# Designing for Shared Cognition in Air Traffic Management

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***Abstract*—It is to be expected that the task of an air traffic controller will change with the introduction of 4D (space and time) trajectories for aircraft, as can be seen in ongoing developments in ATM systems in Europe (SESAR) and the US (NextGen). However, the role of the human operator in these systems in not well defined yet.**

**This paper presents one approach to a user-centered design for ATM based on 4D trajectory management. The design is based on Cognitive Systems Engineering (Vicente, 1999). Using a top-down approach in the analysis of the work domain, a step-wise refinement in the planning and execution of 4D trajectories is proposed. The design is described in three Abstraction Hierarchies, one for each phase in the refinement. The implications of the analysis for display design are outlined.**

***Foreword* – This paper describes a project that is part of SESAR Workpackage E, which is addressing long-term and innovative research. The project was started early 2011 so this description is limited to an outline of the project objectives augmented by some early findings.**

***Index Terms*—Ergonomics, human factors, interfaces, automation, Air Traffic Management**

## I. INTRODUCTION

Currently, air traffic controllers (ATCo's) perform a sector-based tactical form of control. They are responsible for planning and managing traffic within their assigned airspace, often with little help from automated tools [1]. In the coming decades, the task of an air traffic controller is predicted to undergo a large transformation. The pull for transformation comes from the increasing demands which are placed on the air traffic management (ATM)-system [2], [3], [4]. A push is provided by technological advances on the air- and ground side of the ATM-system, which make a new form of air traffic control (ATC) possible [5], [6]. This is expected to result in a situation where aircraft 4D (space + time) trajectories stored in automated support tools form the basis for the ATCo's work [7], [8], [9], [10].

Although considerable research has been devoted to exploring this future approach to air traffic control with 4D trajectory support [11], [12], [13], [14], [15], a definite concept on a distribution of the roles of automation and human users has not yet been defined. A fundamental difference between current practice and future air traffic management is the explicit use of a 4-dimensional definition of the airplane's trajectory (4DT) as a shared representation between air and ground segments. In SESAR, this has been defined as a Reference Business Trajectory. Supported by a communications network, the System Wide Information Management (SWIM), the information on the 4DT is to be shared such that all parties involved have access to relevant and the most up-to-date flight information.

This paper explores one possible design for the automated and human work in such an ATM system. An approach based on Cognitive Systems Engineering (CSE) is taken [16], [17], [18]. CSE starts from an analysis of the work domain, identifying goals and functions in this work domain, and in a design, it is possible to start top-down, initially independent of the chosen solutions for the system.

Given that the stakes are too high, and the ATM work domain will provide too many unforeseen situations to create a fully automated solution (i.e., the work domain can be characterized as "open", [17]), human users will have to remain involved in the system. The future air traffic controller will not, as he or she is doing currently, provide hands-on instructions to the aircraft, in essence creating the aircraft's 4D trajectory in real time. Rather, controllers will work on a definition of the 4D trajectory, using computers to visualize and represent this trajectory. Future or modernized aircraft will have the capability to receive this trajectory on the flight deck, and implement their flight according to this trajectory with a high degree of precision.

This paper outlines a step-wise approach to the definition and refinement of 4DT's,

## II. THE STRUCTURE AND FUNCTION OF AIRSPACE

The re-engineering of the air traffic management system is a design process, which will be approached here following the paradigm of Cognitive Systems Engineering (CSE). That means that the first step in CSE, the Work Domain Analysis (WDA), will be started in a top-down fashion. Part of the WDA will reflect the constraints innate in the work domain itself, for example the fact that aircraft need to have sufficient clearance from terrain and other aircraft (separation). However, other functions in the WDA are influenced by the design choices, both for the current system and for the envisaged new ATM systems.

