NASA Technical Memorandum 102229

Design of a Final Approach Spacing Tool for TRACON Air Traffic Control

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SYMBOLS

AAS	Advanced automation system
ARTCC	Air Route Traffic Control Center
ATC	Air traffic control
DA	Descent Advisor
E	Early relative to scheduled arrival time
ETA	Estimated time of arrival
FAA	Federal Aviation Administration
FAST	Final Approach Spacing Tool
IAS	Indicated airspeed
ID	Identification
KIAS	Knots, indicated airspeed
L	Late relative to scheduled arrival time
n.mi.	Nautical miles
PPI	Plan position indicator
RI	Route intercept
Rwy	Runway
STA	Scheduled time of arrival
TMA	Traffic Management Advisor
TRACON	Terminal Radar Approach Control (facility)
VOR	Type of navigation station providing range and bearing
WC	Waypoint capture mode of horizontal guidance
4D	Four-dimensional (three dimensions plus time)

SUMMARY

This paper describes an automation tool that assists air traffic controllers in the Terminal Radar Approach Control (TRACON) Facilities in providing safe and efficient sequencing and spacing of arrival traffic. The automation tool, referred to as the Final Approach Spacing Tool (FAST), allows the controller to interactively choose various levels of automation and advisory information ranging from predicted time errors to speed and heading advisories for controlling time error. FAST also uses a timeline to display current scheduling and sequencing information for all aircraft in the TRACON airspace. FAST combines accurate predictive algorithms and state-of-the-art mouse and graphical interface technology to present advisory information to the controller. Furthermore, FAST exchanges various types of traffic information and communicates with automation tools being developed for the Air Route Traffic Control Center. Thus it is part of an integrated traffic management system for arrival traffic at major terminal areas.

INTRODUCTION

The management of terminal area arrival traffic has become one of the most difficult problems in the nation's air traffic control (ATC) system. Because of increased traffic and the fact that the controllers have a limited range of "tools" to assist them in the various control tasks, delays and congestion have become common. In addition, controller workload has increased with adverse effects on safety.

To help resolve these problems, NASA Ames Research Center and other research laboratories have been investigating methods for introducing automation aids or tools to assist in terminal area traffic management. The research begun in the 1960s was limited in effectiveness by the technology of that period (ref. 1). Although it was shown that computer generated airspeed and heading advisories would give a slight increase in runway throughput, the controllers found that their workload was increased and rated the automation unfavorably. A very recent investigation reaffirmed, by using fast-time simulation studies, the potential benefits of decreasing interarrival time errors by utilizing computer-generated heading and speed advisories (ref. 2). Neither of these studies, however, provided an effective, flexible, real-time controller interface.

Recently the prospects for using higher levels of automation have improved because of the installation of a new generation of ATC host computers and plans for introducing new controller suites, which incorporate color graphics workstation technology, into the national airspace system. The new controller suites, which will become operational in the mid-1990s, are a key element of the Federal Aviation Administration (FAA) Advanced Automation System (AAS). In support of introducing these new computer technologies, recent research at Ames and elsewhere has provided new insights into the appropriate role of automation in ATC and has yielded promising methods for designing such systems (refs. 3-6).

The current work at Ames focuses on introducing automation aids for controlling traffic from 200 n.mi. from touchdown down to the runway (refs. 4-6). This requires developing effective aids that address procedures and problems unique to each controller in the arrival sequence including traffic managers, enroute and descent controllers in the Air Route Traffic Control Center (ARTCC), and Terminal Radar Approach Control (TRACON) controllers. An integrated automation system has been developed at Ames incorporating all of these control positions and is being evaluated in real-time simulation studies. Its key elements are the Traffic Management Advisor (TMA), the Descent Advisor (DA), and the Final Approach Spacing Tool (FAST).

The purpose of this paper is to address the design and implementation of an automation "toolbox" for TRACON air traffic controllers referred to as the Final Approach Spacing Tool (FAST) and to present preliminary results of its evaluation in real-time simulation. FAST addresses many of the unique problems of TRACON ATC. The tool is designed to provide an effective controller aid for: 1) obtaining speed and turn advisories to meet scheduled times of arrival; 2) vectoring aircraft off standard arrival routes, if required, while maintaining accurate trajectory predictions; and 3) rescheduling aircraft late in the arrival sequence to accommodate special situations.

The paper is organized to first provide an overview of the three main components of the ATC automation system concept being developed at Ames (i.e., the TMA, DA, and FAST). The overview is followed by a description of controller procedures in the TRACON and a detailed description of FAST in its current implementation on a Sun Microsystem workstation. Specific examples which demonstrate FAST's flexibility and utility are described. The examples are followed by a brief review of observations from a recent real-time simulation of FAST. Finally, remarks regarding TRACON automation and future simulation plans are presented.

The authors would like to thank Bill Nedell of San Jose State University for his many suggestions and for his contributing software expertise in implementing FAST. We also thank Ted Lichtenstein and Laurie Engle of Sterling Software, Palo Alto, CA for their superb support in the software implementation of FAST.

AMES AUTOMATION SYSTEM CONCEPT

In general, the functions of the TMA include assisting the ARTCC traffic manager in coordinating and controlling traffic flow between ARTCCs, between sectors within an ARTCC, and between the ARTCC and TRACON. The primary function of the TMA is to plan the most efficient landing order and to assign optimally spaced landing times to all arrivals. Schedules may be based on a first-come, first-served basis or on an optimal sequence to minimize overall system delay. These time schedules are generated while aircraft are 150-200 n.mi. from the airport. The TMA algorithm plans these times such that traffic approaching from all directions will merge on the final approach without conflicts and with optimal spacing. The TMA also assists the ARTCC traffic manager in routing traffic from an overloaded sector to one more lightly loaded or to route and reschedule traffic in response to a runway change or weather disturbance.

The DA is designed to provide ARTCC controllers handling descent traffic with a set of flexible automation tools. ARTCC controllers are responsible for merging and descending the arrival traffic from the ARTCC boundary (~200 n.mi. from the airport) down to the TRACON boundary (~30 n.mi. from the airport). The DA assists the ARTCC controller in implementing the traffic plan generated by the

TMA to meet specific in-trail spacing requirements and to predict and efficiently resolve conflicts long before they arise. The DA uses detailed performance models of specific aircraft types, a four-dimensional (4D) trajectory synthesis and prediction algorithm, and an interactive graphical interface and display. A detailed description of both the TMA and the DA is given in reference 5.

