Visualization of Aircraft Approach and Departure Procedures in a Decision Support System for Controllers

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Abstract. This paper reports on 3D visualization of airport requirements for approach and departure trajectories. The work is undertaken within the FP6 SKY-Scanner project that develops a new lidar (laser radar, Light Detection And Ranging) equipment. The fusion of radar and lidar data improves aircraft surveillance within aerodrome traffic zone (ATZ). We propose a new surveillance paradigm which enables the controller to estimate visually a current situation without mental calculations of altitude and distance. Trajectory requirements are defined threefold: normative regulation of aircraft trajectories, vertical and horizontal safety distances, and flight plans. The paper proposes a visualization paradigm based on 2D and 3D view integration. Trajectory constraints are shown in 2D projections. The paper explores how innovative visualizations create new opportunities for controlling air traffic in the ATZ.

Keywords: 3D visualization, controllers’ needs, situational awareness, air traffic control.

1 Introduction

An airport comprises a large amount of specialized systems such as passenger and baggage registration, gate for flight assignment, approach and departure management, etc. The paper is devoted to decision making for air traffic control (ATC) systems dispatchers. The research is on the development of a decision support system (DSS) for a new generation air traffic management (ATM) paradigm (Fig. 1). The work is conducted within the FP6 SKY-Scanner¹ project. The topics include aircraft collision risk evaluation and a DSS.

Air traffic management rules combine technological, economics and regulatory aspects that synchronize plans and actions of different stakeholders in both airborne and ground systems. ATC is a service provided by the ground-based controllers for the purpose of preventing collisions and maintaining an orderly flow of traffic [11].

Each airport determines its approach and departure procedures. Each flight is performed according to an assigned flight plan.

New ATM systems have long implementation cycles. Research and development projects generate ideas that are elaborated in subsequent projects. A proposed solution is verified from different perspectives.

The presented work is performed as a part of the Single European Sky Air traffic management Research (SESAR) programme [14]. SESAR aims at increasing the capacity and efficiency of the European Air Traffic Management (ATM) system [13]. SKY-Scanner explores, among others, avoiding the risks identified by SESAR.

Constantly rising air traffic requires more information to display on a dispatcher’s screen. With an increased amount of information the risk of a human error grows. The reason is that errors appear when important information is mixed with less important one and some aspects are accessed by scrolling. Therefore visualizations aim to enable the user to focus on the large volume of data without losing context awareness.

SKY-Scanner solution employs the visualization ideas proposed in 3D-in-2D Displays for ATC project [15]. The resulting system extends controller’s capabilities to control the adherence of aircraft landing and take-off trajectories with airport procedures. Current systems leave the final landing and initial take-off phases under pilot’s responsibility. The controller gives the pilot a clearance to land. The pilot performs the maneuver and reports. The controller can also observe the landing visually from the tower. The SKY-Scanner system visualizes an actual situation on the screen. The system enables a human operator to estimate visually whether the aircraft meets trajectory constraints.

1.1 Background to the Project

The SKY-Scanner system aims at detecting and tracking aircraft up to at least 6 nautical miles from the ATZ barycentre [12]. In the terminal area an aircraft climbs to the desired altitude. While achieved the destination airport it descents from the cruise altitude and lands. The manoeuvres are performed at low altitude.
Current ATC systems are based on radar devices that have significant disadvantages. The radar receives signals reflected from rain, trees and the ground. It is difficult to distinguish aircraft targets and background clutter at low altitude. In most cases in ATZ, the radar cannot determine the height to the accuracy needed as altitudes are below 300 m. Radar equipment has a margin of error of 200 m. Hence, approach and departure procedures cannot be tracked with a proper accuracy when the altitude is less than the equipment’s margin of error.

The lidar accuracy has a margin of error measured in centimetres and is exact when directed to the target. An approximate position received from the radar facilitates the deflection of the lidar to the target. When the target is found, the lidar switches to the tracking mode and provides the exact target position for the SKY-Scanner system.

Surveillance equipment (primary radar, secondary radar, etc.) is used to establish the controllers’ situational awareness of their assigned airspace. A lidar is installed on ground. Unlike other surveillance systems (secondary surveillance radar or automatic dependent surveillance broadcast), the lidar requires no additional equipment to be installed on the aircraft. The lidar is more precise than the primary radar but it may function worse in certain weather conditions such as rain and fog.

The combination of both devices (Fig. 1) covers their shortcomings. This also enables to track the flight from the beginning till the end. Allowed distances between aircraft are extracted from the rules of air traffic management. Airport procedures define the Ought to Be trajectories. DSS output provides the fused aircraft position and estimated risks of violations. Lidar and radar data are fused in order to better estimate the risks and to propose corrective actions for the controller.

