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iFly

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

Specific Targeted Research Projects (STREP)

Thematic Priority 1.3.1.4.g Aeronautics and Space

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Abstract

This report proposes an overall Validation Strategy/Plan regarding the further development of advanced airborne self separation including its integration with SESAR long term development.

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1 Introduction

1.1 iFly project

Since the "invention" of free flight [RTCA, 1995], airborne self separation research has received significant attention. Nevertheless, the current situation is that two schools of researchers hold different beliefs. One school believes airborne self separation can be safely performed at traffic demands well above current demands. The other school believes airborne self separation cannot be carried out sufficiently safe in busy airspace. Both schools also agree on two key points:

- At very low traffic demand, safety will be improved by equipping aircraft with an appropriate Airborne Separation Assistance System (ASAS).
- There will be some limit on the air traffic demand that can safely be managed.

From a research perspective this means there is an urgent need to address the question: Which traffic demands can safely be accommodated by airborne self separation? The key aim of the iFly project has been to find an answer to this question.

1.2 Free flight background

The free flight "invention" has motivated the study of multiple airborne self separation operational concepts, implementation choices and requirements, e.g. [Duong&Hoffman, 1997; FAA/Eurocontrol, 2001; Hoekstra, 2001; ICAO, 2003; Krozel, 2000; NASA, 1999; NASA, 2004; RTCA, 2002]. Although all concepts make use of some ASAS onboard an aircraft, there are large differences, e.g. on the coordination between aircraft.

Both [Duong&Hoffman, 1997] and [Hoekstra, 2001] assume all aircraft to be equipped with an ASAS that supports pilots with conflict resolution using an implicit form of coordination. Using this approach, a full ConOps has been developed for conducting airborne self separation over the Mediterranean area [Gayraud et al., 2005; Maracich, 2005]. For this ConOps in-depth human in the loop simulations have shown that pilots are very well able to manage high traffic demands [Ruigrok et al., 2005; Ruigrok&Hoekstra, 2007]. Subsequently [Blom et al., ATC-Q, 2009] has shown that this Autonomous Mediterranean Free Flight (AMFF) ConOps falls short in safely accommodating high en-route traffic demands, because in some infrequent cases, it takes too many manoeuvring trials and time to resolve conflicts involving many aircraft.

Because AMFF has shown to work very well most of the time, it is expected that a more advanced airborne self separation approach can safely accommodate higher traffic demand. A potential candidate is the [NASA, 2004] proposed airborne self separation ConOps. Here, ASAS conflict resolution is assumed to work intent based, both strategically and tactically, again through an implicit form of coordination. [Consiglio et al., 2007] shows through standard Monte Carlo simulations that under nominal conditions, the strategic layer resolves all medium term conflicts well, also under very high en-route traffic demand. In follow-up studies [Consiglio et al., 2008, 2010] the effects of pilot response delays on the performance of the strategic layer have been studied using standard Monte Carlo and human in the loop simulations. [Consiglio et al., 2009] evaluates the effect of wind deviations on the strategic layer using standard Monte Carlo simulations. These results show that the strategic layer alone is not always able to resolve all conflicts. From safety perspective this means that there is need for an airborne self separation design which incorporates an effective combination of strategic and tactical layers, including coverage of various non-nominal situations [iFly D7.1b, 2009]. Such an airborne self separation ConOps has been designed within the iFly project.

1.3 iFly's Advanced airborne self separation A^3 ConOps

During the first part of the iFly project, the [NASA, 2004] ConOps has been used as starting point for the development of an advanced airborne self separation concept for en-route traffic under the name A^3 ConOps [iFly D1.3, 2010]. This A^3 ConOps intentionally addresses the hypothetical situation of 100% well equipped aircraft, and no help from air traffic controllers on the ground. For further details of the A^3 ConOps, also see the A^3 Operational Services and Environmental Description (OSED) [iFly D9.1, 2009]. Here we give a high level description of the A^3 intended operations only.

Similar to the SESAR2020 ConOps [SESAR, 2007], the A^3 ConOps works with Reference Business Trajectories (RBT's). In contrast to SESAR2020, however, A^3 ConOps RBT management is done without help from ATC. Moreover, voice communication between pilots is assumed to be mainly for use under emergency situations. Typically, information exchange between aircraft is assured through ADS-B, which is extended over the horizon through a System Wide Information Management (SWIM) network. Each aircraft broadcasts information about its state and intent (as part of its RBT) to other aircraft. This allows each aircraft to predict the intended trajectories of other aircraft, and to act such that separation criteria are adhered to. Each aircraft is assumed to be equipped with a dedicated ASAS system which is monitoring the surroundings and helps the flight crew to detect and resolve conflicts. This ASAS supports two lines of defense in the resolution of potential conflicts: Medium Term Conflict Resolution (MTCR) and Short Term Conflict Resolution (STCR). Both MTCR and STCR are assumed to use implicit coordination only.

MTCR aims to identify 4D trajectories which are conflict free over a time horizon of at least 15 minutes. Once an identified 4D trajectory is accepted by the crew it is adopted as the aircraft's RBT, and it is broadcasted to the other aircraft. When a Medium Term Conflict with an RBT of another aircraft is detected, then the aircraft having lowest priority has to resolve the medium term conflict. The aircraft with higher priority simply sticks to its RBT. The priority of an aircraft is primary determined by the remaining time to CTA. The lower priority aircraft should adapt its RBT in order to solve the conflict as well as not creating a conflict with any of the other aircraft RBT's.

