Helicopter IFR Approaches into Major Terminals Using RNAV, MLS, and CDTI

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Helicopter Instrument Flight Rules routes at hub airports have been investigated in an air traffic control (ATC) system simulation involving a piloted helicopter simulator, computer-generated air traffic, and air traffic controllers. Problems studied included 1) pilot acceptance of the approach procedure and tracking accuracy; 2) ATC procedures for handling a mix of helicopter and fixed-wing traffic; and 3) utility of the Cockpit Display of Traffic Information (CDTI) for the helicopter. Results indicate that the helicopter routes were pilot acceptable and were noninterfering with fixed-wing traffic. Merging and spacing maneuvers using CDTI were successfully carried out by the pilots, but controllers had some reservations concerning CDTI.

Introduction

At present, there is a lack of instrument-approach procedures specifically designated for helicopters operating in major terminal areas. The helicopter must use the same Instrument Landing System (ILS) approach as that designated for fixed-wing aircraft. Because of the difference in speeds between helicopters and fixed-wing aircraft, this technique causes large average separations and high controller workload.

However, capacity must be increased and controller workload decreased if the air traffic control (ATC) system is to handle the anticipated growth of helicopter operations in major terminals. According to current forecasts, the U.S. civil helicopter fleet is expected to total some 20,000 by 1990 at an annual growth rate of 12-15% (Ref. 1). Within this total, business/corporate helicopters will increase at an expected annual growth rate of 15-20% to about 5000 by 1990. During this same period, business/corporate operators are expected to exceed 4000, and commercial helicopters are expected to reach 10,000 with about 3000 operators.

The projected increased number of helicopters, coupled with the complexity of handling mixes of helicopter and fixed-wing aircraft on the same approach, invites consideration of techniques and procedures that result in independent, noninterfering Instrument Flight Rules (IFR) approaches for helicopters into major terminal areas. At the same time, such techniques should not add significantly to the controller workload, at least under low and moderate helicopter traffic conditions. A candidate procedure investigated herein is an area navigation (RNAV) approach which transitions to a Microwave Landing System (MLS) for the final approach course to a landing pad at a high-density airport. It has been generally agreed that RNAV and MLS are complementary navigation/landing systems that could enhance the safety and efficiency of the terminal area operations while reducing controller and pilot workload.[2]

Three major problem areas relating to this procedure were investigated: 1) pilot acceptance of procedures and tracking accuracy for helicopter instrument approaches using RNAV and MLS at major terminal areas; 2) air traffic control procedures and controller acceptance of handling helicopter traffic in addition to conventional traffic, and reducing the minimum separation between helicopters flying the helicopter approach routes from 3 to 1.5 n.mi.; and 3) the potential uses of a Cockpit Display of Traffic Information (CDTI) in a helicopter cockpit. The reason for including the third objective is discussed in the following paragraphs.

Other studies[3,4] are under way to examine the utility of CDTI for fixed-wing aircraft. However, the utility of CDTI for helicopters needs to be examined separately, particularly in a major terminal area environment. Independent helicopter routing in major terminal areas will confine helicopters to airspace unused by fixed-wing traffic. The improved situational awareness provided by CDTI may be helpful to the pilot under these circumstances. In addition, the helicopter operates at lower speeds than fixed-wing aircraft, thus spacing and merging operations from the cockpit might be easier to accomplish. Hence an examination of a CDTI equipped helicopter was included as part of the study of helicopter operations at major terminals.

The study is part of a joint program of real-time simulation studies using facilities at the NASA Ames Research Center and the Federal Aviation Administration (FAA) Technical Center, Atlantic City, N.J. Previous study areas by the joint program have included fuel-conservative approaches, such as delayed flap and profile descents, and time-controlled guidance.[5]

This study was conducted in June 1980 at Ames by using a piloted helicopter simulator and an air traffic control simulation. FAA Technical Center personnel participated in the experiment design and evaluation of results. In addition, the Technical Center provided controller subjects. In the following paragraphs the simulation facilities, the scenario, and the test conditions are described. Results corresponding to the three objectives are presented, followed by conclusions.

Simulation Facilities

The simulation facility is illustrated in Fig. 1. It includes two air traffic controller positions, each having its own color computer graphics display. In this study, one position was designated approach control and the other, final control. In proximity to the color displays, there was a keyboard with which ATC-display-related requests were entered into the controller displays and the simulation computer. Such inputs

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included changing the leader length or the position of an aircraft identification tag; transferring an aircraft between control sectors; or stopping and restarting the flow of traffic at the feeder fixes. The helicopter simulator, located in an adjacent room, was driven by its own digital computer. Controller clearances to the pilot were transmitted via voice link, and the helicopter position was transmitted via data link to the ATC-simulation computer. Air traffic, in addition to the helicopter piloted simulator, was required in order to provide a realistic workload for the controller. This additional traffic consisted of computer-generated aircraft. These aircraft would respond to traffic clearances that were appropriately coded and entered through the keyboard pilot station.

The helicopter simulator had a cockpit configured as a Bell UH-1H. The pilot's displays (Fig. 2) included an electronic multifunction display (MFD) in addition to the standard instrumentation. Vertical and lateral guidance and range (DME) information were provided by the horizontal-situation indicator. A detailed description of the cockpit can be found in Refs. 6 and 7. During the instrument-approach segments, the generated visual scene could display fog to simulate instrument meteorological conditions (IMC). At decision height, the simulated fog was programed to dissipate so that the terminal area could be seen. A 6-degree-of-freedom math model controlled the translation and rotation of a video camera located above a model terrain board to provide the appropriate visual cues. Navigation errors were not included in the simulation.

