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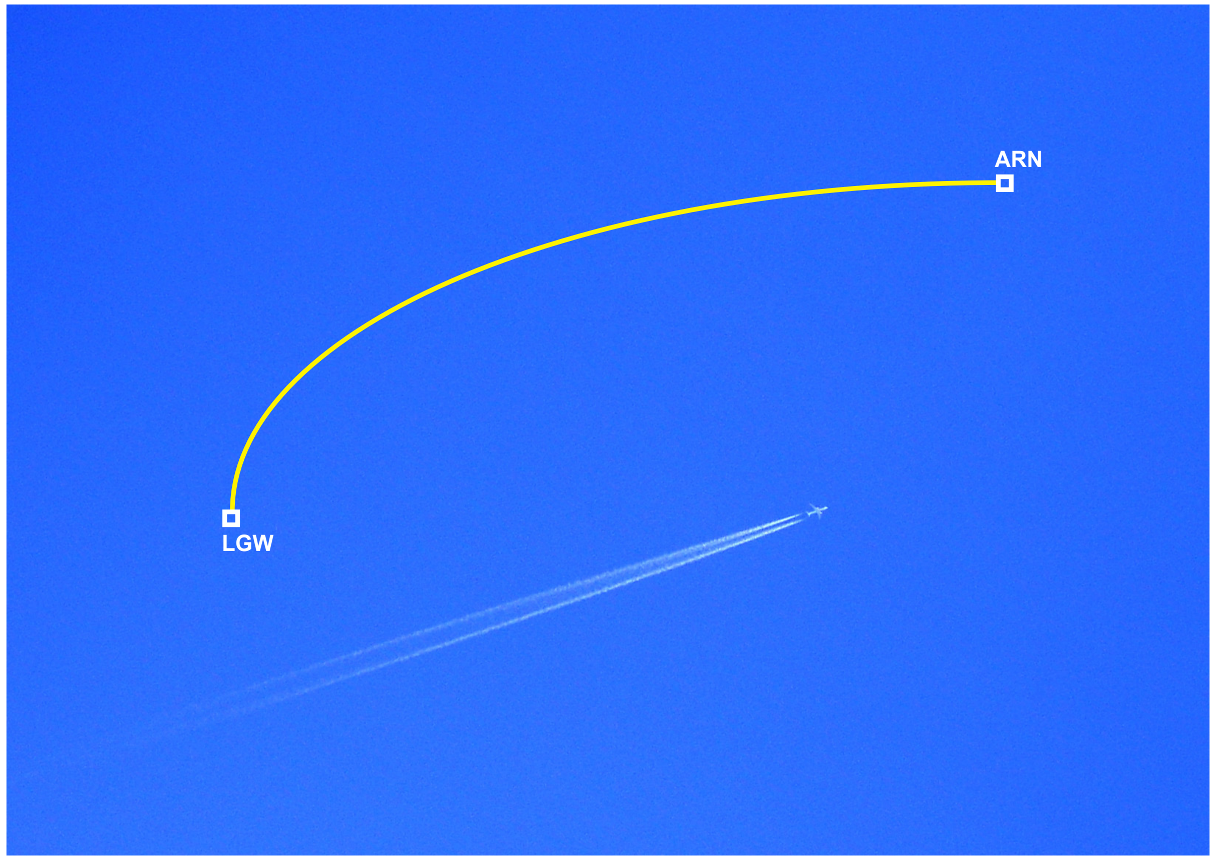
4D Trajectory Management Decision Support

DAVID LINDGREN, ANDERS TÖRNE



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Abstract

In international cooperation, LFV Group develops air traffic control methods that in the future will allow more predictable and environmentally friendly flights. An increasing number of aircraft have today capability to automatically follow four-dimensional (4D) trajectories, which means that the pilot can plan where, on a geometric trajectory, the aircraft should be at every time instant of the flight. How could this fairly new control technique be used to reduce environmental impact and improve passenger comfort and flight time keeping? To answer this and related questions, LFV Group develops new traffic control methods that are evaluated by extensive simulations, where both ground personnel and pilots act in their professional roles.
The Swedish Defence Research Agency (FOI) has during 2007 studied this area, firstly to understand the issues related to airport approach control, secondly to propose areas where FOI and LFV Group jointly could advance both the control and the evaluation methodology. Without drawing any final conclusions, this document describes a selection of these development areas.

Keywords

ATC, Air Traffic Control, Command and Control

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Sammanfattning LFV Group utvecklar i internationell samverkan luftledningsmetoder som i framtiden ska tillåta miljövänligare och mer förutsägbara flygningar. Alltfler flygplan har idag möjlighet att automatiskt följa fyrdimensionella flygbanor, vilket innebär att piloten i förväg noggrant kan planera var på en geometrisk bana flygplanet ska befinna sig i varje ögonblick. Hur ska denna relativt nya styrteknik ur ett ledningsperspektiv effektivt utnyttjas för att minska flygtrafikens miljöpåverkan och öka passagerarkomfort och tidshållning? För att besvara denna och liknande frågeställningar utvecklar LFV Group nya ledningsmetoder som utvärderas genom omfattande simuleringar, där både markpersonal och piloter agerar i sina yrkesroller. FOI har under 2007 fört en dialog med LFV Group för att dels förstå ledningsproblematiken vad företrädesvis gäller flygplatsernas ankomstflöde, dels föreslå områden där FOI of LFV Group kan göra en gemensam insats för att föra lednings- och utvärderingsmetodiken framåt. Utan att dra några bestämda slutsatser beskriver denna rapport ett urval av dessa områden.		
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Contents

