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Aerospace Cyber-Physical and Autonomous Systems

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Aerospace, Defence and Transport Systems @RMIT

SIR LAWRENCE WACKETT CENTRE AIR SPACE LAND SEA

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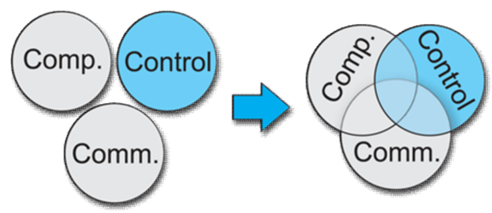
Lecture Outline

- ❖ **Aerospace Cyber-Physical and Autonomous Systems Research**
  - The Digital Transformation and Cyber-Physical Systems (CPS)
  - Aerospace CPS and Autonomous Systems Research
- ❖ **Next Generation CNS/ATM and Avionics Systems**
  - CNS/ATM and Avionics (CNS+A) Systems for Trajectory Based and Performance Based Operations (TBO/PBO)
  - Multi-Objective 4D Trajectory Optimisation in Flexible Airspace
- ❖ **Robust Autonomous Navigation and Guidance Systems**
  - GNSS Integrity Augmentation for UAS
  - Low Size, Weight, Power and Cost (SWaP-C) Navigation Systems for UAS Operations
- ❖ **Trusted Autonomous Systems**
  - A Novel Sense-and-Avoid (SAA) System for Trusted Autonomous Operations
  - Adaptive Human-Machine Systems for Aerospace and Defence Applications
  - Distributed and Intelligent Satellite Systems
  - Multi-Domain Traffic Management (ATM 2.0)
- ❖ **Questions and Discussion**

Cyber-Physical Systems – What are they?

- **Cyber-Physical Systems (CPS) are engineered through the seamless integration of digital and physical components, with the possibility of including human interactions**
- This requires **three fundamental functions** to be present: **Control, Computation and Communication (C³)**
- Practical CPS typically combine sensor networks and embedded computing to monitor and control physical processes, with feedback loops that allow physical processes to affect computations and vice-versa



Our Research Focus

- We performs research, education and community outreach activities in the field of CPS for aerospace, transport, defence and related applications (e.g., civil security and humanitarian mission systems)
- **We focus on two special categories of CPS: Autonomous Cyber-Physical (ACP) systems and Cyber-Physical-Human (CPH) systems**
- **ACP systems operate without the need for human intervention or control. For ACP systems to work, formal reasoning is required** as these systems are normally used to accomplish mission/safety-critical tasks and any deviation from the intended behaviour may have significant implications on human health, well-being, economy, etc.
- A sub-class is that of Semi-Autonomous Cyber-Physical (S-ACP) systems, which perform autonomous tasks in a specific set of pre-defined conditions but require a human operator otherwise

Our Research Focus (2)

- **A separate category is that of CPH systems. These are a particular class of CPS where the interaction between the dynamics of the system and the cyber elements of its operation can be influenced by the human operator and the interaction between these three elements is regulated to meet specific objectives**
- CPH systems consist of three main components: **physical elements** sensing and modelling the environment, the systems to be controlled and the human operators; **cyber elements** including the communication links and software; and **human operators** who supervise/monitor the operation of the system and can intervene if and when needed

CPS for Trusted Autonomous Operations

- **Our research aims at developing robust and fault-tolerant ACP and CPH system architectures that ensure trusted autonomous operations with the given hardware constraints, despite the uncertainties in physical processes, the limited predictability of environmental conditions, the variability of mission requirements (especially in congested or contested scenarios), and the possibility of both cyber and human errors**
- A key point in these advanced CPS is the control of physical processes from the monitoring of variables and the use of computational intelligence to obtain a deep knowledge of the monitored environment, thus providing timely and more accurate decisions and actions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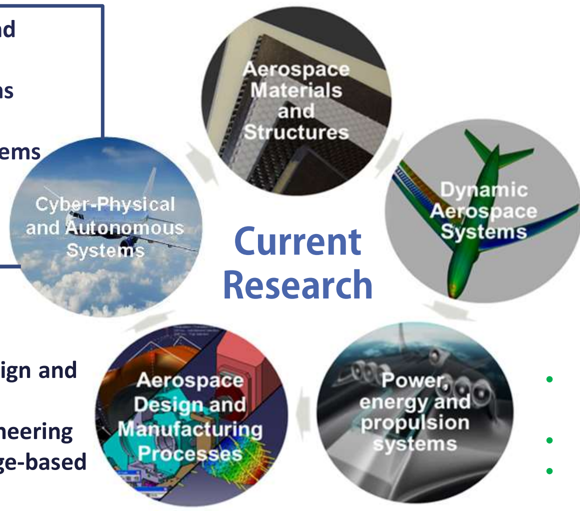
Aerospace CPS and Autonomous Systems Research


Aerospace Materials and Structures
Dynamic Aerospace Systems
Power, energy and propulsion systems
Aerospace Design and Manufacturing Processes
Cyber-Physical and Autonomous Systems
Aerospace Industry Pillars

- Metallic and multifunctional composite technologies
- Fatigue, fracture and damage tolerance
- Modelling and simulation
- Repair and joining technologies

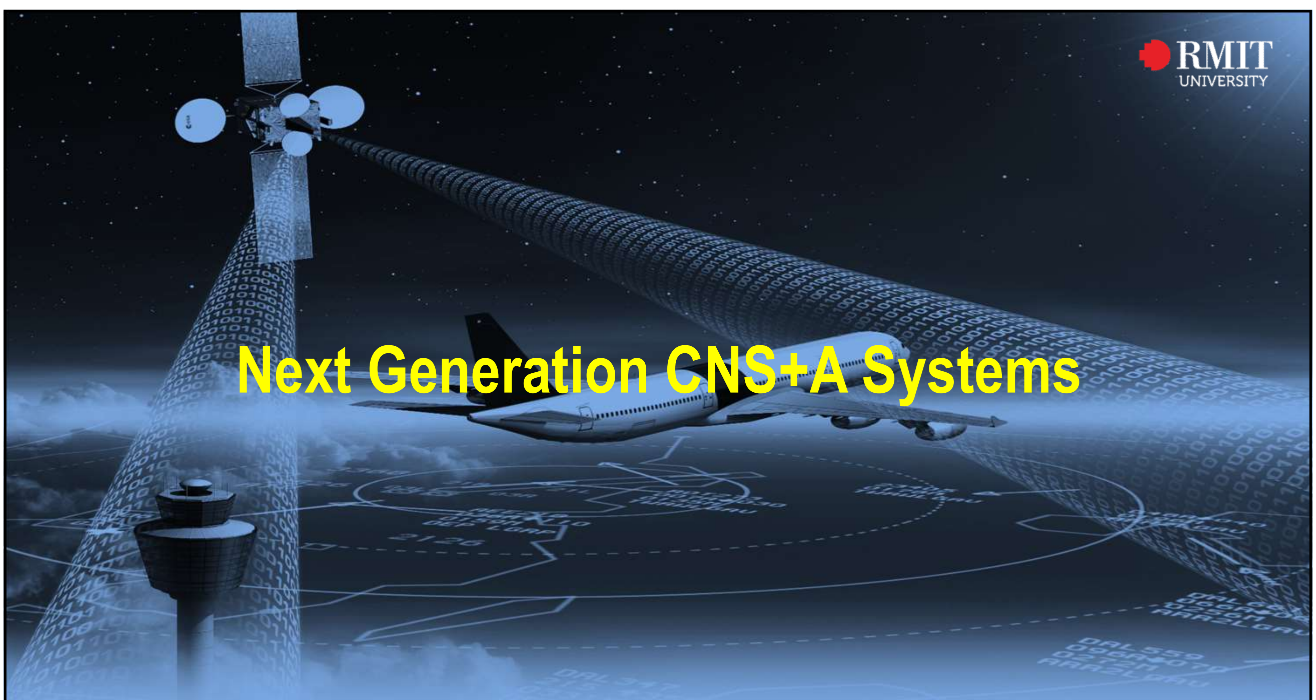
- Air traffic management and avionics systems
- Unmanned aircraft systems and trusted autonomy
- Embedded intelligent systems
- Smart satellite systems
- Health monitoring and prognostics



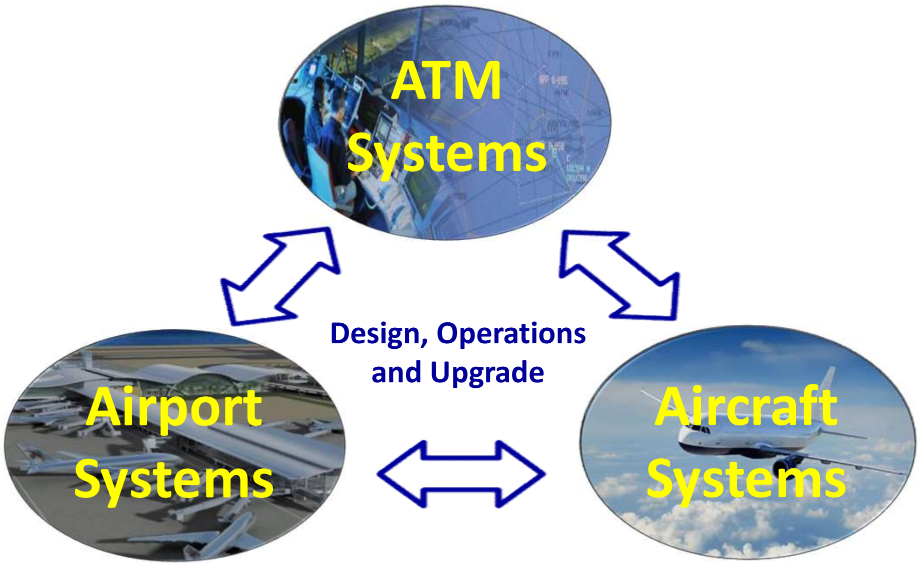
- Flow-structure interaction and aerodynamic loading
- Dynamics, modelling, control and optimisation
- Hypersonics

- Multidisciplinary design and optimisation
- System support engineering
- Virtual and knowledge-based engineering
- Advanced manufacturing processes

- Novel energy and propulsion systems
- Reversible fuel cells, solar systems
- Alternate fuel systems, and piezoelectric systems

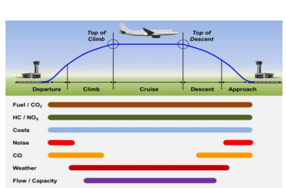


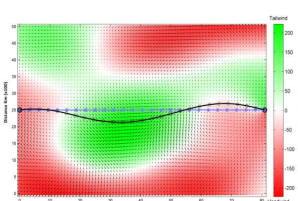
CNS+A Systems Research Pillars

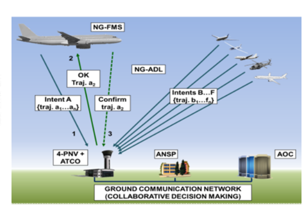


ATM and Avionics Systems Research

- **Research Focus:** **Air Navigation Safety, Efficiency and Sustainability (Systems Design/Operations and Human Factors Engineering)**
- **Next Generation CNS/ATM and Avionics Systems (CNS+A)**
  - Fault-Tolerant, Secure and High-Integrity CNS+A Systems for IBO/PBO
  - Unmanned Aircraft Systems (UAS) Integration and Traffic Management (UTM)
  - Cooperative/Non-Cooperative Separation Assurance (SA) and Sense-and-Avoid (SAA)
  - Advanced Forms (Adaptive/Cognitive) of Human-Machine Interface and Interactions (HMI^2)





ATM Modernisation

The **key performance improvement areas** identified in the ICAO **Global Air Navigation Capacity and Efficiency Plan** are [1]:

- Airport operations
- Efficient flight path planning and execution
- Optimum demand/capacity balance and flexible flights
- Globally interoperable systems and data

Safety | **Capacity** | **Efficiency** | **Cost-effectiveness**

Flexibility | **Interoperability** | **Environmental Sustainability**

ATM Modernisation

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More Automation and Information Sharing (CNS+A) → **Towards Full Automation**

CNS+A Evolutions

Key Objectives and Enabling Technologies [2-3]

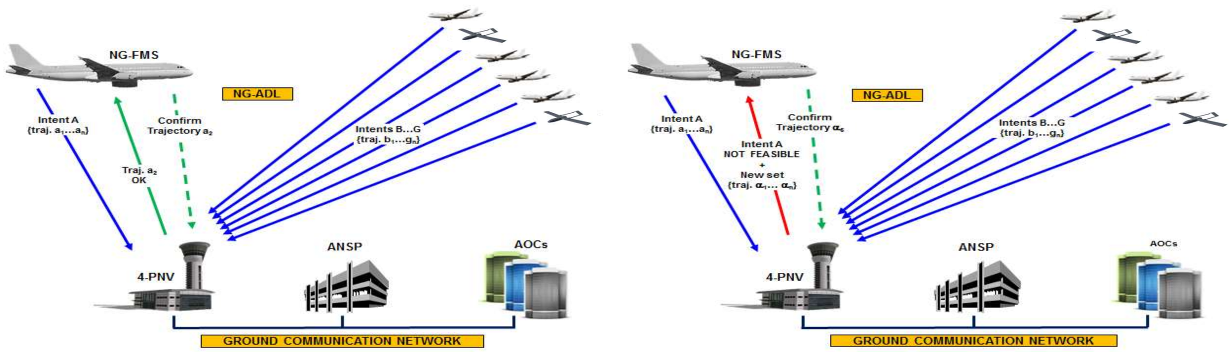
Safety	Dependable safety-nets and enhanced situational awareness of human operators adopting more advanced CNS+A decision support systems
Capacity	Freeing up additional capacity through the dynamic allocation and optimised reconfiguration of airspace and airport resources
Operational Efficiency	Innovative air traffic flow management techniques based on CNS+A advances for a more efficient and effective exploitation of the available capacity
Environmental Sustainability	Multi-objective optimisation of aircraft flight trajectories and arrival/departure scheduling to minimise environmental impacts

NextGEN SESAR oneSKY

- 4-Dimensional Trajectories (4DT) and Intent Based Operations (IBO)
- Dynamic airspace management (strategic and tactical)
- Migration from voice-based to data link/network communications (SWIM)
- Human operators as central decision-makers
- Dynamic Airspace Management and ATFM automation
- HMI^2 evolutions and interoperability

Required CNS+A Technologies

- Multi-Objective 4D Trajectory Optimisation (MOTO-4D) and Dynamic Airspace Management (DAM)
- Next Generation Flight Management System (NG-FMS)
- 4DT Planning, Negotiation and Validation (4-PNV)
- Next Generation Airborne Data Link (NG-ADL)



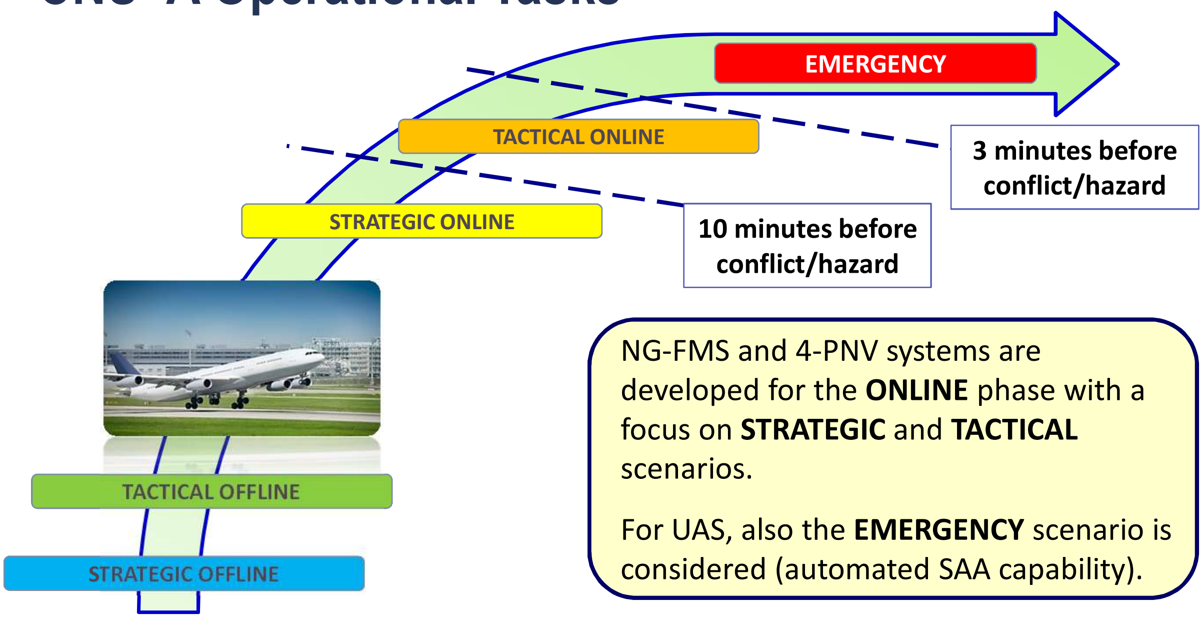
Fuel-Burn, Emissions and Noise Reduction Goals

	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

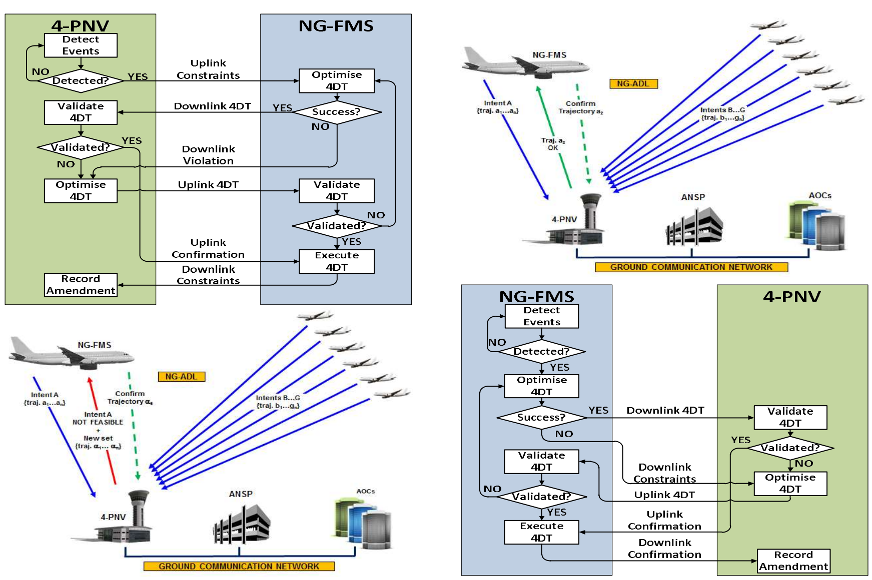
CNS+A Operational Tasks



NG-FMS and 4-PNV systems are developed for the **ONLINE** phase with a focus on **STRATEGIC** and **TACTICAL** scenarios.

For UAS, also the **EMERGENCY** scenario is considered (automated SAA capability).

