DIRECT-TO TOOL FOR EN ROUTE CONTROLLERS[1]

Heinz Erzberger[2], David McNally[2], Michelle Foster[3], Danny Chiu[4], Philippe Stassart[4]

Introduction

In recent years, advances in air traffic control have often been evaluated by how effectively they further the goals of "free flight." Although the notion of free flight is difficult to define precisely, any method that reduces constraints and increases the freedom of airspace users to operate aircraft in a manner they consider optimum is considered to be a step toward free flight. Since the notion became popular a number of years ago, numerous innovations, technologies and automation methods have been investigated under the umbrella of free flight. Some of these were recommended for national development by a consensus of airspace users, operators and air traffic control experts [1]. In response to these recommendations, the Federal Aviation Administration established the Free Flight Project Office to lead and execute the deployment effort. That effort is now well under way for the initial (Phase 1) free flight technologies.

This paper describes the design of a new automation tool for en route controllers, called the Direct-To Tool, that advances the goals of free flight in the climb-to-cruise and en route segments of flight. It also provides a compatible extension of the Free Flight Phase 1 technologies.

The insight that led to the design of the Tool originated with experience gained in evaluating the Conflict Probe/Trial Planner (CPTP) built into the Center TRACON Automation Systems (CTAS). During the field test of CPTP at the Denver Center in the Fall of 1997, controllers would usually attempt to resolve conflicts predicted by the Probe by trial-planning resolution trajectories that led from the conflict aircraft's current position to a down-stream fix along the aircraft's flight plan [2]. In about 20% of such attempts, they succeeded in finding trajectories direct to a fix that resolved the conflict. Thus, when this method was successful, the solution had the additional advantage of reducing the path distance to fly to the destination. It was a surprise finding that this strategy was so often successful. In the Denver Center tests, only aircraft that were "fortunate" to have been identified as being in conflict had the potential to benefit from path shortening direct-to fix trajectories. This finding suggested the following hypothesis: Since conflicts are random events, there must exist a similar percentage of non-conflict aircraft that could reduce their path distances by direct-to fix trajectories. Armed with this knowledge, controllers at a follow-on test of CPTP at the Fort Worth Center used the Trial Planner to manually search for non-conflict aircraft that could benefit from direct-to fix trajectories [3]. Through trial and error with CPTP they found many aircraft, especially departures from DFW, that were eligible for path shortening direct-to fix trajectories.

While effective for finding and resolving conflicts and conflict probing direct routes for any aircraft selected by the controller, CPTP lacked the ability to automatically identify all aircraft eligible for direct-to routes and to determine and display the corresponding time savings. To aircraft operators, time saving, which accounts for the effect of winds, and not necessarily path length saving is the appropriate measure of flight efficiency. The need to solve these problems formed the nucleus for the requirement of the Direct-To Tool, which is the subject of this paper.

Requirements and Operational Constraints

The primary requirement guiding the design of the Direct-To Tool was to improve both controller productivity and aircraft trajectory efficiency within the constraints of the current air traffic control environment. This requirement ruled out dependencies on new infrastructure technologies such as an

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[2] NASA Ames Research Center, Moffett Field, CA.
[3] FAA ARTCC, Fort Worth, TX.
[4] Raytheon, Moffett Field, CA.

automated two-way air-ground data link. It also eliminated from consideration the specification of curved or multi-segment trajectories that provide the minimum time to fly to the destination in a spatially varying wind field. Neither the infrastructure of today's air traffic control system nor the navigation equipment on most aircraft support the specification of such types of trajectories to aircraft while in flight. Moreover, making extensive in-flight routing changes to an aircraft's flight plan requires the controller to specify strings of alphanumeric data to the pilot via voice communications. This approach is impractical for routine use because of its high controller and pilot workload. The use of these more complex techniques will have to await the deployment and integration of new infrastructure, such as the planned air-ground data link. When that has taken place, the constraints built into the Direct-To Tool described here can be relaxed, if not eliminated.

In view of the constraints described above, the only currently feasible opportunity for increasing the efficiency of aircraft routes in flight with the controller in the loop centers on the use of the so called direct-to clearance. This type of clearance is well understood and is already being used by controllers, usually when requested by pilots, but also at the controller's initiative. The argument or specification parameter in the direct-to clearance is the name of a navigation fix or waypoint contained in the aircraft's flight plan, which are known to both the controller and pilot. The spoken form of the clearance is "airline flight 123, fly heading XYZ proceed direct ABC, when able, rest of route unchanged." It directs the pilot to fly to a new heading, taking the aircraft in a straight line from its current position to the specified navigation fix.

In order to explain the need for an automated method of generating direct-to clearances, it is necessary to review briefly the basic structure of flight plans and the routes derived from them. Typically, for an airline flight between major airports, a flight plan consists of three types of concatenated route segments: a standard instrument departure (SID) route, an en route path, and a standard terminal arrival route (STAR). The en route path is defined by a sequence of three letter identifiers for fixes, five letter identifiers for route intersections, and airway identifiers. The geographical coordinates of waypoints are also acceptable entries in a flight plan and may either be specified by their latitude/longitude coordinates or their polar coordinates (angle and distance) relative to a named fix. The latter method is referred to as a fix radial distance (FRD). An example of a typical flight plan between Dallas/Fort Worth and Boston is given in figure 1.

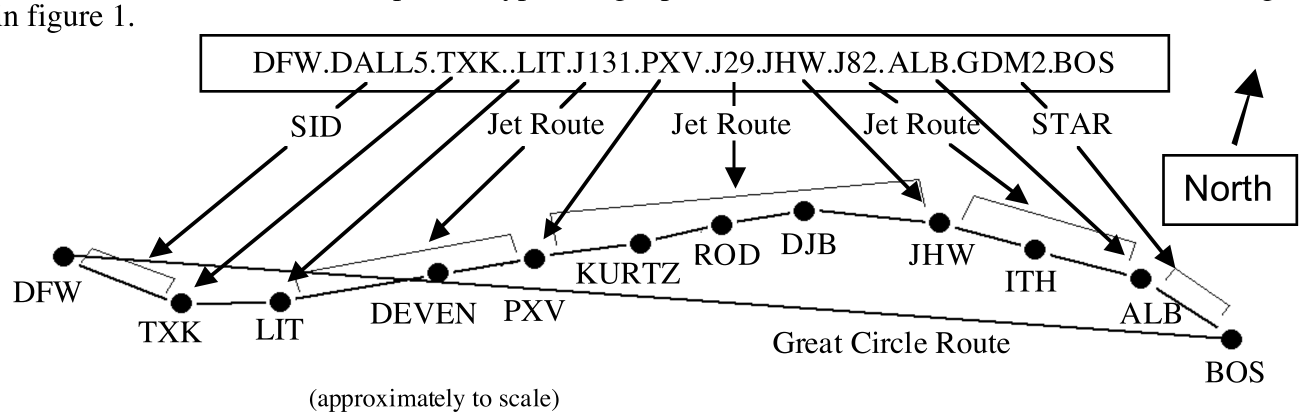

Figure 1. Decomposition of a flight plan into its waypoints and horizontal route segments. For reference, great circle route between DFW and BOS is also shown.

