Project no. TREN/07/FP6AE/S07.71574/037180 IFLY

iFly

Safety, Complexity and Responsibility based design and validation of highly automated Air Traffic Management

Specific Targeted Research Projects (STREP)

Thematic Priority 1.3.1.4.g Aeronautics and Space

iFly Deliverable D2.2

SITUATION AWARENESS, INFORMATION, COMMUNICATION AND PILOT TASKS OF UNDER AUTONOMOUS AIRCRAFT OPERATIONS

Due date of deliverable: 22 November 2007
Actual submission date: 7 January 2008

Start date of project: 22 May 2007

University of Tartu

Version: 1.3

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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DOCUMENT CONTROL SHEET

Title of document: *Situation Awareness, Information, Communication and Pilot Tasks of under autonomous aircraft operations*

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Deliverable number: *D2.2*

Project acronym: *iFly*

Project title: *Safety, Complexity and Responsibility based design and validation of highly automated Air Traffic Management*

Project no.: *TREN/07/FP6AE/S07.71574/037180 IFLY*

Instrument: *Specific Targeted Research Projects (STREP)*

Thematic Priority: *1.3.1.4.g Aeronautics and Space*

DOCUMENT CHANGE LOG

Version #	Issue Date	Sections affected	Relevant information
0.1	14/11/2007	all	
0.2	20/11/2007	all	
0.3	22/11/2007	all	
1.0	17/12/2007	all	
1.1	19/12/2007	all	
1.2	02/01/2007	1.3, 1.4, 6.3.1, 9	
1.3	08/04/2009	all	Change in iFly

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Abstract

The second deliverable of the iFly project, Work Package 2 titled *Situation Awareness, Information, Communication and Pilot Tasks of under autonomous aircraft operations* is devoted to the analysis of situation awareness of the pilots and its assurance in the conditions of airborne self separation. The essence of the situation awareness, its key aspects and requirements in fulfilling new functions of pilots in autonomous aircraft operations are covered.

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Acronyms

3D – Tree-Dimensional
4D – Four-Dimensional (Space And Time)
A^3 – iFly concept of airborne self separation
ADS-B – Automatic Dependent Surveillance - Broadcast
AOCC – Airline Operational Control Centre
ASAS – Airborne Separation Assurance System
ATA – Air Traffic Advisor
ATC – Air Traffic Control
ATCo – Air Traffic Controller
ATM – Air Traffic Management
CDTI – Cockpit Display Of Traffic Information
CD – Conflict Detection
CR – Conflict Resolution
CFIT – Controlled Flight Into Terrain
CFMU – Central Flow Management Unit
EEG – Electroencephalogram
EOG – Electrooculogram
ERP – Event- Related Potentials
EGPWS™ – Enhanced Ground Proximity Warning System from Honeywell
ETOPS – Extended range Twin-engine Operational Performance Standards
FF – Free Flight
FFACS – Free Flight Airborne Cognitive System
FFAS – Free Flight Airspace
FM – Flow Management
FMS – Flight Management System
GA – General Aviation
GPS – Global Positioning System
HMI – Human- Machine Interface
ICAO – International Civil Aviation Organization
iFly – EC DG TREN Project
IFR – Instrument Flight Rules
IMC – Instrument Meteorological Conditions
"INAV" ™ – A line of Avionics from Honeywell
NASA – National Aeronautics And Space Administration
NASA TLX – NASA Task Load Index
ND – Navigation Display
NLR – National Airspace Laboratory, Netherlands
NOTAM – Notices to Airmen
OCC – (Airline) Operational Control Centre
PASAS – Predictive Airborn Separation Assurance System
PFD – Primary flight display
"Primus EPIC"™ – A line of Avionics from Honeywell
RTA – Required Time Of Arrival
SA – Situation Awareness
SAGAT – Situation Awareness Global Assessment Technique
SART – Situation Awareness Rating Technique
SWAT – Subjective Workload Assessment Technique
TCAS – Traffic Collision Avoidance System
UAS – Unmanned Aerial System
VFR – Visual Flight Rules

1 Introduction

According to the current understanding expressed recently by SESAR Consortium (2007), the European Air Traffic Management is operating close to its limits and needs radical changes in the light of increasing air traffic flow over Europe. The solutions planned are based on the broad ideas of

- sharing data in the networks,
- developing new data communication systems in the air and on the ground and
- using new airborne and ground automated air traffic management systems.

These ideas are developed in the iFly project in concordance with SESAR ideology under the autonomous aircraft airborne self separation concept. As SESAR, the iFly project foresees challenging changes in procedures, human roles and responsibilities, approaches to the planning versus flexibility contradiction, introduces new division of roles and responsibilities from ground to air for safe flight control, automates the tasks inaccessible to humans and puts the pilots in the cockpits of autonomous aircraft into more demanding role for achieving up to six time increase in the air traffic flow density over Europe compared to current traffic levels.

1.1 The iFly project

Air transport throughout the world, and particularly in Europe, is characterised by major capacity, efficiency and environmental challenges. With continued growth in air traffic a three to six times increase is predicted for 2020. These challenges must be addressed if we are to improve the performance of the Air Traffic Management (ATM) system.

The iFly project definition was begun as a response to the European Commission (EC) 6th Framework Programme call for Innovative ATM Research in the area of “Aeronautics and Space”. The program is expected to develop novel concepts and technologies with a fresh perspective into a new air traffic management paradigm for all types of aircraft in support of a more efficient air transport system. It is aimed at supporting the integration of collaborative decision-making in a co-operative air and ground based ATM end to end concept, validating a complete ATM and airport environment, while taking into account the challenging objectives of Single European Sky and EUROCONTROL's ATM2000+ strategy (iFly Project Annex 1, 2007, p. 4).

iFly will develop a highly automated and distributed ATM design for en-route traffic, which takes advantage of autonomous aircraft operation capabilities and which is intended to manage a three to six times increase in current en-route traffic levels. Analysis of safety, complexity and pilot/ controller responsibilities, as well as subsequent assessment of ground and airborne system requirements will deliver a coherent set of operational procedures and algorithms, thus demonstrating how the results of the project may be exploited (*ibid.,* p 5).

The aim of the iFly project is to develop two operational concepts of airborne self separation. The first, A^3 concept, develops an approach to self separation, fully based on airborne responsibility. According to this concept, all the aircraft in free flight airspace are capable of providing self separation without the ATC support from the ground. The second, refined A^3 concept, involves the ATC support for the aircrews in solving critical issues in overwhelming situations, which may facilitate crew performance through distributing the responsibilities of keeping separations between airborne and ground partners.

1.2 Background and objectives of iFly WP2 Deliverable 2.2

Work Package 2 (WP2) of the iFly project is divided into two parts: "airborne responsibilities" and "bottlenecks and potential solutions" which will be addressed in four separate reports, the two first of them on airborne responsibilities:

1. Report with description of airborne human responsibilities in autonomous aircraft operations (Deliverable 2.1)
2. Report on Situation Awareness, Information, Communication and Pilot Tasks under autonomous aircraft operations (Deliverable 2.2)

These two deliverables address the A^3 concept only. The objective of the previous report (D2.1) was to cover the topic of airborne responsibilities with the purpose of identifying current and new responsibilities of the cockpit crew during the en-route phase of the flight in an autonomous aircraft environment. The current report rests on many human factors issues, analyzed in the previous iFly Deliverable 2.1 (2007).

The aim of the current WP is to identify the SA to be maintained by the crew, the information and communication needs and the tasks of the controller. This involves several questions to be taken into account. While total situation awareness is prohibitively costly in terms of both financial and human workload costs, it is recognized that there will be some minimum prerequisites for satisfactory situation awareness for iFly crews. A lot of questions to be answered by human factors approach in the Work Package 2.2 were raised in the iFly Project Annex 1 (2007, p. 44):

How does one create active and engaged iFly pilots who are sensitive not only to their own aircraft but also those around it?
How does the system support iFly pilots so that they can make the appropriate delegation of tasks with the iFly automation, particularly when the pilots are not exactly sure what their neighbours will be doing?
How will an iFly crewstation effective support recognition and projection of future automation actions?
How will they be able to intuitively predict how neighbouring iFly aircraft will perform?
How will an iFly crewstation support information abstraction and distillation to the appropriate level for effective iFly operation?

How will iFly support salient mode transitions so the pilots will know how their own aircraft and those around them will be behaving so they know what to expect next?

What type of human cognitive support will be necessary for the flight crew to be an effective iFly participant?
What will be the best way of presenting system uncertainty “information” to the flight crew?
Considering the potential state-of-the-art of avionic technology and the supportable human-system interface

1) what will the information needs of the flight crew be and to what extent will it be possible to meet or support those needs?

2) How does one make clear the level of responsibility and related roles as a function of time & place in the system?
3) How does one assure that the information available matches with the responsibility at the moment?
4) What does the crewstation need from system wide information management and what will the crew contribute?
5) What new roles will the flight crew take on and how will the needs of those tasks to be supported?

1.3 The relations of the report to SESAR

As SESAR will serve like an "umbrella" to most of EC ATM-related projects, it is adequate to evaluate how the present report relates to SESAR. In the SESAR Consortium deliverable "The ATM Target Concept. SESAR Definition Phase – Deliverable 3" (2007) the Chapter 2.3 is devoted to Human Aspects, so it is appropriate to compare the suitability of the present report to meet the criteria, described in the mentioned Chapter of SESAR Deliverable 3.

In the iFly project the key issues – human roles and tasks will change, rising new demands on system design, staff selection, training, competence requirements and relevant regulations. In the A^3 concept, pilots will obtain new demanding responsibilities, participate in strategic planning and tactical decision making on airborne self separation, participate in the advanced airborne data communication, have higher than current demands onto SA, will improve the overall system performance with their participation in free flight, serve in command and are backing the systems up in emergency, achieving high error resistance and error tolerance. In the A^3 concept pilots are seen as actors among the airspace users, who will acquire new additional roles which today belong to Air Traffic Controllers.

On the basis of this brief overview it can be concluded that the aspirations motivating the A^3 concept are in full concordance with the pilots' roles and responsibilities under SESAR D3 in unmanaged airspace.

1.4 The structure of the report

The current report is devoted to the topic of situation awareness of the autonomous aircraft crew, the information and communication needs to assure the situation awareness and the tasks of the controller. The present report consists of nine main subdivisions plus References. Section 1, "Introduction" describes briefly the aims of the iFly project, in more detail Work Package 2, and mostly the present deliverable, D2.2.

In Section 2, titled "Situation awareness: introduction and definition", the SA is discussed mainly from the point of view of Endsley's three-level theory of situation awareness, where conditionally differentiated levels of SA from lower to higher (according to the cognitive processes involved) are perception, comprehension and projection.

In Section 3 "Key elements of SA related to surveillance", a brief overview of several authors' views on pilots' SA is given and two kinds of SA – traffic awareness and mode awareness are introduced as necessary key elements to iFly pilots' surveillance capability.

In Section 4 "SA and workload: interrelated or independent constructs?" the possible relationships between pilot SA and his/ her workload are discussed together with the brief introduction of methods of measuring both constructs. As unambiguous answer to the question asked in the title of the chapter is impossible, it is concluded that at the certain phase of the system development and testing both SA and workload should be measured in free flight pilots' new working environment, as these constructs may be interrelated and influence onto each other.

In Section 5 "iFly Airborne Cognitive System functions/ responsibilities" the airborne cognitive system, including the pilot and sophisticated automated systems is reanalyzed on the basis of understanding developed in the D2.1 of the iFly project.

The new functions/ responsibilities of the autonomous aircraft pilot are covered and the limitations of their functions at four basic flying tasks – aviate, situate, navigate and communicate – in airborne self separation environment are discussed.

Section 6 “Knowledge and Information Requirements“ describes these issues from three different perspectives – non-traffic SA, strategic planning and tactical decision making, covering a broad range of detailed topics, which may become important in achieving/ maintaining the SA of the iFly crew.

In Section 7 “CDTI – Cockpit Display of Traffic Information & ASAS – Airborne Separation Assurance System“ the state of the art of these displays is briefly discussed together with the design issues suggested by ICAO.

