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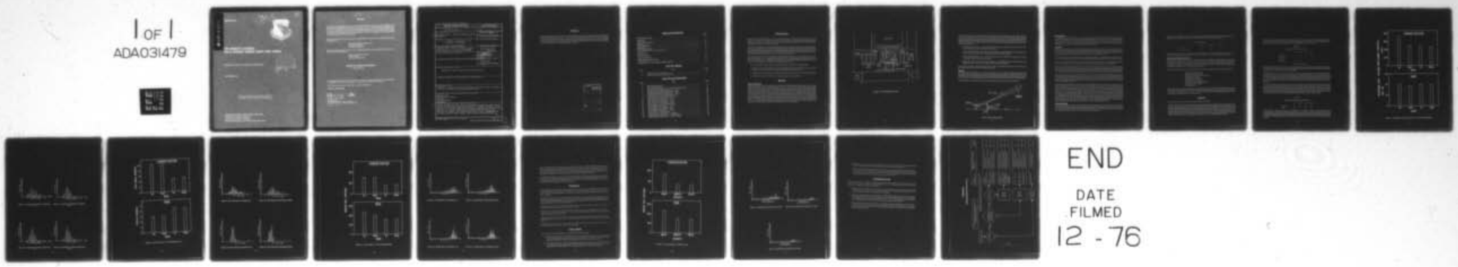

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AEROSPACE MEDICAL RESEARCH LABORATORY

SEPTEMBER 1976

AEROSPACE MEDICAL RESEARCH LABORATORY
AEROSPACE MEDICAL DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

NOTICES

TECHNICAL REVIEW AND APPROVAL

AMRL-TR-76-69

This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

ROBERT E. VAN PATTEN
Acting Chief
Environmental Medicine Division
Aerospace Medical Research Laboratory

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A man-in-the-loop simulation study was performed to investigate remote operator control of an RPV during approach and landing in instrument conditions. Pitch attitude and flight path angle stabilization were compared using both pilots and nonpilots. The results showed better performance with flight path angle stabilization; however, loss rates were high for all modes. Recommendations were made concerning remote operator control during routine operations.

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PREFACE

The experimentation reported herein was conducted by the Aerospace Medical Research Laboratory, Environmental Medicine Division, in 1975 as a study on human operator control of remotely piloted vehicles. It was conducted in support of the Air Force Flight Dynamics Laboratory's work on a landing system for the Compass Cope reconnaissance vehicle. The AMRL project was 6893, task 02, "Optimization of Crew Effectiveness in Weapon Delivery systems."

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INTRODUCTION

Remotely Piloted Vehicles (RPV) are in development as future Air Force operational systems. In the design of these unpiloted aircraft, many options are open to the control designer. The degree of remote operator involvement in the flight control process is an important consideration, not only for individual aircraft types, but even for mission segments.

In 1974, the AF Flight Dynamics Laboratory (AFFDL) undertook a research and development program to gain insight into the problem of all weather operations of RPV, particularly during approach and landing. That effort was directed at establishing design guidelines for adverse weather takeoff and landing systems for the Compass Cope reconnaissance aircraft. The program was designed to investigate the landing guidance, flight control, and remote operator criteria.

As part of that overall effort, the Aerospace Medical Research Laboratory was requested to investigate the ability of a remote operator to control the RPV during an approach and landing in zero visibility conditions and to determine the effect of various control-display configurations on his performance. Specifically, the objectives of the AMRL study were to:

1. Train pilot and nonpilot subjects to operate the RPV by instrument reference alone.

2. Determine whether satisfactory levels of performance could be achieved, given a remote operator manual takeover at various points during the landing approach.

3. Compare four control-display configurations to determine the best for remote operator control.

4. Compare the results of using pilots versus nonpilots as remote operators.

METHOD

SIMULATION SETUP

A remote operator's console configuration similar to the AFFDL console was chosen for use in the AMRL study. The panel layout is depicted in Figure 1. The active instruments were the following: Attitude director indicator (ADI) with flight path angle tape, horizontal situation indicator (HSI), sensitive lateral deviation indicator, airspeed indicator, instantaneous vertical speed indicator, radar altimeter, barometric altimeter, and range-to-touchdown indicator. In addition, annunciator lights indicated the status of the automatic approach and landing system, including failures of both vertical and lateral-directional axes. A pictorial view of the approach and runway environment was displayed on the video screen for initial subject familiarization and training only. The vertical and horizontal needles on the ADI displayed glide slope and localizer error. The instruments displayed raw flight data only; i.e., no flight director commands. Aircraft control was accomplished through pitch and roll (coordinated turn) inputs into a two-axis displacement side-arm controller.