SID's, jet routes and STAR's are themselves composed of a series of straight line segments, separated by waypoints. Any flight plan, constructed according to the standardized format, can be parsed into a concatenated sequence of straight line segments, with waypoints separating each segment as illustrated in figure 1. Two basic parsing rules are illustrated. Entry and exit points for SID's, STAR's and airways, such as J131, are defined by fixes whose identifiers are separated from the route identifiers by periods. A double period, such as between fixes TXK and LIT, denotes that a straight line (great circle) route connects the corresponding fixes. When the connected segments of a parsed flight plan are plotted on a map, they can deviate substantially from a great circle route, which would give the shortest distance between two points on the earth's surface. This can be seen in figure 1 where both the great circle and flight plan routes have been drawn approximately to scale. The difference in path length between the routes was calculated to be 45 nmi. This translates to a difference in flying time of about 6.5 minutes, assuming no winds are present. In general, as the figure shows, each of the segments can have a different heading direction, giving a non-linear appearance to the route of flight. Aside from the necessity to avoid weather and restricted airspace, non-direct (non-great circle) routes are used for the following reasons: 1. Limitations in the performance of traditional (non-RNAV equipped) navigation systems based on VOR/DME ground stations. 2. Constraints on departure and arrival routes necessary to achieve an orderly, safe and manageable flow of traffic near large airports. 3. Non-direct routes optimized to take advantage of favorable winds.

Since most flight plans are generated by the flight planning services of airlines before being sent to the air traffic control system, it is not always obvious to a pilot or controller if the efficiency of the flight route can be improved after departure. Because of the significant effect of spatially varying wind fields on time to fly along a specified route, a direct-to clearance to a down-stream waypoint that bypasses one or more route segments in the flight plan could either increase or decrease the time to fly to the destination. Except in obvious situations, neither pilot nor controller has reliable information at hand to guide them in deciding whether a direct-to clearance will increase or decrease flight efficiency. Furthermore, in transition airspace near a terminal area, an aircraft deviating from a departure or arrival route could cause problems and disrupt the orderly flow of traffic.

The preceding analysis has demonstrated the need for a new automation tool for controllers that guarantees an improvement in the efficiency of flight whenever direct-to clearances are issued. The design requirements for such a tool can be summarized as follows: 1. Automated search for and identification of all aircraft that can benefit from a direct-to clearance. 2. Selection of an appropriate fix or waypoint chosen from the aircraft's flight plan that will reduce its time of flight to the destination. 3. Identification of potential conflicts along the direct-to route. 4. An appropriate controller interface for the tool including a method for updating the flight plan. The algorithm described in the next section meets the first three requirements, and the human interface design described in the section thereafter addresses the fourth.

Direct-To Algorithm

A method for generating four dimensional (4D) trajectories provides the analytical and computational engine for the direct-to algorithm. Four dimensional trajectories predict the future position and altitude of an aircraft along a specified route as a function of time, starting at the current time, position and altitude, and terminating at or near the destination airport. Because a properly computed 4D trajectory incorporates all information that is currently known about an aircraft, including its current state, performance capabilities, climb and descend procedures, flight plan and winds along the route, it provides the direct-to algorithm with the rational basis for comparing the time to fly along alternate routes.

4D trajectories also form the basis for the controller automation tools in the Center-TRACON Automation System (CTAS) [4-6]. Therefore, the 4D trajectory synthesizer in CTAS together with its real time software infrastructure provided a convenient and efficient platform for implementing the direct-to algorithm.

The CTAS software suite offers several advantages as a platform for implementing the direct-to algorithm. After several years of daily operational use by controllers at several centers and TRACON's, the CTAS software has reached a high level of accuracy and reliability. In particular, the 4D trajectory synthesizer in CTAS has been upgraded several times, increasing its flexibility, accuracy and speed of computation. The two most important features of the trajectory synthesizer used in implementing the direct-to algorithm are the ability to rapidly generate multiple trajectories and its method for handling winds. Wind speed and direction, as well as temperature and pressure are modeled as a discretized function of horizontal position coordinates and altitude. These atmospheric parameters are specified on a 40 km by 40 km horizontal grid covering all of the continental US airspace. CTAS receives an update of this atmospheric model from the National Weather Service every hour. The model was developed by the Forecast Systems Laboratory of the National Oceanic and Atmospheric Administration and represents the highest accuracy in mesoscale atmospheric modeling currently available [7]. CTAS interpolates the gridded data for any three dimensional point along the trajectory. The trajectory itself is generated by a complex process using a second order Runge-Kutta variable step size integration method. Accounting for the wind field as implemented in CTAS is essential to the direct-to algorithm, since comparison of time to fly to a fix along two different routes is at the heart of its operation.

For each aircraft eligible for a direct-to clearance, the CTAS trajectory synthesizer will compute the time to fly to a fix in the route of flight and to the same fix along the direct-to route, whereupon a comparison of the times to fly will determine whether the aircraft is eligible for a direct-to clearance. However, before the trajectories can be computed and the comparison made, it is first necessary to determine a method for choosing the direct-to waypoint from the potentially large number of waypoints in the flight plan. One such method would be to always choose the destination airport itself or a waypoint near the airport, such as a feeder fix, as the direct-to fix. While this method is appropriate for some destination airports, it would give erroneous results if applied to airports several thousand nautical miles away, and especially for transoceanic and transpolar flights. Such distant airports are likely to be located outside the area covered by the wind model used in CTAS. For those airports the CTAS trajectory synthesizer would generate grossly inaccurate times to fly, providing misleading advisories to controllers. Another problem with using direct-to routes to fixes more than approximately a 1000 nmi away is that their use would have to be restricted to aircraft equipped with advanced avionics such as inertial navigation or GPS systems. Finally, direct-to routes to some distant hub airports would frequently run counter to air traffic control procedures in effect in the en route airspace feeding these airports. So in consideration of these problems and in observance of the cardinal rule of automation *to do no harm*, it is necessary to limit the range of the direct-to fixes generated by the algorithm.

