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iFly

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

**iFly Deliverable D2.1**  
**Description of airborne human responsibilities**  
**in autonomous aircraft operations**

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**Abstract**

The present report is the first deliverable of Work Package 2 of iFly project. The report begins the process of identifying of how current human responsibilities in en-route phase of flight will change compared to new responsibilities of autonomous flight conditions. While most pilot tasking will remain unchanged in airborne self separation conditions, some are expected to change substantially and some totally new tasks could appear.

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## List of Acronyms

A/C – aircraft  
ACAS – Airborne Collision Avoidance System  
ACARS (Datalink) – Aircraft Communications Addressing and Reporting System  
ACO – Air Coordination Order  
ADF – Automatic Direction Finder  
ADS-B – Automatic Dependent Surveillance - Broadcast  
ANSP – Air Navigation Service Provider  
AP – Autopilot  
ATC – Air Traffic Control  
ATCo – Air traffic Controller  
ATO – Air Tasking Order  
ATM – air traffic management  
AWACS – Airborne Warning and Control System  
EC – European Commission  
EO – Electro- Optical  
ER – En-route  
EVS – Enhanced Vision System  
FL – Flight Level  
F/O – First Officer  
FMS – Flight Management System  
GAT – General Air Traffic  
GDTA – Goal- Directed Task Analysis  
GPS – Global Positioning System  
HAL – Heuristically Programmed Algorithmic Computer  
HIS – Horizontal Situation Indicator  
ICAO – International Civil Aviation Organisation  
IFF – Identification Friend or Foe  
IFR – Instrument Flight Rules  
IMC – Instrument Meteorological Conditions  
IR – infrared  
LNAV – Lateral Navigation  
MFF – Mediterranean Free Flight  
NASA – National Aeronautics and Space Administration  
NEAN – Northern Europe ADS-B Network  
NLR – National Lucht- en Ruimtevaartlaboratorium  
NUP – NEAN Update Program  
OAT – Operational Air Traffic  
PF – Pilot Flying  
PNF – Pilot Not Flying  
RTCA – Radio Technical Commission for Aeronautics  
SA – Situation Awareness  
SOP – Standard Operational Procedure  
SME – Small- Medium Enterprise  
SVS – Synthetic Vision System

TCAS – Traffic Collision Avoidance System  
TRA – Temporary Reserved Area  
UAS – Unmanned Aerial System  
UGV – Unmanned Ground Vehicle  
VFR – Visual Flight Rules  
VHF – Very High Frequency  
VMC – Visual Meteorological Conditions  
VOR – VHF Omni-Directional Range  
WP2 – Work Package 2

# 1 Introduction

The concept of Free Flight has been developed extensively since 1995, when Radio Technical Commission for Aeronautics defined it as “...a safe and efficient flight operating capability under instrument flight rules in which the operators have the freedom to select their path and speed in real time ...” (RTCA, 1995). Airborne self separation promises an important advantage over current managed air traffic if aircraft separation assurance, potential conflict detection and resolution with other aircraft can effectively become the primary responsibility of the airborne system. It has also been argued that Airborne self separation removes the main present bottleneck in increasing airspace capacity – the excessive workload of ATM personnel in very busy traffic sectors. This change in ATM workload is achieved by distributing ATM responsibilities mainly to the airborne systems.

## 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) 6<sup>th</sup> 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).

## **1.2 Background and objectives of iFly WP2 Deliverable 2.1**

Work Package 2 (WP2) of iFly project is divided into two parts: “airborne responsibilities” and “bottlenecks and potential solutions” which will be addressed in four separate reports – two on airborne responsibilities and two on bottlenecks and potential solutions:

1. Report with description of airborne human responsibilities in autonomous aircraft operations
2. Report on Situation Awareness, Information, Communication and Pilot Tasks under autonomous aircraft operations
3. Report with description of bottlenecks identified in an autonomous aircraft concept design
4. Report describing ground operational assistance to autonomous aircraft

The objective of the current report is 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. As stated in the Annex 1 of iFly project, current developments in ATM show a shift towards a more decentralised system, with increasing tasks and likely more responsibilities for the airborne side, i.e. the cockpit crew. Thus, the airborne side forms the starting point for the current project, therefore the question that arises is: “What responsibilities can be assigned to the airborne side of the system assuming a new task distribution implied by autonomous ATM?” Work Package 2 considers these issues in more detail (*ibid.*, p 43).

Airborne responsibilities An initial analysis has been carried out to identify the responsibilities of the cockpit crew during the en-route phase of the flight in the current operational environment to be used as a starting point for the design and a point of comparison for an autonomous aircraft system that evolves.

Basically this Work Package will perform a task analysis to identify what tasks the crew currently has to perform during the en-route phase of a flight. This analysis needs to be performed on an operational scenario of the en-route flight phase, to map out the tasks of the cockpit crew during the en-route phase.

The description of tasks also provides a description of the goals of the crew which will be valuable as input for the identification of autonomous aircraft responsibilities. This analysis will thus provide a basic overview of the current operational environment. The already existing responsibilities can be considered in the autonomous aircraft concept. To achieve a highly automated air traffic management system, the possibility for assigning more responsibilities to the airborne crew than in the current situation, will also be investigated. This may be a necessity for a more autonomous operation of the aircraft.

Responsibilities of a cockpit crew go beyond issues related to air traffic management only. For example, the cockpit crew is also responsible for monitoring the functioning of the system (i.e., the aircraft). An autonomous aircraft shift in responsibility with respect to ATM issues should not result in conflicts with other responsibilities. Therefore, consequences of this responsibility shift should be reviewed and resulting bottlenecks (in relation to human tasks) – when consequences appear to be outside acceptable limits – need to be identified (*ibid.*, p 44).

### **1.3 Relevant reference documents**

Several EC funded programs have been working on different aspects of airborne self separation concept and considerable progress has been achieved. In the human factors domain NLR/NASA Free Flight, and two EC funded projects – INTENT and Mediterranean Free Flight (MFF) – have contributed significantly to future airborne self separation human factors issues. Probably the best overview available about these issues is in the recent paper by Ruigrok, & Hoekstra (2007). Main findings of these studies confirm that:

- (1) airborne self separation is a viable concept,
- (2) airborne primary separation responsibility offers several times higher traffic density compared to ground control primary responsibility,
- (3) human-machine interfaces developed in the projects have been favourably rated by the flight crews.

The authors consider these as resolved issues from the human factors point of view (*ibid.*, p. 453). In addition, there are a number of unresolved issues that need further human factors studies. For example, how should information necessary for conflict detection and resolution be presented to pilots both in state-based (using ground speed, track and vertical speed of aircraft involved) and intent-based (using the flight plans of aircraft involved) mode and behaviour of flight crews in both information display modes has been evaluated. The results obtained leave open the question, which mode of information presentation is better and “the best of both worlds” – combination of state-based conflict detection and resolution with a limited amount of intent information needs further studies (*ibid.*, p 453-454). Also an open question is how to use the rules of conflict resolution by aircrews: “The pilots in the MFF experiments were not in agreement on the use of priority rules versus co-operative conflict detection and resolution in the state-based conflict detection and resolution system. Some liked priority rules, some liked the co-operative approach. From an analytical point of view, this issue is also not clear yet.” (*ibid.*, p. 454-455). And because issues of information display are open (for example, the necessity of a VND in Airborne self separation operations), the favourable ratings of human-machine interfaces received in previous research have not solved all the interface issues yet (*ibid.*, p. 454-455). And still, pilot workload issues during airborne self separation remain open – in conflict situations the demands of the situation may exceed the resources available to the pilot and in problem-free situations suboptimal workload may cause the decrease the level of activation of the pilot.

#### **1.4 The structure of the report**

The present report is devoted to the current and new airborne responsibilities of the cockpit crew during en-route phase of flight. New responsibilities of the crew are characteristic in airborne self separation conditions (in autonomous aircraft operations). The present report consists of six main subdivisions plus References and Appendices. Part 1, “Introduction” describes briefly the aims of iFly project, in more detail its Work Package 2, and especially of the present deliverable.

In Chapter 2, titled “Theoretical framework”, the use of the terms “responsibility” and “accountability” in the present context is analysed and the use of the first term is suggested.

Further on the interrelations between responsibilities, goals and situation awareness are discussed together with function congruence between man and machine as more promising approach compared to function allocation between man and machine. The chapter ends with the introduction of theoretical background to the goal- directed cognitive task analysis.

In Chapter 3 empirical data from commercial and corporate aviation is presented to characterise the current tasks of pilots. The information gathered is based on interviews and cognitive task analyses. The present tasks changing in airborne self separation situation have been indicated and new tasks are named. In Chapter 4 the relations of military aviation to airborne self separation are discussed in brief. It has been concluded that in military aviation the airborne self separation conditions can rarely occur.

In Chapter 5 the general aviation as a model of airborne self separation is discussed. It is concluded that the basic task of general aviation pilots “see and avoid” is a good starting point for understanding the new tasks of the crew in airborne self separation.

Chapter 6 describes Unmanned Aerial Systems (UAS) from the human factors point of view, indicating onto interaction, interface, workload and responsibility issues. The “sense and avoid” principle should be guiding UAS flights.

In Appendix 1 the detailed cognitive task analysis results are presented. Appendix 2 gives a listing of tasks in cruise flight with modern general aviation aircraft, Appendix 3 differentiates the current tasks from those that change in airborne self separation conditions.

An overall result of the report gives the description of airborne human responsibilities in current and autonomous aircraft operations.

## 2 Theoretical framework

### 2.1 Responsibilities or accountabilities

WP2 of the iFly project is entitled “Human responsibilities in autonomous aircraft operations” and in the work description it has been said that “responsibility is a core issue in aerospace operations, because it determines who makes what decision and can take action if required without being required to request permission from another actor” (iFly Project Annex 1, 2007, p. 43).

This is an important statement and needs some semantic analysis for its justification in the situation where voices have been heard that question the appropriateness of the use of the term *responsibility* in above mentioned context because of its semantic ambiguity and suggests the term *accountability* instead. It is true, that the everyday meaning of the term *responsibility* is ambiguous, as anyone can ascertain by looking for the explanations of the word in any kinds of dictionaries. Mostly the liability, the *legal responsibility* connotation prevails in the consciousness of the users of *responsibility* term. This dominance of one semantic facet over the others in understanding the word meaning has its causes that will not be the topic of the analysis here, but it also has some unwanted consequences that need to be refuted.

In a recent ICAO document, *Safety Management Manual* (ICAO, 2006) a small subsection “Responsibilities and accountabilities” has been included, which states:

“2.3.1 Responsibility and accountability are closely related concepts. While individual staff members are responsible for their actions, they are also accountable to their supervisor or manager for the safe performance of their functions and may be called on to justify their actions. Although individuals must be accountable for their own actions, managers and supervisors are accountable for the overall performance of the group that reports to them. Accountability is a two-way street. Managers are also accountable for ensuring that their subordinates have the resources, training, experience, etc. needed for the safe completion of their assigned duties.

2.3.2 A formal statement of responsibilities and accountabilities is advisable, even in small organisations. This statement clarifies the formal and informal reporting lines on the organisational chart and specifies accountabilities for particular activities with no

overlap or omission. The contents of the statement will vary depending on organisational size, complexity and relationships.” (*Ibid.*, p. 2-6)

The text cited explicitly states that responsibility and accountability are closely related concepts, but the use of term *accountability* is preferable in safety issues according to the frequency of its use (8 to 3 times in this small piece of text).

This example show how the two words, found as synonyms in dictionaries, may obtain different preferences in certain domains of use. It has to be shown that the term *responsibility*, widely used in iFly project Annex 1, is still bearing the facets of meaning which are appropriate for human- machine interaction and safety domains and can be used further in the course of the project without any doubts about its suitability.

It seems that some important developments in semantic analysis of the term *responsibility* are not well known but should not be ignored. Typically in philosophical references the term *responsibility* is discussed in three or four wider contexts – as social, collective, moral and legal responsibility. None of these views cover well all the semantic aspects of the term *responsibility*, neither its specific connotations used in the iFly project context.

Fortunately enough an article by Coleman (2005) in the *Stanford Encyclopaedia of Philosophy* about computing and moral responsibility gives a needed and solid foundation for continuing use of the term *responsibility* in iFly project context. Coleman gives an exhaustive review of the literature and introduces the four facets of responsibility, derived by Heart (1985) – Role-Responsibility, Causal-Responsibility, Liability-Responsibility, Capacity-Responsibility and explains how many important and useful positive aspects of the term *responsibility* (Ladd, 1988) tend to vanish in (at least in some sense negative) liability semantics of the term. Further on Coleman cites Kuflik (1999), who has identified even six semantic facets of responsibility, relevant in human- computer interaction context: (1) Causal Responsibility, (2) Functional Role Responsibility, (3) Moral Accountability, (4) an honorific sense of responsibility, (5) Role Responsibility, and (6) Oversight Responsibility. Kuflik uses these facets of *responsibility* for asking a crucial question about: How much responsibility (in either sense (2) or sense (5)), could responsible (sense (3)) human beings responsibly (sense (4)) allocate to a computer, without at the same time reserving to themselves oversight-responsibility (sense (6))? (Kuflik, 1999, p. 189). This question touches all main aspects of co-ordinated functions of human and machine in a system and can be considered equally valid

for future air traffic management systems. Much deeper and broad-range discussion of moral responsibility in the domain of human- computer interaction is given by Ladd (1988), whose views will be the basis of the attempt of the synthesis given at the end of the present section.

Historically the roots of the concept of responsibility used here lie in the philosophical concept of moral responsibility that has mainly been developed in the broader discussions about the free will concept. For the first time the concept of moral responsibility was explicitly outlined by Aristotle. According to Aristotle, a voluntary action or voluntary trait of an actor has both (a) a control condition and (b) an epistemic condition. The control condition means that the action or trait of the agent must have its origin in the agent (the agent is in control) and the epistemic condition has to assure that the agent is aware of the essence he/she is doing or bringing about (so both conditions confirm the existence of free will of the agent).

Since the sixties of the last century important developments in the concept of moral responsibility have taken place thanks to the discussion initiated by Strawson (Eschleman, 2005). For Strawson the personal relationships expressed in attitudes of an agent form the essence of moral responsibility. These *participant reactive attitudes* may be excused or justified if the good will had been the purpose of the reactions (i.e. if the good aims had been pursued). These attitudes – positive, indifferent or negative in their qualitative emotional nature – are expressed to indicate how much we actually mind, how much it matters to us as the actors. (In reality these participant reactive attitudes are formed both on our expectations and guesses about other people around us and on the expectations we think the others have about us – this explains why the attitudes discussed here are called reactive.) In general, the social and reflective nature of the concept of moral responsibility has been disclosed better in these recent developments.

In the same contemporary context of philosophical analysis of moral responsibility a distinction has been drawn between responsibility understood as *attributability* and responsibility as *accountability*.

Responsibility as attributability means that the agent's actions disclose something about the nature of his/her self (here some authors say that the self should be measured against a certain standard). In the extreme example the attributability can be explained by the "ledger view" of moral responsibility – each agent will receive credit or debit recorded in his/her "ledger-book"

for his/her actions. Responsibility as attributability is a kind of precondition for responsibility in the sense of accountability.

