NASA Technical Memorandum 81301

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(NASA-TM-81301) ATC SIMULATION OF HELICOPTER IFR APPROACHES INTO MAJOR TERMINAL AREAS USING RNAV, MLS, AND CDTI (NASA) 55 p HC A04/MF A01 CSCL 01C

N81-27061

G3/03 Unclas 26852

April 1981

National Aeronautics and
Space Administration

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Moffett Field, California 94035

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ATC SIMULATION OF HELICOPTER IFR APPROACHES INTO MAJOR TERMINAL AREAS USING RNAV, MLS, AND CDTI

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SUMMARY

The introduction of independent helicopter IFR routes at hub airports has been investigated in a real-time air traffic control system simulation involving a piloted helicopter simulator, computer-generated air traffic, and air traffic controllers. The helicopter simulator was equipped to fly area navigation (RNAV) routes and Microwave Landing System (MLS) approaches. 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 in the hub airport environment. Results indicate that the helicopter routes were acceptable to the subject pilots 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 the acceptability of the CDTI procedures.

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 differences 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 ATC system is to handle the anticipated growth of helicopter operations in major terminals. According to current forecasts, the total U.S. civil helicopter fleet is expected to total some 20,000 by 1990 at an annual growth rate of 12 to 15% (ref. 1). Within this total, business/corporate helicopters will increase at an expected annual growth rate of 15 to 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 inefficiency of handling mixes of helicopter and fixed-wing aircraft on the same

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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 (ref. 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 nm to 1.5 nm; 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 (refs. 3 and 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 and thus it might be easier to accomplish spacing and merging operations from the cockpit. 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 National Aeronautics and Space Administration (NASA) Ames Research Center and the Federal Aviation Administration (FAA) Technical Center, Atlantic City, New Jersey. Previous study areas in the joint program have included fuel-conservative approaches, such as delayed flap and profile descents and time-controlled guidance (ref. 5).

This study was conducted in June 1980 at Ames by using a piloted helicopter simulator and an Air-Traffic-Control (ATC) simulation. FAA Technical Center personnel participated in the experiment design (ref. 6) 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 figure 1; it includes two air traffic controller positions, each having its own color computer graphics display. In this study, one 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 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 (fig. 2). The pilot's displays (fig. 3) 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 references 7 and 8. 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 six-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 or altimeter 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 figure 4. 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 flightpath 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 were simulated. Specifically, the approach controller handled all the

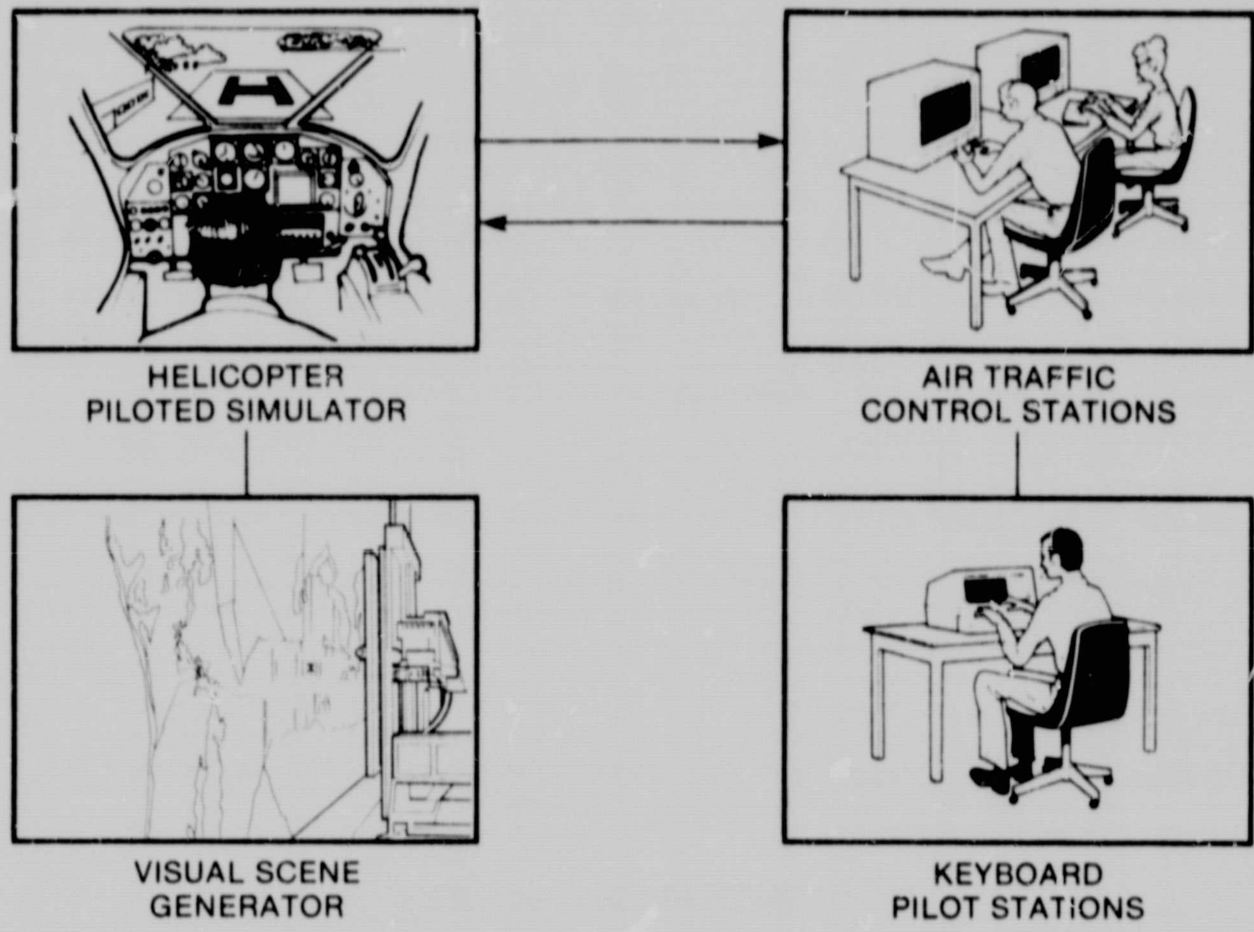


Figure 1.- Simulation facility.

Figure 2.- Photograph of helicopter simulator.

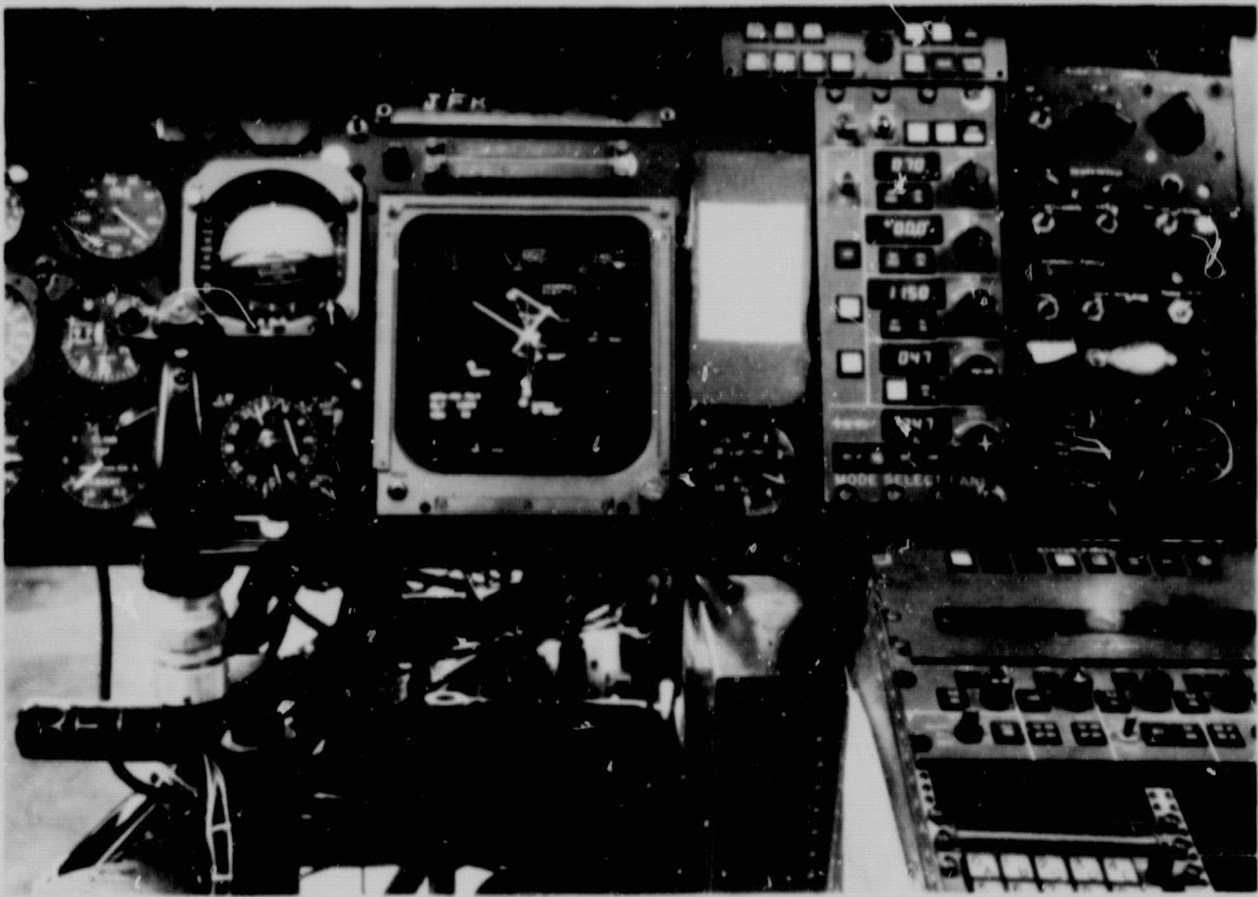


Figure 3.- Pilot displays.

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. Also, 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 figure 4. It is an RNAV route leading to a 2-nm straight-in final approach that was flown as a 6° MLS approach. The feasibility of using a 6° approach had been established in an earlier study in which MLS landings were conducted for a range of glide slopes up to 9° (ref. 9). 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 candidate 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 (ref. 10).

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 per hour (a/c/hr) to a heavy rate of 35 a/c/hr. 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 to 15 helicopters/hr.

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. 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 positions to investigate these areas and handle CTOL traffic simultaneously. Accordingly, a second route structure for helicopters only was also investigated; it is shown in figure 5. 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, and they coordinated their spacing to avoid conflict at the 2-nm fix. An arrival rate of 35 helicopters per hour was used, equally distributed between the COP and LEE routes. Separation distances of 3 nm and 1.5 nm were investigated.

