A CONTROLLER TOOL FOR TRANSITION AIRSPACE

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Abstract

This paper describes simulation and field test evaluation of an integrated decision support tool for trial planning and arrival metering in transition airspace, i.e., en route airspace near the terminal area. The challenge for this tool will be to solve tactical arrival-metering problems. The tool calculates fuel-efficient descent trajectories, arrival sequencing and metering, and includes a trial-planning function for conflict resolution. Simulation evaluations were conducted at NASA Ames in April and July of 1998 and field-test evaluation was conducted at Fort Worth Center in November 1998. Results indicate the trial-planning function provided benefits for strategic conflict resolution but controllers preferred not to use it in the more tactical arrival-metering environment. Controllers often used the trial planner to determine if a direct route to a downstream fix along the aircraft's route of flight was feasible. The test also confirmed the high controller acceptance of the trial-planning capability.

Introduction

The growth in air traffic and the increase in terminal-area delays have fueled user demand for fewer operating restrictions and greater route flexibility. NASA, in cooperation with the FAA, has for several years been conducting research and developing decision support tools for management of air traffic. A well-known product of this ongoing effort is the Center/TRACON Automation System (CTAS), which is a set of tools designed to assist traffic management coordinators and controllers in each Air Route Traffic Control Center (ARTCC, or Center) and Terminal Radar Approach Control (TRACON) in the management of traffic. This paper describes the modification and integration of two existing CTAS tools to create a single tool for use in transition airspace.

At the core of CTAS is the Trajectory Synthesizer[1] (TS). The TS computes trajectory predictions for all aircraft within its scope, based on radar track and flight plan data from the FAA Host computer, wind predictions from the Rapid Update Cycle (RUC) atmospheric model and aircraft performance from models like those used in a Flight Management System (FMS). Trajectory predictions are updated approximately every 12 sec as new radar data become available, and whenever flight plans and RUC data are updated. A Conflict Probe[2] compares trajectories once every six seconds and any conflicts detected are displayed to the appropriate controller. Interaction with CTAS is accomplished through the Planview Graphical User Interface[3,4] (PGUI) that displays a planview of the Center airspace and aircraft positions. The PGUI is an advanced version of the planview display (PVD) that controllers use in Center facilities.

The studies reported in this paper were initiated to evaluate the CTAS Trial Planner (TP) tool in a busy transition airspace such as Fort Worth Center (ZFW). The Trial Planner is an interactive tool that helps a controller quickly examine alternative trajectories prior to issuing a clearance to an aircraft. A trial plan might be initiated to resolve a conflict, to accommodate a pilot request, or to find a more direct route. The TP was first evaluated at the Denver Center (ZDV) in September 1997[5]. (The ZDV airspace is largely an overflight environment.) The tool was well accepted by controllers and provided measurable benefits to airspace users. A major finding was that controllers used the Trial Planner to resolve a large

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percentage of conflicts by clearing one aircraft direct to a downstream fix on the route of flight. The direct routes always resulted in a short cut for the aircraft. At ZDV, only conflict aircraft received clearances for direct routes, although the trial planner can also facilitate direct-route checking for non-conflict aircraft as well.

The CTAS Traffic Management Advisor[6] (TMA) is in operational use at ZFW. The TMA is a CTAS tool that computes arrival sequence and schedule advisories that help Center controllers maintain orderly flow as aircraft transition from Center to TRACON airspace. Arrival aircraft are sequenced to cross arrival fixes at scheduled times. In order to evaluate the CTAS Trial Planner at ZFW, it was necessary for it to be integrated with the TMA. This paper examines the use of the Trial Planner integrated with the TMA as a single tool to assist controllers in solving traffic problems in a transition airspace. Among the questions raised during this study were: 1) Can the TP/TMA tool be used to aid the arrival-metering problem? 2) Can it help controllers simultaneously solve conflict and metering problems in transition airspace? 3) What other benefits might be realized with the integrated tool in transition airspace ?