NG-ADL Negotiation and Validation Loops [5]



A high-throughput, fail-safe and secure Avionics Data Link (ADL) is required!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Multi-Objective 4D Trajectory Optimisation in Flexible Airspace
THALES
Cranfield University
POLITECNICO DI TORINO 1859 1906
KARI
Korea Aerospace Research Institute
6/2/2020
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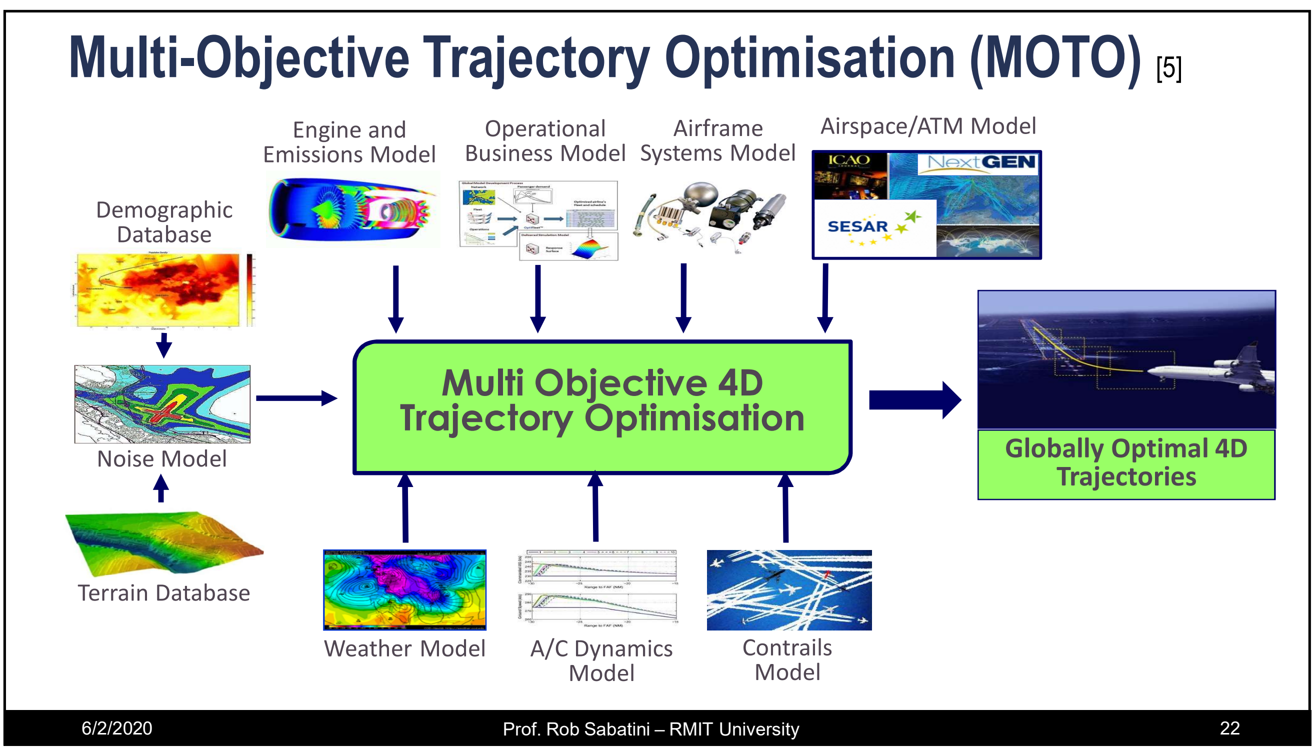
Multi-Objective Trajectory Optimisation (MOTO) [5]
Demographic Database
Engine and Emissions Model
Operational Business Model
Airframe Systems Model
Airspace/ATM Model
ICAO
NextGEN
SESAR
Noise Model
Terrain Database
Multi Objective 4D Trajectory Optimisation
Globally Optimal 4D Trajectories
Weather Model
A/C Dynamics Model
Contrails Model
6/2/2020
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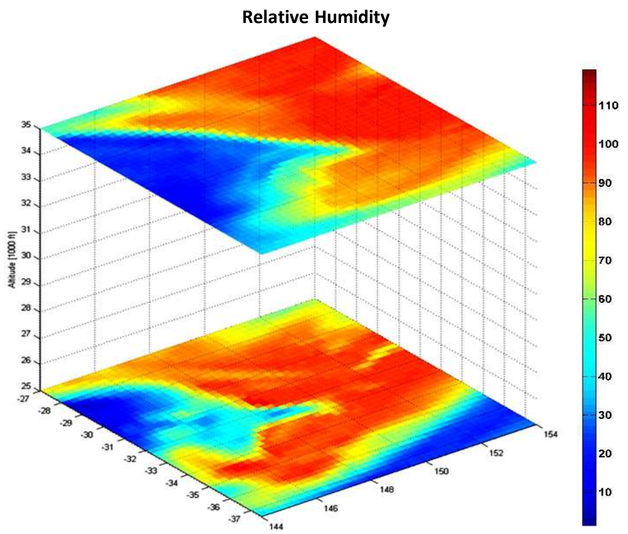
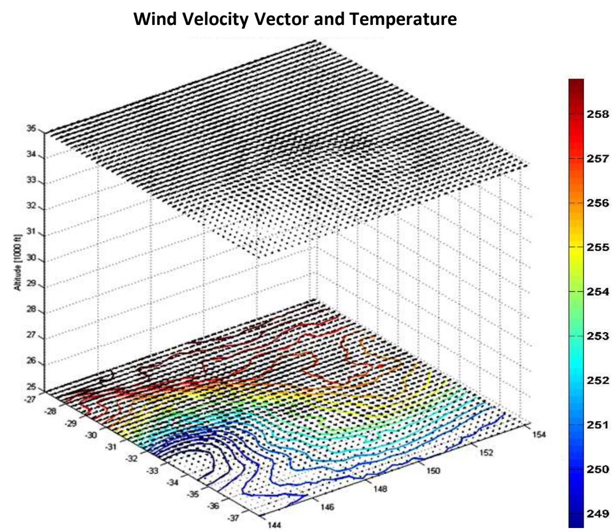
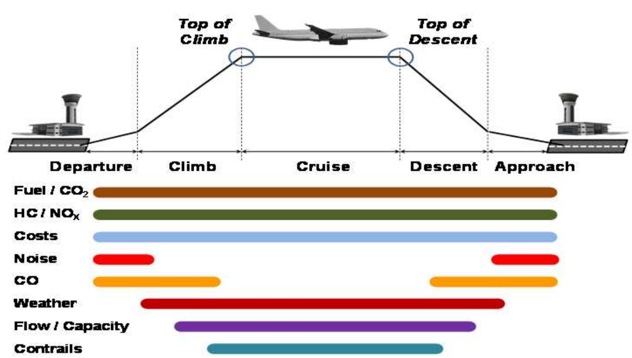
4D Weather and Non-Standard Atmosphere Models





Pollutant Emission Models



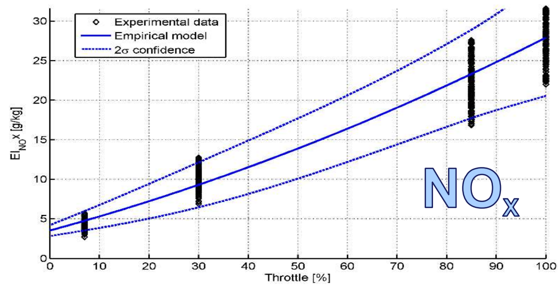
- Carbon Oxides (CO_X)
- Nitrogen Oxides (NO_X)
- Sulphur Oxides (SO_X)
- Unburned Hydro-Carbons (UHC)
- General Expressions:

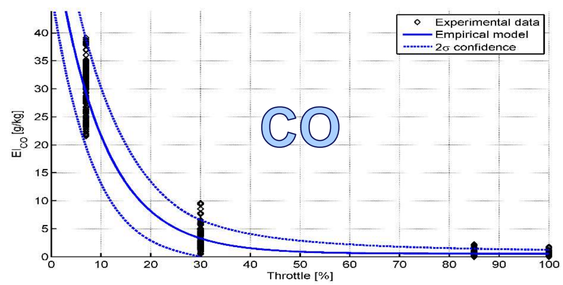
$$GP = \int_{t_0}^{t_f} EI_{GP} \cdot FF \, dt \quad [\text{Kg}]$$

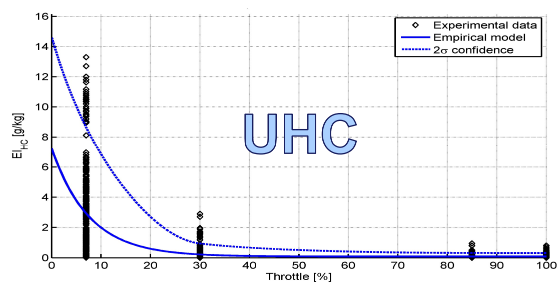
(HBR Turbofan Engines)

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

Pollutant Emission Models







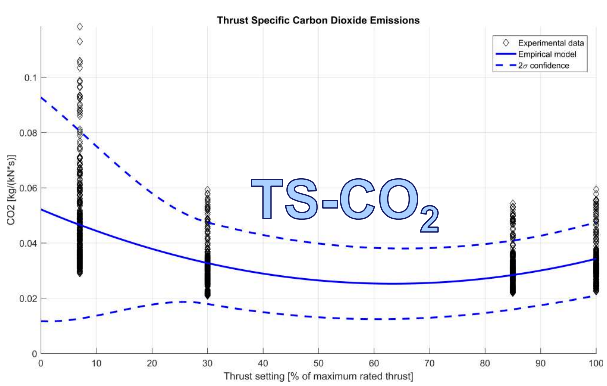
$$T_{MAX} = C_{T1}\left(1 - \frac{H_P}{C_{T2}} + C_{T3}H_P^2\right)\left[1 - C_{T5}(\Delta T - C_{T4})\right]$$

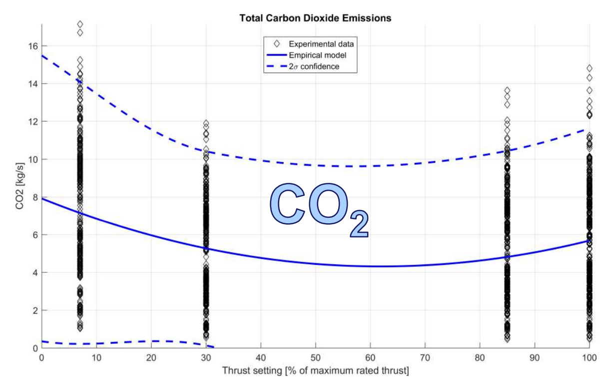
$$FF = \max\left[\tau\, T_{MAX}\, C_{f1}\left(1 + \frac{v_{TAS}}{C_{f2}}\right), C_{f3}\left(1 - \frac{H_P}{C_{f4}}\right)\right]$$

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

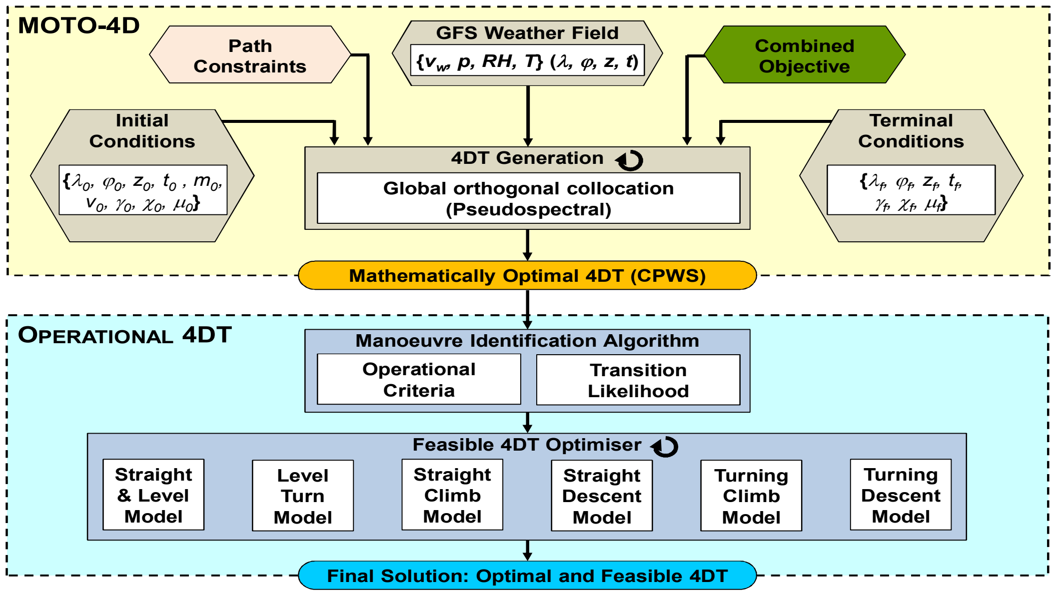
$$EI_{NO_X}(\tau) = 7.32\,\tau^2 + 17.07\,\tau + 3.53 \quad \left[{}^{g}/_{Kg}\right]$$

Pollutant Emission Models (cont.)

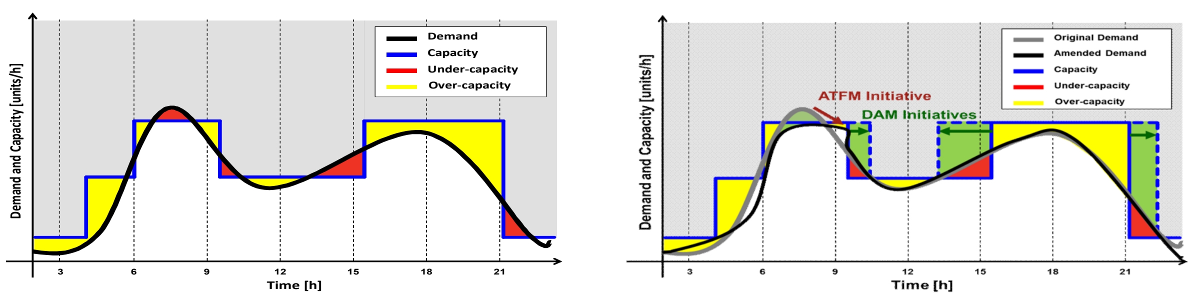




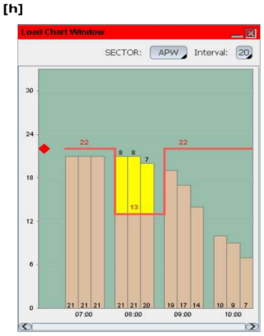
Online Tactical 4DT Planning Algorithm [5]



Airspace Management: Demand-Capacity Balance



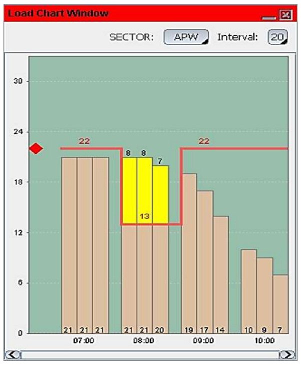
- Air traffic demand is highly variable in time
- Assessment of demand/capacity balance [6, 7]:
  - Analysis of trajectories and weather to predict traffic states
  - Continuous monitoring of air traffic demand levels
  - Evaluations performed both at sector level and regional level

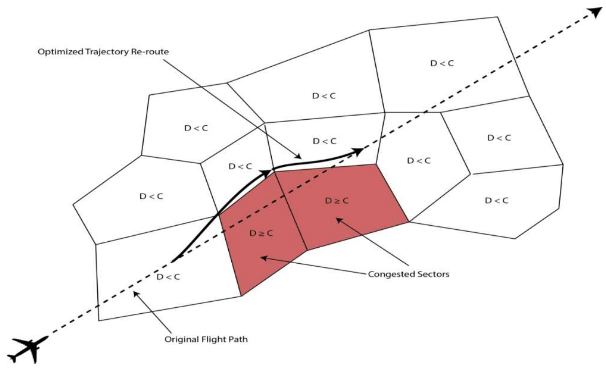


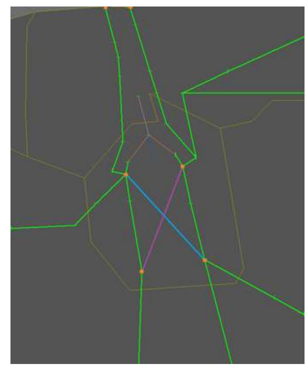
Air Traffic Flow Management Initiatives

❖ **Short-term approach** [7]

- When D/C flags indicate that demand exceeds capacity: initiate re-routings to sectors with reduced traffic densities
- MOTO-4D to minimise the costs of re-routings

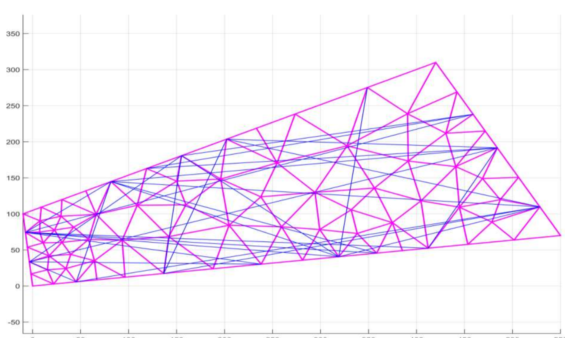






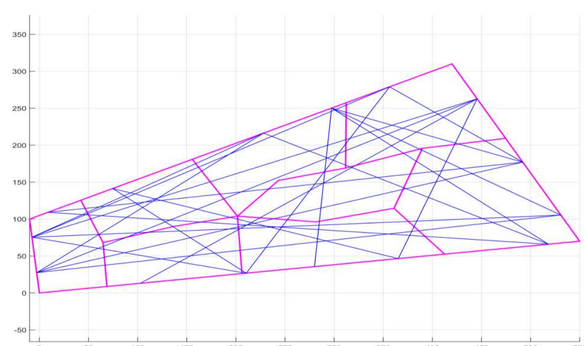
Airspace Optimisation

Flow analysis step



31 routes, up to 15 aircraft/hr/route

Final result



8 consolidated sectors meeting capacity constraint (max 20 aircraft)

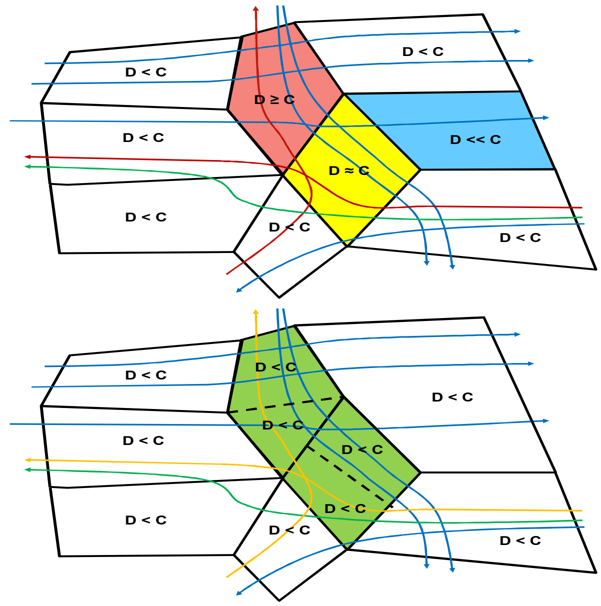
Dynamic Airspace Management

❖ **Longer-term solution**

- Capacity levels account for the maximum available CNS performance, supporting high-density operations
- Sectors can continuously change in number and shape (4D morphing)
- Sectors or portions can also be dynamically allocated for military/ segregated operations
- Based on Euler flow modelling [7]:

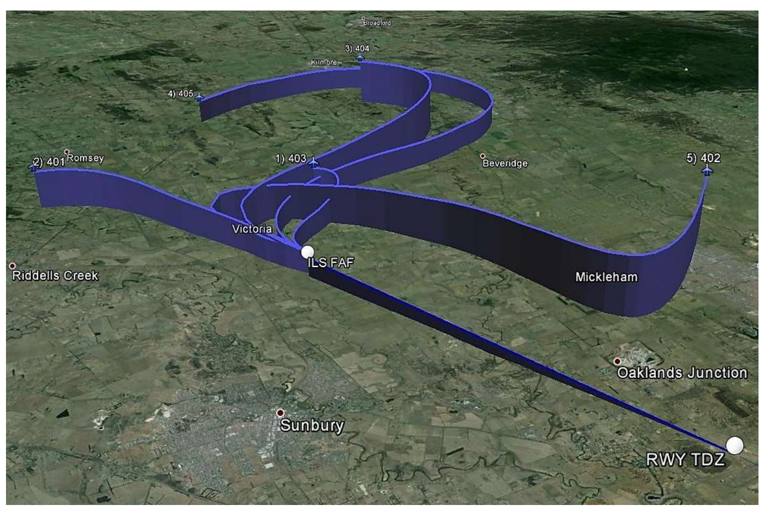
$$\dot{\Delta}_i(t) = \frac{d\,C_i(t)}{dt} - \frac{dD_i(t)}{dt}$$

$$\frac{\partial \rho_i(x,t)}{\partial t} + \frac{\partial q_i(x,t)}{\partial x_i} + \sigma_i(t) = 0$$



Simulation Case: Melbourne Arrivals (RWY 16)

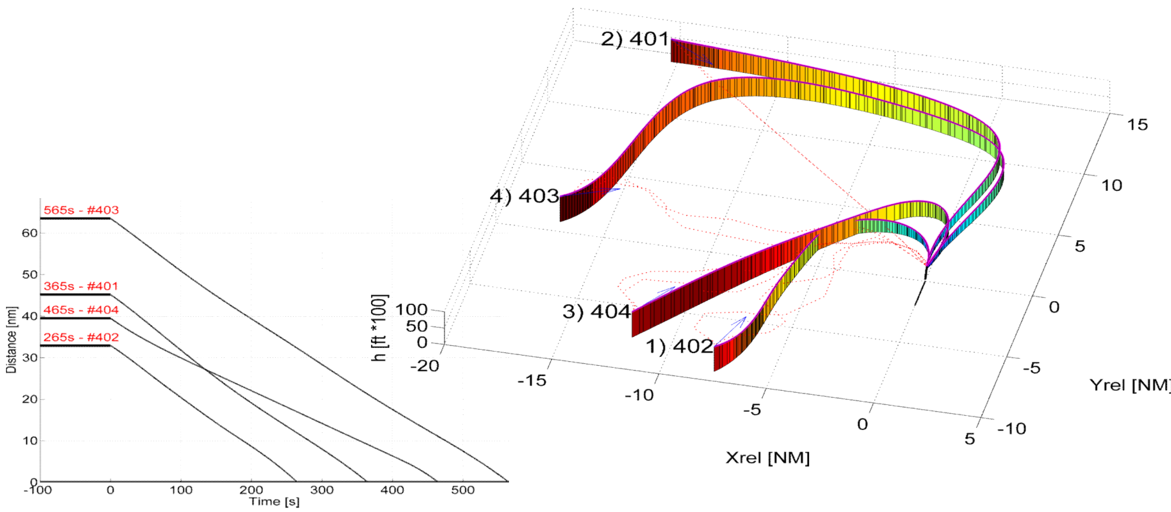
Initial position	Allocated arrival
S 38° 33' 15" E 144° 57' 30" 6851 ft	(1) 152 s
S 38° 33' 53" E 144° 58' 19" 5125 ft	(2) 242 s
S 38° 36' 37" E 144° 36' 58" 8511 ft	(3) 332 s
S 38° 30' 59" E 144° 33' 22" 8328 ft	(4) 422 s
S 38° 43' 8" E 144° 51' 2" 8916 ft	(5) 512 s