Several methods exist for limiting the range of the direct-to fixes. One method would limit the range to a maximum distance relative to the current position of the aircraft; for example, 500 nmi downrange. A second method would limit the reduction of the time to fly to a specified maximum; for example 8 minutes, thereby implicitly limiting the ranges to the direct to fixes. A third method would limit the choice of the direct-to fixes to a specified region of airspace surrounding an enroute center. In the algorithm described herein the third, or airspace, method provides the primary control over the range of the direct to fixes. But, the second method which limits the time savings (eight minute is used in the current system), is also incorporated to provide additional control. To implement the airspace method, a limit rectangle is defined that restricts the choice of direct-to fixes to the interior of the rectangle. The rectangle is oriented along North-South and East-West directions and is centered on or near the geometric center of the home Center where the Direct-To Tool is installed. At the Fort Worth Center, for which the prototype system is being designed, it is centered on the Dallas/Fort Worth airport and its dimensions are 1000 nmi East-West and 600 nmi North-South. An alternative to the rectangle method is to limit the location of the direct-to fixes to the combined airspace of the home Center and all adjacent Centers surrounding the home Center, the so-called first-tier Centers. The rectangle has the advantage of being simple to implement and computationally efficient.

At each Center where the Tool is installed, the limit rectangle parameters, which determine the location of the center and the dimensions of the rectangle, must be chosen appropriately by taking into account the unique shape and size of a Center's airspace. Furthermore, the choice of limit rectangle parameters is influenced by the need to include particular fixes located in adjacent Centers which controllers frequently offers two pilots as direct-to fixes.

The next step is to develop the appropriate list of direct-to fixes for airports located within the limit rectangle. This problem was solved in consultation with an air traffic control specialist. It was determined that the choice of nearest direct-to fixes for an airport depends on the traffic density and airspace structure of the destination airport. For low density airports surrounded by low activity airspace, the airports themselves may be used as the direct-to fixes. For large airports where arrival aircraft approach via STAR's and cross into the TRACON airspace at feeder gates, fixes or waypoints along the STAR's must be selected to be the direct-to fixes. The selected fixes must comply with facilities' internal procedures and not violate any letters of agreement between Center and TRACON. Thus, in preparing the Direct-To Tool for operational use at a Center, a database must be created containing the set of appropriate direct-to fixes for as many airports as possible within the limit rectangle. Airports included in this database are referred to as the adapted airports. Air traffic specialists familiar with the airspace in the limit rectangle or its equivalent should be enlisted to help in creating this database.

At this time, the initial implementation of the algorithm excludes arrivals into the main hub airport within a Center, such as the DFW airport within the Fort Worth Center. For the direct-to algorithm to handle such arrivals it is necessary to incorporate arrival metering delays and airport arrival rate restrictions into the decision process. This information is readily available within CTAS's Traffic Management Advisor (TMA) [4-5]. At a Center such as the Fort Worth Center, where both Tools will be operating concurrently and will share CTAS software and infrastructure, integration of functionalities will be greatly simplified. Later implementations may include these arrivals.

Figure 2 illustrates the concepts described above for the airspace within and surrounding the Fort Worth Center. Direct-to routes for two flights are illustrated, one for a flight to Houston Intercontinental Airport (IAH) located inside the rectangle, the other for a flight to Boston located far outside. The adapted direct-to waypoint for the IAH bound flight is CUGAR, which lies on the CUGAR6 arrival route. The farthest allowed direct-to fix for the Boston-bound flight was found to be PXV located just inside the limit rectangle near the North-East corner (see figure 1 for the corresponding flight plan).