The paper proceeds as follows: The next section briefly describes each tool, including the addition of automated altitude probing for the TP, and covers the integration of the tools. A subsequent section discusses what was learned during simulation tests held at NASA Ames in April and July 1998. The results of field-test evaluation performed at ZFW in November 1998 are presented in a final section.

Trial Planning in Transition Airspace

The objective of this study was to integrate TP and TMA capabilities into a single tool and determine how controllers would use the tool in transition airspace. A common traffic scenario in the airspace near major airports involves two or three streams of arrival aircraft descending from cruise altitude and speed about 200 nmi from the airport. These streams typically merge at a single Center-to-TRACON entry point (meter fix) at 10,000 ft and 250 kn about 40 nmi from the airport. In some Centers, overflight (cruising) and departure (climbing) traffic may pass through the arrival airspace, complicating the traffic management problem. If the airport is capacity constrained, as is typical during rush periods or adverse weather, Center controllers restrict the arrival flow, often increasing delay to the meter fix. Maintaining aircraft separation while meeting delay times can be very workload intensive. Techniques used by controllers to manage this situation include descending aircraft early, changing speed, issuing vectors, and putting aircraft into holding patterns. Before considering how controllers might employ the TP in this environment, it may be helpful to discuss how the TMA operates.

Traffic Management Advisor

The TMA is a time-based metering tool that provides information and advisories that help Center traffic management coordinators and controllers balance arrival demand with airport capacity. Capacity can be very dynamic and is heavily influenced by weather, runway availability, capacity changes at nearby airports, and controller staffing levels. The TS trajectory-prediction algorithm provides estimated time-of-arrival (ETA) to meter fixes and runway thresholds for all arrival aircraft in the Center. ETA data are combined with air traffic control (ATC) constraints to generate an arrival sequence and scheduled times-of-arrival (STA) to meet but not exceed airport acceptance rate (the number of aircraft per hour that can safely land at the airport). During arrival rush periods at busy airports a TMA meter list is presented on the sector controller's radar display. The meter list is ordered according to the arrival sequence and shows the call sign, the meter fix crossing time (STA) and the required delay for each aircraft. Center radar controllers then issue clearances in order to absorb the delays to within 1 min before arrivals cross the meter fix and enter the TRACON.

Trial Planner

The Trial Planner allows controllers to interactively create route, altitude, and speed changes through point-and-click, menu-based manipulation of the flight-data block on the PGUI traffic display. As the controller creates a trial plan, the Conflict Probe provides rapid feedback (1 sec update) on the predicted separation between the trial-planned aircraft and any other aircraft with which it may be in conflict along its route. The TP tool has been refined and improved since its field-test evaluation at Denver Center. For example, altitude trial planning has been enhanced by the addition of an automated altitude probing capability. This enhancement should be particularly useful in transition airspace, and is described in the following.

Automated altitude probing gives a controller rapid feedback on separation status for a climb or descent to other altitudes. For a departure aircraft, an altitude trial plan will automatically probe all climb-and-maintain trajectories from current position and altitude to each flight level between current altitude and requested cruise altitude. This refers to the probing for conflicts along the climb segment, and then along the level segment for a specific time interval. For arrival aircraft the process is reversed: an altitude trial plan will automatically probe all descend-and-maintain trajectories from current position and altitude to the meter fix crossing altitude. For arrivals there is also an updated computation of each segment of the descent trajectory, all the way to the meter fix. These segments are idle-thrust descents ("minimum fuel"). For aircraft in level cruise flight an altitude trial plan will check climbs to two flight levels above current altitude and descents to two flight levels below current altitude.