Section 8 “Solving the conflict“ gives an understanding of the human conflict solving, describes the factors influencing human conflict detection and solving actions, conflict resolution strategies, information requirements and conflict resolution, decision making and recommendations for designing the support for human decision making and actions in conflict resolution.

In Section 9 the conclusions drawn from the previous chapters are presented.

2 Situation awareness: introduction and definition

Everyone who had the chance to dabble in piloting knows how difficult it can be to know what is going on around while trying to keep the blue side up and the nose into the preliminary designated direction. To update this knowledge over and over again and maintain being aware of the situation is one of the most critical and challenging tasks of a pilot's job, indeed. If a pilot is asked to describe what it means to him to be aware of the situation he might probably answer: "being ahead of the aircraft". Asking an air traffic controller would likely lead to the answer "having the big picture in mind". So, everyone involved in that highly dynamic aviation domain has an intuitive sense of what it means to have a high level of situation awareness (SA). But if everybody has a slightly different interpretation of the meaning of the term "situation awareness" it is difficult to reason about this concept within the iFly context.

Over the years many researchers dedicated their studies to the psychological construct of situation awareness with the result that there are as many definitions as researchers are working on that topic. Dominguez (1994) provides a long table of SA definitions which have been developed as a consequence of the difficulty of explaining, measuring and in the end defining this huge construct and its' underlying mechanisms. These definitions can be assigned to the three different theoretical approaches which are dominating the literature:

- the activity approach
- the ecological approach, and
- the information processing approach

The activity approach is based on the same named "theory of activity" and was introduced by Bedney and Meister (1999). Situation awareness is therein defined as a component of an action, with reflection in its center of attention. The hence derived definition can be analogous resumed as follows:

> SA is a conscious and dynamic “reflection” of a situation which gives the possibility to show the past, present and future. This reflection contains logical, concept related, conscious and unconscious components which allow the development of mental models.

This approach focuses on the individual and gives the possibility to specify the information processing activities inside the humans head and its’ ideal to investigate underlying functions and their interaction.

The ecological approach is a more system oriented one and is based on the perception cycle of Neisser (1976, cited in Guski, 2000). SA is here seen as a dynamic interaction between the three elements: the object, which is the information available in the external environment, the schema – the internal knowledge, developed trough training/ experience and stored in the long-term memory when not in use, and the exploration – the continuous search of the environment. It is stated that the schema is modified by the object – the schema directs the exploration – and in turn the exploration leads to the sampling of the object (cf. Adams, Tenney and Pew, 1995; Smith and Hancock, 1995).

The most often cited, formal and widely accepted definition of situation awareness is the one suggested by Endsley (1988). Endsley describes situation awareness as

> *“The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and projection of their status in the near future, which serves as basis for timely and effective decision making.”*

Endsley’s concept is mainly based on the information-processing model developed by Wickens (1992). She uses cognitive mechanisms, e.g. short-term sensory stores, schemata, and attention to describe the achievement and maintenance of situation awareness in the Three-Level theory described below.

2.1 The Three- Level theory

2.1.1 Level 1 SA – Perception

The entering wedge in achieving SA is the perception of relevant cues in the environment. From the pilot’s point of view this means to perceive e.g. other traffic, terrain, weather, own system information or red flags combined with their relevant features.

2.1.2 Level 2 SA – Comprehension

SA is more than just perceiving information. It also includes the comprehension – how people interpret, store, combine and retain single pieces of information to determine the relevance to their goals. Flach (1995, cited in Endsley, 2000) points out that “the construct of situation awareness demands that the problem of meaning be tackled head-on. Meaning must be considered both in the sense of subjective interpretation (awareness) and in the sense of objective significance or importance (situation)”. For example, if the pilot is approaching hazardous terrain and sees the terrain, he/she has successfully achieved level 1 SA, but when he/she also identifies this terrain as a hazard, the pilot has comprehended the situation and reached level 2 SA.

2.1.3 Level 3 SA – Projection

Reaching the highest level of situation awareness means that the pilot is able to project from current events and dynamics to estimate future state of the situation, which allows timely decision making. So if the pilot is able to estimate the time when the aircraft would collide with the terrain and decides if and when he/ she has to manoeuvre, the pilot projected the future state of the situation.

Endsley’s three level model focuses on the cognitive aspects (e.g. perception, memory, knowledge…) more than on the environmental aspects and can be used to find types of data that might be sought from individuals when achieving situation awareness. In airborne self separation responsibilities of aircrew and ATC will change and most of present ATC responsibilities will shift to the aircrew. It will be important to identify the information needs of the aircrew to meet the new requirements. This is possible by following Endsley’s approach and by performing the underlying cognitive task and requirement analysis. Further, this approach is well established in ATC studies concerning requirement analysis and if to consider the fact that pilots will become their own ATCo-s, this approach seems to be even more appropriate.

All in all, SA from the aircrews' point of view "can be thought of as an internalized mental model of the current state of the flight environment. This integrated picture forms the central organizing feature from which all decision making and action takes place. A vast portion of the aircrew's job is involved in developing SA and keeping it up to date in an rapidly changing environment" (Endsley, 1999, p. 257).

With respect to current ATCo job, the picture "provides the basic understanding of the traffic scenario as a whole on which planning, scheduling, predicting, solving problems and making decisions depend,…", (Hopkin, 1995, p. 312). A precise picture is based on an underlying mental model and the strategies involved, e.g. trajectory prediction and comparison of altitude, time, or distance (Nunes & Mogford, 2003). In case of conflict detection currently ATCo relies on these strategies.

3 Key elements of SA related to surveillance

Due to the fact that the construct of SA in its total is hardly manageable, researchers have decided to identify elements, which are related to pilots' monitoring activity during en-route flight. Most of the identified elements are not explicitly differentiable due to the knowledge assigned, and include sometimes a combination of other elements. Uhlarik and Comeford (2002) listed in their review of relevant SA literature four components which are related to surveillance:

Environmental awareness
Spatial awareness
Temporal awareness
Navigation awareness

Environmental awareness is achieved if the pilot gains knowledge of weather, wind shear, traffic, airport conditions and icing (Regal et al., 1987). Endsley (1999) on the other hand defines environmental awareness as the knowledge of weather formation (area and altitudes affected and movement; temperature, icing, clouds, ceiling, sun, visibility…; IFR vs. VFR conditions; areas and altitudes to avoid; flight safety; projected weather conditions) – whereas traffic is not explicitly mentioned.

To achieve spatial awareness, according to the literature, a pilot needs to have knowledge of attitude, location relative to terrain, waypoints and navaids, flight path vector and speed (Regal et al., 1987). In Endsley's definition spatial awareness is associated with temporal SA and includes additional knowledge of aircraft capabilities, projected flight path, projected landing time, deviation from flight plan and clearances. Wickens (1992) agrees with Endsley's definition of temporal SA in the way as he states that the pilot has to know how much time remains before deadlines.

The last component in this definition, regarding the required knowledge/ information is not clearly distinguishable from the above mentioned key elements. Wickens (1992) stated that it is achieved if the pilot can answer the following questions appropriate: “Where am I with regard to other aircraft, the terrain and local weather conditions?” Endsley (1999) defines this component as Geographical awareness, which can be obtained if one has the knowledge of location of own aircraft, other aircraft, terrain features, airports, cities, waypoints and navigation fixes; position relative to designated features; runway and taxiway assignments; path to desired locations; climb and descent points.

Two “additional” components, which are not mentioned above, have become more important these days. One is described by Endsley (1999) as System Awareness and it requires knowledge of system status, functioning and settings; settings of radio, altimeter and transponder equipment; ATC communication present; deviation from current settings; flight modes and automation entries and settings; impact of malfunctions/system degrades and settings on system performance and flight safety; fuel; time and distance available on fuel.

And if one considers the amount of automation in today’s and future cockpit, the introduction of Mode awareness, the knowledge of the status quo/mode of automation seems obvious.

The paragraphs above don’t lay claim to completeness – not at all, but give a short overview of the complexity of the “situation awareness” construct and of the need for iFly to use a clear working definition/ description of relevant key components of SA to identify coherent knowledge and information requirements, based on task and requirement analyses, to effectively investigate human behaviour in highly dynamic aviation domain.

3.1 Traffic and Mode awareness: working definitions in iFly

With the concept of Airborne self separation and the improved technologies more control and responsibility can be given to the cockpit and airline as well, with the basic idea that capacity can be increased with acceptable level of workload on the ground as well as in the air. But for all that these changes might have an impact on performance, workload and for a certainty on how pilots achieve a high level of situation awareness – they become their own air traffic controllers!

Today's responsibility of airline and corporate pilots or even GA pilots operating under IFR in IMC regarding maintaining separation and the therewith associated necessity to achieve high level of traffic situation awareness is reduced to a minimum. Pilots are committed to obey controllers' instruction and as the last instance to react on TCAS advice, as it is common practice these days for commercial pilots. Despite all that every pilot tries to achieve a rough picture of what is going on around by looking out of the window and listening to radio communication. This more or less slack attitude towards achieving high traffic situation awareness – sometimes even leading to a very low level of workload in the cockpit – has to change and will change as a consequence of the new responsibility of the aircrew to maintain self separation in free flight. Therefore Traffic Situation Awareness together with Mode Awareness seem to be the most important elements in the new concept/environment, when especially looking at tactical decision making to avoid conflicts with respect to safety, efficiency, and airline policies.

> *"Traffic awareness is achieved by knowledge and information about own and other aircraft in vincinity, necessary for safe flight under normal or non-normal conditions."*

Today ATCo substantially participate in generating the traffic awareness of the pilots, but in the free flight environment the pilots will have to manage on their own, being additionally responsible for obtaining, maintaining and regaining self separation. These new active tasks extend the demands to pilots' traffic awareness in free flight airspace, requesting support form airborne automation (A^3) and from ATC (at the refinement phase of A^3 concept).

3.2 Automation and SA

Primal the purpose of automation was to replace the variety of human tasks, like manual tasks, planning and decision making by automatic devices, on the basis that human operators are unreliable or inefficient. But the ironic thing is that the same human is still needed to control, adjust or improve the automated system and has to do tasks nobody knows how to automate. Another function assigned to the human in the system is to serve as a backup controller for the system failure or emergency. But the only way to achieve this – having the human in the back acting as a back up – is to keep the human in-the-loop, which means to give the aircrew the possibility to be aware of actions of the automated systems.

It is not yet clear to which extent SA may suffer under all forms of automation. Endsley stated that pilots, who have lost SA due to being out-of-the-loop may be slower in detecting changes and problems, which would lead to extra time in gathering relevant system parameters to proceed with problem diagnosis and further on with manual performance in the case of an automation failure. This sounds reasonable when one considers the following factors that result from the “being out-of-the-loop” stage: loss of vigilance, receiving information passively instead of actively processing information and loss of or changes in feedback concerning state of the system (Endsley & Kirsis, 1995).

When pilots get used to some types of automation or even to assisting tools they begin highly to rely on these systems without trying to get to the bottom of it. Pilots don’t scrutinize if displays are correct. Such behaviour can be observed in general aviation cockpits although automation and assisting tools are very rare in this field. But for example since GPS systems are affordable also for private pilots, several major accidents, e.g. controlled flight into terrain (CFIT), can be referred to over reliance on GPS systems and longer head-down times instead of looking out of the window. Many pilots don’t make any plausibility checks anymore. They don’t look out of the window to compare external information to what they see on the map.

Back to the commercial aviation and its’ highly automated cockpit: pilots tend to pass responsibility to automated systems without knowing how the system works or which inputs are used to provide, for example, conflict solutions. Latest at the time point when the aircrew fails to maintain self separation and conflict resolution algorithms come into play on a more or less automated level, the key component “Mode Awareness” must be considered as it is defined below:

> *“Mode awareness is defined by having the knowledge and information which is necessary to know about the status quo/mode of automation, the configuration, the current sub-processes and their future behaviour.”*

There are some aspects which should be considered when developing supporting automation tools. The pilot should be kept in-the-loop for certain aspects of a task and their workload should be kept at a reasonable level, so that the pilot has the possibility to keep the important SA information in his/her memory. Further on, the automation should be designed in such a way, that the pilot is aware what the system will do next. The pilot should have the possibility to keep track of relevant information in order to react as quickly and appropriately as possible in case of automation failure. So to sum up:

Ideal automation should include the understanding of the operator, the task requirement, and the environment. A way to include the understanding of the operator into automated systems is to base the tool on the mental model of the operator, on his perceptions of how to solve for example traffic conflicts. This enables a clear understanding, shorter response times, and advances the trust into the system. When developing an assisting tool, the designers and engineers must have a profound knowledge of the task requirements for the given situation, the new tool would assist in and include this knowledge in the design cycle. The same holds true for environmental conditions.

