TR-01-230

ADA023728

AD

3699

Technical Memorandum 7-76

INFLUENCE OF PILOT INCAPACITATION ON LOW SPEED AND HOVERING FLIGHT

Douglas P. Harvey
John D. Waugh

January 1976
AMCMS Code 502F.11.81900

U. S. ARMY HUMAN ENGINEERING LABORATORY

Aberdeen Proving Ground, Maryland

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Memorandum 7-76	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) INFLUENCE OF PILOT INCAPACITATION ON LOW SPEED AND HOVERING FLIGHT		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Douglas P. Harvey John D. Waugh		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Human Engineering Laboratory Aberdeen Proving Ground, Maryland 21005		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS AMCMS Code 502F.11.81900
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE January 1976
		13. NUMBER OF PAGES 31
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Helicopters
Pilots
Incapacitation of Pilots
Wounds
Human Factors Engineering

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

Very little quantitative information exists as to survivability of a lone or surviving helicopter pilot who is incapacitated by wounds received during a mission. Since the pilot normally uses all four limbs, his ability to maintain control of an otherwise flyable aircraft is expected to be impaired. A safe, yet realistic approach to the investigation was to physically restrain single hands, limbs, etc. of Army aviators hovering a DHT-1 Whirlymite Trainer—a semitethered but otherwise genuine single-place helicopter. The relative accuracy with which subjects followed a prescribed flight path under the restraints was the primary means of comparison. Statistical

20. Abstract (Continued)

analysis of integrated error scores showed that the only effective restraints were those involving an entire limb. Since this investigation only involved hovering flight, recommendations included further work in cruise considerations in favor of multiple-limb restraints.

AMCMS Code 502F.11.81900

Technical Memorandum 7-76

INFLUENCE OF PILOT INCAPACITATION ON LOW SPEED AND HOVERING FLIGHT

Douglas P. Harvey[1]
John D. Waugh

January 1976

APPROVED: John D. Weisz
JOHN D. WEISZ
Director
U. S. Army Human Engineering Laboratory

[1] U. S. Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD

U. S. ARMY HUMAN ENGINEERING LABORATORY
Aberdeen Proving Ground, Maryland 21005

CONTENTS

FIGURES

TABLES

INFLUENCE OF PILOT INCAPACITATION ON LOW SPEED AND HOVERING FLIGHT

INTRODUCTION

A rotary-wing pilot normally uses both of his hands and arms, and both legs to fly a helicopter. Wounds which deny the full use of his limbs and extremities, or interferes with his visual functions, would degrade to some level the control he exercises over the aircraft. The chances of his survival are a direct result of his residual capacity for maintaining control of the aircraft. This is, of course, assuming a single surviving pilot, and that any aircraft damage will not prevent control of the aircraft to at least an immediate and safe landing. While anecdotal statments abound, there is no quantitative assessment of performance capability as a function of incapacitation.

The immediate and perhaps greatest problem in answering the question is how to create degrees of incapacitation experimentally? Actual wounds cannot be inflicted and the use of pharmacological means poses other problems beyond the scope of this investigation. The method selected to simulate incapacitation was to physically restrain specific parts of the pilot's body. Further, even with a safety pilot on-board, actual helicopter flight had been considered out of the question by the Army agencies responsible for pilot activities. The net effect is that the only alternative is to simulate incapacitating wounds by restraining a pilot flying a simulated helicopter.

An initial investigation along these lines was conducted by Doss (3), using a selected splint-type restraint, and a Basic Instrument Trainer 45; Device 1-CA-1, modified for rotary-wing simulation. The right hand of Doss' pilot subjects' was balled into a rigid first, with wrist immobilized, representing injury to the lower right arm with a loss of grip and wrist functions. The results, however, showed no significant change in the flight parameter criterion measures. The reasons given were that perhaps the Link trainer was too insensitive in assessing pilot performance coupled with the fact that the splint restraint may have not been severe enough to have a measurable detriment.

Another approach given thought at the time was to fit pilots with a harness arrayed with miniature switches to make contact and administer a mild avoidance-type electrical shock whenever the excursion of the pilot's limbs exceeded some predetermined limit. Motion-picture records of cyclic control motion during the 1-CA-1 experiment pointed out the fact that the normal range control motion was smaller than the accuracy with which the switches on a harness could be adjusted for each individual.

It was with the idea of increasing the sensitivity of measurements that this second attempt at the problem was initiated.

OBJECT AND SCOPE

The purpose of this investigation was to assess pilot-helicopter performance utilizing a more sensitive helicopter simulation, which happens to be considerably more realistic, in conjunction with a number of physical restraining devices for different body parts simulating various levels of incapacitation.

The initial (Doss) investigation concentrated on helicopter flight in the cruise regime with

Instrument Flight Reference (IFR), by virtue of the Link instrument trainer. The present effort deals with the low speed and hovering flight regime Visual Flight Reference (VFR) because the aircraft used this time was thus constrained. Both of these flight regimes are important in order to fully assess the effects of pilot incapacitation, however, simulation hardware covering all aspects of helicopter flight are not generally available.

Method

Five different types of restraints were used to physically hinder pilots while performing their flying task. The impairments administered to the subjects (Ss) were as follows:

Restraint 1—Right Hand; balled into a fist and tightly covered (Fig. 1). Prevented gripping and digital functions. Right hand was essentially reduced to a rigid stump. Wrist movements were unimpaired however.

Restraint 2—Left Hand; fingers joined to prevent independent motion or spreading (Fig 2). Left thumb was tightly lashed down alongside the index finger. Gripping function was impaired because of the lashed-down thumb. Wrist motion was not inhibited.

Restraint 3—Right Eye; was fitted with a standard eye patch, eliminating vision. (Fig. 3).

Restraint 4—Left Leg; was lashed down to the cockpit structure completely denying its use on the helicopter antitorque pedals (Fig.4).

Restraint 5—Right Arm; lashed securely to the torso rendering it unavailable for any cockpit control (Fig.5).

The S's task was to pick the aircraft up to a hover at the starting point marked on the ground; then, hover diagonally across the rectangular maneuvering area to a turning point, also marked on the ground, 350 feet away; stop and turn around over it, still hovering, and return to the starting point; turn the aircraft around to face in the original direction and set it down on the starting point. All this was to be done in as straight a line and with as much accuracy and precision as possible. No altitude, time or speed criteria were imposed.

