An industry perspective on future RPAS operations

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Benefits & obstacles in UAS/RPAS insertion

Benefits

• Potentially huge advantages and benefits (economic, environmental, societal, ...)

• Apparently clear business case (emerging market, highly qualified jobs, ...)

• Catalyst for technology advances (automation, sensors, energy efficiency, materials, ...)

Obstacles to RPAS insertion

• Many obstacles pushing back RPAS operations (regulations, airspace access, standards, technology robustness, datalink, ...)

• Coupling between RPAS insertion and ATM modernization

• Key concerns: safety, security & privacy

• Additional concerns: cost-effectiveness, liabilities & public acceptance
The long-term perspective

Full & seamless integration of RPAS operations in ATM

- All aerial vehicles enabled access to airspace on a fair basis
- Highly automated ATM environment
- Distributed collaborative decision making
- Net-centric service-oriented architecture
- (Strategic) trajectory-based operations (TBO) & performance-based operations (PBO)
Today: RPAS – The chicken or eggs problem

No regulations → No operations

No standards → No market

No mature technology
Stepwise approach to RPAS insertion – Short term

- No regulations
- No mature technology
- No standards
- No market
- No operations

Niche applications
- Very high value
- Trusted operators (low security risk)
- Small UAVs (MTOW <25Kg)
- Segregated airspace (low safety risk)
- Loose coupling with ATM
- Minor regulatory challenges
- Initial realization of UAS benefits
- Start of emerging businesses
- Boost technology maturation
- Build experience and confidence
- Learn and get prepared for major changes in regulations

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Stepwise approach to RPAS insertion – Mid term

No regulations

No standards

No market

No mature technology

No operations

Extended applications
- Larger UAVs (MTOW <150Kg)
- Mixed-traffic scenarios
- Major regulatory challenges
- Boost growth of UAS businesses
- Exploitation of UAS benefits to larger extents
- Technology maturity
- Large levels of experience and confidence
- Opportunities for technology transfer between UAS and ATM
Stepwise approach to RPAS insertion – Long term

Business as usual
- Full seamless integration of UAS in ATM
- All aerial vehicles enabled access to airspace on a fair basis
- Highly automated ATM environment
- Strategic trajectory-based operations
- Collaborative decision making
- Net-centric service oriented architecture
Short term: Key drivers for early RPAS applications

- UAS applications of very **high social / economic / environmental value**
- that can be conducted in **segregated class-G airspace** (safety risks associated with manned traffic reduced to incidental unauthorized incursions)
- by means of **small UAVs** (lower safety risk / higher cost-effectiveness)
- performed by **trusted operators** (lower security/privacy risks)
- in a way that results **cost-effective**

E.g.
- Wildfire survey
- Wildfire firefighting support (COM rely)
- Precision agriculture
- Disaster relief (inspection & COM rely)
- People search & rescue
- Critical infrastructure survey
- Ecology
- Etc…

UAS imagery examples, courtesy of HEMAV, Gradiant & INSITU
Key RPAS integration requirements

1. Airworthiness
2. Remote pilot qualification & training
3. ATM policy & ATC procedures
4. ATC A/G link
5. ATC G/G link
6. C2 link
7. Detect & avoid
8. UAV surveillance
9. UAV navigation

Loss of Separation!
Loss of GPS!
Loss of Control!
Loss of Engine!
Loss of Link!
Critical flight contingencies

1) Loss of separation (LoS)
2) Loss of (C2) link (LoL)
3) Loss of GPS (LoG)
4) Loss of engine (LoE)
5) Loss of control (LoC)
The need for autonomy in flight contingency management

- 5 flight contingencies identified (LoS, LoG, LoL, LoE & LoC), which can occur individually or in any combination, giving rise to different severity conditions.

- Assuming that any combination of contingencies can happen along with LoL, some sort of autonomous flight management (FM) capability on board the UAV is inescapably required to safely handle the situation.

- Such autonomous FM function must be able to generate recovery maneuvers/trajectories that allow the UAV effectively coping with the contingency situations and, to the extent possible, resume mission execution or, otherwise, gracefully abort it (which may involve terminating the flight) without causing a safety incident.

- Thus, at the very least, autonomy in trajectory generation & execution is required for contingency management in case of command and control (C2) link unavailable.

⇒ This challenges the philosophy advocated in civil aviation where UAS are disregarded in favor of RPAS, assuming the existence of a remote pilot in command all the time.
**RPAS vs UAS**

(ICAO circular 328-AN/190)

**UAS**

Unmanned aircraft systems (UAS) are an aircraft and its associated elements which are operated with no pilot on board.