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

More Complex Scenarios

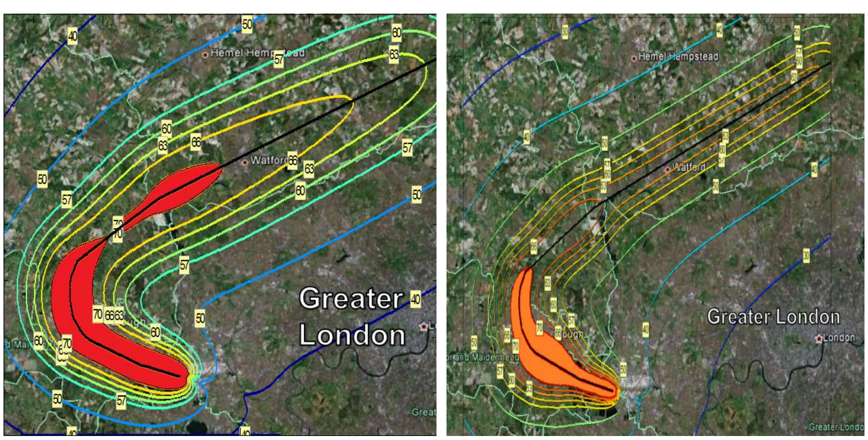
Sequencing of 4 conflicting arrivals using GNSS [11]



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

Departure case study

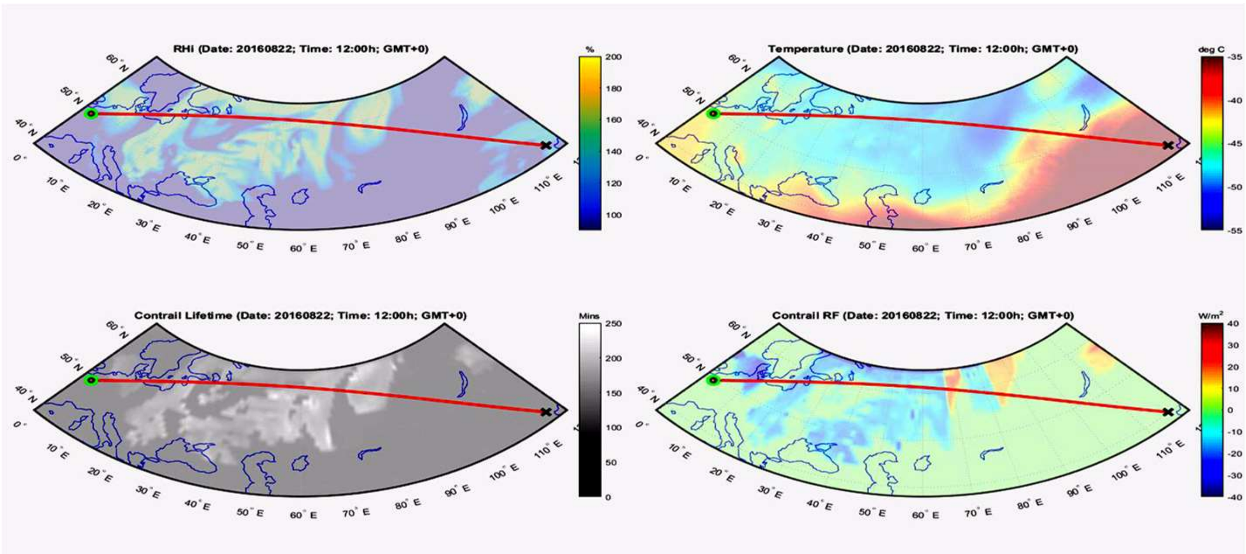
Real commercial flight profile used as benchmark
- Departed at 19:27 GMT (night flight)
- Optimisation: Min Fuel and Noise (SEL 70dBA)



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

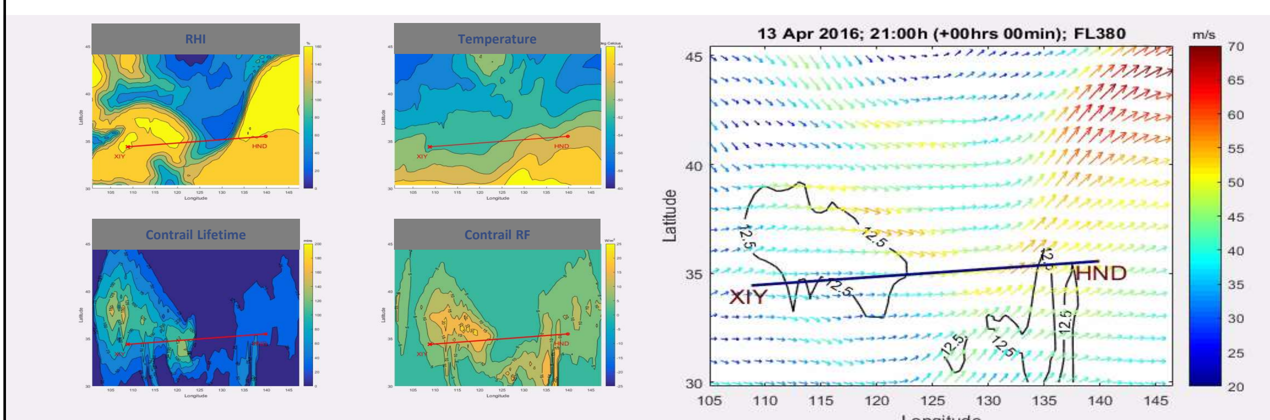
R. Sabatini, Cranfield University in Clean Sky: Avionics and CNS/ATM Re-search Focus, Presented at the Clean Sky 2 Academia and Clusters, Brussels, Belgium, 2013.

Mitigation of Contrail RF



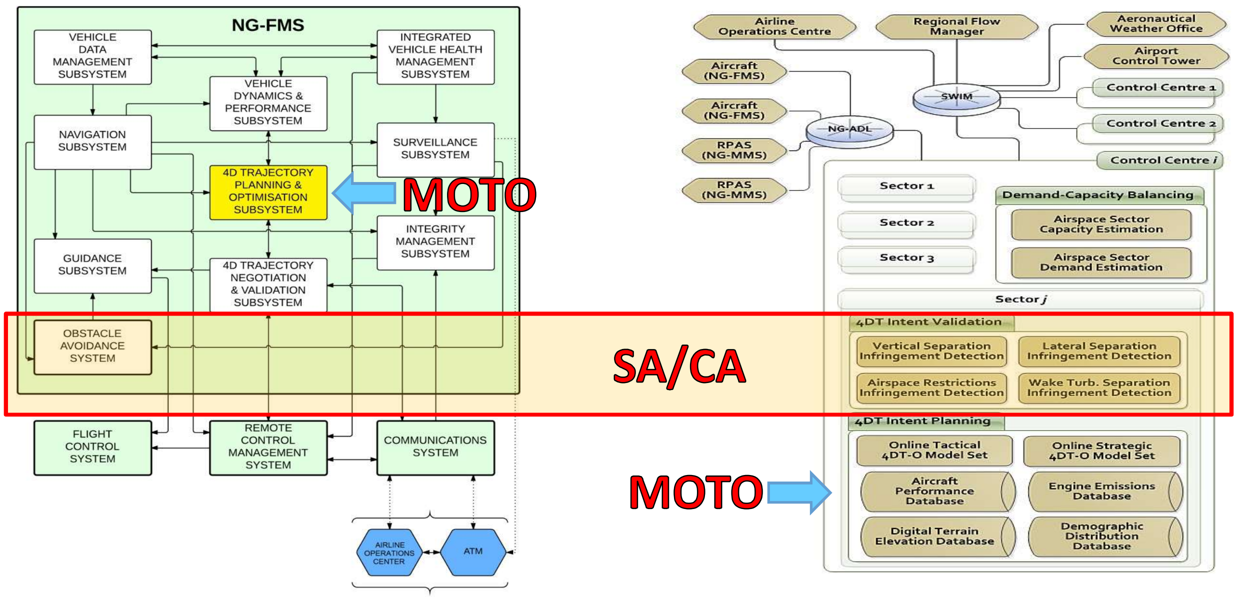
Boeing B777-200 4449 NM – 10h 24min flight time (CDG to PEK) [8]

Case study – Tokyo to Xi'an

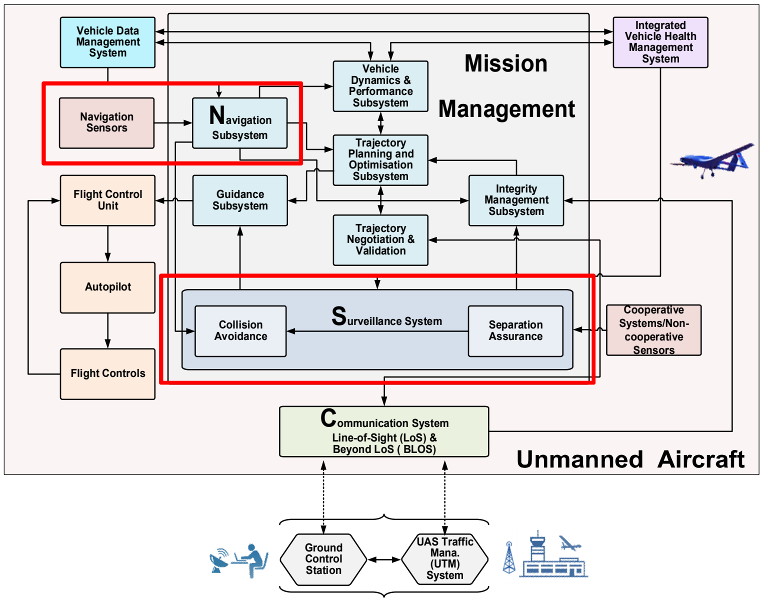


Optimised trajectory for minimum contrail RF and CO_2/fuel

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



Unmanned Aircraft Systems [9]



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GNSS Integrity Augmentation for UAS

Cranfield University

The University of Nottingham

UNITED KINGDOM · CHINA · MALAYSIA

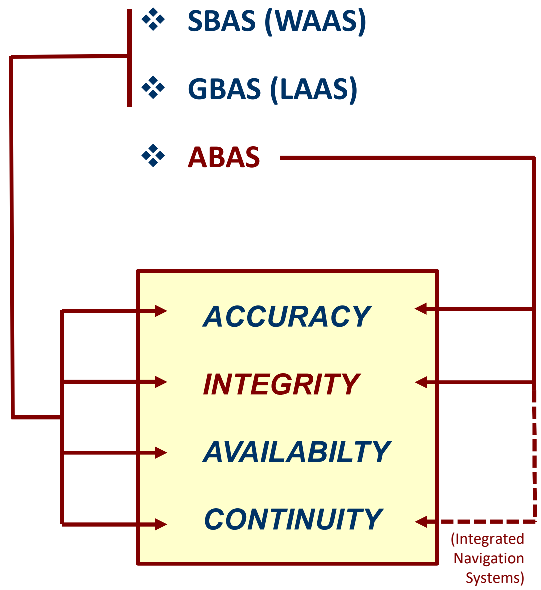
GNSS Augmentation Benefits

❖ **GNSS augmentation benefits** include:

- Precision approach and landing autonomous ops
- Operations in urban environments
- Interference and jamming resistance/avoidance
- Reduced and simplified equipment on board aircraft
- Predictive integrity for optimal AI/ML data fusion

❖ In addition to SBAS and GBAS, GNSS augmentation may take the form of additional information being provided by **other avionics systems**

❖ A system such as this is referred to as an **Aircraft** (or Avionics) **Based Augmentation System (ABAS)**

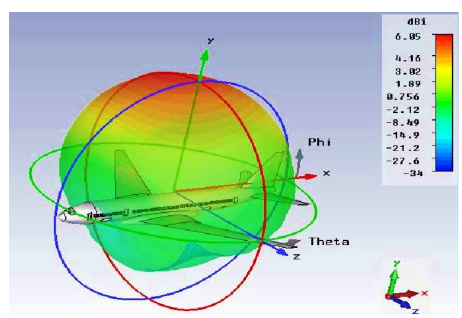


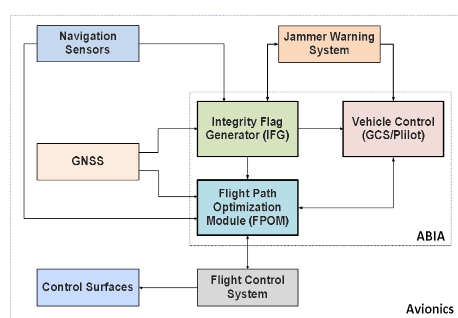
GNSS Integrity Augmentation

❖ **Avionics Based Integrity Augmentation**

- The additional avionics systems used in ABAS operate via separate principles than the GNSS and, therefore, are **not subject to the same sources of error or interference** [10, 11]
- Focus is on Integrity (in addition to accuracy and continuity) augmentation obtained by system/software redundancy and suitable analytic approaches
- Using suitable data link and data processing technologies, a certified Avionics Based Integrity Augmentation (ABIA) system can be a core element of a future GNSS Space-Ground-Avionics Augmentation Network (SGAAN)

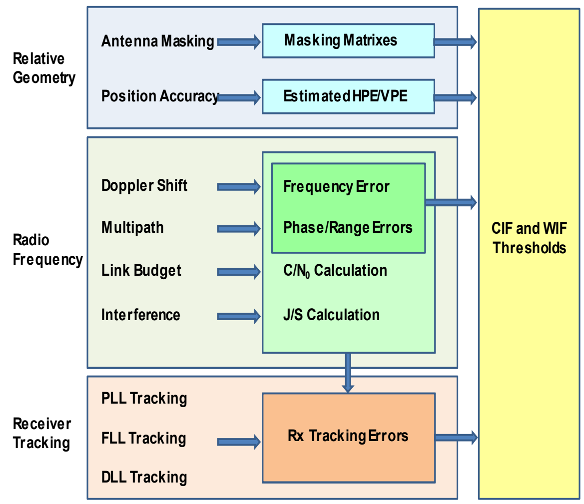
❖ **Developing ABAS for mission-essential and safety-critical GNSS applications (operations with jamming/spoofing, aircraft precision approach/landing, UAS sense-and-avoid, etc.)**





GNSS Performance Threats

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



ABIA Integrity Flags

A L E R T S

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

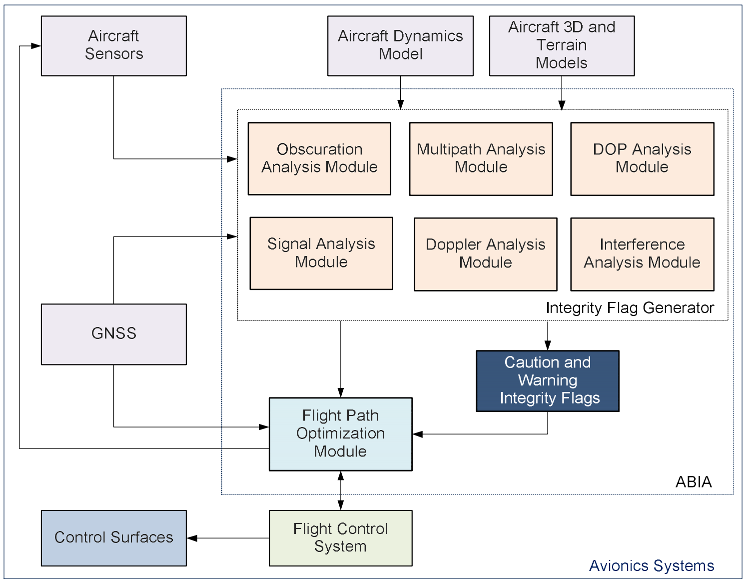
Warning Integrity Flag (WIF):
A ***reactive annunciation*** that the GNSS data delivered to the avionics system has exceeded the Required Navigation Performance (RNP) thresholds specified for the current flight operational task (GNSS fault status)

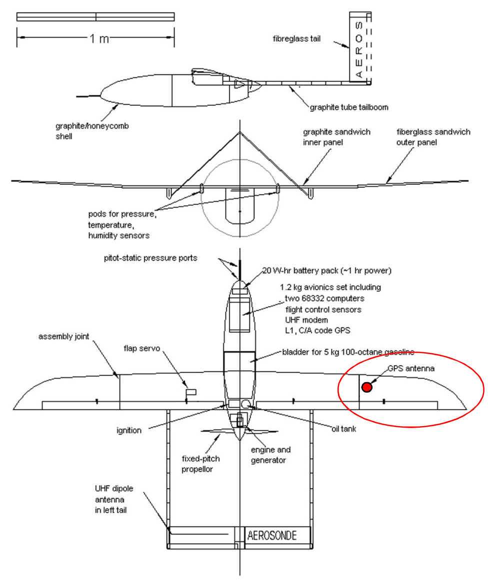
T T A

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

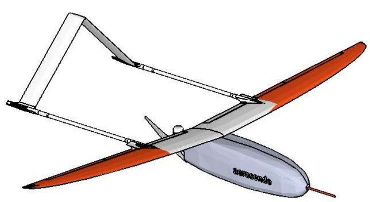
ABIA Time-to-Warning (TTW):
The **maximum time allowed** from the moment a GNSS fault resulting in an unsafe condition is detected to the moment that the ABIA system provides a warning flag to the user

ABIA Case Study – Aerosonde

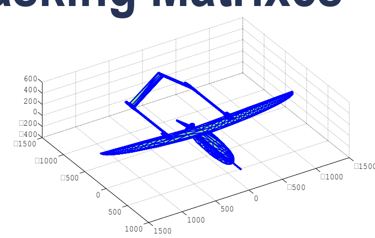




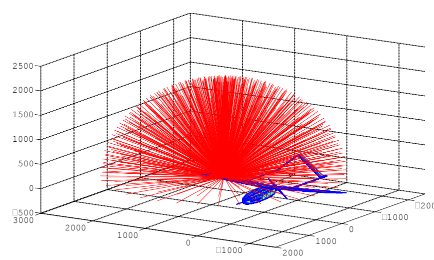
AEROSONDE Masking Matrixes

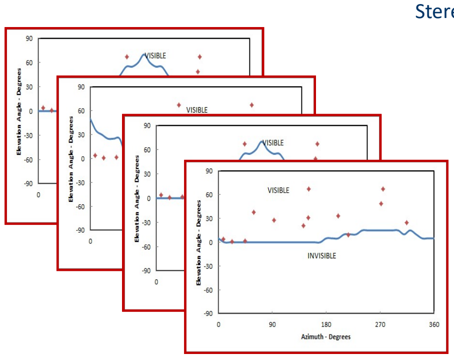


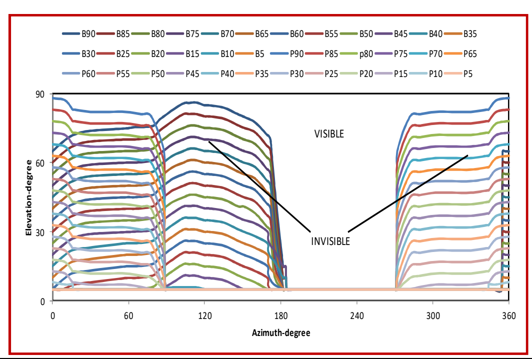
CAD Model



Stereo-Lithography (STL) Format





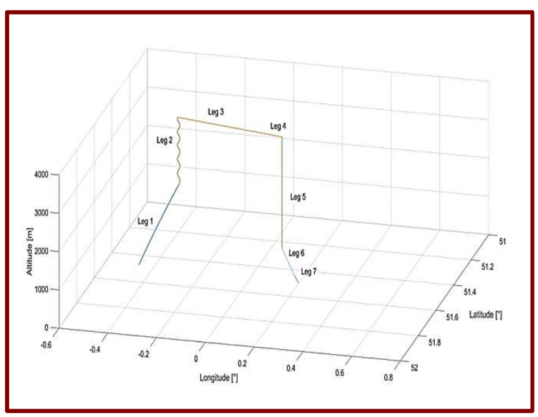


CIF/WIF Criteria

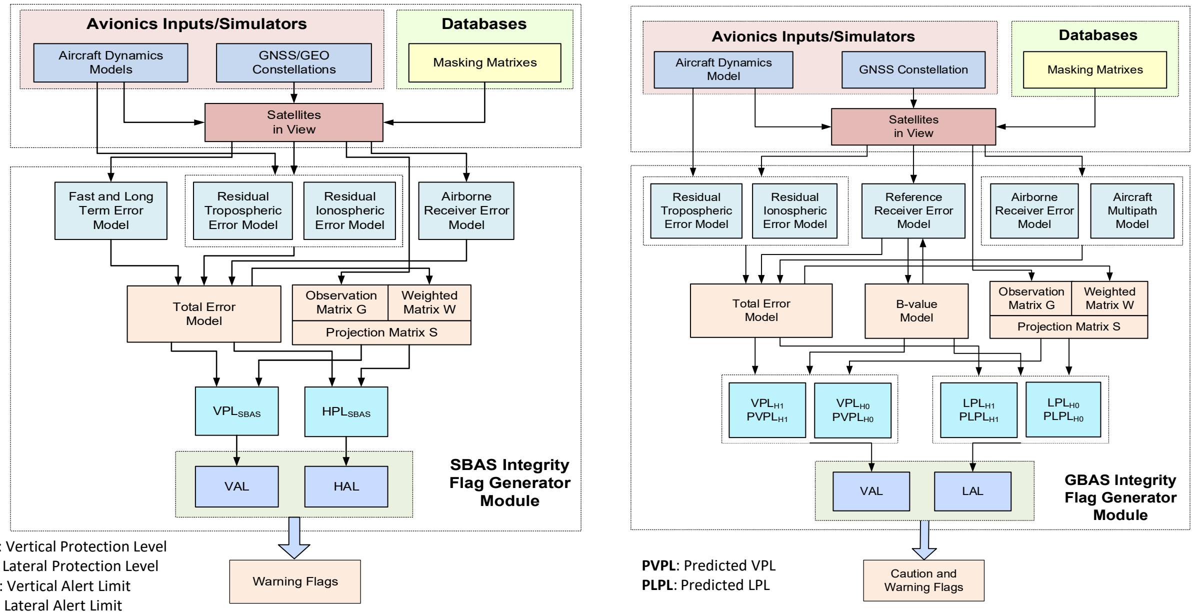
Integrity Event	Integrity Flags Criteria
Obscuration	***CIF*** – When the current A/C manoeuvre will lead to less the 4 satellite in view, the CIF is generated
	WIF – When less than 4 satellites are in view, the WIF is generated
Elevation	***CIF*** – When one (or more) satellite(s) elevation angle (antenna frame) is less than 10 degrees, the caution integrity flag is generated
	WIF – When one (or more) satellite(s) elevation angle is less than 5 degrees, the warning integrity flag is generated
Multipath	***CIF*** – When the ELP exceeds 0.1 radians, the caution integrity flag is generated
	WIF – When the multipath ranging error exceeds 2 metres and the A/C flies in proximity of the ground (below 448.5 metres) the warning integrity flag is generated
Tracking loops	***CIF*** – When either $42.25° \le 3\sigma_{\mathrm{PLL}} \le 45^{\circ}$ or $0.2375\mathrm{T} \le 3\sigma_{\mathrm{FLL}} \le 0.25\mathrm{T}$ or $0.05\mathrm{d} \le 3\sigma_{\mathrm{DLL}} \le \mathrm{d}$, the CIF is generated
	WIF – When $3\sigma_{\mathrm{PLL}} > 45^{\circ}$ or $3\sigma_{\mathrm{FLL}} > 1/4\mathrm{T}$ or $3\sigma_{\mathrm{DLL}} > \mathrm{d}$ the WIF is generated
C/N_0	***CIF*** – When the C/N_0 is less than 26 dB-Hz the CIF is generated
	WIF – When the C/N_0 is less than 25 dB-Hz the CIF is generated
Jamming	***CIF*** – When the difference between the received (incident) jammer power (dBw) and the received (incident) signal power (dBw) is 1 dB below the J/S performance of the receiver at its tracking threshold, the CIF is generated
	WIF – When the difference between the received (incident) jammer power (dBw) and the received (incident) signal power (dBw) is above the J/S performance of the receiver at its tracking threshold, the WIF is generated
Doppler	***CIF*** – When the C/N_0 is below 28 dB-Hz and the signal is lost, the caution integrity flag is generated if the estimated acquisition time is less than the application-specific TTA requirements
	WIF – When the C/N_0 is below 28 dB-Hz and the signal is lost, the warning integrity flag is generated if the estimated acquisition time exceeds the application-specific TTA requirements