1.2 Motivation for the Paradigm

User needs analysis was performed reviewing the literature. Mainly EUROCONTROL project results and the reports of the National Aerospace Laboratory (NLR) in the Netherlands were concerned.

Fig. 2. Typical radar display
The report on accidents which occurred in 1980-2001 concludes that 12.7% accidents occurred in take-off and landing phases [5]. Take-off accidents comprise 6.1% of overall accident amount and landing – 6.6%. The analysts of the ATM-related accidents arrived at the conclusion that the causal factors were low visibility and incorrect or inadequate instruction/advice given by ATC. A frequent event factor in landing accidents was non-adherence to procedures by flight crew. Thus the current situational awareness is insufficient.

A standard 2D radar display does not show the third dimension. Therefore the controller interprets alphanumerical characters and holds in his mind the altitude [15]. Current systems present the recent situation in 2D plan view. Here aircraft horizontal position is shown (Fig. 2). The third dimension (altitude) and speed are presented with an aircraft label. In order to follow the actual situation and to indicate possible future troubles, the controller performs mental calculations of the altitude and speed. Mental overload could be reduced by more elaborate visualization.

A conclusion is that improving the situational awareness is an important user need. It should be reflected while developing a new DSS paradigm.

The conclusions accord with the ATM vision of SESAR Consortium [14]. Their four future air traffic scenarios predict the growth of air traffic in various scopes. The SKY-Scanner paradigm encompasses two goals which are shown in Fig. 3.

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<th>The goals of SKY-Scanner visualization</th>
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Fig. 3. User goals of the SKY-Scanner DSS paradigm

Section 2 describes instrument approach procedures. From the modeling perspective, departure is analogous. Section 3 presents contemporary visualization approaches for ATC. Section 4 describes the SKY-Scanner visualization model. Section 5 presents a decision support scenario. Finally conclusions are drawn.

## 2 Instrument Approach Procedures

The SKY-Scanner DSS is designed to incorporate the knowledge about the procedures below. Instrument flight rules serve as a source for the Ought to Be trajectories. They define constraints to evaluate the observed trajectories.

Instrument approach procedure is a series of predetermined maneuvers from the initial approach fix to a point from which a landing can be completed [11]. The
procedures are depicted in the Instrument Approach Charts. All aerodromes, where instrument approach procedures are established, should issue Instrument Approach Charts [7].

**Fig. 4.** An example of the approach procedure [8]
Approaches are classified as either precision or nonprecision, depending on the accuracy and capabilities of the navigational aids used. There are different procedures for different navigational aid types. The number of controlled parameters is also different. Precision approaches utilize both lateral (localizer) and vertical (glide path) information. Nonprecision approaches provide lateral course information only. Procedures depict prescribed altitudes and headings to be flown, as well as obstacles, terrain, and potentially conflicting airspace. In addition, they also list missed approach procedures and commonly used radio frequencies (Fig. 4).

The approach procedures determine a certain approach structure defined by approach stages and fly-over points (Fig. 5). A visualization model proposed further is based on this structure.

![Fig. 5. Approach procedure in terms of fly-over points](image)

An instrument approach is divided into five segments: initial, intermediate, final, and missed approach [8]:

1. **Arrival**: where the pilot navigates to the Initial Approach Fix (IAF), and where holding (keeping an aircraft within a specified airspace while awaiting further clearance) can take place.
2. **Initial Approach**: the phase of flight after the IAF, where the pilot commences the navigation of the aircraft to the Final Approach Fix (FAF), a position aligned with the runway, from where a safe controlled descent back towards the airport can be initiated.
3. **Intermediate Approach**: an additional phase in more complex approaches that may be required to navigate to the FAF. Intermediate Approach begins at the Intermediate Fix (IF).
4. **Final Approach**: between 4 and 12 nautical miles (NM) of straight flight descending at a set rate (usually an angle of between 2.5 and 6 degrees).
5. **Missed Approach**: an optional phase; should the required visual reference for landing not have been obtained at the end of the final approach, this allows the pilot to climb the aircraft to a safe altitude and navigate to a position to hold for weather improvement or from where another approach can be commenced.

### 3 Related Work on DSS Visualization

The way computer systems present information to a human controller is of crucial importance for the effectiveness of future ATC systems. Considering an increasing
amount of information made available, a traditional 2D radar representation becomes overloaded [6]. Therefore 3D interfaces are being created. A 3D view requires significantly less cognitive effort to interpret altitude information. However, pure 3D visualizations make distance estimation inconvenient due to perspective distortion effects. The camera restricts the view to a certain sector. Therefore, the controller cannot oversee global traffic.

