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SIMULATION STUDY OF INTRACITY HELICOPTER OPERATIONS UNDER INSTRUMENT CONDITIONS TO CATEGORY I MINIMUMS

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16. Abstract

A fixed-base simulator study was conducted to define pilot workload and task performance associated with instrument flight operations for an intracity helicopter passenger service. Displays considered necessary to provide a minimal capability under Instrument Flight Rules conditions were used to fly a representative commercial helicopter route structure in the New York area, with each terminal assumed to be equipped with a precision approach guidance system. A cross section of pilots participated as test subjects, and despite the high workload level, the results indicated that for the assumptions employed, minimums of 61 m (200 ft) ceiling and 805 m (0.5 mile) visibility (Category I) were feasible.

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SUMMARY

Worsening congestion associated with conventional ground transportation modes in metropolitan areas provides the impetus for developing a viable short-haul air transportation system that would extend commercial flight operations to service terminals conveniently located within the central business districts of cities or near population centers. In order to define the pilot workload and the task performance associated with instrument flight operations for an intracity helicopter passenger service, a piloted simulation was conducted by using a fixed-base, general-purpose cockpit equipped with displays considered necessary to provide a minimal Instrument Flight Rules (IFR) capability. A real-time digital computer program was used to allow simulated flight over the New York Airways route structure. A precision approach guidance system was assumed at each terminal. A minimum of currently available equipment was installed in the cockpit to establish the level of piloting effort required and capability achievable with minimal IFR instrumentation. Each of six pilots flew the route twice. Results showed that under the assumptions used, minimums of 61 m (200 ft) ceiling and 805 m (0.5 mile) visibility were feasible but the workload was high.

INTRODUCTION

Worsening congestion associated with conventional ground transportation modes in metropolitan areas provides the impetus for developing a viable short-haul air transportation system that would extend commercial flight operations to service terminals conveniently located within the central business districts of cities or near population centers. The flight characteristics of helicopters make them ideally suited for such operations because their inherent agility and steep climb and descent capability can be used routinely (1) to gain access to restricted sites in built-up areas, (2) to permit the use of trajectories optimized for fuel conservation and noise abatement, and (3) to utilize available airspace more efficiently. The lack of a suitable capability for city-center terminal operations for flight under Instrument Flight Rules (IFR), however, has been shown to be a major obstacle to scheduled helicopter operations.

The experience gained by operators of passenger-carrying helicopters, although limited to a few geographical areas, has convincingly defined the need for an IFR capability and identified the constraints that must be dealt with. For example, the loss of only 4 to 5 percent of the scheduled Visual Flight Rules (VFR) operations, due mainly to bad weather, may mean the difference between a reasonable profit and a substantial loss. Furthermore, the revenue lost will, in general, be disproportionately higher than the percentage of flights canceled because bad weather tends to occur in the morning and evening hours when load factors peak with commuters. Also, a loss of revenue results when a passenger, knowing that an IFR capability does not exist, opts for a more certain, if less convenient, transportation mode when the weather appears marginal. Unfortunately, achieving an IFR capability by sharing existing ground and approach facilities with conventional air traffic results in unacceptable delays for short-haul helicopter operations when stage lengths might be as short as 5 to 7 minutes. From a pilot-workload standpoint, if anything approaching VFR schedules were to be maintained during IFR conditions, the pilot would make up to 40 instrument approaches in 1 day. Although it is unlikely that such a frequency would ever be achieved, it is apparent that the approach task difficulty, which results from the combined effects of task complexity, aircraft handling characteristics, and cockpit displays, must be minimized.

In order to define the pilot workload and the task performance associated with instrument flight operations for an intracity helicopter passenger service, a piloted simulation was conducted by using a fixed-base, general-purpose cockpit. The cockpit was equipped only with the displays considered necessary to provide a minimal IFR capability. The simulated aircraft represented a generic single-rotor helicopter having a stability augmentation system for the three angular degrees of freedom. The task consisted of a simulated Category I IFR operation utilizing airports in the New York metropolitan area, with the airway route structure generally conforming to the IFR routes approved in November 1964 for use by New York Airways, Inc., with a Decca navigation system. Pilots of varying backgrounds, including pilots from New York Airways, participated in the tests.

ABBREVIATIONS

ADI attitude/director indicator

ATC Air Traffic Control

Category I weather conditions of 61 m (200 feet) ceiling and 805 m (0.5 mile) visibility

DME distance-measuring equipment

H	heliport
HSI	horizontal situation indicator
IFR	Instrument Flight Rules
LF	low-frequency navigation signal
MLS	microwave landing system
NDB	nondirectional beacon
NYA	New York Airways, Inc.
RMI	radio magnetic indicator
SAS	stability augmentation system
VFR	Visual Flight Rules
VHF	very high frequency
VOR	VHF omnidirectional range

Navigation facility designators:

CAT	Chatham
CRI	Canarsie
EWR	Newark
JFK	Kennedy
JRB	Wall Street
LGA	LaGuardia
MMU	Morristown

SIMULATION DESCRIPTION

Cockpit

A fixed-base, general-purpose cockpit, shown in figure 1, was utilized for this simulation. It was equipped with standard helicopter controls including a center stick for pitch and roll control, pedals for yaw control, and a collective-pitch lever for height control. A stick-force trim system was provided for pitch and roll and was actuated by a thumb switch on the center stick. The instrument display, shown in figure 2, contained an airspeed indicator, altimeter, attitude/director indicator (ADI), horizontal situation indicator (HSI), torque meter, rate-of-climb indicator, and radio magnetic indicator (RMI). The instrument configuration was selected to closely represent current commercial practice. It should be noted that the director command bars on the ADI were not actuated during the tests.

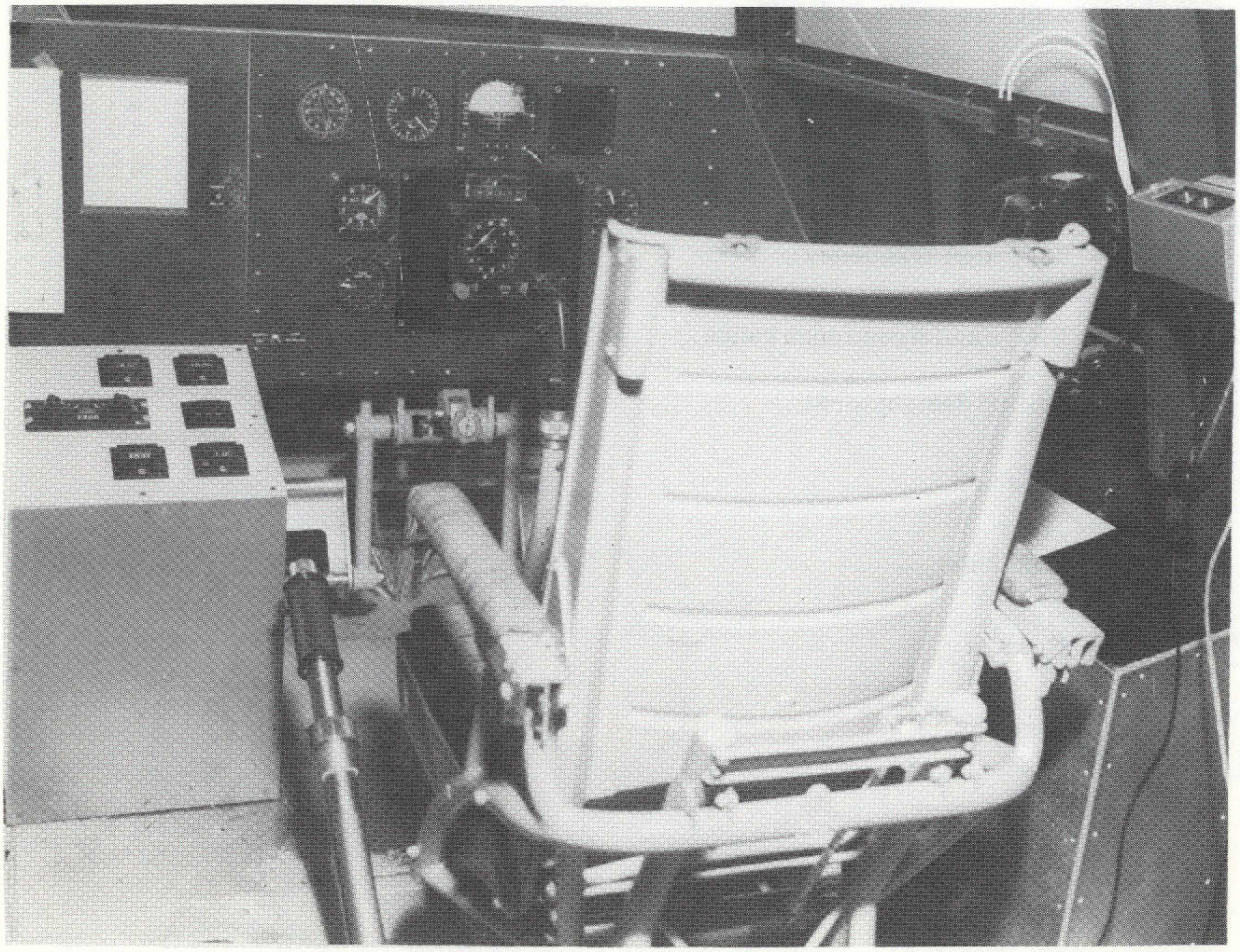

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Figure 1.- Simulator cockpit.