1 Introduction

During the first half of 2007, FOI and LFV have jointly discussed areas where LFV would benefit from FOI support, FOI being a research provider and technical expert within the area of decision support. Focus of the discussions has landed on the *TMA approach control*, and circled around ways to improve or complete the support tools to accommodate NUPII+ concepts for more efficient flights, for instance, *green approaches*. In this respect, it has also been discussed whether the simulations LFV conducts to evaluate new techniques and concepts would benefit from exploiting a distributed test bed based on standardized architectures. The overall objective of the FOI support would be to make the ATC more efficient under maintained traffic throughput. Efficiency is interpreted in terms of improved abilities to safely handle 4D trajectories, and to safely allow aircraft to approach with minimum fuel burn and maximum predictability.

This document comprises six tracks that have been found interesting to pursue, or at least worth to describe. The first track (Chapter 2) is about simulation tools, and is rather stand alone. The remaining five chapters describe ideas that are more related to decision support tools and control procedures. They are also rather stand-alone, but together they represent a collective idea on how different *control objectives* and pre-defined *intentions* in the future may beneficially adapt the support tool to the current traffic situation, and to some extent affect the way the controller operates. For each track there is a roadmap to outline a continued exploration of the idea.

2 Distributed Simulation Platform

The MOSART test bed could be an alternative, or a complement, to the simulation tools LFV uses today (NARSIM). In the long run, such a transition to a new platform is believed to pay off in reduced cost and effort for setting up and running simulation experiments. Another benefit is believed to be reduced development and integration time of new prototypes, as well as reduced effort to interchange and reuse different modules in the simulator.

2.1 MOSART

MOSART is a test bed for integration of distributed components at large-scale simulations and demonstrations. MOSART is developed at FOI, se [2], and is based on

- IEEE 1516, *high level architecture (HLA)*, and
- IEEE 1278, *distributed interactive simulation (DIS)*, see [3].

MOSART is designed to increase cost efficiency for researchers, developers and other users, to stimulate cross-disciplinary activities, and to learn how to efficiently connect various data sources. MOSART is a modular environment providing fundamental tools to integrate custom-developed as well as commercial software components. The three main parts of MOSART are

1. Integration software,
2. Simulation support, and
3. Applications and prototypes.

Altoghether, these parts aim to support validation and demonstration of concepts and software prototypes in an environment which is common to other users. This generally leads to more realism.

Modules for integration The integration software of MOSART lowers the threshold for making large distributed simulations and demonstrations. Users are not required to have expert knowledge about distributed simulations. The MOSART package comes with a basic set of support modules like *scenario engine*, *scenario editor*, *2D and 3D visualization*, *maps and high resolution synthetic environments*, *real sensor data*, *logging tools*, *synchronization*, see Figure 2.1. In addition, there is a set of user-contributed modules that can be reused, see Figure 2.2 for some examples.

Technology Transfer By complying to the HLA and DIS standards, MOSART is compatible with similar environments at The Swedish Defence Material Administration (FMV), The Swedish Armed Forces, DSO Singapore, and at various industry partners. This indeed facilitates technology transfer.

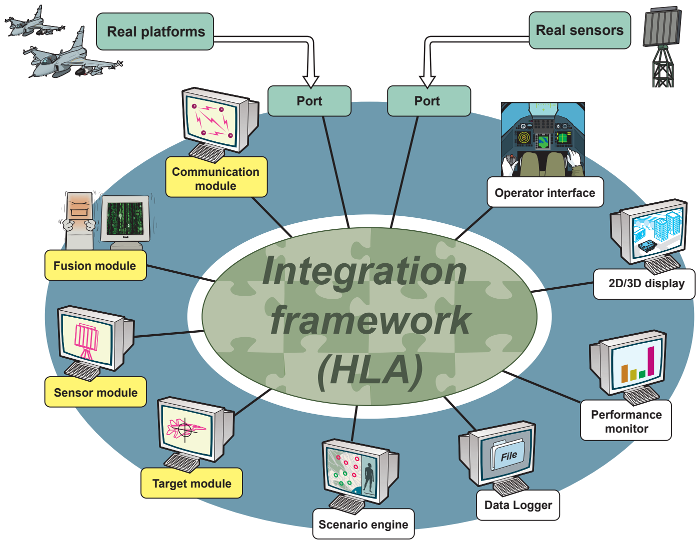

Figure 2.1: Integration in MOSART. HLA ties together modules for visualization, databases, sensors, and so on.