The work domain analysis will be done by construction an Abstraction Hierarchy [19]. In constructing an AH for a new domain, the main challenge is to select the proper choice for the abstract functions in this domain. In process technology and energy generation systems, where CSE originated, the abstract functions that describe the energy and mass balances in a system form an appropriate choice [16]. In the description of a single vehicle, the WDA at this level focuses on locomotion and on (potential and kinetic) energy balances [20]. For the case of ATM, the principal functions at this level are proposed to be identified as travel space, locomotion, localization, communication, and separation.

Locomotion is a function of the moving elements in the ATM, realized by flight for aircraft, and drifting for weather. Localization is the function that determines the position of these moving elements, either on-board, by the navigation system, or on the ground, by the ATM surveillance systems. Communication supports localization and decision making in the system by sharing intentions, plans, and localization results. Separation is the principal means for safety in the ATM system, at all times a proper clearance to other aircraft, terrain and hazardous weather must be maintained.

The identification of "travel space" as a separate functionality in this analysis warrants additional explanation. We define travel space as the function offered by the air and infrastructure to the moving elements in the ATM system – the aircraft – to implement their locomotion. Other elements in the system, such as weather, terrain and including other aircraft, affect the possibility to use the available airspace in certain ways [21], [22]. Identifying these possibilities for travel as a function in our analysis enables us to use a representation of the effect of the total of 4D trajectories in our design of new ATM systems. Many constraints in this function are unavoidable; removing them would require removing terrain or other traffic. However, the solutions chosen for our ATM system, such as the communication and navigation systems, the legal infrastructure and the way in which we plan and coordinate trajectories, affect the shape and characteristics of the travel space function.

*Communication limitations*. Current ATM mainly uses voice communication. To enable efficient use of this communication channel which is limited in bandwidth – on the other hand, it is extremely flexible – the actors taking part in this communication need to have agreed on extensive background information. This makes it possible to only use pre-defined and published way points and discrete altitude levels for defining tracks. The use of digital data-link communications means that the use of airspace can become more flexible.

*Navigation systems*. Traditionally, limitations of navigation systems provided constraints on where flight was possible. In the early days of commercial aviation, railroads and other landmarks formed the basis for the air structure. Later, radio navigation aids, such as the four-course radio range, VOR and NDB beacons largely determined the use of airspace. The navigation aids thus determined which parts of the airspace are usable as travel space, and how these can be used. Much of this restriction will be removed as aircraft are increasingly able to perform Area Navigation (RNAV), meaning that flight can be performed independently from the location of (ground) navigation beacons.

*Legal infrastructure*. A further constraint on the locomotion is provided by the administrative organization of airspace. The (current) division in airspace sectors imposes restrictions on the paths of aircraft, basically because the handling and the transition of an aircraft from one sector to another requires a buffer zone between the sectors, and effort from the controllers and pilots. Aircraft trajectories are effectively constrained to transitions between sectors with more or less perpendicular angle to the sector boundaries. Short paths through sectors, such as perpendicular traversal of narrow sectors, or passing through a corner of a sector, are difficult to manage and therefore uncommon.

*Planning and coordination*. Currently, the control of the traffic within an airspace sector is normally the job of a single ATCo, or of a small team of two to five. Support by tools is fairly limited, and the extent to which a 4D trajectory is known ahead of time is very limited. This forces an ATCo to impose additional structure on the use of airspace.

The technological advances in navigation systems and communications foreseen in SESAR and NextGen can remove part of the constraints on the travel space function, opening the way for more economical, and shorter – direct – routes.

## III. OPERATIONAL CONCEPT

### A. *Overview*

This paper sketches an operational concept for the future ATM system that largely uses the functionality foreseen in the ATM master plan [23]. In particular, the functionalities provided by 4D trajectory management, information exchange with a System Wide Information Management (SWIM) system are combined in a concept that assumes a central role for the human actors in the system.

A step-wise refinement of the 4D aircraft trajectories is proposed. A central role is reserved for the human actors in this process. However, to enable a useful contribution from human operators in defining 4D trajectories, proper support for visualizing, evaluating and modifying these trajectories is required. Also, the amount of work involved in defining 4DT's for all aircraft using the ATM system is expected to be very large, so human users have to be supported by automated systems in this task.