Tracking the aircraft yielded data describing its flight path which was then analyzed for error-type behavior with respect to the restraining devices applied versus no-restraint flights for each S. Format for the raw data are six channels of analog information recorded on magnetic tape, along with a time-base channel. Each channel of data represents angular data; coarse azimuth, fine azimuth, and elevation for each of the two video-tracking cameras. Each channel was converted to digital form and combined with a computer program, developed at the US Army Ballistic Research Laboratories, Aberdeen Proving Ground, MD, to yield the flight path of the aircraft. It was in this format that the data was analyzed.

Apparatus

Aircraft: The aircraft employed in this investigation was a Del Mar DHT-1 Whirlymite Trainer, which can be considered a simulator but is more accurately called a partially-tethered aircraft. The Whirlymite is a single place-powered helicopter with fully articulated three-bladed rotor capable of free flight in the absence of the tethering apparatus. As a trainer, the helicopter

Fig. 1. Right-hand restraint.

Fig. 2. Left-hand restraint.

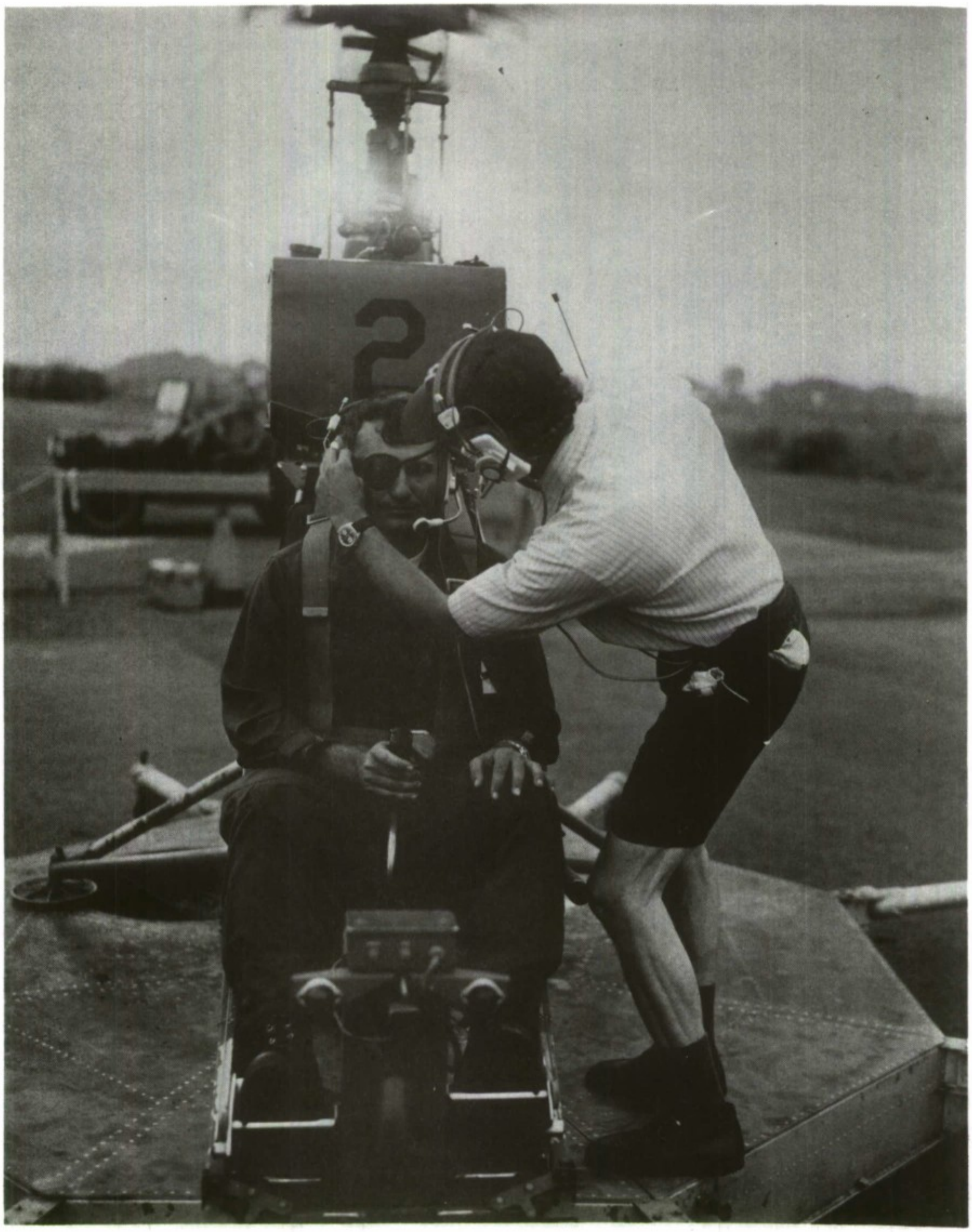


Fig. 3. Right eye covered.

Fig. 4. Left-leg restraint.

Fig. 5. Right-arm restraint.

is attached to an independently powered-ground-effect platform by an articulated linkage. This linkage always maintains the platform direclty beneath the helicopter, yet allows the helicopter to rise and hover, pitch, roll and yaw through 360 degrees, and prevents overturning (Fig. 6). The aircraft can hover and air-taxi over any smooth paved surface at speeds up to 40 miles per hour.

Fig. 6. DHT-1 Whirlymite trainer.

Tracking Equipment: Ground position and height of the Whirlymite was obtained in real time by a pair of DBA video trackers located orthogonally with respect to the flight maneuvering area (Fig. 7). Each tracker locked onto and followed a set of high-intensity lights mounted on the Whirlymite rotor mast below the swash plate, and therefore, in line with the center of gravity of the helicopter. Azimuth and elevation information from each tracker were recorded as analog voltages on magnetic tape via a CEC 3600 recording system for later resolution to position coordinates. Ultimate accuracy of the tracking equipment is approximately ± 6 inches in the ground plane, and ± 3 inches in height, with an equivalent sampling rate of 60 per second.

Subjects

Twelve Army pilots, rotary-wing rated, participated as S s. There were two Warrant Officer 1's, one Chief Warrant Officer 2, two Chief Warrant Officer 3's, one Second Lieutenant, four Captains, one Major, and one Lieutenant Colonel. Flight experience ranged from a low of 220 hours to a high of 3,918 total hours. Seven S s were dual rated (both fixed-wing and rotary-wing). Experience in flying various model helicopters ranged from four to ten different types. While most of the Ss had heard of or seen the DHT-1 Whirlymite, none had ever flown it before. Their consensus was that it handled similarly to the Army's light training helicopters such as the TH-13 and TH-55.