Four levels of display capability were evaluated in the helicopter simulations: (1) basic display only; (2) basic display with an electronic area-map display; (3) basic display with a cockpit display of traffic information (CDTI) in the passive mode; and (4) basic display with a CDTI in the active mode. It

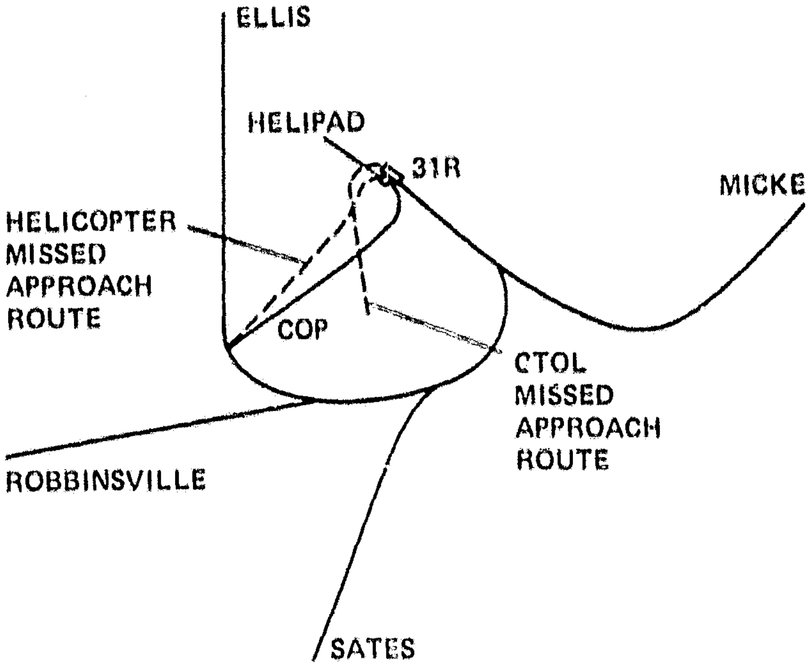


Figure 4.- CTOL and helicopter route structure.

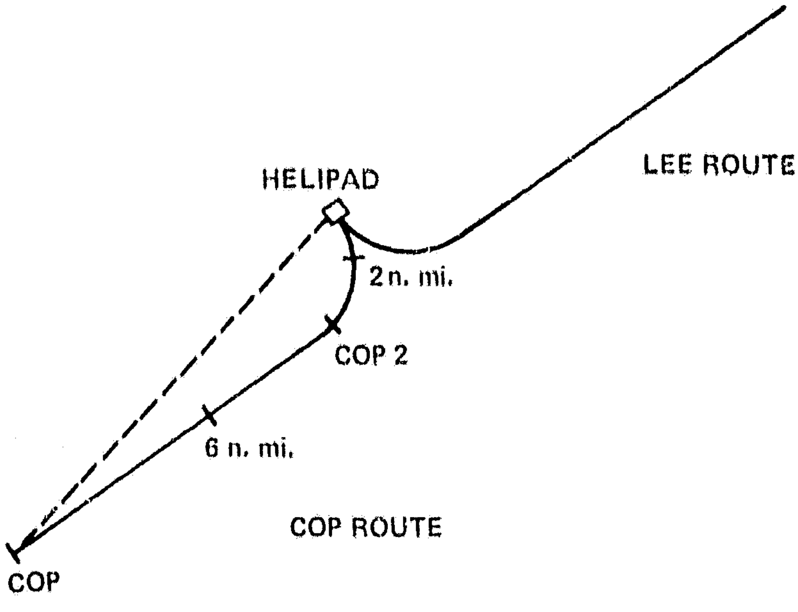


Figure 5.- Route structure for helicopters only.

should be noted that the actual display used for active and passive CDTI is the same; however, because pilot procedures differ for active and passive CDTI, they will be considered different modes. 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; ground track was superimposed on a horizontal, heading-up, moving map of the enroute and terminal areas. 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 figure 6. The surrounding traffic was superimposed on the "heading up" map display. 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° 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 (with identification tags A1 and E1), both of which are conventional aircraft, are heading for landing on runway 31R. (Up to three aircraft were displayed, provided they were within 10 nm and 2000 ft of the simulator cab position.) The triangular symbol provides aircraft-position information (actual position is in the center of the triangle), the heading being indicated by the symbol orientation. Below the aircraft identification is listed its speed in knots and its altitude in feet. Thus, for example, aircraft A1 is flying at a speed of 180 knots and an altitude of 500 ft.

The CDTI was used in both a passive and an active mode. In the passive mode, the pilot monitored the position of adjacent aircraft, and he was expected to report any irregularities to ATC rather than to 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 figure 7, are intrail spacing, merging, and route crossing. In each of these maneuvers, the helicopter pilot was instructed to fly the helicopter no closer than 3 nm from adjacent aircraft. In the intrail-spacing mode, the controller first verified that the pilot had the lead aircraft in sight on his CDTI, and then he cleared the helicopter via the COP route to follow the lead aircraft. In this case, 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 mode, 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.

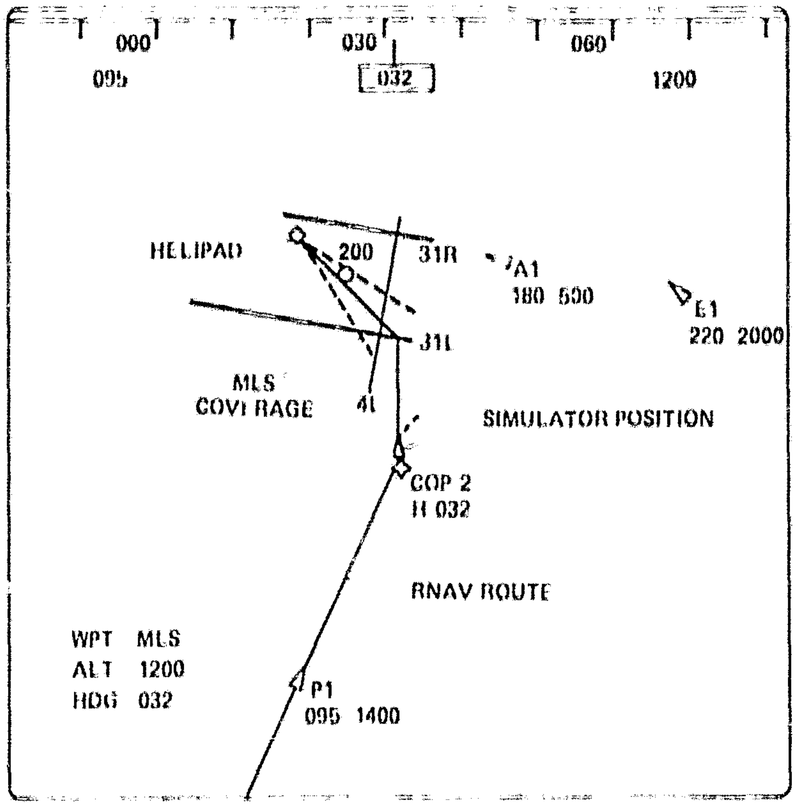


Figure 6.- Typical helicopter-simulator CDTI display.

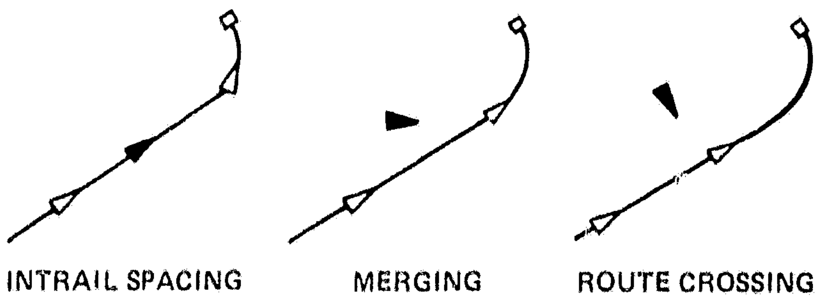


Figure 7.- CDTI maneuvers; active mode.

In a third maneuver, the route-crossing maneuver, the helicopter was vectored off the COP route and cleared to fly across the COP route between two helicopter targets, which the controller had positioned about 6 nm apart on the COP route.

Twenty-eight data runs were made, each 70 min long (4 runs/day). Twenty runs utilized the CTOL/helicopter-route structure shown in figure 4; the remaining eight involved only helicopter approaches. 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. Copies of the questionnaires are contained in appendixes A, B, and C.

RESULTS AND DISCUSSION

PILOT ACCEPTANCE OF APPROACH PROCEDURES AND TRACKING ACCURACY

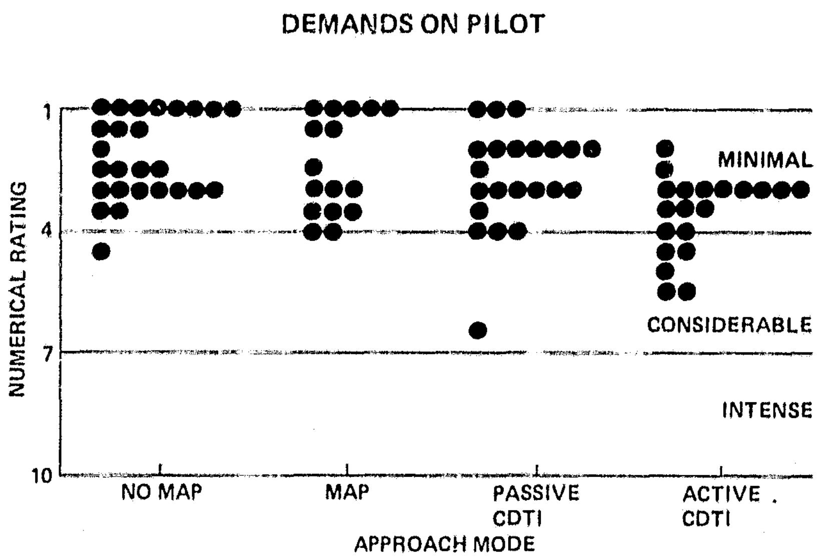
Pilot Evaluations of Approach Procedures

The evaluation pilots were asked to rate each approach at its conclusion by using the pilot rating scale shown in table 1. Numerical ratings from 1 to 10 were assigned to reflect the demands on the pilot and the adequacy of the associated system. The pilot ratings were plotted as functions of the four display configurations tested; results are shown in figure 8(a). The means and standard deviations of these ratings are shown in figure 8(b). It can be seen that the means for all four display configurations and the standard deviations for the No-Map, Map, and Passive-CDTI display modes fall within the range of "minimal" demands on the pilot, whereas the standard deviation for the Active CDTI display mode extends slightly into the range of "considerable" demands on the pilot. The mean ratings for the No-Map and Map display configurations are essentially equivalent. The mean rating for the Passive-CDTI mode is approximately one-half a pilot rating lower (numerically higher) and the mean rating for the Active CDTI mode is approximately one pilot rating lower than the mean ratings for the No-Map and Map modes. The slight decrease in pilot ratings for the CDTI modes reflects a slight increase in pilot scan workload in order to use the additional information being provided. However, the pilots commented that they prefer to have the additional information provided by the CDTI displays, despite the resultant higher workload, especially in high-density traffic environments.