Being accountable means that the behaviour of the agent is governed by an interpersonal normative standard of conduct that generates expectations in the members of shared community. So it can be said that the social nature of moral responsibility opens in full due to accountability responsibility. (It has to be noted here, that the use of accountability as a synonym of responsibility is very different from the term “accountability responsibility” used in the present subsection of the analysis.)

All the important developments of moral responsibility and its manifestations in the field of computer use that may be useful for iFly project purposes have been gathered into the table at the end of the present section in an attempt to systematise the related concepts and to show the relations between different aspects of the broader moral responsibility concept developed. The greatest impact into this synthesis comes from Ladd (1988), whose ideas are both theoretically sound and practically applicable. Before the synthetic table showing the relationships between the different concepts will be presented, the extensive definition of the positive concept of moral responsibility in the domain of computer use by Ladd (1988) will follow:

"The comprehensive conception of moral responsibility ... implies that human agents are, in the final analysis, responsible for the systems themselves – that is, for the way that intermediaries function – and that human responsibility for disasters (past and potential) is not limited to the direct input of particular individuals, such as operators. Responsibility in the full moral sense covers indirect and remote causal relations, partial and contributory causes, as well as direct and proximate ones; even though individual persons are only indirectly or remotely connected with the outcome, they are not freed from the requirements of responsibility. ... Which people in particular are responsible? To answer this question requires tracing the causal connections and responsibility relations for outcomes to particular individuals and to their individual failures stemming from such things as self-centered projects, narrow and single-minded interests, unconcerns, and moral mindlessness." (p. 216) ... "The structured processes themselves, as adopted and employed in formal organisations, perform the role of intermediaries in a way that is comparable to the role of technological systems. ... In both types of intermediaries, however, individual human agents are not let off the hook as far as responsibility is concerned. The comprehensive conception of responsibility makes room for indefinitely large numbers of people to be morally responsible for an outcome, although their various contributions are at different levels and vary considerably in amounts and degrees. " (p. 217-218) ...



<b>Moral responsibility</b>		
Useful subdivisions of moral responsibility [see Ladd (1988), Gotterbarn (2001)]	<b>Positive responsibility</b>	<b>Negative responsibility</b>
Main approach	Broad and nonexclusive	Narrow and exclusive
Main dichotomy	Responsible – irresponsible	Responsible – nonresponsible
Basic explanation	Responsibility expresses a certain level of moral and social relationship between persons. Responsibility has both subjective (mental attitude or value- based) side such as concern of the safety or welfare of another person and objective (technically based) side such as causal connection between agent's actions (or omissions) and the (fortunate or unfortunate) outcome for the other person.	Responsibility expresses (unsuccessful) attempt to find an issue, which exempts one from the blame and liability.  Exemption from the blame means exemption from moral responsibility and exemption from the liability means exemption from legal responsibility.
Subdivision: <b>Causal Responsibility</b> [see Hart (1985), Ladd (1988), Kuflik (1999)]	Causal influence is extended: it is not only immediate, but also extended to the past and future, not only proximate, but also extended to intermediaries and remote agents, not only dichotomous, but also gradual, not only direct, but also indirect.	Causal influence is immediate, proximate, dichotomous, direct.
Subdivision: (Functional) <b>Role Responsibility</b> [see Hart (1985), Ladd (1988), Kuflik (1999)]	Broad and extended, incorporates three arbitrary subdivisions by Kuflik (1999): moral accountability, honorific sense of being responsible and oversight responsibility. Hart (1985): "Role" is extended to include a task assigned to any person by agreement or otherwise.	Narrow and exclusive
Subdivision: <b>Liability Responsibility</b> [see Hart (1985), Ladd (1988)]	See basic explanation of negative responsibility.	
Subdivision: <b>Capacity Responsibility</b> [see Hart (1985)]	Psychological conditions (criteria) required for liability (having the capacity to understand what a person is required by law to do or not to do, to deliberate and to decide what to do and to control one's conduct in the light of such decisions. Possession of these normal capacities is often signified by the expression "responsible for his/her actions".	

Figure 1. An attempt to summarise different approaches to moral responsibility

"It is a bit anthropomorphic nonsense to ascribe moral responsibility to systems, whether they be technological or social, in addition to or instead of the individuals that

make and use them. ... Individuals, whoever they are and however minor their contribution, cannot escape either their retrospective or their prospective moral responsibilities in an organisation by appeal to the doctrine of *respondeat superior*. For the same reason, computer professionals, users, operators, programmers, and managers cannot escape their responsibilities for outcomes by appeal to a doctrine of *respondeat computer!*" (p. 218).

In a certain sense the table replaces the (almost impossible) attempt to give an original formal definition of moral responsibility in the context of human- computer interaction that is central for iFly project. Although the parts of the definition by Ladd given above are clear, thorough and self-explanatory, some important relations between different concepts can still be added into the table to develop the concepts further.

This overview given proves that we need not feel cheap while using the term *responsibility* in iFly project and do not need to replace it with any kinds of synonyms or euphemisms. The term *responsibility* has all the relevant connotations to communicate adequately the ideas expressed in the iFly Project Annex 1, especially of human- machine systems, while its synonym *accountability* has obtained its philosophically analysable facets of meaning mainly in the fields of organisational, public and political affairs which makes its use less suitable for iFly purposes.

The need for further discussion of the moral responsibility issues in the iFly project may appear at the later stages of the project specifically for human- machine interaction, ATC, autonomous aircraft and airborne self separation purposes.

### **2.1.1 Responsibilities, goals and situation awareness**

One of the important functions of responsibility issue is its relationship to having / obtaining / accepting *goals*. This relationship should be seen as mutual one, because from one side the state of being responsible needs having, obtaining or accepting certain specific goals like "I as the pilot am responsible for the safety on board; for fulfilling the flight plan; for fuel economy etc." From the other side having or acquiring goals becomes real if the person in charge decides to take the responsibility to achieve these goals. It can be said that a person having goals proves through having these goals that he/ she has taken responsibility / has become responsible for achieving these goals and having (real or potential) conscious awareness about

them. This state of affairs is typical to fulfilment of any functions by human independently or as a participant in the human- machine system.

The goals can be broader and narrower in their scope, higher or lower in the hypothetical hierarchies of possible goals, they can be individual or team goals and according to human-machine ideology system or subsystem goals etc. For further illustrative purposes the goals could be characterised as being at high, medium or low level in the hypothetical hierarchy of all possible goals. The level of the goal in the hierarchy is determined by its scope and timing. An example of a high level (both broad in scope and long-term) goal could be a pursuit of a person to become a good professional pilot; a kind of medium level goal (having both medium breaths and timing) for the same person could be “having a successful, error- free and safe forthcoming flight from New York to Rome” and a low level goal (being both narrow in scope and having definite short timing) fulfilling of certain task like “to execute a change in the flight path on ATC clearance”.

The idea of giving these examples is to recall that as a rule people have several goals of different scopes and timings at the same time and achieving minor goals typically serves the aim to contribute into fulfilling the major ones. It also reminds us that for achieving a certain goal we have to concentrate our mental and physical effort on this goal at least for some time. In the hypothetical hierarchy of goals we can have them on several descriptive levels, like high, medium or low level goals and subgoals.

The taking of responsibility and achieving goals brings in another issue important for our analysis – the situation awareness (SA). It can be said that taking responsibility means accepting goals and means also acquiring situation awareness, so responsibility, goals and SA issues are all interdependent and as the order of appearance of these psychological states may vary, they may be depicted as interdependent phenomena :

### ***Acquiring SA ~ accepting goals ~ taking responsibility***

In the same way how we brought examples of higher level and broader goals compared to lower level and narrower goals, we can also speak about higher levels of SA and of responsibility. We can say that safety and quality goals demand (and accordingly generate)

higher levels of SA and of responsibility. This means that the goals, responsibility and SA are in concordance or congruence and our activities differ in the level of their scope:

<b>Goals</b>	<b>Responsibility</b>	<b>Situation awareness</b>
High level	High level	High level
Medium level	Medium level	Medium level
Low level	Low level	Low level

At the same time it is important not to take the discussed level of SA as a quality index of SA, but as an indication of the level of current analysis.

One important issue not yet covered is linking behavior to goals, responsibility and situation awareness. From psychology it is known that about 95 % of goal-directed behavior is automatic, it means, un- or subconscious (Franken, 2002, p. 391). It seems to be so because we need our (limited span) of consciousness to be free for higher levels of mental activities – cognitive tasks like planning, organizing, solving problems etc. – and spending it mostly to monitoring skilled actions would be prodigal, at least in standard situations. It also means that executing automatic behavior brings our goals, responsibility and situation awareness, which are directly linked to this behavior, to un- or subconscious level. Typically this can happen at the low hierarchical levels of activities, because higher levels need more complex and variable chains of behaviors that can not become fully automatic and demand conscious cognitive processing for their execution and control.

In conclusion to the present paragraph it can be said that fulfilling certain functions means obtaining / accepting goals, taking responsibilities and acquiring situation awareness about the factors that can be of influence on fulfilling these functions.

### **2.1.2 Situation Awareness (SA)**

There are different ways of defining situation awareness, one of the most popular is Endsley's (1995). She defines SA as:

The perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.

Endsley's three stages of the situation awareness (*perception, comprehension* and *projection*) are useful attributes for explaining both the persistence and change in SA. The cognitive processing necessary for SA can be predominantly *goal-driven* or *data-driven* at different moments. Goal driven cognitive processing can explain persistence of SA – active goal is determined and SA is being kept mostly unchanged until the goal is achieved or needs a change. Data driven processing explains changes of SA, which take place when perceived information from the system and / or environment determines the need for changing one goal to another (Endsley, Bolte, & Jones, 2003).

Goal-driven and data-driven processing generate current and forecasted situation model or SA on the basis of certain cognitive resources that can be called *mental models*. Each mental model contains both *theoretical knowledge* (mainly descriptive information) and *schemata* (mainly prescriptive information). People normally have developed many different mental models and their active goals determine, which of these models should be activated at the moment. The prescriptive information is mostly available in the form of schemata, which could also be seen as a kind of heuristics, that help people to find the appropriate ways to behave more or less adequately in a certain situation. In some mental models the prescriptive information may persist in the form of even more developed and detailed *scripts* (checklist-like collections of necessary behaviors to initiate).

A single mental model from many available ones and one schema (or script) from the list of several schemata or scripts is active at a time. The active mental model with an active schema comprises the resources (or *resource mode*) of SA.

Besides the resource mode of SA there is the *processing mode* of SA, which is a synthesis of attention processing (directing, focussing, distributing, switching, sustaining attention) together with perception, comprehension and projection. Perception takes new information in, attention processing steps adjust the mind to the information relevant in the current (and forecasted) situation both for comprehension and projection to the nearest future.

Choosing appropriate mental models, schemata and scripts for generating adequate SA mainly depends on operator's knowledge and experience, i.e. professional qualities, but also depends on *expectations*, which can be seen as an additional useful shortcut for avoiding information

overload. This shows expectations generally in positive light, but besides their advantages the same expectations may also cause harm, if the shortcut suggests to ignore the information relevant to task at hand. While there are many examples of great use of expectations in directing our attention to important information, there are also a plenty of opposite examples available.

In their user centered approach to design, Endsley, Bolte, & Jones (2003) suggest to organize technology around the user's goals, tasks and abilities: "Whereas traditional human factors approaches are quite suitable for linear, repetitive tasks, user-centered design is more suitable for complex systems in which users need to pursue a variety of (sometimes competing) goals over the course of time, and no set sequence of tasks and actions can be prescribed. In these types of systems, interfaces and capabilities need to be designed to support the changing goals of the operator in the dynamic fashion" (*ibid*, p 8).

This approach may demand that the technology must keep the user in control and aware of the state of the system. It turns the SA the key feature for user-centered design. From previous analysis we saw how the SA is not simply goal-related, but more specifically *goal-oriented*. Supporting SA means supporting cognitive processes of the operator and keeping the operator in control leads to keeping his / her situation awareness at appropriate quality level.

## **2.2 Function congruence versus function allocation**

### **2.2.1 Cognitive System Engineering and Automation**

Traditionally, the issue of automation has been a matter of function allocation. The allocation of functions between men and machines has a lot in common with the division of labour. This work of allocating functions to either men or machines has a number of limitations.

First of all, it is much easier to allocate tasks than functions (that tend to be more abstract). Thus function allocation usually goes together with task decomposition, while the idea is to improve the cooperation between men and machines, to improve the capability of men and machines to work together to accomplish a given and common goal. And we thus tend to

forget that functions depend on each other in ways that are more complex than a mechanical decomposition can account for: “small changes affect the whole”.

This sort of reasoning tends to make us think of human as bio-automaton. This comparison allows to compare which tasks are ‘better performed’ by machines, which are ‘better’ performed by humans; and in the end this comparison allows us to allocate functions (Fitts’ list is probably the most known example of such reasoning). We tend to force human in a model of simple automaton, of finite state automaton.

In order to go beyond these limits, Hollnagel (1999) proposes to think in terms of function congruence (instead of allocation). According to him, function congruence, or function matching takes into account the dynamics of the situations. In fact, this proposition is well in accordance with the idea that a cognitive system is defined by what it does and not how it does it. His proposal is to work on cognitive functions such as ‘observation’, ‘identification’, ‘planning’ and ‘action’. These functions are the ones to be fulfilled by the joint cognitive system in order to fulfil its goal. Then, Hollnagel (1999) proposes that for each of these functions we reflect in terms of how the changes will impact the performance: is it some sort of

- amplification?
- delegation?
- substitution/replacement?
- extension?

Coming back to our concern: we shall try to follow the lessons of cognitive systems engineering to:

- avoid the allocation of functions,
- think in terms of what the joint cognitive system does, instead of how it does it,
- base our discussion on functions to be fulfilled, and not on tasks to be accomplished

### **2.2.2 Function congruence instead of function allocation**

The moral responsibility issue in computing has dealt with function allocation between people and computers, the issue that is in the very heart of the WP2 activities in iFly project. Recent developments in philosophy of human- machine systems have created an advanced view on

the division of human and machine functions in the system. Accustomed function allocation approach may need revision as Hollnagel (1999) states, because the search for function congruence is a preferable approach in human-machine systems compared to function allocation between human and machine (computer). “The principle of function congruence emphasises that the functions assigned to various parts of the system must correspond to each other and provide the ability to redistribute functions according to current needs, ... keeping in mind that the primary objective is the ability of the joint system to maintain control” (Hollnagel, 1999, p. 52-53.).

Designing changes in the systems by automation can actually result in an *amplification* of human functions by machines (and while maintaining the human in control we get a preferable outcome in the system, but with the diminishing the control by human we may easily get an unpreferable function *substitution (replacement)*, which in fact can result in turning the system into prosthesis of its operator). The danger of function substitution lies mainly in its degrading effect on situation awareness leading to inability of the operator to perform the functions needed. In the best cases of automation the amplification of function does not harm the human control function, giving at the same time a certain advantage (*e. g.* , providing easier access to information, sorting out relevant information from irrelevant, supporting decision making) compared to situation before the change.