The controller initiates altitude trial planning by clicking the altitude field in the data block on the PGUI. Altitude probing results are displayed (R for no conflict, C for conflict) in the trial-plan panel as shown in Fig. 1. Altitude probing is updated every 6 seconds while the trial plan is pending. The panel indicates that if the Eastbound climber (AAL123) were to level off at FL240 it would be in conflict with the Westbound aircraft level at FL240, but a climb through FL240 would not cause a conflict at FL240. (Predicted conflict points are indicated by black dots.) The Westbound traffic at FL270 prevents a climb to any altitude above FL260, as indicated in the panel. The conflict with the FL270 traffic would occur while AAL123 is climbing and therefore prevents a climb to FL270 or any altitude above FL270. For climbing aircraft the trial plan defaults to a conflict-free altitude (boxed entry) nearest to the requested altitude, while for descending aircraft the trial plan defaults to the highest altitude that is conflict free. For level aircraft the trial plan defaults to the current altitude.

The Trial Planner allows the conflict-detection separation criteria to be set independently for trial planning. Separation criteria for the conflict probe are often set at 8 nmi horizontal and 2000 ft vertical above FL290 (1000 ft below FL290). In the altitude trial-planning example of Fig. 1, the horizontal criterion was expanded to 12 nmi. The vertical setting depended on phase of flight: for both aircraft in level flight it was 2000 ft above FL290 (1000 ft below); for either aircraft climbing or descending it was 4000 ft above FL290 (2000 ft below). These settings were also used in the simulations and the field test to be discussed in a later section. Using expanded separation criteria for trial planning helps account for uncertainty in predicted climb and descent trajectories.

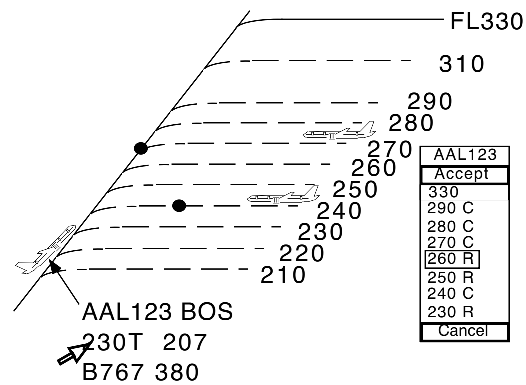

Fig. 1. Altitude probing for a climbing aircraft.

The Integrated TP/TMA Tool

Integration of the TP and TMA tools in the CTAS hardware/software platform was straightforward. Few software changes were required since CTAS has a modular architecture, and both TP and TMA share the trajectory synthesizer. The hardware/software architecture for the integrated TP/TMA system is shown in Fig. 2. Elements enclosed by the dashed lines include a TMA system with one additional processor connected for trial-plan processing (PFS_C). An additional processor is needed for each planview graphical user interface (PGUI). The CTAS Dynamic Planner (DP) performs the TMA computations and the timeline graphical user interface (TGUI) is the TMA user interface for the traffic management coordinator. The PFS_C module and additional PGUI modules were connected to the same Communications Manager (CM) running the TMA system.

The simple traffic display in Fig. 3 shows aircraft targets (&) and flight-data blocks, along with a Conflict Prediction list and a TMA meter list for DFW arrivals. Each entry in the conflict list includes call signs, time-to-first-loss of separation (TIME) and predicted minimum vertical (FL) and horizontal (NM) separations. The TMA meter list shows the call sign (ACID), scheduled-time-of-arrival (STA), and required metering delay (DLY). Using a mouse pointer, the user clicks a box next to a conflict pair to show trajectory predictions (bold in figure) from current position to first loss of separation. For arrival aircraft the trajectory is shown from current position to the meter fix and includes the top-of-descent (TOD) point for the user-preferred idle-thrust descent. In the example, AAL629 is the first aircraft scheduled to cross the meter fix. The required metering delay is 2 min. The arrival sequence number and metering delay were added to the 4th line of the data block to allow the controller to keep focused on the traffic display. Under current TMA operations, controllers have only the meter list and must shift their attention between the traffic display and meter list. The 4th line of the data block also contains the call sign of any conflict aircraft. With the addition of metering and sequencing as well as conflict information to the data block, a substantial reduction in controller workload is anticipated.