STCR forms the next line of defense with a time horizon of at least 3 minutes. When STCR detects a potential infringement of these separation criteria, then it is obliged to resolve this through a tactical manoeuvre, i.e. the priority rules do not apply anymore.

1.4 Key iFly finding

During the second part of the iFly project, the A^3 ConOps has been evaluated on cost-benefit and accident risk under the assumption of 3x busy 2005 en-route traffic demand. The main finding of both the safety risk and the cost-benefit evaluation studies are very positive for the A^3 ConOps analysis. Based on these results the discourse between the two schools of thought has converged to a joint view that in theory, airborne self separation is a very healthy concept for future ATM.

1.5 Aim of this report

The aim of this report is to develop an E-OCVM[1] compliant validation strategy/plan for follow-up R&D regarding further development of airborne self separation with emphasis on

[1] European Operational Concept Validation Methodology

potential transition paths from conventional to advanced ATM and potential integration with SESAR2020 ConOps.

This report is organized as follows. Section 2 provides an overview of the iFly project results obtained and the innovative meaning of these results relative to state-of-the-art. Section 3 places the A^3 ConOps in perspective of the advanced ATM design space. Section 4 identifies how the current progress in A^3 ConOps development and validation fits in the E-OCVM framework. Based on this, Section 5 proposes a follow-up validation strategy/plan. Finally, Section 6 presents concluding remarks.

2 Overview of iFly results

This section sketches the airborne self separation status at the beginning of the iFly project, summarizes the achievements of the project, and explains how this relates to the state-of-the-art.

2.1 Status airborne self separation before iFly

At the start of the iFly project the amount of scientific support in favour of airborne self separation already was very good. Human factors research of pilot-in-the-loop simulations of airborne self separation had shown that pilots are very well capable in managing the additional role of maintaining separation with other aircraft, also under high en route traffic demands [Ruigrok & Hoekstra, 2007]. In addition to these human factors research, also an RTCA DO-264 (=EurocaeED78a) event sequence based safety analysis has been performed for situations of two aircraft encounters [Scholte & Klein Obbink, 2005]. The outcome of this study were requirements posed on the dependability of ASAS supporting technical systems, such as ADS-B and GNSS. Because of these earlier results that airborne self separation could be done sufficiently safe in terms of pilot perception and in terms of system dependability, the focus of the iFly project has been on safety risk analysis using rare event Monte Carlo simulations of an advanced airborne self separation ConOps.

2.2 Achievements of the iFly project

The achievements of the iFly project are of two types:
- Airborne Self Separation achievements
- Generic achievements

The airborne self separation achievements are as follows:
1. The A^3 ConOps has been developed for en-route traffic which goes beyond the limits posed by the airborne self separation concepts in literature [iFly D1.3].
2. Study of the conflict detection and resolution problems of the A^3 ConOps can be managed using algorithms that have modest computational requirements [iFly D5.4].
3. Study of shared situation awareness issues has stimulated the development of mitigating measures for some safety critical conditions [iFly D4.2].
4. Through conducting large scale rare event MC simulations for a model of this A^3 ConOps it has been shown that it can safely accommodate 3x the 2005 European traffic demand [iFly D7.4].
5. Through conducting a cost-benefit analysis it has been shown that the introduction of this A^3 ConOps is economically sound [iFly D6.4].
6. A vision has been developed how A^3 equipped aircraft fit best within the SESAR thinking regarding future ATM [iFly D8.3].
7. By conducting an early cycle through the EUROCAE ED78A method, for this A^3 ConOps preliminary safety and performance requirements have been derived on the applicable functional elements of the concept [iFly D9.3].
8. A human factors study has been performed, which has identified the principles for advanced cockpit design in A^3 equipped aircraft [iFly D2.4].
9. Novel directions for traffic flow control in support of the A^3 ConOps have been identified [iFly D8.2]

In addition to this the iFly project also has various more generic achievements:

1. Further extension of a powerful method in compositional modelling and analysis of complex socio-technical systems [iFly D4.1].
2. Development and initial performance evaluation of three novel complexity metrics for advanced ATM [iFly D3.2]
3. Development of four novel medium and short term conflict resolution algorithms some of which can guarantee conflict free resolutions [iFly D5.3].
4. Development of powerful extensions of the rare event Monte Carlo simulation method IPS [iFly D7.2g].
5. An inventory of options for the possible refinement of the A^3 ConOps [iFly D8.1]

All these achievements have been documented well. Moreover a steady stream of research papers has been produced in support of disseminating these achievements.

2.3 Relating the achievements of the iFly project to state-of-the-art

Advanced airborne self separation Conops

Development of advanced airborne separation applications is a long term process which will be strongly dependent on the practical experience from the deployment of earlier ADS-B In applications, such as In-Trail Procedure or Interval Management (airborne spacing). In this context the envisioned implementation timeframe of airborne self separation is expected to be 2025+, i.e., beyond the SESAR scope. Although several associated research activities were performed in past both in the US and in Europe (Free Flight, MFF, ASSTAR), there are several elements of the iFly project that goes considerably beyond them. For instance, the previous research was typically based on the use of a single communication channel (ADS-B broadcast) of only state information, and operations in low density traffic. On the contrary, the iFly project targeted high density traffic and a lot of effort was paid to develop a concept having communication and information backup and profiting from different types of information. Specific achievements beyond the state-of-the-art in advanced ATM development are:

i) A^3 ConOps [iFly D1.3]
ii) Inventory of options for the refinement of an advanced ATM concept [iFly D8.1];
iii) Innovative approaches towards traffic flow management in support of the A^3 ConOps [iFly D8.2]; and
iv) Development of a vision to integrate A^3 –equipped aircraft with the SESAR 2020 thinking [iFly D8.3].
v) SPR documents provide a novel level of detail and enhanced analysis (in particular, with respect to safety) of self separation operations comparing to the previous airborne self separation research [iFly D9.1 - D9.4].
vi) Setting out the principles to be adhered in the development of an A^3 directed HMI design in the cockpit, such that this HMI provides optimal support to the crew, in support of their new tasks and responsibilities [iFly D2.4].