Another type of the change in the system induced by the design is *delegation* of function to another agent or subsystem while maintaining the control to the human operator. As an example it may mean that the user who had to monitor the conditions and to perform a certain function, now has only to monitor it, while another agent or subsystem performs the function. As a result the control on a high level is maintained but has been lost over the details. As Hollnagel (1999, p. 46) explains, “This follows from the nature of delegation – a task is given to another system and until a specified goal has been accomplished (a specific sub-task) there is no need or no possibility of controlling the performance. ”

Yet another and perhaps more revolutionary step towards change in the system automation is *extension* or adding new functionality or new resource to the system. At one extreme one can argue that it is impossible to introduce a completely new function or a resource, but Hollnagel sees an extension of function already if the function was not “excecised in a recognisable way



and to a meaningful extent” beforehand. It is important to see, that like in function amplification, also in function delegation and extension there is a danger to fall into the trap of function substitution.

At the present stage of iFly project all the possible benefits of the function congruence philosophy over the function allocation approach cannot be fully estimated, but the ideas supported by this design philosophy should be kept in mind during the progress of the project. One important aspect of it means that instead of focussing on the tasks to be completed it is necessary to look at the cognitive functions the system has to fulfill (cf Lorenz, 2004; Schick, 2004). In the design process it also means that while amplifying, delegating and extending functions we need caution not to create function substitution and turning the function into prosthesis of human operator.

### **2.3 Goal- directed cognitive task analysis**

In the Age of Information Processing cognitive task analysis methods have largely replaced earlier methods of “traditional” task analysis. The reason for this has been that “... as machines become more intelligent, they should be viewed as “equals” to humans ... the maxime now became to design the joint human-machine system, or more aptly phrased, the joint cognitive system” (Schraagen, 2006, p.192). Interest to cognitive task analysis has markedly grown in XXI century and several handbook- type publications are available to potential users of the analysis (Crandall, Klein, & Hoffman, 2006; Ericsson, Charness, Feltovich, & Hoffman, 2006; Stanton, Salmon, Walker, & Jenkins, 2005).

The analysis done so far takes us to the main method used for conducting the task analysis of the cockpit crew during en-route phase of flight. Endsley, Bolte & Jones (2003) call the type of appropriate analysis *goal- directed task analysis* (GDTA). To be more precise, this analysis should be called *goal-directed cognitive task analysis*. Goal-directed cognitive task analysis focusses on

- (a) dynamically changing goals of the operators, which addresses the analysis onto the
- (b) cognitive tasks, which need
- (c) decisions to be made to accomplish these goals and have certain

(d) information requirements of these decisions to keep the necessary SA.

In other words this means that described task analysis starts with defining the goals the cockpit crew has to achieve during en-route phase of flight. These goals can in some cases be differentiated as being lower or higher in the hierarchy of goal scope and timing. So it is possible to differentiate between goals and subgoals and higher and lower task levels accordingly. In other occasions it is (almost) impossible to estimate which task is higher in hierarchy (broader in scope and timing) compared to others. Then it is appropriate to leave these cognitive tasks on the equal level of analysis.

One of the critical issues in task analysis is a question, where to stop. In pure task analysis it is possible to go to the “end” of the task, downway in the level of task decomposition, until further subdivision of tasks becomes impossible, unreasonable or inappropriate. In cognitive task analysis the same situation is much more difficult to solve, because cognitive tasks reside at much higher level of abstraction and complexity.

As suggested by Endsley, Bolte, & Jones (2003), the type of cognitive task analysis used in the present study was oriented to finding task levels that needed decision to be made. This means that the final results of our goal-oriented cognitive task analysis are the divisions and subdivisions of cognitive tasks, which lead to decisions. Although not done in the present analysis, it is comparatively easy to go on with the analysis and formulate decision to be made to solve the goal-oriented cognitive tasks derived through the analysis. And together with these decisions to be made we can follow with the analysis to find out the information requirements for these decisions (see Figure 1).

These information requirements form the conditions of SA and comprise the input for design processes. As the above mentioned authors state it, “The GDTA seeks to determine what operators would ideally like to know to meet each goal, even if that information is not available with current technology. The ideal information is the focus of the analysis; basing the SA requirements only on current technology would induce an artificial ceiling effect and would obscure much of the information the operator would really like to know from design efforts” (Endsley, Bolte, & Jones, 2003, p. 65).

At the further stages of the iFly project the selected parts of cognitive task analysis made and especially the results of task analysis for new and changing tasks will undergo a new analysis for deriving the iFly crew decisions to be made and for defining the SA requirements for these decisions in a way, depicted on Figure 2.

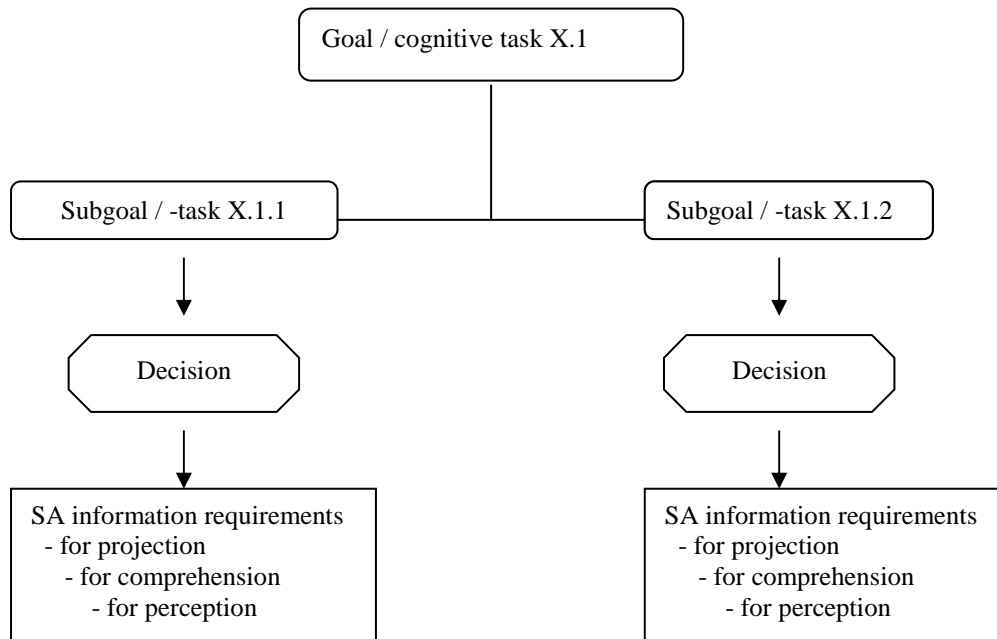


Figure 2. Providing information requirements of a goal / cognitive task for SA. Modified from Endsley, Bolte, & Jones (2003).

### **3 Empirical data from commercial and corporate aviation**

#### **3.1 *What is en-route phase of flight?***

To answer the question, data from interviews with pilots was collected. From a crew point of view, en-route (ER) phase of flight starts when the aircraft reaches the ‘cruise’ altitude. The en-route or ‘cruise phase’ of flight may be considered from the top of climb up to the top of descent. But in some cases (mainly for long-haul flights) the aircraft can be cleared to reach a cruise flight level in a specified time. From a pilot’s point of view, this can mean flying above FL 100. After this point, the autopilot (AP) is activated, and the crew starts performing his ‘routine’ tasks like fuel management, communication, etc. It is as well the ‘end’ for the ‘sterile cockpit SOP’. This transition is also marked by the release of the passengers from the ‘fastened seat belt’ and the authorization of the cabin crew to access the cockpit if necessary.

For cross-Atlantic flights, ER starts when entering the Atlantic-routes control centre: then communication only occurs via ACARS (Datalink).

There are no fundamental distinctions between ‘En-route’ tasks accomplished during one flight or another; only the duration of the ‘En-route phase’ changes, and thus the crew has to accomplish these tasks during different period of time in different flights. For example, the ‘cruise’ of a long-haul flight over Atlantic ocean can last for 9 to 10 hours, compared to only 20 minutes in the case of a Paris-Amsterdam flight or even 10 minutes in the case of a Paris-Clermont-Ferrand flight.

#### **3.2 *Analysis of crew tasks from interviews with commercial and corporate aviation pilots***

##### **3.2.1 Interview method**

The present report was written on the basis of several semi-direct interviews. The objective of these interviews was to obtain the crews’ point of view on their responsibility during the en-

route (ER) phase of flights. The pilots were asked to describe their activity during this phase of flights. The basic interview guide we had mentioned the following points:

- Definition of en-route,
- Beginning of ER: what happens?
- Tasks being performed during ER?
- Communications with ATM during ER? For what purpose? Etc.
- Changes of flights plan during ER: Reasons for change? How does it happen? Etc.
- End of ER: what happens?
- Technical failure management: what happens in case of a technical failure? How is separation maintained in such a case? Etc.

### **3.2.2 Interviewee profiles**

This report summarises the interviews of 4 pilots:

- Type of Operation: Commercial Aviation (\*2), corporate aviation (\*2)
- Aircraft Types: B737, B747-400, Be200, F20, F10, F50
- Flight ranges: short, medium and long haul flights

It should also be noted that one member of the WP2 team is a former military pilot who also has extensive experience in light general aviation aircraft.

### **3.2.3 Crew tasks and work analysis in en-route phase of flight**

The identified high level tasks are as followed:

- Aircraft systems checking (T1)
- Fuel Management (T2)
- Passengers safety and comfort management (T3)
- Navigation (T4)
- Radio 'watch' (T5)
- Communication with ATC (T6)
- Logbook and flight documents (T7)
- Flight path and flight plan changes management (T8)
- Operational and commercial communication with the airline line base (T9)
- Crew coordination (T10)

- Airborne separation management (T11)
- Technical Failure management (T12)
- Flying the aircraft (T13)

The level of abstraction used here is the one used by the pilots we interviewed. It is interesting to note that pilots do not naturally use a description at a low level (“press button X”). Two of these “tasks” are on a quite high level of abstraction: “navigation” and “flying the aircraft”. However, for these two tasks it is interesting to note that:

- All the activities related to navigation are not put under this task,
- The task “flying the aircraft” was not mentioned by the pilots: we identified it mainly when discussing the management of technical failures.

Instead of reasoning on a high level (somewhat close to the “responsibilities” we are trying to identify), they situate their description on a level closer to the reality of their activity, but still on a level that give sense to their actions.

These “tasks” are outlined (within the context of normal airline operations) in the following paragraphs. Their current ordering is unimportant.

#### T1. Aircraft systems oversight

- The crew monitors all the aircraft systems; e.g., the electrical, hydraulic, temperature (cabin, cargo,) and the pneumatic system which can not be verified before 14 000 ft flight level in some aircraft.
- These tasks are often assigned to the Pilot Not Flying (PNF), but is also performed by the Pilot Flying (PF) usually on specific points of the flight path. It seems to be ‘a transparent task’ (means no verbal interaction between the crew members) until the PNF declares “safety visual control accomplished” (in case no default is actually noticed).
- This task is often performed at every ‘turning point’. On a cross-Atlantic flight this can happen every 10 degrees of latitude or approximately every 30 to 40 minutes. However, on a Paris-Pointe-à-Pitre flights, this may only occur only every 90 minutes.
- Crews tend to more and more rely 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 once every hour only.

#### T2. Fuel Management

- This task starts once the safety visual control is accomplished.
- It is one of the main tasks of flight management.
- It is usually fulfilled by the PNF.
- Its aim is to check any fuel leak, fuel transfer pumps failures or malfunction, unintended transfers, etc.
- The PNF checks the fuel quantities and records the data (estimated fuel quantity, waypoints estimated overtime, arrival fuel quantity) on the operational flight documents.
- 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.
- This task is accomplished at every turning point, which can mean nearly each ten minutes for short-haul flights, up to once every hour for long-haul flights.

#### T3. Passengers safety and comfort management

- The cabin crew may inform the flight crew of any cabin temperature changes requested by passengers (mainly each 15 or 30 minutes)
- In such cases, the PNF who may be busy with the radio, has to manage these interruptions.
- In addition to this management of the Air conditioning system, the crew (mainly the PNF) of corporate jets also has to play a safety and commercial role.

#### T4. Navigation

- The pilot flying (PF) is typically responsible for the aircraft navigation: maintaining the aircraft on the planned flight-path.
- In case of a flight-path change, both pilots have to
  - o enter the new cleared route in the FMS,
  - o check the waypoints on the HSI
  - o validate the proposed new flight-path
  - o and request the aircraft to follow the new parameters (by pushing the LNAV button).
- Weather conditions can have a consequent impact on navigation. For instance, cross-Atlantic flights are usually quiet (from the crew's point-of-view), except when "the weather starts to intervene". The impact of the weather conditions depends on the

routes and on seasons... except for some particularities that are always present (such as the inter-tropical front).

- Today, the flight-path is obtained from ATM control centres.

#### T5. Radio 'watch'

- The pilot non flying is typically in charge of radio communications with ATC and of the radio watch-over: listening of other aircrafts transmissions on the same frequency
- This task is not a 'two way' communication. Its objective is to allow the crew to have an overview of the traffic around. It participates to the crew's awareness of the surrounding traffic. Listening to the other aircraft messages and mainly to the clearances helps the crew to built it's own representation of the surrounding 'world'.
- In some areas, communication failures with the ATC are frequent, so listening to other aircraft messages helps,
- In cross-Atlantic flights, there is no continuous radio watch-over, as it would require too much attention.
- On the other hand, over Africa, there is a radio frequency (126,9) on which every flight has to use to report its position every 20 minutes (as well as 5 minutes before crossing a route). This allows covering for potential limitations of the technical equipment of some countries.
- It has to be mentioned that not all the messages are relevant to the flight.

#### T6. Communication with ATC

- The pilot non flying is in charge of radio communications with ATC.
- Managing the radio communication is a continuous task: in certain countries, like Russia for instance, the airspace is still broken up between many control centres, which thus requires frequent changes in frequencies.
- The communication mainly concerns the ATC clearances and requests, but may also concern the latest weather data.

#### T7. Logbook and flight documents

- Typically the PNF fills up the logbook, the ATL, the Lognav, etc.

#### T8. Flight path and flight plan changes management

- Managing the ATC requests, or clearance following a crew's request to change a flight-path (e.g., flight level, routes/airways).



- Depending on the cleared slot, the estimated time of arrival, the en-route traffic, military zones or weather conditions, etc., the ATC may request from the crew to deviate from the planned flight plan.
- The request may be an acceleration, which implies a change in the flight level, or even a flight level change which in both cases need an additional fuel management as well. It can also be a route change, offering a more direct flight path to the crew.
- The request may also be made by the flight crew, in order to optimize the flight time, the aircraft performance; by requesting the authorization to fly more direct airways, a higher (or lower) flight level.
- These changes occur very regularly: in average at least once in every flight.
- Even when the change is demanded by the crew, it is the ATM's responsibility to check the possibility of the change and to manage potential conflicts.
- Such changes may oblige to crew to more coordination regarding its strategies in case of troubles.

#### T9. Operational and commercial communication with the airline line base

- Air-ground communication requesting the latest weather data,
- Communication with the line base, or the airline's operational control centre: commercial messages, or requests, like ACAS messages with estimated time of arrival, number of passengers, etc. (The captain is typically responsible of this communication).

#### T10. Crew coordination

- Before the en-route phase (during the cruise climb), the PF typically performs an exhaustive briefing about his strategies in case of troubles (engine failure, aircraft depressurization, electrical/radio failure,..). Some flights, overlying mountainous, oceanic or specific areas seek more detailed briefing (altitudes, decision waypoints, etc),
- New coordination may be required as a consequence of flight-path changes.