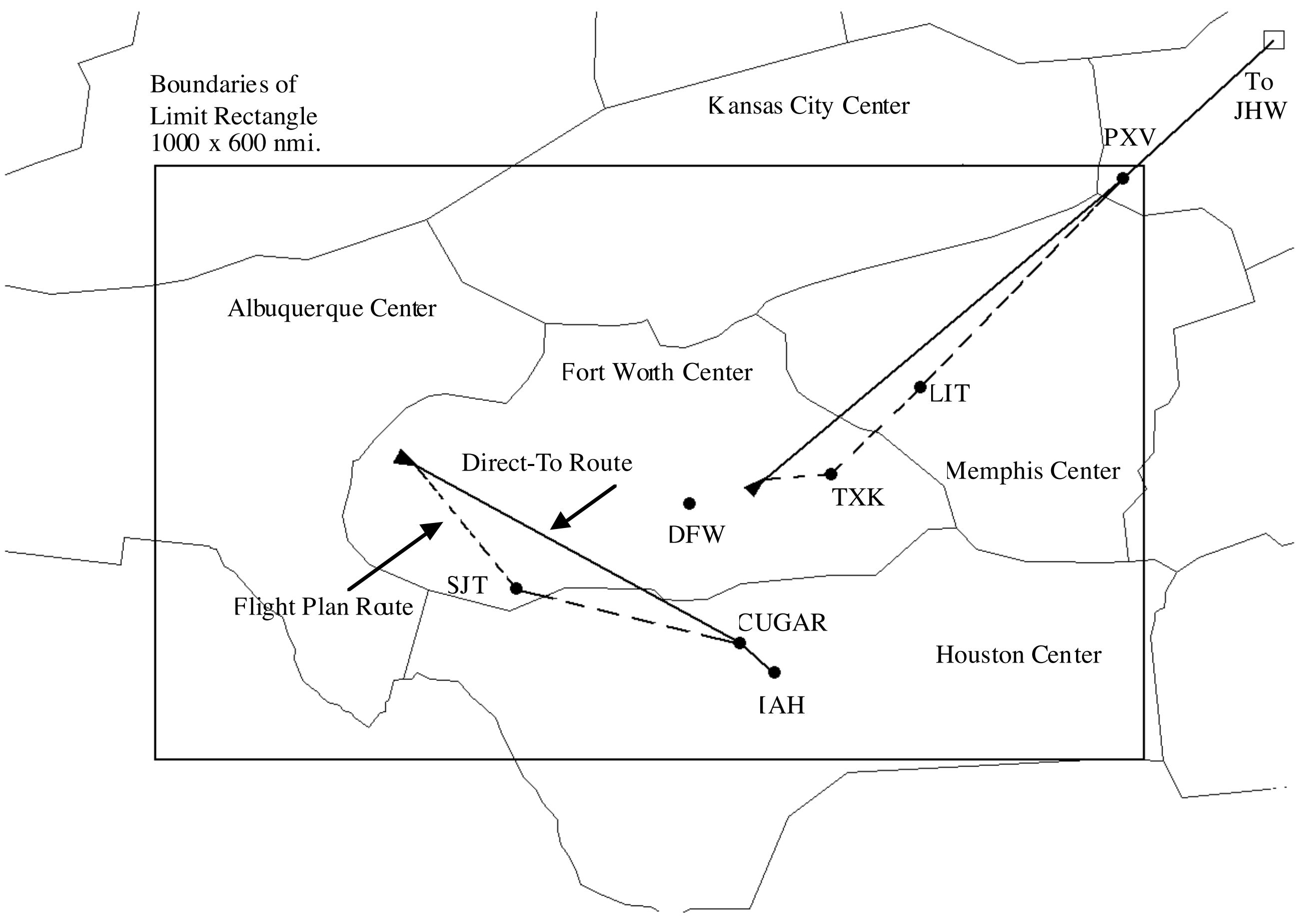

Figure 2. Limit rectangle superimposed on Fort Worth Center airspace. Also shown are two examples of direct-to routes.

When an aircraft on a direct-to route to a fix in a downstream (adjacent) Center equipped with the Tool enters that Center's airspace, the aircraft again becomes eligible for another direct-to route clearance. That is, as soon as the aircraft is tracked and accepted by the adjacent Center, the algorithm tests the aircraft for direct-to route eligibility based on the limit rectangle adapted for that Center. For example, this would occur when the DFW to Boston flight, currently eligible for a direct-to route to PXV, as illustrated in figure 2, reaches the Memphis Center boundary. The process of re-testing and possible direct-to rerouting repeats in every Center traversed by the aircraft until it reaches its destination Center. Thus, an aircraft on a transcontinental flight could receive several direct-to's, each of limited range but each contributing incrementally and additively to improved flight efficiency.

A flow chart of the algorithm for generating the direct-to eligible aircraft and the direct-to fixes is shown in figure 3.

The algorithm requires access in real time to the set of all aircraft being actively tracked by the radar sensors and surveillance system of the Center where the Tool is installed. For each tracked aircraft, its identification symbol, together with its current position, velocity, altitude, flight plan and aircraft type must be provided at the update rate of 12 seconds which matches the track update rate of the Host computer. This information is available in CTAS when it is installed at a Center.

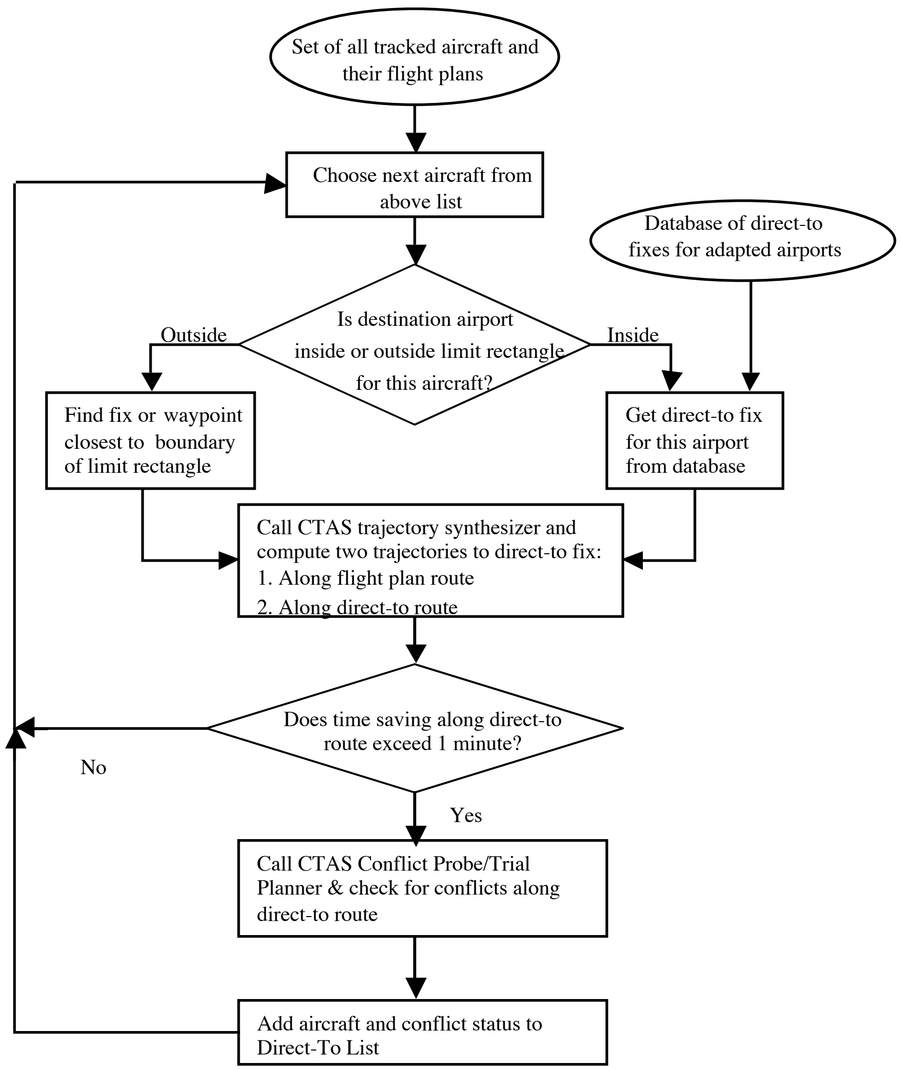

Figure 3. Flow chart of direct-to algorithm.

The algorithm tests each aircraft in this set sequentially, repeating the test at 12 second intervals, which is standard for CTAS's en route tools. The first test after an aircraft has been chosen from the set determines if its destination airport is inside or outside of the limit rectangle. If outside, it tests each fix/waypoint on the flight plan in succession, starting at the next waypoint to which the aircraft is headed , to find the one closest to a boundary of the limit rectangle, thereby establishing the direct-to fix. If inside, it retrieves the direct-to fix from the adaptation database by specifying the destination airport and arrival route. Then the algorithm requests the CTAS 4D trajectory synthesizer to generate two trajectories to the computed direct-to fix, one along the flight plan route, the other along the direct-to route.

