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INOUI

INNOVATIVE OPERATIONAL UAS INTEGRATION

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Thematic Priority: AERO-2005-4.g Open Upstream Research

D2.3 CONCLUSIONS AND RECOMMENDATIONS ON NEW TECHNOLOGICAL DEVELOPMENTS

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1 Introduction

The main objective of the INOUI project is to success 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 how to integrate 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, filling the possible existing gaps in regard to the particularities of UAS.

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 (regarding to the 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 it, INOUI defines an operational concept, propose operational procedures and assess 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

The scope of INOUI WP2 is to evaluate all existing and future systems and technologies that are intended to be applied on ground and airborne to enable the ATM 2020 paradigm and to assess their impact on UAS and individual aircraft operation.

The purpose of this document is to present the final step in the definition of the ATM architecture to integrate the UAS operation. Work Package 2.3 deals with the proposal of any technology that would suppose an area of investigation for the future in order to cope with those ATM 2020 operational requirements not covered by the technologies analysed in previous work, in particular INOUI D2.2 "Assessment of Technology for UAS Integration". This way, the roadmap resulting in WP2.1 will be further complemented here by presenting in this document the proposals for further technology developments and their corresponding timeframe. Figure 1 depicts the methodology used for the study of UAS technology developments.

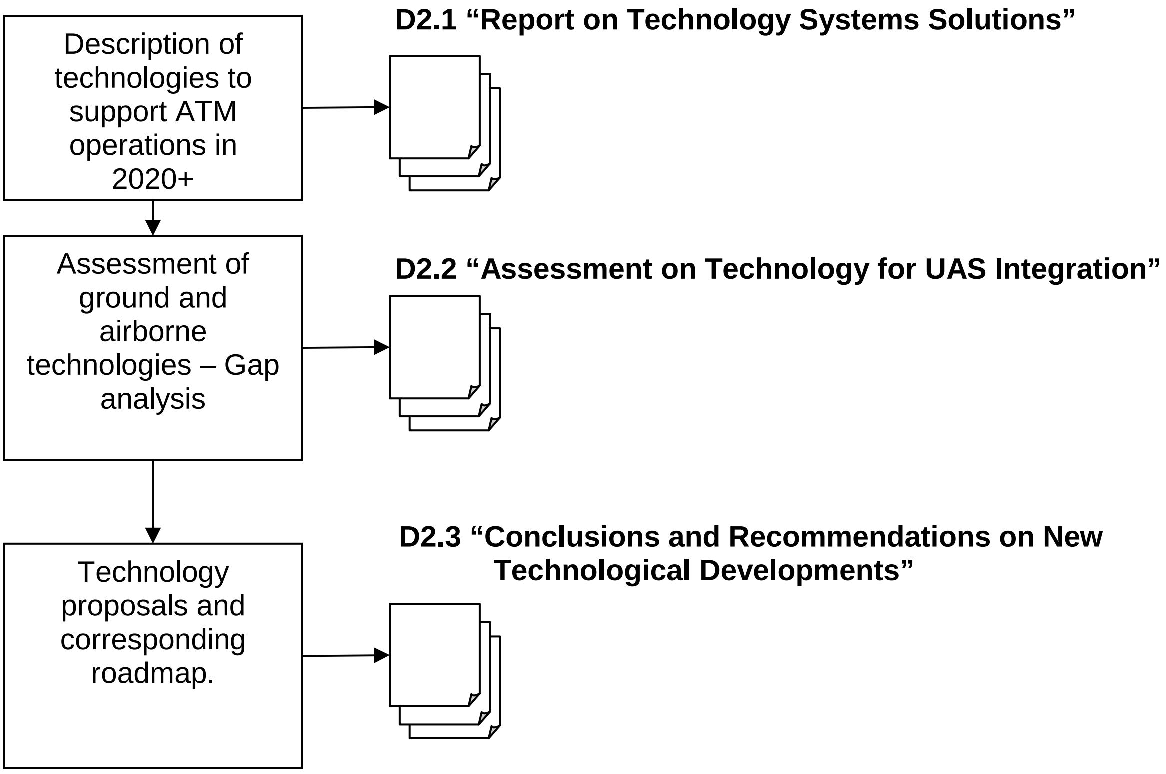

Figure 1 – "UAS methodology for Technology developments under WP2" (Source: INOUI)

1.3 Document Structure

This document has been structured in three 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 the technology gaps which were identified in previous INOUI work.

Section 1 deals with UAS 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. Technologies currently under development and those foreseen for the future were analysed and their importance discussed. This section now looks in more details at three areas of UAS technology considered key for the operation of UAS in the 2020 ATM environment. The areas considered include Communications, Navigation and Surveillance.

Section 2, ATM Technology Proposals, 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 is the final section in this document and deals with recommendations to build a reference roadmap for the integration of technologies identified above. The objective behind this roadmap is to serve as reference for deploying such technology.

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
[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,	A casualty risk analysis for Unmanned Aerial System (UAS)

Reference tag	Document description
Fulton and Campbell]	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.
[DFS SA Handbook]	Safety Assessment Handbook, Version 2.0, DFS Deutsche Flugsicherung GmbH, Corporate Safety and Quality Management (VY),15 December 2004
[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
[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

Reference tag	Document description
	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"
[INOUI D4.2]	INOUI (Innovative Operational UA Integration) , Deliverable 4.2 "New UAS – related Common Operating Picture actors"
[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
[UA Task Force 2004]	UA Task-Force Final Report. A concept for European Regulations for civil Unmanned Aerial Vehicles (UAs). The Joint JAA/Eurocontrol

Reference tag	Document description
	Initiative on UAs, May 11th, 2004
[Van Es, 2003]	G.W.H. van Es, Review of Air Traffic Management-related accidents worldwide: 1980 – 2001, NLR Technical Publication 2003-376, August 2003
[Weibel and Hansmann, 2005]	Safety Considerations for Operation of Unmanned aerial vehicles in the NAS. R.E. Weibel and R.J. Hansmann. Report No, ICAT-2005-1. March 2005

1.5 Glossary

Acronym	Definition
4D	Four Dimensions
ACARE	Advisory Council for Aeronautics Research in Europe
ACARS	Aircraft Communication Addressing and Reporting System
ACAS	Airborne Collision Avoidance System
ACC	Area Control Centre
ACL	Anti-Collision Lighting
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
AoA	Angle of Attack
AOC	Airlines Operational Communications
ASAS	Airborne Separation Assistance (Assurance) Systems
AS	Airspeed
ASI	Actuator Sensor Interface
A-SMGCS	Advanced Surface Movement Guidance and Control System
ATC	Air Traffic Control
ATCO	Air Traffic Controller
ATIS	Automatic Terminal Information Service
ATFCM	Air Traffic Flow and Capacity Management
ATM	Air Traffic Management
ATN	Aeronautical Telecommunications Network
BRLOS	Beyond Radio Line Of Sight
BR&TE	Boeing Research and Technology Europe SL
C^2	Command and Control
C^3	Command, Control and Communication
CASCADE	Co-operative ATS through Surveillance and Communication Applications Deployed in ECAC
CDM	Collaborative Decision Making
CFMU	Central Flow Management Unit
CNS	Communication, Navigation, Surveillance
CPDLC	Controller Pilot Data Link Communication
CS	Control Station
CTR	Control zone
DB	Data Base
DFS	DFS Deutsche Flugsicherung GmbH
DME	Distance Measuring Equipment
RoD	Rate of Descent
DVP	Development Plan
EC	European Commission
ECAC	European Civil Aviation Conference
EFB	Electronic Flight Bag

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
FMS	Flight Management System
FP	Framework Programme
FPL	Flight Plan
FRF	Flight Reconfiguration Function
G2G	Gate To Gate
GAT	General Air Traffic
GBAS	Ground Based Augmentation System
GCS	Ground Control Station
GLONASS	GLObal'naya NAvigatsionnaya Sputnikovaya Sistema (Global Navigation Satellite System)
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
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
PBIT	Power-up Built-In Test
PMP	Project Management Plan
PSR	Primary Surveillance Radar
RCS	Radar Cross Section
RDE	Rheinmetall Defence Electronics GmbH
RLOS	Radio Line Of Sight
RoC	Rate of Climb
RVSM	Reduced Vertical Separation Minima

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
SSR	Secondary Surveillance Radar
TCAS	Traffic Collision Avoidance System
TGD	Taxi-Guidance Display
TIS-B	Traffic Information Service - Broadcast
TMA	Terminal Manoeuvring Area
TO	Take-off
UAC	Upper Area Control Center
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UAV-p	UAV pilot
UIR	Upper Flight Information Region
VDL	VHF (Very High Frequency) Data-Link
VFR	Visual Flight Rules
VHF	Very High Frequency
VNAV	Vertical NAV
VoIP	Voice over IP (Internet Protocol)
VOR	VHF Omni-directional Radio Range
WAAS	Wide Area Augmentation System
WAM	Wide Area Multi-lateration
WG	Working Group
WP	Work Package
WRC	World Radiocommunication Conference
XPDR	Transponder
E-OCVM	European-Operational Concept Validation Methodology

2 UAS Technology Proposals

From the point of view of the UAS technologies, three areas of technology are considered key elements for the operation of UAS in the 2020 ATM environment. These areas have been defined as Communications, Navigation and Surveillance. During the work performed in [INOUI D2.1] an identification of the UAS technologies for the operation of UAS in the 2020 ATM environment – those currently under development and those foreseen – was performed.

In the aforementioned document, three types of UAS communications were considered, i.e., communication between UAS and ground, communications between UAS and UAS or other aircraft, and communications between ground and ATC. The first two types of communications are currently performed by data links. These data links are the same as those used for manned aviation. These communications means can be performed in two ways depending on the distance and the obstacles that may be encountered between the air vehicle and the control station. If the distance is not very large and there are no obstacles between CS and UAS then the communications are performed via Line of Sight (LOS). In case the distance is very large or there are obstacles in between the air vehicle and the control station, then communications are performed via Beyond Radio Line of Sight (BRLOS), which currently implies the use of satellites to relay the communications. Communications between the control station and ATC are still voice via VHF radio.

UAS Navigation technologies are currently based on those used in conventional aircraft but adapted to unmanned systems. The types of navigation equipment are inertial, satellite and radio navigation.

UAS Surveillance technologies constitute a critical issue. This is due to the fact that there is no pilot on board and therefore the ability of the pilot to see and avoid is lost. Currently surveillance is done from the control station, the UAS pilot receives data from the UAS or from ATC and modifies the UAS trajectory to avoid a conflict with either other UAS or manned aircraft, adverse weather conditions or obstacles. There are also some technologies that are used by general aviation as is the case of FLARM that can be adapted to UAS.

Apart from CNS technologies, there are other technologies foreseen. These technologies will allow UAS pilot to control the UAS in a better and comfortable manner as well as perform the UAS missions more safely and effective.

In [INOUI D2.2] the technologies identified and described in [INOUI D2.1] were cross checked with the INOUI operational concept described in [INOUI D1.3] in order to find whether there was any gap jeopardising the integration of UAS in the ATM 2020+ environment or not. It was found that there are no technological issues critical for their integration into the non-segregated airspace from the point of view of navigation and communication areas. However there are some known problems in these fields that come from the adaptation of existing technologies used in manned aviation for its use in UAS.

Moreover, in the case of communications, the lack of available spectrum for UAS has revealed a key issue that needs to be solved.

In the field of surveillance the problem is more complex, because there is not any sense and avoid technology, to replace the human capability of see and avoid, currently available for civil or governmental UAS and current initiatives are only dealing with concept developments and in certain cases with the development of a very initial prototype, thus there is a medium/high risk that a seamless integration of UAS in the Single European Sky cannot be achieved by the 2020+ timeframe.

In the military area the development of a set of requirements for military UAS as established in [NATO S&A] issued by NATO and currently under assessment by the NATO Industrial Advisory Group (NIAG), sets the basis for a certification framework for Sense and Avoid technology. However in the civil area there is not any certification framework for the development of this technology yet. It is important to mention that first analyses for technical requirements for Sense and Avoid were performed in [INOUI D4.2].

The following sections in this document aim at proposing potential solutions to fulfil the gaps identified in [INOUI D2.2] in the fields of communication, navigation and surveillance.

2.1 Communication

This section aims primarily to assess which are the communication requirements for a UA flying in a non-segregated airspace in order to give clues to the different organisations involved in the determination of the radio spectrum quantity for the control of unmanned aircraft, including command and control by the UA pilot, the relay of ATC communications to the UA pilot, etc. It excludes the payload requirements which depend on the specific type of application.

