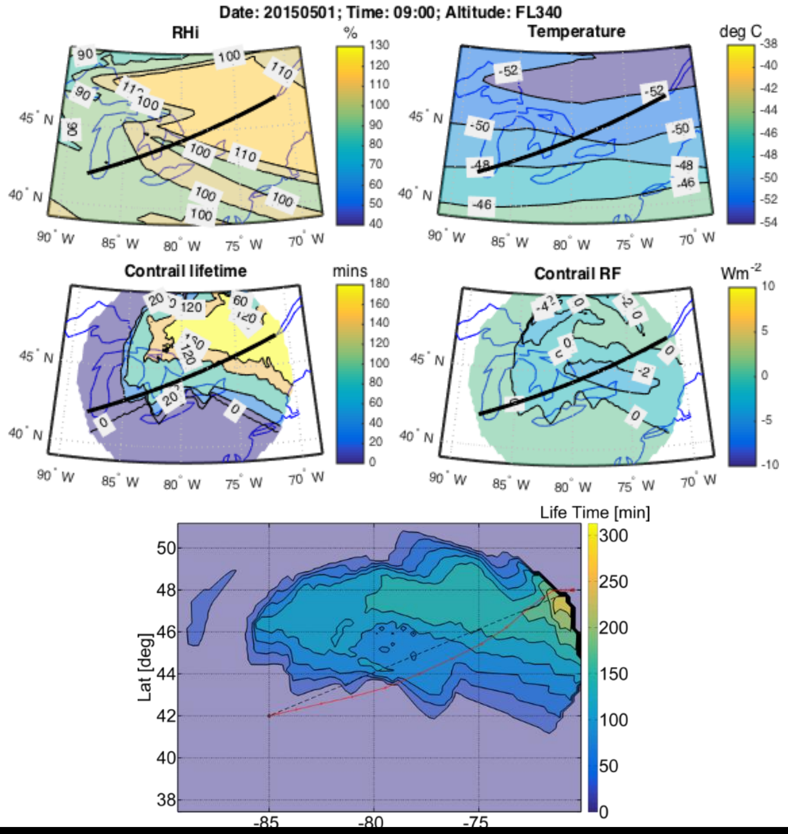
(a) $P = 400$ Hpa (b) $P = 300$ Hpa (c) $P = 250$ Hpa

(d) $P = 200$ Hpa (e) $P = 150$ Hpa (f) $P = 100$ Hpa



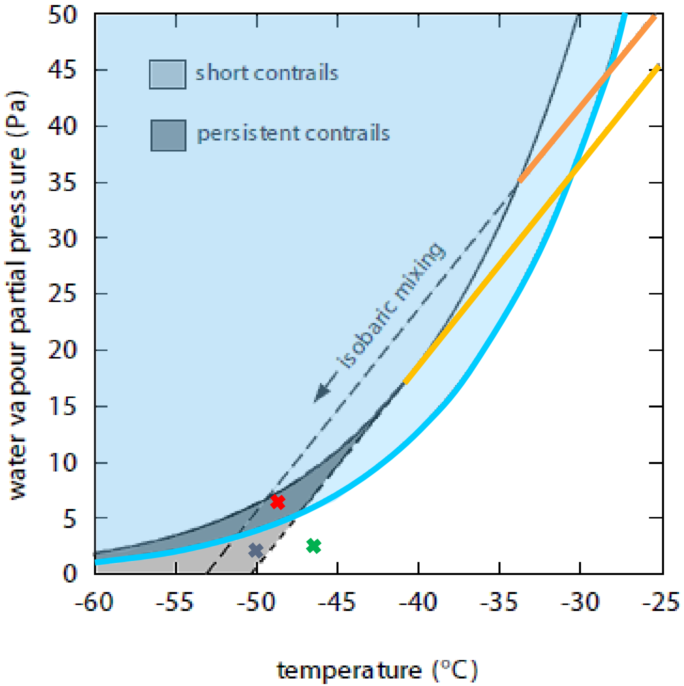
MOTO for Contrail Mitigation – Research Objectives

- Most of the existing literature employs **simplified contrail models** (often based on formation criteria) to designate regions that are consequently approximated as **avoidance volumes of simple geometric shape**
- ✓ This project aims at a more **in-depth evaluation of the estimated environmental impacts** and at the implementation in a **multi-objective flight trajectory optimisation framework**



MOTO for Contrail Mitigation – Contrail Physics

- Contrails form at cruising altitudes in areas of low temperature and high relative humidity
- As a rule of thumb, temperatures of $T < -40°C$ are required for formation
- The contrails grow and age by absorbing water vapour from ambient air
- Relative humidities with respect to ice of $RH_i > 0.8$ is required for the growth and persistence of the contrails



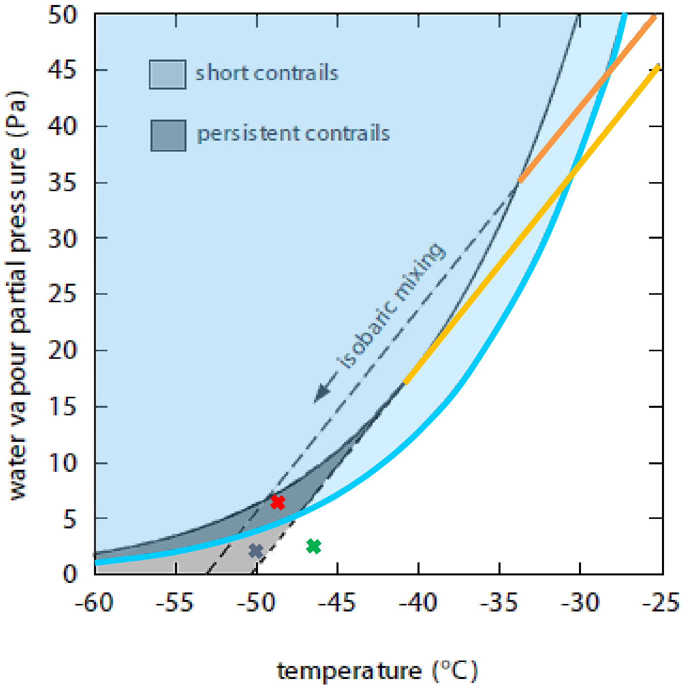
(Gierens et al 2008)

MOTO for Contrail Mitigation – Contrail Physics

❖ **Jet phase**

- Timescale of ~20 sec
- Governed by thermodynamics in the exhaust plume

- Cooling of exhaust plume follows a mixing line
- Condensation and freezing of water vapour
- Schmidt-Appleman diagram



(Gierens et al 2008)

MOTO for Contrail Mitigation – Contrail Physics

❖ **Vortex phase**

- Timescale of ~2 min
- Governed by the wake vortex
- Plume sinks
- Local increase in pressure
- Adiabatic warming
- Ice sublimation / losses

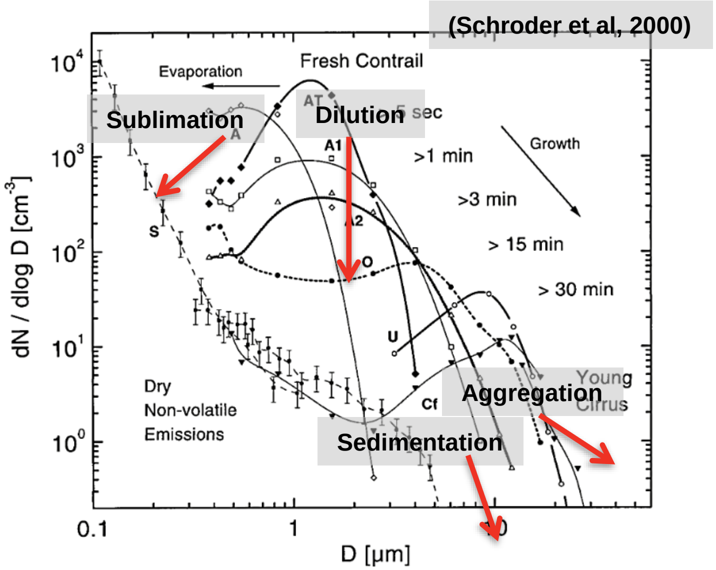
MOTO for Contrail Mitigation – Contrail Physics

❖ **Dispersion phase**

- Timescale of mins to hrs
- Persistence depends on ambient conditions
- Horizontal wind: advection
- Vertical updrafts: adiabatic cooling
- Wind shear: spread
- Ice super-saturation: growth
- Sedimentation and aggregation

MOTO for Contrail Mitigation – Contrail Physics

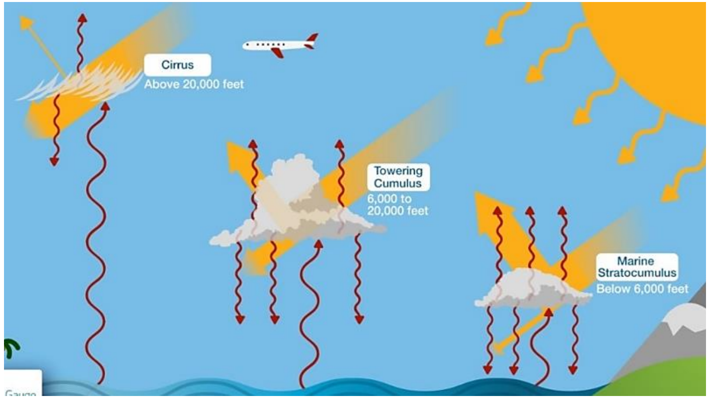
- **Dispersion phase**
  - Timescale of mins to hrs
  - Persistence depends on ambient conditions
  - Horizontal wind: advection
  - Vertical updrafts: adiabatic cooling
  - Wind shear: spread
  - Ice super-saturation: growth
  - Sedimentation and aggregation

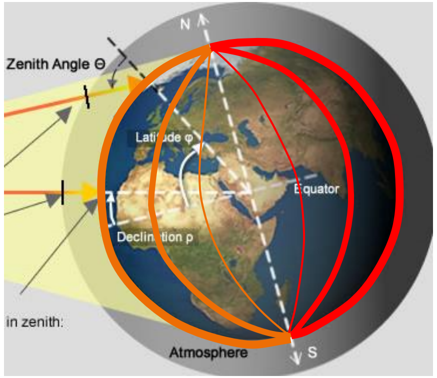


MOTO for Contrail Mitigation – Environmental Impact

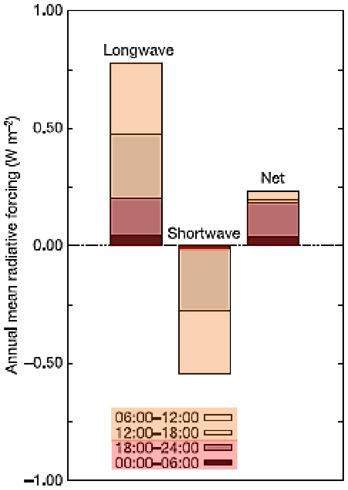
❖ **Radiative Forcing (RF)**

- **Greenhouse effect**: trapped longwave emissions
- **Albedo effect**: incident shortwave radiation
- Reflected shortwave radiation dependent on solar zenith angle
- Optical depth dependent on particle micro-properties





(Stuber et al 2006)

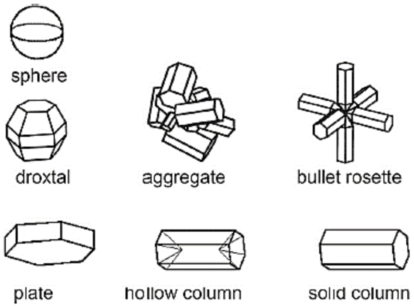


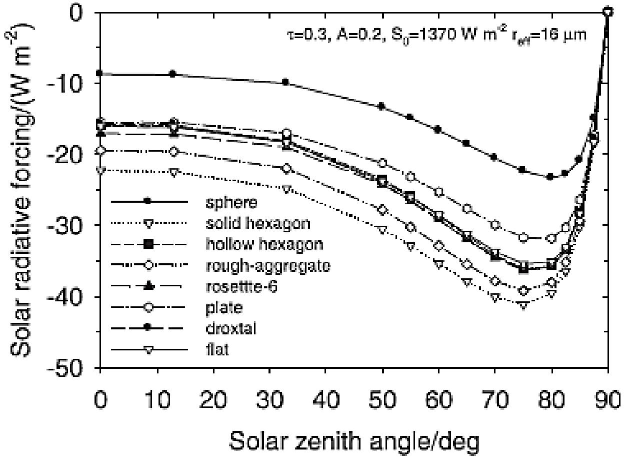
MOTO for Contrail Mitigation – Environmental Impact

❖ Radiative Forcing (RF)

- **Greenhouse effect**: trapped longwave emissions
- **Albedo effect**: incident shortwave radiation
- Reflected shortwave radiation dependent on solar zenith angle
- Optical depth dependent on particle micro-properties

(Schumann et al 2012)

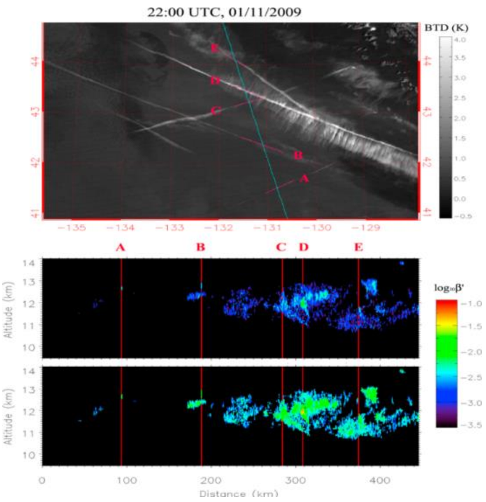




MOTO for Contrail Mitigation – Empirical Studies

- Voigt et al (2011) sampled contrails in the Contrail and Cirrus Experiment (CONCERT) campaign
- Iwabuchi et al (2012) tracked persistent contrails using a combination of:
  - MODIS - Moderate Resolution Imaging Spectroradiometer
  - CALIOP - Cloud-Aerosol Lidar with Orthogonal Polarization

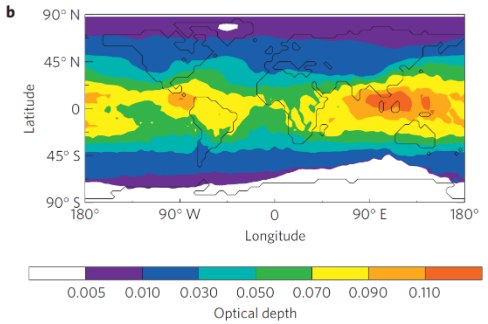
(Voigt et al 2011)



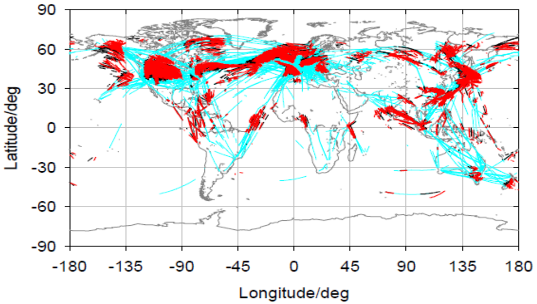
(Iwabuchi et al 2012)

MOTO for Contrail Mitigation – Computational Models

- Burkhardt & Kärcher (2010) developed a parametric model to simulate contrail-cirrus within a global climate model
  - European Center for medium-range weather forecasts – Hamburg (ECHAM)
- Schumann (2012) developed a parametric model to simulate the full contrail lifecycle as a result of global air traffic



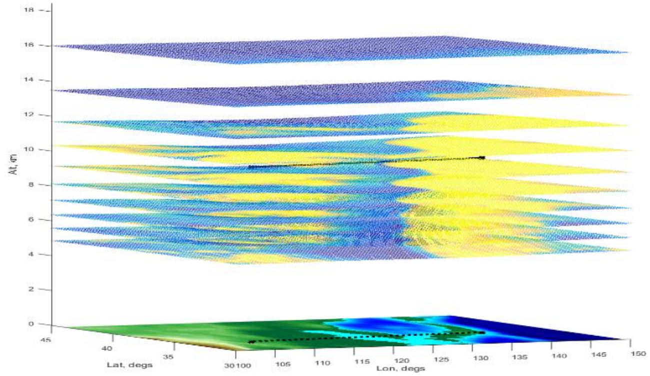
(Burkhardt & Kärcher 2010)

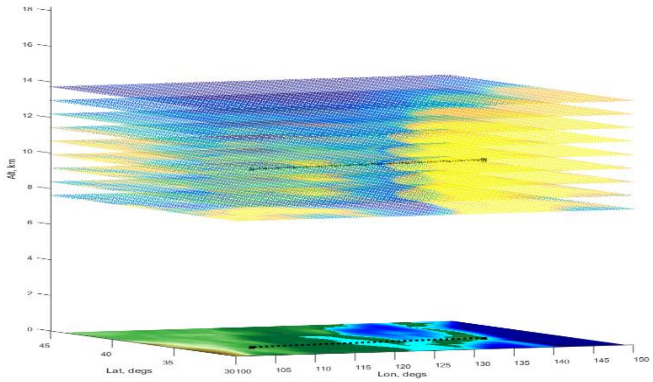


(Schumann 2012)

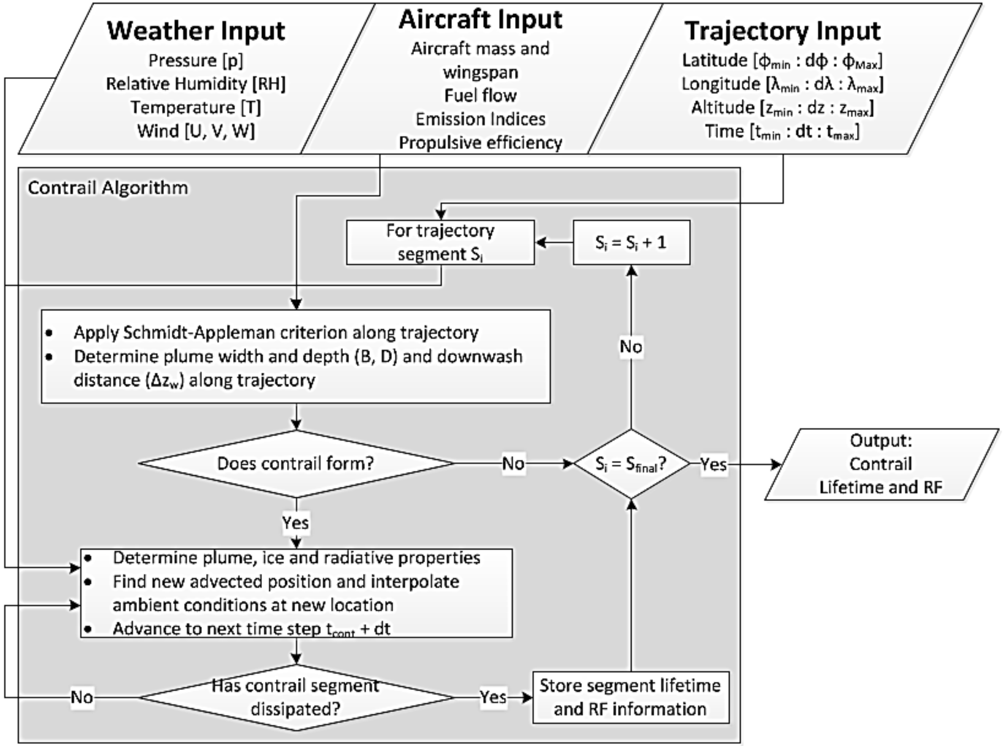
MOTO for Contrail Mitigation – Weather Model

- Weather data is required to model the contrail life-cycle
  - Temperature, relative humidity, wind and wind shear, pressure
- Global Forecasting System (GFS) provides Numerical Weather Prediction (NWP) data
  - Model is run every 6-hours (four times a day)
  - Forecast is given in 3-hour intervals
  - 16 days of advance prediction is given at each run

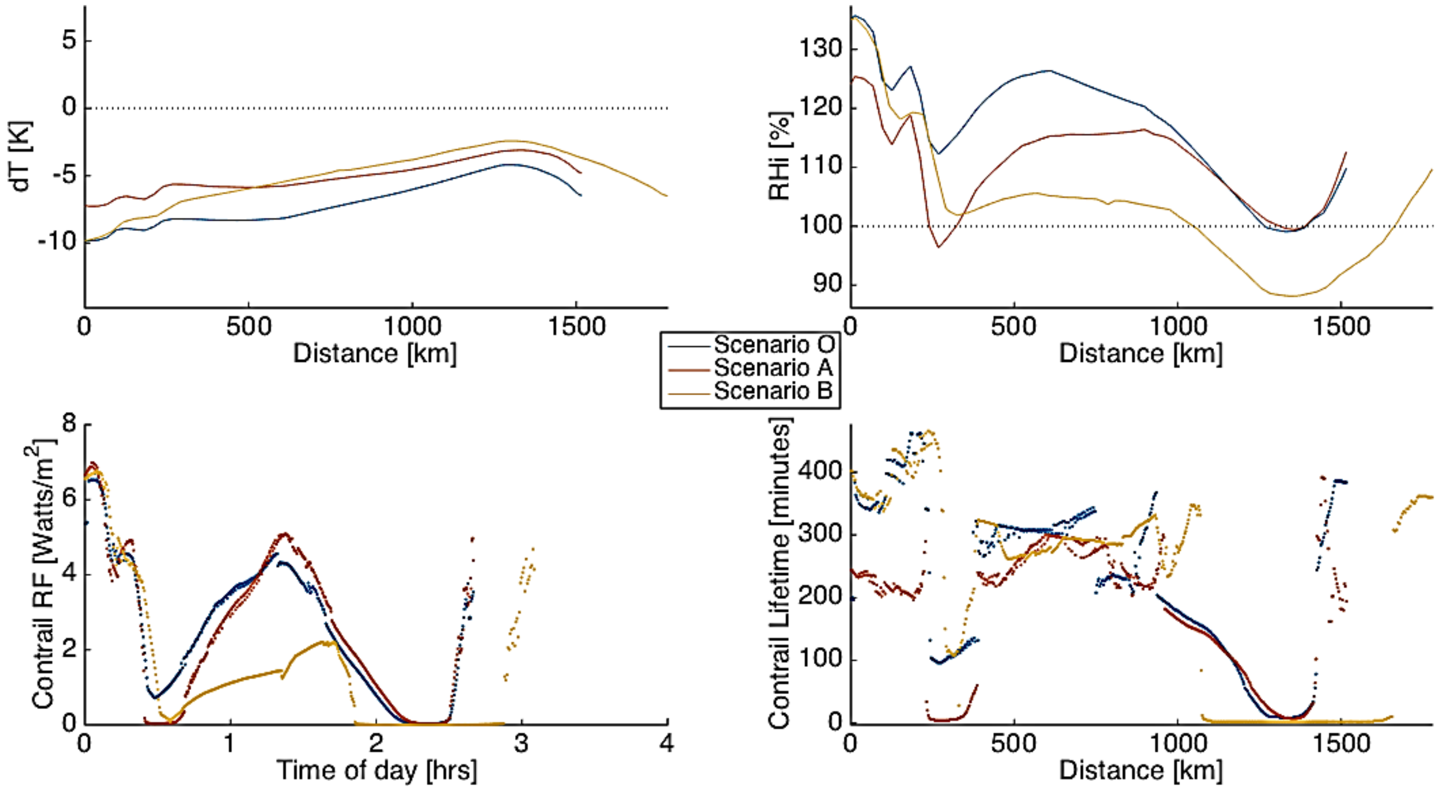




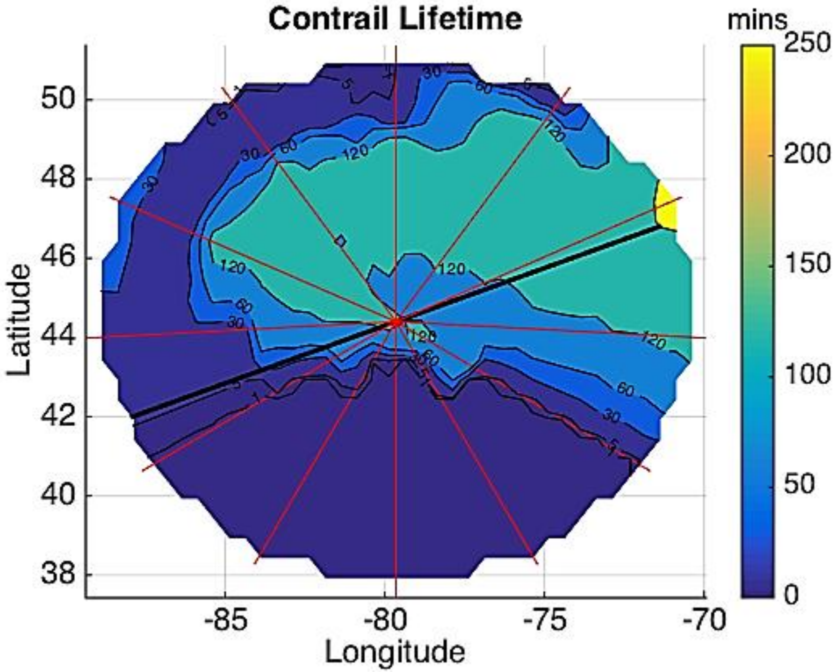
MOTO for Contrail Mitigation – Contrail Model