Cost benefit of A^3 ConOps

Apart from using the proposed analysis approach in [D9.4] to assess economic impacts on involved stakeholders, it can be used to identify the ConOps economic targets under which the emerging ATM system could be sustainable. A tool has been developed in order to perform the calculations required for applying the proposed CBA approach. This CBA tool could be used by policy makers as a decision support tool for estimating alternative costs and benefits targets under which the proposed ATM ConOps may lead to a desired level of economic performance. In addition, the analysis of the institutional issues arising from the introduction of the A^3 ConOps provided useful recommendations for revising the institutional framework in order to facilitate the implementation of the proposed ATM changes.

Safety of A^3 ConOps
Thanks to the results obtained through rare event MC simulations in [iFly D7.4], it has become clear that one school of researchers was right: those who believed that airborne self separation can safely accommodate very high en-route traffic demands. This removes large uncertainty for the aviation industry which ATM directions can safely support increasing traffic demands. Now this uncertainty is resolved, it is expected that this may trigger novel developments in advanced airborne self separation, and the integration of conventional aircraft with advanced aircraft.

Mathematical results
In air traffic complexity the state of the art is to model and predict complexity of air traffic through explicitly adopting limitations of air traffic controllers and sector boundaries. The research in [iFly D3.1-D3.2] has led to the development of novel complexity metrics that avoid these limitations. However, it is not yet clear whether these novel developed complexity metrics are of specific use in the further refinement of the A^3 ConOps.

The impact of situation awareness consistency in the safe evolution of ATM scenarios is high, as also demonstrated by a posteriori analyses of ATM related disasters. Early studies of situation awareness in ATM were based of psychological analysis. The integration with engineered ATM is in general a hard task because the models employed by psychologists and engineers are of different nature. The approach pursued in [iFly D4.1-D4.2] provides a unified formal framework that integrates psychological studies of situation awareness with mathematical models of technical devices in ATM. This approach can be considered as “qualitative” in the sense that it answers yes or no to the question of whether a situation awareness inconsistency can lead to a safety-critical situation.

Finally, conflict detection and resolution research has produced the following clear improvements over state-of-the-art:

1. Provide systematic ways to deal with the requirements of the autonomous aircraft concept of operations developed in iFly. The extensive literature review in [iFly D5.1] and the comparison of the features of the available methods with the requirements of the autonomous aircraft concept in [iFly D5.2] suggest that none of the existing methods were suitable for this task without further extensions. [iFly D5.3-D5.4] provide precisely such extensions for the selected short-term and mid-term conflict resolution methods.
2. Strive for theoretical guarantees on the quality of the conflict resolution manoeuvres that they produce. In literature this is not yet a consideration for most of the available conflict resolution methods. However, solid theoretical foundations and the development of formal guarantees may for example obviate the need for extensive, expensive and time-consuming validation experiments.
3. Demonstrate ways of coupling short- and mid-term conflict resolution methods. Clearly this is an important consideration since most operational concepts envision conflict resolution methods operating simultaneously at different levels. To the best of our knowledge in literature no methodology is available for determining the effect that the actions of one conflict resolution level will have on the others. Hence the

novel results in [iFly D5.3-D5.4] show a potential novel direction for introducing such cross-layer considerations in the conflict resolution process.

3 A^3 ConOps results in perspective of advanced ATM development

The iFly project addressed the early development phase of an advanced airborne self separation ConOps, and showed that this A^3 ConOps can safely and economically accommodate very high levels of en-route traffic demand. These favourable findings for the A^3 ConOps mean that it is a feasible solution for the future, though does not mean that it also is the best choice for the future. The aim of this section is to introduce this wider view, through placing the A^3 ConOps in the broader perspective of the advanced ATM design space.

3.1 A^3 ConOps differences and similarities with SESAR 2020

In [iFly D8.3] a comparison has been made between the SESAR2020 ConOps and the A^3 ConOps. This showed that both concepts have many key enablers of advanced ATM in common. Both concepts are based on the sharing of Reference Business Trajectory (RBT) among aircraft. Both concepts embrace ADS-B In & Out, and System Wide Information Management (SWIM). Both concepts also give ASAS an important role, although with more functionality in the A^3 ConOps.

The key difference between the two is that in SESAR2020 most separation responsibilities remain with ground ATC, whereas in the A^3 ConOps all medium and short term separation responsibilities have gone to the pilots. This difference is made explicit in Table 1 for the four ATM levels: Flow Management, Medium Term CD&R, Short Term CD&R and ACAS. This Table also includes Conventional ATM and a Cross-over between SESAR2020 and A^3 ConOps.

Another important similarity between SESAR2020 and A^3 ConOps is that for both it is not clear at all how to accomplish the transition from conventional ATM. The typical problem is that it will take a long term until the aircraft fleets are fully ASAS equipped. During this term proper solutions are needed for ATC in handling mixed aircraft fleets, while during this period the increasing traffic demand should also be safely accommodated.

Table 1. High level characterization of Conventional ATM, SESAR2020, A^3 ConOps and a Cross-over of A3 and SESAR2020.

