

An airborne human machine interface for 4D-trajectory based operations

A study of needs for the A30X HMI in the ATM target
concept of 2020 described by SESAR



Willem van den Dungen

Final thesis submitted
for the degree of

MASTER OF SCIENCE

in

Electrical Engineering

Company Supervisors

S. Vieyres

Cockpit and ATM operations, Airbus

S. Marché

Cockpit and ATM operations, Airbus

Thesis Committee

Prof. Ir. P. Van Genderen

Faculty EEMCS, Department IRCTR, Delft University of Technology

Prof. Dr. Ir. E. Theunissen

Faculty EEMCS, Department IRCTR, Delft University of Technology

Dr. Ir. C.A.P.G. van der Mast

Faculty EEMCS, LS-MMI, Delft University of Technology

Ing. O.F. Bleeker

Rockwell Collins, Amsterdam

Willem van den Dungen

Student ID: 1092863

E-mail: willem_dungen@hotmail.com

An airborne human machine interface for 4D-trajectory based operations

A study of needs for the A30X HMI in the ATM target
concept of 2020 described by SESAR



Radio Navigation Group
Department of Telecommunications
Faculty EEMCS, Delft University of Technology

Mekelweg 4
2628 CD, Delft
The Netherlands
www.ewi.tudelft.nl



Service Operations and ATM
Cockpit Functions
Airbus France

316, Route de Bayonne
31060 Toulouse
France
www.airbus.com

Preface

This thesis discusses the research conducted for the graduation of the master Telecommunications at the faculty Electrical Engineering, Mathematics en Computer Science of the University of Technology Delft, the Netherlands. My master specializes in Avionics by means of a Minor and it is in this domain that I carried out my research, in particular in Human Machine Interaction. The compulsory final thesis project is meant to show the independent research capabilities of the student, completing its formation as an engineer ready for post-academic life.

The research has been conducted at AIRBUS France in Toulouse, France, where I was situated as intern at the department Cockpit Operations & Air Traffic Management. Working for nine months at the heart of one of the largest aeronautics companies in the world has been a great opportunity for me. It has given me an in-depth view of the aeronautical world, access to a large knowledgebase and insight in the functioning of a large enterprise. Apart from that, the human aspects and the value of people in such an enterprise have become apparent.

French being the customary speaking language and I not being a native 'francophone', communication was somewhat slower. However this did not prevent me to perform my work, including holding meetings and interviews, and formed an opportunity to improve my French skills considerably. My time in France also allowed me to profit from the young and dynamic city of Toulouse, also known as "La ville rose".

I wish to express my gratitude to all the members of the department Cockpit Operations (EDYAV1) for their support, advice and above all the sociable reception. Special thanks go to Sabine Vieyres and Stéphane Marché, my supervisors at Airbus, and Erik Theunissen, my graduation supervisor at the TU Delft who made it possible to take on my final thesis project abroad, for his support and expertise.

This report is meant to serve three groups of people. Firstly it is intended for the professors of the Telecommunications and Avionics departments of the University of Technology Delft. Secondly it provides a reference of my work for the people at AIRBUS. The third group is composed of people having a special interest in 4D-navigation or Human Machine Interaction and interested individuals in general.

Summary

The current SESAR program is carried out to ensure that air traffic management will be able to cope with the predicted air traffic growth. SESAR ('Single European Sky ATM Research') forms an all-embracing airspace system modernization and defines a target concept for the year 2020. A cornerstone of that concept is managing air traffic through 4D-trajectories that are based on the three spatial dimensions plus time.

This project forms the early stage of the design of a human machine interface for managing 4D-trajectories in Airbus cockpits and is characterized by the identification of needs from an operational, user and system perspective. They have been identified in cooperation with pilots using multiple iterations of static mock-ups and evaluation sessions on a research simulator. The cockpit concept of the Airbus A30X, the new short range aircraft to enter service around 2020, has been used as a research platform for the HMI. Studied aspects are concentrated to the field of navigation, more specific monitoring, managing, negotiation and optimizing 4D-trajectories.

Solutions are proposed for HMI that include important functions like trajectory display and information access, modification, weather predictions and revision support. The HMI did not fully meet design criteria related to the usability of the solutions; they were too complex in the context of the task to be performed. Recommendations for follow-up development are presented for further research and the conception of a human machine interface for 4D-trajectory management.

Part of these recommendations is a result of an analysis of the assumptions made earlier. This has been done to place the research described in this report in a larger, more scientific perspective.

Contents

Preface	I
Summary	III
Contents	V
1 Introduction	1
2 Problem description	2
2.1 Objective and scope of the report	2
2.2 Problem definition	3
3 4D-trajectory based concept of operation	7
3.1 4D concept description	7
3.1.1 The 4D-trajectory	7
3.1.2 Trajectory lifetime	7
3.1.3 Trajectory de-confliction	9
3.1.4 Revision and update	11
3.1.5 Scenarios of operation	12
3.2 The impact of using 4D-trajectories	13
3.3 Other 4D concepts	14
3.3.1 PHARE	14
3.3.2 NextGen	14
3.4 Airborne operational requirements for 4D operations	15
4 Identification and analysis of the pilot task	16
4.1 Identification of operational task	16
4.1.1 Pilot involvement	16
4.1.2 Operational task description	17
4.2 Pilot task analysis	19
4.2.1 Monitoring the 4D-trajectory	20
4.2.2 Handling the 4D-trajectory	22
4.2.3 Revision of the 4D-trajectory	23
4.2.4 Negotiation of the 4D trajectory	25
4.3 Validation of information requirements	26
4.4 Functions and information requirements	27
4.4.1 Required functions	27
4.4.2 Information requirements	27
4.4.3 Repartition of function and information requirements	28
5 Performing tasks in the A30X cockpit	29
5.1 Future system capabilities	29
5.1.1 Weather and automation	29
5.1.2 Direct feedback of modifications	30
5.2 Influence of the A30X concept	30
5.2.1 Main properties of the A30X cockpit concept	30
5.2.2 Parallels between A30X and 4D concepts	31
5.2.3 Effects on improvement areas	31
5.3 A30X functions and information	31
5.3.1 Trajectory display	32
5.3.2 Trajectory modification	32
5.3.3 Weather	33
5.3.4 Business properties	33
5.3.5 Negotiation	33
5.3.6 Handling	33
5.4 Improvement areas	34
6 Previous work	35
6.1 Overview of previous work	35
6.1.1 PHARE - AHMI	35
6.1.2 NASA - CDTI	36
6.1.3 Airbus	37
6.2 Previous work and improvement areas	38
6.2.1 Trajectory display	38
6.2.2 Trajectory modification	39
6.2.3 Weather	39

6.2.4	Business properties.....	39
6.2.5	Negotiation.....	40
6.2.6	Handling	40
6.3	Design goals	40
7	Design phase.....	41
7.1	Design procedure.....	41
7.2	HMI solutions	43
7.2.1	Access to trajectory information	43
7.2.2	Weather predictions.....	47
7.2.3	Modification	48
7.2.4	Revision support.....	49
7.2.5	Handling: an overview of trajectory transitions	55
7.3	Implementation	57
7.3.1	Research simulator O3P.....	57
7.3.2	Limitations of implementation	58
7.4	Evaluation	59
7.4.1	Evaluation objectives and criteria.....	59
7.4.2	Evaluation setup.....	60
7.4.3	Evaluation results.....	61
8	Assumption analysis.....	65
8.1	Automatic construction of trajectories	65
8.2	Direct feedback	67
8.3	Weather in 4D.....	67
9	Conclusion and recommendations	68
9.1	Conclusion	68
9.2	Recommendations.....	69
	Retrospect.....	71
	Glossary	72
	Literature	74
	Appendix A: SESAR.....	75
	Background and target.....	75
	SESAR timeline	75
	Key enablers of SESAR.....	76
	Target concept.....	76
	Appendix B: A380 EFIS.....	78
	Control and display system	78
	Mailbox	82

1 Introduction

On a peak day European air traffic management (ATM) controls roughly 30.000 commercial flights executed by around 5.000 aircraft. Until now ATM has been able to cope with this number, but the growing number of flights as a result of increasing demand in air transport will reach the limits of ATM in its current form around 2015.

SESAR stands for 'Single European Sky ATM Research' and is the European ATM modernization programme to cope with the predicted increase in air traffic. Led by Eurocontrol and supported by a consortium of aviation organisations it addresses virtually all aspects of ATM and is expected to revolutionize the way air traffic is managed. The programme defines a target ATM concept for the year 2020 and aims at four key performance areas: safety, capacity, environmental impact and costs.

Like previous ATM modernization efforts, the SESAR concept relies on improved navigation, communication and surveillance performances to be able to shift from vector to 4D-trajectory based operations and improved deconfliction methods in order to meet these goals. The 4D-trajectory concept of operation defines commonly agreed reference business trajectory (RBT) through a collaborative decision making process between airspace user and air navigation service provider (ANSP). The RBT consists of pre-deconflicted routes with one or more time constraints and can be revised during flight by the pilot or air traffic controller in case of e.g. weather hazards or traffic bunching.

This revision process raises the need for new functions and information in the cockpit to be able to manage and share 4D-trajectories. As a leading aircraft manufacturer and member of SESAR, Airbus has a substantial interest in researching and developing solutions for these new functions and information requirements for the cockpits of its (future) aircraft.

The objective of this report is to identify the needs for the A30X human machine interface to manage and share four-dimensional trajectories in the air traffic management concept of beyond 2020 as defined by SESAR.

In order to achieve this objective an analysis of the 4D-based concept of operation will be performed to obtain the pilot task and the role of automation. The requirements for correct execution of the pilot task will be evaluated for the cockpit concept for a future aircraft – the A30X – to yield areas interesting for research. Work that previously addressed these areas is to be consulted and a comparison will be made with the needs as expressed by pilots. All this leads to a set of design goals that forms the input for the design of a human machine interface.

Designing a human machine interface is an iterative process and in this research the HMI design will be used to refine the needs obtained in the analysis. Conform to Airbus practice the design process will be conducted in cooperation with experimental test pilots and flight test engineers. Static mock-ups will be used to obtain pilot needs for the design of the HMI. Simulator sessions will be conducted for evaluation and the refinement of the needs. For that purpose the HMI design will be software-implemented on a dynamic mock-up.

Report of this project is divided in an analysis and a design part, because topics in the design part are classified confidential. The analysis part treats the rational derivation of the design goals as well as the conclusion and recommendations of the entire research. The design part treats the considerations and decisions during the design process as well as the evaluation results. This report covers the analysis part and an extract of the design part (refer to chapter 7).

The objective and the associated problem of this project will be analysed in the next chapter. Chapter 3 marks the start of the design phase, in which a description of the operational concept of SESAR is given. Chapters 4, 5 and 6 will describe the gradual transformation of operational requirements to design goals. As has been indicated chapter 7 summarizes the design phase.

The project is concluded in chapter 8 and 9 where previously made assumptions are analysed and the conclusions and recommendations are presented.

2 Problem description

The goal of this chapter is to give a clear objective, scope and outline for this project. For this purpose the objective as stated in the introduction is elaborated first in section 2.1. The requirements as imposed by the institutions concerned (Airbus, TU Delft) and limitations imposed by the author are presented that determine the scope of the researched topics. Once the scope of the report is sufficiently known, the method to achieve the objective is determined. Important research questions will be stated that will be used as a guideline throughout this report.

2.1 Objective and scope of the report

The objective of this report is:

Identify the needs for the A30X human machine interface to manage and share 4D-trajectories in the air traffic management concept of beyond 2020 as defined by SESAR.

This phrase is elaborated part by part in the remainder of this section, but first some expressions concerning 4D-trajectories are explained. The exact definition of 4D-trajectories is given in chapter 3. For now it is sufficient to know that 4D-trajectories are flight paths described by four dimensions: the three spatial ones and time. 4D-navigation is the term for navigation using these 4D-trajectories and 4D-operations are the actions involving 4D-trajectories needed to operate in concept of operation, in this report defined by SESAR.

This section continues with the elaboration of the objective:

Identify the needs

Needs are defined as functions and information *required* from an operational perspective together with the functions and information *needed* from user and system point of view.

Less stringent needs are considered a supplement to requirements and in the objective the term needs thus incorporates requirements. For illustration needs as expressed by pilots often contain requirements from operational point of view. It is important to understand that the sources are different, which is clarified in the remainder of this chapter.

The statements hereunder define the working method of the project. Two phases are distinguished: an analysis phase and a design phase. The goal of the analysis phase is to determine the needs. The goal of the design phase is to refine and confirm those needs as opposed to developing a fully working HMI. It comprises the development and evaluation of possible solutions.

The requirements for the working method are stated below:

Analysis phase:

- A *rational analysis* of the pilot task in 4D-operations has to be performed to identify function and information requirements of the HMI. (TU Delft Requirement)
- The development must take into account the *current status of technology*. Existing systems and research concepts that address the same design goals are to be examined. Attention must be paid to recommendations in earlier work. (TU Delft Requirement)
- Introduce 4D-trajectory based navigation of the SESAR programme to *experimental test pilots*, so they can *express the needs* they foresee in the frame of 4D-operations. (Airbus requirement)

Design phase:

- The development and evaluation of the HMI is in cooperation with *experimental test pilots and flight test engineers*. (Airbus requirement)

- *Propose a HMI design* based on a synthesis of the needs. Multiple iterations on a static PC-based mock-up are used for the evolution, selection and specification of the HMI. (Airbus requirement)
- *Flight simulations* will be conducted for evaluation and for that purpose the selected HMI will be software-implemented on a dynamic mock-up. Dependent on time and resources multiple iterations may be performed to tune proposed solutions. The output of the evaluations is recommendations for follow-up research and proposition for HMI principles. (Airbus requirement)

The A30X human machine interface

The interfaces between the pilot and the avionic systems are the subject of this project. Details of algorithms and calculations of 4D-trajectories in the flight management system (FMS) will not be the focus of this report. Because the early stage of the design, requirements concerning human factors are outside the research scope. This project is applicable to airborne systems in commercial aviation; ground-based systems are not part of this project.

There is an important requirement:

- The HMI will be designed for the short-range single aisle *Airbus A30X*, the future replacement for the A320 aircraft family. The A30X was chosen as platform because the introduction of this aircraft coincides with the SESAR target date of 2020. The consequence is that the needs that arise from the cockpit concept are taken into account. They are presented in chapter 5. (Airbus requirement)

Manage and share

Managing of trajectories refers to the onboard handling of multiple trajectories as an entity, but also the interaction with the properties of a single trajectory. Sharing of trajectories refers to the exchange of trajectory information with actors on the ground. In this project the subject of sharing is limited to the interface with the pilot. The meaning of managing and sharing will be explained in more detail in chapter 4. Note that this part of the objective is closely related to the pilot task and the limitations presented here influence the pilot task analysis.

The following limitations apply to managing and sharing:

- This project concentrates on navigation. Details of surveillance and communication are outside the scope of this project. This means that needs resulting from surveillance and communication are not taken into account, except when they are linked with navigation using 4D-trajectories. This limitation is introduced because of overlap with other projects at Airbus (Author limitation)
- Managing and sharing of the ground part of the 4D-trajectory is not studied in this project. The entirely different set of requirements of ground operations makes that this problem is entirely different than airborne operations. Ground operations are addressed by another project at Airbus, but compatibility remains important. (Author limitation)

Four-dimensional trajectories in the ATM concept beyond 2020 defined by SESAR

As there have been other concepts of 4D-operations, it is important to point out that the 4D-trajectories in this project are those described in the SESAR concept for 2020. Managing and sharing 4D-trajectories are only a part of the SESAR program, but proposed solutions have to fit in the global ATM concept. Compatibility with other operational concepts of SESAR such as separation and spacing procedures remains important, but is not part of this project.

This corresponds to one requirement:

- The project must fit in the operational concept of 2020, one of the target dates defined in SESAR. (Airbus requirement)

2.2 Problem definition

In order to attain the objective described above, the following question is central in this thesis:

- What are the HMI needs that support managing and sharing 4D-trajectories in the A30X?

The procedure to obtain the answer to this question and its relation with the structure of the report is discussed next.

Analysis phase

In the previous section needs were defined as functions and information *required* from an operational perspective together with the functions and information *needed* from user and system point of view.

The design of a HMI is dictated by the task the user has to perform. In turn, this task depends on the operational concept and the situation of the user therein. A logical starting point for the identification of the needs is thus an examination of the (known) operational concept. It should lead to the requirements for the pilot and the aircraft system together to operate within the operational concept (operational requirements). Besides it should lead to an understanding of the impact on the pilot task as known in conventional operations.

Consecutively a rational analysis of the pilot task will be performed. It should make clear when the pilot is involved and what decisions will have to be made. This leads to function and information requirements that form the first set of requirements for the HMI; the pilot must be able to make informed decisions. When analysing the pilot task the boundary between pilot - and automated functions is established. This is important because, as the name suggests, the HMI is the link across this boundary.

According to the requirements associated to the working method, needs for the HMI have to be expressed by pilots as well. The pilot feedback will consist of two aspects: information requirements for the HMI and additionally needs from a user point of view.

It is underlined that the statements for the analysis phase are possibly incompatible: requirements are identified by the rational analysis, but also expressed by pilots. Pilot feedback will be used to validate the results obtained with the rational analysis. Any discrepancy between the results of the two should be examined to resolve any ambiguities in requirements. It is expected that differences in outcome of the two methods are small and that it will be sufficient to treat only remarkable aspects.

The next step in obtaining the HMI needs is examining the influence of the implementation platform. The operational requirements and pilot needs are compared to the available functions found in the cockpit of the A30X. The limitations and possible enhancements of the A30X define areas that are interesting for improvement. Besides, the A30X concept is designed according to a certain philosophy, which causes some additional needs for the HMI design.

Subsequently a study is performed to check whether the improvement areas have been the subject of previous studies. Improvement areas are no longer interesting for research if the solutions in previous work meet two criteria: fit in the operational concept and fit in the A30X cockpit. If one of the criteria is not met, further design is necessary. In that case previous solutions can be used to generate possible solutions, which meet the requirements of this project.

To summarize; design goals for the HMI are thus a result of the function and information requirements augmented with needs from an operational, user and system perspective. Besides, previous work makes some design superfluous, while giving indications for possible solutions.

The procedure for the analysis phase is shown in Figure 2-1. The four main phases are described and some research questions stated. The contents of chapter 3 to 6 of this report holds on to the presented scheme of which each block is represented by a separate chapter.

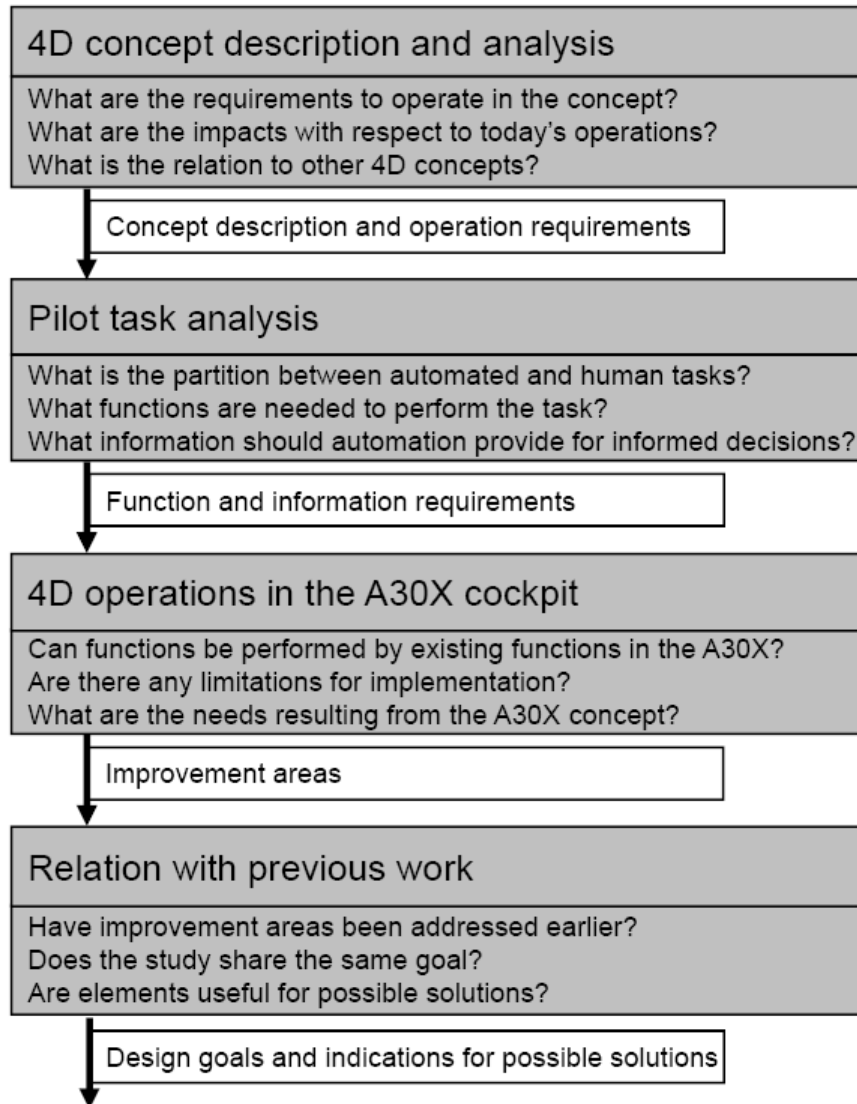


Figure 2-1: Schematic overview of the analysis phase

Design phase

The objective of the design phase is to refine the needs identified in the analysis phase. A HMI design solely based on a rational analysis will not yield the optimum solution, for such a design does not support the pilot optimally in performing his/her task. In relation to the analysis phase the design phase is more oriented to the 'how' aspect of the HMI in contrast to the 'what' aspect. This corresponds to an emphasis on user and system needs, but because of the early design the detail level will be low.

The design phase consists of three elements:

- Generation and selection of possible solutions
- Implementation of the resulting HMI proposal
- Evaluation of the HMI

Three iterations on a static mock-up are conducted to obtain a HMI proposal that corresponds to the design goals. This is done in cooperation with one pilot who is assigned referent for the SESAR related development. During consultations possible solutions are presented and in response the pilot expresses needs from a user perspective, including feedback about integration in the cockpit concept.

A selection of the possible solutions will be implemented on a dynamic mock-up (simulator) for evaluation. This is done by a subcontractor, but a close relation with the designer is maintained to make sure the resulting HMI is suitable for evaluation purposes.

The proposed solutions will then be evaluated by multiple pilots for a larger feedback base. Pilots with knowledge of the A30X concept and ATM Operations are invited to obtain feedback relevant to the project.

Criteria for the evaluation of the proposed HMI are related to the usability of the proposed solutions with respect to the pilot task to be performed. It is checked whether the proposed HMI is covering the operational requirements, and if these operational requirements are validated (like in the analysis phase, only now supported by a larger feedback base).

The results of the evaluation are needs and recommendations for follow-up HMI design.

Due to confidentiality a summary of the design phase is given in chapter 7. This includes an overview of the implemented HMI solutions, without the details of the pilot feedback during design iterations, and the results of the evaluation.

Assumption analysis

Chapter 8 presents an assumption analysis that was added in a later stage to put the report in a larger, more scientific context. It addresses the inaccuracies and inconsistencies as well as the risks associated with the assumptions taken in this report.

3 4D-trajectory based concept of operation

This chapter consists mainly of a general description of the concept of 4D-operations used in SESAR, focusing on the target date of 2020. First the definition of the 4D-trajectory is given and in the succeeding sections it will be described how they used before several scenarios are presented. Other 4D-concepts will be presented briefly in section 3.3 to place the SESAR 4D-concept in a larger perspective. The chapter will finish with the presentation of the impact on conventional operations and the operational requirements of 4D-operations.

For a description of the global ATM concept of SESAR the reader is referred to Appendix A: SESAR. The reference on which the concept descriptions are based is found under [15].

3.1 4D concept description

3.1.1 The 4D-trajectory

The 4D-trajectory consists of a set of segments that link waypoints defined in 4 dimensions: latitude, longitude, altitude and time. Altitude and time are described by estimates or constraints. Constraints can be 'AT', 'AT or below', 'AT or above' or 'window' constraints and form the limits for allowed estimates. The FMS (flight management system - airborne based) or the TP (trajectory predictor – ground based) calculates the segments with vertical profiles according to lateral transitions, constraints, user intention, aircraft performance and weather data. Although calculation algorithms will be coordinated, the airborne calculated trajectory is more precise due to accurate knowledge of aircraft parameters and therefore will be the primary source of the trajectory.

There are two kinds of 4D-trajectories. The reference 4D-trajectory corresponds to the strategic and commonly agreed trajectory from gate to gate to be flown by the aircraft (waypoints and constraints only). The predicted 4D-trajectory is the trajectory really flown by the aircraft depending on local circumstances like wind and aircraft performance. The predicted trajectory is calculated to join the reference trajectory.

Throughout the report different names and definitions for trajectories are used. 4D-trajectory or simply trajectory are general denotations and can be either kind (at the same time), but most of the time the exact meaning will be clear from the context. The different names are summarized in Table 3-1.

Trajectory Denotation/Name	Type	Definition
Business Development Trajectory (BDT)	Reference	Trajectory used internally at airline
Shared Business Trajectory (SBT)	Reference	Shared trajectory for planning purposes
Reference Business Trajectory (RBT)	Reference	Agreed trajectory used during operation
Route	Reference	General term, emphasis on lateral part
Predicted Trajectory (PT)	Predicted	The trajectory predicted to be really flown
Flight profile	Predicted	Emphasis on the vertical part
4D-trajectory (trajectory)	Either or Both	Context dependent

Table 3-1: Denotations of reference and predicted trajectories

As is described in Appendix A: SESAR, 4D-operations are introduced in phases that each uses a slightly different definition for 4D-trajectories. In 2013 initial 4D will be using 4D-trajectories that consist of 2D lateral containment with altitude constraints and one time constraint at destination. The 4D trajectory will consist of 3D-tubes and multiple time constraints in 2020 and will evolve eventually to the full 4D or 4D-contract principle by 2025-2035. This principle describes a moving box containing the aircraft. Following project requirements the 4D-trajectory defined for 2020 is used.

3.1.2 Trajectory lifetime

The trajectory to be flown is initiated by the airspace user (normally airlines). Up to years before departure the airspace user creates a business development trajectory (BDT), which as a result is

user preferred. The BDT stays inside the organization that created it and is used for business planning purposes. The BDT undergoes a number of iterations to match it to infrastructure and environmental restrictions. About six months prior to departure the BDT is shared with airports, air navigation service providers (ANSP) and other actors. From this point in time the trajectory is called shared business trajectory (SBT) and is part of a collaborative planning process. In this process the trajectory is deconflicted from trajectories scheduled to be flown by other aircraft and hazards (e.g. weather). This process iterates until about an hour before pushback to incorporate last-minute updates on weather and traffic and leads to a pre-deconflicted gate-to-gate trajectory, called the reference business trajectory (RBT). The user agrees to fly the RBT and the air navigation service provider (ANSP) plus the airports agree to facilitate. The owner of the RBT is the airspace user, except for time critical situations when the RBT is the responsibility of the ANSP.

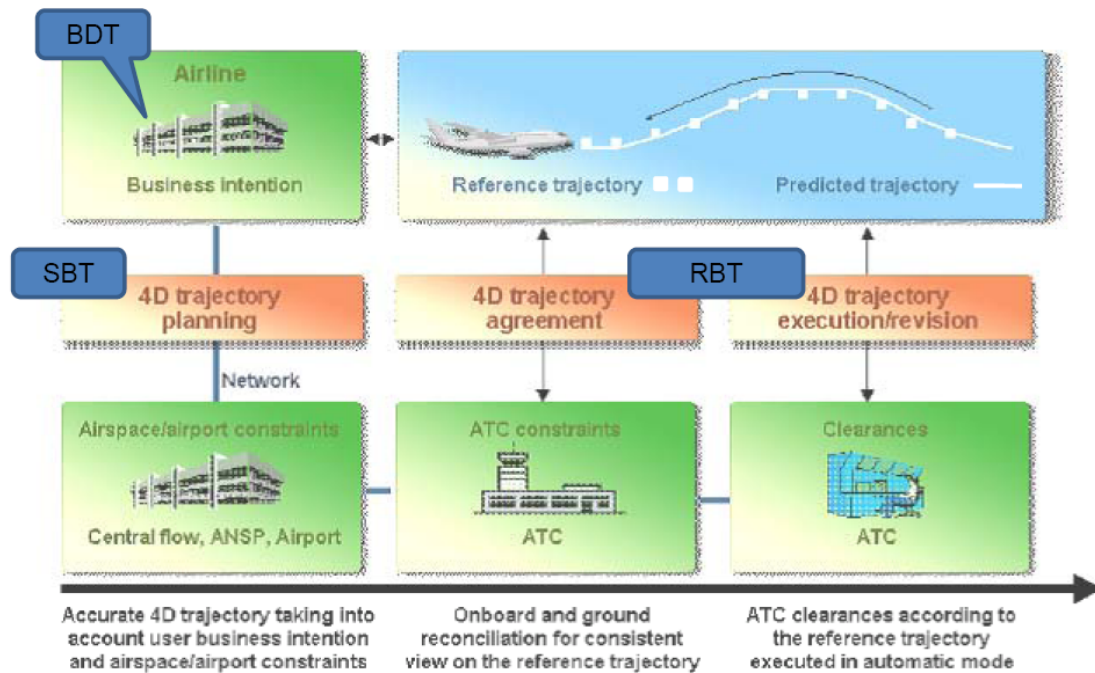


Figure 3-1: Trajectory lifetime [15]

The RBT is then cleared segment by segment by air traffic control (ATC) for the ground part of the trajectory as well as the airborne part. In Figure 3-1 and Figure 3-2 the trajectory lifetime and the different sections that arise from ATC clearances are represented respectively.