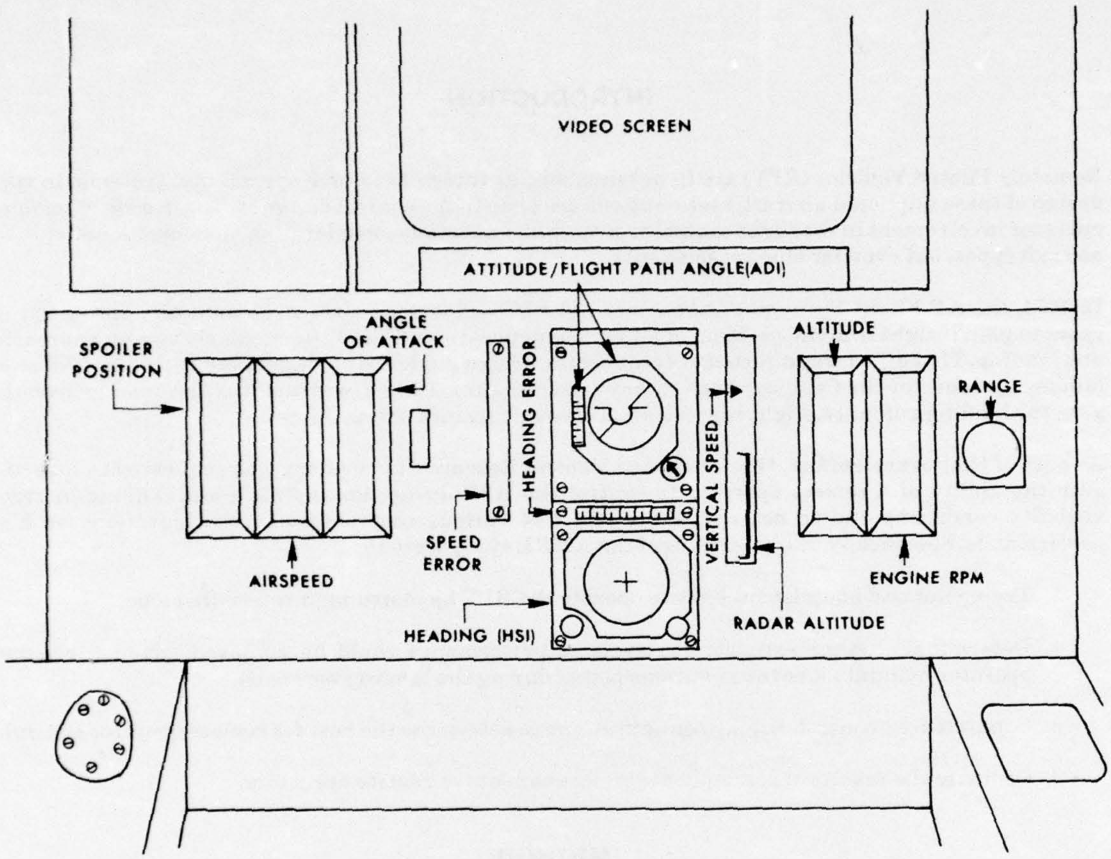


Figure 1. RPV Simulator Console

The aerodynamic data was simplified and linearized from the Compass Cope data. Two vertical control modes were simulated: pitch attitude (PA) and flight path angle (FPA). The FPA mode employed fast-acting spoilers and conventional elevator inputs to stabilize on the commanded FPA. Throttle/speed control and turn coordination were accomplished automatically by the flight control system. Two methods of information display were used for each control mode, thus giving four possible control-display configurations:

1. Pitch attitude (PA) only — stick displacement commands proportional pitch attitude, pitch attitude displayed, flight path angle not displayed.

2. Pitch attitude with flight path angle display (PA/FPA) — stick displacement commands proportional pitch attitude, pitch attitude and flight path angle both displayed.

3. Flight path angle (FPA) only — stick commands proportional flight path angle; pitch attitude not displayed, flight path angle displayed.

4. Flight path angle with pitch attitude (FPA/PA) — stick displacement commands proportional flight path angle, both pitch attitude and flight path angle displayed.

The aircraft dynamics, trajectory computation, scoring, and display generation were handled by an EAI 680 Pacer hybrid and a PDP 11/40 digital computer.

PROFILE

The flight profile consisted of a ten-mile final approach at a nominal 4° glide slope, flare, and touchdown. The true airspeed was constant at 100 knots. The approach profile is shown in Figure 2. The control system automatically performed the approach and landing until a simulated failure occurred; at that point the remote operator took over the failed axis or axes of control and completed the landing.

Low pass white noise simulated vertical and lateral gusts, but no wind shear was included.

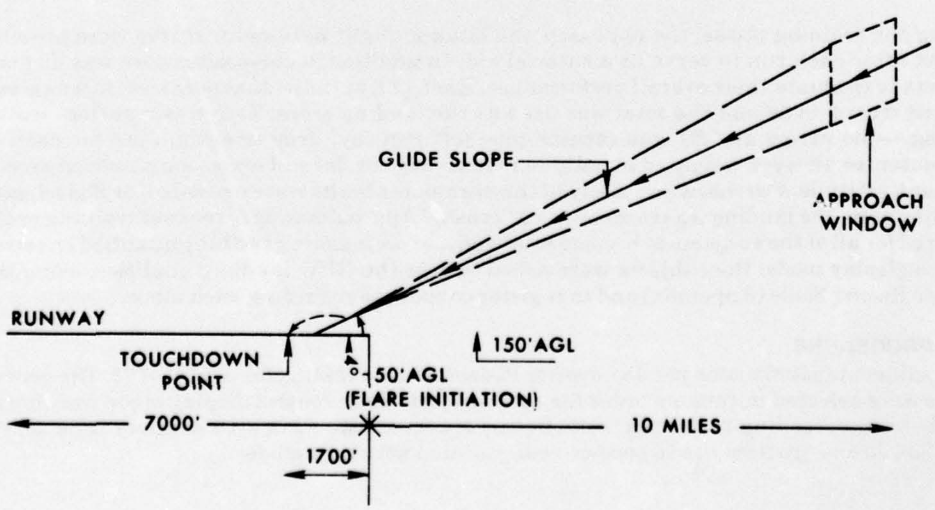


Figure 2. RPV Landing Profile

TEST SUBJECTS

Ten subjects participated in the study. Six began as naive members of a panel of trackers used for various experiments involving human operator performance. The other four were experienced instrument pilots. Two were regular KC-135 aircraft commanders, and two were civilian instrument instructor pilots. These four pilots were all between 25 and 30 years of age. Each had approximately 1300 flight hours except one civilian pilot with over 2000 hours.

TRAINING

All ten subjects were given an initial briefing during which the objectives of the study and the outline of the experimental plan were presented. Following this briefing, they completed a questionnaire to evaluate any preexisting attitudes they might have had concerning the overall task and the potential workload and accuracy associated with any of the four control-display modes.

Since the first objective of the study was to qualify the subjects to a predetermined degree of proficiency in the manual approach and landing task, the following procedures were developed for training.

First, an initial familiarization session acquainted the subjects with the information presented in each readout, the operation of the controls, and the control techniques necessary to fly the RPV.

Second, a control-display configuration was randomly selected for each subject on which to begin training. Using both the flight instruments and the outside world video display (a simulated TV view of the runway from the nose of the vehicle), each subject was taught to track the localizer and glide slope and to land the aircraft. After some degree of proficiency was attained, the video display was removed.

Third, the subjects were evaluated for proficiency level. If six successful (noncatastrophic) approaches and landings could be completed consecutively on a given day, they were considered qualified in that control-display mode and proceeded to learn another mode. If not, then remedial training was given until such proficiency could be attained. Upon completion of training for all four modes, the subjects were ready to begin data runs.

During the training phase, the approach and landing flight parameter scores were presented to the subject after each run to serve as a tutorial aid. In addition, a composite score was displayed to the subjects to evaluate their overall performance. Each of five individual parameters was given a figure of merit from 0 to 30 and the total was used as the landing score. Zero was a perfect score (nominal landing — no error) and 30 was catastrophic (off runway, drag wingtip, etc.) for each individual parameter, so all were weighted equally — rate of descent, lateral error, longitudinal error, heading, and bank attitude. Furthermore, if any of the parameter limits were exceeded, or if pitch attitude was less than zero, the landing was recorded as a "crash." Approximately 6 weeks of training each day were required for all of the subjects to become proficient. After reaching the fully qualified criterion for each control-display mode, the subjects were asked to rate the RPV handling qualities, using the Cooper-Harper Rating Scale (Appendix) and to register comments regarding each mode.

