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INOUI

INNOVATIVE OPERATIONAL UAS INTEGRATION

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D6.2 TECHNOLOGY WATCH FOR UAS OPERATIONS IN AIRPORTS

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Table of Contents

List of Figures

List of Tables

1 Introduction

The main objective of the INOUI project is to research in the challenge of integrating UAS in the 2020 airspace environment. By taking into account the context of the ever changing ATM environment, the goal is to develop a roadmap that can support the integration of UAS into the operational concept and architecture for the mentioned temporal framework. Development of the INOUI project runs in parallel with SESAR (Single European Sky ATM Research) and aims complementing its development phase, proposing new areas of development and further work.

1.1 Background

INOUI (Innovative Operational UAS Integration) project is a response to the Research Domain 4.g « Innovative Air Traffic Management Research » of the FP6-2005-AERO-4, Research Area « Open Upstream Research ».

The main objective of INOUI is to develop a roadmap how to integrate UAS into the operational concept and architecture for the future by assessing different domains of the ATM system. The idea of integrating UAS into the 2020 airspace environment came up from the following two facts:

- The increasing demand of UAS operations coming from different sources
- The fact that actually UAS fly only at a very low altitude or in segregated airspace (mostly military nature of the operations)

It is forecast that air traffic will increase three times its actual figures and that is without considering UAS. In order to ensure that the future Air Traffic Management (ATM) is able to face this challenge, SESAR was founded which is defining the future European Air Traffic Management (ATM) System for 2020 and beyond. Main goals of SESAR are to increase actual ATM capacity, to improve the safety performance, to reduce the effects on the environment produced by the flights and to reduce ATM service costs to the airspace users.

Now, bearing in mind that UAS traffic comes on top of the above forecast to the future air traffic, additional considerations shall be taken into account. INOUI aims complementing SESAR by facilitating the integration of the UAS in the foreseen airspace and airport environment. To do so, INOUI defines an operational concept, proposes operational procedures and assesses the technologies to support them, trying to fill in the gaps of the SESAR definition phase with regard to the particularities of UAS.

1.2 Purpose of the Document

Work package 6 (WP6) “Aerodrome Concepts for UAS Operations” focuses on the operational and technological aspects of UAS from an aerodrome needs perspective, providing a global view of UAS operation in the air transport system. The work under this task, aims to complement and support the studies performed previously under WP1 and WP2. The objectives of work package 6 are:

- To define an operational concept to integrate UAS into the aerodrome 2020 and beyond
- To assess systems and technologies for enabling UAS operation in the aerodrome 2020 and detect needs in the subject
- To study and investigate the potential of future “solutions” to improve the integration of UAS into the aerodrome 2020 and beyond

The purpose of this report is to evaluate all existing and future systems and technologies that are intended to be applied on ground and airborne to enable UAS aerodrome operations and complementing previous INOUI work regarding operational and technological issues.

This document is the second deliverable (D6.2) of work package 6 “Aerodrome Concepts for UAS Operations”. As a result of this study, this document presents a proposal for technologies and their applications to enable the safe operation of UAS on aerodromes. Figure 1 depicts the methodology used for the study of WP6 “Aerodrome Concepts for UAS Operations”.

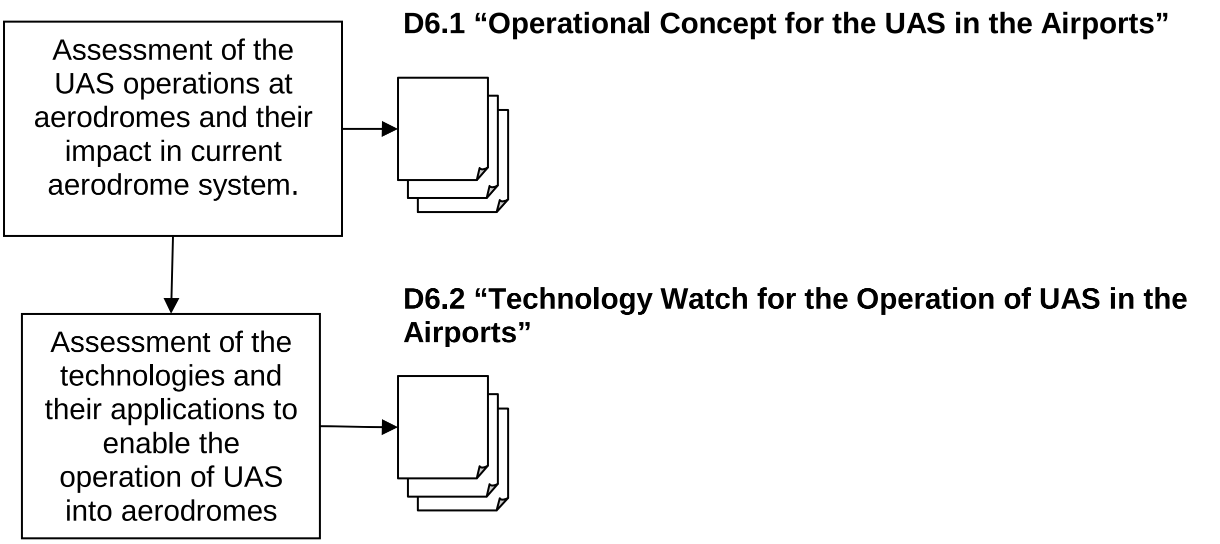

Figure 1 – UAS methodology for Technology developments under WP6 (Source: INOUI)

It has to be noted that the scope of this document is restricted to controlled aerodromes (i.e. Air Traffic Services are provided within it) and civil aerodromes (i.e. only those aerodromes which are used for civil operations are considered), accordingly to the scope of work of the INOUI project. Aerodromes with mixed traffic, manned and unmanned aircraft operating together are also considered.

1.3 Document Structure

This document has been structured in four main sections focusing on technology proposals for both the UAS and ground ATM elements. The objective of this document is to identify and propose a number of potential technologies required to fill potential technology gaps focusing on aerodrome operations.

Section 1 deals with current technology proposals. During previous INOUI work, in particular under document [D2.1- Report on Technology System Solutions] a number of technologies were identified as potential candidates for the operation of UAS in the 2020 ATM environment. These technologies have been reviewed with special interest on aerodrome operations.

Section 2, follows on from the previous section to provide detailed information on how UAS may be dealt with and managed under the future ATM 2020 environment. In particular SWIM is considered as part of this future ATM 2020 environment.

Section 3 aims to identify those technologies which may be required and not considered in the current technology roadmap, as described under Sections 1 & 2.

Section 4 is the final summary and conclusions regarding technological needs for operating UAS at aerodromes.

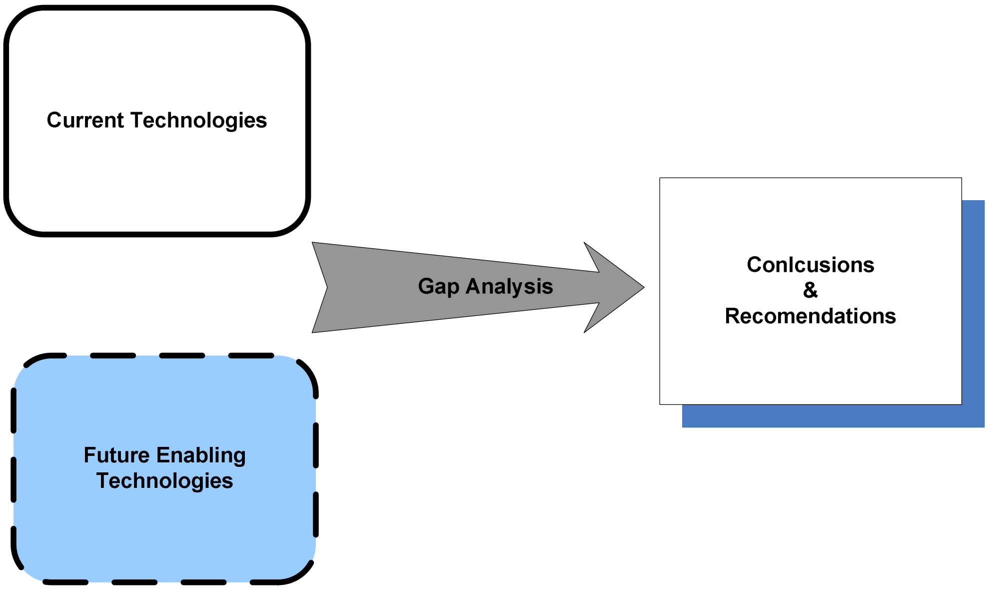

Figure 2 – D6.2 Methodology (Source: INOUI)

1.4 Applicable and Reference Documents

Reference tag	Document description
[14CFR 23]	Code of Federal Regulation – Part 23
[AENA Safety Target]	Resolucion de la Direccion General de Aviacion Civil por la que se Establecen los Niveles Objetivo de Seguridad para el año 2007
Air4All	Final Air4All Report for 'UAS insertion into General Air Traffic (GAT) Follow On Contract'
[AIRCHIEF 2003]	European Air Chief Conference 2003
[Andersson and Tegner, 2004]	Evaluation of taxonomy and system support for risk based analysis within the Swedish Aviation Safety Authority, M. Andersson and S. Tegner, 13-02-2004
[ATM 2000+]	EUROCONTROL ATM Strategy for the Years 2000+, 2003 Edition, approved by the Permanent Commission for the Safety of Air Navigation, on 10 April 2003, available at http://www.eurocontrol.int/eatm/gallery/content/public/library/ATM2000-EN-V1-2003.pdf
[CAST ICAO Occurrence Categories]	Aviation Occurrence Categories; Definitions and Usage Notes, November 2008 (4.1.4), the CAST/ICAO Common Taxonomy Team, available at http://www.intlaviationstandards.org/Documents/CICTTOccurrenceCategoryDefinitions.pdf
[Clothier, Walker, Fulton and Campbell]	A casualty risk analysis for Unmanned Aerial System (UAS) Operations over Inhabited areas. R. Clothier, R. Walker, N. Fulton and D. Campbell
[De Jong & Van Es, 2008]	How many accidents is a collision? Paper presented at the EUROCONTROL Safety R&D Seminar, September 2008 in Southampton.
[EASA AMC 25.1309]	EASA Acceptable Means of Compliance for Certification Specification 25.1309
[EASA CS-25]	EASA CS-25. Certification Specifications for Large Aeroplanes. Amendment 5 – September 5th, 2008
[EASA A-NPA No 16/2005]	Advanced Notice of Proposed Amendment (NPA) No 16/2005. Policy for Unmanned Aerial Vehicles (UA) Certification.
[EASA CS-23]	EASA CS-23. Certification Specification for normal, utility, aerobatic and commuter category airplanes. Initial Issue – 14/11/2003.
[EC Common Requirements]	COMMISSION REGULATION (EC) No 2096/2005 of 20 December 2005 laying down common requirements for the provision of air navigation services, Official Journal of the European Union (English) L 335/13-30, 21.12.2005
[EC No. 549/2004]	Regulation (EC) No 549/2004 of the European Parliament and of the Council of 10 March 2004 laying down the framework for the creation of the single European sky (the framework Regulation), 31.3.2004 EN, Official Journal of the European Union L 96/1