The TRACON controllers take over control of traffic at feeder gates which define the entry points into the TRACON airspace. They merge the traffic converging on the final approach path while making sure that aircraft are properly spaced. If the ARTCC controllers have delivered aircraft at the feeder gates at the correct time by using the DA tools, the TRACON controllers ordinarily will need to make only small corrections in the relative positions of aircraft to achieve the desired spacing. FAST assists the TRACON controller in making these corrections with high accuracy and a minimum number of heading vectors and speed clearances. Although different in several ways from the DA, FAST also uses a 4D trajectory synthesis-and-prediction algorithm, a scheduling algorithm, and an interactive graphical interface and display.

It is important to note that any one of these automation tools should significantly improve the ATC system. However, the total system design that is being developed allows the various tools to exchange information with and thereby complement each other. This should result in a more orderly and expeditious flow of traffic and an overall reduction in controller workload.

TRACON CONTROLLER PROCEDURES FOR MANAGING ARRIVAL TRAFFIC

An understanding of controller procedures for managing arrival traffic provided important insight and motivation for designing FAST. Hence these procedures are reviewed in preparation for describing the TRACON automation tools in the next section.

Typically, arrival traffic is handed off from the ARTCC to the TRACON airspace at designated points, called feeder gates, about 30 n.mi. from the airport and 10,000 to 15,000 ft above ground level. Some airports utilize as many as four or five such gates or corner posts which approximately form a rectangle with the airport at the center.

Once the aircraft have been handed over to the TRACON, they are initially handled by a feeder controller. The feeder controller's task is to descend and slow the traffic into a single stream from each feeder gate while maintaining adequate (safe) spacing between aircraft. Typical spacing goals for the feeder controller depend heavily on traffic density but are usually 5 to 12 n.mi. A final controller then merges arrival traffic from the various feeder gate streams onto the final approach course using separations ranging from 3 to 6 n.mi. at the runway threshold depending on aircraft weight categories. Because aircraft are relatively close to each other in the TRACON and must be merged from separate arrival paths onto one single final approach path, the feeder and final controllers are kept extremely busy communicating with the aircraft and selecting which aircraft will be first, second, third, and so on.

Both feeder and final controllers attempt to keep aircraft on a fastest or shortest path to the runway. They often utilize speed changes, altitude changes, and path stretching to ensure proper spacing. If the arrival traffic rate is too high, controllers will begin slowing all traffic. This slowdown may not always be necessary for all aircraft in busy traffic periods, and in some cases may actually create new problems and conflicts. Path stretching could involve extending or compressing the downwind leg of an approach or taking an aircraft out of its arrival stream and into a less dense arrival stream. Accurate control of interarrival spacing is further complicated by wind speed and direction changes.

Both feeder and final controllers must also merge "popup" (unexpected) and missed approach aircraft into one of the arrival streams. The controllers accomplish this by the previously mentioned method of speed control, path stretching, and searching for an open slot in an arrival stream in which to merge the aircraft.

In this paper, all procedures and examples are based on Denver's TRACON for arrivals to Stapleton International Airport's Runway 26L (Rwy 26L). Figure 1 shows the nominal routes in the northern half of the TRACON for arrival traffic to Rwy 26L and the airspace delegated to the feeder and final controller. As soon as an aircraft enters the TRACON, they are cleared to 11,000 ft. If the aircraft is arriving from Keann, it will be slowed to 210 knots indicated airspeed (IAS) before being turned to base and handed off to the final controller. Aircraft arriving from Drako are slowed to 210 knots at the turn to the downwind leg, and just before handoff from the feeder to the final controller. After being handed off to the final controller, and, in the case of Drako arrivals, after clearing the departure runways (35R and 35L) at 11,000 ft, the aircraft are descended to 8,000 ft. As the aircraft are given a base turn clearance, they are slowed to 170 knots and a short time later are given a right turn clearance to 240° and cleared for the approach. Note that the Denver Stapleton International Airport field elevation for Rwy 26L is 5,333 ft.

Most speed adjustment advisories (nominally 210 knots IAS) are issued at the point where aircraft are handed off to the final controller (fig. 1). Path extension is usually given as an extension of the base leg turn. Path shortening procedures employed by controllers typically consist of directing the aircraft from the inbound Drako radial to a point on a shortened downwind leg and directing aircraft from the inbound Keann radial to a point on a shortened base leg (fig. 2).

FINAL APPROACH SPACING TOOL (FAST)

Figure 3 is a diagram of the components of FAST. The TRACON Scheduler is designed to nominally accept the scheduled times of arrival (STAs) generated by the TMA. However, it is designed to reschedule the aircraft, if required, to accommodate special circumstances such as large time errors, popups, or missed approaches. The scheduler uses trajectory information along with earliest and latest possible arrival times to establish the revised STA. Once the revised STA has been defined, the trajectory synthesis algorithm is used to compute a 4D path that meets the generated STA. The graphical advisory interface is designed to allow the controller to make more effective use of these tools in sequencing and spacing aircraft. In today's ATC environment, the controller would issue the clearance by voice to the aircraft. However, when a data link becomes available, the clearances could be transmitted to the cockpit automatically. Brief descriptions of the scheduler, trajectory synthesis and prediction algorithms, and graphical advisory interface are given in the following sections.

Terminal Radar Approach Control (TRACON) Scheduler

The TMA initially generates schedules for all arrival aircraft while they are still in ARTCC airspace. These schedules are optimized so as to provide the maximum runway throughput for a given traffic load. If the traffic flow remains relatively smooth and uninterrupted, aircraft will arrive at the feeder gates with little or no time error. In this case, the STAs will remain unchanged by the TRACON Scheduler.

Suppose, however, that some traffic arrives with a significant time error for various reasons. In order to handle such errors, a rescheduling horizon, nominally set at 10 min. flight time from the runway, is implemented within the TRACON. As an example, two aircraft were scheduled in the ARTCC in a certain order at the runway, but due to time errors they arrive at the TRACON boundary in reversed order. They then become candidates for a position shift, i.e., reversal of the STAs to conform with the new estimated times of arrival (ETAs). They are both monitored by the TRACON Scheduler and if the ETAs are reversed as they cross the rescheduling horizon, the TRACON Scheduler will advise a position shift. All subsequent advisories will assist the controller in achieving the reversed order.