The times to traverse each route, obtained from the 4D trajectories, are compared. If the direct-to route saves at least one minute, that aircraft's ID will be added to the controller's Direct-To List; to be described in the next section. The one minute criterion was chosen because it represents the quantum of time saving considered significant in airline operation, and also to limit the number of aircraft in the List. If the time saving is less than one minute, the aircraft is eliminated, but it will be re-tested again in the next update cycle. In the last step, an aircraft that has passed the time saving test successfully is tested for predicted conflicts by CTAS's Conflict Probe/Trial Planner function against all other actively tracked aircraft that are known to CTAS [8,9]. Following the recommendation of a controller who advised on the design of the interface, it was decided to include direct-to eligible aircraft with predicted conflicts in the List. The rationale behind this design decision is explained in the next section. Here it should be mentioned that the conflict probing is performed with the conflict alert parameters set to 12 nmi horizontal for all aircraft and 4000 ft vertical separation for transition aircraft. These are significantly larger than the regulatory limits of 5 nmi and 2000 ft. The extra margin gives the controller, who is responsible for issuing the clearance, increased confidence that the direct-to route will be problem free for down-stream controllers. In the CTAS Conflict Probe, the alert parameters are adjustable and therefore can be adapted to meet the requirements of each facility. The newly discovered direct-to eligible aircraft, together with its time saving, direct-to fix identifier, conflict status and certain other information are now added to the Direct-To List.

The algorithm as implemented in CTAS can accommodate two enhancements that will further increase the efficiency of the direct-to trajectories. One is to extend the search for the best direct-to fix to more than one fix. By computing trajectories to several candidate fixes lying within the limit rectangle, it is possible to identify the fix that produces the greatest time saving. The second enhancement is to evaluate the effect on time saving when the cruise altitude is changed one or more levels above and one or more levels below the current cruise altitude. This will identify the altitude level where winds are the most favorable. While these enhancements will increase the computational load, they are considered feasible to implement, because the multiprocessor architecture of CTAS's trajectory engine was designed to handle this load and is doing so successfully in supporting the operation of other CTAS Tools with similar requirements.

Controller Interface and Its Operational Use

The controller interface for the Direct-To Tool has been designed to be accessible from the controller's display monitor. It employs a graphical user interface similar to software running on workstations and personal computers. With the Direct-To Tool, the controller selects items from menus and sends flight plan amendments from the controller display to the Host computer using point-and-click actions executed with a mouse or track ball. Experience gained from field tests of the CTAS Conflict Probe/Trial Planner established strong controller preference for a point-and-click graphical user interface that minimizes, if not altogether eliminates, the time-consuming keyboard entries currently in use [2, 3]. An efficient and controller-friendly interface not only will ensure controller acceptance of the Direct-To Tool but also will increase the likelihood that controllers will use the Tool when the opportunity arises. For a Tool such as this, whose use is not safety-critical but is essentially voluntary, a friendly and low workload interface provides the main incentive for controllers to use it. The Tool interface consists of the Direct-To List, point-and-click executable commands, and graphical display of trajectories.

The Direct-To List appears as a panel on the controller's display and is illustrated in figure 4. The first, and most important, items in the List are the aircraft call signs (ACID's) of all aircraft which the algorithm has determined are eligible for direct-to clearances. Only those eligible aircraft currently "owned" by the controller of a specific sector are displayed in the panel. The eligible ACID's, if there are more than one, are ordered by the amount of potential time saving, with the ACID's having the highest time saving shown at the top of the List. The List is refreshed and reordered every 12 seconds. This time interval corresponds to the refresh cycle of trajectory computation in CTAS. In the typical evolution of this List, an aircraft initially appearing near the top of the list migrates gradually toward the bottom with each update cycle. The aircraft is removed from the List either when the potential time saving has become less than the threshold value of one minute or as a consequence of the controller having issued a direct-to clearance that reduces the time saving to less than one minute.

In addition to the ACID, the List contains other essential information to assist the controller in deciding whether to issue a direct-to clearance for an eligible aircraft and, if so, what type of clearance to issue. Figure 4 shows a screen photo of a Direct-To List containing three eligible ACID's.

As illustrated in figure 4, the aircraft equipage code and the destination-airport identifier follow the ACID and are separated from each other by slashes. The equipment identifier tells the controller the type of navigation equipment carried by that aircraft. Seventeen types, each identified by a letter code, are recognized in air traffic control. The three shown in figure 4 (G, E, A) refer to GPS equipped, flight management system equipped, and conventionally equipped, respectively. The controller uses the equipage code to determine the type of clearance to issue. For example, an A-equipped aircraft, the least sophisticated of the three, will generally require the controller to issue both a heading direction and a navigation fix as part of the direct-to clearance. On the other hand, for aircraft with E, G or certain other equipage codes, the controller need specify only a navigation fix to the pilot when issuing the direct-to clearance.

Figure 4. Screen photo of Direct-To List panel. See text for explanation.

The next field gives the amount of time saving, in minutes, provided by a direct-to trajectory, compared to the currently planned trajectory. When there are several aircraft in the List, comparison of time savings helps the controller prioritize the order in which to issue direct-to clearances. For example, during periods of high workload, she may only have time to issue one or two direct-to clearances. In that case, issuing direct-to clearances to aircraft with the highest potential time savings will maximize the controller's productivity.

The next field gives the identifier of the direct-to fix computed by the algorithm and the heading to that fix, separated by a slash. As explained in the preceding section, the direct-to fix is always a fix along the route of flight and located down-stream from the current position of the aircraft. The heading angle is the magnetic heading and is corrected for wind speed and direction. Thus, it is the magnetic heading that the aircraft must fly starting at the current position in order to be on course to cross the fix. The fix identifier and the heading provide the information the controller needs to issue the clearance to the pilot.

The next to last field gives the predicted conflict status of the aircraft along the proposed direct-to trajectory. An "OK" indicates no conflict, whereas a "C" indicates a conflict is predicted. Furthermore, on the color monitor where the List is displayed, the conflict status symbols are color-coded to enhance recognition, with "OK" drawn in green and "C" in red. Observation shows that aircraft are predicted to come into conflict along the direct-to route infrequently, and that only about one in ten aircraft ever show a conflict at any time while they are on the List. When several aircraft appear on the List, some with and some without conflicts, the controller could initially skip aircraft with conflicts and work only with the conflict-free aircraft. Then, when the conflicts have cleared, as they frequently do after a short time, the controller can consider issuing direct-to clearances, to these, now conflict-free, aircraft.