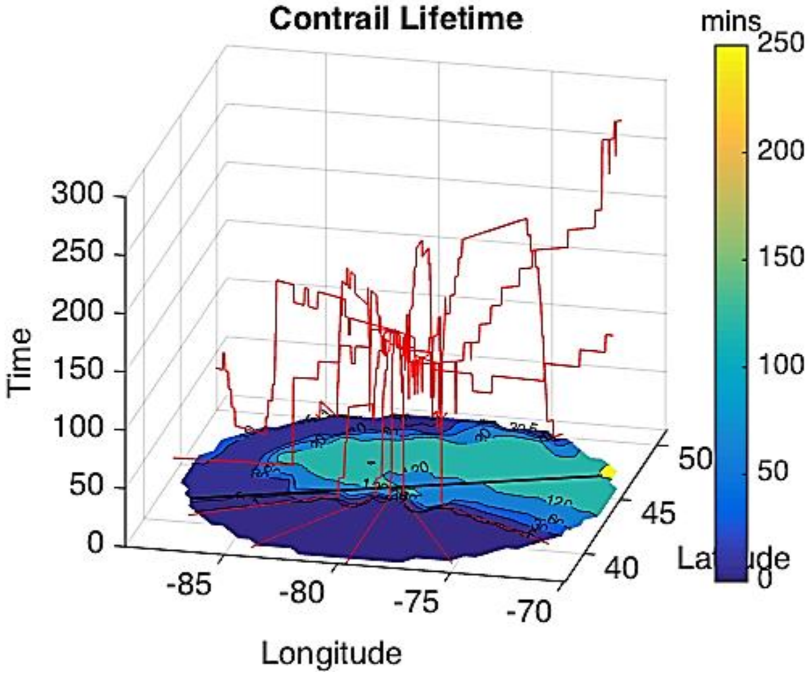


MOTO for Contrail Mitigation – Contrail Model Verification

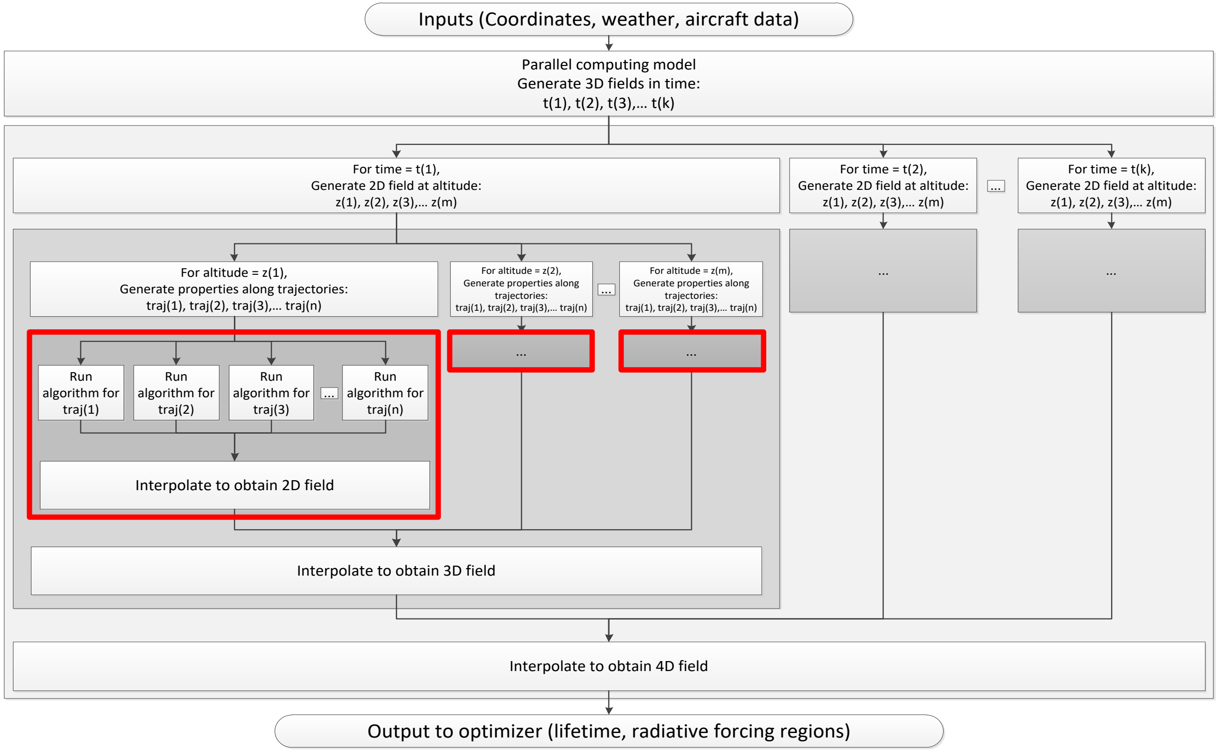


MOTO for Contrail Mitigation – 2D Mapping





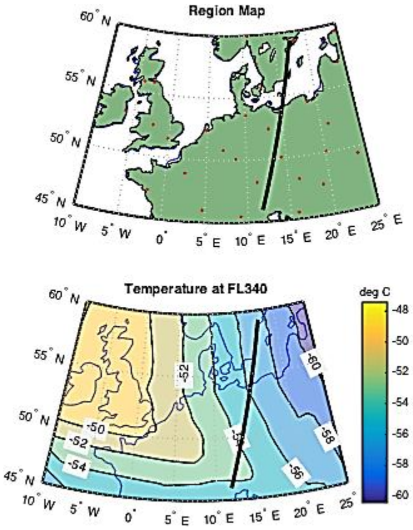
MOTO for Contrail Mitigation – Contrail Model



MOTO for Contrail Mitigation – Contrail Mapping Results

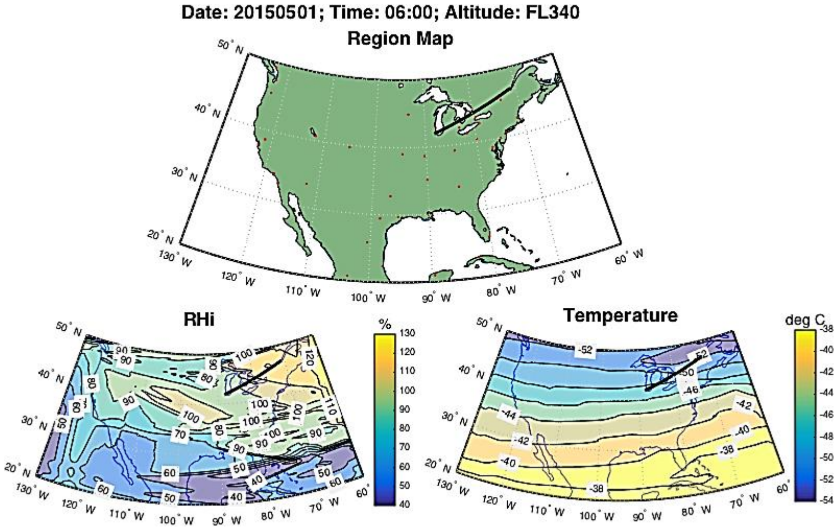
Case study 1: Europe

Stockholm to Venice
Date: 11 Apr 2015
Flight time: 0000 to 0240

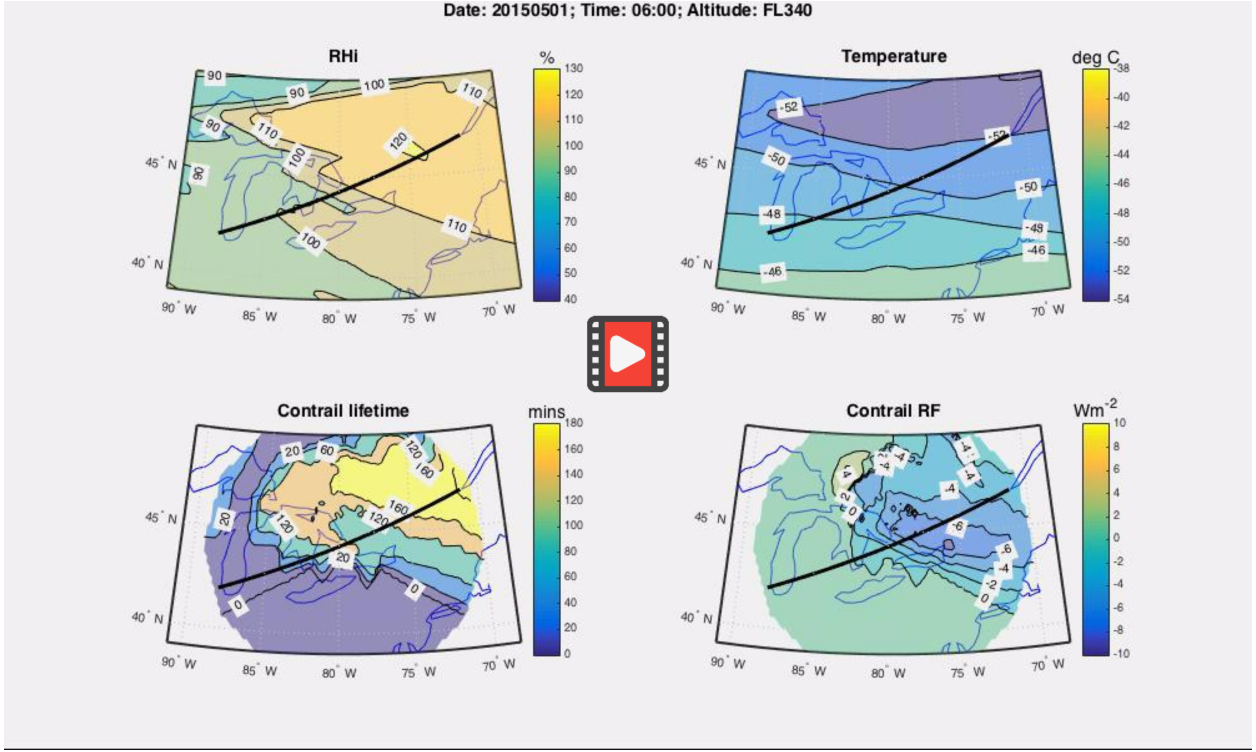


Case study 2: USA/Canada

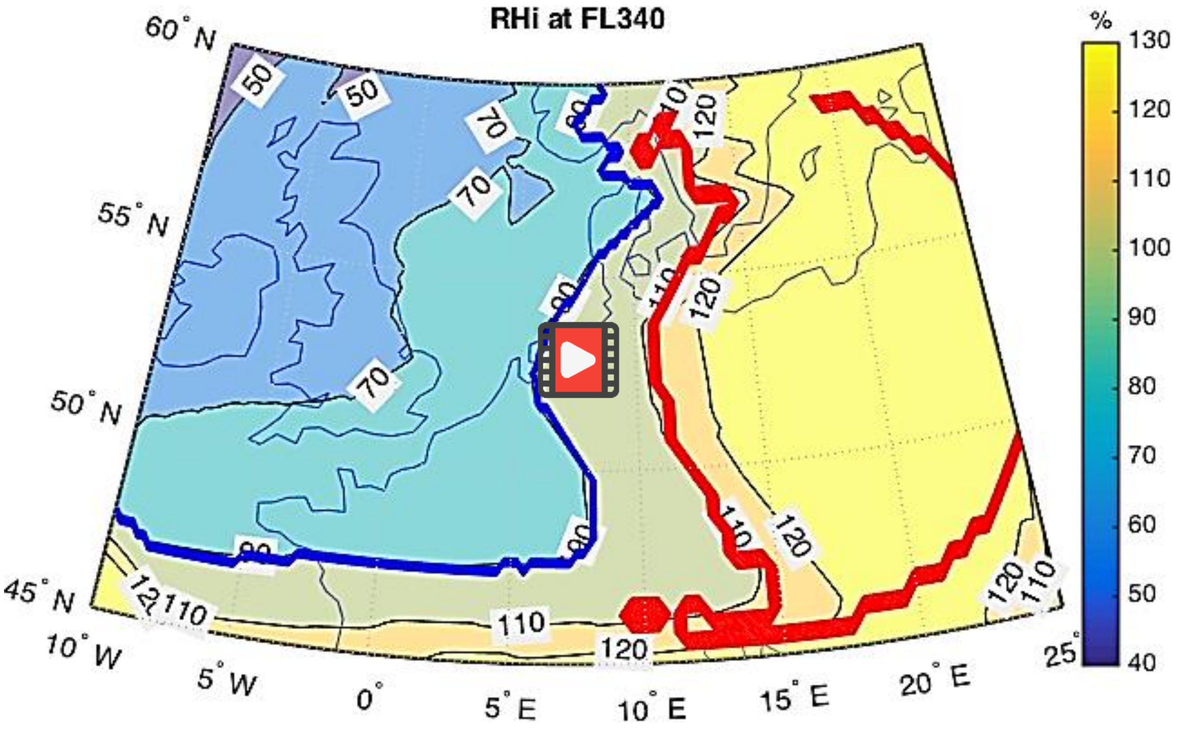
Chicago to Quebec City
Date: 1 May 2015
Flight time: 0600 to 0825



MOTO for Contrail Mitigation – 4D Mapping



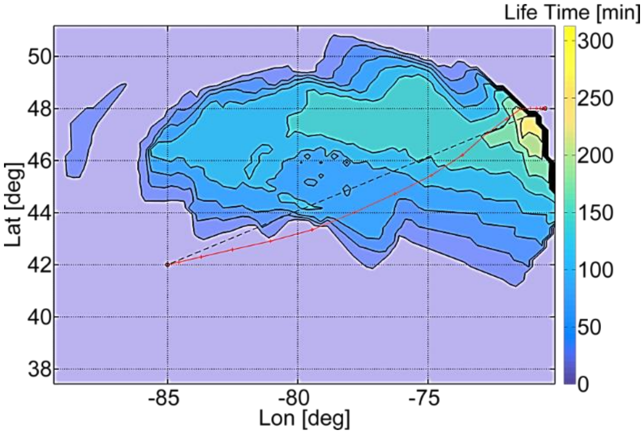
MOTO for Contrail Mitigation – Formation vs Persistence/RF



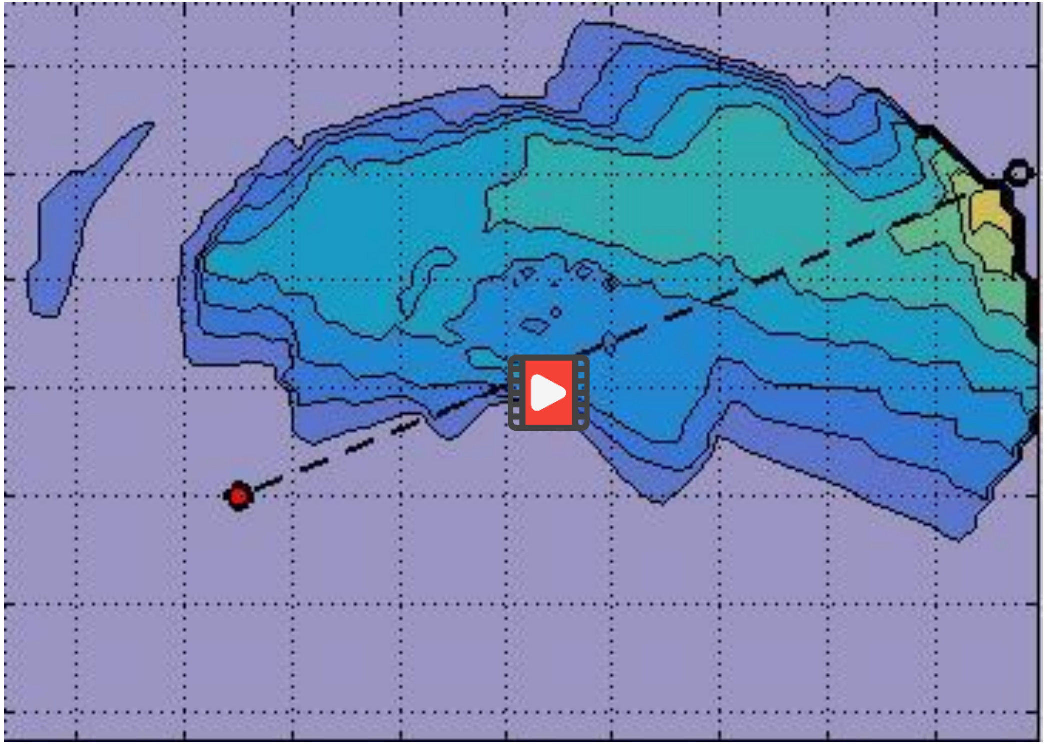
MOTO for Contrail Mitigation – 2D+Time Trajectory Optimisation

Minimisation of RF associated with persistent contrails and CO_2

- Optimised trajectory accounting for the contrail lifetime and TOD -

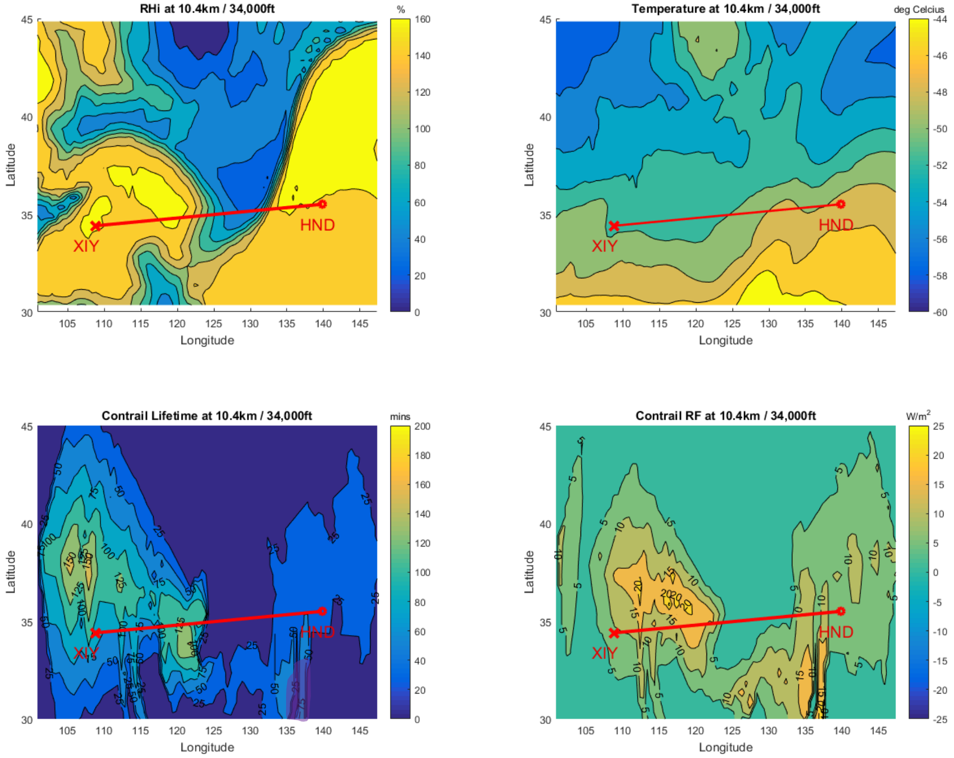


Airbus A320 – 765 NM – 2h 25 min



MOTO for Contrail Mitigation – Verification Case Study

- Tokyo HND to Xi'an XIY
- 13th April 2016
- Depart HND at 2100hrs (GMT+9)
- Cruise at constant altitude of FL340 (2D+t simulation)
- Highest RF regions do not necessarily correspond to highest lifetime regions
- Nor do they correspond to the highest RHi or lowest temperature regions



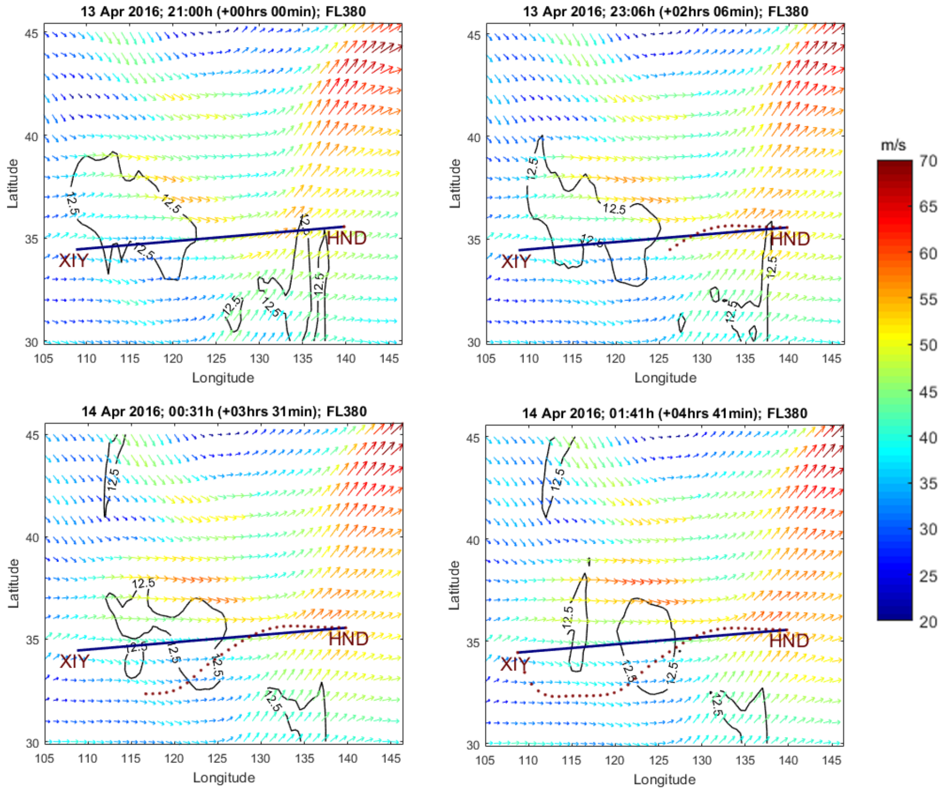
MOTO for Contrail Mitigation – Verification Case Study

- Optimised trajectory took into account:
  - Distanced-averaged RF:

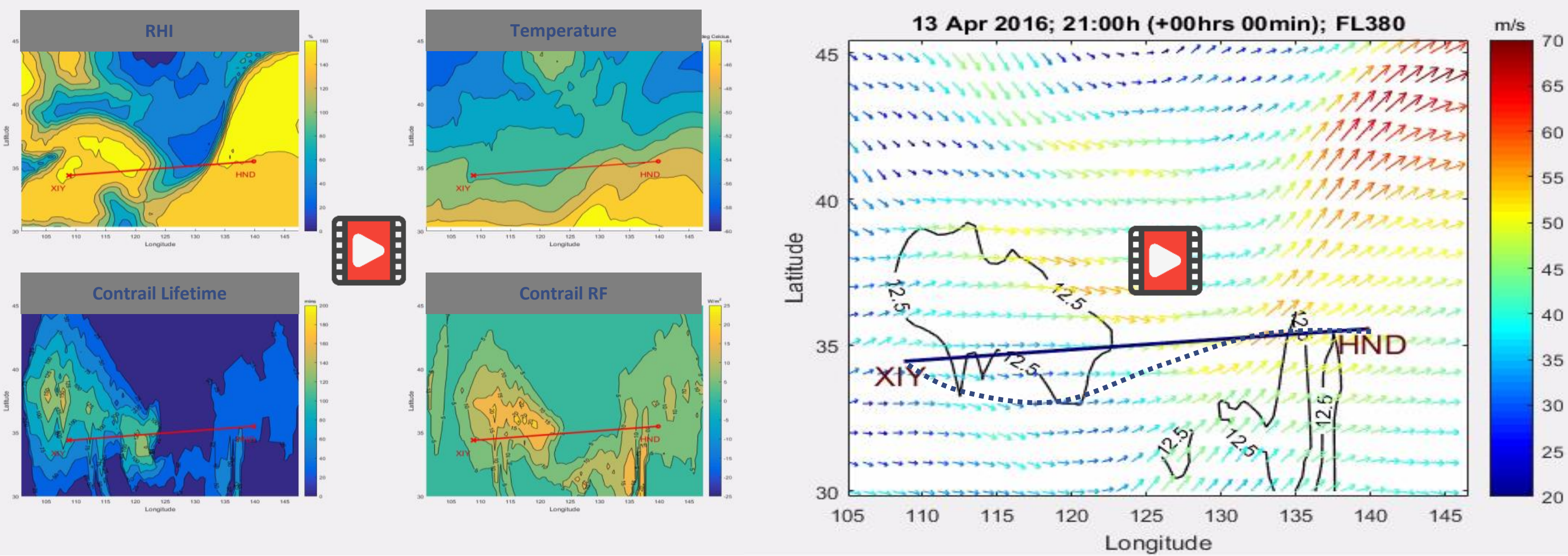
$$J_{DARF} = w_{cont} \frac{\sum_{i=1}^{n} RF_i \cdot s_i}{\sum_{i=1}^{n} s_i}$$

  - Wind-affected travel time

	Original	Optimized	Change
Time	5h 35 mins	4h 42 mins	-15.8%
Distance	3451 km	3477 km	+0.8%
DARF	10.1 W/m2	8.2 W/m2	-18.8%

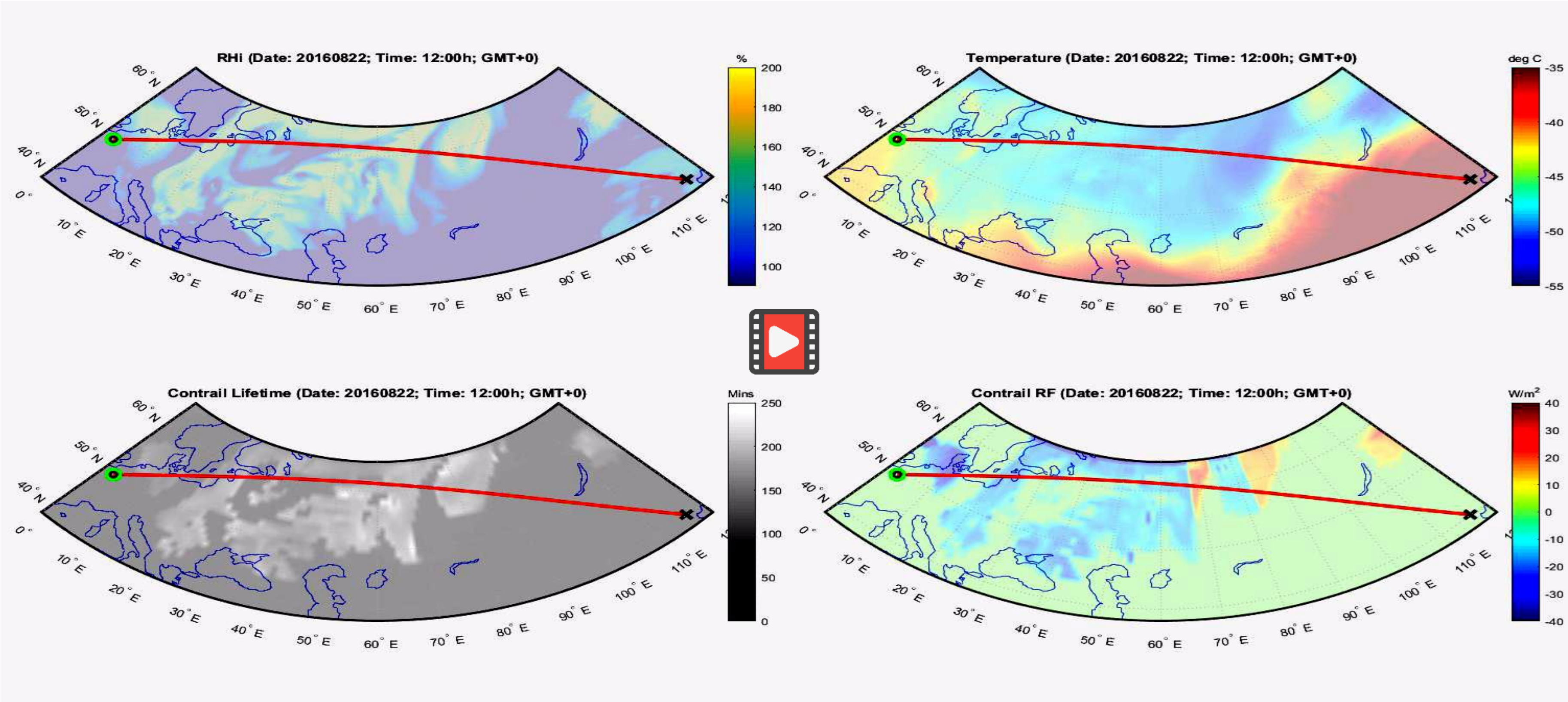


MOTO for Contrail Mitigation – Cruise (Tokyo to Xi'an)



