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Visualization of Conflicts and Resolutions in a "Free Flight" Scenario

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ABSTRACT

"Free Flight" will change today's air traffic control system by giving pilots increased flexibility to choose and modify their routes in real time, reducing costs and increasing system capacity. This increased flexibility comes at the price of increased complexity. If Free Flight is to become a reality, future air traffic controllers, pilots, and airline managers will require new conflict detection, resolution and visualization decision support tools. This paper describes a testbed system for building and evaluating such tools, including its current capabilities, lessons we learned, and feedback received from expert users. The visualization system provides an overall plan view supplemented with a detailed perspective view, allowing a user to examine highlighted conflicts and select from a list of proposed solutions, as the scenario runs in real time. Future steps needed to improve this system are described.

CR Categories and Subject Descriptors: I.3.8 [Computer Graphics] Applications; H.5.2 [Information Interfaces and Presentation] User Interfaces.
Additional Keywords: air traffic control, collision detection, aircraft, decision support tools, interactive 3D graphics

1 MOTIVATION

The FAA has declared that the existing Air Traffic Control (ATC) system will transition to a new system known as "Free Flight." While Free Flight has not been precisely defined in a way that is universally accepted, the basic concept is to reduce the centralized control in the existing system to allow pilots greater freedom in choosing and altering routes, leading to reduced costs and increased capacity [10, 11]. In today's system, controllers issue commands and pilots follow them. Pilots wishing to change their routes must issue requests and receive clearance from controllers. The control and responsibility for safe operation is centralized in the controllers. In contrast, Free Flight will allow pilots to change their routes in real time, with controllers intervening only when necessary to ensure adequate separation. In some definitions of Free Flight, pilots themselves are responsible for avoiding conflicts in simple situations.

If Free Flight is to succeed, new conflict detection, resolution, and visualization tools must be developed to support the needs of controllers, pilots, and airline managers. Controllers must mentally project the future courses of the aircraft that they monitor, which is a cognitively difficult task, shown by the spatial relationship tests on examinations given to prospective controllers [9]. The restricted nature of the existing ATC system aids them in performing this projection. Aircraft usually follow established jetway paths and their intended routes are known to an experienced controller. These restrictions may end in Free Flight, leading to a need for decision support tools that augment a controller's capabilities. Furthermore, pilots and airline operation centers (AOC's) need improved situational awareness of the traffic that affects them. Today, pilots are not provided with much information about their local airspace. If Free Flight demands that pilots perform conflict resolutions on their own, then they must also be provided with tools that clearly show the conflicts, the surrounding traffic, and appropriate options for resolving the conflicts.

This paper describes a testbed we are developing for the construction and evaluation of conflict detection, resolution, and visualization tools for the Free Flight environment. The testbed runs interactively, in real time, on a realistic Free Flight scenario. This paper describes lessons we have learned in experimenting with different visualizations and summarizes feedback received from expert users.

2 PREVIOUS WORK

While there have been several earlier efforts in areas related to this project, we do not know of another visualization system that specifically focuses on conflict detection and resolution in the Free Flight domain. Related works include conflict probe algorithms and 3-D visualizations for ATC applications.

[9] is a textbook that describes the existing ATC system. [11] is a good introduction to the history of ATC, the terminology and some of the projected technologies and directions. In particular, it mentions the Center-Tracon Automation System (CTAS) from NASA Ames and the User Request Evaluation Tool (URET) from Mitre. CTAS is primarily concerned with separating aircraft that are flying into an airport; thus the display is often 1-D (or 2-D for airports with overlapping runways, such as Dallas-Ft. Worth). URET performs conflict probes in the en route airspace for the existing ATC domain. The FAA has also funded Mitre's Center for Advanced Aviation System Development (CAASD) to examine Free Flight issues. These systems have not focused on visualization techniques.

Currently-deployed ATC displays show 2-D plan views. Several 3-D visualizations have been built for ATC applications as research systems, such as [12]. Raytheon has a product called the Dynamic Airspace Management System (DAMS) which displays 3-D airspace zones and routes for the existing ATC system. Numerous human factors studies have been performed to evaluate the effectiveness of 3-D displays in this domain; examples include [2], [5] and [6]. [7] suggests the use of nonlinear magnification fields that automatically zoom in on areas where conflicts may occur. The primary difference in our work is the focus on conflict detection and resolution in the Free Flight domain and the development of a testbed to explore and evaluate both the visualizations and the conflict algorithms in a realistic

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Free Flight scenario. We also built a previous system to explore 3-D graphical and audio visualization aids for aircraft flying in the terminal area of Boston's Logan Airport [1, 4]. Our current system described in this paper is radically different from the Logan-based system, with a more realistic scenario, integrated conflict detection and resolution tools, and improved visualization modes.