The addition to showing predicted conflicts for the direct-to routes, the List also uses a symbol, a red asterisk (*), located to the left of the AICD, to indicate if the direct-to eligible aircraft is in conflict on its current flight plan route. In figure 4, asterisks indicating such conflicts are shown for COA1914 and COA1494, the second and third ACID's on the List. The asterisk essentially serves to cross-reference ACID's which are simultaneously present in the Direct-To List panel and the CTAS Conflict Prediction panel. This is illustrated in the screen photo of the controller's display shown in figure 5, where both panels are found at the top of the photo. The Conflict Prediction panel is the controller's interface to the CTAS Conflict Probe. It lists all pairs of aircraft in a region of airspace which the conflict search algorithm predicts will violate specified separation criteria within a search time horizon [2, 3].

Checking for the presence or absence of the two categories of predicted conflicts helps the controller make the most timely and productive choice of the next direct-to eligible aircraft. To demonstrate how this is done, consider the situation illustrated in figure 4 by the third aircraft in the List, COA1914. This direct-to eligible aircraft is predicted to be in conflict along its current (non-direct) route, as indicated by the asterisk, but is predicted to be conflict-free along the proposed direct-to route. A controller recognizing this situation would have a high incentive to choose this aircraft since a direct-to route amendment issued to this aircraft not only reduces flight time but also resolves the predicted conflict in a single clearance. For the situation where both categories of conflict are predicted, as for COA1494 in figure 4, the choice is not as unambiguous as was the previous case but still may be worthy of investigation by trial planning. For example, the controller may be able to resolve the conflict by choosing a different direct-to fix or a different cruise altitude and still achieve some reduction in flight time.

The last field is a square button, used to delete a direct-to entry from the Direct-To List panel. For example, a controller may wish to delete an aircraft from the List because that aircraft's route includes a necessary detour around a region of severe weather.

Controllers, who have evaluated the List in shadow mode with live traffic from the Fort Worth Center, do not consider the conflict status as the definitive accept/reject criterion for issuing a direct-to clearance. Instead, they base their decision to issue a direct-to clearance on their overall assessment of the traffic situation, their knowledge of the airspace as well as the conflict status shown in the List. These controller opinions reflect a basic characteristic of this or any decision support tool, namely that the information provided by the Tool is advisory only and as such is not a substitute for good controller judgment. Thus, the controller should always augment the advisory information provided by the Tool with her analysis of the traffic situation before issuing a direct-to clearance.

Integration of Direct-To List with CTAS Trial Planner

In order for the controller to access additional information on aircraft in the List and to simplify making flight plan amendments, the Direct-To List and the CTAS Trial Planner have been interconnected through an on-screen button in the Direct-To List. The button, in the form of a small square, is located to the left of each ACID in the List [see figure 4]. The button is a select/deselect switch that puts the corresponding aircraft into the trial planning mode when it is clicked with the mouse into the select position. A check mark, as shown for the first ACID on the List in figure 4, indicates that the corresponding aircraft has been selected for trial planning.

The Trial Planner provides the controller with special tools and interactive graphics for managing the trajectories of aircraft in climb, cruise, and descent. With few exceptions, all interactions with the Trial Planner are conducted by point-and-click actions with the mouse (or trackball). Thus, "heads down" keyboard entries are almost entirely eliminated. Conflict probing using the CTAS conflict detection algorithm is an integral part of the Trial Planner. The Trial Planner allows the controller to put any aircraft, not just aircraft in the Direct-To List, in trial planning mode. The Conflict Probe/Trial Planner has been evaluated in field tests at the Denver Center [2] and the Fort Worth Center [3]. The design of the CTAS detection algorithm is described in [8] and [9].

When the controller selects an aircraft from the Direct-To List for trial planning by clicking on the select button, additional information appears on the screen. A representation of the controller's display covering the North-West quadrant of the Fort Worth Center airspace is shown in figure 5 when trial planning a direct-to route for flight AAL2076. The ampersands (&) designate the location of other traffic. Both the flight plan route and the direct-to route are displayed for this flight. A panel at the bottom of the screen displays the complete flight plan. At the bottom left, a menu lists the fixes and waypoints in the flight plan that may be used as alternate direct-to fixes. The direct-to fix selected by the algorithm (PUB) is marked by an asterisk in the menu. The time saving (2.0) and the heading to the fix (310) are also displayed adjacent to the fix. The area labeled altitude at the bottom left and adjacent to the waypoint menu is a menu button for selecting altitude trial planning. It is clicked on when an altitude amendment is required in addition to the direct-to route amendment.