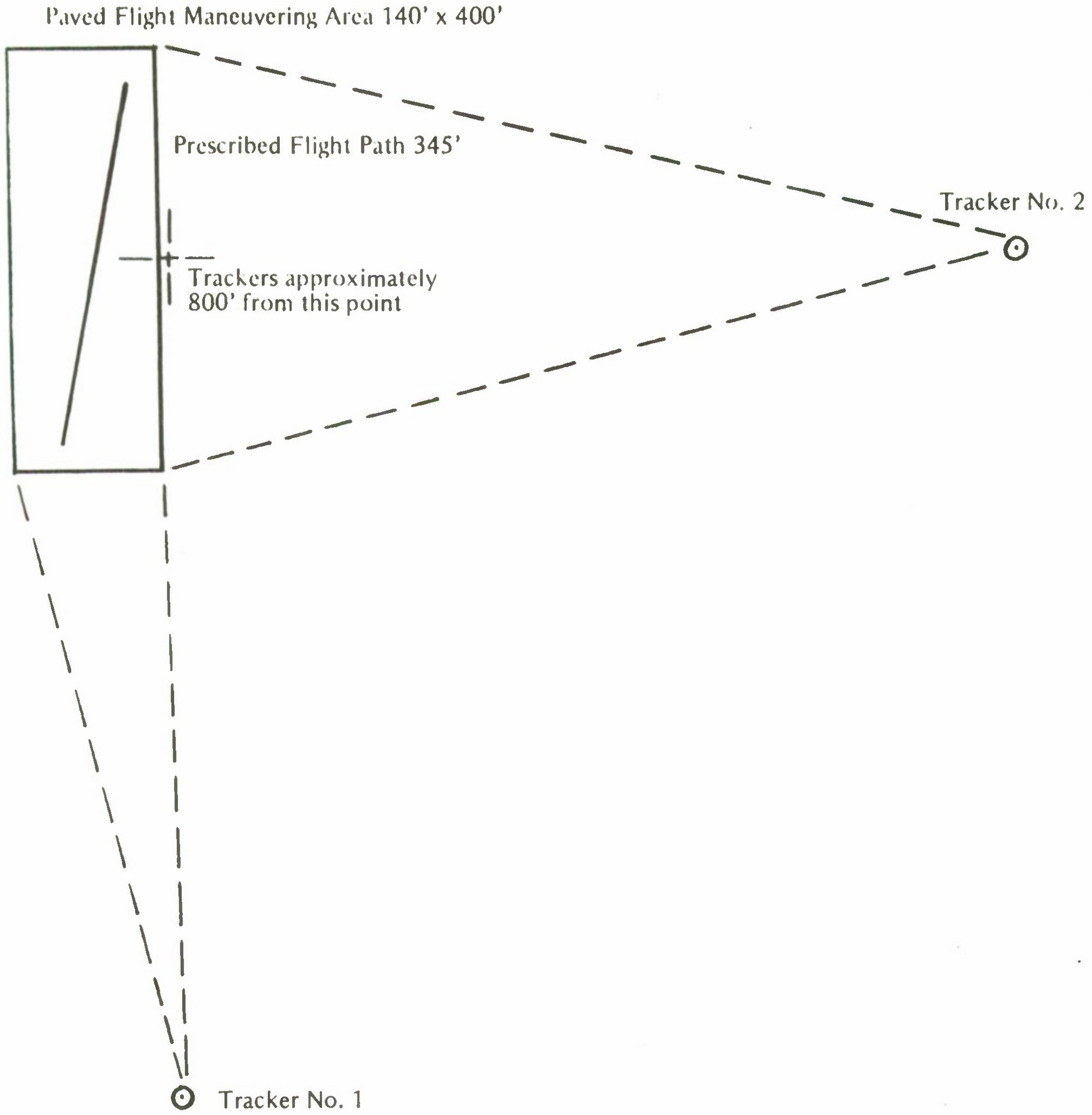


Fig. 7. Tracker locations and flight manuevering area.

Experimental Design

The investigation used a subjects X treatments design (5) wherein all Ss were exposed to all treatments in a random order of presentation. This design is intended to allow statistical analysis of the resulting data with respect to the pilots alone and the treatments alone.

DATA REDUCTION

The data, as originally submitted for reduction and analysis, was in the form of six-channel magnetic tapes. Each channel contained digitized data that were originally obtained during the experiments in analog form; the digitization rate was 60 data points/second. The specific data contained in each channel was as follows:

Channel	Data
1	Elevation, camera 1
2	Azimuth Fine, camera 1
3	Azimuth Coarse, camera 1
4	Azimuth Coarse, camera 2
5	Azimuth Fine, camera 2
6	Elevation, camera 2

where cameras 1 and 2 were situated with respect to the airfield as in Figure 8. It should be noted that the original analog data tapes contained a seventh timing track in order that data contained in the remaining six tracks could be correlated with respect to time.

The elevation, coarse and fine azimuth data could take a values between ±10 volts—which were the cutoff values of the analog signals.

The first data run on each tape was for calibration purposes. The calibration procedure was to place a light at each of the four positions G1, E2, B19 and A20 (Fig. 8) at two elevations, 4-1/3' and 5-1/3' above ground level (AGL), and then allow the light-sensitive tracking units to lock on to this target. With respect to azimuth calibrations, it was determined that the fine azimuth readings would not improve the accuracy of the track and were not used (Appendix I). The coarse azimuth calibration readings at the low positions, 4-1/3' AGL, of G1 and A20 were used to determine the following equations.

For an aribtrary point P on the airfield, we wish to transform the coarse azimuth readings RP and $R'P$ from T_1 and T_2, respectively, into the angles θ_1 and θ_2 (Fig. 8) where θ_1 is measured from $\overline{T_1G_1}$ and θ_2 is measured from $\overline{T_2A_{20}}$.

