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THE PROBLEM OF MINI-UNMANNED AERIAL VEHICLE NON–SEGREGATED FLIGHT OPERATIONS

ABSTRACT

The paper first illustrates the future civil application opportunities for unmanned aerial vehicles and their unique operational capabilities. The expectations of the main stakeholders are summarized and the main concerns and problem areas of non-segregated civil unmanned aerial vehicles flight operations are identified considering relevant aviation regulatory aspects. The key technologies necessary for a safe unmanned aerial vehicles operation are explained. The intention of the paper is to contribute to finding the optimal approach to the development strategies and safe solution for the integration of today's and future civil unmanned aerial vehicles into the non-segregated airspace.

KEY WORDS

Unmanned Aerial Vehicle, Non-Segregated Flight Operations, Sense-and-Avoid

1. INTRODUCTION

Unmanned Aerial Vehicles (UAV) constitute a rapidly evolving sector. The world market over the next decade will be worth $15 billion. Analyses are predicting progressive investment of $3.1 billon to meet the European armed forces demand of 2000 complete UAV systems by 2015 [6].

However, these figures do not reflect the status of civil UAV market. The use of UAVs for civil applications is highly preferable over manned flights where manned flights are too dangerous, expensive or monotonous. Due to the relative ease of implementing them numerous civil applications of UAV flight operations have come into focus [11].

I. Security applications:
- monitoring vital infrastructure sites of national and public interest,
- land and sea international border patrol,
- security surveillance of drug and arms trafficking,
- law enforcement missions.

II. Emergency applications:
- search and rescue,
- disaster operations management and catastrophic situation assessment:
  - oil slick observation,
  - firefighting,
  - flood watch,
  - hurricane watch,
  - earthquake monitoring,
  - volcano monitoring,
  - nuclear radiation and biological emission monitoring.

III. Communications applications:
- GPS/Galileo augmentation system – pseudo satellite,
- broadband communications,
- telecommunication relay services,
- cell phone transmission.

IV. Monitoring operations:
- maritime patrol and coastline monitoring,
- fisheries monitoring,
- height accuracy terrain mapping,
- crop and harvest monitoring,
- environmental monitoring,
- high voltage power line inspection,
- forest fire detection,
- road traffic monitoring and control.

V. Environmental applications:
- geological surveys,
- volcano study and eruption alert,
- oceanographic observation,
- atmospheric research,
- hurricane evaluation and research,
- weather forecast.

The obvious nature of the supplemental interaction of missions from different areas of utility clearly indicates the integral potential of UAV flight operations as well as direct and indirect benefits of their civil applications.

2. PROBLEM

At present, UAVs flight operations in Europe are restricted to airspace that is segregated from that of other aircraft or they are flown on special case-by-case basis arrangements. Where operations are permitted outside the segregated airspace, numerous restrictions to ensure the safety of other airspace users apply. In spite of efforts of the projects and working groups such as UAVNET, CAPECON, USICO, HELIPLANT, IFATS, the Joint JAA/EUROCONTROL Initiative on UAVs, Eurocontrol UAV-OAT TF, NATO UAV FINAS WG, which have provided the exhaustive draft points of departure, the process of introducing the non-segregated civil UAV flight operations has stalled.

As the result of the need for some regulation, Eurocontrol UAV-OAT TF draft ATM specifications for the use of military UAVs flying as Operational Air Traffic outside segregated airspace are currently applicable to civil UAV operations as well. The set of 33 specifications were chosen as the most appropriate category because their voluntary status would leave individual states free to decide whether or not to incorporate them into their own national regulations. These high-level and generic specifications cover areas such as [3]:

- ATM categorization of UAV operations,
- chase aircraft,
- mode of operation,
- flight rules,
- right-of-way,
- separation from other airspace users,
- sense and avoid,
- separation minima,
- airfield operations,
- emergency procedures,
- airspace management,
- interface with ATC,
- meteorology,
- flights across international borders and across FIR and UIR boundaries,
- OAT CNS equipment requirements.