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 figure 9. The ratings are in comparison to

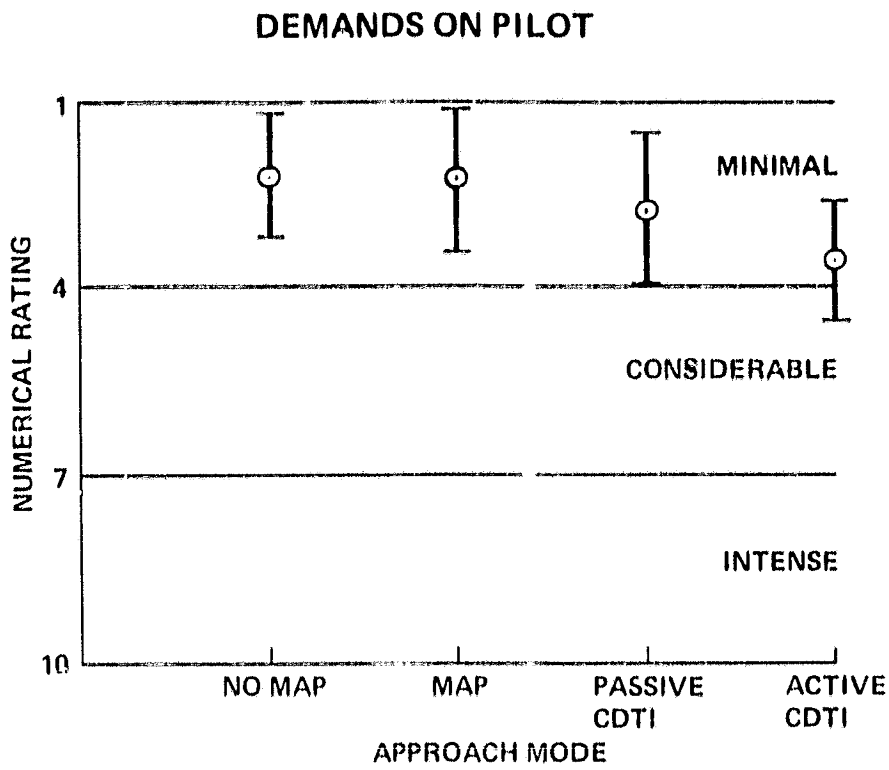
TABLE 1.- IFR PILOT RATING SCALE

SYSTEM ADEQUACY		DEMANDS ON PILOT	PILOT RATING	MISSION ACCOMPLISHED
NEGLIGIBLE DEFICIENCIES NO IMPROVEMENT NECESSARY	SATISFACTORY	MINIMAL	1	YES
			2	YES
			3	YES
MODERATELY OBJECTIONABLE DEFICIENCIES IMPROVEMENTS WARRANTED	UNSATISFACTORY	CONSIDERABLE	4	YES
			5	DOUBTFUL
			6	DOUBTFUL
MAJOR DEFICIENCIES IMPROVEMENTS REQUIRED	UNACCEPTABLE	INTENSE	7	NO
			8	NO
			9	NO
AIRCRAFT LOST		INDESCRIBABLY HIGH	10	NO



(a) Ratings as functions of display configurations.

Figure 8.- Pilot ratings.



(b) Means and standard deviations of ratings.

Figure 8.- Concluded.

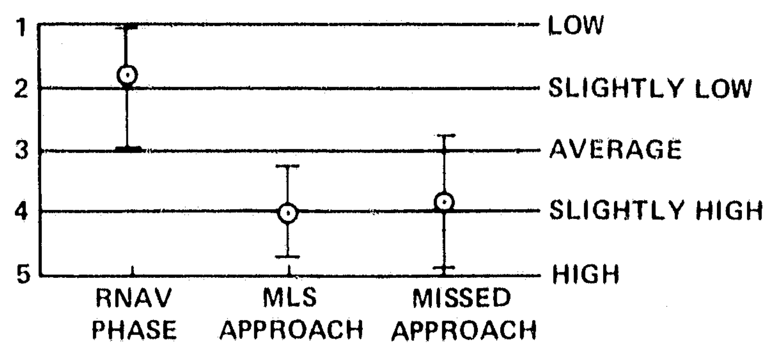


Figure 9.- Overall pilot-workload rating.

standard approach and missed approach procedures. The means 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 advanced 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. The means and standard deviations for the responses to this question are shown in figure 10. 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° glide slope and the 200-ft decision height acceptable. The pilots liked the 6° 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 nm). Altitude restrictions further complicated the approach profile and resulted in a glide-slope intercept within 0.1 nm of MLS localizer capture (fig. 11). 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 to 1 nm 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.

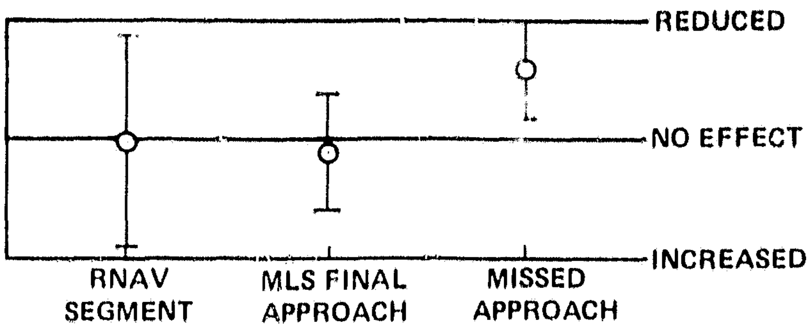


Figure 10.- Effect of advanced display on pilot workload.

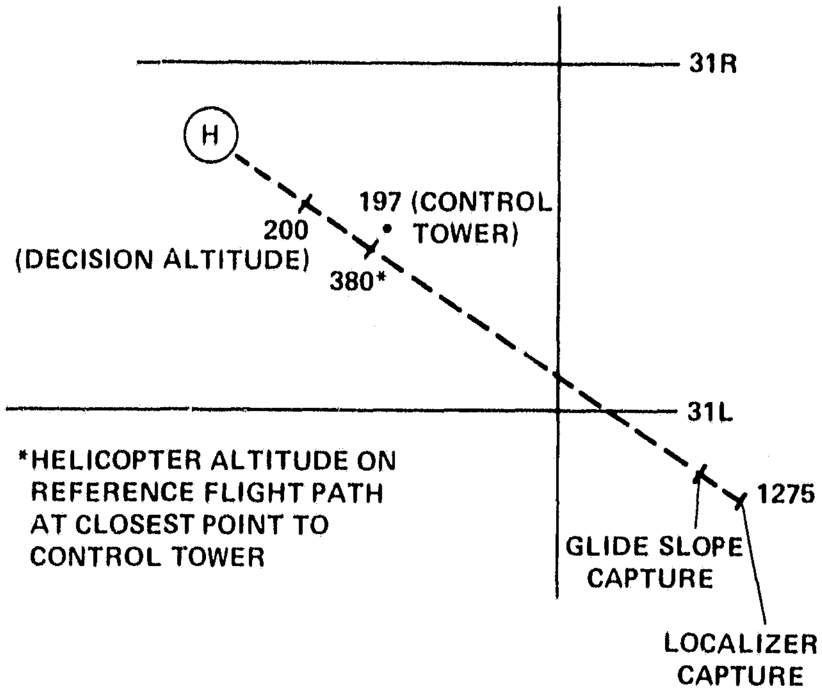


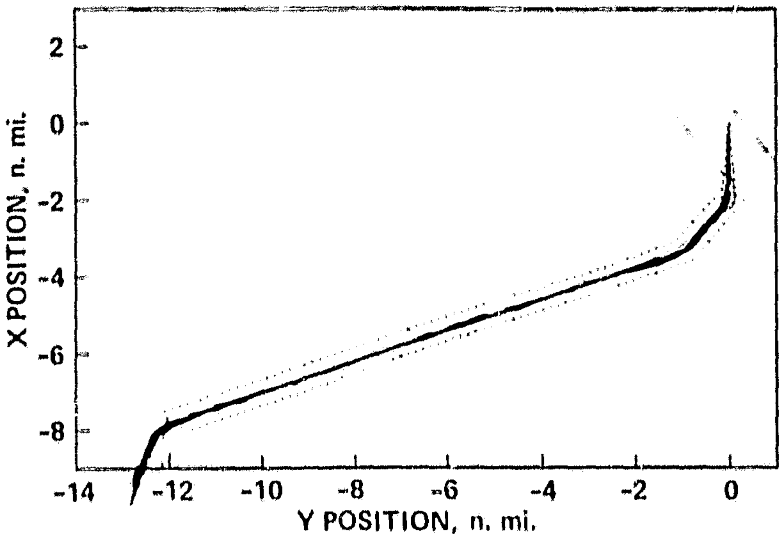
Figure 11.- Helicopter route and CTOL runway configuration.

The pilots who considered the intercept distance to be satisfactory indicated that, with training and advanced preparation, the maneuver could be satisfactorily accomplished.

The missed-approach procedure was a source of some difficulty for 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. 11). 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 except one 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 his basic training"; the one unsuccessful missed approach procedure resulted in an overflight of the active runway as a result 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. The pilots indicated a willingness to conduct this maneuver, however, if it improves rotorcraft instrument approaches in high density terminal environments.