TEST PROCEDURE

Each subject made six runs per day during 12 days of data taking, for a total of 72. The control-display modes were selected in random order for each subject. Each control-display mode was flown for three days before proceeding to the next one. Before starting data runs with a different mode, the subject was allowed one practice run to become reacquainted with that mode.

During the six runs given each day, a random order of three points of automatic system failure in the approach and two degrees of failure were simulated, as shown in the following matrix.

	FAILURE POINT		
	5 Miles	*150' AGL*	*50' AGL*
Vertical Only	X	X	X
Vertical and Lateral	X	X	X

The task the subject was to accomplish consisted of taking over the failed automatic functions and manually completing the landing. No go-arounds were permitted; i.e., a landing was mandatory.

DATA COLLECTION AND ANALYSIS

Before beginning the experiment, each subject filled out a questionnaire to measure any preexisting biases. After each day's runs, the subjects completed a Cooper-Harper rating on that day's mode and recorded any comments they wished concerning the modes or runs. The Cooper-Harper ratings were tallied and averaged to determine the subjective preferences. The comments were summarized to determine deficiencies and to support the pilot ratings.

To measure performance, the following data were recorded on digital tape at 25 samples per second:

- Localizer deviation in feet
- Glideslope deviation in feet
- Distance to runway threshold in feet
- Bank angle in degrees
- Pitch attitude in degrees
- Flight path angle in degrees
- Vertical velocity in feet per second
- Heading error in degrees
- Altitude in feet

These data were recorded throughout the approach to facilitate modelling of the human operator if that became desirable. However, for the primary objectives of this study, the parameters existing at the instant of touchdown were analyzed to determine the quantitative differences between control-display mode configurations and subject groups.

RESULTS

The results of the experiment are listed by objective, as follows:

The first objective, that of training, took considerably longer than anticipated for several of the naive subjects, although all had extensive tracking experience from other programs. The most difficult area proved to be that of recognizing and correcting a dangerous vertical descent close to touchdown, as the required visual scanning rate and control bandwidth increased. The pilots, too, found this to be the most troublesome area, although they adapted much more quickly. The average training time was 2 weeks for the pilots versus 6 weeks for the nonpilots. The only consistent preexperimental bias that could be found was toward more displayed information; i.e., the combined display modes.

The second objective was to determine whether satisfactory remote operator performance could be achieved with any of the four modes used. The first measure used was that of Level 1 performance, or no crashes. Table 1 shows the distribution of crashes experienced in each mode.

TABLE 1

DISTRIBUTION OF CRASHES — 38

	PA	*PA/FP*	*FP*	*FP/PA*
Lateral error	2	4	0	1
Pitch down	1	0	0	0
Bank angle	0	0	1	0
Descent rate	19	12	1	1

(180 trials for each mode)

These figures indicate that even with best control/display modes, the operators had difficulty attaining consistent Level I performance. The percentage of approaches in the Level II performance category (acceptable for routine operations) was below 60%.

The third objective was to determine which of the four control-display modes tested would give the best landing performance. Of all the data collected, the only parameter found to have statistically significant differences between modes were longitudinal touchdown dispersion, pitch attitude, and rate of descent. Any differences in other measured parameters were not significant. The means and standard deviations of these three parameters are plotted, along with the actual distribution functions, in figures 3-17.

The largest differences appear between the pitch attitude control modes and the flight path angle control modes. Display variations seemed to have less effect upon performance. In general, the flight path angle control modes exhibited 30 to 50 percent improvements in the standard deviations of these three parameters. The Cooper-Harper ratings and subjective comments were in agreement with the performance results. Table 2 contains the average ratings given to each mode by both the pilots and the nonpilots, and it shows the excellent correlation of the ratings between subject groups.

TABLE 2

AVERAGE COOPER-HARPER RATINGS

	PA	*PAFP*	*FP*	*FPPA*
Nonpilots	3.5	3	2.5	2.5
Pilots	3.5	3	2	2

The subjective comments pointed out the tendency to overflare, or balloon, when using the pitch attitude modes. In addition, the workload with total system failure was considerably higher for the pitch attitude control modes than for the flight path angle control modes. The pilots, however, regarded the pitch attitude display as more familiar and therefore easier to learn than the flight path angle only display.