Reference tag	Document description
[ESARR 2]	EUROCONTROL Safety regulatory Requirement ESARR 2, Reporting and Assessment of Safety Occurrences in ATM, Edition 2.0, 3 November 2000, available at http://www.eurocontrol.int/src/gallery/content/public/documents/deliverables/esarr2_awareness_package/esarr2e20ri.pdf
[ESARR 4]	Risk Assessment and Mitigation in ATM, Edition 1.0, 5 April 2001, http://www.eurocontrol.int/src/gallery/content/public/documents/deliverables/esarr4v1.pdf
[Eurocontrol OAT Spec 0102]	Eurocontrol Specifications for the use of Military Unmanned Aerial Vehicles as operational Air Traffic outside segregated airspace, Eurocontrol-Spec-0102. M. Strong, 26/07/2007
[EUROCONTROL SRC SCS]	EUROCONTROL SRC - Severity Classification Scheme for Safety Occurrence in ATM, 12-11-1999
[FAA AC 23.1309-1C]	Federal Aviation Administration Advisory Circular, “Equipment, Systems, and Installation in Part 23 Airplanes,” AC 23.1309-1C, March 1999
[FAA AC 25.1309-1A]	Federal Aviation Administration Advisory Circular, “System Design & Analysis,” AC 25.1309-1A, June 1988
[FAA Order 8040.4]	Federal Aviation Administration Order 8040.4 - Safety Risk Management (SRM). 26-06-1998.
[FAA SSH]	Federal Aviation Administration. System Safety Handbook. 30 December, 2000
[ICAO Annex 11]	Annex 11 to the Convention on International Civil Aviation, Air Traffic Services, Thirteenth Edition July 2001
[ICAO Annex 13]	Annex 13 to the Convention on International Civil Aviation, Aircraft Accident and Incident Investigation, Ninth Edition July 2001
[ICAO Doc 4444]	International Civil Aviation Organization, Doc 4444, Procedures for Air Navigation Services, Air Traffic Management, Fourteenth Edition — 2001
[ICAO Doc 9082/7]	ICAO’S Policies on Charges for Airports and Air Navigation Services, Doc 9082/7, Seventh Edition – 2004
[ICAO Doc 9574]	ICAO Doc 9574-AN/934, Manual on Implementation of a 300 m (1 000 ft) Vertical Separation Minimum between FL 290 and FL 410 Inclusive, Second Edition – 2002, Corrigendum 16 April 2002
[ICAO Doc 9689]	ICAO Doc 9689-AN/953, Manual on Airspace Planning Methodology for the Determination of Separation Minima, First Edition – 1998, Amendment 30 August 2002
[INOUI Annex 1]	INOUI (Innovative Operational UA Integration) Annex 1 – “Description of Work”, Proposal/Contract no 037191, date of preparation 10 April 2007, signed August 2007
[INOUI D1.3]	INOUI (Innovative Operational UA Integration) , Deliverable 1.3 “Integration of UAS into the airspace”
[INOUI D2.1]	INOUI (Innovative Operational UA Integration) , Deliverable 2.1 “Technology Watch”
[INOUI D2.2]	INOUI (Innovative Operational UA Integration) , Deliverable 2.2 “Assessment of Technology for UAS integration”

Reference tag	Document description
[INOUI D4.1]	INOUI (Innovative Operational UA Integration) , Deliverable 4.1 “UAS in a SWIM enabled Environment”
[INOUI D4.2]	INOUI (Innovative Operational UA Integration) , Deliverable 4.2 “New UAS – related Common Operating Picture actors”
[INOUI D4.3]	INOUI (Innovative Operational UA Integration) , Deliverable 4.3 “UAS Operations depending on the level of Automation and Autonomy”
[LVNL Safety Criteria]	LVNL Safety Criteria, Hans H. de Jong (DFS) and J.C. (Hans) van den Bos (LVNL), paper presented at the Eurocontrol Safety R&D Seminar in Rome, 2007
[Minutes 2 and 3 September 2008]	Minutes of INOUI Technical Meeting 2 and 3 September 2008, distributed by Marita Lintener (DFS) on 4 November 2008
[NATO S&A]	NATO Sense and Avoid Requirements for Unmanned Aerial Vehicle Systems Operating in Non-segregated Airspace
[NATS SPS 2004]	NATS Strategic Plan for Safety, 2004
[NATS SPS 2007]	NATS Strategic Plan for Safety, 2007
[SAF-SAM1-FHA]	EUROCONROL Institute of Air Navigation Services -Training Document SAF-SAM1-FHA, 12-11-2007
[SESAR Safety Target]	White Paper on SESAR Safety Target, Episode 3, Deliverable D2.4.3-01, Owner: Eric Perrin, Eurocontrol, Version 1.2 (Draft)
[SRC Policy Doc 1]	EUROCONTROL Safety Regulation Commission Policy Document 1, ECAC Safety Minima for ATM, Edition 1.0, 14 February 2001
[STANAG 4671 - Draft]	STANAG 4671 (Edition 1) – Unmanned Aerial vehicle Systems Airworthiness Requirements (USAR) - Draft version
[INOUI 2nd SW]	INOUI Second Stakeholder workshop, UAS Technologies at Aerodrommes. March 12th, 2009, Gran Canaria.

1.5 Glossary

4D	Four Dimensions
ABAS	Aircraft Based Augmentation System
ACARE	Advisory Council for Aeronautics Research in Europe
ACAS	Airborne Collision Avoidance System
ACC	Area Control Centre
ADF	Automatic Direction Finder
ADS-B	Automatic Dependent Surveillance Broadcast
AFTN	Aeronautical Fixed Telecommunication Network
AMHS	Aeronautical Message Handling Service
ANSP	Air Navigation Service Provider
ASAS	Airborne Separation Assistance (Assurance) Systems
A-SMGCS	Advanced Surface Movement Guidance and Control System
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
BR&TE	Boeing Research and Technology Europe SL
C^2	Command and Control
C^3	Command, Control and Communication
CAATS	Cooperative Approach to ATS
CASCADE	Co-operative ATS through Surveillance and Communication Applications Deployed in ECAC
C-ATM	Collaborative ATM
CDM	Collaborative Decision Making
CFMU	Central Flow Management Unit
CNS	Communication, Navigation, Surveillance
CPDLC	Controller Pilot Data Link Communication
CS	Control Station
DB	Data Base
DFS	DFS Deutsche Flugsicherung GmbH
DME	Distance Measuring Equipment
DVP	Development Plan
EC	European Commission
ECAC	European Civil Aviation Conference
EGNOS	European Geostationary Navigation Overlay System Services
ESARR	EUROCONTROL Safety Regulatory Requirement
EU	European Union
EUROCAE	European Organization for Civil Aviation Electronics
EUROCONTROL	European Organisation for the Safety of Air Navigation
EVS	Enhanced Vision System
FCS	Flight Control System
FIR	Flight Information Region
FMC	Flight Management Computer
FMS	Flight Management System

FP	Framework Programme
FPL	Flight Plan
G2G	Gate To Gate
GAT	General Air Traffic
GBAS	Ground Based Augmentation System
GLONASS	GLObal'naya NAvigatsionnaya Sputnikovaya Sistema (Global Navigation Satellite System)
CS	Control Station
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HUD	Head-Up Display
ICAO	International Civil Aviation Organisation
IFATS	Innovative Future Air Transport System
IFR	Instrumental Flight Rules
ILS	Instrument Landing System
INA	Innaxis – Fundación Instituto de Investigación
ISD	Isdefe – Ingeniería de Sistemas para la Defensa de España
JPALS	Joint Precision Approach and Landing Systems
LAAS	Local Area Augmentation System
LED	Light Emitting Diode
MLAT	Multi Lateration
MLS	Microwave Landing System
MMR	Multi Mode Receiver
MSPSR	Multi Static Primary Surveillance Radar
NDB	Non-Directional Beacon
OAT	Operational Air Traffic
ONERA	Office National d'Etudes et de Recherches Aéronautiques
PCO	Project Co-ordinator
PMP	Project Management Plan
PSR	Primary Surveillance Radar
RCS	Radar Cross Section
RDE	Rheinmetall Defence Electronics GmbH
SATCOM	Satellite Voice and Data communications
SBAS	Satellite-Based Augmentation System
SES	Single European Sky
SESAR	Single European Sky ATM Research Programme
SMGCS	Surface Movement Guidance and Control System
SMR	Surface Movement Radar
SSR	Secondary Surveillance Radar
TIS-B	Traffic Information Service - Broadcast
TMA	Terminal Manoeuvring Area
UA	Unmanned Aircraft
UAC	Upper Area Control Centre
UAS	Unmanned Aircraft Systems

UAS	Unmanned Aerial Vehicles
UIR	Upper Flight Information Region
VDL	VHF (Very High Frequency) Data link
VFR	Visual Flight Rules
VHF	Very High Frequency
VOR	VHF Omnidirectional Radio Range
WAAS	Wide Area Augmentation System
WAM	Wide Area Multi-lateration
WG	Working Group
WP	Work Package
WRC	World Radio communication Conference
XPDR	Transponder

2 Current Technologies Enabling UAS Aerodrome Operations

2.1 Introduction

Great effort has been dedicated during previous INOUI work, in particular under document [D2.1- Report on Technology System Solutions], to identify a number of technologies which may be key potential candidates for the integration and safe operation of UAS in the future 2020 ATM environment. Technologies currently under development and those foreseen for the future were analysed and their viability discussed. In this section of the report, the focus is again on currently existing UAS technologies, but with the particularity that only those for the safe operation of UAS at aerodromes are considered. Operations outside the aerodrome are not considered here.

2.2 Aerodrome Services Technologies

The safe operation of UAS at aerodromes includes the adherence to operational procedures in conjunction with basic surveillance functions to prevent collisions, runway incursions and to ensure safe, expeditious and efficient movement on the ground (control function). The aerodrome services technologies described in the following sections were identified and considered during the INOUI 2nd Stakeholder Workshop [INOUI 2nd SW] as key technologies currently available.

The following areas and technologies were identified as key topics for the study:

In the surveillance area, at the surface operations level, most airports still rely on the basic SMGCS concept, although A-SMGCS is gaining acceptance especially in major airports in ECAC. The SMGCS concept, as defined by ICAO, consists of the provision of guidance to, and control or regulation of, all aircraft, ground vehicles and personnel on the movement area of an aerodrome.

Traffic surveillance on the airport surface is performed by the flight crews based primarily on the “see and be seen” principle to maintain safe separation. The controllers (mainly ground controllers) aid pilots in maintaining adequate separation through appropriate instructions and information using primarily visual cues to give ground guidance/clearances.

The guidance function is basically performed by air traffic controllers that give instructions to pilots to follow a cleared taxi route. In addition, at airports with more complex layouts, controllers can also use the taxiway lighting system and the stop bars to provide some kind of basic visual guidance to the aircraft. The pilots use these aids and airfield markings, signs and fixed lighting to navigate on the surface using traditional paper charts.

During the night or under low visibility conditions this might cause problems associated with the guidance function as the controller and the pilot may have difficulties to see. As a result, problems associated with the guidance function are even increased when night or low visibility operations are in place, and either the controller or the pilot has difficulties to see with control procedures being more restrictive, and capacity decreased.

2.3 ATCO Technologies

The technologies used by an Air Traffic controller (ATCO) are generally heterogeneous and differ significantly depending on the size of the aerodrome and the owner of the tower, including its facilities and technical equipment. At smaller regional aerodromes the owner could be the aerodrome operator who provides the equipment to a certified company responsible for air traffic control. An Air Navigation Service Provider (ANSP) could also be the owner of the tower which is usually the case at larger/ international airports.

In any case the technologies provided to ATCO utilise the CNS technologies available a) for information provision or b) to interact with the ATM system in a specified manner or c) to control systems necessary for aerodrome operations.