Task division between humans and automation is often approached as an allocation problem; either the human actor or the automation is selected for a task. Prime examples for this can be found within the aircraft themselves; the task of stabilizing the aircraft is normally allocated to the autopilot, and the navigation along a trajectory is performed by a combination of autopilot and Flight Management System.

The first guiding principles in task allocation have been laid out in what is now known as Fitts' list [24]. In this concept, part of the tasks in the foreseen ATM concept are indeed assigned with these principles, such as the tactical monitoring for deviation between actual flights and the agreed 4D trajectories. However, other tasks are foreseen to be performed jointly by automation and humans, and some tasks can be done in parallel by automation and humans.

In most complex systems, however, many tasks are too ill defined to be handled by automation. Such tasks are typically assigned to human operators. To support operators in those cases, a proper visualization of the problem space can help. Examples of such visualizations are the Ecological Interface Design for the example process system DURESS [25], or, more recently, visualizations for airborne traffic avoidance [26], [27], can be seen as automation support, where algorithms are used to visualize the work domain in such a way that operators can implement appropriate control strategies. This leads to a task that can be performed jointly by automation and humans. The resulting cognition can be seen as a joint effort of the automation, and in particular the visualization of the problem, and the human user [28].

Within the SESAR overall operational concept, several stages in the refinement of 4D trajectories are foreseen. This design will focus on three stages, covering, respectively, 24 to 12 hours in advance of the flight, several hours to 30 minutes in advance of the flight and a tactical phase (30 minutes to now). In contrast, the full SESAR design starts with seasonal planning. The interaction foreseen between users, their display and support tools and automated agents is discussed in the following sections. A summary of the foreseen phases is given in Figure 1.

### B. *Short term planning*

Short term planning – termed short-term here to correspond with SESAR terminology – takes place approximately 24 to 12 hours in advance. This phase starts with an inventory of intended flights, initially designed as the shortest and most economical route to the destination. A visualization will be used to show the use of airspace, including "hot spots", with high concentration of traffic. The human planners use this representation to create a global structuring of the airspace (e.g., restricting the number of flights in certain areas, reserving altitudes for certain headings, making sure that there is "spare" airspace to handle unforeseen disturbances or to re-structure the flows to be able to handle a change in runway at an airport, etc.). The function of the automation in this stage is mainly to provide visualization and identification of hot-spots.

The result of this stage is a planned airspace "structure", i.e., the travel space will be partly pre-allocated. NextGen flow corridors [4] might be an example of this. The 4D trajectories are then modified by automated algorithms to conform to this structure resulting in an indirect de-confliction (e.g., to adhere to capacity limits defined for the airspace), but overlapping conflicts that may exist between the 4D trajectories are not identified or resolved, since the actual 4D trajectories are not yet sufficiently defined to perform this step.