A rescheduling horizon also aids in the handling of a popup aircraft. When a controller accepts a popup aircraft, the aircraft is vectored into an arrival stream through the rescheduling horizon. The TRACON Scheduler will reschedule other aircraft so as to build a slot for the popup. This operation may cause aircraft scheduled behind the popup to be delayed. As before, all subsequent advisories would reflect the new schedule.

Descent Trajectory Model

The FAST descent trajectory synthesis algorithm is a modified version of the ARTCC DA algorithm. A detailed description of the algorithm is given in reference 6. Similar to the ARTCC DA, it employs a second-order Runge-Kutta forward integration scheme to synthesize a path to the runway based on standard TRACON operations, aircraft state and type, and wind speed and direction. Piloted simulator evaluations of this algorithm have demonstrated an arrival time accuracy of ±20 sec at the feeder gate (ref. 7).

Upon arrival into TRACON airspace, the FAST DA predicts the arrival time of an aircraft at the outer marker based on its current position, altitude, speed, and heading. It assumes a horizontal arrival route and a nominal air speed deceleration schedule and altitude profile similar to Denver's TRACON operations. Next, the DA computes a range of arrival times based on the aircraft speed envelope and allowable path extension. These predicted trajectories are updated every 15 sec. If the STA and ETA are the same, the aircraft is maintained on its present nominal altitude and speed profile to the runway. If the ETA shows the aircraft to be early, the DA will synthesize a descent trajectory that attempts to eliminate the time error by first decreasing the aircraft airspeed and then if necessary, extending the path distance to the runway as previously described.

If the ETA shows the aircraft to be late, the controller is advised and he or she can speed up the aircraft or shorten its path to the runway by utilizing the Horizontal Guidance Modes that will be described in the next section. As the suggested speed or path adjustments are displayed, the FAST DA continues to update the aircraft ETA in order to issue subsequent advisories.

Horizontal Guidance Modes

In the preceding description of descent trajectories, the construction of the horizontal route is not mentioned. This is a crucial element in the accuracy of the prediction given the large amount of vectoring required in the TRACON and the effect of ever-changing wind direction and magnitude.

Construction of the horizontal route always begins at the current position and heading of the aircraft and terminates at the outer marker. The current position need not be on a standard path. The controller may vector the aircraft anywhere in the TRACON arrival airspace and a horizontal route will be synthesized based on either a route-intercept (RI) procedure or a waypoint capture (WC) procedure. These synthesis modes will now be described.

Route Intercept Mode– This mode operates in conjunction with a set of standard or nominal arrival routes converging on the final approach course to the runway. The routes comprising the nominal arrival path from the north to Rwy 26L at Denver's Stapleton International Airport are the final approach course extending 10 n.mi. beyond the outer marker (Altur), a base leg positioned 5.5 n.mi. from the outer marker and extending 15 n.mi. north from and perpendicular to the final approach course, and a downwind leg positioned 5 n.mi. north of and parallel to the final approach course (see fig. 1). Each route has a corridor width of ±1 n.mi. relative to its center line.

As an aircraft enters the TRACON airspace from one of the feeder gates (Drako or Keann) the FAST DA algorithm puts the aircraft into a free vector mode. In this mode, the algorithm seeks an interception of one of the defined route segments by extending the instantaneous heading vector. From the first point of interception, the algorithm completes the path by following along the nominal route to the outer marker (fig. 4). After the aircraft has captured the downwind leg, the horizontal synthesis computes a new RI of the base leg. Similarly, once the aircraft has intercepted the base leg, a new RI of the final approach course is computed. The path to the runway is recomputed approximately every 15 sec based on the current position and heading. This free-vector mode with RI logic allows the controller the freedom to vector aircraft anywhere in the arrival airspace and still maintain a highly accurate estimate of arrival time as long as the aircraft is heading for a standard route segment.

Waypoint Capture Mode– This mode was originally developed for on-board flight guidance (ref. 8) but was recently integrated into the Ames controller automation tools for predicting and controlling arrival times of aircraft which are being vectored to a waypoint on another route. It differs from the RI mode in that a controller may bypass large portions of routes or entire routes along the nominal arrival path by vectoring the aircraft direct to a waypoint on the final approach course, base leg, or downwind leg.

The horizontal path synthesized by this mode consists of an initial circular arc starting at the current position and course followed by a straight-line segment leading directly to the capture waypoint, and ending with a circular arc turn intercepting the route containing the capture waypoint. The geometry of this construction is illustrated in figure 5. The algorithm determines the radius of the turn from the airspeed, wind speed, and maximum allowable bank angle. Furthermore, the direction of the turn toward the capture waypoint is chosen so that the total length of the path is minimized. In order to compensate for computational delays and to allow for controller response time, the algorithm also moves the start of the turn at each computational cycle a distance equivalent to 10 sec of flight time ahead of the current aircraft position. As in other trajectory synthesis modes, the predictive algorithm refreshes the WC profile in a 15-sec cycle using updated aircraft state information.

Graphical Advisory Interface

In order to effectively lay out design constraints for the graphical advisory interface, TRACON controllers were interviewed to determine methods for displaying and interacting with automation tools in the TRACON. The TRACON controllers felt that automation must harmonize smoothly with their current operation. This implies that the automation advisories should be consistent with the standard methods for handling traffic and must be easy to access. The controllers also emphasized that because they devote their entire concentration to the aircraft, most advisory information should be located at or near the aircraft symbol. The use of auxiliary displays or a keyboard for making frequent entries is not feasible since they take attention away from the control task.

Therefore, FAST was designed to allow the controller to select the level of automation desired, but once selected, to have all advisories appear automatically. FAST was also designed to allow the controller to increase or decrease the level of automation, or to use it for "quick look" advice in the middle of a traffic rush with minimal interaction. It also provides predictive trajectory information on individually selected aircraft. This feature is particularly useful for nonstandard situations such as popups, missed-approaches or off-route vectoring.