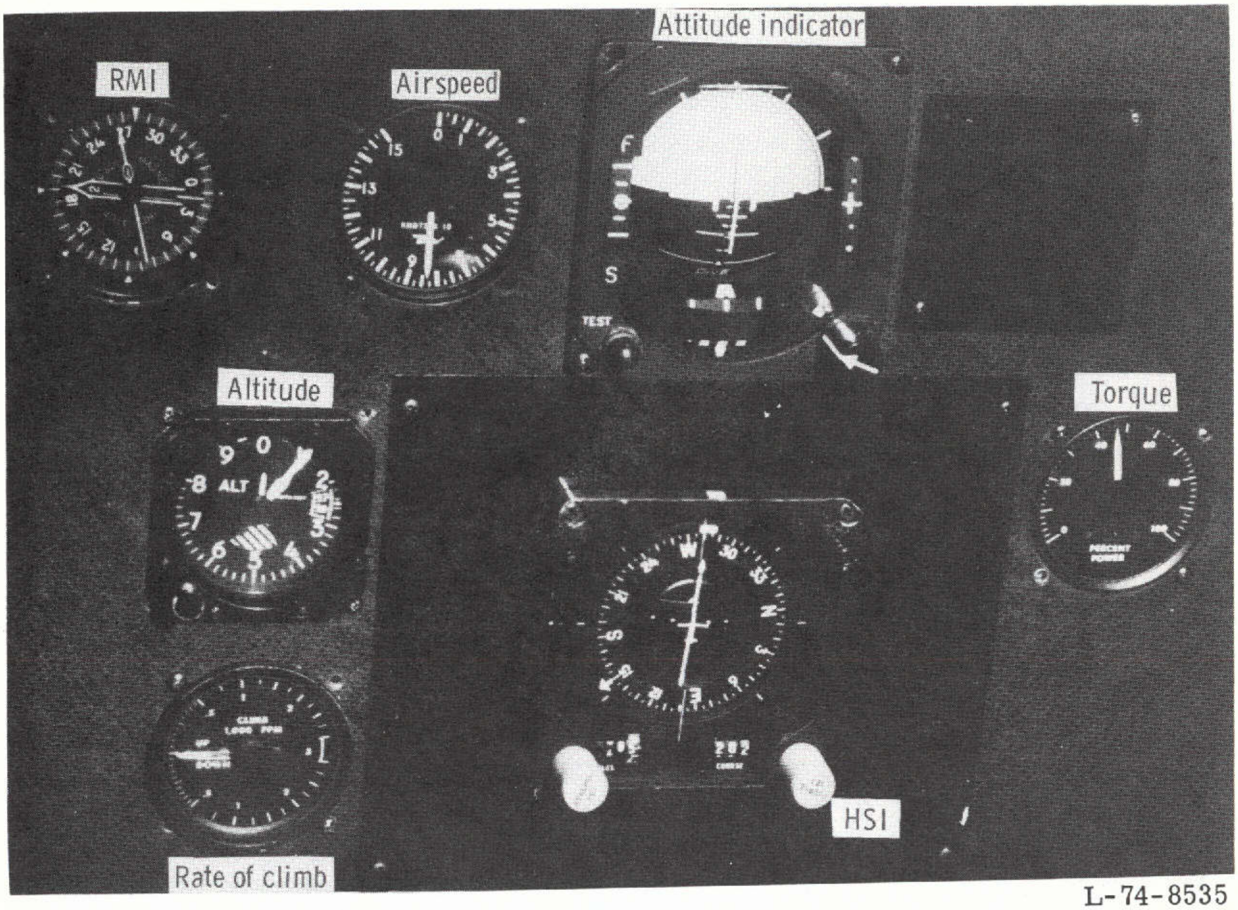

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Figure 2.- Simulator instrument panel.

Three radio-control heads for tuning the navigation receivers were also installed in the cockpit and labeled MLS, VOR, and LF. The MLS deviation information was presented on the ADI and HSI, along with range information on the HSI. The VOR receiver drove the number 2 needle on the RMI and presented a relative bearing to the selected station. Similarly, the LF receiver drove the number 1 needle on the RMI to give a relative bearing to the selected NDB station.

Simulation Model

A mathematical model and a real-time simulation computer program described in reference 1 were developed to represent a single-rotor helicopter. This program was modified to represent approximately the Sikorsky S-61, a commercial 24-passenger helicopter used by New York Airways, Inc., and San Francisco-Oakland Helicopter Airlines, Inc., the two major helicopter airlines in the United States. The major modifications to the basic model were the inclusion of an attitude SAS for the three angular degrees of freedom and new mathematical models for navigation and winds. It should be noted that the heading-hold feature of the SAS was not employed. The simulation model included mathematical representations of the main- and tail-rotor aerodynamics, blade dynamics, fuselage aerodynamics, engine dynamics, and stability augmentation system. Also included in the model were the aircraft force and moment equations, body derivative equations, and transformation equations used to define the position of the aircraft in relation to an Earth-fixed axis system for use in navigation.

The navigation model represented the radio navigation facilities existing in the New York metropolitan area, which are indicated on the map in figure 3 along with the simulated route structure. These radio facilities included VOR stations existing at Kennedy, LaGuardia, and Canarsie, and low-frequency stations at Newark and Chatham. The mathematical model computed aircraft position relative to the particular radio aids tuned by the pilot for display on the cockpit indicators. Data provided by the Federal Aviation Administration concerning radio coverage in the New York area indicated marginal signal strength at low altitudes; nevertheless, it was assumed for these tests that an altitude of 335 m (1100 ft) would be adequate for the selected route structure, which provides corridors 4 n. mi. wide, as shown in figure 3.

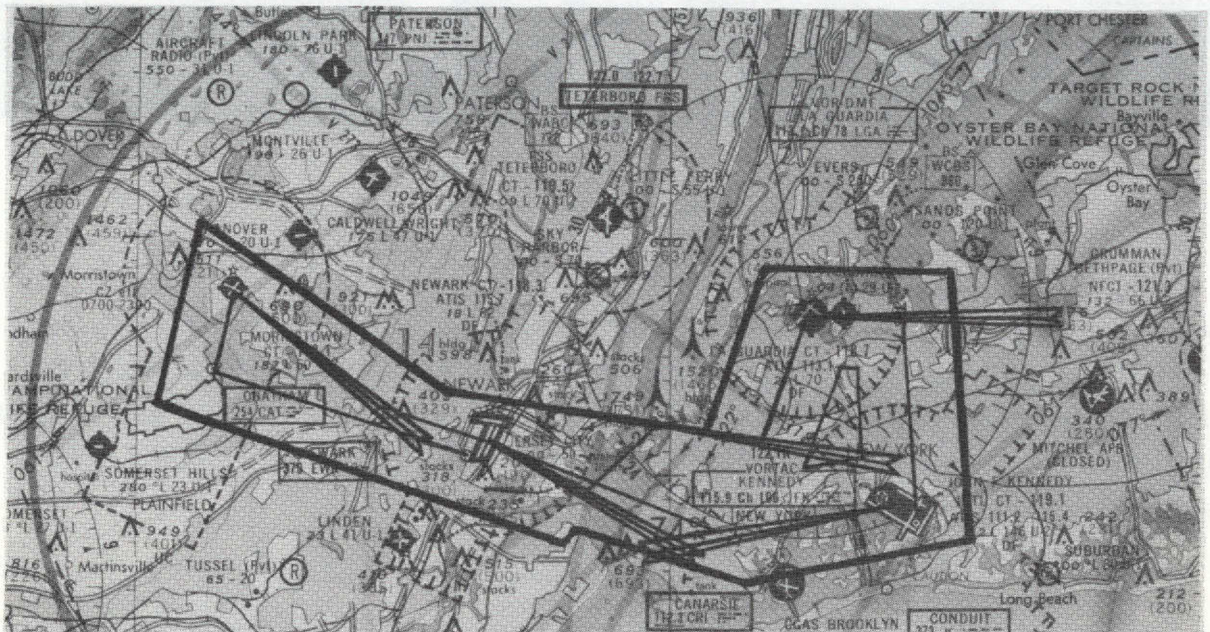

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Figure 3.- Airway design.