The UAS as any other airspace user has to communicate with its environment. Two communication links, excluding the payload link, are expected:

- ATC link: Communications with Air Traffic Controllers and ground systems will be carried out through this link. Reporting to ATC and requesting or receiving ATS information such as weather are also activities performed through this link. The ATC link currently carries voice transmission and will be gradually complemented or supplemented by ATC data link as the ATC authorities consider it as the primary means communication with ATC in the long term (SESAR 2020+ environment).
- Command and Control (C2) of the flight either in light-of-sight (LOS) when the UA is within the radio coverage of a terrestrial ground station, or beyond-line-of sight (BLOS) in the case where the radio link has to be maintained via another aircraft relay or by other means such as satellite communications.

In the near term, it is envisioned that UA will communicate with their respective CS through dedicated links either directly (LOS links) or via communications relay. In the far term such a solution could be complemented by a set of networked RF stations, CS and ATC facilities, terrestrial and/or satellite based.

Data link technology is not a technological gap by itself, since past, recent and future (short term) developments will allow any airspace user to operate in the SESAR environment, however the total bandwidth required to support the whole European amount of UAS with the anticipated levels of activity in the future is significant. Radio Frequency spectrum is in limited supply and in many areas is already heavily used. Therefore, solving the challenge of finding suitable spectrum for the operation of UAS is an important and necessary step in the growth of the UAS industry. At international level, the allocation of spectrum is the responsibility of the International Telecommunication Union (ITU). For major spectrum decisions, national representatives of all countries meet approximately every four years at the World Radio communication Conferences (WRC) to agree on new or revised spectrum allocations and associated procedures to use them. The ITU WRC07 (held in October/November 2007) decided to put on the agenda of ITU WRC-11 the spectrum requirements for UAS Operation.

Communication between UAS pilot and ATC is of paramount importance. Currently not every UA available on the market is equipped with ATC voice communication equipment. However, in order to allow UA to fly in controlled airspace, the UA pilot should be able to communicate with air traffic controllers and other pilots in the same way as nowadays in the case of manned aircraft. Depending on the UA mission, the voice communication equipment must be carried on board the UA or on the CS so that the pilot can communicate with the appropriate ATC centre.

Line-of-sight (LOS) communications are used when the Control Station (CS) is sufficiently close to the UA, while beyond line-of-sight (BLOS) communications are employed when additional relaying communication facilities are available to allow the UA to be flown far away from the location of the CS and UA pilot. Some current UAS are equipped with beyond line-of-sight systems. Currently these BLOS systems are mostly satellite based. Other solutions are used or envisioned, such as using other aircrafts as relays or using several transceiver ground stations connected to the CS.

Take-off and landing activities are currently carried out using LOS systems, i.e., at times when critical response to UA pilot commands are vital. The pilot using the LOS system to control the aircraft is not necessarily the same pilot controlling the aircraft using the BLOS system.

Dual redundant Command and Control links offer advantages such as overall availability. For example, if one of the links is temporarily suffering from degradation, due to interference or propagation – related effects, then the other link could take over the missing part of information and maintain the transmission of commands from the UA pilot to the UA and vice versa. The vast majority of UA have built-in procedures to accommodate lost link situations. In these cases the level of autonomy plays a major role in what the UA does after losing the link. However it is expected that the vehicle will fly a pre-planned manoeuvre trying to re-establish radio-visibility to recover the C2 link while heading to a predetermined location.

Seamless flight of UA within conventional air traffic is becoming vital for the further development of UAS, their missions and their markets. The key issue is to comply with civil aviation safety standards before UA traffic is allowed to operate with conventional air traffic in non-segregated airspace.

In order to achieve this goal a certain technological level has to be attained, mainly represented by avionics. And the classes of airspace and the type of flight determine this level of ATC avionics equipment.

For civil aircraft under IFR rules, the following table provides the ATC avionics requirement expected by 2020

Avionics	Band	Comment
HF	2-20 MHz	Oceanic and low density continental areas
VOR	112-118 MHz	See B-RNAV
GBAS cat 1	112-118 MHz	Considered at selected airports
ILS	108-118 MHz and 300 MHz	Mandatory
VHF voice (25 or 8.33 kHz)	118-137 MHz	Mandatory
VDL mode 2	118-137 MHz	Considered at selected airports
DME	960-1164 MHz	See B-RNAV and P-RNAV
UAT	978 MHz	Considered in the USA
SSR	1030 and 1090 MHz	Generally mandatory but can vary within each national airspace
ACAS II	1030 and 1090 MHz	Mandatory for aircraft with more than 19 seats or more than 5,7 tons
ADS-B	1090 MHz	Expected to enter in operation by 2020
FCS	960-1164 MHz	Considered for operation by 2020
GNSS	1164-1215 MHz	See B-NAV and R-NAV
SATCOM	1.5 and 1.6 GHz	Oceanic and low density continental areas
Radio Altimeter	4200-4400 MHz	See EGPWS
MLS	5030-5150 MHz	Considered at selected airports
Airborne weather radar		Mandatory for passengers aircraft

Table 1 - ATC avionics requirement expected by 2020 for civil aircraft under IFR rule (Source: INOUI)

B-RNAV (± 5 NM accuracy): mandatory in all en route airspace in Europe. A single B-RNAV system is acceptable provided there are conventional terrestrial navaids (VOR and/or DME) available in the route being flown to cope with a hypothetical B-RNAV equipment failure.

P-RNAV (± 1 NM accuracy): not expected to be mandatory before 2010. Earlier introduction is expected in Terminal Areas.

For aircraft flying under visual flight rules, operations are permitted only under sufficiently good visibility conditions. The pilot must ensure that, during the flight, the aircraft remains in these good visibility conditions (for example by avoiding clouds). The pilot must have the ability, without the aid of navigation instruments, to see and avoid other aircraft and obstacles and to navigate by visualising the terrain below. The aircraft may only be equipped with basics avionics such as air speed indicator, altimeter and vertical speed indicator.

The shortage of appropriate spectrum is a key issue in UAS development since there is not enough bandwidth to provide sufficient protection against interference to communications and to ensure sufficient safety levels. A trade-off analysis is required between the use of link electronic redundancy or protection techniques (requiring much more bandwidth) and the capability of using certain level of autonomy for a limited time.

A solution being explored is that the ATC will provide information directly to the remote pilots through wired link instead of mobile radio transmission. This approach would solve the potential latency problem for SATCOM BLOS links. Radio links need to be designed so as to make the UA transparent to the air traffic controller. There are however some difficulties with this approach as the deployment of an ATC infrastructure dedicated to unmanned aircraft might be too complex and costly. The solution would require a change of the overall ATM architecture and would become economically acceptable only where an important number of unmanned aircraft will fly. Considering that the proportion of unmanned aircraft is currently very small, this approach would not significantly increase the possibilities to neither integrate UAS into the non-segregated airspace nor reduce the amount of radio spectrum necessary for the flight of unmanned aircraft.

It is clear that UAS necessitate the same ATC communication requirement in the same way that a manned aircraft does, i.e. the same type of exchange between the air traffic controller and UAS, with the same level of performance in order to make UAS transparent to the ATC.

Two types of links for ATC communication are envisaged: (1) a direct link between ATC and the UA when the ATC communication avionics is on board the flying UA, (2) a relay between the on board ATC avionics and the CS.

The ATC-UA exchange will be made via an communication transceiver on board the flying UA which is similar of the transceiver on board a manned aircraft. It is possible for some type or mission of UA that the communication transceiver is not onboard the UA but located in a flying or ground-based CS.

It is foreseen that by the year 2020 this type of solution (implying no onboard transceiver) will be only employed by a limited number of unmanned aircraft and therefore will not require a large spectrum allocation for the direct ATC communication.

As a conclusion direct ATC-UA communication does not necessitate additional spectrum requirement.

When the communication transponder is on board the UA, as it is predicted on the majority of cases, the ATC messages should be relayed to the remote pilot in the CS.

The most economically acceptable solution could be the one in which the ATC relayed information use the same avionics as Command and Control link. As Command and Control avionics are safety critical systems, this will also constitute a suitable solution in terms of performance for the ATC relay.

Command and Control avionics are likely based on digital circuits, so when an analogue ATC transceiver (25 or 8.33 kHz spacing) is used, ATC relayed information should be digitised. In the future ATC communication infrastructure will be primarily based on digitised information, however the need of analogue-digital conversion may likely not disappear as the ATC analogue voice system will likely remain at least as a back up.

ATC voice messages are currently transmitted as analogue signals. At the horizon 2020 and beyond there are several potential digital technologies that will support voice transmission. There will be also likely an important number of UA that will use their digital command and control avionics to relay also digitised voice.

If ATC voice relay links are digital, they will presumably have a bit rate similar to 4800 bps as it was defined for the coder of the VHF Digital Link Mode 3 (VDL3).

A system providing ATS data services of various kinds such as SWIM is expected to be in place by 2020+.

The analysis of the data-loading requirements for each kind of ATS message has been made in ITU 5B meetings. Results show that ATS data rate is not significant (between 20 and 200 Kb/s depending the phase of flight) compared to the requirement for ATC voice.

Therefore the ATS data relay requirement could be considered integrated in the ATC voice requirement.

The bandwidth requirement for the Command and Control link will depend upon the level of autonomy needed to operate the UA. The Command and Control link load for a UA which only accepts waypoint changes is significantly less than for a UA receiving control surfaces commands. Therefore requirements for highly autonomous UA will be less stringent.

2.2 Navigation

Air Traffic Management is the aggregation of the airborne functions and ground-based functions required to ensure the safe and efficient movement of aircraft during all phases of operations.

One of the key elements of the future SESAR environment is the Business Trajectory (BT). This trajectory is always associated with all the data needed to describe the flight. In particular, air traffic service units need to know the capabilities of the aircraft concerned to enable them to select the most appropriate and efficient trajectory management methods (including the separation methods). UAS as any other airspace users will have to comply with the concept of business trajectories in order to allow their integration into the non-segregated airspace.

2.2.1 Business Trajectory concept

In order to determine which technologies will enable the integration of UAS in the future SESAR environment, a short overview of the business trajectory concept is shown below.

The lifecycle of the Business Trajectory starts with the development of a flight by the airspace user and ends with post-flight activities after the aircraft has reached its final point of destination.

The intention of the future ATM system is to enable this to happen with the minimum number of constraints. Trajectories will be expressed in all four (4D) dimensions and flown with high precision. The Business/Mission Trajectory evolves out of a layered Collaborative Decision Making (CDM) planning process.

The different development phases of the trajectory are the:

- Business Development Trajectory (BDT):

  The airspace user develops a Business Development Trajectory (BDT) which is not shared outside the airspace user organisation. The BDT goes through a number of iterations and is constantly refined by taking into account constraints arising from infrastructure and environmental considerations. Depending on the category of airspace users this process may be short or effectively non-existent (as is most likely the case for the majority of GA airspace users).

- Shared Business Trajectory (SBT):

  When the user has sufficiently stabilised the BDT, the latter will be made available as the Shared Business Trajectory (SBT) to the ATM system for planning purposes. Based on the aggregated information on the BTs the ANSP will consider the potential need to adjust airspace organisation to match the traffic flow and airports will adjust their planning for the needed capacity as much as possible. When qualitative and quantitative information becomes increasingly available, the ANSP will plan the management of the airspace in terms of services required taking account of the traffic complexity and density. Coordination with the military and the airports will start to develop an initial operating schedule. During this phase potential discrepancies between the SBT and network constraints might already be detected and the airspace users will be notified with the request to adjust their Business Trajectory. This process is iterative until the optimum result for the users is achieved taking into account the need to ensure an optimum overall network performance.

- Reference Business Trajectory (RBT):

  The iterative process of Shared Business Trajectories (SBTs) ultimately leads to a final trajectory just before flight execution: the Reference Business Trajectory (RBT), which the airspace user agrees to fly and the ANSP and airport agrees to facilitate. The RBT becomes instantiated before the first ATC clearance is requested or issued but it does not constitute a clearance to proceed. The RBT is the goal to be achieved and will be progressively authorised. The authorisation takes the form of a clearance by the ANSP or is a function of aircraft (crew/systems) depending on who is the designated separator. Most times indicated in the RBT are estimates, however, some may be target times to facilitate planning and some of them may be constraints to assist in particular in queue management when appropriate. The RBT continues to evolve during flight execution in order to reflect all the applicable clearances and constraints and in accordance with the applicable trajectory change rules. There are two distinct processes to modify the RBT:

  - An RBT automatic update is triggered on specific events or when the Predicted Trajectory (PT – the trajectory continually computed/updated on-board in capable aircraft, which corresponds to what the aircraft is predicted to fly) differs from the RBT by more than predefined thresholds. The events and the thresholds are indicated in Trajectory Management Requirements (TMR). This process aims to notably improve the performance of automation support. Ground systems will support trajectory prediction and its updating for the aircraft not capable to manage the automatic update of the RBT;
  - An RBT revision is triggered at air or ground initiative when constraints are to be changed (modified by ATC or by flight crew if the RBT cannot be achieved by the aircraft).