ATM function	**Conventional ATM (C)**	**SESAR 2020 (S)**	**Cross-over ConOps (X)**	**A^3 ConOps (A)**
Flow Management	ATFM	RBT compliant ATFM	RBT compliant ATFM	RBT compliant ATFM
Medium Term CD&R	State based by ATC	RBT based by ATC	RBT based by ATC	RBT based by Aircraft
Short Term CD&R	State based by ATC	RBT based by ATC	RBT based by Aircraft	RBT based by Aircraft
ACAS	TCAS II	Improved TCAS II	Improved TCAS II	Improved TCAS II

3.2 Advanced ATM design space perspective

From a theoretical perspective, the challenge of designing an advanced ATM design can be seen as an exercise in identifying the best point in the multi-dimensional design space of possible ATM ConOps. In this large design space there is a point C representing the conventional ATM design. There also are points S, A and X representing the SESAR2020 design, the A^3 ConOps and the Cross-over ConOps in Table 1 respectively. Points C and A form the extreme corners of the advanced ATM space that we consider. Points S and X represent two ConOps versions which lie somewhere halfway the two extreme points C and A.

For almost all points in this abstract ATM design space very little is known regarding their capability in safely supporting very high en-route traffic demands. In fact, point A is at this moment the only one for which this capability has been shown. The conventional point C is known to be safe under current traffic demands, but is expected to fail on safety under 3x high 2005 en-route traffic demand. Also for point S it is not yet known whether it can safely accommodate 3x high 2005 en-route traffic demand or not. From this perspective the A^3 ConOps is at this moment better understood than the SESAR2020 ConOps.

The above way of thinking leads to the following questions:

Q1: Are there other points in the ATM design space which can safely accommodate 3x high 2005 en route traffic demand?

Q2: Does the SESAR2020 ConOps (point S) belong to this set of points?

Q3: Does the Cross-over ConOps (point X) belong to this set of points?

If either Q2 or Q3 receive a positive answer, then this implies that the answer to Q1 also is positive. The best way to identify the answers to Q2 and Q3 is to evaluate the safety risk of SESAR2020 and the Cross-over ConOps for very high en-route traffic demand similarly to the way this has been done for the A3 ConOps [iFly D7.4].

3.3 Transition through mixed aircraft fleets

The key challenge is how to manage transitions from conventional ATM (point C) to a much better point in the design space. This applies to A^3 ConOps (point A) as well as to SESAR 2020 (point S) and the Cross-over ConOps (point X).

One of the largest problems faced by all three advanced ConOps in Table 1 is that there does not yet exist well developed transition paths from Conventional ATM to any ConOps that supports adequately equipped aircraft only. This problem applies to SESAR2020, to A^3 ConOps, as well as to the Cross-over ConOps. Complementary to these differences in equipment of aircraft fleets, there is the problem to find transition paths that can handle temporary differences in equipment at ATC ground centres.

This leads to the following additional questions:

Q4: Which feasible transition paths are available to gradually evolve from the 0% ASAS equipped aircraft under Conventional ATM to a situation of 100% ASAS equipped aircraft?

Q5: Do these transition paths depend on the ASAS functionality?

Q6: If yes, what are the differences for SESAR2020, A^3 ConOps and the Cross-over ConOps?

A possible way to identify the answers to Q4 through Q6 is to first develop potential transition paths from Conventional ATM to the A^3 ConOps, to the SESAR2020 and to the Cross-over ConOps. Subsequently it would make sense to identify similarities and differences in these transition paths, and to evaluate the most promising transition paths on the high level performance indicators such as capacity, safety and economy.

4 Which E-OCVM phase should be addressed next?

4.1 E-OCVM life cycle

A lack of clear and understandable information to support decision making on air traffic management system implementation in the mid 1990s motivated validation research in Europe. The European Commission provided support for this and brought together industry, R&D organisations, service providers and Eurocontrol. The findings eventually converged into the European Operational Concept Validation Methodology (E-OCVM). The E-OCVM has become the major source of reference for all European Commission and Eurocontrol validation activities [E-OCVM, 2010]. The iFly project has been conducted within a clear E-OCVM setting. In order to explain this, first a short description of E-OCVM is given.

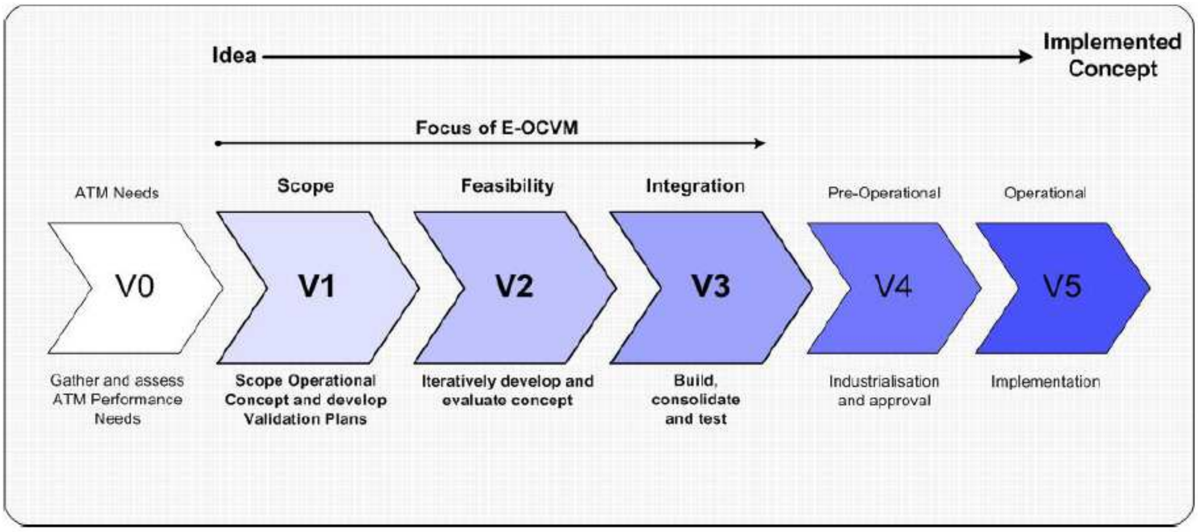

Figure 1: Concept Lifecycle model of E-OCVM [E-OCVM, 2010]