Scenario and Test Conditions

The simulated terminal area is based on the John F. Kennedy International Airport (JFK), New York. The route structure and runway configuration investigated are shown in Fig. 3. Conventional takeoff and landing (CTOL) aircraft enter the terminal area from one of four feeder fixes—Robbinsville, Sates, Micke, or Ellis—and proceed to runway 31R. Missed approaches were basically vectored along the dashed flight path emanating from runway 31R for holding; however, before reaching the holding fix, missed approaches were normally vectored for a second approach before crossing the Robbinsville route. CTOL traffic clearances and controller procedures were in accordance with the New York Common IFR Room (CIFRR) procedures as of April 1978. It should be pointed out, however, that, because of limitations of the simulation capabilities, only two controller positions—an approach and a final-control position—could be used. Hence only a portion of the approach procedures was simulated. Specifically, the approach controller handled all the fixed-wing arrivals from Robbinsville and Sates. He also handled all helicopter traffic from the feeder fix to the helipad. The final controller handled arrivals from Micke and Ellis; he was also responsible for all fixed-wing landings on runway 31R. Because of display limitations, no departure traffic, which uses runway 31L in this configuration, was simulated.

One of the helicopter routes, denoted as COP, is shown in Fig. 3. It is a RNAV route leading to a 2-n.mi. straight-in final approach that was flown as a 6-deg MLS approach. The feasibility of using a 6-deg approach had been established in an earlier study in which MLS landings were conducted for a range of glide slopes up to 9 deg (Ref. 8). The helipad was located at what is presently a parking area at JFK; however, the site was selected by New York CIFRR, JFK tower personnel, and FAA Eastern Region personnel as a reasonable location for a helipad. In view of the control tower, it allows for a helicopter route design that is noninterfering with fixed-wing traffic flows, except for missed approaches that require some controller action. The pad location also results in reasonably noninterfering helicopter routes when other fixed-wing runway configurations are in use, although other landing configurations were not examined in this real-time study. The COP route connects into the RNAV helicopter route network designed for the Northeast Corridor.[9]

Variables in this configuration were the arrival rates at the feeder fixes for the CTOL and helicopter traffic. CTOL arrivals varied from a moderate rate of 30 aircraft/h to a heavy rate of 35 aircraft/h. The percentages of arrival aircraft at each of the feeders and the distribution of CTOL types were based on JFK data. Helicopter traffic was light to moderate: 8-15 helicopters/h.

There were other aspects of helicopter operations at major terminal areas that could not be investigated with the CTOL and helicopter route configuration described previously because of the limited number of controller positions.

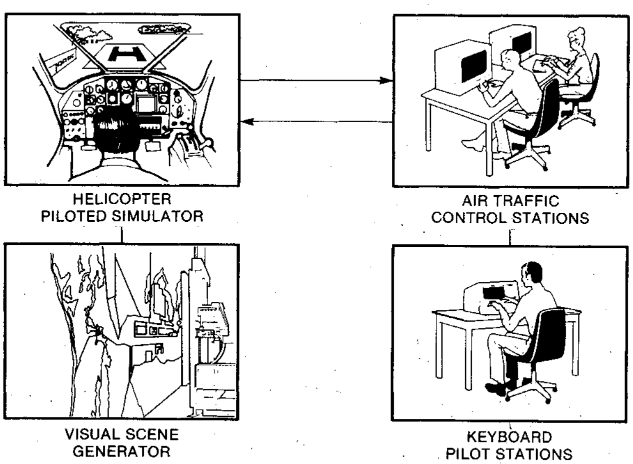

Fig. 1 Simulation facility.

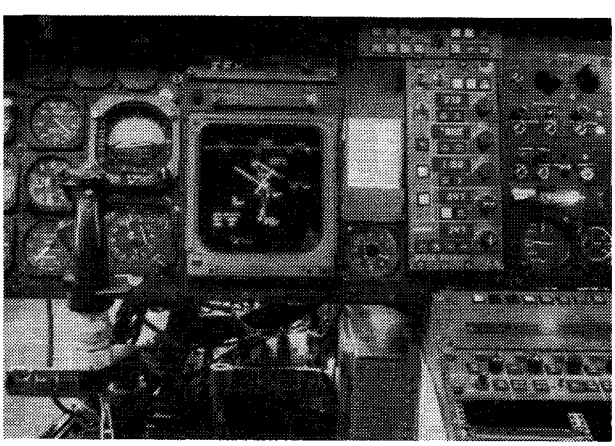

Fig. 2 Piloted simulator instrumentation panel.

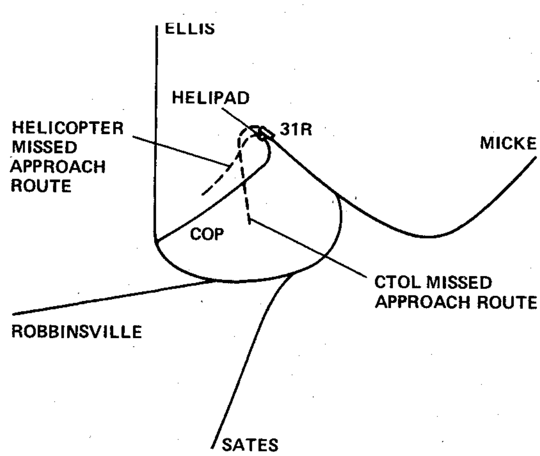

Fig. 3 CTOL and helicopter route structure.

Specifically, these aspects were 1) higher helicopter arrival rates; 2) merging of traffic from two separate helicopter routes; and 3) reduced minimum-separation-distance requirements between helicopters. Operations under these conditions increased the controller workload to the point that it was not possible with only two controller workload to the point that it was not possible with only two controller positions to investigate these problems and handle CTOL traffic simultaneously. Accordingly, a second route structure for helicopters only was investigated; it is shown in Fig. 4. Neither the helicopter route denoted COP nor the missed-approach routes were changed. A new helicopter arrival route denoted LEE, which is symmetrical to the COP route, was added. For this configuration, each of the two controllers was responsible for one route. The controllers coordinated their spacing to avoid conflict at the 2-n.mi. fix. An arrival rate of 35 helicopters/h was equally distributed between the COP and LEE routes. Separation distances of 3 and 1.5 n.mi. were investigated.