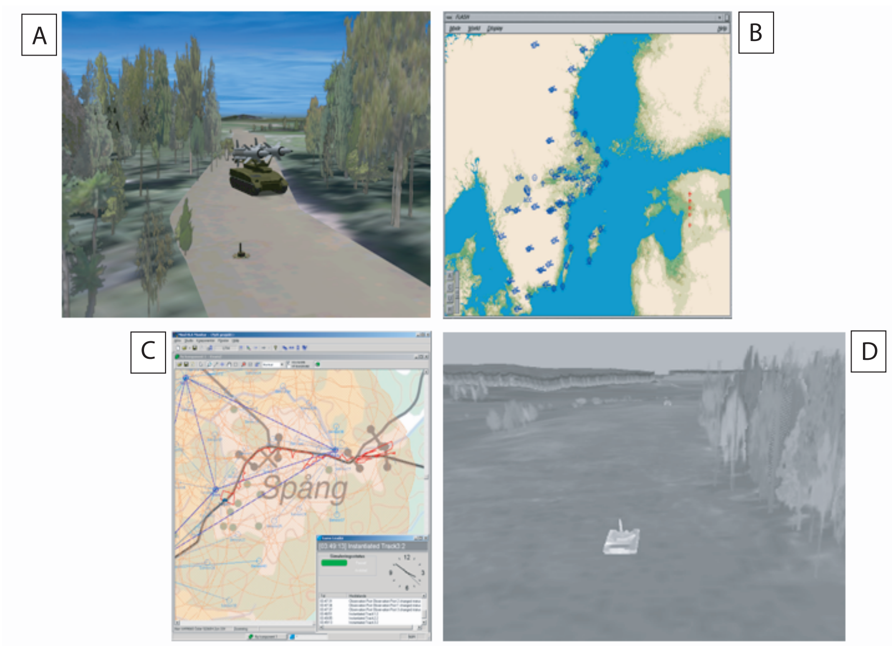

Figure 2.2: Example of available modules and/or modules in MOSART: A) 3D visualization and 3D worlds, B) Flames, simulation framework, C) 2D visualization, D) IR sensor simulation.

2.1.1 Design Overview

The MOSART integration framework is sketched in Figure 2.3 and is based on the HLA standard. The bottom layers comprise the HLA *run-time infrastructure* (RTI), which is a required middleware when implementing the HLA. The RTI provides software services needed to coordinate operations and data exchange between simulation modules during a runtime execution. In a way, it implements the HLA interface specification, although it is not itself part of the specification. MOSART does not itself include an RTI implementation, but relies instead on commercially available RTIs, and is compatible with Pitch pRTI 1.3 v2, Pitch pRTI 1516, Mäk RTI 1.3 and DMSO RTI 1.3 NG v5.

MOSART Kits MOSART includes a number of software libraries or *kits* that facilitate rapid development of new simulation modules. The kits take, for instance, care of adapting data to the simulation network, position and vector conversion between different coordinate bases (map projections), and dead reckoning. All libraries are available in both Java and C++ and are independent of chosen platform.

Federation Agreements The *federation agreements* comprise a set of requirements on the simulation modules, the *federations*, to be executed in MOSART. The federation agreements postulate how dynamic and static scenario information should be distributed in the simulation network. Apart from the federation agreements, there is a reference *federation object model* (FOM) including standard objects and interactions commonly used. By using the reference FOM, the repeated modeling of similar phenomena in different modules can be avoided.

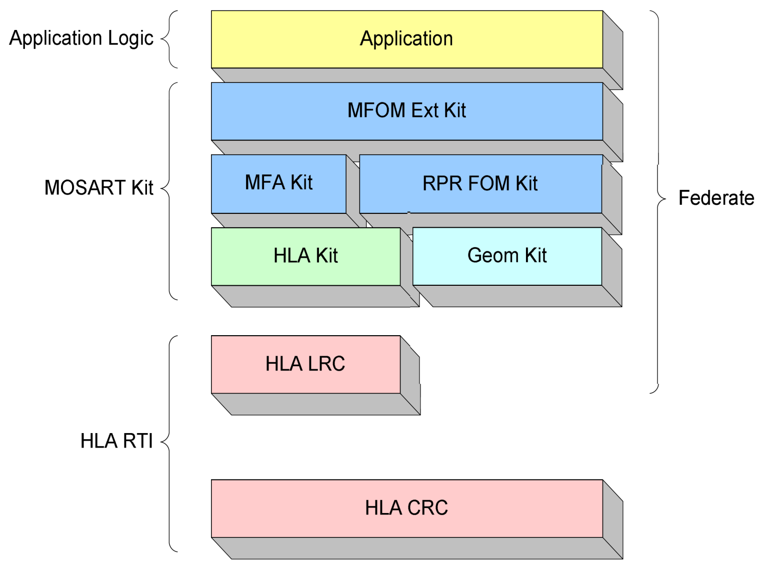

Figure 2.3: Mosart integration framework.

Modules The modules of MOSART are stand alone tools that can be used on a need or a preference basis. Some of the modules are specially developed for the test bed (the federation manager and the scenario editor NetScene), while other are adapted research results (MIND) or commercial tools for visualization (Vega). Many modules are plain research results that are left after a successful integration and demonstration, for instance, sensor models.

2.2 Benefits using MOSART in LFV Simulations

The incentive using MOSART in LFV simulations would of course be increased efficiency in a wide sense. At this stage, FOI cannot evaluate this efficiency monetarily. Some foreseeable efficiency-related benefits are listed below.