Central in E-OCVM is the Concept Lifecycle Model, which is depicted in Figure 1. Phases V0-V5 are described in Table 2.

Table 2. Overview of the E-OCVM phases V0 – V5.

"The first six phases of the Concept Lifecycle Model are: **V0 ATM Needs –** As a prerequisite of concept validation, the ATM performance needs and barriers must be identified. To complete the validation of the concept, the concept must show that it can alleviate these barriers enough thus enhancing ATM performance to the anticipated required level. **V1 Scope –** The phase where the concept should be described in sufficient detail to enable identification of the potential benefits mechanism (i.e. the change to systems and/or operations that will enable a known barrier to be alleviated). Some aspects of the concept will be unknown or unclear at this stage. There may exist a number of options to be assessed during the further validation process.

V2 Feasibility – This phase aims to develop and evaluate, in an iterative way, the concept until it can be considered operationally feasible. During this phase system prototypes will be used that make assumptions about technical aspects in order to avoid system engineering which can be costly and lengthy. Aspects that should be focused on are operability and the acceptability of operational aspects. It is during this phase that operational procedures and requirements should become stable. The number of iterations depends on the complexity of the concept and how often unexplained situations occur that need to be explained. At the end of this phase HMI, Operating procedures (for normal and key non-normal conditions) and phraseology should be thoroughly tested. This stage will establish the behaviours of the new system.

V3 Integration – The phase to integrate any required functionality into pre-industrial prototypes. Engineering processes can be explored to provide experience that will be useful to building the end system. This phase is focused on integrating operating procedures by using realistic scenarios that are representative of what the concept must be able to manage in the target end-system. The focus is therefore on system level behaviour, performance and establishment of standards/regulations necessary to build and operate the required technical infrastructure. This work will enable costs and benefits to be clearly identified and provide information about the potential performance of the overall ATM system.

V4 Pre-Operational – Pre-operational preparation takes place during this phase. Pre-operational prototypes will be transformed into industrial products ready for implementation and all institutional issues concerned with procedures approval should be addressed (Out of direct scope for R&D).

V5 Implementation – This is the phase when products and procedures are combined to create an operational system at a specific site. Implementation is a complex and risky procedure and it can be expected that many pragmatic ‘fixes’ will be required to complete implementation successfully. (Out of direct scope for R&D).

The ‘Concept Validation Methodology’ is most applicable to the phases V1, V2 and V3 of the Concept Lifecycle Model. V0 is considered as pre-requisite information for validation to commence. During the later phases of Pre-operational (V4) and Operational (V5) different methodologies than those proposed here will be required (e.g. The V model).”

The E-OCVM also explains how the Case-Based Approach and the Structured Planning Framework play a role in each of the phases of the Concept Lifecycle Model. The EC project CAATS II aims the further development of the Case-Based Approach in the E-OCVM.

For the development of an advanced ATM ConOps, the focus is on E-OCVM phases V0 through V3. During these phases a case based approach should be taken such that at the end a well informed decision can be taken regarding the start of the industrialization and implementation phases. This case-based view is depicted in Figure 2.

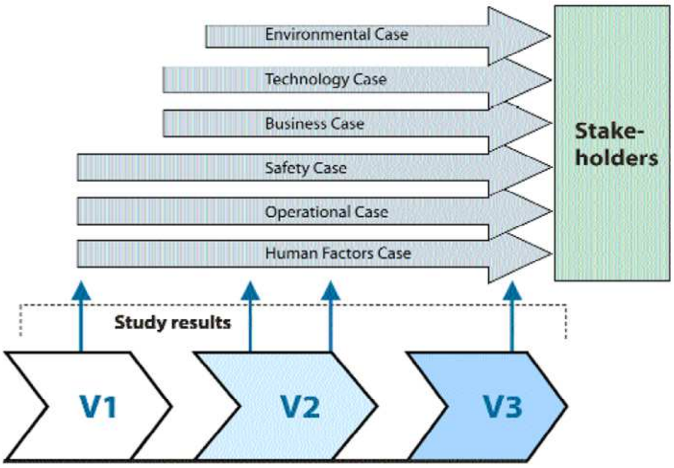

Figure 2: E-OCVM Case-based View

The iFly project has addressed phases V0 (ATM needs) and V1 (Scope). Hence the results produced by iFly do not constitute completed cases. The aim of this report is to provide a strategy and plan for follow-up Validation work.

4.2 Criteria for transition from phase V1 to phase V2

According to ([E-OCVM, 2010], page 38) phase V2 may start as soon as the following key questions are adequately answered:

1. What are the operational concept/enablers to meet the needs?
2. What are the potential contexts of use/application/ deployment?
3. What are the related operational concepts and their possible implications?
4. What are the potential benefits/costs?
5. What are the potential alternatives?
6. What needs deserve to be validated (R&D needs)?
7. Is there an adequate work plan for phase V2?