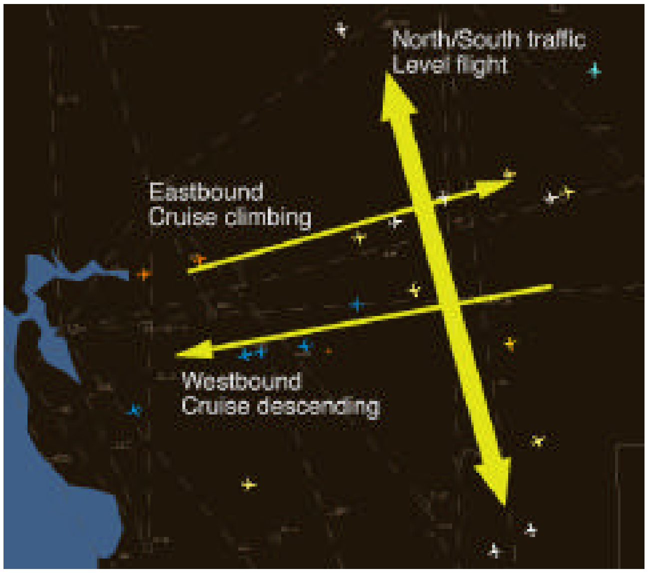

Figure 1: Traffic flows through Coaldale sector

3 SYSTEM OVERVIEW

Since only very limited Free Flight exists today, we had to make a set of assumptions and build a full Free Flight scenario to provide the data for conflict detection, resolution and visualization. We assume that aircraft cruise climb to their desired altitude, then maintain that altitude until they cruise descend into the destination airport. "Cruise climbing" means that an aircraft climbs at an optimal rate to the target altitude without spending time in level flight at intermediate altitudes. Aircraft fly direct routes to their destinations whenever possible, ignoring existing jetways. However, they avoid flying through restricted airspace, such as zones around military bases. We placed this scenario in an area east of San Francisco, in what is currently called the Coaldale sector, because crossing traffic naturally occurs there. Westbound traffic cruise descends into the three major airports in the Bay Area. Eastbound traffic cruise climbs away from those airports. North and southbound aircraft, which stay at their cruising altitudes, cross that area, potentially conflicting with the eastbound and westbound traffic (Fig. 1). Aircraft must maintain a minimum five mile horizontal or 1000 foot vertical separation from each other (the Protected Airspace Zone around each aircraft), or a conflict occurs. The scenario consists of 87 aircraft and lasts 35 minutes. About 25% of the flights were based on real data that was recorded from the Oakland en route Air Route Traffic Control Center (ARTCC) on Sept. 1, 1996. These provided good estimates of the routes and density of aircraft typically flying through Coaldale. We assume Free Flight does not extend to aircraft at low altitudes or in TRACON regions (areas near airports); thus in our scenario aircraft below 10,000 feet are not displayed. All aircraft are tracked with an augmented GPS system (such as WAAS, the Wide Area Augmentation System) and broadcast their positions and intended routes to other aircraft and ground stations via a data link such as ADS-B (the Automated Dependent Surveillance-Broadcast system). We do not currently model uncertainty in the flight paths or include weather features.

The system consists of several processes that communicate through shared memory. Figure 2 shows the processes and the communication flow. We have run the system on an SGI O2 but it performs best on a multiprocessor system, such as an SGI Onyx, due to the computational burden from the conflict detection and resolution modules. The flight path module is responsible for maintaining the "true" paths that the aircraft follow. This module places the current aircraft positions and up to 20 minutes of intended route information in a shared memory data structure, which both the visualization and conflict detection/resolution (CD&R) modules read. The CD&R module identifies conflicts between sets of aircraft and potential alternate routes to the visualization module, which displays them and allows the user to select new routes. These new routes are sent back to the flight path module, which updates its internal database of the true flight plans for the affected aircraft. The system runs in real time. Thus, a user sees and resolves conflicts at the same rate that he would if these were real aircraft.