Because controllers find it difficult to sequence traffic based on time rather than distance, it is important to display most advisory information in a manner which is compatible with their "distance-based" control strategies. As an example, if an aircraft is directed to enter a base leg, the controller doesn't think about what time it will be given, but rather visualizes where it should be given such that there are no conflicts and proper spacing is maintained. It thus makes sense that if an automation tool is designed or programmed to advise the controller <u>when</u> to turn aircraft such that spacing and schedules are maintained, the advisory should be given in a pictorial representation similar to his visualization of <u>where</u> to turn the aircraft in order to achieve these goals. This "picture" should be available well in advance so that the controller has sufficient time to plan and issue the necessary advisory to the aircraft, yet not clutter his display.

Controller/FAST Interface Panel– The Controller/FAST interface provides a panel window on the controller's display, or Plan Position Indicator (PPI), which lists the automation options. If the controller does not want any advisories displayed, he would choose "Manual." The automation tools available include "Timeline," "Speed/Vector" advisories, and "Time Error." One or more of these automation tools may be selected at any time by toggling them on the interface panel with the mouse. In addition, the timeline can be turned on or off and moved to either side of the display with a function key toggle button. When any of these automation functions are selected, the controller will receive the associated advisory information for all the aircraft without further interaction. In addition the controller can obtain advisories for special horizontal routing of individual aircraft by selecting the individual aircraft through the mouse. A description of the timeline, speed/vector advisories, time error indications, and the interface to the Horizontal Guidance Modes for individual aircraft follows.

Timeline– A display of arrival time for each aircraft is a useful tool for the controller. This information not only gives the controller a list of current aircraft, but also of future traffic density. A vertical timeline is used to display the current STA and ETA at the outer marker for all aircraft in, or expected to arrive in, the TRACON airspace. STAs are originally received by FAST from the TMA but are updated by the TRACON Scheduler. ETAs are calculated and updated on a regular basis by the FAST DA.

The timeline is on the right side of the PPI in figure 6. The right side of the timeline displays the current ETA for each aircraft in green. The left side of the timeline displays the current STA for each aircraft in blue if arriving from the West and white if arriving from the East. This gives the controller the ability to quickly distinguish from which direction an aircraft is arriving and to correlate this information with displayed aircraft symbology described in the next section on Turn Vectors. If the STA and ETA are different during the aircraft's flight in the TRACON, FAST will provide speed advisories and heading vectors required for the aircraft to meet the STA. As the advisories are displayed, the ETA on the timeline will adjust itself to reflect the effect of each advisory. If the advisory is not followed, the ETA will be readjusted based on subsequent aircraft state updates.

Speed/Vector Advisories– One of the most effective methods used by controllers to sequence and space arrival traffic is by speed adjustments. If the TMA and TRACON Scheduler have sequenced the aircraft properly, slowdowns should become less frequent and the function of an advisory algorithm such as FAST can be used in "fine-tuning" traffic.

When FAST determines that a speed adjustment is necessary at a given point and the aircraft is within 5 n.mi. of that point, the advised IAS is displayed on the aircraft data tag below the ground speed in orange. The use of color on the tag alerts the controller that an advisory is pending. Putting the advised speed on the tag allows the controller to maintain his concentration on the aircraft progress. In addition, the point along the current predicted path where the speed adjustment should be issued is high-lighted with an orange marker to coincide with the orange speed advisory on the data tag. The 5-n.mi. advance notice and spatial display of where the speed adjustment should occur allows the controller to plan ahead for its issuance. Figure 6 shows an aircraft (EA10) receiving a speed advisory of 210 knots.

Another common technique used by TRACON controllers to delay or advance an aircraft is to extend or compress the downwind leg of the approach path or vary the intercept of the final approach course. Accuracy is poor since the controller must estimate how much to extend the downwind leg, where to intercept the final approach course, or what heading to give aircraft on these turns in order to delay or advance an aircraft the necessary amount. This problem can be solved more accurately using the FAST DA. The FAST graphical interface provides color-coded turn vectors on the PPI with the proper heading and point where the controller should issue the turn.

For example, when an aircraft arrives from the West to land on Rwy 26L at Denver's Stapleton International Airport and is within 5 n. mi. of its advised turn to base or turn to final, the data block is colored blue and a blue turn vector appears at the position where the turn should be issued (see IA69 and UA17 in fig. 6). Once the aircraft has completed the base or final turn, the aircraft color reverts back to green, and the turn vector for that aircraft disappears. When the next aircraft is within 5 n.mi. of its advised turn, the same process is used for that aircraft. Only one aircraft at a time is given a base or final turn advisory from any given arrival feeder gate. Similarly, aircraft arriving from the East are color-coded white for base and final turn advisories. The base and final turn advisories vary for each aircraft depending on its current time error relative to its STA and are displayed in the position that will resolve the current arrival time error for proper separation. As in the case of the speed advisories, the color coding and spatial display of where to turn the aircraft are designed to be compatible with the way controllers visualize traffic flow.

Time Error Indications– Although the timeline gives a convenient display of each aircraft's current arrival time error relative to its STA, it is sometimes helpful for the controller to have that information available directly on the aircraft's data tag. FAST continuously updates each aircraft ETA and thus its expected arrival time error relative to its STA. If the controller selects "Time Error" on the automation tool interface panel, this information is given in orange below the altitude slot on the third line of each aircraft's data tag (see fig. 6). The actual expected arrival time error, which is updated every 15 sec., is given as either "E" for early or "L" for late, followed by the time error in seconds. For example, if the FAST DA has calculated that an aircraft will be late by 7 sec relative to its STA, "L7" is displayed on that aircraft's data tag. The controller may use this "Time Error" mode alone or in combination with the Speed/Vector and Timeline advisory mode to improve accuracy.

Interaction with Horizontal Guidance Modes– As described earlier, an aircraft entering the TRACON is put into the RI or free-vector mode by default. If the controller wishes to display the current projected path to the runway, the aircraft is selected with the mouse (by clicking on its position indicator). At this time the aircraft's tag turns yellow and the intercept arc for merging onto the next route segment is displayed as a yellow arc along with the aircraft's ID. The remainder of the path to the runway is the nominal path, and as the aircraft proceeds toward and becomes established on each route segment, the displayed intercept arc moves ahead to the next route segment.