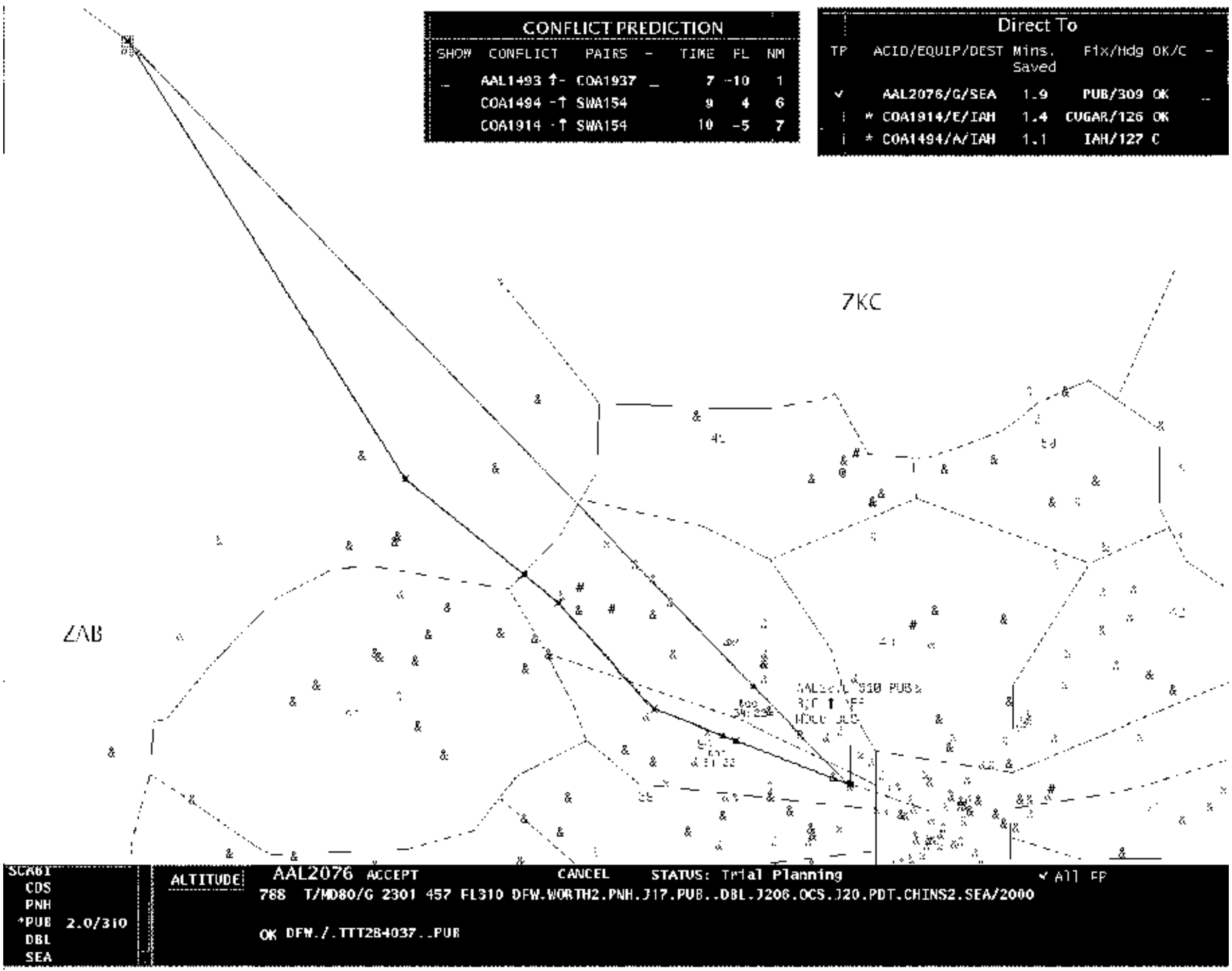

Figure 5. Screen photo of Direct-To display.

To the right of the altitude button are several lines of information pertaining to the aircraft selected for Direct-To trial planning. The first line contains the ACID and buttons to Accept and to Cancel trial planning. The second line contains the current flight plan. The third line (shown blank in the figure) is reserved for displaying the ACID and its flight plan of an aircraft predicted to be in conflict with the aircraft selected for trial planning. The bottom two lines pertain to the trial plan. The first bottom line contains the trial Flight Plan, including the proposed direct-to route amendment. The second bottom line, (shown blank in the figure) would show the ACID and flight plan of an aircraft predicted to be in conflict with the selected direct-to aircraft along its trial direct-to route. Both conflict lines are blank in the figures because neither type of conflict was detected for the trial direct-to aircraft. Both the trajectory display graphics and the information in the trial planning panel are identical to that in the CTAS Conflict Probe/Trial Planner system. If a conflict is predicted along the direct-to route, then the conflict ACID together with pertinent conflict information is also included in the flight plan panel (not shown in figure 5 because no trial planning conflicts were found). This information is identical to that in the CTAS Conflict Probe/Trial Planner display.

The content and arrangement of the information shown on the screen has been designed to tell the controller at a glance whether to accept or reject the direct-to route amendment. If her decision is to accept, then the controller need only click on the "accept" button in the panel in order to amend the flight plan. This action sends the direct-to flight plan amendment message from CTAS into the Center's Host computer. Under normal circumstances, the only actions required by the controller in executing a direct-to route amendment consist of two consecutive mouse points and clicks. This simple procedure contrasts sharply with the multiple keyboard entries required by the current operational system to execute direct-to route amendments, referred to as the 6-7-10 amendments, route key amendments or field 10 amendments.

The Trial Planner provides the ability to evaluate and select any one of numerous alternatives to the trajectories generated by the direct-to algorithm. For example, the controller can select any fix/waypoint along the route of flight as the direct-to fix by clicking on the appropriate fix identifier in the fix/waypoint menu. The Trial Planner will check the new direct-to trajectory for conflicts and update the corresponding time savings, fix identifier and heading angle displayed in the Direct-To List. Controllers found the ability to easily change the direct-to fix to be a useful feature, especially when the direct-to trajectory shows a conflict. These conflicts can sometimes be resolved by choosing a direct-to fix that is either up-range or down-range of the advised direct-to fix or it may be resolved by creating an auxiliary waypoint, or adding an altitude amendment. In summary, the integrated capabilities of the Direct-To List and Conflict Probe/Trial Planner provide an effective environment by increasing controller productivity and reducing workload.

Shadow Mode Evaluation and Benefits Analysis

A prototype of the Direct-To Tool, consisting of the algorithm and controller interfaces, has been implemented as a new software process that is integrated into CTAS. The new process is an extension of the Conflict Probe/Trial Planner, which was evaluated extensively in simulation and field tests at the Denver and Fort Worth Center, as described in [2-3].

Since completion of the basic software in early January 1999, the Tool has been running in shadow mode using the live input of the all flight plan/all tracks data stream received in the CTAS laboratory at Ames from the Fort Worth Center over a high speed data link. In the shadow mode, the CTAS software receives the same input data in real time from the Center's Host computer system as does the version of CTAS that is in daily use by controllers at the Fort Worth Center. The difference is that in the shadow mode, CTAS only receives data from the Host; it does not send data back into the Host, as it does when used operationally. As was the case for the earlier CTAS tools, shadow mode evaluation of the Direct-To Tool has proven to be an efficient and indispensable method for validating the software and for developing and refining the controller interface. During the more than six months of shadow operation, an air traffic controller familiar with the Fort Worth Center operation has exercised the Tool to help improve the controller interface and to assess its potential utility. While a definitive assessment must await the completion of field tests scheduled for the Fall of 1999, the controller's limited assessment of the Tool operated in the shadow mode has been favorable. She rates favorably both the Tool's ability to improve service to aircraft "customers" and its controller friendly interface. In particular, the point-and-click method of entering direct-to flight plan amendments is considered the single most important feature for making the tool acceptable to controllers. Service oriented controllers already make every effort to accommodate pilot requests for direct-to routes or to recommend direct-to routes on their own initiative, workload permitting. By identifying direct-to eligible aircraft automatically, checking their conflict status and simplifying the flight plan amendment process, the Tool complements as well as amplifies the controller's desire to provide good service. Finally, controllers recognize that the Tool's ability to compensate for the effects of complex wind fields ensures that direct-to routes will be issued only to aircraft that can actually benefit from them. Working without this Tool, controllers cannot be certain that this will be the case.