#### T11. Airborne separation management

- The airborne separation is defined and managed by the ATC: according to the aircrafts speed, and flight levels, the minimum distance and time between aircrafts is given by the ATC.
- The crew manages the TCAS through a visual management of the HSI display:

- the crew has to check aircrafts flying in the area around the HSI centreline (about 40 nautical miles around)
- The crew has to check the concordance with the received radio clearances
- The ATC informs the crew of any aircraft crossing its flight path at specified altitudes. This information is useful for the crew to identify a crossing aircraft, especially in bad weather, where the altitudes are hardly exactly maintained, which will cause TCAS alarms.
- The crew keeps a look outside the cockpit (the surrounding area) in order to maintain an aware representation of the traffic around.
- In other words, except for short term conflicts resolution (through TCAS and visual watch) airborne separation management is not the responsibility of the crew.

#### T12: Technical failure management

- (not analyzed here)

#### T13 – Flying the aircraft

- The first responsibility of the crew is to maintain control of the aircraft. Hence, for instance in the case of technical failure management: the priority is given to controlling the aircraft (descending if necessary, reducing speed is necessary, deviation to the closest airport, etc.). “Priority is to trajectory”. If the ATM starts asking question, the crew would reply “stand by” until the aircraft and the technical failure is back under control.

This priority is also observed when the crew is asking for a flight-plan change because of weather conditions: the crew can ask for a deviation, and deviate before obtaining an answer from ATM if this is necessary for maintaining control of the aircraft.

### **3.3 Goal-directed task analysis on commercial aviation tasks**

#### **3.3.1 Procedure and the results**

Goal-directed cognitive task analysis of pilot tasks at the en-route phase of flight was carried out in collaboration with a subject matter expert MK who works as Boeing 737 first officer in a small airline, also as a chief flight instructor in an aviation college and Masters student at the university. After several adjustments of the balance between generality and granularity of

candidate cognitive tasks the acceptable solution was found when the basic criterion for goal-directed task analysis – divisions and subdivisions of cognitive tasks, which lead to decisions – was consistently followed.

It has to be mentioned that the high level task analysis described in the section 3.2 and the analysis described in the present section (3.3) have been carried out independently and had the aim to gather current pilot tasks data using diverse approaches. The high level analysis in 3.2 does not give much detail of the tasks, but the analysis presented here gives the opportunity to go to the level of decisions, when needed. At the later stages of the project the need to map the results of one approach to the other may appear in some domains of pilot tasks.

The results of the goal-directed cognitive task analysis are given in the Appendix 1 of the report. Three major divisions of the analysis were (1) Normal situations, (2) Special situations (supplementary procedures) and (3) Abnormal and emergency situations. Under these headings the goal-directed cognitive tasks and subtasks were listed with minimal comments to help the specialists to identify the tasks from the list without difficulties. As the whole variety of task analysis methods has been criticized because of questionable validity and reliability (Stanton, Salmon, Walker, Baber, & Jenkins, 2005), an attempt was made both to validate and check the reliability of the result of the analysis through expert opinions. Two pilots (AK and EC) as subject matter experts independently reviewed the results of the cognitive task analysis and gave their opinions both in the form of comments onto the tasks list and in the text form. Reliability and validity check generally supported the task categories found.

### **3.3.2 Potential changes in pilot tasks under iFly flight conditions**

An important issue after receiving validity and reliability support of the pilot task analysis results is to differentiate between the pilot tasks that remain the same and that change substantially in iFly airborne self separation conditions. This analysis was done on the current list of tasks, where all the tasks were evaluated by the subject matter expert (MK) after obtaining an understanding on airborne self separation ideas on the basis of reports, papers and presentations (*c.f.* Hoekstra, van Gent, & Ruigrok, 1999; Ruigrok, 2004; Ruigrok, & Hoekstra, 2007). The result of the analysis is given in Appendix 3, under the “iFly flight” heading. For better comparison the original task list has been preserved, but the tasks

changing substantially are printed in gray (and are less visible) and comments have been added to them. The following comments are used:

- No task** – this task is missing in iFly flight, no replacement
- Pilot resp.** – substantial change in responsibility, pilot (cockpit crew) is responsible
- Change?** – responsibility is changing, but not clear yet, how
- New instru.** – new devices will influence the essence of the task

Tasks that remain unchanged or largely unchanged in iFly flight are printed in black. As expected, most of the changes are related to ATC communication under the following groups of tasks:

- Monitoring lateral cruise profile
- Monitoring vertical cruise profile
- Monitoring speed
- Monitoring of the airplane systems
- Planning of arrival and approach
- Keeping ATC communication

Although most of airline pilot tasks remain unchanged in the airborne self separation conditions, the changes to occur are substantial and will need further analysis in later reports.

New pilot tasks in iFly conditions are related to their new responsibilities of monitoring separation information and solving separation conflicts. Precise specification of these tasks is dependent on technical solutions and function congruence between the system and the crew.

## 4 Relations of Military Aviation to Airborne self separation

One of the differences between European and US airspace is the European concept of General Air Traffic and Operational Air Traffic (respectively GAT and OAT). The GAT system is designed to accommodate civil and military IFR traffic that chooses to utilize the procedures and regulations established for civil IFR traffic. Civil controllers currently manage this GAT system. The OAT system is designed to accommodate military air traffic only and is managed by military controllers only using discrete communication. Suitably equipped military aircraft are given the option of filing as either GAT or OAT. Civil aircraft are required to file as GAT. The needs of military air traffic and ATM support are normally beyond the scope of civil aviation and therefore not sufficiently covered by ICAO provisions for GAT. For military training and mission accomplishment, OAT provides the regulations and ATM arrangements necessary. The only major difference between European and US airspace is the lack of uncontrolled airspace in Europe.

Airspace can be divided into civil airspace and military airspace. In the earlier days military airspace was only for military purposes. However nowadays civil aviation is allowed, under certain conditions, to cross the so-called military 'Temporary Reserved Areas' (TRA's), to somewhat relieve the busy European air traffic ways and offer shortcuts. For the Netherlands (and a lot of other European countries), all military flights above national 'grounds' (in civil airspace) are controlled by military air traffic control. They will provide the flight levels, speed levels and information about traffic and weather. Only so-called ferry flights, across the Atlantic or Europe, are controlled by civil ATC (with some rare exceptions still executed by military ATC). When flying in civil airspace, military aircraft need to conform civil procedures and regulations. In common with civil aircraft, the military aircraft will use the standard airways. In the contrary, when flying in military airspace, there are no airways which have to be followed. In this airspace, military aircraft are more flexible in their route on condition that they are according to their flight plan.

Because some of the military aircraft have different physical characteristics than civil aircraft (e.g., very high speed), this might result in specific questions to ATC. These different

characteristics can cause implications in the flight (plan). For example, a fighter aircraft has more trouble with icing but can endure more turbulence than an unwieldy big passenger aircraft (subordinate to construction and passenger comfort). The fighter aircraft can ask ATC respectively for lower flight levels or take the (shorter) way through the turbulence area. Besides differences in physical characteristics, there is in some cases the difference in crew composition. Fighter pilots have to execute the whole flight and the accompanying tasks and procedures on their own. They have no other crew members to share the tasks.

Military flights are *almost* always under supervision of ATC. As mentioned before, this can be military ATC or civil ATC. Exceptions of military aircraft flying without ATC are;

- Military exercises in assigned areas (e.g., TRA's)
- VFR flights (or low level flights 1000'). These flights occur nowadays less often, and are most applicable for fighter jets and helicopters.
- Special operating procedures during missions

During missions where there is no ATC radar coverage, Airborne Warning and Control System (AWACS) personnel can provide additional information about the location of other aircraft in that relevant area and can give flight directions to the pilot. However, this can not be counted as full ATC.

At all times, the military pilot has to compile a flight plan which states route, flight levels, speed etc. For all military missions (ATC or no ATC), a kind of pre planned ATC will be carried out in the form of an Air Coordination Order (ACO) and Air Tasking Order (ATO). By means of these orders an 'air picture' is given about which airplane will be where at what time to prevent conflicts. 'Safe lanes' will be provided to enter and cross the mission theatre. Radar, Identification Friend or Foe (IFF, a transponder system), hearing out radio communications between other aircraft and ATC/aircraft and looking out of their cockpit helps the pilots to develop good situation awareness.

Military pilots who were interviewed all stated that military airborne self separation (no ATC, an iFly-like situation) hardly ever occurs, certainly not during en-route flight. In 'no ATC' situations, there is not much air traffic to get in conflict with. When pilots have no ATC instructions or backup they acknowledge that they are more concentrated on radar displays, IFF and looking out of the window; more time and energy is spent in obtaining a good SA.

For military flight there is always some coordination; between formation members, in the form of ACO/ ATO regulations, or AWACS instructions. Furthermore, military pilots often have more advanced systems (radar, displays, IFF, Night Vision Goggles) than civil aircraft to obtain a good Situation Awareness.

To summarise;

- Military en-route tasks do not differ from civil en-route tasks, leaving aside the difference originating from crew composition, systems and physical characteristics of the aircraft.
- Military flights have almost always ATC, civil ATC or military ATC.
- When flying in GAT (civil airspace for example during ferry flights), military aircraft have to operate conforming civil regulations and procedures.
- Pilots have to compose and file their flight plan, which states their route, flight levels, speed etc. For combined air operations, an ACO and ATO will be composed which states the coordination and tasking of the participating aircraft.
- Airborne self separation (with no ATC) occurs very seldom.
- During the occasional flights without ATC, pilots are more concentrated and focused to achieve a good SA. They make more extensive use of their radar system, IFF and are looking more often out of the window.

## 5 General Aviation as a Model of Airborne self separation

### 5.1 Current General Aviation Crew Responsibility

The traditional behavior and operational characteristics of general aviation very much mimic the expected behaviors and operations of what one would probably assume for a airborne self separation system. Therefore, in many ways, general aviation may be one of the best sources of knowledge for futures operational guidelines as well as, the place where one will be most like to identify where problems requiring technical support will exist and what technology might provide the best support.

**Definition:** According to ICAO, “general aviation comprises all aircraft that are not operated by commercial aviation or by the military.” Business aviation<sup>1</sup>, one of the components of general aviation, consists of companies and individuals using aircraft as tools in the conduct of their business. Other forms of general aviation include aerial work, agriculture, flying schools, tourism, sport, etc. Because the higher end members of general aviation, e.g., corporate jets, tend to operate in the same way as airlines, they will not be covered directly in this section to avoid unnecessary redundancy. Rather this section will address issues associated with light aircraft that are flown by people primarily for pleasure, personal transportation, and/or education.

**Legal:** General aviation has the same basic legal responsibility as the other types of aviation operations. However, in those operations that that do NOT involve flying for hire (e.g., flying for pleasure) the extent of the legal liability tends to be narrower.

**Policies:** How do established policies differ from reality (i.e., what behaviors are, in fact, rewarded and punished)? For example, as fuel costs become a bigger issue for the general aviation will the pilots start to look for ways of reducing fuel burn? Because of the extremely wide variance in general aviation operations, as noted above, the issue of the impact of policy will vary dramatically in the general aviation community. For the “policy” the part of the



general aviation that will be described here, the community will be divided into three general categories: owner operator, flying clubs, and rental aircraft.

**Owner operator:** In this case, the person flying the aircraft also owns it. Given that the owner/pilot is not only the policy maker but is also the pilot, it is extremely likely that the way the aircraft is operated is one and the same with the operational policy.

**Flying Club:** There are several different types of flying clubs, but this report will assume the definition that a “flying club” is a group of people who co-own one or more aircraft and who share the operating and fixed costs. In these types of flying clubs, it is the group of owners who sets the policies (either the entire group or more often an elected group of officers). Because the members of the club also have a financial link via their membership (in a sense they are somewhat like a mini owner operator) and the cost of that link is based on proper operation of the aircraft, they tend to have reasonable policy compliance. For example, if they over lean the engine to save fuel, they recognize that they will directly share in the cost of the engine overhaul. However, because in such a group there can be some members who abuse the system, most flying clubs have ways of eliminating members who are seen as violators of club policy, e.g., usually by the forced buying back of that member’s share in the club.

**Aircraft rental:** These commercial operations generally work the same way as most car rental companies, with the possible exception that the aircraft rental companies often rents the aircraft “wet” (meaning that the gas costs are included in the rental costs). This is usually done so that renters do not over lean the fuel/air mixture in order to save on the fuel costs. These rental operations generally have strict rules on checkout and currency (these rules are quite often established by their insurance company). Rental companies also tend to have rules that define reasons for not allowing a person to continue to rent their aircraft. But it is probably in these rental operations that one might expect to see more deviations from established policy, particularly those that are difficult to verify.

**Priorities:** The segment of general aviation being discussed here tends to have lower technology in their aircraft that support the pilots efforts related to the classic Aviate, Situate, Navigate, & Communicate tasks. The technology levels are lower primarily due to the cost of

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<sup>1</sup> . It should be noted that the term “business aviation” is not included in the official ICAO vocabulary

the technology and because a significant fraction of these aircraft are only used for pleasure flying and for relatively short cross countries (e.g., flying to a neighboring airport for lunch). In these cases if the weather is bad, one simply goes home or chats with fellow “grounded” pilots.

As a result the aviate, situate, navigate, & communicate demands do typically involve very different levels of pilot attention and tasking when compared to the higher technology segments of aviation. For example, the cost of installing some high-end avionics can easily exceed the cost of the remainder of the aircraft. As a result the types and kind(s) of avionics found in general aviation aircraft tend vary significantly across general aviation aircraft. With some having only the minimum needed to operate legally, while others are filled to the maximum. In the minimally equipped aircraft there will probably be a higher level of cognitive and physical workload in some tasking, e.g., instrument flying. In the higher tech cockpits the physical workload will be lower (e.g., with a good autopilot), but cognitive workload may still be high from trying to remember how to use an obscure function in rarely used part of a piece of avionics. For the purpose of this analysis we will primarily (but not only) focus the lower technology cockpit to allow the analysis process relative for iFly to explore the full range of options.

**Aviate:** In general aviation the physical task of flying the airplane will tend to be a manual one for several reasons: the pilot is probably flying out of love of flying and actually enjoys the task. In addition, the cost of a good autopilot tends to high (relative to the cost of a typical general aviation aircraft). In addition, lower cost autopilots tend to be less accurate and require significant monitoring and tweaking. The remaining cockpit instruments tend to independent basic electro-mechanical and vacuum operated instruments. Each instrument collects and displays data about one variable (e.g., airspeed, altitude, vertical speed) and cannot talk to each other. Thus, such instruments involve more data sampling and data integration by the pilot in order to safely fly the aircraft in instrument conditions.

In visual meteorological conditions (VMC) the pilot of such aircraft rely significantly on visual cues from outside the cockpit, e.g., pitch of the nose or the distance of the wing tips relative to the horizon, wind noise, rather than aircraft instruments. Given that these aircraft

are usually flown in VMC the cost of relatively expensive avionics becomes even more cost significant while providing little in the way of significant operational aviating support.

**Situating:** Developing strong situation awareness again requires considerable cognitive effort because of the lack of higher end technology such as moving maps, TCAS, and GPS. For example, a pilot may have to rely on monitoring radio traffic to estimate the locations of other aircraft or listen to ATC messages to other traffic to get a better feeling of weather ahead because of not having weather radar. In addition, location estimation may be as basic as time elapsed from the last waypoint times estimated ground speed and good map reading skills.