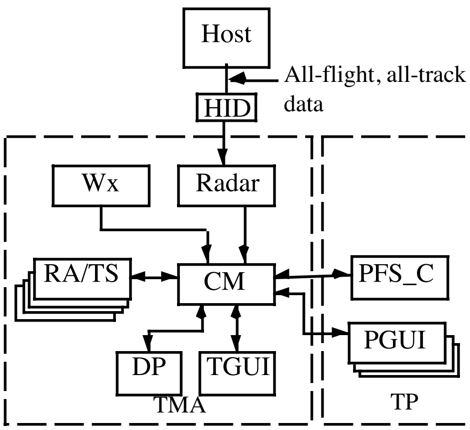

Fig. 2 CTAS TP/TMA architecture.

Shown in Fig. 4 is a vector trial plan for a metered arrival aircraft AAL629 that resolves a conflict and zeros out metering delay. The controller has initiated the trial plan by clicking (with mouse pointer) the destination airport field (DFW) in the flight data block and then dragging an auxiliary waypoint to define the trial-plan trajectory shown. As the controller adjusts the trial plan, the changing conflict status is shown in the Trial Conflict panel and metering delay is shown in the TPDLY column of the Meter List (also displayed in the 4th line of the data block). The wind-corrected magnetic heading and estimated time to the auxiliary waypoint replace the destination airport in the first line of the data block. As shown in Fig. 4 the trial plan for AAL629 solves the conflict with NWA732 and reduces the metering delay from 2 min to 0 min. It should be noted that all trial-planning information (predicted trajectory, metering delays, magnetic heading) is displayed in yellow to avoid confusion between nominal trajectory predictions and pending trial-plan predictions.

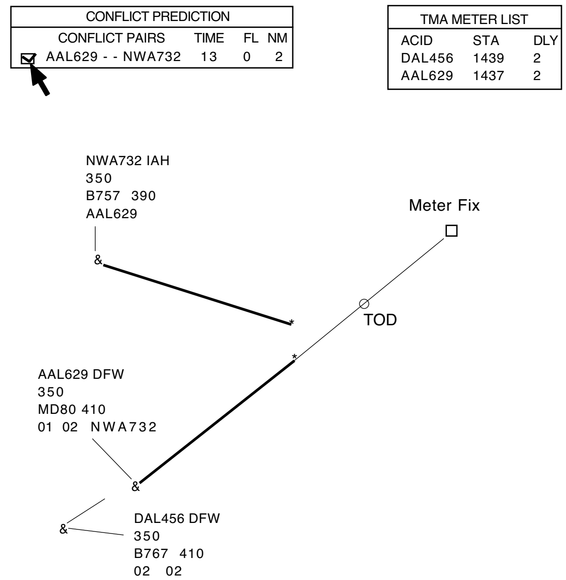

Fig. 3. Conflict and TMA lists on PGUI display.

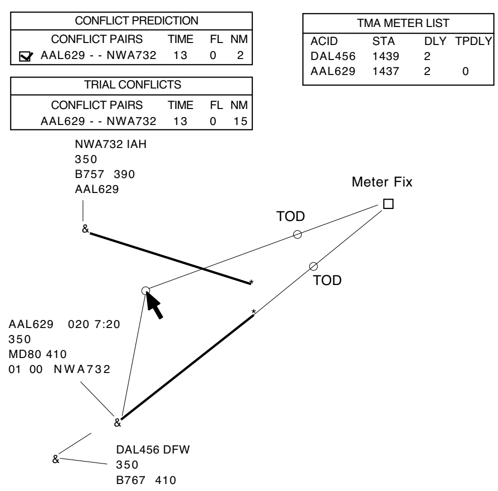

Fig. 4. Vector trial plan for conflict resolution.