1. What are the operational concept/enablers required to meet the needs?
The assessment will examine whether the operational concept and supporting technical enablers are defined at the level of detail required for the development of benefit mechanisms and for the identification of major feasibility and performance related R&D needs. It will check whether any operational concept and technical enabler options are adequately identified.

2. What are the potential contexts of use/application/deployment?
The assessment will check whether: the context in which the concept should be implemented is defined adequately (e.g. airport, TMA, en-route, traffic density, airspace structure, etc.); the target Initial Operational Capability (IOC) date and area of application are identified adequately (e.g. local, regional, pan-European).

3. What are the related operational concepts and their possible implications?

The assessment will establish whether related concepts are identified. It will also check whether potential impacts (enhancements or negative impacts) between the subject concept and all related concepts are elaborated adequately.

4. What are the potential benefits/costs?
The assessment will focus on whether the potential benefits are identified adequately and fit with the performance targets and strategic objectives identified in lifecycle phase V0. It will also check that the potential cost has been adequately identified (order of magnitude).

5. Initial comparison with alternative concepts?
The assessment will focus on whether alternative concepts/enablers are adequately identified. It will also assess whether the potential benefits/costs are compared with the potential (or known) benefits/costs of alternative concepts/enablers to justify R&D work in that area.

6. What needs deserve to be validated (R&D needs)?
The assessment will address whether the major operational, technical and transition related feasibility issues are identified adequately. It will also check whether the need to assess these feasibility issues is justified (i.e. do all available results indicate feasibility or are there contra-indications?). Further, the assessment will address whether the major performance related issues (R&D needs) are identified adequately, covering all relevant KPAs. It will also look at whether potential solution risks are identified.

7. Is there an adequate work plan for phase V2?
The assessment will verify whether there is a work plan for phase V2 which adequately covers all the major feasibility and performance related R&D needs/issues that have been identified during phase V1.

4.3 Evaluation of A^3 ConOps against criteria regarding transition to phase V2

In order to find out whether the A^3 ConOps is ready for further development and validation in phase V2, we now perform an evaluation against each of the seven criteria given in the previous subsection.

Regarding 1. What are the operational concept/enablers required to meet the needs?
Within the iFly project the operational concept/enablers required to meet the needs of the A^3 ConOps have largely been defined in sufficient detail for the development of benefit mechanisms and for the identification of major feasibility and performance related R&D needs. This has specifically been done in [iFly D1.3] (A^3 ConOps), [iFly D8.1] (Evaluation of best options for refinement of A^3 ConOps), [iFly D8.4] (non-airborne requirements) and [iFly D9.1 - D9.4] (airborne requirements). The main enablers that can benefit from additional research in V1 are long term, medium term and short term Conflict Detection & Resolution (CD&R). Complementary there is the issue of validation and certification of advanced CD&R decision support systems.

Regarding 2. What are the potential contexts of use/application/deployment?
For the A^3 ConOps there still are large uncertainties regarding the context in which the concept should be implemented. Major issues are for example: interfacing with TMA, feasible transition paths, and area of application (e.g. local, regional, pan-European). Hence on this issue the A^3 ConOps is not yet ready for further development and validation in E-OCVM phase V2.

Regarding 3. What are the related operational concepts and their possible implications?
For the A^3 ConOps, the main related concept identified is SESAR2020. In [iFly D8.3] a good start has been made towards identifying the similarities and differences between A^3 ConOps and SESAR2020. However, the possible implications of these similarities and differences have not been identified yet.

Regarding 4. What are the potential benefits/costs?
For the A^3 ConOps the potential benefits have adequately been identified in [iFly D6.4] (cost-benefit) and [iFly D7.4] (safety) relative to the performance targets and strategic objectives identified in lifecycle phase V0. Hence on this 4th issue the further development and validation of the A^3 ConOps is ready to move to E-OCVM phase V2.

Regarding 5. Initial comparison with alternative concepts?
The iFly project had no objective to also identify and/or evaluate alternative concepts/enablers. Hence no assessment has been performed yet how potential benefits/costs of the A^3 ConOps compare to those of alternative concepts/enablers. Hence on this 5th issue work remains to be done in E-OCVM phase V1.

Regarding 6. What needs deserve to be validated (R&D needs)?
The iFly project had no objective to address transition related feasibility issues. In Section 3 these transition issues have been identified as the key ones to be resolved. Hence on this 6th issue major transition related feasibility work remains to be done in E-OCVM phase V1.

Regarding 7. Is there an adequate work plan for phase V2?
Because important issues remain to be investigated for the A^3 ConOps within E-OCVM Phase V1 (see criteria 1, 2, 3, 5 and 6) there is need for a plan to complete the remaining phase V1 work, rather than a plan for phase V2.

In summarizing, the A^3 ConOps is not yet ready for being moved from E-OCVM phase V1 to V2. Full compliance has been realized for criterion number 4 (potential benefits/costs) only.

4.4 What remains to be done in E-OCVM phase V1?

In summarizing the findings of the previous sub-section, the main remaining issues that should be addressed within E-OCVM phase V1 are:

- To further study advanced long term, medium term and short term CD&R techniques, and their integration in the A^3 ConOps as well as in SESAR2020. In addition the issue of validation and certification of CD&R decision support systems should be studied (criterion 1).
- To develop the potential contexts of use/application/deployment, including interfacing with TMA, transition path alternatives, and area of application (criterion 2).
- To extend the comparison of A^3 ConOps versus SESAR2020 and the Cross-over ConOps, also regarding safety/capacity and cost-benefit (criterion 3).
- To perform initial assessments of how potential benefits/costs of the A^3 ConOps compare to those of alternative concepts/enablers, including transition path alternatives (criterion 5).
- To identify which feasibility validations have to be conducted in E-OCVM phase V2, including the selected transition paths (criterion 6).