In particular, the general aviation pilot needs to continually visually “clear” the airspace around her aircraft for other airborne traffic and if any is observed determine if it is a threat. Even if the aircraft is not an immediate threat the pilot will need to track it until it is obvious that it is not going to be a threat.

**Navigating:** At the very low end (basic aircraft without an electrical system), navigation may be performed using a paper chart marked with a pencil line (so it can be erased and reused) an accurate time piece and a thumb at the last confirmed waypoint (usually a visually distinctive location). In the middle one generally sees some form of basic radio navigation equipment (e.g., VOR receiver and perhaps an ADF). More and more one sees a basic GPS system containing both geographic and airspace data even in basic general aviation aircraft.

**Communicating:** At the low end is an aircraft without an electrical system and no radios. One does more and more see hand-held battery powered two way radios in such aircraft. In the majority of the general aviation aircraft one typically finds one or two built-in VHF communications radios, and quite often a headset and noise canceling boom-mike operated by a push-to-talk switch mounted on the control stick or yoke.

It is also important to remember that most light general aviation aircraft are very noisy inside the cockpit. This is due in large part to the lack of sound absorbing materials due both to the desire to reduce weight and cost. Thus, the ambient noise will impact the ease and accuracy of radio communications. The use of headsets are often utilized to improve the communication process.

### 5.1.1 System Flexibility

The bottom line in the civil regulations, as applied to all aviation operations, is that the flight crew always has the final authority with regard to how the aircraft is operated, even to the point of over-riding a request by ATC. In addition, the act of declaring an emergency will always give the aircraft the right of way. This is not to say that the pilot will not be held to a requirement of explaining why they violated a regulation or policy, or explicitly disregarded a controller's request or clearance. But pilots still retain the right of final decision making.

### 5.1.2 Impact of the Physical Environment

One of the advantages of general aviation is that it can get to places that lack a ground transportation infrastructure. For example, there are many places in Northern Europe, Canada, and Alaska where even the basic necessities (food, mail, groceries, and even educational materials & class assignments) are delivered by general aviation aircraft. In such regions, one can still find many places in general aviation that still operate very much like the early aviation descriptions of Antoine de Saint-Exupéry's *Night Flight* and Ann Morrow Lindburgh's, *North to the Orient*.

In places like the Alaskan bush and Northern Europe, one does not necessarily fly the most efficient routes, but rather route is based on other considerations such as height of the terrain. Pilots will pick waypoints (and thus routes), for example, based on the ability to see the waypoints at the planned altitude (e.g., Will I be able to see over the mountain?) and in the expected weather (particularly visibility) conditions.

### 5.1.3 Social Organization

General aviation social organizations tend to be established to help the members achieve a particular goal (e.g., support or hinder pending regulation). While there are several very large pilot international organizations focused on the general aviation pilot (e.g., Aircraft Owners & Pilots Associations, Experimental Aircraft Association) the number of members who actually

actively participate in classic social activities tend to be relatively small. However, there is a strong virtual social network that is called upon when political pressure is need to try and influence legislation that might have a negative impact on general aviation. This also holds true for members of flying clubs, where social activities often revolve around tasks on the aircraft (e.g., oil changes, washing aircraft). Such activities tend to be performed by a small subset of the members.

#### **5.1.4 Individuality**

While the nature of the world's air systems are based in no small part to military models, general aviation tends to be much more individualistic. One can see this at fly-in events in the variety of designs and paint jobs. This individualism is reinforced by hours of flying where one never sees another aircraft.

### **5.2 General Aviation Responsibility: Current Operations**

The following pages are a first attempt to identify the basic set of factors for which general aviation pilots are currently held accountable. In practice degree of responsibility varies as a function of the type of flight rules one is operating under and the weather.

#### **5.2.1 Visual Flight Rules**

The most basic (and perhaps most fun) part of general aviation operates under what is known as visual flight rules, which while not all that common in Europe, is common in many places in the world. Visual flight rules need to be discussed in the iFly context because the airborne self separation concept in many ways is a high technology system that has it intellectual roots in basic VFR operations.

Under visual flight rules the weather needs to be such that pilots have the ability to see other aircraft and navigational hazards (e.g., towers, buildings, mountains) far enough in advance to be able to maneuver in such a way as to avoid any hazards. The flight crew makes all navigation, flight, and safety decisions as long as the aircraft maintains its required visibility and operates in the appropriate class(es) of airspace.

The second type of operation is generally known as instrument flight rules (IFR). In this category the regulations are based on the ability of the flight crew to maintain control of the aircraft only by reference to instruments and without the ability to see the world. Instrument flight rules assume that there exists an air traffic control systems which assists in the act of separation the traffic. Instrument flight rules are the basic operational standard for airline operations.

### 5.2.2 Instrument Flight Rules

Under instrument flight rules there are two fundamental operation environments: visual meteorological conditions (VMC) and instrument meteorological conditions (IMC).

**Instrument Flight Rules in VMC:** Generally, when an aircraft is operating under IFR but is in VMC the flight crew shares the responsibility for the separation task with the air traffic control system. For example, it is possible to be operating under IFR and to have other aircraft operating under VFR in the same airspace. In addition, when operating IFR in VMC, the pilot's response that he sees the traffic that the ATCo has called to him, causes that pilot to now share the task of separation from that aircraft with the ATCo. The "tallyho" implies that he, the pilot, will continue to visually track and avoid the other aircraft.

Also, in busy airport environments during VMC, it is not uncommon for controllers to clear an aircraft operating under IFR for "visual approach" which not only includes managing the navigation task of attaining and maintaining alignment with the runway, but also to maintaining required spacing on other aircraft in the landing queue ahead of them.

**Instrument Flight Rules in IMC:** When meteorological conditions become such that it becomes impossible to have the required visibility to safely maintain your own separation and you are operating in controlled airspace, then you must be on an IFR flight plan and under positive control. One should remember that positive control does NOT necessarily mean under radar control. For example, except the northwest and southeast corners of Australia there is no en-route air traffic control radar on the entire Australian continent!

When operating under IFR in IMC the ATC system completely assumes the responsibility for maintaining separation between all aircraft legally in that airspace. Thus, while knowing that the responsibility for separation belongs to the ATCo, the vast majority of pilots flying in that environment attempt to maintain a rough mental model of the locations and headings of aircraft around them by listening to the radio communications between the controllers and the other aircraft for which they are responsible. This practice is common enough to even have name: the party line.

There are regions of the world, e.g., Northern Canada, where it is legal to fly general aviation aircraft in IMC without contacting ATC and without having an IFR clearance. The logic is that it would be too expensive to operate an ATC system in such a location and the flights are so rare that the chance for mid-air is statistically not significant.

It should also be noted that when operating a general aviation aircraft under IFR in IMC in uncontrolled air space (not common, but possible), air traffic control does not and cannot guarantee separation from uncontrolled aircraft which may also be in that airspace. In many places in the world, including developed countries, it is possible to take-off from a remote airport into IMC without an IFR clearance.

Also, in many places in the world one can take-off from a small general aviation airport that does not have a control tower (the vast majority) or the ability to contact ATC (too low for the radio signal to be picked up by the receiving antenna) within an assigned time window and altitude and to pickup the details of the clearance once airborne.

### **5.2.3 Current responsibility – Instrument Flight Rules (VMC)**

#### **1. Aviate:**

- a. Control attitude (pitch, roll, & yaw)
- b. Control airspeed & angle of attack
- c. Control velocity vector
- d. Monitor status of expendables

#### **2. Situate**

- a. Know where you are

- b. Be aware of where everyone else is
- c. Know where everything else is
- d. Knowledge of expendables available
- e. Knowledge of Quantity of expendables required
  - i. Quantity needed for primary objective
  - ii. Quantity needed for secondary objective(s)
- f. Awareness of operational environment
  - i. Airspace limitation
  - ii. Communications available
  - iii. Support available
    - 1. ATC
    - 2. Company dispatch
    - 3. Flight Service
    - 4. Weather
  - iv. Mission goals
    - 1. Desired destination
    - 2. Secondary destination(s)
    - 3. Decision trade-off criteria

### **3. Navigate**

- i. Know where you are
- ii. Know where you are going next
- iii. Know meteorological environment
- iv. Know the operational environment

### **4. Communicate**

- i. Crew
- ii. Ground support
  - 1. ATC
  - 2. Flight Service
  - 3. Company operations
  - 4. Tower, Unicom, or equivalent
- iii. Other aircraft



#### 5.2.4 Basic Assumptions: Separation Standards

Contrary to what some people appear to believe, the current separation standards were not engraved on the back of the tablet that Moses brought down from the mountain. The current separation standards have been established not based on pilot skills or aircraft capability. Again, looking back in aviation history the Allied Air Forces in World War II flew bomber missions of a thousand planes. These thousand planes were escorted by hundreds of fighters. And for the most part the aircraft were being flown by young men fresh out of pilot training with less than 200 hour flying experience. And while there was definitely carnage, it was not due to midair collisions. So placing an extremely large number of aircraft together in a very small space is not necessarily an extremely dangerous thing to do.

The current separation standards are based on a number of non-aircraft technical and environmental issues. These begin with the technique used to identify the location of each individual aircraft. At the extremely low resolution end of air traffic control techniques would be the use of pilot reports (which is still utilized in a very large part of the world's airspace). In this environment, routes and procedures are divided up into segments. Once an aircraft reports into a segment everyone else is keep out of the segment until that aircraft calls out. Is such a system very large blocks of airspace are protected because the granularity of the system can be 20 or 30 nautical miles.

Even with the current radar system the inaccuracy of aviation radar makes it unable to exactly calculate the exact location of an aircraft from the radar return is a significant issue. This inaccuracy of radar is such that some advanced air traffic management systems use datalink position data from each aircraft's flight management system to get a more accurate idea of where the aircraft is in space. In addition, even if the system had significantly higher accuracy, the scale of the radar scope to the area under control results creates a gross distortion of the scaled size of the aircraft. In short, it is impossible for a controller to know exactly where the aircraft is in space being controlled. Thus the controller has to be very conservative in her actions.

In addition, the current minimum separation standard also must take into account several time issues. For example, once an ATCo recognizes the possibility of a conflict, it takes him a

small but practically significant amount of time to formulate a plan. It then takes a small but practically significant amount of time to transmit the plan to one or both of the aircraft. It then takes another small but practically significant amount of time for the flight crew to respond verbally and yet another small but practically significant amount of time to begin to maneuver the aircraft. Because airline aircraft are big and designed to be stable (i.e., keep the passengers comfortable) that stability also significantly limits the ability of those aircraft to change attitude, direction, speed, etc. quickly, thus adding additional time needed to initialize a change. Also built into the separation standard is the assumption that occasionally the flight crew will ask for a clarification, will turn the wrong way, or want to negotiate the clearance. If this happens the ATCo will then need several more of those small but practically significant amounts of time to recognize the issue, create & transmit a corrected clearance, the flight crew to respond verbally and to physically change the course and/or speed of their aircraft to the correct clearance.

Finally the separation standards are also established assuming that the ATCo could be really busy because of heavy traffic, bad weather, or other technical problems and thus be less efficient than normal in identifying potential problems and thus be later than normal in creating and transmitting that first clearance message.

In an iFly environment the stability of the aircraft would not change, but a significant number of “the small but practically significant amounts of time” will either be eliminated or reduced. Thus it may be possible to significantly reduce the currently required separation requirements. There are perhaps three environments in which one could currently examine low technology approximations of an iFly environment. They are: 1) certain military operations which need to be done with no or minimal communications of any type; 2) the Capstone Program in Alaska and/or the Northern European ADS-B Network, and 3) the approach and arrival at Oshkosh, Wisconsin during the week of the Experimental Aircraft Association’s annual Fly-In (i.e., Air Adventure).

## 6 Unmanned Aerial Systems

### 6.1 Introduction

Because Unmanned Aerial Systems<sup>2</sup> (UASs) are such a new player in the aviation environment, it was felt that some additional general background material should be provided to the reader to help provide some underpinnings for the way this section of the report will be different from those describing the other three aviation communities: i.e., general aviation, military, and commercial. In addition, because UAS operations are still in their infancy, it will be very difficult to generate a single representative task analysis because there are currently so many different approaches to UAS operations.

**(Robin) Murphy's Law:** any deployment of robotic systems will fall short of the target level of autonomy, creating or exacerbating a shortfall in mechanisms for coordination with human problem holders (Casper & Murphy, 2002).

Robin Murphy's observation is something that all airborne self separation UASs operators need to keep in mind when working with highly automated systems like modern military UASs. While there are obviously parts of the automation in modern military UASs that are very reliable and relatively straight forward to use (e.g., straight and level flight, holding patterns), but because they are used in war, the enemy (no matter how technologically challenged they may be) will always be looking for ways to minimize their effectiveness. And it is in gaps (also called brittle boundaries) in the design that one will find significant additional operational challenges and places where errors will be made. Errors that will result in personal embarrassment at the low end up to loss of forces due to friendly fire on the high end.

This section will address a subset of these kind of human factors problems both from a traditional human factors engineering perspective (e.g., what is wrong with the human-UAS interface) to less traditional areas more related to what might more traditionally be called organizational psychology (differences in crew stress related to delivering weapons on a suspected enemy) while being in theater versus being stateside and living with ones family.

There is no intention to identify all such issues, but only to highlight those that may be less recognized and particularly those that might be mitigated (if not completely solved) through the application of superior design based on good human factors. It will also not address either the verification and validation or the certification of such systems but answers to such questions can be found in Wise & Wise (2000), Wise & Hopkin (2000), Wise, Hopkin, & Stager (1993a) and Wise, Hopkin, & Stager (1993b).

### 6.1.1 Assumptions

The following discussion will assume

- The use of certified pilots to control UASs
- The simultaneous operation of more than one UAS by one operator
- UAS will be “controlling” itself using a high quality autopilot most of the time

UASs have quickly become an extremely valuable tool to the military and many commercial operations. In many situations the utilization of UASs offers significant advantages when compared to manned aircraft. Perhaps the most important advantages include: 1) significantly lower purchase cost compared to a manned aircraft, 2) no potential loss of a flight crew, and 3) very long loiter times.

UASs also offer other advantages including potential lower cost of operation, very long mission and loiter times. In terms of civilian use their visual stealth characteristics can be critical because of their small physical size, and in some cases the ability to operate at very high altitudes for a long duration.

The relatively brief history of their use has shown that like all new (and old for that matter) technology they have a set of basic design problems, as well as a number of inherent issues that are the result of them being either partially or fully reliant on a remote operator, e.g., their loss rate runs as high as 100 times that of a piloted aircraft.

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<sup>2</sup> The term “unmanned aerial system” is used in this document to indicate that it includes not only the aircraft but all the support equipment and personnel on the ground that is necessary to successfully operate the aircraft.

Because the military is clearly the largest and most active operators of UASs this report will rely heavily on their experiences and research findings. This focus on military operations is NOT intended to suggest their approach will be used in civilian operations, but only that currently it is the largest available source of information.