In the following the different possible technologies used by an ATCO are listed.
Note: The list provides an overview of the most important technologies but is not necessarily complete.

a) Information

- Air situation display: typically a radar display (primary and secondary radar) providing position and (as far as available) altitude information of aircraft in flight in the vicinity of an aerodrome.
- Ground radar: a primary radar displaying position of ground targets (aircraft, vehicles, buildings, obstacles, etc.). It is used basically for the detection of mobile targets and their movement, but some configurations additionally allow identification.
- Weather information: ATCOs need to be informed about all relevant weather data (METAR, SPECI, TAF, AIRMET, SIGMET). They include wind direction and speed, cloud base and type of clouds, temperature, dew point, QNH, etc.
- Aerodrome operation specifics: Runway in use, breaking coefficient, unavailability of taxiways and runways, etc.
- Flight data processing system: Display of flight plan information (flight strips on paper or electronically).
- AMAN: arrival manager, a tool which assists ATC to optimise the arrival sequence.
- DMAN: departure manager, which is used to optimise the departure sequence
- Display of CDM information: collaborative decision making, which integrates the information provided by the different actors on an aerodrome (ATC, airline operation centre, ground handling crew, etc.). CDM data could be coupled with AMAN and DMAN.

- Display for video cameras: cameras can be used to monitor areas on the aerodrome which are not directly visible from the tower.

b) Interaction

- Flight data processing system: flight plan information (flight strips on paper or electronically)
- Radio and telephony equipment: obviously used for communication, information or transmission of instructions
- Data link processing system: utilised to transmit start-up clearance and en-route clearance (clearance delivery) to the cockpit.

c) Control

- Lightening: to control the different lightening systems for runway and taxiway, etc.

3 Future Technologies Enabling UAS Aerodrome Operations

3.1 Introduction

During previous INOUI work, in particular under document [D2.1- Report on Technology System Solutions] a number of technologies were identified as potential candidates for the operation of UAS in the 2020 ATM environment. Technologies currently under development and those foreseen for the future were analysed and their importance discussed. This section now focuses on the future UAS technology considered key for the operation of UAS at aerodromes.

3.2 ATCO Technologies

Nowadays large international airports are often working at their capacity limit and thus create a serious bottleneck in servicing the demands of aviation. Small disturbance of airport operations can have a major impact on punctuality. Because of the tight turn-over scheduling of airlines and interdependencies to hubs, those disturbances have more than a local effect at the airport concerned. Other destinations and the en-route traffic can be affected as well. This is one of the reasons for (air navigation) service providers at big hub airports to look for computer-based systems supporting the controllers to improve the utilisation of the available resources. More runway capacity, i.e. increased runway utilization, has to be obtained from arrival and departure management tools optimising the arrival and departure sequences including taxi procedures, start-up, clearance-delivery and push back.

3.2.1 AMAN (Arrival Manager):

AMAN is a tool assisting Air Traffic Controllers in organising the optimum arrival sequences and thus is concerned with the efficient utilisation of runways for arrival flights. This tool computes and displays the optimal arrival sequence times of flights for landing on an aerodrome. It meters and sequences flights to a constraint point (for example e.g. IAF – Initial Approach Fix close to the final approach) for one or more runways. It can be used either by Approach controllers, Tower controllers and even ACC controllers.

Controllers managing the inbound traffic perform the following tasks:

- Build an arrival sequence.
- Assign an (absolute or relative) arrival time at the runway threshold (and other significant waypoints) to each aircraft in the sequence.
- Predict a trajectory for each aircraft which implements the assigned landing time.
- Transform the trajectory into appropriate guidance instructions which are transmitted to the pilot via voice or data link.

The above steps are performed manually at small airports. Arrival Manager tools which claim to support the controllers have to match with fulfilling these four tasks. At some larger airports throughout Europe and the US, automated arrival management systems have already been installed as a first step for runway-use optimisation and reduction of delays.

3.2.2 DMAN (Departure Manager)

DMAN is an ATM tool that determines the optimum departure sequence and departure times from an aerodrome (for multiple runways if appropriate) taking into account all applicable constraints due to the surrounding terminal airspace. In addition to providing sequencing at the runway a DMAN may also provide sequencing at other route fixes such as terminal area exit. Automated departure management systems are planning tools developed to improve the departure flows at airports and to increase its capacity. As a result the DMAN provides a planned departure flow with the goal to maintain an optimal throughput at the runway, reduce queuing at holding point and distribute the information to various stakeholders at the airport (i.e. the airline, ground handling and Air Traffic Control). DMAN systems are just becoming operational in Europe. But most tower controllers today still manage the departure sequences manually.

The main purpose of Departure Management will be to meter traffic through Aerodrome exit points. It will assist controllers in optimising the sequence of departures from one or more runways, and in achieving the maximum capacity with the least average delay, whilst preserving safety in aircraft operations.

3.2.3 AMAN/ DMAN Integration

For optimal usage of existing capacities at large airports arrival and departure management systems have been developed which support the air traffic controllers in managing in- and outbound traffic flows. Terminal Area Air Traffic Management handles both arriving and departing traffic. For many years, research on terminal area operations has focused primarily on the arrival flow; departures have only partially been taken into account. Consequently there are some AMAN systems operational, e.g. in Zurich (CALM, OSYSRIS), Paris (Maestro), Frankfurt (4D-Planer), but only one DMAN so far, i.e. in Zurich (darts). Meanwhile some DMAN functionalities might be integrated into a CDM (Collaborative Decision Making) process support tool, e.g. sequence planning.

However arrivals and departures are highly coupled processes, especially in the terminal airspace. They share the same airport resources and are highly interdependent. Therefore, the addition of automation-aids for departures in cooperation with arrival flow automation systems could make a profound contribution in enhancing the overall efficiency of airport operations.

Integration of AMAN and DMAN systems and the turnaround milestone data shall enable coordination of departure times to meet arrival constraints. Through an integrated planning of arrival and departure traffic the runway capacities shall be used to the maximum extent. The aim of coupling AMAN and DMAN is to provide all necessary, accurate and up to date information to all parties involved (i.e. ATC, airport operator, airlines) and thus to optimise the airport operation processes.

Benefits of coupling and integrating AMAN and DMAN are expected in stability of planning and scheduling, in improved communication between parties involved and in better use of runway capacities.

Planning stability: By integrating arrival and departure sequences the interdependencies of mixed mode runways are better considered. With an early and integrated planning of departure and arrival times, the planning of on- and off-block times becomes more reliable. In consequence the airline and airport operation processes can be carried out with higher efficiency.

Enhancement of communication: By allocation of coordinated target times at all relevant workplaces, the efficient communication of Centre, Approach, Tower and Apron controllers will be enhanced. This way all controllers are able to improve runway usage while avoiding overloads.

Optimised use of runway capacity Through an integrated planning with flexible, situation specific prioritisation of arrivals or departures on runways operated in mixed mode, the available runway capacity is used at an optimal level an thus the punctuality increases, especially in bottleneck situations.

3.2.4 SMAN (Surface Manager)

SMAN is an ATM surface movement planning tool that determines optimum start-up sequence, surface movement plans (such as taxi route plans with taxi times) involving the calculation and sequencing of movement events and improved resource usage (e.g. de-icing facilities).

Predicting the taxi times and routing of inbound and outbound traffic, the surface management tool can provide stable and reliable planning (target) times and is prerequisite for pre-departure sequencing and an optimised usage of the departure runways. Integration of the SMAN tool with the arrival and departure management tools (AMAN/ DMAN) and creating an optimised result is the future challenge to gain the full benefit of these tools. SMAN in collaboration with AMAN/DMAN will help to determine the optimal arrival and departure sequence. SMAN can also be a sub-function of A-SMGCS to identify the optimal movement plans determining the surface movements and optimising resources usage.

3.2.5 CDM (Collaborative Decision Making)

This is a concept of co-operative sharing and acting on relevant information provided by all partners involved (i.e. airline operation centre, ATC, airport). This has to be seen as an environment in which the consequences of decisions taken are visible to all partners and rather a process related to planning than a tool. CDM can work equally effective in all circumstances where ATM decisions need to be made.

Better decisions can be made taking all of the newly available information (e.g. landing time, departure time, turnaround time, taxi time, airport capacity, constraints) into account, comparing the data and generating advice to the human operators. Though CMD itself is not a tool for controllers, the outcomes of the CDM processes need to be displayed to them. Whether this is achieved through special displays or integrated into AMAN/ DMAN display needs to be defined locally.

CDM processes implemented in today's systems are often limited to information sharing only. In the future, a collaborative process will be a major enabler for performance based management of airspace and airports.

CDM is one of the cornerstones of the future SESAR operational concept. In the Pre-SWIM phase (2008-2010), the existing Airport and Aerodrome ATC sub-systems (AMAN, DMAN, and SMAN) providing the first generation of integrated airport operations controllers' tools are further developed to meet the Airport-CDM concept. Aerodrome ATC and Airport Demand and Capacity management sub-systems are introduced in support of strategic and pre-tactical airport operational planning. CDM will be embodied in the SWIM environment.

3.2.6 A-SMGCS:

Advanced Surface Movement Guidance and Control Systems (A-SMGCS) are expected to provide adequate safety and capacity levels at night or under low visibility conditions by making use of modern technologies, improved means of surveillance, enhanced procedures, clearly defined roles, etc. For ATC and apron control an A-SMGCS is one of the means to improve safety, capacity and environmental impact. A-SMGCS including conflict detection and warning systems provides enhanced information to controllers for better situational awareness and thus will increase not only safety but also surface movement capacity.

By providing the pilot with conflict free routing, together with target times, the system will considerably improve taxiway throughput and reduce taxiway delays and support situation awareness to prevent runway or taxiway incursions.

The difference of an A-SMGCS to conventional SMGCS is the ability to provide service over a much wider range of visibility conditions, traffic density and aerodrome layout complexity. Particularly where visibility is low, A-SMGCS promise to provide more precise guidance and control for all aircraft and vehicles on the movement areas and ensure spacing, where this would not be possible with conventional methods of visual surveillance or surface movement radar (SMR).

3.3 UAS Technologies

The objective of this paragraph is to describe the future types of technology which could be required by the UAS for a safe and efficient operation at aerodromes. By "future types of technology", it should be understood that technologies currently existing in the manned aviation world that could be used by UAS (such as ADS-B, etc.) are not mentioned here.

Before screening any existing or future technology, it is necessary to identify the functions required for each phase of operation. Aerodrome operation itself is very often a challenging task for the crews involved. This task occurs prior to take-off, after landing and for every movement on the ground, as for moving the aircraft to the maintenance stand.

There will be a distinction between active and passive movements, as towing an aircraft is also part of ground operations and may be a suitable means to overcome technology gaps between future technology and current system design at the time of writing. However, the precondition for certain ground operations in the following sections is a suitable undercarriage allowing the typical movements on the surface of an aerodrome.

Aerodrome operation comprises functions to control the aircraft itself, to navigate, the knowledge of rules, to avoid collisions with obstacles and other vehicles including other aircraft as well as to communicate with others. In other words, it comprises nearly every function as for an aircraft in the air but only on the ground.

The following sections will set the focus on the unmanned system and describe possible interfaces for interacting areas outside this system. As the unmanned system has to be seen as a combination of different subsystems, the tasks will be broken down into the UA and the control station (CS).

The adopted working principle is a top down approach with the missions pre-take-off and post-landing aerodrome operation as starting points and a subsequent look at the details such as necessary equipment and possible hurdles, barriers or challenges for the envisaged type of operation.

3.3.1 Aerodrome Operations

The aerodrome operations assessed in the following sections are restricted to movements on the surface of an aerodrome. Flying and traffic patterns are not in the scope of this section.

The term *"passive aerodrome operations"* relates to any kind of operation that is applied to the air vehicle, without involving any kind of positive action or anything other than passive cooperation by the air vehicle itself, e.g. pushing an aircraft, whereas the term *"active aerodrome operations"* relates to any kind of operation that is either reliant on the active cooperation or assistance of the air vehicle or must be performed by the air vehicle itself, such as communication with the tower.

