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16. Abstract

Helicopter sling-load operations have been limited during pick-up and delivery of external cargo by the lack of precision achieved by the combination of pilot, helicopter, and sling load. Use of a closed-circuit television as a pilot aid during sling-load delivery and placement was documented along with additional cases representing procedures currently employed by military and commercial operators. Although an increase in pilot workload was noted when the television system was used, the results indicated a comparable level of performance for each test case.

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SUMMARY

Helicopter sling-load operations have been limited during the pick-up and delivery of external cargo by the lack of precision achieved by the combination of pilot, helicopter, and sling load. Previous attempts to improve precision have included stabilization of the load and helicopter and the addition of a pilot station directly facing the load. In the present tests, the use of a closed-circuit television as a display that would permit sling-load delivery and placement by the forward-facing pilot was evaluated by use of a CH-54B helicopter. In all, three test cases were documented; they included the following: (1) a forward-facing pilot using the television display, (2) a forward-facing pilot using verbal commands from a load-facing observer, and (3) an aft-facing pilot having an out-the-window view of the load. The results indicate that a comparable level of performance was achieved for each test case; however, an increase in pilot workload was noted when the television system was used.

INTRODUCTION

The use of helicopters to carry sling loads is not a new concept. However, extension of the sling-load capability for improved effectiveness is continually being sought, particularly for operations under restricted conditions. A major operating problem stems from the concern for the onset of sling-load oscillations. This problem, when controllable, causes increased mission time, particularly when extreme precision is required. When the oscillations become uncontrollable, mission abort or even payload loss can occur. Further problems are reflected in terms of the need for highly trained pilots and requirements for additional personnel onboard the aircraft and on the ground to relay information to the pilot. Consequently, sling-load helicopter operations have been restricted to relatively simple pick-up and delivery tasks.

Techniques currently employed or under consideration for reducing these limitations in operational situations have included load stabilization schemes (refs. 1 and 2),

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improved flight control systems (refs 3, 4, and 5), and implementation of various load-restraint schemes (ref. 6). Although these techniques have improved sling-load handling characteristics, attendant compromises have resulted in the form of special sling arrangements which complicate pick-up and delivery procedures, and adverse coupling between the aircraft-load combination caused by control inputs from the load stabilization system, which can compete with the pilot for control of the aircraft on a short-term basis.

A brief, exploratory investigation was recently conducted during a joint Army and National Aeronautics and Space Administration flight program to evaluate a simple closed-circuit television (CCTV) display as an aid to the pilot during the low-speed delivery and sling-load-placement task. To provide a data base against which to assess the merits of a closed-circuit television system, a series of test runs using techniques presently employed by sling-load operators were also conducted. In all, 231 test runs were recorded using an instrumented aircraft which was flown by a total of five pilots from the NASA, the Army, and industry. Results are presented in the form of load-placement errors, run times, and pilot commentary.

DESCRIPTION OF EQUIPMENT

Aircraft

The test aircraft, shown in figure 1, was a heavy-lift crane helicopter of the type used by the military and commercial operators for specialized sling-load operations. The single-rotor helicopter was powered by two gas turbine engines, each rated at 3581 kilowatts, with a maximum gross weight capability of 21 319 kilograms. The cockpit arrangement included side-by-side pilot and copilot stations, as well as a rearward-facing


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Figure 1.- CH-54B test helicopter with sling load.

pilot station located behind the copilot. All the test runs conducted from the forward cockpit location were flown without the aid of the vehicle's automatic flight control system (AFCS). The rear station, which afforded the pilot direct visual contact with the sling load, was equipped with a standard three-axis proportional side-arm controller, with the normal control authority limitations removed for these tests. Since this side-arm controller could be used only with the AFCS engaged, the vehicle had augmented angular-rate damping for those runs flown from the rear station.

Closed-Circuit Television

The monochromatic (black and white) closed-circuit television system used throughout these tests employed 525 scan lines which yielded a picture resolution comparable to the home television system. Two airborne cameras were mounted aft of the cable hoist well as shown in figure 2, and provided the pilot with a downward-looking view of the payload. The camera nearest the hoist well provided a depression angle of 87°, whereas the camera furthest from the hoist well provided a depression angle of 64°. Each camera had a fixed 25-mm lens which, in conjunction with the overall television system, provided a monitor field of view of 47° in the longitudinal direction and 32° in the lateral direction. A perspective view of the coverage area for each camera, as limited by the television monitors, is shown in figure 3. The display was a 20-cm high-brightness monitor, installed immediately to the left of the instrument panel, as indicated in figure 4. With the monitor located about 61 cm from the eye position of the pilot, the magnification factor was approximately 0.4. The use of a special effects generator allowed the image from each camera to be displayed simultaneously on the pilot's monitor, through split-screen techniques.

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Figure 2.- Closed-circuit television camera locations on test vehicle.

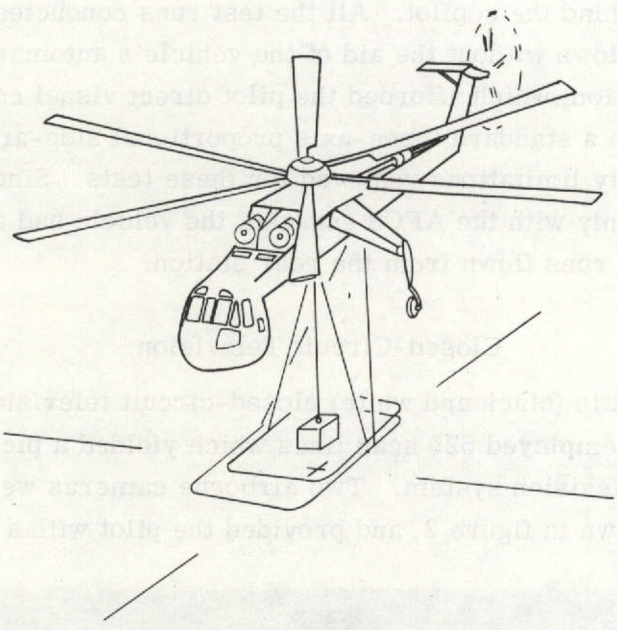

Figure 3.- Schematic of television system coverage areas displayed to pilot.