Four levels of display capability were evaluated in the helicopter simulations: 1) basic instrumentation only; 2) basic instrumentation with an electronic area-map display; 3) basic instrumentation with a CDTI in the passive mode; and 4) basic display with a CDTI in the active mode. Although the actual display used is the same for the active as well as the passive CDTI modes, the modes are considered different because the pilot procedures are different. The MFD was used for the area-map and CDTI displays. In the area-map mode, the MFD provided a digital display of the airspeed, altitude, and heading of the helicopter and included a symbol representing the position of the helicopter as well as its trend vector. The RNAV route structure, waypoints, MLS final-approach geometry, and significant terrain features were also depicted.

In addition to this information, the CDTI display indicated the relative position, altitude, heading, and groundspeed of aircraft in close proximity to the helicopter. A typical CDTI display used by the simulated helicopter is shown in Fig. 5. The helicopter-simulator position is in the lower center of the screen as shown. The dashed lines emanating from the aircraft symbol are trend-predictor lines; the dots are past-history information. It can be seen from the figure that the helicopter is on the COP route and has just passed the COP 2 waypoint. The present heading of 32 deg is provided at the top center of the display. The present altitude of 1200 ft is shown at the top right, and the present speed of 95 knots is shown at the top left of the display. The sample display shows three other aircraft: one aircraft (denoted P1) is following the helicopter simulator along the COP route; the other two (identified as A1 and E1) are conventional aircraft heading for landing on runway 31R. The triangular symbol provides aircraft position information (actual position is in the center of the triangle); the heading is indicated by the symbol orientation. Below the aircraft identification are the speed listed in knots and the altitude in feet, e.g., aircraft A1 is flying at a speed of 180 knots at an altitude of 500 ft. Up to three aircraft were displayed, provided they were within 10 n.mi. and 2000 ft of the simulator cab position.

In the passive CDTI mode, the pilot monitored the position of adjacent aircraft and was expected to report any irregularities to ATC rather than initiate any corrective actions on his own. In the active mode, operational procedures were established between the controller and the helicopter pilot to transfer control to the pilot to perform certain maneuvers. These maneuvers, illustrated in Fig. 6, are intrail spacing and merging. In each of these maneuvers, the helicopter pilot was instructed to fly the helicopter no closer than 3 n.mi. from adjacent aircraft. In the intrail-spacing maneuver, the controller first verified that the pilot had the lead aircraft in sight on his CDTI and then cleared the helicopter via the COP route to follow the lead aircraft. The pilot was responsible for maintaining the separation distance from the lead aircraft, and the controller was responsible for maintaining the appropriate separation distance from other aircraft. At the beginning of the merging maneuver, the helicopter simulator was on the helicopter missed-approach route. After being cleared, it was the responsibility of the helicopter pilot to proceed from the missed-approach route and merge onto the COP route behind the assigned helicopter. The controller was responsible for the appropriate spacing of the trailing helicopter traffic.

Twenty-eight data runs were made, each 70 min long (4 runs/day). Twenty runs utilized the CTOL/helicopter route structure shown in Fig. 3; the remaining eight involved the helicopter-only route structure shown in Fig. 4. During a 70-min run, the helicopter simulator typically flew three approaches. The controller subjects were FAA research controllers from the FAA Technical Center. Nine helicopter pilots, representing the FAA, NASA, and various industrial organizations, conducted 127 approaches in the piloted helicopter simulator. Pilots made evaluations at the end of each flight and also at the completion of all their flights. Controllers completed a questionnaire after each 70-min run and a final questionnaire at the conclusion of the study. The major results will now be described. Further details can be found in Ref. 10.

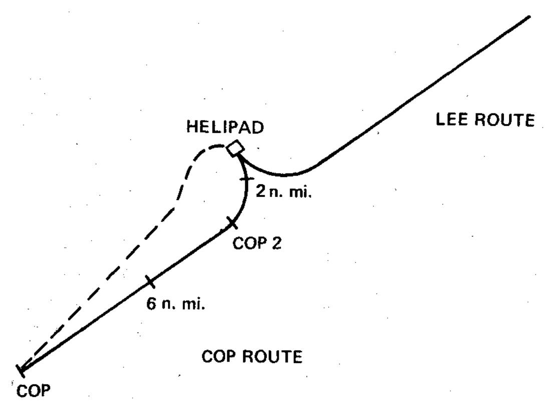

Fig. 4 Route structure for helicopters only.

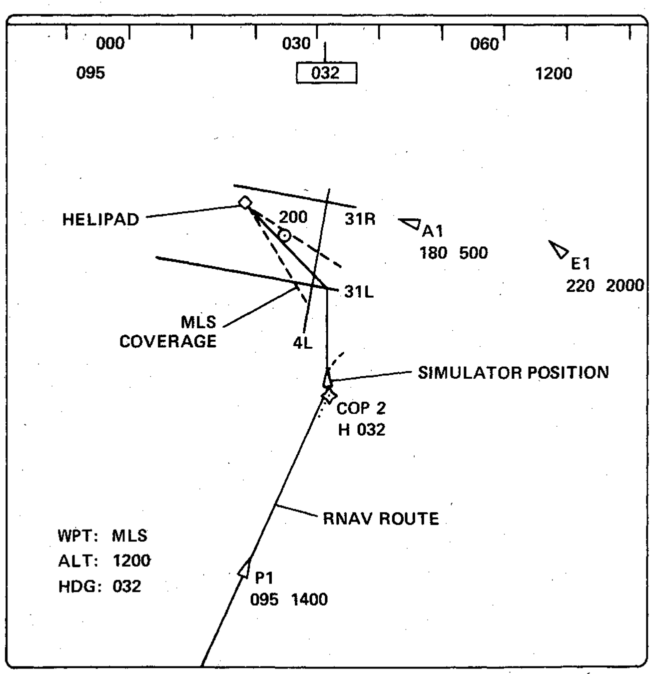

Fig. 5 Typical helicopter-simulator CDTI display.