## **6.2 Human – UAS Interaction**

As with all human-machine systems there are a number of significant human factors issues addressing the relationship between that human UAS controller/operator and the capabilities/intelligence of the UAS itself. These issues vary from the basic human-UAS interface issues (e.g., how much should it look like a traditional cockpit?), to the more esoteric but very important issues relating to who is *responsible* for the actions of a “smart UAS<sup>3</sup>.” In trying to get a grasp on these issues we will look at a couple of interesting perspectives on effective relationships between humans and robots.

In our technological world there is a natural bias toward the *weltanschauung* that has been labeled a robot-focused interaction perspective. In this worldview, the most significant design decisions are perceived as those that focus on advances in robotic *technology* (e.g., UASs) and only when these are solved are the “non-technical” questions about issues such as operator interfaces considered (because such issues are considered residual or secondary). After all, according to this worldview, UAS operators are only currently there so UASs can do things that they could not until the state of the art of the technology will allow it to be done completely automatically (see Woods, Tittle, Feil, & Roesler, 2002 for a more in depth discussion).

In the eyes of designers with such a *weltanschauung*, operators are only there to *improve* what UASs can *currently* do autonomously (in a one sense their primary task is to advance UAS technology capabilities). These designers believe that advances in robotic technology should

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<sup>3</sup> In this case a “smart UAS” includes everything from a UAS with a good autopilot to a truly intelligent UAS capable of making any number of mission critical decisions.

*necessarily* come first, *and only then* should questions about human-UAS interfaces be discussed but only as residual or secondary issues.

A logical extension of the above *weltanschauung* predicts that UASs will become more intelligent and acting more like “artificial human pilots” (or perhaps HAL of 2001 fame) rather than a well trained dog to which they might now be compared. One cannot just tweak an interface for a relatively dumb machine to make it usable with an intelligent one. For example, try interacting with your spouse in the same way as you interact with your dog.

When such advances in the intellectual capabilities of UASs do begin to occur, consideration will also need to be given to human interaction issues not only in terms of the traditional approach of building ergonomically correct and efficient interfaces; but *perhaps* more importantly interfaces that allow remote humans to effectively, efficiently, and naturally communicate, guide, instruct or takeover control of a truly intelligent UASs which will be very different than dealing with a “dumb” UAS. When dealing with, or taking over from, an intelligent UAS, the interchange will necessarily be more like a “change of shift brief” than a traditional “I’ve got it.”

And last, but perhaps more interesting in the long run, when as UASs become more intelligent there will be a need to give a serious consideration to the *sociological* consequences of having “HAL-like” UASs as “colleagues” into a traditional human sphere of operations. Working with truly intelligent machines will be very different from dealing with dumb machines. Indeed, Woods et al. (2002) have argued that in operational environments with human control of intelligent UASs that human interaction should be addressed in terms of both:

1. Interfaces that allow the remote humans to communicate, guide, instruct or takeover control of the UASs, and
2. Social/organizational consequences of advances in UAS capability.

### **6.2.1 Who gets blamed (who is responsible)?**

Given the inherent potential for surprise in complex systems that operate near limits of automata, there are two human roles which must be planned for in UAS interface design. The first role is that of UAS operator, who is responsible for managing the UASs robotic capabilities *in situ* as a valued resource and focuses on supporting the knowledge, practice, and interfaces needed to manage the robots in a physical environment. This differs from *Problem Holder Role* which focuses on the human responsible for achieving mission goals and the associated knowledge and experience (Woods et al., 2002). These are two very different roles which require different sets of data provided in different ways.

### 6.2.2 Stress

An unusual set of stressors have been reported by military UAS operators who are operating the UAS remotely in theater while stationed out of theater. The first is the fear that a UAS they are controlling might have a midair with a comrade (whose family he/she may know well) who is actually flying a mission in-theater. They fear that they may put comrades in a war zone even more at risk, while they are safe at home.

Another stressor is the occasional need for a constant surge mode. While this may be the norm when in-theater, it is much more stressful when spouse and children want to know why you cannot be home more, attend more school functions, etc. It is much easier for family to understand and accept these situations when the person is away from home, than when they are “home.” In fact, a recent U.S. Air Force study indicated that UAS operators working from their home base in the US, reported as twice as much stress as those working in theater (Tvaryanas, 2006).

### 6.2.3 Stress and Operator Performance

The reason for the above discussion is two fold. First, it is well known that stress can significantly impact human performance. Too little and too much stress precipitates decreases in human performance. Thus, the ability to keep the UAS crews at optimal stress levels is an important operational characteristic. One can obtain better performance by either manipulating the stress environment to put the operators with the desired stress range, or one

can select personnel whose optimal stress levels match those of the environment. Both are effective, but a mix of the two is probably the most effective approach.

Traditionally the military has expended a significant effort to develop test instruments that select the people with the “right stuff” for a given specialty. Thus, it might be worthwhile to identify the personality and skill characteristics that might be used to predict who would have the greatest success performing remote UAS type missions. It would also probably be worthwhile to be able to identify who would derive the greatest satisfaction from this type of duty. It seems reasonable to believe that appropriate personality types might not only do a better overall job, but may also want to stay with UASs and thus, over time, help build a stronger and possibly operationally superior cadre of UAS operators and command staff.

### 6.3 Pilot – UAS Interface Issues

**Interface** (noun): an arbitrary line of demarcation set up in order to apportion the blame for malfunctions. (Kelly-Bootle, 1995, p. 101).

The human-machine interface has always served several purposes beyond getting relevant information in the appropriate format to the human in a timely manner. The Kelly-Bootle definition above is not only cute, but very relevant to the issue of responsibility. In many accidents reports there is a paragraph or two that describe that the necessary data or controls were present, and ergo it must be pilot error. In an early film (circa 1960) produced by the American Psychological Association for television entitled “Of Men and Machines,” one of the opening scenes is at an aircraft accident and a voice over of a pilot describing the interface, “Pilot error hell! It takes 30 seconds to switch fuel tanks and you only have 10. Try it once & you will see.” The battle to assign the blame to someone or something else will continue as long as there are accident investigation boards. The real and very important issue is that the data *not only* needs to be there, but needs to be in a format that is perceptually obvious and clear, while its meaning being intuitively obvious to 1) a high stressed operator (people’s lives may be on the line) who is 2) also under high workload (e.g., operating multiple UASs and supporting several groups of fatigued soldiers who are in contact with the enemy), while 3) being circadian desynchronistic.



### 6.3.1 What is a normal interface?

Inevitably, sooner or later critical resources will be lost or will fail during missions. As systems become more complex (i.e., large numbers of interdependent components) there will be an increase in the probability that the failure of one component will have negative impact on other components and thus the entire system (see Perrow 1964). Highly automated UASs tend by necessity to be complex and are designed to be resistant to chain reaction failures. But as every military pilot has been told, they are lucky to be flying the finest aircraft in the world that were designed and built by the lowest bidder. Cost (and weight) always trumps redundancy at some point in the design so there will always be system brittleness at some point for chain reaction failures.

As assets are lost, how can the interface support the operator's ability to dynamically reconfigure or gracefully degrade the UAS so that the mission can be successfully completed? Therefore, a general but *very significant* human-machine interface issue for UASs will be how to assist human team members

- 1) to recognize the approach to brittle boundaries within the system (i.e., where things are more likely to fail or degrade),
- 2) to understand, when and how to intervene, and
- 3) to act effectively, e.g., to effect a natural and intuitive transfer of control (cf. Woods, Tille, Feil, & Roesler, 2002).

This cannot be solved by creating procedures for every possible set of interacting failures; the potential N is way too large. Nor can it be always solved by engineering - weight, cost, and complexity limits will provide the natural limits.

The best hope for a solution is a natural and transparent interface. That is an interface whose operations are so natural to the user that it significantly decreases the time till the operator "becomes one with the UAS" as well as that when something off-normal happens the operator quickly and naturally moves to perform the correct actions. The creation of such an interface cannot be accomplished by another wise highly skilled software engineer, or by an UAS operator. Rather it requires a design team that is lead by a skilled human factors professional.

The interface needs to take into account not only aviation traditions but also human cognitive, perceptual, and motor capabilities. The interface needs to be standardized not only in the normal sense organizing components, but also in the way that Apple standardized their interface such that after a small amount of experience one could go to any application, by any vendor and perform basic operations without any previous experience.

### 6.3.2 Change Blindness

To demonstrate the significance of ecological information one only needs to look at what is called “change blindness.” In a number of studies change blindness has been demonstrated when very large and significant visual events can occur and be totally missed by an active viewer. For example, participants asked to watch a group of people and count the number of times the ball was caught by person wearing a certain color shirts, missed a woman walking through the scene carrying an umbrella (Neisser, 1975; Neisser, 1979) or a man walking through the scene dressed in a gorilla suit (see Figure 1 below) over half of the time (Simons & Chabris, 1999). This phenomenon has also been labeled *inattention blindness* (Simons & Ambinder, 2005).



Figure 3. Gorilla walking through basketball passing experiment (from Simons & Chabris, 1999).

If missing a person walk through a scene in a gorilla suit can happen to active viewers (i.e., people actively monitoring a display look for a data contained in the same area as the very unusual test stimulus) then it might explain a lot of “pilot error” accidents where the subsequent investigation indicates that all the technology was operating ‘correctly’ and the data was indeed there (e.g., the classic L-1011 accident in the Everglades). Now, if one imagines an UAS operator who is monitoring a small flock of UASs for all the assigned data, one can quickly envisage how change blindness might result in a significant event being missed.

A basic question then is: does change blindness occurs in an operational, rather than an experimental environment? It is a pretty safe bet that it happens regularly, but that the expertise and experience of the operator combined with the redundancy of the operating system (e.g., ATC, wingman, avionics) catch and either eliminate or minimize their consequences. A military pilot involved in a combat mission, by necessity is directly and continuously involved in monitoring the state of the systems and the geographical and operational position of the mission. As such there is a greater chance, as indicated by empirical evidence (e.g., Werner & Thies, 2000), that the active pilot will have a higher chance of overcoming the negative potentials of change blindness. Now, if we imagine an UAS operator who is monitoring a small flock of UASs, where only partial attention can be paid to any one of them, it does seem reasonable to assume that they will be more likely to miss significant events.

### **6.3.3 Mitigation of change blindness**

Because there are currently few ways of identifying and mitigating change blindness in a true natural environment not to mention an environment where the enemy is trying to hide their “gorilla,” research needs to be done that will identify what can be done in terms of ecological interface design and the “social interaction” suggested by Woods et al. (2002) so that it minimizes the probability of change blindness in the one operator to many UASs scenario. What interface design changes need to be in place to assist the operator to more quickly become aware of the potentially missed event or events and to assist in either eliminating or mitigating the consequences of that blindness.

Another, but much less explored, approach would be to apply the techniques and tools that have been used by motion picture directors and editors for decades to naturally draw the observer's eye to the point that the director wants the observer to fixate on (see Wise & Debons, 1987b for a discussion of some of these techniques).

#### **6.3.4 Ecological issues**

Another significant ambiguity which occurs for UAS operators involves perceived rate of motion. The relationship between optic flow and rate of motion in the environment depends on our eye's focal length versus camera's in the UAS platform. Thus, the optic flow rate in the image could result in the natural human perceptual process perceiving a much faster or slower moving object than it is. When viewing video from a remote UAS system our visual system is processing the optic flow without motion feedback information and based on an eye past experiences while flying. These perceptual discrepancies will introduce ambiguities and misperceptions of perceived events by the human operators both with and without extensive flight experience (see Woods et al. 2002 for a discussion of this phenomenon in ground based robots).

Woods et al. (2002) defined functional presence as the ability of remote observers to have sufficient information available to their senses to as effectively function as well as if they were directly perceiving and acting in the remote environment. When the designer fails to appreciate the impoverished nature of the *ecological* information available in remote perception, they are surprised by the problems the operators have. In one study remote ground controller of ground based robots were asked to track their spatial location and identify objects based on video from a remote reconnaissance mission, and found that neither task could be performed very well. Such results lead to the conclusion that the raw information needs to be enhanced to recover what was lost by the decoupling the human perceptual system from the environment being explored.

When one looks at the state-of-the-art UAS control stations one see a decrease in available ecological information, when compared to even a low end aircraft crewstation. This

diminution of information is evident long before one even considers the loss of all the traditional “seat-of-the-pants” cues that have been eliminated by being a remote ground based operator. However, to achieve effective coordination between the remote operator and a UAS, past research has shown that there needs to be an *increase in the levels and kinds of ecological feedback* between the operator and the UASs. The increase needs to include information not only about their current status, but particularly about their future activities.

### 6.3.5 Situation Awareness

Absolute situation awareness is prohibitively costly in terms of both financial and human workload costs. However, it is recognized that the following issues are minimum prerequisites of good situation awareness in the control of UASs:

1. An active and engaged human operator – engagement is a challenge when controlling multiple UASs that are performing different types of missions in a variety of locations.
2. Delegation of the appropriate tasks to automation – this becomes a challenge as the amount of control for the various UASs being controlled changes through out the mission.
3. Observability and projection of future automation actions – being able to intuitively predict how the UAS will perform without the traditional seat-of-the-pants cues and other emersion cues is a design challenge.
4. Information abstracted and distilled to the appropriate level for UAS operation is always a challenge, while being able to maintain the proper level of abstraction as the degree of control changes is very difficult and usually ignored.
5. Provide salient mode transitions – not knowing the UAS has changed operating modes can be even more disastrous in a UAS than in a manned aircraft.

### 6.3.6 Aviation Specific Skills

Another reason why the background of the operator has been raised in a paper primarily addressing human factors of the operator interface is that different UAS interfaces *may* be more effective for operators with different types of flying experience. It might also be useful to consider how a UAS interface might be different for operators with only a UAS flying

background, as opposed to those who have significant experience in traditional flying. For example, current certified pilots *may* feel more comfortable with having continual access to the traditional basic flight instruments even though they *may* provide very little value to the successful completion of UAS missions. On the other hand UAS-only pilots without any type of *significant* flight experience might quickly derive significant situation awareness from non-traditional format based on forms one might find in video games.

## **6.4 Workload Issues**

It has been reported that the remote operators of Unmanned Ground Vehicles (UGV) used in search and rescue operations (e.g., World Trade Center, Hurricane Katrina) have experienced such high workload and stress levels that they needed breaks every 30 to 45 minutes. In addition, it is well established in the psychology literature for decades that there is a significant relationship between workload levels and human performance (see Alkhouri, Hall, Wise, & Smith, In Press and Alkhouri, Hall, Wise, & Smith, 2002). That relationship takes the form of an inverted “U” curve, such that best human performance takes place with medium stress, while low or high levels of stress have a significant negative impact on human performance.

It has also been recognized that the workload/performance curve moves left and right as a function of the task being performed. A simple or easy task needs higher workload to obtain the best system performance, while a very complex task needs a lower level of workload to achieve the best system performance. Thus, a UAS operator controlling the same UAS but in two different operation environments could have two very different points of optimal performance.

### **6.4.1 Potential UAS Crew Responsibility**

The current behavior and operational characteristics in the flight of UASs vary dramatically even in what one would consider the most conservative operators, the military. For example in the United States military the Air Force used current military pilots (i.e., commissioned officers) who are assigned to UAV duty for one tour, while the Army used non-pilot enlisted

personnel. Not only does the distinction of use of trained combat pilots versus non-pilot UAS controllers tell the reader about the drastically different visions of the correct operating philosophy of these two branches of the military of one country, but perhaps the differences in the perception of the level of accountability might best be demonstrated by the selection of commissioned officers versus enlisted personnel.