In order for a controller to put an aircraft into a WC mode, the capture waypoint is selected with the mouse, causing that waypoint to turn yellow. The aircraft is then selected with the mouse and a popup menu is used to change the navigation mode of the aircraft from the nominal RI mode to the WC mode. The controller may reinstate the RI mode on any aircraft at any time. A yellow turning arc from the current aircraft position to the beginning of the straight line segment that will take the aircraft to the capture waypoint, and the magnetic heading for the straight line segment are displayed on the PPI. The heading and turn arc are refreshed as the FAST DA updates the predictions every 15-sec.

EXAMPLES

The following are examples of the use of various tools in FAST. It should be noted that the tools may be used in many ways other than those illustrated here. It should also be noted that controllers can solve all of these example situations without automation. However, with FAST the controller has tools to augment his own decisions and plans.

Busy Traffic Period

Figure 7 shows a controller's PPI during a high density traffic period. All of the automation aids have been selected which includes the timeline, speed/vector advisories and time error indications. A landing schedule was generated by the TMA and is displayed on the left side of the timeline. Virtually all of the traffic has arrived in the TRACON with less than 20 sec of time error, which is evident both on the timeline and on the time error indications on aircraft data tags. These relatively small arrival time errors have been achieved in large part by the ARTCC controller using the DA to issue profile descent advisories (ref. 5).

In the display in figure 7, the controller was advised that UA904 was early by 13 sec and should be given an extended final turn in order to preserve adequate spacing with preceeding aircraft. IA69 is being given an advised speed reduction to 200 knots IAS also in order to maintain adequate spacing. SP596 which was late over the Keann feeder gate by 18 sec was being advised to turn left and proceed directly to an intercept of the base leg at Candy. This will allow it to make its STA ahead of IA69, and thus not impact other traffic. Other aircraft have their current time error displayed and will be given subsequent advisories in order to keep all aircraft on schedule.

Popup Aircraft

Frequently, a popup is a general aviation aircraft, however, for the purpose of illustrating how the tools may be used for a popup, assume that in figure 8, AA486 is a popup aircraft and wishes to land as soon as possible at Stapleton Airport. The controller notices an empty slot on the timeline in front of UA774 and wishes to determine if vectoring AA486 direct to an intercept waypoint at the outer marker (Altur) will fit AA486 into the empty slot without affecting other traffic flow. The controller sees that by putting AA486 into the WC mode direct to Altur, the aircraft will overtake the other aircraft and fill the slot. The controller is given the vector clearance (left to 122°) to achieve that goal. If the aircraft did not fit the slot, the controller could leave AA486 on its current course and in the WC mode and subsequent trajectory synthesis updates would assist in determining when and how to safely expedite AA486 to the runway. Because all aircraft ETAs are continuously updated, the controller is able to safely monitor this maneuver and detect problems before they occur.

Missed Approach Aircraft

Procedures for controlling aircraft on a missed approach in a time-based traffic management system were originally studied in reference 9. FAST makes use of those general procedures and provides a means for the controller to merge the aircraft back into the arrival stream. Using Denver's missed approach procedure as an example (fig. 9), an aircraft on a missed approach to Rwy 26 makes a right climbing turn passing over the Denver VOR station and ascending to 10,000 ft outbound on the 046 radial. The controller tries to find an open slot in the arrival stream and merge the aircraft into the slot conflict-free.

FAST assists the controller in completing this task in the following way. First, the controller selects the aircraft with the mouse and selects "Waypoint Capture" on the popup menu (UA693 in fig. 10). He then selects an appropriate waypoint with the mouse at which to merge the aircraft into the arrival stream (Candy in fig. 10). The controller may select any waypoint or change the capture waypoint at any time. From that point on, FAST automatically updates the ETA based on a WC procedure and its current position, heading, and speed. As the ETA is updated, the required heading to capture the merge waypoint is posted on the screen next to the aircraft symbol and the tag on the timeline updates simultaneously. When its ETA fits into an open slot on the timeline, the controller issues a turn heading to the merge waypoint. In figure 10, an open slot exists after UA163. FAST continues to update the ETA until the aircraft reaches the outer marker and thus the controller has continuous information on the missed approach aircraft and how it fits into the arrival sequence. In the case where no arrival slots exist for a considerable time, the controller may adjust the speed, altitude, and heading of other aircraft so as to build or open an arrival slot. As he makes these adjustments to aircraft states, changes in the ETAs will be reflected on the timeline, rescheduling will occur, and the opening arrival slot will be evident. It is important to note that although in this example the aircraft was vectored based on the standard published missed approach chart, the controller could have vectored the aircraft anywhere in the arrival airspace and still have received the WC advisory information to the merge waypoint.

Simulation Results

A real-time preliminary simulation of an approach scenario was conducted in conjunction with a simulation of the ARTCC DA and TMA in order to gain initial comments from FAA controllers on FAST. Although this initial simulation was not of sufficient depth to gain comprehensive results, the controllers rated the system favorably and found the tools useful in sequencing and spacing traffic. They commented that FAST usually confirmed their own plan for controlling aircraft, and sometimes devised a better plan. With FAST, they had an earlier and better idea of how to resolve conflicts. Specifically they considered the information provided by the timeline, turn vector and WC automation tools useful in organizing and controlling traffic. Most importantly, they considered the ability of FAST in maintaining accurate information on aircraft that were vectored off-route an essential requirement for a TRACON automation tool. In-depth simulations of FAST are planned in order to obtain detailed data on the adequacy of the algorithms and graphical interfaces.

CONCLUDING REMARKS

The automation tools described in this paper are primarily for Terminal Radar Approach Control (TRACON) controllers. However, they were derived in large part from automation tools developed for the Air Route Traffic Control Center (ARTCC) and more specifically the Descent Advisor. The tools under development for the ARTCC and Traffic Manager are critical to the success of automation in the TRACON. If those tools are effective in delivering traffic to the feeder gates well sorted and with little time error, the TRACON controller's job becomes that much easier. Therefore, automation in one segment of air traffic control may be useful, but a total-systems approach that integrates the ARTCC and TRACON automation tools is clearly the best method to increase efficiency and safety.

As in the ARTCC automation tools, the interactive graphic interface of FAST is probably its most innovative as well as its most critical design feature. It was designed by building upon the user environment incorporated in certain types of high performance engineering workstations. That this workstation technology can be so easily adapted to the needs of air traffic control automation is remarkable and fortunate for progress in this area.