**RPAS**

Remotely piloted aircraft systems (RPAS) are a set of configurable elements consisting of a remotely piloted aircraft, its associated remote pilot station(s), the required command and control (C2) links and any other system elements as may be required, at any point during flight operations. **RPAS are remotely piloted by a human operator in command all the time.**
Traffic issues in segregated UAS operations

Concurrent multi-vehicle operations (i.e. traffic) may potentially take place even in segregated airspaces due to:

- **Single mission requiring a fleet of vehicles** (e.g. survey of large geographical areas)
- **Multiple missions concurrently operated by different users within the same airspace**
- **Any combination of the above**

Concurrent multi-vehicle operations pose several challenges:

- **Trajectory interactions** (i.e. LoS contingencies)
- **Datalink conflicts** (interference, frequency collisions, etc)
- Depending on the density of operations and complexity of the environment, **capacity issues** (e.g. converging traffic nearby launch/recovery facilities)

Besides scheduled UAS operations, unexpected incursions of unaware (possibly, uncooperative) manned aircraft in the segregated airspace can also occur

⇒ Traffic issues create the need for **traffic surveillance**, **traffic management services** as well as for **a solution to guarantee acceptable C2 link performance**
Net-centric service-oriented UAS TBO management architecture

**Mission critical**

**Mission**
- Mission sensors
- Mission actuators

**Mission execution**
- Payload management
- Payload control
- Sensor/mission data processing
- Mission data recording

**Mission services**
- Mission-specific geographical info
- Post-operation mission data processing & exploitation

**Mission planning**
- High-level mission modeling primitives (goals, merit)
- Resource allocation
- Task breakdown & allocation
- Low level mission primitives (trajectory patterns)

**Flight**

**Flight execution**
- Flight management (autonomous flight contingency management)
- Flight guidance & control
- Flight data recording

**Flight planning**
- Trajectory modeling primitives (waypoints, guidance/control)
- Trajectory feasibility (vehicle performance, meteo scenario)
- Trajectory safety (airspace constrains, terrain/obstacles, NFZs)
- Trajectory optimization
- Trajectory allocation

**Traffic**

**Traffic execution**
- Collision avoidance

**Traffic planning**
- Capacity and demand balance
- Airspace allocation
- Flight dispatching

**Operations critical**

**Operations planning**

**Operations execution**

**Services**

**Mission sensors**
- SUR sensors

**Mission actuators**
- FC actuators

**C2 COM (Ground)**

**C2 COM (Air)**

**M2M**

**SWIM**

**NAV sensors**

**NAV sources**

**Sur**

**SUR sensors**

**Mission network**

**Common services**
- Vehicle performance info
- Trajectory prediction

**Mission services**
- Meteorological info
- Aeronautical info
- Geographical info
- CNS+I performance monitoring

**Mission planning**
- High-level mission modeling primitives (goals, merit)
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**Flight planning**
- Trajectory modeling primitives (waypoints, guidance/control)
- Trajectory feasibility (vehicle performance, meteo scenario)
- Trajectory safety (airspace constrains, terrain/obstacles, NFZs)
- Trajectory optimization
- Trajectory allocation

**Flight execution**
- Remote flight management (flight contingency management)
- Flight plan conformance monitoring
- Flight data recording

**Traffic execution**
- Traffic management (separation)
- Flight plan conformance monitoring
- Traffic data recording

**Traffic planning**
- Capacity and demand balance
- Airspace allocation
- Flight dispatching

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Net-centric service-oriented UAS TBO management architecture

### Mission
- **Mission execution**
  - Payload management
  - Payload control
  - Sensor/mission data processing
  - Mission data recording
- **Mission avionics**
  - Flight management (autonomous flight contingency management)
  - Flight guidance & control
  - Flight data recording
- **Mission COM**
  - Mission COM (Ground)
- **Mission COM+I infrastructures**
  - Mission-specific geographical info
  - Post-operation mission data processing & exploitation
  - Remote payload management
  - Mission management (payload, flight plan)
  - Mission data recording
  - User Operations Center (Mission)
  - High-level mission modeling primitives (goals, etc.)
  - Resource allocation
  - Task breakdown & allocation
  - Low-level mission primitives (trajectory patterns)

### Flight
- **Flight execution**
  - Flight management (autonomous flight contingency management)
  - Flight guidance & control
  - Flight data recording
- **Flight avionics**
  - Flight management (autonomous flight contingency management)
  - Flight guidance & control
  - Flight data recording
- **C2 COM**
  - C2 COM (Ground)