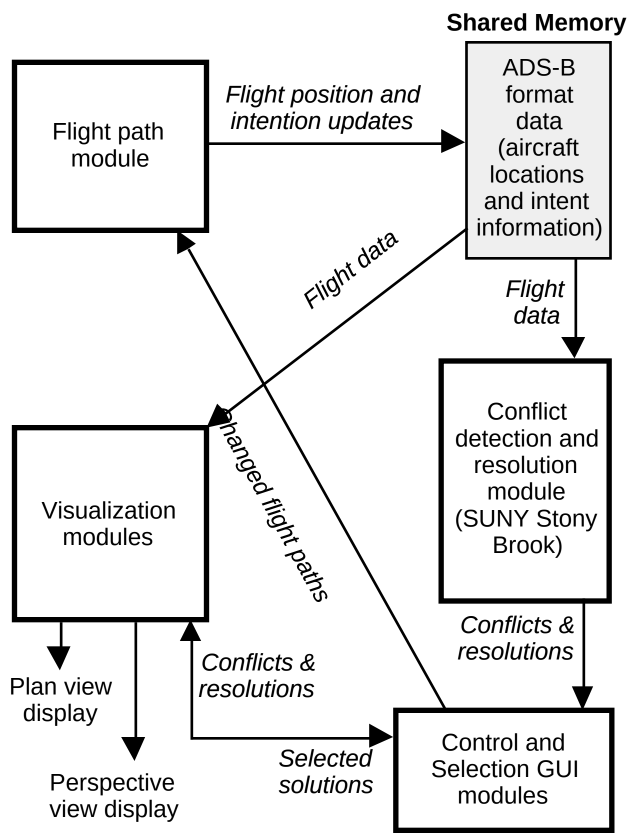

Figure 2: System dataflow

The CD&R algorithms were provided by SUNY Stony Brook and are described in [3]. We have also worked with Seagull Technologies to use their CD&R algorithms [8]. The next section describes the features of the visualization module.

4 VISUALIZING CONFLICTS AND SOLUTIONS

The visualization module draws two windows: a 2-D plan view display and a 3-D perspective view display. Both windows provide a view into the same situation, but the plan view display is used for an overall view while the perspective display provides a detailed view of a particular conflict or area. The visualization module is written in C and WorldToolKit 7. Two small control windows are written in Tcl/Tk and control parts of the interface. Both displays update at over 15 Hz on an SGI Onyx with 4 R10K CPUs. Most of the processing is consumed by the conflict detection and resolution algorithms

The plan view display (Fig. 3, see color plate) is similar to standard existing ATC plan view displays except that ours supports pan and zoom and the selection of conflicts and detail areas for examination in the perspective display. The dotted yellow line indicates a region that the user has selected with the mouse. The gray square region matches the area covered by the altitude plane in the perspective display, clearly marking the relationship between the overall and detail views. Aircraft icons are colored based on direction and altitude. Eastbound aircraft are orange; westbound aircraft are blue, with lighter hues indicating higher altitudes. This allows quick visual determination of aircraft that may appear to be on a collision course in a 2-D display but are actually safely separated by altitude. The data block associated with each aircraft indicates the call sign, altitude in hundreds of feet, ground speed in knots, and whether it is climbing or descending.

The perspective view display (Fig. 4, see color plate) shows the matching gray region from the plan view display, except that the user has selected a solution to the given conflict. This solution, outlined with green extension lines, reroutes the southbound Southwest Airlines aircraft to avoid the conflict location (where the solid red cylinder is). Numerous depth cues are used to make the situation easier to understand. The transparent altitude plane can be moved up and down, shortening the altitude lines and providing motion cues. Shadows are projected onto the altitude plane. An optional "rocking mode" changes the viewing angle by a varying offset controlled by a sinusoid, enabling cues from motion parallax. The user can view the perspective situation from different angles and ranges through a virtual trackball mechanism. The Protected Airspace Zones around each conflicting aircraft are highlighted in red. The 2D circles, triangles and rectangles drawn over the extension lines specify inflection points in the aircraft trajectories: locations where an aircraft changes heading or its ascent/descent rate.

Both displays use an automatic label deconfliction algorithm and draw line extensions to indicate intended routes. The data blocks linked to each aircraft can cover important features in the display or other labels, making the labels difficult to read. The label deconfliction algorithm automatically moves the labels to avoid such problems, reducing the work a controller normally performs in manually specifying the label positions. Line extensions from current aircraft locations indicate future aircraft routes; the user selects how many minutes into the future to extend the lines, allowing the interactive exploration of potential problem areas.