How will use of the Tool affect controllers in downstream sectors? Whether the controller uses the Tool or current keyboard methods to make direct-to route amendments, the Center's Host computer will provide new flight progress strips for affected downstream sectors when necessary. In the current implementation the Tool does not provide additional functions for automating coordination between sectors. However the Tool's automated graphical display of both the flight plan and direct-to routes, together with Conflict Probe information, allow the controller to assess the effect on downstream sectors more quickly and comprehensively. Thus, the controller is in a better position to decide if further coordination with downstream controllers is necessary. It is therefore reasonable to expect that the workload of downstream controllers will not be substantially changed when the Tool is in use. However, a definitive answer to this issue must await a field test where the impact on operations of a higher rate of direct-to routings expected from use of the Tool can be evaluated.

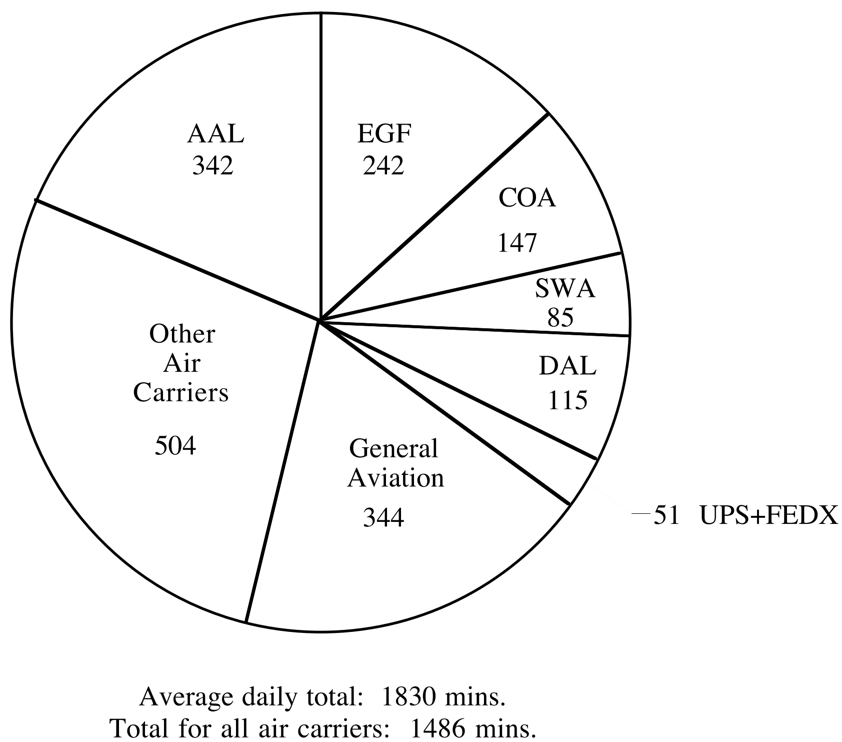

Figure 6. Direct-to time savings, Fort Worth Center.

The most important result obtained from shadow operation of the Tool is an estimate of total time saving for all aircraft operating in a Center's airspace. The overall measure of benefits is chosen to be the accumulated number of minutes of flight time that could be saved in an interval of time when the Tool is in operation. To obtain this measurement, a software function was incorporated into the Tool that records the total minutes saved for all aircraft that are displayed in the Direct-To List. With the Tool running for several months, 24 hours a day, a large amount of benefits data was collected and analyzed for the Fort Worth Center's airspace.

A useful way of analyzing the data is to calculate the average, daily (24 hours) time savings. For the Fort Worth Center, the savings were found to be about 1800 minutes/day, which extrapolates to 657,000 minutes per year. The recorded data also permitted the time savings to be computed separately for each airline and for all general aviation aircraft. The pie chart in figure 6 shows the results in minutes of daily savings for several categories. It can be seen that American Airlines (AAL) and its regional affiliate, American Eagle (EGF), benefit the most, reflecting the fact that they are the dominant air carriers and air taxi serving the Dallas/Fort Worth Airport. The savings for several other carriers and for all general aviation aircraft are also shown. The average time saving per direct-to clearance was found to be about 2.5 minutes. By assuming that the direct operating cost per flying minute for air carriers is $35, the yearly cost savings for all air carriers operating in the Fort Worth Center are estimated to be $18,000,000. This estimate excludes potential savings for arrivals into the DFW airport.

The maximum number of aircraft appearing in the List at any time varies between 10 and 20. That number is generally less than 10% of all aircraft operating in the Fort Worth Center at any time. When these aircraft are divided among the sectors who have ownership of them, the maximum number on the List for any sector will seldom exceed 2-3 aircraft in a 20 minute interval. The increase in workload on controllers to issue the additional clearances for these relatively few aircraft is mitigated by the effectiveness of the point-and-click interface and therefore does not raise a concern with controllers.

So far, the measurement and analysis of benefits for the Tool have centered on the potential for time savings. Now it should be noted that the reduction in the time to fly along a more efficient route also reduces the fuel consumption, provided that the pilot holds the airspeed fixed at the planned value. If an aircraft operator is indifferent to the time saving produced by the direct-to clearance or does not wish to arrive earlier than required by the schedule, then the pilot can trade all or any portion of the time savings for additional fuel savings by reducing the planned airspeed appropriately. Fuel consumption is reduced by flying at a lower airspeed because the planned cruise speed of an aircraft is usually well above the airspeed where fuel consumption is minimized. Thus, the additional degree of freedom offered by the ability to trade time savings for additional fuel savings implies that direct-to advisories generated by the Tool are generally cost effective and operationally advantageous as long as they do not violate safety constraints.

Concluding Remarks

The design and operational use of the Direct-To Tool represents a proactive approach to problem solving in that it actively searches for and points out opportunities for improving the efficiency of trajectories to controllers. This approach contrasts with the reactive approach embodied in the design of a Conflict Probe which alerts controllers only when problems are predicted to occur. The proactive approach to the design of the Direct-To Tool extends to the en route airspace what the several CTAS tools have done for the management of arrival traffic. The commonality existing between the Direct-To Tool and the other CTAS tools not only includes the design philosophy but, more importantly, also includes the trajectory algorithm, software and system architecture. This makes it possible for an installer of the Tool to reuse the software, adaptation techniques, and CTAS-to-Center Host computer interfaces being used in the current CTAS deployment effort. By exploiting this opportunity the cost and time to deploy the Tool will be significantly reduced.

Installation and field evaluation of the Tool is being planned for the Fort Worth Center starting in the last quarter of 1999. In order to expedite the development and potential for early deployment, the Tool will be installed on displays at the data position, or D-side, of each sector. Eventually the Tool will be integrated into the radar display, or R side, position where controllers have indicated they prefer it to be installed. A provisional patent application for the Tool was filed in January, 1999.

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