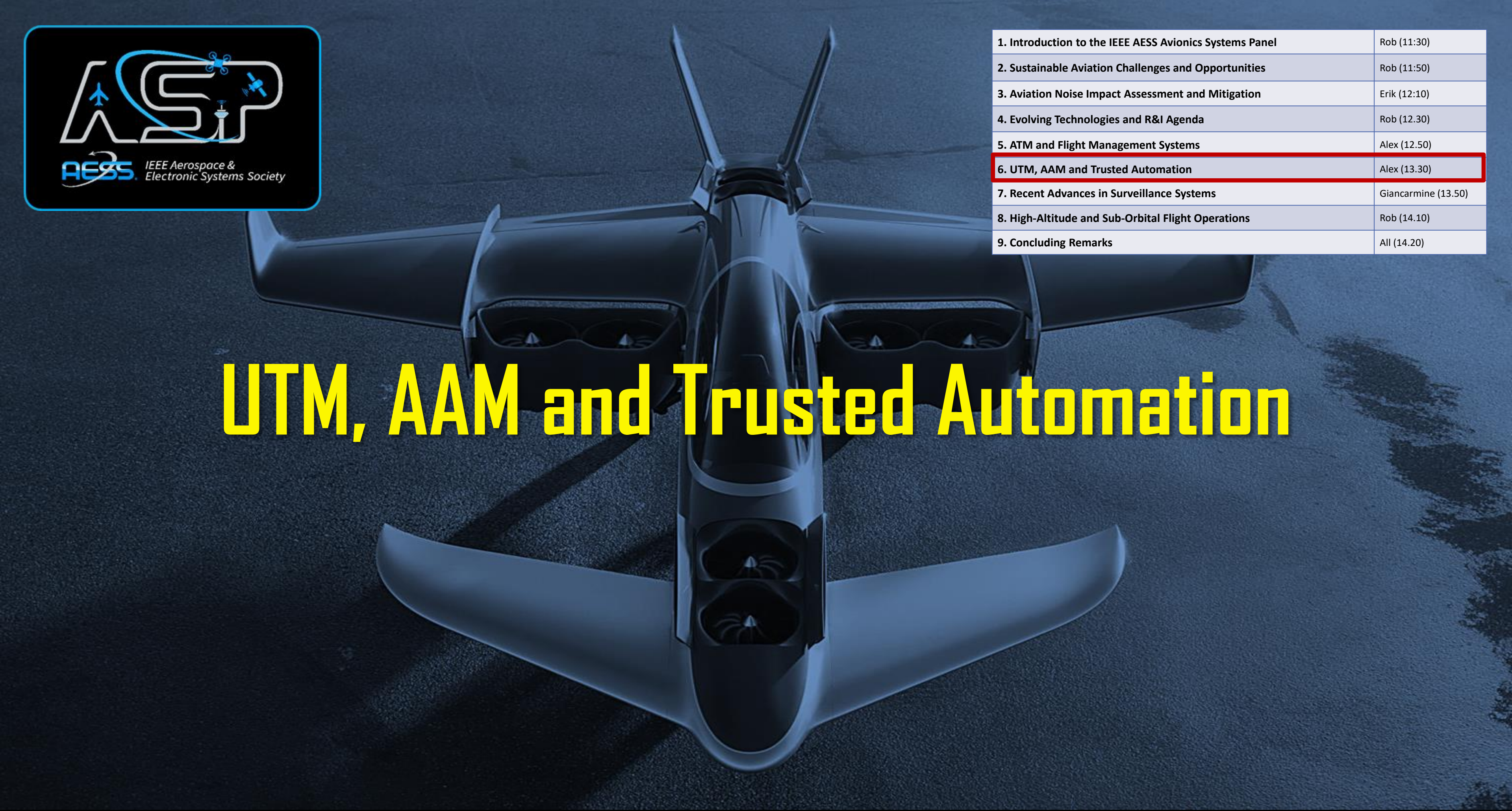
Optimised trajectory for minimum CO_2/fuel and contrail RF

MOTO for Contrail Mitigation – Radiative Forcing



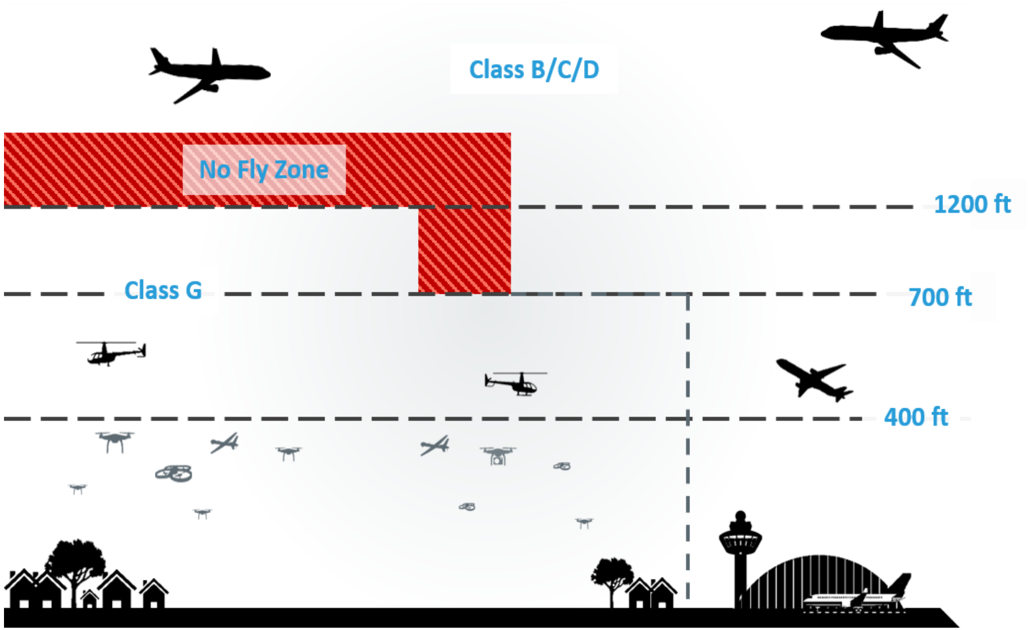
Boeing B777-200 4449 NM – 10h 24min flight time (CDG to PEK)

1. Introduction to the IEEE AESS Avionics Systems Panel	Rob (11:30)
2. Sustainable Aviation Challenges and Opportunities	Rob (11:50)
3. Aviation Noise Impact Assessment and Mitigation	Erik (12:10)
4. Evolving Technologies and R&I Agenda	Rob (12.30)
5. ATM and Flight Management Systems	Alex (12.50)
6. UTM, AAM and Trusted Automation	Alex (13.30)
7. Recent Advances in Surveillance Systems	Giancarmine (13.50)
8. High-Altitude and Sub-Orbital Flight Operations	Rob (14.10)
9. Concluding Remarks	All (14.20)



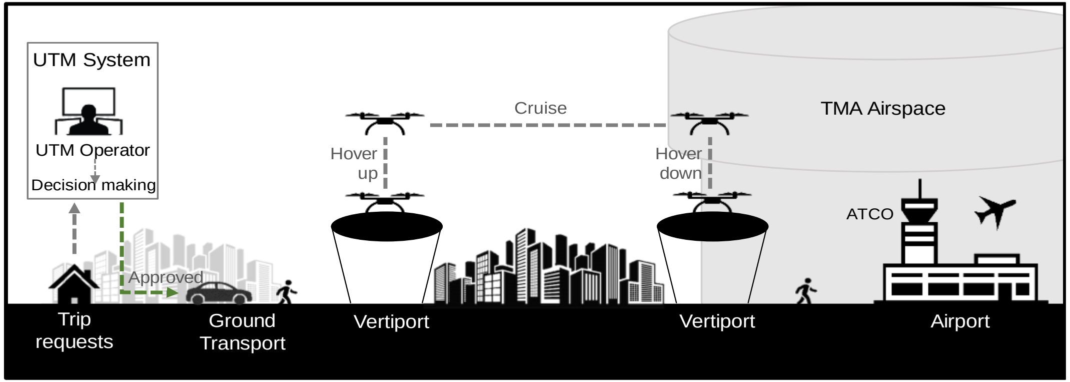
UTM, AAM and Trusted Automation

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

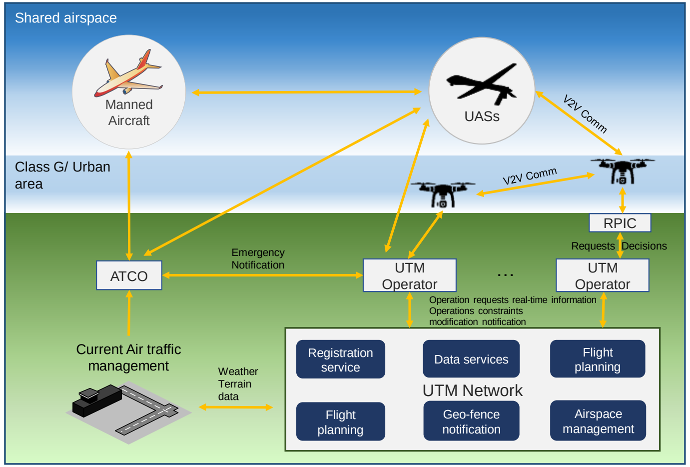
UTM and Advanced Air Mobility (AAM)



Advanced Air Mobility

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

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

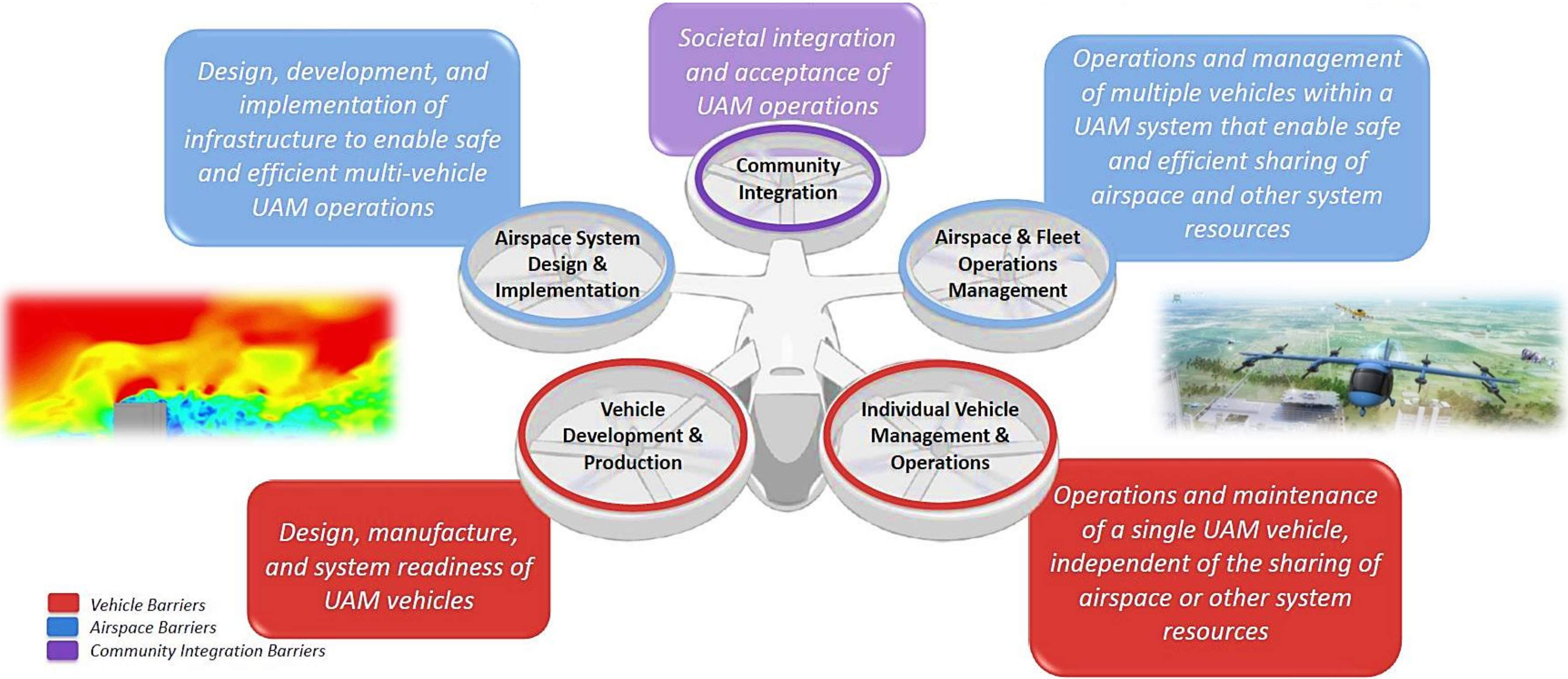


- UTM/AAM are moving towards trusted autonomy
- Highly automated human-in-the-loop operations bring about issues of responsibility allocation and mandate evolutions in the legal and regulatory frameworks (liability concerns)

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

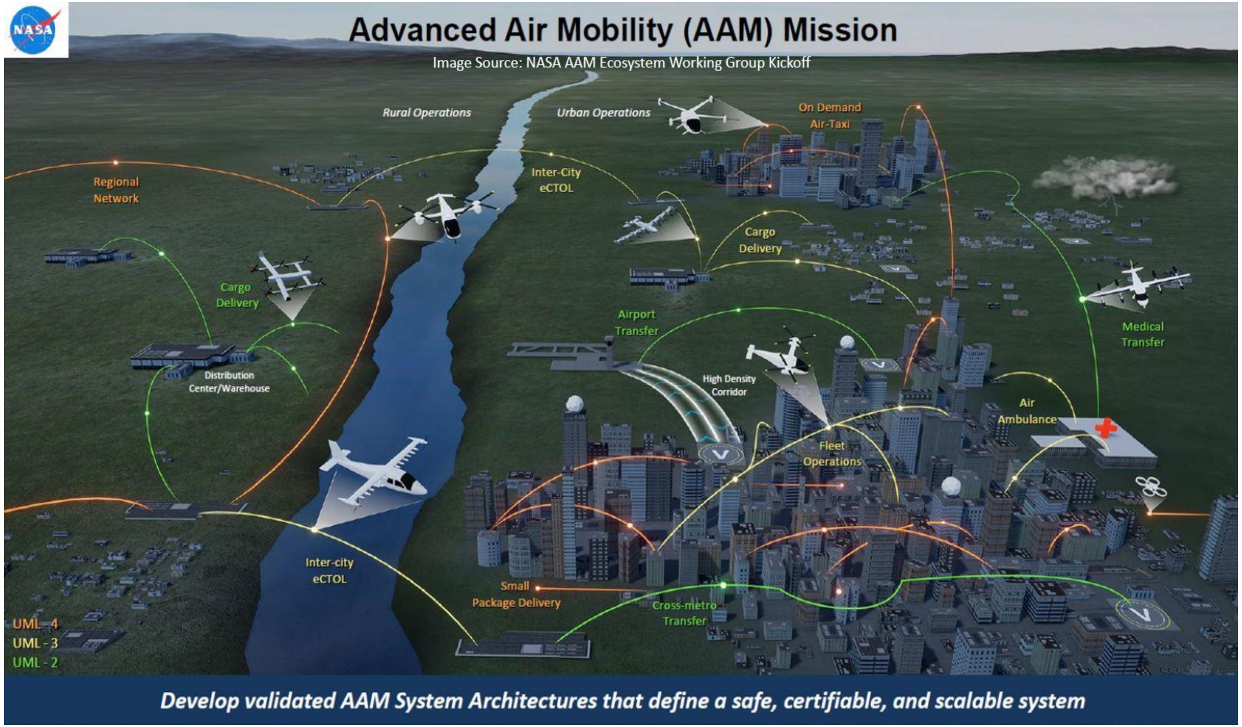
AAM Research Framework

Vision: Revolutionise mobility of metropolitan and regional areas by enabling a safe, efficient, convenient, affordable, and accessible air transportation system

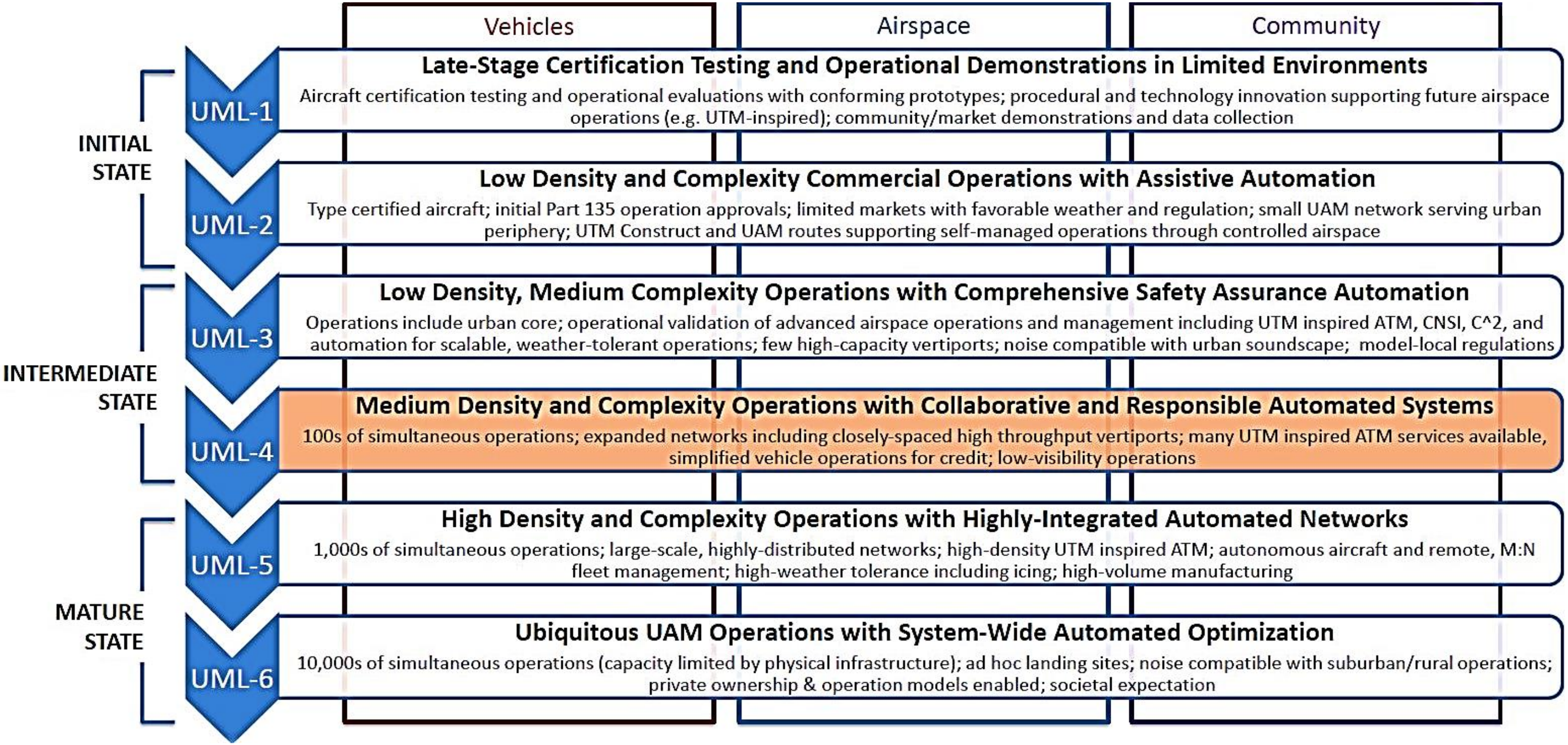


AAM/UAM Missions

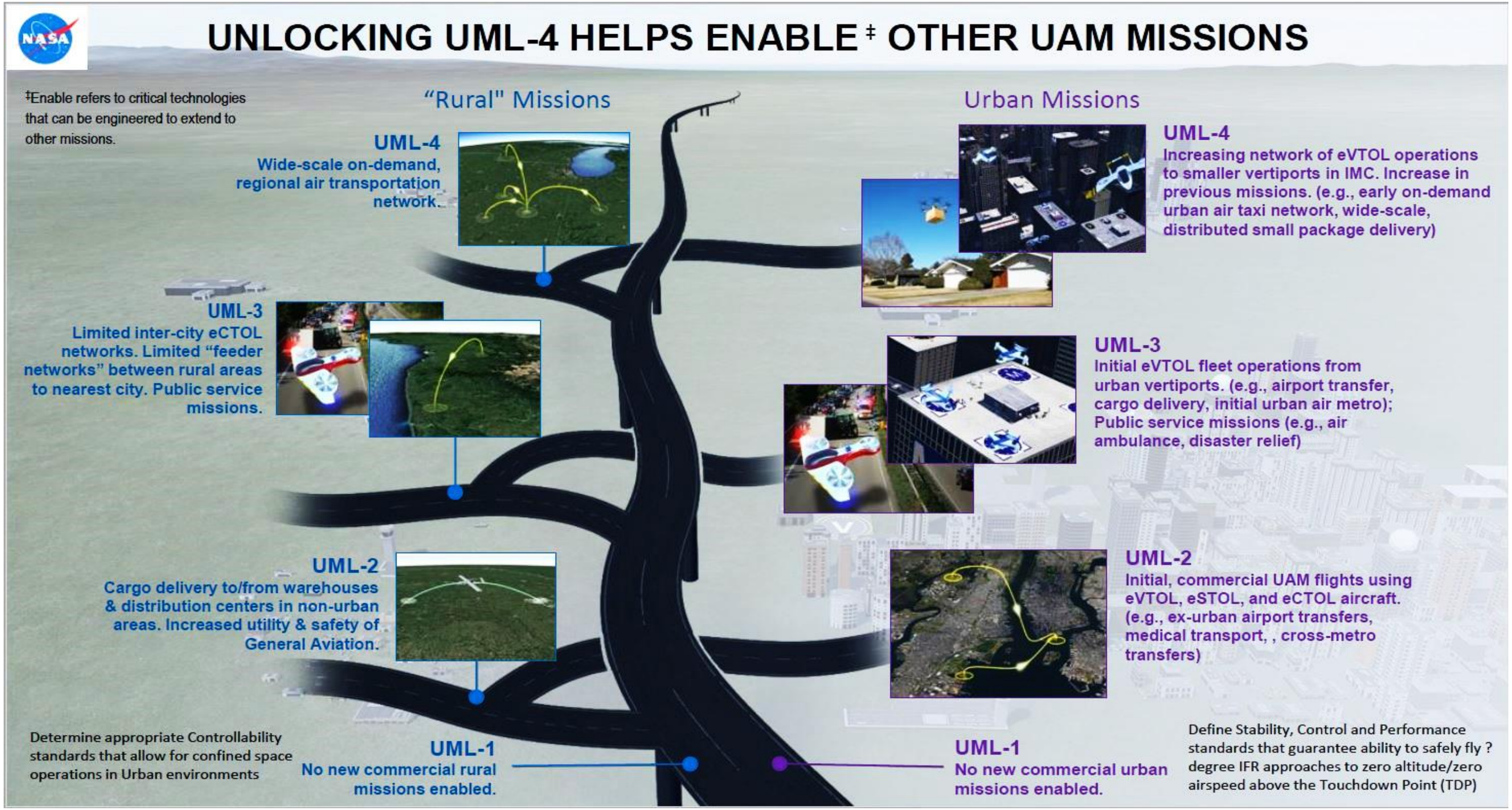
- ❖ Includes rural and urban applications
  - Cargo transport, aerial work, etc.
  - eVTOL, sUAS, hybrid-electric etc.
  - UAM as a challenging use-case
- ❖ Enabled by electrification and scaled through automation
- ❖ Does not include:
  - Supersonic or hypersonic
  - Existing hub-and-spoke



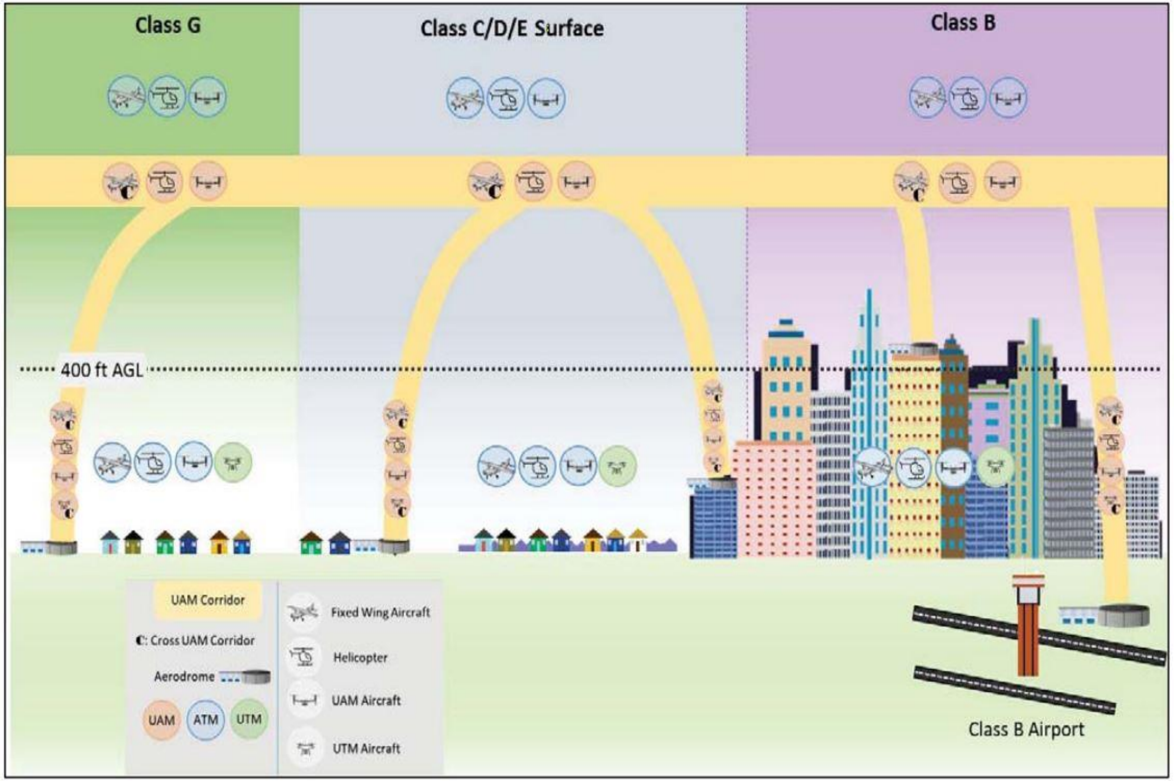
NASA UAM Maturity Levels (UML)



AAM/UAM Missions



Evolutionary systems for UTM and AAM



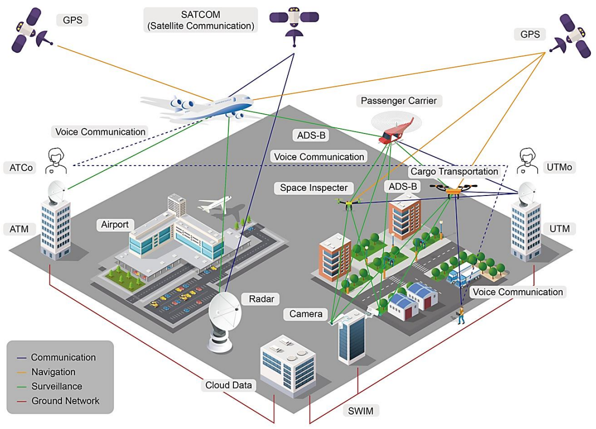
- ❖ Integrated CNS (ICNS) for the large amount of data/information that needs to be exchanged
- ❖ On-board vehicle situational awareness and sensors required
- ❖ Vertiport infrastructure
- ❖ Time-Based Flow Management
  - PBN and TBO
  - Sequencing and Spacing
  - Congestion Management
- ❖ Moving towards **PBO**
- ❖ Health/performance monitory systems (safety-critical)
- ❖ Microclimate sensor requirements
- ❖ Cyber-physical security

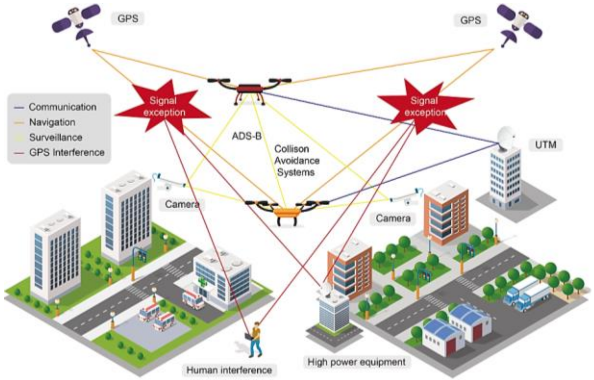
Evolving ATM Cyber-Landscape

- 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 and STM) involves substantially greater amounts of data exchanged in real-time across an increasing number of stakeholders

Key Challenges

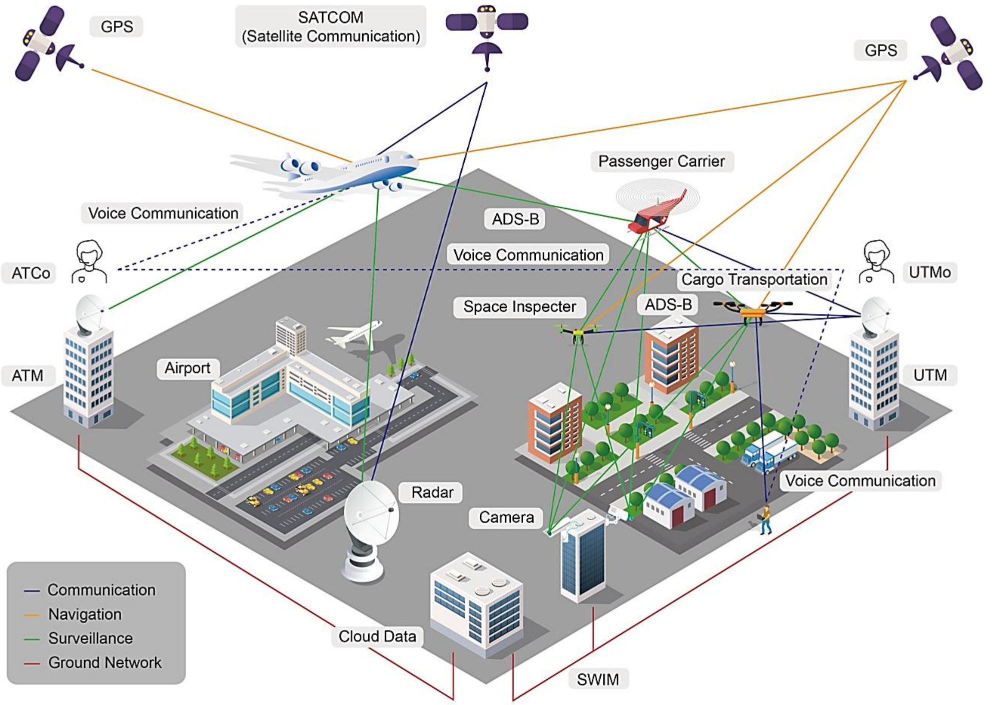
- Evolving ATM & UTM architectures based on big data and AI plus increased interdependence of CNS/ATM and avionics systems result in an increasing attack surface
- AI-based offensive technologies are bound to become very common, requiring AI-based cyber-defenses
- Need for a new generation of security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





Cybersecurity Vulnerabilities in ATM and UTM

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

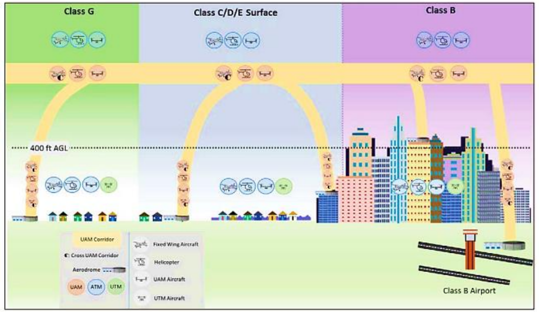


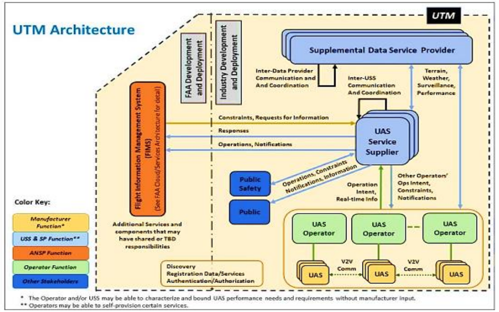
Y. Xie, A. Gardi, and R. Sabatini, "Cybersecurity Trends in Low-Altitude Air Traffic Management", AIAA/IEEE Digital Avionics Systems Conference, DASC 2022.