Pilot Acceptance and Tracking Accuracy

Pilot Evaluations of Approach Procedures

On the postflight questionnaire, the evaluation pilots were asked to rate the overall pilot workload for the RNAV, the MLS approach, and the missed-approach phases of the test runs by using a rating scale that ranged from "low" to "high," as shown in Fig. 7. Workload comparisons are with respect to operations with basic instrumentation only. The ratings are in comparison with standard-approach and missed-approach procedures. The mean and standard deviations of the responses are indicated in the figure. Pilot responses indicated a "slightly low" overall pilot workload for the RNAV phase and a "slightly high" overall pilot workload for the MLS final approach and missed approach procedures.

The pilots were also asked to indicate the effect of the map and CDTI displays on pilot workload for the RNAV, MLS final-approach, and missed-approach procedures by using the rating scale of: reduced pilot workload, no effect, or increased pilot workload. Pilot responses with regard to the effect of the advanced displays on pilot workload for the RNAV segment were evenly distributed with an equal number of responses for "reduced" and "increased" workload. Half of the pilots responded that the advanced displays had "no effect" on pilot workload during the MLS final approach while the remaining pilots indicated fairly evenly mixed responses with a slight bias toward the rating of "increased" workload. Six pilots indicated that the advanced displays reduced pilot workload during the missed approach because of improved situational awareness. One pilot indicated that the displays had "no effect," and one pilot indicated that the displays "increased" pilot workload during the missed approach. Pilot comments accompanying the ratings of "increased" workload indicated that the higher workload resulted from the increased scan required to cross check the advanced displays. Several pilots indicated that the pilot workload on the MLS final approaches was fairly high, and, therefore, the pilots had little time to scan the advanced displays during this segment.

In general, pilot comments concerning the advanced displays were very favorable. The pilots indicated that they preferred having the additional information available, despite a slight increase in pilot workload.

The evaluation pilots were asked to comment on the approach-profile parameters used in the simulation. The pilot responses indicated that the approach was reasonable. All the pilots rated the 6-deg glide slope and the 200-ft decision height acceptable. The pilots liked the 6-deg glide slope and had no trouble decelerating to a hover from the 200-ft decision height.

Airspace limitations at the landing site evaluated during this simulation required the transition from RNAV to MLS navigation to take place very close to the helipad (2 n.mi.). Altitude restrictions further complicated the approach profile and resulted in a glide-slope intercept within 0.1 n.mi. of MLS localizer capture (Fig. 8). Seven pilots considered the transition from RNAV to MLS satisfactory; one pilot suggested that the transition should be farther away from the helipad to allow more time for localizer capture prior to glide-slope intercept. Three pilots indicated that there was insufficient time to establish localizer tracking prior to glide-slope intercept, and they recommended a minimum distance of 0.5-1 n.mi. between localizer capture and glide-slope intercept. The other five pilots considered the distance between localizer capture and glide-slope intercept to be satisfactory, even though most of the pilots experienced an almost simultaneous localizer and glide-slope capture when they turned onto final approach too early and intercepted MLS closer in. The pilots who considered the intercept distance to be satisfactory indicated that, with training and advanced preparation, the maneuver could be satisfactorily accomplished. It should be noted that navigational errors were not simulated in these tests and could have a significant effect on the acceptability of transitioning the MLS so close to the helipad.

The missed-approach procedure was a source of some difficulty for some of the pilots because of the airspace and helipad site limitations in the terminal area simulated. The helipad was located in close proximity to an active runway (31R). Furthermore, the final-approach course of the helicopter was directed toward the active runway (Fig. 8). Thus the approach geometry for the helicopter during a missed approach required an immediate climbing left turn to avoid overflying the active runway. The proximity of fixed-wing route structures in the immediate missed-approach area further required that the climb during the missed approach be arrested at 500 ft. Although these missed-approach procedures were successfully conducted by all of the pilots, the procedures presented problems for some of them. Some pilots tended to initiate their climb while continuing straight ahead and then roll left to avoid the active runway. One pilot stated that it was difficult for him to execute an immediate climbing left turn at missed approach because "it went against most of my basic training"; one unsuccessful missed-approach procedure resulted in an overflight of the active runway because of a straight-ahead climb before the pilot executed the turn. Several pilots commented on the low altitude of the missed-approach procedure; they found it difficult to arrest their climb at 500 ft and would have preferred to continue the climb to a higher altitude. Even though the procedure was not considered ideal, the pilots

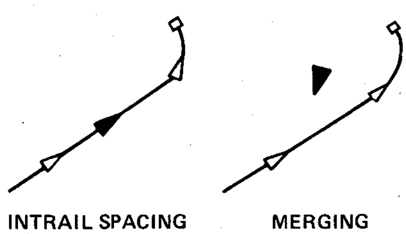

Fig. 6 CDTI maneuvers: active mode.

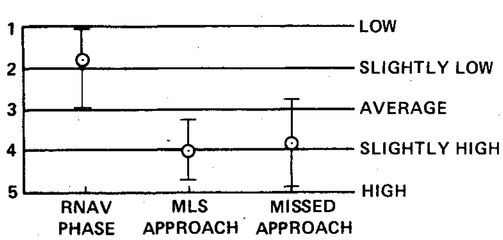

Fig. 7 Overall pilot-workload rating.