For the navigation model, the existence of a heliport at Kennedy, LaGuardia, Wall Street, Newark, and Morristown was assumed. Further, a precision approach guidance system was simulated at each heliport. This system was modeled after a candidate interim microwave landing system (MLS) which had the operational characteristics summarized in the following table:

Radio transmitter frequency, GHz	15.5
Power (average), W	10
Glide-slope angle (adjustable), deg	2 to 6
Glide-slope beam width (adjustable), deg	1.5 to 2
Localizer coverage, deg	±30
Localizer beam width (adjustable), deg	4 to 6

Orientation and details of the approach and route segments associated with each terminal are given in figure 4. It should be noted that an M prefixed to the standard airport designator was used in figure 4 to designate the simulated instrument landing system; for example, MLGA indicated the simulated approach system at LaGuardia. The geometric characteristics simulated for the guidance system are illustrated in figure 5, along with the coverage window at the Category I decision height of 61 m (200 ft).

A wind model, consisting of a steady-state wind component on which random gusts were superimposed, was developed for this study. The wind velocities selected were between 10 and 15 knots, and the direction was progressively varied in 30° increments prior to the initiation of each circuit to minimize any data bias caused by wind direction. Figure 6, which is a plot of the data obtained from reference 2, shows that the wind velocities seldom exceed the wind spectrum chosen for the simulation. A Dryden gust model (refs. 3 and 4) was used to generate gust disturbances by passing the output of a white-noise generator through three shaping filters, one for each aircraft body axis. The root mean square of the resultant gust intensity was approximately 2.6 knots.

Test Procedure

Six pilots were used for the data runs: two were NYA senior captains, two were NASA research pilots, and two were aeronautical engineers who had operational piloting experience in helicopters. Each pilot received approximately 1 hour of training time on the simulator before starting his data runs.

Each pilot flew the entire route structure, consisting of six segments, twice. The initial conditions consisted of an airspeed of 70 knots at an altitude of 30 m (100 ft) over JFK. The pilot was directed to climb to an altitude of 335 m (1100 ft) while accelerating to 120 knots, navigate by VOR or NDB to the next terminal, reduce airspeed to 70 knots,

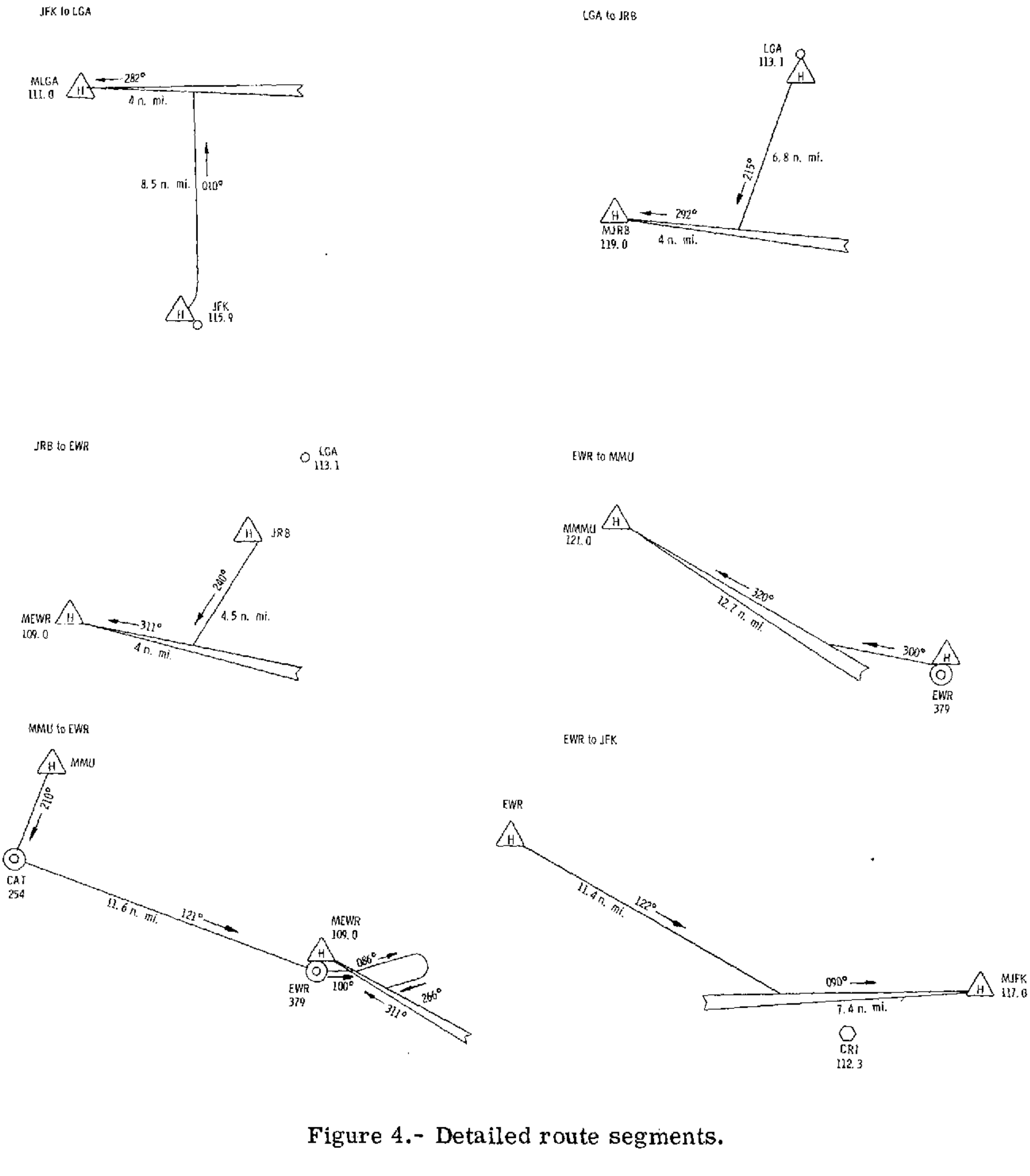

Figure 4.- Detailed route segments.

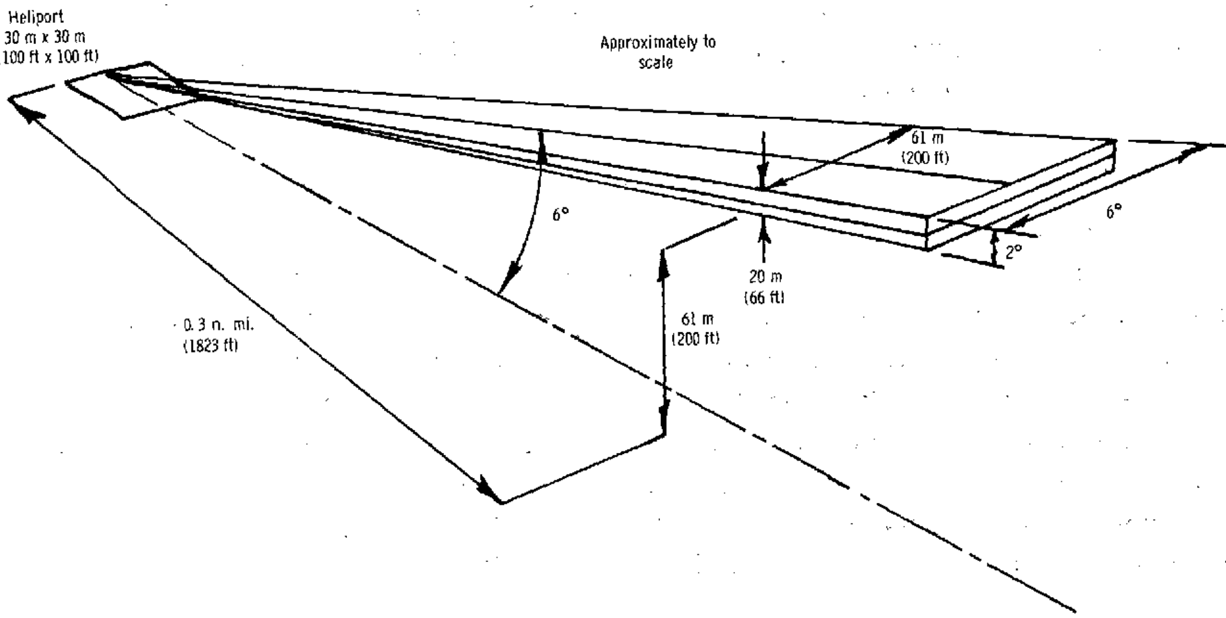

Figure 5.- Geometry of simulated guidance system showing decision height dimensions.