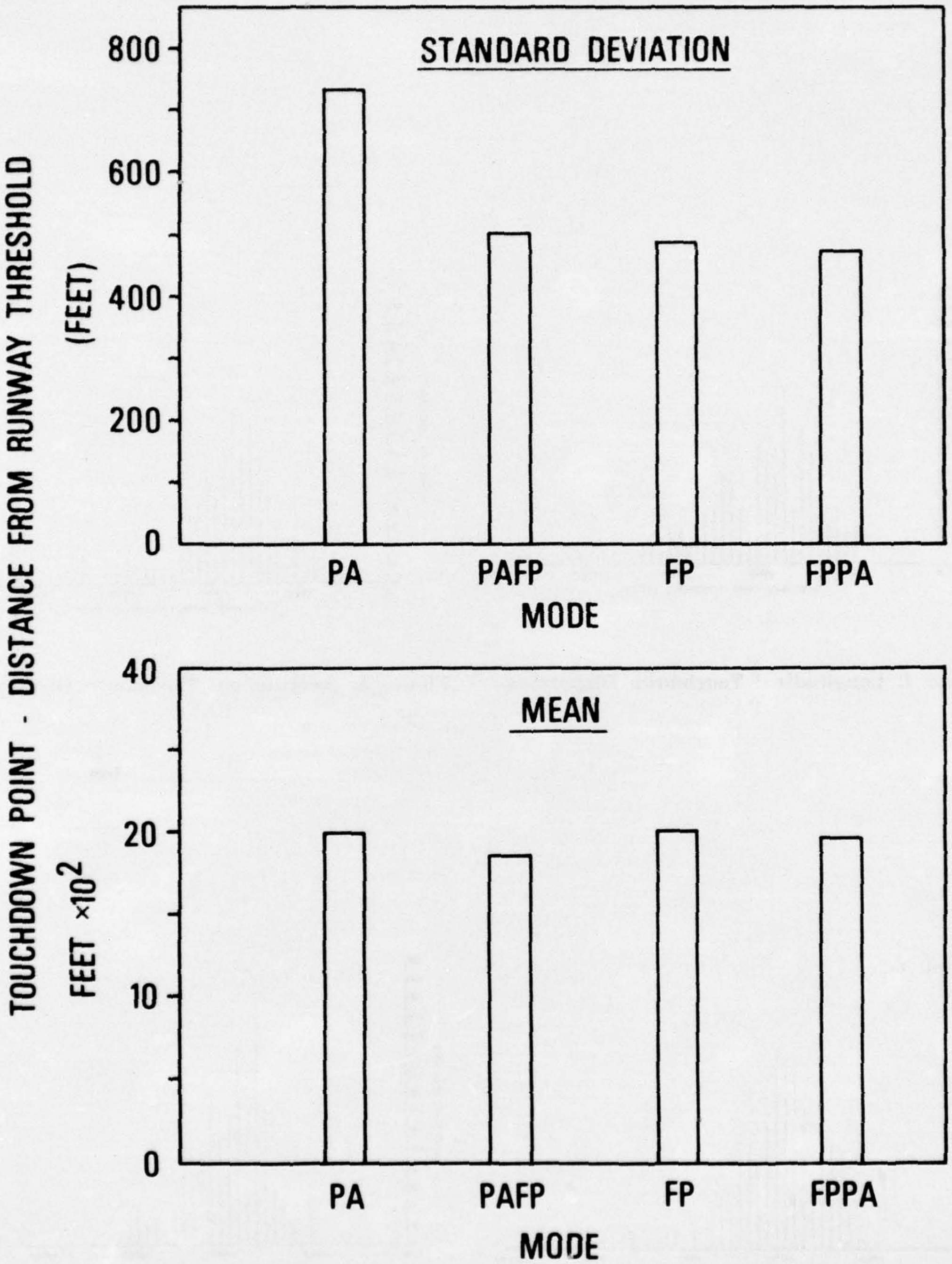


Figure 3. Touchdown Point Dispersion vs. Control-Display Mode

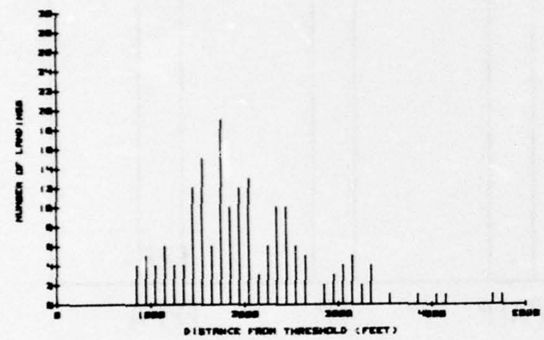


Figure 4. Longitudinal Touchdown Dispersion-PA

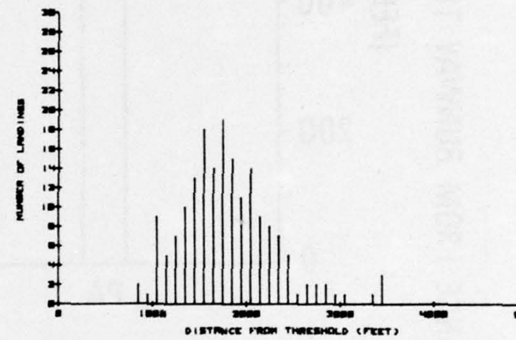


Figure 5. Longitudinal Touchdown Dispersion-PAFP

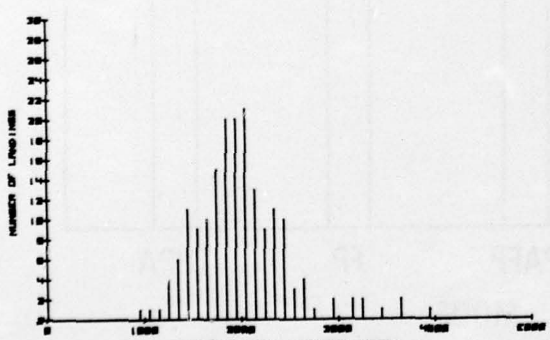


Figure 6. Longitudinal Touchdown Dispersion-FP

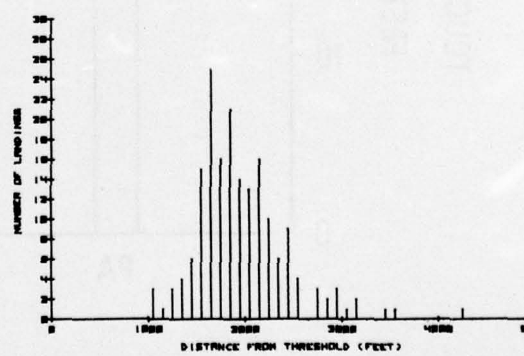


Figure 7. Longitudinal Touchdown Dispersion-FPPA

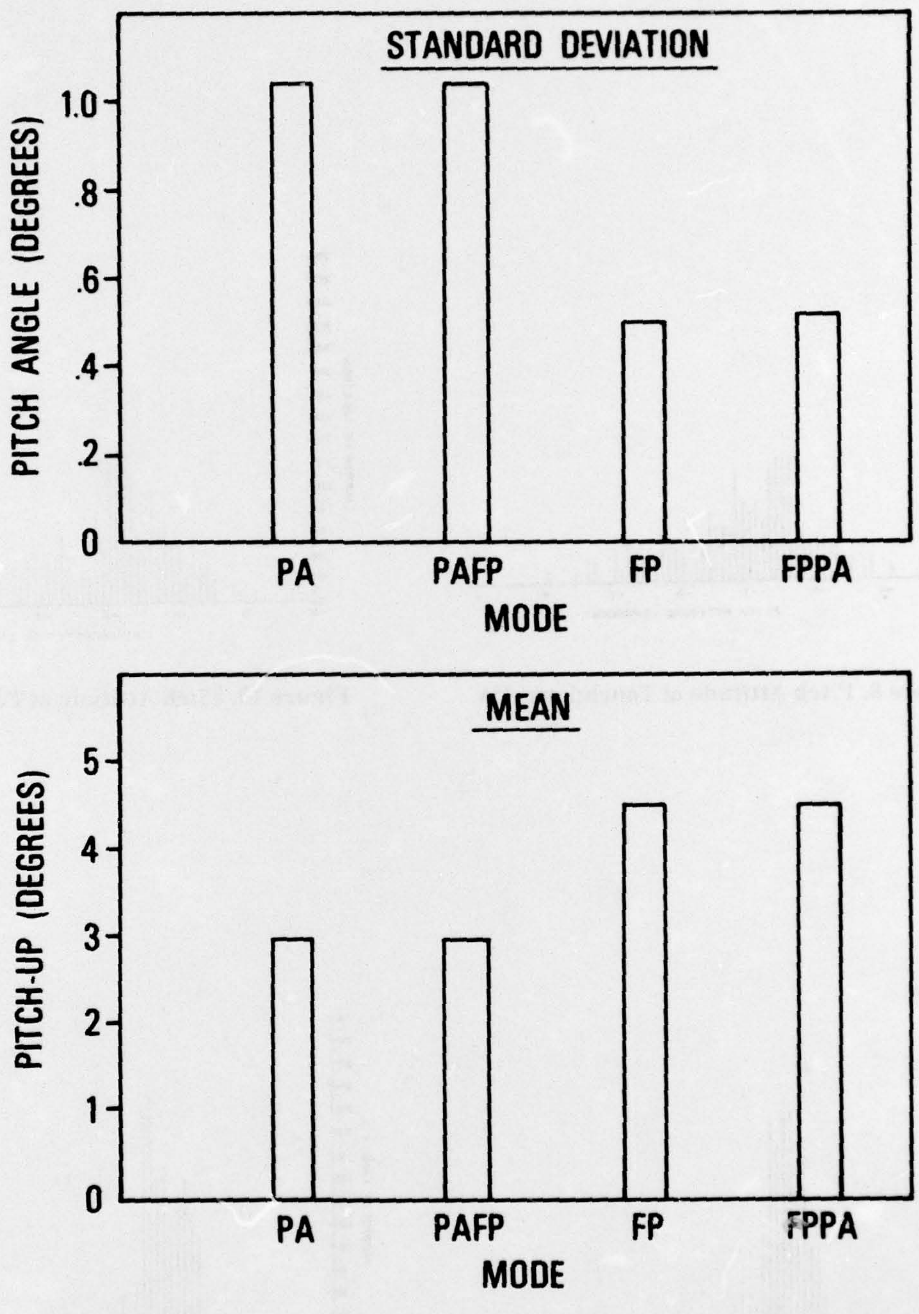


Figure 8. Pitch Attitude vs. Control-Display Mode

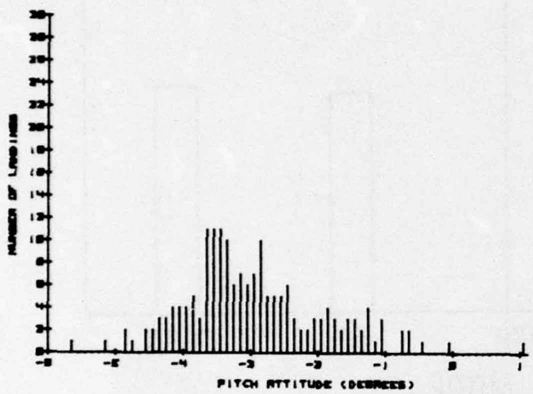


Figure 9. Pitch Attitude at Touchdown-PA

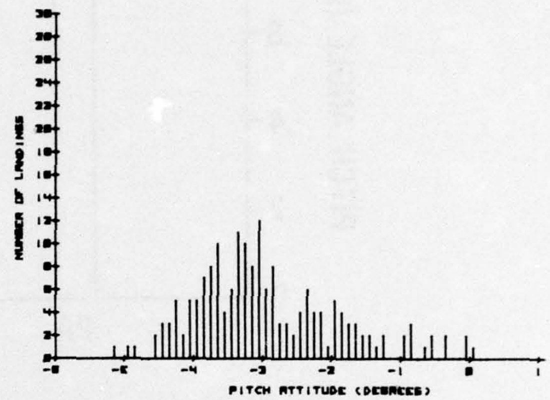


Figure 10. Pitch Attitude at Touchdown-PAFP

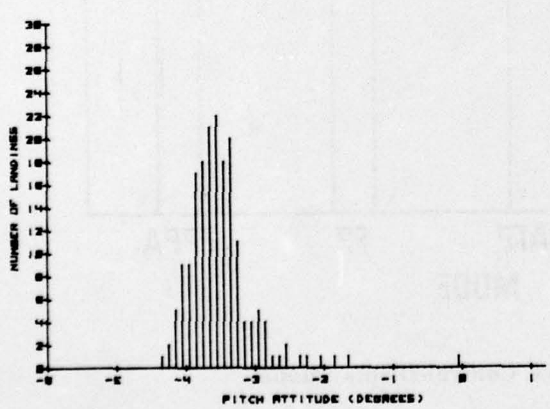


Figure 11. Pitch Attitude at Touchdown-FP