Sections of a trajectory can have four different statuses; they can be flown (executed), cleared ('authorized' in SESAR conventions), agreed and not-agreed. The last three will be referred to as ATC-statuses. Not-agreed means that there has not been a successful negotiation with ATC for (that part of) the trajectory. If a trajectory has been successfully negotiated, it is agreed.

Directly after take off the aircraft computes and downlinks an estimated time of arrival (ETA) and receives new required times of arrival (RTA) (up to destination) from ATC revising the RBT. Unexpected events such as adverse weather or traffic bunching can trigger a revision process of the RBT from the air (by the pilot) or from the ground (by the controller). A revision of the RBT is a collaborative decision making (CDM) process, iterating until both aircraft and ATC (and others actors) approve the new RBT. At the top of descent the aircraft downlinks an ETA together with an enhanced profile (e.g. continuous descent approach (CDA) or minimum noise) and for the last time the RBT is revised with a RTA by the ground.

From this point in the report the reader can forget about the BDT and the SBT because they are used before flight and this report treats in flight operations. What is important to understand is that a user preferred, commonly agreed and deconflicted trajectory is available before push-back.

In flight other trajectories may exist in the form of temporary trajectories that are used for various planning purposes, revision of the RBT, training or 'what if' situations.

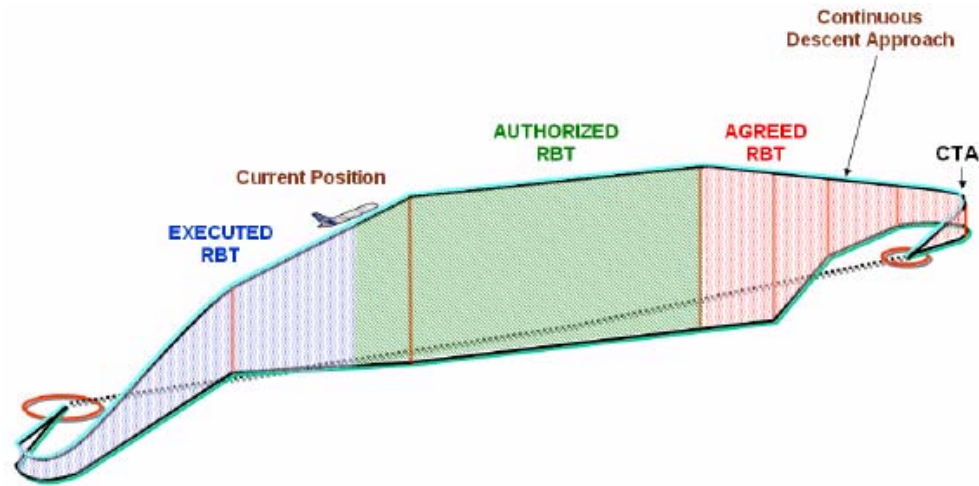


Figure 3-2: Schematic illustration of the different sections of a 4D trajectory [15].

3.1.3 Trajectory de-confliction

When required the RBT is pre-deconflicted conform to structured routes. Improved navigation performance makes it possible to define more air routes, while sharing intentions using RBT's allows deconfliction of the RBT in the planning phase.

The de-confliction of trajectories will focus on the dense airspace in the terminal manoeuvring area (TMA). Trajectories will be organized in fanned standard instrument departures (SID) and standard arrival routes (STAR). Aircraft will be dispatched on diverging pre-deconflicted SID's according to aircraft performance. Pre-deconflicted STAR's will converge as close as possible to the runway where flights are separated (sequenced) by different required times of arrival (RTA). Time is the only separation dimension possible on the merging point (runway threshold). This explains the importance of the time dimension in 4D-trajectories.

Initially routes higher in the TMA will be less constraint allowing aircraft to fly their individual optimum profiles (e.g. CDA), while routes lower in the TMA will gradually be narrower focusing on the runway. Cone-shaped routes are the result, which in 2020 will be 3D-tubes adapted to individual aircraft performances. Routes in TMA will be configured in such a way that sensitive areas like populated areas are avoided.

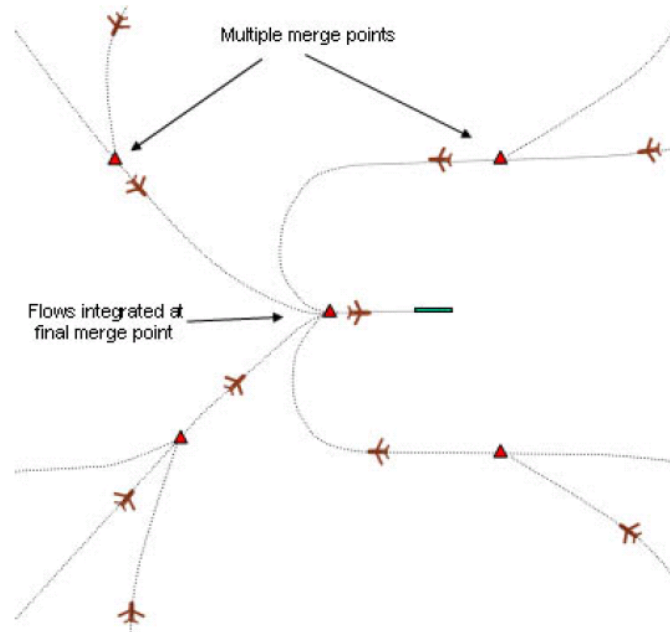


Figure 3-3: Merging of traffic streams, time is the only separation dimension at multiple merge points. [15]

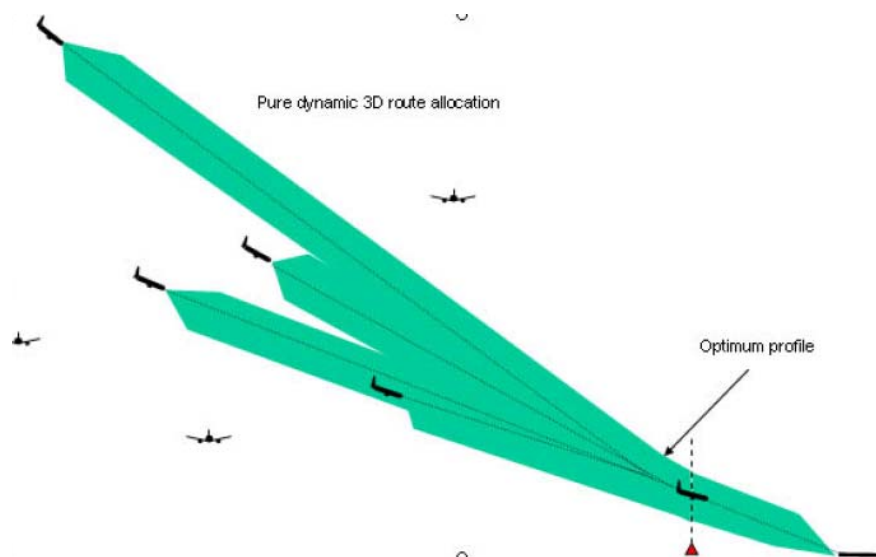


Figure 3-4: Optimum profiles in final approach described by 3D-tubes (within constraints) and time constraints. [15]

En-route traffic is separated according to its complexity. High complexity traffic may be managed by ATC like today using 2D routes with different assigned levels or 4D-trajectories. Routes may be fixed or dynamic depending on the situation of the operational environment. User preferred routing is applied to airspaces with low complexity. Users will be allowed to fly their optimum profiles, deviating only from their routes to achieve separation from traffic or other hazards. Separation may be delegated to the aircraft by ATC (see note about ASAS).

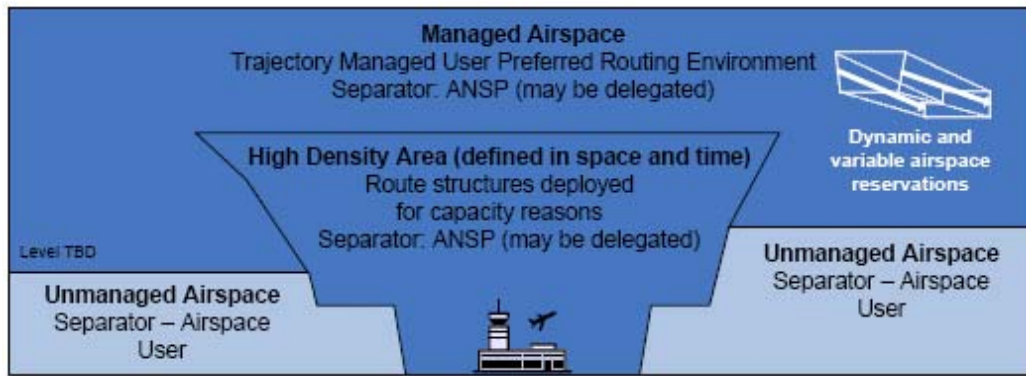


Figure 3-5: Overview of separation methods in different airspaces. [15]

A note about ASAS

ASAS stands for Airborne Separation Assistance System and is next to 4D the second main operational pillar of SESAR. It relies on inter-aircraft communications to cooperatively avoid other traffic in medium-term and – more important - perform cooperated manoeuvres. Four important development steps are:

2010: Air traffic situational awareness; display of traffic in the cockpit

2013: ASAS Spacing; automatic spacing with aircraft. Separation is responsibility of ATC.

2020: ASAS Separation; ATC delegates responsibility to flight crew under conditions.

2025-2035: ASAS Self Separation; The flight crew has the separation responsibility. (It will not be applied for scheduled flights in Europe)

ASAS is complementary to 4D trajectories. For example, aircraft are pre-sequenced at a merging point by 4D operations. From that point the aircraft perform an approach with a designated spacing between them. The needs for the ASAS function are addressed by other projects.

3.1.4 Revision and update

Air traffic is dynamic and therefore the need to update the trajectory during flight will be unavoidable. Two processes are defined, the revision process and the update process.

A revision process modifies the RBT and is executed if one or more waypoints or constraints in the RBT can no longer be attained. Events such as delays by adverse weather or traffic bunching can trigger the process, either from the air (by the pilot) or from the ground (by the controller). A revision of the RBT is a CDM process, iterating until aircraft, ATC and other actors approve the new RBT. In the revision process the RBT is thus altered and shared with relevant actors.

It is important that the negotiation of a revision converges in a short amount of time. The flight crew is allowed to express their preferred trajectory to facilitate this, but the ATC retains the final authority.

An aircraft will never exactly fly the RBT and the predicted trajectories changes continuously. As long as the predicted trajectory does not miss waypoints or constraints there is no need to initiate a revision process. However, if the predicted trajectory exceeds certain predefined thresholds an update process is started to share the latest predictions. Predictions will be known by the aircraft more precisely than by the ground. In order to enhance separation the predicted trajectory is continuously and automatically computed by the FMS and repeatedly downlinked to the ground where it is shared with relevant actors. This is known as the update process.

Examples of both processes are illustrated in Figure 3-6. A revision thus changes a reference trajectory, while an update changes the predicted trajectory.

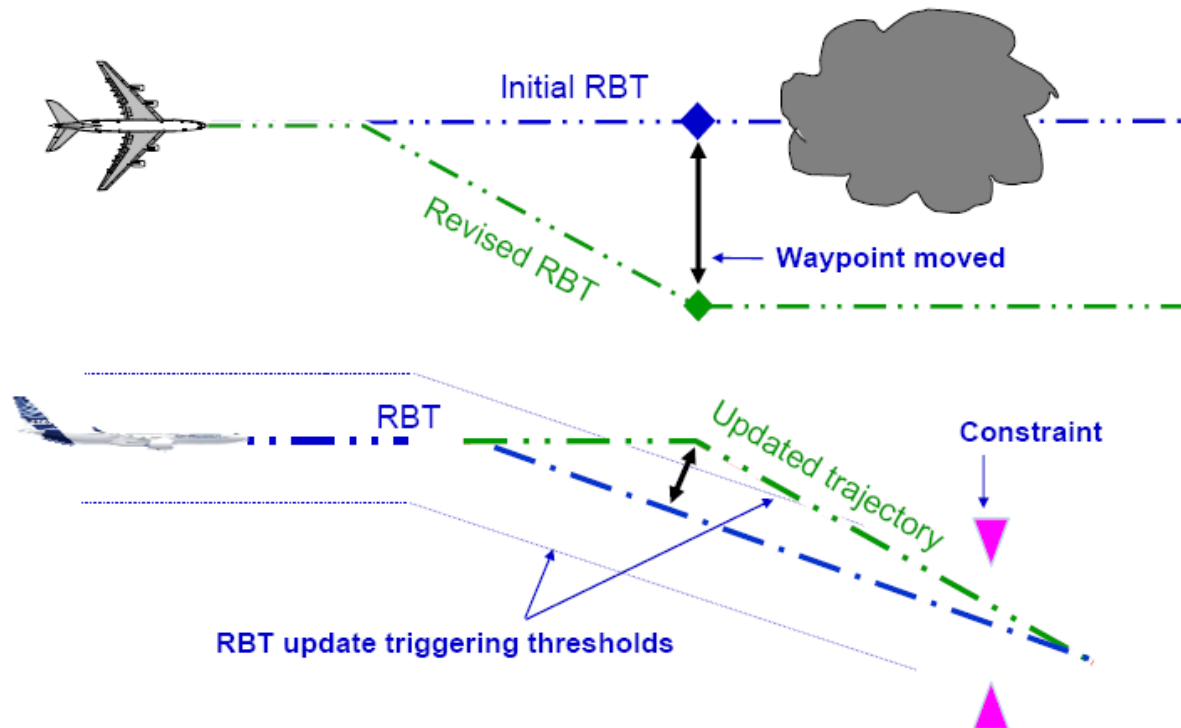


Figure 3-6: A revision (top) and an update (bottom). An update is the same as the predicted trajectory and does not alter the RBT (no waypoints or constraints modified).

3.1.5 Scenarios of operation

Two scenarios are presented that illustrate the management of 4D-trajectories from an airborne point of view.

Normal Operation

The 4D-trajectory is downlinked from the airline company to the aircraft and just before push back it is updated with the latest information about weather, taxi routes, departure runway and departure route. The aircraft is now the primary source of the RBT. When the takeoff time is known with sufficient accuracy the first part of the RBT (including taxi route) is cleared by ATC and the aircraft takes off. Directly after takeoff the aircraft downlinks the Predicted Trajectory (PT) updated with the actual take off time. Along the way consecutive parts of the RBT are cleared successively. Once the aircraft enters the horizon of the airport's arrival manager (about one hour prior to landing) it receives a confirmation of the estimated time of arrival (ETA) as a required time of arrival (RTA) from ATC. The pilots make sure that the aircraft is following its RBT and meets route, altitude and time constraints. The PT is continuously computed by the FMS and is automatically downlinked to ATC. At the top of descent (TOD) the aircraft downlinks a final ETA together with a continuous descent approach (CDA) profile. This is the last moment that the RBT can be revised without compromising the CDA. After final approach the aircraft lands, takes the optimal runway exit and follows the taxi route to the gate.

The revision process

A patch of adverse weather may prevent an aircraft in flight to fly the intended route described by the RBT. The flight crew analyses the situation and modifies the RBT so that the adverse weather is avoided. The implication of the modification is that the anticipated RTA is no longer attainable. The modified trajectory is sent to ATC, which finds that the downlinked ETA does not fit in the arrival sequence. A constraint (RTA) is imposed so that the ETA fits in the arrival sequence. The trajectory has been altered and is negotiated with the flight crew. They agree to the modifications in the lateral trajectory (origin of the pilots) and the new RTA (imposed by ATC). The new RTA is quite a time later and the FMS reacts by giving a lower speed command to the autopilot once the RBT is activated.

A little while later traffic bunching causes the ATC to issue a new flight level. ATC modifies the RBT and sends it to the flight crew. After analysis the flight crew agrees with the proposed flight level change and a new predicted trajectory is sent to ATC. The revised trajectory means that the aircraft has to fly faster to attain the RTA and the FMS adjusts the speed accordingly. This revision is illustrated in the figure below.

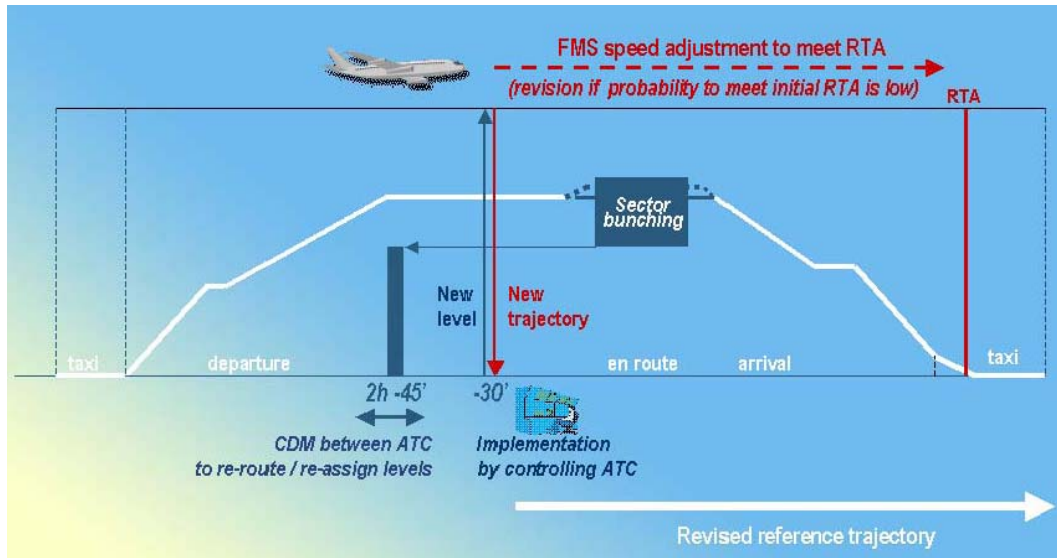


Figure 3-7: Schematic representation of a revision initiated by ATC because of traffic bunching. [15]

3.2 The impact of using 4D-trajectories

It is important to know the fundamental changes with respect to conventional operations, because it leads to a better understanding of the concept and how the pilot task will change. In this section key properties of 4D-trajectories are presented that should give a clear understanding of the impact they have. It is assumed that readers are somewhat familiar with current vector based operations. SESAR formulates the impact of the use of 4D-trajectories as follows [14]:

The introduction of 4D-trajectories in the cockpit imposes the move from partial trajectories - segments that are produced and used independently - to a shared trajectory including the surface part. In addition the trajectory is managed and shared during both the planning and execution phase.

And the important properties are:

- The use of an integral gate-to-gate trajectory instead of segments
The 4D-trajectory is handled as a whole. It exists before pushback and serves as a reference throughout the flight. Revisions are kept to a minimum. A revision to a part of the trajectory will influence the trajectory as a whole (notably time).
- Long-term constraints and predictions of the 4D-trajectory are much more precise defined
The horizon of established flight information of the 4D-trajectory is much larger than of today's flight plans. 4D-trajectory development and operations are pro-active instead of reactive: e.g. at the moment of takeoff the RTA at the destination is actively defined. More accurate predictions of future situations allow earlier strategic deconfliction and reduce the need for trajectory revisions. 4D-trajectory based operations are thus strategic.
- Improved time information and the use of target times
Today's flight plan contains limited time information. Instead of one RTA, 4D-trajectories (in 2020) will have multiple time constraints, which are precisely defined. Time constraints linked with distance information result in required speeds, creating a speed-profile that is a priori determined. It is time constraints that control speed settings and not speed settings that control the time of arrival. This change is important, because time is the only

separation means on merging points and airway crossroads. More than any other dimension it is time that fuses different parts of a trajectory to one entity.

- Improved vertical information
Today's flight plan contains limited altitude information. 4D-trajectories enables enhanced vertical profiles to be flown that allow fuel efficient and environmental friendlier flights.
- Integration of surface and airborne navigation
The 4D-trajectory extends from gate to gate, so information about surface navigation is incorporated in the trajectory. This includes among others takeoff times, taxi routes and gate allocation. Information about turn-around activities can link 4D-trajectories of consecutive flights, increasing coordination and expanding prediction horizon for short-haul flights. 4D-trajectories support air-ground continuity. Ground operations are not further discussed in this project.
- Improved ATC communication
Segments of the 4D trajectory will be cleared successively like in conventional operations. Negotiation with ATC is an integral part of the revision process. In a revision the entire trajectory will be negotiated instead of flight levels and headings. The extensive use of datalink means that a modified trajectory is sent to ATC before activating it. Extensive revisions will be done on the ground between airlines and ATC (and other actors) and then uploaded to the aircraft. The airborne predicted trajectory is shared automatically with the ground in the update process.

3.3 Other 4D concepts

3.3.1 PHARE

In 1989 Eurocontrol and partners from Germany, France, the Netherlands and the UK launched the 10-year Programme for Harmonized ATM Research in Eurocontrol (PHARE). The purpose was "to organise, co-ordinate and conduct – on a collaborative basis - studies and experiments to demonstrate the feasibility and benefits of a future air-ground integrated air traffic management system in all phases of flight" [8].

PHARE is the predecessor of SESAR and the operational concepts are therefore very similar.

The operational concept of PHARE features 4D-trajectories as a moving box to describe each aircraft's present position and intentions. It can best be compared with the full-4D principle of SESAR.

Although PHARE has been an important demonstration of collaboration and innovative technology that has paved the way for further development of the ATM (SESAR), the objectives of PHARE were not fully achieved. PHARE did not prove the operational concept in the sense that no increase in capacity has been demonstrated. Contrary to the airborne part which was considered successful, difficulties were encountered in the operation of the ground part of the system. Some examples are a shift in workload due to a more planning-oriented working method, the need for exception handling (e.g. due to unequipped aircraft) and human factors associated with increased automation. PHARE did not demonstrate the use of gate-to-gate trajectories, as was originally intended.

At project level valuable lessons were learnt concerning collaboration. It turned out that individual interests of actors in some cases were more important than the common interest. An important conclusion for future work was that collaboration must be truly collaborative were all actors pursue the same goal.

In that aspect SESAR has evolved significantly; virtually all stakeholders are involved to form what is called SESAR joint undertaking. It consists of global (not only European) actors from public and private sectors, including industry, that share the cost of investment for a new ATM system.

3.3.2 NextGen

The equivalent in future ATM implementation of SESAR on the other side of the Atlantic (US) is called NextGen for 'next generation air transportation system'. Originally being based on the distributed air-ground traffic management concept that relied in some extent on self separation,

recent evolutions bring NextGen and SESAR operational concepts closer to each other. Certain important differences remain however:

- Implementation horizon (2025 vs. 2020)
- SESAR copes with segmented ATM structure
- NextGen is more comprehensive (environment, security is integrated in the concept)
- It seems that NextGen is more advanced concerning weather; centralized weather acquisition and provision is part of NextGen, where this is outside the scope of SESAR.

A more exhaustive and detailed list of differences between SESAR and NextGen can be found in [18]

Major challenges for NextGen are identified to be the reliability of the network structure on which it relies, the collaboration between different actors and securing funding for the ATM system development. [17]

3.4 Airborne operational requirements for 4D operations

An aircraft must be capable of flying a trajectory in a safe (conflict free) manner according to concept conventions. The requirements to do this in the 4D-operational concept are mainly determined by an increase in performance requirements in fields of communication, navigation and surveillance (CNS). Technical advancements in these fields have been the enablers for the concept in the first place. The functional requirements are determined for communication, navigation and surveillance - with a focus on navigation - and will be elaborated in the next chapter. There also the novelty of each function with respect to current operations is evaluated.

The aircraft (including pilot) must be able to:

Navigation

- Determine position of own ship
- Generate and hold one or more RBT
- Determine predicted trajectory (long-term)
- Guide itself along the RBT.
- Revise RBT if necessary

Communication

- Treat clearances from ATC
- Negotiate RBT (as one entity)
- Update (and receive) predicted trajectory to other actors

Surveillance

- Predict and detect hazards and obstacles
- Ensure separation and spacing (using intentions of other actors if available)

4 Identification and analysis of the pilot task

One of the key features of SESAR's target concept of operation is that the human is at the centre. The goal is that in this way the best of both the human and automated world is exploited. In the concept humans are aided by more automation to cope with increased complexity. The goal of this chapter is to identify function and information requirements.

In section 4.1 the important and novel tasks to be examined for 4D are determined. This is done by first eliminating the operational requirements that don't involve any pilot action and those that are outside the scope of this report. Secondly a task description is given for pilot and automation together (called operational task) according to the operational requirements. A selection of novel tasks will be made that are impacted by the operational concept and thus important for this report.

Subsequently an analysis of these tasks will be performed by determining the pilot task and thus the boundary between automation and human. This is used to identify the required functions of the HMI. The resulting pilot task is analysed further to obtain the required information to make informed decisions. The functions and information together are the requirements for the HMI.

The last section of this chapter treats the feedback of pilot consultations. The requirements obtained in section 4.2 are validated and additional pilot needs are identified.

4.1 Identification of operational task

4.1.1 Pilot involvement

If the operational requirements are investigated for pilot involvement, a high level task description is generated. This leads to the following high level task requirements:

The pilot must be able to:

Navigation

- Initiate and handle one or more RBT
- Guide the aircraft along the RBT
- Revise RBT if necessary

Communication

- Treat clearances from ATC
- Negotiate RBT

Surveillance

- *Ensure separation and spacing (outside scope)*

Positioning and trajectory prediction involves very limited pilot action and is not included in the pilot task. The same goes for the update process, which is the entirely automatic downlink of the predicted trajectory to the ground. In the surveillance domain, the prediction and detection of hazards and obstacles is also done by automated systems.

'Initiate and handle' covers better the pilot task than the term 'generate and hold' used for operational requirements, because the pilot is actively involved in handling trajectories and initiation can be done by loading or construction.

Separation and spacing were considered to be beyond the scope of this project and are therefore featured in *Italic font*.

Relation with SESAR task definition

In the SESAR target concept description [15] a definition of the pilot task is given as well:

- Conduct flight according to RBT and applicable rules. This is the primary function of the pilot.
- Modify the RBT if required.
- *Assure separation.*
- *Avoid collision.*
- Optimize queuing. (In other words: achieve RTA)
- *Plan trajectories.*

Here the items in *Italic font* are beyond the scope of this project. ('Plan trajectories' is only applicable to general aviation pilots.) The entry 'Conduct flight according to RBT and applicable rules' corresponds to all navigation and communication tasks in the high level task requirements. An exception is 'Revise RBT if necessary', which is covered by 'Modify RBT if required'. Further comparison yields that the only discrepancy is 'Optimize queuing', which is added to the pilot task.

The RBT plays a central role in the pilot task. When a focus is put on the RBT, the pilot tasks can be expressed in one concise phrase:

Monitor, manage, share and optimize the RBT

In which they are arranged as:

- | | |
|------------------------|-----------------------------------|
| - Monitor | (watch out for abnormalities) |
| - Manage | (follow the appropriate RBT) |
| o Initiate | (start a RBT if not present) |
| o Handle | (organise existent trajectories) |
| o Revise | (change the active RBT) |
| - Share | (get approval of ATC) |
| o Treat clearances | (obtain guarantee of safe flight) |
| o Negotiate trajectory | (obtain an agreed trajectory) |
| - Optimize | (ensure smooth total operations) |

The term 'guide' can be replaced by 'monitor' when the assumption is made that the FMS guides the aircraft. This assumption has already been indicated in the previous chapter and will be elaborated later on. Note that the terms 'manage' and 'share' coincide with the definition in the problem description.

4.1.2 Operational task description

In the figure below the pilot tasks and the relationship between them are illustrated. Monitoring and handling are tasks that are performed continuously. Under certain conditions a clearance request is issued, a new trajectory is initiated or a revision is started. The first two are quite straightforward, but the revision task is more complex and incorporates the greatest novelties. It is therefore divided in sub-tasks that include negotiation with ATC. The boundaries between the sub-tasks are not always unambiguous; the layout is therefore clarified in this section.

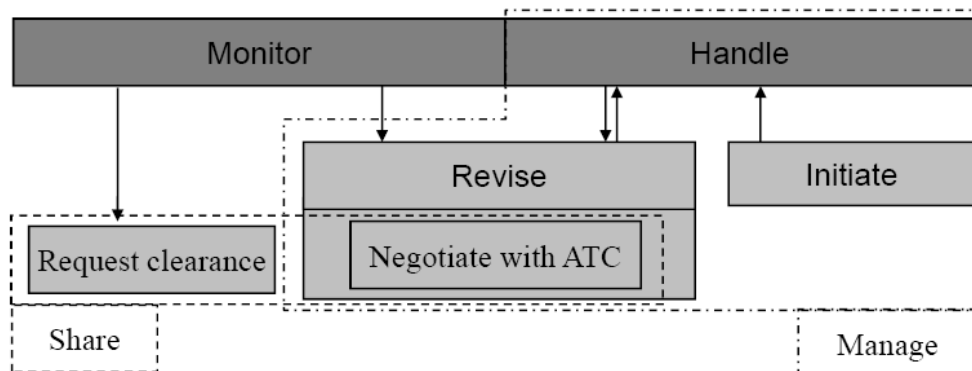


Figure 4-1: Schematic representation of the pilot tasks. Dark grey blocks represent continuous tasks.

Monitoring the 4D-trajectory

Monitoring is continuously checking the progress along the active RBT and watching out for any abnormalities that endanger following the RBT. This means that it has to be checked if:

- Hazards and conflicts are avoided
- The destination can be reached safe and economically according to the RBT
- The clearance limit is not crossed

If one of these conditions fails an action has to be undertaken to resolve the issue, for example a revision of the RBT. Automation will play a significant role in monitoring, but the pilot will still be the authority that verifies correct functioning of automation. The monitoring task is affected by 4D-operations and elements of the monitoring task will be important during revisions.

Managing the 4D-trajectory

Managing consist of 3 parts: initiation, handling and revision of the 4D-trajectory.

Initiation

Before a trajectory can be flown, it has to be available in the cockpit. The pilot can initiate the RBT in two ways. Normally the RBT is loaded from the airline company to the FMS using portable data storage or datalink. This is always done before push-back, but can also be done during flight in certain situations. Secondly the pilot can construct a trajectory manually with the aid of the FMS. The initiation of a trajectory is affected by 4D operations (e.g. negotiations of departure information and the update of the trajectory with last-minute information). However, an Airbus project dealing with ground operations is also charged with this subject [31]. This means that initiation is not interesting for further research.