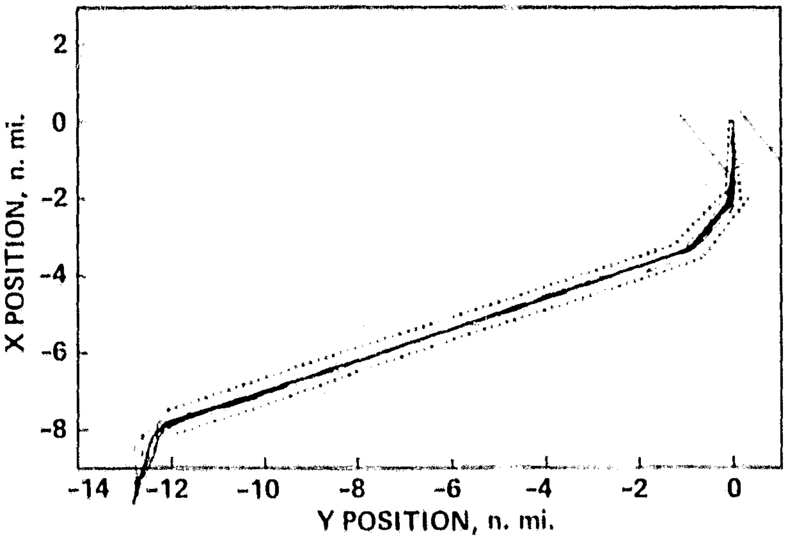
Tracking Performance

Lateral composite plots of individual approaches for the four display configurations evaluated are shown in figures 12(a) through 12(d). (It should be noted that only the intrail-spacing mode is shown for the active CDTI.) The dotted lines on either side of the reference flightpath 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°) 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 plots, the lateral tracking performance is universally good, independent of display configuration. It should be noted that the data do not include navigation error and, therefore, the plots do not represent airspace requirements. Statistical data were computed from the lateral crosstrack errors at the COP and COP 2 waypoints, the IX47 intermediate 6-nm fix, the MLS localizer intercept, and at decision height. The mean and two-sigma standard-deviation lateral-performance windows are summarized in table 2 for the four display modes tested. The two-sigma lateral-performance windows are well within the CDI display limits for all four display configurations.



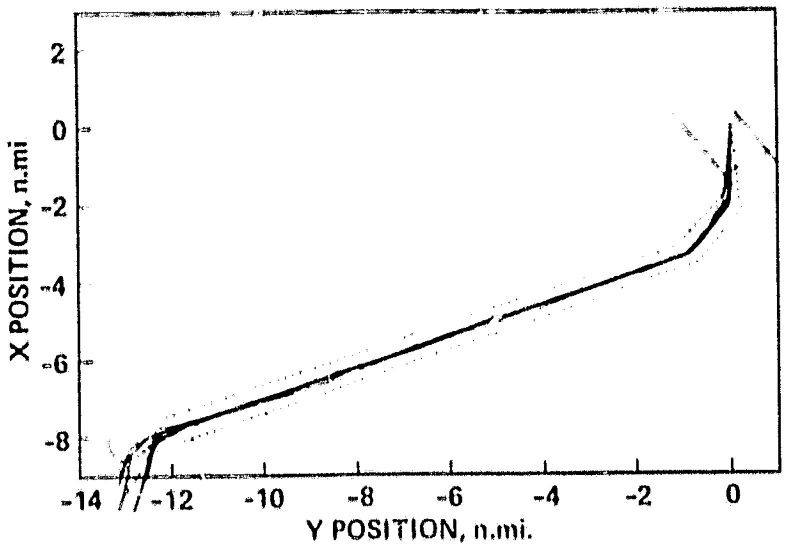
(a) No map.

Figure 12.- Lateral tracking performance.



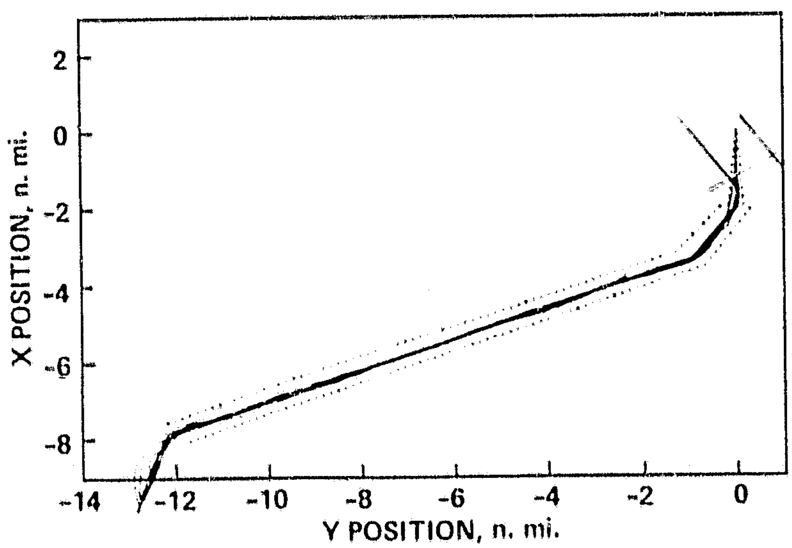
(b) Map only.

Figure 12.- Continued.



(c) Passive CDTI.

Figure 12.- Continued.



(d) Active CDTI.

Figure 12.- Concluded.

TABLE 2.- LATERAL APPROACH WINDOWS AT WAYPOINTS AND DECISION HEIGHT

WAYPOINT	NO MAP	MAP DISPLAY	PASSIVE CDTI	ACTIVE CDTI
	MEAN LATERAL CROSSTRACK ERROR (ft)			
COP	269	34	67	-10
I x 47	-26	22	-37	-114
COP2	194	177	161	-18
MLS INTERCEPT	177	291	530	104
DECISION HEIGHT	14	7	6	23
	TWO SIGMA STANDARD DEVIATION (±ft)			
COP	643	793	468	710
I x 47	291	177	274	256
COP2	442	441	206	404
MLS INTERCEPT	689	521	550	700
DECISION HEIGHT	100	116	83	127

Vertical composite plots of individual approaches for the four display configurations evaluated are shown in figures 13(a) through 13(d). (It should be noted that only the intrail-spacing mode is shown for the active CDTI.) The dotted lines on either side of the reference flightpath 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 vertical course width (±2.0° 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 apporach. 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.

As was the case for the lateral tracking data, the final-approach performance appears to be universally good, independent of the display configuration. (See figs. 13(a) through 13(d).) Statistical data were computed from the vertical deviation errors at the COP and COP 2 waypoints, the IX47 intermediate 6-nm fix, the MLS localizer intercept, and at decision height. The mean and two-sigma standard-deviation vertical-performance windows are summarized in table 3 for the four display modes tested.

The two-sigma vertical-performance windows are well within the display limits provided by the VDI for all four display configurations.

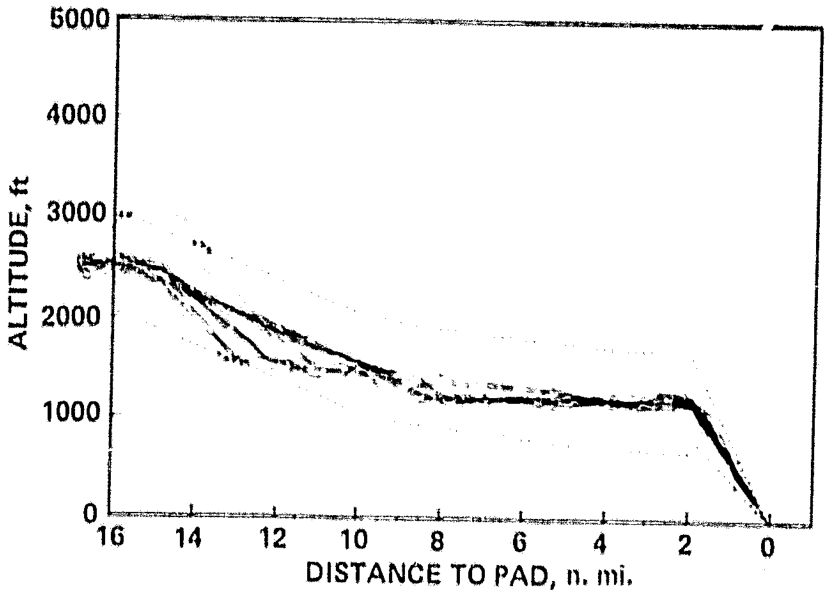
ATC PROCEDURES

Handling Helicopter Traffic in Addition to Conventional Traffic

Observations and Controller Evaluations

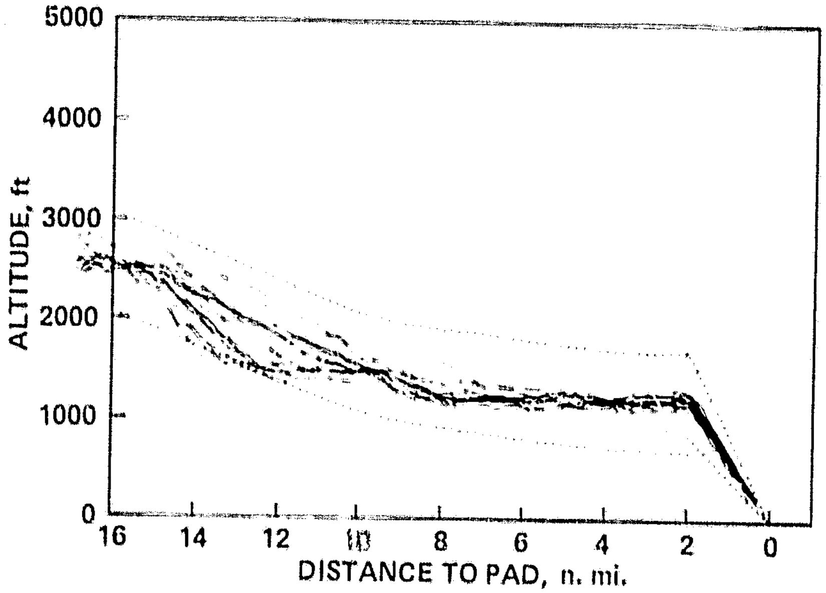
Qualitative data were obtained from controller-written evaluations and by observing the controller activity during the course of the experiment. Copies of the postrun and postexperiment questionnaires are given in appendixes B and C.

Two rates of arrival were investigated for both helicopter and CTOL traffic. The CTOL rates were 30 and 35 a/c/hr. 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 a/c/hr to be less desirable than the arrival rate of



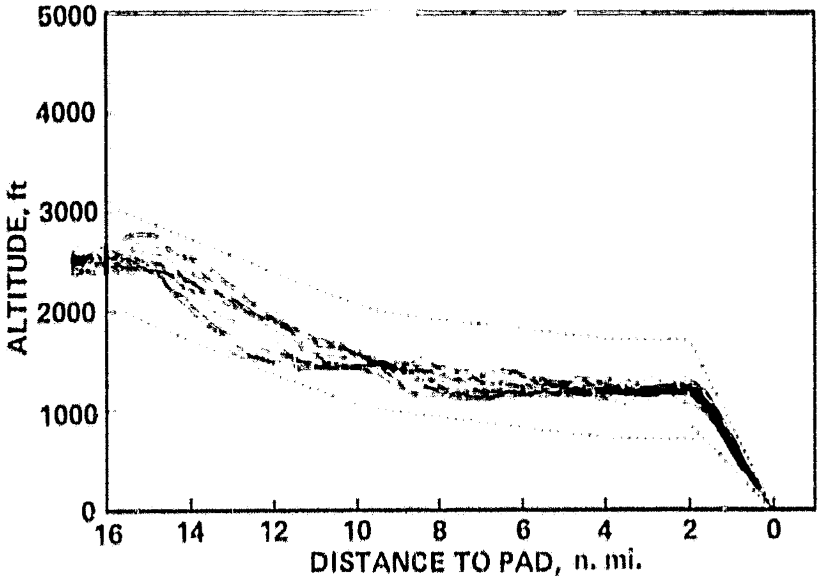
(a) No map.