4 SA and workload: interrelated or independent constructs?

Mental workload is defined in terms of an interaction between demands of the task and the ability of the operator to fulfil these demands accurately and in a timely fashion (Wickens & Hollands, 1999). According to a definition:

> „Mental workload can be viewed as a pool of resources, which start at a certain capacity due to a subjects' skill and knowledge and are either all dedicated to one primary task or are partially diverted to secondary environmental tasks, leaving the less-than-full resource pool for the primary task“ (Wierwille et al., 1992).

Probably there is no definite answer to the question stated in the title of the present chapter. Wickens (2001) addressed this question and said: “Most importantly, these links are defined by the fact that maintaining a high and accurate level of situation awareness is a resource-intensive cognition process” (p. 448). On one side the achievement of situation awareness needs a lot of resources which could compete with other concurrent cognitive tasks. On the other side one can state, that the performance of concurrent cognitive tasks may divert necessary resources from the task of “maintaining SA”. This must not necessarily end up in a loss of SA unless the pilot gets into an abnormal situation and an appropriate projection is not possible due to missing information. And this is even not the whole truth, because expertise and skills are intervening factors. Experienced pilots may maintain a high level SA with less resources involved, compared to an inexperienced pilot. Training and experience helps to complete different tasks with less mental workload. In contrast Endsley (1993) stated that SA is necessarily at risk when workload demands exceed the human capacity. But problems may also occur in the case of low or moderate workload.

Due to the fact that there is no definite answer about the relations between SA and workload, it is of most importance during evaluation of a design concept to measure both SA and workload independently in order to get an exhaustive understanding of both concepts in the new conditions.

4.1 Measuring SA

Several methods have been developed to measure different aspects of situation awareness (cf. Durso & Gronlund, 1999). The main question is, when to use which method. This is highly dependent on the test environment and the task to perform. Methods of measuring SA can be subdivided into three main categories.

- *Subjective measures* are more an estimation of situation awareness and are conducted by individual operators or experienced observers. One well known example of subjective scales is the “situation awareness rating technique” (SART) developed by Taylor (1990).
- *Implicit Performance Measures* use performance indices as an implicit measure of SA (e.g. Andre et al., 1991; Pritchett & Hansmann, 2000).
- *Explicit Measures* are based on self reports of human operators – on retrospective reconstruction of situations and their subjective awareness during ongoing or interrupted performance. Pilots for example might be asked to recall information concerning most recent state parameters (e.g. altitude, speed) of the aircraft. This information can be obtained via “retrospective measures” (after the task is completed), “concurrent measures” (like verbal protocols during task performance) or by using the “freeze technique” (participant is asked to answer questions mid-task: e.g. SAGAT by Endsley, 1995b).

4.2 Measuring workload

The techniques for measuring this complex and multifarious concept can be differentiated into three main categories:

- *Subjective measures* – The NASA Task Load Index (NASA TLX, Hart & Staveland, 1988) and the Subjective Workload Assessment Technique (SWAT, Reid et al., 1981), as examples, are both multidimensional scales. These self-report measures enable to obtain an overall workload score based on a weighted average of ratings on different subscales. For example the NASA-TLX consists of six subscales, namely: mental demands, physical demands, temporal demands, own performance, effort, and frustration.
- *Performance measures* – Primary task performance measures are oriented to measurement of operators ability to perform the (primary, actually the only) task

under analysis. Secondary task performance measures are oriented to measurements of operators' ability to perform an additional (secondary) task concurrently with the main (primary) task (Wickens & Hollands, 2000).

- *Psychophysiological measures* – monitoring e.g.: heart rate, blood pressure, electrooculogram, electroencephalogram etc. of the human operator.

  Psychophysiological measures are used to assess changes in mental workload in demanding environments, particularly in piloting. In applied settings as well as in the laboratory, psychophysiological measures can provide information that is not easily available from performance measures or subjective ratings. These measures are used to study reactions of operators to job demands and environmental stressors. Especially heart rate and its' variability has a long history as a measure of mental workload in simulations and in actual flights. Heart rate can provide a continuous record of fluctuations in mental workload without including additional signals into the piloting task (Roscoe, 1993). Also EEG (Electroencephalogram) and ERP (Event related potentials) measures have shown promising results concerning changes in mental workload under adverse conditions. EOG (Electrooculogram) measures are for example sensitive to variations in mental workload, but not diagnostic regarding specific variations of workload that are maybe involved in the operator- task interaction (Gaillard & Kramer, 2000).

  One big advantage of psychphysiological recordings is that they can be taken continuously without interrupting the work flow and are not subjected to "faking" such as psychological scales. One disadvantage is that various biochemical and bioelectrical measures are often not easy to obtain at real workplaces. Recording artefacts caused by body movements or electromagnetic fields limit their use. Another disadvantage is related to the fact that correlations between workload level and the psychophysiological indicators are not unequivocal and easy to interpret.

At this point it has to be mentioned that using only one measure, signal, evaluation or activity is not adequate neither for studying the situation awareness nor workload. For a more detailed overview of situation awareness and workload measures in use one should consult the book by Stanton, Salmon, Walker, Baber, and Jenkins (2005).

5 A^3 Airborne Cognitive System functions/ responsibilities

5.1 Introduction

Deliverable 2.1 put forth a number of issues regarding the evolution of responsibilities under A^3 conditions.

First of all, the notion of responsibility itself was discussed. According to the definition suggested in D2.1 what is meant by “responsibility” is quite close to “high level goals” of the activity.

Second, a first identification of high level tasks of current responsibility of commercial and corporate aviation crews was performed. As a result 13 high level tasks were identified:

1. Aircraft systems checking
2. Fuel management
3. Passengers safety and comfort management
4. Navigation
5. Radio watch
6. Communicating with ATC
7. Logbook and flight documents management
8. Flight path and flight plan changes management
9. Operational and commercial communication with the airline base
10. Crew coordination
11. Airborne separation management
12. Technical Failure management
13. Flying the aircraft

Thirdly, general aviation was proposed as a model of free flight. And the responsibilities of the crew were in that specific context identified as follows:

1. Aviate
2. Situate
3. Navigate
4. Communicate

Based on these tenets a proposal of the possible evolution of responsibilities under A^3 conditions will be given in the following paragraphs. Moreover, a more detailed task analysis was realized in D2.1 that might help when trying to understand the detailed content of the responsibilities more completely.

5.2 Actual functions necessary for safe flying in non-free-flight airspace (controlled airspace)

As mentioned above, a first set of crew functions (responsibilities) was presented in WP2 D2.1 based on empirical data collected from interviews with commercial and corporate aviation pilots. A set of high level responsibilities was also derived from general aviation experience. Based on these inputs, a list of high level responsibilities which highlight the elements of a safe flight in controlled airspace, was developed in the present paragraph. The starting point was the golden rule for good airmanship: *Aviate, Navigate & Communicate* - the three, incontestable, prioritized acts of flight; whether piloting a commercial aircraft, a military fighter, a helicopter or general aviation trainer. To these three high level responsibilities situation awareness or “the Situate function” was added, which ensures the safety of the flight with regard to the surrounding environment, i.e. other traffic, weather conditions and terrain or other threats.

Thus, a list of high level crew responsibilities, and a set of sub-functions related to each high level responsibility, is then derived and presented hereafter:

A. Aviate responsibility and its sub-functions

To be *in control* of the aircraft during the flight, within the certified limit of operation, the related sub-functions are:

- **Aircraft systems monitoring**

  Performed usually on specific waypoints of the flight path, the crew responsibility is to *monitor* all the aircraft systems; e.g., the electrical system, hydraulic system, air systems (air conditioning, pressurization*),* flight instruments and displays, doors and windows, fuel systems,…etc.

Some systems may need additional testing (to verify correct functioning, i.e. fire protection system, pressurization, engine temperature, etc). It is also about monitoring of altitude and flight parameters (comparing speed and altitude with target parameters), thrust, airplane lateral balance (symmetry of thrust, fuel quantity, trim). Crews tend to rely more and more on the alarm systems of the aircraft as current flight-decks present as little information as possible, except if there is a problem. Thus, crews tend to *scan* systems status periodically (for example once every hour).

- **Fuel Management**

One of the main tasks of flight management is the responsibility of the crew for monitoring the use of fuel during the flight. It aims to check fuel quantity or any fuel leak, fuel transfer pumps failures or malfunction, unintended transfers, etc. This helps the crew in determining the estimated trip fuel quantity, estimated time of arrival,...etc.

Any change in the flight-path, altitude or speed implies changes in the estimated fuel consumption and thus in the capacity of the aircraft to maintain its expected performances. The crew needs to keep an updated status of the remaining fuel quantity compared to the estimated one, which is accomplished mainly at turning points or in case of flight path changes (altitude, speed,...).

- **Logbook and flight documents management**

Even though not related directly to the safety of the flight, management of records and updating operational and voyage documents are part of the responsibility of the crew, which is mainly performed during en-route phase, as it is considered a less critical phase of flight compared to take-off and landing.

- **Passenger's safety and comfort management**

This function, specific to commercial and corporate aviation, is part of the crew duties: *monitoring* cabin temperature and pressure, making announcements about upcoming turbulence or other safety concerns.

- **Technical Failure/emergency situation management**

The ultimate priority of the crew in case of any critical system failure, and/or emergency or non-normal situation is to minimize the impact of inoperative airplane systems on safety performance of the aircraft, and to recover the airplane to the normal flight envelope.

B. Navigate responsibility and its sub-functions

- **Monitoring aircraft profile and speed**

Flight management being assured by FMS, the responsibility of the crew consists of monitoring the lateral and vertical parameters compared to the targets (bank angles, speed, heading, thrust, etc).

- **Trajectory determination and flight plan changes management**

In the current system, mainly when considering commercial aviation, the flight plan is predetermined by the airline based on international published routes (Flight routes) and optimized flight time, taking safety and operational constrains (ETOPS rules, alternate airport availability, ground infrastructure and support,...) into consideration. The computerized flight plan is then automatically established, and adjusted with regard to the flight commercial weight, fuel boarded, weather conditions, etc.

- **Airborne separation management**

The separations are nowadays completely determined by the Air Traffic Controller, based on standard procedures, basic knowledge and operational data (weather, contingencies,..), and transmitted to the crew, who is only responsible for respecting the assigned separation distance (lateral and vertical).

- **Conflict Management (TCAS management)**

Reasonably all the conflicting situations are predicted and resolved by the Air Traffic Controller based on his/her overall situation awareness of the traffic within the airspace. In such configuration, the crew is only responsible to manage short-term conflicting situations and thus to avoid collision with other aircraft by relying completely on TCAS.

C. Communicate responsibility and its sub-functions

- **Communicating with ATC**

This type of communication concerns mainly the ATC clearances and requests related to flight path changes (flight level, speed, lateral separation, restricted areas...), but may also be related to the latest weather data request from the crew and flight routing changes (direct routes).

- **Operational and commercial communication with the airline base**

Air-ground communication with airline operational control centre (or line base) is mainly about latest weather data requests, as well as about commercial messages such as ACAS messages with estimated time of arrival, number of passengers, etc. For larger airliners, this communication is supported by data link systems, but some airlines still use radio communication.

D. Situate function and sub-functions

- **Weather and Terrain**

For weather prediction, crew already uses predictive equipment and radar systems which enable them to forecast weather conditions. Weather information is also available upon request trough direct communication with ATC or airline OCC (Operational Control Centre) or even other aircraft over flying the same airspace.

As for terrain prediction, a large number of aircraft is equipped with EGPWS (Enhanced Ground Proximity Warning System) or even GPWS supported by updated geographical maps. For light aircraft the “see and avoid” concept is the best solution.

- **Radio watch-over**

As explained in WP 2.1, the interviews with the pilots highlighted that this function provides the crew with a real representation of the surrounding environment in terms of traffic, weather, turbulence, or any other hazard (birds, etc).