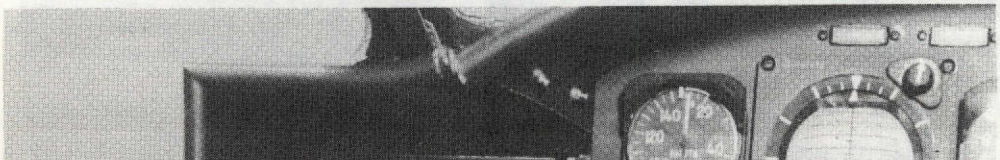

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Figure 4.- Television monitor location in cockpit of test helicopter.

Instrumentation

A Langley-developed piloted aircraft data system (PADS) was used to record 40 flight parameters. All data channels were encoded using a serial pulse coded modulation (PCM) system having a 9-bit resolution (1 part in 512). Each PCM signal was sampled at a rate of 80 samples per second, and recorded directly on an analog magnetic tape. Signal conditioning was provided to interface the sensors and the PCM system, to allow presample filtering, and to implement preflight calibration. A standard NASA 36-bit time code was also generated and recorded directly on the magnetic tape which had a 2-hour capacity when operated at a tape speed of 19 cm per second. Playback of the flight information was in the form of data tabulations and time histories presented in engineering units.

TEST PROCEDURE

The primary objective of this investigation was to explore the usefulness of a closed-circuit television (CCTV) display as an aid to the forward-facing pilot during precision sling-load placement. The following three test cases were documented:

(1) Sling-load deliveries by the forward-facing pilot using the CCTV system

(2) Sling-load deliveries by the forward-facing pilot using verbal commands from a load-facing observer

(3) Sling-load deliveries by a rearward-facing pilot having an out-the-window view of the load

The latter two cases, which represent procedures currently employed, were flown to provide a relative assessment of the merits of the CCTV.

Prior to starting the test runs, several practice approaches were made. The load-placement target was a cross pattern painted on the ground with the axes marked at each 1/2-meter point, out to $\pm 3\frac{1}{2}$ meters (fig. 5). Corner points to highlight 1-meter, 2-meter, and 4-meter squares were also included. The sling load was a 4536-kilogram concrete block which measured just over 1 meter on each side and covered the inner square when placed squarely at the center of the target. A cable length of 7.6 meters was used for all tests.

In conducting the tests, the aircraft was flown to an offset point approximately 122 meters from the touchdown point, with the exception of those runs flown from the aft seat, for which the offset point was about 61 meters. All runs were conducted with the nose of the aircraft headed into the ambient wind. Ambient wind velocities did not exceed 25 knots throughout the test series. When operating from the rearward-facing cockpit, the aircraft was flown tail first toward the target, which is the procedure normally

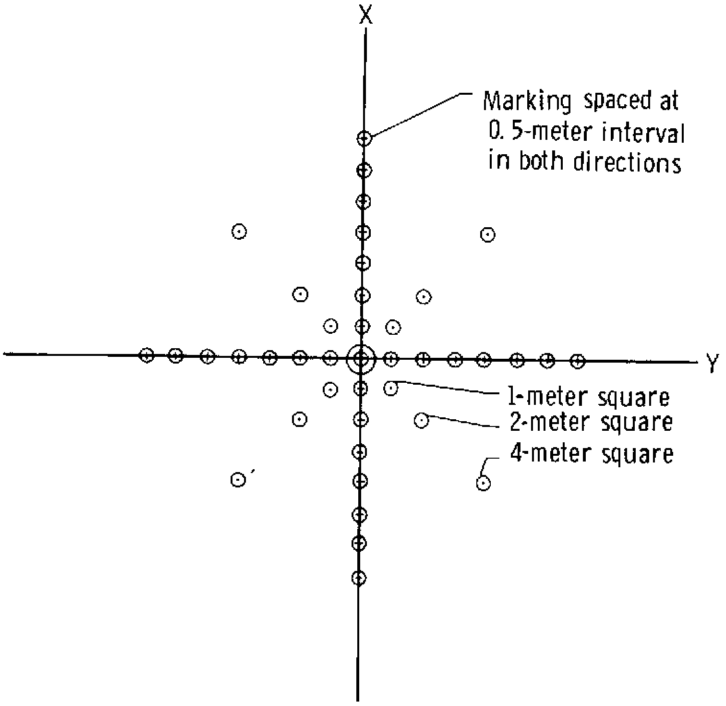


Figure 5.- Sketch of ground target used for load placement task.

employed to provide good visibility of the target area. After announcing the start of the run and noting time, the pilot proceeded to fly to the target and to place the load as accurately as possible. Although no time restriction was placed on the task, the pilot was instructed to be as accurate as possible within a reasonable amount of time. Following the load placement, the longitudinal and lateral dispersions from the origin of the target were noted along with the time required to complete the run. The aircraft was then returned to the initial offset point and the run sequence repeated 5 to 10 times for each case. In all, 72 runs were documented for case 1, 73 runs for case 2, and 86 runs for case 3.

LOAD PLACEMENT RESULTS

The basic data obtained for case 1 (forward-facing pilot using television), case 2 (forward-facing pilot using verbal commands), and case 3 (aft-facing pilot having an out-the-window view of the load), are presented in tables I to III, respectively. Data in the tables include longitudinal error ϵ_x, lateral error ϵ_y, radial error ϵ_r, and the time required to complete each run. Positive errors reflect a placement ahead of and to the right of the target. The error data were analyzed in the form of maxima, mean values, and standard deviations. The standard deviation σ as used herein is defined as the square root of the sum of the squares of the difference between each sample and the mean value divided by one less than the total number of samples. Results for each case are presented separately and are supplemented with pilot comments.

Closed-Circuit Television (Case 1)

In figure 6 the boundaries of the load-placement error in X and Y are noted for each subject pilot using the closed-circuit television system. Maximum overshoot was 3.0 meters, whereas the largest undershoot was just under 1.5 meters. The greatest dispersions to the right and left of the target center line were 1.0 and 2.5 meters, respectively. Also presented are the ranges of times required for each pilot to complete the task. The longest time required was 120 seconds whereas the shortest time was 34 seconds.