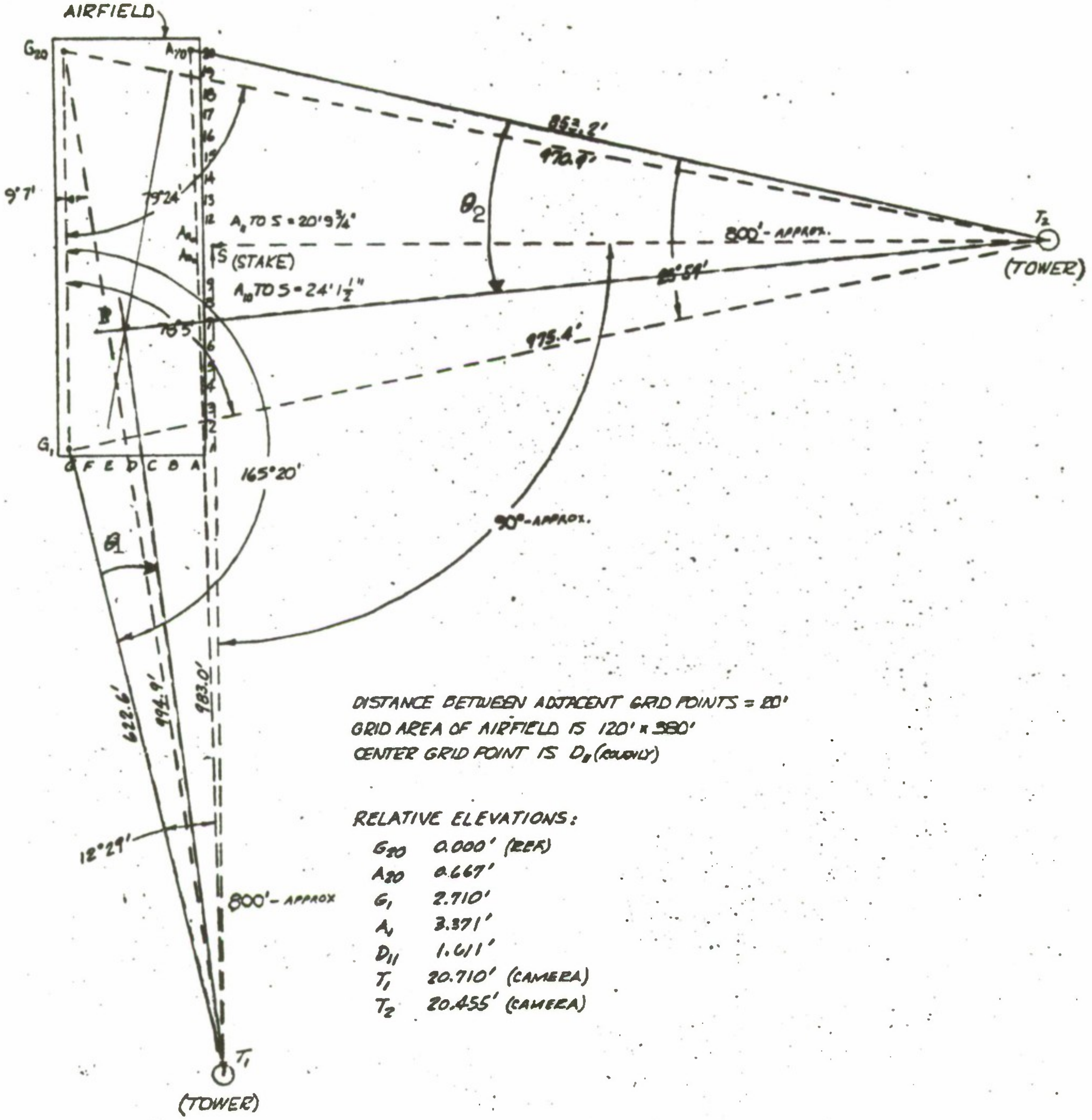
From T_1: Let RG_1 be the coarse azimuth calibration reading for G_1, RA_{20} the coarse azimuth calibration reading for A_{20} and RP as above. Then $RG_1 \sim 0^\circ$ $RA_{20} \sim 12.48^\circ$ and we have

$$\theta_1 = \left|RP - RG_1\right| [12.48/\left|RA_{20} - RG_1\right|] \qquad (1)$$

From T_2: Let $R'G_1$ be the coarse azimuth calibration reading for G_1; $R'A_{20}$ the coarse azimuth calibration reading for A_{20}. Then we have:

$$\theta_2 = \left|R'P - R'A_{20}\right| [23.98/\left|R'G_1 - R'A_{20}\right|]$$

where $R'P$ is defined above.



DISTANCE BETWEEN ADJACENT GRID POINTS = 20'
GRID AREA OF AIRFIELD IS 120' x 380'
CENTER GRID POINT IS D_8 (ROUGHLY)

RELATIVE ELEVATIONS:

G_{20}	0.000' (REF)
A_{20}	0.667'
G_1	2.710'
A_1	3.371'
D_{11}	1.611'
T_1	20.710' (CAMERA)
T_2	20.455' (CAMERA)

Fig. 8. Detail geometry of test site.

Given θ_1 and θ_2 we now will determine the accordinates of the point P with respect to the airfield (Fig 9). At T_1 construct a perpendicular to $\overline{T_1 G_1}$ this will be the x-axis of our coordinate system while $\overline{T_1 G_1}$ will be the y-axis. We will first obtain the coordinates of T_2 with respect to this system (Fig 10): From Figure 1 we have $|\overline{T_1G_1}| = 622.6'$, $|\overline{G_1T_2}| = 975.4'$ and we may deduce that $\measuredangle T_1G_1T_2 = 87.25^\circ$.

$$\therefore \; x = 975.4 \sin (87.25) = 87.25) = 974.2$$

$$y = 622.6 - 975.4 \cos (87.25) = 575.8$$

The coordinates of P with respect to the system will be obtained by the simultaneous solution of the equations for the lines L_1 and L_2 (Fig 9).

The equation of L_1, given θ_1 and the point T_1 at (0,0) lying on L_1, is simply

$$y = x \tan (90 - \theta_1) = x \cot \theta_1 \qquad (3)$$

In order to determine the equation of L_2 we need, in addition to the point T_2 at (974.2, 575.8), the angle of inclination θ^* expressed in terms of θ_2. From Figure 8 we may deduce that $|\overline{G_1A_{20}}| = 398.5, \Rightarrow \sin \omega_3$ (Fig. 9) $= \frac{120}{398.5} \Rightarrow \omega_3 = 17.53^\circ$. From Figures 8 and 9 we have $\measuredangle G_{20}G_1M = 14.67$

$$\Rightarrow \; \varepsilon = 180^\circ - [14.67^\circ + 87.25^\circ + \omega_3] = 60.55^\circ$$

$$\Rightarrow \; \omega_1 = 180^\circ - [23.98^\circ + \varepsilon] = 95.47^\circ$$

$$\Rightarrow \; \omega_2 = 180^\circ - \omega_1 = 84.53^\circ$$

$$\Rightarrow \omega_4 = 180^\circ - [14.67^\circ + \omega_3 + \omega_2] = 63.27^\circ$$

$$\Rightarrow \omega_5 = 180^\circ - [90^\circ + \omega_4] = 26.73^\circ$$

Since $\omega_5 = \theta_2 + \omega_6 = \theta_2 + |180^\circ - \theta_*|$ we have $\theta_* = 153.27^\circ + \theta_2$.