5.3 Changed / new Airborne Cognitive System functions / responsibilities in A^3 conditions:

5.3.1 Know when Airborne Cognitive System is in A^3 airspace

In controlled airspace, the beginning (or the exit) of the en-route phase does not imply any change for the crew but the starting of routinely procedures and the end of departure or the beginning of the approach.

In A^3 airspace, the entrance of the “en-route phase” will significantly change in terms of responsibilities and behaviours: it will require from the crew a preparation (before entering the A^3 phase), and execution of new or changed tasks. Responsibilities and tasks similar to current VFR operations are expected. This means higher concentration and workload compared to current en-route activities. In fact crew will manage not only the safety and efficiency of their flight, but will also manage airborne separation and conflict resolution, which were previously the responsibility of ATC.

In addition, the transition from take-off phase to en-route- phase is nowadays considered as a *relief* phase with regard to workload. Under the A^3 concept this transition phase (configuring aircraft for entering and cruising in the A^3 airspace) is expected to be more demanding than it was in the past.

5.3.2 Airborne responsibilities under A^3 concept

A^3 concept will undoubtedly change crew responsibilities by modifying actual responsibilities and introducing new ones. Based on the set of responsibilities and their associated sub-functions described above, in the following paragraphs the identified changes concerning the actual responsibilities and sub-functions and the new ones, to be considered as specific A^3 responsibilities, will be discussed briefly.

A. Aviate function and sub-functions

- **Aircraft systems monitoring**

  The A^3 concept will apparently be based on additional airborne equipment and automation. In fact, this new concept will require from each aircraft participating in airborne self separation to be “updated with the most accurate picture” of the surrounding traffic, as well as an anticipated awareness of the approaching aircraft vectors. So, there will be more reliance on aircraft systems, to ensure the aircraft airworthiness and safety functioning. This will require from the crew more system monitoring and checking. The human-machine interaction is an important issue that must be investigated in the aircraft systems and equipment conception phase.

- **Fuel Management**

  Current fuel management tasks cover fuel quantity calculation and strategic flight management (speed, flight level, etc) and are performed mainly on specific waypoints, and/or in the case of any flight path changes. In the A^3 context a high importance is expected to be given to optimization of fuel consumption. Of course it is understood that in a hazardous traffic situation priorities will be given to conflict resolution and a decision to change the flight path to resolve a conflict will override the considerations of fuel consumption optimization.

  Nevertheless, it is assumed that the issue of fuel consumption may represent an important input from a financial point of view to be taken into account by airlines policies in trajectories determination. Thus, some optimization of fuel use will be necessary in the determination of the flight routings without compromising the flight safety level. This could be an interesting advantage/ benefit of A^3 as today's manoeuvres induced by ATC are not fuel-optimized.

- **Logbook and flight documents management**

New airborne parameters and traffic status will need monitoring and records. Thus, additional workload may be expected in terms of documents fill in and update.

- **Passengers safety and comfort management**

This function, specific to commercial aviation, is part of the crew duties. There may be additional announcements due to flight path changes, conflicting situations or just to explain flight details to comfort passengers about the safety and punctuality of the flight. Other comfort parameters such as cabin pressure and temperature may need more monitoring and adjustment in accordance to the flight levels and aircraft profile.

- **Technical Failure and emergency situation management**

In controlled airspace, the crew has to concentrate exclusively on failure management and controlling the aircraft, i.e. on the *Aviate* function, considering that ATC have cleared out the surrounding airspace. In A^3 airspace, a technical failure affecting the aircraft capabilities and/or its ability to maintain safely the planned trajectory and separation, represent an emergency situation not only to that considered aircraft but also to the other aircraft within the A^3 airspace. Thus, an additional priority of the crew, other than recovering from failure and managing the emergency situation caused by internal threat, is to maintain awareness of the outside threat caused by traffic situation. At the same time the crew has to manage the consequences of the additional risks to other aircraft within the same airspace, produced by their emergency situation.

B. Navigate and sub-functions

- **Trajectory determination and flight plan changes management**

As outlined above, the trajectory determination is more a responsibility of the airline than of the crew. The established flight plan being computerized based on international standard routes and adjusted prior to each flight with regards to the commercial and updated specifications.

The A^3 concept will be based on optimized flight paths routing without being restricted to specific standard routes, turning waypoints, etc. Still, the idea of a pre-planned flight plan is hardly avoidable. The only difference is that changes to the flight plan will no more be rare and obey to the request of the ATC, or due to crew willingness to optimize the flight path (direct route), but changes will be as frequent as necessary. In these cases, the changes are not only motivated by the optimization of the route (as it is already an optimized one, unless to take advantage of updated situation of traffic, tail wind, ...etc.), but also to manage separation, conflict resolution, in addition to other conditions such as bad weather or turbulence conditions, aircraft system failure, etc.

Thus, under A^3 concept, this responsibility should be assigned entirely to the crew and their airline operation centre.

- **Monitoring aircraft profile and speed**

As flight plan is composed of distinguished “paths/routes” joining waypoints, speed and altitude changes during the en-route phase are not frequent, unless it is requested by ATC or it is necessary to avoid bad weather conditions.

Within A^3 airspace, aircraft speed and profile will depend primarily on the pre-planned flight plan (computerized upon the estimated traffic on the intended route) but will continuously be updated by the crew with regard to the real traffic, performance of other aircraft, etc.

- **Airborne separation management**

One of the new challenges, which will be introduced by the A^3 concept, is to assign the separation determination responsibility to each airborne system. The airborne system will do more than “executing” but will have to calculate and predict the separation of its aircraft from others during the whole phase of flight.

- **Conflict Management**

In the A^3 concept, the responsibility to predict long, medium and short term conflicting situation will be assigned to the airborne system. We expect that a major part of this task will be managed through delegation to automation. The definition of the level of automation and its particularities will not be discussed at this point of the project. Still, it can be expected that TCAS/ACAS will certainly remain a useful system to resolve short term conflict situations.

C. Communicate and sub-functions

- **From Communicating with the ATC to Airborne Information sharing system**

The new A^3 concept is based on the idea of eliminating direct crew communication with ATC, who is nowadays in charge of traffic management. The need of *intent information* from other aircraft will thus be necessary as a mean for an airborne system to be able to manage safely its trajectory. Hence, we may imagine the replacement of communication with ATC as a source of information by another source which will provide the sufficient elements to build complete (actual and future) traffic situation awareness. An airborne information sharing system is one of the sources identified so far to help the crew keeping an updated situation awareness of the traffic.

- **Operational and commercial communication with the airline base**

Future air/ ground communication being more and more based on data link, the role of AOCC (Airline Operational Control Centre) is going beyond the supervisory role both from the flight safety and commercial standpoints. In the free flight concept, we expect more reliance on AOCC communication to update computerized flight plan, weather and other useful information for the flight, as well as significant support in the case of failure or emergency situation.

Mainly for long term flight planning, traffic and weather conditions prediction, these tasks may be supported by the AOCC in charge to supervise the flight. In this context we can also speculate that on special occasions (crowded airborne self separation airspace, adverse weather conditions, … etc.) AOCC-s of different airlines may develop a kind of temporary collaboration. It is difficult to predict the forms and the content of this collaboration, but the main aims of it should be keeping the safety in the airspace and facilitating performance of the aircrews.

D. Situate function and sub-functions

- **Weather and Terrain**

As mentioned above, crew relies mainly on automated onboard equipment for weather and terrain prediction and related threat identification. But even though recent technology evolutions have made equipment more and more reliable, the crew still needs updated information from ATC. In the case this information is not available by traditional ways, the airborne systems need to be highly technically reliable.

- **Radio watch-over**

As outlined in WP D2.1, radio watch-over is mainly a mean for the crew to construct an updated and real mental representation of the surrounding environment; i.e. traffic, weather conditions and other possible threats (flock of birds, turbulence, ground support failure etc).

In the new A^3 concept, there is no reason to imagine that the use of radio watch-over will change: the crew will have more and more needs to update its representation of the surrounding real ‘world’ and radio watch-over will be an appreciated complementary resource to other information source(s) (to be defined) in helping the crew to keep an optimal situation awareness.

It is conceivable that this function, considered as a communication task, will help the crew to fulfil its need to be in direct contact with the external environment, i.e. mainly with other traffic, as an ultimate way to recover from uncertainty about traffic situation.

- **Traffic awareness**

This responsibility, previously largerly managed by ATC, will be assigned to the airborne system under the A^3 concept. Thus, it is a new responsibility specific to airborne self separation, and will need additional cognitive resources from the crew. It may be interpreted as *an extension* of the actual ATC responsibility to airborne system [in reference to the function decomposition introduced by Hollnagel (1999)].

Because of the new assignment of trajectory determination to the crew, needs for situating capabilities will be significantly of higher importance.

5.4 Know the sources of information for new and/or changed A^3 airborne responsibilities

In order to fulfil the new and/or changed responsibilities, the crew needs to build an updated long, medium and short term representation of the internal (the state of the aircraft) and external environment (traffic, weather, terrain), based on updated and widely shared information. The sources of these necessary information will be other airborne systems and ground support (mainly airline OCC, but may be automated ground support, etc).

5.5 Know the rules of using the tools and information provided

A new responsibility of any crew flying within free flight airspace must be correct and adequate use of the available information and tools defined for safe flight in airborne self separation conditions.

6 Knowledge and Information Requirements

In one point all theories concerning situation awareness agree: Humans are actively obtaining SA for themselves to do their tasks, achieve their goals and meet the responsibilities. Today's avionic systems are able to produce and provide an enormous amount of information, regarding own state and external environment. So, as Endsley (2000) stated, "the problem of today's systems is not a lack of information, but finding what is needed when it is needed". This means, that situation awareness cannot be provided from outside by technical means and environment, but pilots have to perceive relevant details, necessary information, and make them useful. This in turn means that the gathered information must be integrated and interpreted correctly as well.

This raises the following main questions:

- What are the new responsibilities regarding strategic planning during pre-flight and in-flight?
- What are the new responsibilities concerning tactical decision making during en-route flight?
- Which knowledge and information will be required as a function of the underlying goal, in terms of strategic planning and tactical decision making?
- Which technologies and information displays will be needed to support the changes in operational responsibilities during en-route self separation?

This section contains three subsections. First of all a short overview of non-traffic human factors issues related to SA responsibilities will be given in general. The subcsection "Strategic planning" will stress special topics related to flow management, whereas the third subcsection will concentrate on issues related to tactical decision making (conflict detection, conflict resolution) covering today's required knowledge and information during en-route flight, the source of information, and will survey upcoming changes and possible problems in association with A^3 en-route self separation. Additionally, possible approaches for solutions will be given. The following breakdown into the three levels of Endsley's SA theory is based on the analysis regarding SA requirement elements for en-route air traffic controllers

(Endsley & Rodgers, 1994), which seems to be obvious when thinking of the shift of responsibilities (concerning separation) from ground to the air.

6.1 Non-Traffic Situation Awareness Issues

6.1.1 All Forms of Aviation

- Overall Financial Awareness

Because the vast majority of the A^3 aircraft flying will be doing so to either directly – By making a profit on each passenger carried (e.g., an airline) – or indirectly by reducing some other cost (e.g., a corporate jet that allows as executive to have more effective use of their time). As a result professional pilots are being tasked with the responsibility to meet established financial goals imposed by their employer. While the fuel cost issue has already been addressed, the flight crew may have the responsibility to bring a flight in at or under some overall cost. For example the most efficient fuel cost may be completely wiped out by the cost of rerouting passengers or the cost of *per diem* for those who complete miss their connections. Therefore, an effective A^3 system will need to support the financial requirements of its users. This does not necessarily mean support each individual aircraft's needs all the time, but rather that the overall costs are held low, and so that one segment of the airspace user's are not systematically always the least efficient.

With the volatile and high price of fuel steadily becoming a larger fraction of the operations cost for any aircraft owner and operator, flight crews will need to be aware of more than just fuel burn/unit of time but also of when weather or traffic require something else than very efficient fuel usage and then the flight crew must be able to make an optimal fuel usage decision.