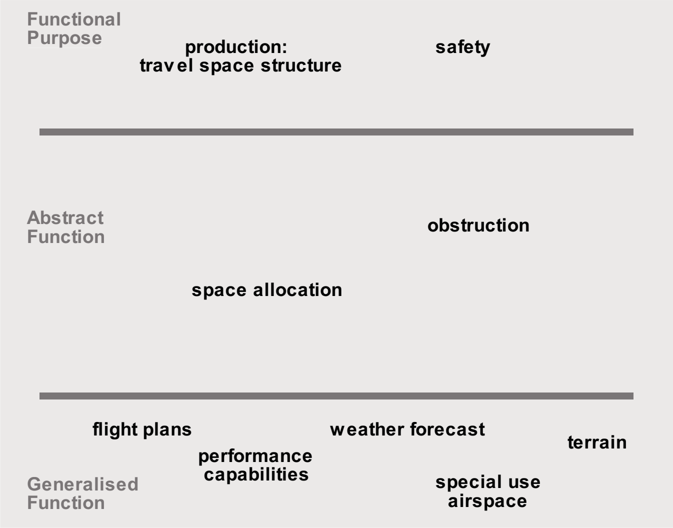

**Fig. 2:** Short term planning stage, top three levels of Abstraction Hierarchy.

Part of the work domain analysis is given in the Abstraction Hierarchy in Figure 2. The work domain analysis describes the functionality and constraints of the work domain, in this case of Air Traffic Management. An Abstraction Hierarchy describes one and the same system or work domain at different levels of abstraction. The top level is the functional purpose level, containing the goals identified for the system. The "abstract function" level describes the basic principles and processes in the work domain that enable the realization of these goals. In this case, the basic mechanisms at work are obstruction (e.g. by weather) and allocation of space. The generalized function level further specified this in terms of "systems solutions". Normally, and AH has two further – more detailed – levels, that are not yet specified for this study [29].

The product that comes out of the short-term planning step is a "structure" for the travel space; choices are made to reduce traffic at places where large volumes of traffic are expected, and additional capacity is reserved where needed, for example as a contingency for weather phenomena. This planned structure should achieve the goals identified at the top level in the AH.

### C. *Pre-tactical planning*

This takes place from several hours up to approximately half an hour in advance of current time. Using adjustments to the 4D path, and taking into account aircraft performance and weather, the 4DTs are further defined to be – in principle – conflict free. The adjustments to 4DTs can be performed by human operators and automated agents in parallel. A proper visualization of the travel space functions are used as a template for the cognitive process; human operators can use this visualization to directly perceive the effects of path

**(a)** short term **(b)** pre-tactical **(c)** tactical

**Fig. 1:** Summary of the stages in refinement and implementation of 4DT's. Only for the tactical control the actual aircraft flight data is used (radar symbol). For the pre-tactical and tactical control, assistance from automated agents is foreseen.