Simulation Evaluation

The objective of controller-in-the-loop simu5lations conducted at NASA Ames prior to the field test was to obtain controller feedback on use of the TP/TMA in transition airspace. The simulation included one PGUI configured to emulate a radar controller display (R-side) and another to emulate the data controller display (D-side). Generally, each sector will have two controller positions, an R-side and a D-side. The R-side is responsible for monitoring the radar display and issuing clearances to the aircraft in the sector. During periods of heavy traffic, a D-side controller assists the R-side controller by monitoring aircraft flight plans, which are printed on paper strips, and helps to coordinate traffic. For each sector in the simulation, one PGUI was configured to emulate an R-side PVD showing aircraft targets with flight data blocks and the TMA meter list. A D-Side PGUI with full TP/TMA functionality was set up next to each R-side display.

Several Fort Worth Center (ZFW) scenarios, some involving arrival metering, were generated using the Pseudo Aircraft Simulation (PAS) system[7]. The scenarios were developed with the cooperation of a ZFW Traffic Management Coordinator. Six other ZFW controllers participated during six days of simulation. Verbal feedback and observations of controller usage were recorded. The D-side controllers operating the Trial Planner found the tool was most useful for resolving conflicts that occurred when overflights or departures passed through an arrival stream. In most of these cases, the trial-planned aircraft was <u>not</u> an arrival. With the D-side controller suggesting conflict resolutions with the aid of the Trial Planner, the R-side controller was free to concentrate on the metering of arrival aircraft.

The simulation revealed that controllers preferred to use the Trial Planner for conflict resolution in transition airspace, rather than to vector arrival aircraft to meet required delays to a meter fix. Generally, arrivals are metered only during arrival rush periods when controller workload is high. Controller feedback indicated that even a D-side controller may be too busy to create vector trial plans during a rush period without further automation. While the TP is easy to use, it is still a manual tool, requiring the user to point, click, and drag an auxiliary waypoint to implement a vector trial plan. To make the TP/TMA tool useful for arrival metering, further automation will be necessary. This was confirmed during the field test in discussions with controllers.

<u>Field Test Evaluation</u>

The TP/TMA system was tested on the operational floor at ZFW in November 1998. Three adjoining high-altitude sectors participated: Ardmore (sector 48), with a mix of arrival, departure, and overflight traffic; Wichita Falls (sector 47), primarily with arrivals to the NW meter fix; Woven/Abilene (sectors 39 and 94, considered as one), primarily with Westbound departures from DFW. Two CTAS PGUI displays were set up next to an unused PVD located between the Woven/Abilene and Wichita Falls sector positions. A third PGUI was located directly adjacent to the operational PVD at Ardmore High. A typical PGUI setup is shown in Fig. 5. The rest of the CTAS system (shown in Fig 2), was set up in an area close to the operational floor (Fig 6). This area served as a control and data-analysis station for the test and included a repeater display for each PGUI on the operational floor. Six controllers, who normally work the participating sectors, operated the TP/TMA system at the PGUI displays on the operational floor during the test.

The test controllers operated the system in “shadow” mode, using the tool as if they were actually controlling traffic but not communicating their clearances to the aircraft or to the sector controller. Test controllers were asked to "accept" only those trial plans they would have issued as clearances had they been the on-duty sector controller. When the controller clicked on the “accept” button, a comprehensive data set pertaining to that aircraft was recorded. These data included the active and trial-plan trajectory predictions. Trajectories for any aircraft predicted to be in conflict with the trial-planned aircraft were also recorded. All flight plan and track data sent to CTAS from the ZFW Host were recorded separately. As TP/TMA was being operated in the shadow mode, no changes were made to the active route of the trial-planned aircraft.

Fig. 5 Typical PGUI setup at ZFW.