Momentum is gaining towards allowing UAVs into civil aerospace over Europe, bringing with it the thorny issue of certifying UAV airworthiness. If the parallel to the certification process of manned aircraft is adopted, then the common philosophy of civil certification of UAV would be to apply defined codes of airworthiness requirements, based on long lasting experience, to the design of any UAV. The recognition of compliance with those requirements would be given by the granting of a Type Certificate for the approved design and Certificate of Airworthiness to individual UAVs. However, experience with civil UAVs are nonexistent and for that reason the codes of airworthiness requirements regarding UAVs have not been defined yet; consequently, we have the actual situation of segregated civil or military UAV flight operations (Fig. 1). Equivalent problems arise in the domain of licensing of UAV crews, technicians, operators and their maintenance organizations.

The alternate method of UAV airworthiness certification is to adopt a top-down safety target approach of setting an overall safety objective for the UAV within the context of a defined mission role and operating environment where potential hazards are addressed by a combination of design and operational requirements. Under such a philosophy constructed on the basis of an assessment of third party risks the acceptability of a UAV would have a dependency on the frequency and duration of missions and limitations relating to them may be part of the justification of acceptable airworthiness. Because various operators might use markedly different philosophies to compile their safety records, such a system would be difficult to

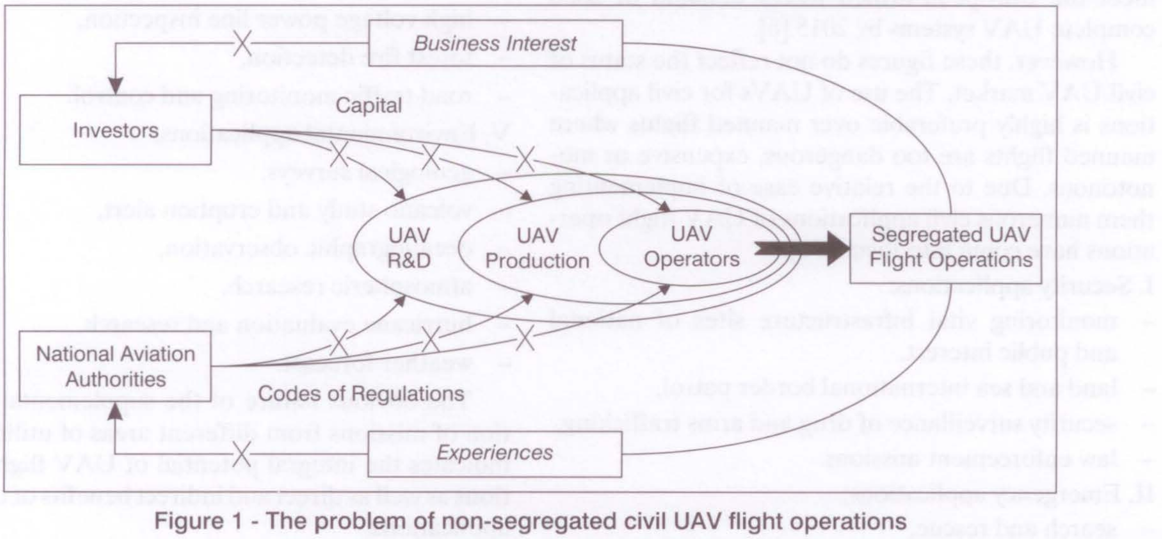

Figure 1 - The problem of non-segregated civil UAV flight operations

administer in the transparently equitable manner required. It could place the national aviation authority in the position of giving permission for one commercial operator to fly his UAVs in preference to a competitor on the basis of an assessment of the relative airworthiness of the competing fleets. The alternative then dictates a scenario in which investments are deterred from the nascent civil UAV market (Fig. 1).

3. ENABLING TECHNOLOGIES

Largely owing to the growth in non-aerospace markets, there has been tremendous progress in the technologies enabling fast UAV evolution. The most significant development of all has been the establishment of the global positioning system. The mobile phone and digital photography boom have driven communications, display, optics, charge-coupled devices (CCD), and energy storage technology, as well as reductions of energy consumption. The personal computer market has driven the increasing processing power and data storage capacity, and at the same time reduction of computer size and costs. The video games market and the internet have driven developments in information processing, imaging, simulation, encryption, and data management, analysis and compression.