$\therefore$ The equation of L_2 is $y = (x - 974.2) \tan (153.27 + \theta_2) + 575.8 \qquad (4)$

For points on the airfield that are close to G_1 equation (3) would not yield valid results since $\lim \cot \theta_1 = \infty$ as $\theta_1 \to 0$. Therefore, it was necessary to determine a constant K such that, given $y = x \cot (K + \theta_1)$ and (4) the equations yield results of x = 0 and y = 622.6' when θ_1 approach 0° and θ_2 approaches 23.98°.

By an iterative routine, an appropriate value of K was found to be .003.

This value of K, while solving the problem with respect to points lying close to G_1, was also shown not to generate significant errors for points lying close to A_{20}, therefore following equation was used for L_1:

$$y = x \cot (.003 + \theta_1) \qquad (3')$$

Substituting (3') into (4) yields:

$$x = \frac{575 - 974.2 \tan (153.27 + \theta_2)}{\cot (.003 + \theta_1) - \tan (153.27 + \theta_2)} \qquad (5)$$

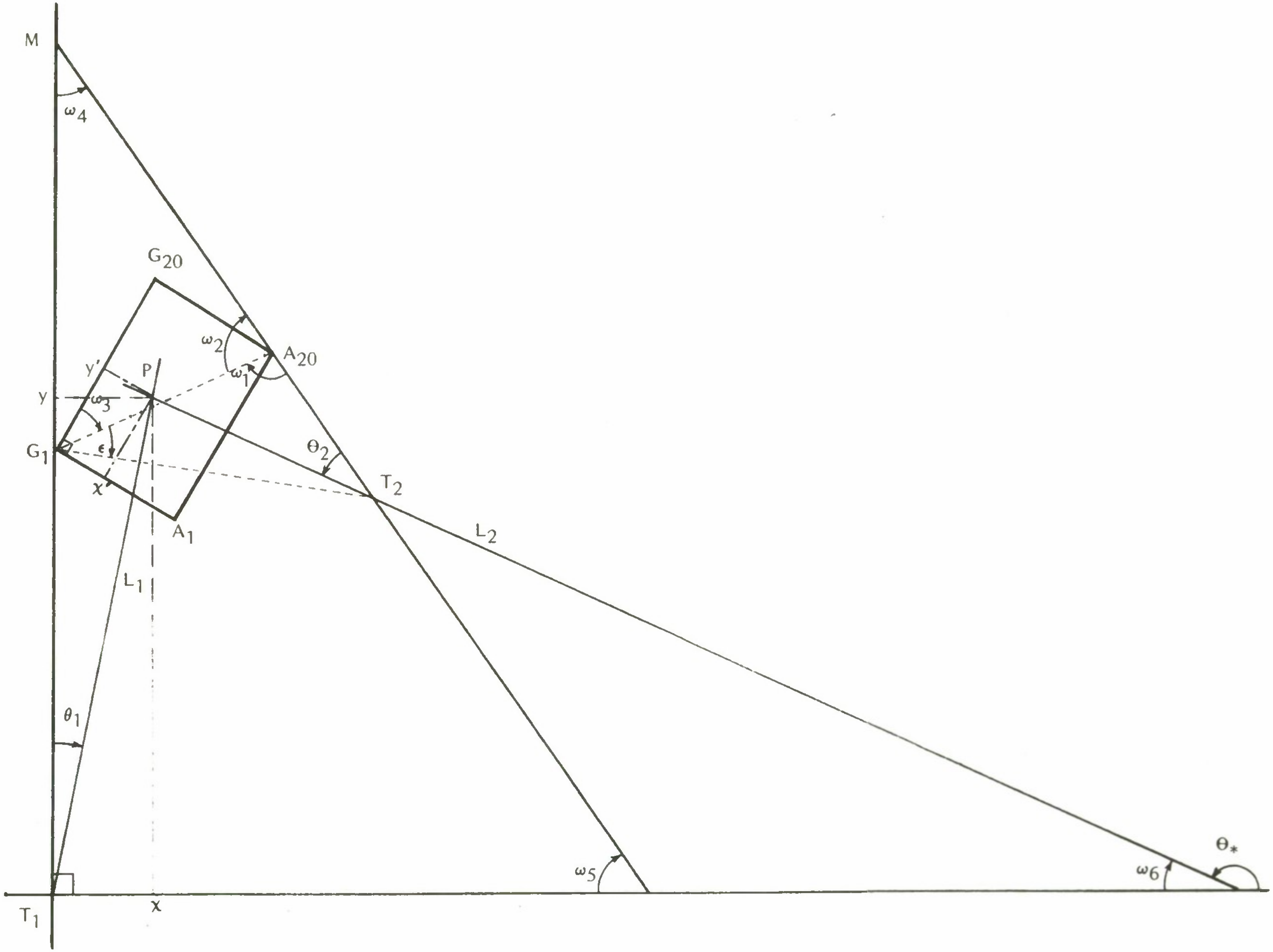


Fig. 9. Coordinates of P.