**Legal:** The rules and regulations for what is defined as a UAS, versus what is not a UAS are still in a state of flux around the world. For example, would a teenager flying a remotely controlled model airplane fall under the regulation? If not, what if the model airplane she is flying had a 3 meter wing span? What about a 10 meter wingspan??? What if it weighed 0.25 kilos? What if it weighed 250 kilos? As a result the legal responsibilities are still in a state of flux and probably will depend more on the skill and resources of the respective attorneys involved in resolving any legal issues.

**Policies:** In the UAS domain the possible set of policies will again vary dramatically. The military will have the strictest set of policies that can be enforced quite rigidly. In the middle would be the commercial operations trying to determine how to break into the business of hauling freight. At the lowest level might be a high school science class using a small UAV to do an aerodynamics study.

**Priorities:** The UAS being discussed here will tend to have a wide variety of technology (e.g., the ability to control a UAS on the other side of the world in near real time with the ability to collect and analyze environmental samples to that high school class doing it aerodynamics study within the confines of a sport's stadium). Therefore, the technology that supports the operator's efforts related to the classic Aviate, Situate, Navigate, & Communicate tasks will also vary dramatically both in terms of quality and quantity.

As a result, the aviate, situate, navigate, & communicate demands will involve very different levels of pilot attention and tasking. In addition, the complete loss of any "seat-of-the-pants" feedback can add to the control challenge. Also, the large number of unknowns in this rather new domain will impact the ability to determine how an UAS operator will aviate, situate, navigate, and communicate. Thus the results will likely be subject to significant variance even if one were looking at only one type of operation, e.g., military.

**Aviate:** In UASs the physical task of flying the airplane can vary from highly an autonomous to a manual one depending on not only on the level of technology, but also on the physical environment (e.g., can control signals reach the UAS), and the mission (e.g., a military mission may require direct operator for safety reasons such as to avoid a friendly fire incident). Again depending upon the level of technology the operator may have a either a synthetic<sup>4</sup> and/or an enhanced<sup>5</sup> vision system of the environment around the UAS to an extremely simple “needle, ball, and airspeed” set of instruments. Thus, the difficulty of effectively aviating an UAS can vary dramatically.

**Situate:** The ability to develop strong situation awareness again requires considerable cognitive effort depending on the ability of the operator to relate how the UAS relates to its operating environment and mission requirements. For example, the operator may have to rely on monitoring radio traffic to estimate the locations of other UASs and aircraft and even listen to ATC messages to other traffic to get a better feeling of weather ahead because of not having weather radar.

Location estimation may be as basic “dead reckoning” (i.e., flying a fixed heading and speed for a given amount of time), to the use of GPS data be data linked back.

When the UAS lacks of ability to “sense and avoid” they are often restricted to operations in protected airspace.

**Navigate:** At the very low end navigation may be as basic “dead reckoning” (i.e., flying a fixed heading and speed for a given amount of time), to the use of GPS data be data linked back and coordinated with the available SVS and/or EVS. Precision in navigation can significantly vary in terms of both time and location accuracy.

**Communicate:** Again depending on the level of technology and mission the ability to communicate with the UAV and its controlling entity will vary dramatically – from high bandwidth data-link from the other side of the world to line of sight of the UAV from the operator standing in a field with a hand held control unit.

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<sup>4</sup> Synthetic vision is a computer generated scene using fixed and updatable data bases.



### **6.4.2 System Flexibility**

Again flexibility of the UAS will vary dramatically depending once again on the level of technology.

### **6.4.3 Impact of the Physical Environment**

The physical environment can dramatically impact the operability of UASs. For example, turbulence and other weather can significantly degrade the ability of the UAV to fly safely. Likewise, terrain can impact the line-of-sight between the controller and the UAV required for a clear communication channel with the UAS. Other weather may likewise negatively impact the signal going to and from the UAV.

### **6.4.4 Social Organization**

Because of the relative newness of UASs the authors know of no social or professional organizations for UAS operators. In addition, the environment for most UAS operations are more like an office, than a cockpit. Cockpits often have a knowledge of a shared fate<sup>6</sup> that pulls the individuals of a crew closer together socially even after a mission, but it is not clear, whether such bonding can emerge in the office.

## **6.5 UAS Responsibility: Current Operations**

The following pages are a first attempt to identify the basic set of factors for which UAS operators are currently held accountable. In practice degree of responsibility varies as a function of the type of flight rules one is operating under and the weather.

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<sup>5</sup> Enhanced vision system use sensors to present a scene relevant to operating the UAS

### 6.5.1 Visual Flight Rules

Primarily, (non-military) UASs operates under what is known as visual light rules. Under visual flight rules the weather needs to be such that pilots have the ability to see other aircraft and navigational hazards (e.g., towers, buildings, mountains) far enough in advance to be able to maneuver in such a way as to avoid any hazards. In UASs the term “sense and avoid” is being used to describe this type of operation when the UAS is out of direct sight of the operator. Sense and avoid describes the use of sensors (e.g., IR, EO, radar) to detect aircraft and other hazards to either maneuver around them or inform the operator. To date there are no civil aviation regulations that define what is needed for an UAS to say it has the capacity to “sense and avoid.” As a result, non-military UASs are basically restricted to very limited restricted airspace. Therefore, new regulations will need to be created for UASs to be able to operate in a “VFR like” environment outside of their current restricted airspace.

### 6.5.2 Instrument Flight Rules

The second type of operation is generally known as instrument flight rules (IFR). In this category the regulations are based on the ability of the flight crew to maintain control of the aircraft only by reference to instruments and without the ability to see the world. Instrument flight rules assume that there exists an air traffic control systems which assists in the act of separation the traffic. Instrument flight rules are the basic operational standard for airline operations.

Even for operations in positively controlled airspace the requirement to be able to see/sense and avoid when the aircraft are in VMC still holds. So again, until the regulations are modified so that sense and avoid is possible IFR operations outside of restricted airspace is currently not permitted.

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<sup>6</sup> Shared fate refers to the belief that if the aircraft crashes everyone is likely to die.

## 7 Conclusions

On the basis of the work done the following conclusions can be drawn:

- The term *responsibility* has all the relevant connotations to communicate adequately the ideas expressed in the iFly Project Annex 1, especially of human- machine systems, so there is no need to replace it with *accountability* term.
- Persons having goals have become responsible for achieving these goals and having (real or potential) conscious awareness about them. This state of affairs is typical to fulfilment of any functions by human independently or as a participant in the human-machine system.
- Situation awareness is specifically *goal-oriented*. Supporting SA means supporting cognitive processes of the operator and keeping the operator in control holds his / her situation awareness at appropriate quality level.
- While amplifying, delegating and extending functions in the design process we need caution not to create function substitution and turning the designed function into prosthesis of human operator.
- Goal-driven task analysis has been performed on commercial aviation en-route data and listings of current and changing tasks under airborne self separation conditions are available. Changing tasks of cockpit crew are: Monitoring lateral cruise profile, Monitoring vertical cruise profile, Monitoring speed, Monitoring of the airplane systems, Planning of arrival and approach and keeping ATC communication.
- The separation information monitoring and conflict resolution become the new tasks and new responsibilities of the cockpit crew in airborne self separation conditions.
- In military aviation the occasions of airborne self separation are rare. Under airborne self separation, pilots are focussed to achieving good situation awareness.
- Flying by visual flight rules with the use of the “see and avoid principle” is a good model of low end airborne self separation.

- In the case of UAVs the similar “sense and avoid” principle holds for detecting aircraft and other hazards to either manoeuvre around them or inform the operator. Today there are no civil aviation regulations that define what is needed for an UAS to say it has the capacity to “sense and avoid.”
- The results of the present report will be used and undergo further development in the following deliverables of the Work Package 2. In the deliverable 2.2 the concept of SA under airborne self separation will be extended to introduce traffic and mode awareness as two key elements to surveillance; relations between SA and workload of pilots and the necessity of measuring both of them at a later stage of airborne self separation concept development will be discussed. Knowledge and information requirements for non-traffic SA, for strategic planning and tactical decision making will be reviewed. The cognitive functions and responsibilities of the airborne self separation system in normal situations and in solving of conflicts will also be analyzed in the next deliverable of Work Package 2. In the same document the relations of this airborne self separation with SESAR will be evaluated.

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## 9 Appendices

### Appendix 1. The results of goal- oriented cognitive task analysis: Listing of tasks during en-route phase of flight

#### Cruise (en-route part of flight with modern jet airliner from waypoint A to waypoint B)

##### 1. Normal situations

###### 1.1. Monitoring lateral cruise profile

- 1.1.1. Asking 'shortcuts' from ATC (*direct track; skipping some waypoints*)
- 1.1.2. Asking weather avoidance from ATC (*e.g. clouds, thunderstorms*)
- 1.1.3. Getting shortcuts from ATC
- 1.1.4. Getting radar vectors from ATC (*for traffic separations*)

###### 1.2. Monitoring vertical cruise profile

- 1.2.1. Asking climb from ATC (*considering: airplane weight and/or navigation system calculations and distance to top of descent; weather conditions - winds, turbulence, tropopaus; maximum certified flight altitude; altitude in ATC flight plan*)
- 1.2.2. Asking climb/descent due to weather conditions (*turbulence - tropopaus, jetstream etc; area of turbulence - how long & on what altitudes; strong headwinds etc*)
- 1.2.3. Changing flight levels due to ATC restriction (*other traffic; change of odd/even level etc*)
- 1.2.4. Asking of climb above optimum flight level (*assuming ATC restrictions to climb later during peak hours in intense traffic area*)
- 1.2.5. Asking/getting early descent (*assuming ATC restrictions to descent during peak hours in intense traffic area*)
- 1.2.6. Asking early descent (*expecting shortcuts during arrival and/or approach*)

###### 1.3. Monitoring speed

- 1.3.1. Changing speed to arrive according plan (*punctuality*)
- 1.3.2. Reducing speed for passenger comfort (*due to turbulence*)
- 1.3.3. Changing speed due to ATC restrictions (*traffic separations*)
- 1.3.4. Changing speed due to ATC restrictions for arrival (*estimated approach time*)

###### 1.4. Monitoring of the airplane systems

- 1.4.1. Flight instruments and displays
- 1.4.2. Doors and windows
- 1.4.3. Air systems (*air conditioning, pressurization*)
- 1.4.4. Anti-icing systems

- 1.4.5. Automatic flight
- 1.4.6. Electrical systems
- 1.4.7. Powerplants
- 1.4.8. Fire protection systems
- 1.4.9. Flight controls
- 1.4.10. Navigation systems
- 1.4.11. Fuel systems
- 1.4.12. Hydraulic systems
- 1.4.13. Landing gear
- 1.4.14. Warning systems
- 1.4.15. Communication systems

### **1.5. Monitoring of attitude and flight parameters**

- 1.5.1. Monitoring of attitude (*comparing bank and pitch with target parameters*)
- 1.5.2. Monitoring of actual flight parameters (*comparing speed, altitude and heading with target parameters*)
- 1.5.3. Monitoring of thrust (*comparing of engine thrust with target parameters*)

### **1.6. Monitoring airplane lateral balance**

- 1.6.1. Check of fuel quantities
- 1.6.2. Check of aircraft trim
- 1.6.3. Check of symmetrical thrust

### **1.7. Informing passengers about flight progress**

- 1.7.1. Making passenger announcement in the beginning of cruise
- 1.7.2. Making passenger announcement before starting descent

### **1.8. Planning of arrival and approach**

- 1.8.1. Getting weather for destination aerodrome
- 1.8.2. Getting additional information for destination aerodrome (*from NOTAMs, ATIS, ATC etc about aerodrome operations - expected delays, system degradations, works in progress etc*)
- 1.8.3. Selecting and setting up for appropriate arrival and approach
- 1.8.4. Planning of starting descent (*considering ATC restrictions, passenger comfort, terrain etc*)
- 1.8.5. Making arrival and approach briefing

### **1.9. Documentation management**

- 1.9.1. Using appropriate maps and charts
- 1.9.2. Monitoring and filling in operational flight plan
- 1.9.3. Performing engine monitoring (*if applicable*)
- 1.9.4. Keeping voyage report updated (*if applicable*)
- 1.9.5. Preparing general declarations (*for destination aerodrome - if applicable*)
- 1.9.6. Preparing manual loadsheet for next leg (*if applicable*)
- 1.9.7. Preparing information for next leg (*for supervisor: fuel numbers, trip time, alternates, mass and balance information*)

### **1.10. Keeping ATC communication**

- 1.10.1. Changing frequencies
- 1.10.2. Complying clearances
- 1.10.3. Receiving any other information

### **1.11. Manage resources efficiently**

- 1.11.1. Planning operations according everyone's competency, reliability, fatigue, etc.
- 1.11.2. Keeping optimum level of automation
- 1.11.3. Keeping everyone (*crew, ATC etc*) appropriately informed
- 1.11.4. Planning operations according airplane's capability and operability
- 1.11.5. Keeping airplane and it's systems in appropriate configuration

## **2. Special situations (*supplementary procedures*)**

### **2.1. Additional testing of airplane systems (*to verify normal operation of system*)**

- 2.1.1. Altimeters (*difference*)
- 2.1.2. Window heat system
- 2.1.3. Wing-body overheat
- 2.1.4. Fire protection system
- 2.1.5. Weather radar
- 2.1.6. Navigation system check (*comparison of airplane position determined by raw data and navigation system*)
- 2.1.7. Other systems

### **2.2. Using manual mode of pressurization system**

### **2.3. Balancing fuel**

### **2.4. Minimizing impact of adverse weather**

- 2.4.1. Heavy rain
- 2.4.2. Turbulence
- 2.4.3. Windshear
- 2.4.4. Thunderstorms
- 2.4.5. Lightning strike
- 2.4.6. Static electricity

### **2.5. Recovering airplane to normal flight envelope**

- 2.5.1. Recovering from stall
- 2.5.2. Recovering from overspeed
- 2.5.3. Recovering from unusual attitude

### **2.6. Informing passengers about special events**

- 2.6.1. Encountering turbulence (*to fasten seatbelts*)
- 2.6.2. Diverting to alternate aerodrome
- 2.6.3. Other special events

### **2.7. Helping other aircraft (*distress calls*)**

### **2.8. Communicating with dispatch and/or maintenance (*technical issues*)**

### **2.9. Minimizing impact of inoperative airplane systems**

- 2.9.1. Taking account of inoperative systems allowed with MEL (*minimum equipment list*)
- 2.9.2. Taking account of in-flight malfunctions

## **2.10. Minimizing impact of loss of ATC communication**

- 2.10.1. Following the communication failure procedures
- 2.10.2. Finding out the reason of communication failure
- 2.10.3. Trying to establish communication by alternate means

## **2.11. Correcting flight path to avoid conflict situations**

- 2.11.1. Avoiding restricted airspace
- 2.11.2. Avoiding other traffic (*e.g. reducing vertical speed to avoid TCAS warning*)

## **3. Abnormal and emergency situations**

### **3.1. Correcting situation conditioned of non-normal operation of airplane systems**

Solving non-normal situations related with...