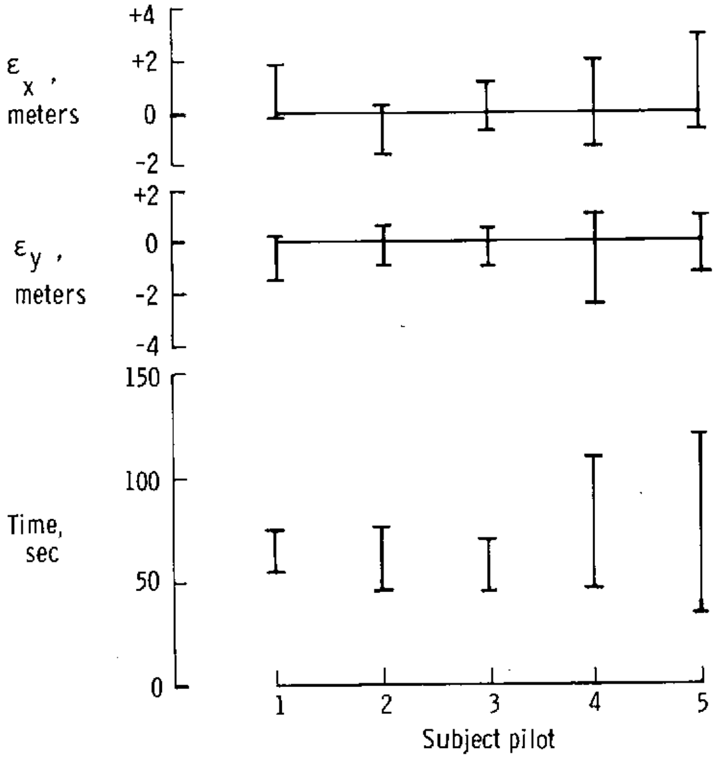


Figure 6.- Boundaries of load-placement errors and run times when pilot used closed-circuit television (case 1, 72 runs).

Tests with the television display system fostered several ideas which would improve the usefulness of the system. Although no further attempts were made to optimize the television system after the initial setup, several deficiencies were noted: narrow field of view, lack of load-height information, insufficient horizontal lead information, and an objectionable cockpit-monitor location.

Forward Seat With Verbal Commands (Case 2)

The boundaries of the displacement errors associated with delivery of an external sling load by the forward-facing pilot when receiving verbal commands from an observer located in the aft cockpit are given in figure 7. For this case, the maximum value of target overshoot was 3.5 meters whereas the largest undershoot was 2.5 meters. The largest lateral errors noted were approximately 2.4 meters to the right and 1.9 meters to the left. The time increment required to perform the task varied between 32 and 85 seconds.

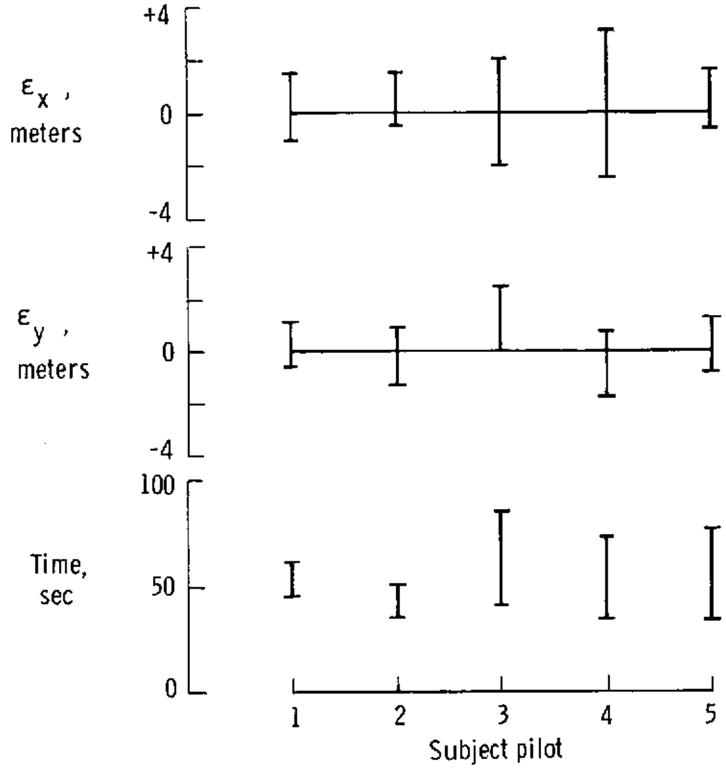


Figure 7.- Boundaries of load-placement errors and run times when pilot received verbal commands (case 2, 73 runs).

Since the pilots did not have a view of the external load for this case, they noted that they were somewhat detached from the problem. Reliance on verbal assistance caused a lag in applying corrective commands; the lag, in turn, led to difficulty during attempts to stabilize an oscillation or adjust the load position for accurate delivery. For such reasons, the pilots emphasized the importance of having the same pilot and load-observer team to enhance operational efficiency.

Aft Seat (Case 3)

The boundaries of the sling-load placement errors associated with flying from the aft-facing cockpit are presented in figure 8. Because of the additional training and proficiency required to fly from the aft cockpit, only three of the five pilots were used for this case. As shown in figure 8, the largest excursion that occurred either ahead of or behind the desired touchdown point was slightly over 2.0 meters. The maximum errors to the right or left of the target were approximately 1.1 and 1.7 meters, respectively. The delivery times ranged from 29 to 76 seconds. As previously noted, the distance traversed during the load-placement task was reduced by 50 percent for this case.