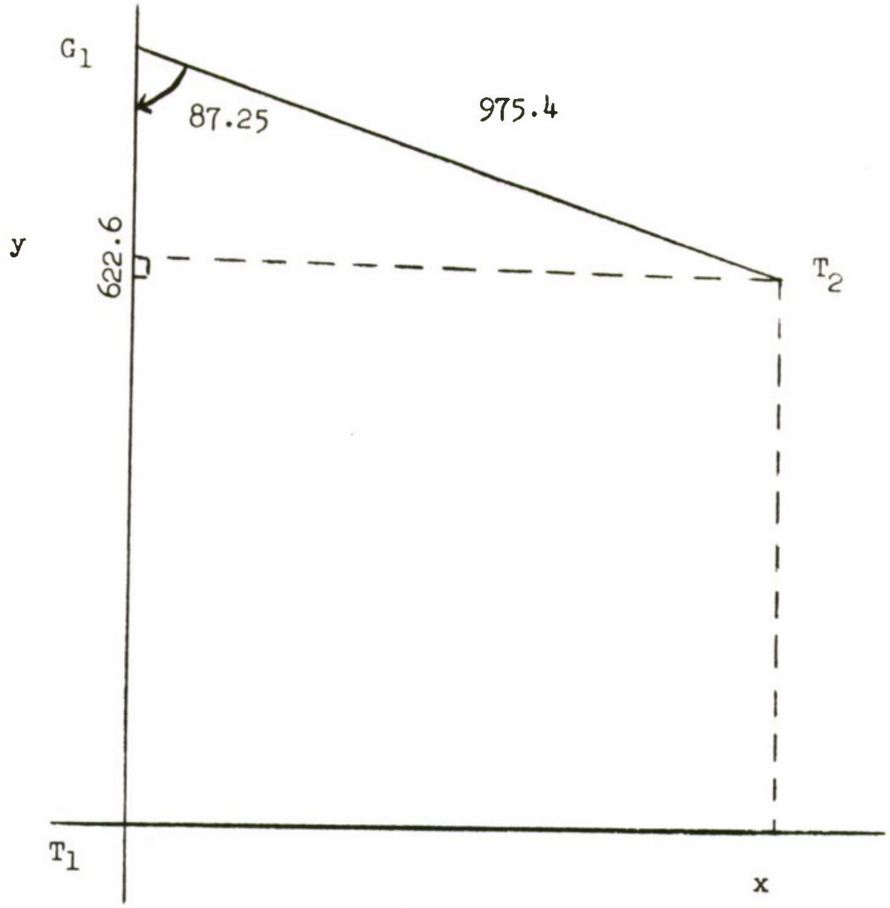


Fig. 10. Coordinates of T_2.

Equations (3′) and (5) give the coordinates of P with respect to the coordinate system with origin at T_1 as mentioned earlier. Consider $\overline{G_1A_1}$ the x-axis of a new coordinate system and $\overline{G_1G_{20}}$ the new y-axis (Fig 9). To transform x and y as given by (3′) and (5) into the new system, we have

$$x' = .97x - .25\,(y - 622.6) \qquad (6)$$

$$y' = .97\,(y - 622.6) + .25x \qquad (7)$$

x' and y' are now the coordinates of P with respect to the airfield with origin at G_1. Thus, using equations (1), (2), (3′), (5), (6) and (7) we are able to transform the azimuth readings obtained when the light-sensitive tracking units at T_1 and T_2 are following the target into coordinates with respect to the airfield.

While equations have been developed to reduce the elevation data contained on channels 1 and 6, it was decided not to include this in the analysis of performance for two reasons: First, the device used in the flight tests was a ground-effects machine which meant it was able to rise only a small distance above the ground. Secondly, the Ss were not instructed to maintain a constant altitude while in straight and level flight. For these reasons, the S's performance was evaluated only with respect to azimuth, i.e., heading, control.

RESULTS

In order to quantitatively evaluate a S's performance, it was first necessary to define some measurable quantity which would, insofar as experimental procedures would allow, reflect the different levels of proficiency exhibited by the Ss under the various restraints. To this end, the plan view area within the flight path flown by the S was defined to be the Basic Measure of performance (Fig 11). More specifically, for this study, the Performance Index of a S while under a particular restraint was defined to be the difference between the area within the flight path flown while restrained and the area obtained from the unrestrained flight. Thus, the Performance Indices are measures of the amount of change from normal conditions for each S under the following restraints:

U - Unrestrained

r1 - Right Hand Balled Into A Fist

r2 - Left Thumb Immobilized

r3 - Right Eye Covered

r4 - Left Leg Immobilized

r5 - Right Arm Immobilized

The Basic Measurements and Performance Indices obtained for each S are given in Tables 1 and 2 respectively. It may be inferred from Table 2 that the restraints have the following rank ordering and normalized values in increasing order of severity:

r1	r3	r2	r5	r4
5.77	12.08	14.97	90.28	99.47

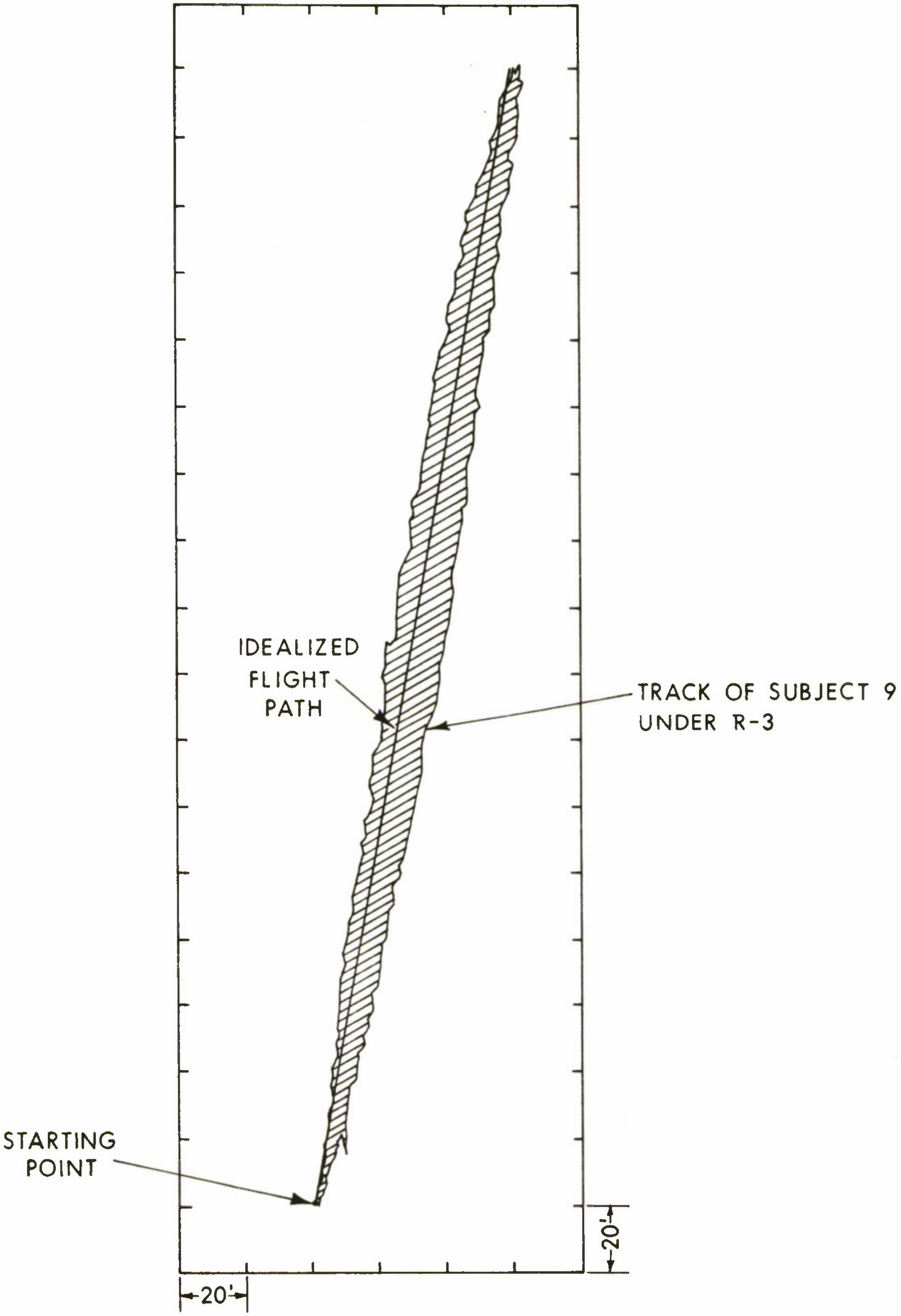


Fig. 11. Basic measure of performance.

Analysis of Results

Missing Data Points

Tables 1 and 2 each have two asterisked values representing lost data during the running of the experiment. The first instance is for the flight of S number 1 with Restraint number 3. After-the-fact review of the magnetic data tapes revealed that for reasons unknown he was initially picked up more than half way down the prescribed course, instead of at the starting point. Because it was impossible to meaningfully reconstruct his ground track for the first part of the course, the run was dropped from further analysis. Review of the tapes also showed that the flight of S number 9, restraint 5 was blank, indicating that the equipment failed to actuate in the record mode.

A method known as the "correct least squares estimate" (1, 6) was employed to generate substitute numbers for the missing scores. Missing scores are estimated by the formula

$$x = \frac{aT + bB - S}{(a-1)(b-1)}$$

where a = number of Treatments

b = number of Blocks (in this case S's)

T = sum of scores with same treatment as missing score

B = sum of scores with same block (S) as missing score

S = sum of all observed scores

For more than one missing data point, an iterative solution of the equation is indicated such that the sum of all observed scores is updated for next solution. After five iterations (both missing scores estimated in one iteration) S1, R3 converged to 1352.53, and S9, R5 converged to 4695.21. The sum converged to 279905.85 from an original 273858.12. In the ensuing analysis of variance, the degrees of freedom for the Total sum of squares, and the Error sum of squares must be reduced by 1 for each missing point, which reduces the power of the analysis somewhat.

An Analysis of Variance (4) was performed on the basic scores for all restraints and the unrestrained flights. Summary of this analysis appearing as Table 3 shows that a significant F ratio was the result for both treatments and Ss. This is interpreted as meaning that at least one treatment (restraint or no restraint) was significantly different than at least one other treatment; and at least one S's overall performance was significantly different from at least one other S.

Since a change in the S's flight in a restrained condition over how they flew unrestrained is of more importance, the analysis was repeated on the scores or indices generated by subtracting the unrestrained score for each S from their restrained scores. The summary Table 4 indicates that the F ratio for Ss was not significant but the F ratio for treatments was significant. This means that examining the change in the S's performance due to the restraints used, there were no differences from S to S. With regard to the restraints, all of the pilots flew in the same fashion; with respect to restraints, at least one restraint is significantly different from at least one other.

A multiple range test (6) was conducted between the various restraints. Table 5 shows the mean indices for each restraint rank ordered in increasing difficulty along with the significant differences (beyond the 5 percent level of probability) illustrated.

TABLE 1

Basic Measurements

Subject	Restraint					
	R-1	R-2	R-3	R-4	R-5	U
1	1704.80	1719.20	1352.53*	3476.18	2591.27	1894.41
2	1619.31	3079.14	2129.03	7090.45	2503.67	3179.21
3	5667.81	5141.45	6792.99	12174.75	10616.24	4938.42
4	882.55	1542.10	1219.29	10011.83	1281.85	894.77
5	2109.39	2509.04	3500.17	4589.60	3065.22	2438.10
6	6138.19	4581.06	5467.43	4443.48	4725.29	4999.12
7	2682.10	2434.91	3089.52	5301.80	6824.94	3059.49
8	1527.14	8037.06	2494.70	1558.69	2526.32	2442.55
9	3467.90	1973.00	3941.18	2371.81	4695.21*	2547.98
10	3113.63	4173.12	2707.60	10867.96	7484.15	1516.55
11	1544.52	2113.29	2959.93	3684.08	8881.85	2242.25
12	4902.79	1457.72	1975.58	3520.33	10585.82	3129.05

* missing data procedure

TABLE 2

Performance Indices

Subject	Restraint R-1	 R-2	 R-3	 R-4	 R-5
1	-189.61	-175.21	-541.88*	1581.77	696.86
2	-1559.90	-100.07	-1050.18	3911.24	-675.54
3	729.39	203.03	1854.57	7236.33	5677.82
4	-12.22	557.33	324.52	9117.06	387.08
5	-328.71	70.94	1062.07	2151.50	627.12
6	1139.07	-418.06	468.31	-555.64	-273.83
7	-377.39	-624.58	30.03	2242.31	3765.45
8	-915.41	5594.51	52.15	-883.86	83.77
9	919.92	-574.98	1393.20	-176.17	2147.23*
10	1597.08	2656.57	1191.05	9351.41	5967.60
11	-697.73	-128.96	717.68	1441.83	6639.60
12	1773.74	-1671.33	-1153.47	391.28	7456.77

* missing data procedure

TABLE 2 (Continued)

Subject	SUBJECT'S PERFORMANCE RANKED FROM BEST TO WORST				
1	R-3	R-1	R-2	R-5	R-4
2	R-1	R-3	R-5	R-2	R-4
3	R-2	R-1	R-3	R-5	R-4
4	R-1	R-3	R-5	R-2	R-4
5	R-1	R-2	R-5	R-3	R-4
6	R-4	R-2	R-5	R-3	R-1
7	R-2	R-1	R-3	R-4	R-5
8	R-1	R-4	R-3	R-5	R-2
9	R-2	R-4	R-1	R-3	R-5
10	R-3	R-1	R-2	R-5	R-4
11	R-1	R-2	R-3	R-4	R-5
12	R-2	R-3	R-4	R-1	R-5

TABLE 3

Analysis of Variance of Basic Scores

Source	DF	SS	MS	F	
Total	69	4.8611E+08			
Subjects	11	1.3909E+08	12644404.1663	2.8268	P<.01
Restraints	5	1.0995E+08	21989911.9460	4.9161	P<.005
Error	53	2.3707E+08	4473018.868		