Passive Aerodrome Operations

Tag	Task	Technological Enablers/Remarks
1	Pushing an aircraft out of service (power off)	Steering Handle, airframe that allows pushing, undercarriage allowing to steer, brakes off, situational awareness around the aircraft
2	Pulling an aircraft out of service (power off)	Towing truck, towing bar, undercarriage designed for pulling, brakes off, situational awareness around the aircraft
3	Pushing an aircraft in service (power on)	Manpower, Steering Handle, airframe that allows pushing, undercarriage allowing to steer, brakes off, situational awareness around the aircraft to become transmitted to GCS, on controlled aerodromes: ATC clearance
4	Pulling an aircraft in service (power on)	Towing truck, towing bar, undercarriage designed for pulling, brakes off situational awareness around the aircraft to become transmitted to GCS, on controlled aerodromes: ATC clearance

Table 1 – Passive Aerodrome Operations

Active aerodrome operations

The approach for identifying active aerodrome operational functions is by starting at top level to define the mission (level 1), then to identify the phases (level 2), the standard elements (level 3), followed by the standard procedures (level 4), identifying hurdles, challenges and risks (level 5) and finally with proposing work around (level 6).

The following Table 2 gives an example of this procedure.

Level	Task	Example
1	Identification of the mission	Operating an unmanned aircraft (UA) on the surface of an aerodrome.
2	Identification of the different phases of aerodrome operations	Taxiing, Take-off, landing, taxiing
3	Identification of standard elements in every phase	Controlling of speed, position, direction, controlling the UA, communication
4	Identification of - standard procedures for the element communication - standard action-reaction scenarios, - necessary equipment - information	 Radio communication (applying for clearances) Talk, listen, answer, act Radio, XPDR, altimeter, magnetic compass Position, technical status of the UA, Intentions
5	Identification of enabling technologies	Transfer of situational awareness from aircraft to control station Reliability and delay of data transmission Malfunction of sub-systems / components
6	Defining related workarounds/solutions/risk mitigating possibilities	Local GCS (redundancy), back up communication systems such as telephone, reduction of airport's capacity

Table 2 – Active Aerodrome Operations, Levels of Operational Functions

3.3.2 Phase identification

The following Table 3 identifies the different phases of aerodrome operations. Operations become out of scope of this assessment when leaving ground and before touching ground.

Level	Phases	Remarks
2	**Identification of the different phases of aerodrome operations**	
2.1	Pre-T/O-Taxiing	From parking position to holding point
2.2	Take-Off (T/O)	From holding point until leaving ground
2.3	Landing	From touching down until leaving the runway
2.4	Post-Landing Taxiing	From leaving the runway until parking position
2.5	Parking	When in parking position

Table 3 – Level 2 for aerodrome operations

3.3.3 Identification of standard elements and related procedures

Pre-Take–Off taxiing

The different phases which have been identified in the previous section are composed of standard elements. These standard elements are repeated every time a phase occurs. They consist of standard procedures. The following table lists the standard elements of phase 1, "Pre-Take–Off taxiing"

Phase	Standard elements	Standard procedures
2.1	**Pre-Take-off taxiing and associated standard elements**	
2.1.1	Identify parking position	Verify UA position on the aerodrome's chart
2.1.2	Request start up, Departure information, Taxi clearance	Selecting the applicable frequencies, perform radio communication with standard phrases, understand clearances
2.1.3	Taxi according to clearance to holding position(s)	Command the cleared taxi route from CS to UA. Ability to follow/verify the aircraft's path in the CS; ability to interact if situation requires. (maintaining situational awareness in the CS),

Table 4 – Levels 3 and 4 for phase 2.1

Take-Off

Phase	Standard elements	Standard procedures

Phase	Standard elements	Standard procedures
2.2	**Take-off and associated standard elements**	
2.2.1	Holding point runway “XY”	Ability to follow/verify aircraft's path in the CS, maintain situational awareness in the CS, ability to interact on power setting, brakes, steering
2.2.2	Request Departure instructions	Selecting the applicable frequencies, perform radio communication with standard phrases, understand clearances
2.2.3	Line up runway	Ability to line up on the runway, control power setting, brakes, steering, alignment to centre line. Perform take-off check, control and monitor settings for radio, flaps, power and pitch
2.2.4	Ground roll	Accelerate, keep centre line, compensate cross-wind, check V_1 & V_2 for last abort, control and verify settings for power, pitch, breaks, flaps steering and speed
2.2.5	Rotate	Control and verify settings for power 2.3.4, pitch, flaps, steering and speed compensate cross-wind, monitor angle of attack

Table 5 – Levels 3 and 4 for phase 2.2

Landing

Phase	Standard elements	Standard procedures
2.3	**Landing and associated standard elements**	
2.3.1	Touch down on runway “XY”	Keep centre line, control and verify settings for power, pitch, flaps, steering and speed, compensate

		cross-wind, monitor angle of attack and wheels on ground
2.3.2	Reduce speed	Engage (auto) brake, or reverse thrust. In case of command by Tower or necessity detected by pilot command go around
2.3.3	Leave runway at appropriate taxi-way	Ability to leave runway, at appropriate taxiway, need to command and control (power setting, breaks, steering, position), radio, and flaps

Table 6 – Levels 3 and 4 for phase 2.3

Post landing taxiing

Phase	Standard elements	Standard procedures
2.4	**Post-Landing- Taxiing and associated standard elements**	
2.4.1	Taxi according to clearance to holding position(s)	Ability to taxi according to clearance (power, breaks, steering, position), aerodrome chart, radio, known taxi procedures (right of way rules)
2.4.2	Follow the Marshal (“Follow-Me Car” FMC)	Ability to taxi according to clearance, (power, breaks, steering, position), aerodrome chart, radio, known taxi procedures, (right of way rules) keep the Distance to “FMC”
2.4.3	Parking position	Aerodrome Chart, GPS, Breaks
2.4.4	Switch anything off/external power	Access to master switches, remote control

Table 7 – Levels 3 and 4 for phase 2.4

3.3.4 Challenges, hurdles and risks

Phase	**UAS**	Level 5 Enabling Technology	Level 6 Mitigation
	Phase of Aerodrome Operation		

Phase	UAS	Level 5 Enabling Technology	Level 6 Mitigation
2.1	**Pre-T/O-Taxiing**		
2.1.1	Identify parking position	Visual, GNSS, APT.(A)	0 (3/4) (A)
2.1.2	Request start up, Departure information, Taxi clearance	VHF radio communications (A)	–
2.1.3	Taxi according to clearance to holding position(s)	visual guidance R/C through wide FOV camera (A/B*) VHF radio communications (A) Aircraft position GNSS (A)	0 (3/4) (A)
2.2	**Take-off**		
2.2.1	Holding point runway “XY”	as 2.1.3	as 2.1.3
2.2.2	Request Departure instructions	VHF communications (A)	–
2.2.3	Line up runway	as 2.1.3	as 2.1.3
2.2.4	Ground roll	automatic T/O capability (A)	R/C; implies data link (A)
2.2.5	Rotate	as 2.2.4	as 2.2.4
2.3	**Landing**		
2.3.1	Touch down on runway “XY”	automatic landing capability (A/B*)	R/C; implies data link (A/B*) external guidance (MW or laser) (A)
2.3.2	Reduce speed	Brakes (A)	–

Phase	UAS	Level 5 Enabling Technology	Level 6 Mitigation
2.3.3	Evacuate runway at cleared taxi-way	visual guidance remote control through wide FOV camera (A/B*) exit ID marker (B**) VHF radio communications (A) a/c position GNSS (A)	induction loop*** (B) RFID gates*** (B/C) Aircraft position tracking on aerodrome chart (A) visual reference by external observer (A) 0 (3) (A)
2.4	**Post-Landing Taxiing**		
2.4.1	Taxi according to clearance to holding position(s)	visual guidance remote control through wide FOV camera (A/B*) VHF radio communications (A) Aircraft position GNSS (A) exit id*** (B**)	induction loop*** (B) RFID gates*** (B/C) Aircraft position tracking on aerodrome chart (A) visual reference by external observer 0 (3/4) (A)
2.4.2	Follow the Marshal (“Follow-Me Car” FMC)	visual guidance R/C through wide FOV camera (A/B*) automatic tracking of FMC (e.g. automotive convoy management system) (B*)	0 (4) by FMC (A)
2.4.3	Parking position	as 2.1.1	as 2.1.1
2.4.4	Switch anything off/external power	auto shutdown (A/B)	manual shutdown (A)
2.5	**Parking**		
2.5.1	securing aircraft	ropes, chocks.(A)	hangar (A)

Phase	UAS	Level 5 Enabling Technology	Level 6 Mitigation

A – mature state of technology:
devices, technology or procedures already exist with no or minor adaptation or modification required, such as devices used in manned aircraft, i.e. VHF radio equipment, transponder etc.; implies that mitigation is not required

B – technology that already exists in a mature state but must be adapted to the aeronautical environment, such as RFID gates or induction loops

C – technological solution based on first principles, e.g. a conceptual design, that needs validation and development

* depends upon visibility and weather, video link capabilities

** depends essentially upon visibility and weather, video link capabilities

***APT : Aerodrome Position Transponder, see 3.3.5

Table 8 – UA Level 5 for all phases

It is evident that most functions can easily be provided by a wide field-of-view (WFOV) ("panoramic") camera system in conjunction with an appropriate, i.e. in terms of bandwidth, video downlink (resolution, contrast, latency). The camera system may consist of one camera with a WFOV lens or several cameras with image fusion.

Because such a video link may not be necessary for IFR flight, it should be considered to provide such a video link locally at the aerodrome rather than as an integral part of the UAS.

Further investigations and trials should be conducted to assess the requirements for the aforementioned technologies, in particular for the capabilities of the WFOV camera system and the accuracy required for the determination of the aircraft's position. However, any active involvement from the CS to the unmanned aircraft relies on the data link. But due to the nature of ground operations, where the unmanned aircraft moves on the ground, parallel activities of other moving objects on the ground may lead to unintended interruptions of the data link. The following effects will have to be considered:

- Masking due to other objects passing through a point to point connection,
- Shadowing in case of moving behind hangars, buildings or other obstacles
- Reflections due to the close distance to the ground

Taking into account these effects, it may be necessary to conduct on-site trials to elaborate the best possible antenna position to guarantee smooth operations.

For any kind of technology that provides a "robot" or "traffic light" function such as RFID gates or induction loops, a market survey should be initiated with regard to aeronautical compatibility. However, the benefit for aeronautical transportation in general to amend new technologies for traditional ground operations may be seen as enhancing safety on the one hand while, in parallel, environmental benefits may additionally result. Trials of steering the push-back to tow the aircraft to its holding point with engines off have shown a potential of drastic reductions in pollution as well as saving a tremendous amount of fuel.

If such an operational approach is used for the ground movements of unmanned aircraft, data link interruptions may become prevented as well as safe operation being enhanced. The adaptation to unmanned aircraft should be possible by changing roles such as switching power on, starting the engine(s) and reporting operational readiness from the push – back to the CS.

Command and Control link assurance

The command and control link between the UA and the related antenna is a necessary element for active aerodrome operation that needs special attention by the planners of aerodrome operations with UA. The loss of the C2 link may lead to critical situations, especially in the Terminal Manoeuvring Area (TMA) or for ground operations. (See also INOUI D2.2 for requirements to ensure safe operation)

In this example, the landscape surrounding the aerodrome has a raised pattern (mountains, hills, etc.). Referring to INOUI D4.1, where data links have been explained in depth, the following picture shows how certain geographical conditions may endanger the C2 line of sight- link, if the antenna is located such that the UA is shadowed by a hill.