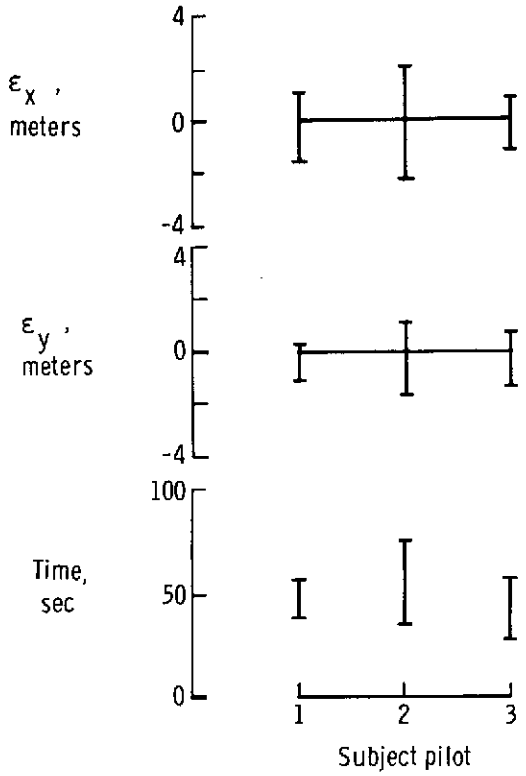


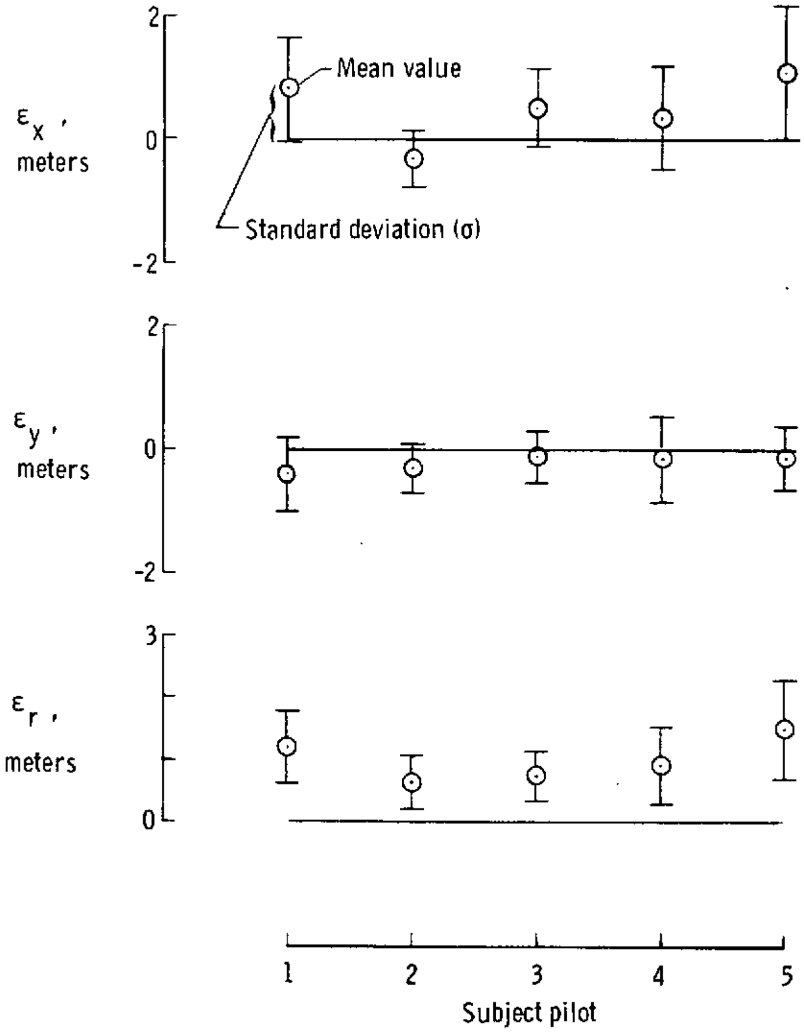
Figure 8.- Boundaries of load-placement errors and run times when pilot had an out-the-window view of the load (case 3, 86 runs).

All subject pilots agreed that a high level of confidence was afforded by the direct view of the payload and surrounding scene. This factor also reduced pilot apprehension. From a performance standpoint, the placement accuracy was enhanced, although attempts to be very precise with load placement could easily cause pilot-induced sling-load oscillations. In an attempt to avoid these oscillations, the pilots tended to place the load prematurely.

DISCUSSION OF RESULTS

Performance

The mean error values and the standard deviations computed to assess the relative performance of each test case are shown for each subject pilot and test case in figure 9. The task performances noted for case 1 (CCTV) and case 2 (verbal commands) as shown in figure 9(a) and figure 9(b), respectively, are comparable because of the close agreement

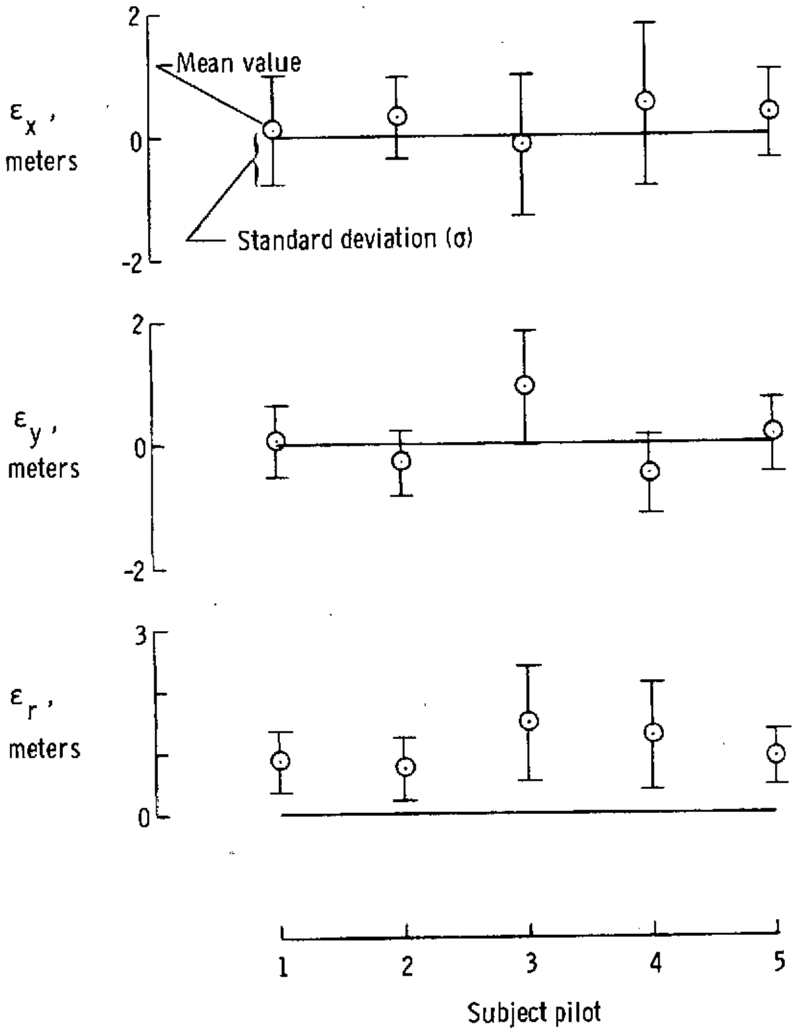


(a) Closed-circuit television (case 1).

Figure 9.- Mean values and standard deviations of displacement errors for individual subject pilots.