- 3.1.1. ...airplane structural damage (*doors, windows, body*)
- 3.1.2. ...air systems
- 3.1.3. ...anti-icing systems
- 3.1.4. ...automatic flight
- 3.1.5. ...communication systems
- 3.1.6. ...electrical systems
- 3.1.7. ...powerplants (*engines and APU*)
- 3.1.8. ...fire protection systems
- 3.1.9. ...flight controls
- 3.1.10. ...flight instruments and displays
- 3.1.11. ...navigation systems
- 3.1.12. ...fuel systems
- 3.1.13. ...hydraulic systems
- 3.1.14. ...landing gear
- 3.1.15. ...warning systems

### **3.2. Correcting situation to avoid collision**

- 3.2.1. Manoeuvring to avoid collision with other airplane
- 3.2.2. Manoeuvring to avoid terrain

### **3.3. Minimizing the outcome of medical emergency**

- 3.2.1. Passenger health problems
- 3.2.2. Crew member incapacitation

### **3.4. Solving the situation caused by external threat**

- 3.4.1. Hijacking
- 3.4.2. Bomb warning

### **3.5. Correcting any other abnormal or emergency situation**

## Appendix 2. The listing of the cognitive tasks in General Aviation en-route flight

### Cruise flight with modern general aviation aircraft from point A to point B

#### 1. Normal situations

##### Monitoring lateral cruise profile

Identify current position

Look out window & compare to map

VOR-DME

Cross triangulation of VORs and or ADFs

GPS

Compare actual to desired position

Given conditions identify the best track for the purposes of the flight (*e.g., delivery of goods, sight seeing*)

Plan the revised track including issues such as fuel burn and timing

Checking weather conditions along new from appropriate sources

Perform maneuvers to attain new track using dead reckoning and or navigation aids (*e.g., VOR, GPS*)

Monitor performance in maintaining desired track & make corrections as necessary

Monitor area for other traffic maneuver

Getting radar vectors from ATC (*for traffic separations*)

##### Control lateral cruise profile

Manipulate pitch, bank, & power to attain desired lateral profile

##### Visually scan airspace for other aircraft

Perform maneuvers as necessary to be able to clear areas blocked by airframe

##### Visually monitor meteorological conditions

##### Visually monitor terrain for potential emergency landing locations

##### Monitoring vertical cruise profile

Determine optimal cruise altitude considering: airplane weight; weather conditions - winds, turbulence, maximum flight altitude of aircraft and humans (Oxygen availability), determine optimum altitude and purposes of the flight (*e.g., delivery of goods, sight seeing*). Begin climb or descent



using appropriate power and configuration. Clear for traffic (particularly significant in descent for look below and in climb for looking for what is hidden behind nose of aircraft).

### **Control vertical cruise profile**

Manipulate pitch, bank, & power to attain desired vertical profile

### **Monitoring speed**

Change speed to meet arrival goals

Change speed to achieve efficient fuel burn

Reducing speed for passenger comfort (*due to turbulence*)

### **Control speed**

Manipulate pitch, bank, power, & propeller pitch to attain desired speed

### **Monitoring of the airplane systems**

Flight instruments and displays

Anti-icing systems

Automatic flight

Electrical systems

Powerplants

Flight controls

Navigation systems

Fuel systems

Hydraulic systems

Landing gear

Warning systems

Communication systems

### **Control of attitude and flight parameters**

Monitoring of attitude (*comparing bank and pitch with planned*)

Adjust attitude as required

Monitoring of actual flight parameters (*comparing speed, altitude and heading with planned*)

Monitoring of engine (*comparing of engine RPM and fuel flow with plan*)

Adjust engine as required as required

### **Monitoring airplane lateral balance**

Check of fuel quantities

Cross feed as necessary

Check of aircraft trim

Adjust as required

Check of symmetrical thrust (Multi engine aircraft only)

Adjust engines as required

Communicate with passengers about flight progress

### **Planning of arrival and approach**

Getting weather for destination aerodrome

Getting additional information for destination aerodrome (*from NOTAMs, ATIS, ATC etc about aerodrome operations - expected delays, system degradations,*

*works in progress etc)*

Selecting and setting up for appropriate arrival and approach

Planning of starting descent (*considering ATC restrictions, passenger comfort, terrain etc)*

### **Documentation management**

Using appropriate maps and charts

Monitoring and filling in operational flight plan

Performing engine monitoring (*if applicable*)

Keeping flight plan updated

Preparing general declarations (*for destination aerodrome - if applicable*)

Preparing manual loadsheet for next leg (*if applicable*)

Preparing information for next leg (*for supervisor: fuel numbers, trip time, alternates, mass and balance information*)

### **Keeping ATC communication - where necessary**

Changing frequencies

Complying clearances

Receiving any other information

### **Manage resources efficiently**

Planning operations according everyone's competency, reliability, fatigue, etc.

Planning operations according airplane's capability and operability

Keeping airplane and it's systems in appropriate configuration

## **2. Special situations (*supplementary procedures*)**

### **Additional testing of airplane systems (*to verify normal operation of system*)**

Navigation system check (*comparison of airplane position determined by raw data and navigation system*)

Other systems

### **Balancing fuel**

Change fuel flow

Monitor balance

Return fuel flow to normal

### **Minimizing impact of adverse weather**

Heavy rain

Turbulence

Windshear

Thunderstorms

Lightning strike

Static electricity

### **Recovering airplane to normal flight envelope**

Recovering from stall

Recovering from overspeed  
Recovering from unusual attitude

### **Helping other aircraft (*distress calls*)**

Communicating with dispatch and/or maintenance (*technical issues*)

### **Minimizing impact of inoperative airplane systems**

Taking account of in-flight malfunctions

### **Minimizing impact of loss of ATC communication (when necessary)**

Following the communication failure procedures  
Finding out the reason of communication failure  
Trying to establish communication by alternate means

### **Correcting flight path to avoid conflict situations**

Avoiding restricted airspace  
Avoiding other traffic

## **3. Abnormal and emergency situations**

### **Correcting situation conditioned of non-normal operation of airplane systems**

Solving non-normal situations related with...

- airplane structural damage (doors, windows, body)
- air systems
- anti-icing systems
- automatic flight
- communication systems
- electrical systems
- powerplants (engines and APU)
- flight controls
- flight instruments and displays
- navigation systems
- fuel systems
- hydraulic systems
- landing gear
- warning systems

### **Correcting situation to avoid collision**

Maneuvering to avoid collision with other airplane  
Maneuvering to avoid terrain

### **Minimizing the outcome of medical emergency**

Passenger health problems  
Crew member incapacitation

### **Solving the situation caused by external threat**

## Correcting any abnormal or emergency situation

### Appendix 3. Changes in pilot tasks during iFly flight compared to current situation (en-route part of iFly flight from waypoint A to waypoint B)

See explanations of abbreviations and of color coding and comments at the bottom of the table.

	iFly flight
<b>1. Normal situations</b>	
<b>1.1. Monitoring lateral cruise profile</b>	
1.1.1. Asking 'shortcuts' from ATC ( <i>direct track; skipping some waypoints</i> )	No task
1.1.2. Asking weather avoidance from ATC ( <i>e.g. clouds, thunderstorms</i> )	Pilot resp.
1.1.3. Getting shortcuts from ATC	No task
1.1.4. Getting radar vectors from ATC ( <i>for traffic separations</i> )	Pilot resp.
<b>1.2. Monitoring vertical cruise profile</b>	
1.2.1. Asking climb from ATC ( <i>considering: airplane weight and/or navigation system calculations and distance to top of descent; weather conditions - winds, turbulence, tropopaus; maximum certified flight altitude; altitude in ATC flight plan</i> )	Pilot resp.
1.2.2. Asking climb/descent due to weather conditions ( <i>turbulence - tropopaus, jetstream etc; area of turbulence - how long &amp; on what altitudes; strong headwinds etc</i> )	Pilot resp.
1.2.3. Changing flight levels due to ATC restriction ( <i>other traffic; change of odd/even level etc</i> )	Pilot resp.
1.2.4. Asking of climb above optimum flight level ( <i>assuming ATC restrictions to climb later during peak hours in intense traffic area</i> )	No task
1.2.5. Asking/getting early descent ( <i>assuming ATC restrictions to descent during peak hours in intense traffic area</i> )	No task
1.2.6. Asking early descent ( <i>expecting shortcuts during arrival and/or approach</i> )	Pilot resp.
<b>1.3. Monitoring speed</b>	
1.3.1. Changing speed to arrive according plan ( <i>punctuality</i> )	
1.3.2. Reducing speed for passenger comfort ( <i>due to turbulence</i> )	
1.3.3. Changing speed due to ATC restrictions ( <i>traffic separations</i> )	Pilot resp.
1.3.4. Changing speed due to ATC restrictions for arrival ( <i>estimated approach time</i> )	Pilot resp.
<b>1.4. Monitoring of the airplane systems</b>	

#### 1.4.1. Flight instruments and displays

**New  
instru.**

#### 1.4.2. Doors and windows

**iFly flight**

#### 1.4.3. Air systems (*air conditioning, pressurization*)

#### 1.4.4. Anti-icing systems

#### 1.4.5. Automatic flight

#### 1.4.6. Electrical systems

#### 1.4.7. Powerplants

#### 1.4.8. Fire protection systems

#### 1.4.9. Flight controls

#### 1.4.10. Navigation systems

#### 1.4.11. Fuel systems

#### 1.4.12. Hydraulic systems

#### 1.4.13. Landing gear

#### 1.4.14. Warning systems

#### 1.4.15. Communication systems

### 1.5. Monitoring of attitude and flight parameters

#### 1.5.1. Monitoring of attitude (*comparing bank and pitch with target parameters*)

#### 1.5.2. Monitoring of actual flight parameters (*comparing speed, altitude and heading with target parameters*)

#### 1.5.3. Monitoring of thrust (*comparing of engine thrust with target parameters*)

### 1.6. Monitoring airplane lateral balance

#### 1.6.1. Check of fuel quantities

#### 1.6.2. Check of aircraft trim

#### 1.6.3. Check of symmetrical thrust

### 1.7. Informing passengers about flight progress

#### 1.7.1. Making passenger announcement in the beginning of cruise

#### 1.7.2. Making passenger announcement before starting descent

### 1.8. Planning of arrival and approach

#### 1.8.1. Getting weather for destination aerodrome

#### 1.8.2. Getting additional information for destination aerodrome (*from NOTAMs, ATIS, ATC etc about aerodrome operations - expected delays, system degradations, works in progress etc*)

#### 1.8.3. Selecting and setting up for appropriate arrival and approach

#### 1.8.4. Planning of starting descent (*considering ATC restrictions, passenger comfort, terrain etc*)

#### 1.8.5. Making arrival and approach briefing

**Pilot  
resp.**

### 1.9. Documentation management

#### 1.9.1. Using appropriate maps and charts

#### 1.9.2. Monitoring and filling in operational flight plan

#### 1.9.3. Performing engine monitoring (*if applicable*)

#### 1.9.4. Keeping voyage report updated (*if applicable*)

1.9.5. Preparing general declarations (*for destination aerodrome - if applicable*)

**iFly flight**

1.9.6. Preparing manual loadsheet for next leg (*if applicable*)

1.9.7. Preparing information for next leg (*for supervisor: fuel numbers, trip time, alternates, mass and balance information*)

### **1.10. Keeping ATC communication**

1.10.1. Changing frequencies

1.10.2. Complying clearances

1.10.3. Receiving any other information

**Change?**

**No task**

**Change?**

### **1.11. Manage resources efficiently**

1.11.1. Planning operations according everyone's competency, reliability, fatigue, etc.

1.11.2. Keeping optimum level of automation

1.11.3. Keeping everyone (*crew, ATC etc*) appropriately informed

1.11.4. Planning operations according airplane's capability and operability

1.11.5. Keeping airplane and it's systems in appropriate configuration

## **2. Special situations (*supplementary procedures*)**

### **2.1. Additional testing of airplane systems (*to verify normal operation of system*)**

2.1.1. Altimeters (*difference*)

2.1.2. Window heat system

2.1.3. Wing-body overheat

2.1.4. Fire protection system

2.1.5. Weather radar

2.1.6. Navigation system check (*comparison of airplane position determined by raw data and navigation system*)

2.1.7. Other systems

### **2.2. Using manual mode of pressurization system**

### **2.3. Balancing fuel**

### **2.4. Minimizing impact of adverse weather**

2.4.1. Heavy rain

2.4.2. Turbulence

2.4.3. Windshear

2.4.4. Thunderstorms

2.4.5. Lightning strike

2.4.6. Static electricity

**iFly flight****2.5. Recovering airplane to normal flight envelope**

- 2.5.1. Recovering from stall
- 2.5.2. Recovering from overspeed
- 2.5.3. Recovering from unusual attitude

**2.6. Informing passengers about special events**

- 2.6.1. Encountering turbulence (*to fasten seatbelts*)
- 2.6.2. Diverting to alternate aerodrome
- 2.6.3. Other special events

**2.7. Helping other aircraft (*distress calls*)****2.8. Communicating with dispatch and/or maintenance (*technical issues*)****2.9. Minimizing impact of inoperative airplane systems**

- 2.9.2. Taking account of in-flight malfunctions

**2.10 Minimizing impact of loss of ATC communication**

- - 2.10.1. Following the communication failure procedures
  - 2.10.2. Finding out the reason of communication failure
  - 2.10.3. Trying to establish communication by alternate means

**2.11 Correcting flight path to avoid conflict situations**

- - 2.11.1. Avoiding restricted airspace
  - 2.11.2. Avoiding other traffic (*e.g. reducing vertical speed to avoid TCAS warning*)

**3. Abnormal and emergency situations****3.1. Correcting situation conditioned of non-normal operation of airplane systems**

Solving non-normal situations related with...

- 3.1.1. ...airplane structural damage (*doors, windows, body*)
- 3.1.2. ...air systems
- 3.1.3. ...anti-icing systems
- 3.1.4. ...automatic flight
- 3.1.5. ...communication systems
  
- 3.1.6. ...electrical systems
- 3.1.7. ...powerplants (*engines and APU*)
- 3.1.8. ...fire protection systems
- 3.1.9. ...flight controls
- 3.1.10. ...flight instruments and displays
- 3.1.11. ...navigation systems
- 3.1.12. ...fuel systems

**iFly flight**

- 3.1.13. ...hydraulic systems
- 3.1.14. ...landing gear
- 3.1.15. ...warning systems

**3.2. Correcting situation to avoid collision**

- 3.2.1. Manoeuvring to avoid collision with other airplane
- 3.2.2. Manoeuvring to avoid terrain

**3.3. Minimizing the outcome of medical emergency**

- 3.2.1. Passenger health problems
- 3.2.2. Crew member incapacitation

**3.4. Solving the situation caused by external threat**

- 3.4.1. Hijacking
- 3.4.2. Bomb warning

**3.5. Correcting any other abnormal or emergency situation****Notes:**

Tasks that remain unchanged or largely unchanged in iFly flight are printed in black.  
Tasks changing in iFly flight are printed in gray.  
Filled cells in “iFly flight” column have comments below.

Explanations and abbreviations used in the column “iFly flight”:

**No task** – this task is missing in iFly flight, no replacement

**Pilot resp.** – substantial change in responsibility, pilot (cockpit crew) is responsible

**Change?** – responsibility is changing, but not clear yet, how

**New instru.** – new instruments will influence the essence of the task