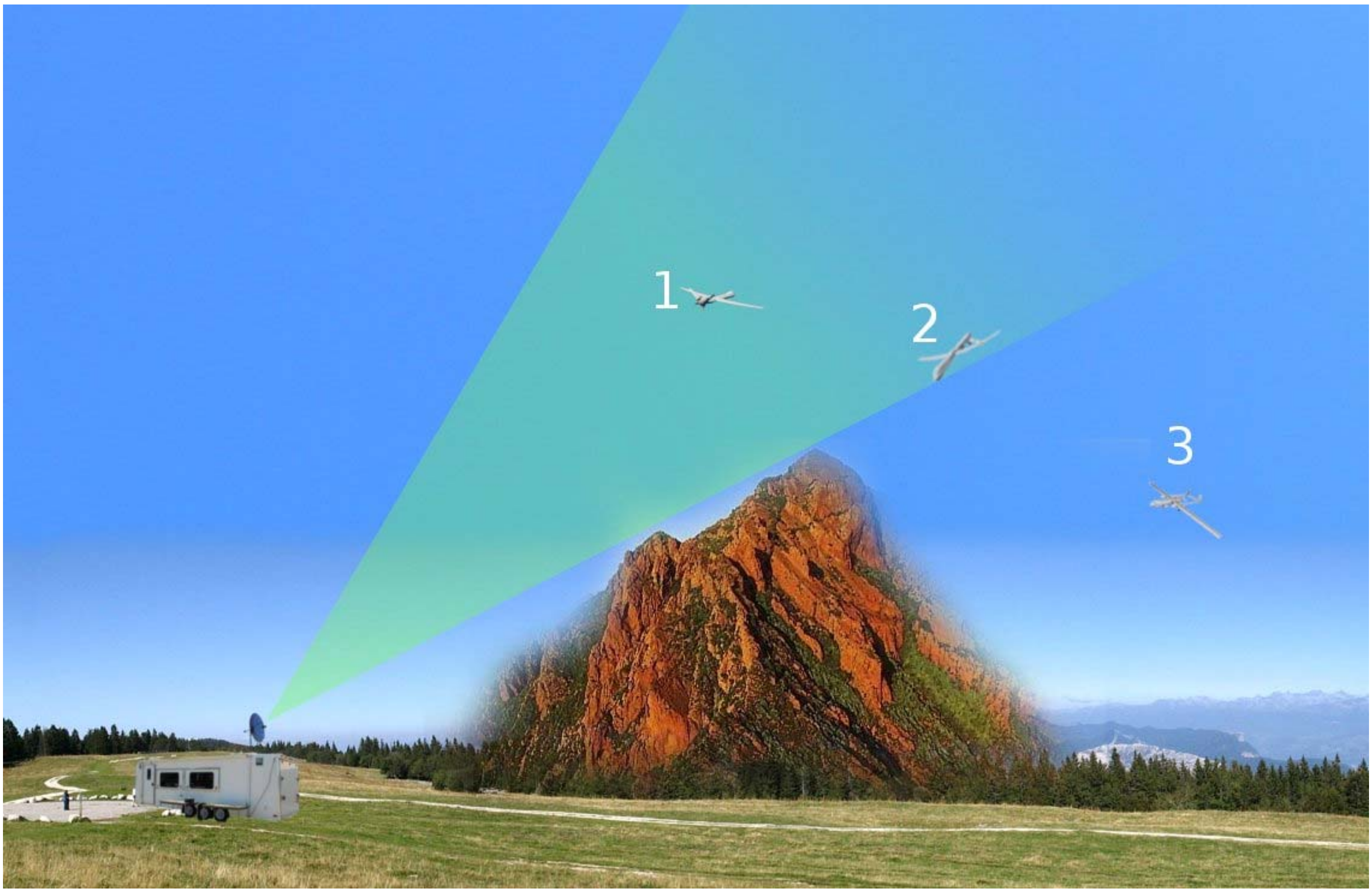

Figure 3 - C2 link loss illustration - Case 1 (Source: INOUI)

Figure 3 shows 3 possible situations in case of flying in an area with raised pattern landscape:

- UA #1 is in the C2 beam (RLOS) as in a nominal situation. The C2 link is available.
- UA #2 is at the edge of the C2 beam, continuing the flight path may lead to the situation that the UA will be in the situation #3.
- UA #3 is out of the C2 link beam. The pilot cannot control the UA any more. This situation has to be avoided by defining approach procedures taking into account the ICAO rules, mentioning that the pilot should keep full authority on his aircraft at any time.

INOUI D 2.2 gives further information about requirements to ensure smooth and safe operation while INOUI D1.3 describes proven procedures to either prevent this situation or to deal with it. However, as long as no automatic functions of the system may assure safe operation even under marginal conditions, the warning philosophy of the system should enable the UA pilot to act correctly. Further information is given in section 3.3.5 of this document.

Engine failure during aerodrome operation

Another situation that can threaten the safety of the UA operation at aerodromes is an engine failure during the approach or while taking-off, as indicated in "Table 5, Phase 2.2.4". In the case of a single-engine UA, examples how to deal with it may be seen in operational procedures for aircraft being powered with Certification Specification 22 by EASA certified aeronautical engines. As these engines only have one ignition circuit, every flight manual indicates, that due to safety reasons, flights should be planned in a way that an emergency landing is possible at any time.

For aerodrome operations, there are two scenarios to be analysed:

a) Traffic pattern and approach

Traffic pattern and approach should be defined such that a landing is possible even with engine – off; i.o.w. while gliding (energy supply for the airborne data link components via back – up batteries).

b) Take – off and departure

As the take-off phase is the most critical phase of any flight, regardless of whether manned or unmanned, it requires perfect situational awareness.

Depending on the system design, runway length and safety areas in the runway direction and around an aerodrome should become a selection criteria for the envisaged operation in order to allow either a safety landing at the aerodrome, while being in the departure phase, to allow a return to base while gliding (energy supply for the airborne data link components via backup batteries). System requirements are to be found in INOUI D2.2.

Both scenarios require a perfect and comprehensive situational awareness as well as a good knowledge of the aircraft performances and emergency procedures. This leads to certification as well as to training and licensing of crew members. Moreover, the provision of information to the pilot of the UA depends upon an adequate human-machine interface. Such an HMI will be part of the control station and is illustrated in the following section 3.4.5.

3.3.5 Control Station

Technologies enabling safe operation of UAS at aerodromes are closely linked to that described in the previous section, especially with regard to C^2 link stability. However, apart from pure technology issues, the Human Machine Interface (HMI) also requires attention when reflecting upon operational concepts.

According to the United States Government Accountability Office report, published in May 2008[1], 17% of the accidents which occurred during the 4.5 year period covering the Enduring Freedom and Iraqi Freedom operations were due to human factors, i.e. issues associated with how humans interact with machines.

Their analysis shows that UAS developers have not yet fully incorporated human factors engineering in their products. FAA officials noted that UAS today are at a similar stage as personal computers in their early years, i.e. designed by engineers for engineers and not for conventional users.

Current designs of control stations vary greatly, from the conventional method of piloting an aircraft using stick and pedals (Predator) to the use of a keyboard and mouse to control the aircraft (Global Hawk or the German KZO). Aside from the general principles, which are discussed frequently for the control station layout, ground operations also need special attention. Even if tremendous efforts are carried out to generate "sense and avoid" capabilities or equipment, these capabilities are mainly linked to airborne operations. Here we have fast moving objects that allow radar based solutions within a relative low density airspace compared to the situation on the ground where warning signs, runway lights, towing trucks or baggage containers will have to be detected together with parking or taxiing aircraft.

The report also states that a remote pilot's lack of situational awareness serves as another human factor related challenge for the safe operation of UAS. As situational awareness is one criterion for any pilot to come to a correct decision, the design of a control station will have to take into account the fact that different situations will lead to actions specific to that situation. The FAA statement that engineers have designed control stations for engineers shows that HMI analysis covering the complete flight from starting the engines to securing the aircraft on the apron afterwards has not been conducted prior to the design of the crew's working environment.

The aforementioned keyboard and mouse solution is a perfect approach for UA systems operating with pre-planned mission elements where, in combination with unique flight envelopes or procedural enablers for their mission profiles, immediate interactions of the UAS pilot are restricted to a minimum.

Ground operation is different from flying and manoeuvres to avoid collisions are not possible in three dimensions. Furthermore, due to the relatively low speeds involved, the distances between obstacles and moving objects are quite short. For this reason, it makes no sense, to enter a command such as "Engage brakes" with the keyboard, and

[1] Unmanned aircraft systems – Federal actions needed to ensure safety and expand their potential uses within the National Airspace System – GAO report to congressional Requesters – May 2008

finally to confirm with the mouse on a "pop – up menu" the question: "Are you really sure to engage the brakes?" on the button "YES".

Activities that need immediate reaction of the UAS pilot need to be assessed, listed and answered with the appropriate means to carry out these actions.

As no standard currently exists, manufacturers and designers have created solutions that are based upon their own experience or field experience reports from their customers.

Besides the traditional pedal and stick solution, the use of a "joystick" for ground movements allowing the control of speed, direction, camera(s), brakes and the main power switch have been found very useful for active and safe ground movements.

Manned aircraft cockpit design and pilot's selection, education, training and qualifications are now the result of a century-long process. As UAS are currently novel systems; it would be unreasonable to consider that the best UAS pilot interface/CS design will be achieved without substantial R&D effort.

Known successful efforts to elaborate HMI oriented concepts for new generation control stations in Europe have been published under the umbrella of the EDA project "UAS Insertion into General Air Traffic" of the Air4All consortium by the company Alenia Aeronautica as Task 3A. The corresponding comprehensive report shows the broad range of applications from ruggedised laptops via typical "engineering solutions" to a combination of traditional means of command taken from manned aircraft together with computer interfaces.

The top level task of the control station is to provide a front-end for the functions required by the UA for active aerodrome operations as outlined in section 3.3.1

As per definition, the control station is the pilot's HMI and thus the front-end of the UA. As such, it contains all front ends of the installed devices in so far as they need to be operated or monitored. For instance, the Control Station will have a suitable front-end for operating the onboard VHF radio (on/off/standby, dial frequency etc).

In principle, every equipment above required for operation could simply be replicated or installed in the control station using the same principles as for the arrangement in manned aircraft. Any deviation from such principles must be validated so that they do not impact and reduce safety.

The key enablers for safe aerodrome operations are, as outlined above,:

a) VHF radio communication
b) visual perception, implemented by a WFOV camera system and a possible aerodrome local video downlink
c) precise self localisation, such as per DGPS or EGNOS
d) some kind of aerodrome ground traffic control (other than visual or communications), implemented by induction loops or RFID transponders, which

shall be referred to here as *Aerodrome Position Transponder* (APT) which must have front-ends in the Control Station.