ABIA IFG Simulation

FLIGHT LEG	CIF Time	WIF Time
Straight Climb	---	---
Turning Climb	---	---
Straight & Level	---	---
Level Turn	2241 ~ 2311 s, 2413 ~ 2485 s, 2491 ~ 2650 s	2259 ~ 2263 s, 2273 ~ 2283 s, 2432 ~ 2436 s, 2446 ~ 2485 s, 2609 ~ 2612 s, 2621 ~ 2630 s
Turning Descent	2688 ~ 2752 s, 2811 ~ 2881 s, 2944 ~ 3012 s, 3079 ~ 3100 s	2690 ~ 2739 s, 2814 ~ 2869 s, 2946 ~ 3003 s, 3081 ~ 3100 s
Straight Descent	---	---
Approach	3301 ~ 3400 s	3303 ~ 3400 s



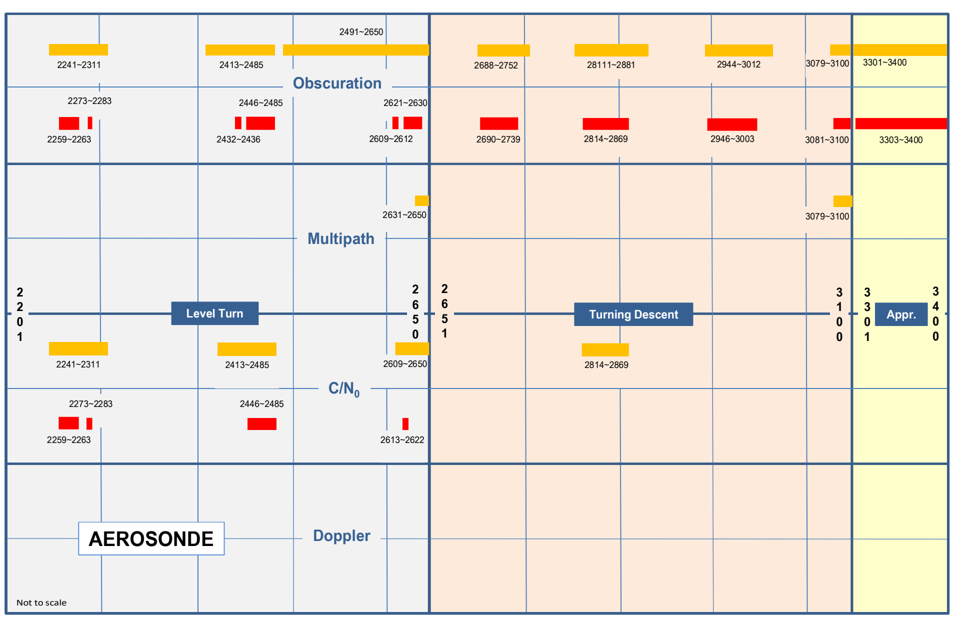
SBAS and GBAS IFG Architecture [11]



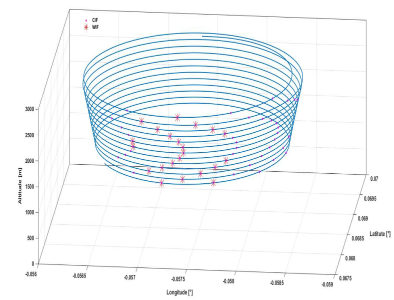
VPL: Vertical Protection Level
LPL: Lateral Protection Level
VAL: Vertical Alert Limit
LAL: Lateral Alert Limit

PVPL: Predicted VPL
PLPL: Predicted LPL

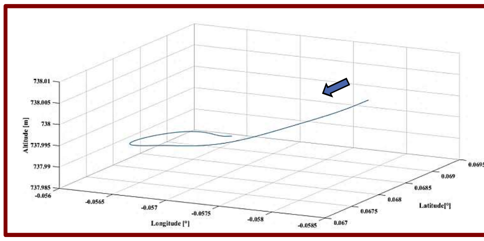
ABIA IFG Simulation



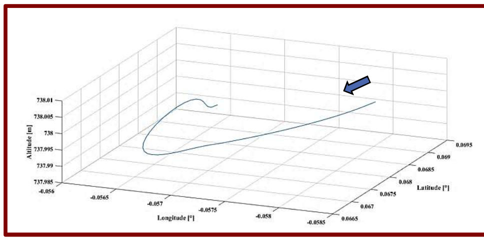
Trajectory Optimization Results



CIFs and WIFs generated



TD leg segment optimised with PMO

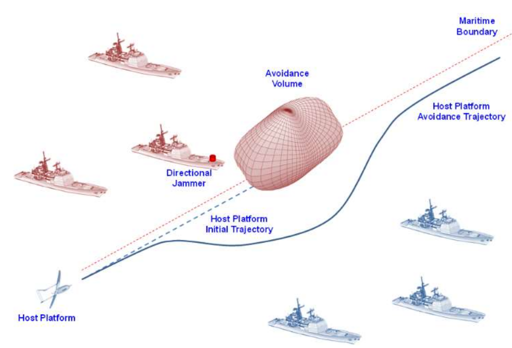


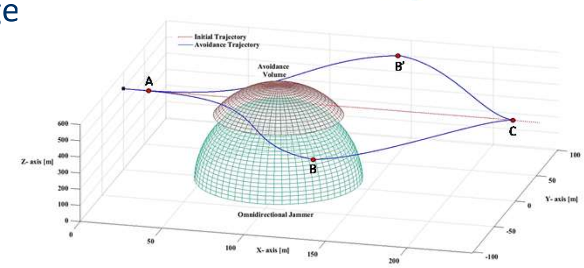
TD leg segment optimised with CGO

- ❖ CIF not followed by WIF
  - ➢ Pseudo-spectral methods produce quasi real-time solutions (acceptable for mission planning and some flight management implementations)
  - ➢ More efficient (real-time) geometric algorithms are used in other cases

Autonomous Navigation and Guidance in GNSS-denied Environments

- ❖ Jamming radiation pattern estimated based on J/S, C/N_0 and jammer type
- ❖ ABAS predictions used to avoid jamming volume [11]
- ❖ Simulation of spot, sweep and barrage type jamming
- ❖ Generation of optimal avoidance trajectories, preventing degradation or losses of navigation data





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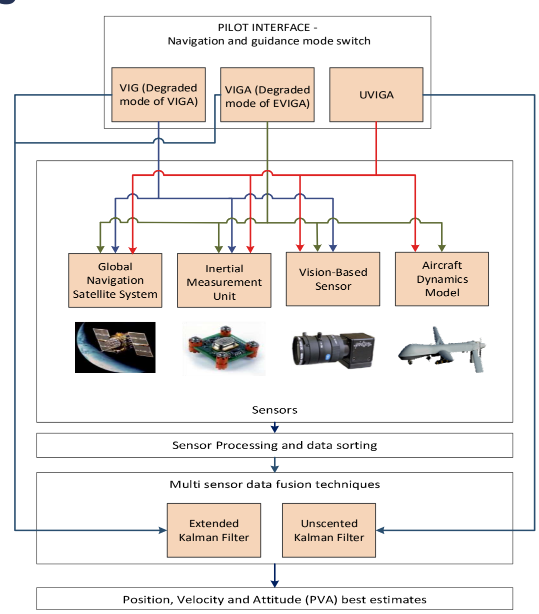
Integrated Navigation Architecture [12]



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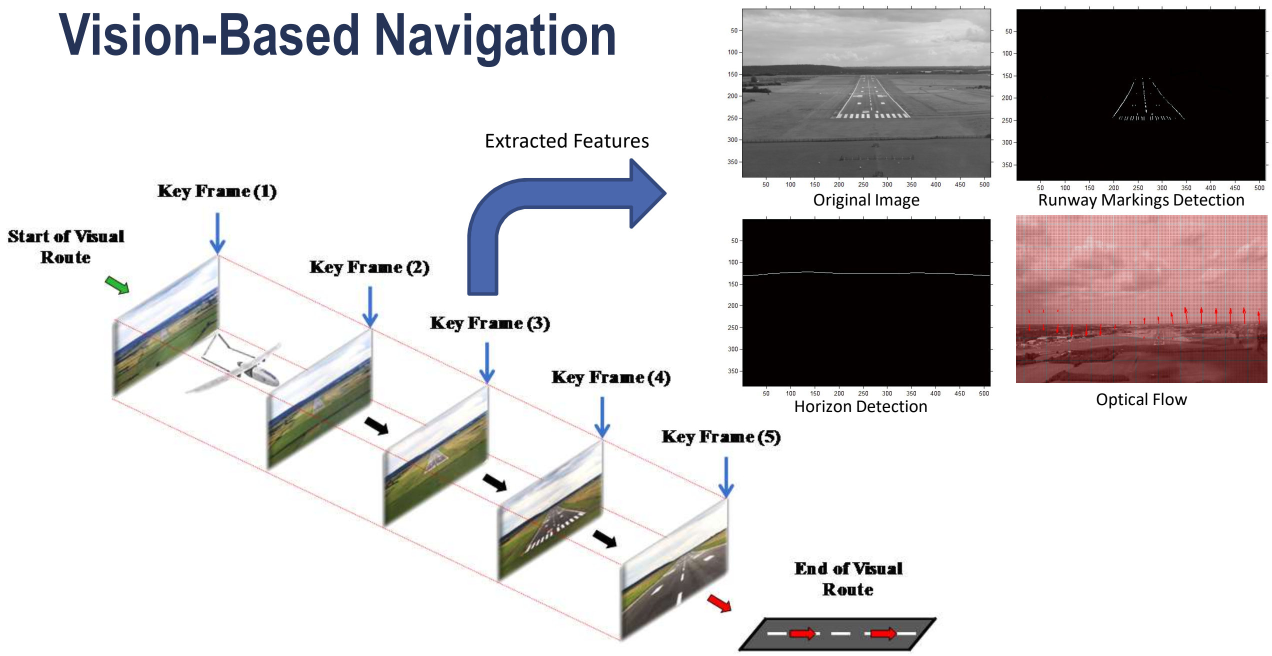
Vision-Based Navigation



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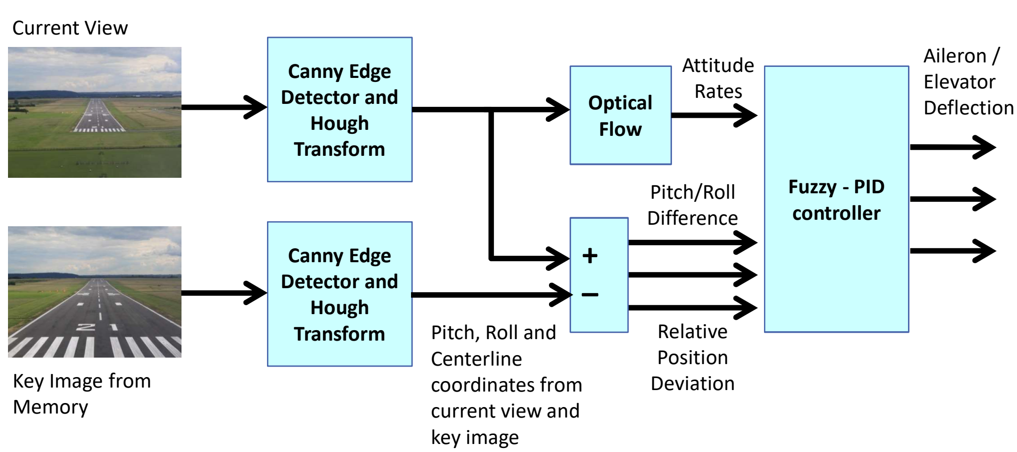
VBN Image Processing Module



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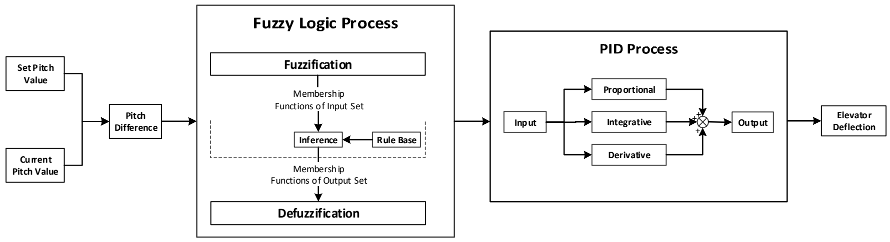
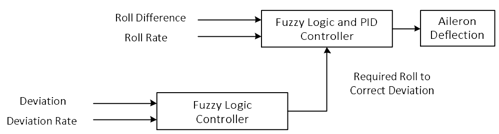
Fuzzy-PID Controller Design [12]

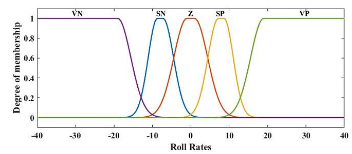
❖ Longitudinal Controller



❖ Lateral Controller

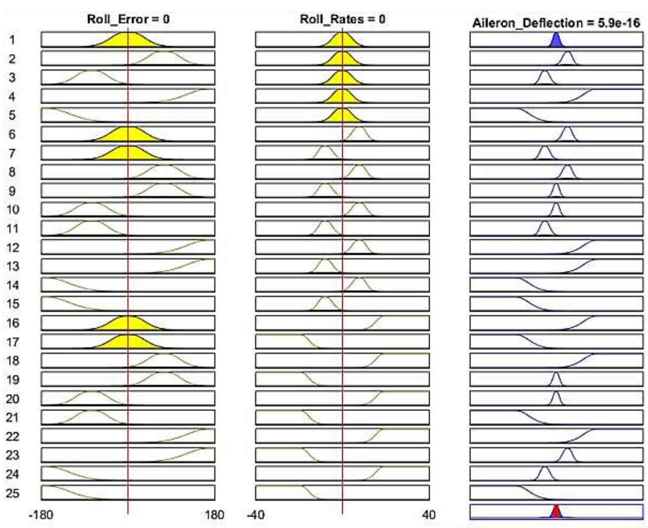


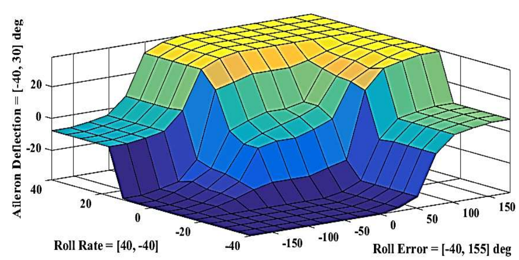
❖ Membership Function



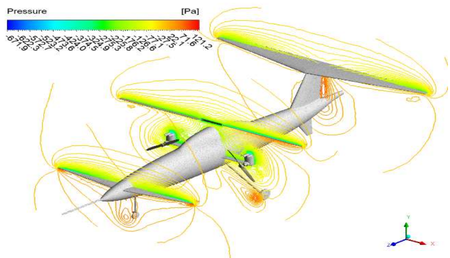
Fuzzy-PID Controller Design (2)

❖ Set of Rules [12]



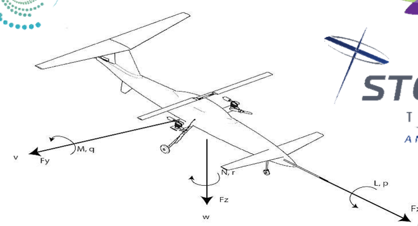


GNC for the StopRotor VTOL UAS [16]



DEFENCE INNOVATION HUB

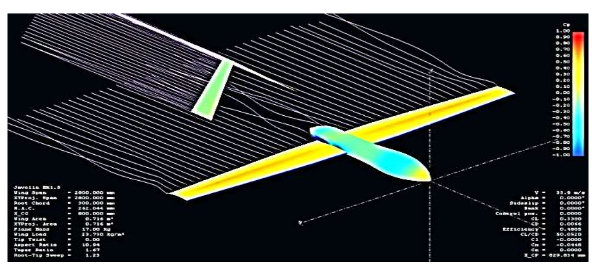
defence science institute



STOPROTOR
TECHNOLOGY
A NEW DIMENSION IN FLIGHT

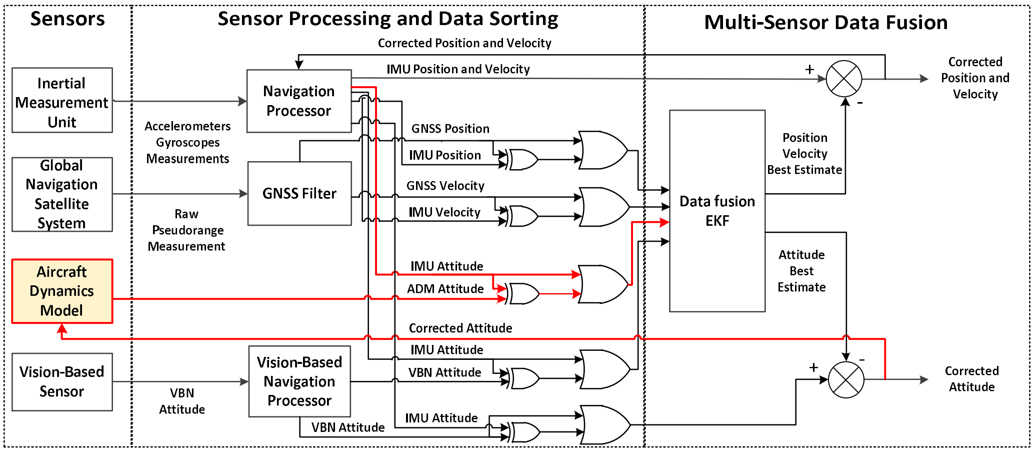
GNC for Javelin UAS

Length [mm]	2000
Height [mm]	650
Wingspan [mm]	2800
Aspect Ratio	11
Empty Weight [kg]	8.7
MTOW [kg]	15+
Fuel Capacity [L]	2
Endurance [hours]	~3
Engine [cc]	20
Max Power [kW]	1.28