The UAVs offer more capability, less risk, lower cost, shorter service lives and faster and more frequent upgrades [9, 14]. Consequently, UAV systems can be matched to the existing threats and, with greater flexibility than manned counterparts, are able to adapt more readily to changes in the nature of threats or to completely new threats. Not surprisingly, in the military arena over 32 nations are developing or manufacturing more than 250 different models of UAVs, and 41 countries operate over 80 types of UAV systems [6]. Over the past 30+ years the military operational mission use of UAVs has only intensified with a continuous and significant increase in flight hours [9]. This story might be translated into the civilian domain; however, as mentioned (Fig. 1), only the incoming capital flow can start the wheels of civil UAV use revolution.

In the UAV sphere size matters with capabilities directly related to their complexity. As a function of take-off mass the UAV's complexity is a convex parabola (Fig. 2) with its minimum saddle in the category of mini-UAVs or UAVs class 0. At the lower end of the

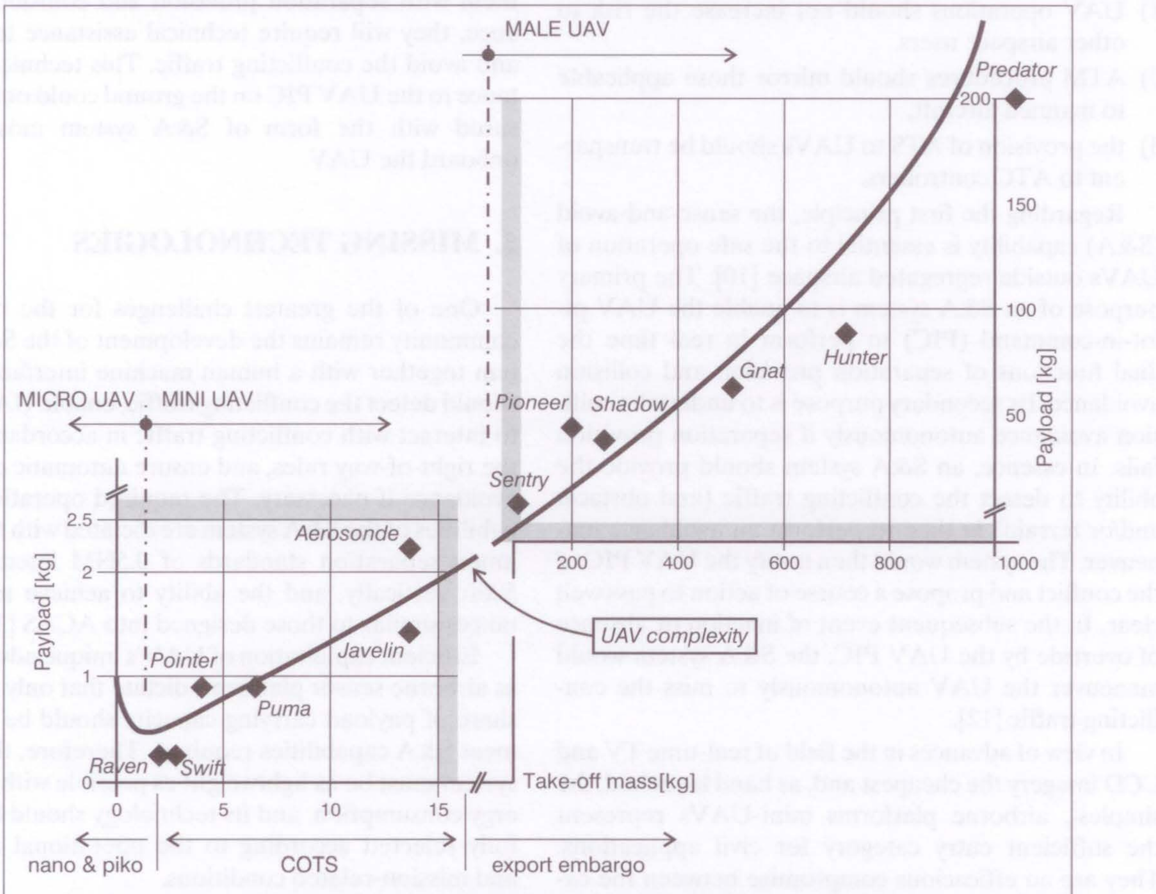

Figure 2 - Complexity of UAV systems

complexity curve the investments into the category of micro-UAVs are inversely proportional to the size due to the systems miniaturization. At the other side of larger UAVs, the potential civil operators will have to cope with investments driven to the power of size as well as with the restricted trade on the prohibitive military hardware market.