The field test was conducted over a period of six days, usually with two sessions per day (10:45–12:45 and 15:45–17:45 CST). In a total of 54 sector-hours, test controllers created and accepted 86 trial plans that resolved conflicts, and 90 trial plans for aircraft that were not in conflict. The trial-plan types are as follows:

DIR – direct to downstream fix from current position
VEC – heading change to auxiliary waypoint, then direct to downstream fix
ALT – altitude change
SPD – airspeed change
MUL – some combination of the above types

Fig. 6 Control and data analysis area.

A first observation is that controllers trial planned non-conflict aircraft about as often as aircraft predicted to be in conflict. Figure 7 shows accepted trial plans, categorized by type and phase of flight (departure - DP, overflight - OV, or arrival - AR), for conflict cases in Fig. 7(a) and non-conflict cases in Fig. 7(b). Note that SPD and MUL types were so few in number that they were not included in Fig. 7.

Figure 7(a) shows that many altitude trial plans were created for departure aircraft in conflict. Many of these were "temporary altitude" plans, that would resolve conflicts by holding aircraft at intermediate levels before proceeding to cruise altitudes. Figure 7(b) shows that many direct-route trial plans were created for non-conflict departure aircraft, indicating that controllers used the Trial Planner to check direct routes to downstream fixes. Under current procedures, controllers regularly clear DFW departures direct to downstream fixes to help separate traffic transitioning to cruise altitude. Test controllers at ZFW, like those at Denver Center in September 1997, identified the trial planner as a very useful tool since it allowed them to quickly visualize and conflict-probe direct routes before issuing clearances.

A sample direct-route trial plan for a Westbound departure from DFW passing through Woven/Abilene sector is shown in Fig. 8. This planview of the ZFW Center airspace shows some of the high altitude

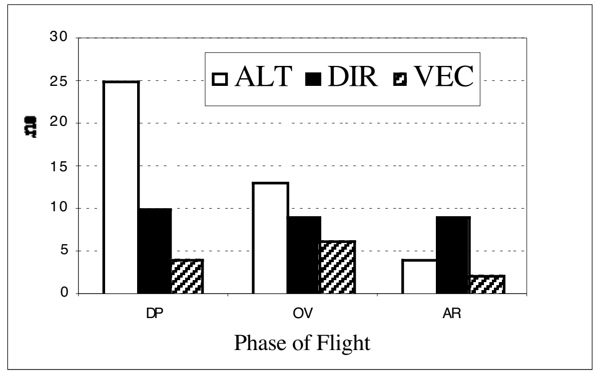

Fig. 7(a) Conflict-resolution trial plans (82 total).

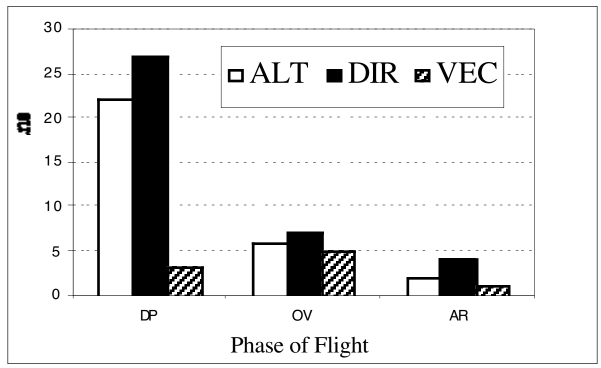

Fig. 7(b) Non-conflict trial plans (77 total).

sector boundaries. Included are the flight plan route (FP - dashed line) through several navigation fixes (boxes), the accepted trial plan (TP - solid line), and radar tracks (TR - x) showing the actual aircraft path. It appears that the sector controller issued a direct clearance to the same fix, about 10 min after the trial plan was accepted. Note that the trial-plan route is a shorter distance to the final fix compared to the flight-plan route. However, not all shorter routes achieve time savings, because of the influence of winds.