1. The component models in MOSART follow international and well documented standards, which facilitate technology transfer between organizations and research providers.
2. Thanks to the open standard, LFV would not be dependent or tied to any single commercial supplier.
3. Simulations can more easily be distributed over different geographical locations. There is no need for all participants to be gathered at one place. Traffic controllers and pilots can, by preference, be seated at Arlanda, at Sturup, perhaps even at home.
4. Functions such as AMAN and TP become modular components that are easily replaceable and that can be reused or shared among many clients in the system.
5. An effect of the fine grained modularity and component reusability is reduced effort to design and set up experiments. The federation object model forces a development method that structures and modularizes the simulation component design. The distribution is then straightforward.
6. Simulations can be synchronized in real time, but can also be executed slower if needed or as fast as the computer capacity allows.
7. There are many plug-and-play tools readily available to offer 2D/3D visualization, advanced computations, coordinate transformations/map projections, and much more.

2.3 Potential Drawbacks using MOSART

1. Although there are many both free and commercial HLA-compliant products available, the major part is developed by the military establishment. Today, HLA is not widespread within the area of ATM, and there are few ATM-components that are directly HLA-compatible.
2. Data does not always follow the shortest path and the centralized control (the RTI) is a bottleneck, which put high demands on the network infrastructure if large data sets are going to be transferred between modules.

2.4 Roadmap

The introduction of HLA based distributed simulation should be done with care and in carefully selected steps. LFV is advised to perform the following steps and evaluate the result for each step.

1. Select a prototype module, for instance, a weather module that simulates the actual weather (for input to actual A/C trajectories), the weather data to the TP and the weather information to the controller.

2. Design a suitable FOM where the interface to the NARSIM simulation is well-defined. Let the weather simulation module(-s) have its (their) own time. Then design the gateway itself and the required weather modules (for instance, weather simulator, weather data acquisition process, weather information presentation to controllers).

3. Make a prototype evaluation of the weather simulation in MOSART and, if successful, run a integrated experiment with the NARSIM to test the concept. Make another evaluation. Possibly use in a user experiment.

4. With the aim to make distributed simulations, adapt or possibly break down selected modules of NARSIM, into HLA compliant components. These components are then integrated into MOSART.

5. Adapt or possibly break down other modules, for instance, with the aim to support *plug and play* for suitable decision support tools, into HLA compliant components. These components are then integrated into MOSART.

3 Study of ATC Logs and Modeling

As a result of earlier project activities at LFV (not described in this document) logs with ATC data have been stored, and may after some anonymizations become available for research. This type of data, if sufficiently rich, could be used to estimate statistical models and to find recurring patterns. Below some different approaches with different purposes are described. First some terminology concerning models will be established.

3.1 Notes on Modeling

A *model* is a formal or mathematical representation of our knowledge about how nature or part of nature (an aircraft) behaves in various situations. *Physical models* are derived from insights and laws like Newton's motion laws or Maxwell's electromagnetic laws, while *statistical models* rely on systematic differences and indifferences in repeated observations of nature. *Dynamic models* have a memory or a state that are allowed to evolve over time (the location and speed of an aircraft), while in contrast *static models* are inherently time-independent ($e = mc^2$).

The use of models is a rational approach to solve many practical problems. For instance, an appropriate model of a telecommunication link may be used to compensate for negative filter effects that otherwise restrict the transmission rate. A valid model of bacterial growth can be used to control the nourishment feed and temperature of biochemical reactors. A model of an aircraft can be used to predict the fuel consumption or calculate an ETA. And so on. Of course, less accurate or less detailed models are less useful and may not always do a satisfactory job. To that end, for practical and/or economical reasons, not all factors that significantly influence the modeled phenomena are necessarily observed or measured by the model user, a fact that also typically limits the accuracy or performance of the model exploit.

3.2 Improved Prediction with Dynamic Modeling

Eurocontrol develops dynamic models to be used for trajectory prediction, and publishes these models in the base of aircraft data (BADA), see [1]. These are physical models that rely on the conservation of energy, and equate the rate of work done by forces acting on the aircraft to the rate of increase in potential and kinetic energy. However, a large data set with log files of observed aircraft during descent, gives the opportunity to identify dynamic models on a *statistic basis*. With these models it is possible to predict, for instance, the *average* height response to a flight level change instruction, and to give confidence intervals based on the statistics. As with the BADA models, accurate prediction relies on access to certain information about the aircraft, the flight and the weather conditions.

The statistical models identified from log data can be used much the same way as the physical BADA models to predict aircraft trajectories. However, without actually conducting the modeling, it is very difficult to say whether the statistical models will be superior or inferior to the BADA models. The quality of the statistical models naturally depends on the statistical material they are based on. If this material is sufficiently large, the statistical model may very well outperform the BADA model, and give reliable statistical confidence intervals on the trajectory prediction as a bonus.

The following steps should be taken to investigate further this possibility to improve trajectory prediction for the approach phase.

1. Collect any complementary information available, for instance, weather logs.
2. Organize data in a database that allows specific passages and phenomena, like the response to certain instructions, to be extracted.
3. Find appropriate model structures and adapt them to data.
4. Evaluate the models in terms of prediction accuracy and compare the results to the BADA models.