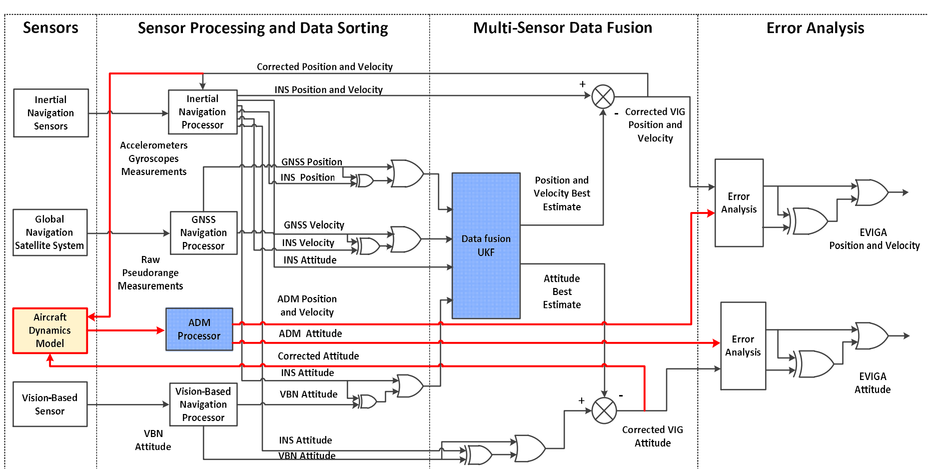
Integration Architectures

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



Integration Architectures (2)

- Unscented Kalman Filter (UKF)-based Configuration (UVIGA)



Simulation Results (2)

Position Error Statistics:

NGS System	North Position [m] µ	North Position [m] σ	East Position [m] µ	East Position [m] σ	Down Position [m] µ	Down Position [m] σ
VIG	-0.32	1.73	-1.54	1.39	-0.08	0.87
VIGA	0.54	1.02	-0.37	0.95	-0.13	1.28
UVIGA	0.48	1.02	-0.37	0.94	-0.17	1.28

Attitude Error Statistics:

NGS System	Theta (θ) [degrees] µ	Theta (θ) [degrees] σ	Phi (ϕ) [degrees] µ	Phi (ϕ) [degrees] σ	Psi (ψ) [degrees] µ	Psi (ψ) [degrees] σ
VIG	0.17	2.29	1.20	2.12	-0.85	2.19
VIGA	-0.08	2.06	0.91	2.17	-1.7E-04	1.43
UVIGA	-0.05	2.00	0.91	2.12	-1.7E-04	1.31

Precision Approach and Landing Performance:

Category of approach	Horizontal Accuracy (m) 2D RMS-95%					Vertical Accuracy (m) RMS-95% Down				
	Reqd.	VIG	VIGA	VIGGA	UVIGA	Reqd.	VIG	VIGA	VIGGA	UVIGA
CAT I	16					4				
CAT II	6.9	5.3	5.2	5.2	4.9	2	1.8	1.7	1.7	1.7
CAT III	4.1					2				

Simulation Results (3)

VIGA ADM Validity Times:

VIGA ADM Validity Time [sec]

Horizontal Channel		CAT III	CAT II	CAT I
	1 Sigma	1.90	2.15	4.06
	2 Sigma	1.35	1.54	2.90
Vertical Channel		CAT III	CAT II	CAT I
	1 Sigma	1.60	3.23	4.99
	2 Sigma	1.26	2.72	3.98

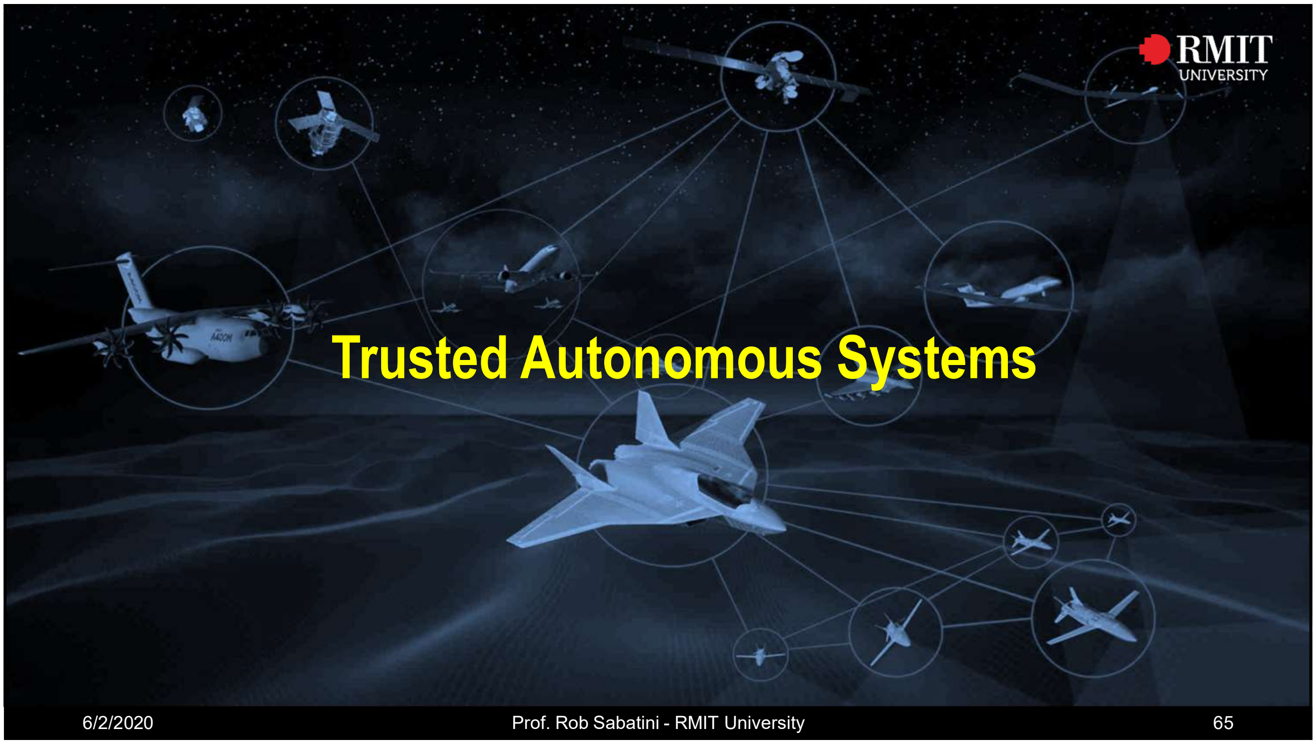
UVIGA ADM Validity Times:

UVIGA ADM Validity Time [sec]

Horizontal Channel		CAT III	CAT II	CAT I
	1 Sigma	1.24	1.33	2.27
	2 Sigma	0.93	1.01	1.58
Vertical Channel		CAT III	CAT II	CAT I
	1 Sigma	3.81	4.68	8.10
	2 Sigma	1.29	2.04	3.34

Precision Approach and Landing Performance:

Accuracy Threshold	ADM Validity Time [sec] VIGA	ADM Validity Time [sec] UVIGA
CAT III	13	23
CAT II	47	81
CAT I	105	126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A Novel Sense-and-Avoid System for Trusted Autonomous Operations
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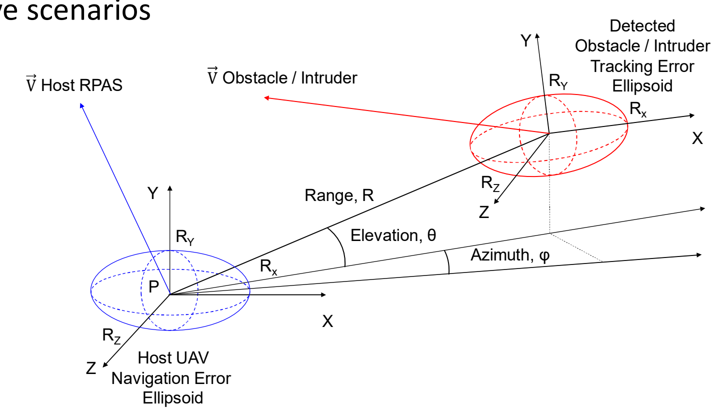
Requirements Overview

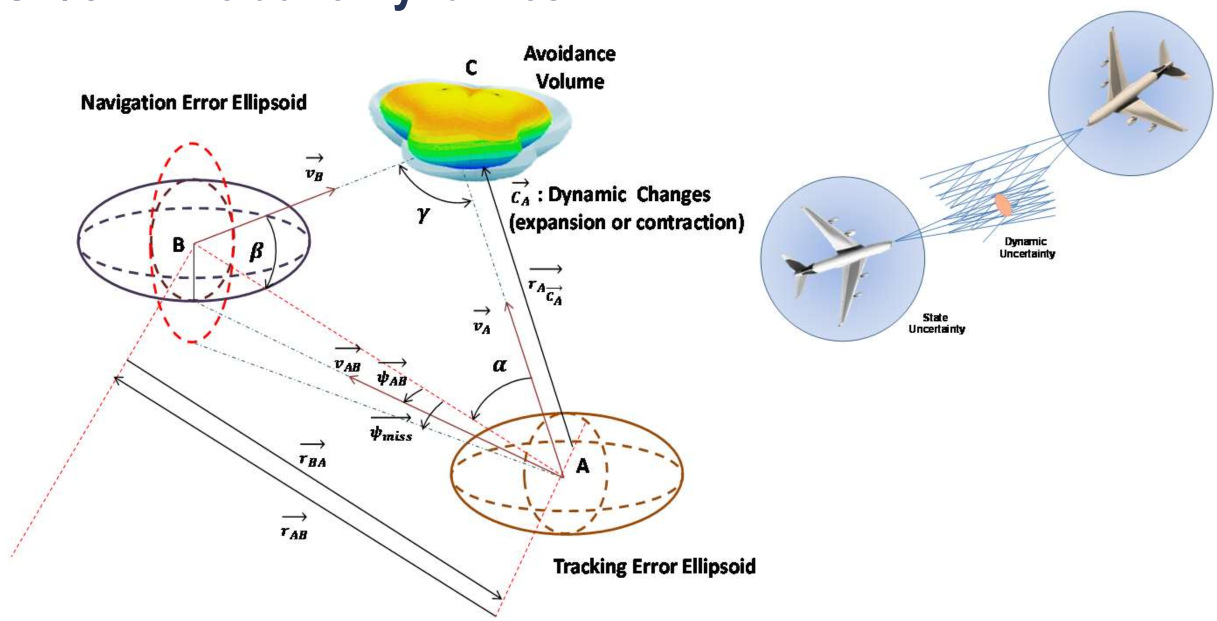
- **Cooperative and Non-Cooperative Separation Assurance** and **UAS Sense-and-Avoid** (SAA) are paramount capability to enable manned and unmanned aircraft to coexist in all classes of airspace
- A new unified framework is required for a seamless integration of UAS in the ATM system (UTM) with no impacts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

SA/CA – Avoidance Volume

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

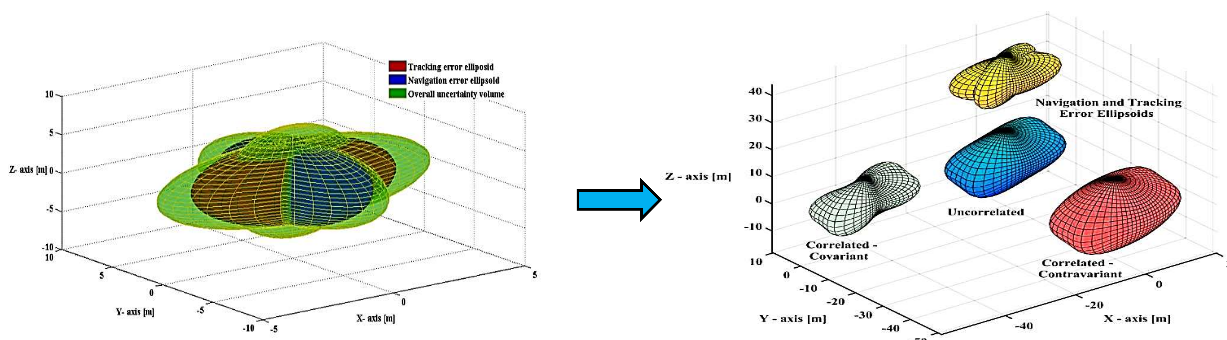


SA/CA – Relative Dynamics



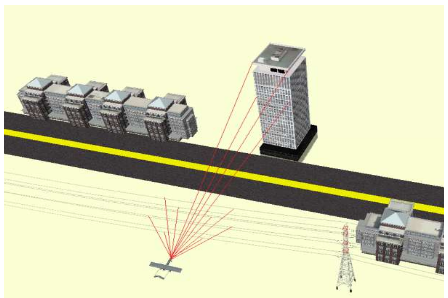
SA/CA – Error Analysis

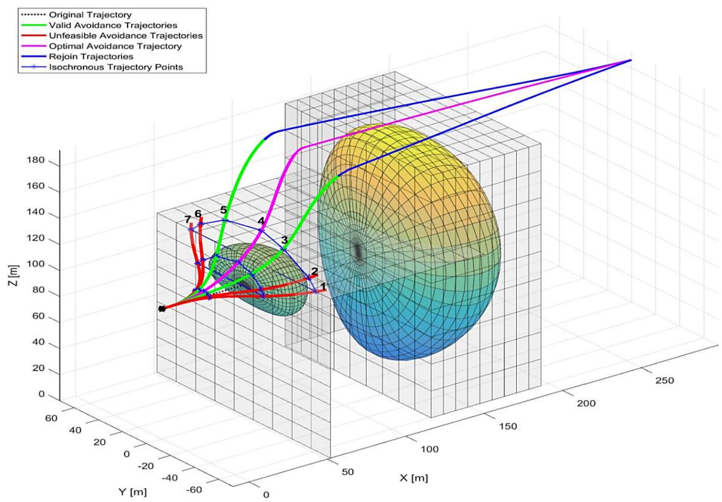
- ❖ Errors are statistically correlated (e.g., ADS-B) or uncorrelated (e.g., NC-SAA)
- ❖ The avoidance (uncertainty) volume for uncorrelated measurements is obtained by inflating the navigation ellipsoid with the tracking error components
- ❖ The uncertainty volume for correlated errors is obtained using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



SA/CA – Safety-critical Applications

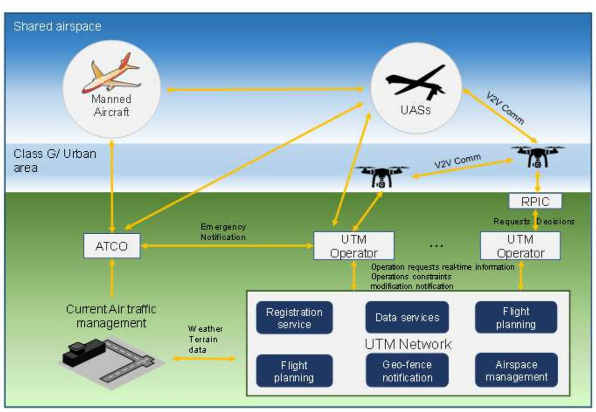
- ❖ Uncertainty volumes for avoidance of ground obstacles
  - A set of feasible avoidance trajectories is generated in real-time

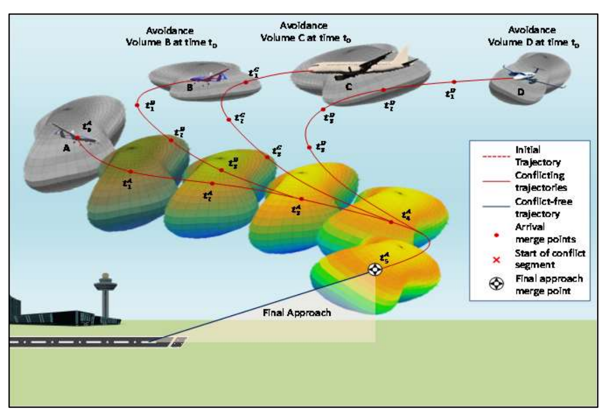




UAS Traffic Management

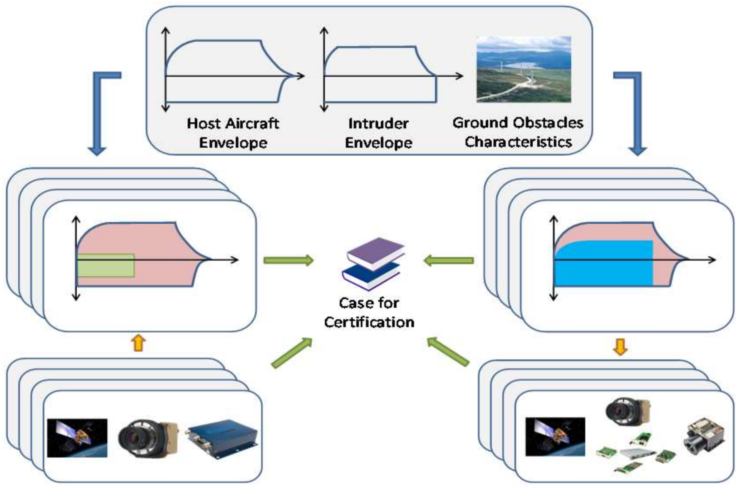
- ❖ The unified approach supports trusted autonomous operations in the UAS Traffic Management (UTM) context
- ❖ Avoidance volumes (i.e., dynamic geo-fences) are generated in real-time to allow computation of the optimal avoidance flight trajectories





SA/CA – Pathway to Certification

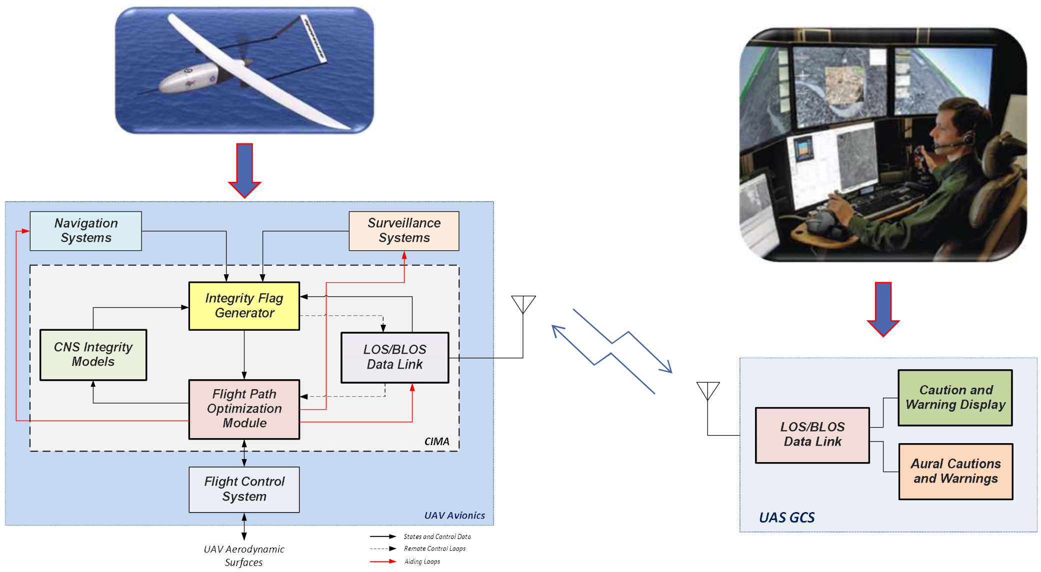
- Distinctive advantage: ability to determine the safe-to-fly UAS envelope based on the on-board sensors and alternatively to identify the required sensors in order to achieve a certain predefined safety envelope [15]



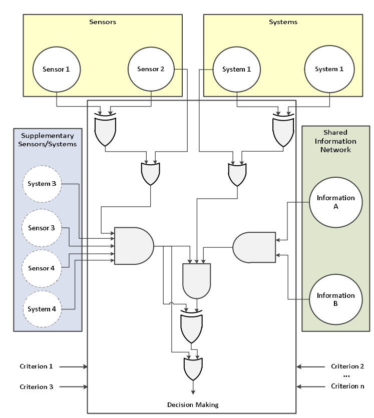
CNS Integrity Monitoring and Augmentation for SAA

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

CNS Integrity Augmentation Architecture [11]



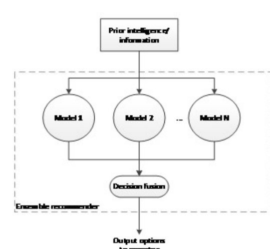
Multi-Criteria Decision Making



❖ Adaptive Boolean decision logics

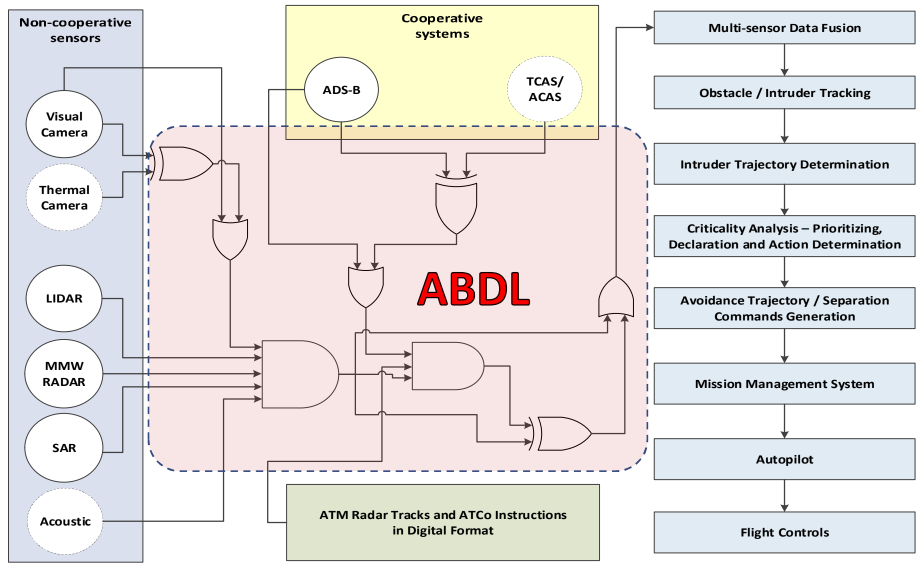
- Instead of implementing hardwired logics, we propose the adoption of dynamically reconfigurable or Adaptive Boolean Decision Logics (ABDL) based on CNS Integrity Monitoring and Augmentation (CIMA) features
- The sensors/systems providing the most reliable solution are automatically selected, providing robustness in all flight phases and supporting all-weather operations
- Error and performance models
- System/sensor performance based reconfigurations