Figure 13.- Vertical tracking performance.



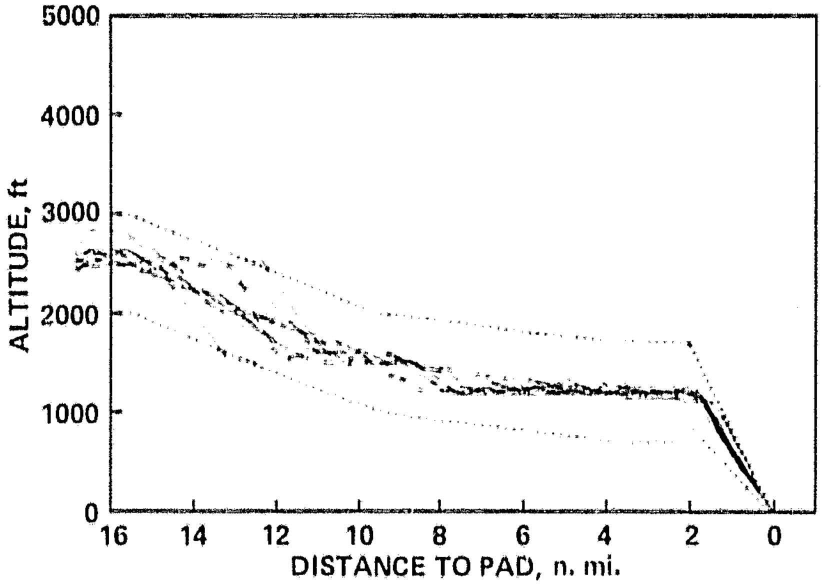
(b) Map only.

Figure 13.- Continued.



(c) Passive CDTI.

Figure 13.- Continued.



(d) Active CDTI.

Figure 13.- Concluded.

TABLE 3.- VERTICAL APPROACH WINDOWS AT WAYPOINTS AND DECISION HEIGHT

WAYPOINT	NO MAP	MAP DISPLAY	PASSIVE CDTI	ACTIVE CDTI
	MEAN VERTICAL ERROR (ft)			
COP	49	14	23	66
I x 47	23	17	-24	1
COP2	5	9	5	2
MLS INTERCEPT	-14	-13	-13	-14
DECISION HEIGHT	3	13	8	-1
	TWO SIGMA STANDARD DEVIATIONS (±ft)			
COP	250	111	148	194
I x 47	81	126	110	193
COP2	66	79	93	77
MLS INTERCEPT	97	97	123	86
DECISION HEIGHT	36	33	48	32

30 a/c/hr [1]; their evaluations were based on safety, expeditiousness, orderliness, total workload, stressfulness, frustration, and the individual-workload categories of manual, visual, mental, and verbal. Thus, with respect to the CTOL arrivals, the difficulty of handling traffic was proportional to the traffic density. In going from the CTOL arrival rate of 30 to 35 a/c/hr, the controllers were required to give a full set of vector clearances to five additional aircraft. Also, 30 a/c/hr represented a moderate traffic flow, whereas 35 a/c/hr was a heavy arrival rate for the scenario chosen and the number of controllers available. The two levels of helicopter traffic were 8 helicopters/hr and 15 helicopters/hr. However, except for stressfulness (the 15 helicopter/hr rate was rated more stressful), the two helicopter arrival rates were rated the same. Both rates (8 and 15 helicopters/hr) are in the low to moderate range and, 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 (ref. 11) not utilizing RNAV and MLS, the conclusion was that, at arrival rates of 2 to 4 helicopters/hr, the same controller could handle helicopter and fixed-wing traffic, but at arrival rates of 5 to 15 helicopters/hr, use of separate controller positions was recommended. In this RNAV-MLS experiment, the controller merely cleared the aircraft for an MLS 6° 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. One type of problem occurred when a CTOL executed a missed approach: If left alone, and if there was helicopter traffic flying along the COP route, inadequate spacing resulted. 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.

The exact division of controller responsibilities was as follows: the approach controller was responsible for all helicopter traffic from feeder-fix departure to touchdown, and he was also responsible for the missed-approach CTOL aircraft. The controllers felt that it would be easier for this one controller to coordinate any problems due to a CTOL missed approach. However, at the completion of the study, controllers' opinions were divided with respect to how the helicopter traffic should be handled in actual terminal-area operations. One controller felt that the final controller for the CTOL traffic would also have to control helicopter approaches to the pad because of proximity of the pad and the runway. Another controller felt that a

[1] It should be noted that all runs discussed in this context had both helicopter and fixed-wing traffic. Thus during operations at 30 a/c/hr and 35 a/c/hr there was also 8 helicopter/hr traffic. Similarly, during the 8 helicopter/hr and 15 helicopter/hr operations there was also 35 a/c/hr fixed-wing traffic.

separate helicopter-control position would be established in real-world operations and that coordination between helicopter and CTOL positions would not be a problem. Obviously there are still questions relating to the controller procedures that need to be resolved, even though the controllers in this study felt that they were able to handle the helicopter traffic in addition to the CTOL.

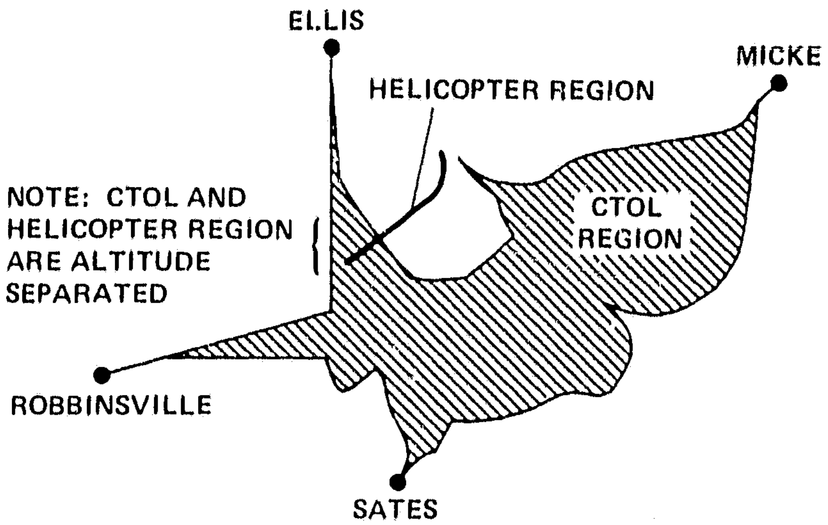
System Operation and Airspace Usage

Table 4 shows a comparison of the operations at the two CTOL arrival rates of 30 and 35 a/c/hr. It provides the average time in the system of an aircraft as a function of the CTOL arrival route and the total number of clearances issued. The time in the system for a given aircraft is the time from feeder-fix departure until touchdown. As can be seen, for the Ellis route the average times for both arrival rates were about the same. However, for the other three routes, the extra time in the system caused by the heavy arrival rate averaged from 31 to 103 sec. This extra time in the system translates into extra fuel used. There is also extra controller workload, as can be seen in table 4. The total number of clearances issued by the controller in the 70-min data run is given, averaged as a function of the two arrival rates. There is a 15% increase in workload for the heavy arrival rate, as measured by the following controller clearances: heading, speed, altitude, and cleared for approach.

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. They are shown in figures 14(a) through 14(c). Figure 14(a) is a composite plot for all runs for which the CTOL arrival rate was 30 a/c/hr and the helicopter arrival rate was 8 helicopters/hr. 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 14(a) represents the envelope of 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 the 30 a/c/hr arrival rate. Two additional composites are shown in figures 14(b) and 14(c); figure 14(b) shows a composite for a CTOL arrival rate of 35 a/c/hr and a helicopter arrival rate of 8 helicopters/hr, and figure 14(c) shows a composite for a CTOL arrival rate of 35 a/c/hr and a helicopter arrival rate of 15 helicopters/hr. The results

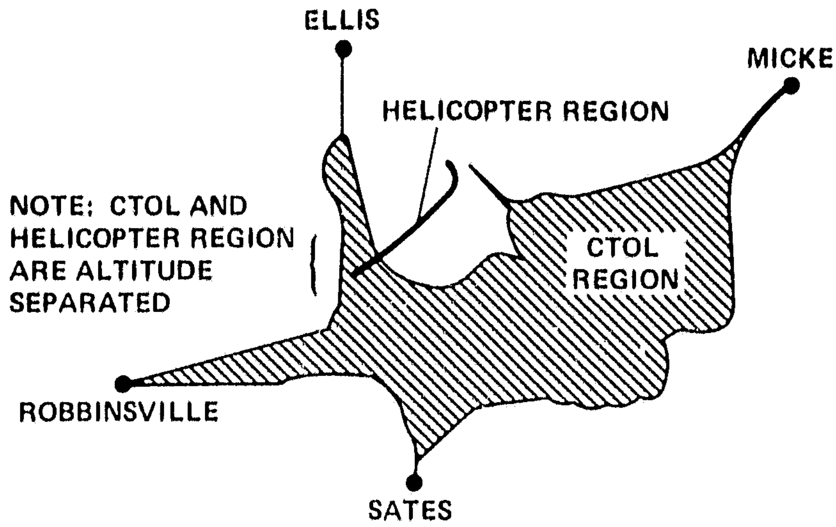
TABLE 4.- COMPARISON OF ATC OPERATIONS AT 30 AND 35 A/C / HR

CTOL ARRIVAL RATE, A/C / hr	AV. TIME IN SYSTEM / A/C, sec				TOTAL NO. CLEARANCES/RUN			
	ELLIS	ROBBINSVILLE	SATES	MICKE	HEADING	SPEED	ALTITUDE	CLEARED FOR APPROACH
30	1033	1087	708	691	125	106	79	35
35	1030	1190	742	722	142	124	88	44
DIFFERENCE	-3	103	34	31	17	18	9	9



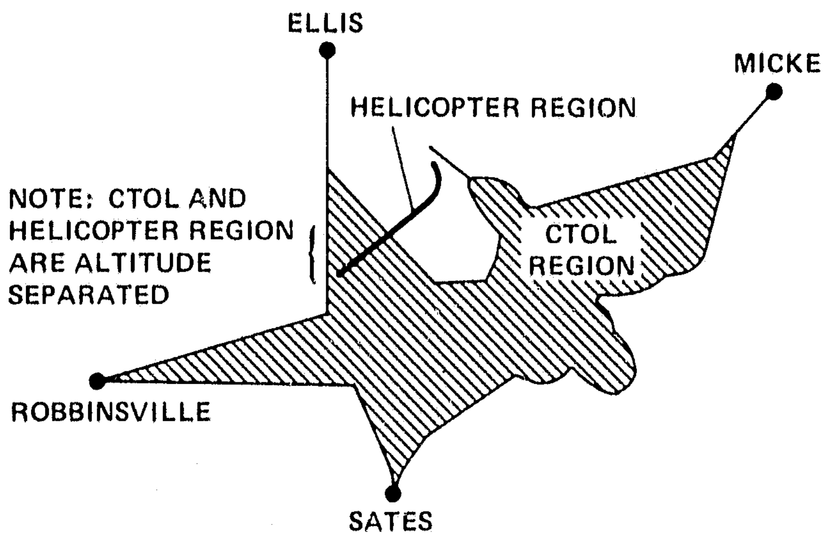
(a) Airspace used for 30 a/c/hr CTOL arrival rate (8 helicopters/hr).