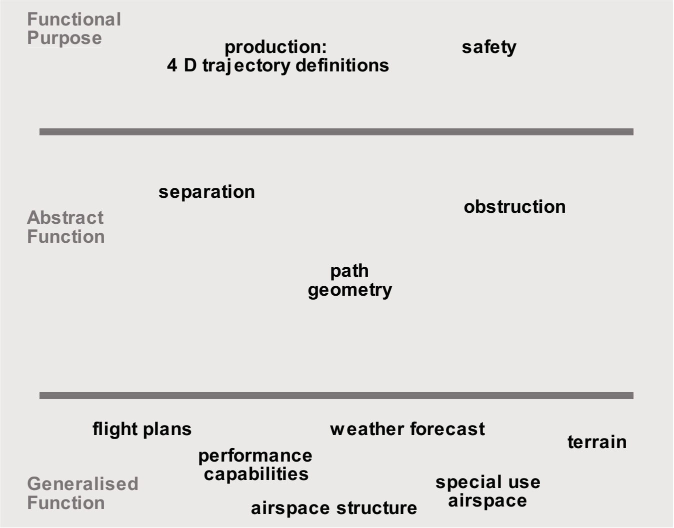

**Fig. 3:** Pre-tactical term planning stage, top three levels of Abstraction Hierarchy.

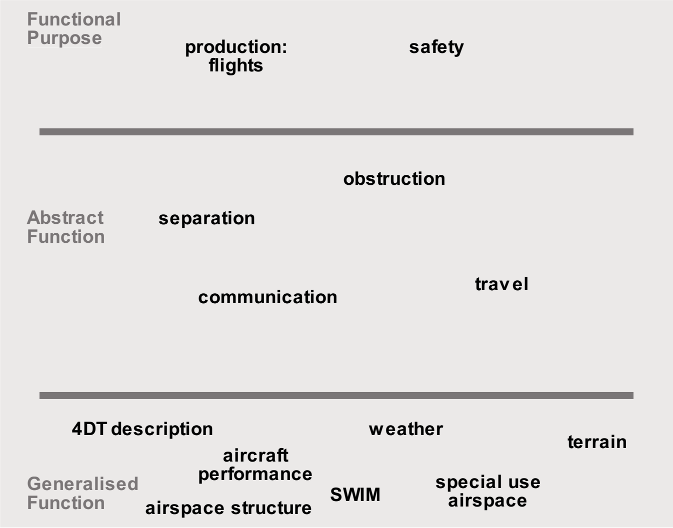

**Fig. 4:** final planning stage, top three levels of the Abstraction Hierarchy.

and speed manipulation. It also serves as a shared memory, offering a workspace to automation and human agents alike. The result of this stage is that the 4DTs are de-conflicted and in accordance with the airspace structure defined in the previous step.

Part of the work domain analysis for this stage is given in Figure 3. The airspace structure generated in the previous stage is now a generalized function; it defines a rough plan for the generation and modification of trajectories for individual flights, and it functions as an additional constraint in this analysis, imposing limits on flights but providing an overall means to simplify the planning process, analogous to the way the current airway structure is used to shape air traffic. Observing the needed separation, possible obstruction by terrain, weather, etc. and the geometric constraints of each flight's path, this stage results in refined definitions for the 4DT's.

### D. *Tactical monitoring*

At this stage the *planned* 4DTs of the different flights are conflict free. However in the execution of flights, small deviations from these planned trajectories are expected to be unavoidable. Automated agents monitor the execution of the trajectories and provide limited solutions (e.g., speed and minor path adjustments) to keep the flights conflict-free. The visualization now serves to inform the human users of the progress of the flights and of the actions of the automated monitoring agents. The situation awareness thus built up permits the human user to perform the higher — system – level monitoring, and to step in when unforeseen circumstances make this necessary.

Part of the work domain analysis for this stage is given in Figure 4. At this stage, the physical function level will be formed by the functionality related to the aircraft and physical devices in the ATM system. While the previous stages mainly involved planning flights (first globally, resulting in the travel space structure, then in more detail), the result from this stage are the actual flights. Real-time communication therefore becomes an important function at this stage.

The three stages sketched above differ in their nature of the joint cognition by human users and operation. In the short term planning, the contribution by the automation is mainly the visualization. The human users are the primarily responsible for the planning result. In the pre-tactical planning, the automation and human users contribute on a more or less equal basis. The visualization serves here as the representation of the commonly used (space) resources. The tactical monitoring situation most closely resembles current high levels of automation, with a large contribution of automated agents, utilizing a probabilistic road-map method, to the final solution.

The work domain analysis, which in current approaches to Ecological Interface Design serves as an input to the display design process, will in this project be used for both the design of the automation and the displays.

## IV. DISPLAY DESIGN

In CSE, the analysis of the work domain is a primary input for the actual design of the display. However, the design of a display presentation is still a creative step, the WDA does not result in a “recipe” for how the display is to be created, it only provides guidance in determining what functions should somehow be made visible in the display. The following first inventory of the important elements, and the way they might be visualized, is given here:

Short term For the short-term planning of the travel space structure, obstruction and space allocation are considered primary functions at the abstract function level (Figure 2). The product of this stage should be the travel space structure for the next day, indicating how airspace will be allocated for flights, and where disruptions are expected and thus buffers are reserved. The input to this work is the set of flight plans as filed by airline companies. Important aspects of the visualization will be the obstruction, by weather cells, terrain, or temporary restricted airspace. A global visualization of the traffic flow (not per 4D trajectory, but as a whole), and a visualization of the means to modify this flow by structuring the travel space is needed.

Pre-tactical Pre-tactical planning should result in initial conflict-free 4DT’s. The visualization should show the travel space structure created in the previous step. Since the planning is done in parallel by automated agents and human users, communication between the agents and humans on the ongoing work, and allocation of (space) resources is important (Figure 3). The result is mainly the path geometry of the 4DT’s. At this stage, the constraints by the aircraft performance capabilities, and the separation should be visible. An important feature of the display is the visualization of the relation between the possible modifications to the 4DT’s and the effect on separation and performance.