As long as capital investments are concerned the best chance the future civil UAVs evolution has is in the mini category where required technology is already available for commercial off-the-shelf in a more or less free market. In this category the basic ready-to-fly UAV systems with visual light sensor equipment cost approximately between 1000 and 2000 Euro per kilogram. However, a UAV cannot be operated outside segregated airspace for such a marginal price.

4. UAV FLIGHT OPERATIONS OUTSIDE SEGREGATED AIRSPACE

The specifications defined by Eurocontrol UAV-OAT TF to govern the integration of UAV flight operations with civil manned air traffic follow three basic principles [3,5]:

1) UAV operations should not increase the risk to other airspace users,
2) ATM procedures should mirror those applicable to manned aircraft,
3) the provision of ATS to UAVs should be transparent to ATC controllers.

Regarding the first principle, the sense-and-avoid (S&A) capability is essential to the safe operation of UAVs outside segregated airspace [10]. The primary purpose of an S&A system is to enable the UAV pilot-in-command (PIC) to perform in real time the dual functions of separation provision and collision avoidance. Its secondary purpose is to undertake collision avoidance autonomously if separation provision fails. In essence, an S&A system should provide the ability to detect the conflicting traffic (and obstacle and/or terrain) in time to perform an avoidance maneuver. The system would then notify the UAV PIC of the conflict and propose a course of action to pass well clear. In the subsequent event of inaction or absence of override by the UAV PIC, the S&A system would maneuver the UAV autonomously to miss the conflicting traffic [12].

In view of advances in the field of real-time TV and CCD imagery the cheapest and, as hand launched, the simplest, airborne platforms mini-UAVs represent the sufficient entry category for civil applications. They are an efficacious compromise between the capabilities and capital investments required to start civil UAV operations. The category of mini-UAVs is characterized by: maximum take-off mass in the range between 2 and 10kg, maximum speed between 35 and 60kt, maximum altitude of 3000ft with the maximum rate of climb up to 600fpm, maximum task radius up to 6NM; while endurance, powered with electric motor supplied from lithium batteries, is up to approximately 2 hours, yet they can carry only up to 2kg of payload, and even the top end class 0 (MOTM below 25kg) UAV cannot carry more than 5kg of payload (Fig. 2) [1,4].

Regarding their capabilities the mini civil UAVs will mix with all sorts of general aviation in the G class airspace which leads consequently to a two-fold problem. Since while flying in the G class airspace the UAVs should not deny the airspace to other users, an effective separation provision must be ensured. However, obviously, ATC separation provision is not a feasible option at all. The G class airspace is uncontrolled, with only FIS available to the users equipped with radio communication, and, furthermore, even position reporting to the FIS by the airspace users is not mandatory, since radio communication equipment, not to mention transponders, is not mandatory. Therefore, in any circumstances the UAV PIC will be responsible for the separation assurance, and having surveillance information available to them to assist them with separation provision and collision avoidance, they will require technical assistance to detect and avoid the conflicting traffic. This technical assistance to the UAV PIC on the ground could only be assured with the form of S&A system most likely onboard the UAV.

5. MISSING TECHNOLOGIES

One of the greatest challenges for the research community remains the development of the S&A system together with a human machine interface which should detect the conflicting traffic, enable UAV PICs to interact with conflicting traffic in accordance with the right-of-way rules, and ensure automatic collision avoidance if necessary. The required operational capabilities of the S&A system are dictated with the minimum separation standards of 0.5NM laterally and 500ft vertically, and the ability to achieve miss distances similar to those designed into ACAS [3,4,5].

Efficient exploitation of UAV's unique advantages as airborne sensor platforms dictate that only a minor share of payload carrying capacity should be used to meet S&A capabilities required. Therefore, the S&A system must be as lightweight as possible with low energy consumption, and its technology should be carefully selected according to the operational in-flight and mission-related conditions.