❖ Ensemble and multi-model decision making

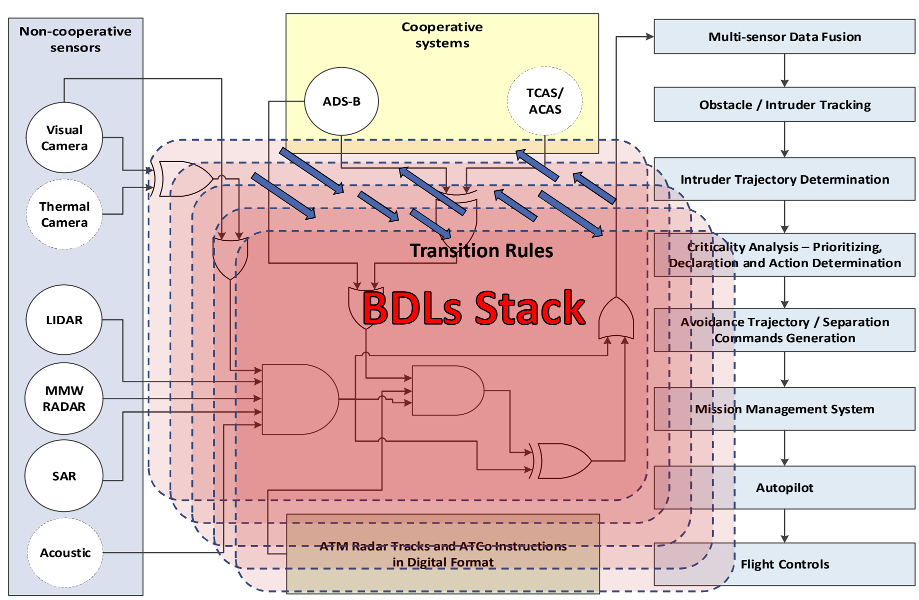


- A diverse set of recommender systems is more robust in the presence of noise and uncertainty
- Diverse models: the dynamics of the system is modelled based on different assumptions
- Diverse classifiers: the method of identifying patterns in the data varies based on the classifier used and the method of training

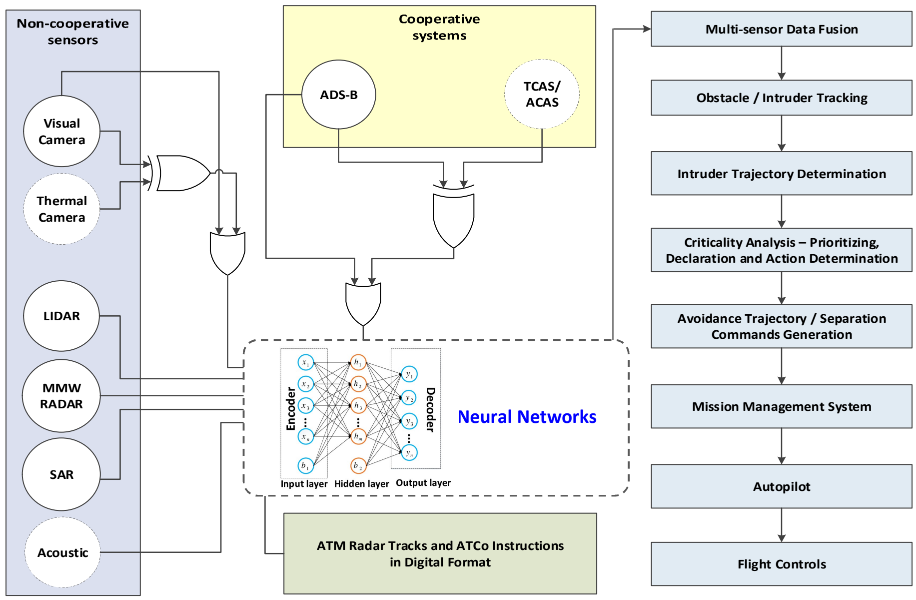
SA/CA Reference Architecture [15]



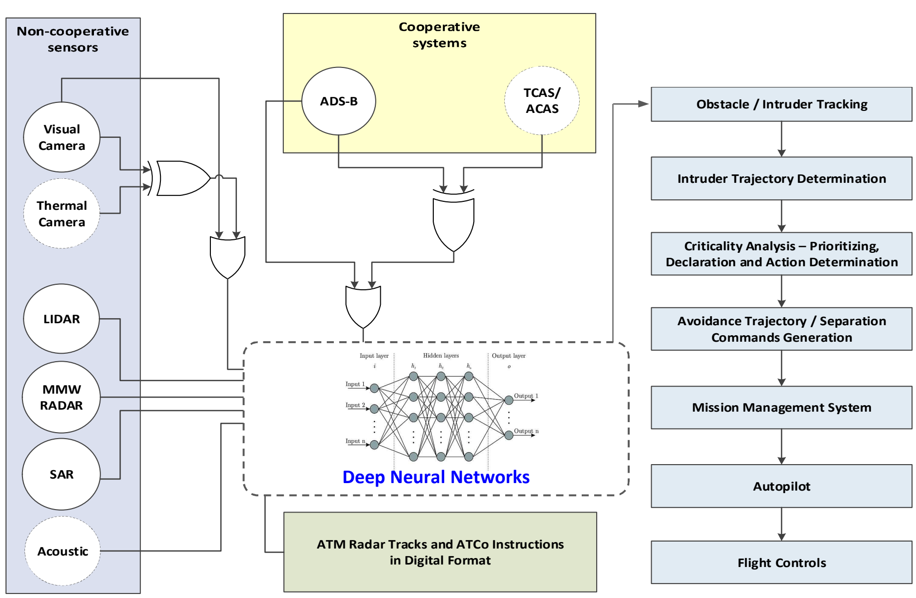
SA/CA Reference Architecture



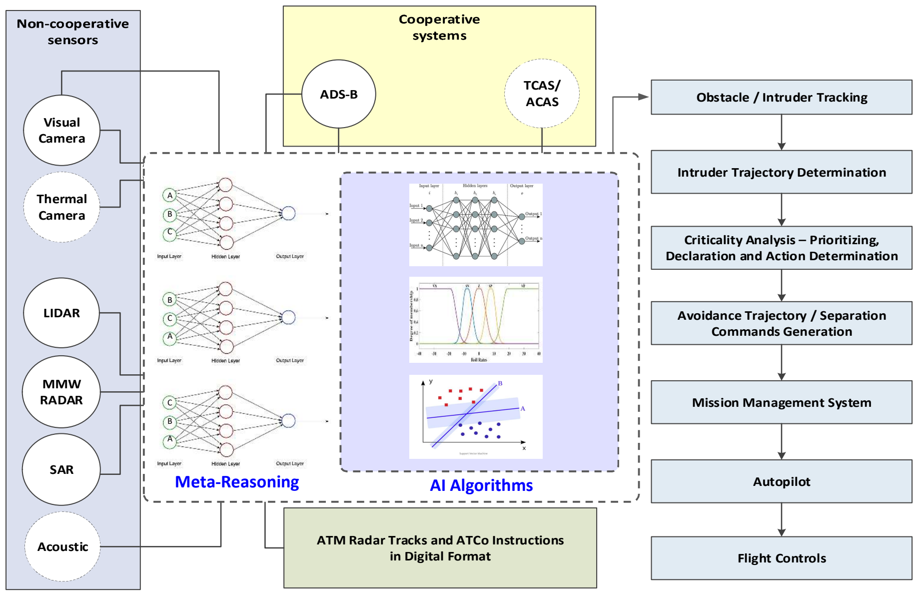
SA/CA Reference Architecture



SA/CA Reference Architecture



SA/CA Reference Architecture



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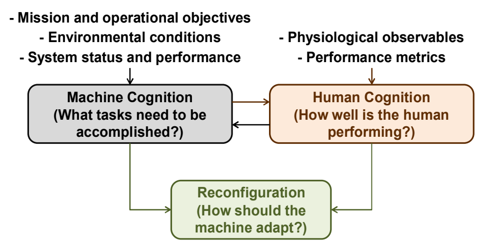
The CHMI² Concept

❖ This project addresses the development of closed-loop human machine systems implementing Cognitive Human Machine Interfaces and Interactions (CHMI²)

❖ CHMI² supports human machine teaming whereby a system senses and adapts to the mission environment and the cognitive state of the operator

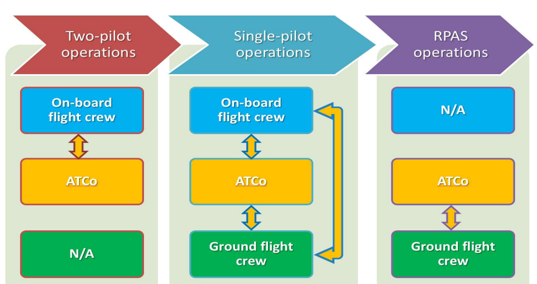


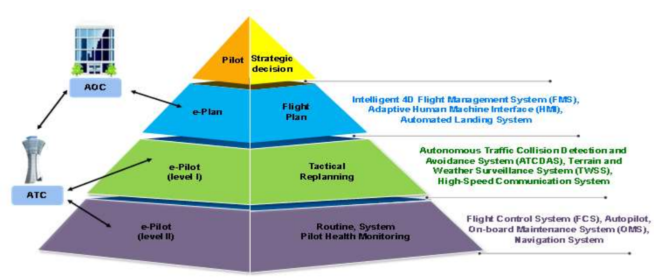
❖ The CHMI² concept enables **Trusted Autonomous Operations** in both mission-critical and safety-critical applications

CHMI² Aeronautical Applications

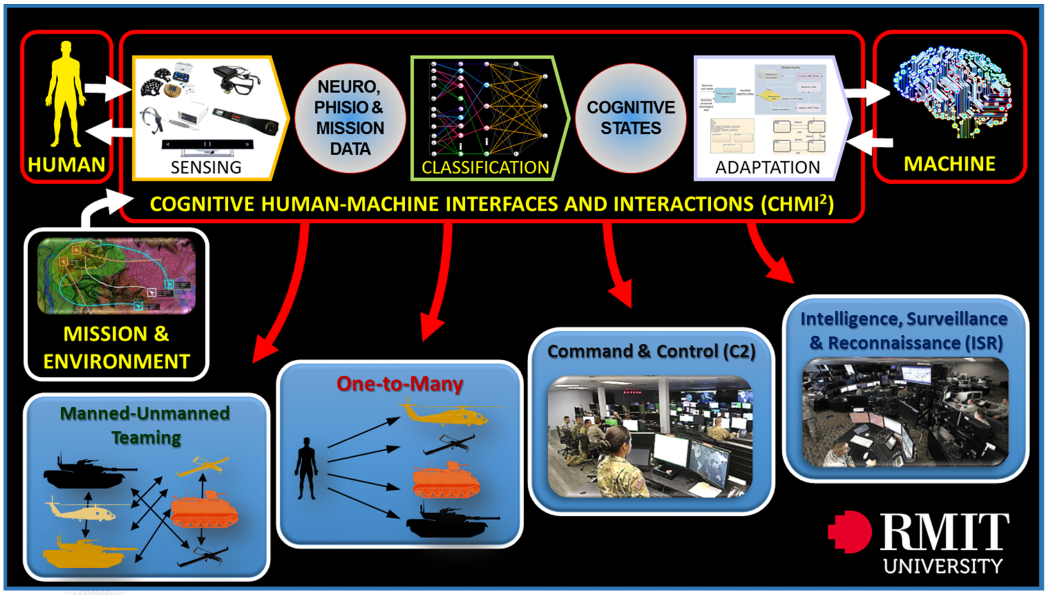
❖ **System Requirements**

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

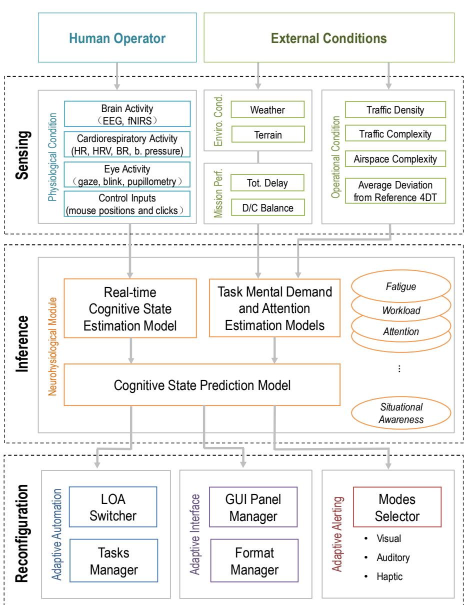


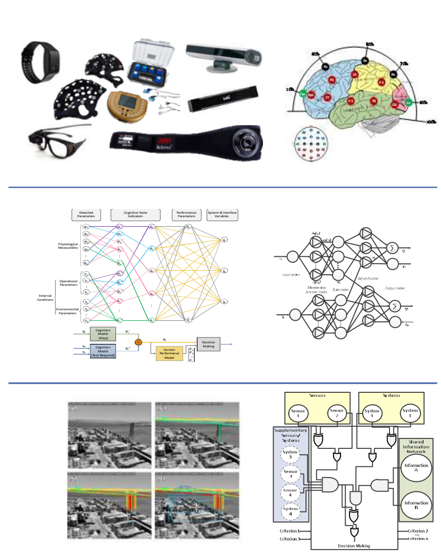


CHMI² Defence Applications



CHMI² Framework [17-19]



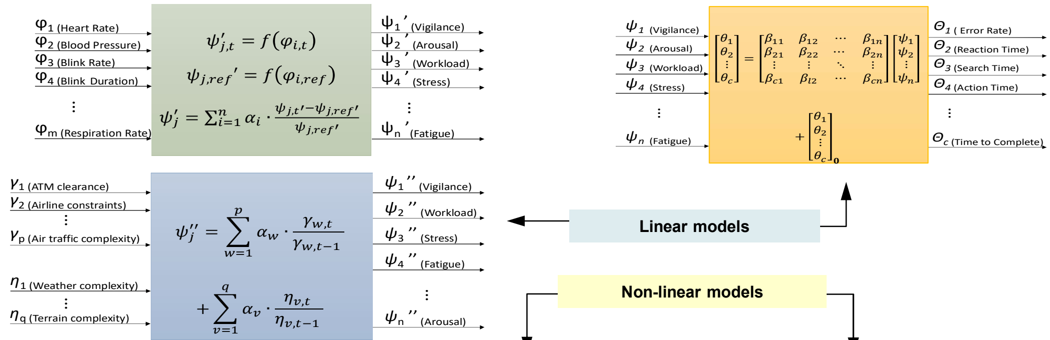


Sensing: uses a suite of sensors to measure neuro-physiological observables in real time, and extracts relevant features from the observables

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

Adaptation: module drives the HMI² based on inferred cognitive states and key mission performance metrics

CHMI² Mathematical Framework [19, 20]

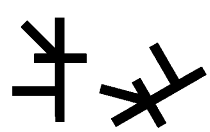


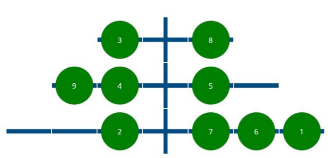
	Fixation time	Glance count	Saccade dispersion	Dwell time	Visual Entropy	Pupil dilation	Heart rate	Resp. Rate	Blink rate
Vigilance	Q-N	L-P	Q-N	Q-N	Q-N	L-P	-	-	L-N
Workload	SPL-P	-	L-N	SPL-P	L-N	L-P	L-P	L-P	L-N
Attention	L-P	SBL-N	L-N	L-P	L-N	L-P	SPL-P	-	L-N

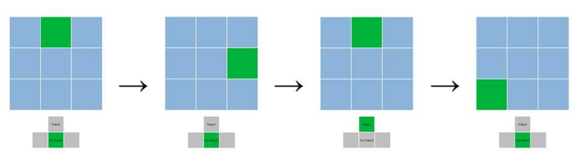
	Vigilance	Workload	Attention
Error rate	L-N	SPL-P	L-N
Reaction time	L-N	Q-P	Q-P
Situational awareness	L-P	Q-N	L-N
Efficiency	L-P	SBL-N	Q-N
Precision	L-P	SBL-N	L-P

Offline Calibration – Cognitive Test Battery

- A battery of cognitive tests was developed to support the offline calibration of the ANFIS classifier
- The Cognitive Test Battery (CTB) comprises a number of standardized tasks:
  - Mental rotation – spatial processing
  - Hampshire tree – reasoning and planning
  - N-back – working memory





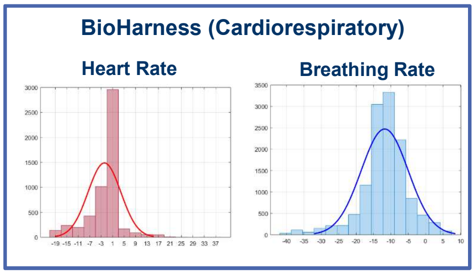


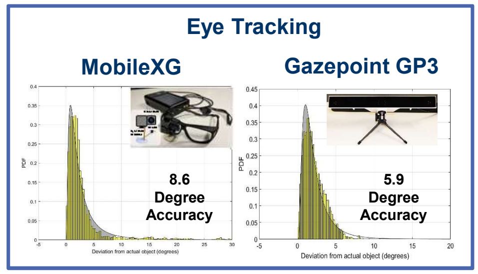
- The CTB is being revisited by adopting the NASA Multi-Attribute Test Battery (MATB-II) software

Neuro-Physiological Sensor Network

Sensor Performance Characterization

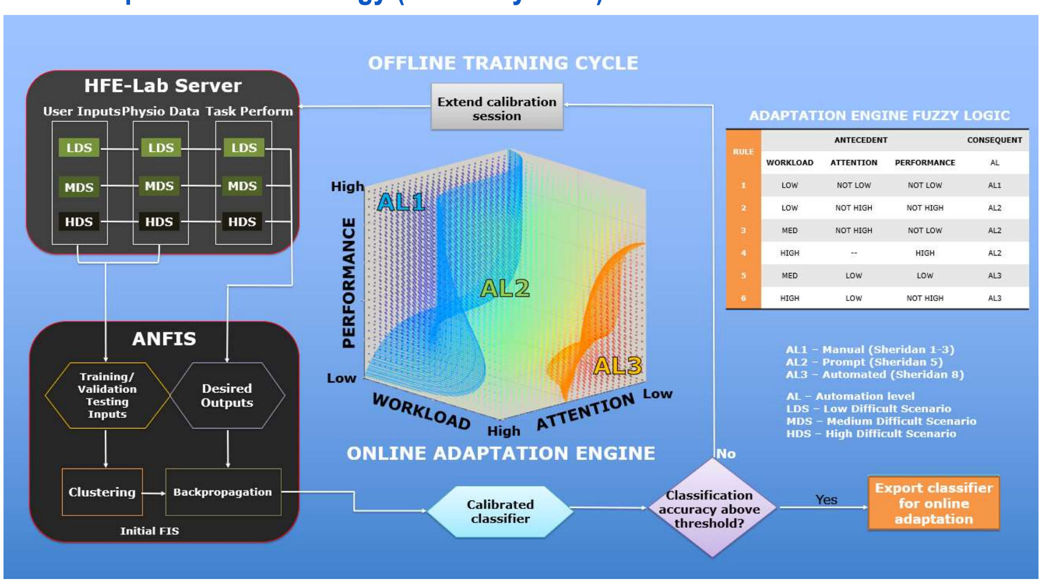
- Characterisation activities of Neuro-Physiological Sensors (NPS) used for the operator cognitive inference
- The uncertainty associated with the neuro-physiological observations is quantified and propagating through the classifier to obtain uncertainty in inferred cognitive states [20-23]





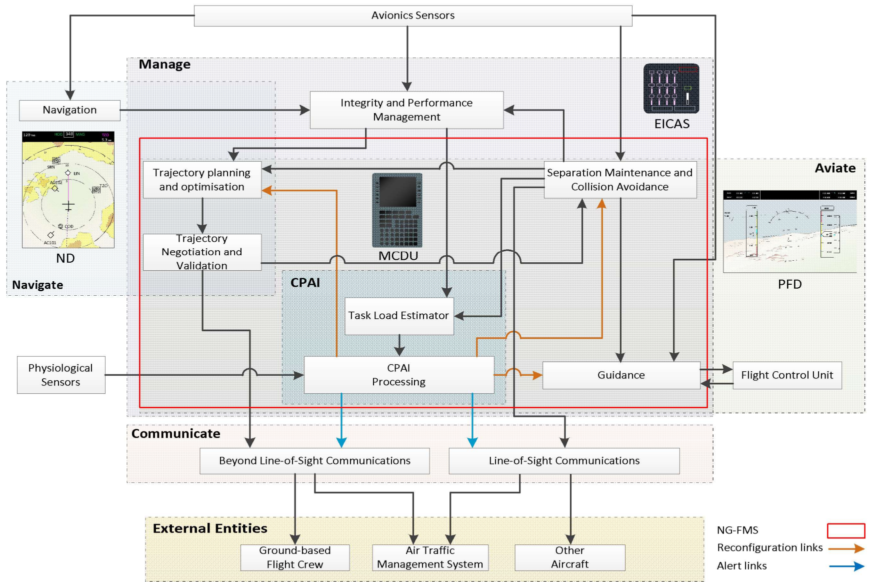
Inference Engine

Cognitive Adaptation Methodology (Summary View)