- Structural Awareness

The functional life of the different physical components of aircraft can vary significantly as a function of operational environment to which they are exposed. For example, in engines the extra wear is called lifing. The lifing penalty is dependent on the magnitude and dwell time at the speed. Likewise, airframe fatigue may be X%

higher during moderate turbulence than during flight in calm air. In addition, there are interactions between the variables, e.g., the impact of turbulence on airframe life will vary with current gross weight and/or airspeed. Again, the ideal awareness for the flight crew would be not only a recognition of the change in lifetime but also how one can modulate the different variables to obtain a mission specific optimal outcome, like: What is the maximum of freight it can haul in this condition versus the temporal limits e.g., how will it impact length of the times between certain structural inspections.

- Passenger Awareness

The flight and the cabin crew will need to understand any special needs of their passengers as function of where they are in their mission and all relevant exogenous conditions.

- Circadian Desynchronosis Awareness

The flight crew will need to have an awareness of their circadian state so as to understand and control any circadian desynchronosis consequences induced by deviations from the original planned mission. This need goes beyond crew duty limitations to include flying at non-optimal times from a circadian perspective.

- Sense and avoid awareness in IMC

Current aviation regulations defining the “safe avoidance of other aircraft” assume either visual meteorological conditions which allow the flight crew to see and avoid other traffic or ATC to vector all aircraft to maintain their requirements. In A^3 operations, it will be necessary for the flight crew to operate by using sense and avoid in the cockpit when the aircraft is operating under A^3 rules in IMC. The flight crew will have the responsibility to know how to effectively use the sensor(s) to keep the technology within the operational criteria for the flight to create and maintain their awareness of other airborne traffic in their vicinity.

6.1.2 Airlines Non-traffic SA needs in Particular [1]

- Awareness of passenger connections

Not getting a passenger to the airport in time to catch their connection can be expensive to an airline – e.g., the administrative support needed to change a reservation; an unhappy passenger; perhaps money for food & lodging if no suitable connection can be found. Unaccompanied children (i.e., children flying without a responsible adult) have a potentially more significant financial impact if the flight is diverted or if unaccompanied minors miss a connection. Flight and cabin crews need to aware of the consequences of the child not making the connection, options to mitigate the consequences, and their responsibilities given a lack of infrastructure at the destination. And international passengers (i.e., those passengers with destinations in another country) also have a potential significant financial impact if the flight is diverted or if an international passenger will miss a connection. International passenger can be particularly expensive to an airline because the frequency of international flights is relatively low, thus increasing the probability that they will need to be provided a hotel room and other support defined by ICAO.

- Awareness of passenger and cabin crew safety

This will remain a prime responsibility for the flight crew. Given the crews' potentially higher workload in iFly environments, one might suspect that some additional decision aids might become valuable. For example, even at today's workload levels the flight crew often forget that it turned on the "Fasten the seatbelt" light. (The onset cue, i.e., turbulence, is much more salient than the termination cue i.e., lack of turbulence for X amount of time.) As a result passengers generally assume after a certain amount of time without turbulence that the flight crew simply forgot to turn it off and begin to move about the cabin. If the crew has a higher workload one would expect an increase in the forgetting to turn it off and thus passengers will assume that it is OK to get up and stretch. Thus passenger and cabin crew safety may decrease…

[1] : The airline specific issues were generated with the assistance of a retired Delta Airlines dispatcher whom the author of this chapter has known for many years. He remains professionally active as a dispatch consultant and as a leader in the dispatcher's international professional organization.

6.1.3 Unmanned Aerial Systems (UAS) SA needs in Particular

- Strength of awareness

While the basic SA needs for the UAS operator will generally be the same as for airline flight crew (with the exception of there being no passenger awareness issues today) they will be modified along several dimensions. The most obvious is the remote operation, which creates a slightly less intense psychological state because the operator is not sitting in the blunt end of the aircraft. Second, busy airspace remote operation may induce an ATCo-like worldview in the UAS pilot, again mentally pulling that operator out of the individual UAS's cognitive workspace.

- Awareness of State of Data link

The UAS operator must maintain an awareness of the data link status. When flying in the crowded airspace, where the consequences of either degraded or complete loss of control will increase the probability of an accident, the crew will need a high awareness of the data link status & forecast. When an UAS operator is the sole operator of multiple UASs, that operator will need to remain continuously aware of the data link for each UAS under his/ her control.

- Sense and Avoid Awareness

While sense and avoid is becoming more available on traditional aircraft (e.g., TCAS, ADS-B) and has proven itself to be very useful, using it as the sole means of maintaining awareness of multiple UASs may significantly increase workload and thus potentially negatively impact the operators' overall situation awareness. This could be particularly significant when different mental rotations and/or translations are required to establish a unified awareness. In UASs in particular, the sense and avoid data will need to be presented in a way that meets normal human affordances for 3D orientation so that the crew can mentally quickly move from one UAS to another and be able to instantly and intuitively gain the awareness of each UAS being directly controlled.

- Awareness of Personal Circadian Desynchronosis

Circadian desynchronosis may be a more significant issue for operations crews of UASs that are used to haul freight (which is usually done at night). Currently freight pilots tend to have much higher rate of addictions and other physiological conditions than do other commercial pilots. Combine this with the less “exciting” world of remotely controlling aircraft when the operators are in desynchronosis and the design challenge to keep the UAS operator sufficiently aware of each UAS will be significant[2].

- Awareness of Freight

It has already been noted that flying controlled materials (e.g., military weapons, export controlled items) into airspace where it is not allowed is becoming a bigger and bigger issue around the world. When a UAS operator has more than one aircraft to attend to (each of which might be carrying different types of freight, the operator will need to not only know what freight each UAS is carrying, but also how that freight might impact future mission decisions for each UAS. This could be particularly critical in the case where all of the UASs being controlled are diverted and one or more have restrictions.

6.2 Strategic planning

6.2.1 All Forms of Aviation

- Temporal Awareness

Within A^3 operational environment pilots will have the responsibility to meet certain temporal restrictions, e.g., RTAs. The flight crew will need to be aware not only of the RTA but also the probability of meeting the RTA, but also a sense of the major variables involved and their relative impact on the overall temporal requirement. A^3 technology will need not only to provide the crew effective 4D navigation performance required of the aircraft, but also clear and intuitive displays that assist the flight crew to achieve and maintain clear cognitive model of the 4D goal. The model needs to allow to quickly and accurately understand the impact of meeting the RTA of overall mission goals.

[2] There is significant data on problems associated with traditional ATCos operating under desynchronosis which could most probably be applicable to UAS operators. In addition, there is a large amount of data currently available for the air crews that flight only at night carrying freight.

- Weather Awareness

A3 flight crew will need to establish and maintain a level of meteorological awareness, such that they can effectively use meteorological information (both current and forecast) to help them meet or exceed their system level objectives. For example, by selecting the side of a front that provides a tail wind may save the mission time and fuel even though the distance may be greater. Having the awareness to be able to set the aircraft up for such a manoeuvre an hour ahead of time may even further enhance overall performance. In addition, using this type of knowledge to reduce turbulence could also enhance the reputation of the airline in the eyes of customers in terms of more comfortable flights and less time spent strapped in a seat.

- Geographic Awareness

The flight crew will have a greater responsibility for either using geographical information. The selection of a route or a deviation could be impacted by the type of terrain flown over. For example, in certain types of operation that may be a requirement to be able to glide clear of certain area (e.g., large body of water or mountains). Having foreknowledge of these issues during a deviation could allow for a safer trip and a more efficient use of their resources. For example, the most time efficient path over the undesirable terrain could be selected.

- Environmental awareness

As environmental issues gain more and more scientific, political and popular support, the flight crew will have the responsibility to make sure that their operation conforms with overall particular environmental requirements (for example geographically based limits such as sound limits may be more strict over a densely populated area than a lightly populated area) and temporal limits (e.g., particulate emissions limits may be more stringent during temperature inversions than during other metrological conditions).

- Awareness of emergency or diversion airport(s)

There are a number of reasons that could require a diversion to a non-planned airport, e.g., equipment problems, passenger or crew health, severe weather or geographical conditions (e.g., ash from a volcano). The crew will need the ability to quickly and accurately select the most appropriate diversion airport within the constraints of the mission, aircraft, personnel on board, and the phenomenon causing the diversion can be critical.

- Flight area Awareness

Because legal requirements for a particular piece of airspace can vary as a function of time (e.g., noise requirements at night and pollution requirements as a function of weather conditions) or operational conditions (e.g., military special use airspace) the flight crews will have the responsibility to meet those requirements without the assistance of ATC.

6.2.2 Airlines Non-traffic SA needs in Particular[3]

- Pre-Awareness of next mission

Flight crews often have only 1-2 hour turns between flights (ever notice the flight crew are often off the airplane before you are?). There is a critical need to assist the flight crew to quickly obtain 1) a correct mental model of the mission, 2) the goals of the next mission, and 3) to provide the flight crew “cognitive support” in the A^3 decision making process throughout the mission.

- Freight Awareness (e.g., military weapons, export controlled items) into airspace were it is not allowed

Given that 1) airlines do carry freight beyond the passengers baggage and 2) the flight crew will be directly responsible for navigation around other traffic and weather, therefore the flight crews will need not only have an awareness of what freight they are carrying, and the potential limitations of en-route and neighbouring airspace with regard to the cargo. This awareness should include how the potential manoeuvring limitation might potentially impact mission decisions that could involve the inability to manoeuvre into the “wrong” airspace.

[3] See footnote 2.

6.3 Tactical decision making

To make tactical decisions it is recommended to define the airspace of interest with regard to the SA requirements for medium term look-ahead time (5-15min) and short-term look-ahead time (1-5min). This airspace should be understood as a “sliding window” in time, e.g. the focus moves along the ownship movement.

Knowledge and Information Requirements to achieve Traffic SA during en-route today and in free flight will be considered by the levels of situation awareness.

6.3.1 Level 1 Situation Awareness – Perception

Knowledge of the aircraft

Ownship state

- Identification
- Predetermined flight plan (destination; filed plan)
- Current route (horizontal position; heading; ground speed; climb/ descent rate; altitude; attitude; immediate destination)

It is the aircrews’ responsibility to search for that specific information, which they can mainly find on the Navigation Display and the FMS. In case of display failures/ malfunctions they can ask AOC for advice. AOC would provide vectors to a specified waypoint or even to the field.

Today’s Navigation Displays are relative clear. It has its predefined position in the cockpit and is integrated into the scanning process of the aircrew. Information is easily readable, used symbolism is more or less standardized, colours are carefully chosen.

Due to airborne self separation, and the therewith associated changes in responsibilities, it will be necessary to provide the aircrew with more relevant information. There are two possibilities to solve this issue: integrate the additional information into existing displays or create a completely new one. This question is not easy to answer; both solutions have pros and cons.

The navigation display could easily be used to integrate e.g. weather, traffic, suggestions for conflict resolution etc. But this would raise questions concerning e.g. overload, time needed – head down time – to filter relevant information or symbols. Pros would probably be that the existing display has a defined and established position in the cockpit already included in the scanning process. Furthermore the additional information is clearly related to the navigation task. To have all the information integrated into one display could be an advantage.

Other aircraft state

- Identification
- Predetermined flight plan (destination; filed plan)
- Current route (horizontal position; heading; ground speed; climb/ descent rate; altitude; attitude; immediate destination)
- Number of aircraft nearby/ traffic density
- Number of aircraft within a user- specific range of ownship

Until now there is no need for the aircrew to receive or search for this information. This is based on the fact that currently, the ATCo accounts for maintaining separation between aircrafts. So the aircrew is just required to keep a rough picture of the traffic in mind. To accomplish this task pilots listen to radio communication which either takes place between ATC and other aircrafts, for example when pilots are constrained to report their actual position, or between aircraft and aircraft.

Under A^3 this situation will change completely, if only during the en-route phase of flight. As it is proposed to assign the responsibility for separation to the aircrew, the above mentioned information has to be accurately provided to the aircrew. The so far most important source of information, namely radio communication, especially between ATCo and aircraft, will not longer exist in that way, e.g. for gathering information.

So one of the main questions is which kind of information must be presented: state based or intent based information? Or providing a system, which can handle both modes? No decision has been made so far.

In the future the main sources to gather this information will be a traffic display (Cockpit Display of Traffic Information; CDTI), and additionally the view out of the window. To have enough time left to perform the look out of the window it is of major importance to design the CDTI in a proper way.