The trajectories of departure aircraft for which controllers accepted direct-route trial plans were analyzed to determine the potential savings in distance and flying time associated with these clearances. Distance and time saved for direct routes were computed for 23 of the departures. The results are summarized in Table 1. The largest potential saving is the difference between the flight plan and trial plan routes (FP-TP). The actual saving is the difference between the flight plan and radar track routes (FP-TR). In each case, distance and time were measured from the point at which the controller accepted the trial plan to a fix where the aircraft rejoined the original flight-plan route.

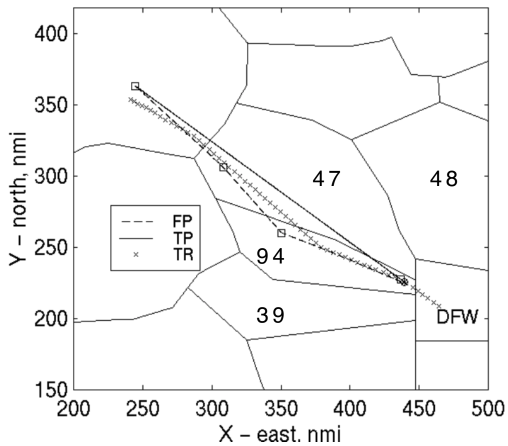

Fig. 8. Direct route trial plan for departure aircraft.

Note that direct routes yield, in most cases, a savings in flying time, which from an airline operator's point of view, is important. However, several routes show little time saved or even a small loss. This may be because controllers do not consider time a priority when deciding which direct-route trial plans to accept. Also, it may be difficult for them to take into account wind influences that could cause a direct route to result in a time loss. The frequent use of the Trial Planner to probe direct routes suggests the need for additional automation, which is currently under development

Table 1 Direct-route savings for 23 departure aircraft

Distance (FP-TP) (nmi)	Time (FP-TP) (min)	Distance (FP-TR) (nmi)	Time (FP-TR) (min)
78.5	11.6	49.13	7.1

Table 2 shows the number of conflict pairs displayed to, and the number of conflict-resolution trial plans accepted by, the test controllers during the ZFW field test, categorized by flight type (overflight - OV, arrival - AR, departure - DP). Arrivals are to any airport within ZFW; departures are from any airport within ZFW. The trial plans accepted for conflict resolution during the Denver Center field test are shown for comparison. The largest percentage of conflict predictions (30%) and trial plans (30%) accepted during the ZFW test involved OV-DP aircraft. During the Denver Center test, the largest percentages of trial plans involved OV-OV aircraft (26%) and OV-AR aircraft (27%).

Table 2 Conflicts and accepted trial plans

Flight Phase	ZFW Conflicts	ZFW Trial Plans	ZDV Trial Plans
OV-OV	215 (12%)	16 (19%)	27 (26%)
OV-AR	272 (16%)	15 (17%)	28 (27%)
OV-DP	530 (30%)	26 (30%)	17 (17%)
AR-AR	251 (14%)	6 (7%)	11 (11%)
AR-DP	254 (15%)	10 (12%)	12 (12%)
DP-DP	234 (13%)	13 (15%)	7 (7%)
Totals	1756	86	102

The actions of the on-duty sector controllers are compared to those of the test controllers for the ZFW conflicts listed in Table 2. Actions of the sector controllers were determined by analysis of the recorded radar tracks, flight plan data, and audio tapes of R-side communications during the test. Figure 9 compares test and sector controller conflict-resolution decisions. Note that in 3 cases, sector controllers let aircraft pass without issuing a conflict-resolution clearance. (Recall that the conflict probe horizontal separation criterion (8 nmi) is larger than legal separation (5 nmi).) The figure shows that test controllers chose direct-route resolutions in 33% of the conflicts, whereas sector controllers chose direct-route resolutions in 19% of conflicts. This is a 74% increase in direct-route resolutions when using the Trial Planner. A similar increase was observed in the Denver Center test.