- To develop an adequate work plan for E-OCVM phase V2 (criterion 7).

The above implicitly shows that SESAR2020 neither is ready to move to E-OCVM phase V2. This implies there is not only a need to address E-OCVM phase V1 for the remaining issues, but also to address them in the broader perspective of making use of the full advanced ATM design space, rather than the A^3 ConOps only.

5 Strategy/Plan for completing E-OCVM Phase V1

The main conclusion of the E-OCVM analysis in the previous section is that neither A^3 ConOps nor SESAR2020 is ready for their move to E-OCVM phase V2. In this Section we propose a strategy/plan for an integrated completion of E-OCVM phase V1, i.e. one which considers the full ATM design space, not just A^3 ConOps. The strategy/plan consists of four main streams of research:

1. Top down stream: Comparing main ConOps versions under very high traffic demands,
2. Bottom up stream: Comparing possible transition paths to advanced ATM,
3. CD&R integration stream: Integration of mathematical techniques in advanced ATM,
4. Certification of CD&R decision support systems.

These four streams are further explained in the next four subsections.

5.1 Stream 1: Comparing ConOps versions under very high traffic demand

From the advanced ATM design space perspective it is quite difficult in making the best design decisions as long as there is general agreement about the key enablers, but not on the best allocation of separation responsibility, i.e. ground ATC or aircraft crew. As shown by Table 1, this issue of separation responsibility applies both to medium term as well as short term CD&R. The aim of stream 1 is to find out how A^3 ConOps, SESAR2020 and the Cross-over ConOps compare to each other in terms of safety/capacity and cost-benefit. In order to realize this for safety/capacity, it is proposed to extend the rare event MC simulations from the A^3 ConOps in [iFly D7.4] to SESAR2020 and the Cross-over ConOps in Table 1. For the cost-benefit analysis the one conducted in [iFly D6.4] should be extended to SESAR2020 and the Cross-over ConOps.

The main activities to be addressed in stream 1 are:

1. To compare A^3 ConOps, SESAR2020 and the Cross-over ConOps on safety/capcity and cost-benefit.
2. To extend the A^3 ConOps as well as the Cross-over ConOps for the TMA.

5.2 Stream 2: Transition paths from conventional to advanced ATM

This is a bottom-up stream which identifies and evaluates possible transition paths from Conventional ATM to A^3 ConOps, SESAR2020 and the Cross-over ConOps. Subsequently it would make sense to identify similarities and differences in these transition paths, and to evaluate the most promising transition paths on the high level performance indicators such as capacity, safety and economy.

The main activities to be addressed in stream 2 are:

1. To identify transition paths to A^3 ConOps, SESAR2020 and the Cross-over ConOps.
2. To evaluate important points on the most appealing transition paths.

As long as the possible transition paths for these three ConOps coincide, then evaluation can be done independently of the outcomes of stream 1. However, at a certain point there will be significant differences in the branching of the transition paths for different end ConOps. In order to make proper selections will be made of the outcomes of stream 1.

5.3 Stream 3: Integration of mathematical techniques in advanced ATM

Human factors research in [iFly D2.3,D2.4] has clearly shown that aircraft crew have the need to maintain situation awareness of the conflict resolution maneuvers of own aircraft. Within iFly this crew-in–the-loop requirement has been taken into account during the safety directed rare event Monte Carlo simulations [iFly D7.4]. In these safety directed MC simulations the CD&R approach is based on Velocity Obstacles in combination with some well working rules. Although this is fine for safety risk assessment, in advanced ATM there will be a need for mathematical techniques that are even better in conflict resolutions. Such mathematical techniques have been studied and simulated in [iFly D5.3, D5.4], though without having the aircraft crew in the loop. Hence there is a key need to continue the development of powerful mathematical techniques and their integration within the human decision-making loop. Another issue that remains to be studied is how Flow Management should work in support of RBT based conflict resolution.

The main activities to be addressed in stream 3 are:

1. To further the development of ATFM that provides best support of RBT based ATM.
2. To further the development of medium term CD&R, including the integration with human decision-making.
3. To further the development of short term CD&R, including the integration with human decision-making.

5.4 Stream 4: Certification of CD&R decision support systems

In advanced ATM, the CD&R algorithms are able to identify combinatorial solutions that cannot be provided by human anymore. This means that the pilots and controllers critically depend on the proper functioning of their CD&R decision support systems. This may pose novel certification challenges. As an illustration of the kind of problems one might encounter, we consider the TCAS II example. TCAS II is a decision support system for the pilots. The validation and certification of a TCAS II system initially worked as follows. RTCA gives a detailed specification of how a TCAS II system should work. Such level of detail easily leads to ambiguities, and does not allow to conduct verification tests. Decades later only, this problem has been solved by the development of a battery of verification tests [FAA, 2000]. Would this also be the way to go for advanced CD&R decision support systems, or is there a better approach? The earlier this question is addressed, the better it is. Hence we propose to use E-OCVM phase V1 for developing a proper understanding of the problems and the possible solutions. This asks for conducting the following studies in phase V1:

1. To identify the future needs and problems in validation and certification of advanced CD&R decision support systems for controllers and pilots.
2. To identify the potential directions for resolving these future needs and problems.