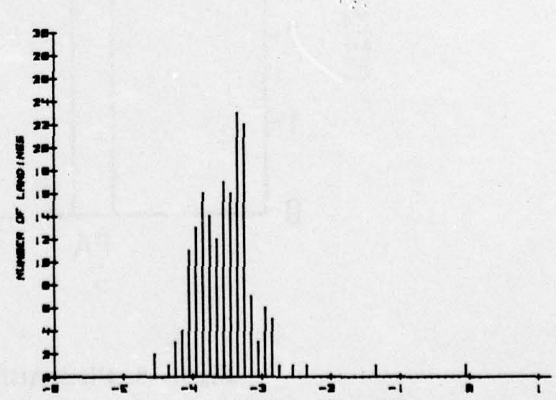


Figure 12. Pitch Attitude at Touchdown-FPPA

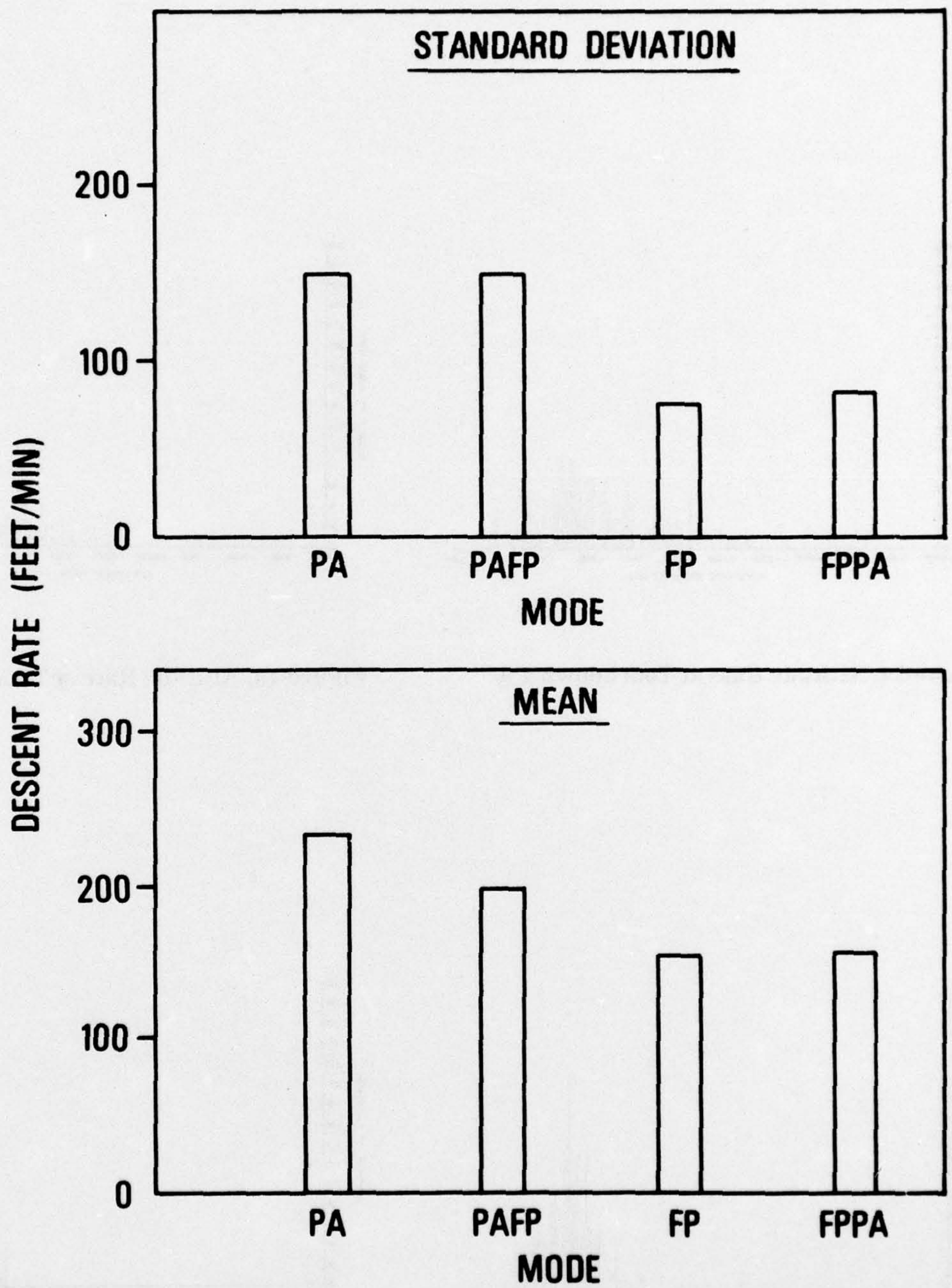


Figure 13. Descent Rate vs. Control-Display Mode

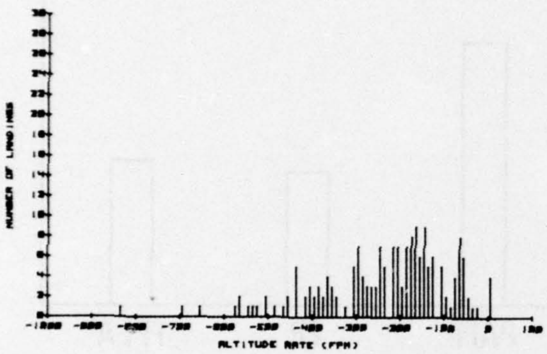


Figure 14. Altitude Rate at Touchdown-PA

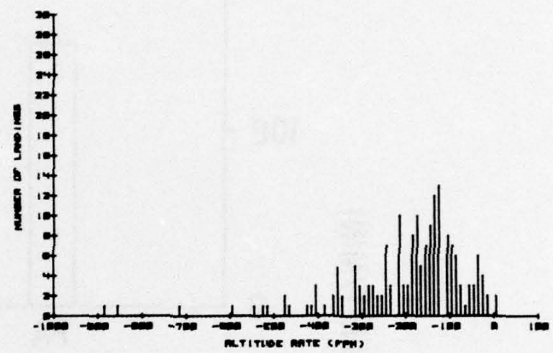


Figure 15. Altitude Rate at Touchdown-PAFP

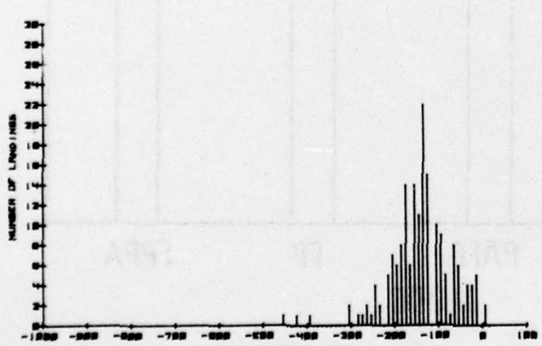


Figure 16. Altitude Rate at Touchdown-FP

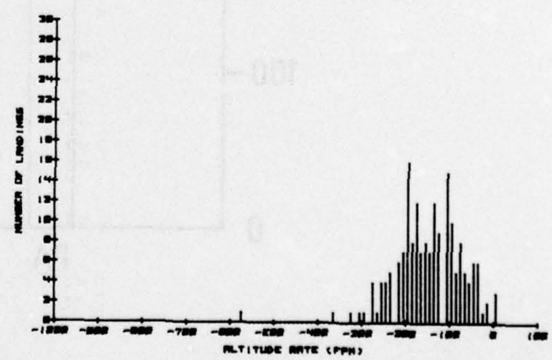


Figure 17. Altitude Rate at Touchdown-FPPA

The fourth objective was to compare the results of using pilots vs. nonpilots as RPV remote operators when accomplishing a manually controlled landing. An analysis of variances among subject groups revealed no significant differences in any parameters except rate of descent, shown in Figures 18-21. Furthermore, this difference was found only in the pitch attitude mode with displayed flight path angle (PA/FPA). The reduction in error for the pilots was 50 percent from the nonpilots.

In addition to the above analyses, checks were conducted to determine whether the results were consistent with variations in failure point in the approach (5 miles, 150 feet AGL, 50 feet AGL) and in the degree of system failure (longitudinal only or total system). No statistical differences or interactions could be found among any of those conditions.

DISCUSSION

Several aspects of this experiment were felt to be worth mentioning regarding the results. The first was that the simulated runway size was 7000 feet long and 150 feet wide; 2000 feet of runway length were required for rollout. A differently sized runway might have changed the percentage of unsatisfactory landings.