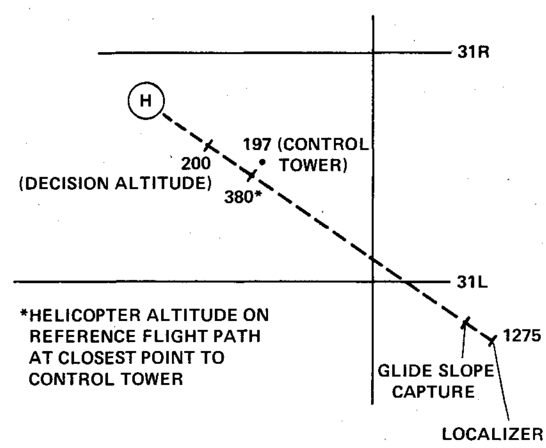

Fig. 8 Helicopter route and CTOL runway configuration.

indicated a willingness to conduct this maneuver if it improves rotorcraft instrument approaches in high-density terminal environments.

Tracking Performance

A lateral composite plot of individual approaches for the map-only mode is shown in Fig. 9. Similar composite plots were generated for the other test modes. The dotted lines on either side of the reference flight path represent the full-scale course deviation indicator (CDI) limits. The constant width of the CDI limits along the RNAV portion of the approach corresponds to the constant lateral course width (±2000 ft) provided by the CDI during the RNAV approach segment. The angular dotted fan emanating from between the runways in the terminal area corresponds to the angular MLS course width (±5.0 deg) provided by the CDI during the MLS final approach. Thus relative tracking performance can be obtained graphically by comparing the composite tracking data with the full-scale display limits, as shown by the dotted lines for both the RNAV and final-approach segments. As can be seen from the composite plot, the lateral tracking performance is good. It should be noted that the data do not include navigation error and, therefore, the plots do not represent airspace requirements.

A vertical composite plot of individual approaches for the map-only mode is shown in Fig. 10. The dotted lines on either side of the reference flight path represent the full-scale vertical deviation indicator (VDI) limits. The constant width of the VDI limits along the RNAV portion of the approach corresponds to the full-scale vertical display limits (±500 ft) provided by the VDI during the RNAV approach segment. The angular dotted fan emanating from the reference touchdown point corresponds to the angular MLS course width (±2.0 deg) provided by the VDI during the MLS final approach. Thus relative tracking performance can be obtained graphically for the MLS final-approach data by comparing the composite tracking data with the full-scale display limits, as shown by the dotted lines for the MLS final approach. The vertical tracking performance data for the RNAV approach segment are not easily evaluated, however, as pilots were given the option of either following the VDI guidance between waypoints or descending directly to the next waypoint reference altitude. In any case, the RNAV tracking workload was considered to be relatively light, and the RNAV VDI vertical displacement limits were sufficiently wide that vertical tracking performance would easily fall within the limits of the display sensitivity.

Statistical data from the lateral crosstrack errors and vertical deviation errors at key waypoints along the route were also computed. Details can be found in Ref. 10.

ATC Procedures

Handling Helicopter Traffic in Addition to Conventional Traffic

Observations and Controller Evaluations

Qualitative data were obtained from controller written evaluations and by observing the controller activity during the course of the experiment.

The rates of arrival were investigated for both helicopter and CTOL traffic. The CTOL rates were 30 and 35 aircraft/h. It should be noted that this rate refers to the arrival rate at the four CTOL feeder fixes combined, and it is not necessarily the touchdown rate. Controllers considered the CTOL arrival rate of 35 aircraft/h to be less desirable than the arrival rate of 30 aircraft/h.§ Their evaluations were based on safety, expeditiousness, orderliness, total workload, stressfulness, frustration, and the individual workload categories of manual, visual, mental, and verbal. In going from the CTOL arrival rate of 30-35 aircraft/h, the controllers were required to give a full set of vector clearances to five additional aircraft. Also, 30 aircraft/h represented a moderate flow, whereas 35 aircraft/h was a heavy arrival rate for the scenario chosen and the number of controllers available. The two levels of helicopter traffic were 8 and 15 helicopters/h. However, except for stressfulness (the 15-helicopters/h rate was rated more stressful); the two helicopter arrival rates were rated the same. Both rates (8 and 15 helicopters/h) are in the low-to-moderate range; therefore, even at the higher rate, it was not necessary for the controllers to perform a spacing function, since helicopters were nominally spaced upon arrival and the arrival rates did not require a fine tuning. The primary reason that the additional helicopter traffic did not overload the controller was that each helicopter was on an RNAV and MLS approach and, therefore, vectoring was generally not required. It is interesting to note that, in an earlier helicopter IFR study[11] not utilizing RNAV and MLS, the conclusion was that, at arrival rates 2-4 helicopters/h, the same controller could handle helicopter and fixed-wing traffic, but at arrival rates of 5-15 helicopters/h, use of separate controller positions was recomended. In this RNAV-MLS experiment, the controller merely cleared the aircraft for an MLS 6-deg glide-slope approach via the COP route. Additional clearances were the exception, not the rule.

Thus the controllers felt that they could handle the helicopter traffic in addition to the conventional traffic at either helicopter arrival rate as long as no special problems developed. However, if a CTOL aircraft executed a missed approach with helicopter traffic flying along the COP route, inadequate spacing resulted unless the controller intervened. Generally, the controllers did not disturb the helicopter traffic in such situations. Instead, the missed-approach aircraft was assigned a higher (conflict-free) altitude and/or was directed around the helicopter traffic.

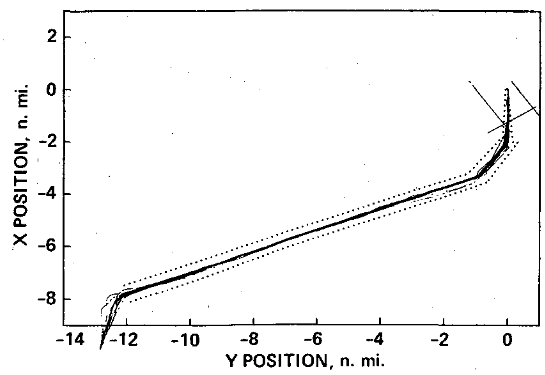

Fig. 9 Lateral tracking performance: map only.