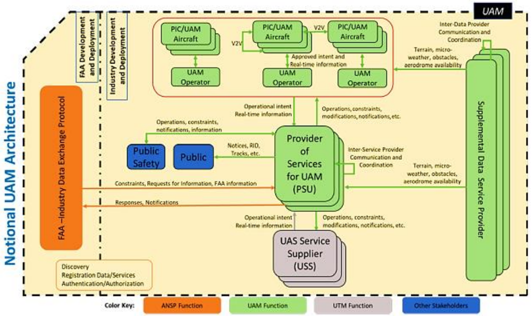
Y. Xie, A. Gardi, and R. Sabatini, “Cybersecurity Risks and Threats in Avionics and Autonomous Systems.” 8th IEEE Cyber Science and Technology Congress (CyberSciTech 2023), Abu Dhabi, UAE, November 2023.

Future 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)



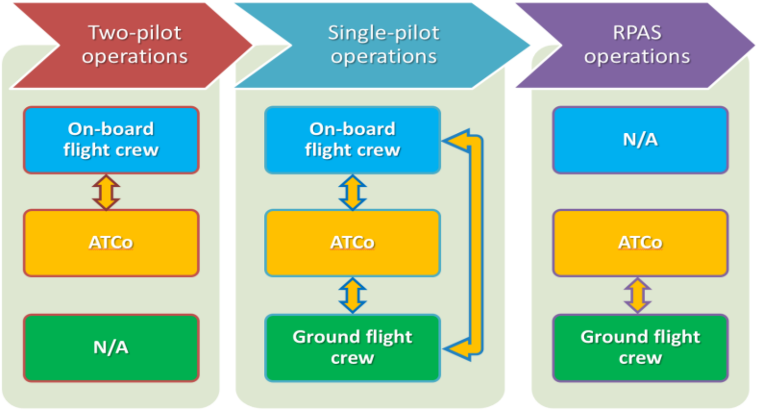


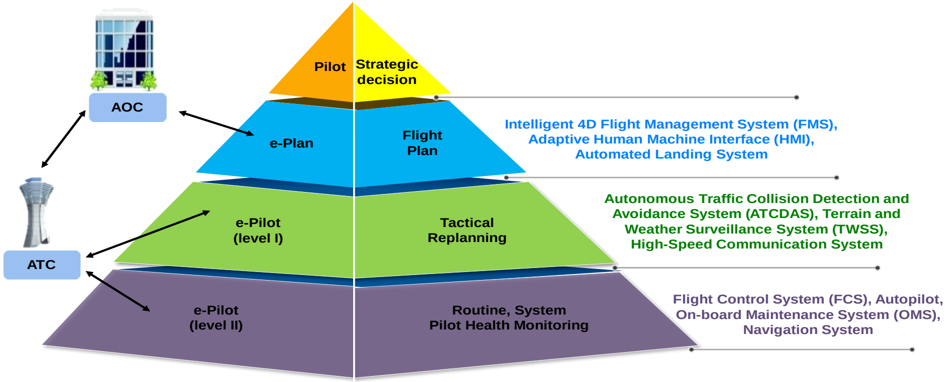


Trusted Automation Research: Focus on SiPO and RPAS

SiPO to RPAS in Conventional Airspace

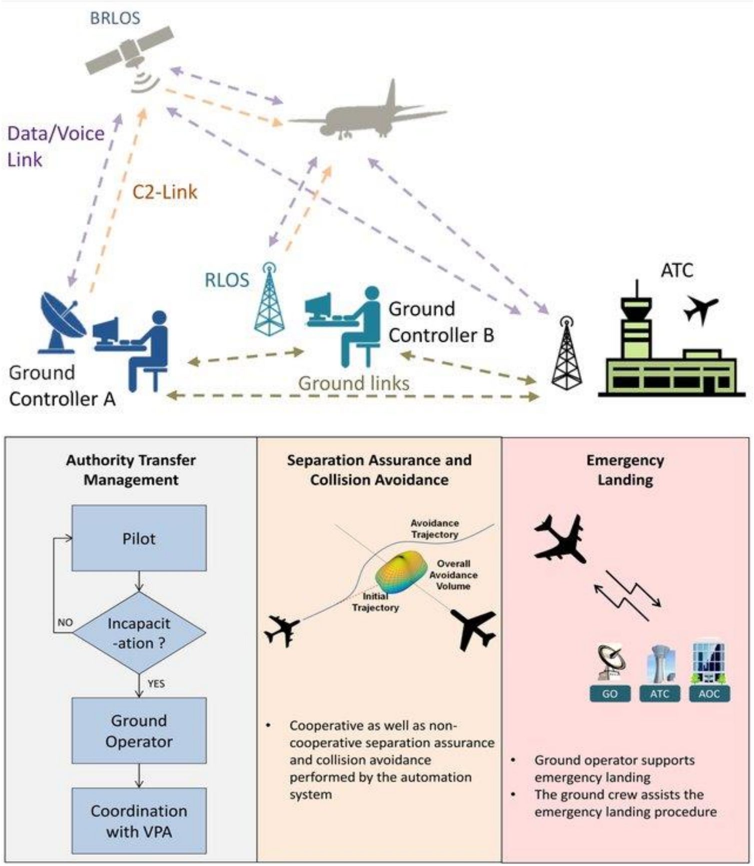
- Improve the total system performance through highly automated CNS+A systems supporting human-machine teaming
- Adaptive Human-Machine Interfaces and Interactions (HMI2) based on:
  - Real-time avionics systems integrity monitoring
  - Sensing of neuro-physiological parameters and AI-based estimation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

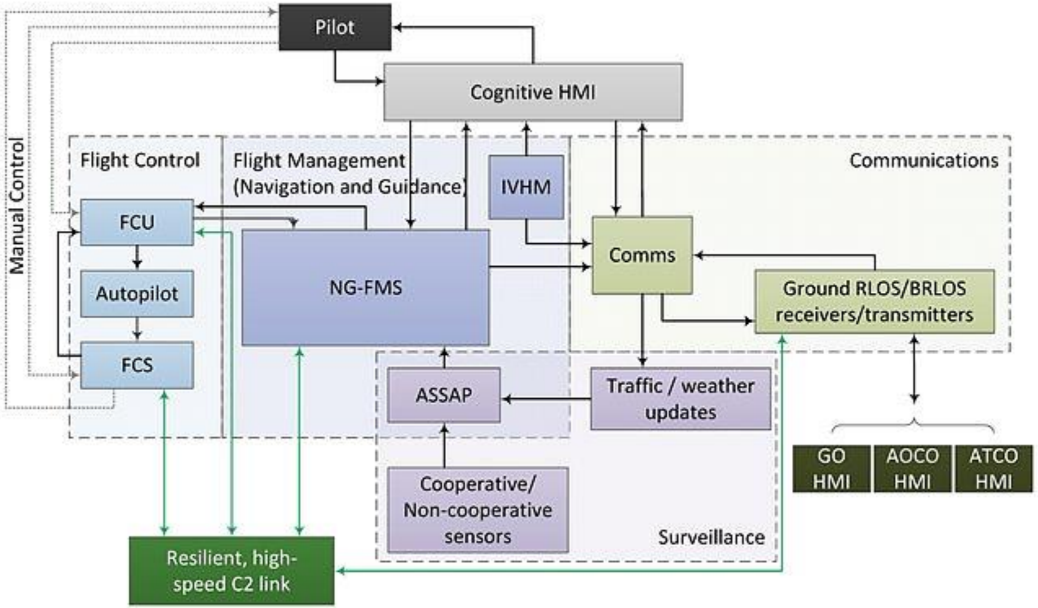




Ref.: Y. Lim, V. Bassien-Capsa, S. Ramasamy, J. Liu, and R. Sabatini, "Commercial airline single-pilot operations: System design and pathways to certification", IEEE Aerospace and Electronic Systems Magazine, vol. 32, pp. 4-21, 2017. DOI: 10.1109/MAES.2017.160175

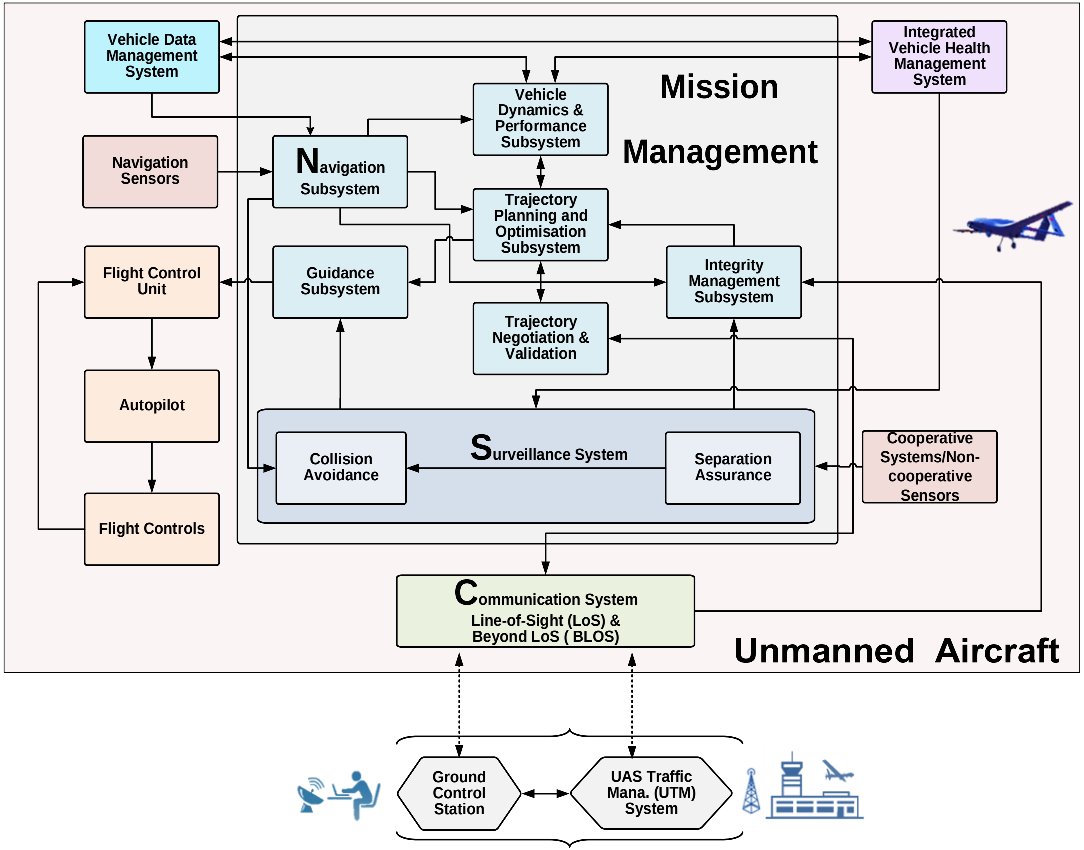
SiPO Avionics Architecture





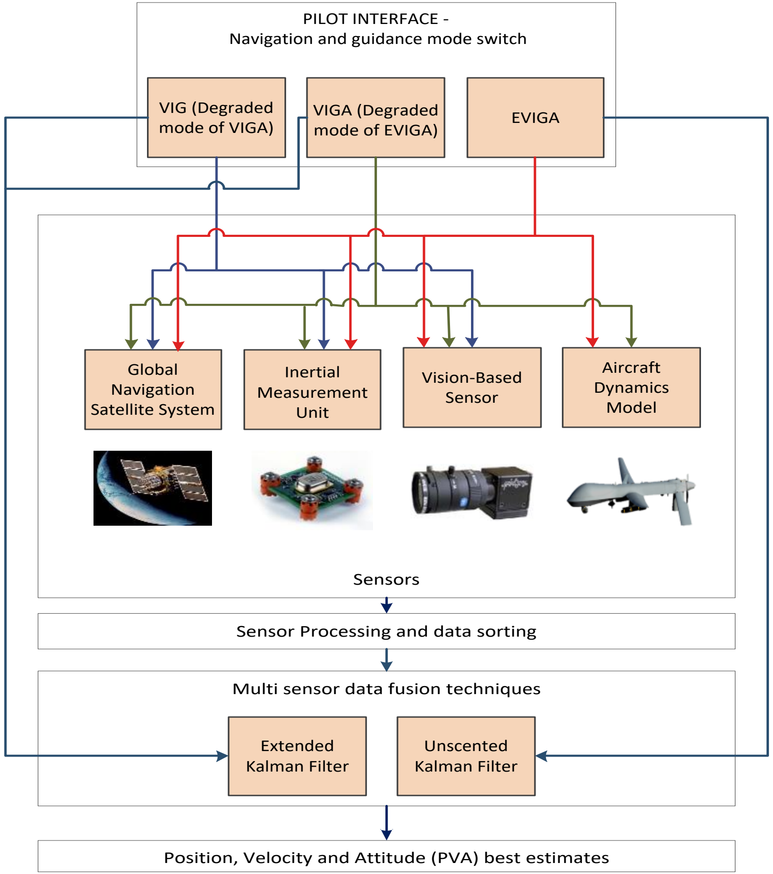
Ref.: Y. Lim, V. Bassien-Capsa, S. Ramasamy, J. Liu, and R. Sabatini, "Commercial airline single-pilot operations: System design and pathways to certification", IEEE Aerospace and Electronic Systems Magazine, vol. 32, pp. 4-21, 2017. DOI: 10.1109/MAES.2017.160175

UAS Avionics Developments



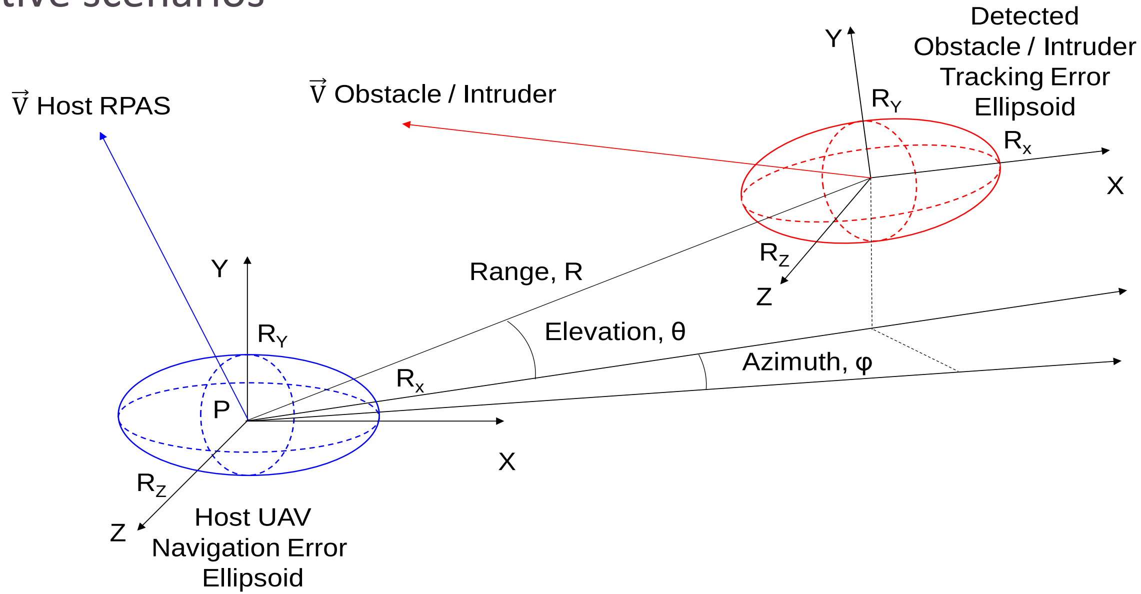
Low SWAP-C Navigation Systems

Data	Position	Velocity	Attitude Angles	Attitude Rates
IMU	✓	✓	✓	✓
GNSS	✓	✓		
ADM	✓	✓	✓	✓
VBS			✓	✓



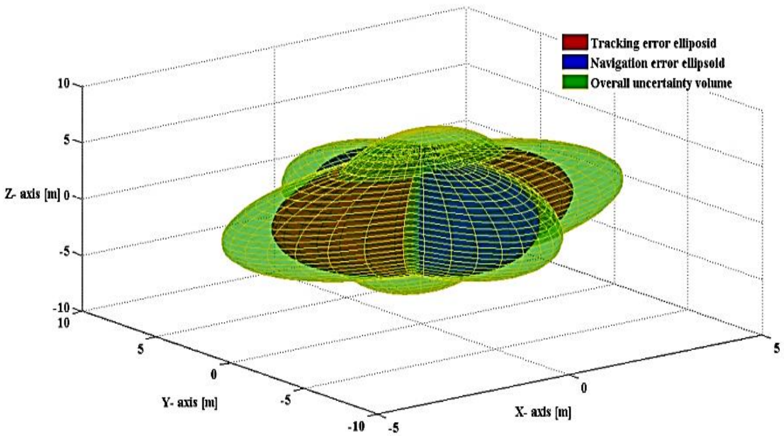
Separation Assurance and Collison Avoidance

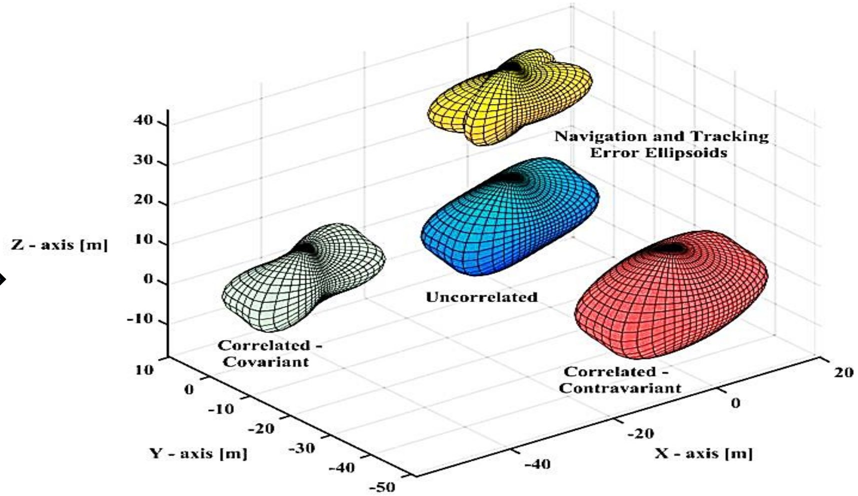
- **Avoidance volume** in the airspace surrounding each track is determined
- Accomplished by **considering both navigation and tracking errors** affecting the measurements (plus disturbances) and translating them to **unified range and bearing uncertainty descriptors**, which apply both to cooperative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



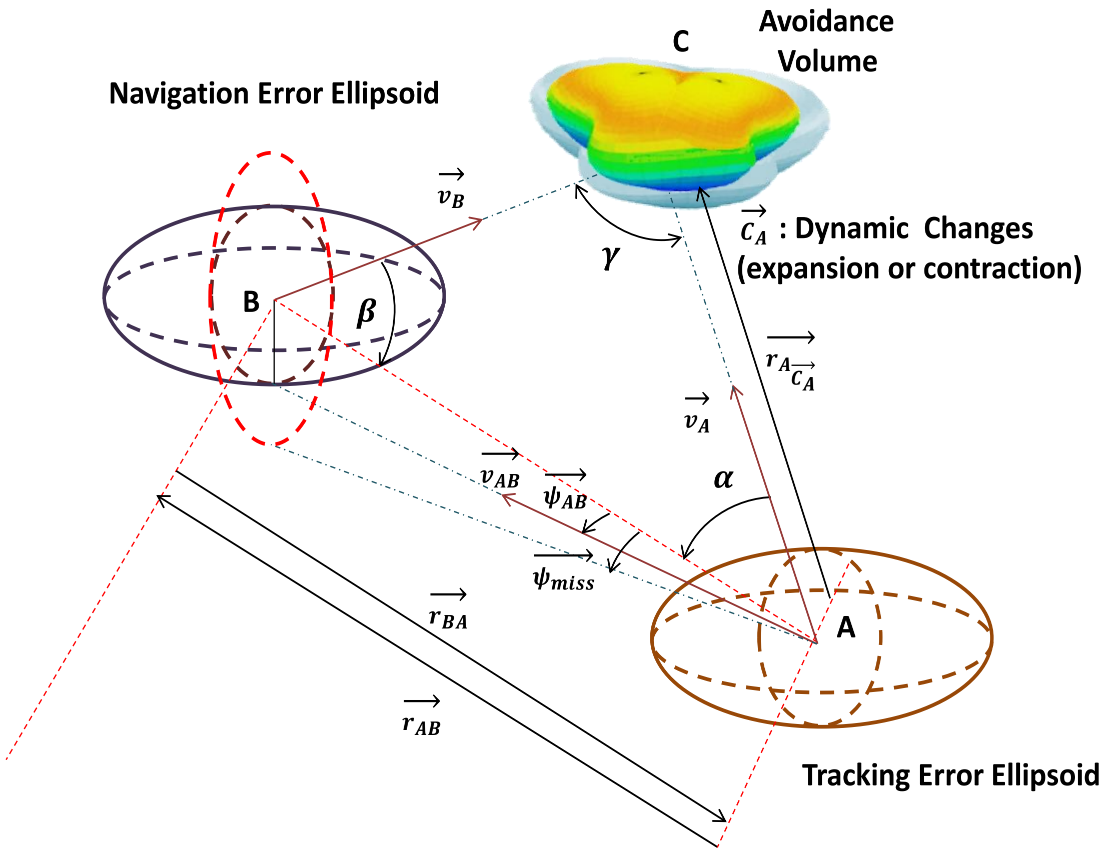
SA/CA – Error Analysis

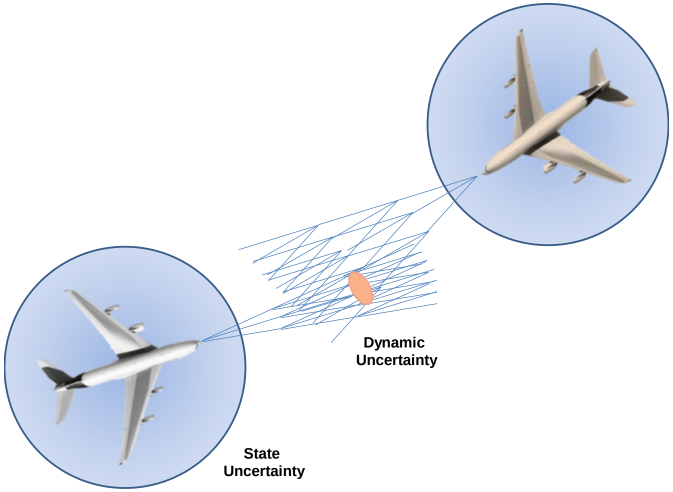
- Errors are statistically correlated (e.g., ADS-B) or uncorrelated (e.g., NC-SAA)
- The avoidance (uncertainty) volume for uncorrelated measurements is obtained by inflating the navigation ellipsoid with the tracking error components
- The uncertainty volume for correlated errors is obtained using vector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





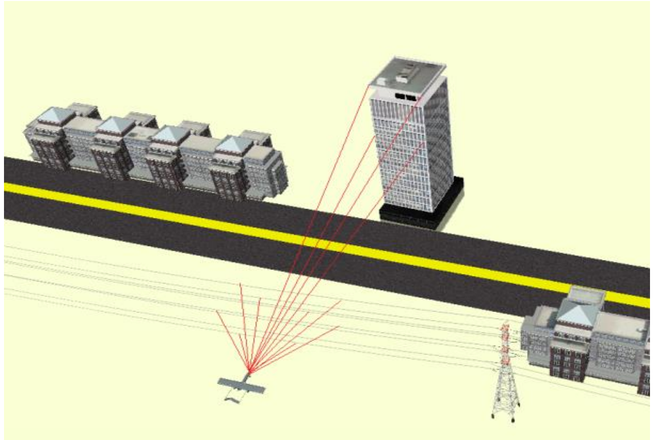
SA/CA – Relative Dynamics and Inflations