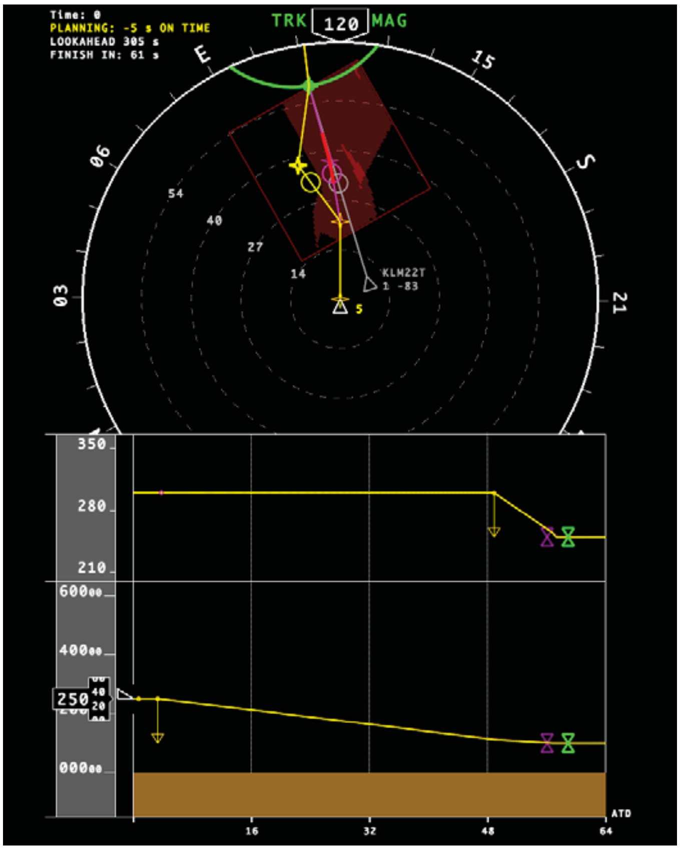

**Fig. 5:** Visualization of waypoint choices for an timed entry to another airspace, with traffic in the vicinity [30]

As a starting point for this stage, the display in Figure 5 might serve as inspiration; this is a path planning display intended for approaching aircraft; the display shows which path modifications result in a timely and conflict free entry into a neighboring zone.

Tactical In the tactical planning, much of the actual work should be performed by automated agents. Flights that are operating on or near the 4DT defined in the previous stage can be monitored automatically. The visualization for the human user should enable checking of conformance to the 4DT at a glance. At this stage the detection of anomalies is important. Since the actual implementation depends on real-time communication, an indication of communication health for all flights should be given (Figure 4). Handling flights with problems, that need to be diverted from their route, needs a visualization of separation from other flights and of buffer zones that can be used to safely divert the flight.

## V. CONCLUSIONS AND FUTURE WORK

This paper outlines a possible approach for the creation of the new work domain in Air Traffic Management. The envisaged future situation in SESAR and NextGen, in which aircraft will be able to fly 4-dimensional (space and time) trajectories, requires planning, monitoring and if necessary modification of these trajectories. The approach proposed in this paper is based on Cognitive Systems Engineering, and assumes three successive steps in the refining and final implementation of the 4DT's. Automation support comes in the form of visualization of the constraints in the planning phase, and collaborating agents in the execution phase. An initial Work Domain Analysis has been done for these three phases, and critical functions for each of the phases have been identified. Further work will focus on the refinement of the WDA, the creation of actual interfaces and the evaluation of the design.

## ACKNOWLEDGMENT

The authors acknowledge the inspiration from EUROCONTROL and the SESAR Joint Undertaking. The work was co-financed by EUROCONTROL on behalf of the SESAR Joint Undertaking in the context of SESAR Work Package E. This work reflects only the authors' views and EUROCONTROL is not liable for any use that may be made of the information contained herein.