In both cases of modifications, the new RBT becomes the new common reference that is analysed from a conflict management and network viewpoint by the ANSP who will take the necessary actions in case of adverse effects.

Figure 2 shows the business trajectory lifecycle process from its initiation to manage the flight throughout t he time leading up to and on the day of operation and its execution.

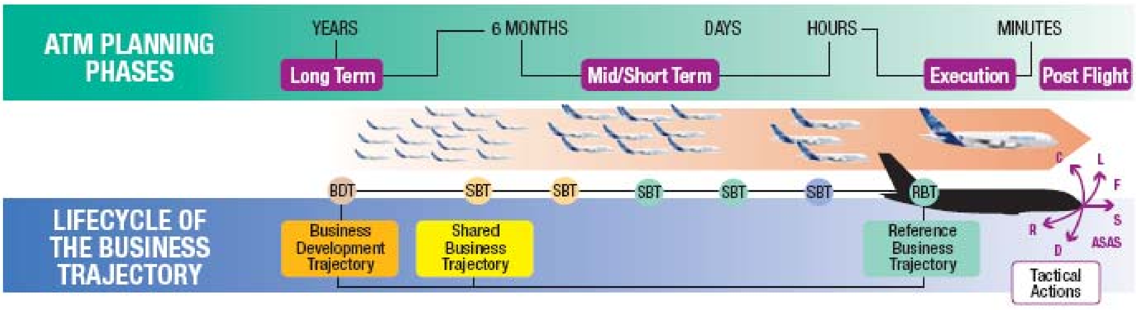

Figure 2 – "Business Trajectory Lifecycle" (Source: SESAR)

General Aviation flights operating under Instrument Flight Rules (IFR) will have access to aeronautical information on ground and in the air and will have the ability to enter and change trajectories. The Business Trajectory must be negotiated with the ANSP by the airspace user, when an aircraft enters airspace where the separation service is provided by the ANSP or request a ground based separation service.

The ANSP will issue clearances and instructions to the airspace user that either authorise successive segments of the RBT or cause the RBT to be revised. Similarly, the airspace user will follow the authorised RBT and respect any applied constraints or will initiate an RBT revision. As part of the clearance process, all capable aircraft will receive Trajectory Management Requirements (TMR) for each flight.

Once the RBT is cleared by the ANSP and is being executed by the aircrew, the aircraft becomes the prime source of its 4D trajectory data (except for non capable aircraft where the prime source are ground airspace user and/or ANSP systems). The RBT is subject to automatic and regular synchronisation through the RBT automatic update process. On-board systems will guide the aircraft along the cleared trajectory.

Requests to change the trajectory may come from the ground or air for reasons which may include separation provision, sequencing, weather, changing arrival constraints, etc. These are managed by the RBT revision process. The means for the ANSP to implement non-tactical changes is by the imposition, amendment or removal of constraints. The User will propose an RBT amendment that meets the changed constraints. The ANSP will accept the amendment if no additional problems is created by the change. For tactical changes the controller will issue instructions/clearances that may result in an RBT amendment. Otherwise, it is the controllers' role to make tactical changes by issuing instructions/clearances to resolve tactical conflicts, if the controller is the separator.

If the aircraft is intending to fly IFR and is not capable of negotiating a Business Trajectory it has to communicate its intentions to ATC conventionally. The controller will update the ATC-system accordingly and issue a conventional clearance to this aircraft. The trajectory calculated by the ATC-system will be updated during the execution of the flight and all available data will be present on the ATM Network.

The role of the separator may be delegated to the pilot following specific rules (e.g. approved aircraft equipment and pilot qualification) within specified limits (in time, distance or in respect to one or more aircraft). In unmanaged airspace, the pre-determined separator is the airspace user (the majority of which is GA). The majority of General Aviation is foreseen to fly in accordance to Visual Flight Rules (VFR) below flight level 130, outside terminal areas. Most operations are not expected to interfere with other civil operations. It is the responsibility of the pilot in command to ensure that the flight can proceed safely when entering airspace where the airspace user is the separator or when requesting self-separation.

2.2.2 UAS Technological enabler

UAS have to be compliant with the business trajectory concept; therefore avionics equipment capable to execute 4D trajectories shall be installed.

Currently a flight management system is a fundamental part of a modern aircraft in that it controls the navigation. The flight management system (FMS) is the avionics that holds the flight plan, and allows the pilot to modify as required in flight. The FMS uses various sensors to determine the aircraft's position. Given the position and the flight plan, the FMS guides the aircraft along the flight plan. The FMS is normally controlled through a small screen and a keyboard.

FMS contain a navigation database. The navigation database contains all of the information required for building a flight plan and information relevant to it. These may include:

- Waypoints
- Airways (highways in the sky)
- Radio navigation aids including DME (Distance Measuring Equipment), VOR (VHF Omni directional Range) and NDB (Non directional beacons)
- Airports
- Runways
- Standard Instrument Departure (SID)
- Standard Terminal Arrival (STAR)
- Holding patterns
- And a variety of related and often installation specific information

The flight plan is generally determined on the ground, before departure either by the pilot for smaller aircraft or a professional dispatcher for airliners. It is entered into the FMS either by typing it in, selecting it from a saved library of common routes or (Company Routes) or via a data link with the airline dispatch centre.

During pre-flight other information relevant to managing the flight plan is entered. This can include performance information such as gross weight, fuel weight and centre of gravity. It will include altitudes including the initial cruise altitude. For aircraft that do not have a GPS, the initial position is also required.

The pilot uses the FMS to modify the flight plan, in flight for a variety of reasons. Significant engineering design minimizes the keystrokes in order to minimize pilot workload in flight and eliminate any confusing information (Hazardously Misleading Information). The FMS also sends the flight plan information for display on the Navigation Display (ND) of the flight deck instruments (EFIS). The flight plan generally appears as a magenta line, with other airports, radio aids and waypoints displayed.

Special flight plans, often for tactical requirements including search patterns, rendezvous, in-flight refuelling tanker orbits, calculated air release points (CARP) for accurate parachute jumps are just a few of the special flight plans some FMS can calculate.

Once in flight, a principal task of the FMS is to determine the aircraft's position and the accuracy of that position. Simple FMS use a single sensor, generally GPS in order to determine position. But modern FMS use as many sensors as they can in order to determine and validate exactly their position. Some FMS use a Kalman filter to integrate the positions from the various sensors into a single position. Common sensors include:

- Quality GPS receivers act as the primary sensor as they have the highest accuracy and integrity.
- Radio aids designed for aircraft navigation act as the second highest quality sensors. These include;
  - Scanning DME (Distance measuring equipment) that check the distances from five different DME stations simultaneously in order to determine one position every 10 seconds or so.
  - VOR’s (VHF Omni-directional Radio Range) that supply a bearing. With two VOR stations the aircraft position can be determined, but the accuracy is limited.
- Inertial Reference Systems (IRS) use ring laser gyros and accelerometers in order to calculate the aircraft position. They are highly accurate and independent of outside sources. Airliners use the weighted average of three independent IRS to determine the “triple mixed IRS” position.

The FMS constantly crosschecks the various sensors and determines a single aircraft position and accuracy. The accuracy is described as the Actual Navigation Performance (ANP) a circle that the aircraft can be anywhere within measured as the diameter in nautical miles. Modern airspace has a set Required Navigation Performance (RNP). The aircraft must have its ANP less than its RNP in order to operate in certain high-level airspace.

As can be seen FMS description above is based on the flight plan concept instead of business trajectory concept. FMS developers are aware of this problem and currently there are already in use the so-called Advanced Flight Management Systems which include the business trajectory concept and enable the system to uplink/downlink flight intents from/to air traffic control.

These advanced flight management systems are a serious candidate to enable the integration of UAS into the non-segregated airspace and to be compliant with the business trajectory concept.

However these current systems are technically designed for their use in commercial, business and general aviation, i.e. they are specified with weight, size, and power consumption characteristics according to the needs of these kinds of aircraft which have in general higher figures than UAS could afford. Table 2 below show the typical FMS characteristics for systems used on board commercial aircraft with 4D trajectory management capabilities.

Characteristic	Value
Height (in/cm)	7.62 / 19.3
Width (in/cm)	5.06 / 12.8
Depth (in/cm)	16.25 / 41.2
Weight (lbs/kg)	15.6 / 7
Power Consumption (W)	35-40

Table 2 - Typical FMS characteristics for systems used on board commercial aircraft (Source: INOUI)

Table 3 below show typical FMS characteristics for systems used on UAS. Current FMS used on UAS do not have 4D trajectory management.

Characteristic	Value
Height (in/cm)	5.6 / 14.2
Width (in/cm)	3.0 / 7.6
Depth (in/cm)	2.4 / 6.1
Weight (lbs/kg)	0.46 / 0.212
Power consumption (W)	5-10

Table 3 - Typical FMS characteristics for systems used on UAS (source: INOUI)

As can be seen from the tables above, both kinds of FMS have very different values, notably regarding weight and power consumption. There is still one more important issue: FMS used on board commercial aircraft have 4D trajectory management capabilities while FMS used on UAS do not have this capability.

Therefore there is no possibility for a trade-off for these FMS between UAS and commercial aircraft.

It has to be noted that the figures above are general values and they depend on the kind of aircraft, especially in the case of the FMS used on UAS where the variety of UAS sizes, weights and power consumptions are very different, depending on the UAS type and mission to be carried out. Therefore it is likely to think that the Northrop Grumann's Global Hawk could perfectly use an FMS as those used in commercial aircraft with 4D trajectory management capabilities but a smaller UAS could not and thus its integration into the non-segregated airspace could not be possible.

Since FMS capabilities allowing aircraft to fly following 4D trajectories are already developed, there is no need for proposing a new technology but to adapt it. Two possible solutions can be proposed:

- to improve current FMS used on UAS in order to give them the capability of 4D trajectory management.
- to reduce size, weight and power consumption of FMS used on commercial aircraft with 4D trajectory management capabilities in order to adapt them for UAS.

The first solution could be beneficial depending on how the 4D trajectory management solution is implemented. If the implementation needs an increase of FMS functions and algorithms, probably the size and weight and, even more important, the power consumption, will also increase.

The second solution could be satisfactory not only for UAS but also for manned aircraft, since the reduction of size, weight and power consumption of avionics equipment will allow improving aircraft operations.

No matter which solution is selected, certification processes for the new systems have to be carried out for each solution in order to ensure the safe operation of UAS and commercial aircraft.

It is important to mention that 4D trajectories have been already tested with a commercial aircraft. The first downlinking of four-dimensional FMS trajectory information from a commercial aircraft was demonstrated over Scandinavia. A B-737-600 aircraft operated by SAS Sweden, flying between Stockholm's Arlanda airport and Oslo, transmitted data link messages containing the aircraft's intended path from climb out to touch down, including its estimated time over respective waypoints. The flight was part of the NUP2+ (second phase of the NEAN or North European ADS-B Network) update project that is validating a number of applications that would use 4D trajectory information.

It is also important to mention that SESAR foresee that aircraft navigation will be improved with a combination of global navigation satellite system, self-contained navigation systems and navigation aids enabling progressive implementation and exploitation of GPS navigation concepts complemented by ABAS systems. However it is also foreseen that terrestrial navigation aids such as DME/DME will be kept as back-up means, as most aircraft are already equipped, crews are trained and a basic ground infrastructure exists. The transition to GNSS based operations will enable the necessary decommissioning of conventional navaids (VOR, NDB/ADF), freeing up valuable radio spectrum that could be exploited for new or other aeronautical services (including UAS). This lack of conventional navaids in the far future has to be considered in the above mentioned flight management systems not only in those developed for UAS but also for those developed for conventional aircraft.

2.3 Surveillance

Probably the main gap jeopardizing the safe integration of UAS into the non-segregated airspace is the lack of surveillance capabilities on-board the UAS to replace the human capability of "see and avoid" in manned aviation. Two potential solutions reveal as key concepts to fulfil this gap: ASAS (Airborne Separation Assurance System) and Sense & Avoid. In INOUI D4.2 "New UAS-Related COP Actors", a set of requirements that a Sense and Avoid should have were given, therefore in this section only a high level description of technologies and algorithms which may allow the development of Sense and Avoid technologies (including conflict detection and resolution techniques) is presented. Another key concept has been mentioned above: ASAS. In this section it is also briefly described the concept of ASAS to assess whether the introduction of this technology will enable the integration of UAS into the non-segregated airspace or not.