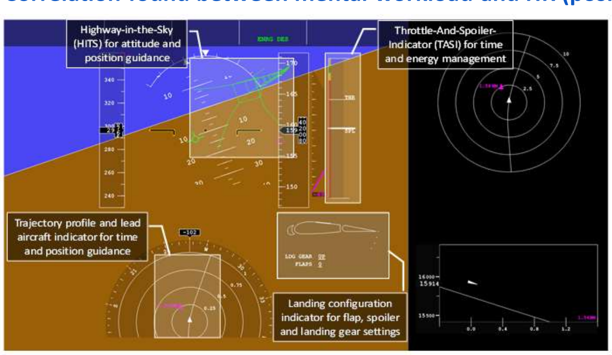
RULE	ANTECEDENT			CONSEQUENT
	WORKLOAD	ATTENTION	PERFORMANCE	AL
1	LOW	NOT LOW	NOT LOW	AL1
2	LOW	NOT HIGH	NOT HIGH	AL2
3	MED	NOT HIGH	NOT LOW	AL2
4	HIGH	--	HIGH	AL2
5	MED	LOW	LOW	AL3
6	HIGH	LOW	NOT HIGH	AL3

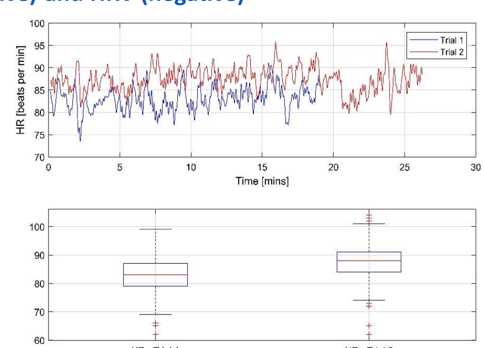
CHMI² SiPO Case Study



CHMI² SiPO Case Study (2)

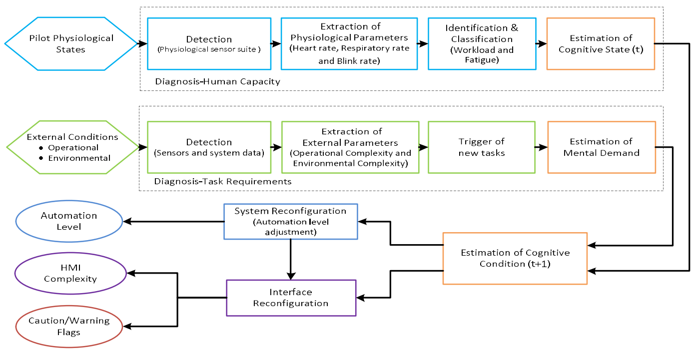
- Simulated **A320 SYD-MEL flight** in adverse weather conditions
- Development of **novel formats and functions** to generate and follow a **time-and energy optimal descent trajectory** (MEL)
- **Human-in-the-loop experiments** were carried out, with a pilot manually flying the aircraft under different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

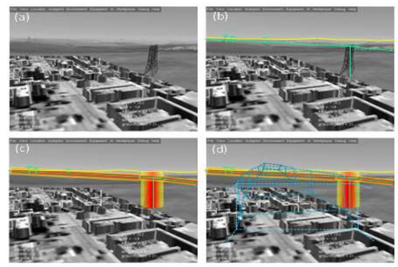




CHMI² Low-Level UAS Case Study

- ❖ Sensing, estimation and reconfiguration
- ❖ Physiological state assessment and external condition assessment
- ❖ Dynamic task allocation [18]





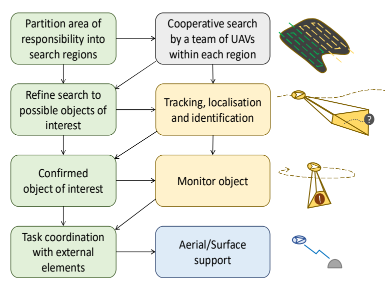
New formats and functions developed based on human-in-the-loop studies [15]

CHMI² One-to-Many Case Study

Bushfire Fighting Scenario [23]

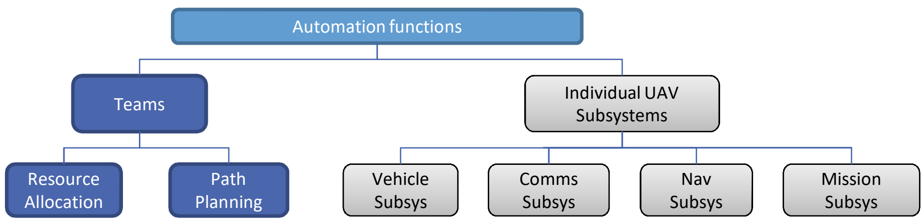
- ❖ Human-in-the-Loop (HITL) verification of the CHMI² system
- ❖ Participants tasked with coordinating multiple UAVs in a bushfire surveillance mission
  - Tasks are structured around the mission objectives
- ❖ UAVs are equipped with a **combination of active/passive sensors** and can be assigned to subregions in the AOR
- ❖ Primary objective: **find and localise any bushfires within the Area of Responsibility** (AOR)
- ❖ Secondary objectives:
  - **To maximise the search area coverage**
  - **Ensure that the UAV flight systems, as well as navigation, communication and surveillance systems performance are maintained within serviceable limits**
- ❖ The scenario comprises three phases with increasing difficulty and complexity

15 mins	10 mins	10 mins	10 mins	10 mins
Briefing and familiarisation	3 UAVs	6 UAVs	9 UAVs	De-briefing
		Env change	Env change	



Bushfire Fighting Scenario

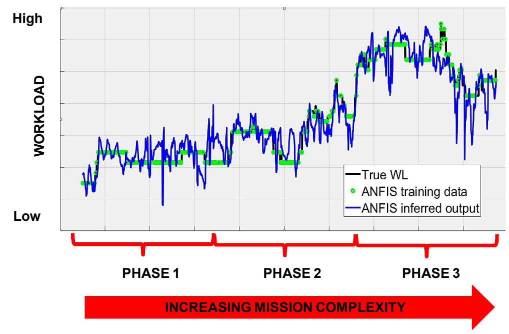
- Automation is employed to assist in the optimal management of UAV teams and vehicle/CNS subsystems of individual UAVs
- **Three discrete levels of automation**
  - **Manual** (Sheridan Lv 1-3): indicates current status of system/task but does not offer additional information.
  - **Prompt** (Sheridan Lv 5): indicates current status and in the event of degraded performance, provides operator with recommended resolution.
  - **Auto** (Sheridan Lv 8): indicates current status and in the event of degraded performance, executes resolution action automatically



Bushfire Fighting Scenario

Offline Training Results

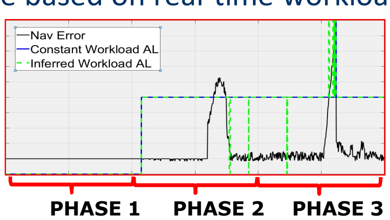
- Training of the inference engine based on scenario workload
  - Workload was calculated from the number of currently unattended tasks over time
  - Neuro-physiological features were fed as inputs to the inference engine
    - Visual entropy, blink rate
    - Heart rate, heart rate variability
    - fNIR oxygenation, blood volume
    - EEG bands, ratios
- **Across all participants (8 RPAS Pilots), the training error was 2.2% to 7.2%**

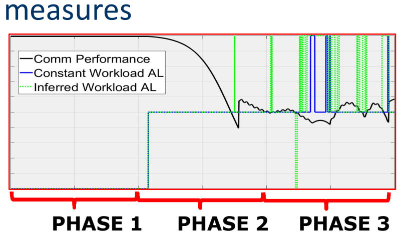


Bushfire Fighting Scenario

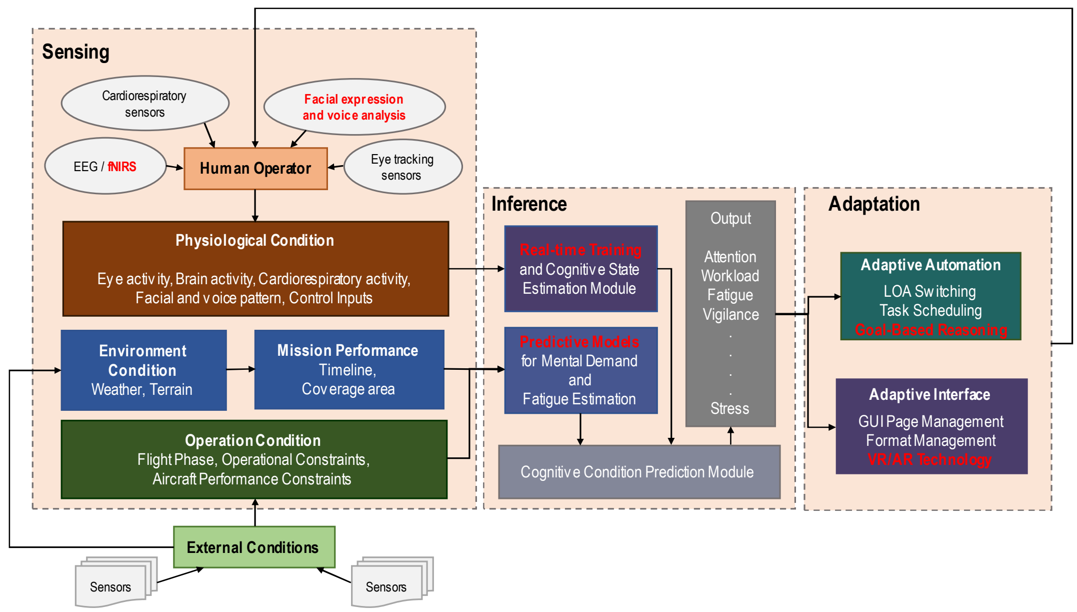
Adaptation Results

- The adaptation module is able to dynamically adjust the AL based on user workload, attention and system performance
- Verification activities compared the behaviour of the module using different workload inputs
  - Online: a constant nominal workload value was fed to the adaptation engine
  - Offline (post-processing): the subjective workload collected during experiment was used
- Results show that **AL changes occur earlier than the experienced shifts in workload (predictive behaviour)**, supporting the CHMI^2 capability to adapt system automation in advance based on real-time workload measures





CHMI² Current Evolutions – Data Fusion



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Current Evolutions – Sensor Network

Wearable sensors

Electroencephalography (EEG)

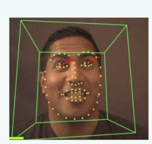
Cardiorespiratory Sensor [P4]

Functional near-infrared spectroscopy (fNIRS)

Remote sensors

✓ Eye tracking sensors

Facial Expression



Voice pattern analysis

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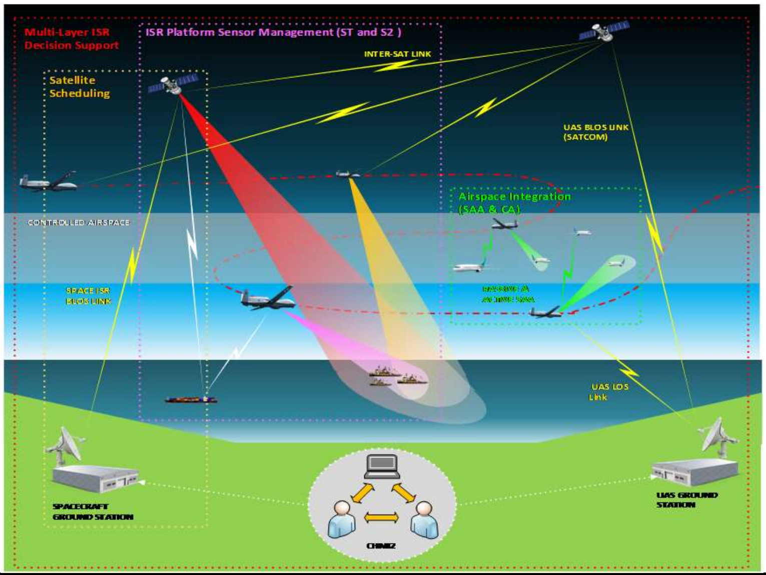
Current Evolutions: Multi-domain ISR Operations



Multi-Domain Decision Support

Platform Sensor Management

- The implementation of sensor management support systems to aid the operator
- Modelling of multiple ISR sensor modalities to inform the design and real-time reconfiguration of payload functions to meet dynamic mission objectives

Satellite Scheduling

- Optimal allocation of user requests (uplink & downlink) for efficient communication between ground operations teams and constellation of spacecraft systems

CHMI2

Spacecraft Deconfliction

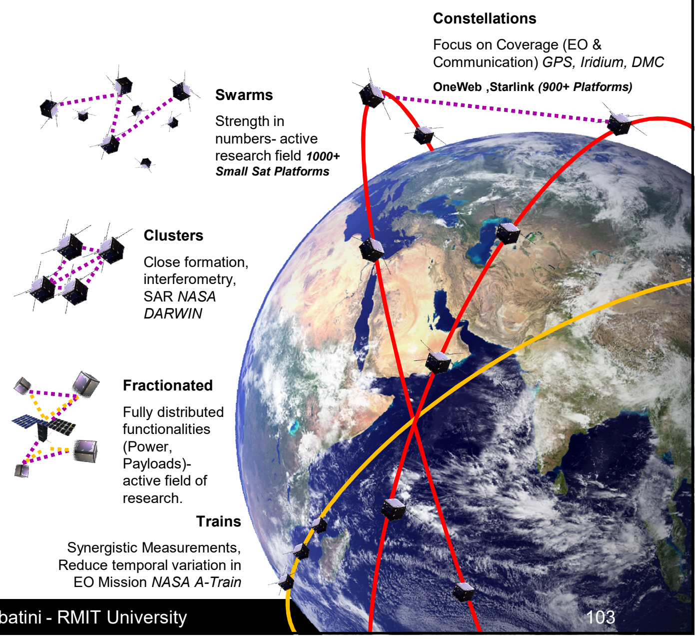
- The effect of closure rates, communications and processing latencies on the sequencing and managing of ground-based operators (space situational awareness and trusted autonomous operations).
- The development of a novel HMI to display relevant information to the operator before, during and after encounter events.

Distributed Satellite Systems

What Are Distributed Satellite Systems (DSS)?

DSS mission architectures move away from ***monolith*** *system to that of* ***multiple*** *space elements that* ***interact***, ***cooperate*** *and* ***communicate*** *with each other, resulting in* ***new systemic properties*** *and/or* ***emerging functions*** [24, 25]

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 heterogeneous	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



Distributed Satellite Systems (2)

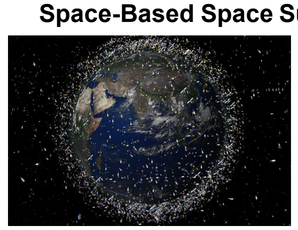
Why do we need *truly* Distributed Satellite Systems?

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

Earth Observation (EO) [26]

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

Space-Based Space Surveillance (SBSS) [27]



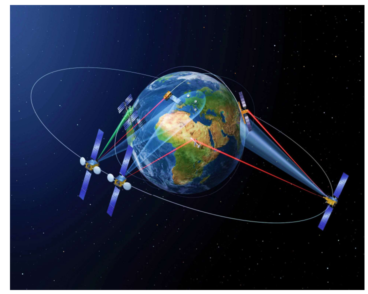
- Increase of Resident Space Objects (RSO) perpetuating hazardous *"Kessler Syndrome"*
- Reduction of uncertainty by Tracking of <10cm RSO's elusive to ground infrastructure

DSS and SmartSat Research Context

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

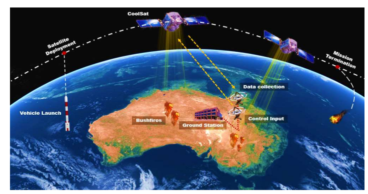
Strengths/Discriminators

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



Research Capabilities

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



DSS Mission Control

Enhancing Ground Station Performance via Closed Loop Human-Machine Interactions

Optimal teaming between DSS ground station operators and system autonomy, future decision support systems must adopt an architecture that supports **Cognitive Human-Machine Interfaces and Interactions** (CHMI^2)

Supervisory Operational Tools

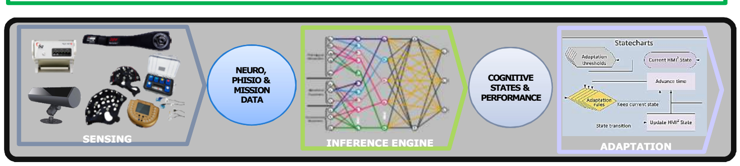
Cognitive Drivers

- **Transitioning to a one-to-many operations**
- **Staying on the loop**
- **Maintaining situational awareness**
- **Modulating cognitive load**

Enhanced by

Closed-Loop Functionality

- The core functionality of the CHMI2 framework is the **real-time adaptation of HMI and system automation**
- Based on physiological **sensing** and **inferring** the **cognitive states** of the operator and mission observables.
- **Verified in time and mission critical missions**: C2 of multiple UAS for wide-area surveillance & ATM operations.



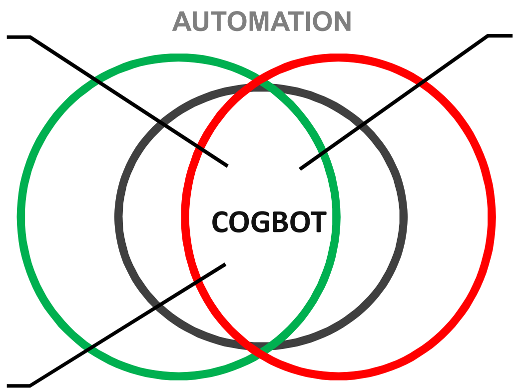
Proposed Solution

Design and Development of a Cognitive Goal Based Operations Toolset (COGBOT)

A fusion of NASA's Mission Data System framework (AMAS) and our CHMI^2 concept

Enhances Human-Machine Interactions (closed-loop HMI adaptation)

Supports Distributed and Intelligent SV Architectures

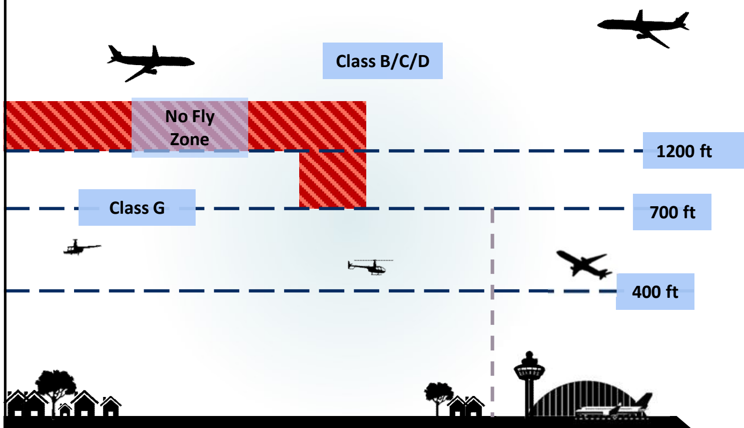


Provides Supervisory Tools for Goal-Based Operations

Current ATM…

Air traffic management mission:
- Prevent collisions between aircraft
- …. and obstacles
- To expedite an orderly flow of traffic

Air traffic services include:
- Alerting service
- Flight information service
- Air traffic advisory service
- Air Traffic Control (ATC) service

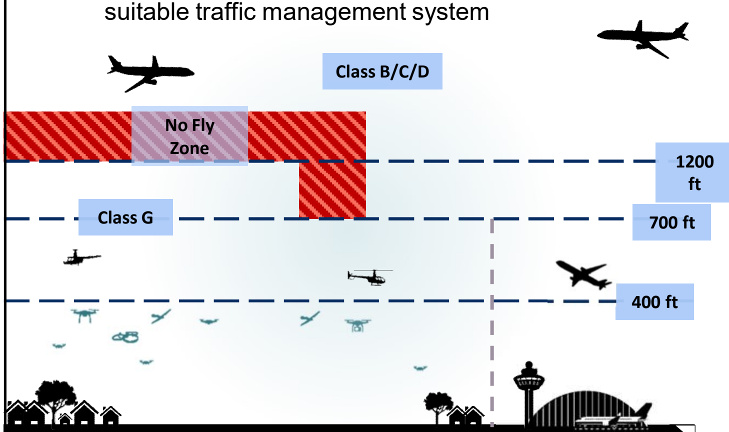


Air Traffic Controller (ATCo) tasks:
- Tactical deconfliction
- Update/monitor routings
- Manage airspace reservations
- Coordinate with neighbouring sectors

…and Low-Level Evolutions (UAS Traffic Management)

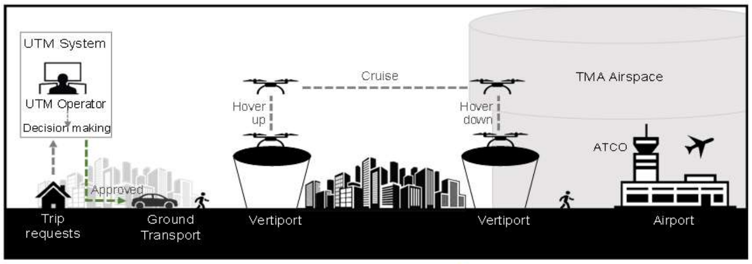
- **Beyond Visual Line of Sight** (BVLOS) operations are **not allowed to fly unsegregated** from other traffic because the coexistence of manned and unmanned aircraft in the same airspace requires a suitable traffic management system

- The conventional heavily manual ATC paradigm cannot fulfil the needs of manned/UAS traffic integration
- **A higher degree of automation is necessary** in UTM framework

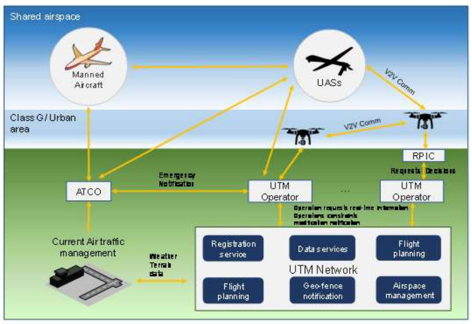


- **The tactical deconfliction approach of traditional ATM cannot be scaled down to apply in UTM**
- **Low altitude airspace needs restructuring of air traffic services**

UAS Traffic Management



Urban Air Mobility
The ability to start/end trips essentially anywhere, and low predictability of traffic



- UTM is going towards autonomy
- Highly automated human-in-the-loop operations bring about issues of responsibility allocation and mandates evolutions in the legal and regulatory frameworks (liability concerns)

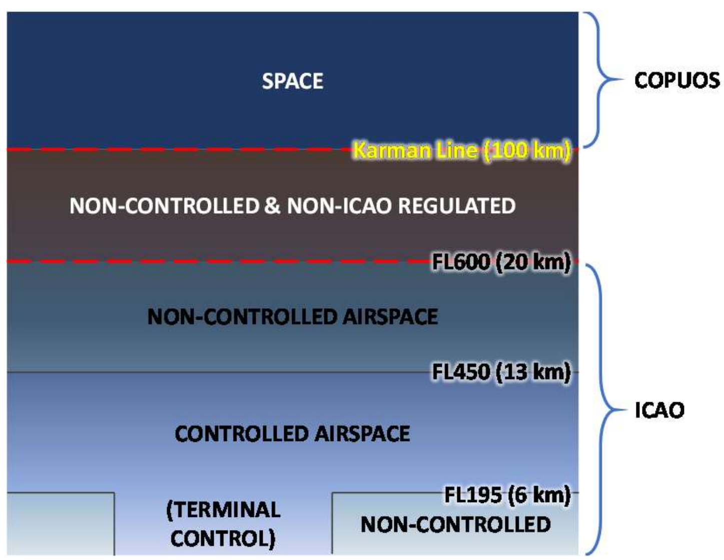
The task and responsibility of humans and AI agents in UTM are yet to be defined

ICAO and COPUOS Jurisdictions

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.