## REFERENCES

[1] E. A. P. B. Oprins and M. Schuver, "Competentiegericht opleiden en beoordelen bij LVNL in Dutch: Competence based training and assessment at LVNL," *HUFAG nieuwsbrief*, no. 6, pp. 2–4, 2003.

[2] O. Dlugi, T. Astheimer, C. Baldoni, J. M. Bara, R. Brown, R. Cato, G. O'Connell, M. Standar, J. Stenson, and G. Tauss, "The ATM target concept," www.eurocontrol.int/sesar/gallery/content/public/docs/DLM-0612-001-02-00.pdf, SESAR Consortium, Toulouse, France, Deliverable 3 DLM-0612-001-02-00, 2007.

[3] O. Dlugi, T. Astheimer, C. Baldoni, R. Brown, R. Cato, M. Erb, D. Hilton, G. O'Connell, A. Sohn, and J. Stenson, "The ATM deployment sequence," www.eurocontrol.int/sesar/gallery/content/public/docs/DLM-0706-001-02-00.pdf, SESAR Consortium, Toulouse, France, Deliverable 4 DLM-0706-001-02-00, 2008.

[4] Anon., "Concept of operations for the next generation air transportation system. version 2.0." www.jpdo.gov/library/NextGen_v2.0.pdf, Joint Planning and Development Office, Report, 2007.

[5] R. A. Slattery, "Examination of Possible Future Terminal Area Procedures," *AIAA Guidance, Navigation, and Control Conference, San Diego, California*, July 29-31 1996.

[6] M. G. Ballin, J. M. Hoekstra, D. J. Wing, and G. W. Lohr, "NASA Langley and NLR research of distributed air/ground traffic management," *AIAA's Aircraft Technology, Integration and Operations 2002 Technical, Los Angeles, California, USA*, October 1-3 2002.

[7] M. J. Whiteley and I. Wilson, "Phare advanced tools problem solver," www.eurocontrol.int/phare/gallery/content/public/documents/98-70-18-v8_ps.pdf, Eurocontrol, Brussels, Belgium, Final Report PHARE/EEC/PAT-6.5/FR; 1.0, DOC 98-70-18, August 1999.

[8] P. G. A. M. Jorna, D. Pavet, M. Van Blanken, and I. Pichancourt, "PHARE ground human machine interface (GHMI) project," www.eurocontrol.int/phare/gallery/content/public/documents/99-70-02ghmi.pdf, Eurocontrol, Brussels, Belgium, Summary Report PHARE/NLR/GHMI-7/FR/1.0, DOC 99-70-02, August 1999.

[9] W. W. M. Heesbeen, J. M. Hoekstra, and M. S. V. Valenti Clari, "Traffic manager, traffic simulation for validation of future ATM concepts," *AIAA Modeling and Simulation Technologies Conference and Exhibit, Austin, Texas, USA*, August 11-14 2003.

[10] T. Prevot, P. U. Lee, N. Smith, and E. A. Palmer, "ATC technologies for controller-managed and autonomous flight operations," in *AIAA Guidance, Navigation and Control Conference, San Francisco, California, USA*, San Francisco, (CA), August 15-18 2005.

[11] D. Lindgren and A. Törne, "4d trajectory management decision support," FOI, Swedish Defense Agency, Linköping, Tech. Rep. FOI-R–2405–SE, January 2008.

[12] R. Weber and C. Eva, "Subliminal atc utilizing 4d trajectory negotiation," in *7th ICNS Conference*. Herndon (VA): IEEE, 2007, pp. 1–9.

[13] M. Jackson, "Role of avionics in trajectory-based operations," *Aerospace and Electronic Systems Magazine, IEEE*, vol. 25, no. 7, pp. 12 –19, 2010.