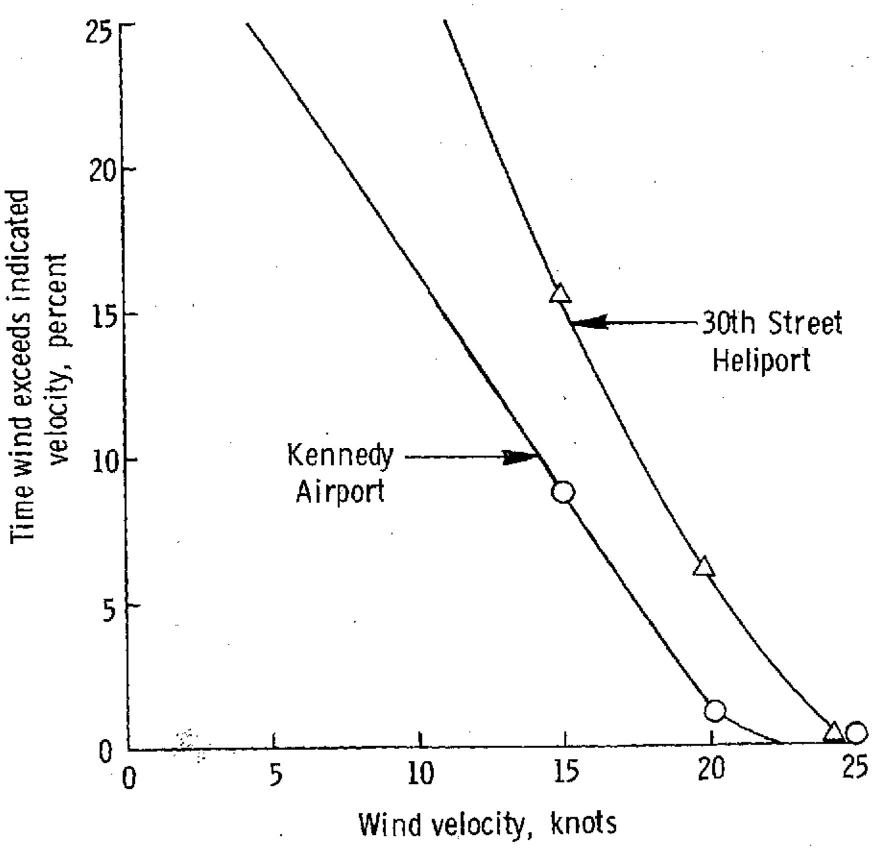

Figure 6.- Results of wind studies of New York area.

intercept the localizer, and make an approach to a simulated breakout at an altitude of 61 m (200 ft). At that point, the approach was terminated, and the pilot prepared for the next leg of the route by retuning the radios.

Data

Ground tracks were recorded by an x-y plotter on an aeronautical chart of the New York metropolitan area. Two eight-channel recorders were used for producing time histories of pertinent parameters desired. Localizer error, glide-slope error, and airspeed were recorded on computer printouts for statistical processing. For each run, data points were then selected at predetermined distances from touchdown. These points, in the form of data cards, were processed with a standard statistical computer program to obtain such measurements as standard deviations and mean values. These data were then plotted. Where values are given in both SI and U.S. Customary Units, the measurements and calculations were made in U.S. Customary Units.

RESULTS AND DISCUSSION

En Route Navigation

A composite of the 12 test runs of the complete route structure, 2 for each pilot, is presented in figure 7. The figure also shows the outline of the overall route comprising en route and approach corridors which were 4 n. mi. wide. Even though such a corridor could not be defined for the approach to the Wall Street Heliport because of the proximity of obstructions extending into the airspace, this segment was retained in the simulation to provide a basis for comparison of test results with the VFR experience of NYA. In any event, the pilot had no explicit indication of his position relative to any of the corridor boundaries. Their primary purpose was to provide a qualitative basis for assessing en route navigation performance and for defining the routes in a realistic manner, whereas the minimum en route altitude would provide an obstruction clearance of 152 m (500 ft).

Inspection of figure 7 indicates that no violation of the 4 n. mi. corridor occurred during the en route phase. Although, as shown in the figure, one departure from JFK was inadvertently initiated in the wrong direction, the recovery was still within the corridor. Also, even the procedure turn required on the approach to Newark from the west stayed within the corridor.

Final Approach

Intercept.- Final approach guidance was provided by the MLS. Flight procedures with the MLS were similar to those for a conventional instrument landing system (ILS). The only significant difference was in the course-deviation information; an ILS always

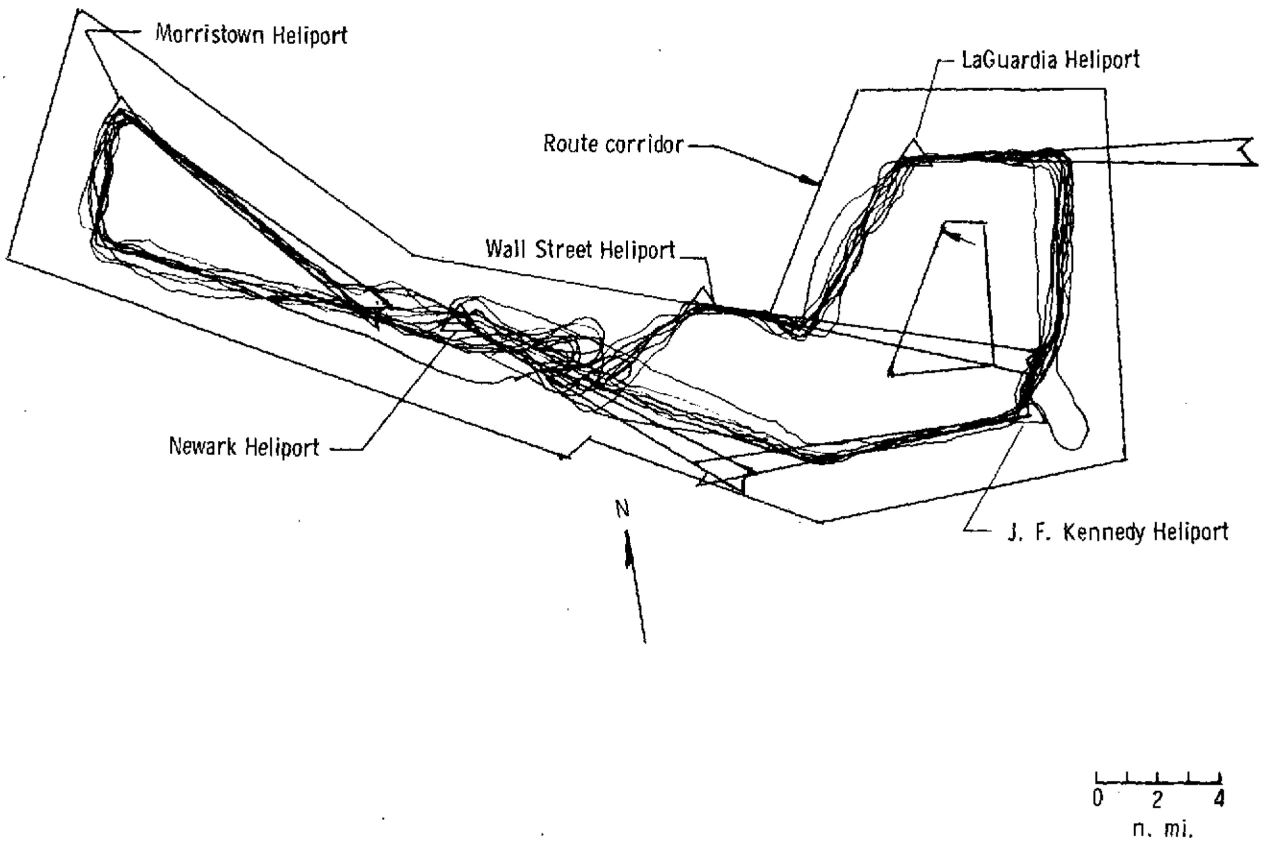

Figure 7.- Ground-track composite.

indicates the direction of the course center line, whereas the simulated MLS provided no information outside a $\pm 30^{\circ}$ angle from the center line. The pilots regarded this as an undesirable characteristic which, coupled with the fact that the course-deviation indicator was not driven out of view prior to interception of the localizer beam, sometimes resulted in a tendency to turn in the wrong direction.

Some of the intercept angles were considered to be too large, which resulted in overshoots during localizer capture; however, all the pilots were able to accomplish the task. Although a smaller angle would probably have increased precision, it would have tended to increase flight time because of the need to start the turn-on farther out.