As depicted in Figure 3, operations in civil airspace are based on a multi-layered approach to provide safe flight operations. While the outer layers provide a common set of regulations, procedures, equipment, training, and monitoring to minimize any risk of airborne collision, the responsibility for an aircraft pilot (manned or unmanned) to use their eyes to «see and avoid» air traffic remains the foundation for safe collision avoidance.

The avoidance of collisions is usually managed at two functional levels: the separation provision function and the collision avoidance function. Two aircraft are said to be in conflict if their vertical and horizontal separation is strictly less than defined by the relevant authority. A body in 3-D space, called protected zone, is assigned to each aircraft such that a conflict is equivalent to an intrusion of other airplane into its protected zone. The protected zone forms a cylinder of altitude $2H$ and radius D around the position of the aircraft. In this context, *Conflict Detection and Resolution* (CDR) algorithms are designed to detect an imminent loss of separation (and warn pilots about it), and to perform corrective manoeuvres or flight plan modifications (and assist pilots to perform them). In CDR related literature, *tactical* refers to the exclusive use of state information to project aircraft trajectories. Due to this intentionally limited source of information, they are rather used with short look ahead times (a few minutes, typically 5-10) during which aircraft are assumed to follow straight flight paths. *Strategic* approaches, in contrast, use intent information such as flight plans, and are aware of hazards such as weather conditions. They may have look ahead windows of several minutes and even hours.

When a collision is imminent, *Collision Avoidance* techniques are used, which include TCAS for cooperative aircraft. The last resort for collision avoidance is "see & avoid" level, in which any aircraft (cooperative or non-cooperative) should be detected with enough anticipation to perform manoeuvres to avoid it. This function is performed by the human pilot in manned aircraft. In UAS, since there is no human pilot onboard, this function should be performed by the pilot in the CS or an automatic system, a process which is known as "*Sense & Avoid*".

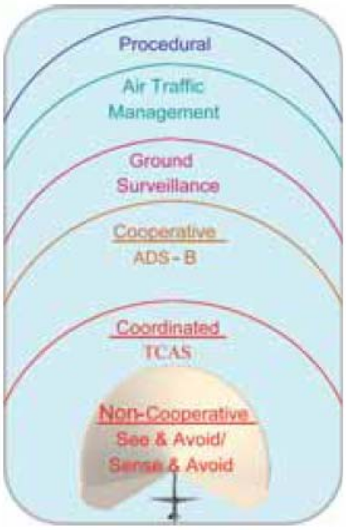

Figure 3 - Safety mechanisms for civil aviation (Source: SESAR)

The task of sensing obstacles in the environment can be performed by different kinds of sensors, most of which are limited to one degree or another. The fundamental information that a sensor needs to acquire is the range, azimuth and elevation of all targets of interest. This information can be acquired directly or indirectly, depending on the type of sensor. If, over several scans of the sensor, the target angles do not change and the range is decreasing, then a collision is possible.

Modelling aircraft trajectories is another method used to determine the potential for a collision. Surveillance for collision avoidance can be performed through two fundamental methods: 1) cooperative sensors, wherein a target transmits information about its position, and 2) non-cooperative sensors, which sense a target indirectly, through either passively sensing an attribute of the target, or by actively deploying energy to seek out the target. A brief summary of each sensor type follows:

2.3.1 Cooperative Sensors, ADS-B

Surveillance methods that sense a cooperative target will usually employ a transponder method by which the target transmits information about its position. TCAS relies on this method to discover other aircraft. This works well for aircraft (and eventually UAS) that fly in controlled airspace where all aircraft are required to carry a Mode A/C altitude-encoding transponder by regulations. This does not permit sensing of non-transponding targets, so such targets must be identified through other means.

ADS-B is a technology where aircraft avionics autonomously broadcast the aircraft position, altitude, velocity and other parameters. The data is broadcasted to all listeners in contrast to ADS-C, where point to point communication is established for data transfer. ADS-B data can be broadcasted via several communication techniques (UAT, 1090 MHz Extended Squitter and VDL4).

The ADS-B specification in RTCA/DO242A identifies three types of reports:

- Surveillance State vector report,
- Mode-Status vector report,
- and various on-condition reports that includes the following report type:
  - Status Change Report,
  - Air Referenced Velocity Report,
  - Target State Report,
  - Trajectory Change Report (TC+0 or TC+n reports),

Among these reports, three of them can be especially useful for estimating the flight trajectory. The first report type is the State Vector (SV) report, which contains the aircraft's 3D position and velocity. The second report type is the Target State report (TS) which contains information on the horizontal and vertical targets of an aircrafts' flight guidance system for the current flight segment. The third interesting report is the Trajectory Change (TC) report which describes the characteristics of one Trajectory Change Point (TCP) and its preceding flight segment. These characteristics include latitude and longitude, track to and from the TCP, turn radius, expected crossing altitude and time and various conformance tags. Multiple TC reports are used to describe the series of TCPs that comprise a portion of either the command or the planned trajectory of the aircraft.

ADS-B is a technology that is being adopted widespread; almost all new commercial aircraft are equipped with ADB-S transponders. Eurocontrol has issued a report (August 2007, [CASCADE ADS-B]) indicating that around 74% of flights in Europe are equipped with ADS-B Mode S extended squitter, of which 79% are broadcasting position.

2.3.2 Non-cooperative sensors

Surveillance methods that sense non transponding targets indirectly are considered non-cooperative sensing methods. A target is sensed and tracked, either (1) through passively acquiring information about the target (e.g., optical camera recording the reflected light, or acoustic sensor perceiving the target by passively listening); or (2) by actively deploying energy to seek out the target (e.g., radar which emits an electronic pulse and determine range and bearing by the angle of sensor and timing of the response, or laser range finder which emits infrared coherent light and detects reflections).

Passive sensors, such as optical cameras, can be smaller and of lighter weight, since they do not need the power to transmit energy. Most optical solutions provide a good field of regard, especially with the appropriate lenses, and can be high resolution. However, this also drives a very high processing requirement to reduce the high resolution field of view to the objects of concern. Techniques such as optic flow have been used to reduce the processing requirements. Optical solutions do provide accurate information on azimuth and elevation angles, but most of them cannot provide range information directly, which must be inferred or sensed in other ways.

Active sensors, such as a laser range finder, require more energy, so they tend to be bigger and heavier. These sensors typically can provide more accurate range information, though they are not good at angle resolution because their field of regard is either very small (laser range finder point) or very large (radar or acoustic omni-directional ping).

Most of the non-cooperative sensors operate over a much shorter range than cooperative sensors, usually only in line of sight. Thus, they are most applicable to the very short time frames of the “see and avoid” level of collision avoidance.

The use of multiple sensors can be recognised as one of several strategies to manage the shortfalls of the above sensor types. One could employ multiple sensors to cover a larger area, or multiple sensor types. One could reduce the detection and tracking requirement from fine resolution object tracking to area sensing (i.e., if there is anything detected in this sector, avoid the sector). One could simplify the avoidance reaction manoeuvres, so that the sensing requirement is limited (as in TCAS).

2.4 ASAS applications in ATM OPERATIONAL concepts

Airborne Separation Assurance System (ASAS) is an airborne system that allows the flight crew or the automated FMS to maintain separation between their aircraft and one or more other aircrafts, and provides information concerning the surrounding traffic. An ASAS key enabler technology is Automatic Dependent Surveillance – Broadcast (ADS-B).

An ADS-B transmitter allows an aircraft to broadcast its identification, position, velocity and intent information over a range of the order of 100 nautical miles. Aircraft equipped with an ADS-B receiver can then process and present this surrounding traffic information to pilots on a cockpit display of traffic information (CDTI) or in the control station (CS) in the case of UAS, or transmit to an automated FMS. ADS-B receivers on the ground can also be used to enhance the traffic information available to air traffic controllers. ADS-B main characteristics are presented in the next subsection.

Taking into account various considerations (conceptual, operational procedures, human factors, aircraft systems, enabling technologies, users' perspectives and implementation), [FAA-EUROCONTROL AP1] has defined four ASAS application categories:

i) Airborne Traffic Situational Awareness applications: These applications are aimed at enhancing the crews' knowledge of the surrounding traffic situation, both in the air and on the airport surface, and thus improving the crew's decision process for the safe and efficient management of their flight. No changes in separation tasks or responsibility are required for these applications.

ii) Airborne Spacing applications: These applications require the flight crews to achieve and maintain a given spacing with designated aircraft, as specified in a new ATC instruction. Although the crews are given new tasks, separation provision is still the controller's responsibility and applicable separation minima are unchanged.

iii) Airborne Separation applications: In these applications, the controller delegates separation responsibility and transfers the corresponding separation tasks to the crew, who ensures that the applicable airborne separation minima are met. The separation responsibility delegated to the crew is limited to designated aircraft, specified by a new clearance, and is limited in time, space, and scope. Except in these specific circumstances, separation provision is still the controller's responsibility. Implementation of these applications will require the definition of airborne separation standards.

iv) Airborne Self-separation applications: These applications require crews to separate their flight from all surrounding traffic, in accordance with the applicable airborne separation standards and rules of flight.

2.5 ASAS applications in development

More than 80 ASAS applications have been identified by EUROCONTROL/FAA. Among these, [ASAS TN-2] have identified 15 ASAS applications which are in a more mature development state. These applications are described briefly in this subsection, grouped in the following ASAS categories.

i) Enhanced traffic situational awareness during flight operations (ATSA-AIRB)

ATSA-AIRB is the basic application. It provides crews with information about nearby traffic including at least the aircraft identifier and its position. This display supplements verbal traffic information provided either by controllers or other crews, as well as normal out-the-window visual scans.

ATSA-AIRB can be used in all visual conditions and therefore is relevant to both Instrument Meteorological Conditions (IMC) and Visual Meteorological Conditions (VMC) operations. It is also applicable to all flight rules, i.e. Instrument Flight Rules (IFR) and Visual Flight Rules (VFR), and to all types of aircraft.

The objectives of this application are to improve the flight safety and efficiency in all airspace.

This Airborne surveillance application contains two sub-applications, which aim at enhancing some current procedures. They are defined by the operational goal and the airspace involved with the associated services provided by ATS. The two sub-applications are:

- *Enhanced visual acquisition for see-and-avoid*: in airspace where separation service is not provided by ATC, it aims at making the visual acquisition task easier and more reliable by the addition of an appropriate on-board traffic display.
- *Enhanced TIBA (Traffic Information Broadcast by Aircraft)*: in airspace where TIBA is applied it improves the current TIBA procedure by the addition of an appropriate on-board display of surrounding traffic to provide surveillance additional to listening to the TIBA VHF frequency.

The objective of the first application is to improve efficiency of flight in controlled airspace. The objective of the second application is safety.

ii) Enhanced traffic situational awareness on the airport surface (ATSA-SURF)

This application provides the crews with information on the surface traffic that supplements out-the-window observations and see-and-be-seen procedures. The goal is to reduce the potential for conflicts, errors and collisions (e.g. runway incursion) by providing enhanced situational awareness to the flight crew operating an aircraft on or near the airport surface.

iii) In-trail procedure in non-radar oceanic airspace (ATSA-ITP)

This application permits a “climb-through” or “descend-through” manoeuvre to pass a “blocking” aircraft, using a distance-based longitudinal separation minimum with the blocking aircraft during the ITP manoeuvre. This distance-based longitudinal separation minimum is less than the standard separation minimum applied in oceanic airspace. The goal is to enable aircraft that desire flight level changes in oceanic and remote airspace to achieve these changes on a more frequent basis, thus improving flight efficiency and safety.

iv) Enhanced visual separation on approach (ATSA-VSA)

This application helps crews to achieve the visual acquisition of the preceding aircraft and then to maintain visual separation from this aircraft. The goal is to allow an increased use of visual separation on approach in order to provide an optimum flow of traffic.

v) Sequencing and merging operations (ASPA-S&M)

The objective is to redistribute tasks related to sequencing (e.g. in-trail following) and merging of traffic between the controllers and the crews. The controllers will have a new set of instructions allowing them, for example, to instruct the crews to establish and to maintain a given time or distance in trail from a designated aircraft. The crews will perform these new tasks using a suitable human-machine interface. One anticipated benefit is increased capacity through better adherence to the ATC-requested spacing.

vi) Enhanced crossing and passing operations (ASPA-C&P)

The objective is to provide the controller with a new set of procedures to solve conflicts directing, for example, the crews to cross or pass a designated traffic aircraft while maintaining a given spacing value. The crews will perform these new tasks using a human-machine interface. The main expected benefit is increased efficiency through the reorganization and the streamlining of tasks.

vii) Lateral crossing and passing (ASEP-LC&P)

The ASSTAR project (Advanced Safe Separation Technologies and Algorithms) is currently defining a "Lateral Crossing" procedure allowing an aircraft (the "clearance" aircraft) to cross or pass a "target" aircraft using ASAS. Responsibility for separation is delegated to the crew of the clearance aircraft, although ATC remain responsible for separation of the clearance aircraft from all other aircraft. This responsibility is limited in time, space and scope for the duration of the Lateral Crossing procedure. Except in these limited specific circumstances where the crew takes responsibility for separation, ATC retains all other separation responsibility.

viii) Vertical crossing and passing (ASEP-VC&P)

The ASEP-VC&P application will consist of scenarios such as Pass Above or Pass Below, in which a trailing aircraft will be able to climb or descend two or more flight levels relative to a blocking aircraft such that during the vertical manoeuvre, the aircraft do not approach closer than some specified horizontal distance, until the vertical separation is recovered. There also exists RVSM (Reduced Vertical Separation Minima) to non-RVSM transition scenarios which will support flight level transitions in the presence of opposing traffic when flying from RVSM to non-RVSM airspace.

ix) In-trail procedure (ASEP-ITP)

ASEP-ITP is the In Trail Procedure defined as an Airborne Separation application, as opposed to an Airborne Traffic Situational Awareness application as currently being defined. ASEP-ITP is currently subject of work in the ASSTAR project.