[14] S. Landry, "Human centered design in the air traffic control system," *Journal of Intelligent Manufacturing*, vol. 22, pp. 65–72, 2011, 10.1007/s10845-009-0278-6. [Online]. Available: http://dx.doi.org/10.1007/s10845-009-0278-6

[15] D. McNally and C. Gong, "Concept and laboratory analysis of trajectory-based automation for separation assurance," in *AIAA-MST-2006*, AIAA. Keystone, CO: AIAA, August 2006, pp. 1–17.

[16] K. J. Vicente and J. Rasmussen, "Ecological interface design: Theoretical foundation," *IEEE Transactions on Systems, Man and Cybernetics*, vol. 22, no. 4, pp. 589–606, 1992.

[17] K. J. Vicente, *Cognitive Work Analysis. Toward a Safe, Productive, and Healthy Computer-Based Work*. Mahwah, NJ: Lawrence Erlbaum Publishers, 1999.

[18] C. Borst, M. Mulder, M. M. van Paassen, and J. A. Mulder, "Theoretical foundations of an ecological synthetic vision display," in *AIAA Guidance, Navigation and Control Conference*. Chicago IL: AIAA, August 2009, p. 20, aIAA-2009-5982.

[19] J. Rasmussen, *Information processing and human-machine interaction : an approach to cognitive engineering*. New York: North-Holland, 1986.

[20] F. M. Heylen, S. B. J. Van Dam, M. Mulder, and M. M. van Paassen, "Design of an ecological vertical separation assistance cockpit display," in *Proceedings of the 15th International Symposium on Aviation Psychology*. Dayton OH: Wright State University, April 27–30 2009, pp. 367–372.

[21] M. M. van Paassen, "Functions of space and travellers," in *XVIII European Annual Conference on Human Decision Making and Manual Control*, Loughborough, 1999, pp. 268–274.

[22] J. J. Gibson and L. E. Crooks, "A theoretical Field-Analysis of Automobile-Driving," *The American Journal of Psychology*, vol. 51, no. 3, pp. 453–471, Jul. 1938, ArticleType: research-article / Full publication date: Jul., 1938 / Copyright © 1938 University of Illinois Press. [Online]. Available: http://www.jstor.org/stable/1416145

[23] S. Consortium, "The ATM target concept, document d3," SESAR Ex Com, Tech. Rep. DLM-0612-001-02-00a, September 2007.

[24] P. M. Fitts, "Human engineering for an effective air-navigation and traffic-control system," Ohio State University Research Foundation, Tech. Rep., 1951.

[25] K. J. Vicente and J. Rasmussen, "The ecology of human-machine systems ii: Mediating "direct perception" in complex work domains," *Ecological Psychology*, vol. 2, no. 10, pp. 207–249, 1990.

[26] S. B. J. Van Dam, M. Mulder, and M. M. van Paassen, "The use of intent information in an airborne self-separation assistance display design," in *AIAA Guidance, Navigation and Control Conference*. Chicago IL: AIAA, August 2009, p. 19, aIAA-2009-5745.

[27] J. Ellerbroek, M. Visser, S. B. J. Van Dam, M. Mulder, and M. M. van Paassen, "Design of an airborne three-dimensional separation assistance display," *IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans*, vol. 41, no. 5, pp. 863–875, September 2011.

[28] M. M. van Paassen, M. Mulder, and S. B. J. Van Dam, "Cognitive work analysis for vehicle locomotion – aircraft short-term trajectory planning," in *IFAC/IFIP/IFORS/IEA Symposium "Analysis, Design and Evaluation of Human-Machine Systems"*, Atlanta GA, 2004, p. 5.

[29] A. M. Bisantz and K. J. Vicente, "Making the abstraction hierarchy concrete," *Int. J. Human-Computer Studies*, vol. 40, pp. 83–117, 1994.

[30] P. Panman, "Assisting pilots at the transition from self-separated to controlled airspace," Master's thesis, TU Delft, Faculty of Aerospace Engineering, 2010.