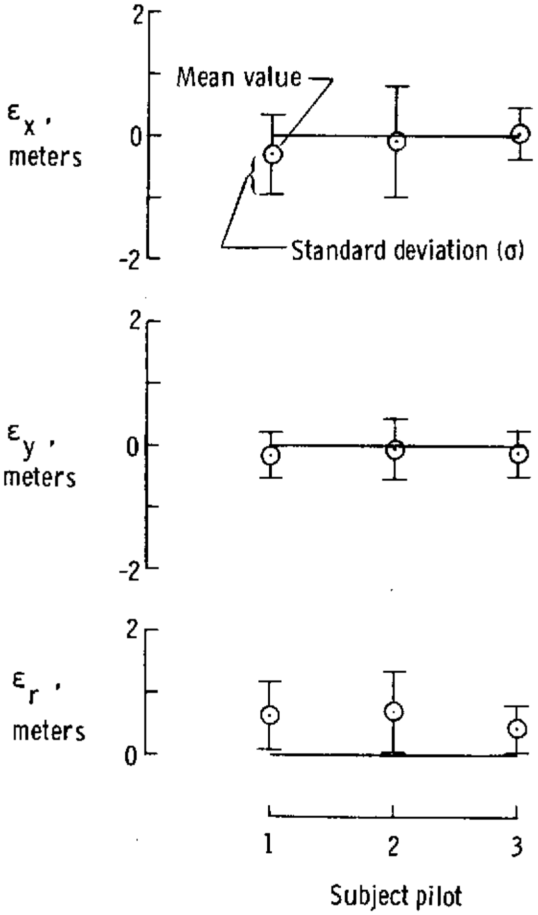
between the means of the radial errors, which are approximately 1 meter for both cases. The data for case 3 (out-the-window view of load), shown in figure 9(c), indicate an improved performance since the mean radial error was about 1/2 meter. When flying from the aft-seat location, the pilots indicated they had better overall control which, coupled with an unaided view of the payload and target area, contributed to the improved placement accuracy. This improved vehicle-payload control may have resulted, in part, from the added level of angular-rate damping provided when using the aft-seat controls.

In addition to the individual subject-pilot data (see fig. 9), the total mean values and standard deviations were determined for each test case and are presented in figure 10.



(b) Verbal commands (case 2).

Figure 9.- Continued.



(c) Out-the-window view of the load (case 3).

Figure 9.- Concluded.

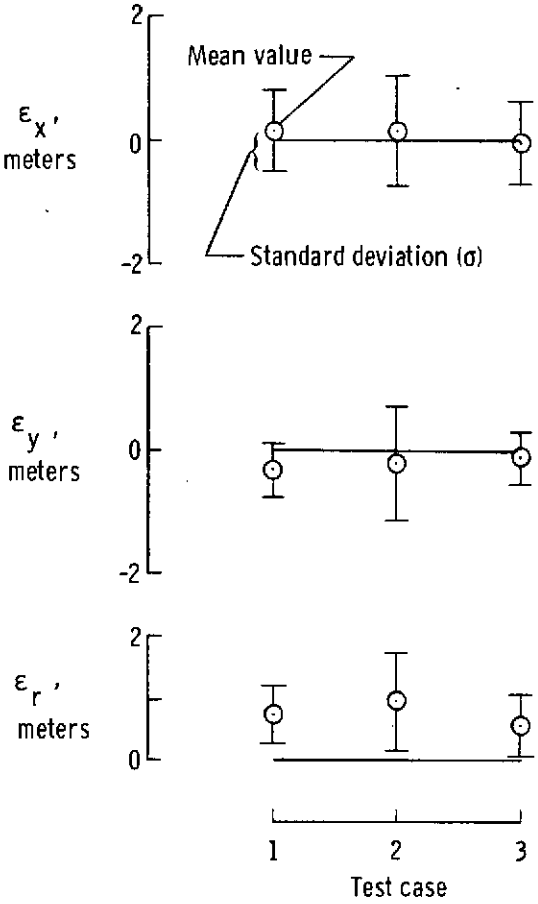


Figure 10.- Mean values and standard deviations of displacement errors for combined runs of first three subject pilots for each test case.

These mean values and standard deviations were computed by combining all the test runs for the same three subject pilots (that is, pilots 1, 2, and 3) who participated in each test case, to provide a consistent comparison. The individual subject pilot and total case mean values and standard deviations are given in table IV. This information represents an overall performance measure for the task employed by denoting the ability with which the pilots were able to deliver the payload to the desired target, as reflected by the mean values, and the precision or consistency about that point, as indicated by the standard deviation. The performance is shown to be comparable for all cases, with the use of the CCTV (case 1) providing a slightly improved precision capability (lower standard deviation) over that associated with the verbal command technique (case 2). When the pilot had an out-the-window view of the externally slung load and the target area (case 3), the best performance was noted as shown by the lowest mean error values and standard deviations.

Pilot Workload

Although the mean errors noted in figure 9 for the first two cases are comparable, important differences in the pilot workload were noted. When using verbal commands (case 2), the pilot was primarily concerned with flying the aircraft using the normal visual cues and making small control inputs based on the commands received. When using the television system (case 1), attention was shared between the television display for load control and external visual references for aircraft control. The pilots indicated that switching between these visual cueing sources was bothersome and contributed to a higher workload. This higher workload was reflected in terms of an increase of approximately 13 seconds in the average time required to complete the task using the television system as compared with receiving verbal commands. Specifically, the average times to complete the task were 60 seconds for case 1, as compared with 47 seconds for case 2. Even with the higher workload, the pilots preferred the television over verbal commands because of the reduced apprehension afforded by an overall view of the payload and background. The television picture provided the pilot with the information needed to acquire the target and plan the approach. It was indicated that a load-facing observer would not be mandatory if the television system were improved.

Time histories of control inputs, along with selected attitudes, rates, and accelerations, are shown in figures 11 and 12, and represent typical runs for cases 1 and 2, respectively. Although the pilots noted a higher level of work associated with the use of the television system, this is not apparent from the time histories since the control activity and aircraft motions appear to be very similar for the first two cases.