6 Concluding remarks

This report proposes a strategy/plan for E-OCVM based further validation of the iFly results obtained. The development of this strategy/plan has been based on evaluations conducted in Sections 2 through 5. Section 2 reviewed the main iFly achievements over state-of-art. Section 3 placed the main achievements in perspective of the advanced ATM design space. Section 4 used the E-OCVM transition criteria to identify which phase V1 issues remain to be addressed. Section 5 collected the results obtained in a strategy/plan for completing E-OCVM phase V1. This strategy/plan consists of four streams:
- Top down stream addressing the main end ConOps versions,
- Bottom up stream addressing the transition paths,
- CD&R stream, addressing mathematical techniques integration with the ConOps,
- CD&R certification stream.

An important outcome of the systematic analysis conducted in this report is that the proposed strategy/plan is no longer focussed on pure airborne self separation. Instead it takes the broader view that the right choice between ground and air regarding separation responsibility can best be made on the basis of outcome of objective analysis.

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Annex A. Acronyms

A^3	Autonomous Aircraft Advanced
A^4	Automated-ATM supported Autonomous Aircraft Advanced
ACAS	Airborne Collision Avoidance System
ACI	Airports Council International
AEA	Association of European Airlines
AIS	Aeronautical Information Services
ANS	Air Navigation Service
ANSP	Air Navigation Service Provider
AOC	Airline Operational Centres
APW	Airborne Proximity Warning
AQUI	University of l'Aquila
ASAS	Airborne Separation Assistance Systems
ASD	Aerospace and Defence Industries Association of Europe
ASM	Air Space Management
A-SMGCS	Advanced Surface Movement Guidance and Control System
ASOR	Allocation of Safety Objectives and Requirements
ATC	Air Traffic Control
ATCEUC	Air Traffic Control European Unions Coordination
ATCO	Air Traffic Controller
ATFM	Air Traffic Flow Management
ATS	Air Traffic Services
ATM	Air Traffic Management
AUEB	Athens University of Economics and Business Research Centre
BIP	Background Intellectual Property
CA	Consortium Agreement
CAA	Civial Aviation Authority
CAATS	Cooperative Approach to Air Traffic Services
CANSO	Civil Air Navigation Services Organisation
CARE	Co-operative Action of R&D in Eurocontrol
CNS	Communication, Navigation and Surveillance
ConOps	Concept of Operations
DSNA	DSNA-DTI-SDER (formerly CENA)
EASA	European Aviation Safety Authority
EATCHIP	European Air Traffic Control Harmonisation and Integration Programme
EATMS	European Air Traffic Management System
EBAA	European Business Aviation Association
EC	European Commission
ECA	European Cockpit Association
ECAC	European Civil Aviation Conference

EEC	Eurocontrol Experimental Centre
EHQ	Eurocontrol HeadQuarter
ELFAA	European Low Fares Airline Association
EM	Exploitation Manager
ENAC	Ecole Nationale de l'Aviation Civile
E-OCVM	European Operational Concept Validation Methodology
ERA	European Regional Airlines Association
ESA	European Space Agency
ESARR	Eurocontrol Safety Regulatory Requirement
ETHZ	Eidgenössische Technische Hochschule Zürich
EU	European Union
FAA	Federal Aviation Authority
FAR	Federal Aviation Regulations
FIP	Foreground IP
FIS	Flight Information Services
GAT	General Air Traffic
GPWS	Ground Proximity Warning System
HNWL	Honeywell
HYBRIDGE	Distributed Control and Stochastic Analysis of Hybrid Systems Supporting Safety Critical Real-Time Systems Design (EC 5th Framework Programme)
IACA	International Air Charter Association
IAF	Initial Approach Fix
IAOPA	International Council of Aircraft Owner and Pilot Association
IATA	International Air Transport Association
ICAO	International Civil Aviation Organisation
IFALPA	International Federation of Air Line Pilots Associations
IFATCA	International Federation of Air Traffic Controllers Associations
IFR	Instrument Flight Rules
INRIA	Institut National de Recherche en Informatique et en Automatique
IP	Intellectual Property
IPR	Intellectual property rights
JAA	Joint Aviation Authorities
JAR	Joint Aviation Requirements
LVNL	Luchtverkeersleiding Nederland
MET	Meteo
MUAC	Maastricht Upper Airspace Control
NATS	NATS En Route Ltd.
NEXTGEN	Next Generation Air Transportation System
NLR	National Aerospace Laboratory NLR
NSA	National Safety Authority
NTUA	National Technical University of Athens

OHA	Operational Hazard Assessment
OPA	Operational Performance Assessment
OPS	Operations
OSA	Operational Safety Assessment
OSED	Operational Services and Environment Description
PC	Project Co-ordinator
PMP	Project Management Plan
PoliMi	Politecnico di Milano
R&D	Research and Development
RGCSP	Review of General Concept of Separation Panel
RTD	Research, Technology and Development
R/T	Radio Telecommunication
SA	Situation Awareness
SAR	Search and Rescue
SES	Single European Sky
SESAR	Single European Sky ATM Research
SITA	Societe Internationale de Telecommunication Aerienne/Aeronautiques
SME	Small and medium sized enterprises
SPR	Safety and Performance Requirements
SRC	Safety Regulation Commission
SWIM	System Wide Information Management
TCAS	Traffic Collision Avoidance System
TLS	Target Level of Safety
TOPAZ	Traffic Organization and Perturbation AnalyZer
TWEN	University of Twente
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
UCAM	University of Cambridge
ULES	University of Leicester
UTartu	University of Tartu
WP	Work Package
WPL	Work Package Leader