5 LESSONS LEARNED

We demonstrated versions of this testbed at the Air Traffic Controllers' Association conference in October 1996 and November 1998. This provided evaluation and testimony from expert users: air traffic controllers, pilots, and airline operations personnel.

The scenario we built was judged to be realistic and the CD&R mechanisms were effective in identifying problems 10-20 minutes in the future. Both pilots and controllers accepted the scenario as presented. The only complaints came from one controller who actually worked the Coaldale sector, and even those criticisms were minor. Controllers stated that they would not be able to spot these types of Free Flight conflicts 10-20 minutes before they occur without the information provided by the CD&R algorithms and the visualizations. This supports our belief that such decision support tools can contribute to future air traffic management systems.

Designing visualizations in this area is often an exercise in choosing what not to draw, rather than what to draw. Minimizing clutter and distractions is vital to controllers. For example, we originally drew "beads" on the extension lines that indicated future aircraft locations at one minute intervals (Fig. 5). They added too much clutter. We also changed the perspective view to provide solely detail information because in an overall perspective view, background information often hid the vital foreground information the user wanted to see.

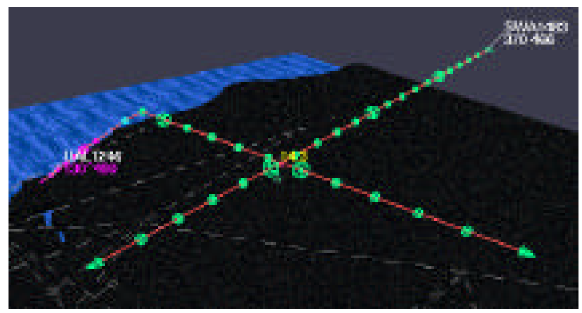

Figure 5: Clutter caused by using beads to indicate one minute spacings on extension lines

In general, controllers were more conservative in the features they accepted than pilots or airline personnel. Controllers are familiar with plan view displays and believe they can extract all required information from that, although the cognitive load may be high. Controllers found the label deconfliction routine most useful. But pilots and other personnel who do not have extensive training to recover the 3-D situation from a plan view found the detail views and CD&R visualizations useful and stated their need for increased situational awareness in a Free Flight situation. They also wanted displays specifically tuned for their needs.

6 FUTURE WORK

Much remains to be done to improve this testbed. Alternate visualization displays must be developed that are tuned to the needs of pilots and Airline Operation Centers, rather than just controllers. The testbed must be expanded to support multiple simultaneous users, simulating the collaborative interaction between pilots, controllers, and AOC's. The scenario could be more sophisticated, including the effects of uncertainty in the sensor measurements and the limitations of how accurately aircraft can follow their intended routes. Weather is not currently modeled in this testbed, although we plan to address this in future systems.

Our evaluation so far has been limited to testimonials from expert users (primarily air traffic controllers and pilots). We need to investigate more controlled ways of evaluating this testbed. These evaluations must provide useful design information about the overall problem, rather than providing a specific result about a tiny subset of the testbed.

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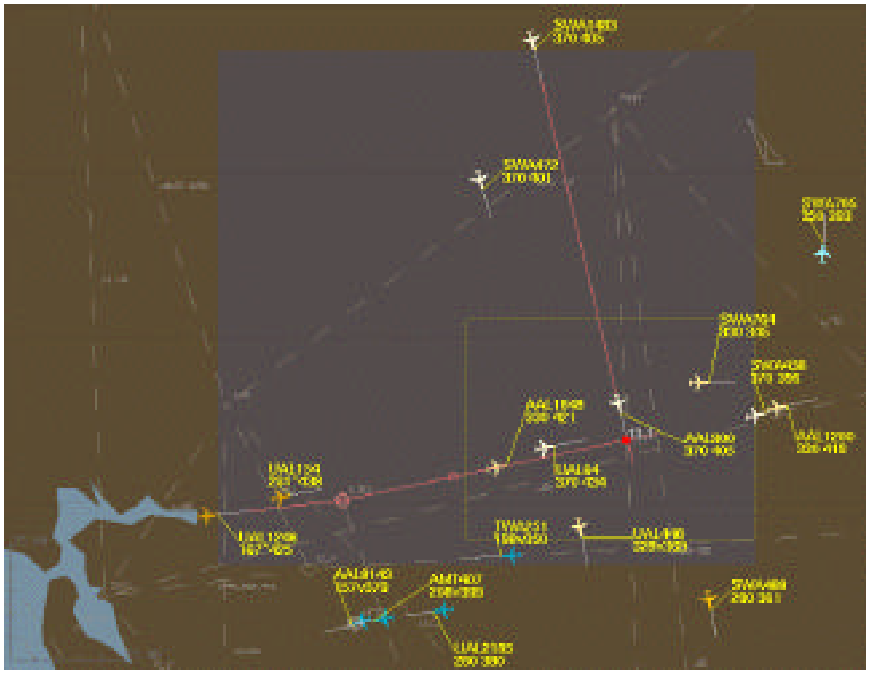