3.3 Controller Plan Identification and Advise

When the conditions are undisturbed, the controller sees to that each aircraft follows one of several nominal approach 4D-trajectories. A nominal trajectory is given by type of aircraft, approach direction, weather conditions, etc. A disturbed situation arises when there is, for example, a delayed aircraft that affects other aircraft or in general when there is a risk that the safety regulations are violated if no deliberate action is taken. In the disturbed situation the 4D-trajectories no longer become nominal. This abnormal trajectory is the manifestation of the controller plan to resolve the disturbed situation.

If we assume that similar situations result in similar controller plans and similar abnormal trajectories, then it should be possible to map situation characteristics to a controller plan. Thereby a controller advise could be constructed based on the situation characteristics. This contains several challenges:

- The way to characterize situations is practically unknown, at least to the detail required here. The problem amounts to finding parameters for disturbed situations that groups similar plans together (clustering).
- Different controllers might use different strategies in similar disturbed situations. This means that the mapping from abnormal trajectory to controller plan characteristics will be difficult to find.
- To establish criteria for defining similar plans, the detail of the controller plan (that is, what are "similar" plans) must be adequate. Otherwise a possible advise to the controller will be too "weak" to actually give any help.

A large set of observed behavior of approaching aircraft will mean that solid evidence may be found that answers the challenges above. This can lead to that also a negative answer may be found—"It is not possible to predict which plan to resolve the situation the controller will use, given the situation data available in the data set".

Roadmap A possible roadmap for this concept is to:

1. Find nominal trajectories and filter out abnormal trajectories. Each abnormal trajectory deviates in some way from the nominal trajectory.

2. If the result of 1. is satisfactory then make a clustering analysis—determine what are similar situations and similar deviations—if possible.

3.4 More Realistic Simulation Models

To evaluate ATC support tools in the approach phase, it is essential that validated scenarios are used, that is, that they actually correspond to possible traffic situations. A large data set of approach scenarios together with knowledge about nominal approach trajectories can be characterized by a stochastic model, where for each simulation the parameters can be changed.

This will validate the simulation scenarios and pinpoint the requirements on the support tools. By means of the experimental observations, new tools may be developed and tested, and by using a stochastic model, comparative analysis is believed to be more cost efficient, compared to existing methods. This development means that the following steps must be taken:

1. Develop a stochastic model that reproduces significant characteristics of the trajectories in the data set.

2. Perform a comparative experiment using the model and then vary the parameters in the model.

4 Interactive Prediciton for Approach Control

The aircraft arrivals at an airport are usually sequenced and planned relatively early under a strategic phase. At this phase, an absolute landing time is estimated, an ETA. However, due to unexpected weather conditions etc., the ATC cannot always follow the plan. Aircraft may from time to time arrive at the airport earlier or later compared to the ETA. This occasional disturbance may of course affect other aircraft approaches. *Tactic* flexibility is implemented by the (TMA) controllers, who are working interactively with both other controllers, and the aircraft pilots, to safely and efficiently land the aircraft despite uncertainties in the strategic plan.

Indeed, the controllers today have computer based tools to support their tactic work. It is, however, interesting to discuss ways to improve these support tools, particularly in the light of new requirements on efficiency and predictability. It is believed, that one improvement would be to let the controller work with an *explicit* or computer based plan for the aircraft *all the way to touch-down.* Such a plan exists from the strategic phase, where aircraft are assigned ETAs to produce an appropriate traffic throughput. Here we would like to propose, that when the controller alter the strategic plan to implement TMA flexibility, the controller does so explicitly in his or her support tool. This way, more accurate predictions are feasible. Without any increase in work load, the controller's awareness of traffic situation evolvement will be improved to gain earlier instructions and/or fewer restrictions (when possible).

4.1 Advancing the Controller Support Tools

A *quality assessment* of the controller's performance would be to establish the ability to safely lead aircraft to landing with few restrictions and no unnecessary fuel burn. These qualities are indeed put to the test when granting some aircraft a green approach during a high traffic load. One possible way to improve the tools used by the controller would be to give means to do more accurate planning and prediction long time ahead. This will in turn allow the controller to give earlier instructions to the pilots, who then have better chances to approach economically. Early instructions seem particularly important to minimize the restrictions on green approaches. To summarize, advanced support tools should

1. Give improved support for traffic situation awareness and prediction
2. Allow the controller to give earlier instructions
3. Give support to meet demands on more efficient (green) flights

4.2 From Mental to Explicit Planning

Today, any replanning or rescheduling under the tactic phase is done mentally and in consensus with other controllers. The controller's intention to, for instance, adjust the flight path in order to delay an aircraft, is thus never registered in the support system, and consequently, the controller will not receive any support for the intention. Moreover, without knowing the controllers' (collective) intentions, it will not be possible for the support system to accurately predict how the traffic situation will evolve. The point is, to improve the accuracy of the supportive traffic situation prediction, it is required that the controller intent is registered.