Approach precision.- During the tests, 72 approaches were initiated, of which 3 were aborted. The aborted approaches would have resulted in the execution of missed-approach procedures under operation conditions, but such procedures were not defined for these tests. Two of the approaches were aborted because of excessive localizer error at or near the decision height, whereas the third was aborted because of excessive deviation from the nominal airspeed.

Plots showing localizer, glide-slope, and airspeed control achieved by each pilot are presented in figures 8, 9, and 10, respectively, for the six approaches involved in one

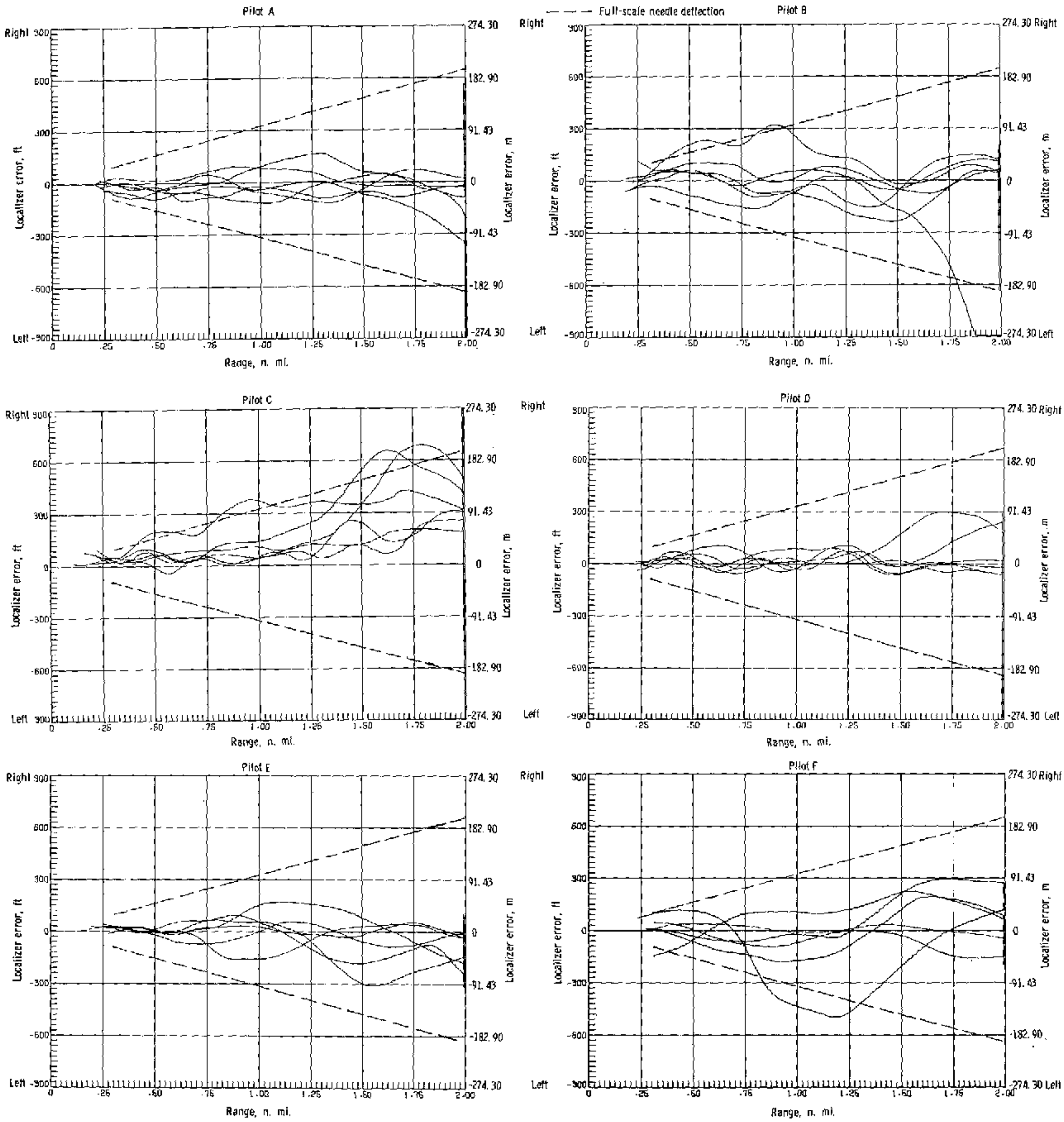

Figure 8.- Localizer tracking.

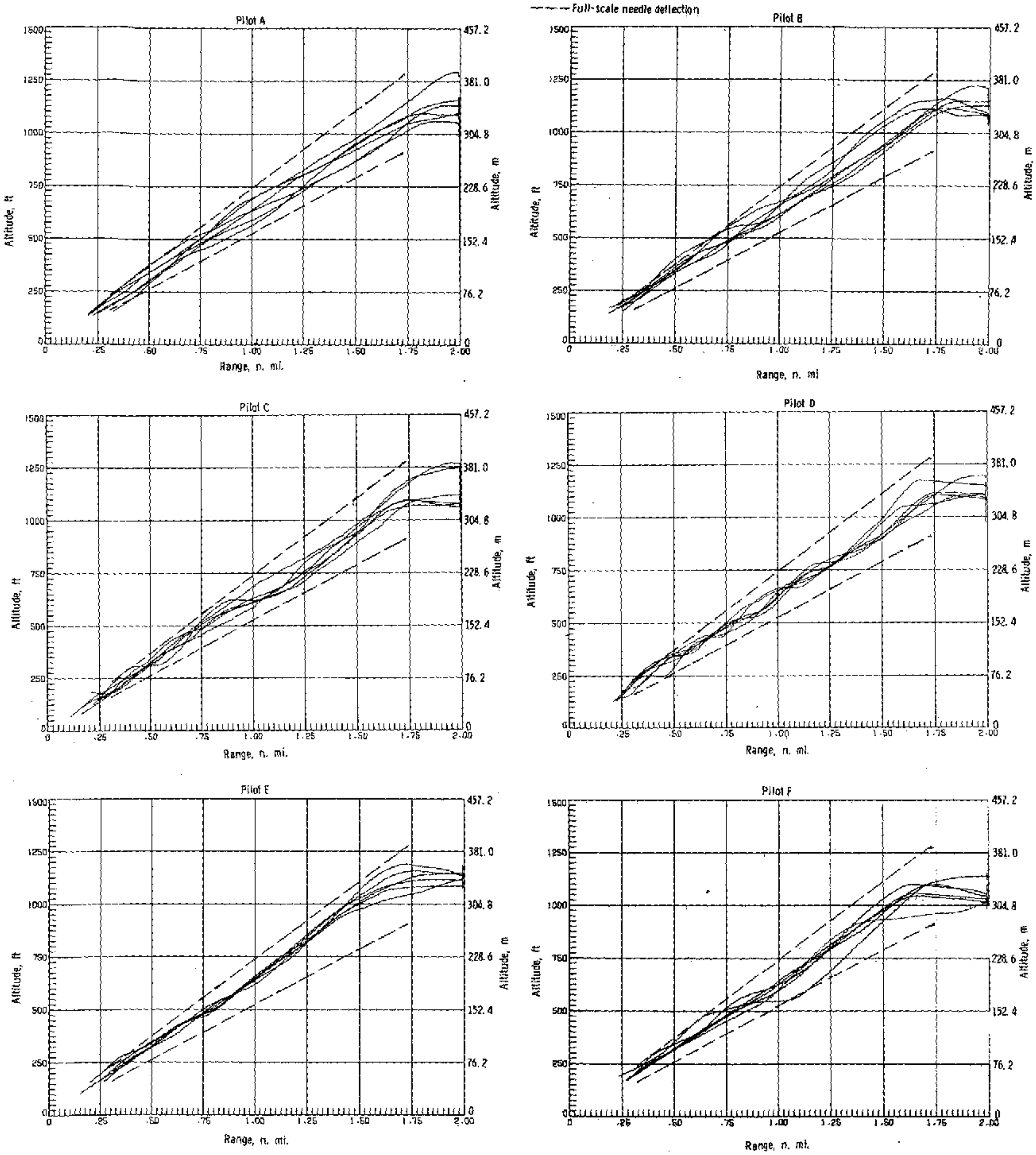

Figure 9.- Glide-slope tracking.