Figure 14.- Airspace-usage plots.



(b) Airspace used for 35 a/c/hr CTOL arrival rate (8 helicopters/hr).

Figure 14.- Continued.



(c) Airspace used for 35 a/c/hr CTOL arrival rate (15 helicopters/hr).

Figure 14.- Concluded.

are the same as for the 30 a/c/hr case discussed previously; namely, there is no interference of the helicopter path in the CTOL airspace.

A comparison of the composite regions reveals another interesting fact, as shown in figure 15 by the superposition of the three composite regions. It is clear that the regions are quite similar regardless of arrival rate. Thus, even though the higher arrival rates 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 mentioned earlier, another objective of the study was to investigate higher traffic rates, merging situations, and lower minimum separations for the helicopter traffic; however, it was not possible for the controllers to cope with these situations and still handle a full complement of CTOL traffic. Hence, a dual-helicopter route structure, shown in figure 5, was set up. The combined arrival rate at the feeder fixes was 35 helicopters/hr, randomly distributed equally between the two fixes. Two minimum separation distances were used, the standard 3 nm and a reduced separation of 1.5 nm. No CTOL traffic was considered.

The controllers rated the 1.5-nm traffic spacing consistently less desirable in all categories: 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-nm 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-nm separation. Their evaluations indicated that, with appropriate training, a 2-nm 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° glide-slope approach. (See fig. 16.) Based on responses to a question concerning recommended spacings behind specific helicopters, the recommended minimum spacings ranged from 1 to 2 nm. 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-nm separation when behind light to medium helicopters and a 4-nm separation when behind heavy helicopters.

A comparison of operations with 1.5-nm and 3-nm spacing is given in table 5. In the table are compared 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

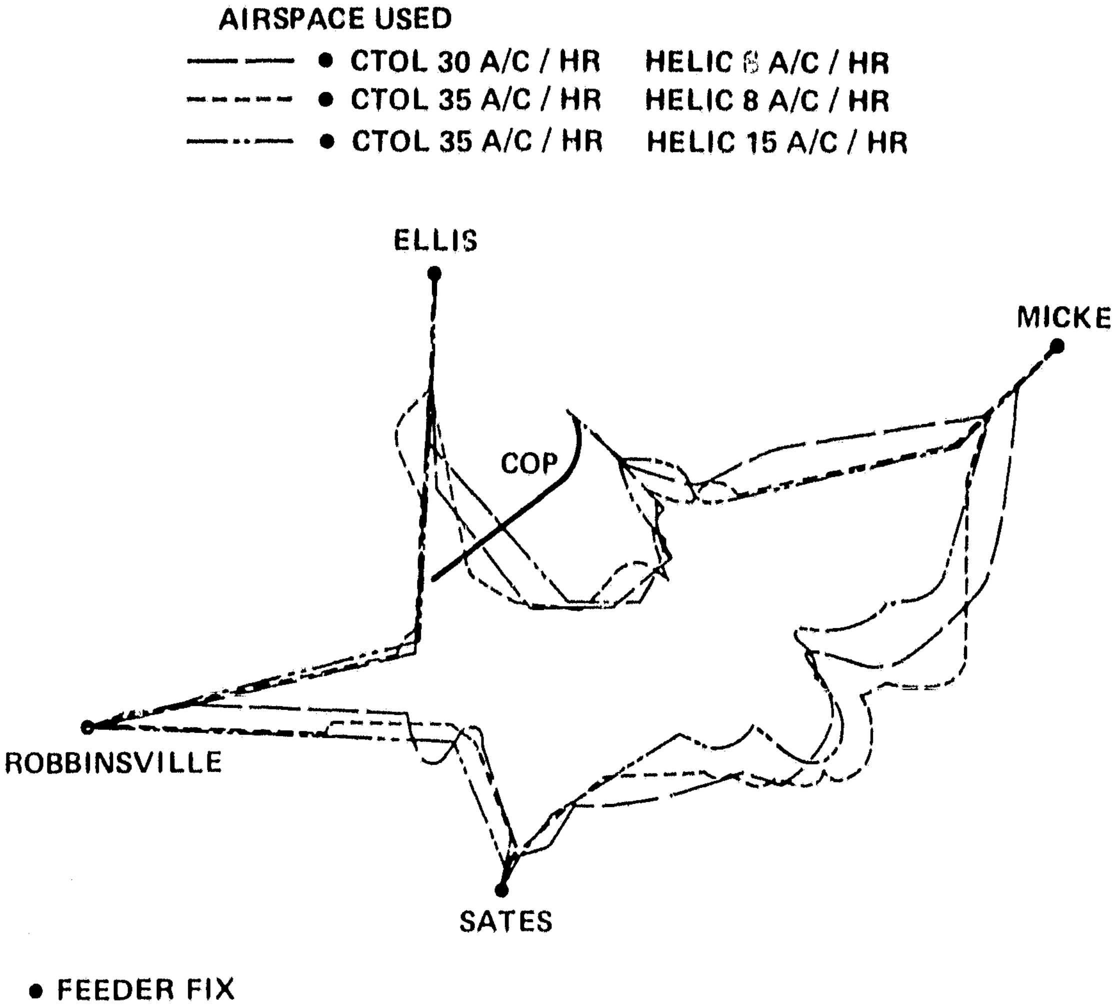


Figure 15.- Composite of airspace used.

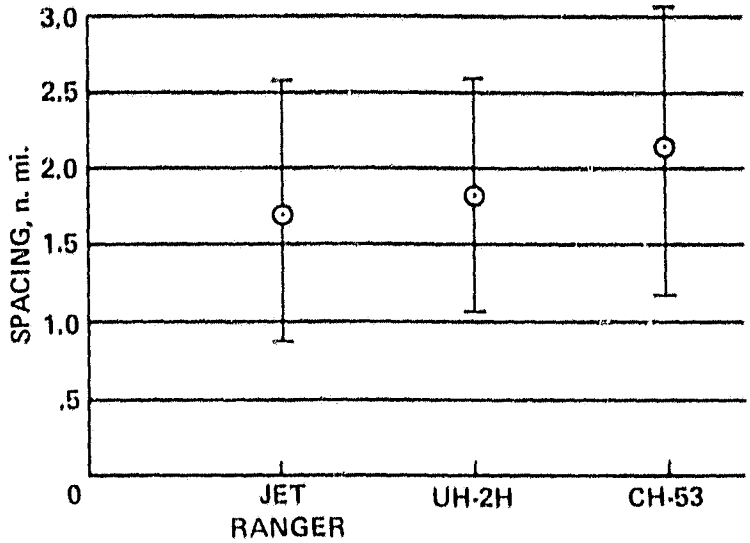


Figure 16.- Closest acceptable spacing.

TABLE 5.- DUAL HELICOPTER ROUTES

DISTANCE SEPARATION (n.mi)	AVERAGE TIME IN SYSTEM (min:sec)		TOTAL HALT TIME (min:sec)	TOTAL NO. CLEARANCES/RUN (SPD, ALT, HDG, CLA)
	COP	LEE		
1.5	12:17	11:54	7:23	127
3	13:58	12:28	22:41	105
DIFFERENCE	1:41	:34	15:18	22

number of ATC-transmitted clearances per run (e.g., heading, speed, altitude, and cleared for approach). At the given arrival rate of 35 helicopters/hr, 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 to handle the extra aircraft by various path-stretching maneuvers. The results in table 5 indicate that a significant benefit is gained when the 1.5-nm 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-nm minimum separation was that, at the 3-nm separation, the arrival-traffic flow had to be stopped for 22.68 minutes in a 70-minute run, 15.3 minutes more than when the minimum separation was 1.5 nm. The system delays and feeder-fix delays result in a much larger fuel usage for the 3-nm case. However, the controller workload is increased in the 1.5-nm case, as evidenced by the total number of clearances/run in table 5 and by the 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 indicated previously, the controllers felt that, for a 2-nm 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, three active CDTI maneuvers were considered: intrail spacing, merging, and route crossing. 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 nm 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-nm range and 200-ft altitude." Another pilot recommended changing the vertical advisory altitude to "within 500 ft," as opposed to the 1500-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 both 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 just the opposite; namely, 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 pilots performing the active CDTI roles as follows: intrail spacing — good; merging — fair to good; and route crossing — fair to good.

The active CDTI maneuvers were conducted on or near the COP route. For the intrail-following maneuver, first a lead helicopter was 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 17 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 the distance along the route. The plot shows that when the helicopter simulator departed from the feeder fix it was about 5 nm from aircraft L1, and the pilot gradually decreased this distance to a little less than 3 nm 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 nm when F1 departed from the feeder fix, and the controller decreased this distance to 3 nm by the time the helicopter simulator reached the landing pad. This procedure was followed eleven times in the simulation, and the average minimum separation distance between the helicopter simulator and the lead aircraft was 2.86 nm. The minimum separation distance ranged from 2.41 nm to 3.03 nm. 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 18 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 nm, which is indeed typical of the average of 2.26 nm for thirteen such runs. This separation distance is lower than the desired minimum separation of 3 nm. 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 flightpath is flown. It probably would 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.