### Traffic
- **Traffic execution**
  - Collision avoidance
- **Traffic services**
  - Traffic planning
  - Capacity and demand balance
  - Aircraft allocation
  - Flight dispatching
- **Traffic planning**
  - CNS+I performance monitoring

### Common services
- Meteorological info
- Aeronautical info
- Geographical info
- CNS+I performance monitoring

### CNS+I infrastructures
- CNS+I data recording
- Post-operation flight/traffic data analytics
- Etc.

### User Operations Center
- (Flight)
  - Trajectory modeling primitives (waypoints, guidance/control)
  - Trajectory feasibility (vehicle performance, metro scenario)
  - Trajectory safety (airspace constraints, terrain/obstacles, NFZs)
  - Trajectory optimization
  - Trajectory allocation
Legacy UAS solutions

Mission
- Mission sensors
- Mission execution
  - Payload management
  - Payload control
  - Sensor/mission data processing
  - Mission data recording
- Mission actuators
- Mission COM (Air)
- Mission COM (Ground)
- Mission network
- Mission services
  - Mission-specific geographical info
  - Post-operation mission data processing & exploitation
- Mission planning
  - High-level mission modeling primitives (goals, merit)
  - Resource allocation
  - Task breakdown & allocation
  - Low level mission primitives (trajectory patterns)

Flight
- Flight execution
  - Flight management (autonomous flight contingency management)
  - Flight guidance & control
  - Flight data recording
  - Remote flight management (flight contingency management)
  - Flight plan conformance monitoring
  - Flight data recording
- Flight planners
  - Trajectory modeling primitives (waypoints, guidance/control)
  - Trajectory feasibility (vehicle performance, meteo scenario)
  - Trajectory safety (airspace constrains, terrain/obstacles, NFZs)
  - Trajectory optimization
  - Trajectory allocation
- FC actuators
- C2 COM (Air)
- C2 COM (Ground)
- NAV sensors
- NAV
- NAV sources
- SWMM

Traffic
- Traffic execution
  - Collision avoidance
  - Traffic control (separation)
  - Flight plan conformance monitoring
  - Traffic data recording
- Traffic sensors
- SUR
- SUR sensors

Mission services
- Mission-specific geographical info
- Post-operation mission data processing & exploitation

Common services
- Vehicle performance info
- Trajectory prediction
- CNS+I data recording
- Post-operation flight/traffic data analytics
- Etc...

Mission actuators
- FC actuators

Mission COM (Air)
- C2 COM (Air)

Mission COM (Ground)
- C2 COM (Ground)

NAV sensors
- NAV

NAV sources
- NAV

SWMM

Common services
- Vehicle performance info
- Trajectory prediction
- CNS+I data recording
- Post-operation flight/traffic data analytics
- Etc...
Legacy UAS solutions

**Mission critical**
- **Mission execution**
  - Payload management
  - Payload control
  - Sensor data recording
  - Mission data recording
- **Mission services**
  - Mission-specific geographical info
  - Post-operation mission data processing & exploitation
- **Mission planning**
  - High-level mission modeling primitives (goals, merit)
  - Resource allocation
  - Task breakdown & allocation
  - Low-level mission primitives (trajectory patterns)

**Flight execution**
- Flight management
  - Flight plan conformance monitoring
  - Flight data recording
- **Flight services**
  - Trajectory modeling primitives (waypoints)

**Traffic execution**
- Collision avoidance
- **Traffic services**
  - CNS+I data recording
  - Post-operation flight/traffic data analytics
  - Etc…

**Ground Control Station (GCS)**
- **Autopilot + mission**
  - Mission COM (Air)
  - Mission COM (Ground)
  - Mission network

**Autopilot**
- **Flight critical**
  - Remote flight management
  - Flight plan conformance monitoring
  - Flight data recording
- **Flight planning**
  - Trajectory modeling primitives (waypoints)

**Traffic planning**
- Capacity and demand balance
- Airspace allocation
- Flight dispatching

**Common services**
- Meteorological info
- Aeronautical info
- Geographical info
- CNS+I performance monitoring
- CNS+I data recording
- Post-operation flight/traffic data analytics
- Etc…
Main limitations of legacy UAS solutions (small UAS)

1) **Multi-vehicle operations.** Today’s UAS solutions barely consider the traffic dimension if at all (i.e. the problems associated with concurrent operations of multiple vehicles).

2) **RLOS COM.** In general, pioneering UAS solutions consist on a ground control station (GCS) linked with an onboard autopilot (AP) or a combined AP-onboard mission system through typically a unique RLLOS A/G datalink that serves both C2 and mission purposes. No A/A or G/G communication possibilities envisaged nor provisions made to avoid datalink collisions among concurrent UAS operations. No BRLOS enabled.