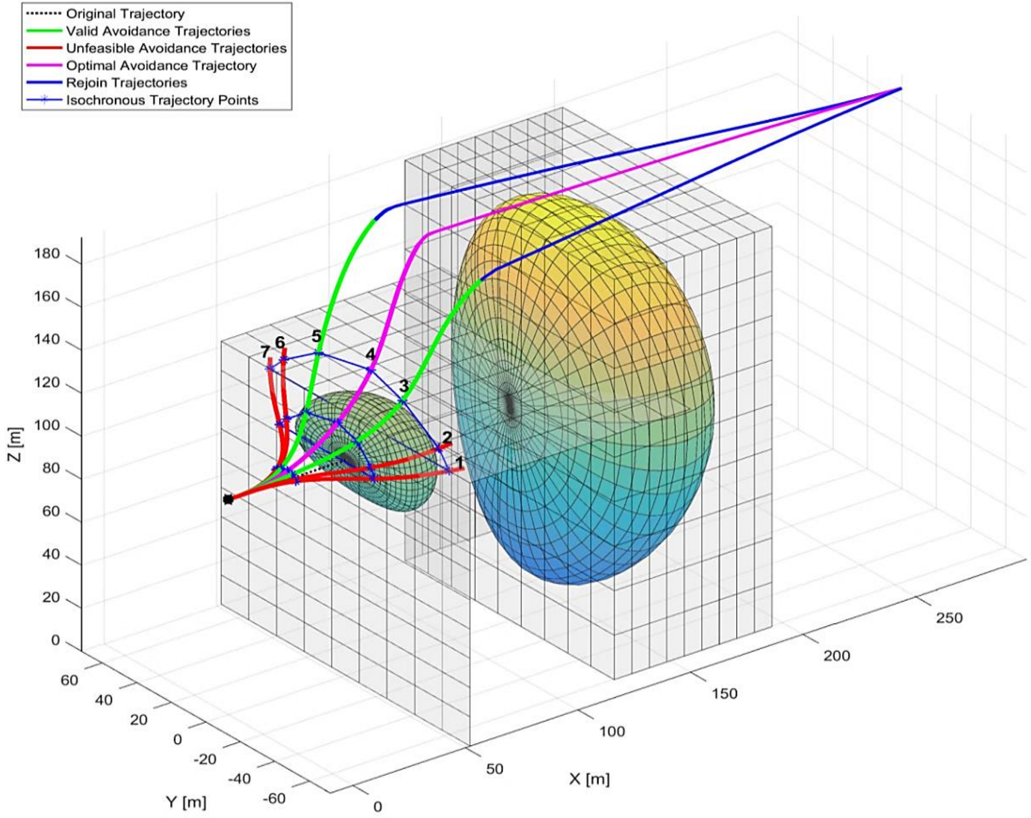




SA/CA – Safety-critical Applications

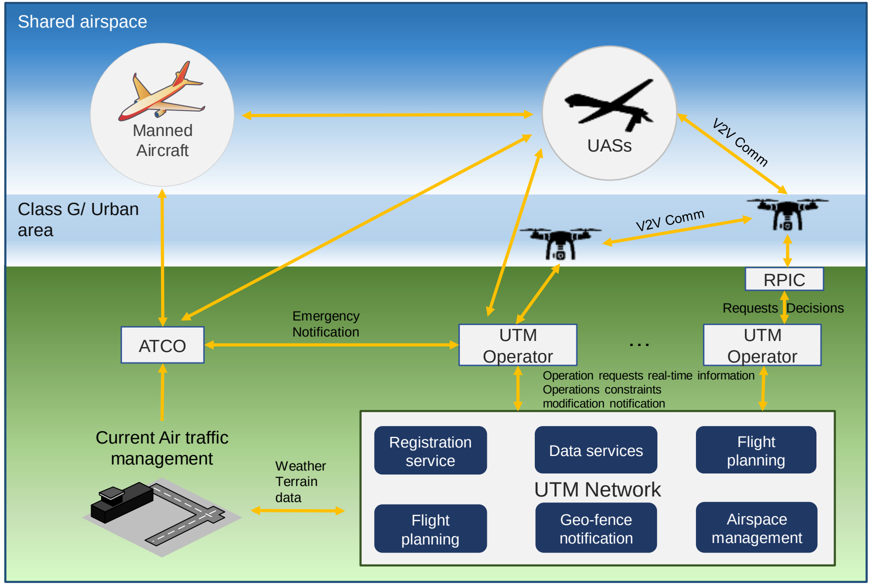
- Uncertainty volumes for avoidance of ground obstacles
  - A set of feasible avoidance trajectories is generated in real-time

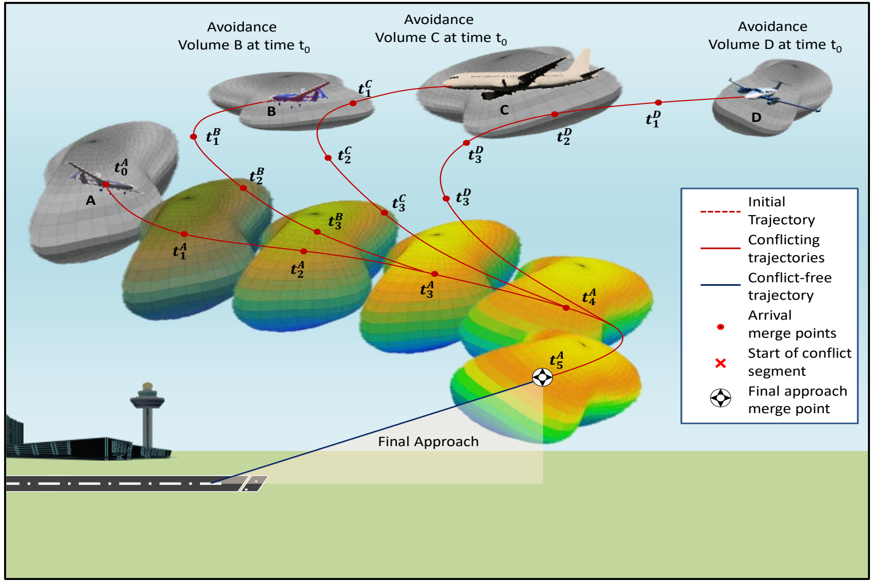




UAS Traffic Management

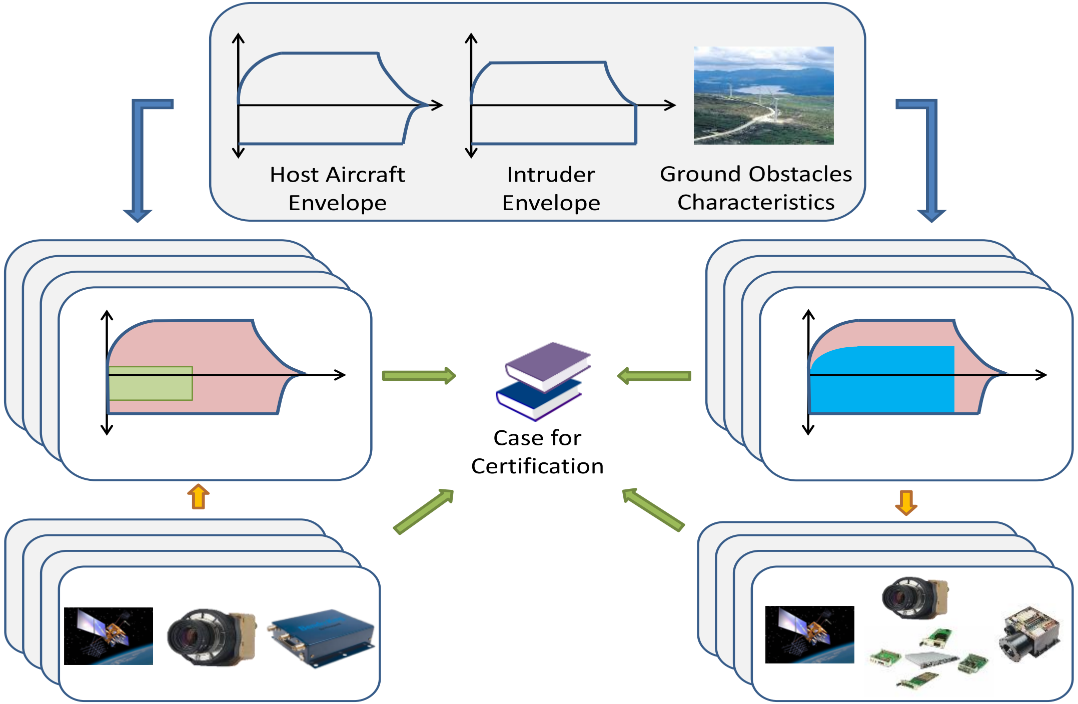
- The unified approach supports trusted autonomous operations in the UAS Traffic Management (UTM) context
- Avoidance volumes (i.e., dynamic geo-fences) are generated in real-time to allow computation of the optimal avoidance flight trajectories





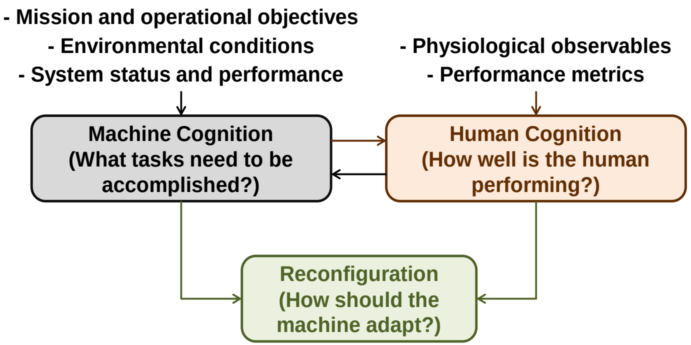
SA/CA – Pathway to Certification

- 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



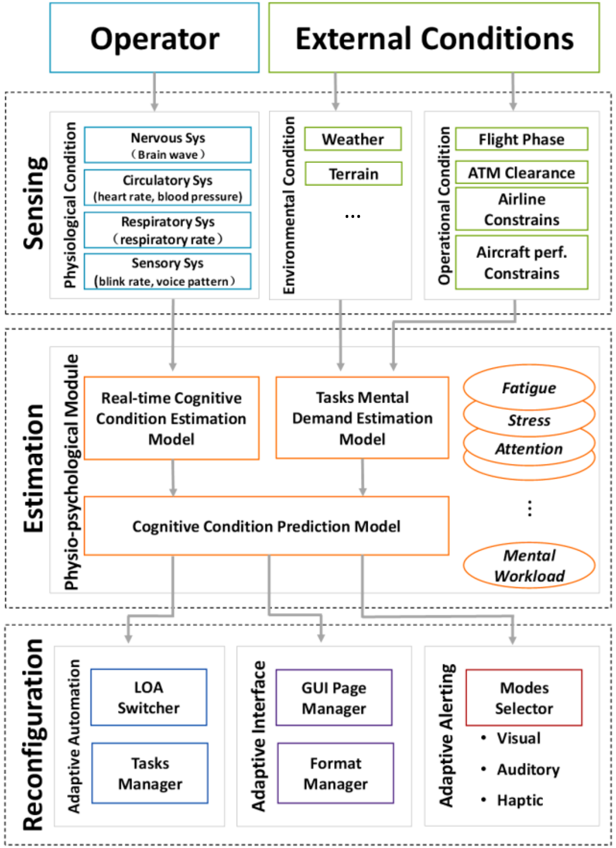
Human-Machine Interfaces and Interactions

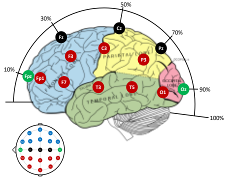
- This project addresses the development of closed-loop human-machine systems implementing Cognitive Human Machine Interfaces and Interactions (CHMI^2)
- CHMI^2 supports human-machine teaming whereby a system senses and adapts to the mission environment and the cognitive state of the operator



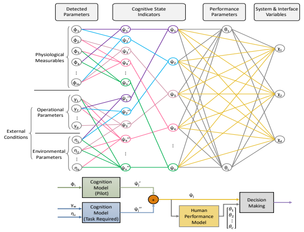
- The CHMI^2 concept enables **Trusted Autonomous Operations** in both mission-critical and safety-critical applications

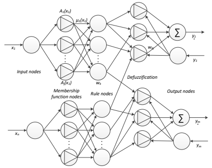
CHMI^2 Framework



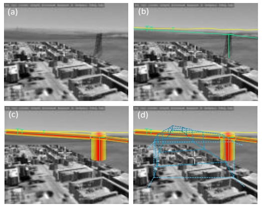


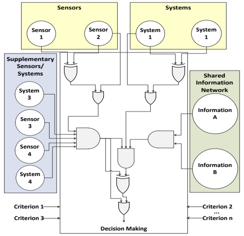
Sensing: uses a suite of sensors to measure neuro-physiological observables in real time, and extracts relevant features from the observables





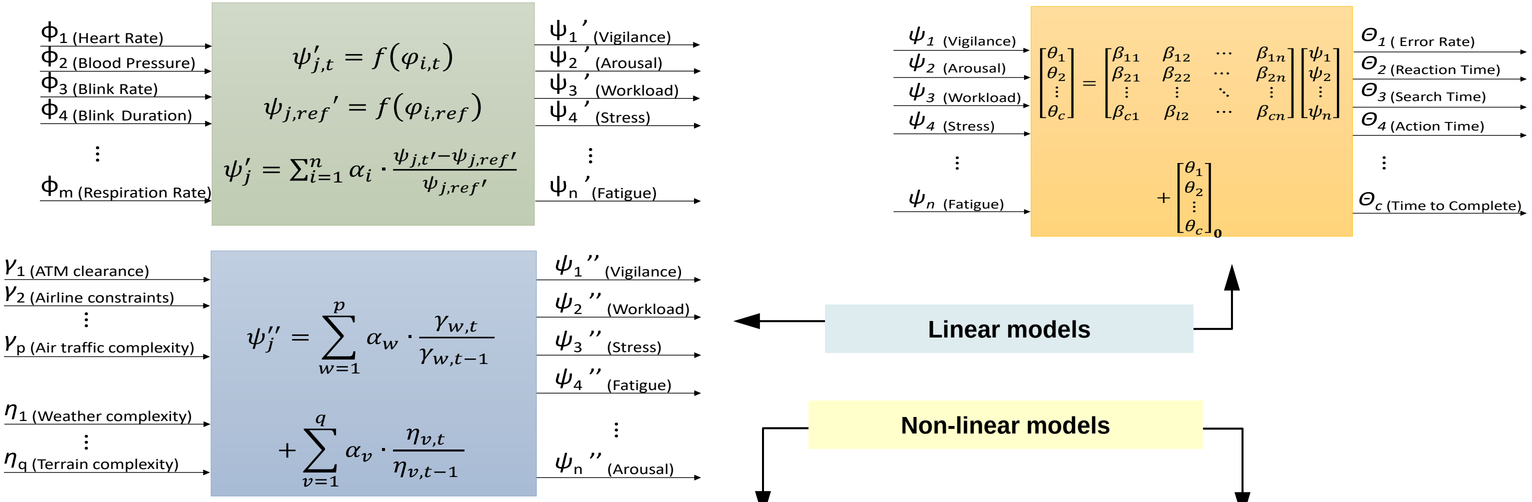
Inference: infers cognitive states from the features in the sensing layer using various artificial intelligence (and machine learning) techniques





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

CHMI[2] Mathematical Framework

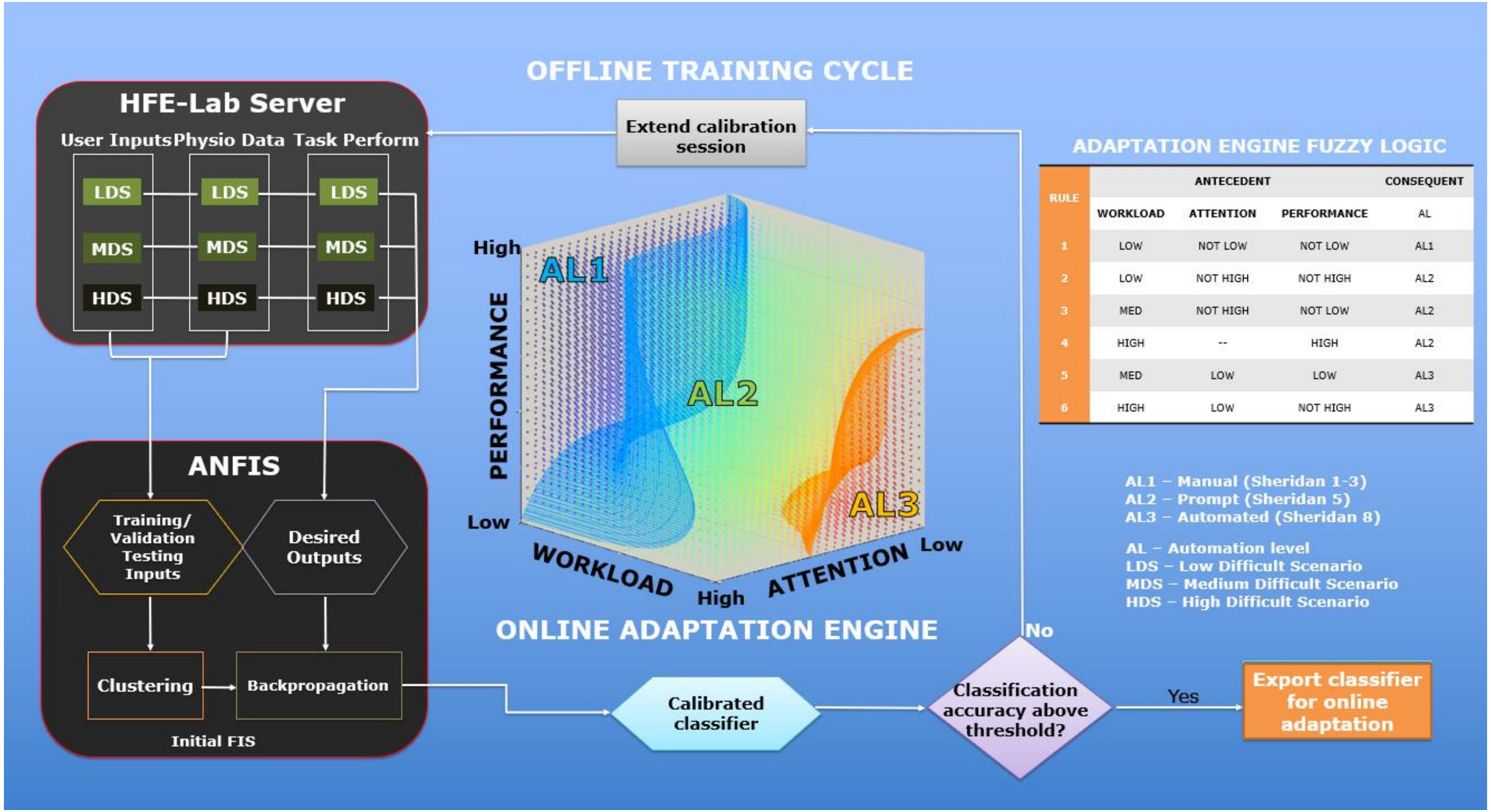


	Fixation time	Glance count	Saccade dispersion	Dwell time	Visual Entropy	Pupil dilation	Heart rate	Resp. Rate	Blink rate
Vigilance	Q-N	L-P	Q-N	Q-N	Q-N	L-P	-	-	L-N
Workload	SPL-P	-	L-N	SPL-P	L-N	L-P	L-P	L-P	L-N
Attention	L-P	SBL-N	L-N	L-P	L-N	L-P	SPL-P	-	L-N

	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

Inference Engine

Cognitive Adaptation Methodology (Summary View)

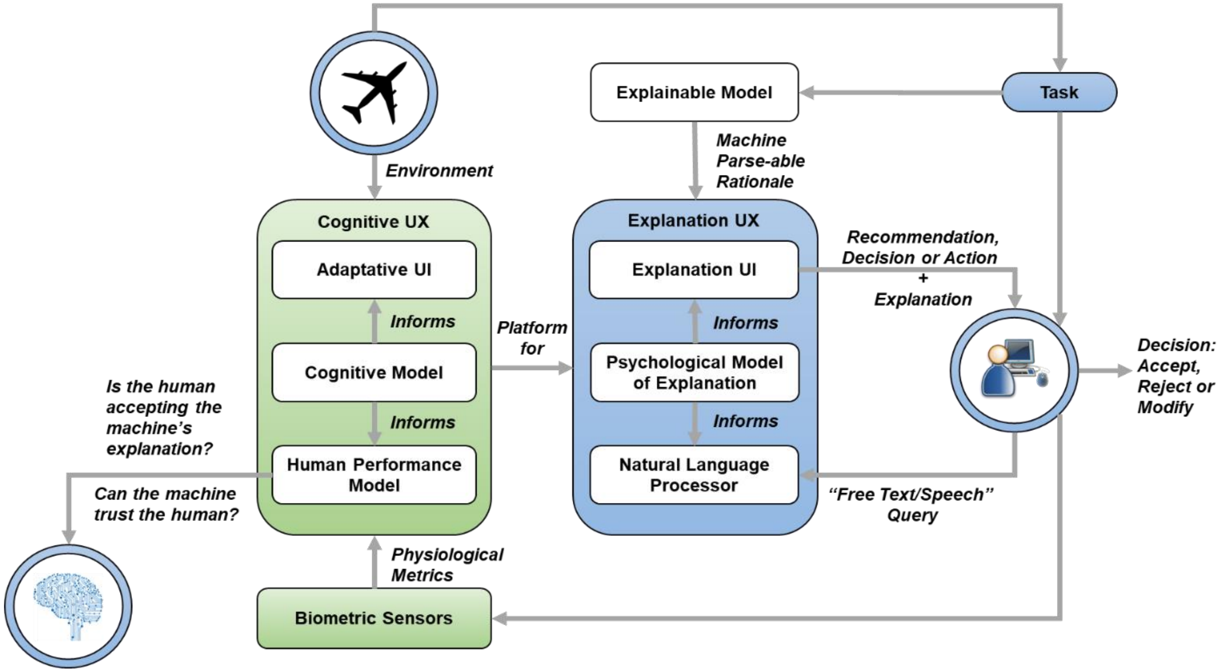


RULE	ANTECEDENT			CONSEQUENT
	WORKLOAD	ATTENTION	PERFORMANCE	AL
1	LOW	NOT LOW	NOT LOW	AL1
2	LOW	NOT HIGH	NOT HIGH	AL2
3	MED	NOT HIGH	NOT LOW	AL2
4	HIGH	--	HIGH	AL2
5	MED	LOW	LOW	AL3
6	HIGH	LOW	NOT HIGH	AL3

Challenges for AI Certification in Aviation

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

Current Research: Cognitive HMI and Explanation UX



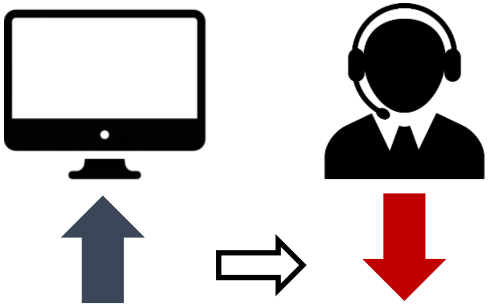
- Explainable AI
- Trusted AI
- Certifiable AI

Current Research: HOTL Dynamic Interactions

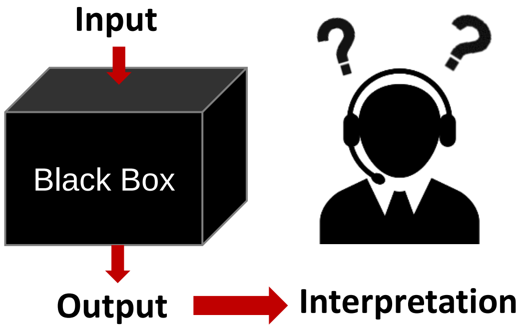
Challenges

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

- Lower cognitive capability
- Progressive deskilling
- Lower situational awareness



Human Factors



AI Explanation

Solution

Adaptive HMI based on Explainable and Trusted AI

Cognitive Human-Machine Systems (CHMS)

1. Introduction to the IEEE AESS Avionics Systems Panel	Rob (11:30)
2. Sustainable Aviation Challenges and Opportunities	Rob (11:50)
3. Aviation Noise Impact Assessment and Mitigation	Erik (12:10)
4. Evolving Technologies and R&I Agenda	Rob (12.30)
5. ATM and Flight Management Systems	Alex (12.50)
6. UTM, AAM and Trusted Automation	Alex (13.30)
7. Recent Advances in Surveillance Systems	Giancarmine (13.50)
8. High-Altitude and Sub-Orbital Flight Operations	Rob (14.10)
9. Concluding Remarks	All (14.20)

Recent Advances in Surveillance Systems

Autonomy and CNS/ATM Technologies for Sustainability

- Advanced autonomy can indirectly enhance aviation sustainability in different operation scenarios, ranging from conventional ATM to the new UAM/AAM ecosystem

- CNS/Traffic Management technologies as key enablers

Autonomy and CNS/ATM Technologies for UAM and AAM

- ❖ UAM and AAM: a new and disruptive dimension for aviation, potentially enabling mobility of goods and people at a different scale compared with current operations
- ❖ UAM/AAM can be considered as a part of the aviation de-carbonization strategy, with sustainability as a priority
- ❖ Autonomy supported by CNS/ATM technologies has emerged as a key technological tool to realize the UAM/AAM vision

https://www.nasa.gov/mission/aam/

Autonomy and CNS/ATM Technologies for UAM and AAM

- Autonomy as a pre-requisite to scale up operations while keeping the required levels of efficiency, safety, and security

- High density scenarios involving **Beyond Visual Line of Sight** (BVLOS) operations: need to move towards **adaptive M-to-N scenarios** where aircraft are highly autonomous and the role of human is more and more connected to the concept of supervision and fleet management

- Reliable autonomous **navigation** is needed to ensure safe and secure operations in spite of the many potential issues affecting navigation sources in urban environments

- Autonomy is also required within the **traffic management** architecture, where the role and functions of human controllers in traditional ATM systems cannot be extended and need to be conceived in a different perspective, with intelligent path planning approaches to be exploited both at strategic and at tactical level.