The ASEP-ITP application is designed for use en-route in an Oceanic environment. The main objective is to increase efficiency. This will be achieved by allowing climbs or descents with temporarily reduced longitudinal separation minima. For ASEP-ITP, a limited transfer of separation responsibility between the controllers and crews is assumed (i.e. the duration of the ITP climb or descent). The crew has to monitor and maintain spacing to specific aircraft during the manoeuvre.

The ITP criteria for ASEP-ITP will most likely differ from the ITP criteria for ATSA-ITP to enable a further reduction in longitudinal separation minima during the ASEP-ITP manoeuvre.

Within ASSTAR, there are six ITP climb or descent manoeuvres, as follows:

- A Following Climb.
- A Following Descent.
- A Leading Climb.
- A Leading Descent.
- A Combined Leading-Following Climb.
- A Combined Leading-Following Descent.

x) In-trail follow (ASEP-ITF)

The ASEP-ITF application is currently being studied in ASSTAR which uses the MFF (Mediterranean Free Flight) Operational Concept as the basis for defining the ASEP-ITF application.

The application is designed for use en-route in an Oceanic environment. The objective is to reduce controller workload and to increase capacity and flight efficiency. This will be achieved by redistributing tasks and separation responsibility related to the in-trail following of traffic between the controllers and the aircrews.

Both oceanic and domestic controllers will be provided with new ATC procedures directing, for example, the aircrews to establish at the oceanic entry point and to maintain a given time or distance from a designated aircraft. The aircrews will perform these new tasks using new aircraft functions (e.g. airborne surveillance, display of traffic information, spacing functions). Within the context of ASSTAR, the use of ASEP-ITF procedures will replace most of the controller's use of the sliding Mach technique to separate traffic in the NAT (North Atlantic) Organized Track System, or more general in NAT airspace for traffic flying the same route.

xi) Sequencing and merging operations (ASEP-S&M)

The application is designed to delegate the tasks related to sequencing (e.g. in-trail following in approach) and merging of traffic from the controllers to the crews. The controllers will utilize a new set of instructions allowing them, to delegate the responsibility for maintaining separation from a designated target (lead aircraft) to the crew for a limited duration and under specific conditions. The crews will perform these new tasks using a suitable human-machine interface. The expected benefits are increased flight predictability, airspace throughput and the enabling of more efficient flight profiles.

xii) Self-separation in segregated free flight airspace (SSEP-FFAS)

The "Airborne Self Separation" concept, also referred to as "Free Flight", is where crews are allowed to select their trajectory freely in real-time, at the cost of acquiring responsibility for conflict management. EUROCONTROL defines Free Flight as the flight through 'Free

Flight Airspace' (FFAS) (see ATM2000+ Strategy), where, suitably equipped aircraft are able to fly user-preferred routings and responsibility for separation assurance from other aircraft operating in the same airspace will rest with the aircrew.

xiii) Self-separation in managed airspace (SSEP-MAS)

The SSEP-MAS concept is slightly different from the definition as provided by EUROCONTROL. In the SSEP-MAS concept, equipped aircraft are allowed to freely choose their trajectory in Managed Airspace, provided that they avoid the non-equipped aircraft in MAS which are conventionally controlled by ATC.

xiv) Self-separation in an organized track system (SSEP-FFT)

The SSEP-FFT concept is a variation of the SSEP-FFAS concept, although more restricted. The concept assumes equipped aircraft to be flying on a designated track within the oceanic Organized Track System (OTS), segregated from the non-equipped aircraft. The crew is able to choose their trajectory freely, albeit with some limitations in the horizontal direction. This concept is expected to be a first implementation towards SSEP-FFAS.

xv) Cluster control (SSEP-CC)

The Cluster Control application aims at delegating from controllers to involved crews the responsibility for maintaining an assigned minimum horizontal separation amongst a cluster of two or more aircraft. This ASAS application is defined for en-route airspace with a high traffic density. Participating aircraft may be flying across one or more control sectors at the same flight level.

It has been defined to address an operational problem, which currently induces a heavy workload for controllers. They have to vector groups of aircraft onto parallel tracks in order to let one aircraft overtake another (or more). This requires a considerable amount of work to establish and maintain safe minimum separation. Special care has to be taken when the aircraft are passing turning points.

With this ASAS application, the controller selects some aircraft planned to fly the same route, arranges the aircraft in cluster, assigns a minimum separation distance or time and fully delegates the responsibility of separation to the involved flight crews (e.g. VHF co-ordination between flight crews for passing). Then aircraft may follow or pass each other until the clearance limit.

2.6 Sense & Avoid

Sense & Avoid systems are being designed in order to let UA fly in non-segregated airspace with other aircraft. The requirement is that the system should have at least the same (or better) capabilities of the human pilot "see & avoid" function. It also needs to have the reliability of a flight critical system. Several "Sense & Avoid" prototypes are being developed that try to fulfil these requirements. Most of them are based on two different sensors: radar systems and visual camera systems.

Some studies have been conducted to define «equivalent level of safety to a human pilot» in terms of detection range and probability by using the Optical Encounter (OPEC) model. These results were subsequently verified in flight tests conducted by DRA (Defence Research Associates, Inc.) and independently by the National Air and Space Agency (NASA). It was summarily determined that on average, a human pilot detects an F-16 at 1.6 NM.

Other studies have addressed the required detection field of view for S&A sensors. The azimuth and elevation field of view requirements for S&A sensors which are commonly agreed are shown in Figure 4.

Field of Regard		
Source	Azimuth	Elevation
Int'l Standards, Rules of the Air, Section 3.2.2.4 (ICAO)	+/- 110°	No guidance
ACC/DR-UAV SMO Sense and Avoid Requirement for Remotely Operated Aircraft (ROA) 25 June 2004	+/- 110°	+/- 15°
American Standards for Testing and Materials (ASTM) 2411.04	+/- 110°	+/- 15°
U.S. DoD Standardization Program Office	+/- 110°	+/- 15°

Figure 4 - Azimuth and Elevation field of view for S&A sensors (Source: ATLANTIDA Project)

Figure 5 shows an example of a collision detection system, based on the use of millimetre wave primary and secondary RADAR systems, coupled with a high resolution CCD (Charge-Coupled Device) imager with a zoom lens, to accurately locate an oncoming air vehicle identified by the primary Radar.

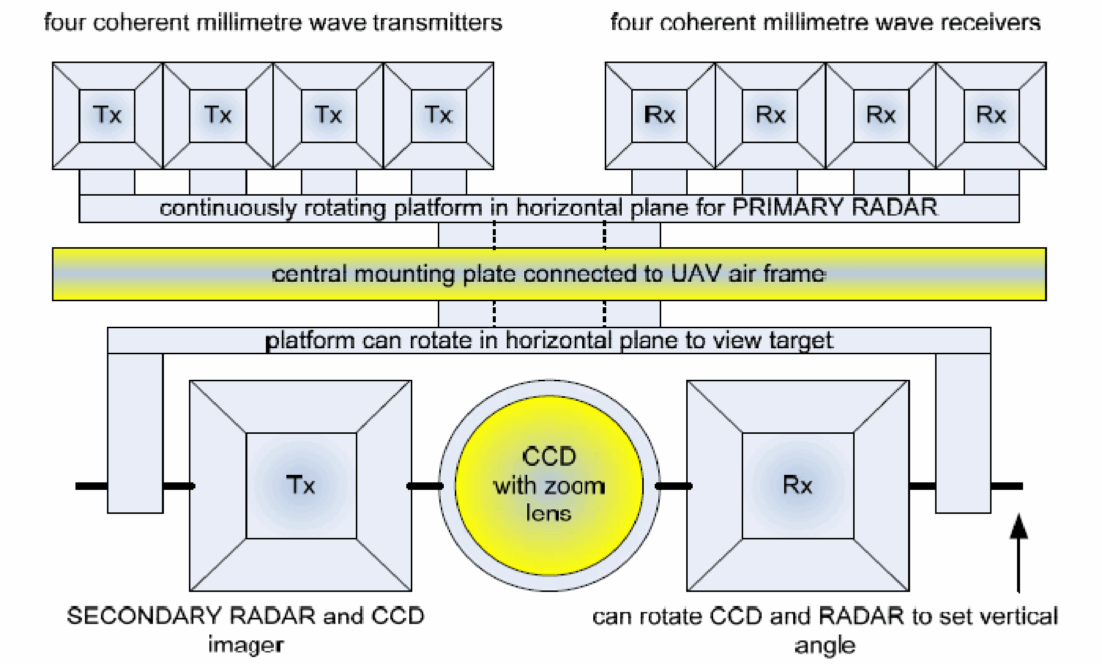

Figure 5 - RADAR based collision detection system (Source ATLANTIDA Project)

Figure 6 and Figure 7 show a system composed of several video cameras that has been developed by DRA. The system consists of several major components, including: sensors, detection/tracking processor and data recorder. All system hardware was commercial-off-the-shelf (COTS) products. The sensors are charge-coupled device (CCD) digital video cameras, with an available resolution of 2048 x 2048 pixels, and an output rate of 20 Hz. The detection and tracking processor utilized Field Programmable Gate Arrays (FPGAs) based reconfigurable computing (RC) hardware. One detection processor was paired with each sensor. The detection processor accepted sensor input (in the form of pixel intensities) and identified detections by measuring motion vs. the local background. The tracking processor accepted detection maps from the detection processor. It then stabilized detections into inertial space (using IMU –Inertial Measurement Unit – data), correlating detections to form sensible tracks. These tracks were monitored over time, with those tracks exhibiting sufficiently low line-of-sight (LOS) rates being declared as collision alerts.