Knowledge of ownship future state

- horizontal position; heading; ground speed; vertical speed; altitude; immediate destination; final destination; route; violations of aircraft capabilities (e.g. speed restrictions)

The knowledge is and will be provided to the aircrew via FMS and the therein entered flight plan. Additional distances and time to the next waypoint are displayed in the Navigation display.

Knowledge of other aircraft future states

- Horizontal position; heading; speed; altitude; destination; route
- Knowledge of configuration modes of other aircraft

To gain knowledge about the future state of other aircrafts is a new goal for the A^3 aircrew. The aircrew should be provided with intent information of other aircraft in proximity. Appropriate filter functions to provide only necessary information for every special situation have to be implemented in future traffic displays. The appropriate presentation of this information, or changes in this information (change between intent or state based information: change in colour) has to be well-wrought.

Current separation

- amount of separation between aircraft/ objects/ airspace along planned route

Knowledge of weather

- Area affected
- Altitudes affected
- Conditions (snow, icing, fog, hail, rain, turbulence)
- Temperatures
- Visibility
- Wind
- IFR/VFR conditions
- Airport conditions
- Wake vortex encounters

During flight, pilot gathers the above information mainly by looking out of the window, listening to radio communication and by monitoring of the weather radar, which is most often integrated in the Navigation display. The information provided by the weather radar today will not be sufficient considering the aircrews' responsibility to make tactical and strategic changes according to weather phenomena. This would raise up the question if, how and to which extent this weather information should also be included into the planned more or less automated conflict resolution tool. In today's ATM concept wake vortex don't affect the aircraft in en-route phase because of the actual separation minima. In FFAS these minima might change, so in this case wake vortex should be considered as a possible hazard and might be handled in conflict resolution algorithms.

Knowledge of airports

- Operational status
- Restrictions in effect
- Arrival requirements
- Active runways

The knowledge of alternates is and will be important information pilots need to have. Especially in case of an emergency during the en-route phase in FFAS this knowledge is of major importance. Until the aircrew reaches the considered transition layers the aircrew is on their own in finding the best alternate in their situation and hence the best exit point for the A^3 flight. During this flight stage the aircrew needs to get the information stated above via data link message as e.g. NOTAMs.

Knowledge of terrain etc.

- Area affected
- Altitudes affected

The importance of the terrain information aircrews operating in FFAS is mainly depending on the definition of the FFAS (geographical dimension; dimension of transition layers).

Knowledge of Occurrence of alert zone warning/ watch

- Auditory and visual signal of an alert zone warning/ watch; type of alert zone warning/ watch (is it a temporary one or will it lead to alert zone contact.

6.3.2 Level 2 Situation Awareness – Comprehension

Comprehension of potentially dangerous terrain/ hazards

- Area affected
- Altitudes affected
- Wake vortex encounters

There are terrain and proximity warning tools available which support the aircrew to identify terrain as a hazard (INAV™ as part of the Primus EPIC™ system; EGPWS™).

Comprehension of emergencies/ equipment malfunctions and alerts

- Ownship (equipment affected, time on fuel remaining…)
- Other aircraft (equipment affected…)

In addition to the “normal"’ malfunction/ system alerts already implemented in today’s cockpit, the implementation of alerts concerning malfunctions of new tools (ASAS, CR), and their functionality (CD and CR possibilities) are a must. Further on other aircrafts involved have to be informed about the aircraft which is no longer equipped to operate in airborne self separation conditions.

Timing

- Projected time in airspace
- Time/distance between aircraft

The information provided regarding time/distance between aircraft has to be explicit.

Accuracy of info

- weather
- aircraft ID; position; altitude; airspeeds; heading

Future of ownship state

- weather
- aircraft ID; position; altitude; airspeeds; heading

Conflict detection

- is a conflict immanent?
- is manoeuvre needed?

Projected distance between intruder's expected trajectory and own planned trajectory

Aircraft relative locations: own location; intruder's location; location of wake turbulence

Projected relative trajectories of own aircraft and intruder

Planned trajectory and airspeed of own aircraft

flight plan

Projected trajectory and airspeed of intruder

aircraft type: aircraft performance capability; airspeed

Intent of intruder aircraft: flight plan

Confidence in predicted flight plan: competency and reliability of intruder aircraft's crew

Ownship planned changes

- Heading changes; speed changes; altitude changes; immediate destination changes; route changes

Significance

- Ownship planned changes: Impact on aircraft separation/safety
- Impact of weather on: aircraft safety/flight comfort
- Impact of malfunctions on: trajectory; communication; aircraft; procedures

The knowledge gathered to achieve level one SA has now to be interpreted, stored and combined to determine the relevance to self separation. The main question is if aircrews are able to detect possible conflicts just by monitoring all the information provided on different displays. At this stage the level of automation has to be included in the discussion. The implementation of ASAS (Airborne Separation Assurance System) tools, indicating possible conflicts with a look-ahead time of about 5 up to 15 minutes could support the aircrew to fulfil the new task. Including the information stated under "Level 1 Situation Awareness" the system could automatically detect possible conflicts and display them automatically.

6.3.3 Level 3 Situation Awareness – Projection

Best plan of action to avoid a future or discontinue a current alert zone contact

- Optimal changes to: horizontal position of ownship; heading; speed; vertical speed; altitude; destination; route. Request other pilot to make changes

Projected ownship route

- position; flight plan; destination; heading; route; altitude; climb/descent rate; airspeed; winds; ground speed; intentions; assignments

Projected other aircrafts' route

- position; flight plan; destination; heading; route; altitude climb/descent rate; airspeed; winds; ground speed; intentions, assignments

Projected ownship potential route

- projected position *x* at time *t*

Projected other aircrafts' potential route

- projected position *x* at time *t* (intent information?)

Projected Separation

- amount of separation along route (aircraft/ objects/ airspace)
- deviation between separation and prescribed limits
- relative projected aircraft routes
- relative timing along route

Predicted changes in weather

- direction/ speed of movement
- increasing/ decreasing in intensity

Impact of potential route changes

- type of change required (heading changes; speed changes; altitude changes; immediate destination changes; route changes)
- time and distance till change
- amount of changes required
- aircraft ability to perform changes
- increase/ decrease in length of the route
- cost/ benefit of changes
- impact of proposed change on: aircraft separation; arrival requirements; number of potential conflict; aircraft fuel and comfort

Resolve traffic conflict

Which aircraft will perform avoidance manoeuvre?

When is a manoeuvre needed?

What type of manoeuvre is needed?

Within earlier MMF project (e.g., Hoekstra, 2002), a PASAS (predictive ASAS) tool was developed and tested. PASAS would calculate which headings and vertical speeds will result in a conflict with another aircraft. The result of these calculations can be for example integrated into the Primary Flight Display (PFD) and the ND as so-called “go“ and “no-go” bands. These results could also be integrated into the

FMS. In case a conflict resolution has to be performed this functionality could be integrated in existing FMS by using additional information like weather to provide the most efficient possibility to solve the conflict to the aircrew.

7 CDTI – Cockpit Display of Traffic Information and ASAS – Airborne Separation Assurance System

One of the main challenging issues is to provide the aircrew with sufficient information to enable the FF airborne cognitive system (FFACS) to make dynamic decision that keep the aircraft in a safe proximity to other aircrafts. To ensure self separation state or even intent information, provided by data broadcast systems, can be used by every FFACS to ensure the separation; data will be processed on-board and displayed on a CDTI.

Many questions concerning general design and appropriate presentation of the required information at the right time occur. These questions range from basic questions of integrating the new functionality into existing displays and positioning to specific ones including symbols, colours, display range, filters, possibility for interpretation, ease of understanding, alerts etc. and their impact on response workload, SA, reaction and head down time etc.

Additionally one might think that a crew is able to predict traffic conflicts just by monitoring a well designed CDTI – under optimal conditions (flight conditions, optimal workload) this assumption might be true. But since these optimal conditions are very rare in today's cockpit and in time conflict detection/prediction is mainly based on calculation, it is useful to provide valuable support via automation – the Airborne Separation Assurance System (ASAS).

To predict a conflict an accurate prediction of the ownship trajectory and the trajectories of the surrounding traffic are needed. The result of this underlying detection module can in turn be presented to the aircrew as an alert on the CDTI including information on the conflict, e.g. identification of intruder or time left to conflict and aurally in order to catch aircrew's attention.

Based on the problem that short term conflicts mainly occur due to turning (horizontally or vertically) a Predictive ASAS (PASAS) system was developed, implemented and tested by NLR (Hoekstra, 2002). In this version the display system shows the result of all possible selected values on the navigation and primary flight display similar to the bands used in the TCAS symbolism.

7.1 Design philosophy

The design of such a supporting tool and its human-machine interface (HMI) should follow the guidelines as stated in the ICAO circular 249-AN/149:

1. The human must be in command
2. To command effectively, the human must be involved
3. To be involved, the human must be informed
4. Functions must be automated only if there is a good reason for doing so
5. The human must be able to monitor the automated system
6. Automated systems must, therefore, be predictable
7. Automated systems must be able to monitor the human operator
8. Each element of the system must have knowledge of the other's intent
9. Automation must be designed to be simple to learn and operate

The main goal is the development of a comprehensive feature set based upon the information needs of the tasks identified in previous work, and incorporating features of human-machine interfaces developed in previous projects that have been favourable rated by the flight crews.

8 Solving the conflict

Airborne self separation or Free Flight promises to make pilots' life more challenging and exciting in the future. But as most of the challenging and exciting things in life also this new task is associated with danger. The most essential peril related to Free Flight lies in the detection and resolution of air traffic conflicts in time**.**

8.1 What is a conflict?

A conflict is a state of disharmony between incompatible or antithetical objectives, ideas, interests or opinions between persons or objects. In the context of the present iFly document, one can define a conflict as an incompatible flight path between aircraft, weather or terrain which, not detected in time and unresolved, will result in a collision. Or, more condense formulated, when there is a predicted loss of separation.

A conflict is not always insurmountable; there might be incompatibilities at that specific moment, but these may be resolved themselves in due time. Take for example two aircrafts that are on collision course; they are in conflict at that very moment, but because one of them will take a turn to his destination in time, the conflict will be solved.

To resolve a conflict, it requires accommodation from at least one of the two parties that are involved. For multiple conflicts (more than two aircraft are involved) more than one party might have to accommodate. From a human factors point of view, airborne self separation should look for the resolution that demands the least amount of accommodations and inflicts least demands to the aircrew.

Today's air traffic control concept is based on predefined airways on which aircraft fly one behind the other. This system is an inefficient use of airspace and limits the possible traffic volume, but it makes conflict detection easier because it is more predictable. Over the years air traffic control institutions have developed a quite accurate understanding of imminent conflicts, typical conflict points and typical conflict areas in the allotted sector. But across controllers there are no coherent strategies how to detect and especially solve the conflicts. In conflict resolution they rather follow broad rules (cf. EUROCONTROL, 2002) e.g.;

- don't create more serious problems than you solve,
- don't overload yourself and loose control of the situation and
- try to resolve the situation once without having to revise the plan later

With the implementation of airborne self separation two main things will change:

Predefined airways will no longer exist

Pilots will accept the responsibility of self separation in the Free Flight airspace.

Pilots will be allowed to choose their own direct routes rather than relying on air traffic control and the airway network. They will follow optimal routes and changes in trajectories will be common, which in turn implies that congested areas and conflicts can occur anywhere at any time – unless Flow Management (FM) is performed in advance.

With the shift of responsibilities from ground to air, pilots become controllers themselves. This will be an additional task they are not experienced with. In comparison with controllers, pilots don't work from a centralized position. They are in the thick of things and to overview the whole situation from this position requires additional information and supporting tools to keep the situation under control. With the increase of traffic enabled by airborne self separation, an increase of congested areas and traffic conflicts might take place. The shape in which they occur might change as well. It is predicted that the number of conflicts experienced by an aircraft will grow linearly with the increase in traffic. However, for controllers it will grow exponentially. As a consequence thereof the avoidance of problems might become more difficult. Taking this into concern, it should not be forgotten that maintaining separation is not the only task an aircrew has to cope with. As the complexity of separation maintaining increases, pilots will not be able to provide separation manually. Hence the implementation of assisting tools is inevitable.