Altitude trial plans were analyzed to evaluate usage of the automated altitude trial-planning function. Of the 23 altitude trial plans for non-conflict DFW departure aircraft, 10 trial plans sent the aircraft directly to its cruise altitude when the sector controller had issued a temporary altitude clearance. An example of this is shown in Fig. 10. The solid line shows the trial plan, the dashed line the temporary-altitude flight plan, and 'x' shows the radar track. In this case, the aircraft pauses at FL290 before continuing to FL330.

The test controller accepted a trial plan that would have sent the aircraft to its final cruising altitude about 500 sec before the aircraft actually climbed to the cruising altitude. Some errors in trajectory climb predictions were noticed during the test. The error sources include uncertainties in pilot intent, engine thrust model, and aircraft weight. The CTAS climb models for some aircraft types are currently being reviewed and improved where necessary.

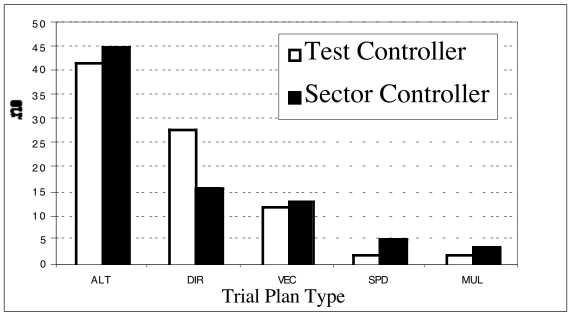

Fig. 9 Comparison of controller resolutions.

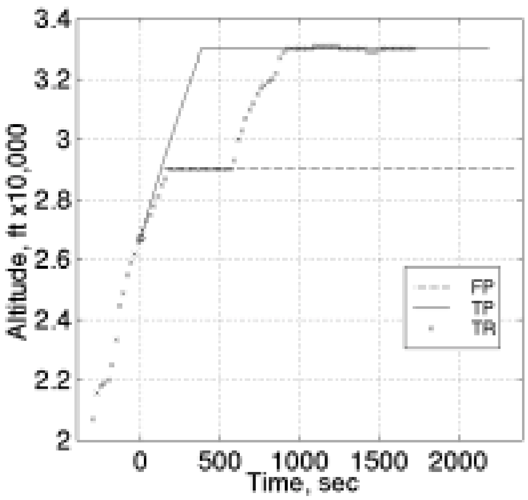

Fig. 10 Example of altitude trial planning.

Concluding Remarks

Controllers consistently used the TP/TMA tool for probing direct routes to downstream fixes, particularly for departure aircraft. The Trial Planner provided controller and airspace user benefits for non-conflict aircraft as well as for aircraft predicted in conflict. Controller feedback on Trial Planner functionality was very positive. This is consistent with controller feedback from the September 1997 Denver Center field test.

It was found during simulation that manual trial planning was generally not useful for creating vectors for arrival metering. Metering situations are very tactical and controllers do not have time to operate the Trial Planner. Adding further automation to the TP/TMA tool could help the controller solve arrival-metering problems under current ATC procedures.

During field test, the altitude trial planning function was used primarily to aid conflict resolution for climbing or descending aircraft. It was found that the automated probing function in altitude trial planning provided additional benefit.

Simulation and field evaluation of the TP/TMA tool has proven to be an effective way to identify further automation that could provide additional benefit. Trial-planning modes that controllers use repeatedly, such as altitude and direct-route probing, are good candidates for automation.

Controller feedback on the user interface consistently indicated that the system could be improved by adding, for example, conflict predictions and descent advisories to the R-side display. Such information would help the radar controller to issue aircraft clearances. However, its presentation must not interfere with the controller's current mode of operation.

In summary, manual trial planning was very useful and well accepted for long-term strategic planning and problem solving, but was of limited use for short-term tactical arrival metering. These tests also showed the Trial Planner was used not only as a tool for conflict resolution but as a tool to check clearances before being issued.

Acknowledgment

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