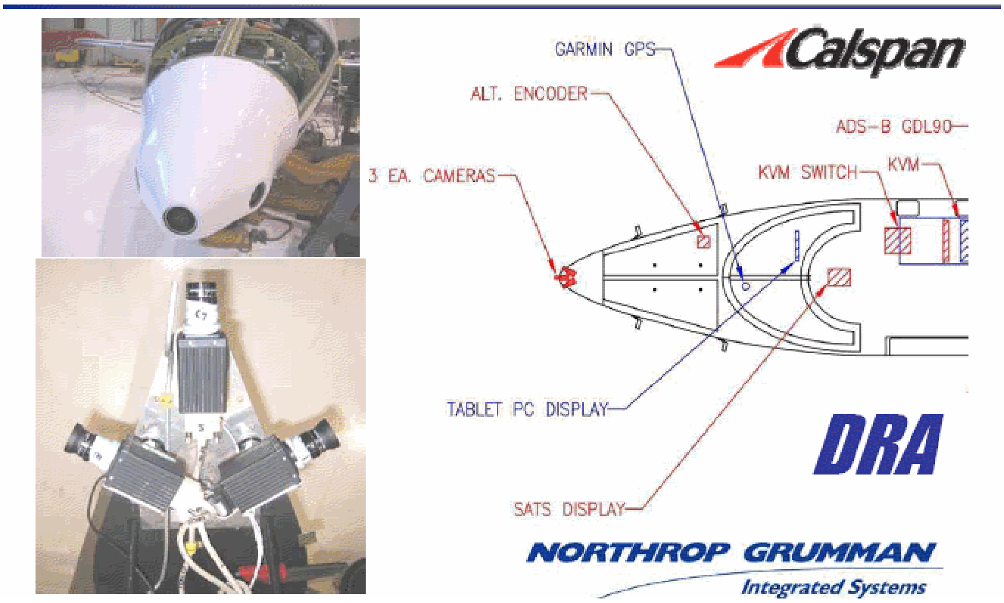

Figure 6 - DRA video cameras based collision detection system (Source: Northrop,DRA, Calspan)

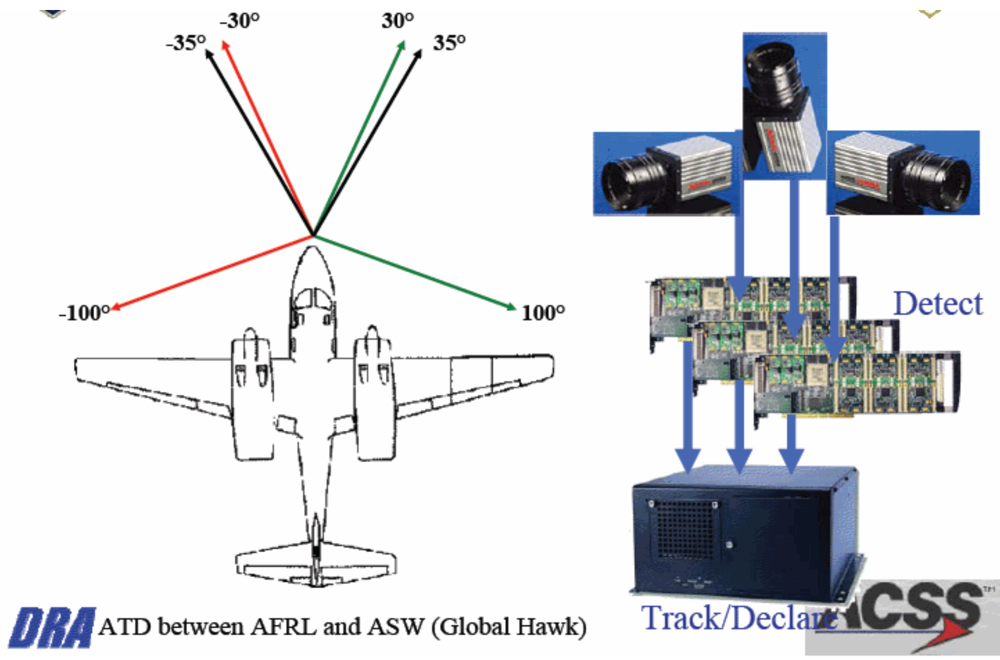

Figure 7 - DRA video cameras based collision detection system (Source: DRA, ACSS)

Conflict Detection and Resolution (CDR) arises as a fundamental technology for UAS integration, and particularly in autonomous ASAS applications. CDR techniques have been thoroughly studied in the ATC literature [CDR Review]. Conflict detection is dependant on trajectory prediction and the sensor technologies used. Conflict resolution has received much attention.

The CDR techniques that have been proposed in the literature in the ATC domain can be roughly divided into two main groups: reactive conflict resolution strategies and planning conflict resolution strategies. Reactive conflict resolution strategies compute flight state conflict resolutions, like velocity vectors or climb rates, while planning conflict resolution strategies determine future conflict free trajectories for the aircraft.

[Strategic CDR] makes a distinction between tactical and strategic CDR. Tactical conflicts require immediate action to avoid the conflict. Strategic conflicts are long term conflicts that can be solved smoothly by using a planning algorithm.

In several studies, principles from Distributed Artificial Intelligence (DAI) techniques have been used for CDR applications. When using DAI, aircraft are regarded as individual agents, which together form multiagent systems. [Cooperative state estimation] proposes two multiagent system-based cooperative schemes, which allow resolving conflicts in a safe and coordinated manner while sharing the resolution cost between all participating aircraft. Principled negotiation techniques for Free Flight are described in [ATCO agent model]. With principled negotiation, a balance arises between the aircraft's individual preferences and overall safety goals. In [Co-operative ASAS] proximate aircraft form teams to establish a plan to maintain safe separation with an agreed set of conditions. A point-to-point data-link is used for the team formations. These team or negotiation based resolution techniques search for solutions that are optimal for all aircraft involved in the resolution process.

Another planning resolution strategy to CDR in a Free Flight environment uses prioritization of the aircraft involved in a conflict. When prioritization is used, aircraft with a higher priority compute new conflict-free trajectories without taking the preferences of aircraft with lower priority into account.

2.7 Proposed research goals for Technology Development

This section presents some research areas in the CDR domain that could be interesting for developing the Sense & Avoid concept for the integration of UAS. The general idea is to combine classical collision avoidance methods with computational geometry to solve CDR applications.

One of the main problems considered not only for UAS but also for manned aviation is the climb/descent approach phase within the TMA (Terminal Manoeuvring Area) due to the high traffic congestion in these areas. When a new aircraft initiates the climb/descent phase, it has to compute a climb/descent trajectory composed of climb/descent and level flight legs so that it maintains separation with all the aircrafts. Given a set of aircrafts going down to a zone in the airport, a separation strategy is applied in such a way that a new aircraft avoids collision when the number of turns in the climb/descent is bounded. The objective in the route planning is to compute a route that minimizes its *weighted length* with respect to a weight function that specifies the cost per unit distance, subject to turn and angle constrains. The routes are considered as polygonal (piecewise-linear) paths that are specified by a sequence of vertices (turn points). Constraints on the geometry of the planned paths are considered, specifically, on the number of turn points, the descent angle and the length of each leg of the path.

3 ATM Technology Proposals

The main objective of the INOUI project is to present novel ideas to successfully overcome the challenge of integrating UAS in the 2020+ airspace environment. Furthermore, one of the pillars behind the INOUI work is that UAS will become, in the near future, frequent air space users. As such, the UAS interoperability with the future flexible ATM, so-called System Wide Information Management, must be a priority in order to aim for the maximum the safety and seamless integration of UAS into the airspace.

In deliverable 2.1 of the INOUI project the descriptions of technologies world-wide foreseen to support the ATM operation in 2020 and beyond were given. Followed by deliverable 2.2 where an analysis of the relation of technologies to operational concepts developed in WP1 was performed to determine the gaps and weaknesses of such technology to cope with the operational concept needs. Thus the gaps in technological developments for both ground and airborne systems have been identified with respects to the operational requirements in the 2020 timeframe.

Based on these two deliverables the technologies necessary to successfully integrate UAS into the ATM 2020+ are specified in this section.

Clearly the technological developments must be oriented to the SESAR programme which defines the European Air Traffic Management (ATM) modernisation. The SESAR Consortium and associated partners have agreed on the Master Plan representing the fundamental coordination tool for all future ATM activities. The SESAR Master Plan addresses the future of ATM in Europe over the next decades and forms the basis for the work programme of SESAR including for the implementation actions during the period 2008-2013.

Several technological enablers in communications, navigation and surveillance (CNS) are defined in the Master Plan and described in detail in INOUI deliverable D2.1. It is rather unlikely that the different partners in the ATM environment are willing to initiate further R&D activities or invest in additional technologies and infrastructure, only to enable UAS to become a new type of airspace user, especially when considering the small number of UAS compared to traditional airspace users. Given the complexity of the ATM environment with its vast number of systems, components and procedures that could be affected by the integration of UAS operations, there is a need to avoid or minimise any such changes. Any subsequent changes to existing systems, components and procedures will be costly, take time to implement and validate, and could have significant impact on ANSPs and the ATM Community. Thus developments of UAS specific technologies should be strongly oriented to the technologies defined within SESAR.

On the other hand it is well possible that developments in UAS specific technologies are usable and beneficial in manned aviation, for instance developments in data link and detect-and-avoid technologies.

3.1 Technology Proposals

ATM technologies are divided into those related to communication, navigation and surveillance. In INOUI deliverable D 2.2 an assessment of technologies for UAS integration was performed, which was oriented to SESAR candidate technologies. There were no technologies identified which would be critical for the integration of UAS into non-segregated airspace, even though adaptations to UAS specific requirements are inevitable, e.g. by reason of size, weight and power consumption.

However while some candidate technologies are in an advanced state of development, such as advanced flight management systems, air-ground and air-air data link communications and surveillance broadcast, others are currently in a research & development process, like technologies to enable SWIM.

The foreseen technological concepts in SESAR partly still undergo definition and development, followed by validation tests and finally their certification in order to be allowed to be used - not only in UAS but also in manned aviation. Therefore the lack of readiness of systems in the designated timeframe is leading to a risk that the integration of UAS into the non-segregated airspace is jeopardised.

3.2 Communication

3.2.1 System Wide Information Management – SWIM

One step to overcome the capacity and flexibility limitations of the current ATM systems the Single European Sky foresees implementation of a European ATM Network. Therein the System Wide Information Management (SWIM) represents the main technical enabler and is a main feature of the SESAR Concept of Operations (ConOps).

The SWIM concept stands for an information integration infrastructure that will enable interconnection of all systems throughout the whole ATM system. All ATM related data are integrated and all ATM actors will have access and collaborative decision making processes are supported. This will underpin the future ATM system with shared and up to date information. Thus SWIM represents the heart of the information management in the future ATM environment in which UAS will fly.

As the civil (commercial) and non-military governmental applications of UAS require the integration in the ATM the SWIM concept must be seen as an opportunity to integrate UAS with the rest of the air traffic.

Due to the importance of the SWIM system, INOUI project develops a concept in order to establish a relationship between SWIM and UAS. More information can be found in INOUI WP4 “2020 UAS Common Operating Picture (SWIM-enabled)”.

Within the context of SESAR, SWIM involves the sharing of large amounts of ATM data across all timeframes - long-term planning, med/short term planning, execution phase, post-flight phase.

The ATM data includes the following domains,

- Flight data (including detailed trajectories),
- Surveillance data,
- AIS/AIM data (Aeronautical Information Service/ Aeronautical Information Management),
- Capacity and Demand data,
- ATFCM Scenario data
- Meteo data

While SWIM is at a conceptual level within SESAR, there is an especially devoted project called SWIM-SUIT (http://www.swim-suit.aero). SWIM-SUIT (System Wide Information Management Supported by Innovative Technologies) is a research project supported by the European Commission Directorate General 'Transport and Energy' within the 6th Framework Programme.

It aims to demonstrate the feasibility of initial System Wide Information Management functionality for the Air Transport System and will develop the SWIM concept within the general framework defined in SESAR.

Within the SWIM-SUIT Project the following activities will be performed:

- Specification of the requirements for the SWIM implementation, including the identification of the information to be managed, the analysis of the Quality of Service (QoS) policies to be addressed as well as safety and security aspects;
- Design and Development of a SWIM test platform (SWIM Prototype) supporting the validation of the SWIM concepts where different domains of the ATM context (e.g. ATC, Airports, Aircraft Operators, etc.) will be integrated;
- Validation of the technologies identified as enablers of the SWIM concept by means of a test campaign performed on the developed test-bed;
- Assessment of the Organizational, Legal and Financial Implications including an analysis of the possible impact they may have on the SWIM implementation and thus to the associated enabling technologies.

From a large set of initial candidate technologies the following where selected as final candidate technologies:

- Common Object Request Broker Architecture (CORBA)
- Data Distribution Service (DDS)
- Enterprise Service Bus (ESB)
- Web Services (J2EE)

- Message oriented Middleware (MOM)

It is beyond the scope of this report to describe these technologies in detail. The interested reader is advised to look for more information on the SWIM-SUIT webpage. Nevertheless, the output of the SWIM-SUIT project will feed into SESAR Joint Undertaking (SJU) WP 14 which is devoted to SWIM. Whether the proposed technologies will be fully adapted within this work package or new developments will be initiated is currently not fully clear, as SJU is in its initiation phase and the contents of this work package are still being defined in detail.

3.2.2 Communication with ATC

VHF voice

Though it is clear that a reliable and effective communication between UAS and ATC is a prerequisite for the operation of UAS in managed airspace, the technological solution has not been fully defined yet. One option is to communicate with ATC using a VHF (very high frequency) radio relay aboard the UA. This allows for transparent operations with the controller and provides situational awareness to other aircraft ("party-line-effect" - pilots can listen to clearances to other pilots or their intentions).

Though ATC can require analogue VHF radio-telephony, this does not necessarily mean a radio on-board the UA. Other options can be based on an architecture where one or more VHF ground stations for analogue radio-telephony, in radio line-of-sight with relevant ATC antennas, provide connectivity between ATC and UAS flight crews. For instance besides the VHF radio on-board, there might be the possibility of few ground VHF stations installed by the UAS operator, if intending to operate in limited areas. Or a communication service provider, using a network of VHF radios on the ground to connect different UAS operators with different ATC units during their mission.