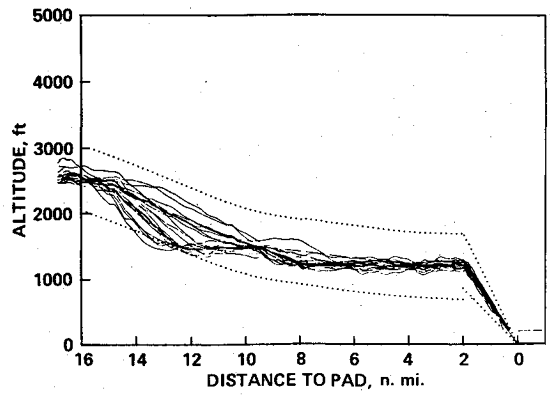

Fig. 10 Vertical tracking performance: map only.

§It should be noted that all runs discussed in this section had both helicopter and fixed-wing traffic. Thus, during operations at 30 and 35 aircraft/h, there was also 8-helicopters/h traffic. Similarly, during the 8- and 15-helicopters/h operations there was also 35-aircraft/h fixed-wing traffic. The helicopters-only runs are not discussed in this section.

Airspace Usage

In order to investigate the extent to which the helicopter traffic interferes with the conventional routes, a series of composite plots of airspace usage were drawn. Figure 11 is a composite plot for all runs for which the CTOL arrival rate was 35 aircraft/h and the helicopter arrival rate was 8 helicopters/h. It was obtained as follows: For each aircraft, an *x-y* plot was drawn. The individual *x-y* plot shows the trajectory that the CTOL aircraft followed from feeder-fix entry until touchdown on the runway. (It should be noted that missed approaches have been excluded from these plots. As mentioned when discussing controller comments, the point at which interference might have occurred without controller intervention was when a CTOL executed a missed approach and had to cross the COP route. This interference was easily avoided by the controller.) Figure 11 represents the envelope for all the individual *x-y* plots for this CTOL arrival rate. Hence, the enclosed area is the total airspace required for all the CTOL aircraft from feeder-fix entry to touchdown. Also shown on this composite plot is the airspace used for the helicopter route, COP. As can be seen, for the helicopter traffic there is minimal deviation from the RNAV and MLS routes. There is a region where CTOL and helicopter horizontal paths overlap, but in this case there is a vertical separation of at least 3000 ft between the helicopter and the CTOL aircraft paths. Thus the nominal helicopter route is independent and noninterfering with the airspace required by the CTOL traffic for this test condition. Similar composites were obtained for the other test conditions.[10] Even though the higher arrival rates (35 aircraft/h) represented additional aircraft for the controllers to handle, they did not result in a widening of the airspace required. Controllers were able to process these aircraft, and their comments indicated that, even though they felt the pressures of the extra traffic, the extra traffic did not result in a need to stretch the aircraft paths or intrude into the helicopter airspace.

Reducing Minimum Separation for Helicopters

As previously discussed, a dual-helicopter route structure, shown in Fig. 4, was used to investigate minimum separation for helicopter traffic. The combined arrival rate at the feeder fixes was 35 helicopters/h, randomly distributed equally between the two fixes. Two minimum separation distances were used: the standard 3 n.mi. and a reduced separation of 1.5 n.mi. No CTOL traffic was considered.

The controllers rated the 1.5-n.mi. traffic spacing consistently less desirable in terms of safety, expeditiousness, orderliness, total workload, stressfulness, frustration, and manual, visual, mental, and verbal workload. Basically, it was a more difficult task to control the greater number of helicopters that resulted from the 1.5-n.mi. separation. The most difficult aspect of the spacing control seems to be the process of properly spacing the helicopter intrail so as to achieve the minimum spacing on final approach. At the completion of these test runs, the controllers were still not comfortable with the 1.5-n.mi. separation. Their evaluations indicated that, with appropriate training, a 2-n.mi. minimum spacing would probably be acceptable.

Five of the evaluation pilots felt that they could handle a reduced separation distance when flying at 60 knots on a 6-deg glide-slope approach (see Fig. 12). Based on responses to a question concerning recommended spacings behind specific helicopters, the recommended minimum spacings ranged from 1 to 2 n.mi. Two pilots felt that there were too many variables and unknowns (e.g., wake turbulence) to make any recommendations. The remaining pilot recommended a minimum 3-n.mi. separation when behind light to medium helicopters and a 4-n.mi. separation when behind heavy helicopters.

A comparison of operations with 1.5- and 3-n.mi. spacing is given in Table 1. The average time in the system along the COP and LEE routes (the time from feeder-fix departure until touchdown), the halt time (the total time per run in minutes and seconds that the arrival flow had to be delayed before departing from the feeder fix), and the total number of ATC-transmitted clearances per run (e.g., heading, speed, altitude, and cleared for approach) are compared in the table. At the given arrival rate of 35 helicopters/h, there were more feeder-fix arrivals than the controllers could handle. The controllers were instructed to halt the arriving helicopters at the feeder fix rather than handle the extra aircraft by various path-stretching maneuvers. The results in Table 1 indicate that a significant benefit is gained when the 1.5-n.mi. minimum separation is used under these test conditions. First, the average times in the system along either the COP or the LEE route indicate less delay within the system when the separation was lower. It should be noted that these delays occurred after feeder-fix departure rather than at the feeder fixes because the need to halt traffic was recognized only after there had been some traffic buildup. The controllers' ability to anticipate this buildup did improve as the experiment progressed. Another benefit gained by using the 1.5-n.mi. minimum separation was that, at the 3-n.mi. separation, the arrival-traffic flow had to be stopped for 22.68 min in a 70-min run, which was 15.3 min more than when the minimum separation was 1.5 n.mi. The system delays and feeder-fix delays result in a much larger fuel usage for the 3-n.mi. case. However, the controller workload is increased in the 1.5-n.mi. case, as evidenced by the total number of clearances per run in Table 1 and by the