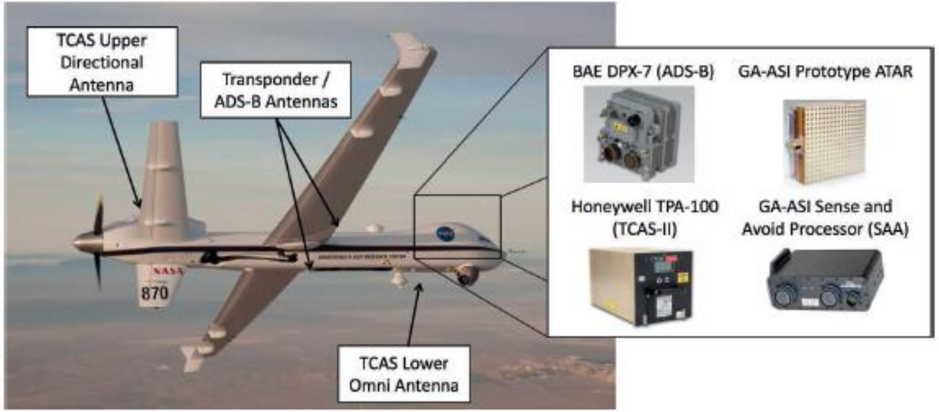
- Furthermore, autonomy is also a key element for **surveillance** and for **detect and avoid** systems which have to represent the last protection layer against the possible losses of separation with ground and air obstacles

Recent Trends in Surveillance Systems

- Detect and Avoid
  - Radar Sensing
  - Visual Sensing
  - Artificial Intelligence
- Ground-based sensing and air/ground interaction

Trends – Radar Sensing

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



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

Trends – Radar Sensing

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

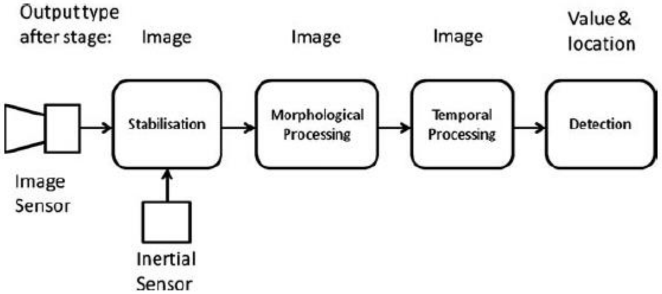
https://echodyne.com/products/echoflight/

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

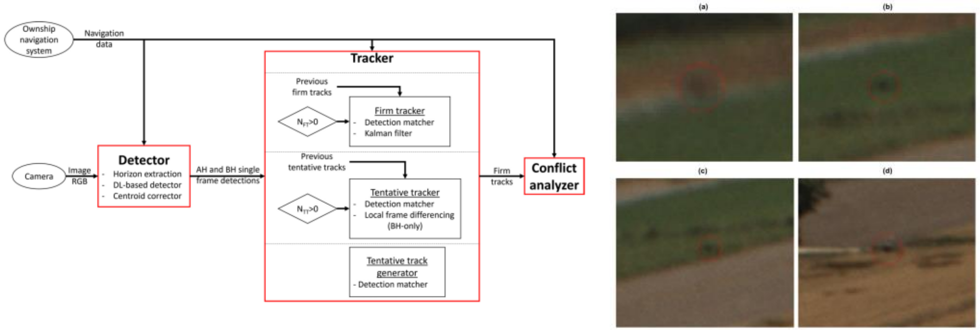
(https://ntrs.nasa.gov/api/citations/20210009973/downloads/NASA-CR-20210009973.pdf)

Trends – Visual Sensing

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



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



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

Trends - Visual Sensing

- ❖ Deep learning also exploited in commercial solutions (airborne and ground-based)

- ❖ Emphasis on detection and tracking of manned aircraft
  - Non cooperative traffic detection to improve safety figures of general aviation

- ❖ Very large datasets for training, based on synthetic and flight data

- ❖ Airborne visual detection and tracking as test case in EASA – Daedalean project “Concepts of Design Assurance for Neural Networks II” (CoDANN II) aimed at examining the challenges posed by the use of neural networks in aviation
  - https://www.easa.europa.eu/newsroom-and-events/news/easa-publishes-second-joint-report-learning-assurance-neural-networks

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

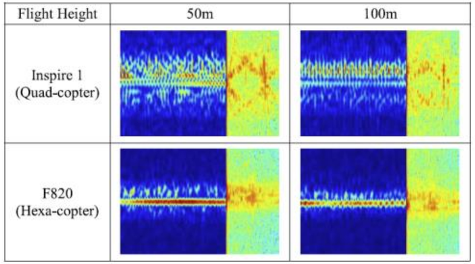
(https://daedalean.ai/products/detection)

AI in Sense and Avoid

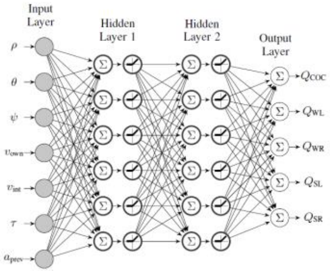
- AI potential is being investigated in the whole SAA pipeline

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

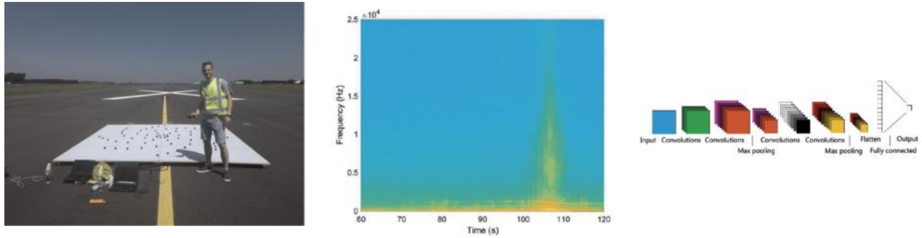
- Decision-making
  - Neural networks to compress look-up tables in ACAS-sXu
  - Reinforcement learning
  - End-to-end AI-based solutions
  - Many recent approaches are relevant to Micro Aerial Vehicles and agile flight in cluttered environments



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



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



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

AI/ML in SAA – Considerations

- AI/ML approaches represent well assessed techniques, especially considering visual sensing

- Research perspectives and upgrades concern the entire SAA pipeline

- Dataset availability
  - Experimental tests in relevant environments
  - Challenges

- Combination of real and synthetic data
  - Generalization, performance/computational trade-offs
  - Datasets for new operating environments

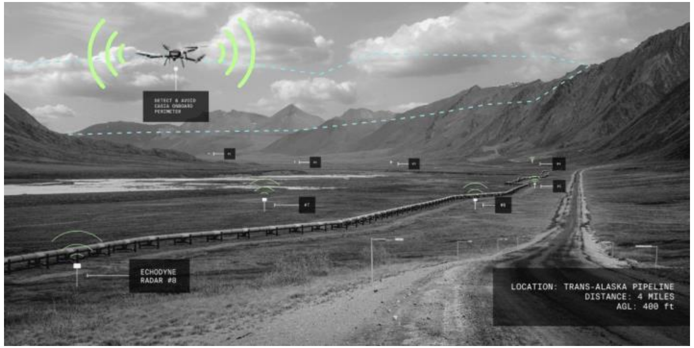
- Certification
  - dataset characterization
  - stochastic nature of non cooperative sensing
  - multi-stage processing pipelines $\rightarrow$ system level perspective

Trends - Ground-based sensing

- Main Technologies

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

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



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

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

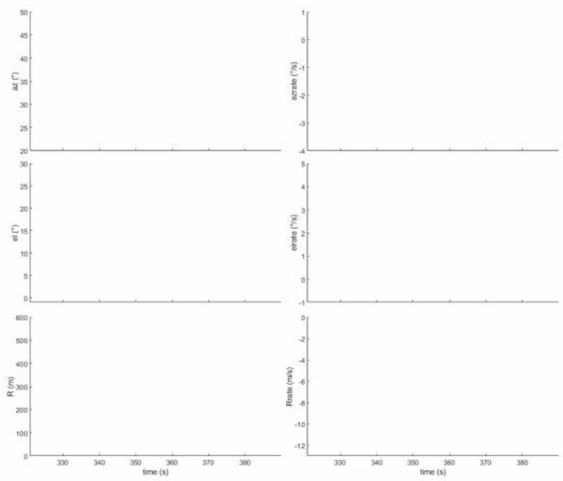
Ground-to-Air Radar/Optical Fusion

- Low altitude sensing challenges due to clutter and slow targets

- Ad hoc techniques needed to remove ground echoes

- Fusion of low SWaP radar and optical sensors can improve sensing accuracy and integrity

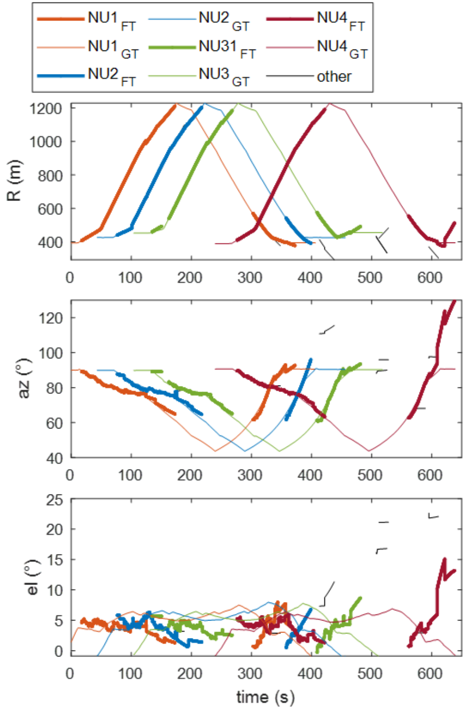
- Ground truth - Firm track ° radar detection



(Vitiello et alii, Radar/Visual Fusion With Fuse-Before-Track Strategy For Low Altitude Non-Cooperative Sense And Avoid, Aerospace Science and Technology 2024)

Distributed Sensing

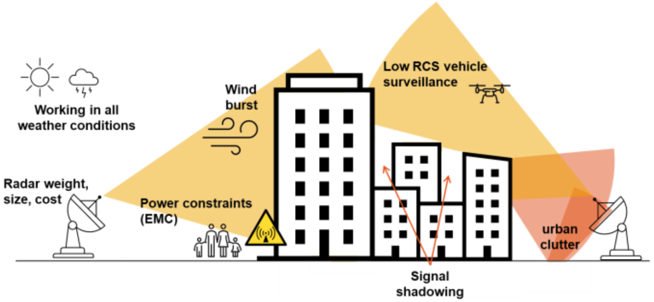
- Exploiting a network of ground-based and airborne sensing sources
  - Radar, optical, multi-sensor-based
- System design and sensing algorithms

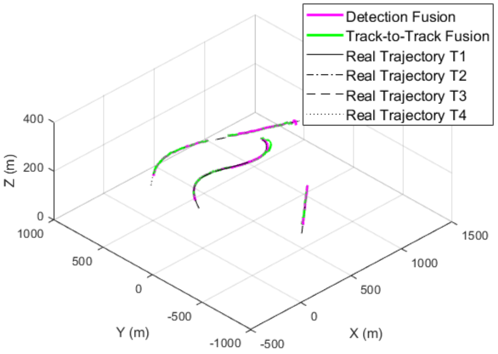


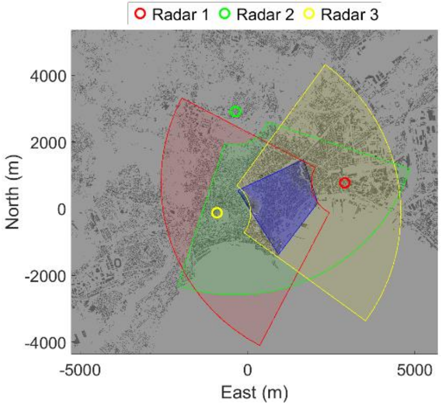
(Vitiello et alii, Assessing Performance of Radar and Visual Sensing Techniques for Ground-To-Air Surveillance in Advanced Air Mobility, AIAA/IEEE DASC 2023
Vitiello et alii, Experimental testing of data fusion in a distributed ground-based sensing network for Advanced Air Mobility, AIAA Scitech 2024)

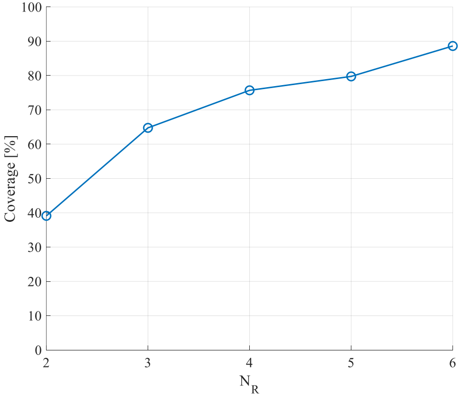
Ground-based radar networks

- Concept of ground-based sparse medium power radar networks for low altitude surveillance in urban environments
  - Radar requirements
  - Sensor placement optimization
  - Tracking and data fusion algorithms
- Interface with airspace structure and management, communication aspects, navigation performance
- Link with weather sensing









N_R	Coverage [%]
2	45,6
3	64,8
4	75,7
5	80,4
6	**88, 9**

(Aievola et al., «Ground-based Radar Networks for Urban Air Mobility: Design Considerations and Performance Analysis", DASC 2022
Milone et al., «Optimization of Radar Networks for Airspace Surveillance in UAM and AAM scenarios", to be presented at DASC 2024)

1. Introduction to the IEEE AESS Avionics Systems Panel	Rob (11:30)
2. Sustainable Aviation Challenges and Opportunities	Rob (11:50)
3. Aviation Noise Impact Assessment and Mitigation	Erik (12:10)
4. Evolving Technologies and R&I Agenda	Rob (12.30)
5. ATM and Flight Management Systems	Alex (12.50)
6. UTM, AAM and Trusted Automation	Alex (13.30)
7. Recent Advances in Surveillance Systems	Giancarmine (13.50)
8. High-Altitude and Sub-Orbital Flight Operations	Rob (14.10)
9. Concluding Remarks	All (14.20)

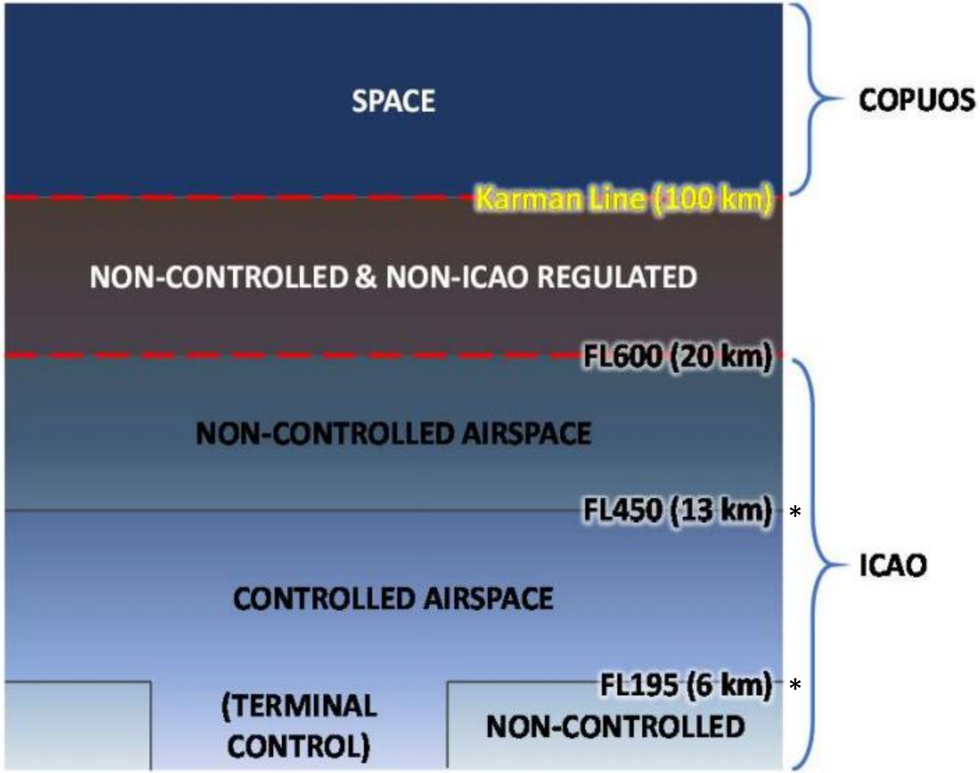
High-Altitude Operations and Space Traffic Management

Regulatory Framework Evolutions

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

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

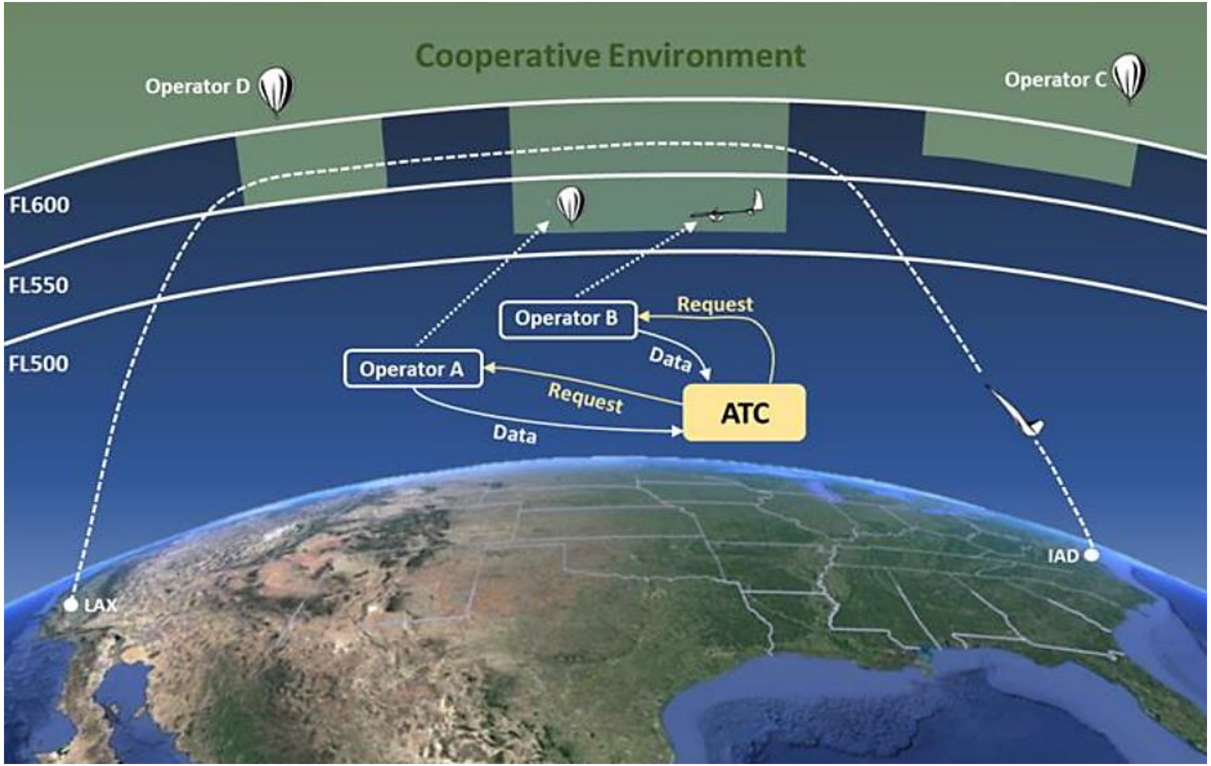
ICAO - International Civil Aviation Organization
COPUOS - Committee on the Peaceful Use of Outer Space
ICCAIA - International Coordinating Council of Aerospace Industries Associations



*Country-specific

Flight Above FL 600

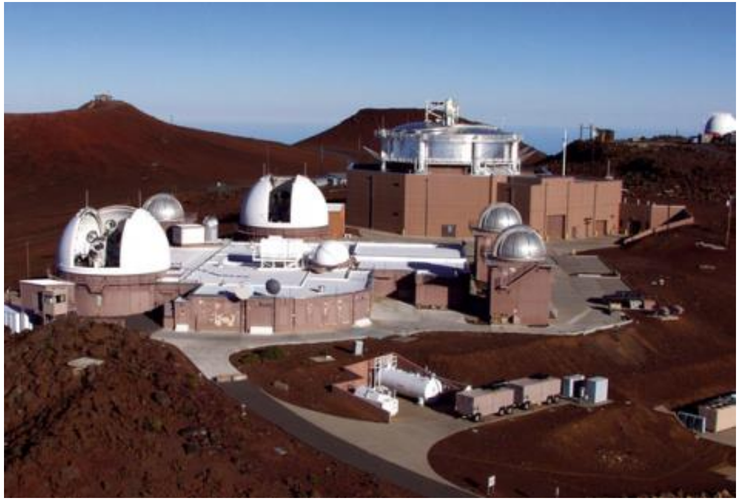
❖ Super/Hypersonic Vehicles, VHALE UAS, Stratospheric Airships, etc.

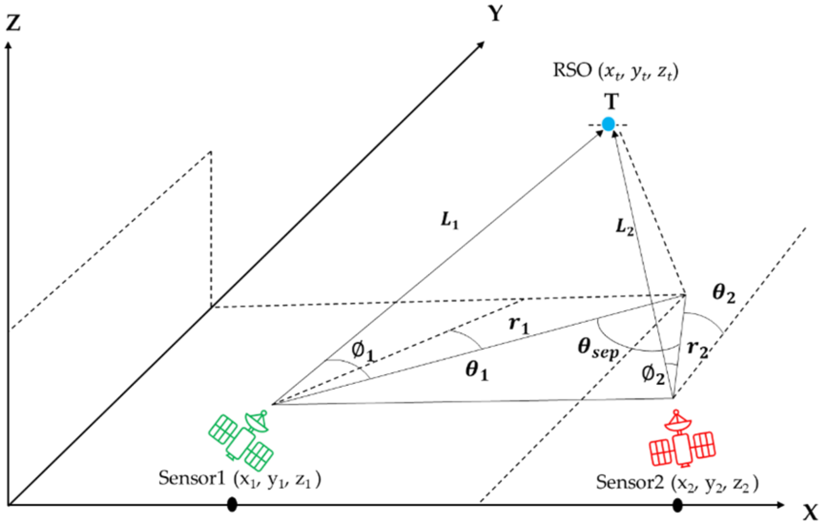


Credit: FAA

Space Domain Awareness

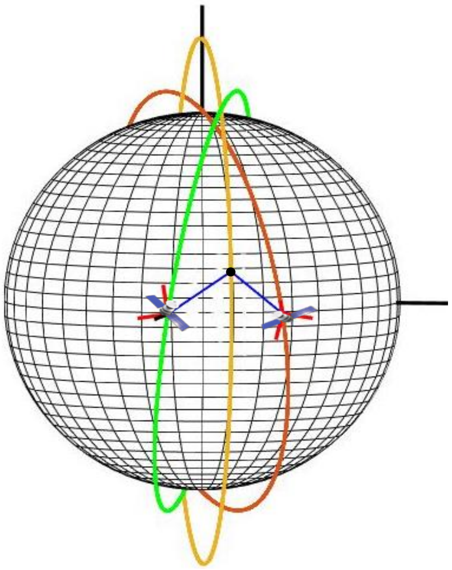
- ❖ Cooperative and Non-Cooperative Surveillance for SDA and STM
- ❖ Ground-Based Surveillance (GBS) and Space-Based Space Surveillance (SBSS)
- ❖ Tracking of <10cm RSO elusive to GBS infrastructure – STM Requires SBSS Integration



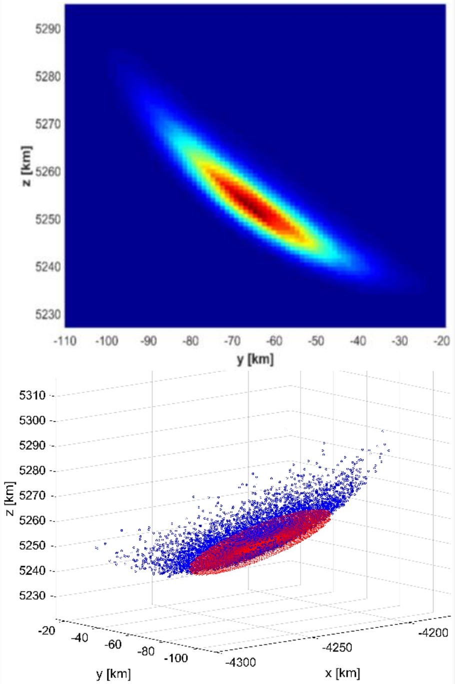


Space Traffic Management

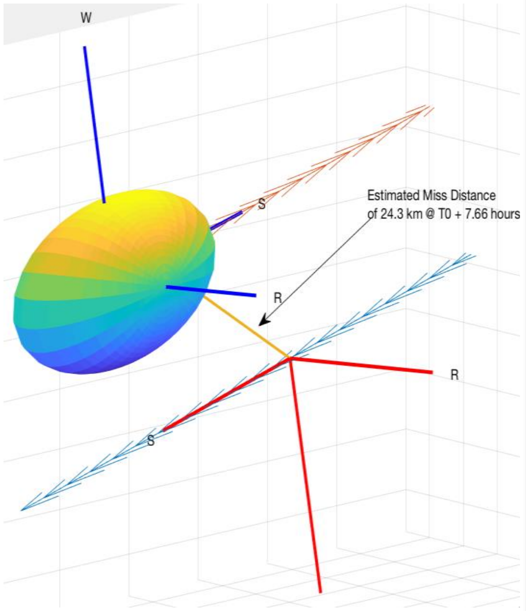
Navigation and Tracking Data Collection and Sharing (Cooperative scenario)



Quantify and Predict Tracked Space Object Uncertainty



Conjunction Analysis and Collision Avoidance



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

Safety risk management for commercial space missions

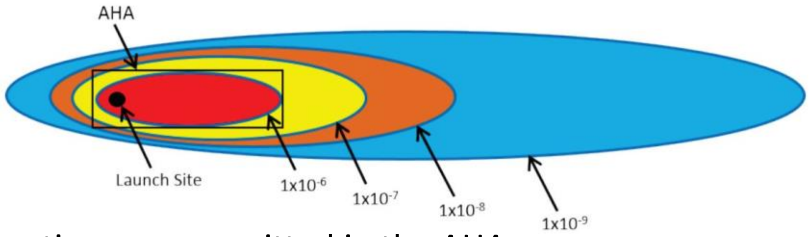
The FAA Office of Commercial Space Transportation (AST) and the Air Traffic Organization (ATO) have separately established public safety risk acceptance criteria that are expressed using different terminology and numerical values

Element	AST	ATO
Acceptable level of safety	1×10^{-6}	1×10^{-9}
Period	Per aircraft, per launch/fly-back operation	Per affected flight hour or air traffic control operation
Consequence	Casualty of an aircraft occupant	Fatality of an aircraft occupant

The ATO proposed using the ***Acceptable Level of Risk (ALR)*** approach to temporarily bridge the differences and accommodate the growth of commercial space launches in the NAS.