Phase	**CS**	Level 5 Enabling Technologies	Level 6 Mitigation
	Phase of Aerodrome Operation		
2.1	**Pre-T/O-Taxiing**		
2.1.1	Identify parking position	camera display, navigation display (A) APT display (B)	visual reference by external observer
2.1.2	Request start up, Departure information, Taxi clearance	VHF communications or (A) voice transmission through VHF communications of UAS (A)	telephone line (A) side-by-side op with controller
2.1.3	Taxi according to clearance to holding position(s)	remote control manipulators (A) wide FOV display (A) VHF communications or (A) voice transmission through VHF communications of UAS (A) navigation display (A)	0 (3/4)
2.2	**Take-off**		
2.2.1	Holding point runway "XY"	as 2.1.3	as 2.1.3
2.2.2	Request Departure instructions	as 2.1.2	as 2.1.2
2.2.3	Line up runway	as 2.1.3	as 2.1.3
2.2.4	Ground roll	flight displays, push buttons (A)	Remote control manipulators (A)
2.2.5	Rotate	as 2.2.4	as 2.2.4

Phase	CS	Level 5 Enabling Technologies	Level 6 Mitigation
2.3	**Landing**		
2.3.1	Touch down on runway “XY”	as 2.2.4	as 2.2.4
2.3.2	Reduce speed	(A)	–
2.3.3	Evacuate runway at cleared taxi-way	Remote control manipulators (A) wide FOV display (A) VHF communications or (A) voice transmission through VHF communications of UAS (A) navigation display (A)	APT display (B/C) visual reference by external observer 0 (3)
2.4	**Post-Landing Taxiing**		
2.4.1	Taxi according to clearance to holding position(s)	Remote control manipulators (A) wide FOV display (A) VHF radio communications (A) navigation display (A)	APT display (B/C) visual reference by external observer 0 (3/4)
2.4.2	Follow the Marshal (“Follow-Me Car” FMC)	Remote control manipulators (A) wide FOV display (A) automatic tracking of FMC controls and display (B*)	0 (4) by FMC
2.4.3	Parking position	as 2.1.1	as 2.1.1
2.4.4	Switch anything off/external power	auto shutdown push buttons (A)	manual shut down
2.5	**Parking**		
2.5.1	securing a/c	n/a	n/a

Phase	CS	Level 5 Enabling Technologies	Level 6 Mitigation

A – mature state of technology:
devices, technology or procedures already exist with no or minor adaption or modification required, such as devices used in manned aircraft, e.g. VHF radio equipment, transponder etc.; implies that mitigation is not required

B – technology that already exists in a mature state, but must be adapted to the aeronautical environment, such as RFID gates or induction loops

C – technological solution based on first principles, e.g. a conceptual design, that needs validation and development

* depends on visibility and weather, video link capabilities

** depends essentially on visibility and weather, video link capabilities

***APT : Aerodrome Position Transponder

Table 9 – CS Level 5 for all phases

Unfortunately there is very little equipment in manned aviation dedicated to the functions allocated to aerodrome operations When performed by a human pilot, most of those functions are based on visual perception. In addition to the eyes of the pilot, he/she also benefits from all the other human senses. It is possible to hear a scratching brake disk, to feel the crushes while taxiing too fast over the airports surfaces. The combination of sensing and the personal experience about what may be the reason for the sensed signals in the moment contributes to acquiring situational awareness.

While sitting in a control station, the UAS Pilot is decoupled from direct sensing. As also described in previous sections, the warning philosophy and the health monitoring of the UA requires the highest attention of man-machine interface designers. The examples of engine failure just after take-off and data link signal strength monitoring may give an impression of the need for either research activities as well as the need for standardisation in the near future, covering information, communication and interpretation. For this reason, it has to be considered that too much information, provided only to the eyes through displays, may overload the capabilities of a human being to understand and assimilate the quantity of information (overload of the visual channel).

In order to allow safe operation, the use of senses other than the eyes should become a common feature of control stations. Caution or warning messages may also be combined with special sounds, to draw the UAS Pilot's attention to a specific message. As previously described in Table 8, 2.4.2, a converted convoy management system, currently used in the automotive industry, may be also a solution to safely follow a “Follow–me” car, and could generate warning signals if a safety threshold is approached. In addition, automatic functions such as “Auto-Brake“ may be initiated in the case of approaching an object too fast or too close. These functions are suitable features to decrease the workload of the UA pilot

4 Technology Gap Analysis

4.1 Introduction

INOUI D6.1 *"New Aerodrome Concepts for UAS"* proposed new concepts for the integration of UAS at aerodromes. The concept, complemented by the safety analyses performed within WP5.4, has shown that UAS should behave as much as possible as manned aircraft for a safe integration of UAS at aerodromes. Although it is clear that procedures for the operation of UAS are needed to operate them at aerodromes, new technologies are also necessary. The current and foreseen technologies, enabling the integration of UAS at aerodromes have been identified in previous sections in this document and have been arranged in three main groups:

- Aerodrome services technologies
  - Communications
  - Navigation
  - Surveillance
- ATCO technologies
- UAS technologies
  - Unmanned Aircraft
  - Control Station

These three main groups have also been addressed from current and future perspectives.

As one of the main objectives of INOUI WP6 is to integrate UAS at aerodromes in the future SESAR environment, technologies identified by SESAR have been addressed. Moreover as has been stated in SESAR D3:

"Specific technologies needed for UAS to ensure a transparent operation similar to a manned aircraft (e.g. dedicated high integrity UA ↔ pilot command and control data links) fall outside SESAR. It is however conceivable that some technologies that will be developed in the coming years by and for the UAS community will find their way to manned aircraft as well as we know of the requirements of advanced business aviation where sense and avoid technologies are sought for in the not too far future."

It can also be derived from this statement that the use of manned aviation technologies by UAS and vice versa is an important aspect that needs to be considered when developing concepts for integrating UAS at aerodromes.

The objective of this section is to match the technologies identified in previous sections of this document with the operational concept developed by INOUI in D6.1 to look for technological gaps or technological needs that are not being, nor foreseen to be, addressed by the UAS community in order to achieve the integration of UAS at aerodromes.

4.2 Operational Concept and Technology Linkage

The objective of this section is to summarise and link the operational concept developed in INOUI D6.1 and the technologies identified in previous sections of this document to provide the reader with a view on the concept and the technologies allowing the operation of UAS at aerodromes and to support the identification of gaps. To obtain a full picture of the proposed concept, please refer to INOUI D6.1 "New Aerodrome Concepts for UAS" to obtain a full picture of the proposed concept.

A UAS concept of operations at aerodromes should be primarily based upon the procedures that a UAS shall perform. It shall comply with the procedures that the Air Traffic Control (Tower and ground control) apply, including any clearance given to the UAS, and should reflect the procedures that the UA crew and ground personnel (maintenance, ground support or ground handling such as air cargo handling, refuelling, hydraulic mules or de-icing) shall carry out in regarding UA movements and activities within the aerodrome environment.

The concept has been developed focusing on these four elements:

- Aerodrome Services and Air Traffic Control
- UAS, decomposed into its standard elements as proposed by EASA in its draft "EASA policy on type-certification of Unmanned Aircraft System (UAS)" in §4 UAS definition, "A UAS *comprises individual system elements consisting of an "unmanned aircraft", the "control station" and any other system elements necessary to enable flight, i.e. "communication link" and "launch and recovery elements". For the purposes of this policy, a UAS consists of a single unmanned aircraft and single control station*".
- UAS crew, and
- Ground personnel, decomposed into maintenance personnel and ground handling personnel.

4.2.1 Aerodrome Services and Air Traffic Control

From the aerodrome services point of view, in the SESAR environment, it is important that ATCOs have the necessary means (technology and procedures) for carrying out their tasks. These include communication, navigation and surveillance activities. Several technologies are and will be used in order to maintain an orderly and safe traffic flow within the aerodrome, e.g. controller-pilot data link communications (CPDLC) and advanced surface movement ground control system (A-SMGCS), as well as several ATCO support tools such as AMAN, DMAN, and SMAN.

This set of technological means is defined by SESAR as technologies enabling ATC services at aerodromes in the SESAR environment. Thus it is assumed that UAS operating at aerodromes will be compliant with these means, in order to assure the transparency of UAS to ATC (as also stated e.g. by the EUROCONTROL/JAA UAV Task Force).

The main Aerodrome Services technological and functional changes that will take place in the SESAR context are shown in Figure 4. Considering such changes, the UA can be tracked and its position displayed to ATCO at every moment during the aerodrome operation.

As stated in Figure 4 below, the surface movement planning will "provide the most appropriate taxi plan for each departing/arriving aircraft (and for extension to UAS as aerodrome legitimate user [2nd INOUI stakeholder Workshop result]) taking into account operational needs of the aircraft operator, accurate estimate data and current operational aerodrome resources conditions".

Moreover, the taxi plans will initially be free of conflicts. However, and considering that the most incidents and accidents in aviation occur on ground, it is very likely to consider (and SESAR also recognizes it) that the probability of an accident occurring on ground will still exist. For this purpose SESAR envisages that ATCO will be assisted by ground traffic information and conflict infringement detection tools. The first one will provide updated information of the traffic situation in the aerodrome movement area, giving the ATCO a clear view of any aircraft's position at every moment and the latter will provide detection and alerting of potentially dangerous situations in the aerodrome movement area.

In case any dangerous situation is presented to the ATCO, he/she has to inform the UA pilot of the situation allowing him/her to react and perform the avoidance manoeuvre. Therefore it is crucial to have good communications in order to allow ATCO to transmit clear, concise and accurate information to the UA pilot.

The fact that data link technologies and frequency spectrum are expected to be available in 2020+, will offer a range of communication possibilities for transmitting long clearances like departure route containing many detailed information, as may be the case with the Controller Pilot Data Link Communication (CPDLC).

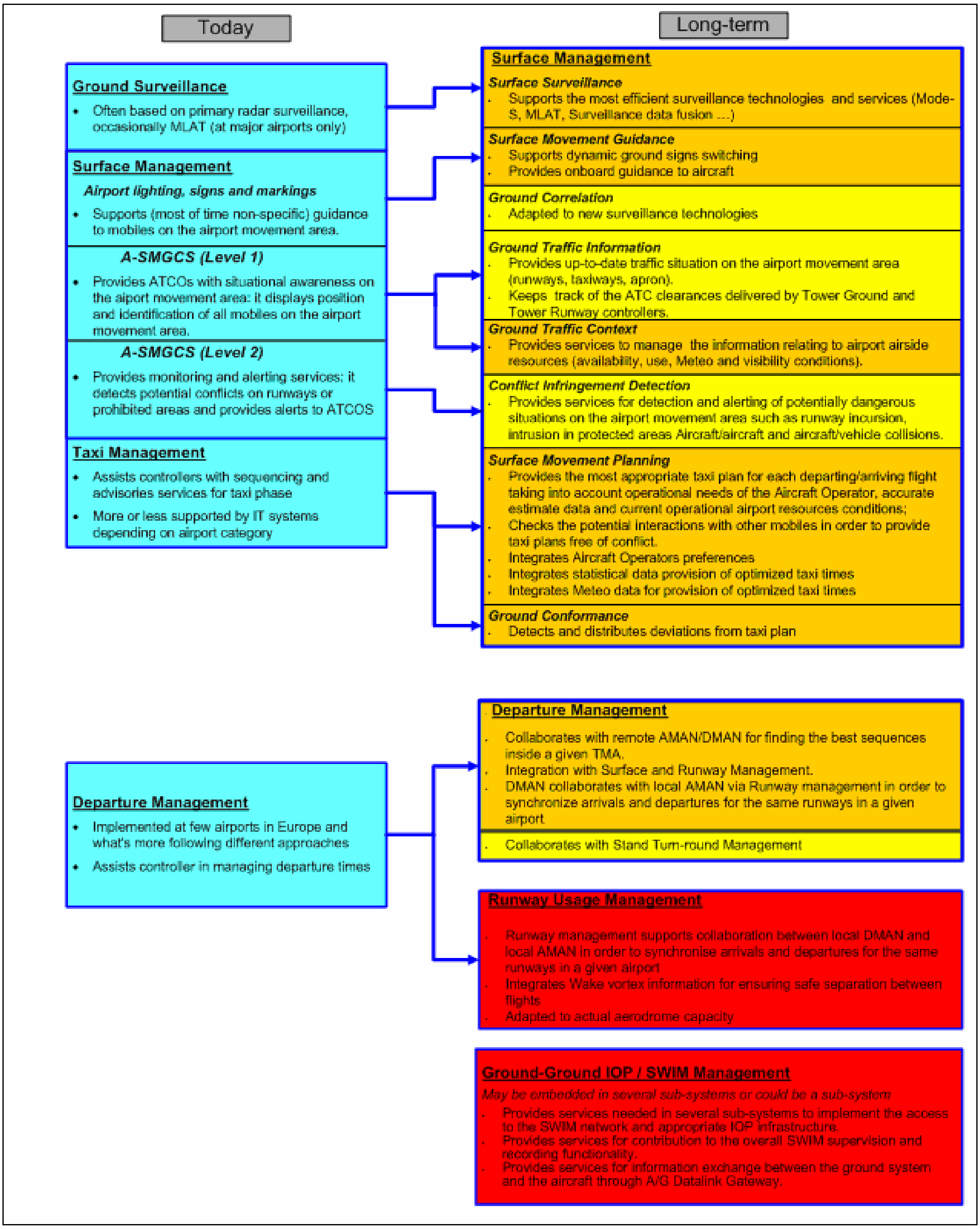

Figure 4 – Aerodrome ATC main functional changes (Source: ATLANTIDA project)

When addressing the specific aerodrome services technologies, for navigation, communication and surveillance which will be used in the future SESAR aerodrome environment, the main reference is SESAR D3, the ATM Target Concept. In this document, the SESAR Consortium established a mapping of communication, navigation and surveillance needs versus technologies. This mapping is summarised below with regard to aerodrome technologies.