Handling

The tasks handling trajectories comes from the fact that multiple trajectories exist. In the ideal situation no revisions are necessary and only the original RBT is needed. However, temporary, alternative and ATC trajectories exist to accommodate revisions and analyse 'what if' situations. Furthermore, RBT of previous or subsequent flights can be loaded as well. All these trajectories have to be identifiably ordered according to their intended use. Activation of a trajectory is considered to be a part of trajectory handling. Handling is different to revision, because handling treats the trajectory as one entity.

Revision

If the situation demands it the pilot must revise a trajectory. This situation is identified by the monitoring task. A revision is performed on the active trajectory, resulting in a revised temporary trajectory that is negotiated with ATC. As is explained in chapter 3, negotiation is part of the revision process. Due to its importance in 4D-operations it is discussed separately in the section 'Negotiation'. If a negotiation is successful, the pilot has to activate the trajectory. Although activation is considered part of the handling task, it ends the revision because at that point the aircraft is guided along the revised RBT. This explains the arrow from the revision task to the handling task in Figure 4-1.

Three different phases are distinguished in the revision process:

- Identify the possibilities for an alternative trajectory
- Modify the trajectory
- Check the result of the trajectory modification

In practice the three different phases described above are executed quasi-simultaneously. Yet each phase corresponds to a particular function that is distinguishable and helps understanding the revision task.

Sharing the 4D-trajectory

Clearance request

In 4D-operations a clearance is a property of the RBT instead of being a property of airspace. Although this is a significant difference, the mechanism of exchanging clearance will not change much. Clearances from ATC repeatedly update the previous clearance of the active trajectory. Updating a clearance remains to be confirmed by the pilot to assure awareness. Normally consecutive segments are cleared by ATC before the clearance limit is reached. If this is not the

case a pilot requests an authorization from ATC. Communication is via datalink, but voice communications remain available. Datalink communications have been the subject of [30], see chapter 6. The limited impact of 4D-operations on the sharing of clearances and the previous effort on this subject means that this subject is not further treated.

Negotiation

Negotiation is a process that has as goal the agreement between all relevant actors that a certain (revised) trajectory becomes a new RBT. Negotiation starts when either the pilot or ATC proposes a trajectory revision. The negotiation process consists of an exchange where pilot and ATC alternately send a (modified) trajectory until a proposal is accepted by both parties. In Figure 4-2 negotiation is linked to the phase 'checking results' of negotiation, which is in fact the same as examining a proposal from ATC and thus used in both the modification loop and the negotiation loop. Being an integral part of the revision process, negotiation has a large impact on operations and is one of the important aspects of this research.

Optimizing the 4D-trajectory

It is up to the pilot to ensure the optimum trajectory according to a certain company policy. Optimization of trajectories is embedded in other tasks and will not be discussed separately in the remainder of this report. It is important to understand that although the 4D-trajectory is a user-preferred trajectory, the goal is to optimize the entire ATM system. This corresponds to the description of the pilot task by SESAR: optimize queuing or achieve RTA.

In the next section we will concentrate on the important aspects (impacts) of the operational concept.

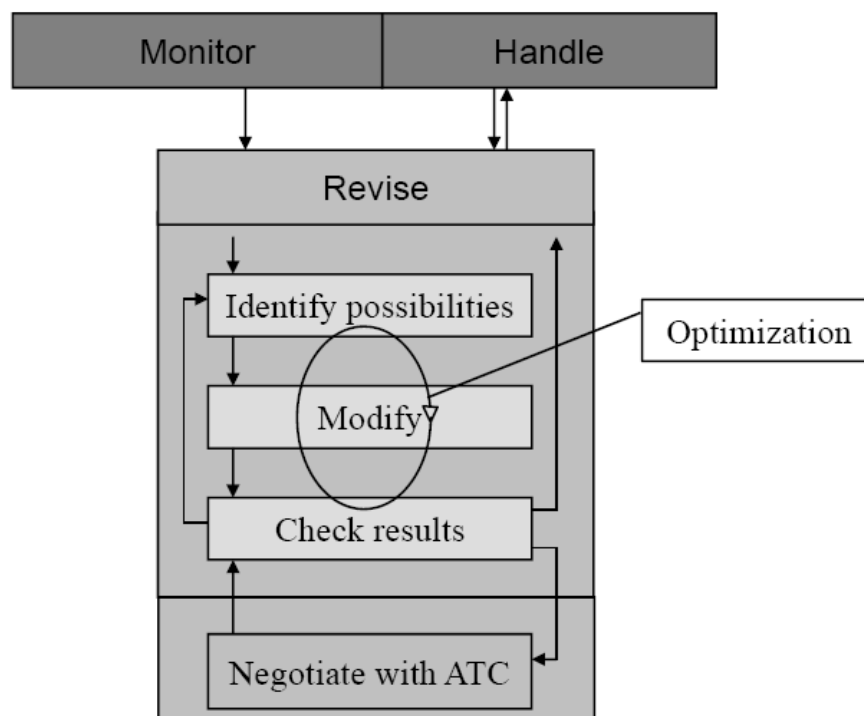


Figure 4-2: Important and novel tasks: revision is divided in three sub-tasks.

4.2 Pilot task analysis

In this section the pilot task will be distilled from the operational task described in the previous section by examining the boundary between automation and human. This will lead to the required functions of the HMI. By examining the decisions the pilot has to make, the required information is determined.

4.2.1 Monitoring the 4D-trajectory

The important decision when monitoring is whether to initiate a revision. The RBT has to be revised if it is no longer *conflict-free* or if it is no longer *valid*. Not being conflict-free means that there are hazards that inhibit the proper follow-up of the trajectory. If a trajectory is invalid, attaining all waypoints and constraints is beyond the performance capability of the aircraft. A trajectory is also invalid from a business perspective if it does not meet business objectives.

In order to assess the level of automation the different causes for a revision are elaborated below.

Assure conflict-free trajectory (Detect hazards)

Four different types of hazards are distinguished:

- Terrain
- Traffic
- Weather
- Restricted Airspaces

Recall that the RBT is used for long-term navigation. Avoiding any short term conflicts is not of interest here, because that does not change the RBT. In such cases priority is to avoid the conflict and not to revise the trajectory. Examples are ACAS (TCAS) and TAWS (EGPWS) resolution follow-ups. If the RBT is defined and followed properly by all airspace users, short-term conflicts do not occur.

Terrain

Terrain is static for air navigation applications, which means that 4D-trajectories can be deconflicted a priori with the aid of a well-defined terrain database. For the execution of the flight it holds that there is no threat from terrain if the trajectory does not change. The case that the trajectory does change will be discussed in section 4.2.3.

Because the de-confliction is handled by automation and no revision is caused by terrain, there is no pilot task associated to terrain hazard monitoring in the framework of 4D operations.

Traffic

Traffic is first and second order dynamic. Being first order dynamic means that the hazard changes in time and being second order dynamic means that the predicted change of a hazard changes in time. In fact, aircraft in flight have to move to stay in the air and thus cannot be static. The RBT's of other traffic are known and thus the majority of traffic can be deconflicted in advance. The changes of RBT's linked with being second order dynamic can be strategic or tactical.

Any conflicts that arise from strategic changes of RBT's are deconflicted in the same way as pre-flight deconfliction under responsibility of ATC. The result is a revision initiated by ATC. This kind of revisions often occurs because of traffic bunching at airports, which needs to be resolved system wide. No information or functions are associated with traffic monitoring, the pilot must only be aware of trajectory receptions from ATC.

A note about ASAS

Tactical (medium-term) traffic avoidance will sometimes be assured by en-route and approach operations as defined by the ASAS concept. In that case ATC delegates the responsibility of traffic avoidance to the flight crew in a certain airspace. Any changes to the trajectory result in an update of the trajectory and not a revision as long as constraints (especially time) are not missed. If time constraints are missed a pilot initiated revision follows. The pilot tasks associated to ASAS are not treated in this project.

Weather

Weather is second order dynamic; weather changes constantly and predictions change as well (mainly because they are inaccurate). The RBT is pre-deconflicted as much as possible before flight, but because of its dynamic nature weather conflicts will occur. Adverse weather will be one of the major causes for pilot initiated revisions.

With the available information, automation can detect conflicts with weather, but not in all cases. If a conflict is detected automatically the pilots need only to be informed. However, to avoid elements that hardly can be detected by radar (e.g. dry air turbulence) the pilot needs to interpret clues from weather data. This issue is elaborated in chapter 5.

The RBT has to be revised if it traverses a patch of adverse weather. To detect this, first of all the information about the RBT has to be available. Important information is waypoints and linking segments together with time and altitude constraints. Secondly, boundaries of adverse weather in 4 dimensions have to be known. 4 dimensions because it is important to know the situation at a certain position when aircraft will be there, in other words predictions are necessary as well.

Restricted airspaces

Restricted airspaces are only first order dynamic; they change in time, but these changes are well defined. 4D-trajectories are thus pre-deconflicted from restricted airspaces in the planning phase and the pilot will not have to initiate a revision caused by airspace conflicts.

Assure a valid RBT (safe and economical reach of destination)

An RBT is no longer valid if at least one waypoint or constraint cannot be attained or if business objectives are not met. Normally all waypoints can be attained, except if obstructed by a hazard (see above) or if not enough fuel is available (see business objectives).

Missed constraints

It is assumed that the aircraft is flown in *full-managed mode*, which means that the aircraft is guided along the RBT by the FMS. This assumption is valid because it is inherent to 4D-operations; it is the FMS that calculates the trajectory between waypoints and constraints with a performance that humans cannot equal. Nevertheless constraints can be missed, because of trajectory modifications or the influence of unpredicted winds.

The assumption of full-managed flight has an important consequence. If a constraint is predicted to be missed, it means that the aircraft is not capable of reaching that constraint, because aircraft performance limitations are known by the FMS. The condition 'At least one waypoint or constraint that cannot be attained' is thus equal to 'at least one waypoint or constraint is missed'.

Indications of missed constraints are required in order for the pilot to initiate a revision.

Business Objectives

It is up to the pilot to initiate a revision when business objectives do not match business properties. However, it may not always be possible to meet business objectives. Business objectives are company imposed targets often closely related to costs.

Business properties are a function of the properties of the entire RBT and additional information. Arrival time and fuel use are important parameters because they are strongly related to operating costs. The role of automation is to process the available information – trajectory properties and other information - and present it in a format that is easy to comprehend. This format should be such that it is easy to weigh against business objectives, so that decision making is easy for the pilot.

The information presented to the pilot must be sufficient to make a well-informed decision. To determine what sufficient means is not an easy task, because there is no way of assuring whether the presented information is complete. Even the information available might not be complete, so that a different decision is made than if this would be the case. Fortunately history and experience of airline operations (business!), cockpit design and ATM provide a strong indication what sufficient information is to make acceptable decisions.

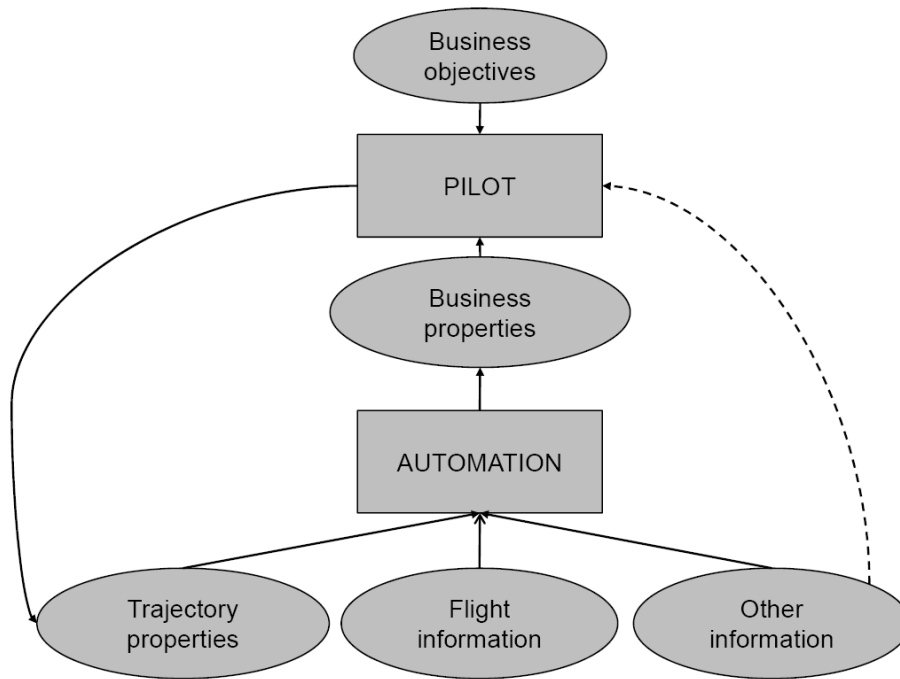


Figure 4-3: Schematic representation of Pilot and Automation and information exchanges related to business properties between them

In the figure here-above a schematic representation is given of the positions of pilot and automation tasks. Consider the following simplified example: A business objective of the pilot is to keep maintenance costs at an acceptable level. One of the associated business properties could be engine and brake wear, which is dependent on the trajectory property braking distance (runway length and runway exit) and other information about runway conditions (e.g. dry or wet). According to the presented business property the pilot can decide to change the trajectory (increase runway length for example).

Automation can integrate business properties to the level that they can be directly compared to business objectives. In the example given above, the maintenance or even overall costs can be determined by integrating more relevant data. Because the business properties are valuable information about how to change the trajectory, the detail level must be well chosen. Raw information will still be important to base decisions on.

If the detail level is such that business properties are comparable to business objectives, automation could also determine whether business objectives are met. This is only possible if these business objectives are (or can be) inserted in the automated system by the pilot, because the pilot knows the business objectives. This issue is elaborated in section 4.3. The pilot remains responsible for changing the trajectory.

Before initiating a revision, the pilot needs to know if a revision yields success from a business perspective. Every RBT has been initially defined according to certain business objectives and unless these business objectives or circumstances have changed, there is little opportunity for optimization and no need for revision. Else, it is unlikely that automation will be able to determine a priori if a revision yields success; this will be elaborated in the next section 4.2.3 (identifying possibilities).

Clearance

The second decision a pilot may have to make is when to request a clearance. A clearance request is necessary if the aircraft already has or is about to cross the clearance limit. It has to be indicated to the pilot when this happens.

4.2.2 Handling the 4D-trajectory

Handle

The trajectories stored in the FMS have to be ordered in terms of usefulness for future use. Origin-destination pair, source and time of creation are fundamental information to sort and identify

trajectories. Besides the trajectory type should be clear (e.g. alternative, active). Sorting is easily done by automation if the right parameters are known. Trajectories that are not used anymore can be deleted. The decision to delete a trajectory can be based on the same information as used for sorting trajectories, but more details like business properties may be needed.

Activation usually follows a successful negotiation and normally only agreed trajectories are concerned. Not-agreed trajectories also qualify for activation, but under responsibility of the pilot. The ATC-status of trajectory segments has to be available.

4.2.3 Revision of the 4D-trajectory

Identifying possibilities

Identifying possibilities is similar to the monitoring task, but with a big difference: all alternative trajectories in the entire 4D space have to be examined instead of only the RBT. Because the operational concept defines negotiation with ATC, it is not possible to find the best possible trajectory using airborne tools only (see also 4.3). The goal of this phase is to find *conflict free* and *valid* trajectories given new circumstances.

Conflict free

To identify conflict free alternatives the space (and time) between the actual position and the location where the original RBT can be joined is analysed for possible hazards.

As has been laid out in section 4.2.1 weather is the important factor for airborne initiated revisions. Terrain and restricted airspaces are well-defined so trajectories can be easily de-conflicted by automation (see section modification (4.2.3)). Separation with traffic is assured by ATC imposed constraints and is treated in the section negotiation (4.2.4).

Identification of an alternative trajectory free of adverse weather could be done manually or automatically.

Manually means that the pilot assesses the situation and determines the best way to avoid adverse weather. The pilot bases his actions on weather data available in the cockpit. Besides it is important to have more information about the hazard that caused the revision, e.g. location, size and severity. The strong point of manual identification is that the pilot is actively aware of the entire process. On the down-side, the process is slow and takes a lot of pilot attention. Furthermore humans have difficulty assessing all 4 dimensions at one time and this can hinder finding the best trajectory.

Three levels of automation are distinguished:

1. Proposition of pre-defined routes from database
Automation identifies possible trajectories along existing routes and checks if they are conflict free. The best candidates (according to business properties) are subsequently proposed as alternative. The pilot verifies and selects the proposed trajectory and continues with the revision. The proposition of segments is under study for the A30X (see also 5.1)
2. Proposition of deconflicted routes (automatic trajectory construction)
Automation calculates new routes conflict-free of hazard zones and proposes them as alternatives. They are not restricted to existing routes and should yield better results. The pilot verifies the proposed trajectory and continues with the revision.
3. Revision of deconflicted routes
Automation calculates one new route conflict free of hazards zones. In the hypothesis that the new trajectory does not contain errors, there's no need for verification by a pilot. The route is accepted and the revision is continued. This opens the door to autonomous flight.

Based on specialist consultation it is assumed that automatic de-confliction from weather *will not be available in the A30X*. This assumption will be elaborated in chapter 5 and 8.

This means that automation levels 2 and 3 will not be considered for HMI in this report (see also chapter 8). Alternatives that are restricted to existing routes do not provide the required flexibility for a revision. Therefore manual identification remains important.

The revision process consists of identification, modification and result checking. An important consequence of manual identification is that the HMI must support every phase of revision iteration. The pilot may want to effectuate some modifications in order to memorize successive steps and to assess the impact of individual modifications on the trajectory. Iterations go on until a suitable alternative is found.

Valid

No missed constraints

The changes necessary to yield a conflict-free trajectory may cause the trajectory to be no longer valid. For example if a detour is made to avoid a thunderstorm and the RTA can no longer be met. In this case the next opportunity (e.g. new RTA or new Flight Level) for the missed constraint must be known. Because imposed constraints are often determined by traffic (especially near airports) these opportunities are dependent of ATC. The concept of operation does not support on-board and direct availability of all constraints and thus all alternatives. This issue is discussed in section 4.2.4.

The absence of ATC constraints has as a consequence that from airborne side only propositions for trajectory revision can be done without taking into account these constraints. Nonetheless the trajectory proposal needs to be free of missed constraints and thus involves deleting missed constraints. To decide what constraints to delete, the reason that the constraint has been imposed must be known, which is related to the source of the constraint. Besides a coherent view is needed of both altitude and time constraints. This allows the flight crew to examine which constraint is most stringent and get an idea of what the impact is of deleting it.

A solution can be to delete all the constraints in the trajectory upon revision. This is however not desirable, because the goal is to keep most of the a priori defined constraints (if viable).

Business objectives

Finding possibilities for business objectives is essentially optimization. Automation optimizes business properties within the envelope defined by the trajectory (Automation can modify altitude and speed profiles, but not the trajectory itself). For example it optimizes braking power according to braking distance and runway conditions.

Automation will not automatically optimize business properties by modifying the trajectory itself, because automatic trajectory construction is assumed not available and alternatives according to ATC constraints are unavailable. The pilot has to perform the translation from business properties to trajectory properties. Proposals of conflict-free routes can however be classified according to business properties.

Because the pilot changes the trajectory, the information available must be such that they allow the pilot to determine how to change the trajectory in order to find the optimum in business properties. The information available consists of the business properties and other information and this should be in the right detail level.

Cost Index in 4D operations.

In conventional operations the Cost Index (CI) is inserted by the pilot and used by automation to determine the (cruise) speed. The CI is thus not a business property, but a flight (automation) parameter that is expressed as the ratio between time and fuel related costs indices. It varies between minimum time (high speed) if time cost is high and minimum fuel (economic speed) if fuel cost is high.

In 4D operations, the required time of arrival is exactly known and the fuel use is optimized by the automation respecting the trajectory. There is thus no more need to insert the cost index, because the insertion of the trajectory constraints (time) replaces this function. Enhanced altitude/speed profiles, such as CDA or a steep approach, are specified by a set of constraints.

Modification

After suitable possibilities have been identified, the modification phase is entered where the actual modification of the trajectory takes place. In the case where trajectory identification is automated, (parts of) the modification can automatically be inserted in the alternative trajectory (after selection by the pilot). Automation of trajectory construction is limited to the proposal of pre-defined routes, of which the selectable options must be clear. To offer more flexibility in addition to pre-defined routes, manual modification of waypoints and constraints has to be possible as well. The FMS calculates the trajectory according to these waypoints and constraints.

The pilot should be aided in the modification by direct feedback of the item that is modified. Invalid entries should be signalled or even inhibited.

Two levels of feedback are defined:

- Feedback without effectuating a modification (direct feedback)
- Feedback after effectuating a modification (results of modification are assessed in checking results phase)

Concerning hazards, automation can only provide feedback for terrain. Feedback about hazards that are dynamic (at least first order) is possible under conditions. This is true for airspaces, weather and traffic.

Direct feedback of performance limitations is possible in some cases (e.g. inhibition of inserting a speed constraint below minimum speed). Any feedback of a modification that requires the (accurate) calculation of time is assumed not possible, because of calculation performance limitations (e.g. Feedback about whether RTA is achieved or the insertion of time constraints that require a speed beyond the maximum speed). Direct feedback about business properties is also not possible, because of the dependence of arrival time.

For the motivation of feedback capabilities see chapter 5.

Because direct feedback is not always possible and a modification thus has to be performed before being able to assess the impact, *modification is done in iterations*. A function to restore the modification is thus beneficial.

Check result of modification

In this phase three separate decisions are made:

1. Whether the previous modification is acceptable
2. Whether another modification iteration is needed
3. Whether the trajectory is to be negotiated or activated

Because revisions are iterative, each individual modification should converge to the targeted result aimed at. Feedback of modifications is needed, which consists of the impact of the modification on the *business properties*. This impact is represented by the difference in business properties before and after the modification. If not acceptable, the modification should be restored.

Secondly the pilot needs to decide if additional revision iterations are necessary. The information requirements for this decision are the same as for monitoring, with the exception that an alternative trajectory is concerned. This concerns a modified trajectory or one that originates from ATC. The pilot thus has to check whether this trajectory is conflict-free and valid. Trajectories from ATC will normally be conflict-free and do not contain missed constraints. For trajectories from ATC, the business properties are most important.

At this point decision has to be made whether the alternative trajectory is good enough to propose to ATC. This does not always mean that the trajectory complies with business objectives, but it should comply with the optimum given a certain situation. Because the optimum in business properties cannot always be established, this decision is the responsibility of the pilot. Recall that the goal is to optimize ATM system-wide.

The third decision is to activate or (re-)negotiate the trajectory that is verified to be conflict-free, valid and having the right business properties. This decision is dependent on the ATC-status of the trajectory. The fact that a trajectory is agreed before being cleared means that trajectories can have three different ATC statuses: cleared, agreed and not agreed. They can be present in a single trajectory at the same time. The flown part of the trajectory has a separate status.

4.2.4 Negotiation of the 4D trajectory

The decision of initiating a negotiation is taken in the checking results phase. If the modified trajectory is considered suitable for proposal, the entire trajectory is shared.

The goal of a negotiation is to acquire a new agreed trajectory. The proposal generated on board should be viable in that the possibility of the trajectory being refused is small, so that negotiation iterations are reduced. The minimum number of iterations is one because ATC remains responsible for separation. To be certain that a trajectory will not be refused all constraints imposed by ATC should be available on-board. In that case alternative trajectories can be created that comply with ATC-constraints. Sharing of constraints for alternative trajectories is however not supported by the operational concept of 2020 defined by SESAR [15]. The reasons for this are that operations are tuned by ATC as a central organism. ATC will assign different constraints to individual aircraft according to a system-wide optimization. Because aircraft cannot do this optimization distributed, traffic constraints are not available on-board.

ATC replies or initiates a negotiation (revision) by sending a trajectory. The pilot needs to decide whether to refuse or accept this trajectory. This is effectively the same as deciding whether another modification is needed in the checking results phase and the same functions and

information requirements apply. Of course the pilot has to be informed if an ATC trajectory is received.

There is however an issue: Because entire trajectories are shared, the modifications performed by ATC are not transparent to the pilot. The modifications the ATC has made must be presented to the pilot. Because these modifications are not always communicated [11], they are deduced from the dissimilarities between the received and the sent trajectory.

4.3 Validation of information requirements

Consultations are held to validate the required functions and information requirements to operate in 4D operations. Most were validated, but there have been some adjustments that are discussed in this section. These consultations have been conducted with one experimental test pilot.

Name trajectories

A function to name trajectories was desired as an aid to organize trajectories. The system should give a default name based on origin-destination pair, which can be renamed by the pilot. This is especially of interest for trajectories that are created with a specific purpose.

Business properties are not constraints

Business properties of a trajectory shall not be used as constraints. If (a part of) business properties (costs) are expressed as an absolute value, the danger exists that airlines will link business objectives with personal targets of pilots (e.g. via bonuses). Pilots may trivialize safety aspects in order to attain their personal targets. Therefore no absolute value associated to business properties can be introduced, because this could lead to deteriorated safety.

This operational need thus makes that the presented information is limited with respect to what is technically possible. Certain information is deliberately omitted or presented in less detail to the pilot so that the criteria for decisions less explicit.

Consequently, automation is not allowed to check if business properties (expressed at the level of business objectives) are attained by a certain trajectory. For illustration: The pilot can't insert brake wear (costs) and let automation tell whether this property is met (red arrows in the image below). Neither can brake wear cost be presented as absolute value, because pilots will try to not exceed a certain value in all situations, even if safety limitations do not allow this.

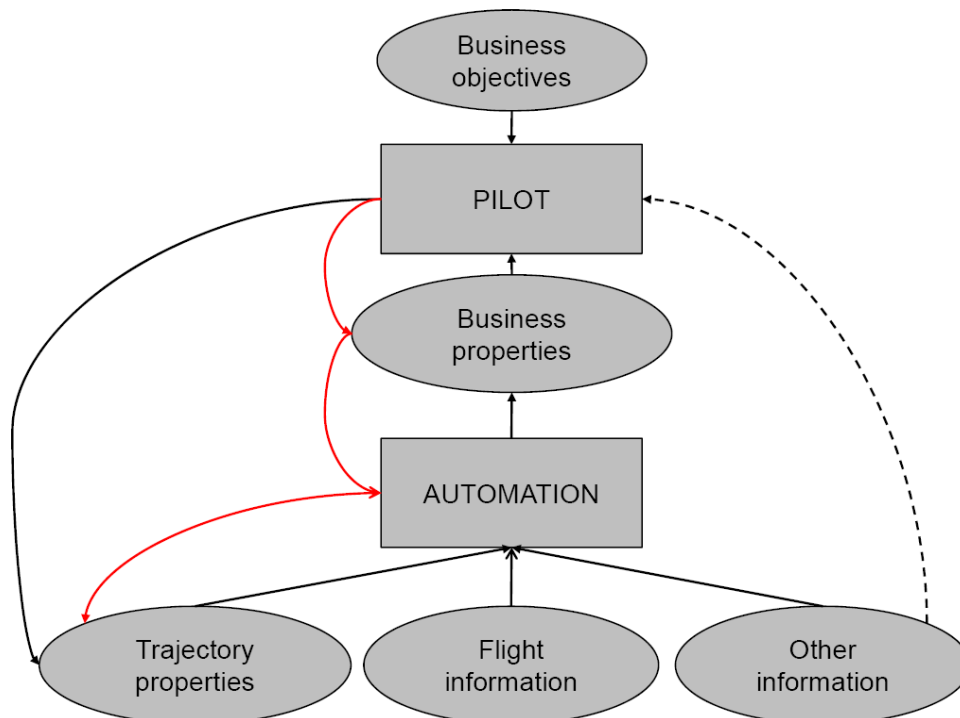


Figure 4-4: The same figure as Figure 4-3. The red arrow indicates the forbidden information streams.

Alternative Trajectories and Negotiation Status

With respect to negotiation with ATC the pilot expressed the need of two elements. The first was to have alternative trajectories according to ATC constraints available in the cockpit (see also 4.2.3). Knowing the possibilities of a trajectory revision, the number of negotiation iterations could be reduced to one, i.e. one request to fly an alternative trajectory and a confirmation of this request. As the second element, the status of negotiation was desired to better anticipate ATC instructions, enabling better task management.

The necessary exchanges for these elements have not been foreseen in the datalink concept [11]. In addition the first element is not supported in the current operational concept. The identified needs present an interest and it is not excluded that these elements will be incorporated in these concepts as they evolve. However in this project the operational and datalink concept as currently defined will be used, so sharing of alternative trajectories and negotiation status is not taken into account.

4.4 Functions and information requirements

From the discussions in this chapter, lists of function and information requirements of the HMI are synthesized.

4.4.1 Required functions

The required functions allow pilots to perform certain operations on the system. The HMI has to provide the following functions.

Task	Function
Monitoring	None
Handling	Swap (including activate) Store Rename Delete
Revise – Identify possibilities	None
Revise – Modify	Request and select pre-defined routes Modify waypoints and constraints Restore
Revise – Check results	None
Negotiation	Send Request Compare

Table 4-1: Required functions for the HMI

A function is associated with every information requirement as well; the HMI must provide a function to access information.

4.4.2 Information requirements

Information requirements are the result of automation that is presented to the pilots. The HMI has to provide the following information.