Second, the 4° glideslope was steeper than the conventional 3°, which had two effects: the high descent rate required a large pitch change for flare and a fast pilot response, thus favoring the flight path angle modes; and the pilots' familiarity with normal 3° systems probably caused some problem for them in adjusting, thus the comments about "ballooning."

Third, the lack of a pitch trim capability caused a greater effort in all modes to maintain a stable pitch attitude or flight path angle than if it had been available.

Fourth, the nature of the controlled experiment forced each subject to complete every landing, no matter how bad the approach looked; i.e., no go-arounds were permitted, even though the need was sometimes recognized by the subjects.

Last, the turbulence in the simulation, representing moderate vertical and lateral gusts, maintained constant intensity to touchdown. In reality, the intensity would decrease with altitude during the flare maneuver.

In spite of the above factors, several pilots from AFFDL felt that the simulation was sufficiently realistic that the experimental results would be reliable.

CONCLUSIONS

The conclusions from this experiment are briefly summarized as follows:

(1) The experimenters felt that satisfactory remote operator performance for routine landings was not demonstrated. As a failure or backup-type operation, the demonstrated performance might be acceptable if vehicle loss rates in excess of one percent could be tolerated.

(2) The flight path angle control modes displayed better performance than the pitch attitude modes. Rate of descent, longitudinal touchdown dispersion, and pitch attitude control were all significantly improved. Display variations appeared to have less significant effects.