In the field of communications, SESAR identified the need of developing mobile communications in the area of air-ground (ATS and AOC data). For this purpose the technology proposed by SESAR will be a new airport data-link to support surface communication using a derivation of IEEE 802.16.

In the field of Navigation SESAR explicitly mentions that:

"*Whilst ILS is the core landing technology, the trend will be to move to GNSS based landing in order to improve airport accessibility, either in Cat I conditions (ILS and GNSS as backup/complementary systems) or Cat II/III conditions (GBAS Cat II/III with ILS/MLS backup).*

As GNSS landing is progressively introduced, ILS will revert to a backup system to support the risk of GNSS outage. CAT I performance will be widely provided as there may not be a need for an ILS backup at locations where GNSS CAT I or near CAT is an improvement to previous non precision approaches.

Finally, aircraft will increasingly rely on GNSS to fly steep, curved and segmented approaches in the terminal area, to improve capacity and reduce environmental impact."

Moreover the introduction of moving maps displays in the cockpit will provide the own aircraft position on the aerodrome surface and position of cooperative traffic with GNSS resolution. These systems will not only increase the situational awareness of the pilot in the cockpit but also the situational awareness of the UA pilot.

In the field of surveillance, SESAR identified the following needs with regard to aerodrome operations:

a. **ATC Surveillance means for approach and landing**
b. **ATC Surveillance means for Airport Surface**
c. **A-SMGCS**

In view of these needs SESAR foresees the use of the following technologies split into independent and non cooperative, independent and cooperative and dependent and cooperative

a. **ATC Surveillance means for approach and landing**

- Independent and non-cooperative: use of PSR and multi-static PSR
- Independent and cooperative: use of SSR and WAM

- Dependent and cooperative: use of ADS-B

b. ATC Surveillance means for Airport Surface:

- Independent and non-cooperative: use of SMR and multi-static PSR
- Independent and cooperative: use of airport multi-lateration
- Dependent and cooperative: use of ADS-B

c. A-SMGCS

- Independent and non-cooperative: use of SMR and multi-static PSR
- Independent and cooperative: use of airport multi-lateration
- Dependent and cooperative: use of ADS-B

UAS operating at aerodromes in the SESAR context will need to comply with these technologies already identified by SESAR.

4.3 Gap Identification

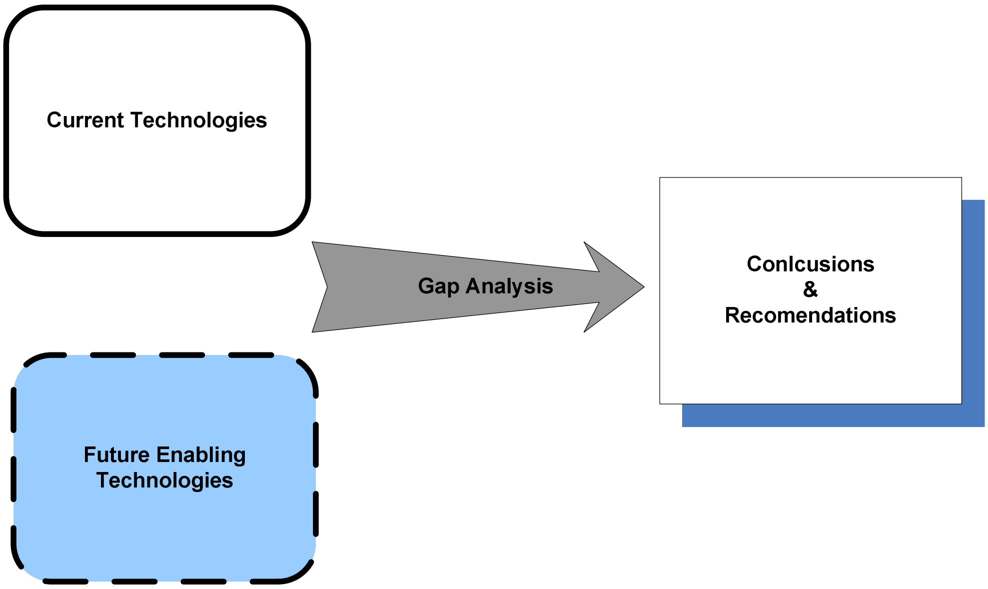

Figure 5 – D6.2 Methodology (Source: INOUI)

From the current and future technology identification made in sections 3 and 4 and the linking of these technologies with the concept of operations made in section 4.2, the technological gaps jeopardising the integration of UAS at aerodromes can be identified. It is important to mention that results are also fed with the results of Session II "Technologies to enable UAS operations at aerodromes" which took place during the second INOUI Stakeholder Workshop.

4.3.1 Airport Services and ATCO Technologies Gaps

No gaps have been identified from the Airport Services (Communication, Navigation and Surveillance) and Air Traffic Controller technologies. The reason for this is that UAS operation at aerodromes, as they have been described within INOUI, will be performed in the SESAR context. This means that the technologies to be used in the SESAR context have been already identified by SESAR and will be further developed within the SESAR programme. It is expected that these technologies will be ready for implementation in the 2020+ framework and also be implemented for UAS operations.

4.3.2 UAS Technologies

As mentioned before, SESAR has already identified technologies that will support aircraft operations in the 2020+ framework. However these technologies have been conceived with the idea of manned aviation in mind.

On the other hand, there are technologies which are outside those specifically identified by SESAR but which are being increasingly used in manned aviation. These technologies will enable the integration of UAS at aerodromes.

These technologies identified during the 2nd INOUI Stakeholder workshop, e.g. Airport Moving Maps or Airport Surface Detection Equipment (ASDE-X), will allow pilots to have a better situational awareness of the aircraft surroundings and to increase their surveillance capabilities.

	Flight Phase			
	Arrival	**Taxi**	**Handling**	**Departure**
Current Enabling Technologies	ILS GPS ADS-B Augmentation Systems by differential correction of the GPS signal Surface Movement Radar Microwave Landing Systems TIS-B	GPS ADS-B Moving Maps (EFB) Augmentation Systems by differential correction of the GPS signal Surface Movement Radar TIS-B	Conventional Push Back TIS-B	ILS GPS ADS-B Augmentation Systems by differential correction of the GPS signal Surface Movement Radar TIS-B

	Flight Phase			
	Arrival	**Taxi**	**Handling**	**Departure**
	JPALS			
Evolving Technologies	Information Sharing (SWIM) Aero Swim (Communications) Smaller on board sensors and technology CPDLC	Information Sharing (SWIM) Enhanced EO and visual cues ASDE-X	Information Sharing (SWIM) Enhanced EO and visual Advanced Docking Systems ASDE-X Smaller on board sensors and technology	Information Sharing (SWIM) Aero Swim (Communications) Smaller on board sensors and technology CPDLC
Obsolete Technology	ILS will move towards differential GPS and multi lateration	Conventional airport signs and markings		

Table 10 – Enabling Technologies for UAS operations at Aerodromes

5 Technology Proposal for UAS Integration in the SESAR Aerodrome Context

As has been shown previously, the main gap jeopardizing the integration of UAS at aerodromes, from a technological point of view, stems from the fact that technologies that will enable the operation of aircraft in the SESAR framework are not focused on UAS.

UAS technology developers and manufacturers should not primarily focus on civil manned aviation but also on military aviation as there are important key technology drivers enabling the integration of UAS at aerodromes in a civil context.

The technologies listed below can be understood as either potential technologies to be directly adapted to UAS or as potential functionalities to be implemented, with different technologies as those used in manned aviation, for UAS.

5.1 List of Technologies

5.1.1 Advanced Visual Docking Guidance System (A-VDGS)

There may be a need for UAS advanced Visual Docking systems, supporting the pilot in certain visual conditions to guide the UA on ground to its parking position. This system may also be a requirement whenever the pilot is remotely controlling the UA on ground from a different location to the aerodrome. From a technological point of view, this system will be based on current technology – nowadays used at major airports for manned aviation. The challenge remains in a data link service powerful enough to provide the data between the pilot and ground vehicle.

Advanced Visual Docking Guidance Systems (A-VDGS) feature electronic displays which perform the functions of an AGNIS (Azimuth Guidance for Nose-In Stand)/PAPA (Parallax Aircraft Parking Aid) installation, although with much greater accuracy. They may also provide collision avoidance from static objects.

A-VDGS systems usually have emergency stop buttons located both on the stand and in the jet way/gate area, which causes the stop indication to appear immediately.

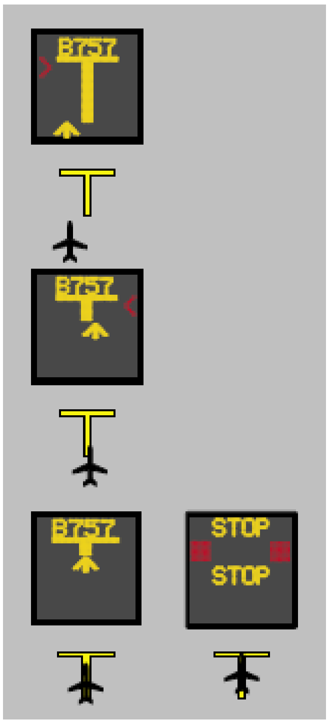

Figure 6 - Advanced Visual Docking Guidance System (Source:Wikipedial)

5.1.2 Airport Surface Detection Equipment (ASDE-X)

ASDE-X is a traffic management system for the airport surface that provides seamless coverage and aircraft identification to air traffic controllers. The system uses a combination of surface movement radar and transponder multilateration sensors to display aircraft position labelled with flight call-signs on an ATC tower display. The integration of these sensors provides data with an accuracy, update rate and reliability suitable for improving airport safety in all weather conditions. Further, the system is architected to support Automatic Dependent Surveillance - Broadcast (ADS-B).

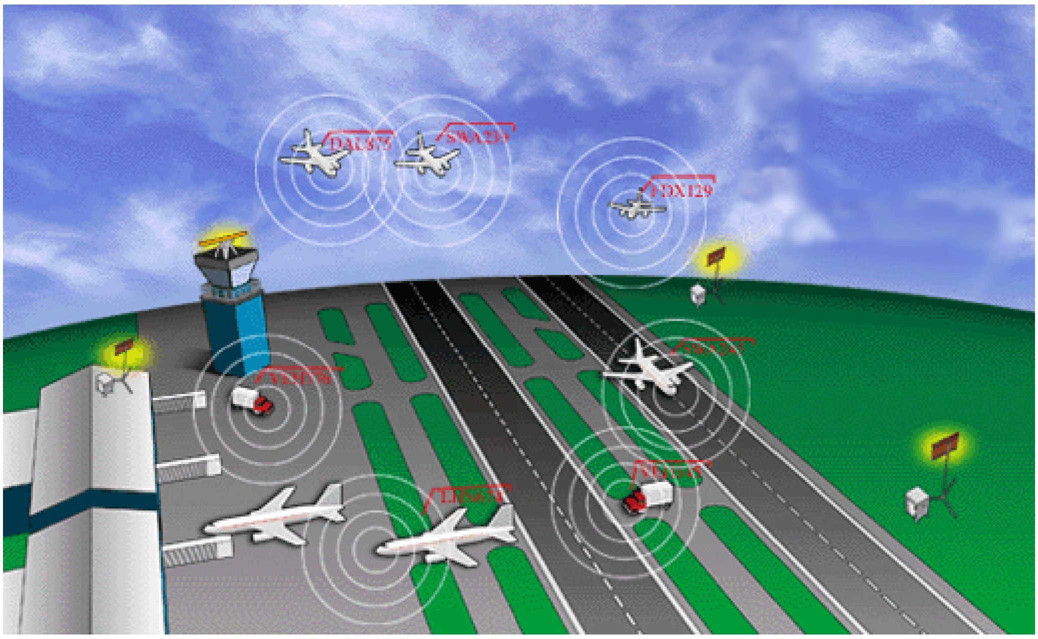

Figure 7 – ASDE-X (Source: Sensis)

5.1.3 Airport Moving Maps

The airport moving maps consist of a pilot display that provides a constantly changing view of an airport's runways, taxiways and structures to help pilots identify and anticipate the airplane's location on the surface. The GPS technology makes possible the representation of the own aircraft's current position on the airport surface and displayed on the moving map.