When flying from the aft-seat location, some difficulty was encountered when the pilot was forced to a forward-leaning position to see the load and target. In this position,

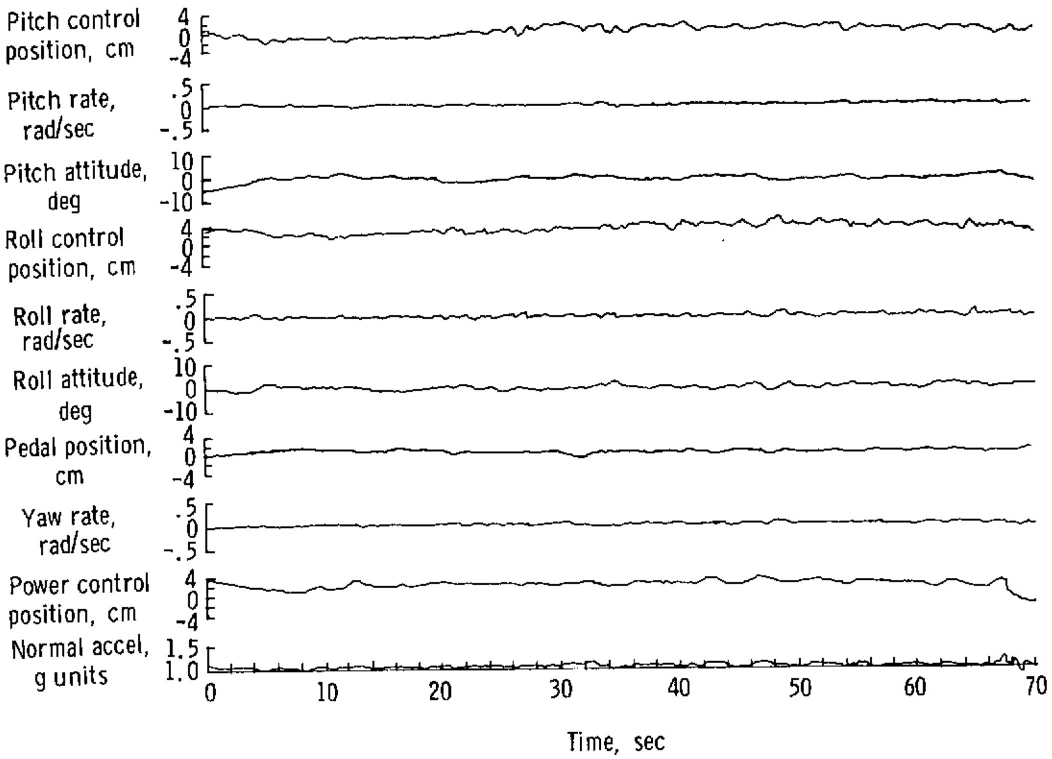


Figure 11.- Time history of typical approach using closed-circuit television (case 1).

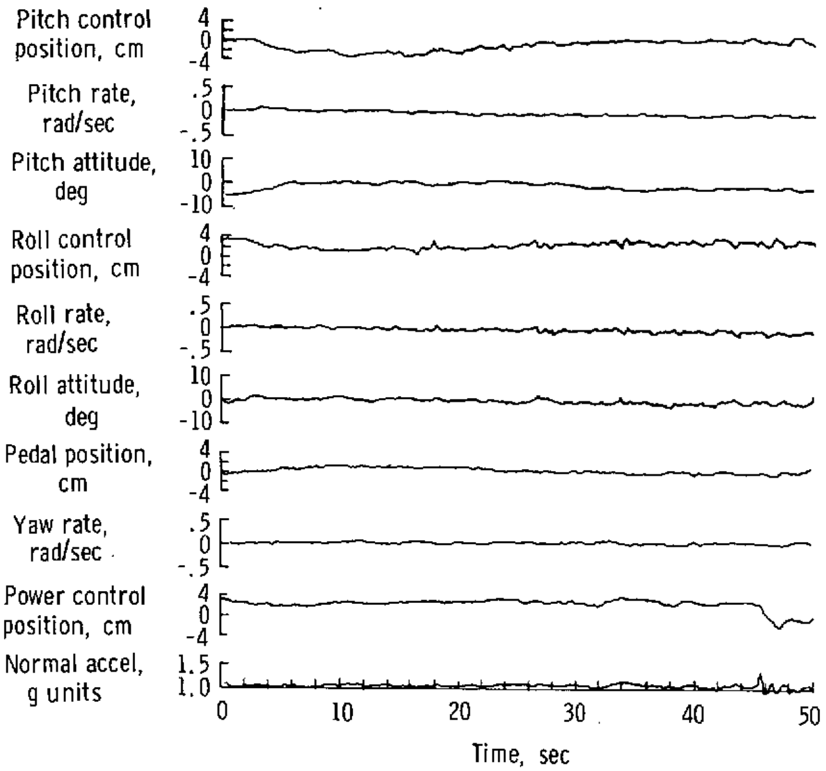


Figure 12.- Time history of typical approach using verbal commands (case 2).

the side-arm controller and collective lever were at the pilot's shoulder level; this position made the controls awkward to manipulate. According to pilot comments, less precise control inputs (of higher frequency content) resulted, with no serious effect on performance, as indicated by comparing the sample time history for an aft-seat run, shown in figure 13, with either figure 11 or 12. In addition, the pilot indicated a tendency to concentrate on flying the load only rather than controlling the vehicle-payload combination.

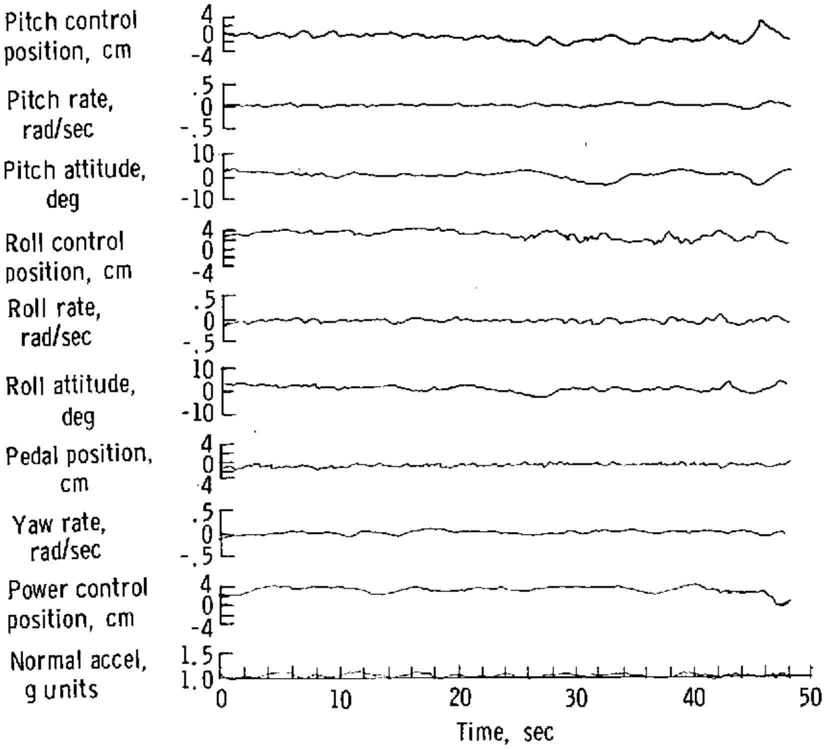


Figure 13.- Time history of typical approach having an out-the-window view of the load (case 3).