3D visualizations suit better for integrated attention tasks, such as instructing an aircraft to descend and turn to intercept the localizer. 2D suits better for focused attention tasks, such as estimating the exact aircraft altitude in a moment.

A method of 3D visualizations for ATC consists of strict 3D and 2D/3D combination displays [15]. For example, a strict 3D was used to detect conflicts in the terminal area of Boston Logan Airport [2]; see Fig. 6. This solution requires filtering to reduce controller’s overload. Each zone requires a different mode of visualization. This example shows that pure 3D has certain disadvantages. Just to mention a few,
there is no possibility to oversee the global traffic out of the camera view, then a difficulty to locate traffic at the far end of the scene [3].

A combination of 3D visualization and a 2D view enables to see both the contextual and the altitude information at the same time [1]. The research identified a strategy to select a portion of the main 2D view and represent it in 3D (Fig. 7, 8, and 9). Thus continuity is preserved. It is easier to identify which aircraft is which within a 3D picture.

2D walls with the projections of an aircraft can be shown in a 3D visualization. The Wall View with Altitude Rulers presents a vertically oriented gradation on the wall (Fig. 10). This provides the user with precise data needed to assess the traffic situation or guide aircraft accurately [15].

The Wall View of Approach Control (see Fig. 11) enables the controller to check whether an aircraft adheres the assigned climb/descent procedures. The view shows unambiguously whether the procedure is strictly followed. This method requires a precise aircraft position that cannot be achieved with the sole radar equipment. Current surveillance technologies cannot implement those visualizations because of inaccuracy of radar devices.

4 A Visualization Model in SKY-Scanner

The DSS visualization subsystem enables controllers to perceive and interact with the following information:
1. aircraft positions
2. predicted trajectories
3. detected risks.

Minimizing clutter and distractions is vital to controllers [3]. Hence, on the one hand, it is important to visualize all required information. On the other hand, this should be done with minimal means in order not to clutter the screen.
4.1 The SKY-Scanner Method

Approach procedures present trajectory constraints in a profile view; see an example in Fig. 12. This view is convenient for aeronautics professionals. The constraints are presented in alphanumeric texts. The constraints can be projected in the Wall View with Approach Control (Fig. 11). Thus display cluttering is reduced.

In SKY-Scanner, the Wall View with Approach Control is enhanced with semitransparent curtains. The walls cover a significant area of the screen. They also hide a context view behind and underneath them. Semitransparent curtains is a solution to avoid the hiding.

An airport zone is divided into two vertical spaces. The space below a determined altitude (transitional altitude) is allowed for an aircraft which obtained a landing clearance. With regard to this space, the approach and departure procedures are visualized.

The space above a determined altitude is devoted to aircraft which approach the airport from outside. In this space, the task of the controller is to ensure appropriate horizontal and vertical separations. Therefore, the altitude rulers are integrated with vertical curtains. The number of rulers depends on waiting loops determined in a concrete airport.

The rulers enable the controller to monitor a holding stack of landing aircraft. SKY-Scanner integrates two interface models:
4. Wall View with Altitude Rulers.
5. Wall View with Approach Control.

4.2 Terrain

A benefit of 3D visualizations is in representing 3D ground surface together with altitude. A drawback is that a realistic map may provide the controller with little
useful information. Instead, a simple 2D color map based on height can highlight major orientation features [9].

An example of a generalized terrain is shown in Fig. 13. Terrain peculiarities are important for an airport near mountains.

![Image](image_url)

**Fig. 13.** Generalized terrain model. The airport is a white icon in the center. Small white indicators depict two aircraft.

### 4.3 Modeling the Curtains

Opaque walls can be replaced with transparent curtains. This enables a transparent view. The surroundings are seen like through a curtain. Transition height is represented with a different color – like in the Wall View with Altitude Rulers (Fig. 10). A trajectory is represented with its projection lines on the curtains. White indicators show an exact position of the aircraft in Fig. 14. Following are other features of this model (Fig. 14):

- FAF and IAF are visualized for the procedure; notice dashed lines.
The approach trajectory is rotated about 90 degrees. Thus, the “back” curtain is clearly seen. The profile view of the procedure which is parallel to the runway is represented on the “back” curtain.

The approach trajectory is not shown, only the projections of the aircraft position. The reason is that due to the selected viewing angle a representation would be imprecise and bring little information.

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5 A Decision Support Scenario for SKY-Scanner

A situation is presented in a 3D view with a generalized landscape and tracks detected by the SKY-Scanner system. This screen imitates the situation that is viewed from the tower but without distracting details. Violations are visualized in 3D view and explained on the message board.