Controller acceptance of this interface, more than any other issue, will determine the viability of this concept. Here, real time simulations are the main avenue for evaluating controller response, for refining the interface and for developing user procedures. Ultimately, however, only tests with live traffic can establish the effectiveness of the interface with a high level of confidence. Such tests with live traffic, considered an essential step in the development of an advanced automation system, will be planned and conducted jointly with the FAA at an appropriate time and location.

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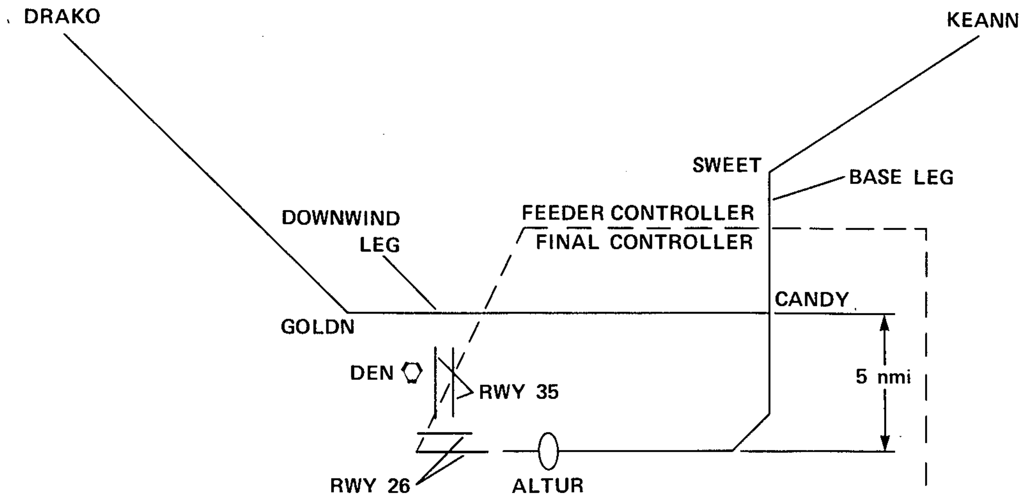

Figure 1.– Arrival procedure for Denver TRACON to Rwy 26L.

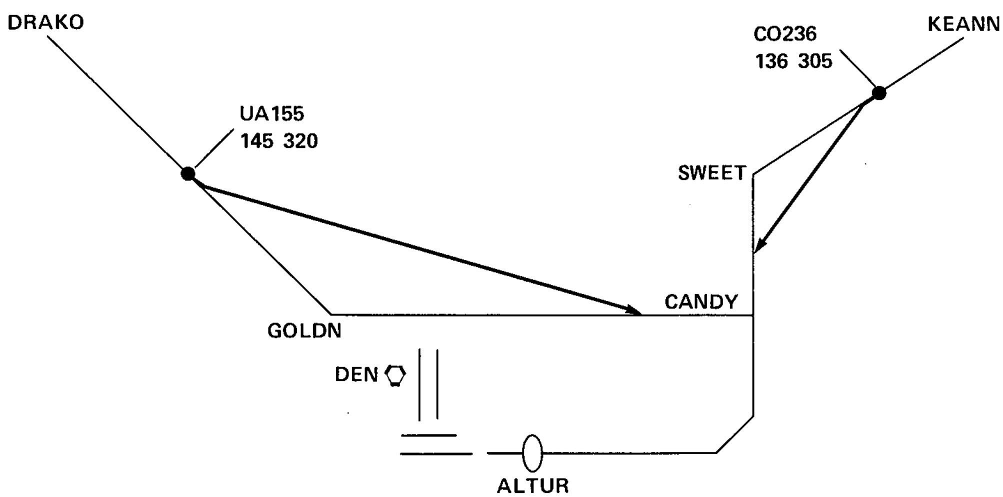

Figure 2.– Path shortening in the TRACON.