Initial planning for aircraft movements and landing scheduling is produced during a strategic planning phase. The stategic setup is however subject to changes. If the planning does not hold due to delays or disturbances from other aircraft, the controller modifies it. An idea is, that the controller should commit this modification explicitly in the support system, for instance move a break point on the STAR, and then immediately receive an updated prediction–a feedback on how the new plan may evolve the traffic situation. This way, the controller uses the supportive prediction capabilities in an interactive way, and may earlier become aware of flight path adjustments needed. The benefit from this interactive prediction increases when the support system better "knows" the controller's intent.

4.3 Interactive Support Tools

Today, the controller has a support tool that allows prediction along a straight line. This tool has its benefits, but it is a short term tool since it is valid only as long as the aircraft follows the trivial plan of flying straight ahead. A better tool, it appears, would support the controller's intent all the way to touch-down; that the aircraft eventually should change course, flight level and finally land. This intent could be shared among all controllers in the TMA to give a common and collective awareness of the traffic situation and how it is likely to evolve.

An aircraft equipped with a modern FMS has capability to navigate along a pre-programmed path, a 4D trajectory. A new tool that support the controller intent all the way to landing, would indeed harmonize with the concept of aircraft flying along 4D trajectories, since the controller intent very well could be represented as a 4D trajectory. In a distant future, the controller could then upload a modified 4D trajectory to the aircraft (FMS), and hopefully be able to do it so early on, that the aircraft still could conduct an economic and comfortable approach.

An improved interactive planning and prediction tool could be implemented directly on the 2D geographical map surface that supports the controllers today. It would then view the planned paths (STARs or modified STARs) that the controller intends the aircraft to follow, but also allow the controller to alter the paths (STARs). To allow the controller to investigate how the traffic situation is predicted to evolve, a special prediction slider could be used to commit a *fast forward scan*.

Other visual support tools could be proposed, that complements the geographical map that the controller mainly uses today. For instance, the planned altitude could be plotted against time relatively to landing, see Figure 4.1. Such a tool highlights the time separation between aircraft. It also clearly indicates how the aircraft altitude profile relates to a landing at predicted time. There are many variations to this theme, for instance, to plot aircraft energy against time, or to plot energy or altitude against remaining miles to travel before landing. Tools like these are all based on the controller intent.

4.4 Summary

To summarize, an improved support for the controller by interactive prediction aims to

1. Give better awareness of the traffic situation and how hit it is likely to evolve,

2. Give means to plan further ahead and advise aircraft earlier, and to

3. Support a framework that is being developed to manage 4D trajectories.

4.5 Roadmap

A roadmap to further exploit the ideas of interactive prediction is proposed to include the following steps:

1. A set of proposals for visualization and interaction techniques are developed in collaboration with HMI and visualization experts.

2. Controllers will help to select and modify a few proposals that are particularly interesting to develop further.

3. Prototypes are built to demonstrate the interaction techniques.

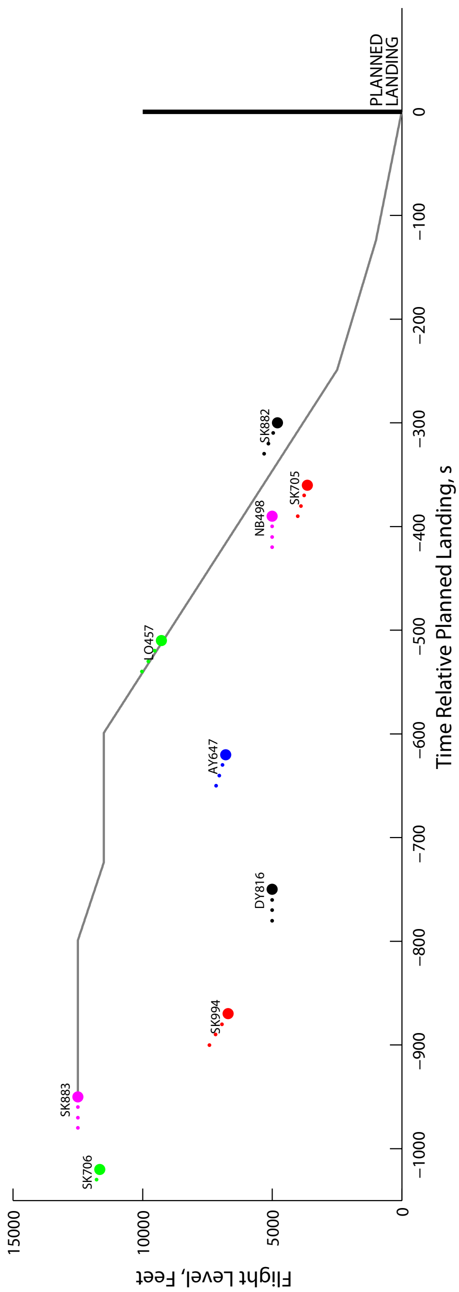

Figure 4.1: Aircraft altitude versus planned, relative time to landing. This visual tool indicates the planned time separation between aircraft at landing. For instance, SK706 is planned to land in about 1025 s, while SK883 is planned to land in about 950 s. Thus, according to the plan, SK706 will touch down 75 s after SK883. At any time, the controller can highlight and if needed modify the planned altitude profile for any aircraft (the gray line in the figure). Alternative units on the axes could be *Remaining Miles to Landing* instead of *Time*, or *Aircraft Energy* instead of *Flight Level*. Tools like this support the controller intentions by predicting and visualizing the consequences of a plan, or the consequence of a change of a plan.