The whole zone under observation is divided into two areas:

1. A soft control area where the collision risk between the detected airplanes is tracked and the altitude is controlled;
2. A strict control area where a certain a landing procedure is assigned to the curtain track and the constraints (altitude, speed, track) are followed.

In the soft control area the aircraft altitude is observed. The longitudinal and vertical distances between aircraft are calculated, too. The main 3D window presents the context view; see Fig. 13. Here aircraft are represented with white indicators. Two aircraft are depicted in an example situation: the first is landing and the second is taking off. If the distance is less than allowed minimum, a collision is fixed and the aircraft icon becomes red. In case the minimal safe distance is calculated from predicted positions, the risk evaluation on the DSS control panel becomes yellow and an appropriate message appears on the message board.

The strict control area is defined within 6 nautical miles, between Final Approach Fix (FAF) and Touchdown Point (TP). The assigned procedure is presented on the curtains (Fig. 15). The green indicator depicts the tracked aircraft. Black indicators on the curtains present aircraft’s projections. The transition altitude is presented with a different color on the top of the curtains.

The white lines present the projections of the approach procedure. The blue lines present the projections of the main approach milestone, the FAF fly-over point.

Aircraft position validity can be easily detected visually and confirmed with colors. The tracked aircraft is depicted in green if it follows the assigned approach procedure. The projections on the walls enable tracking until the touchdown point.

The DSS control panel presents the current information about the actual tracks and possible risks. 2D window comprises user interface buttons and the message board.

Fig. 15. Approach procedure violations are visible in the real time. The green indicator depicts a tracked aircraft. Two black indicators show the projections of the actual position.
When aircraft receives a clearance for landing, the DSS support scenario is as follows (Fig. 16):

1. Turn on projection curtains.
2. Select an approach procedure assigned. The projections of the procedure appear on the curtains.
3. Observe the situation: aircraft position should be on the projection lines.

A path violation can be detected on the projection walls. To adhere the procedure, no deviation is allowed from the safe funnel. The indicators have to follow the projection lines. Path violation risk is visualized with colors:

- green means that risk is evaluated zero
- yellow means a certain risk of the path violation in the future
- red means that a violation already occurred. Aircraft position is out of the safe funnel.

Fig. 16. 3D view with control panel.

Button 1 turns on curtains. Button 2 selects the tracked aircraft.

The upper part of the control panel shows DSS output. The 3D window attracts the controller’s attention when the aircraft deviates from the projection lines. The control panel shows a violated parameter. Risk violation for each tracked parameter is depicted in green, yellow or red and also with a real number from 0 to 1.
5 CONCLUSIONS

The paper reports on the ongoing study of a new ATM paradigm. It is based on (1) lidar and radar data fusion, and (2) 3D visualization of aircraft trajectories within aerodrome traffic zone. A system will enable a human controller to view on a screen both the Is trajectory and the Ought to Be trajectory. Aircraft tracking with lidar enables the controller to observe flight phases that are near the ground. This is not possible using the sole primary radar. Hence, a decision support system will allow for a limited control over the aircraft in approach/departure phases.

In the DSS prototype, two ideas are integrated when visualizing trajectory restrictions. Human operator needs are satisfied in the following way:

- 3D display improves situational awareness; the airport environment is depicted with essential terrain obstacles;
- 3D walls with airport procedures reduce the cognitive workload.

3D display with 2D projections shows the actual trajectory with spatial restrictions on the required one. This enables to estimate the compliance to procedures.

When designing visualizations, initially a decision was made about “what to draw”. Later, to avoid the clutter and distractions, an opposite decision was made, “what not to draw”. Thus a screen became cleaner. Controllers found the projection curtains useful.

Approach/departure procedures provide a complex normative regulation composed of both textual and graphical descriptions. Major constraints form a series of rectangular gates at certain distances from the runway. Moreover, an airport has several procedures. Therefore representing the constraints in a DSS is a challenge.

The prototype was demonstrated to expert users. Air traffic controllers and airline operations personnel were included. The data included real-life tracks and procedures. The scenario was judged as realistic and effective while tracking aircraft in the ATZ. The controllers noted that currently they are not able to track aircraft during the landing. This supports our belief that such a DSS can contribute to future ATM systems. This system can be viewed as an information system that supports spatial-temporal reasoning in real-time air traffic management tasks.

The prototype is required to develop with MATLAB. This symbolic mathematical tool suits for demonstration purposes. However, another programming tool shall be chosen for industrial implementation. MATLAB is too slow for real time applications. Consider scalability issues.

The decision support scenario can be elaborated to visualize predicted positions and conflicts. The current prototype informs this on the message board.

References