8.1.1 Airborne self separation conflicts

The key point for a successful airborne self separation concept is the avoidance of aircraft conflicts. In the airborne self separation context there might be different kinds of conflicts. A distinction can be made between relevant and non-relevant conflicts; relevant conflicts need (immediate) action from the pilot to solve the conflict, but for non- relevant conflicts the problem will be solved in time because of pre planned, known actions by one of the conflict parties involved (think about pre planned turns in route directions). To be able to define a conflict as non-relevant however, advance notice of the intended manoeuvres need to be provided for the aircrew (and these intentions need to have maximum of reliability).

Another distinction can be made between single and multiple conflict situations. In a single conflict situation there is only one conflict between ownship and another conflict party, which can be either traffic, weather or terrain. In a multiple conflict situation, there are several conflict parties involved. A multiple conflict situation can have different scenarios; several parties can be in conflict at the same time, or it can be a chain of conflicts (after the first conflict will be solved a second conflict arises etc.). A chain of conflicts might look like several single conflicts, but considering them as appearing very fast in succession we will identify them as multiple conflicts. In comparison with multiple conflicts, a single conflict and having a good long ‘pause’ until the next one comes, will cause far less stress to the pilot than having several conflicts after each other in a very short time relay.

8.2 Factors of influence on conflict detection and solving action

Time is indisputably the major factor in this highly dynamic aviation domain. Even the best conflict resolution tool is useless if there is no time left to execute changes. But there are some other factors which might have an impact on conflict resolution activity. They can be divided into: Task/ System/ Environmental factors and Individual/ Human factors.

Task/ Systems/ Environmental Factors

Factors of influence on conflict detection and solving action include: system capabilities, the design of the interface the crew needs to use, complexity of the system, the level of automation, speed, traffic density conditions, distance between aircraft involved in the conflict, phase of flight, rules, restrictions, aircraft category, location etc. EUROCONTROL (cf. 2002) divided conflicts into three major dimensions:

- Temporal (how soon separation will be lost)
- Spatial (geometry of the conflict)
- Certainty and seriousness (how close the aircrafts get)

Individual/ Human Factors

Individual, human factors have a high impact on conflict detection and resolution. Systems are programmed; outcomes will be the same for every system for that specific event (input). They are controlled, when to leave aside the “bugs”. Compared with programmed systems, humans however all process differently, which might result in different, far more unpredictable outcomes. This is caused by individual differences in goals, preconditions (expectations, for example about a specific airliner), training, memory capabilities, attention, perception, stress and workload handling, experience, personality etc. For FF, it is important to take into account these individual human factors of influence and overcome them as much as possible within the FF system. Some important factors will be described below.

Vigilance

Vigilance is a state of readiness needed to be able to detect signals, for example a conflict signal originated by the FF system. Vigilance can be long term attentive behaviour, but also selective attention in multiple-source or time-shared tasks. Vigilance tasks have relatively simple, specified, unchanging signals, usually presented infrequently at unpredictable times (via a single source). A decrement in vigilance will occur when operators are overstrained (by increased level of complexity), with the presence of environmental stressors or with signal uncertainty. The level of boredom will have influence on response time. Subjects who report an (extremely) high level of boredom have longer response times than those who report a low level of boredom. It is widely known that during en-route traffic, pilots have very few things to do, so the level of boredom will be higher. A low event environment will result in a low arousal level and a decrease in neural activity. The boredom might have its effect on the level of pilot's vigilance. It will cause longer conflict detection times and slower responses. It also can cause inattention resulting in missing important signals both from the system and/or environment.

This is not desirable in any given situation, but especially not in a FF environment where pilots have to do their own conflict detection with, to some extent, help from FF tools. To combat loss of vigilance it is important to increase sensitivity. Some actions that enhance the increase of sensitivity are (Wickens & Hollands, 1999, 3rd ed.);

- Show target examples (to reduce memory load)
- Increase target salience (blinking, red circled targets, stall – when an alert is imminent, non relevant AC, only target moving in display)
- Minimize event rate, don't show to much irrelevant AC; high event rate can produce larger losses in Vigilance performance
- Train the observers (pilots)

Situation Awareness

Situation Awareness combines different cognitive operations in perception, working memory and long term working memory that enables the decision maker to set hypotheses about current and future state of the world (situation assessment). People must have a relative accurate awareness of the current and evolving situation to plan or solve the problem effectively in a dynamic and chancing environment. Sarter and Woods (1995) found that a higher level of automation reduces workload and improves performance, but may decrease situation awareness. Understanding the situation must form the foundation for effective choices or decisions. Situation awareness is one of the most important components in effective decision making, so the level of automation should not be too high, otherwise it will decrease the level of situation awareness.

Stress

Stressors (factors that are causing stress) have typically degrading influences on information processing and cognition that are not inherent to the person's skills or the content of the information itself. The effect of stress on the performance of tasks will have its influence on information processing; most stressors generally raise the level of arousal, which in turn improves the level of performance, so in this case, a little stress is desirable and healthy. However, excessive stress can cause increased selectivity or attentional narrowing. This can contribute to "tunnel vision", which can be dangerous to decision making in critical situations.

It may narrow down attention to the available cues and some of them, leading to possible alternative problem solving hypothesis, may be ignored. Design solutions against perceptual narrowing and for buffering the stress effects are to reduce the amount of unnecessary information and increase the organization of this information. The displays should be designed in a way that the need of translating the information is minimized; emergency procedures (very stressful and non routine tasks) need to be clear and simply phrased. Where possible, systems should be designed in a way that procedures followed under emergency are as consistent as possible with those followed under normal conditions, to prevent extra stressors as much as possible.

8.3 Conflict resolutions strategies

Air traffic controllers are assisted in conflict detection and resolution by a network of airways – they follow their overall plan but do not mention airline specific business concerns when assigning changes in trajectories. They also do not consider weather phenomena in their initial conflict resolution strategies. Currently three different manoeuvres are used:

- Lateral (turn left or right)
- Vertical (climb or descend)
- Speed changes (increase or decrease)

According to the present separation minima, vertical changes require fewer changes in the flight path due to narrow separation minima. In an A^3 environment these separation minima should be reconsidered to enable more dynamic and combined evasive action, e.g. lateral and vertical changes.

In GA, when performing a VFR flight in VMC, there are just a few rules which must be strictly adhered to avoid traffic:

- Every evasive action has to be performed laterally
- Opposite traffic: each aircraft must evade to the right
- Crossing traffic: the aircraft coming from the right crosses in front of the other traffic
- Overtaking: on the right side
- On final descent: The aircraft below has priority
- The evasion hierarchy: An aircraft has to give way to an airship- has to give way to gliders- in turn has to give way to balloons.

These rules work very well most of the time, considering the lower speed, the mobility, the clear sky etc. In case of an avoidance manoeuvre private pilots do not have to do calculations on efficiency or follow any policies – they just follow some basic rules. Regarding conflict resolution in commercial aviation things are more complex and difficult compared to GA or military air traffic. Aircrews have to consider economic factors, have to provide comfort for the passengers, have to factor in time constraints, etc. So, to find the best resolution strategy will be hardly manageable for humans, due to complexity and the high number of factors which have to be considered. Aircrews have to be supported by more or less automated tools – based on conflict resolution algorithms, where all influencing factors have to be taken into account to find some possible solutions for each unique situation. It should be noted that it will be important to weigh the importance of single factors which go into the calculation.

To achieve a high level of acceptance of such supporting tools, their feasibility and replicability are indispensable. When developing such tools the question of the level of automation plays an important role. And how much of the sphere of influence should and can be left to the aircrew? One important thing is to keep the aircrew in the loop. This would suggest to roughly including the pilots' way of thinking when presenting some solutions on a display. When they have to make their choice of resolution, they need to be aware of the accompanying consequences.

There are two different approaches for multiple conflict resolution; the *pair wise* or the *global approach*. In the pairwise approach, (by pair is meant own aircraft and the other conflict party), the most serious and most of the time most close conflict would be taken first and resolutions offered for it. Once a resolution for this conflict has been implemented, a resolution for the following most urgent conflict, or pair, will be produced. A more ambitious approach would be the global approach, in which all conflicts (the global situation) would be taken into account. This approach looks for the best resolution for all the conflicts, taking simultaneously into account surrounding traffic to prevent new conflicts. This can result in fewer manoeuvres as there may be certain actions that resolve several conflicts at once. A global approach would be most efficient and desirable, but the level of workability for the human operator depends on the level of automation and workload.

Considering conflict strategies in single and multiple conflict situations, some comments can be made. In a single conflict situation, conflict strategy needs to solve only one problem. Humans are naturally confined to solve (or give attention to) problems one at a time, in other words, humans have a serial ability to solve problems. Humans naturally swift their attention between different topics (which allows multitasking). Only very routine tasks depending on different input and output channels (for example listening and writing) can be performed comparatively successfully at the same time. Non routine tasks, and tasks competing for the same information channels, like conflict solving, are demanding more 'bits and bytes' from the human, who is not able to process them in a truly parallel manner. This is referred to as the 'information processing bottleneck'. It might be interesting to note that humans are counterproductive in multitasking; not only does completion of all tasks take longer than when they are performed one at the time, but performance on the tasks is also impaired. In a conflict situation, especially with multiple conflicts, this bottleneck and human inability should be overcome by provided helpful tools.

Single conflict resolution will be less influenced by this bottleneck than multiple conflict resolution strategies. The pilot can focus on that particular conflict, with the only implication of withdrawal his/her attention from other work aspects that also need attention, but are less important at the moment (navigation, communication etc) compared to the conflict resolution.

For multiple conflict resolution strategies however, this human serial processing ability (or lack of parallel processing ability) to solve conflicts will bring along more difficulties. Conditional on the time left to solve these conflicts, the level of task difficulty and inability to solve the tasks will grow. The human limited speed of (a) processing information, (b) reasoning for deducing alternatives and (c) decision making for choosing between the alternatives together with limited geometrical comprehension and limited prediction of multiple trajectories makes humans very badly prepared for solving multiple conflicts evolving quickly one after the other or in parallel in the limited time frame.

On displays the conflict information should be shown to pilots in a way they are able to use it for appropriate actions. Information should be direct, clear and practically usable, none of the pieces of information provided should be irrelevant to the conflict solving task (for example no mathematical calculations, but only direct instructions to act or alternatives to choose). A single conflict is more or less a straightforward problem the pilot can typically comprehend, but for multiple conflicts, information should be given to the pilot, taking the human serial problem solving ability into account (parallel processing should be done by the computer and it should suggest the serial problem solving actions to the pilot). It will not help the pilot, if he or she is said that all conflicts are imminent to his/her plane and should be solved immediately. Pilots should be provided with information about how these challenges should be taken and should be given logical options how to solve these conflicts.

Computerized support in conflict solving should give the pilots the advantage and the change to survive in the sense of (1) better bearing the stress and (2) having a real chance to participate reasonably in conflict solving, enabled by automated conflict predicting and solving tools.

8.4 Conflict resolution: Information requirements and handling

Although the responsibility will be fully transferred from ground to the air, this does not mean that the same task can and will be handled in the air in the same way as on the ground. This also applies for the information needed to solve a conflict at the airborne side. Pilots might need different, maybe more or maybe even less information than controllers on the ground to successfully resolve a conflict. The need for specific information will basically depend on the level of automation and additionally on the question, how much information will be needed to keep the aircrew in the loop.

Nevertheless no one will deny that information about other traffic and its intent, weather and wind, hazards, restricted areas, etc. are necessary facts to answer the questions: When is a manoeuvre needed? Which aircraft will perform an avoidance manoeuvre? What type of manoeuvre should be executed?
After conflict detection (most likely through an alert provided by the system) additional information about the conflict, such as identification of the aircraft involved, time till loss of separation and other geometrical information is needed for the pilot's resolution strategy. But how and to which extent this information will be needed and displayed to the aircrew, has to be studied carefully especially in non-normal conditions.

8.5 Decision making

To develop new supporting tools the aircrews will be trusting in, is a very complex and long process. For this purpose it is necessary to understand same basics of human decision making which will be shortly introduced in the next section.