The final maneuver performed was a route-crossing maneuver. The helicopter simulator was directed off the COP route and the pilot was instructed to cross the COP route between two aircraft flying along the route. Typical geometry is shown in figure 19. The data collected on this maneuver are limited because it was run only five times. It seemed to be difficult for the pilots to anticipate the crossing-maneuver requirement. Generally, they handled the maneuver as shown in the figure; namely, they essentially merged

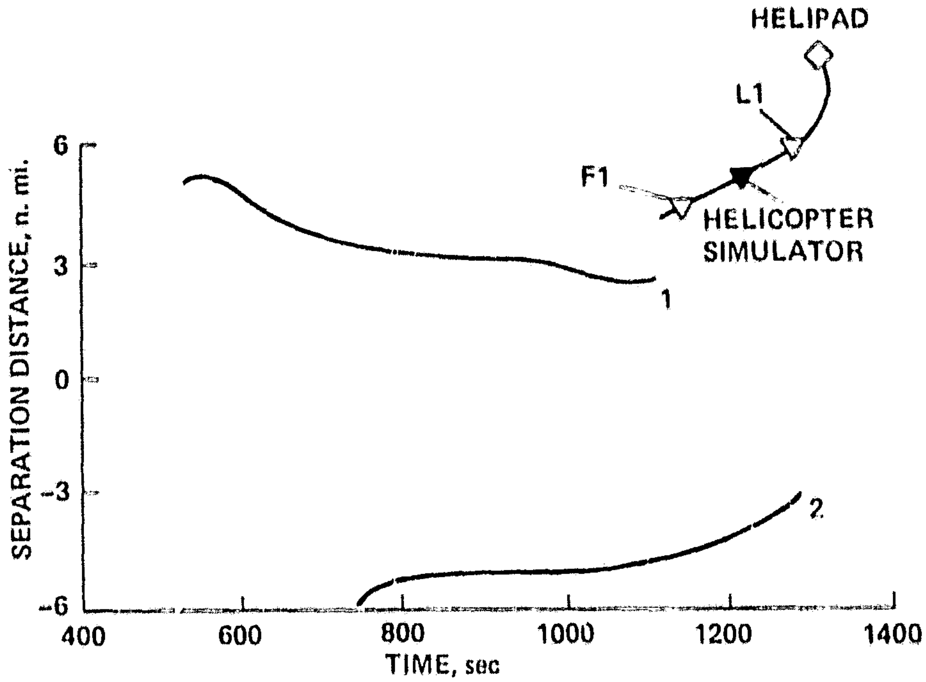


Figure 17.- Separation distance for intrail-spacing maneuver.

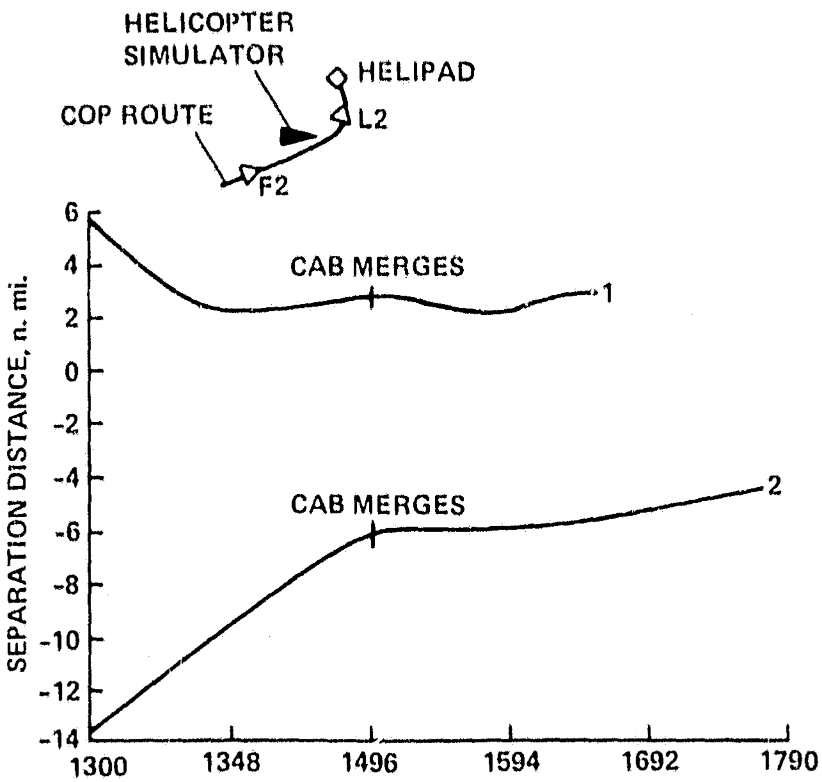


Figure 18.- Separation distance for merging maneuver.

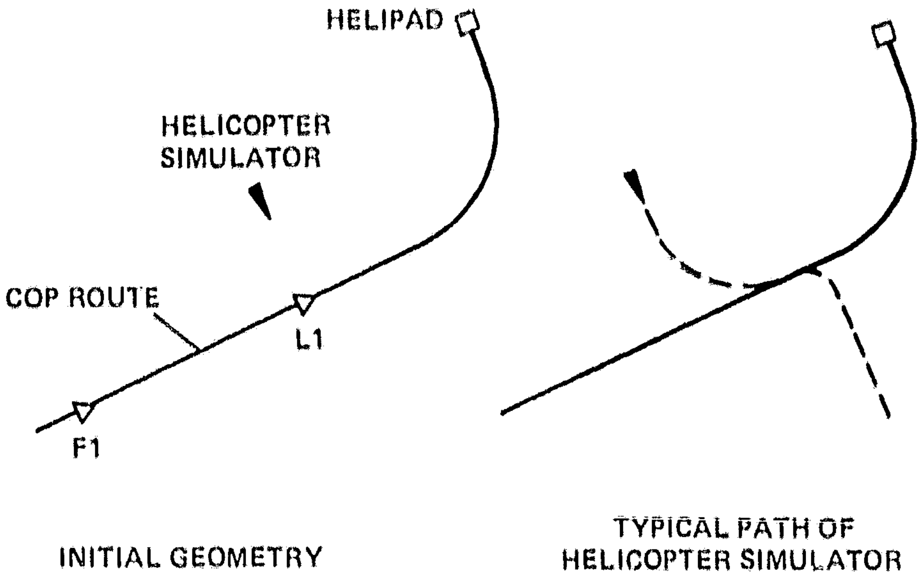


Figure 19.- Route-crossing maneuver.

with the COP route so that they were appropriately spaced behind the lead aircraft, and then made a right turn off the route. Improvements could probably be made by slightly increasing the spacing between the two intrail aircraft, by providing computer assists, or by providing for additional pilot practice.

The pilots successfully completed all the CDTI active-mode procedures; however, the required separation was not maintained during every approach. The lack of a radial-range scale emanating from the symbol, which represented the position of the helicopter, was a contributing factor in the reduced-separation problem. Another contributing factor was the multiple scale factors used for the display. The RNAV route scale of the electronic area-map display was 1 inch = 2 nm; however, since this scale did not permit detailed information of the terminal area, the scale was automatically changed at the intermediate-segment waypoint intercept to 1 inch = 1 nm. Evaluation pilots occasionally overlooked the change of scale during several CDTI active approaches, and this oversight also contributed to the reduced-separation problem. The radial-range scale suggested previously would also help this situation because the range indicator would be changed to be consistent with the scale of the area-map display. The velocity information concerning the CDTI traffic was used very effectively by the evaluation pilots. When a lead aircraft reduced its speed, the evaluation pilots noted the change on the display and reduced the speed of the helicopter simulator to maintain separation. In general, the pilots maintained the required separation very well during most of the approaches.

The active CDTI tests demonstrated a reasonable set of procedures that might be accomplished by the pilot using the CDTI. At no time was there any ambiguity with respect to the pilots' and controllers' responsibilities. Furthermore, it was always clear to the helicopter pilot which helicopters on his CDTI were involved in the maneuver. The intrail-spacing maneuver was performed most accurately. The merging maneuver was more difficult; the pilot performance would improve if range separation were quantitatively displayed. The crossing maneuver was difficult when spacing between the helicopters was near 6 nm. If traffic conditions permit, it is preferable to delay and cross the route after both helicopters have passed. Obviously, a more complete series of tests for each of these maneuvers is necessary. In addition, whether or not controllers can effectively manage the situation when many helicopters are simultaneously performing active CDTI maneuvers remains to be seen.

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/hr) in addition to their fixed-wing traffic load without difficulty.

Precise RNAV approaches for helicopters in unused airspace provide the means for operating fixed-wing and helicopter traffic in an efficient, non-interacting 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 releasing control of some aircraft while retaining it 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 on this concept are highly recommended.

APPENDIX A

PILOT QUESTIONNAIRE

JOINT NASA/FAA HELICOPTER ATC SIMULATION

PILOT QUESTIONNAIRE

Briefing and Training

1. The briefing you received on test procedures was:

   ____ Adequate. ____ Not Adequate.

   If not adequate, indicate the area which was not clear.

2. The training you received on the simulator prior to actual data collection test runs was:

   ____ Sufficient. ____ Not Sufficient.

   If not sufficient, indicate additional training you would have required.

Guidance Display Sensitivities

Pilot workload and tracking precision are closely related to the Course Deviation Indicator (CDI) and Vertical Deviation Indicator (VDI) Display Sensitivities. A high display sensitivity induces high pilot workload as small deviations about the reference flightpath results in relatively large needle deflections of the CDI/VDI guidance indicators. A reduction in the display sensitivity will result in a corresponding reduction in pilot workload; however, airspace requirements increase as the less sensitive display permits greater deviations about the desired flightpath. Display sensitivities which provide minimum airspace requirements consistent with reasonable pilot workload are considered optimum.

3. Rate the suitability of the CDI and VDI sensitivities used during the simulation tests by filling out tables I and II below. Use the Suitability Rating Scale and the Sensitivity Recommendation Scale shown below for your numerical rating.

Table I. CDI Sensitivity

	Suitability Rating	Sensitivity Recommendation
RNAV Segments	______	______
Localizer Intercept	______	______
Localizer Tracking	______	______

Table II. VDI Sensitivity

	Suitability Rating	Sensitivity Recommendation
RNAV Segments	______	______
Glide Slope Intercept	______	______
Glide Slope Tracking	______	______

Suitability Rating Scale

1. Acceptable, and relatively easy to fly.
2. Acceptable, with reasonable effort.
3. Acceptable, but mildly difficult.
4. Marginally acceptable, and very difficult.
5. Unacceptable, almost impossible to fly.

Sensitivity Recommendation Scale

1. Increase sensitivity. (provide tighter tracking)
2. Slightly increase sensitivity.
3. No change in sensitivity.
4. Slightly decrease sensitivity.
5. Decrease sensitivity. (provide coarser tracking)

4. Any other comments on CDI sensitivity?

5. Any other comments on VDI sensitivity?

CRT Display of RNAV Routes

6. During the RNAV flight phase, the RNAV display had the following effect on pilot workload and tracking precision.

Pilot Workload	Tracking Precision
_____ Reduced pilot workload.	_____ Improved tracking precision.
_____ No effect.	_____ No effect.
_____ Increased pilot workload.	_____ Decreased tracking precision.

7. During the MLS final approach flight phase, the RNAV display had the following effect on pilot workload and tracking precision.

Pilot Workload	Tracking Precision
_____ Reduced pilot workload.	_____ Improved tracking precision.
_____ No effect.	_____ No effect.
_____ Increased pilot workload.	_____ Decreased tracking precision.