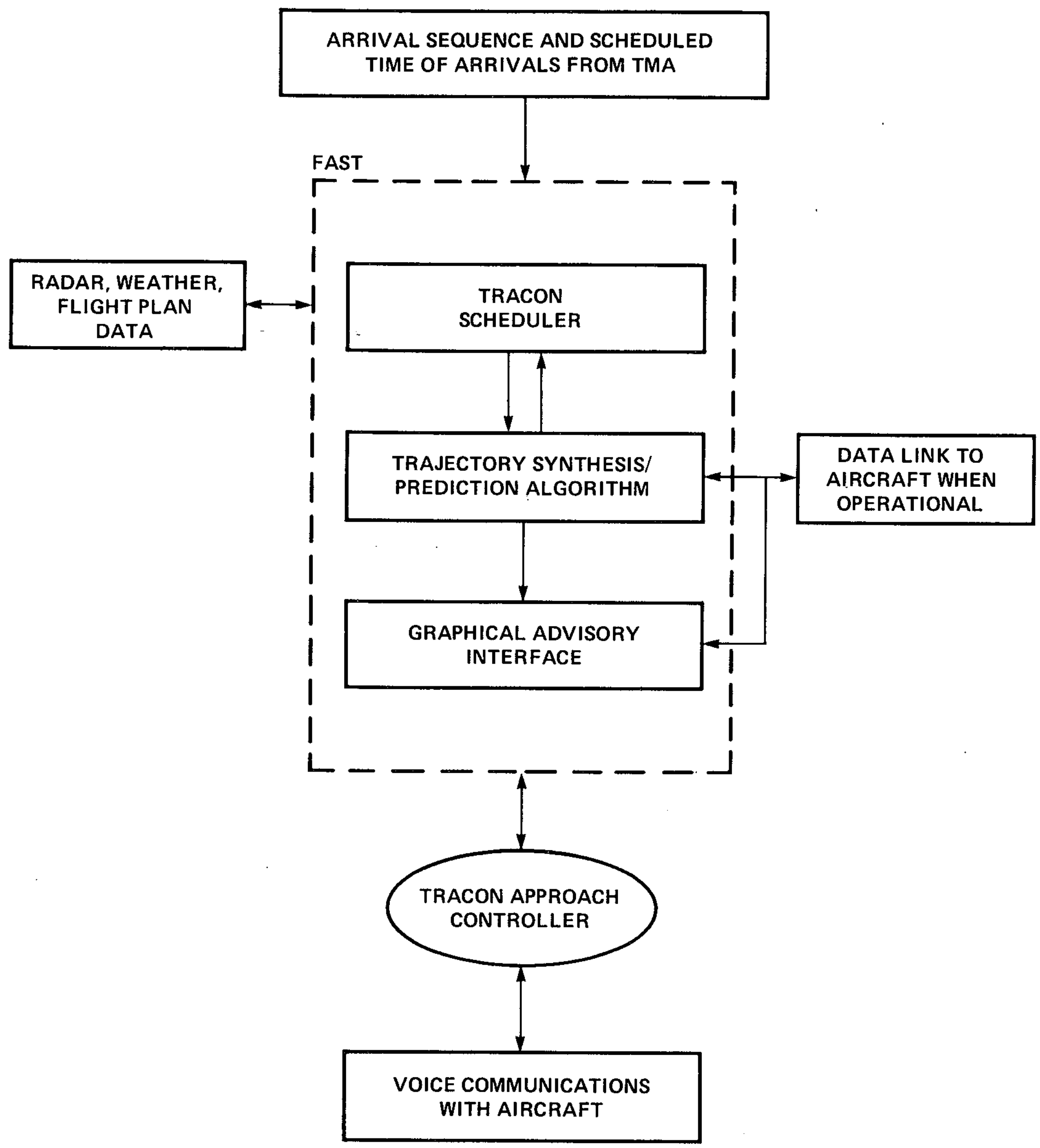

Figure 3.– Final Approach Spacing Tool Concept.

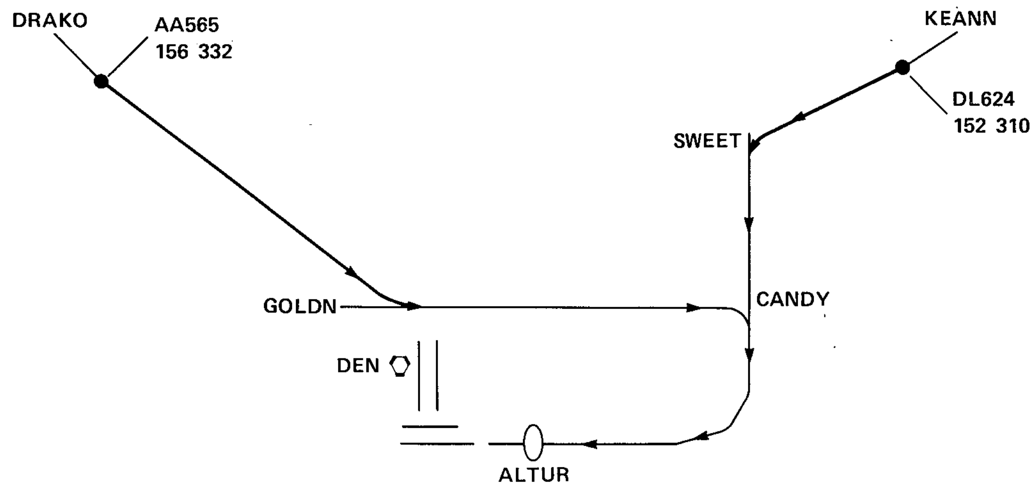

Figure 4.– Route intercept synthesis in free vector mode.

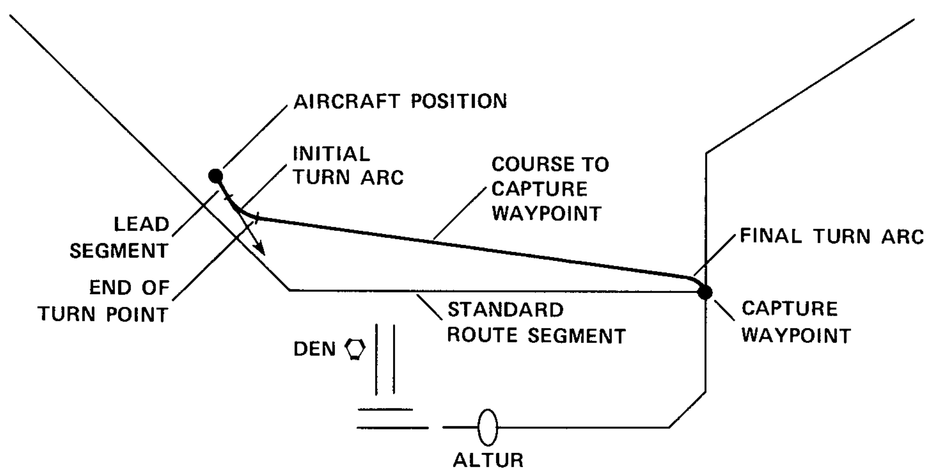

Figure 5.– Waypoint capture guidance.