The decision making process can be confused with problem solving. However, problem solving implies that alternative solutions are produced for a recognised problem and decision making can be defined as making a choice between those alternatives. Recognition of a serious problem can be the starting point for a decision making process. Problem solving processes are mostly associated with thoughtful attempts to overcome obstacles by developing solutions or alternatives. These alternatives need to be evaluated to be able to make a judgement. Eventually, a decision of choice will be made between those alternatives (see Figure 1 from Cooke & Slack, 1991 for an overview).

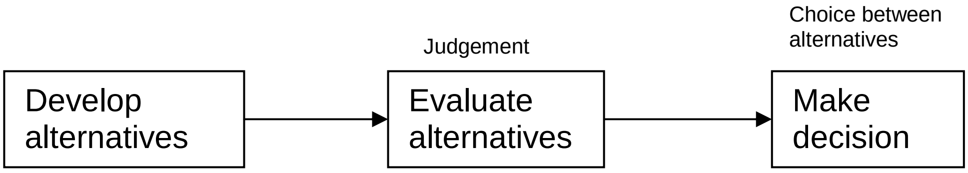

Figure 1. The preparation of decision making (Cooke & Slack, 1991).

Within the decision making process, micro levels will have their influence on decision making and the decision makers differ from each other. These factors of influence can be specific for an individual, but can also be seen in a group of people. Think about limited information processing capabilities, perceptual differences, past experience, (organizational) values and personal (or organizational) background. These factors give an explanation why different individuals are making different decisions when confronted with the same problem. For a pilot, a decision to make in a conflict resolution context has to be considered in a wider context, because his decision will have its impact on the airline organization. And in turn, organizational culture can be of influence on decision making; the pilot may form his decision with this culture‘s “pressure” in mind; which may be, for example, oriented not on safety as usual, but on money saving first.

Human decision-making can be roughly divided into conscious and unconscious activity. Rasmussen (1986, cited in Paunonen, 1997) suggested differentiating between three levels of decision-making:

- knowledge-based,
- rule-based, and
- skill-based.

Knowledge-based decision making uses well founded knowledge about the goal of decision making and information retrieved from it. For example, “the separation between ownship and other aircraft cannot be maintained due to opposite tracks. To regain secure separation a change in trajectory is necessary.” With increasing experience the aircrew would develop their heuristics, shortcuts in thinking. These heuristics speed up decision making, allowing bypassing some longer chains in the thinking process. Rule-based decision making will demand from the person lower level cognitive efforts than knowledge-based decision making, confining only with alternatives derived from the rule. Skill-based decision making refers to an unconscious level where sensory impulses directly start an action.

Paunonen (1997) stated: “A professional decision-maker uses knowledge-based activity to solve high abstraction level problems by selecting and controlling rule-based activities which in turn control skill-based sequences of actions. Each level forms a feedback loop of its own.”

Humans tend to act more on a rule- based than knowledge-based level which can be attributed to the effectiveness of rules in daily life. Looking from one side, this rule-based decision making may be inappropriate in the airborne self separation environment, where every situation will be more or less unique and requires intensive contemplation. To enhance knowledge-based thinking and decision making, the aircrew should be, again, supported by tools and information necessary to make the right decisions in time. From the other side it is clear that adhering to the rules and not going into the depths of problem-solving details will be more time-efficient and effort-efficient for rule-based decision making compared to knowledge-based one.

8.6 Points of Interest and Recommendations

Prior to completing specifications for a design for the FF product, the designer must understand the full range of tasks that the pilot performs with the FF product so that design principles are chosen appropriately and early evaluations of the product will capture task demands. The most useful task analysis is performed hierarchically, starting with top level goals and breaking down in specific actions necessary to obtain the goal.

The FF system should provide resolutions that would seem reasonable to the pilot. If resolutions seem reasonable, it would enhance the operators trust and understanding of the system. In this way the response of the joint system will be fast and more efficient. This reflects on the level of automation. Kirwan (2001), as cited in EUROCONTROL CORA document (EUROCONTROL, 2002b), found that the best levels of automation involved the machine giving advice, and the operator deciding to reject or accept it. One of the conditions that favoured particularly well in this level of automations was called “cognitive tools”. The concept of a cognitive tool is that the tool is based around the operators’ own mental model of how the situation should be resolved, as opposed to being derived from purely mathematical models. Such a model can be seen as a form of “Human Centred Automation”. Therefore, A^3 should aim to provide a pilot centred approach to conflict resolution (taking the human into the loop).

Limited geometric comprehensibility of the human might cause some problems for conflict resolution and what actually is a good resolution originated by the system, may seem an impossible or inappropriate one for the pilot. For the pilot it may still seem that the airplanes will collide. This might trigger an undesired reaction by the pilot, who chooses to follow his own senses. Or it might cause an unnecessary, dangerous, long reaction time when the provided resolution raises strong doubts. Operators won’t use a system (in the way it was designed) when the resolutions provided by the system are seen as a threat to them. The airborne self separation system should take into account the limited geometric comprehensibility of humans.

This way it should offer a view on the course of the conflict resolution offered, or if impossible, the system should choose for a resolution that's providing unambiguous insight into a good development of actions.

9 Conclusions

From the chapters of the deliverable the following conclusions can be drawn:

1. Developing and maintaining SA of A^3 pilots can be analyzed in the framework of Endsley's concept of three levels of SA.

2. As most of the continuous activities of the pilots are related to surveillance, it has been necessary to identify the key elements of SA in this process. In the present report two such elements were identified as (1) traffic awareness and (2) mode awareness.

3. The main purpose of automation in the A^3 environment from the human factors point of view should be supporting and facilitating these elements of pilots' SA.

4. At a certain phase of the system development and testing the measurement of pilots' SA and workload would be necessary to ascertain their acceptable levels in A^3 condition.

5. A^3 airborne cognitive system functions and responsibilities can be analyzed in the broad categories of pilot tasks: *Aviate, Navigate, Communicate* and *Situate*.

6. The airborne systems will acquire several new responsibilities in A^3 conditions:
   a. Knowing when the aircraft is in A^3 airspace
   b. Having the need for a transition phase from managed airspace to unmanaged airspace.

7. While fulfilling *Aviate* functions the crew
   a. Must have the „updated most accurate picture" of surrounding and anticipated traffic (traffic awareness)
   b. Must keep safety the highest priority while making decisions about fuel consumption optimization
   c. Has to consider possible additional workload on flight documents management
   d. Has to consider possible additional workload on passenger safety and comfort management issues
   e. Has to consider higher than current responsibilities in technical failure and emergency situation management (as risks related to ownship will

affect the safety both of ownship and the other traffic in a part of A^3 airspace
 f. Will acquire full responsibility for predicting conflicts with other traffic in A^3 airspace.

8. While fulfilling *Navigate* functions, the crew
   a. Can hardly avoid the idea of pre-planned flights and has to consider more frequent changes into these plans than today
   b. Will have a new challenge of keeping airborne separation compared to the current situation
   c. Will acquire higher than current responsibility in conflict management, while major role in it will be delegated to the automation.

9. While fulfilling *Communicate* functions the crew
   a. Has to consider the lack of direct ATC communication
   b. Will need the traffic intent information from other aircraft through airborne information sharing system
   c. Will have to consider the possible increasing role of communication with airline operational centre compared to current situation.

10. While fulfilling *Situate* functions the crew
    a. Will need updated information about weather and terrain. If the airborne system is not able to acquire it reliably itself, the help from the ground may be needed
    b. May need the radio watch-over function as currently, because it will help to develop and maintain SA in general and traffic SA in particular
    c. Will have the new responsibility to develop and maintain traffic awareness, which can be seen as an extension of the current ATC responsibility to the airborne system.

11. While fulfilling all the functions of flying in the A^3 airspace the crew
    a. Must have the sources of information for new and changed airborne responsibilities
    b. Must have the ability to use the tools and information available on new and changed airborne responsibilities.

12. Knowledge and information requirements of the crew include
    a. Non-traffic SA issues
    b. Strategic planning issues
    c. Tactical decision making issues.

13. Non-traffic SA issues include
    a. Overall financial awareness, which means that an effective A^3 system should support the financial requirements of its users
    b. Structural awareness, meaning the care of the crew against excessive wear of the systems and parts of the aircraft and towards keeping the

periods between structural inspections in the limits specified by regulations

c. Passenger awareness (understanding their needs as a function of exogenous conditions and of the crew mission)
d. Sense and avoid awareness in IMC, meaning being responsible for and able to use the technology for keeping traffic and mode awareness in IMC
e. Awareness of passenger connections (with special care of unaccompanied children and international passengers to get their connections)
f. Awareness of passenger and cabin crew safety.

14. Unmanned Aerial Systems (UAS) SA needs cover the following issues:

    a. Intensity of SA of the UAS operator may be lower than that of the pilot in the cockpit and may need improvement
    b. UAS operator may have compatibility problems between their ATCo-like cognitions of the airspace and pilot-like cognitions of the UAS cognitive workspace
    c. As a subdivision of mode awareness the UAS operators have to maintain an awareness of the data link status
    d. Operators of multiple UAS may become overloaded and may get into difficulties in keeping acceptable overall SA if sense and avoid data is presented to them in a cognitively difficult way
    e. Awareness of personal circadian desynchronosis may be a more serious issue for UAS operators compared to pilots in cockpits, as their environment is less stimulating than that of the pilots
    f. UAS operators must have awareness of the freight each UAS is carrying and of how this freight might impact the future mission decisions for each UAS.

15. Strategic planning issues under knowledge and information requirements of the crew mainly comprise subcomponents of traffic awareness:

    a. Temporal awareness [knowledge of the required time of arrival (RTA) and the probability to meet it] would require to support the pilots' 4D cognitive model of the mission with the appropriate display technology
    b. Weather awareness is necessary for achieving the goals of the mission irrespective of the weather conditions
    c. Geographic awareness means taking into account the terrain peculiarities for achieving effective and safe missions
    d. Environmental awareness means taking into account the limits of emissions (e.g., sound, particulate emissions) while flying over certain geographical regions and/or under certain temporal or meteorological conditions
    e. Awareness of emergency or diversion airports is an important safety issue to be considered
    f. Flight area awareness means the flight crew responsibility to meet the established legal requirements while flying in a particular region of the airspace (e.g. military special use airspace)

g. Airline pilots need pre-awareness of next mission (and perhaps cognitive support to generate this awareness), to be timely prepared for the mission
h. Airline pilots also need freight awareness, as airlines do carry freight and the pilots need to know the limitations related to this freight.

16. Tactical decision making issues under knowledge and information requirements of the crew mainly comprise even more detailed subcomponents of traffic awareness (as was in the case in strategic planning) and components of the mode awareness:

a. By perceiving
   - of the own and other aircraft current state
   - of own and other aircraft future state
   - of current separation
   - of weather
   - status of airports
   - peculiarities of terrain
   - the occurrence of alert zone warning/watch

b. By comprehending
   - potentially dangerous terrain/hazards
   - emergencies/equipment malfunctions and alerts
   - timing
   - accuracy of information
   - future of the ownship state
   - conflict detection
   - ownship planned changes
   - significance of these changes

c. By projecting
   - best plan of actions to avoid a future or discontinue a current alert zone contact
   - ownship route
   - other aircrafts' route
   - ownship potential route
   - other aircrafts' potential route
   - separation
   - changes of weather
   - impact of potential route changes
   - traffic conflict solution.

17. Cockpit display of traffic information and airborne separation assurance system should be designed according to the guidelines from the ICAO circular 249-AN/149.

18. In A^3 the flight crew must have strong support from automation to distinguish between different types of potential conflicts and to avoid them.

19. Major factors involved in conflict detection and resolution by humans are (a) time, (b) task/systems/environmental factors and (c) individual/human factors.

20. While automated systems are able to sense and analyze multiple conflicts in parallel, humans will be able to do it serially one after the other. This puts a serious limitation to human conflict solving ability together with the limited speed of (a) processing information, (b) reasoning for deducing alternatives and (c) decision making for choosing between the alternatives, and together with limited geometrical comprehension and limited prediction of multiple trajectories.

Follow up

- Within WP1, A^3 ConOps will be developed, partly based on the findings of the current D2.2 report.

- Subsequently, WP2 will evaluate these WP1 produced A^3 ConOps against the D2.2 findings and will identify the best ways how extending ground roles and responsibilities could be of help.

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