One can foresee that ultra-wideband micro-pulse radar will most certainly play an active role in providing the S&A capability for UAVs [8]. Since it can assure situation awareness to the UAV PIC in almost any but the harshest IMC, it represents the optimal technology for the purpose. It is reasonable to anticipate that the UWBMP radar with a mass of roughly one kilogram at power supply of ~28V at ~1A will have a range in the order of magnitude of up to one nautical mile. For provision of S&A capabilities in the IMC the dual-use technology especially from the automotive and security industry might come into focus once again. Dutta and Arora demonstrated how to detect and track airborne conflicting traffic using an almost credit card-sized motion radar sensor [2]; however, further technology transfer research is necessary.

Considering again the acceptability of costs of daylight sensor equipment onboard UAV a conclusion is possible that UAVs will fly in VMC only; consequently, the S&A technology operational in the VMC satisfies requirements. For the class of mini-UAVs the sensors currently being investigated for the airborne VMC S&A capability include LIDAR [13] and the computer vision system that detects and tracks obstacle features of the scene [7], both with the promising results from successful demonstrations.

6 CONCLUSION

At present, civil UAV operations in Europe are actually exceptionally restricted to the point that they are all but prohibited mainly due to the lack of regulations, especially in the domain of airworthiness, flight safety, security, and operator training, as well as lack of public confidence. The situation leads to bashful business interest and deterred investments from the civil UAV market. For market introduction of civil UAV it is essential to proceed safely and step by step. To gain access to the whole airspace, stimulating experimental civil UAV missions under experimental operational constraints with flight operations restricted to airspace that is separated from other aircraft should be the first step in the process that will demonstrate UAV reliability to the public, authorities, air traffic controllers and pilots of manned aircraft – entrepreneurs will surely follow. In the step with the market evolution the legal framework for certifying and operating UAVs will be developed.

For the UAV community to gain access to the non-segregated airspace, and to exploit fully the unique operational capabilities that UAV can offer for civil applications there is a generally agreed consensus that the UAVs shall provide the same level of safety as piloted aircraft. To fly in non-segregated airspace in a non-cooperative environment the UAVs shall be equipped with a sense-and-avoid system with a means of detecting conflicting traffic, enable UAV PIC to respond, and ensure automatic collision avoidance. To equip a UAV with an S&A capability is a necessity that poses economic and developmental challenges considering the safety means necessary to conform to current and future controlled or uncontrolled airspace regulations.

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POVZETEK

PROBLEM NESEGREGIRANIH LETALSKIH OPERACIJ MINI-BREZPILOTNIH LETAL

Članek se začne z opisom možnosti uporabe brezpilotnih letal v civilne namene ter njihovimi edinstvenimi operativnimi zmogljivostmi. Povzeta so pričakovanja sodelujočih akterjev, posebej pa je glede na relavantno letalsko regulativo obravnavana problematika uresničevanja nesegregiranih letalskih operacij brezpilotnih letal. Opisane so ključne tehnologije neobhodne za varne letalske operacije brezpilotnih letal. Namen članka je prispevati k najprimernejšemu pristopu snovanja strategije ter varne izvedbe integracije današnjih in prihodnjih brezpilotnih letal v nesegregiran zračni prostor.

ABBREVIATIONS

ACAS	Airborne Collision Avoidance System
ATC	Air Traffic Control
ATM	Air Traffic Management
ATS	Air Traffic Services
CCD	Charge-Coupled Devices
CNS	Communications Navigation Surveillance
COTS	Commercial-Off-The-Shelf
FINAS	Flight in Non-Segregated Airspace
FIR	Flight Information Region
FIS	Flight Information Services
IMC	Instrument Meteorological Conditions
LIDAR	Light Detection and Ranging
MTOM	Maximum Take-Off Mass
OAT	Operational Air Traffic
PIC	Pilot-In-Command
S&A	Sense-and-Avoid
TF	Task Force
UAV	Unmanned Aerial Vehicle
UIR	Upper Information Region
USICOUAV	Safety Issues for Civil Operators
VMC	Visual Meteorological Conditions
WG	Working Group

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