Aircraft Hazard Areas (AHAs)

Risk contour during launch and re-entry per-aircraft probabilities of impact with debris capable of causing a casualty

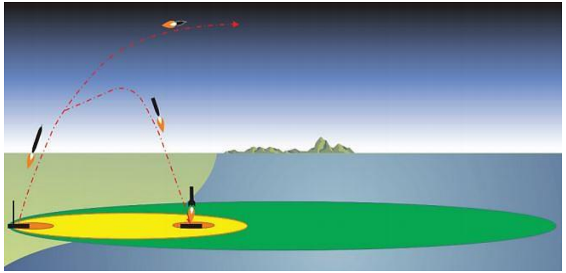


No operations are permitted in the AHA

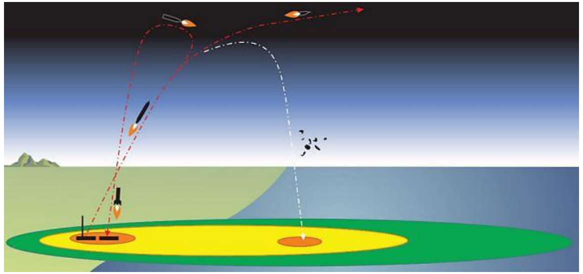
Commercial Space Mission Types

Missions using the ALR approach with the 30-Degree Angular Restriction
ALR for these missions: 1×10^{-6} and the 1×10^{-7} risk contours

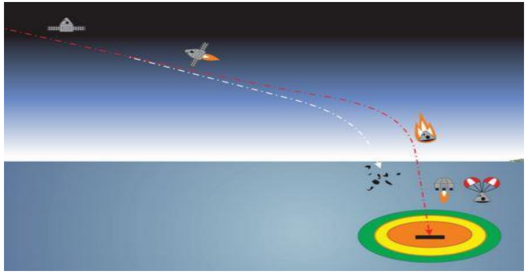
Launch Barge Fly-Back



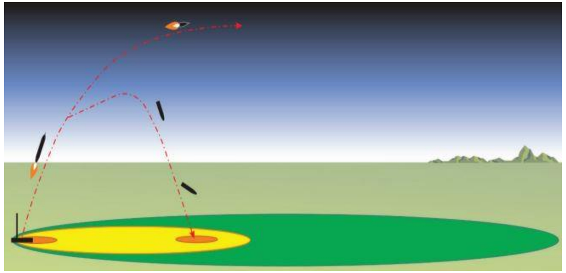
Launch Site Fly-Back



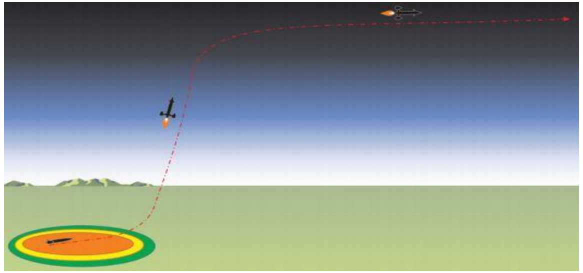
Capsule Reentry



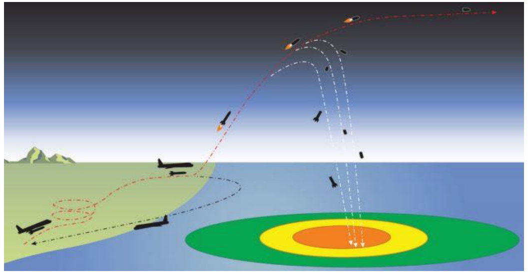
Expendable Launch Without Fly-Back



Horizontal Orbital



Captive Carry Orbital

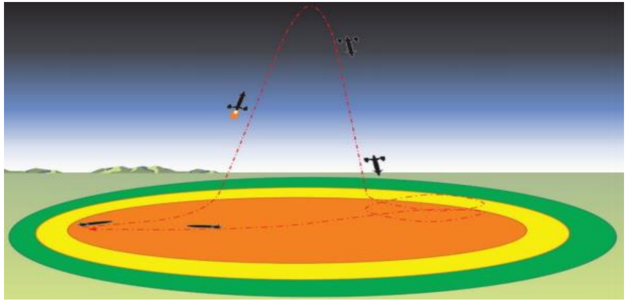


Commercial Space Mission Types

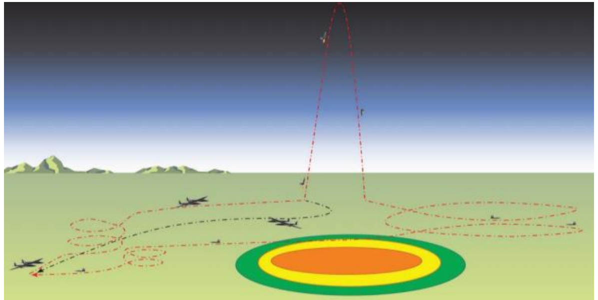
Missions using the ALR approach with a risk buffer

The appropriate risk buffer for each launch to ensure that the 1×10^{-7} individual risk limit

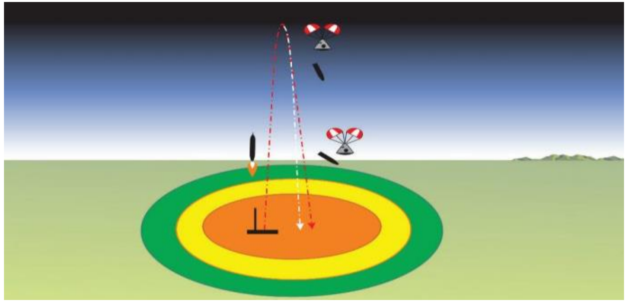
Horizontal Suborbital



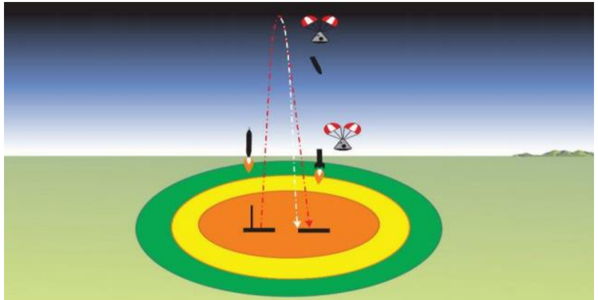
Captive Carry Suborbital



Vertical Launch Suborbital Expendable Booster



Vertical Launch Suborbital Reusable Booster

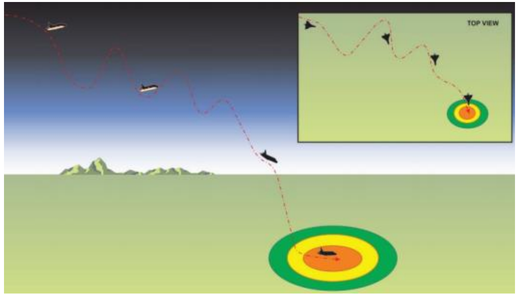


Commercial Space Mission Types

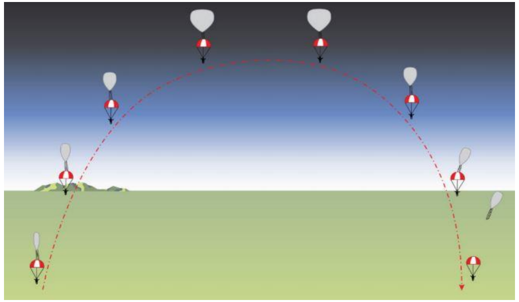
Missions to which the <u>ALR approach cannot be applied</u> at this time

FAA was not able to identify the appropriate parameters, conditions, and restrictions that would allow a direct application of the ALR approach

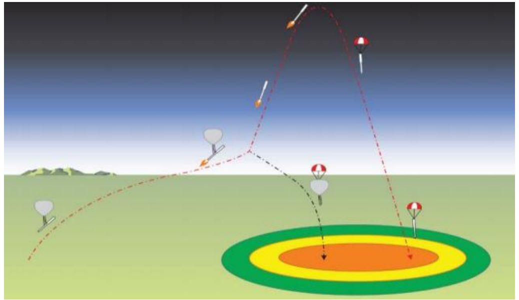
Winged Reentry



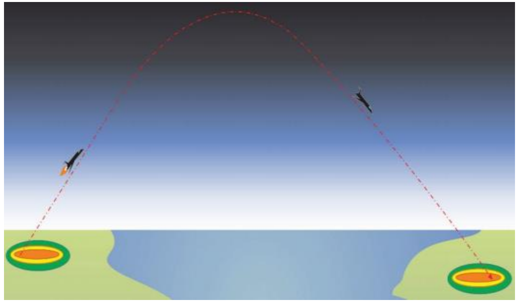
Stratospheric Manned Balloons



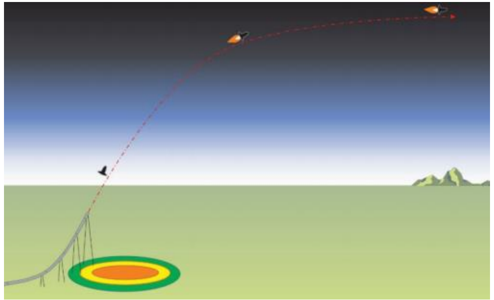
Balloon Launch



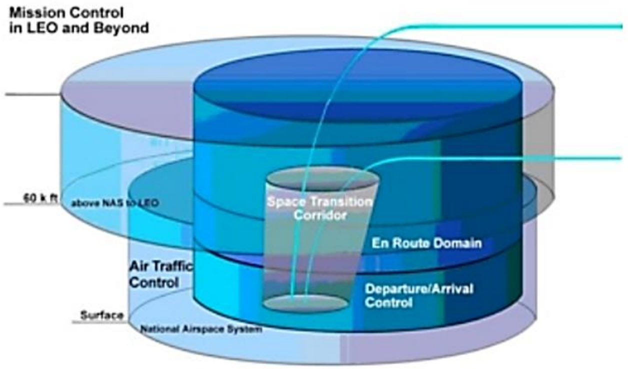
Point-to-Point



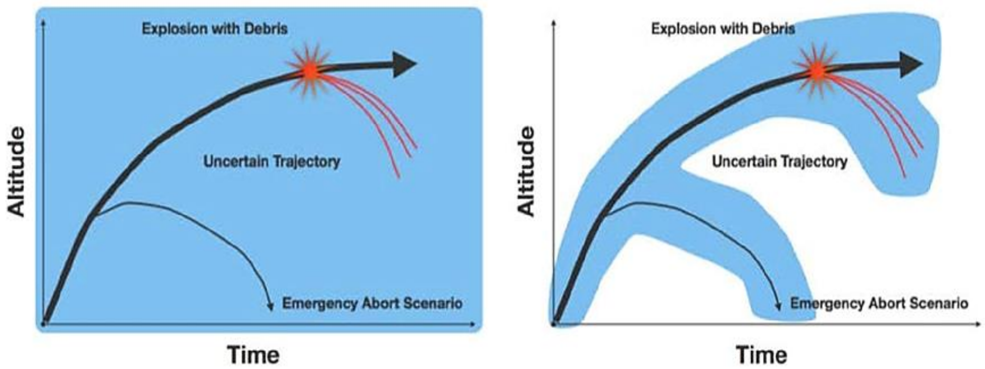
Tube and Rail Launchers



Emerging Airspace Management Concepts



Space Transition Corridor
Courtesy: NextGen US



4 Dimensional Compact Envelopes
Courtesy Stanford University Aerospace Design Lab

Space Transition Corridors

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

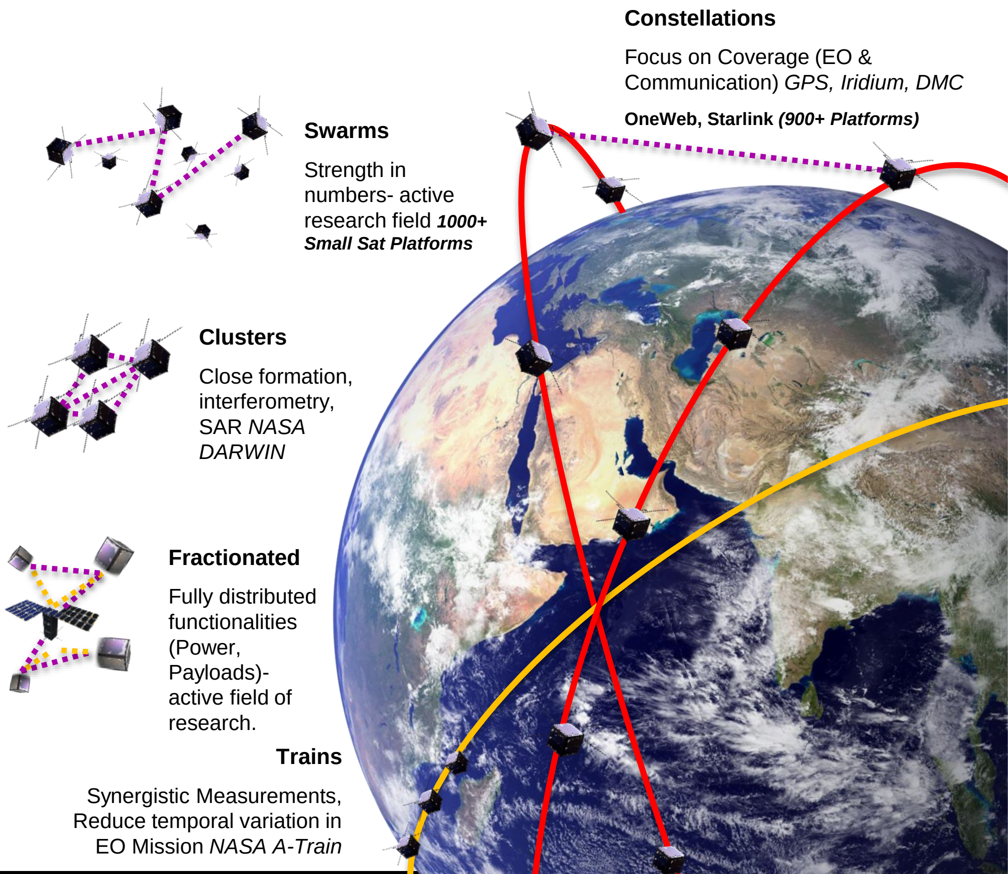
Four-Dimensional Compact Envelopes

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

Distributed Space Systems

DSS move away from the **monolithic** space 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



AI4SPACE Research Context

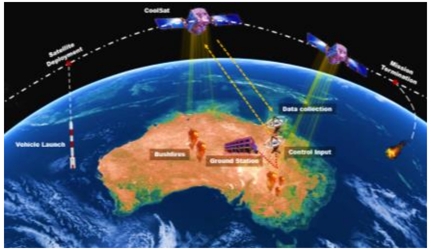
Advanced Satellite Systems, Sensors and Intelligence. Communications, connectivity and IoT technologies. Next Generation Earth Observation Services. Trusted Autonomy and Evolutionary Mission Control Centres

Strengths/Discriminators

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

Research Opportunities

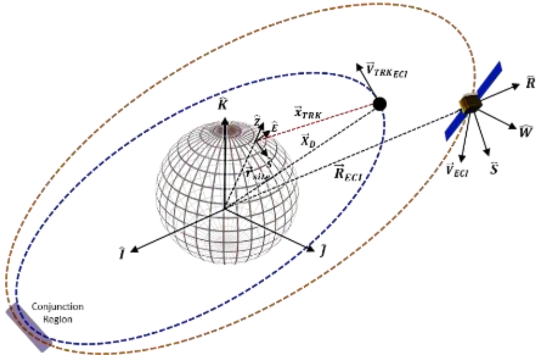
- Artificial Intelligence and Machine Learning (AI/ML) software for trusted autonomous operation
- Fault-tolerant avionics/spaceflight systems research
- Intelligent satellite health management systems
- Passive and active EO/IR sensors and systems

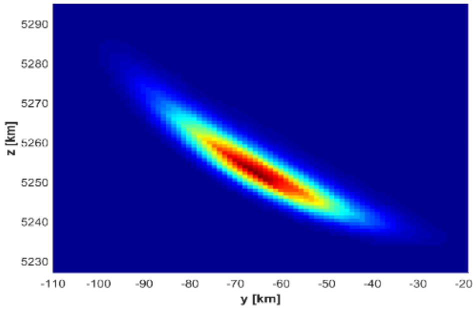


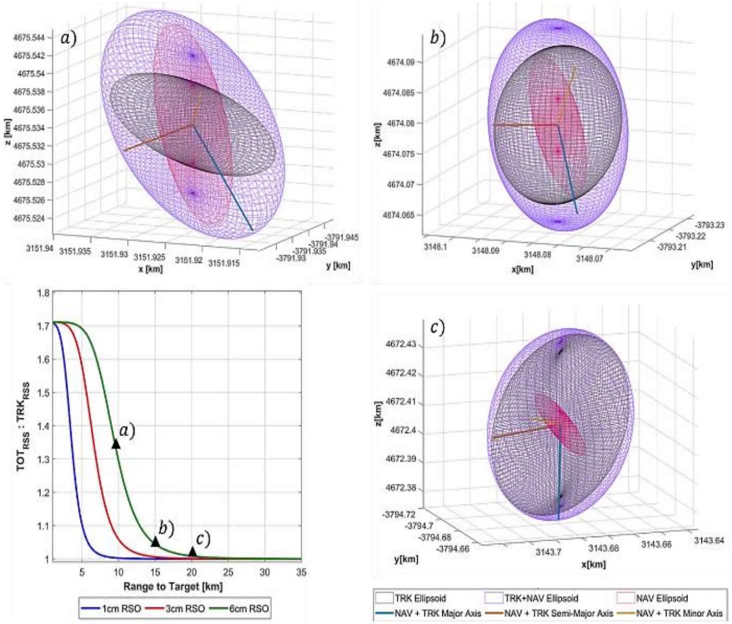
Space Traffic Management Evolutions

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**







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

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

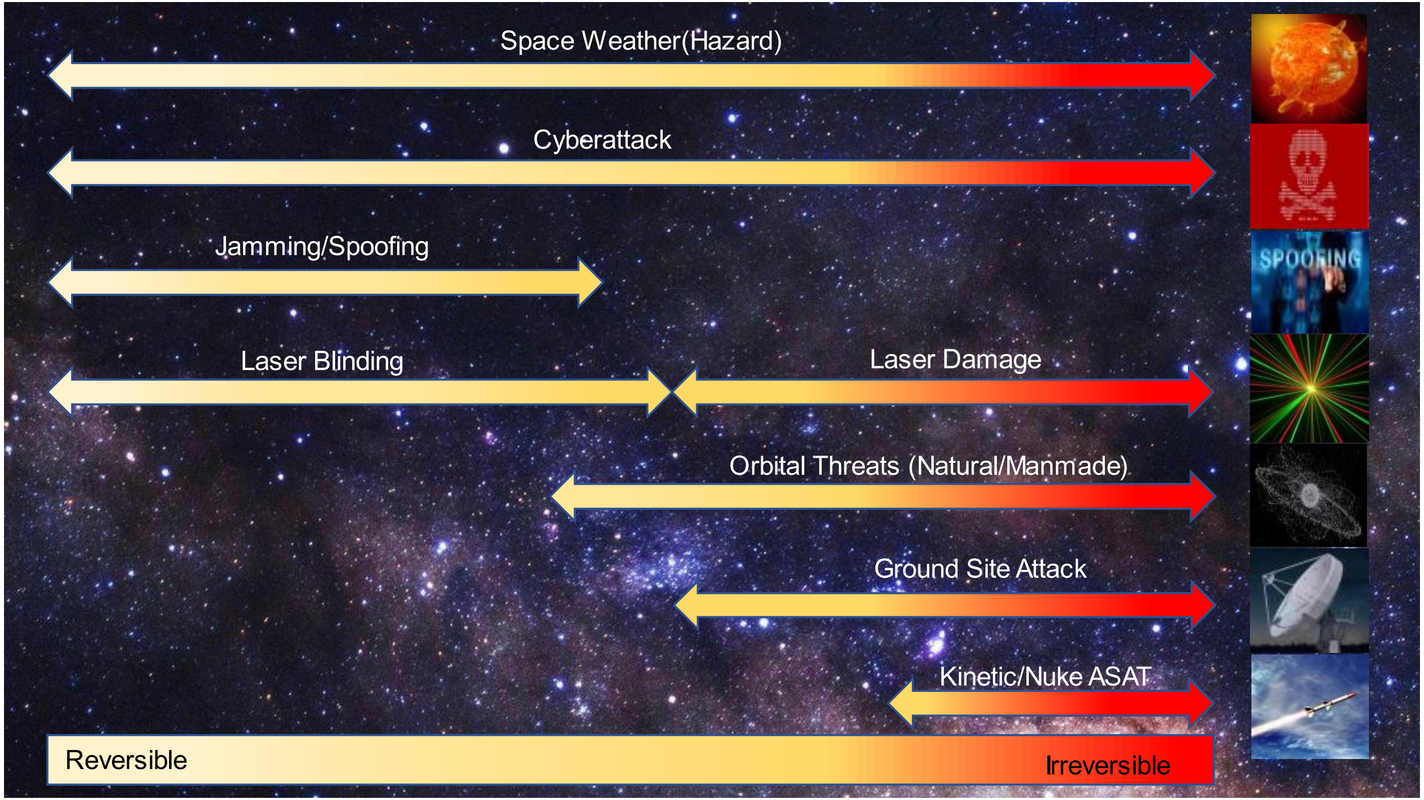
Physical Security

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

Cyber-Physical Systems

- Significant in the context of avionics and space systems
- Trustworthy AI?

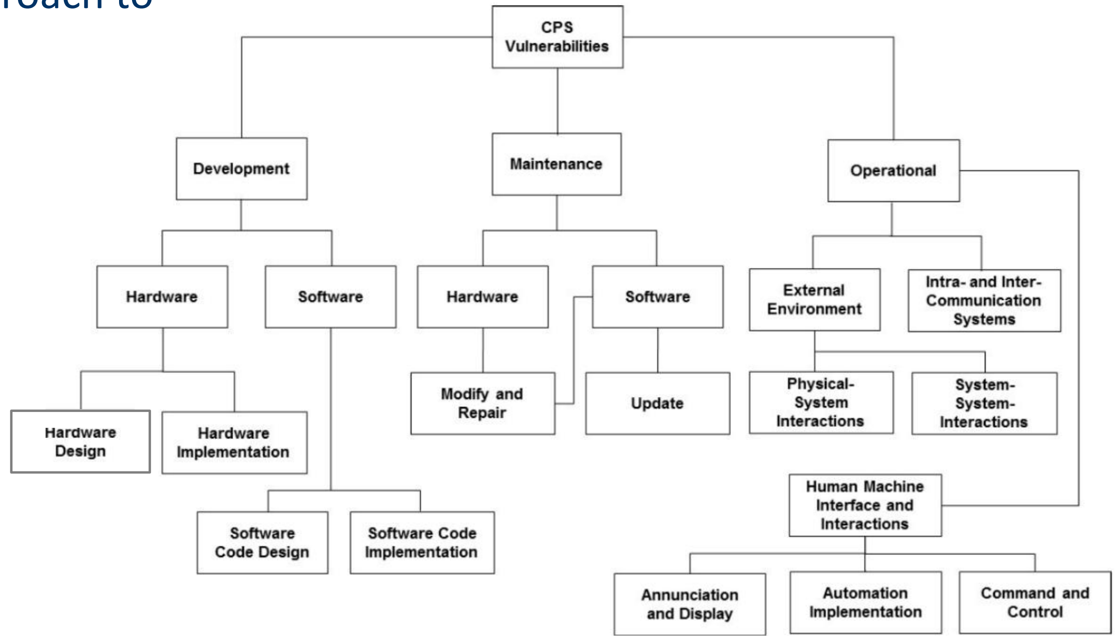
Space Cyber-Physical Threats



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

Vulnerability Assessment

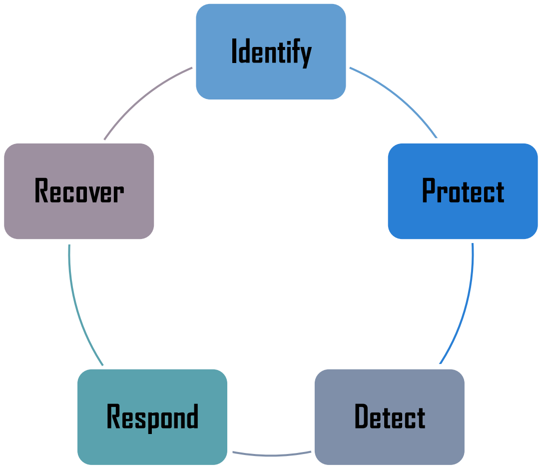
- STRIDE is an abbreviation for various known attack paths, one standard approach to assess vulnerabilities:
  - **S**poofing Identity
  - **T**ampering with Data
  - **R**epudiation
  - **I**nformation Disclosure
  - **D**enial of Service
  - **E**levation of Privilege



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

Towards a Unified Cybersecurity Framework

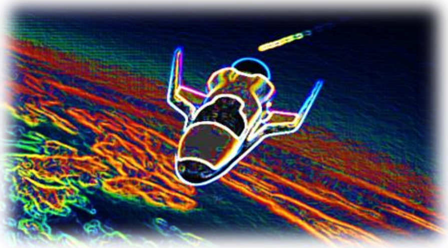
Segment	Vulnerability	Threats
Aircraft/Spacecraft	Systems/Payload Vulnerabilities	• Denial of Service • Hardware Backdoor • Bespoke Malware • Privilege Escalation • Hijacking • Sensor Injection
Comms/C2 Link	Signal Vulnerabilities	• Jamming • Eavesdropping • Spoofing • Metadata-Analysis • Command Injection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



K. Thangavel, A. Gardi, and R. Sabatini, "Cybersecurity Challenges of Multi-Domain Traffic Management and Aerospace Cyber-Physical Systems." 8th IEEE Cyber Science and Technology Congress (CyberSciTech 2023), Abu Dhabi, UAE, November 2023.

Multidomain Air and Space Traffic Management

- Unified approach to cooperative and non-cooperative SA/CA is necessary
- Accounting navigation/tracking uncertainties, relative dynamics and perturbations
- Both ground-based surveillance and SBSS (cooperative and non-cooperative) are needed for a scalable STM system
- Data-centric STM and ATM integration (MDTM)
- Cyber and physical security threats
- AI certification challenges



1. Introduction to the IEEE AESS Avionics Systems Panel	Rob (11:30)
2. Sustainable Aviation Challenges and Opportunities	Rob (11:50)
3. Aviation Noise Impact Assessment and Mitigation	Erik (12:10)
4. Evolving Technologies and R&I Agenda	Rob (12.30)
5. ATM and Flight Management Systems	Alex (12.50)
6. UTM, AAM and Trusted Automation	Alex (13.30)
7. Recent Advances in Surveillance Systems	Giancarmine (13.50)
8. High-Altitude and Sub-Orbital Flight Operations	Rob (14.10)
9. Concluding Remarks	All (14.20)

Concluding Remarks

Conclusions

- **Environmental Challenges:** The aviation industry faces significant challenges in reducing its environmental impact, particularly in terms of greenhouse gas emissions and noise pollution. Despite technological progress, the anticipated growth in air traffic will exacerbate these issues

- **Triple-Bottom-Line (TBL) approach:** A holistic TBL approach must be adopted to balance safety, efficiency and sustainable development objectives, giving due consideration to economic, social, and environmental factors

- **Technological Advancements:** Digital avionics systems are crucial for enhancing the sustainability of aviation and near-Earth space operations. Ongoing developments in aircraft systems and ground-based ICNS/C2 infrastructure support safer and more efficient flight operations, contributing to the development of a more sustainable aerospace sector

- **Cybersecurity Concerns:** As aviation systems become more data-driven and interconnected, cybersecurity has emerged as a critical concern. Ensuring the protection of these systems against potential threats is essential for maintaining safety and operational integrity

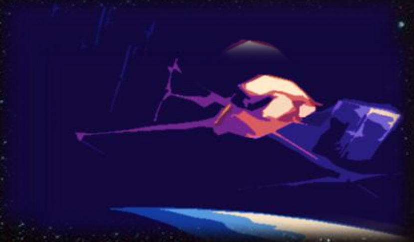
- **Regulatory and Standardization Needs:** The evolving landscape of aviation and spaceflight operations requires updates in regulatory frameworks and standards. Collaborative efforts with international bodies are necessary to harmonize standards and support the integration of new technologies

Recommendations

- **Invest in Research and Innovation:** Increase investment in research and innovation to develop avionics solutions for reduced aircraft emissions and noise (aviation context) and for Space Domain Awareness (SDA), supporting near-Earth spaceflight operations (space context)
- **Focus on Education and Training:** Invest in education and training programs to equip aerospace professionals with the skills needed to design and manage advanced avionics systems, emphasizing practical design skills for certification and environmental impact assessment
- **Enhance AI and Machine Learning Capabilities:** Utilize AI and machine learning to improve the predictive capabilities of traffic management systems. These technologies can optimize traffic flow, enhance situational awareness, and support real-time decision-making, thereby increasing the safety and efficiency of operations
- **Develop Trusted Automation/Autonomous Systems:** Invest in the development of trusted automation/autonomous systems that enhance human-machine collaboration. These systems should incorporate adaptive human-machine interfaces and interactions (HMI2) to ensure that automation complements human decision-making, particularly in complex and dynamic environments.
- **Implement Multi-Domain Traffic Management (MDTM) Frameworks:** Establish comprehensive MDTM frameworks that integrate air, space, and ground traffic management. This integration should leverage advanced ICNS technologies to ensure seamless and efficient operations across different domains

IEEE
Advancing Technology for Humanity

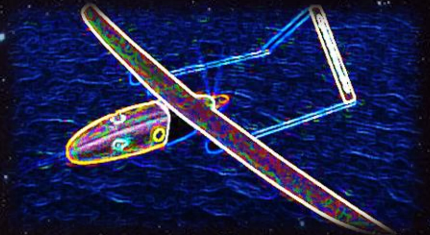
DASC 43rd
Digital Avionics Systems Conference
San Diego, CA, USA - September 29-October 3, 2024



Thank you!

ASP

AESS IEEE Aerospace & Electronic Systems Society



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

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

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

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

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

References

[1] 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.