Task	Information
Monitoring	RBT (Active) Indications of weather hazard conflict Weather along the RBT Indications of missed constraints Business properties Indications of imminent clearance crossing
Handling	Origin-Destination pair Source and Time of creation ATC status Name
Revise – Identify possibilities	Alternative Trajectory (proposed by FMS) Weather in 4D (predictions)

	Indications of missed constraints Coherence of constraints Business properties and other business information
Revise – Modify	Feedback about inhibited entries: - conflicts (terrain/airspace/weather/traffic) - performance
Revise – Check results	(Impact on) Business Properties ATC status Alternative trajectory Indications of weather hazard conflict Weather along the RBT Indications of missed constraints
Negotiation	Indications of trajectory reception Dissimilarities/Sent trajectory Impact on Business Objectives

Table 4-2: Required information to be provided by the HMI

4.4.3 Repartition of function and information requirements

Information requirements are often very similar for different tasks. For example, identifying possibilities has roughly the same requirements as monitoring, only applied to the entire space, including alternative trajectories. In order to have a clearer outline in the chapters to come, the function and information requirements are repartitioned according to six domains.

All different types of trajectories are discussed under trajectory display, together with ATC status, because related and property of trajectory. In the handling domain, of course trajectory properties are important as well.

Domain	Functions	Information
Trajectory Properties	None	Constraints, waypoints and linking segments Coherence of constraints Indications of missed constraints Trajectory type ATC status
Trajectory Modification	Modify waypoints and constraints Selection of pre-defined routes Restore	none
Weather	None	Weather including predictions Indications of weather conflict
Business properties	None	Business properties Other business information Impact of modification
Negotiation	Send Request Compare	Imminent clearance crossing Dissimilarities
Handling	Swap (including activate) Delete Store Rename	Origin-Destination pair Source and Time of creation Sent and received trajectory Name

Table 4-3: Functions and information requirements repartitions according to domains.

5 Performing tasks in the A30X cockpit

This chapter discusses the integration of the function and information requirements obtained from the task analysis in the previous chapter in the cockpit of the A30X.

First future system capabilities - not necessarily associated with the A30X - are discussed. Secondly the general concept of the A30X will be treated, which also mentions parallels between the A30X and 4D concepts. At last there is a comparison of function and information requirements with the A30X concept. By doing so, areas that are interesting for development are determined and a direction is given to the design goal discussed in chapter 6.3. In the last section of this chapter the improvement areas are summarized.

The short range A30X is the replacement for the A320 family of aircraft. With an anticipated introduction around 2020 it is still under development. This has two consequences for this report:

- The A30X concept is *confidential* and details will not be treated. Please keep this in mind when reading this chapter. Considerations and decisions in this chapter should be clear.
- Some design aspects are still unclear and therefore difficult to use as a basis. A fairly well defined concept is available, but some ongoing studies in the frame of the A30X concept are treated in the next chapter.

The cockpit concept of the A30X is based on the A380 cockpit, the latest realization of Airbus. A summary of relevant cockpit functions of this type can be found in Appendix B: A380 EFIS.

5.1 Future system capabilities

Some functions or information cannot be provided, because it is beyond the technical capability of future systems. In this section the assumptions of some technical challenging needs from the previous section are motivated. This motivation is based on consultation of specialists and should not be seen as a feasibility study of future systems. It is a selection of most realistic developments as expected for the A30X to define the boundary of automation.

5.1.1 Weather and automation

Two types of weather data exist in the cockpit, on-board radar weather data and weather data originating from ground-based sources. Radar data is short term; radar range is typically 320NM, which is less than one hour of flight.

A radar image is obtained by measuring the reflections of (precipitation) humidity in the air. Some limitations of radar are:

- Reflection power is not a measure for precipitation density.
- Dry air does not return reflections, so dry air turbulence is not detected.
- Parts of the image can be obscured because radio waves are strongly attenuated.

The limitations of radar have as a consequence that the hazard level is difficult to establish from radar data, because it depends on a large number of variables: e.g. wind, temperature, altitude, geography, cloud size, form and behaviour. This is the reason that today radar weather data may not be used for navigation around adverse weather, but only for weather avoidance.

Radar data can be augmented with long term ground based data (typical 6 or 12 hour forecast). Weather information from ground based weather stations is transmitted by datalink (or loaded before departure). Forecasts are updated periodically and transmitted with a certain delay. Within the SESAR effort, weather forecast and uplink is an important research topic with the main goal to reduce this delay and augment forecast time and accuracy.

In the future weather data will be shared between aircrafts and ground for data fusion in order to get a more up-to-date, detailed and predictable image. Accurate forecasts are even an enabler for long-term trajectory planning.

Weather predictions

Due to the advances in weather technology it is assumed that around 2020 weather predictions will be available in the cockpit with the same quality and performance as radar weather today. The increase in reliability by means of information provided by the ground will make up for the uncertainty that is introduced with prediction time. Because prediction uncertainty increases with

time this is only true for a limited prediction horizon. The result would be an image that has to be interpreted by pilots.

Automatic trajectory construction

Generation of a conflict-free trajectory with respect to weather should result in a trajectory with very little undetected conflicts and sufficient quality with respect to business properties (optimization). Specialists at Airbus anticipate that the development effort (cost) will be too high to obtain these targets with an automated function in the A30X. Expected difficulties are the lack of mature technology that can provide a detailed, up to date weather image and the required processing power to take into account the entire 4D space. Trajectories generated by such a function would have insufficient quality that would limit its usefulness. It is thus assumed that automatic trajectory construction will not be available in the A30X. This corresponds with automation level 1 as explained in chapter 4.

5.1.2 Direct feedback of modifications

In this section the feasibility of direct feedback of modifications is treated. Direct feedback is the presentation of the modification impact in real-time, i.e. before the modification is effectuated. Modification by continuously changing waypoints and/or constraints is considered, because the interest of direct feedback lies in the ability to search the desired impact as a function of the modification.

As a consequence of continuous changing, the entire trajectory changes (to little or great extent), including the time profile (and associated speeds) and the vertical profile. Every tiny change requires a recalculation of an entire new trajectory to obtain the impact and therefore uses a lot of processing power. Current FMS have difficulty calculating several trajectories at a time.

The processing load can be reduced if accuracy is reduced. Using reduced accuracy is not possible for time constraints, because of the strict tolerances for an RTA. Direct feedback can be given about conflicts with a reduced accuracy in time (and of course in space). The usability of such a direct feedback is however questioned, because the pilot needs to verify the outcome. Based on specialist consultation it is assumed that direct feedback of modifications will not be part of the A30X.

Besides, direct feedback has the drawback that it only gives information if a conflict occurs, but not how to resolve it. Information about hazards themselves is better suited for this purpose. The consequence of not considering direct feedback is that iterations are necessary.

5.2 Influence of the A30X concept

Not being able to present the full concept of the A30X, only main aspects of the concept are treated that influence the design of possible solutions. These influences can result in needs from a system point of view.

5.2.1 Main properties of the A30X cockpit concept

Navigation format repartition

The most striking development in the A30X concept is the navigation format repartition. Basically this means that there is an additional larger navigation display (ND) to support a division among short-, medium- and long-term information. The purpose is to provide strategic mission oriented information (flight planning) and thus it focuses on the long-term aspect of navigation. In the remainder of this report we will refer to the display as the Mission Display (MD). The MD can be regarded as a graphical Multi Function Display (MFD), although this analogy does not always hold. Both displays have a VD; to avoid confusion they will be referred to as Navigation Vertical Display (N/VD) and Mission Vertical Display (M/VD) in the remainder of this report.

Shift to pc-like interaction

Another characteristic of the A30X concept is that it strives for pc-like interaction. The rationale behind this principle is to use potential of programmable displays to obtain a more direct interaction. With the implementation of the Keyboard and Cursor Control Unit (KCCU) information and functions can be accessed at a certain place and time on pilot request. The KCCU found in the A380 is enhanced to interact more efficiently with interactive graphical elements on navigation formats. For example, it is equipped with a scroll wheel. Among other things the pc-like interaction

principle means that there will be a shift from an information based interaction structure to a task based interaction structure. Task based interaction means that the interaction structure is adapted to the actions that have to be performed where and when they are needed. An example of a task based interaction is the 'cursor jump' function found in the A380: it is the automatic positioning of the cursor over the next entry field when filling in data.

Open world information.

The second purpose of the MD is to integrate and present open world information with flight information. Open world information is information that originates outside the aircraft, for example from an airline operations centre (AOC). This information is important from a business perspective.

Conventional Operations

The A30X is developed to support both conventional operations and future operations like 4D and ASAS. The reason is that future operations will not be implemented worldwide. The HMI solution must thus be compatible with conventional operations.

5.2.2 Parallels between A30X and 4D concepts

There are some similarities in the evolution of the A30X and 4D-operational concept. In the A30X, the conventional primary flight display (PFD) and navigation display (ND) are augmented with the MD for the presentation of long-term information. This is exactly the information that is provided by the RBT; both concepts add a strategic layer.

The second parallel is that in both concepts there is an integration of information that allows easy and quick access to information. Both concepts rely on the 'omnipresence' of information. In the A30X concept this is represented by the MD that combines information from different sources and in the 4D concept by the information sharing system between sources and users.

5.2.3 Effects on improvement areas

The aspects of the A30X concept influence the improvement areas for this project as defined in the remainder of this chapter. The effects stated in this section can result in needs from a system perspective and thus have an effect on the design phase.

The effects of the A30X concept are:

- The MD is the target display for implementing possible solutions for (long-term) 4D-operations, because both the MD and the RBT are defined for strategic navigation.
- Take into account the development of new or improved existing functions using graphical interaction through the KCCU.
- Take into account the possibility of task based solutions.

The premature design of the A30X also has some effects:

- The relation between the ND and the MD is not clear at this moment and will be defined at a later stage. At this moment both share roughly the same functionalities and therefore it is decided to concentrate on the MD. The main objective of this report is to assess the needs for 4D-operations; it does not mean that certain functions are excluded from the ND.
- Take into account the uncertain status and possible evolutions of the mailbox (see section 5.3.5).

5.3 A30X functions and information

In this section function and information requirements are compared to the functions and information in the A30X concept. For every domain it is checked whether the associated function and information requirements are covered by the A30X HMI. Besides, it is checked whether enhancements related to the properties of the A30X concept are needed (needs from a system perspective). Based on these points it is determined whether the associated HMI is interesting for research, which lead improvement areas. Remind that the goal is to obtain needs and not a fully working cockpit.

Indications through messages

Messages are a useful, efficient and common way to inform pilots about events or draw attention. The location of the messages on the screens and the format of messages are standardized. Because of this standardized format, the implementation is relatively easy. Only details that are important in a later phase in the design process, such as message priority and wording have to be determined. For this early phase of the design process implementation of messages is not considered.

5.3.1 Trajectory display

5.3.1.1 Constraints, waypoints and linking segments

The equivalent of the RBT in conventional operations is the Flight Plan that consists of the same elements as the RBT. One important difference is that the flight plan is used principally as a personal tool for the pilots to plan his route and the RBT is agreed and shared with other actors. Information about the flight plan –waypoints and linking segments - is accessible in the cockpit on the Multi Function Display (MFD). The flight plan is also presented graphically on the Navigation Formats (ND and MD) including their Vertical Displays (N/VD and M/VD).

Constraints are available in alphanumerical form on the second information layer of the FPLN page of the MFD. The presence of a constraint is indicated on the first layer by stars next to waypoints. The number of time constraints of a flight plan is limited to one. Only altitude constraints are available graphically: on the ND/MD as a circle around a waypoint and on the VD as triangles. If the constraint button on the EFIS CP is pushed, constraints are presented numerically next to waypoints on navigation formats.

A coherent view of altitude constraints is given by their display on the VD. Up to now this is lacking for time constraints because only one time constraint is possible. Improvements are possible in a more accessible and more coherent representation of time and time constraints. There is a special interest for the VD, because on the horizontal axis along-track distance is represented, which is related to time by speed.

Whether constraints are missed is indicated by colour coding: the normal magenta indications turn amber when a constraint is missed. On the RTA page missed time constraints are indicated alphanumerically and the words 'early' or 'late' are added.

5.3.1.2 ATC status and trajectory type

In the A30X concept three main types of flight plans exist: The active (ACT), the temporary (TMPY) and secondary (SEC) flight plans. Other trajectory types are not considered for the moment. Green, yellow and white are standard colours that are used for the display on navigation formats. The ACT is represented by a full green line on the ND, MD and VD, while the TMPY is represented by a dashed yellow line only on ND and MD. The SEC is not displayed.

ATC statuses according to the 4D concept consist of cleared, agreed and not-agreed. There is a relation between ATC-status and trajectory types:

- The ACT is always agreed and usually has a cleared part (the cleared part is not distinguished)
- The TMPY is always not-agreed (only known at airborne side)
- The SEC can be agreed or not-agreed, and also can have a cleared segment

Information about ATC status is (logically) not available in the A30X and should be implemented. This has to be compatible with trajectory type display. Also see 7.2.5 about trajectory type display.

5.3.2 Trajectory modification

All modifications of waypoints and constraints are available on the A30X and accessible through the MFD (second layer). Some modifications of waypoints (lateral modification) can be performed interactively on the ND (MD), but the VD is not interactive. Graphical modification of constraints (notably time) is not possible, so this could be examined in order to make time constraint modification more accessible.

Selection of predefined routes is not available in the A30X. A study is being performed in the frame of SEC management that treats the selection of routes (see 6.1.3.2).

Restore functionality exists on the A30X in the form of a CANCEL button for the TMPY. This function is limited to restore only the last modification. This function should be available for the SEC as well (see 7.2.4.3), but this does not add anything extra in the context of the 4D-HMI.

5.3.3 Weather

Weather information display is not yet specified for the A30X concept, but the A380 provides weather radar data that can be explored in three dimensions through selection of vertical and horizontal cross sections. In addition weather charts of forecasts are available on an onboard information system. The aim is to integrate this weather data in order to display and interact with weather in 3D for the A30X.

It is pointed out that this is not a core topic of this research. Weather display is strongly linked to surveillance and details of available information are to be specified. It remains however interesting to examine the HMI needs for 4D weather display and interaction, because it is the 4th dimension that is investigated.

Indications of weather conflicts are given by messages and are not further researched.

5.3.4 Business properties

Predictions for fuel and time are calculated for the entire flight plan and presented as time and estimated fuel on board (EFOB) on the MFD for every waypoint or pseudo-waypoint including destination. This information is to be completed with detailed cost information about aircraft systems and airline operations to yield the business properties of a trajectory. The exact content of business properties must be determined and the presentation of these business properties is subject for improvement. It is important that the pilot is able to deduce how to change the trajectory from the business properties and other information. The presentation of business properties must include the impact on business properties of a modification.

Other business information is available on the MD of the A30X. The definition of the content of the information that will be available is in progress, but it will include airline operations information updated via datalink and instructions from Airline Operations Centre.

5.3.5 Negotiation

On the A380, communication with ATC is done on the Mailbox (MB) or on the MFD communications page. The MB is a permanent display where in- and outgoing communications with ATC are managed. The interaction method for communication with ATC is still open in the A30X concept. As a consequence of pc-like interaction the MB of the A30X will undergo a radical transformation or may even disappear. Evolutions should lead to a more direct (enhanced) interaction.

An indication for an imminent clearance crossing does not exist, but it will be possible to deduce this from ATC-status and ownship position. An additional indication would be implemented by a message.

Functions to directly compare two trajectories do not exist. Apart from the active and TMPY flight plans, no flight plans are simultaneously displayed. For an assessment of an ATC proposition the comparison can be between an active and a SEC, or two SEC. The VD only displays one flight plan. Dissimilarities between two flight plans are not made transparent in the A30X.

5.3.6 Handling

In the A30X handling of flight plans is organized by exactly one active (ACT), at most one temporary (TMPY) and multiple secondary (SEC) instead of three secondary used in the A380. The TMPY is automatically created upon a modification of an ACT and is used for small revisions. The TMPY is not stored, but can be copied to a SEC. SEC are used for more elaborate revisions such as 'what if trajectories' and can be stored. As in the A380, the A30X concept reserves one SEC for the flight plan received from ATC (or AOC). This project will focus on the use of a SEC for revisions because of its more strategic character and the link with ATC.

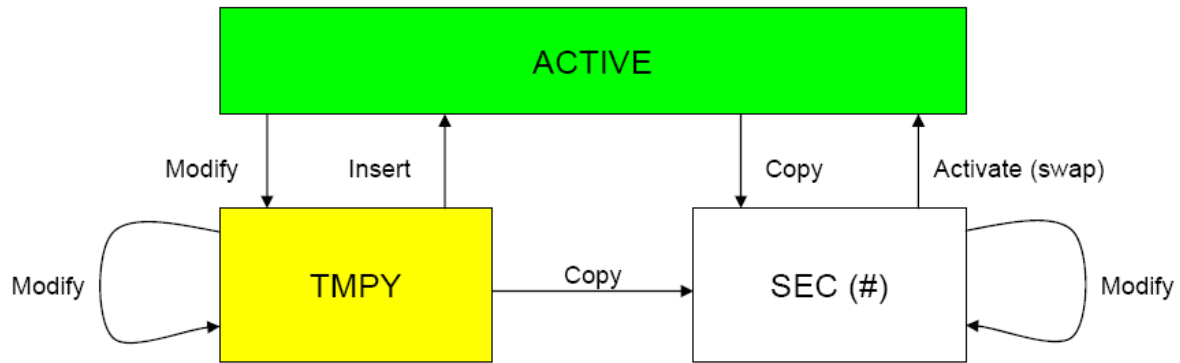


Figure 5-1: flight plan types in the A30X concept and the transitions between them.

In Figure 5-1 the three types of existing on-board flight plans are displayed together with relevant transitions between them (Some transitions are omitted, e.g. delete, receive). The same scheme has to be maintained for trajectory handling. This poses no problem, except that no flight plan equivalent of the sent trajectory exists. In addition, the handling interaction should be enhanced to support direct communication of entire trajectories (TMPY and SEC) with ATC.

The distinction between ACT, TMPY and SEC is easily made. This applies as well for the three SEC in the A380; each has a number. Because the SEC can come in any number, a new organisation mechanism is needed for the A30X. Origin-destination pair and time of creation are existing properties that could be used for automatic ordering. Renaming trajectories does not exist in the A30X concept.

5.4 Improvement areas

The table in this section summarizes the improvement areas.

Domain	Functions	Information
Trajectory Properties	None	Graphical and Coherent constraints ATC status Trajectory Type
Trajectory Modification	Graphical modification of constraints Selection of pre-defined routes	None
Weather	None	Weather predictions
Business properties	None	Business properties Impact of modification
Negotiation	Compare Enhanced send and receive	Dissimilarities
Handling	Rename Improved handling interaction. Automatic ordering by origin-destination or time.	Sent trajectory Name

Table 5-1: Improvement areas

6 Previous work

In this section previous work is examined for HMI solutions that correspond to the improvement areas for the A30X cockpit concept. For every improvement area existing solutions are evaluated, which will fall in the following categories:

- Solutions that fully cover an improvement area; no further development is needed.
- Solutions that need to be integrated in the A30X concept.
- Solutions that need adaptation to fit in the SESAR concept of operation.

Improvement areas not matched to an existing solution are novel and considered as a design goal. The outcomes of this section are design goals that form the input for the design phase, where every solution to be integrated or adapted is validated by a pilot. Design goals describe what is to be designed and – at a high level – how they should be implemented.

In this section a brief description of new developments according to the improvement areas, the interest of applying a particular solution and the design goal as result are presented.

For more details of the previous work please refer to the corresponding documents [5][4].

6.1 Overview of previous work

Two HMI design projects in the scope of other 4D operational concepts have been considered as previous work. A focus has been put on these two studies, because they are considered to be the most mature and the closest to this project. Their solutions will mostly need integration in the A30X concept. They are briefly discussed in 6.1.1 and 6.1.2 and will be referred to as 'previous solutions'. In addition to these two projects research intern of airbus that is not a part of the A30X concept is examined. Solutions originating from these studies will mostly need adaptation to 4D-operations, because none have been developed in that framework.

6.1.1 PHARE - AHMI

Part of the PHARE programme (3.3.1) was the research for the so-called Advanced Human Machine Interface (AHMI) to operate within the 4D ATM system. The AHMI supported the pilot in 4D flight planning, 4D flight negotiation and 4D flight progress monitoring and alerting. The development is on-going and the AHMI has been employed to support and research activities described by SESAR.

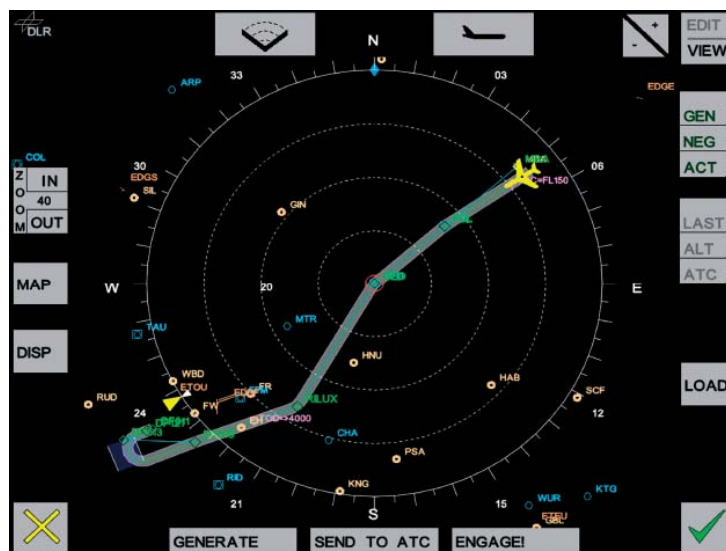


Figure 6-1: Navigation display of the AHMI [7]

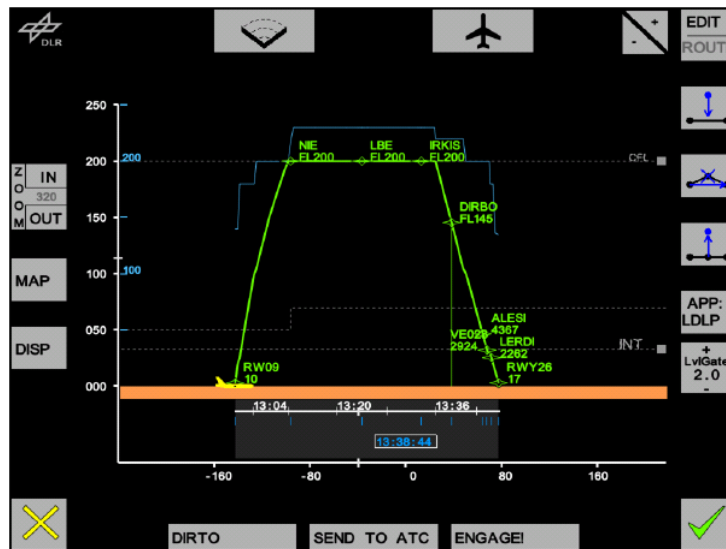


Figure 6-2: Vertical display of the AHMI [7]

The AHMI has roughly similar information and function requirements, because they are based on essentially the same operational concept. The design considerations that led to the AHMI have however been different (and are unknown), because the needs originating from the user and in particular the system have been different.

By looking at Figure 6-1 and Figure 6-2, it is directly clear that the 'look and feel' of the AHMI does not correspond with that of an airbus cockpit (refer to Appendix B: A380 EFIS). The solutions found in the AHMI will be examined for integration in the A30X cockpit concept.

One remarkable conclusion from the evaluation of the AHMI was that [8]:

"Direct manipulation of routes/trajectories on the navigation display was welcomed by the pilots as a significant improvement on today's systems, and the concept of trajectory negotiation was quickly assimilated."

6.1.2 NASA - CDTI

NASA has developed a cockpit situational display (CSD) for use in the distributed air-ground traffic management (DAG-TM) concepts in support of (limited) self-separation. DAG-TM was at the basis of the American Next Generation Air Transportation System (NextGen). The underlying system defines flight routes as 4D trajectories and its primary function is to identify traffic conflicts and to support developing graphically alternative non-conflicting trajectories based on 4D intent information of other aircraft. The cockpit situational display presents other hazards (notably weather) in three dimensions and provides an 'Advanced Route Assessment Tool' to create, visualize and share flight plan modifications.

Because of the different underlying operational concept, the cockpit situational display is more adapted for traffic display and (self) separation procedures than to 4D-trajectory management. It has thus more in common with solutions for ASAS functions, but solutions for 4D trajectory management HMI are present.



Figure 6-3: Image of the cockpit situational tool by NASA

6.1.3 Airbus

6.1.3.1 FANS study

The Future Air Navigation System (FANS) is a datalink system that allows communications of air traffic control clearances, pilot requests and position reporting. Recently a study has been finished at Airbus that had as goal improving the HMI of datalink communication via FANS.

Its achievements included an enhanced interface for ATC communications using graphical interaction with the flight plan and a proposal of a redesigned mailbox. Apart from RTA requests 4D operations have not been taken into account.

6.1.3.2 SEC management study

In a project to upgrade A380 functions a tool is proposed for the management of secondary flight plans. The tool includes among other things a function for the initiation and the modification of SEC and graphical intuitive selection of route segments for departure, en-route and arrival phases of the flight. The tool is divided over ND and MFD, but an A30X version on the MD was suggested as well. Out of confidentiality reasons details of the tool are not given.

6.1.3.3 Cost indication studies

A study at airbus has been conducted to give a detailed indication of cost including flight parameters of the entire flight. The objective was to give a detailed picture of aircraft related cost for one flight in real-time, taking into account aircraft performance, fuel use, brake and engine wear, system maintenance and more. The result was a single cost indication parameter, but no HMI has been developed.

Numerous studies have addressed the subject to more precisely determine the Cost Index that is to be inserted by pilots to arrive at optimum flight economics. Most tools focus on pre-flight (operations) optimization of the cost index, according to parameters such as aircraft performance, flight schedules, aircraft rotation times, crew and maintenance cost, fuel prices, currencies and passenger data. Some airborne tools have been proposed as well.

6.1.3.4 EMMA – trajectory display

EMMA is the name of a project that studied clearances by pilot controller datalink communications for ground operations. Part of the study was the indication of these clearances on an airport navigation display. The clearance mechanism used on ground today is different from the mechanism that will be used for 4D operations. The taxi route is green up to the point where the pilot has acknowledged the route received from ATC. Beyond that, the route proposed by ATC is displayed in light blue up to a potential holding point, the gate or the runway. Because of the air-ground continuity of the trajectory and clearance mechanisms in 4D-operations, the HMI designed for EMMA is taken into consideration.

6.2 Previous work and improvement areas

In this section the improvement areas are compared to solutions in previous work to determine the design goals.

6.2.1 Trajectory display

The trajectory (flight plan) display as defined by the AHMI is most relevant to this report. The CDTI does not have a VD and indicates vertical changes by a dashed line on the ND. Constraints are presented as waypoint data on a waypoint table. Trajectory type and ATC-status have a different meaning and purpose in the underlying concept of operations (e.g. separation responsibility for aircraft instead of clearing a part of a trajectory).

The AHMI displays waypoints on the ND and constraints on the VD; both displays fill the entire screen. Time constraints are displayed as brackets on the main part of the VD on both sides of a waypoint represented by a line. The estimated crossing time is displayed below the x-axis, which represents along track distance. Differences between the estimated time and hi/low constraints are displayed next to the brackets. Time constraints are thus displayed graphically and because the purpose of displaying these constraints is the same as for this project, the design can be adopted by the A30X VDs. Certain coherence is introduced, because estimates and constraints are displayed relative to along track distance, but this is not very precise.

Multiple trajectories types can be displayed on the ND and are distinguished by colour coding. Colour coding is a simple and effective way to display multiple trajectories. The SEC management tool presented SEC trajectories in white and this will be used in possible solutions. The VD only displays one trajectory at a time.

ATC-status does not exist in the HMI solutions but is related to trajectory type. ATC-status is more common for navigation displays on ground. The ATC-status indications of the EMMA project are worth considering for the HMI, but cannot be adopted directly because of the different clearance mechanisms.

4D tubes and boxes

An noticeable feature in earlier versions of the AHMI was the display of a 'tube', the boundaries in space in which the aircraft was flying. The display of the tube has not been identified as a requirement for 4D trajectory management (because automation is keeping the aircraft within the tube). Time was also represented by a box inside the tube, which is associated with the full-4D operational concept.

Performance capabilities

The Ground HMI (GHMI) of the PHARE program was a tool developed to show the performance limits in maximum and minimum arrival time and associated speeds of approaching aircraft. An airborne adaptation of such a display has been considered to present the performance capabilities and constraints coherently. However because managed mode is assumed, display of performance capabilities was not judged interesting by the reference pilot and the further research was abandoned.

6.2.2 Trajectory modification

Graphical interaction with the constraints of the flight plan is featured in both HMI designs. The interaction mechanism used is however not common to the A30X concept and needs adaptation. The AHMI design is closer to the 4D-operational concept, because window constraints are used. The interaction means of the previous solutions are not exactly known, but it is assumed that normal point and click devices are used. Integration with the interaction means of the A30X must be studied with the goal to make the most of its enhanced capabilities.

On the AHMI vertical constraints are dragged to a new position for a constraint modification. Two features enable this, a full screen VD and the fact that each trajectory generation (according to inserted waypoints) is activated by the pilot. This will be explained in the next chapter, but both of these will have to be available to integrate graphical altitude constraint modification possible in the A30X.

As has been written at the beginning of this chapter, the SEC management tool proposed a HMI to select (segments of) standard routes. The routes can be sorted by means of entering sorting criteria to ease the selection (e.g. destination waypoint). The tool is limited to standard segments and does not calculate entire trajectories. It does not determine conflict-free routes nor does it prioritize the proposed routes according business properties. The SEC management tool is integrated in HMI solutions and additionally should target improvement areas that are not yet addressed.

6.2.3 Weather

The NASA CSD has the capability to show full 3D weather, which is a 2D image on which three dimensions are rendered. This is different from the 3D weather exploration function found on the A380. Predictions are not included, but the display of predictions for weather is one of the recommendations for weather display by NASA [9]. Other recommendations important for the HMI design are that:

- 'No-go' areas must be displayed, in line with the discussion in section 5.1.1. A remark is made that the complementary 'Go' areas are not guaranteed to be safe.
- Details of weather resulting in 'no-go' areas consisting of weather type and raw data must be available.