COPUOS - Committee on the Peaceful Use of Outer Space
ICCAIA – Internat. Coord. Council of Aerospace Industry Assoc's



Safety risk 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

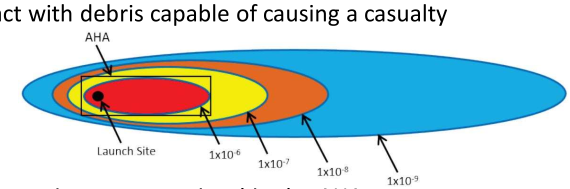
Element	AST	ATO
Acceptable level of safety	1×10^{-6}	1×10^{-9}
Period	Per aircraft, per launch/fly-back operation	Per affected flight hour or air traffic control operation
Consequence	Casualty of an aircraft occupant	Fatality of an aircraft occupant

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.

3-SIGMA DISPERSION AREA

AIRCRAFT HAZARD AREAS (AHAs)

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



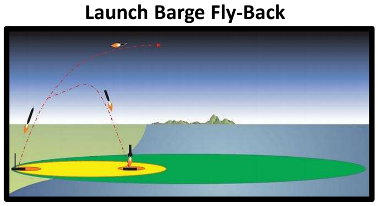
No operations are permitted in the AHA

Commercial Space Mission Types

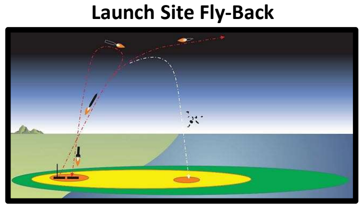
Missions using the ALR approach with a 30-Degree Angular Restriction

ALR for these missions: 1×10^{-6} and the 1×10^{-7} risk contours

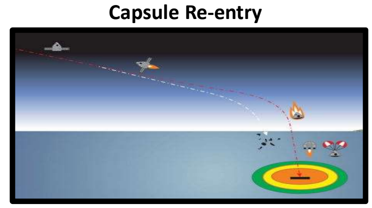
Launch Barge Fly-Back



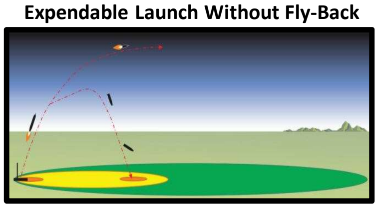
Launch Site Fly-Back



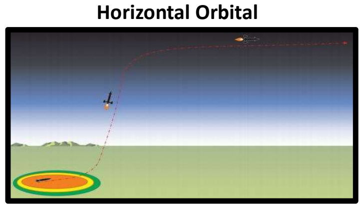
Capsule Re-entry



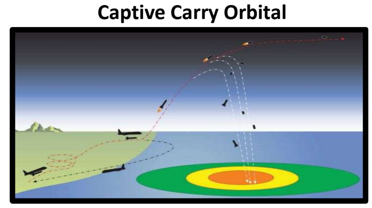
Expendable Launch Without Fly-Back



Horizontal Orbital



Captive Carry Orbital

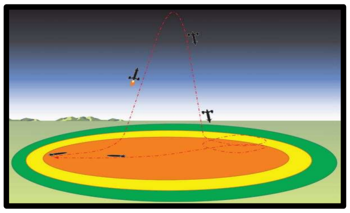


Commercial Space Mission Types

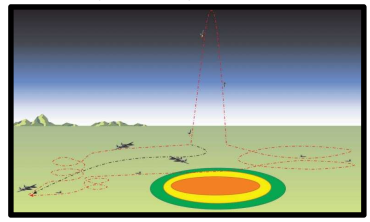
Missions using the ALR approach with a risk buffer

Appropriate risk buffer for each launch to ensure the 1×10^{-7} individual risk limit is not exceeded

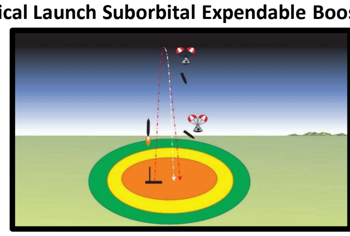
Horizontal Suborbital



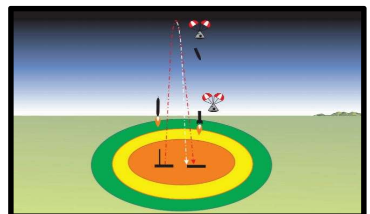
Captive Carry Suborbital



Vertical Launch Suborbital Expendable Booster



Vertical Launch Suborbital Reusable Booster

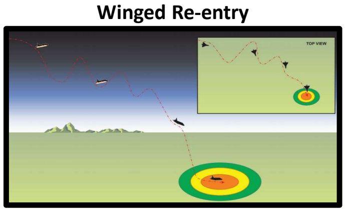


Commercial Space Mission Types

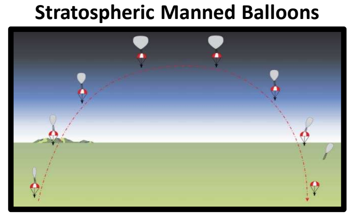
Missions to which the ALR approach cannot be applied at this time

FAA was not able to identify the appropriate parameters, conditions and restrictions that would allow the application of ALR. **An evolution is required to cover the full spectrum of launch and re-entry operations and to accommodate Dynamic Airspace Management (DAM) provisions**

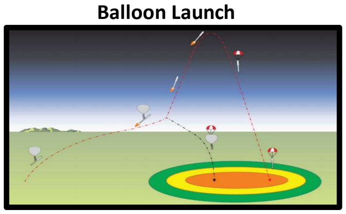
Winged Re-entry



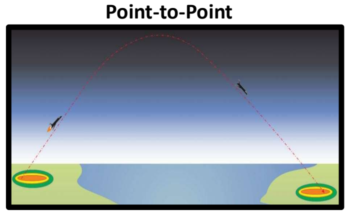
Stratospheric Manned Balloons



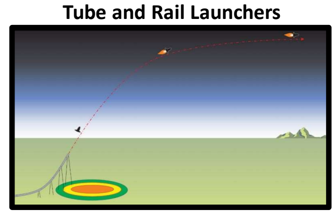
Balloon Launch



Point-to-Point



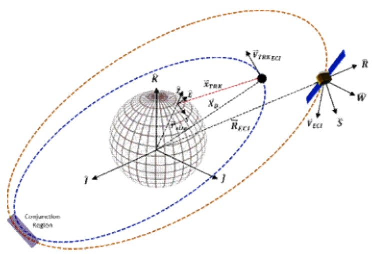
Tube and Rail Launchers

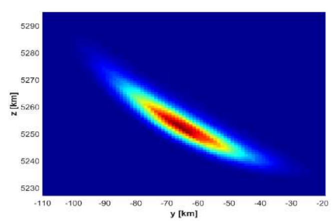


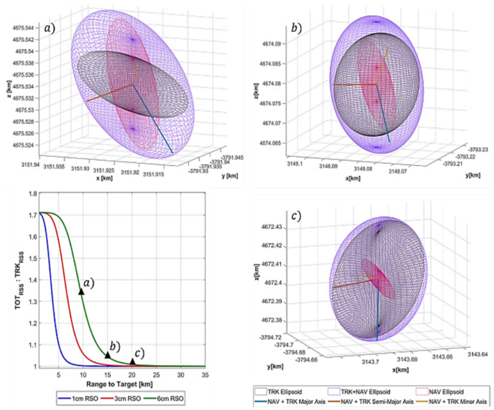
Space Domain Awareness and Traffic Management

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

- **Unified mathematical framework** for 4-Dimensional collision uncertainty quantification and mapping
- Considering both cooperative and uncooperative orbital conjunctions
- Unique software tools employing AI/ML techniques

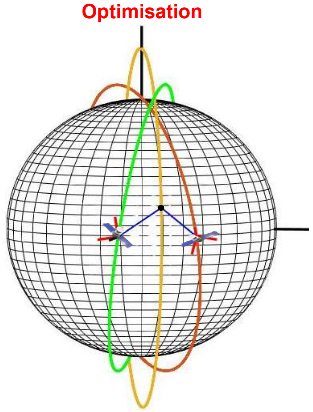




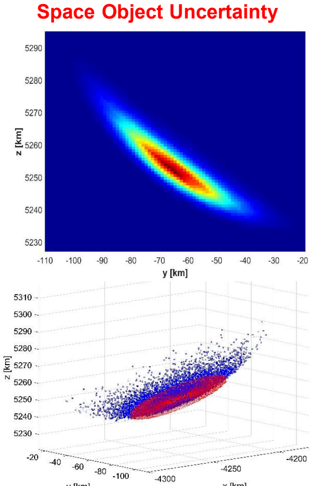


AI-Based STM Decision Support Systems

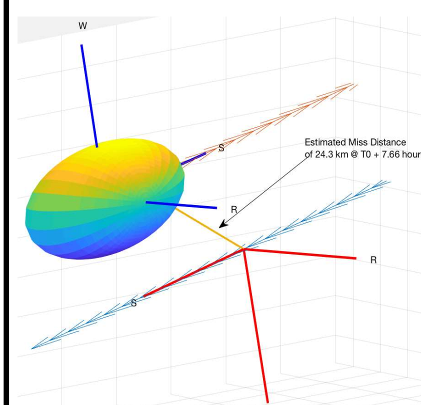
Online Mission Planning and Optimisation



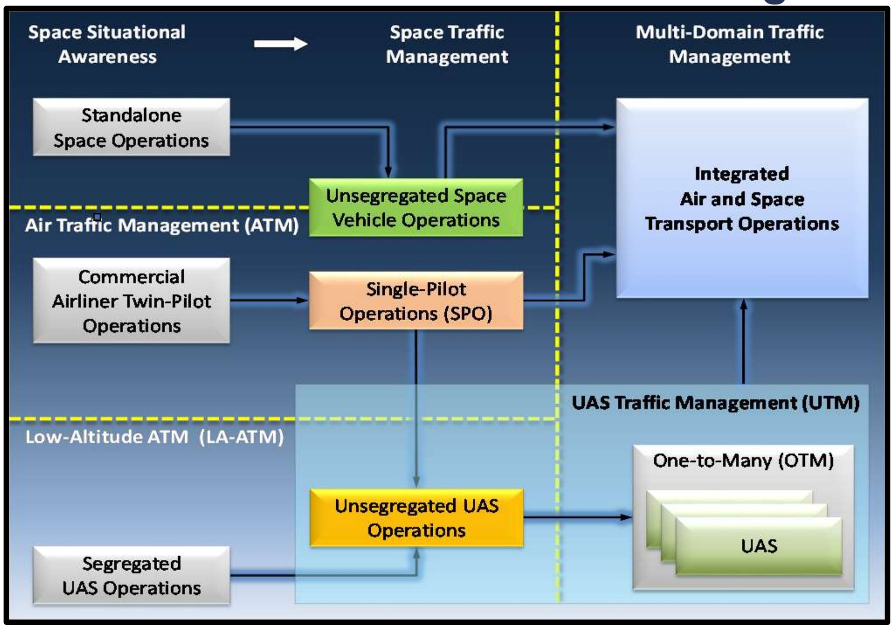
Quantify and Predict Resident Space Object Uncertainty



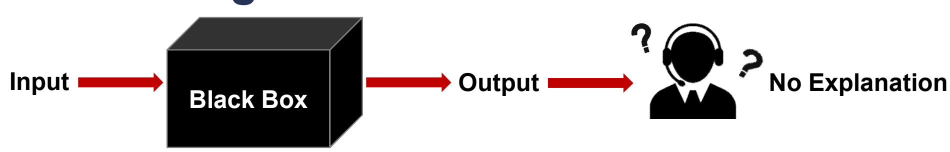
Assess ROC and Implement Corrective Actions



Towards Multi-Domain Traffic Management



Artificial Intelligence in MDTM



- Advanced AI algorithms…
- …create “black box” models…
- …so, they lack transparency…
- …which challenges human ability to verify and understand

- Experienced operators are reluctant to adopt suggested solutions
- Human understanding of automated decision making processes is important to build trust, enhance teaming and support post-mission analysis
- Explainable Artificial Intelligence (AI)

To date <u>no explainable AI</u> techniques have been developed for ATM, UTM and STM applications

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Selected Publications

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- A. 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. DOI: 10.1016/j.paerosci. 2014.06.002
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- 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. DOI: 10.4028/www.scientific. net/AMM.629.164
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AIAS Laboratory

Autonomous and Intelligent Systems Lab

- Supporting research and training activities on aerospace CPS design, operations and human factors
- Cutting edge facilities:
  - Flight simulator (210° FOV, 3 projectors)
  - Traffic Control Tower Simulation Environment (270° FOV, 5 projectors)
  - Industry-grade 2Kx2K 28” Tactical Situation Displays
  - ATM/ATFM Development Tools
- Networking capability and access to external research partners

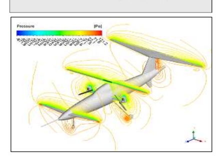



AIAS Laboratory (2)

UAS platforms and payloads

- Javelin Fixed wing UAV with an estimated MTOW of 15-18 kg
- Low Size, Weight, Power and Cost (SWaP-C) UAS Modular, programmable UAS for GNC stack design and testing
- A variety of quad-rotor and hexa/octa-copters, with payload lift capabilities up to 8 kg
- StopRotor UAS capable of both rotary and fixed wing flight allowing VTOL while also capable of loitering attitudes
- Current sensor payloads include electro-optical, thermal IR, and LIDAR






Avionics equipment

- Sandbox avionics prototyping environment and HW-in-the-loop workstations
- Several RF, IR/EO, Acoustic, MEMS-IMU sensors, including a custom tuneable IR LIDAR systems and thermal IR Cameras
- Time & Space Position Information (TSPI) Flight Test Instrumentation with tightly-coupled GPS/IMU for Small UAS
- Several ultrasonic echolocation transceivers and associated interface HW
- Software-Defined Radio (SDR) transceivers
- Real-time centralised and asynchronous collection of simulation data

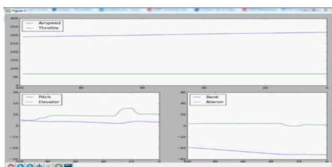
AIAS Laboratory (3)

❖ **Human Factors Engineering (HFE) equipment**

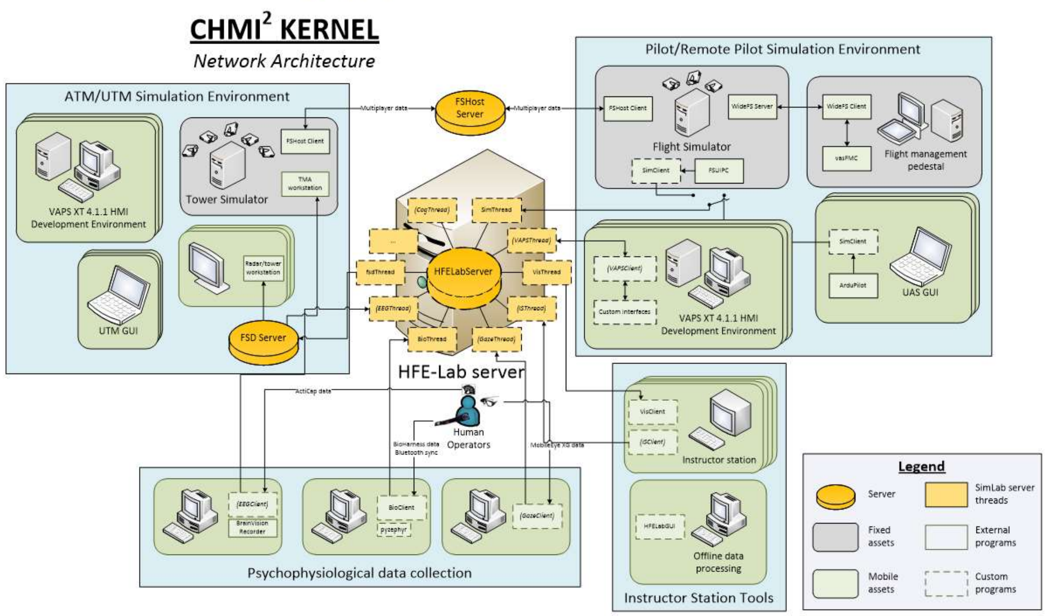
- Zephyr Bioharness: heart rate @250 Hz; breathing rate @25 Hz
- GazePoint GP3 HD: desk-mounted gaze tracking @150 Hz
- ASL MobileEye XG: head-mounted gaze tracking @30 Hz
- BrainProducts actiCAP+ V-AMP (16 channel EEG)
- Biopac Functional Near-Infrared Spectroscopy (fNIRS)
- Emotiv EPOC+ and Neurosky Mindwave
- FOVE Zero VR Headsets with research-grade eye tracker)

❖ **Software Tools**

- Commercial software: Presagis VAPS XT, MATLAB 2020, Prepar3D v4, X-Plane 11, BrainVision Recorder and RecView, ASL MobileEye, Zephyr BioHarness SDK, Eurocontrol's eDEP-SPD, Euroscope
- Open-source software: various including MissionPlanner, BlueSky, FSD, JSBSim, OpenScope, AlbatrossDisplay, pyZephyr
- HFE-Lab Server and Clients (SimClient, BioClient, VisClient, EEGClient, GazeClient)
- Post-processing (HFE-LabGUI)




AIAS Laboratory (4)



Aerospace and Defence Systems Research

- ❖ Navigation in GNSS Denied and Challenged Environments
- ❖ GNSS Augmentation (VBAS and SBAS/GBAS/VBAS Synergies)
- ❖ Low SWaP and High-Integrity Multisensor GNC Systems
- ❖ VLOS and BVLOS Data Communication Systems
- ❖ C4ISR Mission Systems
- ❖ 4D Trajectory Optimisation and Flight Management Systems
- ❖ UAS Separation Assurance and Collision Avoidance

GNC / CNS

- ❖ Decision Support Systems (Mission Planning and Real-Time Ops)
- ❖ Cognitive Human-Machine Interfaces and Interactions
- ❖ One-to-Many UAS and Distributed Satellite Systems

HAI / TAS

- ❖ Low-level ATM, UTM and Urban Air Mobility
- ❖ Space Situational Awareness at STM

CNS/ATM + Avionics = CNS+A

GNC= Guidance, Navigation and Control; Communication, Navigation and Surveillance (CNS);
HAI = Human-Autonomy Interactions; TAS= Trusted Autonomous Systems; UTM = UAS Traffic Management; STM = Space Traffic Management