Operational Considerations

Several ideas to enhance the television system in order to improve the task performance and reduce pilot workload resulted from these tests. One was a provision for payload height information displayed either numerically or symbolically on or near the television monitor. It was of interest to note that the pilots utilized the payload's ground shadow, when available, as a substitute for load-height information while using the CCTV. A second idea involved locating the camera in such a position as to provide the pilot with increased forward field of view to permit additional time to acquire the target and plan an approach. A third improvement would be to locate the cockpit monitor near the top center of the instrument panel to help minimize pilot workload associated with switching between the outside world and television scenes for control of the aircraft and payload, respectively. Additional ideas included providing camera pan and zoom lens features for selectable field of view, improved visual acuity, color, and a three-dimensional capability. These ideas would permit a more flexible application of such a display system to accommodate different payload sizes and cable lengths, and would provide the pilot with a wider range of position information.

CONCLUDING REMARKS

A flight investigation was conducted during a joint program of the Army and National Aeronautics and Space Administration to explore the usefulness of a closed-circuit television system (CCTV) as a pilot aid during a sling-load placement task. Three test cases using a 4536-kilogram concrete block payload suspended from a 7.6-meter cable were documented in order to provide a relative assessment of the merits of the CCTV to those sling-load delivery procedures presently employed by military and commerical operators. The test cases included: (1) a forward-facing pilot using the television display, (2) a forward-facing pilot using verbal commands from a load-facing observer, and (3) an aft-facing pilot having an out-the-window view of the load. When flying from the forward pilot location, the automatic flight control system (AFCS) was not used. Since the aft-pilot controls are mechanized through the AFCS, operation from the rear-seat location resulted in augmented angular-rate damping. Test conditions included operating the helicopter alined with the ambient wind which did not exceed 25 knots for all cases.

Although the most precise results were generally obtained when the pilot had an out-the-window view of the payload, use of the CCTV was found to be a feasible and practical aid during sling-load operations. In terms of overall performance and mission completion for the task employed, the results using the television were found to be comparable to those obtained using either verbal commands or an out-the-window view of the load. However, an increase in pilot workload was noted when using the television system. Modifications were suggested to reduce the workload and improve the system's usefulness and applicability to a wider spectrum of payload sizes and cable lengths. Potentially benefical modifications to the television system include the addition of a zoom lens to permit a selectable field of view, location of one of the cameras to present a more forward-looking scene, and presentation of load-height information on the display monitor. These ideas need not be restricted to a television system, but could be features incorporated into a synthesized real-world display. Also, the television system could provide the pilot with the capability to monitor sling-load activity for cruise flight modes of operation as well as precision hover.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., September 11, 1974.

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TABLE I.- DISPLACEMENT ERRORS RECORDED USING CLOSED-CIRCUIT TELEVISION AS AN AIDING DEVICE (CASE 1)

Time, sec	ϵ_x, m	ϵ_y, m	ϵ_r, m
Pilot 1			
75	+1.83	0	1.83
55	0	-1.48	1.48
55	+1.50	-.13	1.51
75	-.08	-.35	.36
70	+.80	+.02	.80
Pilot 2			
65	-0.46	-0.30	0.55
75	-.50	-.54	.74
50	+.18	-.78	.80
46	0	+.12	.12
50	+.05	-.15	.16
63	+.03	-.60	.60
56	-.08	-.08	.11
76	+.02	-.40	.40
76	-1.48	0	1.48
60	-.50	-1.00	1.12
60	+.03	-.35	.35
50	-.04	+.03	.05
48	-.63	+.65	.91
53	-.65	-.80	1.03
62	-.40	-.82	.91
Pilot 3			
60	+1.00	+0.15	1.01
55	+1.00	+.50	1.12
45	+.50	0	.50
55	+.50	-.25	.56
55	+.95	0	.95
70	-.74	+.32	.81
45	+.34	-.15	.37
45	+1.18	-1.03	1.57
50	+.60	-.45	.75
45	-.09	+.04	.10
Pilot 4			
47	+1.00	-0.52	1.13
52	+.48	-.58	.75
56	-.50	-.56	.75
Pilot 4			
53	+2.00	+0.46	2.05
55	+.01	-.82	.82
58	-.50	+1.00	1.12
58	+.04	-.45	.45
55	-.06	-.45	.45
67	+.48	-.51	.70
56	+.45	0	.45
68	+.50	+.50	.71
50	+1.83	+.23	1.84
60	-1.32	-.31	1.36
53	+.28	+.11	.30
53	+.50	-2.50	2.55
110	+1.65	+.50	1.72
84	-.48	0	.48
66	-.05	0	.05
107	+1.50	+.48	1.57
63	-.50	-.82	.96
59	+.46	+.22	.51
55	+.33	+.25	.41
50	+1.50	-.75	1.68
50	+.10	+1.00	1.00
53	+.15	+.11	.18
65	0	-.13	.13
Pilot 5			
58	+3.00	-0.50	3.04
70	+2.50	-.69	2.59
86	+2.00	0	2.00
39	+1.50	0	1.50
34	+1.50	-.50	1.58
40	+.05	-.45	.45
58	+1.27	+.30	1.30
47	-.29	+.33	.44
58	-.35	+.17	.39
63	+1.45	-.39	1.50
120	+2.00	-1.25	2.36
70	+1.00	+.50	1.12
53	+2.00	0	2.00
58	0	+.92	.92
35	+1.00	-.50	1.12
57	-.73	0	.73

TABLE II.- DISPLACEMENT ERRORS RECORDED WHEN THE FORWARD-FACING PILOT RECEIVED VERBAL COMMANDS FROM REAR-SEAT OBSERVER (CASE 2)