Because weather display is not the core part of this research, only that part of weather display that is important for the revision of 4D trajectories will be examined: 'no-go' zones and especially the display of predictions.

HMI design of weather predictions has not been encountered in other work. The NASA CSD does show predictions of traffic by 'prediction pulses' of which the prediction time can be altered. An adaptation for weather can be considered.

6.2.4 Business properties

Nor the CSD nor the AHMI includes business properties other than time and fuel. The airbus cost indication and cost index determination tools both don't provide what is needed for the HMI design. The first does not include ground (operations) data and the second determines a cost index that is not used in 4D operations.

Both tools should be combined by integrating real time aircraft and external information (a fixed number of parameters that are well-defined). The results should be presented by one indication whether business properties are acceptable and additional information that is used to determine what modification should be effectuated for optimization.

The impact of modification on business properties should be in the same format, no earlier work has addressed this issue.

6.2.5 Negotiation

An enhanced send and receive function is addressed the FANS study. The developments of that study are well integrated in the A30X, but are not conform 4D trajectory sharing. For example flight level changes are not requested directly, but first inserted in the trajectory which is then send to ATC. Element of the FANS developments will be used where possible; its mailbox design is fully adopted to send and receive entire trajectories (also because details about mailbox evolution are lacking). However, send and receive functions may be integrated in the new developed solutions where appropriate.

The differences between two constraint lists (trajectories) are highlighted on the ND of the AHMI design. Selection of two constraint lists is done by the handling mechanism used in the AHMI (see next section). Because only one trajectory is displayed on the VD, no comparison can take place of the vertical profiles of two trajectories. Adopting the highlighting differences is quite straightforward, but the handling mechanism is different in the A30X and should be adjusted to support comparing. Furthermore the vertical part of the trajectory should be compared as well.

6.2.6 Handling

Handling is inherent when two or more trajectories are managed, so all of the previous designs provide a handling mechanism.

Trajectory types (or constraint lists) are limited to five in the AHMI design that all have a dedicated (pre-defined) function. Display of the trajectories is done by toggling tabs on the screen. Multiple trajectories are distinguished by colour. If the trajectories are similar, they are grouped to one tab to be toggled. Because there are only five trajectories, handling is not compatible with the handling mechanism in the A30X. Handling in the CSD has a similar approach, but is more in line with the DAG-TM operational concept; tactical (temporary) resolution trajectories are constructed, multiple of which can be available for selection on a row of buttons.

The most logical is to base a solution on the SEC management tool, on which secondary trajectories are ordered by creation time. A naming function should be quite straightforward to integrate, because it is used in many interfaces in the everyday world. The sent trajectory should be treated in the same way as the received trajectory; by means of a dedicated SEC.

6.3 Design goals

Domain	Design Goal	Potential solution	Source
Trajectory Display	Graphical time constraints Coherent display of time constraints Trajectories Type ATC-Status	Brackets on VD Along-track distance Colour coding	AHMI AHMI
Trajectory Modification	Graphical modification of constraints (using Enhanced KCCU) Enhance selection of trajectory segments (Conflict free and valid/business properties) Feedback of inhibited entries (hazards)	Direct interaction with constraint Conform SEC management tool	Sic AHMI
Weather predictions	Weather prediction	Pulsed predictions with interaction	CSD
Business properties	Indications whether business properties are acceptable and indications what modifications are needed associated with modifications.	none	N/A
Negotiation	Maintain interaction for send/receive Dissimilarities vertical and horizontal	Conform FANS development Highlight/graphical	Sic AHMI
Handling	Improve SEC management function w/ sent trajectories, name function.	Conform SEC management tool	Sic

Table 6-1: Design goals

7 Design phase

In this chapter a summary of the design phase is given, which is sub-divided in four sections. First a short description of the design procedure is given after which the resulting HMI solutions are presented. The implementation process on a cockpit simulator is described followed by the description of the evaluation. As has been mentioned earlier, confidentiality is the reason that a summary is presented. This means that HMI images are only partly presented (or not at all) and certain details are omitted.

7.1 Design procedure

At Airbus, the design procedure is marked by three stages of iterations that use increasing representative simulators to validate the design. As a first step stand-alone static PC-based simulations are used. In this stage consultations are held with a single reference pilot. Once the pilot needs and HMI principles are sufficiently determined the design is implemented on a more realistic simulator. This allows evaluating the design on multiple screens simultaneously and the dynamic interaction. In this stage multiple pilots are consulted and evaluations usually are carried out with two pilots at a time: ideally an experimental test pilot and a flight test engineer.



Figure 7-1: A full design procedure in sets of iterations on three increasing representative simulators.

As a final stage the design is validated in a fully representative cockpit that is equipped with the same interaction elements as a real aircraft. Evaluations in this cockpit are carried out with a representative flight crew according to fully representative operations, procedures and regulations. Evaluation of the design in a fully representative cockpit is beyond the scope of this project and therefore only evaluations in the first two simulators are conducted.

Obtaining pilot needs

To obtain pilot needs it is necessary to consult pilots. Scenarios are presented to conceptualize (envisage) future operations. Specific tasks are associated with each scenario so a pilot knows what is expected from him and he can clearly state his needs to accomplish those tasks.

Pilots will often respond by coming up with solutions to accomplish a task instead of needs. Only when you understand the needs of the pilot is it possible to find a proper solution for the problem. Thus that what the pilot really needs has to be determined.

In order to distil the needs that are the input for the design it is important to ask the right questions. The answers to these questions will aid to transform solutions stated by the pilots to needs. The questions that are to be posed are:

- What do you need (to accomplish a certain task)?
The answer to this question in most cases yields a desired solution.
- How do you want it?
The answer to this question gives more information about the preferences and usage of the desired solution. It is valuable for the interaction between pilot and designer. It can also be posed as: how would you use your solution?
- Why do you need it?
The answer to this question is the purpose or goal. The needs then follow from the answer to the question: what are the means to accomplish this goal?

7.2 HMI solutions

7.2.1 Access to trajectory information

7.2.1.1 Graphical constraints

Graphical time constraints

Time constraints are represented graphically, relative to estimated times. The graphical format used is conform to the representation by magenta triangles of altitude constraints on the VD. Because of the along track distance is displayed on the x-axis of the VD, a horizontal orientation was chosen. In this way the constraints are in line instead of parallel, and therefore the constraints are limited in distance from the estimated time. The result is a time bar with an estimate and maximum two constraint triangles (because of window constraints used). The length of the bar represents a fixed time scale, which is initially fixed at 60 seconds. The optimum scale is to be determined.

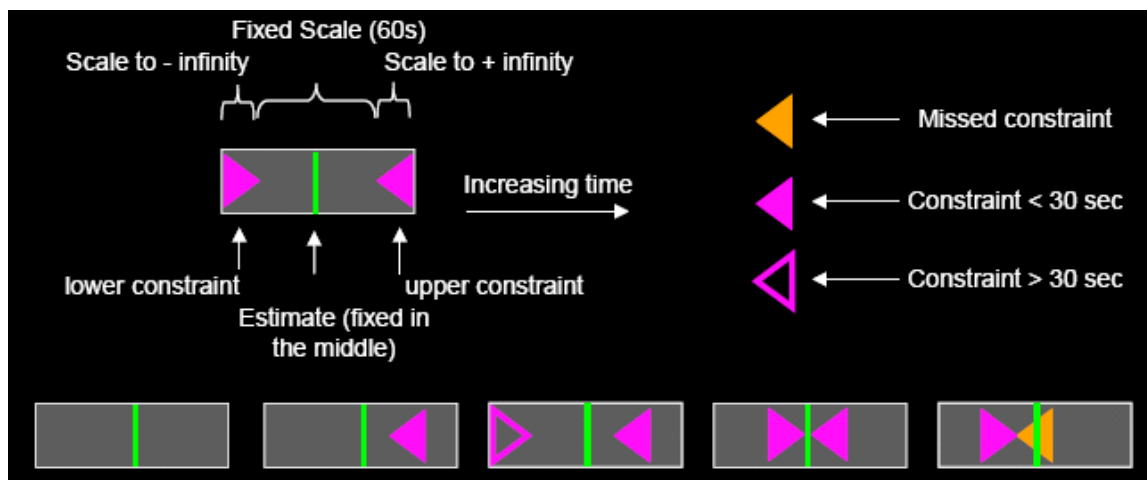


Figure 7-2: Illustration of the time bar. Left the definition of the scale and axes and right the definition of the constraint triangles is explained. At the bottom several states are displayed.

Estimates are used as a reference conform the HMI principles used for display of other parameters (e.g. altitude on the PFD). Constraints in the form of triangles move along the time bar, relative to the estimate. Filled triangles are used when the constraint is inside the fixed scale of the time bar and open triangles are placed at the outer edge of the time bar to indicate that there is a constraint outside the time scale (> 30 seconds difference).

Logic is applied that constraints cannot pass the estimate with the base of the triangle, to limit the different states of the time bar. It is only interesting to show that a constraint is missed, because if a constraint is missed further action has to be taken.

Coherent display of time: time line on the VD

The dimensions used on the ND (MD) and VD (MD_VD) are latitude versus longitude and altitude versus along track distance, which combined result in a 3D representation (along track distance is a combination of longitude and latitude). The fact that time is related with along-track distance via speed provides a possibility to integrate time and to display information in 4D. Parallel to the distance axis on the VD a time line is positioned that is coupled with along-track distance. Along-track distance is to be kept as primary quantity, because it is more important than time in relation to altitude.

The constraints are placed on the timeline or, to be more precise, directly above the timeline. Their estimates aligned with corresponding waypoints. On the timeline itself the estimates are displayed numerically in hours, minutes and seconds. In the case a constraint is missed, the difference in time is shown (only minutes and seconds). A pop-up only showing time constraints is available similar to the one described in the next section.

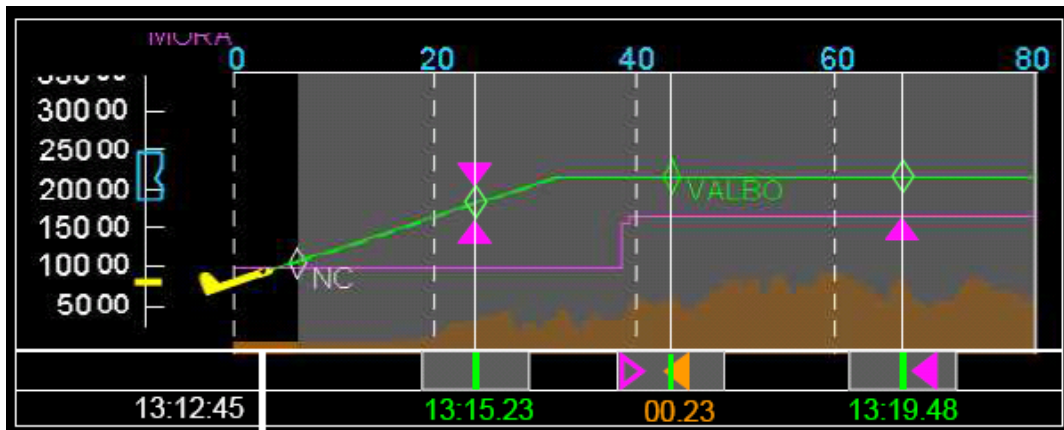


Figure 7-3: Timeline with time bars on the VD

When the range of the VD is adapted, waypoints can get too close to each other to display the time bars separately on the timeline. Whenever this happens, the time bars in question are replaced with a grey bar with a coloured frame, which normally is magenta. The frame turns amber if one of the constraints that the bar replaces is missed. Below the clutter bar the estimated time of the first waypoint or the time difference of the first missed constraint is shown.

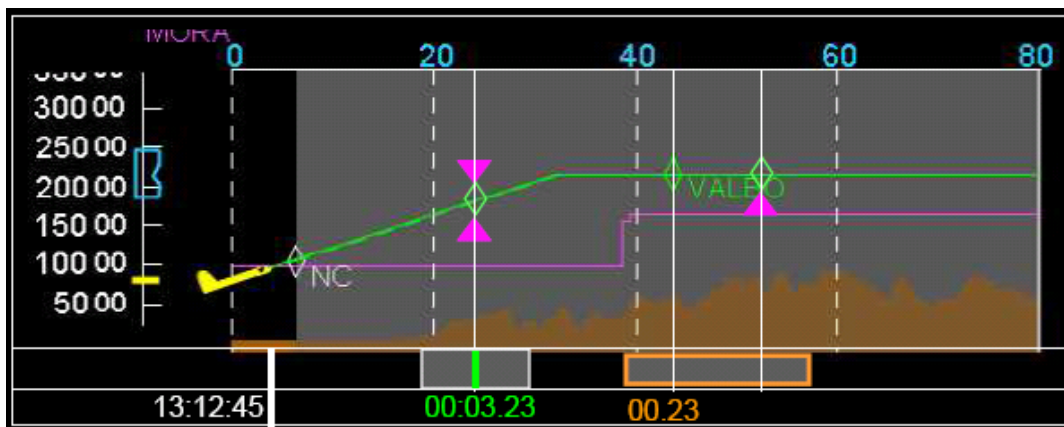


Figure 7-4: A clutter bar replaces two time bars when they overlap

The timeline provides information about time in such a way that that a coherent view is given about constraints along the trajectory. It shows if there are constraints at a certain waypoint, whether they are missed and qualitative information about the distance to the estimate.

In accordance with the reference pilot, the timeline does not completely provide a coherent display of time constraints, because no information is given about speed and the related performance limits.

Access to constraint information on ND

During the design iterations, the desire was expressed that graphical constraints were displayed on the ND. The main reason for this was the implementation of the revision support tool and the fact that the VD is not permanently displayed.

On the MD of the A30X concept hovering over a waypoint results in the pop-up of a label that gives information about the waypoint. It has the advantage that it is not on display all the time, but rapidly accessible if needed. Predicted time, fuel, speed and altitude are given and are augmented with constraint information. The window constraints in 4D-operations have as a consequence that there can be an upper and a lower constraint, which are placed on top and below of the estimate, as is presented in Figure 7-5.

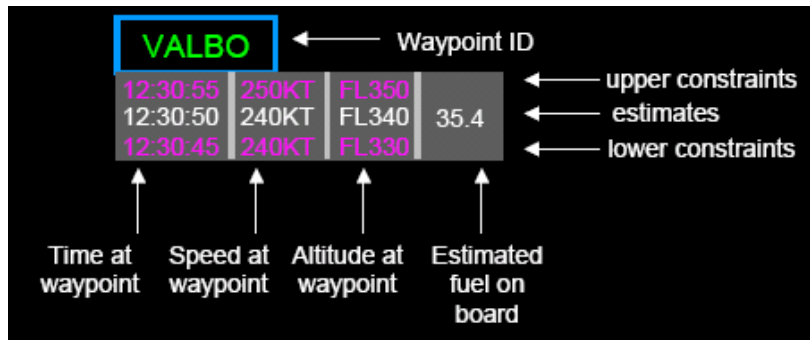


Figure 7-5: The constraint label (configuration for presentation only)

Units and the form of the values indicate the sort of constraint. Fuel (EFOB) does not have constraints, so only the estimated value is given. The constraints turn amber if they are missed. The estimates are displayed in white (for all trajectories) because if displayed in green (the colour of the active trajectory) the label would suffer from colour overload.

An issue with the label format is that an AT-constraint is not easily recognizable as AT-constraint (two equal values above and below the estimate). Numerical values of AT-constraints are therefore replaced by two horizontal lines above and below the estimate. If an AT-constraint is missed, the numerical value of the missed constraint is displayed in amber. See Figure 7-6.

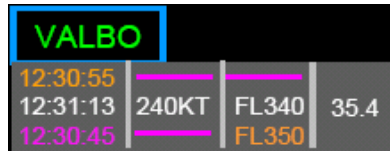


Figure 7-6: Missed- and AT-constraints (configuration for presentation only)

Multiple waypoints

If more waypoints are close together or a waypoint is identical in multiple trajectories a stack of waypoint names is displayed. The colours of the names correspond to the colour of the trajectory. If a waypoint belongs to two trajectories, the name is displayed twice since there can be different constraints for those waypoints. Using a stack means that the time bars of multiple trajectories can easily be accessed (and compared) by simply sliding the cursor over the stack. This method of accessing menus of multiple waypoints is used when clicking as well (see section 7.2.3.1).

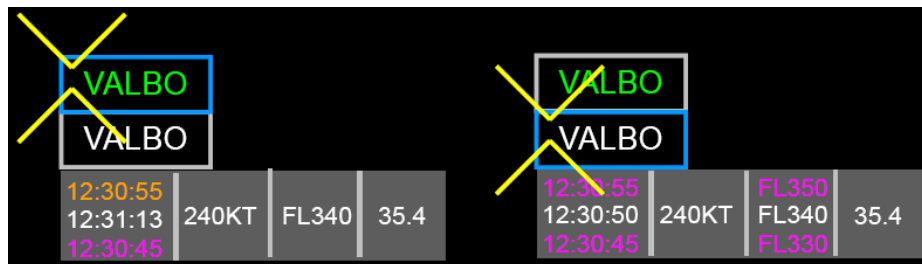


Figure 7-7: Access in the case of multiple waypoints via stacks. Several possibilities are displayed.

7.2.1.2 Trajectory display and ATC status for segments

The different trajectory types and ATC-statuses were identified as follows: Only the active trajectory (ACT) can have a cleared part and is agreed, while temporary trajectory (TMPY) can only be not-agreed as it is only available in the cockpit. The segments of secondary trajectories (SEC) can have all statuses. Trajectory display must be compatible with conventional display and therefore existing colour conventions are used.

Active

A solution is needed that distinguishes the cleared part with respect to existing display of the ACT. Two different approaches have been investigated and evaluated.

The first is the use of magenta for the cleared part. This colour does represent a constraint in the Airbus philosophy. Although the cleared part can be considered as a constraint (ATC 'fixes' the upcoming segment of the agreed trajectory), the reference pilot wanted a second approach that uses the colour green as the first part of a trajectory to fly. The thought behind this is that green means 'good to fly', like the ACT is green at this moment.

A conflict arises distinguishing the cleared trajectory and the agreed trajectory: both have to be green. A solution was found using colour coding and line style. The line style used for conventional flight plan display has a black halo around the green line to make it visible over green backgrounds. For the cleared segment a core colour of dark blue was chosen, and a halo of green. In this way the green is preserved for both the cleared and agreed segments. At the ATC clearance limit two green lines of the halo close to form the green line of the agreed segment.

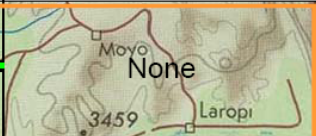
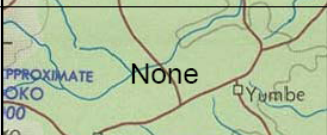
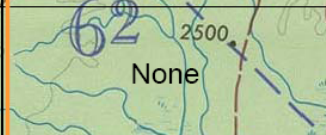
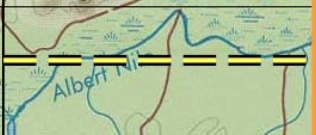
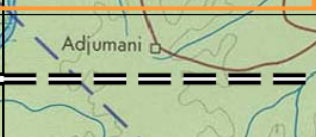
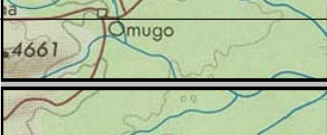
ATC status	Cleared	Agreed	Not-agreed
Trajectory			
ACTIVE			
TMPY			
SEC			
reference SEC			

Figure 7-8: Overview of trajectory display. Three different ATC-status formats versus trajectory sort.

Temporary

The temporary exclusively exists of a not-agreed segment because it is only known on board. It forms the complementary of the active. The temporary keeps its appearance of a yellow dashed line.

Secondary

The SEC characteristic colour is white as has been customary in other studies. The same principle is used to distinct the cleared and agreed part as the ACT. The core colour of the SEC is chosen to be light blue. This has been done to distinct between an actual clearance and a conditional clearance. Conditional, because the clearance limit is only valid if the flight crew has activated the SEC (and notified ATC). In case of a magenta cleared part of the ACT a black haloing is used, in the second case a white haloing is used.

The not-agreed part of the SEC corresponds to the TMPY: it is a white dashed line.

The cleared and agreed parts of a SEC don't stay cleared and agreed all the time. If a SEC stored in the FMS is recalled one hour later, the agreed status of the SEC will no longer be valid. The aircraft has moved in this time, so the cleared part no longer makes sense either. On the ground (and perhaps in flight as well), stored SEC that describes the intention of later flights should retain the agreed status. The validity of the status of the SEC should be associated with a timestamp and perhaps also be linked to the position of the aircraft. This is subject for later iterations.

The reference SEC (see section 7.2.5) has to be distinct from the secondary when two SEC are compared. The reference trajectory is latent, so it was chosen to display the reference SEC in grey.

The not-agreed part is dashed coherent to other trajectories. Since it cannot be activated, no distinction is made for the cleared segment.

Multiple trajectory display

The trajectories can all be displayed at the same time on the ND and MD, with the exception of a SEC and a TMPY. The ACT is displayed permanently. The priority of trajectory is as follows: the reference SEC is always displayed below other trajectories. The ACT is on top, except when a SEC or a TMPY are modified. In that case the trajectory that is modified is on top. The pilot manages the display of trajectories (see section 7.2.4.2).

Multiple trajectories on VD

Multiple trajectory display is needed for the comparison of trajectories.

On the VD trajectories practically cannot be displayed at the same time for the following reasons:

- The vertical axis of the VD adapts to the flight plan displayed
- Trajectories often have a dissimilar lateral path
- It is not feasible to display constraints at the same waypoint for two different trajectories

Instead of displaying trajectories at the same time trajectories can be switched. Three buttons on the lower left part of the VD allow switching between three trajectories: The ACT, the SEC and the reference SEC. Clicking a button displays the corresponding trajectory and after a short time interval the VD automatically reverts to its default state displaying the ACT. The TMPY is not displayed.

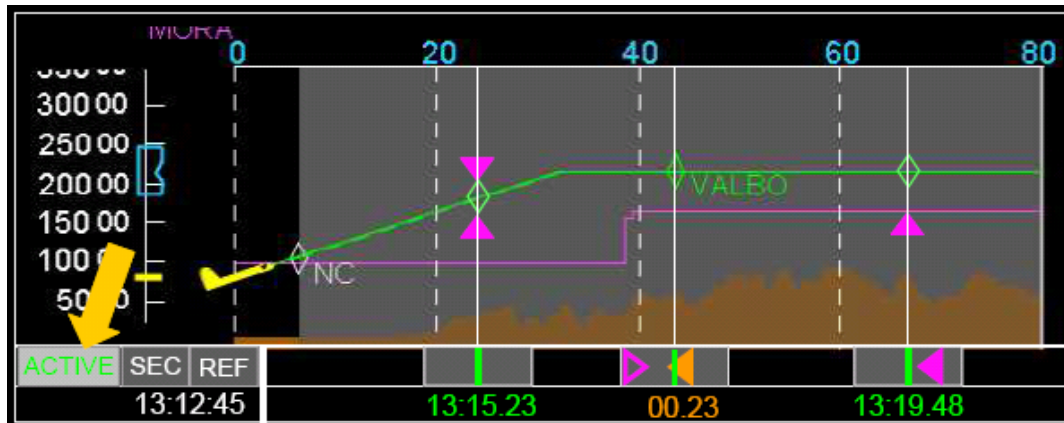


Figure 7-9: Buttons for switching between vertical profiles of different trajectories on the VD

7.2.2 Weather predictions

Some different solutions for weather predictions have been investigated, which lead to the following implementation. It should be mentioned that weather predictions are used as a facilitating function for trajectory modifications during evaluations.

An interactive element that shows the prediction time is placed on the MD. Clicking on it transforms the element in an input field which allows modifying the prediction time. The scroll-wheel on the CCU can be used to rapidly in- or decreasing prediction times, without using the keyboard. This gives the pilot instant control over the prediction time.

When a prediction time other than zero is inserted, the predicted weather is added to the actual weather and distinguished by colour-coding. The actual weather is displayed in the conventional green/yellow/white and the predicted weather is displayed in different tones of grey.

With a certain prediction time the position of the aircraft changes as well. A dummy aircraft symbol is added in grey that shows the future position relative to present position. The same principle can be used to display predictions of other hazards. The image below gives an impression of the resulting weather display.

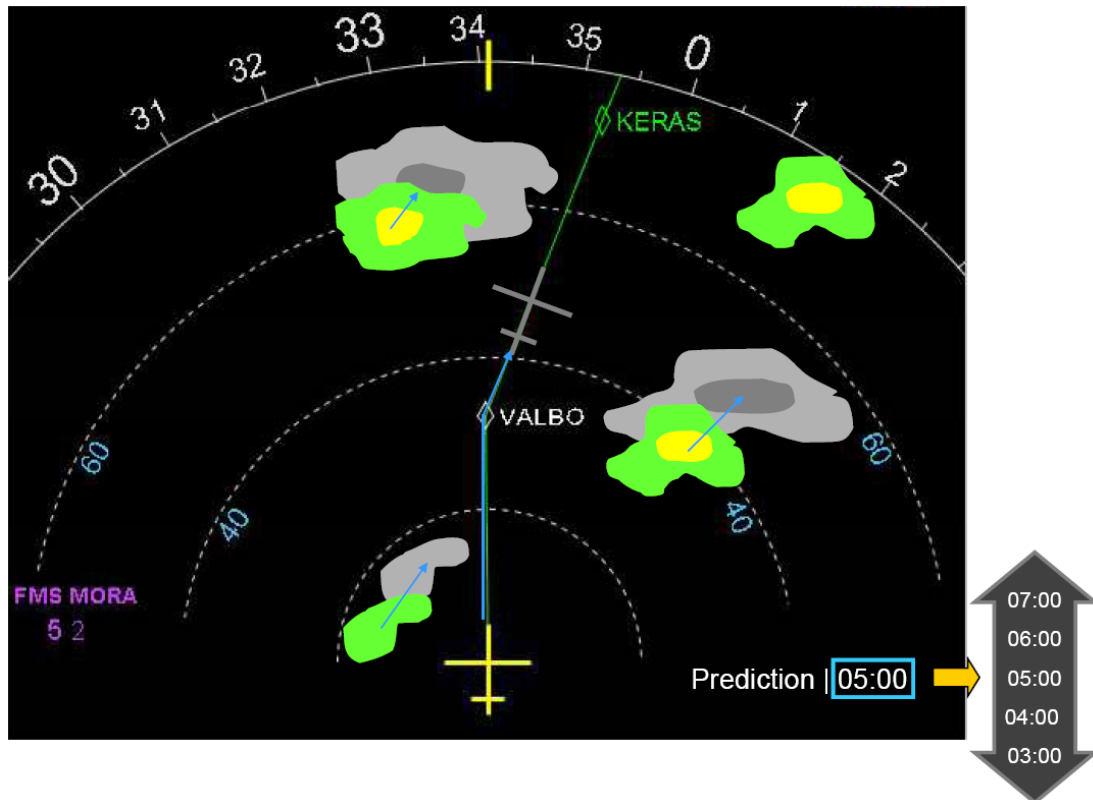


Figure 7-10: Weather prediction time is graphically interactive. Using the scroll-wheel the evolution of predicted weather is tracked.

7.2.3 Modification

In line with the A30X cockpit concept and because of the use of a revision support tool, the modifications are implemented graphically on ND.

A different interaction mechanism is used for performing a modification. The mechanism is clicking on a waypoint instead of hovering over a waypoint. Selecting one waypoint out of several that are close together or belong to different trajectories is done by the method described in the section display of constraints.

7.2.3.1 Graphical modification of constraints

To change or delete a constraint graphically, a sub-menu is added to the left-click menu of the MD called 'constraints'. This sub-menu gives access to a menu tree where the choice can be made between time, speed or altitude constraints: all constraints must be modifiable. On the next level three values are displayed using the same principle as on the constraint label to keep coherence between the two. From top to bottom the values are: the upper or late constraint, the estimate and the lower or early constraint.

The constraints are interactive and clicking on them allows modification. A new value can be entered by keyboard or by using the scroll-wheel (like prediction time). To delete a constraint it is sufficient to enter no value in the input field. Changing the value of a constraint of an ACT results in a TMPY. For a graphical explanation see the sequence in the figure below.

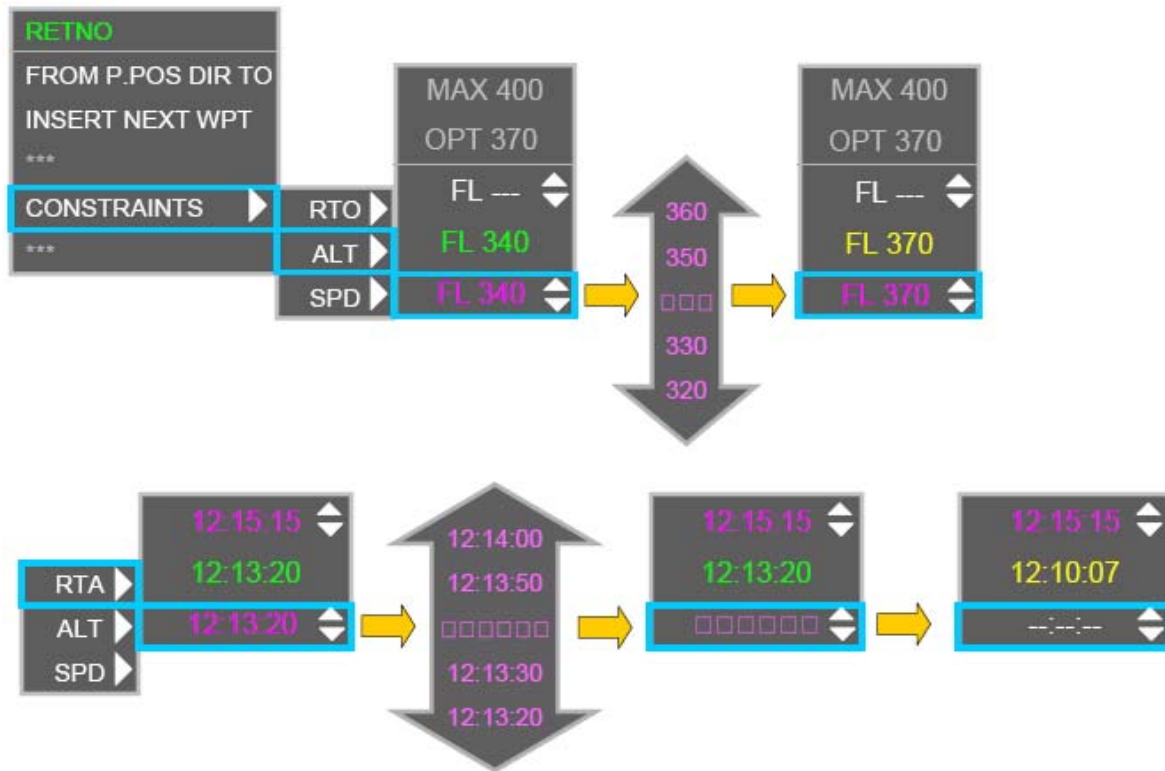


Figure 7-11: Sequences showing the modification of constraints. In the upper sequence an altitude constraint is modified. In the bottom sequence an RTA (early) is deleted. Notice that changing constraints results in a temporary trajectory.