Table 1 Dual helicopter routes

Distance separation, n.mi.	Average time on system, min:s COP	LEE	Total halt time, min:s	Total clearances/run (speed, altitude, heading, cleared for approach)
1.5	12:17	11:54	7:23	127
3	13:58	12:28	22:41	105
Difference	1:41	:34	15:18	22

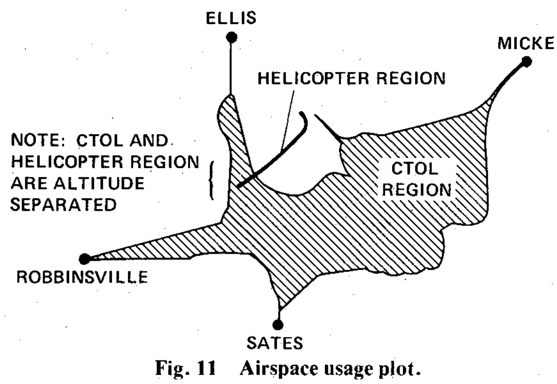

Fig. 11 Airspace usage plot.

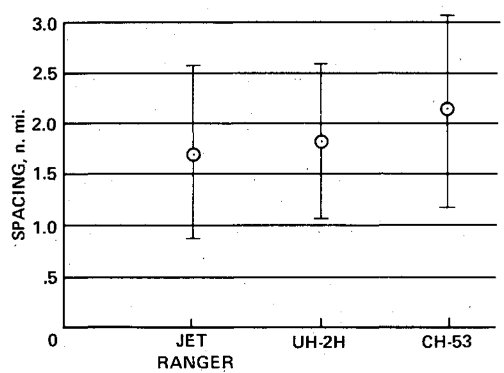

Fig. 12 Closest acceptable spacing.

controller evaluations discussed earlier. Hence there are distinct fuel advantages to lowering the minimum separation, but at the same time it leads to additional workload. However, as previously indicated, the controllers felt that, for a 2-n.mi. minimum separation, the extra workload could be accomplished without compromising safety. Thus, since it appears that safety is not compromised and that delays can be decreased under heavy traffic conditions, a lower-minimum-separation distance for helicopters should be considered.

Utility of CDTI

In order to get initial data for future studies, some runs were made to investigate various active CDTI maneuvers. Finding a useful active CDTI role that enhances safety is an open question. Such a role, if found, must show increased safety compared with a nonactive role. As previously mentioned, intrail-spacing and merging maneuvers were evaluated. Since the number of runs was limited, no definitive conclusions are drawn. However, pilot and controller comments were considered, and some quantitative data are presented.

As previously noted, three aircraft would be displayed on the CDTI if they were within a horizontal distance of 10 n.mi. and a vertical distance of 2000 ft. Six pilots recommended that "no change" be made to the three-aircraft advisory limit or to the dimensions of the advisory airspace. Two pilots indicated that they would like to see more than three aircraft, and one pilot indicated that he would like to see "as many as required" to protect the "safe" advisory area, which he recommended to be "5-n.mi. range and 2000-ft altitude." Another pilot recommended changing the vertical advisory altitude to "within 500 ft," as opposed to the 2000-ft test condition.

Five pilots indicated that they found the CDTI display format "easy to read, and useful for traffic separation." One of these pilots commented that the display became "difficult to read, but useful for traffic separation" when it was superimposed on waypoint information. Two other pilots rated the display as "difficult to read, but useful for traffic separation," while the remaining pilot rated it as "difficult to read, and not useful for traffic separation." The latter pilot did indicate, however, that "with more use, it could have been more effective."

Four pilots indicated that they would like to see trend vectors for the advisory aircraft. One pilot commented on the desirability of adding a proximity-warning device that monitors the closure rate of other aircraft and provides advance warning for potential midair-collision situations. Another pilot suggested the use of "degree of threat symbols" for the aircraft advisories.

In general, the evaluation-pilot comments indicated acceptance of the CDTI in the active and the passive modes. One pilot commented that the CDTI would also be very useful during Visual Flight Rules (VFR) procedures because it provided a clear indication of the proximity of adjacent aircraft. Several pilots indicated that the display would be a great asset in collision-avoidance advisories. On two different occasions, pilots conducting CDTI approaches in the passive mode noticed that potentially dangerous closing situations were developing and contacted the ATC controller for assistance.

Pilot comments regarding the CDTI display format used in this experiment were very favorable. The display provided the pilots with a clear indication of their position during the approach and the relative positions of adjacent aircraft. The display did appear cluttered, however, when the aircraft symbols overwrote the navigation or terrain symbols (i.e., RNAV waypoints, terminal area information, etc.). Masking, or a "moving shadow," which moves with the aircraft symbols to temporarily block out the display areas being overwritten, would eliminate this problem. Varying the display intensity and/or using color displays might also help reduce the magnitude of this problem.

For the passive CDTI mode, controllers did not notice any difference in pilot behavior as compared with pilot behavior during runs without CDTI, except for queries to verify the position of nearby aircraft.

In the active mode, when the pilots assumed some responsibility for separation normally performed by the controllers, the controllers were mixed in their reactions to the use of CDTI. One controller felt that CDTI was advantageous in maintaining separation. Another felt that CDTI would result in an increased workload and a more difficult job because of "second guessing" by the pilots. The controllers closely observed the simulated helicopters on their screens. They rated the pilot performance of the active CDTI roles as follows: intrail spacing—good, and merging—fair to good.