3) **Networking.** No networking support provided; GCS and AP or AP+onboard mission system connections are point-to-point.

4) **Operational information.** GCS consider fairly simple information about atmospheric conditions, airspace layout and operational constraints and aircraft performance characteristics. No official provision of safety-critical operational information exists.

5) **Predictability.** In general, no UAS trajectory prediction support is provided at either planning or execution levels, which hinders opportunities for automation-enabled flight safety and mission efficiency improvements. No provisions have been made to predict and control the trajectory timing.

6) **Contingency management.** Legacy approaches to autonomy in the management of critical flight contingencies reduced to very simple Loss-of-Link (LoL) procedures (such as spiral-up or return-home through straight or back-tracking paths), which severely compromises safety in non-nominal situations. Little or no support provided to LoE, LoG, LoC or LoS. The most common approach to mitigate this is through an emergency flight termination (EFT) system, possibly involving a parachute (to be carried out by the UAV all over its entire life). The EFT solution is detrimental to PL capacity and platform survivability, which, bearing in mind the high cost of mission sensorics in comparison with the UAV platform, may completely impair cost-effectiveness. In addition, the EFT solution does not offer any protection against LoS contingencies, for which a S&A solution is still necessary and not available so far for small UAS.

7) **Flight/traffic data recording.** No official mission and data recording conceived to support addressing privacy concerns, liabilities and incident/accident investigation, all the operational data logging approaches being dissimilar.

8) **Mission automation.** Large opportunities exist for automation support in mission data processing and exploitation at both operation-time and post-operation stages, which greatly impacts mission operator/analyst workload and, thus, cost-efficiency, not to mention safety, as in typical UAS solutions supposedly intended for commercial applications mission operator and (remote) pilot-in-command roles are played by the same human operator.

9) **Architecture.** Legacy GCS and AP components are monolithic; no effective separation between safety-critical and mission-critical functions ensured. No decoupling exists either among mission planning, flight planning, mission execution and flight execution functions, which has implications in terms of safety qualification and certification.
UAS traffic management (UTM) system

ATM System

- ConOps
- Procedures
- Standards (MOPS & SARP)
- Certification
- Regulations
- Licenses
- Training
- Records
- Liabilities

Users of UAS services

QoS performance

UAS platforms

Modifications, maintenance

Payloads

UAS launching & recovering facilities

Pre & post-flight, launch & recovery operators

CNS+I infrastructures

CNS+I service providers

Common services

Providers of common services

Mission planning

Flight planning

Traffic planning

Mission / flight operators

Traffic operators

UAS service management system

UAS service value-chain

UAS services

UAS service providers

Mission services

Mission analysts

Traffic operators

Pre & post-flight, launch & recovery operators
UAS traffic management (UTM) system

- Autopilot
- FMS / FCS / EFB
- GCS / UOC
- AOC
- Air Traffic Services
  - ATC
  - ATFM
  - DAIS
  - DMET
  - ...

Airborne automation
Ground-based automation

ATM SWIM
UAS traffic management (UTM) system

- Holistic solution covering the complete UAS operation life-cycle
- Decoupled from ATM, tough replicating identical design premises to ensure scalability
- Platform-agnostic, net-centric, service-oriented & trajectory-based
Conclusions

• UAS insertion in the airspace is both coupled and synergistic with the modernization of the ATM system

• Civil/commercial use of UAS pose challenging problems in terms of safety, security and privacy, as well as cost-effectiveness, liability and public acceptance concerns

• An evolutionary approach to UAS insertion (in parallel with ATM modernization) should focus first on low-risk, high-value UAS applications that involve minimum interaction with ATM (niche applications)

• Early UAS applications still pose safety issues associated with flight contingencies and concurrent operations of multiple UAVs, as well as cost-efficiency issues, whose solution requires advanced levels of automation & autonomy in operations management

• Technology for autonomous UAS contingency management is a priority, as its capabilities and limitations will critically influence the operational concept for UAS insertion as well as MOPs & SARPs

• Opportunities arise for scaling ATM concepts & solutions down to UTM systems, which can be delegated the responsibility to cope with UAS operations in segregated environments

• As technology matures, conversely, opportunities will arise to feed the experience with advanced automation & autonomy solutions built in the UAS realm back to ATM, as well as to scale up UTM systems to increasingly support further steps of UAS insertion in ATM

⇒ UTM represents an enabler for early UAS applications as well as a lab facilitating ATM evolution