The principle of the modification menu allows the pilot to force a different trajectory in two ways: inserting a numerical constraint (from an external source) and using the original as starting point to insert a constraint relative to the estimate.

The disadvantage of modifying the upper and lower constraint separately is that the insertion of an AT-constraint requires inserting two times the same value. Therefore when the second constraint is accessed it will have the same value by default as the first constraint entered.

Values outside the validity range of the constraints are inhibited from entering (e.g. negative altitude).

7.2.3.2 Selection of routes

Selection of routes is proposed as in the SEC management function, with some exceptions. Only the graphical part of the tool is used in combination with the RST. The FMS only proposes a selection of conflict-free (as far as possible) and valid routes. The business properties are checked using the RST.

7.2.4 Revision support

A revision normally unfolds in a more or less predetermined way in which the trajectory has a central role. Not only is it the object of the revision, but it also forms the carrier of all information related to the revision and therefore is a means of negotiating with ATC. Part of the information is the business properties of the trajectory. The trajectory has this function inside and outside the airborne domain. Several design goals are covered by one HMI solution that exploits the fact that revisions are conducted following a predetermined procedure and that the trajectory is at the centre of revisions. This HMI solution will be referred to as revision support tool (RST). The RST is task-based and integrates handling, negotiation and the evaluation of business properties. It relies on cooperation with graphical information access and modification functions.

7.2.4.1 Revision support tool

The RST aids the pilot performing the following tasks:

- Pilot initiated revision of a RBT
- Analysis (and negotiation) of a trajectory proposed by ATC
- Analysis of what-if situations and alternative trajectories

Modification is an important part of a revision. It can already be done on the MFD and the MD (ND). Combining the tool with the MD solves this problem and lets the RST focus on trajectory handling and display of trajectory properties. Cooperation with the MD is one of the key aspects of the revision tool. Like the SEC management tool the RST is placed at the same place as the FLPN-page of the MD. Access is via the button 'SEC INDEX' at the top of the screen.

The RST is illustrated in Figure 7-12 where the task-based principle is explained according to the following scenarios:

- A trajectory that is to be revised is opened with the '*Handling of the trajectory for modification*' function.
- The problem is examined using surveillance display (on MD) and the '*Missed constraints list*'
- Modifications are made on the MD and potentially a '*Undo*' action is performed to find a valid trajectory.
- The business properties are analyzed on the '*business properties and impact field*'
- When acceptable, the trajectory is shared with the '*ATC negotiation buttons*'
-
- Some time later a trajectory is received from ATC.
- The trajectory is compared with the trajectory sent to ATC via the '*Handling of the reference trajectory*' function.
- Properties are shown on the '*business properties and impact field*'
- Any dissimilarities between the trajectories are accessed by the '*Dissimilarity buttons*'
- When acceptable the trajectory is activated with the '*ATC negotiation buttons*'

The layout of the different functions is illustrated in Figure 7-12 while windows and drop-down lists are illustrated in Figure 7-13.

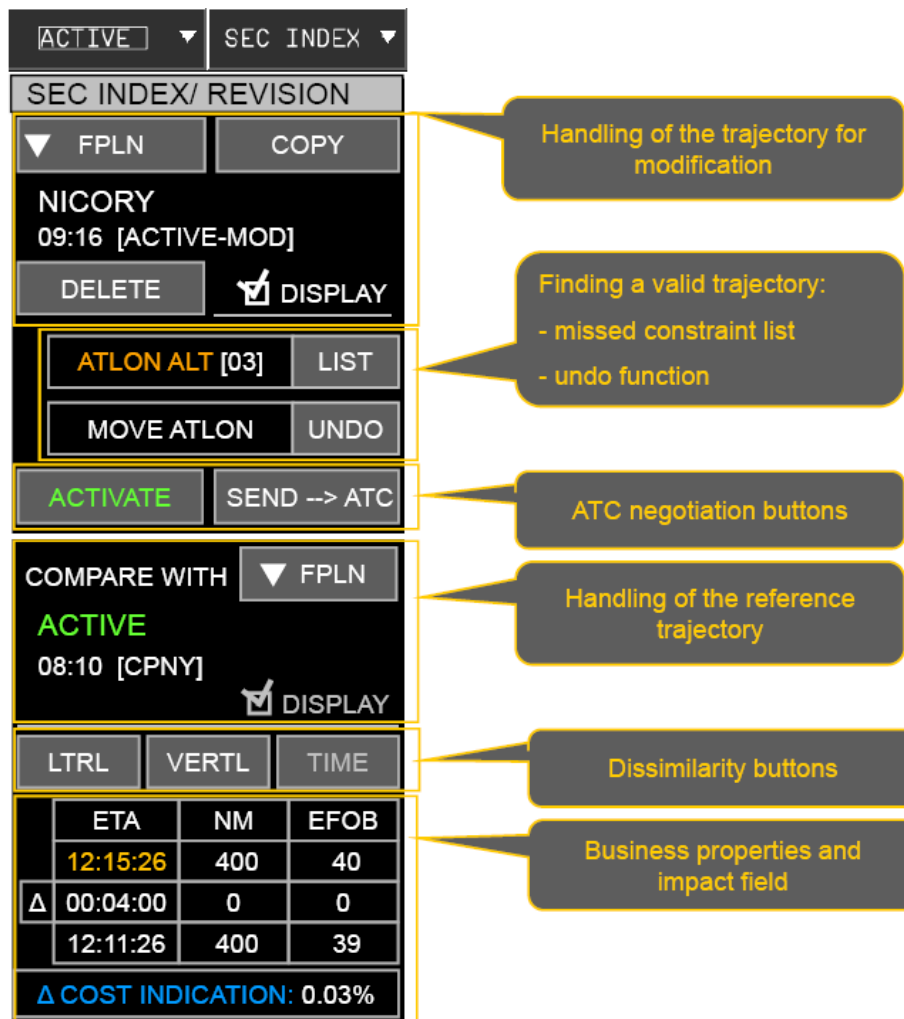


Figure 7-12: The revision support tool replacing the FLPN-list on the MD.

The layout follows globally the revision process from top to bottom: Handling of the trajectory for modification on top, followed by the functions that have to do with modification (missed constraint list and undo). Handling the reference trajectory is done lower on the RST, followed by the dissimilarity buttons. The business properties field occupies the lowest part of the RST.

There are some points of discussion about the layout. Firstly the ATC buttons are grouped and are placed under the first trajectory-handling block. This is done to clarify that it is the trajectory open for modification that is sent or activated. Placing the buttons at the bottom of the RST or separated, according to the sequence of tasks, would result in a conflict. In that case they are closer to the handling block of the reference trajectory, incorrectly suggesting that this trajectory is being sent or activated.

Secondly, the business properties field occupies the lowest part of the RST. Because of the layout of this field, it is plausible to put the field in between the two trajectory-handling blocks. Sandwiching the field means that the values correspond to the closest trajectory. Nevertheless the choice has been made to put it at the bottom because both trajectories must be selected before a comparison is made. Even though the reference trajectory is often active, this still has to be checked. The same goes for the dissimilarity buttons: the reference trajectory has to be verified before checking dissimilarities.

The different functions of the RST are presented in Figure 7-13 and are discussed consecutively.

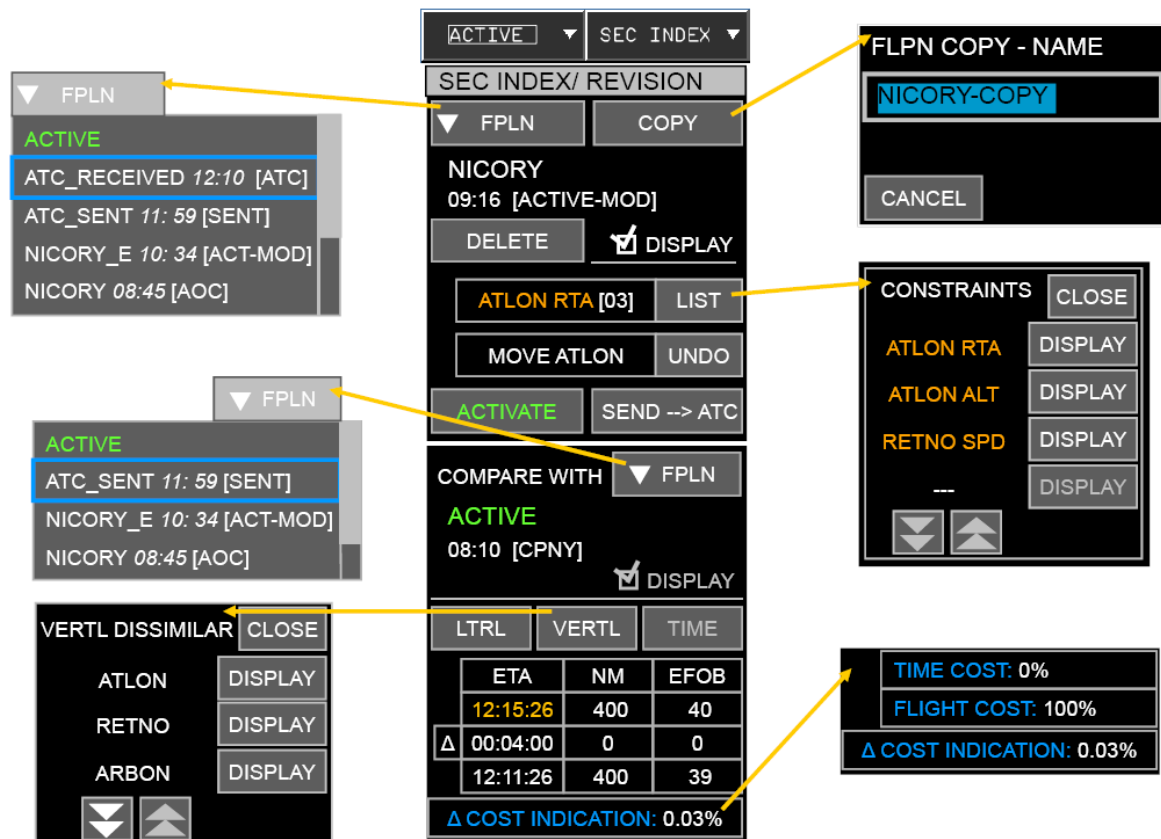


Figure 7-13: Windows and drop-down lists accessible via the RST.

7.2.4.2 Trajectory handling

The first action of a revision and the first function of the RST are to select a trajectory to be revised. This trajectory can be the ACT or a SEC. In order to accommodate negotiation with ATC, two dedicated SEC are available. The block for handling the trajectory to modify is displayed in the figure below.

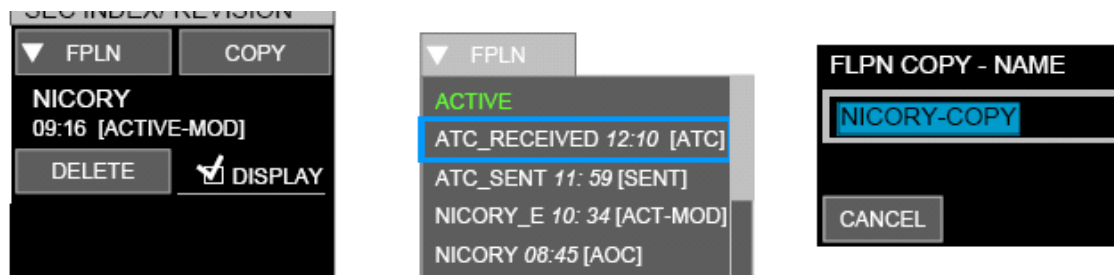


Figure 7-14: The handling block to open a trajectory for modification together with the FPLN drop-down list and the name window.

All the trajectories that can be opened are assembled in a drop-down list accessible via the FPLN button. The name is displayed together with the time of creation and the source of the trajectory to identify the trajectory. The trajectories are ordered in a way that allows fast access the most used trajectories: Line 1 displays the ACT, line 2 and 3 the trajectory received from ATC and the trajectory sent to ATC. Below the three initial trajectories other secondary are displayed ordered to time of creation, the most recent on top. A total of five trajectories are shown on the drop down list. Others are accessible using the scroll-wheel. Once opened, trajectory information is displayed on the central area of the trajectory-handling block. When an ACT is modified, TMPY is displayed as name. Only the information associated with the trajectories is borrowed from the SEC management tool.

The starting point of a revision is a new SEC: a copy from the ACT or (a copy of) one of the other SEC. For this purpose the COPY button (and function) is available. Clicking on it opens a window that allows the pilot to give a name to the SEC. A default name with the suffix '-COPY' is given by the FMS.

Below the trajectory identification field, a delete button and a display checkbox are available. Clicking the delete button removes a trajectory that is no longer of use from FMS. The button is greyed if the ACT or a dedicated SEC for sharing is open, because they cannot be deleted. When a TMPY is open, the button is a CANCEL button.

The display checkbox allows the pilot to display (and hide) the trajectory on the graphical part of the MD. A checkbox is chosen, because it serves as an indication whether the trajectory is displayed and an interaction element at the same time. If the ACT is open, the checkbox is greyed and checked because the ACT is always displayed.

The layout of the trajectory-handling block is such that the name and information of the trajectory is sandwiched between function buttons. The functions that open or create a trajectory are on top and the functions that delete or manage display are below.

7.2.4.3 Finding a valid trajectory

The purpose of the block 'finding a valid trajectory' is to aid pilots in the modification of a trajectory, which is done on the graphical part of the MD. The block is composed of a missed constraint list which purpose it is to easier identify missed constraints and an undo function to support modification by iterations.

The first constraint to be missed is the most important constraint and is displayed permanently. The waypoint name, the type of the missed constraint and the total number of missed constraints is available. Clicking on the button 'list' next to the missed constraint field opens a window where all the missed constraints are available. Next to the waypoint and type of every missed constraint a button 'display' is placed. Clicking on the button auto-adjusts the zoom and position of the MD in such a way that both the aircraft symbol and the waypoint with the missed constraint are visible. In this way the missed constraint is easily located. The list is removed by clicking on the 'close' button.

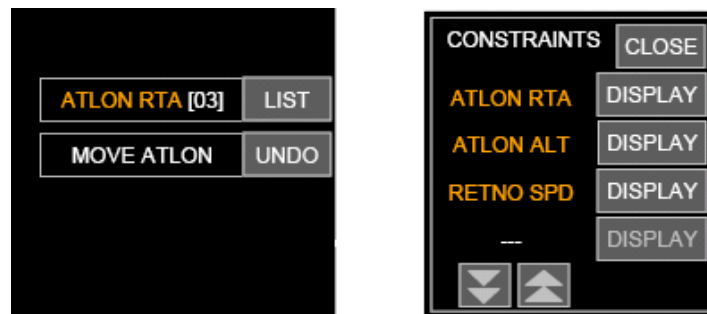


Figure 7-15: Finding a valid trajectory by using the missed constraint list and the undo function.

An undo function is added to the RST by means of a button. Clicking the undo button reverts the state of the trajectory to the point before the last action performed. Unlike on the A380, multiple undo actions can be performed. The last action that can be undone is shown in the field next to the undo button.

Business properties needed to find a valid trajectory are discussed in section 7.2.4.6.

7.2.4.4 Sharing with ATC

Because sharing and activation is linked directly to the opened trajectory, a button of these functions is placed on the RST.

Clicking on one of the buttons hides all trajectories other than the ACT on the MD. This is done because the display of other trajectories is no longer needed. When a response from ATC is received, the received trajectory can be loaded faster, because there are no trajectories to hide first.

Activation swaps the ACT with the SEC. If the ACT is opened activation is not possible and button is grey. If a part of the trajectory is not-agreed, the button is white and if the trajectory has the status agreed (negotiated with ATC) the button is green. Activation of a trajectory is the pilot's responsibility and this colour-coding is to indicate when it is safe to activate the trajectory. When the revision is performed through a TMPY, the button shows 'INSERT' in yellow.



Figure 7-16: ATC buttons

7.2.4.5 Comparison and dissimilarities

Comparison is used for two purposes. The first is determining the trajectory with the best business properties, which will be discussed in the next section. The second is that the modifications made by ATC during negotiation are not always clear, so the dissimilarities between sent and received trajectories should be displayed.

A second, slightly modified, trajectory-handling block is available to select the reference trajectory to compare with. The copy and delete buttons are removed, because these functions are not used for the reference trajectory. The text 'compare with' is added to give the pilot a better orientation on the RST.

A reference trajectory is selected by clicking the FLPN button using the same interaction as selecting the trajectory for modification. By default the ACT is used as the reference trajectory to present the impact of modification. This default state is set when the RST is opened or when the trajectory for modifications is deleted, sent or activated. The display check box has been kept, because it is still necessary to control the display of the trajectory.

A difference between two trajectories means that there is a dissimilar waypoint, time or altitude constraint. Comparison between the profiles of two trajectories is done graphically. The dissimilarities may however lie outside the viewable range of the MD and that's why dissimilarity buttons are available on the RST. Three buttons for lateral, vertical and time dissimilarities give access to three lists similar to the missed constraint list. See figure below

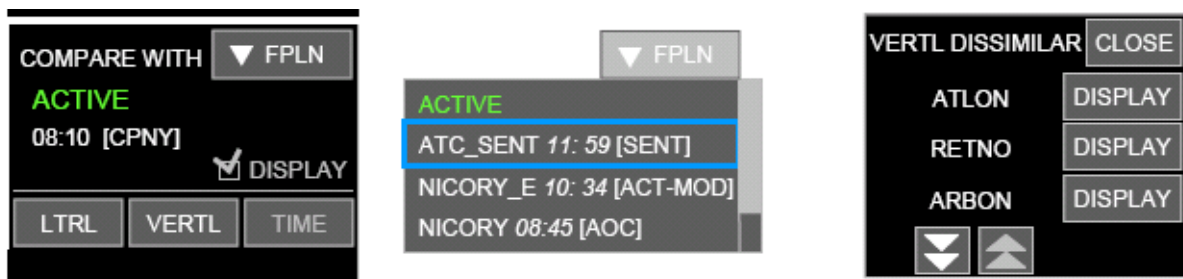


Figure 7-17: Left: the handling block for the reference trajectory and the buttons to access the dissimilarity lists. In the middle and the right the reference trajectory drop-down list and a dissimilarity list is presented; the other lists are the same.

On the list accessible by the 'lateral' button a list of waypoints is displayed that have a dissimilar position. Colour-coding is used to indicate to which trajectory the waypoints belong:

- Green for waypoints of an ACT that have no equivalent in another trajectory.
- White for waypoints of a SEC that have no equivalent in another trajectory.
- Grey for waypoints of a reference SEC that have no equivalent in another trajectory.

The list accessible by the 'vertical' button shows waypoints that have the same lateral position, but have dissimilar altitude constraints.

The list accessible by the 'time' button shows waypoints that have the same lateral position, but have dissimilar time constraints.

The waypoints are ordered on encounter time, so waypoints to be reached first will be on the top of the list. Just like on the missed constraint list, 'display' buttons on the list allow fast navigation to the waypoint in question.

7.2.4.6 Business properties and impact field

Business properties are presented when comparing trajectories in order to aid in optimizing the trajectory. If one trajectory is modified, the difference in business properties with the original represents the impact of the modification. The business properties of a trajectory are given for the entire trajectory.

The business properties field contains the following information (see Figure 7-18):

- Time, length and fuel information including impact.
- The impact of modifications by a cost indication
- Details of the cost indication on a second information layer

	ETA	NM	EFOB
	12:15:26	400	40
Δ	00:04:00	0	0
	12:11:26	400	39
Δ COST INDICATION: 0.03%			

Figure 7-18: Business properties and impact field

The information is given for the final approach fix; beyond that point the margins of trajectory changes are limited. (The ground part of the trajectory could be added in a later stage.)

The left column shows time (Estimated Time of Arrival), the middle column length (distance to go in NM) and the right column fuel (Estimated Fuel On Board) of which the titles are shown on the upper row. Below, on the second row, the values of the trajectory for modification are presented. The bottom row presents the values for the reference trajectory. In between these two rows, the difference of the values is given. The values turn amber if one RTA in the trajectory is missed or distance or predicted fuel is less than the required minimum.

The delta cost indication is the difference in estimated cost for the reference and modified (compared) trajectory, expressed in percent. It is composed of a fixed number of variables that include parameters originating from the aircraft and from the ground. The indication is meant to tell the pilot whether a modified (compared) trajectory does not impose a large cost difference; a cost increase is often unavoidable when modifying a trajectory.

Clicking on the cost indication shows the composition of the delta cost indication. The pilot uses this information to know what modification to make to optimize the trajectory. The underlying business properties are hidden. Clicking again makes the window disappear.

TIME COST: 0%
FLIGHT COST: 100%
Δ COST INDICATION: 0.03%

Figure 7-19: Details of cost indication.

At a high level, the pilot can change the RTA and length of the trajectory. The length should always be as short as possible (assumed that winds don't play a role) and RTA should be such that the costs as a consequence of arrival time and the costs as a consequence of flight are optimized. The window presents the following information:

- Time costs
- Flight costs

7.2.5 Handling: an overview of trajectory transitions

In this part an overview of the mechanism for handling trajectories that is put in place for this HMI is presented.

Conform the principle of the A380; the trajectories received from ATC are put in a dedicated SEC to easily locate the received trajectory. A newly received trajectory thus causes the old one to be overwritten. This is however no problem, because the old trajectory is outdated at the moment the new one is received. Because the concept of comparison is used to find the modifications of ATC,

the sent trajectory is copied in a dedicated SEC as well. In this way both the sent and the received trajectory are found in a fixed place.

The response to a shared TMPY is also received in the dedicated SEC. This is not very consistent, but it avoids that a TMPY is overwritten by a received trajectory when pilot is making modifications. Both the TMPY and the SEC can be activated. A TMPY is inserted only when it has been approved by ATC with the pilot's responsibility. Activating a SEC means swapping with the ACT.

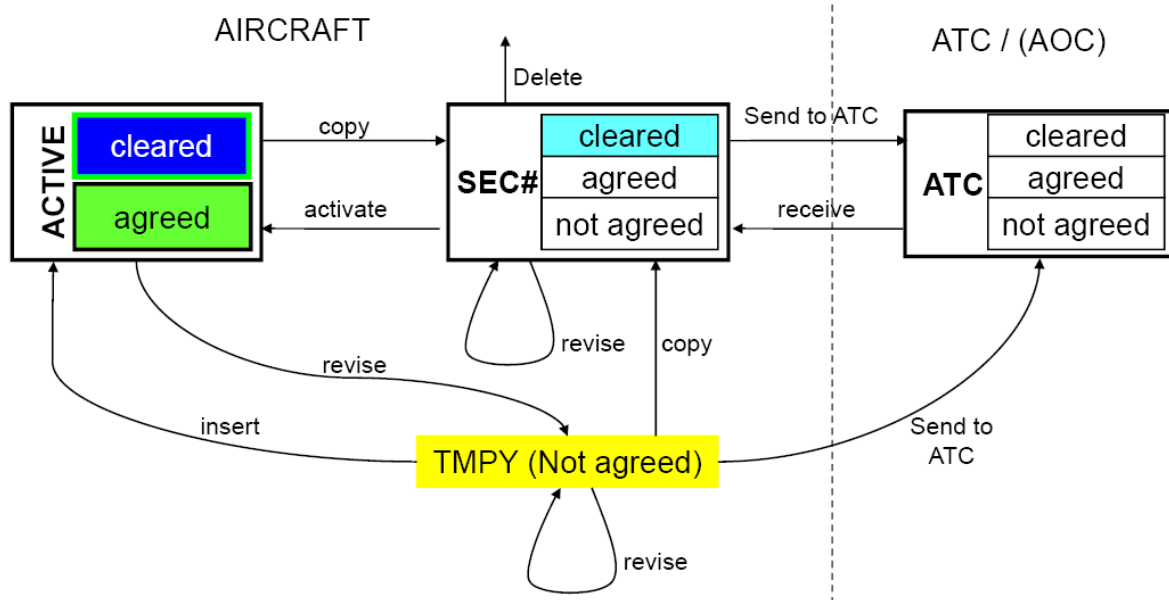


Figure 7-20: A schematic overview of the different trajectories and the actions to switch from one to another. The relation with ATC is also represented.

7.3 Implementation

The HMI design is implemented on an existing research simulator called O3P to evaluate the HMI in a more realistic (dynamic) cockpit environment with the right screen layout and interaction mechanisms. The implementation is carried out by a subcontractor by means of software programming in close cooperation with the designer.

A description of the research simulator is given, followed by the particularities of the implementation.

7.3.1 Research simulator O3P



Figure 7-21: the research simulator is used for early prototyping of HMI design

'O3P' stands for 'Outil de Prototypage des Postes de Pilotage' in French, which means an early prototyping tool for cockpit design. The objective of the simulator is to provide a simulation platform to support determination of needs and validation of HMI design with test pilots and flight test engineers. After validation, functions are tested for ergonomics and human factors in a realistic simulator with representative cockpit hardware and layout. The O3P simulator is relatively easy reconfigurable which permits several iterations to be performed and to support different aircraft programs (A380, A350, and A30X).

O3P consists of displays, (FMS) models and control panels that are linked via a computer network. There are 8 screens, driven by 8 dedicated computers, on which cockpit displays are presented. Three configuration computers are used for hardware, software and model control. The FCU, KCCU and tablet keyboards are implemented by hardware. Other control panels like the EFIS CP, conventional flight control (e.g. thrust levers) and screen configuration buttons are soft implemented. Interaction is achieved via touch-sensitive screens. The different displays (PFD, ND, MD, MFD, and OIS) can be reconfigured on other screens. The FMS models are coupled with a commercially available flight simulator software package to provide outside view projected in front of the pilots.

7.3.2 Limitations of implementation

The design for 4D-operations has quite a large impact on the existing cockpit, including FMS and ATC communication. As a result implementing the HMI design in the cockpit proved to be difficult and it was decided to form a separate branch (entity) in the simulator software to implement 4D functions. Combined with limited time it also meant that concessions had to be made.

Fixed scenarios are used for the evaluations. Pre-defined steps to be followed during the scenarios solve the fact that sharing trajectories with ATC was not possible. Pre-defined trajectories with clearances are inserted manually via a console. Sending a trajectory to ATC triggered the automatic loading of a predefined trajectory after a certain delay. Other functions could be performed more or less randomly.

Certain functions could not be implemented in their original form and others were not implemented at all. The following items are not implemented:

- Functions on the VD are not implemented. This meant that trajectory display, the time bars on the VD and the trajectory switching mechanism are evaluated using PowerPoint.
- Propositions of SEC segments are not integrated in the new software branch. As a consequence there is no implementation of automated selection of conflict free and valid routes.
- Certain functions were not backed up by FMS functions. 4D optimum vertical profiles are not calculated. Cost indications used dummy values.

Limitations for implemented items are:

- Opening waypoint labels by hovering over it of multiple closely spaced waypoints required an intermediate pop-up similar to a waypoint menu for selection of the desired waypoint. As a result, an extra step had to be performed to open a waypoint label and a conflict was created between accessing the constraint label (via hover) and the menu (by clicking). When hovering over a waypoint and the constraint label appeared, it was not possible to access the waypoint menu.
- The constraint label always appeared to the right and below the cursor. This meant that the labels could be displayed outside the viewing area of the screen. The cursor thus has to be placed in such a way that the labels are still visible.
- The not-agreed ATC-status of the SEC is not implemented (dashed white). A global overview of trajectory display is presented using PowerPoint.
- In the constraint-modification menu, constraints are to be entered starting with the low/early one.
- In the constraint-modification menu, both constraints of a window constraint are deleted together.
- Weather prediction display is implemented with pre-defined images. The prediction of the aircraft symbol does not always correspond to the predicted route. In order to assure the right display, ARC mode and a range of 160 NM have to be selected. Weather predictions are accessible via the SIGMET checkbox in the right-click menu of the mission display.
- The FMS limits the number of SEC to 3. This means that next to the dedicated SEC sent and received by ATC only one empty slot is left. Only one copy can thus be made. Every new copy-action overwrites the last one in the slot.
- The UNDO function is unavailable for a SEC.

During evaluations the following problems occurred with functions that were validated earlier:

- ATC negotiation mechanism put in place is not always smooth:
 - o No SEC is received after sending a temporary.
 - o Reset to default of RST after sending/activating does not work.
 - o The trajectory received after sending a SEC to ATC has a discontinuity.
- Making a lateral modification causes the simulator to crash. A restart of the simulator is obligatory.

7.4 Evaluation

7.4.1 Evaluation objectives and criteria

7.4.1.1 Objectives

The main objective of the evaluation is to verify and refine needs that were determined earlier. Functions and information requirements have been verified earlier by the reference pilot. It is believed that the determination of the requirements is performed well and little changes are expected. These changes will appear when evaluating the HMI design.