[2] FAA, "NextGen Implementation Plan." Federal Aviation Administration (FAA), Washington DC, USA, 2013. Available online at: https://www.faa.gov/sites/faa.gov/files/2022-06/NextGen_Implementation_Plan_2018-19%20%281%29.pdf

[3] FAA, “NAC NextGen Priorities Joint Implementation Plan CY2019–2022: 2021 Update.” Federal Aviation Administration (FAA), Washington DC, USA, 2013. Available online at: https://www.faa.gov/headquartersoffices/ang/nac-nextgen-priorities-joint-implementation-plan-cy2019-2022-2021-update

[4] T. Kistan, A. Gardi and R. Sabatini, "Machine Learning and Cognitive Ergonomics in Air Traffic Management: Recent Developments and Considerations for Certification," Aerospace, Vol. 5, Issue 4, October 2018.

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

[6] ICAO , “Improving the Performance of the Air Navigation System through the Aviation System Block Upgrades.” AN-Conf/13-WP/11. Proceeding of the 13th Air Navigation Conference. Montreal, Canada, June 2018.

[7] ICAO, “Annual Report of the Council to the Assembly.” Available online at: https://www.icao.int/annual-report-2019/Pages/the- world-of-air-transport-in-2019.aspx

[8] G. Bisignani, “Vision 2050 Report.” IATA: Singapore, 2011. Available online at: https://www.iata.org/contentassets/ bccae1c5a24e43759607a5fd8f44770b/vision-2050.pdf

[9] Royal Commission on Environmental Pollution, “The Environmental Effects of Civil Aircraft in Flight.” Royal Commission on Environmental Pollution: London, UK, 2002. Available online at: https://www.aef.org.uk/uploads/RCEP_Env__Effects_of_Aircraft__in__Flight_1.pdf

[10] IATA., “20 Year Passenger Forecast—Global Report.” IATA: Geneva, Switzerland, 2008.

[11] ICAO, “Effects of Novel Coronavirus (COVID-19) on Civil Aviation: Economic Impact Analysis.”, March 2022. Available online at: https://www.icao.int/sustainability/Documents/Covid-19/ICAO_coronavirus_Econ_Impact.pdf

[12] B. Graver, “Polishing my crystal ball: Airline traffic in 2050.” International Council on Clean Transportation (ICCT), January 2022. Available online at: https://theicct.org/global-aviation-airline-traffic-jan22/

References (cont.)

[13] BryceTech, “2019 Global Space Economy at a Glance.” A BryceTech publication, 5 October 2020. Available online at: https://brycetech.com/reports

[14] F. Dolce, F. Monaci and E. Del Grande, "ItAF simulation tools in support of a suborbital flight risk assessment." ICAO/UNOOSA Space Symposium. Abu Dhabi (UAE), 15 March 2016. Available online at: https://www.icao.int/Meetings/SPACE2016/Presentations/6%20-%20F.%20Dolce%20-%20Italian%20Air%20Force.pdf

[15] IPCC, “Aviation and the Global Atmosphere.” Penner, J.E., Lister, D.H., Griggs, D.J., Dokken, D.J., McFarland, M. (Eds.) Prepared in collaboration with the Scientific Assessment Panel to the Montreal Protocol on Substances that Deplete the Ozone Layer. Cambridge University Press, UK. 1999. Available online at: https://www.ipcc.ch/report/aviation-and-the-global-atmosphere-2/

[16] M. Janic. “The Sustainability of Air Transportation: a Quantitative Analysis and Assessment.” Farnham (UK): Ashgate Publishing Limited. 2007

[17] JJEI , “UAV TASK-FORCE Final Report - A Concept for European Regulations for Civil Unmanned Aerial Vehicles (UAVs).” The Joint JAA/Eurocontrol Initiative (JJEI) on UAVs. 2005. Available online at: http://easa.europa.eu/system/files/dfu/NPA_16_2005_Appendix.pdf

[18] L. Delgado, G. Gurtner, T. Bolić, and L. Castelli, "Estimating economic severity of Air Traffic Flow Management regulations," Transportation Research Part C: Emerging Technologies, vol. 125, p. 103054, 2021.

[19] C. Mannino, A. Nakkerud, and G. Sartor, "Air traffic flow management with layered workload constraints," Computers & Operations Research, vol. 127, p. 105159, 2021.

[20] 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.

[21] 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.

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

[23] 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.

[24] 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.

[25] 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.

References (cont.)

[26] 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.

[27] 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.

[28] 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.

[29] 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.

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

[31] 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.

[32] M. Marino, R. Sabatini, “Advanced Lightweight Aircraft Design Configurations for Green Operations.” Practical Responses to Climate Change (PRCC) 2014. Engineers Australia Convention 2014. Melbourne (Australia), November 2014. DOI: 10.13140/2.1.4231.8405

[33] 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.

[34] 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.

[35] 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.

[36] 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.

[37] 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.

References (cont.)

[38] 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.

[39] 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.

[40] 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.

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

[42] 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.

[43] 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 2022. DOI: 10.3390/computers10060081

[44] 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.

[45] 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.

[46] 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.

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

[48] 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.

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

[50] Y. Xie, A. Gardi, R. Sabatini, “Cybersecurity Trends in Low-Altitude Air Traffic Management”, IEEE/AIAA 41st Digital Avionics Systems Conference, DASC 2022, Portsmouth, VA, USA, 2022

References (cont.)

[51] 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.

[52] 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.

[53] 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.

[54] D. Woffinden, S. Robinson, J. Williams, and Z. R. Putnam, "Linear Covariance Analysis Techniques to Generate Navigation and Sensor Requirements for the Safe and Precise Landing Integrated Capabilities Evolution (SPLICE) Project," in AIAA Scitech 2019 Forum, 2019, p. 0662.

[55] 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.

[56] 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.

[57] 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.

[58] 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.

[59] 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.

[60] ICAO, "Global Air Navigation Plan.” Doc. 9750 – 6th Edition. International Civil Aviation Organization (ICAO), Montreal, Canada, 2019. Available online at: https://www.icao.int/airnavigation/pages/ganp-resources.aspx

[61] 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.

References (cont.)

[62] S. Lentz, M. Hornung, and W. Staudacher, "Conceptual Design of Winged Reusable Two-Stage-To-Orbit Space Transport Systems," Basic Research and Technologies for Two-Stage-To-Orbit Vehicles, pp. 9-37, 2005.

[63] 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.

[64] 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.

[65] 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.

[66] 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.

[67] 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.

[68] 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.

[69] 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.

[70] 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.

[71] 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.

[72] K. Ranasinghe, S. Bijjahalli, A. Gardi, R. Sabatini, "Intelligent Health and Mission Management for Multicopter UAS Integrity Assurance", IEEE/AIAA 40th Digital Avionics Systems Conference (DASC2021), San Antonio, TX, USA, October 2021.

References (cont.)

[73] N. Pongsakornsathien, A. Gardi, S. Bijjahalli, R. Sabatini, T. Kistan, "A Multi-Criteria Clustering Method for UAS Traffic Management and Urban Air Mobility", IEEE/AIAA 40th Digital Avionics Systems Conference (DASC2021), San Antonio, TX, USA, October 2021.

[74] 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.

[75] 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.

[76] 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).

[77] 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.

[78] 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.

[79] 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.

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

[81] "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.

[82] 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.

References (cont.)

[83] 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.

[84] Y. Zhu, Z. Chen, F. Pu, and J. Wang, "Development of Digital Airspace System." Strategic Study of Chinese Academy of Engineering, vol. 23, no. 3, pp. 135-143, 2021.

[85] M. Xue and A. Ishihara, "Define Minimum Safe Operational Volume for Aerial Vehicles in Upper Class E Airspace." In AIAA Aviation 2021 Forum (virtual event), 2021. 2-6 August 2021.

[86] M. Ackermann, D. Cox, R. R. Kiziah, P. Zimmer, and J. Mcgraw, "A systematic examination of ground-based and space-based approaches to optical detection and tracking of artificial satellites," 2015.

[87] 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.

[88] 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.

[89] 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.

[90] M. Hempsell and A. Bond, "SKYLON: An example of commercial launch system development," JBIS - Journal of the British Interplanetary Society, Article vol. 67, no. 11-12, pp. 434-439, 2014. [Online]. Available: https://www.scopus.com/inward/record.uri?eid=2-s2.0-84940654339&partnerID=40&md5= 3c4e9f3a33939a392e98afe988dcc03e.

[91] T. Masson-Zwaan and S. Freeland, "Between heaven and earth: The legal challenges of human space travel," Acta Astronautica, vol. 66, no. 11, pp. 1597-1607, 2010/06/01/ 2010, doi: https://doi.org/10.1016/j.actaastro.2009. 12.015.

[92] 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.

[93] C. Insaurralde, E. Blasch, R. Sabatini, “Ontology-Based Situation Awareness for Air and Space Traffic Management”, IEEE/AIAA 41st Digital Avionics Systems Conference, DASC 2022, Portsmouth, VA, USA, 2022.

References (cont.)

[94] Y. Xie, A. Gardi, R. Sabatini, M. Liang, “Hybrid AI-based Dynamic Re-routing Method for Dense Low-Altitude Air Traffic Operations”, IEEE/AIAA 41st Digital Avionics Systems Conference, DASC 2022, Portsmouth, VA, USA, 2022.

[95] K. Thangavel, J.J. Plotnek, A. Gardi, R. Sabatini, “Understanding and investigating adversary threats and countermeasures in the context of space cybersecurity”, IEEE/AIAA 41st Digital Avionics Systems Conference, DASC 2022, Portsmouth, VA, USA, 2022.

[96] 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.

[97] K. Ranasinghe, R. Kapoor, A. Gardi, R. Sabatini, V. Wickramanayake, D. Ludovici, "Alternative Approaches for Health Assessment of Vehicle Subsystems", 12th International Conference on Health and Usage Monitoring (HUMS21), Melbourne, Australia, November 2021.

[98] K. Thangavel, A. Gardi, S. Hilton, A. M. Afful, R. Sabatini, "Towards Multi-Domain Traffic Management", 72nd International Astronautical Congress (IAC2021), Dubai, UAE, November 2021.

[99] S. Bijjahalli, A. Gardi, N. Pongsakornsathien, R. Sabatini, "A Unified Collision Risk Model for Unmanned Aircraft Systems", IEEE/AIAA 40th Digital Avionics Systems Conference (DASC2021), San Antonio, TX, USA, October 2021.

[100] S. Bijjahalli, A. Gardi, N. Pongsakornsathien, R. Sabatini, T. Kistan, “A Unified Airspace Risk Management Framework for UAS Operations.” Drones, Vol. 6, No. 184, July 2022. DOI: 10.3390/drones6070184

[101] 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.

[102] R. Kapoor, S. Ramasamy, A. Gardi, R. Sabatini, “UAV Navigation Using Signals of Opportunity in Urban Environments: A Review.” Energy Procedia, Volume 110, March 2017, pp. 377-383. DOI: 10.1016/j.egypro.2017.03.156

[103] N. Pongsakornsathien, A. Gardi, Y. Lim, R. Sabatini, T. Kistan, “Wearable Cardiorespiratory Sensors for Aerospace Applications.” Sensors, Vol. 22, No. 4673, June 2022.

[104] E. Lagona, A. Gardi, A. M. Afful, S. Hilton, R. Sabatini, “Autonomous Trajectory Optimisation for Intelligent Satellite Systems Operations and Space Traffic Management.” Acta Astronautica, Vol. 194, pp. 185-201, May 2022.

[105] M. Burston, K. Ranasinghe, A. Gardi, V. Parezanovic, R. Ajaj, R. Sabatini, “Design Principles and Digital Control of Advanced Distributed Propulsion Systems.” Energy, Vol. 241, No. 122788, February 2022.

References (cont.)

[106] C.H. Flemming and N.G. Leveson, “Including Safety during Early Development Phases of Future Air Traffic Management Concepts.” Proceedings of the 11th USA/Europe Air Traffic Management Research and Development Seminar (2015). Available online at: http://sunnyday.mit.edu/papers/ATM-2015.pdf

[107] A. Gardi, R. Sabatini, S. Ramasamy, M. Marino, T. Kistan, "Automated ATM System Enabling 4DT-Based Operations.” SAE AeroTech Congress 2015, Seattle, WA (USA), Technical Paper 2015-01-2539, September 2015. DOI: 10.4271/2015-01-2539

[108] J. Gentry, “Introduction to Higher Airspace Operations.” MITRE Technical Papers. The MITRE Corporation - Center for Advanced Aviation System Development, 2021. Available online at: https://www.mitre.org/publications/technical-papers/introduction-to-higher-airspace-operations

[109] Y. Xie, N. Pongsakornsathien, A. Gardi and R. Sabatini, “Explanation of Machine Learning Solutions in Air Traffic Management.” Aerospace, Vol. 8, No. 224, August 2022.

[110] 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 2022

[111] 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 2022

[112] T. C. Papavramides and P. Aupee, "Achieving sustainable performance in natural monopolies - the role of strategic planning in the European air navigation services," in 2004 IEEE International Engineering Management Conference (IEEE Cat. No.04CH37574), 18-21 October 2004.

[113] 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, Vol. 128, No. 758, January 2022.

[114] 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.

[115] 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.

[116] S. Hilton, F. Cairola, A. Gardi, R. Sabatini, N. Pongsakornsathien and N. Ezer, “Uncertainty Quantification for Space Situational Awareness and Traffic Management.” Sensors, Vol. 19(20), 4361. October 2019.

References (cont.)

[117] C. Insaurralde, E. Blasch, R. Sabatini, “Ontology-Based Situation Awareness for Air and Space Traffic Management”, IEEE/AIAA 41st Digital Avionics Systems Conference, DASC 2022, Portsmouth, VA, USA, September 2022.

[118] Y. Xie, A. Gardi, R. Sabatini, M. Liang, “Hybrid AI-based Dynamic Re-routing Method for Dense Low-Altitude Air Traffic Operations”, IEEE/AIAA 41st Digital Avionics Systems Conference, DASC 2022, Portsmouth, VA, USA, September 2022.

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

[120] Y. Xie, A. Gardi, R. Sabatini, “Cybersecurity Trends in Low-Altitude Air Traffic Management”, IEEE/AIAA 41st Digital Avionics Systems Conference, DASC 2022, Portsmouth, VA, USA, September 2022.

[121] K. Thangavel, D. Spiller, R. Sabatini, P. Marzocca, and M. Esposito, "Near Real-time Wildfire Management Using Distributed Satellite System." IEEE Geoscience and Remote Sensing Letters, Vol. 20, pp. 1-5, January 2023

[122] K. Thangavel, D. Spiller, R. Sabatini, S. Amici, S. T. Sasidharan, H. Fayek, and P. Marzocca, “Autonomous Satellite Wildfire Detection Using Neural Networks: A Case study on Australian Wildfire.” Remote Sensing, Vol. 15, Issue 3, No. 720, January 2023

[123] G. Fasano, O. G. Crespillo, R. Sabatini, A. Roy, and R. Ogan, "From the Editors of the Special Issue on Urban Air Mobility and UAS Airspace Integration: Vision, Challenges, and Enabling Avionics Technologies." IEEE Aerospace and Electronic Systems Magazine, Vol. 38, No. 5, pp. 4-5, May 2023

[124] K. Thangavel, P. Servidia, R. Sabatini, P. Marzocca, H. Fayek, I. Santiago Husain, M. España, and D. Spiller, “A Distributed Satellite System for Multibaseline AT-InSAR: Constellation of Formations for Maritime Domain Awareness Using Autonomous Orbit Control.” Aerospace, Vol. 10, Issue 2, No. 86, February 2023

[125] B. Milne, S. Samson, R. Carrese, A. Gardi, and R. Sabatini, “High-Fidelity Dynamics Modelling for the Design of a High-Altitude Supersonic Sounding Rocket.” Designs, Vol. 7, Issue 1, No. 32, February 2023

[126] J. Lundberg, M. Arvola, C. Westin, S. Holmlid, M. Nordvall, B. J. B. Josefsson, et al., "Cognitive work analysis in the conceptual design of first-of-a-kind systems–designing urban air traffic management," vol. 37, pp. 904-925, 2018.

[127] P. D. Vascik, R. J. Hansman, and N. S. Dunn, "Analysis of Urban Air Mobility Operational Constraints," Journal of Air Transportation, vol. 26, pp. 133-146, 2018/10/01 2018.

[128] J. M. Hoekstra, J. Maas, M. Tra, and E. Sunil, "How do layered airspace design parameters affect airspace capacity and safety?," Proceedings of the 7th International Conference on Research in Air Transportation, 2016.

References (cont.)

[129] L. Sedov, V. Polishchuk, and V. Bulusu, "Sampling-based capacity estimation for unmanned traffic management," 2017 IEEE/AIAA 36th Digital Avionics Systems Conference (DASC), 2017, pp. 1-10.

[130] SESAR, "Drone DCB Concept and Process," DACUS, SESAR-ER4-31-2019--U-space2021, vol. 01.00.00.

[131] M. Lissone, D. Colin, and P. Barret, "Eurocontrol RPAS ATM CONOPS," 2017 Integrated Communications, Navigation and Surveillance Conference (ICNS), 2017, pp. 1-22.

[132] FAA, "14 CFR: Aeronautics and Space," Electronic Code of Federal Regulations, GPO, Washington, DC, 2017.

[133] SESAR, "U-space Blueprint", Accessed September, 2017.

[134] T. Prevot, J. Rios, P. Kopardekar, J. E. Robinson III, M. Johnson, and J. Jung, "UAS traffic management (UTM) concept of operations to safely enable low altitude flight operations," 16th AIAA Aviation Technology, Integration, and Operations Conference, 2016, p. 3292.

[135] D. P. Thipphavong, R. Apaza, B. Barmore, V. Battiste, B. Burian, Q. Dao, et al., "Urban air mobility airspace integration concepts and considerations," 2018 Aviation Technology, Integration, and Operations Conference, 2018, p. 3676.

[136] P. Kopardekar, J. Rios, T. Prevot, M. Johnson, J. Jung, and J. E. Robinson, "Unmanned Aircraft System Traffic Management (UTM) Concept of Operations," 2016.

[137] D.-S. Jang, C. A. Ippolito, S. Sankararaman, and V. Stepanyan, "Concepts of airspace structures and system analysis for UAS traffic flows for urban areas," AIAA Information Systems - AIAA Infotech @ Aerospace, Grapevine, Texas, 2017, p. 0449.

[138] D. Sacharny and T. C. Henderson, "A Lane-Based Approach for Large-Scale Strategic Conflict Management for UAS Service Suppliers," 2019 International Conference on Unmanned Aircraft Systems (ICUAS), 2019, pp. 937-945.

[139] V. Duchamp, L. Sedov, and V. Polishchuk, "Density-adapting layers towards PBN for UTM," 13th USA/Europe Air Traffic Management Research and Development Seminar 2019, 2019.

[140] E. Sunil, J. Hoekstra, J. Ellerbroek, F. Bussink, A. Vidosavljevic, D. Delahaye, et al., "The influence of traffic structure on airspace capacity," 2016.

[141] K. Dalamagkidis, K. P. Valavanis, and L. A. Piegl, "On unmanned aircraft systems issues, challenges and operational restrictions preventing integration into the National Airspace System," Progress in Aerospace Sciences, vol. 44, pp. 503-519, 2008/10/01/ 2008.

References (cont.)

[142] L. Ren, M. Castillo-Effen, H. Yu, E. Johnson, Y. Yoon, N. Takuma, et al., "Small unmanned aircraft system (sUAS) categorization framework for low altitude traffic services," 2017 IEEE/AIAA 36th Digital Avionics Systems Conference (DASC), 2017, pp. 1-10.

[143] E. Atkins, A. Khalsa, and M. Groden, "Commercial Low-Altitude UAS Operations in Population Centers," 9th AIAA Aviation Technology, Integration, and Operations Conference (ATIO) and Aircraft Noise and Emissions Reduction Symposium (ANERS), 2009, p. 7070.

[144] L. Ren, M. Castillo-Effen, H. Yu, Y. Yoon, T. Nakamura, E. N. Johnson, et al., "Small unmanned aircraft system (sUAS) trajectory modeling in support of UAS traffic management (UTM)," 17th AIAA Aviation Technology, Integration, and Operations Conference, Denver, Colorado, 2017, p. 4268.

[145] K. Thangavel, A. Gardi, and R. Sabatini, “Cybersecurity Challenges of Multi-Domain Traffic Management and Aerospace Cyber-Physical Systems.” 8th IEEE Cyber Science and Technology Congress (CyberSciTech 2023), Abu Dhabi, UAE, November 2023.

[146] Y. Xie, A. Gardi, and R. Sabatini, “Cybersecurity Risks and Threats in Avionics and Autonomous Systems.” 8th IEEE Cyber Science and Technology Congress (CyberSciTech 2023), Abu Dhabi, UAE, November 2023.

[147] E. Blasch, R. Sabatini, A. Roy, K. A. Kramer, G. Andrew, G. T. Schmidt, C. C. Insaurralde, and G. Fasano, "Cyber Awareness Trends in Avionics." 38th IEEE/AIAA Digital Avionics Systems Conference (DASC 2019), San Diego, CA, USA, September 2019.

[148] G. Fasano, O. G. Crespillo, R. Sabatini, A. Roy, and R. Ogan, "From the Editors of the Special Issue on Urban Air Mobility and UAS Airspace Integration: Vision, Challenges, and Enabling Avionics Technologies." IEEE Aerospace and Electronic Systems Magazine, Vol. 38, No. 5, pp. 4-5, May 2023.

[149] N. Safwat, R. Sabatini, A. Gardi, I.M. Hafez, and F. Newagy, “Urban Air Mobility Communication Performance Considering Co-Channel Interference.” IEEE Transactions on Aerospace and Electronic Systems, Vol. 60, Issue 4, August 2024.

[150] N. Safwat, K. Ranasinghe, A. Gardi, and R. Sabatini, "Intelligent Health and Mission Management for UAS-Assisted Wireless Networks." IEEE Transactions on Aerospace and Electronic Systems (early access), 2024.

[151] S. Hilton, K. Thangavel, A. Gardi, R. Sabatini, “Intelligent Mission Planning for Autonomous Distributed Satellite Systems.” Acta Astronautica, Vol. 225, pp. 857-869, December 2024.

[152] Y. Xie. A. Gardi, M. Liang, and R. Sabatini, “Hybrid AI-based 4D Trajectory UTM system for Dense Low Altitude Operation and Urban Air Mobility.” Aerospace Science and Technology, Vol. 153, No. 109422, October 2024.

References (cont.)

[153] L. Ren, M. Castillo-Effen, H. Yu, E. Johnson, Y. Yoon, N. Takuma, et al., "Small unmanned aircraft system (sUAS) categorization framework for low altitude traffic services," 2017 IEEE/AIAA 36th Digital Avionics Systems Conference (DASC), 2017, pp. 1-10.

[154] R. Sabatini and A. Gardi (Editors), “Sustainable Aviation Technology and Operations: Research and Innovation Perspectives.” Aerospace Series, John Wiley & Sons, Chichester, 2023.

[155] V. Estrela, J. Hemanth, O. Saotome, G. Nikolakopoulos, and R. Sabatini (Editors), “Imaging and Sensing for Unmanned Aircraft Systems: Volume 1 – Control and Performance.” Publisher: Institution of Engineering and Technology, 2020.

[156] V. Estrela, J. Hemanth, O. Saotome, R. Sabatini, and G. Nikolakopoulos (Editors), “Imaging and Sensing for Unmanned Aircraft Systems: Volume 2 – Deployment and Applications.” Institution of Engineering and Technology, 2020.

[157] R. Sabatini and A. Gardi, “Sustainable Aviation: An Introduction.” In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[158] Y. Lim, A. Gardi, and R. Sabatini, “Climate Impacts of Aviation.” In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[159] A. Gardi, R. Kapoor, Y. Lim, and R. Sabatini, “Noise Pollution and Other Environmental and Health Impacts of Aviation.” In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[160] A. Zanetti, A. Kumar, A. Gardi, and R. Sabatini, “Systems Engineering Evolutions.” In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[161] E. Crossin, A. Gardi, and R. Sabatini, “Life Cycle Assessment for Carbon Neutrality.” In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[162] A. Gardi, Y. Lim, N. Pongsakornsathien, R. Sabatini, and Trevor Kistan, “Air Traffic Management and Avionics Systems Evolutions.” In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[163] A. Gardi, Y. Lim, and R. Sabatini, “Optimisation of Flight Trajectories and Airspace.” In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

References (cont.)

[164] M. Marino, A. Gardi, R. Sabatini, and Y. Lim, "Advanced Aerodynamic Configurations." In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[165] K. Ranasinghe, K. Guan, A. Gardi, and R. Sabatini, "Low-Emission Propulsive Technologies in Transport Aircraft." In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[166] J. Silva, A. Gardi, and R. Sabatini, "Integration of Naturally Occurring Materials in Lightweight Aerostructures." In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[167] M. Burston, K. Ranasinghe, A. Gardi, V. Parezanovic, R. Ajaj, and R. Sabatini, "Distributed and Hybrid Propulsion: A Tailored Design Methodology." In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[168] J. Sliwinski, A. Gardi, M. Marino, and R. Sabatini, "Integration of Hybrid-Electric Propulsion Systems in Small Unmanned Aircraft." In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[169] S. Rondinelli, A. Gardi, and R. Sabatini, "Benefits and Challenges of Liquid Hydrogen Fuels for Commercial Transport Aircraft." In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[170] A. Gardi, R. Sabatini, and T. Kistan, "Multi-Objective Trajectory Optimisation Algorithms for Avionics and ATM Systems." In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[171] Y. Lim, A. Gardi, and R. Sabatini, "Energy-Optimal 4D Guidance and Control for Terminal Descent Operations." In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[172] Y. Lim, A. Gardi, and R. Sabatini, "Contrail Modelling for 4D Trajectory Optimisation." In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[173] Y. Lim, A. Gardi, R. Sabatini, and T. Kistan, "Trajectory Optimisation to Minimise the Combined Radiative Forcing Impacts of Contrails and CO2." In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[174] A. Zanetti, A. Gardi, and R. Sabatini, "The W Life Cycle Model – San Francisco Airport Case Study." In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

References (cont.)

[175] R. Sabatini and A. Gardi, "Conclusions and Future Research." In Sustainable Aviation Technology and Operations: Research and Innovation Perspectives. Aerospace Series, John Wiley & Sons, Chichester, 2023.

[176] S. Bijjahalli and R. Sabatini, "Introduction to navigation and intelligence for UAVs relying on computer vision." In Imaging and Sensing for Unmanned Aircraft Systems: Volume 1 - Control and Performance. The Institution of Engineering and Technology (IET), 2020.

[177] N. Razmjooy, V. Vieira Estrela, and R. Sabatini, "Vision in Micro Aerial Vehicles." In Imaging and Sensing for Unmanned Aircraft Systems: Volume 1 - Control and Performance. The Institution of Engineering and Technology (IET), 2020.

[178] S. Bijjahalli and R. Sabatini, "Multisensor data fusion for vision-based UAV navigation and guidance." In Imaging and Sensing for Unmanned Aircraft Systems: Volume 1 - Control and Performance. The Institution of Engineering and Technology (IET), 2020.

[179] Y. Lim, A. Gardi, and R. Sabatini, "UAS human factors and human–machine interface design." In Imaging and Sensing for Unmanned Aircraft Systems: Volume 2: Deployment and Applications. The Institution of Engineering and Technology (IET), 2020.

[180] V. Vieira Estrela, J. Hemanth, O. Saotome, and Roberto Sabatini, "Advances in UAV Avionics for Imaging and Sensing." In Imaging and Sensing for Unmanned Aircraft Systems: Volume 1 - Control and Performance. The Institution of Engineering and Technology (IET), 2020.