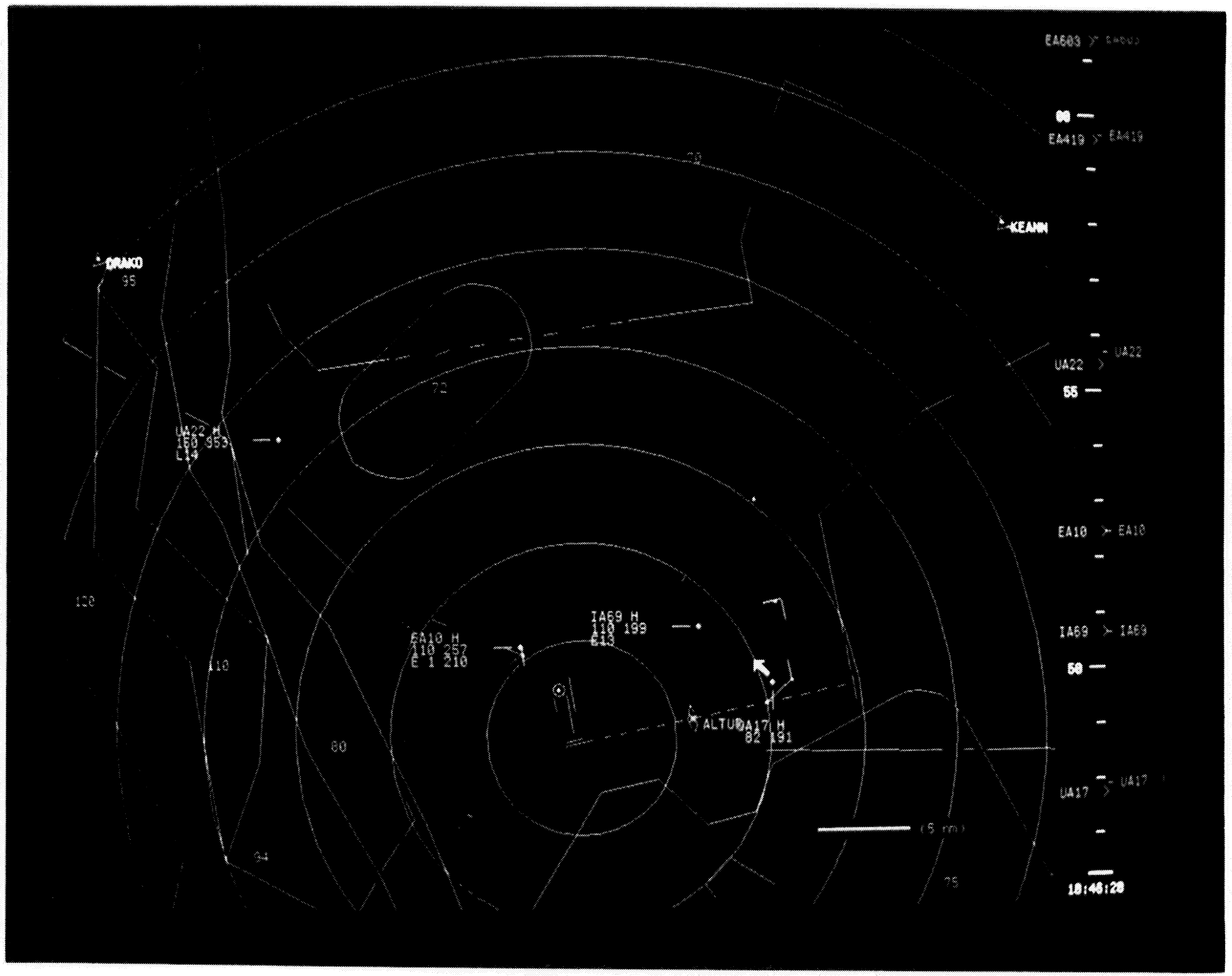

Figure 6.– Automation display for FAST.

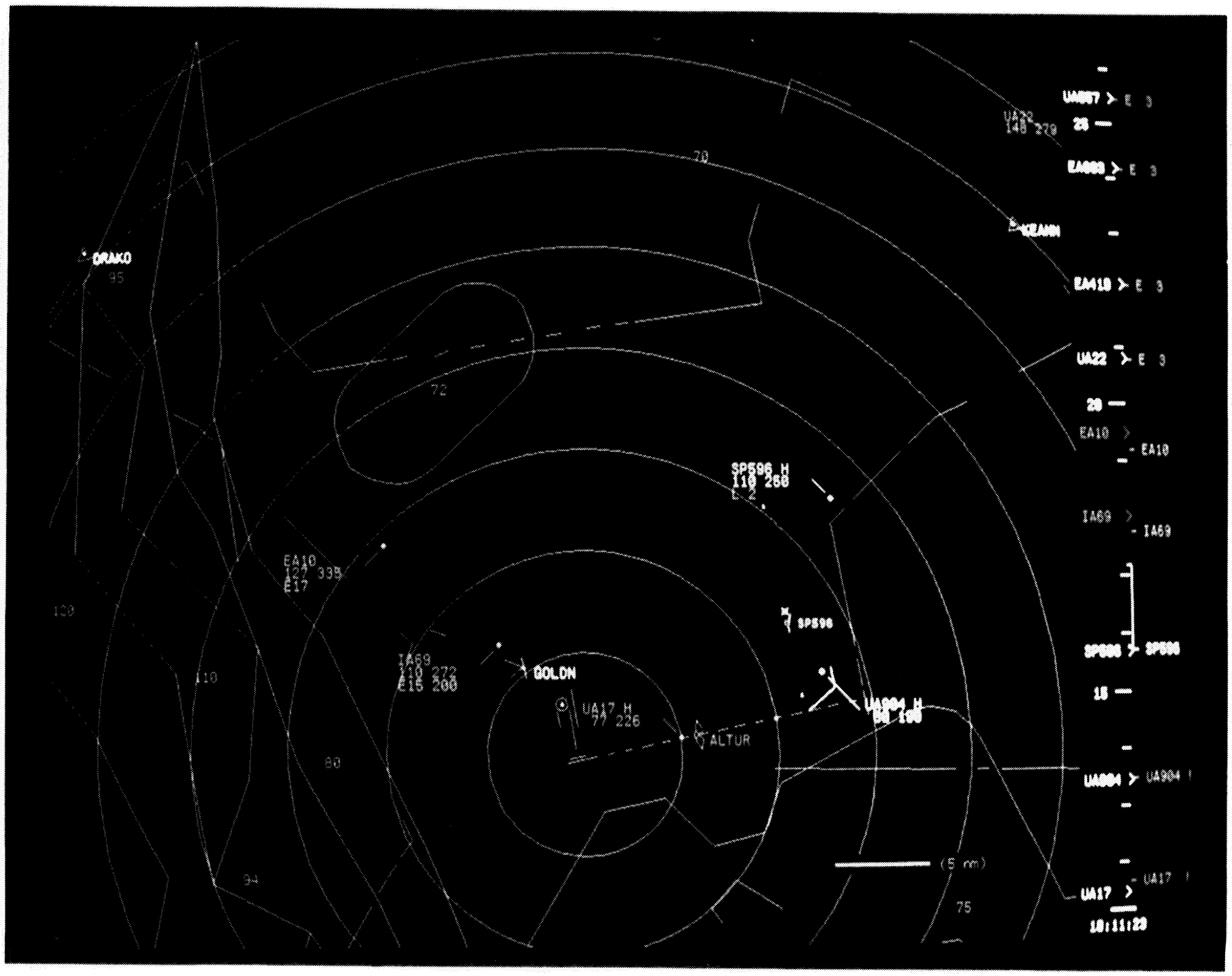

Figure 7.– Example view of busy traffic period.