Besides information and function requirements, it should be checked whether the HMI design corresponds to the needs from a user and system point of view to perform a task. This is determined from feedback on HMI design, which should contain information about the degree that a solution aids in performing a certain task. There will thus be a focus on the functional aspect of a solution (operational value of the HMI) in contrast to details about HMI (Human Factors), as the HMI is the result of the first iteration and not mature. Verification of needs from a system perspective follow from feedback of the HMI related to the A30X concept.

A secondary objective is to obtain recommendations for further HMI design concerning 4D-operations. As stated earlier this is less important, because of the early design phase.

For a productive evaluation, pilots are to be informed about the developments of 4D-operations and A30X cockpit concept. Therefore SESAR and 4D-operations have to be presented, together with an explanation of the A30X concept.

7.4.1.2 Criteria

Every information and functional requirement has to be validated. This is done by stating the task (automation and human) according to the operational concept as laid out in the scenario and asking the pilots to their needs. The question is repeated when the corresponding solution is shown, which shows the boundary between automation and human. The functional need of a HMI solution is verified if the pilots approve that the solution covers information and functional requirements associated to the pilot task for 4D-operations.

System needs are verified when the proposed solutions are well integrated in the A30X cockpit concept. This is to be approved by pilots as well.

Solutions are checked by examining whether the proposed HMI solutions sufficiently cover the pilot task (as laid out in the scenario). Every solution is checked whether it aids in performing the pilot task and - if this is not the case - new needs are to be identified. The procedure is to ask three questions to determine the maturity of the solution according to the scheme below:

Ability: Can the task be accomplished with the solution?

This questions checks if the solution is made for the task. If answered no, the solution is not adequate.

Feasibility (or usability): Can the solution be used in practical circumstances?

The answer to the question has to take into account operations, other pilot task, available time etc. If answered no, the solution is unusable because it requires too much effort of the operator.

Performance: Does the solution present a clear performance benefit?

The solution may provide an enhancement in speed, controllability and perceptual demand. If answered no, the solution is acceptable, but improvements are welcome to make it easier. If answered yes, the solution allows the task to be easily performed.

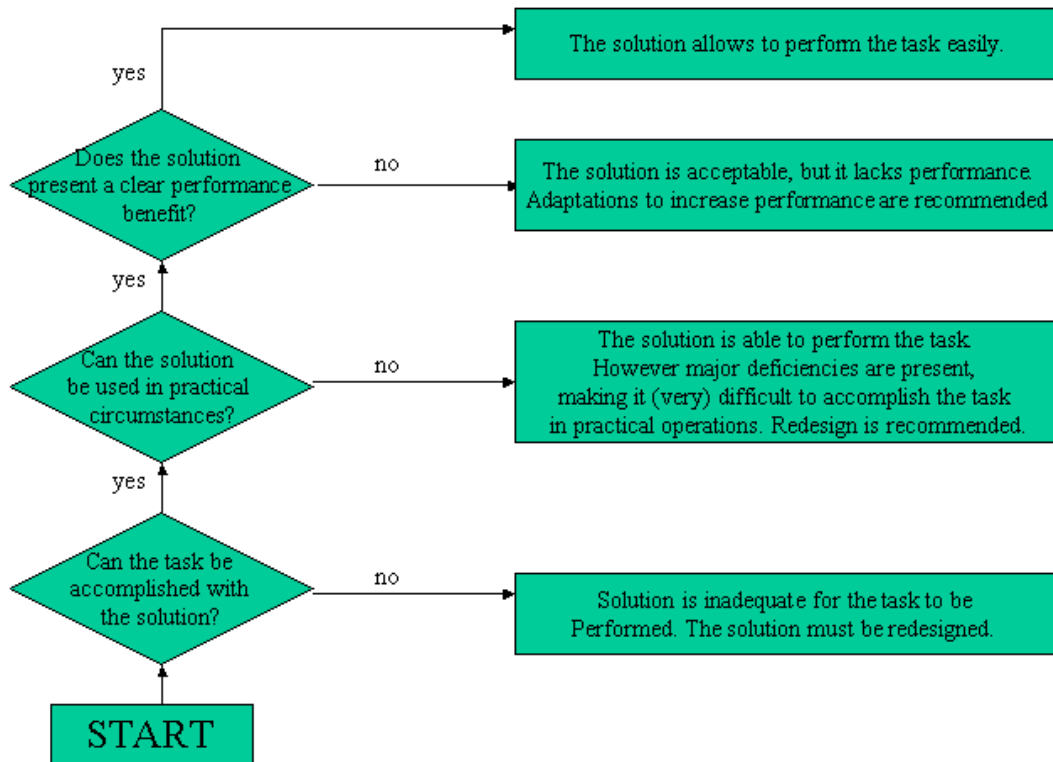


Figure 7-22: Scheme to assess the usability of a HMI solution

This scale is a highly simplified version of the Modified Cooper Harper assessment scale and focussed on the degree a task can be performed instead of mental workload. The reason for this is that the solutions in this research are not optimized according to human factors and it is more important to evaluate whether the solutions provide the right functions to perform a task. Of course mental demand influences strongly the feasibility of the solution and the performance question depends very much on mental workload being low. No other solutions are available to compare with, so pilots value the performance of the solution on speed, controllability and perceptual demand.

7.4.2 Evaluation setup

A number of 6 pilots have participated in the evaluation sessions. 2 pilots convoked could not participate because of other (last-minute) obligations. All pilots are either experimental test pilots or flight test engineers at Airbus. Experimental test pilots are specialized in handling and operations, while flight test engineers have a profound knowledge of aircraft systems. Training pilots work with airline pilots and have knowledge of commercial operations. Each pilot is specialized in a certain domain (task allocation) of which he or she is a referent. Preferably the evaluations are held in a duo: a flight test engineer and a test pilot at a time. Due to planning constraints this has not always been possible. Every session is attended by one or more observers that aid with set up and taking notes. All of these observers possess at least general knowledge about 4D and the A30X cockpit.

Pilot	Session	Function	Task allocation
1	2	Experimental test pilot (Reference pilot)	ATM, SESAR, 4D
2	2	Flight Test Engineer	ATM, SESAR, 4D, COMM
4	1	Flight Test Engineer, Training	A380, Flight control
6	4	Experimental test pilot	A30X, Future cockpit
7	3	Test pilot	FMS
8	3	Flight Test Engineer	FMS

Table 7-1: Details of the pilots that assisted in the evaluation sessions.

The evaluations sessions have a duration of 3 hours and consist of a briefing, a short explanation and tryout of basic functions, 2 scenarios and a de-briefing. The sessions are conducted on the hand of an evaluation guide that states specific pilot tasks, evaluation objectives and questions to be asked.

The first scenario is a revision process without the use of the revision support tool. The goal is to present and obtain feedback about trajectory display, revision of the entire trajectory with ATC in-the-loop and weather predictions. The second scenario follows the task-based layout of the revision support tool. The scenarios for evaluation are described briefly below.

Scenario 1:

A clearance request is issued to ATC and a new cleared segment is received. Successively a short-term revision is performed with ATC in the loop. Weather predictions are analysed. Due to weather a lateral deviation TMPY is constructed from the active trajectory and shared with ATC. The revision is agreed by ATC and received in the form of a SEC. Activation ends the scenario.

Scenario 2:

The pilot investigates a number of possibilities to optimize the trajectory. He makes use of the revision assistance tool to find a valid trajectory. When this is found the trajectory is proposed to ATC. The trajectory is not accepted by ATC, but ATC proposes another solution: the use of another STAR/RWY. The pilot examines proposed RBT by using the revision support tool, in particular the dissimilarity list and the comparison field. After the pilot has decided the trajectory is acceptable, he agrees by activating the trajectory. Finally he deletes the previous made secondary.

7.4.3 Evaluation results

7.4.3.1 Difficulties encountered during evaluation

This project combines the two very new concepts, which are 4D-operations (defined by SESAR) and the A30X. Both concepts are under ongoing development and pilots are only partly familiar with them. As a result it proved to be difficult to give a global picture and at the same time discuss the details of the new way of working. The result of being unfamiliar with a certain subject is that a lot of the time is used for discussion of the concept, and not the needs associated with it. Besides it is difficult to allocate needs specifically to a concept. It is the task of the designer (that conducts the evaluation) to explain the concepts clearly to the pilots.

The following aspects were subject to incomprehension:

- The relation between the MD and the ND in the A30X concept. Secondly the relation between the MD and MFD and the VD on the MD.
- The hypothesis of using managed mode.
- Window constraints and how to use them.
- The principle of departing with a pre-defined intended route.
- The principle of using multiple iterations for negotiation.

The problems and malfunctioning of the O3P simulator caused the evaluation not always to run smooth and sometimes it was unable to use certain functions. This matter has been explained thoroughly at the beginning of the simulation sessions. However, the limitations in the simulator are thought to have influenced the feedback of the pilots somewhat.

7.4.3.2 Access to trajectory information

Time bar on VD

Extensive instruction was needed for correct interpretation of the time bar on the VD. Pilots are unable to interpret the symbology of the time bars, which are therefore not intuitive enough to be feasible.

Waypoint constraint label

The task of monitoring can be accomplished, but mayor deficiencies require redesign. A thorough explanation was needed for the pilots to understand the HMI.

Trajectory display

The proposed solution for trajectory type and ATC status has the appearance of being coherent, but redesign is highly recommended because the proposed solution uses too many states. Magenta is preferred for the cleared part. If the cleared part is seen as a constraint this makes sense.

Trajectory switching on VD

The trajectory switching function is assessed not usable. It is difficult to compare two trajectories when you have to switch between them: no precise comparison can be performed

7.4.3.3 Weather predictions

Although the HMI was not fully developed, the envisaged HMI is feasible, but some modifications are required to increase performance. Points for improvement are:

- The prediction time modification must be continuous. The predictions have to be displayed in real time according to the prediction time. In this way an evolution of the weather is visualized.
- If prediction time is clearly displayed, current weather is not to be displayed at the same time as predictions. When interacting, the pilot knows that it is predicted weather. No difference in colour between actual and predicted weather is needed, because then both will be avoided.
- The weather predictions should stay displayed on the screen in order to construct a trajectory around the weather predictions. There must be a clear button available that allows quickly exiting the prediction mode.
- Prediction accuracy degrades when prediction time increases, this must be accounted for.

7.4.3.4 Modification

Sec selection

The SEC management tool has the potential of being very useful. However dynamic interaction is needed to state in the HMI. A fluent integration with existing cockpit and a future RST is mandatory.

Modification of waypoint constraints

The fact that HMI is based on the possibility of inserting window constraints means that the HMI is not suitable for use in practical circumstances. Changing the constraints in a menu is logical, but integration with the constraint label should be considered.

7.4.3.5 Revision support

The RST was considered complex and not intuitive; an instruction was necessary (which is normal). After the instruction pilots understood better the function and underlying principles of the tool. Pilots had doubts whether the function is usable in practical circumstances.

- The fact that two trajectories are compared is not easily perceived. There are a lot of buttons and information. Texts should be added that guide pilots what buttons to use.
- The coordination with the graphical part of the MD allows enhanced functions using the best of both worlds.

Handling trajectory for modification

The functions of the trajectory-handling block were rated positively. In general pilots were able to open, copy, display and delete trajectories without instructions. Opening a trajectory via the FLPN drop-down proved to be the most demanding task, because no action was associated with 'FLPN'. Modifications to improve this are necessary.

Share and activate

The buttons are intuitive, the activate and send buttons speak for them. Because they are quickly accessible they present a performance benefit.

Handling of reference trajectory

The position within the layout of the RST is not intuitive for handling of the reference RBT. The handling block itself is intuitive; see feedback on the handling for the trajectory for modification.

Dissimilarity lists

The dissimilarity lists are regarded as a good way to find dissimilarities. They are considered feasible; the performance benefit depends on how often and in what circumstances the function is used. Cosmetic improvements are however necessary.

Comparison field and cost indication

The HMI was not intuitive. After an instruction the field was understood, but redesign is recommended for performance benefit. The pilots remark that cost information will be increasingly important.

7.4.3.6 Evaluation conclusion

Although quite some difficulties were encountered during the evaluation sessions, they yielded valuable information about functional needs and HMI of 4D-operations. Comparison of initial and obtained needs pointed out that most functional needs were verified and fine-tuned, due to the larger group of pilots consulted. Some issues remain to be investigated in more detail:

- The display of ATC status is partly supported. The two visions were:
 - o Display of the cleared part and ATC-status of the trajectory is inherent to 4D-operations
 - o Only two statuses (types) are needed: the one that you're flying and the one that you're aren't flying (TMPY).
- The need to insert window constraints was not supported by pilots.
- The need of finding a valid trajectory (the missed constraint list) has not been verified. Based on the pilot's explanation the need certainly existed (I want to see if I am still able to attain the constraint), but the link with showing the (first) constraint that is missed was unclear. When asked what their need was, pilots described exactly what the missed constraint list is capable of. It is feared that it is not understood that the function is only used in managed mode.
- The need for a task based tool that aids with performing a revision is verified. However it is feared that the RST is too complex for the task to perform and the need for such an elaborate tool does not exist. It is hard to say how much the proposed RST will be used in future 4D-operations. None of the pilots was able to give a prediction on this matter.
- The need for comparison is verified to identify dissimilarities between two trajectories. However the need to compare two trajectories to find the optimum is not verified. (This is not the same as the impact of a modification). Other functions are dependent of this need: Trajectory switching on the VD and the use of a reference trajectory.

HMI evaluated positively with respect to the related needs were:

- Weather predictions
- Selection of proposed SEC
- A tool that aids with a revision (RST). The combination of graphical and alphanumerical worlds.
- Business properties and the ability to see the impact of modifications
- Graphical trajectory sharing functions
- Finding dissimilarities

The majority of the proposed HMI did not adequately fulfil the pilot's needs. The criteria posed at the beginning of this chapter were not obtained. Many of the proposed interaction were too complex. Although some training is normal, often detailed instructions were needed, which is a sign that it was not intuitive to use the HMI. All HMI concepts need (thorough) redesign before they meet requirements needed in a representative cockpit.

The proposed solutions did not pose a performance enhancement for monitoring and modifying 4D-trajectories. The real novelty in the design, the RST, suffered from complexity but the principle of a task based revision support tool was considered an improvement, notably the access to the impact of modifications.

The HMI was used to support the identification of pilot needs and the objective was not to obtain a HMI with operational requirements. Valuable feedback has been obtained about the HMI for managing and sharing 4D trajectories, as well as the global cockpit concept.

One of the important discussions was the relation between tactical and strategic operations and the boundary between them. This includes the repartition and relation between different displays.

8 Assumption analysis

Why an assumption analysis?

Why does this report contain an assumption analysis? Normally an analysis is made before stating an assumption. There are however three main reasons for this chapter.

Some assumptions in this report are based on specialist consultation (including pilots). This information source is (often) reliable because of the experience and expertise of specialists. In addition, specialists have been easy accessible. On the downside, specialists are humans that usually have certain subjectivity. This can result in overconfidence or reservation with respect to technological capabilities that in turn influence the assumptions based on specialist feedback.

In this research assumptions have been made about the capability of automation that has a direct influence on the HMI. The technical analysis that takes away the subjectivity has only partly been treated in this research.

The second reason is that due to the assumptions taken there are little real novelties in needs and HMI design with respect to 'previous work'. The requirement that the HMI is designed for the A30X is at the basis of these assumptions. They have inhibited however to take fully into account the current status of technology (refer to 2.1).

The HMI design and evaluations have been based on the taken assumptions. Time and resources for a second set of design and evaluation sessions have not been available. In order not to confuse the (original) design procedure with discussions about assumptions, the assumption analysis is presented in a separate chapter.

The goal of this chapter is to place the research in a larger, more scientific context.

The analysis procedure

The procedure of the assumption analysis starts with stating the original assumption within its context and what the basis has been for the assumption. The risks that are involved in taking a wrong assumption are quickly treated. The main part of the analysis consists of the investigation of inaccuracies or inconsistencies. In this part an assessment can take place for the case that implementation on the A30X is not required. Finally it is evaluated whether the assumption still holds and - if not - what a correct assumption would be.

The assumptions that will be analyzed are restricted to the most contestable ones:

- Automatic trajectory construction
- Direct Feedback
- Weather predictions

For example, the assumption that full managed mode is used will not be analyzed in this chapter, because the reasons for assumption analysis do not apply. Using managed mode is already a standard way of operating, especially for long-term goals.

8.1 Automatic construction of trajectories

In section 5.1.1 the assumption was made that automatic construction of trajectories will not be available in the A30X (automation level 2 and 3). This relates directly to the boundary between automation and human and therefore has a large influence on the HMI.

Specialists estimated the development effort (costs) too high in order to have a function with sufficient quality available for the A30X. Sufficient quality is related the usefulness of the function in the cockpit. Difficult points are thought to be the lack of mature technology that can provide a detailed, up to date weather image and the required processing power to take into account the entire 4D space.

The risk in making the wrong assumption here is that the final product (cockpit) could have a weaker position with respect to products offered by competition. This assumption has a direct and large impact on pilot task, pilot operation and as a result HMI, which are important criteria for customers because they influence operational costs. It should be mentioned that not having state-of-the-art technology is not a risk for this assumption (and in general).

Two critical points are identified for this assumption. At first the performance requirements (in terms of accuracy) for the automatic constructed trajectory may be not as strict as one might expect. The goal is not to generate an automatically generated trajectory that is guaranteed to be totally conflict free, but to aid the pilot in performing his/her task.

The performance baseline is thus the performance of the pilot. If automatically constructed trajectories are better (in terms of business objectives) than trajectories constructed by pilots, there is already an interest in automated construction. Automated trajectory deconfliction of traffic has been investigated in [10] and the result is that automation is better in generating conflict resolutions in a 4D-space. The investigation does not treat weather deconfliction, but if weather is well-defined the result may well be the same.

In addition to less stringent performance requirements, different performance requirements for tactical and strategic trajectory generation could be distinguished. Although the strategic trajectory may not always be 100% conflict free and thus the probability of a revision is higher, it may still be easier to generate several trajectories instead of modifying one manually. This is contrary to the principle of 4D-trajectories (predictable operations), but in line to the concept of operations because certain elements remain unknown; pre-flight planning is done in this way.

The second critical point is the costs associated with the development of automatic trajectory construction. Automatic trajectory construction (often as part of autonomous operations) is a popular research topic, because it is widely regarded as a game-changing step. Autonomous operations are performed by unmanned aerial vehicles today and that experience will lead to better understanding and a higher level of maturity of systems. This means that technology will be more available.

The question remains whether the development costs can be justified by the benefits of automatic trajectory construction (while maintaining safety standards). In the original assumption, commercial and 'likely to happen' arguments have been more important than technological arguments. The critical points however show that there are indications that the cost of useful automatic trajectory construction is lower, so the benefits don't have to be very high to justify the development.

To conclude the assumption analysis it is stated that the original assumption is valid in perspective of the A30X concept, because specialist feedback is the most consistent information available in the context of this report. However, it is too early to freeze the assumption for a development that will last more than 10 years and it should therefore be re-evaluated in later stages of development.

At this stage it is interesting to take the commercial arguments (A30X) out of the equation and see the impact if the assumption is different. The question that emerges directly is: what is a suitable assumption for automatic trajectory construction? In section 4.2.3 different levels of automation were presented, of which level 2 and 3 constitute the difference between pilot supervised and autonomous trajectory construction. Two studies address this topic in a larger context:

- iFLY [20] has the objective to develop airborne self separation with traffic and hazards zones for the en-route phase of flight. The study is situated in the SESAR framework and relies partly on the self separation function of ASAS. The target date is in line with SESAR as well (2025-2035) but earlier implementation is investigated.
- IFATS [19]: The Innovative Future Air Transport System project investigates a fully autonomous air traffic management concept with the approach of investigating the 'technical possible' and not the 'likely to happen' system. It has a long term view with a target date of 2040.

The former is less innovative than the latter and has a target date that is earlier. However both studies have target dates that are well past the target date used in this study. As alternative automation level 2 is assumed: automatic trajectory construction is possible, but verification by the pilot is needed. This corresponds to the view of SESAR: Humans will be central as operators and decision makers.

In this new perspective automatic constructed trajectories can be optimized with respect to business properties and - with the right information - to business objectives (costs). In the last case the additional role of automation would be to respect safety limits (refer to 4.3). Because automation level 2 is assumed as alternative, optimization with respect to business objectives is not taken into account. The discussion whether automation can assure this safety - closely related to the discussion whether autonomous flight is possible - is left for other studies.

8.2 Direct feedback

It was assumed that direct feedback of conflicts when modifying a trajectory is not available in the A30X. Direct feedback would present an indication about the outcome of a modification before it is inserted, thus allowing to avoid iterations when modifying.

Instant feedback of continuous modification is demanding in terms of calculation power, because every slight movement of the cursor triggers another calculation cycle. Lower accuracy or response time decreases calculation power, but the usefulness of inaccurate or slow calculations is doubted. It was assessed that the onboard calculation power of the A30X will not be sufficient to support direct feedback with enough performance.

The inconsistencies of direct feedback follow in great extent the critical points of 8.1, because performance (accuracy) and computation limitations are also at the basis of this assumption. The performance cost ratio may be different than assumed by specialists for the A30X. Like in the previous section, this assumption should be left open until a later stage. It has to be added that direct feedback is no longer of use for the pilot if automatic construction is possible. In that case the iterations of finding a valid and conflict free trajectory are done by automation.

8.3 Weather in 4D

First of all, weather predictions have not been the core of this research. They have been used to illustrate time dependence of hazards and to facilitate trajectory modifications focusing on the time dimension.

It was assumed that, with the advances in technology, weather predictions can be shown with the same quality as radar weather today up to a certain (useful) prediction horizon.

There will be an improvement of weather performance in the cockpit, notably by ground weather uplink, because it is one of the enablers defined and required for the operational concept. Ground based information will make up for the uncertainty that is introduced with prediction time. Because uncertainty increases with time this is only true for a limited prediction time. Following the discussion about automatic trajectory construction, sufficiently well-defined hazard zones will not be available, which means that pilot interpretation is still needed.

Because weather predictions have not been a core topic, the risk of a wrong assumption consists of the impact on the feedback obtained from other subjects (i.e. modification). Because of the assumption, certain needs can arise or be overlooked and therefore this assumption is equally important.

This assumption has however not been thoroughly founded. Ground based weather is not the same as radar weather information. Representing both in the same way is not possible, because a pilot may take wrong decisions if he confuses information. Besides ground based weather information also suffers from prediction inaccuracy and delay. A discussion about accuracy is therefore very much in place.

One important thing remains, and that is that improved weather information is required for the operational concept. Predictions will be part of this information and it is believed that integrity indications of weather information will be part of it as well. In this light the assumption is valid, because the validity of the prediction horizon is available.

Although the HMI has not been representative, it has shown that predictions (time dimension) are important for 4D when modifying. That has been the goal of the implementation of weather predictions.

9 Conclusion and recommendations

9.1 Conclusion

The project described in this report formed the early stage of the design of a human machine interface (HMI) in the A30X cockpit for 4D-trajectory based operations described by SESAR. This early stage is characterized by the identification of needs and answers to the objective stated in chapter 2:

Identify the needs for the A30X human machine interface to manage and share 4D-trajectories in the air traffic management concept of beyond 2020 as defined by SESAR.

The identification of the needs has taken place in two phases: an analysis phase, in which needs have been identified from a operational, user and system perspective, and a design phase, in which these needs have been validated and refined by evaluation of the resulting HMI on static and dynamic mock-ups.

The scope of this project has been defined by requirements and limitations, which have had an impact on the outcome of this project.

Requirements about the working method of the project state that the needs are to be identified by a rational analysis and to be expressed by pilots. The inconsistency between the outcomes these methods have led to questions about the operational concept of SESAR.

As a first step, feedback of one pilot is used to obtain user needs. Although 6 pilots were involved in evaluation sessions, this one pilot has had a large influence in the definition of the HMI. Subjectivities that are not necessarily supported by other users (pilots) can have found their way in the HMI. Resource allocation did not allow changing this, so it should be taken into account when using the results of this project.

Besides requirements, some limitations were posed to alleviate the volume of work. Because of the focus on navigation, subjects like ASAS and the exchange of trajectory information with the ground are only briefly treated. Similarly, the ground part of the trajectory has not been taken into account. Parallel projects address these subjects in more detail [31]. The outcomes will have to be integrated in a later phase of the HMI development, which might bring new needs. In particular the transition from 4D-managed flight to an ASAS procedure and the transition of a trajectory from air to ground (ground to air) are topics that influence the HMI. For example there might be a need to insert ASAS procedures in a 4D-trajectory or to link two trajectories to optimize turn-around.

These topics have not been addressed by the parallel projects either, but it is a common design practice to design in parallel and integrate at a later phase. Because all projects start from the same operational concept and the development progress of other projects is shared, it is expected that the impact is low and the results from this projects are compatible with others.

The requirement to use the A30X as a platform has proven to be the most prominent requirement. It has been at the basis of the assumption analysis and the situation that the requirement was not applicable has been considered. Besides the implementation of the 4D HMI in the A30X cockpit concept did result in difficulties during the evaluation. The immaturity of the A30X cockpit concept is at the source of these difficulties.

This project has led to conclusions on two levels. Firstly there is the research question to be answered and secondly conclusions about the project as a whole are given.

The answer to the research question 'What are the HMI needs that support managing and sharing 4D-trajectories in the A30X?' is not unambiguous; a complete list of validated needs cannot be presented as the result of this project. Too many points remain unclear to be able to consolidate a HMI based on the identified needs.

The following conclusions concerning needs for a 4D HMI are determined:

- There will be a shift to a more supervisory control, where notably the business aspects of trajectory (flight) management become increasingly important.
- Easy trajectory modification (revision) is needed to cope with this aspect and other pilots tasks.

- Business properties may not be presented to the pilot in such a way that it can be used as a constraint. The pilot should be left in charge to optimize the flight according to business objectives.
- Weather data (predictions) in the cockpit will play an increasing role as air traffic demands increase. Weather is expected to be the major (if not the only) cause for pilot initiated revisions.
- Transparency of the ground part of a revision to the flight crew is very important. This does however not mean that ATC loses authority.

In the course of this project a lot has become clear about the subject of 4D-trajectory management. 4D-trajectory management and the associated HMI is a subject that has been well-studied. New studies on this subject are therefore only of interest if there is a novelty that results in new or evolved needs, such as:

- A new technology that allows a higher level of automation
- A new platform for implementation
- Evolution of the operational concept

These three points are continually changing and it is therefore important to continually re-iterate the development of the HMI (of 4D operations).

This project has an interest mainly because the implementation on the A30X. Chapter 6 shows that most needs as determined for the A30X have been addressed by previous work, but that they are not covered by the A30X HMI. However, the limits of automation posed by the A30X also led to conflicts with respect to the trend of increasing automation possibilities.

The importance of this project lies in the early identification of needs and discovery of the stakes when developing a HMI for 4D-trajectories for the A30X. It lays out the main axes of interest for development and research of 4D in the A30X, even in an immature and changing situation. Only by going deeper in the design difficulties at a higher level are understood. The added value is that today actions can be taken to arrive at a more competing product in the end.

The direct way forward from this point for the development of the A30X is a next iteration of identifying needs taking into account the outcomes of this project. For the long term, also this project evokes the in aeronautics much alive debate about autonomous flight, because of the shifting boundary between human and automation.

9.2 Recommendations

Recommendations for future development of an HMI 4D-trajectory managing and sharing are given in this section, in particular for the A30X. They are divided to four domains: project, operational concept, needs and HMI. The numbers between brackets correspond to the principal section that leads to the recommendation.

Recommendations at project level

- Periodically re-evaluate future A30X capabilities, both technical and commercial, in later phases of development to optimize the final result. (8)
- Explore several capability levels in parallel to learn the benefits and costs associated to each of them early in the design. Include the case that no technological restrictions exist to know the ultimate goal of the design. (8)
- When working with pilots, inform pilots minutely about the operational concept and the reasons for the related changes. During evaluations present scenarios that have a small and well-defined periphery to be able to present one topic at a time. (7.4.3.1)

Recommendations concerning the operational concept

- Investigate why there is a limited transparency from the airborne perspective of the ground part of the ATM concept. In particular why alternatives or (ATC) constraints are not shared and secondly, why the status of negotiation is not available. In a second step, examine the possibilities for an increase in air-ground information exchange without losing the central role and the authority of ATC as defined in the operational concept. (4.3)
- Take into account elements of the operational concept that are directly related to 4D trajectories (e.g. ASAS and ground trajectories). Anticipate on potential requirements that follow from these elements by being aware that the operational concept is in evolution and these requirements are not crystallized. (9.1)

Recommendations concerning needs

(In general sections 4.2 and 7.4 (7.4.3.6))

- Support the shift to supervisory control by exploring the possibilities of enhancement of the SEC management study. As a function of A30X capabilities, re-evaluate feasibility of automatic trajectory construction (and potentially autonomous procedures) as a possibility for enhancement.
- Focus on business aspects of 4D-trajectories. In other words: aim at reducing operating costs while maintaining safety. (6.2.4)
- Make the introduction of enhanced weather – in particular weather predictions - in the cockpit a priority. This is not strictly related to 4D-operations, there is an interest for conventional operations as well.
- Make sure that the workload of a revision is in harmony with other pilot tasks. Examine the number and the extent of revisions to determine the appropriate complexity of a revision support tool. This should lead to an optimum in usefulness of a revision support tool.

Recommendations concerning HMI

(In general section 7.4)

- Make the reference business trajectory (RBT) genuinely business orientated by using it as an information container of all relevant business properties inside and outside the cockpit (link with AOC).
- Study and define the boundary between tactical and strategic operations. According to this boundary, repartition displays (MD, ND, MFD and VD) of the A30X and the 4D-functions implemented on them.
- Use task-based interfaces and tools for 4D-trajectory management.
- Use a graphical interface combined with alphanumerical information access on a fixed place.
- Use alphanumerical information to display time. For missed constraints use words like early and late. Time information is best displayed on the VD.
- Use magenta for the cleared trajectory.
- Avoid the use of window constraints for trajectory modification.