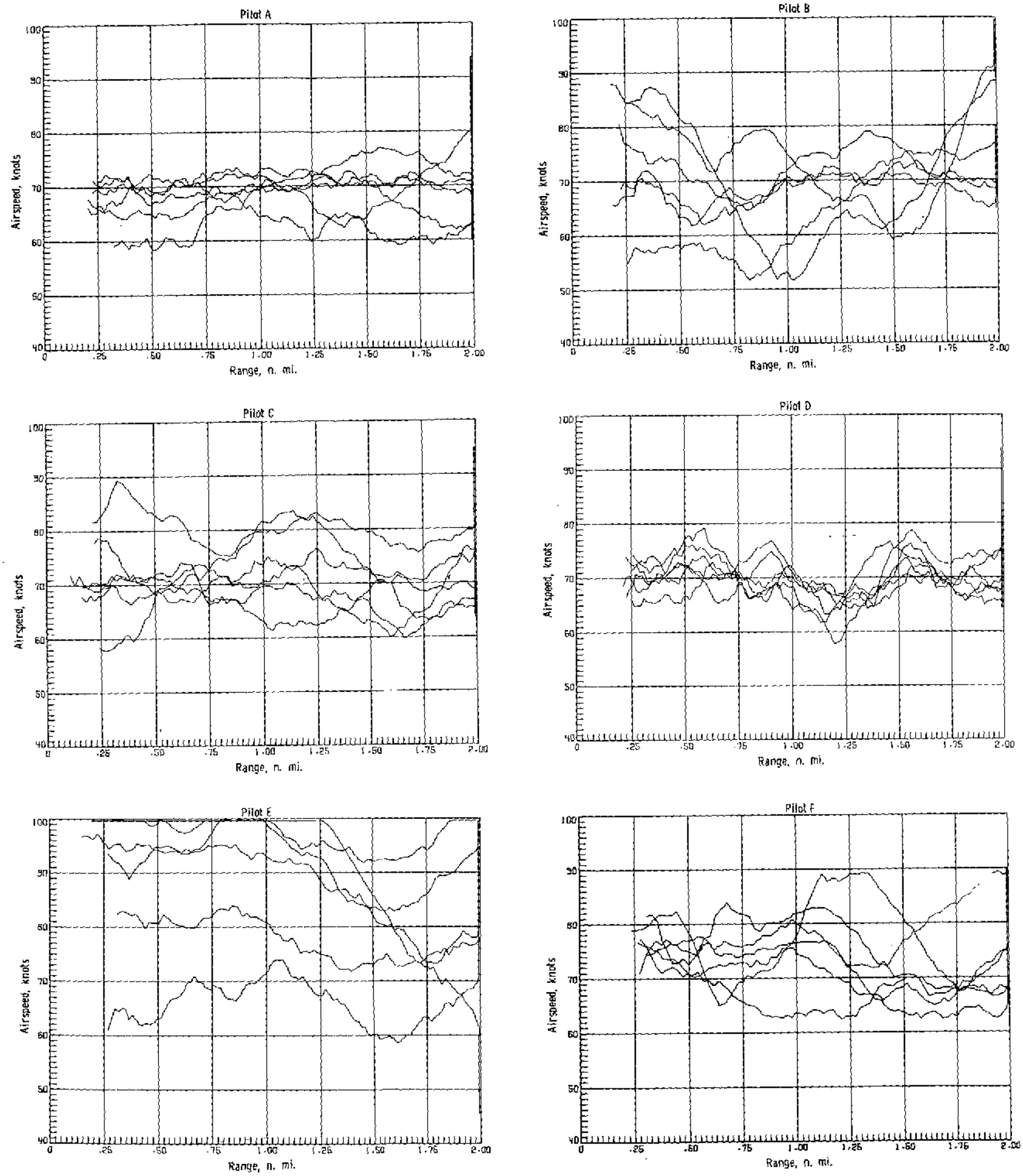

Figure 10.- Airspeed variation (nominal airspeed, 70 knots).

complete circuit of the test course. Sinusoidal variations are quite evident in the localizer tracking performance, but their amplitude generally decreased as range was reduced. Glide-slope control was considered satisfactorily precise, with the pilots tending to track high on the glide slope at the lower altitudes as an added safety margin. Airspeed control was generally poor and erratic, which indicated considerable control difficulty from the standpoint of both precision and accuracy.

A statistical analysis of all approaches, excluding the three aborts, was performed to determine the mean value and the standard deviation, or σ-value, associated with the localizer, glide-slope, and airspeed performance. The results of this analysis for a total of 69 approaches are presented in figures 11, 12, and 13 in terms of the mean value and the 3σ deviation. (Assuming a normal distribution for the deviations, the 3σ deviation would be exceeded only about 0.25 percent of the time.) Figures 11 and 12 show localizer and glide-slope performance, respectively, and include for comparison the deviation levels that would correspond to full-scale instrument deflection. The mean values and 3σ deviations computed at the Category I decision height for altitude, localizer, and airspeed error are summarized as follows:

	Mean	3σ
Altitude error	0.1 m (0.3 ft)	22.9 m (75.0 ft)
Localizer error	1.9 m (6.2 ft)	30.6 m (100.3 ft)
Airspeed error	4.1 knots	30.5 knots

Comparison of VFR and IFR Flight Times

A comparison of VFR and IFR flight times is presented in the following table for each leg of the route:

Route segments	Flight time, min		Time difference	
	VFR	IFR	Min	Percent
JFK to LGA	5.0	9.0	4.0	80
LGA to JRB	4.0	5.4	1.4	35
JRB to EWR	4.0	6.9	2.9	73
EWR to MMU	7.0	8.8	1.8	26
MMU to EWR	7.0	15.1	8.1	116
EWR to JFK	10.0	12.0	2.0	20

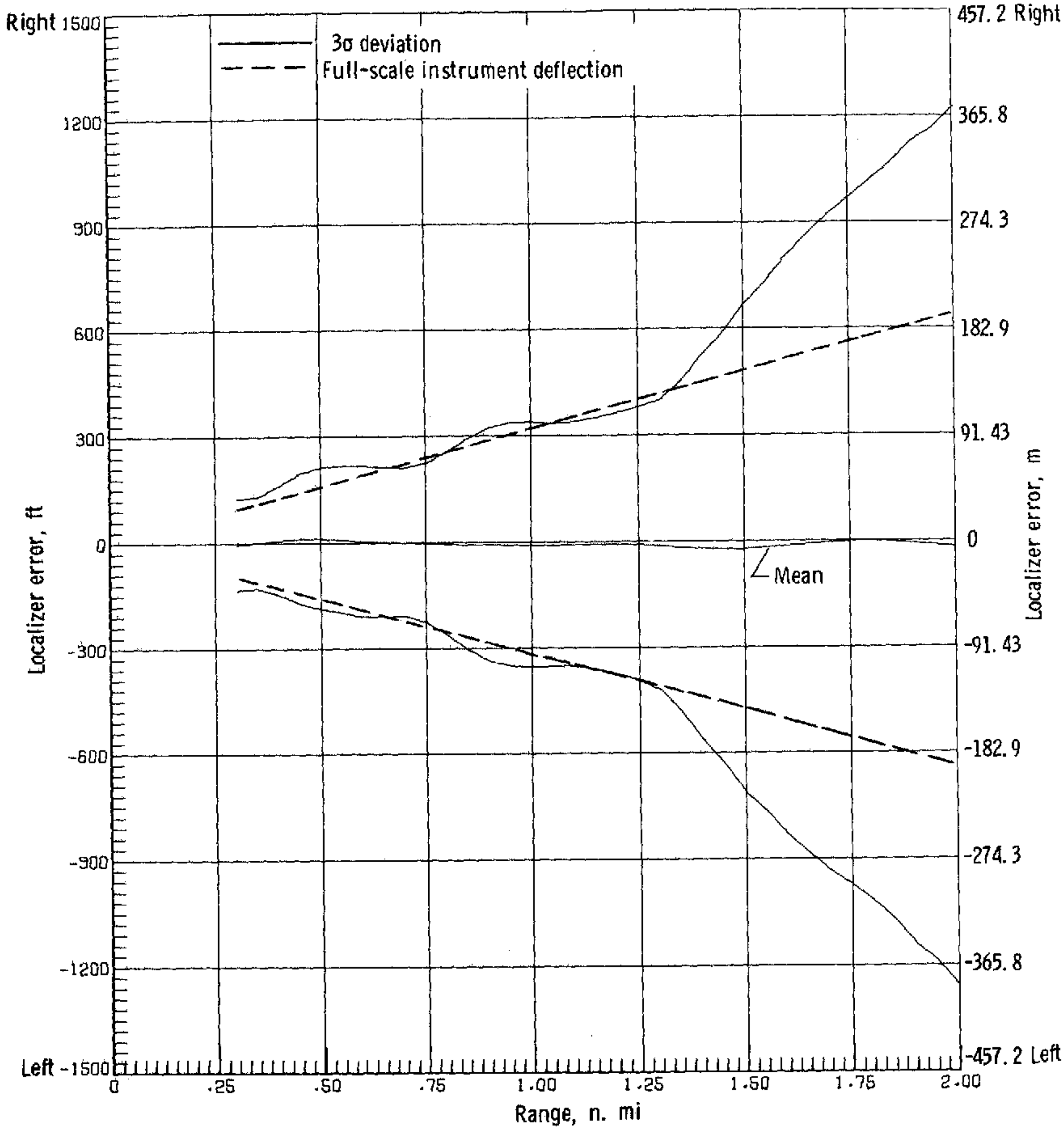

Figure 11.- Statistical localizer error.