8. During the missed approach phase, the RNAV display had the following effect on pilot workload and tracking precision.

Pilot Workload	Tracking Precision
_____ Reduced pilot workload.	_____ Improved tracking precision.
_____ No effect.	_____ No effect.
_____ Increased pilot workload.	_____ Decreased tracking precision.

9. The RNAV display format was:

_____ Easy to read, and easy to use for guidance.

_____ Easy to read, but difficult to use for guidance.

_____ Difficult to read, but easy to use for guidance.

_____ Difficult to read, and difficult to use for guidance.

10. How would you change the format to improve it?

11. Would you recommend that the weather/mapping radar display in helicopters be utilized to provide RNAV route displays?

_____ Yes. _____ No.

12. Any other comments on the RNAV route display?

Cockpit Display of Traffic Information (CDTI)

13. The CDTI advisories were limited in the simulation to the three nearest aircraft. Would you recommend:

_____ More advisories; if so, how many? _____

_____ No change.

_____ Less advisories; if so, how many? _____

14. The CDTI advisories were given for aircraft traffic which was within 40,000 ft (6.6 nm) range and 1,500 ft altitude from your helicopter. What CDTI traffic advisory range and altitude do you recommend?

_____ nm range. _____ ft altitude.

Should closure rate also be a criterion? If so, how much? _____ knots

15. The CDTI display format was:

_____ Easy to read, and useful for traffic separation.

_____ Easy to read, but not useful for traffic separation.

_____ Difficult to read, but useful for traffic separation.

_____ Difficult to read, and not useful for traffic separation.

16. What additional information would you like to see displayed in the CDTI format (for example, "trend vectors")?

17. Any other comments on the CDTI display?

Pilot Workload

18. Rate the overall pilot workload of each of the following phases of the test runs.

	Low	Slightly Low	Average	Slightly High	High
A. RNAV Phase	_____	_____	_____	_____	_____
B. MLS Approach	_____	_____	_____	_____	_____
C. Missed Approach	_____	_____	_____	_____	_____

19. Would use of a flight director have significantly reduced pilot workload during any of the following phases?

A. RNAV Phase	_____ Yes.	_____ No.
B. MLS Approach	_____ Yes.	_____ No.
C. Missed Approach	_____ Yes.	_____ No.

Flight Profile and Procedures

20. Was the 6 degree glide slope used for the MLS approach in these tests:

_____ Acceptable. _____ Unacceptable.

21. What glide-slope angle do you recommend as the optimum glide-slope angle for an IFR helicopter approach?

_____ degrees, single piloted. _____ degrees, dual piloted.

22. Was the 200 ft decision height used for the MLS approach in these tests:

_____ Acceptable. _____ Unacceptable.

23. What do you feel should be the decision height for a 6 degree IFR MLS helicopter approach?

_____ feet, raw data, single piloted.

_____ feet, raw data, dual piloted.

_____ feet, flight director, single piloted.

_____ feet, flight director, dual piloted.

24. What airspeed did you prefer for the following segments:

_____ knots, RNAV Phase.

_____ knots, MLS Approach.

_____ knots, Missed Approach.

25. Did you feel that a deceleration while still IMC was necessary prior to decision height?

_____ Yes. _____ No.

If yes, indicate the altitude at which the deceleration was initiated and the airspeed decelerated to at decision height:

_____ ft altitude. _____ knots at decision height.

26. Evaluate the following distances:

A. Between RNAV waypoints.

_____ Too Long. _____ Satisfactory. _____ Too Short.

B. From COP-2 to MLS intercept:

_____ Too Long. _____ Satisfactory. _____ Too Short.

C. From MLS intercept to touchdown (2 nm).

_____ Too Long. _____ Satisfactory. _____ Too Short.

Any other comments on route structure?

27. Was there sufficient distance to establish localizer tracking prior to glide-slope intercept?

_____ Sufficient. _____ Not Sufficient.

If not sufficient, indicate distance required between localizer and glide-slope intercept.

_____ nm.

28. Were you satisfied with the RNAV to MLS transition used during these tests?

_____ Satisfactory. _____ Needs Improvement.

If needs improvement, explain.

29. You are flying a UH-1H on a 6 degree IFR MLS approach to JFK airport. What is the closest distance (spacing) you would accept on the approach, were you to follow:

_____ nm Jet Ranger, BO-105, Gazelle.

_____ nm UH-1H, Bell 212, Sikorsky S-76.

_____ nm Sikorsky CH-53, Boeing-Vertol Chinook.

30. For these tests, the approach ground plane intercept (GPI) was located 100 feet in front of the landing pad. This distance for deceleration and flare prior to landing on the pad was:

____ Sufficient. ____ Not Sufficient.

If not sufficient, what distance do you feel is required?

____ feet in front of the landing pad.

<u>Simulation Fidelity</u>

31. The helicopter simulation fidelity to the UH-1H handling qualities was:

____ Good.

____ Satisfactory.

____ Poor.

____ Not familiar with actual UH-1H handling qualities.

32. What, if any, were the main simulation fidelity deficiencies?

33. Evaluate the UH-1H <u>simulation handling qualities</u> as they affected your performance during the simulation tests.

____ Became rapidly familiar. Little or no effect on performance.

____ Took awhile getting used to. First few approaches were difficult, thereafter experience helped to improve performance.

____ Never really got used to simulator. Entire set of approaches was very difficult due to unfamiliarity with handling qualities.

34. Evaluate the <u>simulation instrument panel configuration</u> as it affected your performance during the simulation tests.

____ Became rapidly familiar. Little or no effect on performance.

____ Took awhile getting used to. First few approaches were difficult, thereafter experience helped to improve performance.

____ Never really got used to instrument configuration. Entire set of approaches was very difficult due to unfamiliarity with instrument panel configuration.

General Comments

35. Please comment on any additional aspects of the tests you wish.

JOINT NASA/FAA HELICOPTER ATC SIMULATION

SUBJECT PILOT QUALIFICATIONS

NAME: ____________________

AFFILIATION: ____________________

ADDRESS: ____________________

CITY: ____________________ STATE: ______ ZIP: ______

PHONE: ____________________

TOTAL FLIGHT HOURS: ____________________

TOTAL IFR HOURS: ____________________

TOTAL HELICOPTER HOURS: ____________________

HELICOPTER ACTUAL IFR HOURS: ____________________

HELICOPTER HOODED IFR HOURS: ____________________

BELL HELICOPTER EXPERIENCE: YES ______________ NO ______________

FAA HELICOPTER RATINGS: (Private, Comm, ATP, Inst)

FOR SUCCESSFUL PARTICIPATION AS A SUBJECT PILOT IN THE ATC SIMULATION, I FEEL MY PREVIOUS PILOT EXPERIENCE WAS:

_____ More Than Adequate.

_____ Adequate.

_____ Less Than Adequate.

APPENDIX B

CONTROLLER RUN EVALUATION SHEET

Name: ______________________ Run No.: ______________________

Date: ______________________ Condition: ______________________

1. Circle the numbers which best describe how you feel in reference to this run. Comment if you wish in the space provided.

SAFETY	(low)	1	2	3	4	5	6	7	(high)

Comments: ______________________

EXPEDITIOUSNESS	(low)	1	2	3	4	5	6	7	(high)

Comments: ______________________

ORDERLINESS	(low)	1	2	3	4	5	6	7	(high)

Comments: ______________________

TOTAL WORKLOAD	(low)	1	2	3	4	5	6	7	(high)

Comments: ______________________

STRESSFULNESS	(low)	1	2	3	4	5	6	7	(high)

Comments: ______________________

FRUSTRATION	(low)	1	2	3	4	5	6	7	(high)

Comments: ______________________

2. Estimate your visual, verbal, mental, and manual workloads separately for this run.

MANUAL	(low)	1	2	3	4	5	6	7	(high)
VISUAL	(low)	1	2	3	4	5	6	7	(high)
MENTAL	(low)	1	2	3	4	5	6	7	(high)
VERBAL	(low)	1	2	3	4	5	6	7	(high)

3. Compared to the previous runs, this run was:

   a. Much easier than average ______
   b. Easier than average ______
   c. About average ______
   d. Harder than average ______
   e. Much harder than average ______

APPENDIX C

HELICOPTER ATC SIMULATION

POSTEXPERIMENT CONTROLLER QUESTIONNAIRE

1. In the JFK scenario, the helicopter traffic on the COP-2 route was handled by the same controllers who handled the traffic to runway 31R.

   A. Was it difficult to handle the additional traffic on the helicopter route:

      (1) Under moderate helicopter traffic flow?
      (2) Under heavy helicopter traffic flow?
      (3) When a 31R arrival executed a missed approach?
      (4) Because of the slower speeds of the helicopter traffic?

      Comment on each of the above.

   B. Should the helicopter traffic be handled by a separate control position? Explain. If this were done, can you anticipate any coordination problems between the helicopter controller and the existing control positions at JFK? Explain.

2. Was the airspace used by the piloted helicopter reasonable? How about during the helicopter missed approach? Was there a noticeable change in the ability to track the nominal route when the pilot entered the MLS coverage? Explain.

3. The Cockpit Display of Traffic Information (CDTI) was used only by the piloted helicopter (S19) to monitor its surrounding traffic.

   A. Was there any difference in the behavior of the S19 target during these runs? Explain.

   B. Based on observed behavior, if a large percentage of the aircraft were CDTI equipped, would this be advantageous to the controller? Explain.

   C. Speculate on the following: Should controllers delegate some responsibility for longitudinal separation to CDTI-equipped aircraft through miniclearances, where the aircraft does some fine tuning of speed?

4. In some of the runs in the airport X configuration, the minimum separation distance requirement for helicopters was set at 1.5 nm.

   A. What problems were encountered due to this reduced separation?

   B. Would a separation of 1 nm or 2 nm be acceptable?

   C. For lower separation minima, is a larger display magnification required?

   D. Would reduced separation minima be more reasonable to implement if the aircraft were CDTI equipped?

5. Which control position was easiest to handle — the approach or final? In each position, what percentage of your time was spent on the following:

   A. Monitoring aircraft position?

   B. Monitoring flight data table?

   C. Communications with controller?

   D. Communications with controller assistant?

   E. Communications with helicopter pilot?

   F. Leisure?

   G. Other? (please specify)

6. Was it difficult to learn to operate the system? Please comment. What aspects of the system were hardest to learn?

7. What modifications should be made to improve the simulation facility:

   A. Additional data which should be added to the flight data table or placed next to the aircraft target?

   B. Additional features on the map?

   C. What additional clearances would you like the pseudoaircraft to be able to respond to?

   D. Any changes to the communications system?

   E. Any suggestions with respect to layout of the facility?

8. Please add any comments that will help evaluate the experiment that have not been covered in previous questions.

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