5.1.4 Enhanced Synthetic Visual Environment

Enhanced/Synthetic Vision is a term used to describe a group of advanced technology systems that will present or augment out-the-window information. Longer term designs include complete replacement of the out-the-window scene with a combination of electro-optical and/or sensor imagery and database information. In these systems, the pilot would control the aircraft based on a representation of the world displayed in the cockpit, and may not see the actual out the-window visual scene. Such systems present visual information that is needed but would not otherwise be visible (e.g. increased runway visibility in poor weather). With Enhanced or Synthetic Vision Systems, the pilot no longer views the world directly; but views a representation through sensors and/or computerised databases.

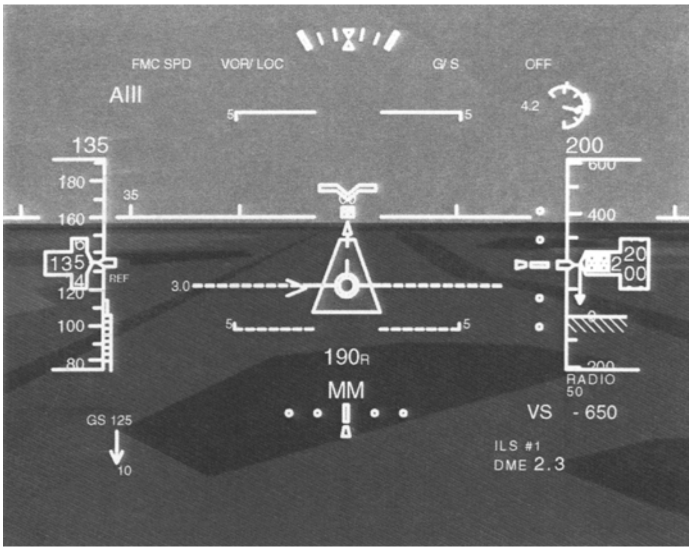

Figure 8 – Possible layout for an enhanced synthetic visual environment

5.1.5 Joint Precision Approach and Landing System (JPALS)

The Joint Precision Approach and Landing System (JPALS) is a military, all-weather landing system based on real-time differential correction of the GPS signal, augmented with a local area correction message and transmitted to the user via secure means. The onboard receiver compares the current GPS-derived position with the local correction signal, deriving a highly accurate three-dimensional position capable of being used for all-weather approaches via an ILS-style display. While JPALS is similar to Local Area Augmentation System, but intended primarily for use by the military, some elements of JPALS may eventually see their way into civilian use to help protect high-value civilian operations against unauthorized signal alteration.

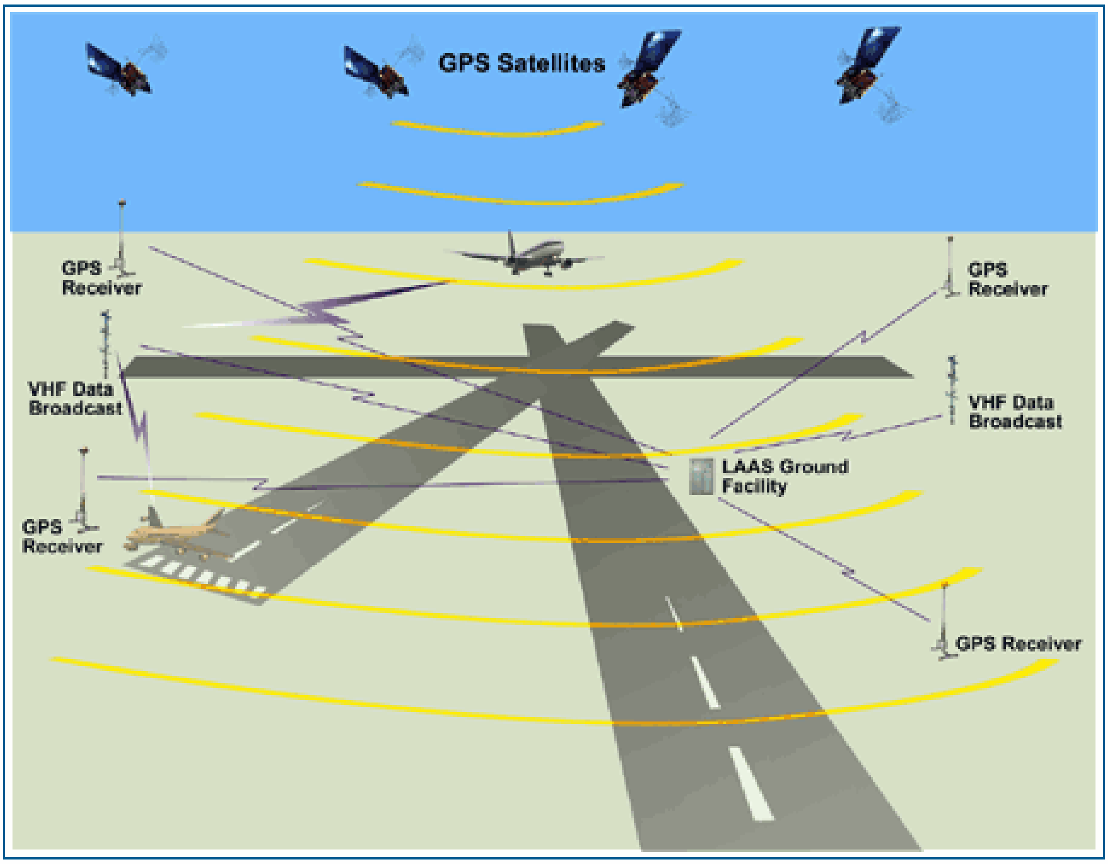

Figure 9 – JPALS architecture

6 Summary and Conclusions

The work conducted under Work Package 6 studied the concept of operations for the integration of UAS at controlled aerodromes (civil, military or mixed). Such a concept included aerodrome layout and infrastructure, the roles of the actors in the UAS operation (pilot, ATCO, ground personnel, maintenance personnel), the task to be accomplished in each flight phase and the UA performance. From here on the needs for the technology to operate UAS at aerodromes has been studied under the scope of this document.

An analysis of the current and future technologies to support the UAS operation at aerodromes has been performed. The analysis considers whether the current and the future systems can cope with the concept of operations expectations. In case the needs are not accomplished, room for further research and development has been identified and proposed. The technologies are related to the UA, the CS, the ATCO position, the ground surveillance systems, the commercial aircraft and the handling and airport operation vehicles.

The current increasing levels of automation in ground systems and the availability of advanced computer systems onboard needs to be used to their full capabilities, and improve the interoperability and integration between them. This situation should be solved in the coming years, and so the existing initiatives at both sides of the Atlantic are directed to increase the integration between ground and airborne systems. A key common technological enabler for the operation of UAS at aerodromes is an enhanced data link which can provide the required performance for command and control and sensor data transfer for ground operations and advanced on board sensors.

To summarise, Table 11 below represents the enabling technologies currently available and those evolving to a mature state that may be key for the operation of UAS in aerodromes.

	Flight Phase			
	Arrival	**Taxi**	**Handling**	**Departure**
Current Enabling Technologies	ILS GPS ADS-B Augmentation Systems by differential correction of the GPS signal Surface Movement Radar Microwave Landing System TIS-B JPALS	GPS ADS-B Moving Maps (EFB) Augmentation Systems by differential correction of the GPS signal Surface Movement Radar TIS-B	Conventional Push Back TIS-B	ILS GPS ADS-B Augmentation Systems by differential correction of the GPS signal Surface Movement Radar TIS-B
Evolving Technologies	Information Sharing (SWIM) Aero Swim (Communications) Smaller on board sensors and technology CPDCL	Information Sharing (SWIM) Enhanced EO and visual ASDE-X	Information Sharing (SWIM) Enhanced EO and visual Advanced Docking Systems ASDE-X Smaller on board sensors and technology	Information Sharing (SWIM) Aero Swim (Communications) Smaller on board sensors and technology CPDLC
Obsolete Technology	ILS will move towards differential GPS and multi-lateration	Conventional airport signs and markings		

Table 11 – Enabling Technologies for UAS operations at Aerodromes

It can be seen from this study that most of the technology required for current UAS operation is currently available for Communications, Navigation and Surveillance of manned aircraft. It has just to be validated for the use in unmanned aviation. It is important, therefore, to highlight the fact that the operation of UAS at aerodromes is possible from a technological perspective. In other words, technology is not the main barrier for future UAS aerodrome operation.

Furthermore, most of the necessary technologies are available under development for manned aviation, and so it is an exercise of adapting, if at all, some of the present technology to unmanned systems. This consequently implies that potential benefits may exist for manned aviation from the technological and operational improvements introduced by the operation of UAS at aerodromes, in particular in the areas of:

- Sense and Avoid
- Virtual map of the aerodrome
- Increased automation leading to improved predictability of the aircraft movement, thus enhancing the ATCO situational awareness
- Potential safety increase due to the new technologies, especially in low visibility conditions (even with an increase in the airport capacity in these conditions)

However, this also implies that further research is required in the adaptation of such technologies and the following questions should be considered:

- How will UA pilot receive data in the control station?
- Will he receive information on time to avoid collisions or collision avoidance should be automatic?
- Will UA be fitted with technologies such as MLAT, ADS-B or similar to comply with the requirements of such manned aviation technologies? Multilateration is a co-operative system, but one which can utilise data received from an aircraft that may be transmitted in response to different technologies. The minimum level of avionics to enable Multilateration with interrogation is a Mode A/C transponder. SSR Mode S or ADS-B avionics will enhance the performance of the system and may remove the need for interrogation. With the availability of various ADS-B and SSR technologies and the cost of equipping or re-equipping aircraft with new avionics, it is unlikely that aircraft will have homogeneous equipment. The introduction of MLAT allows the system to have full surveillance of all transponder equipped aircraft without the hurdle of making the carriage of ADS-B transponders mandatory for a State or large airspace area. It should be remembered that in some MLAT systems, ADS-B is an integral part, so aircraft operators should be encouraged to install ADS-B OUT capability which will benefit the whole airspace system in time, and which can benefit the operator and ATS system directly through improved coverage in areas beyond the MLAT high performance area.
-

- Will size, weight and power consumption (among others) requirements of UAS be capable of support the avionics needed?

Clear UAS specific operational concepts and procedures at an aerodrome need to be defined; technology will then support such procedures. There is a strong need for clear responsibilities for the actors involved supported by procedures for UAS aerodrome operations, including alternative procedures to unmanned aviation needed in case of emergency situations (e.g. data link loss, recovery).

All in all it can be said that the technology required to operate UAS at aerodromes is available or under development, and that focus should be put under regulatory compliance and procedures.