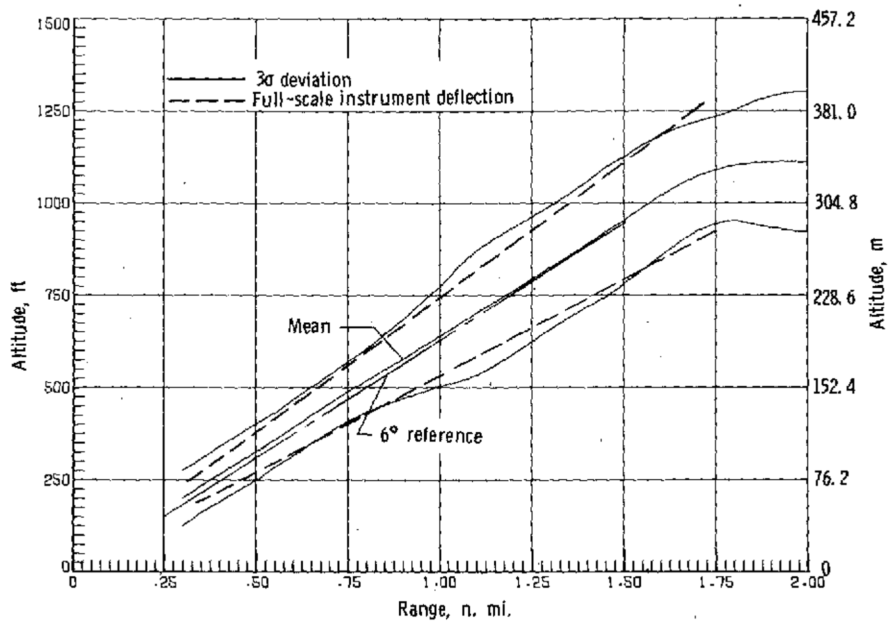

Figure 12.- Statistical glide-slope error.

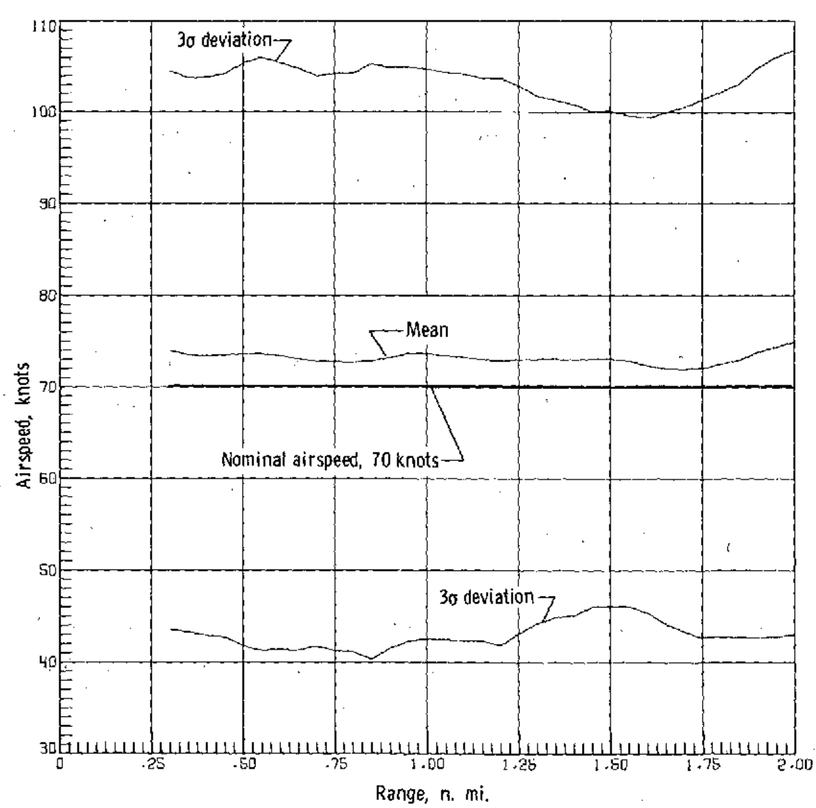

Figure 13.- Statistical airspeed error.

The VFR times were based on schedule block times for the New York Airways' VFR operation, with ground taxi time substracted to yield actual flight times. The IFR times were based on the average point-to-point results obtained during these tests plus an allowance of 40 seconds to compensate for the fact that the tests were initiated at an altitude of 30 m (100 ft) and terminated at an altitude of 61 m (200 ft). As might be expected, the flight time for the IFR task was substantially greater than for the VFR task, which is characterized by direct terminal-to-terminal flight with minimum constraints. By contrast, the IFR procedures resulted in increased stage lengths because it was necessary to operate in the specified route corridors and to cope with airspeed and altitude constraints. The airspeed constraint required deceleration to the low approach speed while still several miles from the landing pad, and the altitude constraint required additional time for climbing to and descending from higher minimum en route altitudes. The total time for the IFR task was about 55 percent greater than for the VFR operation, the greatest loss occurring between Morristown and Newark because of the required procedure turn which took approximately 5 min. A second MLS at Newark would have eliminated this delay. These time differences, however, do not make any allowance for ATC-related delays, which would be most severe, of course, during IFR conditions.

Pilot Workload

An actual IFR operation of the type investigated in this study would typically require a pilot-copilot team to handle the normal tasks including navigation, aircraft control, and ATC communications. Because of simulator constraints, however, the operation was conducted by a single pilot, but the workload was reduced accordingly by eliminating the ATC-communications task and by requiring the radios to be tuned prior to each run. Discussion of pilot workload in this paper, therefore, relates primarily to the navigation and control tasks.

The workload in flying the circuit varied from very low to extremely high. The low workload condition occurred during the en route portion of the task while tracking a station radial at constant speed and constant altitude. The highest workload occurred during the final approach and could range from moderate to extremely high, depending on how well the pilot had been able to establish the desired conditions of speed, crab angle, and power prior to glide-slope intercept.

Sensitivity of both the localizer and the glide slope caused difficulty at short range. With the localizer and glide-slope transmitters colocated at, or near, the landing pad, small linear deviations at short ranges caused large instrument deflections, which gave the pilot the false impression that tracking performance was very poor. This problem could be eliminated, of course, by beam softening to prevent increased sensitivity with reduced range.

Time histories of selected parameters are shown for a typical approach in figure 14. The control movements and vehicle attitude changes give a qualitative insight into the pilot workload and appear to confirm the pilots' impressions of excessively high activity. Also, from a ride-quality standpoint, it seems likely that the vehicle motions evidenced during this approach would be considered objectionable by both pilots and passengers.