Figure 3: Plan view display, with conflict highlighted between eastbound and southbound aircraft

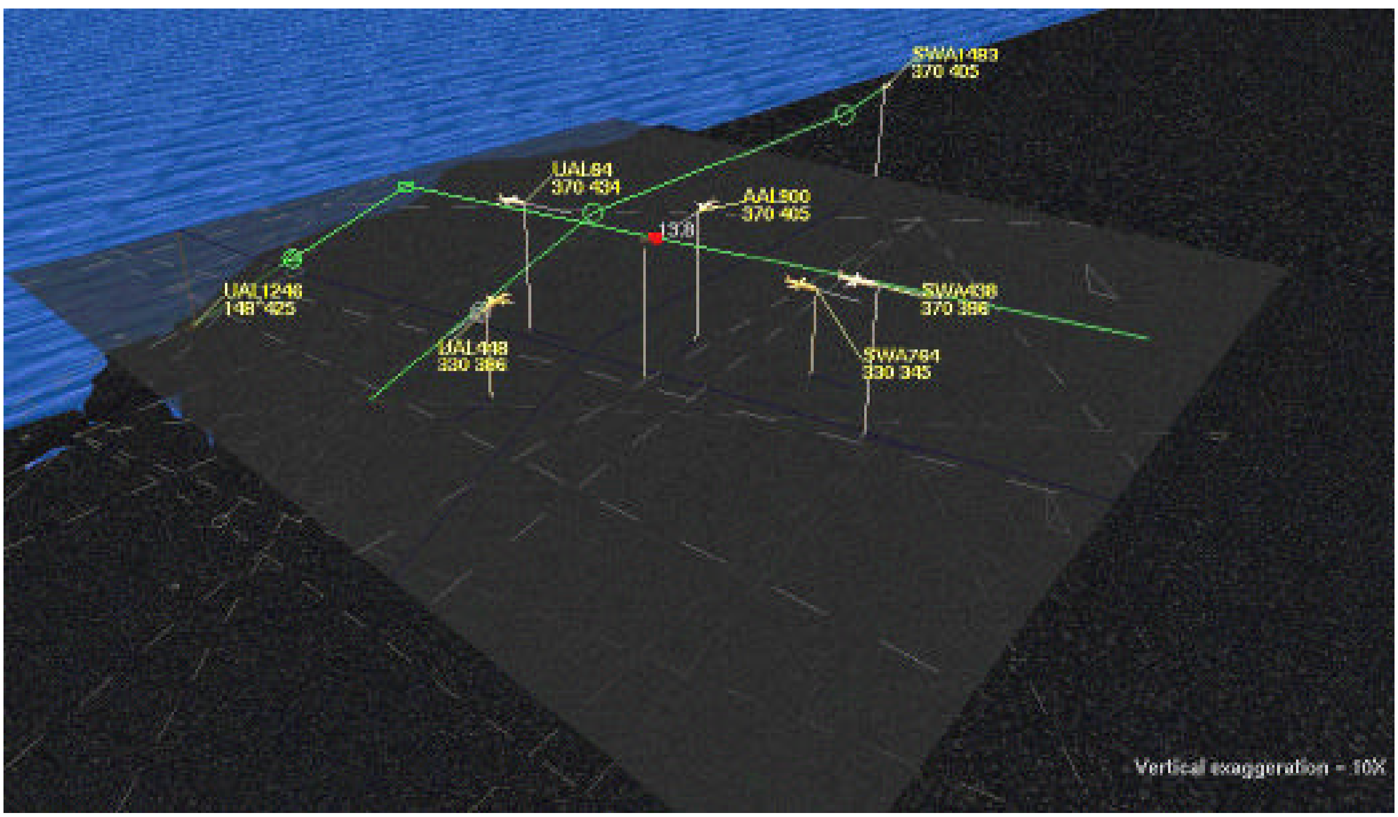

Figure 4: Perspective view display, showing detail view and suggested resolution of conflict

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