5 Trajectory Management in 4D

Strong incentives for equipping aircraft with new technology would be benefits like better fuel economy and better predictable flights. An example of such technology is an FMS that automatically can navigate an aircraft accurately in both space and time, that is, on a 4D trajectory. The traffic controller may grant the pilot flying with such a modern FMS to follow a 4D continuous descent trajectory down to landing, which may reduce fuel burn by hundreds of kilograms (green approach). 4D flights are however inflexible when they follow the trajectory down to landing in absolute time. The flexibility needed to cope with inevitable delays and other disturbances then needs to be implemented by other (old-style) aircraft that are not rigidly controlled in 4D. Granting a flight a 4D approach may thus come at expense of other aircraft lacking the new technology. The problem is, when all aircraft have been equipped with the new technology, the promised benefits will be absent, since there are no old-style aircraft left to implement the flexibility.

5.1 Objective

To persistently take advantage of the new FMS and communication techniques, ways to introduce flexibility in the 4D trajectories must be developed. This probably requires earlier instructions to maintain good fuel economy. This in turn requires better support tools for the controllers to understand and communicate revised 4D trajectories to the pilots. Today, the FMS technology is probably not mature for this type of revised trajectories, but it is nevertheless important to have an idea of how efficiently 4D trajectory management could work tomorrow. Efficiency may here include runway economy, fuel economy, environmental impact, predictability, controller work load. In essence, objectives for a deeper study of 4D trajectory management would be

1. To describe support tools that allow the controllers to understand and manage 4D trajectories
2. To describe how controllers can revise 4D trajectories to achieve a control goal under economy constraints
3. To describe a stable and finite process where controller and pilot agrees on trajectory revisions

5.2 Technique

Some visualization techniques, let be naïve, to better understand 4D trajectories have already been proposed in Chapter 4. A deeper study would involve expertise in HMI and visualization. Also the way the controller revises trajectories has bearing on Chapter 4. To support the controller's 4D trajectory management, prediction techniques and evaluation of cost functions for fuel economy, comfort, and so on, are matters of course.

6 Intention Based Decision Support

6.1 Decision Support Today

Today, the situation awareness for the controller is supported by a global 2D-map, where each aircraft is presented by a position symbol that includes history dots and a leader line. There are also tools that monitor special conditions and requirements, like showing the planned sequence of arrivals or administer conflict detection and monitoring. To monitor the state of each aircraft there is an associated label (a text box). This label has different modes:

- *Standard mode*, where general information, like ID and speed, of the flight is shown for all aircraft.
- *Selected mode*, when the cursor is positioned over the aircraft, where different interaction commands related to the aircraft can be issued—like coordination and editing of future trajectory.
- *Expanded mode*, where more information is shown than in standard mode.

The controller can globally configure the information contents of the label in the different modes, and thereby adapt the decision support to the situation and to individual preferences.

6.2 Goals with the ATC

There is a large number of different goals with the ATC, specifically for an approach sector. A goal may apply to an individual aircraft (a local goal) or an approach sector as a whole (a global goal). A goal for an individual aircraft is to let it fly according to a planned 4D-trajectory, for another it is to delay the landing time and yet for another it is to avoid a specific, monitored conflict with another aircraft. The "mental" assignment of a goal to an individual aircraft and to the sector as a whole is made by the controller based on the approach sector ATC policy, on known requirements from airport control and on personal, informal knowledge about airline operator, pilot, or passenger preferences.

A goal may be achieved to various degrees of satisfaction. Some goals, in particular those related to safety, are binary, either *OK* or *not OK*. Others are ordinal (ordered classification) measures. In general, the controller has a mental picture of how well the goal is achieved. To optimize the goals, the controller relies on calculated characteristics for individual aircraft relative to other aircraft or speed, time, and position—current or projected into the future.

It is obvious that a "delay" goal (because the aircraft is too early) needs another calculated characteristic than "avoid conflict with…". In the first case, the delay specifically refers to time at a certain point (not necessarily actual landing time). In the second case, the aircraft may be on time but has to make manoeuvres to avoid the conflict and the conflict avoidance is the target measure to monitor.

6.3 Controller Intentions

Below we refer to the controller mental interpretation of the external goals (sector, airport, airline operator, pilots and passengers) by the controller as “ATC intentions” and they may refer to individual aircraft, pair of aircraft and the sector as a whole. These ATC-intentions govern what characteristics the controller want to be informed about. Computer support may then be designed for the two following different aims.

1. *To help the controller to interpret/realize the external goals.* This is easy for almost static and global external goals—like policies, rules and safety. Normally, the interpretation is then built into the decision support as global menus/presentation modes and the same calculated information for all aircraft. In contrast, when the goals change dynamically, and are not the same for all aircraft, it might become a stress factor for the controller to decide what goal to apply to an individual aircraft or the sector.

   Conflict detection tools are examples of the latter dynamic case—they support the controller to detect conflicts and with the decision to use conflict avoidance (change of goal/intention).