The active CDTI maneuvers were conducted on or near the COP route. For the intrail-following maneuver, a lead helicopter was first established on the COP route. Soon after the piloted helicopter simulator departed from the feeder fix, the controller contacted the pilot to verify that he had the lead aircraft in sight. The pilot was then cleared to follow the lead aircraft and to maintain the appropriate separation distance. It was the responsibility of the controller to handle the aircraft that followed. Figure 13 shows the helicopter simulator on the COP route with a lead aircraft denoted L1 and a following aircraft denoted F1. Also shown are two typical plots of the separation distance as a function of time. The upper plot is the separation distance between the helicopter simulator and aircraft L1. It should be noted that the distance plotted is the horizontal separation distance between helicopters rather than

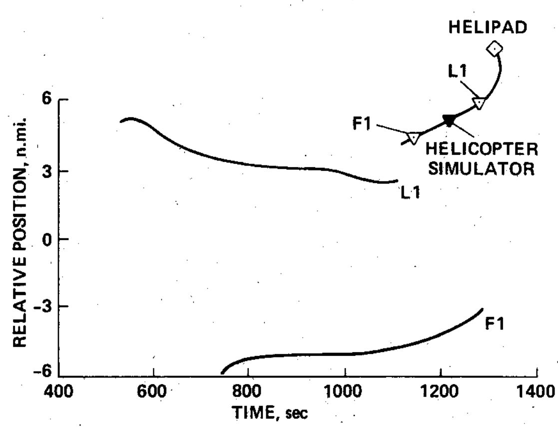

Fig. 13 Separation distance for intrail-spacing maneuver.

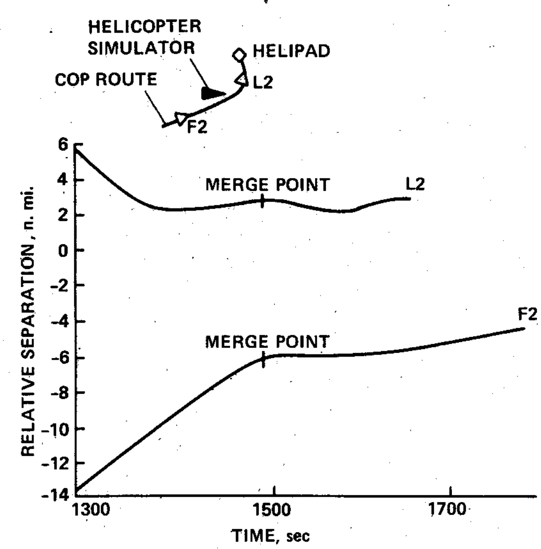

Fig. 14 Separation distance for merging maneuver.

the distance along the route. The plot shows that when the helicopter simulator departed from the feeder fix it was about 5 n.mi. from aircraft L1, and the pilot gradually decreased this distance to a little less than 3 n.mi. by the time the lead aircraft landed. The lower plot is the separation distance between aircraft F1 and the helicopter simulator. (It is plotted for negative values in order to avoid overlap with the upper curve.) The initial separation was about 6 n.mi. when F1 departed from the feeder fix, and the controller decreased this distance to 3 n.mi. by the time the helicopter simulator reached the landing pad. This procedure was followed 11 times in the simulation, and the average minimum-separation distance between the helicopter simulator and the lead aircraft was 2.86 n.mi. The minimum-separation distance ranged from 2.41 to 3.03 n.mi. It should be noted that the only indicator of separation distances was visual observation of helicopter positions displayed on the CDTI.

The second maneuver accomplished using the CDTI was the merge. Figure 14 shows the helicopter simulator flying along the missed-approach route with two aircraft flying along the COP route. These helicopters are denoted L2 for the lead aircraft and F2 for the following aircraft. After a controller clearance, it was the helicopter pilot's responsibility to merge back onto the COP route behind aircraft L2. The figure shows the separation distances as functions of time for the helicopter simulator and L2 and F2. The separation distance between the helicopter simulator and L2 reaches a minimum of 2.20 n.mi., which is typical of the average of 2.26 n.mi. for 13 such runs. This separation distance is lower than the desired minimum separation of 3 n.mi. Part of the reason for the consistently lower separation distance is that merging is a more difficult maneuver to perform than intrail spacing. It is obviously a demanding task to judge what the final separation distance will be after a curved flight path is flown. It would probably be helpful to the pilot to provide some kind of range markings on the CDTI so that he might better gage his separation distance. Obviously, additional studies are required under various geometries, relative speeds, CDTI data displays, etc., before definitive conclusions can be drawn.

Conclusions

Pilots gave satisfactory ratings to the helicopter approaches. They preferred the increased display capability of the MFD, despite some increase in workload necessary to monitor the display.

Because all helicopters were RNAV and MLS equipped and consequently followed the assigned route closely, the controllers could handle moderate helicopter traffic (15 helicopters/h) in addition to their fixed-wing traffic load.

Precise RNAV approaches for helicopters in unused airspace provide the means for operating fixed-wing and helicopter traffic in an efficient, noninteracting manner at major terminal areas.

Pilots and controllers recommended a reduced minimum separation for helicopter operations, although it was noted that closer spacing increases controller workload. Under saturated conditions, delays can be reduced considerably by reducing the separation minima.

Finally, the initial examination of CDTI with both pilots and controllers participating indicated good performance for intrail-spacing and merging maneuvers. The study also revealed the complexity of the problem of sharing control of some aircraft between the pilot and the controller while retaining control by the controller for others, within the same airspace. With the limited data taken, some trends are discernible, but definitive conclusions cannot be drawn. In view of the apparent potential of CDTI, further experiments involving *both* pilots and controllers are recommended. The key point is that although the CDTI is a cockpit development, the *use* of CDTI by some pilots in a terminal area is a *shared* responsibility between pilot and controller.

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Because of the recent move of AIAA Headquarters to 1633 Broadway, New York, N.Y. 10019, journal issues have unavoidably fallen behind schedule. The Production Department at the new address was still under construction at the time of the move, and typesetting had to be suspended temporarily. It will be several months before schedules return to normal. In the meanwhile, the Publications Staff requests your patience if your issues arrive three to four weeks late.