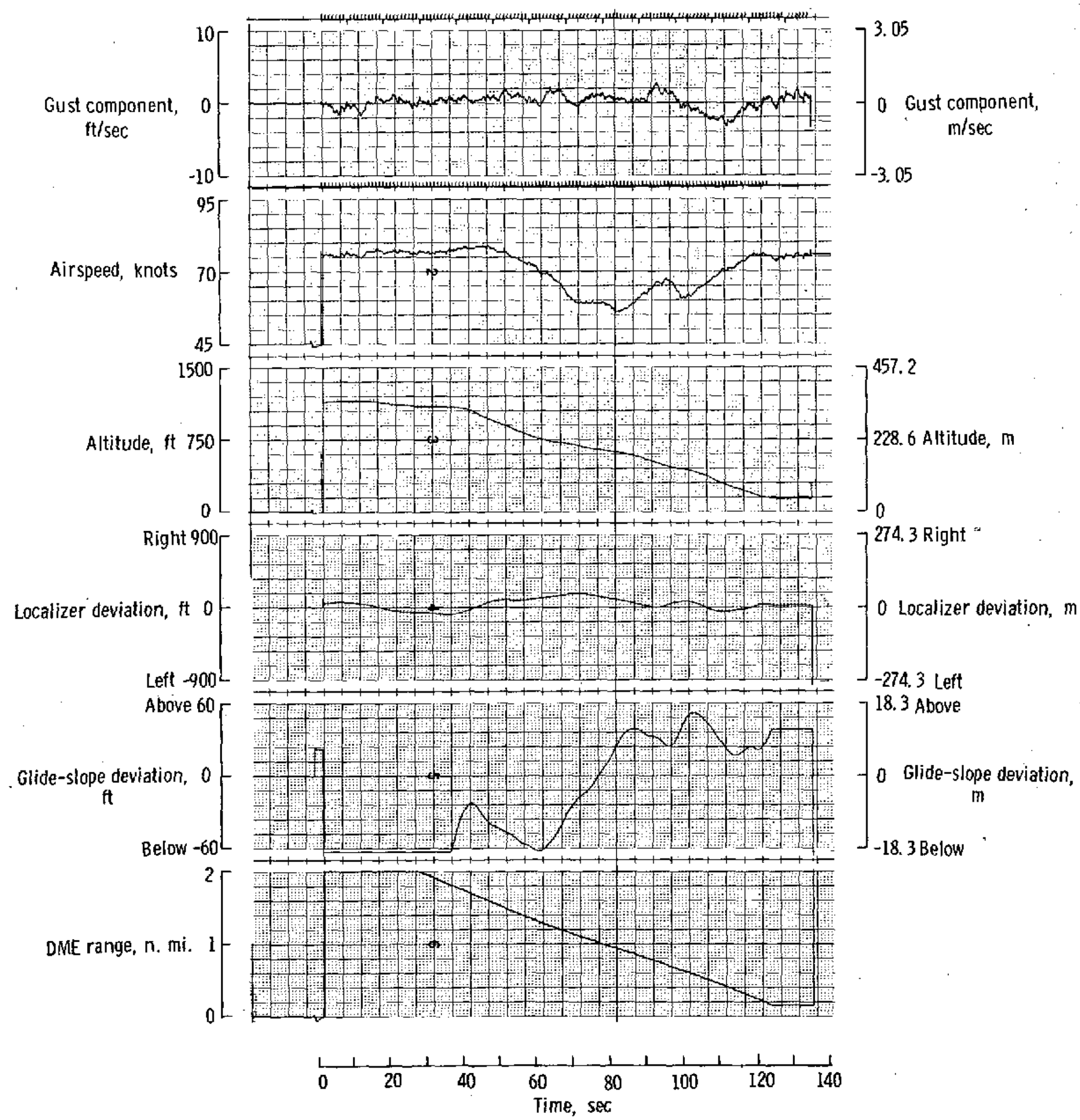

Figure 14.- Time history of typical approach.

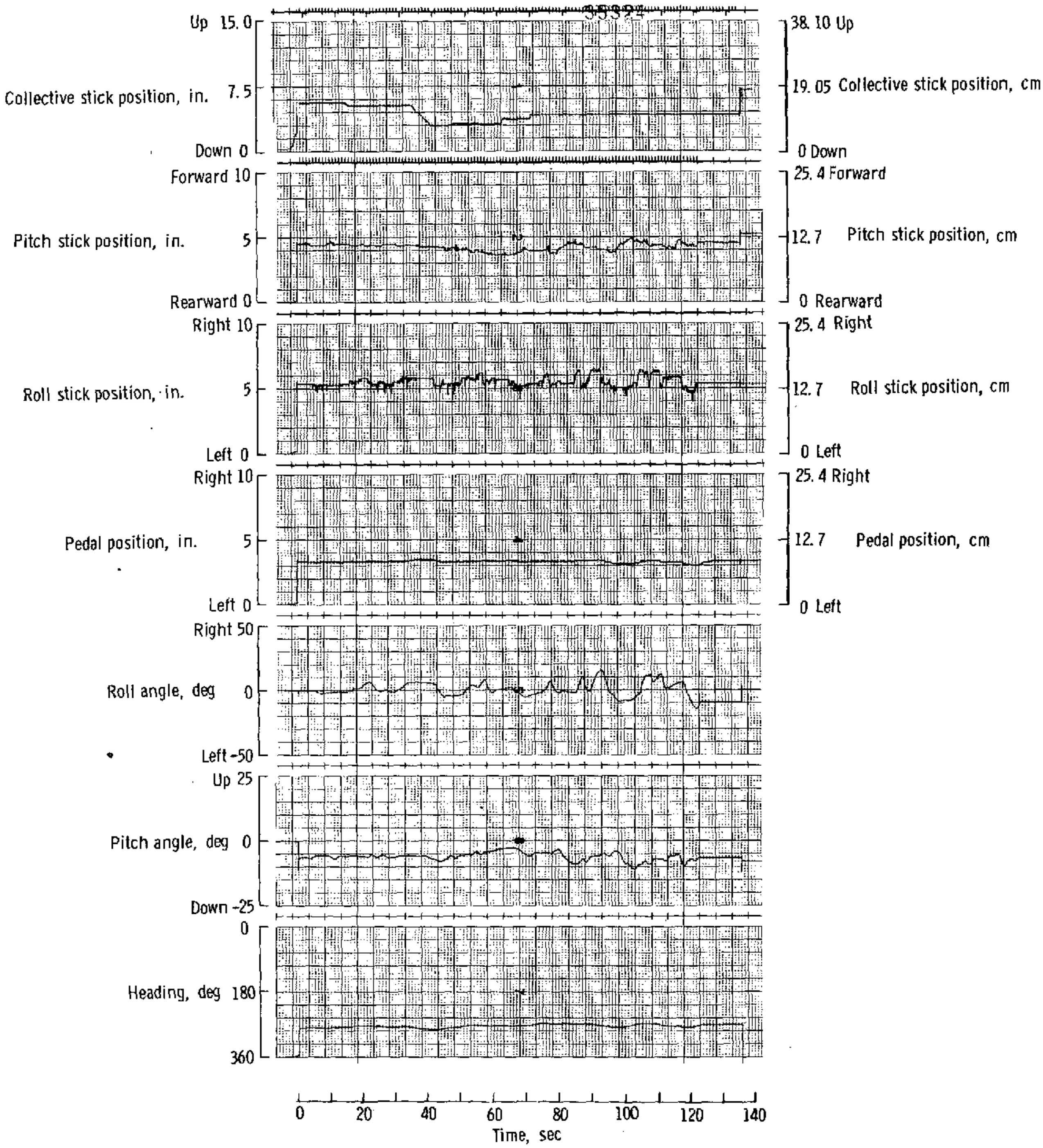

Figure 14.- Concluded.

A substantial factor contributing to the unacceptability of the workload was the high frequency of the take-off and landing operations, which was a consequence of the very short segments making up the route. In segments as short as 8.5 n. mi., for example, the pilot was required to accelerate, climb, decelerate, and perform a precision approach.

Since the ground rules under which this study was conducted specified both minimum display and control system characteristics, the high level of pilot workload experienced was not unexpected; yet the performance achieved in flying the route was judged to be satisfactory. It was the consensus of the pilots that a flight director display, which provides commands for speed, power, and bank angle, would be highly beneficial in reducing their workload by lessening the need for continual cross-check of MLS deviations, airspeed, and vertical rate during the approach. From the standpoint of control-system improvement, the desirability of a heading-hold feature was frequently mentioned as a means of allowing the pilot a greater opportunity to concentrate on speed and power control.

CONCLUSIONS

A piloted simulation of instrument flight operations for intracity helicopter passenger service was conducted during which elementary instrument displays were used to obtain pilot workload and task performance data. Based on the results obtained, the following conclusions are drawn:

1. A primary contribution to the relatively high overall pilot workload was the high frequency of take-off and landing operations, a result of short route segments. Nearly continuous pilot attention was required to execute an instrument approach for route segments as short as 8.5 n. mi.

2. Pilot workload was considered to be unsatisfactorily high for the intercept and the final portions of the precision approach, although task performance relative to flight-path control was satisfactory.

3. Although IFR en route navigation did not present a problem, the IFR flight time for the total route was about 55 percent greater than the VFR flight time. This difference was the result of the increased stage lengths required by IFR procedures and of the reduced speed used during the MLS approach.

4. Analysis of the results suggests that substantial workload reduction would be realized through improvements in the stability augmentation system and in the displays and through modifications to the route structure to reduce the localizer intercept angle.

Langley Research Center
National Aeronautics and Space Administration,
Hampton, Va., November 18, 1974.

REFERENCES

1. Houck, Jacob A.; Gibson, Lucille H.; and Steinmetz, George G.: A Real-Time Digital Computer Program for the Simulation of a Single-Rotor Helicopter. NASA TM X-2872, 1974.

2. American Airlines, Inc.: Airline View of STOL System Requirements. Rep. No. DOT-OS-10075, AAL-ER&D-56, U.S. Dep. Transportation, Feb. 1972.

3. Houbolt, John C.; Steiner, Roy; and Pratt, Kermit G.: Dynamic Response of Airplanes to Atmospheric Turbulence Including Flight Data on Input and Response. NASA TR R-199, 1964.

4. Pritchard, Francis E.: A Statistical Model of Atmospheric Turbulence and a Review of the Assumptions Necessary for Its Use. Stability and Control, Pt. 2, AGARD CP No. 17, Sept. 1966, pp. 907-936.

NASA-Langley, 1974 L-9709