Until replaced by data link communication, radio telephony will remain essential for communication until 2020. However, voice communication between UAS and ATC will remain a special challenge given the continuing need for an immediate response to ATC instructions, i.e. latency of radio telephony communication (= time between end of transmission and begin of reply) shall not exceed 2 seconds and a greater delay might affect ATC operations. Therefore techniques to ensure robust communications, under all conditions will require special attention.

Direct phone line

An alternative to radio telephony could be a direct telephone line connection. But then technical, procedural and legal issues have to be solved. Among them are necessary investments, undefined procedures how to establish and maintain telephone communication, loss of party-line effect, technical and procedural solutions for conference connections if a number of UAS in simultaneous contact with ATC, etc.

Despite necessary solutions to enable communication routinely via telephone line, this possibility is especially useful in case of emergencies, e.g. as back-up for loss of radio communication, which makes this a unique application for UAS with a high potential benefit.

Data link (CPDLC)

Controller - Pilot Data Link Communications (CPDLC) is an application to exchange text messages between controllers and pilots via a data link connection. The idea behind CPDLC is to have an alternative way of information exchange besides voice communications.

In SESAR it is foreseen that data exchange via data link will be progressively introduced for routine communications. The ATM of the future will gradually migrate from a voice-based to a digital communication system and one of the primary technological advancements in ATC communications will be the widespread deployment of data link for all phases of flight. This advanced form of communication will support digital exchanges between ground-based systems and aircraft. The use of this technology will promote information exchange, shared SA, streamlined coordination, and a reduction in radio frequency congestion.

For that type of communication various technologies are possible. Basically the driver for choosing and implementing a specific data link technology is the higher performance required to support advanced services, such as 4D contract, trajectory exchanges, as well as increasing air-traffic volumes and density. These performance requirements are mainly predictability, security, latency, availability, integrity and throughput. Furthermore major constraints for any data link technology are the radiofrequency spectrum availability and aircraft equipment cohabitation. However it has to be considered that due to World Radio Conference (WRC) decisions, different frequency bands are used in different radio areas, i.e. regions in the world. This will pose additional challenge for the interoperability of UAS equipage.

In the near term air-ground data link services will be based on ATN/VDL Mode2 technology (Aeronautical Telecommunications Network/ VHF Data link). To fully support the ATM Target Concept this technology will need to be improved or complemented. To meet the long-term data communication needs, e.g. 4D contract and trajectory exchanges with a high number of airspace users, a dual link system is expected to be necessary to cope with the increased availability requirements.

Additionally the foreseen separation and self-separation applications like ASAS Airborne Separation Assurance Systems) and ACAS (Airborne Collision Avoidance System) require Air-Air data communications. The new terrestrial data link component (L-band technology; frequency spectrum of 1-2 GHz) is the candidate to support them. However, today operational performance requirements for this data link are not available, and thus, they need to be developed expeditiously if this enabler is to be deployed within the expected timeframe.

The final mobile data communication infrastructure will be a set of four components to support the data communication needs necessary to support the SESAR ATM Target concept:

- New L band terrestrial data link;
- Satellite data-link, to complement the terrestrial data link and provide necessary performance;
- Airport data-link based upon WIFI technology (IEEE 802.16e), to provide a high performance airport surface data link;
- VDL2/ATN (VHF Data link 2/ Aeronautical Telecommunications Network).

3.2.3 Communication issues

From a procedural perspective it should be considered whether data link communications are feasible for time critical situations where an immediate response by the pilot and/ or controller is required, for instance for maintaining separation in case of a (potential) conflict between aircraft, or during emergency situations. Furthermore in congested airspace around major hub-airports numerous clearances are issued in short time via radio, which could be impossible using data link given the current operational concept and procedures.

Whether radio or telephone or other means are used for communication, a shared situational awareness has to be assured between airspace users and ATC. A downside to CPDLC often mentioned is the missing "party line" effect which enables everybody on a radio frequency to listen to what everybody else says. These is not an indisputable argument, though, some even say that the "party line" uses much of an individual pilot's attention and does not guarantee that he picks up crucial pieces of information. However further developments should consider whether the party line effect could be modelled by specific broadcasting features.

3.3 Navigation

The objective of navigation technologies is to provide aircraft positioning and trajectory management in all phases of flight. In accordance with SESAR D3 it is expected that the primary navigation system will change from the current ground-based infrastructure to a satellite-based one. This is attributed to increased navigation performance requirements related to 3D and 4D trajectory management.

Thus global navigation satellite systems (GNSS) and at the 2015 horizon, the availability of new GNSS constellations (e.g. Galileo, GPS L5) and the further development of augmentation means will improve the accuracy, availability and the integrity of the navigation signal thus allowing enhanced positioning services in all phases of flight, including airport surface. Augmentation of a GNSS is a method of improving the navigation system's attributes, such as accuracy, reliability, and availability, through the integration of external information into the calculation process, which can be basically ground based, aircraft based or satellite based augmentation systems (GBAS, ABAS, SBAS).

However, still an open question is the institutional establishment of commercial arrangements in aviation. Issues like legal liability, certification and service charges have to be considered. Today it is neither technically nor operationally possible to state that GNSS will be the only means for positioning and it becomes necessary to assess the safety, security, operational and cost aspects linked to a redundant terrestrial positioning solution. Certain risks are associated with GNSS, e.g. intentionally or accidentally jamming the signal or natural disturbances (solar storm), and in cases of GNSS service loss backup mechanisms are still required.

A basic prerequisite for the usage of satellite based navigation is that the user community agrees that by 2020 the latest airborne GNSS equipment will have the capability to use all GNSS signals (e.g. Galileo, GPS, Glonass and SBAS).

The transition to GNSS based operations bears the chance to decommission conventional navigation aids (VOR, NDB/ ADF) and thus make available valuable radio spectrum. Decommissioning of these En-Route and TMA terrestrial navigation aids could be completed in 2025. However this needs to be carefully planned with the users, such as general aviation (GAT) and military, because this could require a significant rate of equipage of aviation users with dual constellation and possibly dual RNAV equipment to ensure the required performance. On the other hand, the worldwide network of existing ground based navigation aids or better their locations today could be used in the future for ground based UAS navigation aiding.

Presumably satellite navigation is used by most UAS already today for mission execution. Yet, there is no interface with ATS, i.e. exchange of flight plan routes, waypoints and in the future 3D/ 4D trajectories. Therefore UAS shall be technically able to process these data and thus follow ATC instructions if necessary. As the ATM Target Concept is formed around the 4D trajectory as the core of the system, a major requirement is to change the current ICAO flight plan into a 4D trajectory with a common definition and exchange format. Therefore the flight management system (FMS) of a UAS must be capable to process and share 4D trajectory information. The precise definition of data format is subject to the SESAR development phase and the SESAR Joint Undertaking.

3.4 Surveillance

As an integral part of Air Traffic Management (ATM), surveillance of positional data of aircraft constitutes the principal means for the efficient execution of Air Traffic Control. The objective of the surveillance service is to provide a complete picture of the actual traffic situation to ensure a safe separation and an efficient traffic flow. ATM surveillance is the observation of an area or space for the purpose of determining the position and movement of aircraft or vehicles in that area or space to enable Air Traffic Control.

Surveillance technologies can be divided into ground based and airborne systems. The former operated by ATC to provide controllers with the traffic picture, the latter is related to air-to-air surveillance and enabler for ASAS (Airborne Separation Assistance System) functionalities which provides assistance to the flight crew supporting the separation of their aircraft from other aircraft.

Among the surveillance technologies three basic surveillance principles are distinguished: independent non-cooperative, independent cooperative and dependent cooperative surveillance.

3.4.1 Independent non-cooperative surveillance

Independent non-cooperative surveillance determines the position (2-D) without reliance on aircraft avionics. It is based on primary surveillance radar (PSR) and by such is independent on any form of airborne avionics. PSR provides an independent surveillance means to detect non-co-operative targets or to provide a safety-net in the event of a co-operative systems failure. The PSR calculates the position of targets based on time delay between transmission and receipt of radar pulses. This basic technology will continue to exist, as necessary, for safety and security reasons, e.g. to identify transponder failures or unidentified vehicles. It is expected that by 2020 new cheaper forms of PSR using multi static techniques (MSPSR) are available.

3.4.2 Independent cooperative surveillance

Independent cooperative surveillance utilises the aircraft transponder to derive position and other avionic data. This is seen as the principal means of surveillance in 2020. It is based on (monopulse) secondary surveillance radar (SSR), SSR Mode S, multi lateration (MLAT) or WAM (wide area multi lateration). The latter uses ground based antennas instead of rotating equipment and thus is less cost intensive. Multi lateration, also known as hyperbolic positioning, is the process of locating an object by accurately computing the time difference of arrival of an signal emitted by the object to three or more receivers.

SSR is a co-operative surveillance system requiring an aircraft to carry appropriate transponders. The SSR calculates the position of targets based on time delay between transmission and receipt of radar pulses. The technique permits the extraction of Mode A code and Mode C (altitude) information. In core Europe, Mode S SSR is the preferred architecture for 2011+, however it is recognised that conventional SSR is still required in some regions of Europe. Mode S SSR is a co-operative surveillance and communication system for ATC. It employs ground-based interrogators and airborne transponders. A principal feature of Mode S that differs from existing monopulse Secondary Surveillance Radar is that each aircraft is assigned a unique 24-bit Aircraft Address. Using this unique address, interrogations can be directed selectively to a particular aircraft and replies unambiguously identified.

3.4.3 Dependent cooperative surveillance

Dependent cooperative surveillance is dependent on aircraft systems and utilises the aircraft derived position and avionic data like identification and altitude among other parameters to broadcast “air-to-ground” and “air-to-air” transmission. The candidate technology for this type of surveillance is ADS-B (Automatic Dependent Surveillance Broadcast).

Currently in most areas of Europe surveillance is relying on radar coverage based Secondary Surveillance radar (SSR) and complemented by Primary Surveillance Radar (PSR). Surveillance is foreseen to remain a mix of PSR (including MSPSR) for safety, SSR Mode S and WAM as independent surveillance and ADS-B Out for dependent surveillance. Service providers will have a flexible choice of technologies depending on the respective operational requirements, geographic location and cost efficiency decisions.

A progressive introduction of newer, more cost effective, types of non-cooperative surveillance technologies is expected to replace the older PSR technology. The challenge concerning UAS is that they are relatively small in size and often consist of composite material resulting in a very low Radar cross section (RCS) but also need to be accommodated by these newer technologies. UAS manufactures could be required to take means to increase the radar signature.

Most States are currently upgrading their Monopulse SSRs to SSR Mode S. Thus, they will not need replacing until about 2020. WAM systems are already being implemented to provide SSR type coverage in locations where, for example, conventional SSR may be unsuitable. Gradually ADS-B Out certified systems will start to become available and this will be the turning point for a change in direction for ground-based surveillance.

ADS-B (Automatic Dependent Surveillance Broadcast) with in/out capabilities is a promising candidate for a future surveillance system and is viewed as a key enabler for ASAS (Airborne Separation Assistance System) functionalities which shall provide an airborne traffic situation picture.

In order to provide ASAS (Airborne Separation Assistance System) functionalities data between aircraft has to be exchanged (air-to-air surveillance). Airborne Separation Assistance System (ASAS) is officially defined (ICAO ASAS Circular) as: "*An aircraft system based on airborne surveillance that provides assistance to the flight crew supporting the separation of their aircraft from other aircraft*". ASAS has significant potential for the future aviation environment and transfer of separation responsibility is not only a significant change from today's operations but it is an important step towards fully autonomous operations.

ADS-B is therefore a key technology with regard to the detect and avoid issue, one of the major challenges for integrating UAS into non-segregated airspace. ADS-B offers data delivery from aircraft-to-aircraft or from aircraft-to-ground. Transmitting data directly air-to-air means that there is no need for a ground infrastructure for performing airborne surveillance. One of the main benefits of air-to-air operations of ADS-B is that it enables airborne situational awareness. By using position reports received from surrounding aircraft, a traffic surveillance picture can be generated in the cockpit of all aircraft. This means that an aircraft can be presented with a surveillance picture of surrounding traffic on a cockpit display, by using ADS-B data transmitted by other aircraft.

ADS-B is also closely related to the ground-to-air transmission of surveillance information. This refers to the transmission of surveillance data (e.g. of non-ADS-B equipped targets) from ground systems to the aircraft. This service is usually described as Traffic Information Service (TIS) or TIS-Broadcast (TIS-B).