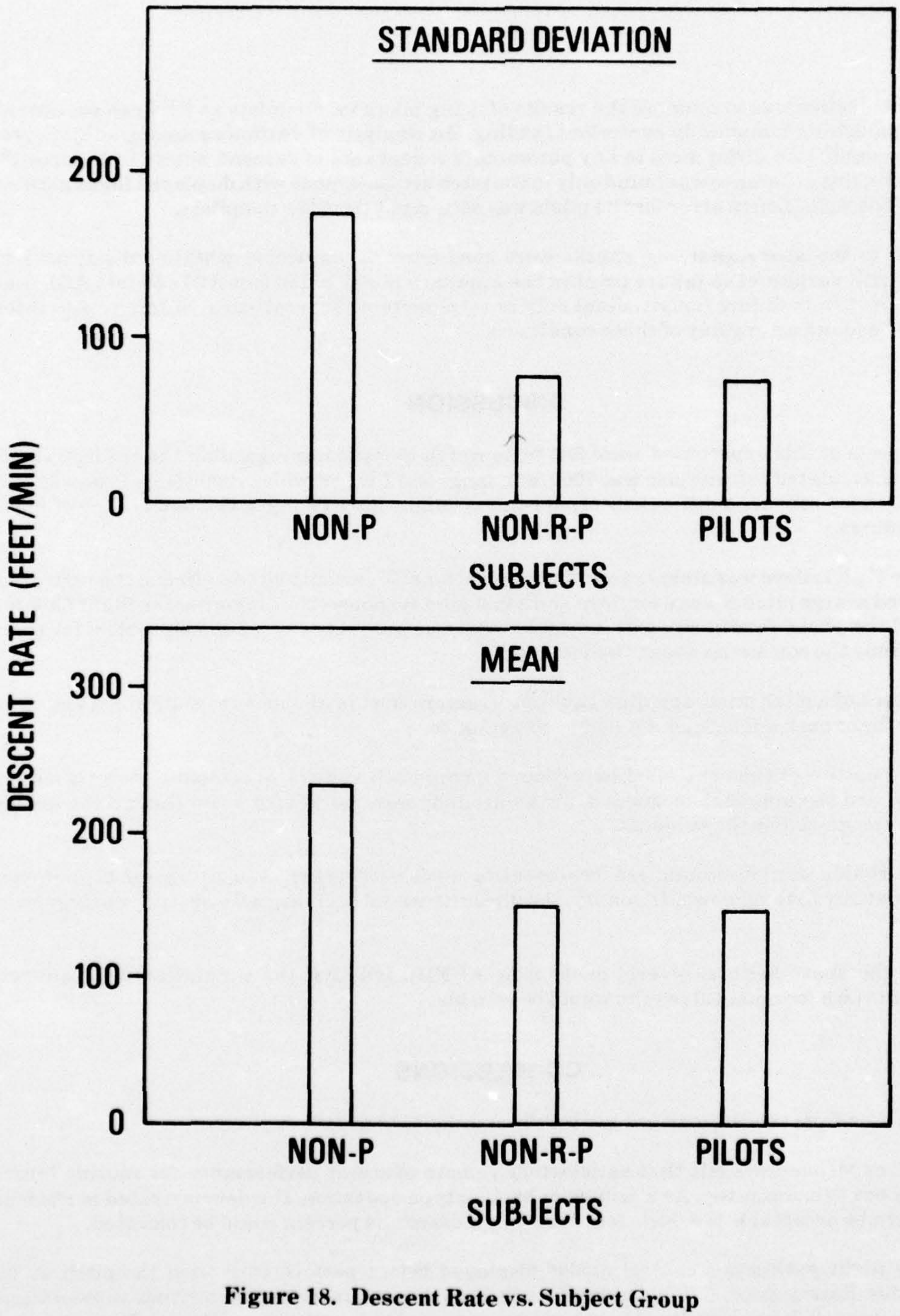


Figure 18. Descent Rate vs. Subject Group

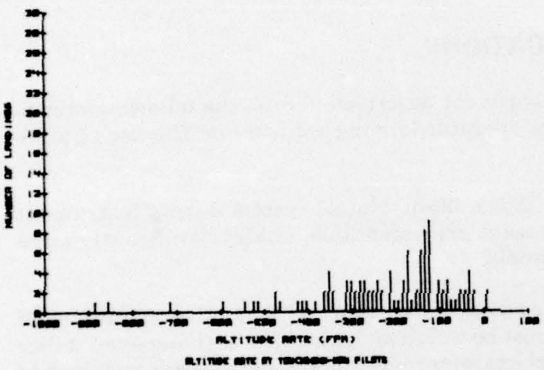


Figure 19. Altitude Rate at Touchdown-Non Pilots

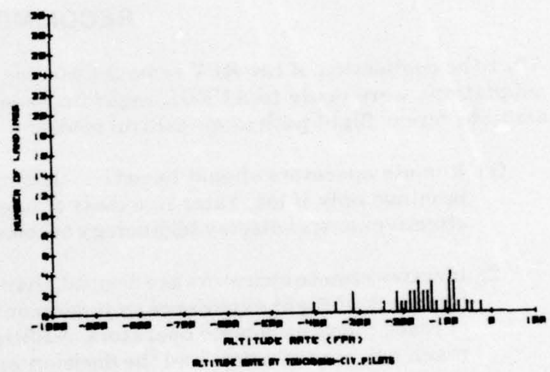


Figure 20. Altitude Rate at Touchdown-Civ. Pilots

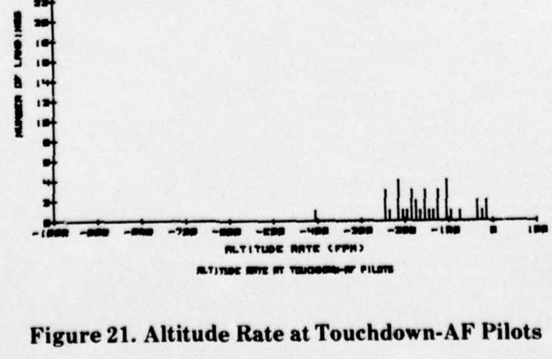


Figure 21. Altitude Rate at Touchdown-AF Pilots

(3) When taken simultaneously with longitudinal control system failures, lateral control system failures increased operator workload but did not adversely affect performance.

(4) Rated aircraft instrument pilots achieved the same remote operator performance capability in one third as much training time as naive nonpilot personnel. Performance in data runs was comparable, except for touchdown rate of descent, which was better for the pilots. Other effects of experience factors on decision making, etc., were not evaluated.

RECOMMENDATIONS

After the completion of the RPV remote operator experiment described herein, the following recommendations were made to AFFDL regarding remote operator landing control and the use of pitch attitude versus flight path angle control modes:

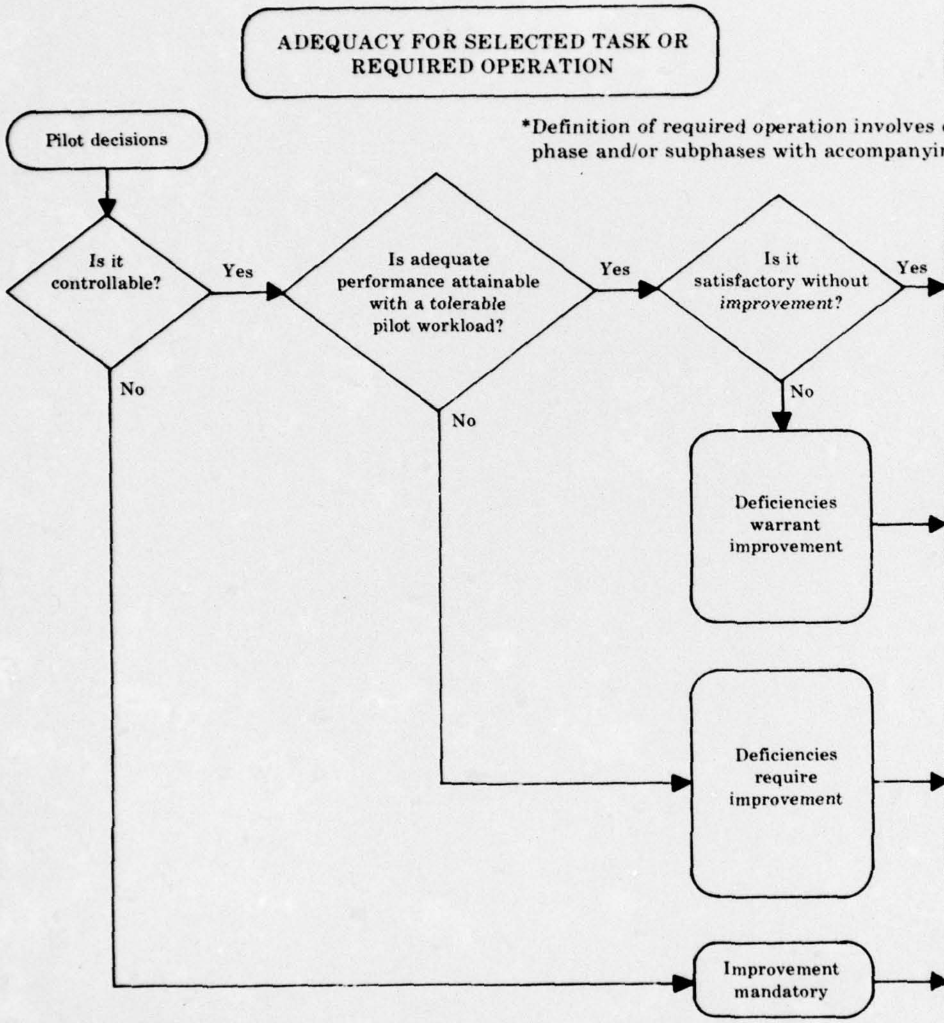
(1) Remote operators should be active elements in the flight control system during instrument landings only if loss rates in excess of one percent are acceptable, unless significantly more effective control-display technology becomes available.

(2) If active remote operators are desired, then the additional costs of training naive operators and their lack of flight experience or judgement must be weighed against the cost and availability of rated pilots as remote operators. Additional experience in this tradeoff area is required to reach a firm conclusion, and the decision will be mission and task dependent.

(3) For remote operator active landing control, flight path angle stabilization is the minimum acceptable level of automation in the longitudinal control system. Reductions in attitude display requirements, operator workload, and operator frequency response are the advantages of such a mechanization.

APPENDIX

COOPER-HARPER RATING SCALE



*Definition of required operation involves designation of flight phase and/or subphases with accompanying conditions.

AIRCRAFT CHARACTERISTICS	DEMANDS ON THE PILOT IN SELECTED TASK OR INQUIRED OPERATION	PILOT RATING
Excellent Highly desirable	Pilot compensation not a factor for desired performance	1
Good Negligible deficiencies	Pilot compensation not a factor for desired performance	2
Fair; some mildly unpleasant deficiencies	Minimal pilot compensation required for desired performance	3
Minor but annoying deficiencies	Desired performance requires moderate pilot compensation	4
Moderately objectionable deficiencies	Adequate performance required considerable pilot compensation	5
Very objectionable but tolerable deficiencies	Adequate performance requires extensive pilot compensation	6
Major deficiencies	Adequate performance not attainable with maximum tolerable pilot compensation. Controllability not in question.	7
Major deficiencies	Considerable pilot compensation is required for control	8
Major deficiencies	Intense pilot compensation is required to retain control	9
Major deficiencies	Control will be lost during some portion of required operation	10

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