Retrospect

I decided to add this section to give feedback about what I have learnt performing this project: The single most important thing is the relation between the commercial world and the scientific world. The approach is very different depending in which world you're finding yourself, however they are not separated worlds that do not interact with each other. On the contrary, they could not exist without each other. The scientific world is the forefront that explores new domains that are so important for the commercial world to keep competitiveness. On the other hand, the commercial world forms the mass that pushes the scientific world forward. In that light it is not a surprise that in recent years these worlds have grown together and have become mixed. However it is the close mutual dependence that has been most eye-opening to me.

Glossary

2D	2 Dimensions / 2 Dimensional
3D	3 Dimensions / 3 Dimensional
4D	4 Dimensions / 4 Dimensional
ACT	Active Trajectory
ADS-B	Automatic Dependant Surveillance - Broadcast
AHMI	Advanced HMI. Tools developed by DLR/NLR
ANSP	Air Navigation Service Provider
AOC	Airline Operations Control
ASAS	Airborne Separation Assistance System
ATC	Air Traffic Control
ATM	Air Traffic Management
BDT	Business Development Trajectory
BTv	Brake To Vacate
CCU	Cursor Control Unit
CDA	Continuous Descent Approach
CDM	Collaborative Decision Making
CDTI	Cockpit Display of Traffic Information
CDU	Command and Display Unit
CI	Cost Index
CNS	Communication, Navigation and Surveillance
COMM	Communication
CONOPS	Concept of Operations
CONT	Continuous
COTRAC	Common Trajectory Coordination
CP	Control Panel
CPDLC	Controller Pilot Data Link Communication
CSD	Cockpit Situational Display, Tool developed by NASA
CTA	Controlled Time of Arrival
DIR TO	Direct To
DLR	Deutsches Zentrum für Luft- und Raumfahrt
ECCU	Enhanced Cursor Control Unit
ECON	Economy
EFIS	Electronic Flight Instrument System
EFOB	Estimated Fuel On Board
EOSID	Engine Out SID
ESVS	Enhanced/synthetic vision systems
ETA	Estimated Time of Arrival
FANS	Future Air Navigation System
FCOM	Flight Crew Operations Manual
FCU	Flight Control Unit
FIS	Flight Information Service
FL	Flight Level
FMS	Flight Management System
FPLN	Flight Plan
GA	General Aviation
GNSS	Global Navigation Satellite Service
HF	Human Factors
HMI	Human Machine Interface
HUD	Head-up Display
ILS	Instrument Landing System
KCCU	Keyboard and Cursor Control Unit
KPA	Key Performance Areas
LTRL	Lateral
MD	Mission Display
MFD	Multi Functional Display
NASA	National Aeronautics and Space Administration
NAV	Navigation
ND	Navigation Display
NextGen	Next Generation Air Transportation System
NLR	Nationaal lucht- en ruimtevaartlaboratorium
NM	Nautical Miles
O3P	Outil de Prototypage des Postes de Pilotage

OIS	Onboard Information System
PFD	Primary Flight Display
PHARE	Programme for Harmonized ATM Research in Eurocontrol
PT	Predicted Trajectory
R&D	Research and Development
RBT	Reference Business Trajectory
RNP	Required Navigation Performance
RST	Revision Support Tool
RTA	Required Time of Arrival
S&M	Sequencing and Merging
SBT	Shared Business Trajectory
SEC	Secondary Trajectory
SESAR	Single European Sky ATM Research
SID	Standard Instrument Departure
STAR	Standard Terminal Arrival Route
SURV	Surveillance
SWIM	System Wide Information Management
TCAS	Traffic Collision Avoidance System
TMA	Terminal Manoeuvring Area
TMPY	Temporary Trajectory
TOD	Top Of Descent
TP	Trajectory Prediction
VD	Vertical Display
VHF	Very High Frequency
VRTCL	Vertical
WILCO	Will Comply

Literature

- [1] 4D Area Navigation System Description and Flight Test Results | TN D-7874 | Homer Q. Lee, Frank Neuman, Gordon H. Hardy | Ames Research Centre, Moffett Field, California 94035 | NASA, August 1975 |
- [2] Airborne Four-Dimensional Flight Management in a Time-Based Air Traffic Control Environment | NASA TM-4249 | David H. Williams, Steven M. Green | Langley Research Centre, Hampton, Virginia; Ames Research Centre, Moffett Field, California | NASA, March 1991 |
- [3] Enabling Strategic Flight Deck Route Re-Planning Within A Modified Air Traffic Control Environment: The Display of 4-D Intent Information on a CSD | 2001-01-5573 | Vernol Battiste, Walter W Johnson | Ames Research centre, Moffett Field, California 94035 | NASA, January 2001 |
- [4] CDTI User manual | Vernol Battiste, Walter W Johnson | Ames Research centre, Moffett Field, California 94035 | NASA, June 2004 |
- [5] PD/3 AHMI Design Document, CDU and Navigation Display for use with EFMS Phase II | DOC 98-70-05 | R. Verhoeven, R.A. Harlow, J.C. Blom | DLR, NLR, DERA, EEC | Eurocontrol, April 1998 |
- [6] PD/3 Airborne Evaluation, Pilot Briefing Guide | DOC 98-70-13 | R. Verhoeven, R.A. Harlow, E. Hoffman | DLR, NLR, DERA, EEC | Eurocontrol, September 1998 |
- [7] AFMS Handbook for Users | DLR ID: IB 112-2004/xx | Vilmar Mollwitz | DLR, Institut für Flugführung | Deutsches Zentrum für Luft- und Raumfahrt (DLR), June 2006 |
- [8] PHARE Final Report | DOC 99-70-09 | M. van Gool, M Schroter | Eurocontrol | Eurocontrol, November 1999|
- [9] Recommendations for a cockpit display that integrates weather information with traffic information | TM-2004-212830 | Doreen A. Comerford | Ames Research centre, Moffett Field, California 94035 | NASA, July 2004 |
- [10] Comparison of pilot and automation generation conflict resolutions | AIAA 2003-5400 | Walter W. Johnson, Karl D. Bilimoria, Lisa C. Thomas, Hilda Q. Lee, Vernol Battiste | Ames Research centre, Moffett Field, California 94035 | AIAA, August 2003 |
- [11] Common Trajectory Coordination (COTRAC) operational service description | Eurocontrol Document | August 2007 |
- [12] 4D performance based concept | 4D Working Group | Airbus Document | December 2006 |
- [13] Aircraft systems innovations derived from 4D | 4D working group | Airbus Document | June 2007 |
- [14] SESAR deliverables 1-6 | Eurocontrol documents | 2008 |
- [15] SESAR deliverable 3 Volume 2, Concept of Operations | DLM-0612-002-00-14 | SESAR consortium | December 2007 |
- [16] Operational Scenarios | ECTL-OS-AP1-01, 0.04 | Eurocontrol, Federal Aviation Authority | May 2008 |
- [17] Problems and challenges associated with the transformation of the national airspace system | Government Accountability Office | GAO 01-25 | Gerald L. Dillingham | November 2006
- [18] Comparison of the SESAR and NextGen concepts of operations | Elinor Ulfbratt, Jay McConville | NCOIC Aviation IPT | May 2008 |
- [19] IFATS – An Innovative Future Air Transport System concept | Claude le Tallec, Antoine Joulia | ONERA, Chatillon, France, F92320 | 4th Eurocontrol Innovative Research Workshop
- [20] iFLY - Description of airborne human responsibilities in autonomous aircraft operations | Deliverable 2.1 | Aavo Luuk, John Wise, Fleur Pouw, Vincent Gautherau | December 2007 |
- [21] Airbus Cockpit Philosophy | Airbus Document | May 2001 |
- [22] A380 Flight Crew Operating Manual | Version 2.5 | Airbus Document | December 2006 |
- [23] A380 Flight Deck Briefing for Pilots | Issue 2 | Airbus Document | March 2006 |
- [24] VD description note | Airbus Documents | May 2006 |
- [25] A30X cockpit concept description | Version 2 | Airbus document | 2008
- [26] Description évolutions fonctionnelles et système FMS A30X, Création intuitive des plans de vol secondaires | Airbus Document | 2008
- [27] Note de guidage latéral FMS | Airbus Document | 1994 |
- [28] Note descriptive vertical FMS | Airbus Document | 2002 |
- [29] Cockpit prototyping, A framework for Airbus cockpit studies | Airbus Document | June 2008
- [30] IHM FANS A30X | Rapport de Stage et Rapport Technique final | François Salmon-Gagneur | July 2008
- [31] EMMA 2, CPDLC ground clearances – Test report and final synthesis | Issue 1 | Airbus Document | May 2008
- [32] OIS A30X, Page init grand écran/préparation du vol | Airbus document | December 2006 |
- [33] GARD project résumé | Airbus Document | March 2005
- [34] Aircraft environment surveillance system, A380 | Airbus Document | May 2008 |
- [35] Getting to grips with the cost index | Issue 2 | Airbus Document | May 1998 |
- [36] Front page image provided by Kris Klop | November 2007 |

Appendix A: SESAR

A brief description of the SESAR program and its 4D-trajectory based operations will be given. This description is sufficient for an understanding of the operational concept in this report. For a detailed view the reader is directed to [15].

Background and target

On a peak day European ATM controls roughly 30.000 commercial flights executed by around 5.000 aircraft. Until now ATM has been able to cope with this number, but the growing number of flights as a result of increasing demand in air transport will reach the limits of ATM in its current form around 2015.

SESAR stands for 'Single European Sky ATM Research' and is the European ATM modernization program to cope with the increase in air traffic. It aims at a target concept of operations that is based on the following ATM vision:

'Europe has an affordable, seamless system of ATM, which enables all categories of airspace users to conduct their operation with minimum restrictions and maximum flexibility while meeting or exceeding the measurable targets for safety, operational efficiency and cost effectiveness, minimizing the environmental impact and meeting national security and defence requirements.'

The measurable targets are:

- A 3-fold increase in capacity while reducing delays to handle traffic growth beyond 2020. From 2005 to 2020 a traffic increase of 73% is predicted.
- Maintain or increase the current level of safety. An increase in safety of 3 is needed for 2020 and of 10 for a 3-fold increase of traffic.
- Decrease of environmental impact by aviation of 10% by decreasing fuel consumption and noise emissions as well as their impacts.
- Decrease of the ATM cost to airspace user of 50%

SESAR timeline

The target concept is realized in three phases. The definition phase spanned the years from 2005 to 2007 and has yielded the roadmap for the next phases of the program. The development phase started in 2007 and lasts until 2013 to produce the component and system design. The development phase will be followed by the deployment phase that will lead to the ATM target concept in 2020.

The systems and operations deployment will unfold gradually. From 2013 functions known as initial 4D are implemented. After 2020 the progress will be made to 'full 4D' or '4D-contract' in 2025-2035.

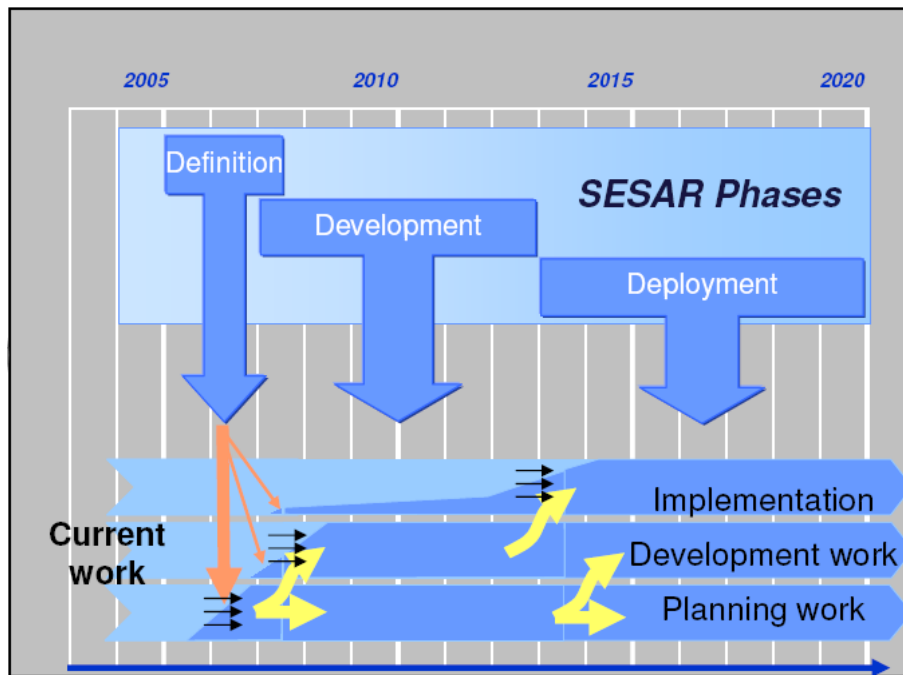


Figure A-1: SESAR Timeline defines a definition, development and deployment phase

Key enablers of SESAR

The following enablers are essential to attain the goals set by SESAR. The program relies on a single master plan for ATM that is supported by all actors in the ATM system. Among others these are airspace users, air navigation service providers, airports, aeronautic industry, military operators and meteorological services. Information is to be shared between all actors with sufficient quality and timeliness in a secure way. Collaborative decision-making processes will be used to exploit the power of shared information. Data to be shared may include flight trajectories, aeronautical information, surveillance and meteorological data.

Furthermore the master plan relies on the advance of technology in the fields of communication, navigation and surveillance. Voice communications will not be able to cope with the information to be exchanged and therefore the capabilities of datalink will be exploited. It will be essential for the correct sharing of more complex data. Satellite based navigation allows the position of aircraft to be precisely defined. Better trajectory prediction will enable determining more precisely the future position of aircraft as well. Cooperative surveillance techniques will be used as principal surveillance means. This requires aircraft to be equipped with properly functioning equipment. The enhanced form of surveillance results in more precise detection of the current and future position of other aircraft in the air and on the ground. A special role is awarded for detection and prediction of meteorological conditions. The importance of meteorological information is expected to grow in the next 10 to 15 years. This will allow better determination of routes in the planning phase and in flight.

The evolutions in technology allow aircraft to operate more accurate, more independent and better communicating, increasing the overall predictability of aircraft movements and thus benefiting ATM.

Target concept

The intention of an airspace user is to execute an individual flight with its ideal trajectory. Because the users of airspace are numerous this will not be possible. A compromise has to be found to optimize the execution of all flights as close as possible to the original individual intentions.

The intention of the airspace user is described in trajectories according to the user's need. Resolving possible conflicts between intentions while minimizing changes guarantees the best outcome for all users. The trajectories will be described in four dimensions with the required precision and necessary other data. These 4D-trajectories form the core of the ATM system.

Flexibility is retained by anticipating on future situations using a proactive approach to conflict resolution. This requires accurate predictions and information sharing.

The key features of the target concept are:

- 4D-trajectory based approach to ATM
Use the capability of aircraft to navigate very precisely in 4 dimensions to be able to manage user-preferred 4D-trajectories from gate to gate for each aircraft individually.
- The transition of fragmented airspace to a continuous airspace
The 4D-trajectory is not to be limited by a fragmented airspace. Dynamically managed airspaces within a single functional design and organization enable the optimal individual profile to be flown.
- Performance based approach to ATM
Not all aircraft will be able to attain the same level of performance at the same time (dependent on installed systems). The performance-based approach will allow mixed traffic to be managed. Most capable aircraft will obtain the highest operational benefits.
- Information sharing between all participants
Incorporate system wide information management (SWIM) so that the performance of the network as a whole is at its best. Use improved communication capabilities to enhance air-to-ground and air-to-air information sharing.
- Collaborative planning and decision making
Aircraft trajectories are planning using collaborative decision-making (CDM) up to the moment of departure. The result is a minimum constraint and commonly agreed pre-deconflicted trajectory. Users will negotiate between them to achieve business objectives.
- Human at the centre supported by more automation.
Human capabilities in decision-making and managing are exploited, but they are assisted with more automation to handle increased complexity. Automation is not to be incorporated because the technology is available, but only to increase efficiency.
- Improved airport capacities
Airports form the greatest bottleneck in today's air traffic system. Airport operations are enhanced and integrated within the ATM system. Runway capacities are improved by implementing the following concepts: The use of controlled time of arrival (CTA) and airborne spacing. Interlaced take-off and landing and reduced runway occupancy times by brake to vacate (BTV). Wake vortex detection systems. Enhanced/synthetic vision systems (ESVS) and head up displays (HUD) to allow for low-visibility operations.
- New separation modes
Present modes of separation are improved, using new ground based separation methods based on precision trajectory clearance and ground based speed adjustments. Airborne cooperative separation and self-separation is introduced to reduce controller workload by means of the use of airborne separation assistance system (ASAS). Usage of spacing procedures such as in trail procedure (ITP) and sequencing and merging (S&M)
- A pro-active approach to environment
Environmental impact is decreased by fuel-efficient procedures such as continuous descent approach (CDA), noise abatement and minimized holding and taxi times.

Appendix B: A380 EFIS

It is beyond the scope of this report to give a full overview of all the cockpit functions that exist. Because of the ongoing developments of the A30X cockpit, common cockpit functions are explained using the latest realization: the A380. There will only be a brief presentation of elements important to trajectory management in which the focus lies on the graphical interaction.



Figure B-1: The state-of-the-art cockpit of the A380

Control and display system

Display and access of information is served by the control and display system (CDS). It receives flight and system information from practically all aircraft systems. Interaction needs are covered as much as possible through intuitive and coherent soft commands. The following cockpit interfaces are available:

- Primary Flight Display (PFD)
- Navigation Display (ND)
- EFIS Control Panel (EFIS CP)

- Engine/Warning Display (E/WD)
- Systems Display (SD)
- Mailbox (MB)
- Multi Function Display (MFD)
- Keyboard and Cursor Control Unit (KCCU)

In this appendix only the KCCU, EFIS (ND+PFD) and MFD are treated.

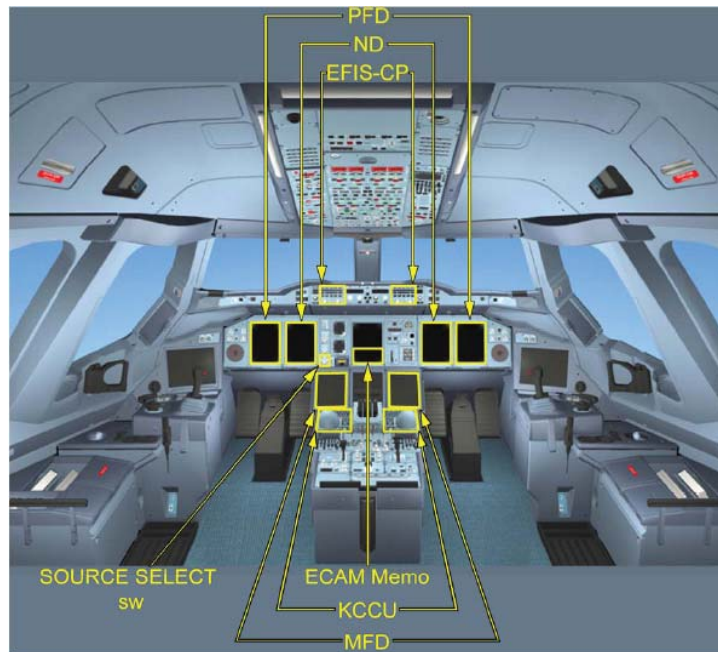


Figure B-2: The elements of the A380 control and display system

9.2.1.1 Keyboard and Cursor Control Unit (KCCU)

The KCCU is the main means of (soft) interaction. The flight crew uses the KCCU to:

- Navigate through the FMS pages on the MFD
- Enter and modify data on the MFD
- Perform some flight plan revisions on the lateral ND
- Interact with the mailbox section of the SD

The KCCUs have two parts:

- A keyboard to enter alphanumeric information
- A cursor control device

9.2.1.2 EFIS: ND and PFD

The ND and the PFD display graphical and textual information related to flight management. The two PFD's provide short-term information that is necessary for flying the aircraft.

The two ND's provide medium- to long-term flight information. The upper section of the ND, called the main zone, displays:

- Aircraft position with respect to navigation aids
- The lateral FMS flight plan and map data
- Weather radar information
- Surveillance information

The lower section of the ND, called the Vertical Display (VD), displays a synthetic view of the aircraft's vertical situation:

- The vertical flight profile
- Weather radar information
- Vertical surveillance information

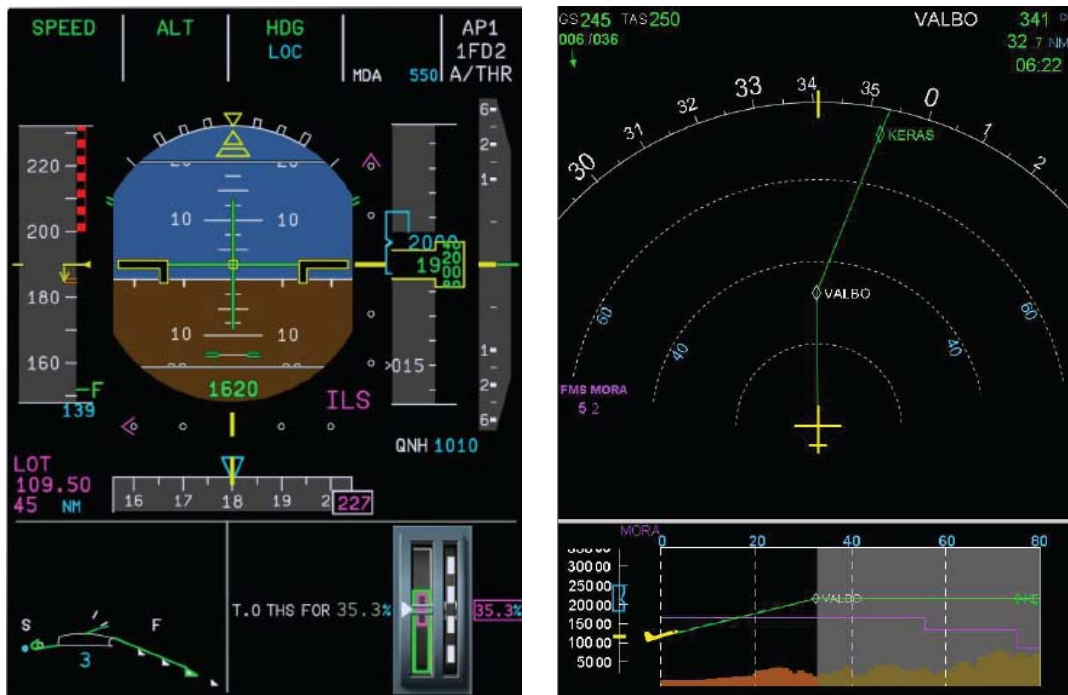


Figure B-3: Guidance and tactical navigation on the primary flight display (PFD, left) and the navigation display (ND, right). The lower part of the ND is called the Vertical Display (VD)

The lateral (main) part of the ND is interactive, which means that the flight crew can make some FMS lateral flight plan modifications with the KCCU.

Weather information

The A380 is equipped with weather radar that can provide 3D weather images for display on the ND and VD. These images can be explored by modifying the azimuth, elevation and tilt cross-sectional cuts of the 3D volume. The weather radar controls are found on the pedestal.

Interactive ND

Some flight planning functions can be performed by interacting graphically with elements on the ND. An example of a DIR TO revision is given below to illustrate the interactive ND:

Figure B-4 illustrates a DIR TO revision on the ND:

1. Upper left: Being an interactive element, the aircraft symbol has a blue frame if the cursor is moved over it. When clicked, a menu displays the choice to perform a DIR TO revision.
2. Upper right: The DIR TO revision is activated. The ND now has the DIR TO page displayed instead of the VD. On this page relative information is shown and several parameters can be altered that affect the DIR TO type. The target waypoint can be chosen on this page as well as on the interactive ND.
3. Lower left: The waypoint NIRAN is chosen as target waypoint and a temporary flight plan is created. Two buttons appear with the temporary flight plan to erase or insert the flight plan.
4. Lower right: The temporary flight plan is accepted and inserted. It is now displayed as the active flight plan. The aircraft is in managed mode and will continue to fly this flight plan.

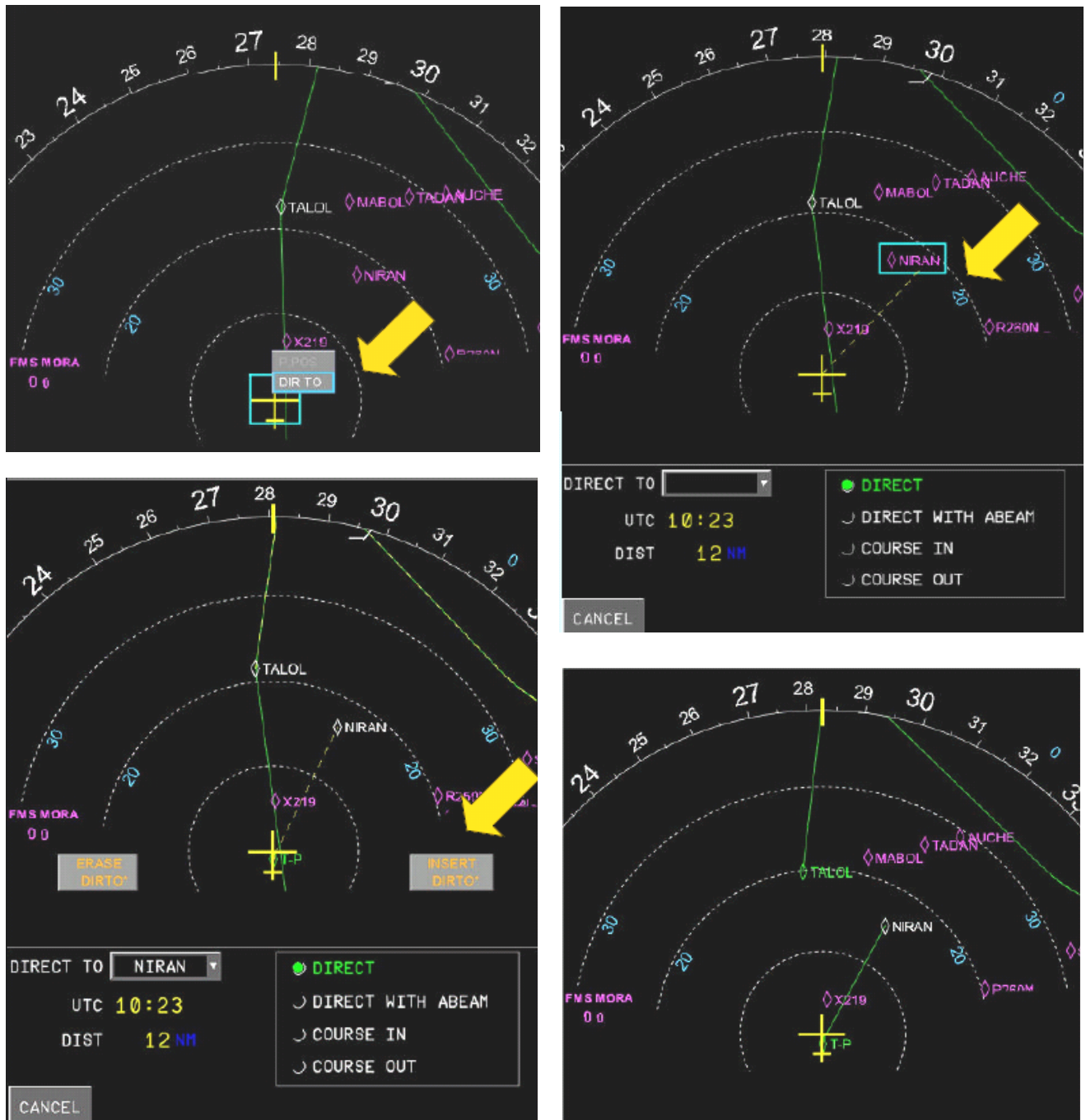


Figure B-4 A DIR TO revision on the ND

9.2.1.3 Multi functional display (MFD)

The MFD displays FMS textual data. There are more than 50 FMS pages that provide information on the flight plan, aircraft position and flight performance. The MFD is interactive: The flight crew can navigate through the pages and can consult, enter or modify the data via the KCCU. The FMS pages and in particular the FLPN page will be discussed in more detail. The flight plan is today's equivalent of the future RBT.

The FLPN page displays textual lateral and vertical flight plan data, including:

- All flight plan waypoints and legs
- Time, speed, altitude, fuel and wind predictions for each waypoint
- Track and distance between waypoints
- Flight path angle for approach waypoints
- Access to all lateral and vertical flight plan revisions

The PLPN page is available for the active and secondary flight plans as well as temporary flight plans. Waypoints of the active flight plan are displayed in green, with exception of the TO waypoint which is displayed in white and the cyan coloured alternative flight plan and missed approach waypoints. Secondary flight plan waypoints are in white and temporary waypoints are in yellow.

The flight crew uses a MFD ATC COM page on the MFD to communicate with ATC, mainly to create a request/report.



Figure B-5: The FPLN and RTA pages on the MFD

Figure B-5: the vertical revision section displaying the RTA tab is presented (left). The flight crew can among other things perform the following vertical revisions:

- Adjust time constraints
- Adjust speed constraints
- Adjust altitude constraints

Time constraints are not automatically attained by the FMS, but advisory is given to attain the RTA.

Mailbox

The lower part of the SD is reserved for the Mailbox to manage ATC messages exchanged between the flight crew and the ATC centres. The mailbox is a smaller, but redundant version of the ATC COMM page on the MFD that is permanently visible. General information about ATC COMM and messages are displayed on the message area. Navigation buttons are used to display previous messages. Simple responses to requests can be sent to ATC: WILCO (will comply), standby and unable. The ATC message indicators and loudspeakers indicate the arrival of an ATC message.



Figure B-6: The mailbox