Time, sec	ϵ_x, m	ϵ_y, m	ϵ_r, m
Pilot 1			
60	+1.50	0	1.50
45	+.13	-.13	.18
45	+.13	+1.00	1.01
60	0	-.62	.62
60	-1.00	0	1.00
Pilot 2			
50	+1.50	0	1.50
40	-.10	-.05	.11
42	+1.38	-.63	1.52
35	+1.48	-.63	1.61
35	0	-.03	.03
45	-.50	-.78	.93
46	-.43	-.46	.63
47	+.25	+.24	.35
49	-.01	+.80	.80
44	+.07	-.13	.15
44	+.20	-1.40	1.41
40	+.83	-.62	1.04
44	-.41	-.97	1.05
46	+.70	+.02	.70
40	-.13	-.08	.15
38	-.08	+.07	.11
Pilot 3			
80	-2.05	0	2.05
55	-1.95	0	1.95
55	0	+2.00	2.00
52	-1.00	+.47	1.10
49	0	0	0
75	+.58	+2.19	2.27
85	+.57	+2.09	2.17
45	-.49	+.34	.60
75	+.20	+.12	.23
40	+2.02	+2.33	3.08
40	-.08	+1.40	1.40
44	+.63	+.12	.64
Pilot 4			
45	+1.70	-0.79	1.87
55	+.90	-.90	1.27
47	+3.50	-.68	3.57
Pilot 4			
57	+0.50	-0.46	0.68
42	+1.49	-.98	1.78
63	+.45	+.17	.48
56	+1.02	-1.88	2.14
44	+1.80	0	1.80
45	+1.00	-1.00	1.41
50	-.50	-.14	.52
35	-2.50	-1.83	3.10
33	-1.00	-.80	1.62
71	-2.00	-1.32	2.40
42	+.50	-1.00	1.12
34	+1.50	0	1.50
52	+.02	-.52	.52
70	+.02	+.46	.46
37	+.20	-.02	.20
51	-.90	+.28	.94
42	+.62	-.13	.63
37	0	-.13	.13
34	+1.38	-.53	1.48
34	+.02	+.44	.44
44	+.05	0	.50
37	+.55	-.52	.76
Pilot 5			
75	+0.75	+0.20	0.78
35	+.20	+.72	.75
44	+.40	-.67	.78
45	+1.50	+1.00	1.80
40	+.50	+.50	.71
61	-.47	+.44	.64
45	-.47	+.16	.50
36	-.76	+.46	.89
42	+1.39	-.54	1.49
40	0	+.14	.14
36	0	-1.16	1.16
40	+.48	+.13	.50
36	0	+.48	.48
32	+1.50	-.56	1.60
33	+.50	+.50	.71

TABLE III.- DISPLACEMENT ERRORS RECORDED USING OUT-THE-WINDOW VISUAL CUES FROM AFT PILOT LOCATION (CASE 3)

Time, sec	ϵ_x, m	ϵ_y, m	ϵ_r, m
Pilot 1			
55	-0.26	-0.45	0.52
57	-1.57	+.29	1.60
53	-.45	+.06	.45
42	-.15	-.30	.34
39	-.55	-.18	.58
43	+.36	-.24	.43
46	+.06	-.06	.08
48	0	0	0
45	-.63	-.09	.64
52	-.50	+.19	.53
49	+.10	-1.16	1.60
Pilot 2			
49	+0.86	0	0.86
76	-1.46	-.45	1.53
43	+.16	+.06	.17
36	-.65	-1.65	1.77
37	-.12	-.10	.16
38	-1.46	+.09	1.46
37	+.70	-.64	.95
37	-1.05	+.45	1.14
40	+1.25	+.85	1.51
43	-.09	+.10	.13
40	+.11	-.33	.35
38	+.40	0	.40
37	-.10	0	.10
42	0	-.07	.07
37	-.22	-.06	.23
40	-.34	-.34	.48
38	-2.13	-.75	2.26
49	-.15	-.15	.21
38	-.35	+.37	.51
46	0	0	0
48	+2.15	+.72	2.27
48	+.32	-.32	.45
39	-1.35	0	1.35
45	+.38	-.64	.74
49	+.04	+.04	.06
44	-.65	+.40	.76
44	+.02	-.10	.10
56	+.52	+.50	.72
48	-.11	-.12	.16
48	+1.07	+1.07	1.51
Pilot 3			
42	-0.06	-0.07	0.09
43	+.24	-.12	.27
43	0	0	0
48	0	0	0
36	+.44	-.26	.51
56	+.95	0	.95
38	0	0	0
44	0	0	0
42	+.29	+.42	.51
44	-.25	-.43	.50
36	+.12	-.06	.13
39	-.14	-.23	.27
35	-.06	-.07	.09
58	-1.13	+.10	1.13
48	+.88	-.54	1.03
34	-.15	-.28	.32
54	+.16	-.17	.73
37	0	-.32	.32
40	-.08	-.07	.11
36	-.06	+.70	.70
36	+.72	-.02	.72
45	-.25	-.22	.33
44	0	0	0
34	-.10	+.12	.16
43	-.08	-.07	.11
38	+.62	-.72	.95
36	+.40	+.35	.53
29	0	-.05	.05
33	-.25	+.28	.38
30	-.05	-.65	.65
48	+.33	-.35	.48
39	+.95	-.51	1.08
50	0	0	0
46	-.12	-1.44	1.44
48	-1.10	-.30	1.14
44	+.31	+.27	.41
40	+.11	-.18	.21
37	-.36	-.33	.49
40	+.06	-.50	.50
38	-.33	+.38	.50
42	-.16	+.16	.23
43	+.55	+.22	.59
39	-.03	-.15	.15
43	-.12	+.07	.14
51	-.26	-.20	.33

TABLE IV.- INDIVIDUAL SUBJECT PILOT AND TOTAL CASE MEAN VALUES AND STANDARD DEVIATIONS

[Totals for pilots 1, 2, and 3 only, for consistent comparison with case 3]

Pilot	Mean values			Standard deviation		
	ϵ_x	ϵ_y	ϵ_r	σ_x	σ_y	σ_r
	Case 1			Case 1		
1	+0.81	-0.39	1.20	0.86	0.63	0.60
2	-.30	-.33	.62	.43	.44	.43
3	+.52	-.09	.77	.59	.43	.42
4	+.38	-.14	.93	.80	.71	.65
5	+1.12	-.13	1.44	1.10	.53	.79
Total	+0.16	-0.26	0.77	0.72	0.47	0.48
	Case 2			Case 2		
1	+0.15	+0.05	0.86	0.89	0.59	0.49
2	+.30	-.29	.76	.68	.53	.56
3	-.13	+.92	1.46	1.13	.98	.95
4	+.43	-.49	1.25	1.24	.64	.89
5	+.37	+.12	.86	.70	.59	.46
Total	+0.12	-0.20	0.98	0.89	0.91	0.81
	Case 3			Case 3		
1	-0.24	-0.18	0.62	0.67	0.39	0.53
2	-.06	-.04	.75	.90	.52	.68
3	+.04	-.13	.43	.41	.36	.37
Total	+0.03	-0.10	0.56	0.65	0.43	0.53

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