TIS-B makes use of the available surveillance sources (e.g. PSR, SSR, ADS-B) which are processed to track the position of aircraft, “ADS-B like” messages are then generated and broadcast by a TIS-B ground station. In the case of TIS-B, the related ground system originating the broadcast has no knowledge of which systems are receiving the broadcast. Any suitably equipped air or ground based user may choose to receive and process this information. For aircraft not equipped with ADS-B-out the TIS-B technology could be used. TIS-B supplements ADS-B air-to-air services to provide complete situational awareness in the cockpit of all traffic known to the ATC system.

4 Technology Roadmap

The future ATM for the timeframe of 2020 and beyond is quiet different from the one in use nowadays. We are moving from a static ATM system based on rigid procedures and tactically-oriented management with limited information sharing and limited automation capabilities towards a more co-operative system that will use advanced automation and intensive sharing of real time information to achieve accurate gate-to-gate flight management.

Important changes will be trajectory based operations, collaborative planning, information sharing through system wide information management, dynamic airspace management and new communication, navigation & surveillance (CNS) technologies. For succeeding in the integration of UAS into the future ATM, it is fundamental that technologies developed for UAS operation is compatible and interoperable with those for ATM operation.

The following CNS areas for technology development have been identified as important areas for consideration in the integration of UAS into the future ATM.

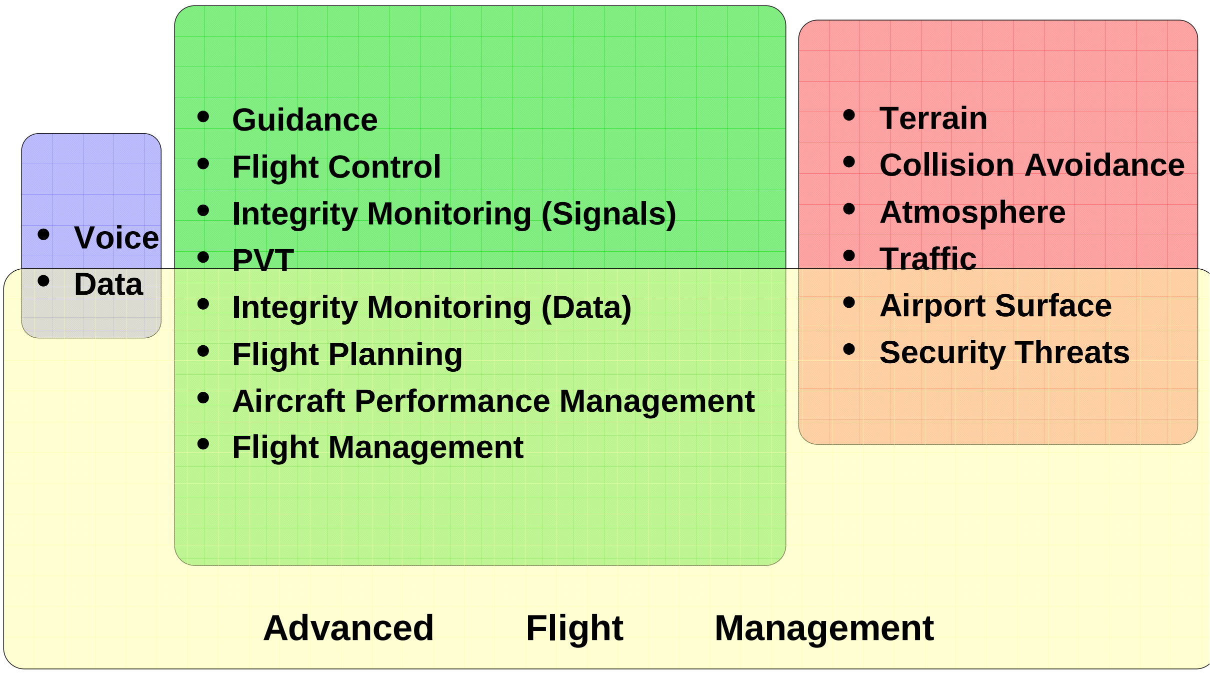

Figure 8 – CNS Areas for Technology Development (Source: OATA)

The industry is working towards new technology developments in systems with the objective of reducing the costs, facilitating the upgrades, improving the efficiency of the system and rationalizing the certification requirements of equipment. As technology evolves, there will be a common understanding of UA trajectory as part of a greater integration of airborne data with ground systems.

Key technological enablers include advanced data link services, improved GNNS system and onboard equipment to support enhanced CNS capabilities.

The transition to integrate UAS into the managed airspace must be an evolution rather than a revolution. In addition to technological advances, changes in roles and responsibilities must also be considered. To begin with, there will be a reduction on voice communications between pilot and controller with an increased use of data links for routine information exchanges. As an example, the use of CPDLC is expected to be widely used.

Surveillance technologies will evolve to enable precision monitoring of all traffic to assure safe and efficient operations, including enhanced Traffic Situational Awareness and ASAS. New surveillance systems e.g. ADS-B will increasingly provide improved 4D-trajectory information (position and time). ADS-B is foreseen for surveillance and data information services and can been designated as the primary means for the Air Situation Awareness; a safety analysis shall be conducted to determine whether TIS-B shall be used as a complementary means.

Figure 9 depicts a roadmap representing CNS evolution on UAS technologies and applications to integrate UAS into managed airspace.

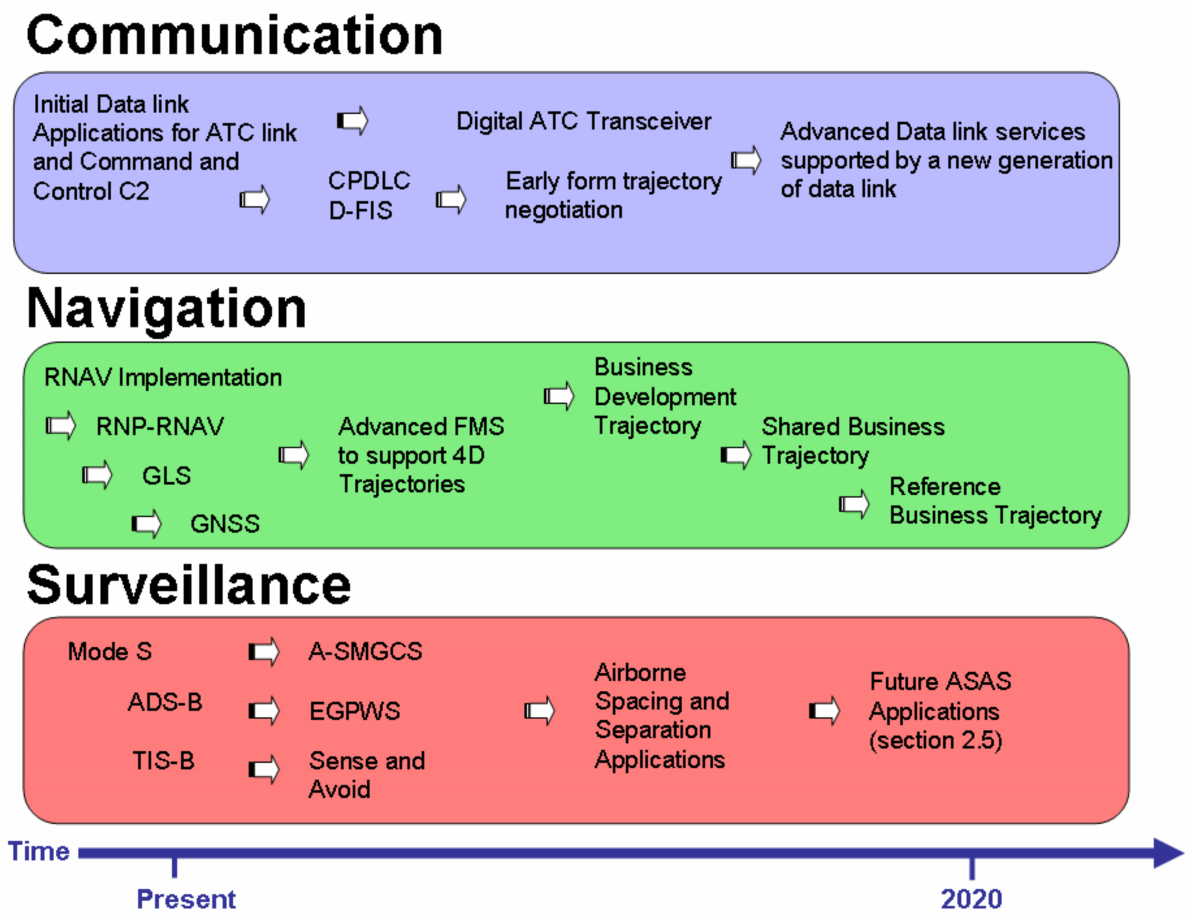

Figure 9 – CNS Technologies and future applications (Source: INOUI)

In a nutshell, there will be a requirement to at least comply with the following technological enablers for a safe integration of UAS:

- A secure advanced data link to support data exchange and improved CNS applications
- The capability to share information across a common information management system (SWIM)
- Advanced guidance and navigational capabilities (4D Trajectory) supported by enhanced FMS
- Next generation of GNSS certified for primary means of navigation

With regards to data link communications, it is foreseen that in the future 2020 ATM environment all communication will be performed via improved and secure data links as stated by SESAR. It is important to recognise that technology being currently developed for manned aviation may have to be adapted if necessary to accommodate the unmanned aviation requirements.

5 Conclusions and Recommandations

The main objective of the INOUI project is to present novel ideas to successfully overcome the challenge of integrating UAS in the 2020+ airspace environment. Furthermore, one of the pillars behind the INOUI work is that UAS will become, in the near future, frequent air space users. As such, the UAS interoperability with the future flexible ATM, so-called System Wide Information Management, must be a priority in order to aim for the maximum the safety and seamless integration of UAS into the airspace.

The objective of this document was to identify and propose a number of potential technologies to support the integration of UAS1. As part of the work involved, a technology assessment in the SESAR framework was performed. This assessment looked at the needs to cover not only specific technologies related to the UAS itself, but also to the environment in which it flies, i.e. the ATM environment.

This document highlight the importance of technology developments as an important driver for the integration of UAS, in particular those technologies and applications in the areas of Communication, Navigation and Surveillance.

To summarize, there will be a requirement to at least comply with the following technological enablers for a safe integration of UAS:

- *A secure advanced data link and next generation of GNSS certified for primary means of navigation to support data exchange and improved CNS applications in particular detect and avoid capabilities.*
- *The capability to share information across a common information management system (SWIM) and comply with interoperability requirements.*
- *Advanced guidance and navigational capabilities (4D Trajectory) supported by enhanced FMS allowing for Business Trajectories to be accomplished.*

One of the conclusions from the technology assessment was that most technologies found key enablers for UAS integration are ready or in development for manned aviation. As identified in previous work, in particular D2.2 “Report on Technology Assessment for UAS integration” it is also important to point out that technologies are not the only means to integrate UAS into the non-segregated airspace but also regulations and procedures, either for ATC, UAS or other airspace users, including operational and training procedures. Furthermore, there is a need for not just technological advances and developments but also for social economical, environmental and political issues around

[1] It must be noted that some technologies around airports are also important and therefore considered under the INOUI scope. However aerodrome technologies are being considered and described in detail under work package 6 – New Aerodrome Concepts for UAS.

UAS. UAS Technological developments must be promoted and supported by regulatory organizations as well as equipment manufacturers who are involved also in the process of standardisation.

However, there is a need for interoperability of such technologies among all airspace users Technologies already in use (or foreseen to be used in the 2020+ framework) in manned aviation are subject to be adapted to the UAS world and vice versa, where needed. This is very much in line with a statement made in SESAR D3, which explicitly mentions that:

"Specific technologies needed for UAS to ensure a transparent operation similar to a manned aircraft (e.g. dedicated high integrity UAS/operator 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"

Regarding the technologies being used and developed, at the end, the industry must be aware that there must be some standards for the technology in order to gain access to a big market, and thus promote interoperability.

As a potential benefit arising from the technology challenge is the fact that UAS could be in the future used as a potential test bed for manned aviation technology. Technologies developed for UAS may reach general aviation or commercial aviation markets. Benefits may include advanced technology designs minimizing size, power consumption and as well as cost efficient solutions.

One of the main conclusions drawn from this document is the importance to recognise that technology being currently developed for manned aviation will have to be adapted if necessary to accommodate the unmanned aviation requirements. Furthermore, such technologies being used and developed will benefit not just the UAS community but also the manned aviation community and consequently support SESAR.