2. *To support the situation awareness of the controller by configuring the presented information for the individual aircraft and the approach sector as a whole to correspond to the current ATC intentions.* A general goal with this is to relieve the controller by removing non relevant information and by selecting a relevant presentation mode, instead of letting the controller configure the presentation by herself or himself. It is obvious that this support is more urgent the more dynamic the ATC intentions are.

Generally, this means that the more dynamic the ATC intentions are expected to be, the more computer support is required[1].

It is important to understand the split into internal ATC intentions and external goals. If the ATC intentions do not correspond to the external goals, the controller actions will be *incorrect*. Moreover, if the visualization is based on other information than the internal ATC intentions, the controller will be lost when they do not correspond.

The conclusion is, if an automatic configuration of the visualization is to be accepted, it must be assured that the data controlling the configuration corresponds to the ATC intentions. If the configuration is automatic, this correspondance can be achieved by presenting the reason for the reconfiguration and explaining it.

6.4 Configuration of Decision Support

It is conceivable that, when more and more support tools or calculated characteristics are introduced, they are adapted for specific traffic situations and therefore possibly adapted to different ATC intentions. This means that there is more information to present than what is relevant in the current situation. The controller may have the following options with increasing ambition level to alleviate the possible information overload.

[1]This is the dynamic/static view. Another is the small/large amount of goals, where a large amount of rules (even if they are static) makes the controller in need of computer support, cf., decision support for “Rules of Engagement” in a military context.

1. (manual) Make a configuration of the label information manually at low level globally. This is what can be done today.
2. (manual) Make a configuration of the label information for an individual aircraft manually at low level.
3. (semiautomatic) Select a visualization mode manually for the label information globally.
4. (semiautomatic) Select a visualization mode manually for the label information for an individual aircraft.
5. (automatic) Select a visualization mode automatically for the label information globally and make explanation information available.
6. (automatic) Select a visualization mode automatically for the label information for an individual aircraft and make explanation information available.

We use here the label information as an example, but any visualized information complex enough—like a trajectory prediction—might be used instead. Options 3-6 above are named “intention based configuration”.

6.5 Roadmap

An automatic configuration has to be introduced with care. This means that a series of user experiments has to be done, before trying the concept in a large scale simulation. It is also unclear, if any systematic inventory of “ATC-intentions” or their corresponding goals is available.

Observe that this intention based configuration complements the design and realization of different *decision support tools* like trajectory planners, conflict resolution assistants, calculation algorithms for characterizing aircraft status, and so on. It means that the approach to decision support is made systematic instead of ad hoc. Ad hoc means that tools are introduced where the visualization of data is not configurable according to controller preferences, but by choosing appearance in the design. View intention based configuration as a way to an architectural design of the user interaction.

Proposal

1. Capture ATC intentions and the method used to implement them. Validate the set of intentions. Make conclusions regarding the general method for analyzing ATC intentions and method for a general airport handbook for capturing and analyzing ATC intentions.
2. Analyze what measurable quality factors there are for each (type of) ATC intention and determine the implications for the ATC decision support (label) configuration.
3. Make comparative experiments between manual configuration and different intention based configuration possibilities.

7 STAR versus Parameterized 4D Trajectory

Although firmly established in the ATC procedures, it seems sensible to question whether the STAR sets used today will be the same used tomorrow, given the introduction of new navigation and FMS techniques, and new requirements on traffic throughput, fuel economy, and predictability. Will there be fixed routes at all? Is it not more likely that the AMAN in the future generates optimal 4D trajectories on the basis of the current and predicted traffic situation[1]? The STAR set is indeed an important tool for the controller, but nothing says there are no tools that are better suited to manage aircraft with highly sophisticated control and navigation capabilities.

The problem with the STAR sets is that they introduce restrictions that are unnecessary when using modern control tools. The consequence is wide-sense suboptimal approach paths. The main incentive to leave the STARs in favor of more freely generated 4D trajectories is to fully take advantage of the 4D capabilities, that will be increasingly common in aircraft, to reduce fuel burn and improve predictability.

7.1 Roadmap

Some steps to analyze the feasibility of alternatives to fixed STAR sets would be

1. Develop a parameterization suitable for 4D flight trajectories.
2. Find tools to evaluate safety and efficiency for trajectory sets.
3. Develop optimization techniques that generate optimal trajectory sets given traffic situation and ATC intentions.
4. Describe how the controllers can understand and revise the trajectories.
5. Implement an AMAN prototype to demonstrate the concept.

[1] Optimal under constraints from safety and noise regulations.

Bibliography

[1] Eurocontrol experimental centre. *User manual for the base of aircraft data revision 3.6*, 2004.

[2] T. Horney, M. Brännström, J. Bergman, D. Andersson, R. Forsgren, S. Ahlberg, B. Lindahl, and A. Törne. Slutrapport MOSART. Technical Report FOI-R–1814–SE, Swedish Defence Research Agency, Linköping, December 2005.

[3] IEEE Std 1516-2000. *IEEE Standard for Modeling and Simulation (M&S) High Level Architecture (HLA)*. Institute of Electrical and Electronics Engineers, Inc (IEEE), 2000.