TABLE 4

Analysis of Variance of Indices

Source	DF	SS	MS	F	
Total	57	4.0101E+08			
Subjects	11	85946777.2539	7813343.3867	1.4727	No Significance
Restraints	4	92234696.4680	23058674.1170	4.3462	P<.005
Error	42	2.2283E+08	5305476.19		

TABLE 5

Multiple Range Test of Indices

	1	2	3	4	5
	R-1	R-3	R-2	R-5	R-4
$\bar{X}$	173.1858	362.3375	449.0992	2708.3275	2984.0883
1		189.1517	275.9134	2535.1417	2810.9025
2			86.7617	2259.2283	2534.9891
3				2170.9600	2446.7208
4					275.7608

$Q_2 = 2.8325$ $D_2 = 953.3345$

$Q_3 = 3.403$ $D_3 = 1145.3477$

$Q_4 = 3.744$ $D_4 = 1260.1181$

$Q_5 = 3.985$ $D_5 = 1341.2315$

$\underline{\text{R-1} \quad \text{R-3} \quad \text{R-2}} \quad \underline{\text{R-5} \quad \text{R-4}}$

Restraints underscored by the same line are not significantly different.

Restraints not underscored by the same line are significantly different.

Discussion

It is concluded from the analysis that the two restraints immobilizing an entire limb were significantly more difficult than the other three which by stretching the point in regard to the eye patch, could be classed as partial immobilization. It would appear that restricting the ability to manipulate or grip does not have much bearing on the ability to hover, but that removing an entire limb from use makes things considerably more difficult.

In the case of the eye patch, there was no apparent difficulty in hovering. It can be argued that loss of binocular vision should not affect the ability to hover in the presence of sources in the field of view whose proximal size, shading, texture gradient, kinetic effects and perspective give distance cues (2). Whether or not binocular vision is a significant aid in judgement of height above ground level in range of from 10 to 80 feet, e.g., a high hover, or flaring to a hover from a descent, cannot be answered here.

It was seen from the raw scores, that even though the mean for unstrained flight was the lowest value of the six treatments or conditions, only two of the Ss scored lowest on their unrestrained flight. The other Ss largely scored their lowest on right hand and left thumb restraints (r-1 and r-2). As a matter of interest, a new set of indices was generated subtracting the lowest score for each S regardless of the condition where it occurred. An Analysis of Variance and Multiple Range Test (Tables 6, 7, and 8) yielded identical conclusions as those of Tables 4 and 5.

There is one flaw in the method of scoring the Ss during their flights which bears discussion. In the event that the S found himself off course during his flight; that is, he has obviously deviated from the established straight course between the markers laid out on the pavement over which they were flying; he did not necessarily have the cues necessary to hover directly back to the course line and then proceed on course. Rather, he would more likely attempt a guess at correcting his deviation and follow the line of sight from there to the marker. The decision was made not to paint a line on the pavement between the markers, as such lines rarely occur in real life! Given the procedure by which he would guess his way back on course, error would continue to be added to his score at a decreasing rate until he reached the marker. Figure 12 showing the plotted ground track of S number 10 with right arm restrained illustrates this very well.

CONCLUSIONS AND RECOMMENDATIONS

Based on the scores and indices generated from the ground track of the Whirlymite Trainer, removal of an entire limb from the controls significantly degraded a pilot's ability to hover and hover-taxi. In a helicopter other than the Whirlymite with its ground effect platform, the pilots may well have at least damaged the aircraft if not sustained injury during the conditions of the entire right arm or left leg immobilization. In contrast, the other three restraints had an effect not really discernible from unrestrained flight. Had it been possible to record and score pitch, roll, yaw, and control motions during the trials, it may have been possible to further discriminate among the various restraints employed; however, the rank order of difficulty in evidence here may not have materially changed.

Normal cruise flight in a helicopter is generally considered less demanding on the pilot than hovering with respect to attention and control manipulation; however, one flight regime outside the scope of this report which ought to be investigated is the approach to landing; including transition from cruise to descent and from descent through flare to a hover (including autorotative descent to landing). These tasks require full attention of the pilot and a high degree of coordination of the controls, which rivals the task of hovering in difficulty.

TABLE 6

Indices Using Lowest Score as Baseline

	Restraint					
Subject	R-1	R-2	R-3	R-4	R-5	U
1	352.27	366.67	0	2123.65	1238.74	541.88
2	0	1459.83	509.72	5471.14	844.36	1559.90
3	729.39	203.03	1854.57	7236.33	5677.82	0
4	0	659.55	336.14	9129.28	399.30	12.22
5	0	399.65	1390.78	2480.21	955.83	328.71
6	1694.71	137.58	1023.95	0	281.81	555.64
7	247.19	0	654.61	2866.89	4390.03	624.58
8	0	6509.92	967.56	31.55	999.18	915.41
9	1494.90	0	1968.18	398.81	2722.21	574.98
10	1597.08	2656.57	1191.05	9351.41	5967.60	0
11	0	568.77	1415.41	2139.56	7337.33	697.73
12	3445.07	0	517.86	2062.61	9128.10	1671.33

TABLE 7

Analysis of Variance of Indices Using Lowest Score as Baseline

	Degree of Freedom	Sum of Squares	Mean Square	F-Ratio
Total	57	3.7517E+8		
Subjects	11	60370693.91	5488244.90	1.035
Restraints	4	92076870.45	23019217.61	4.341
Error	42	2.2272E+8	5302857.14	

TABLE 8

Multiple Range Test of Indices Using Lowest Score as Baseline

	1 R-1	2 R-3	3 R-2	4 R-5	5 R-4
$\overline{X}$	796.7175	985.8192	1080.1308	3331.8592	3607.6200
1		189.1017	283.4133	2535.1417	2810.9025
2			94.3116	2346.0400	2621.8008
3				2251.7284	2527.4892
4					275.7608

$Q_2 = 3.11$ $D_2 = 1012.4505$
$Q_3 = 3.82$ $D_3 = 1243.5888$
$Q_4 = 4.26$ $D_4 = 1386.8294$
$Q_5 = 4.58$ $D_5 = 1491.0043$

$\underline{\text{R-1 \quad R-3 \quad R-2}}$ $\quad$ $\underline{\text{R-5 \quad R-4}}$

Restraints underscored by the same line are not significantly different.
Restraints not underscored by the same line are significantly different.

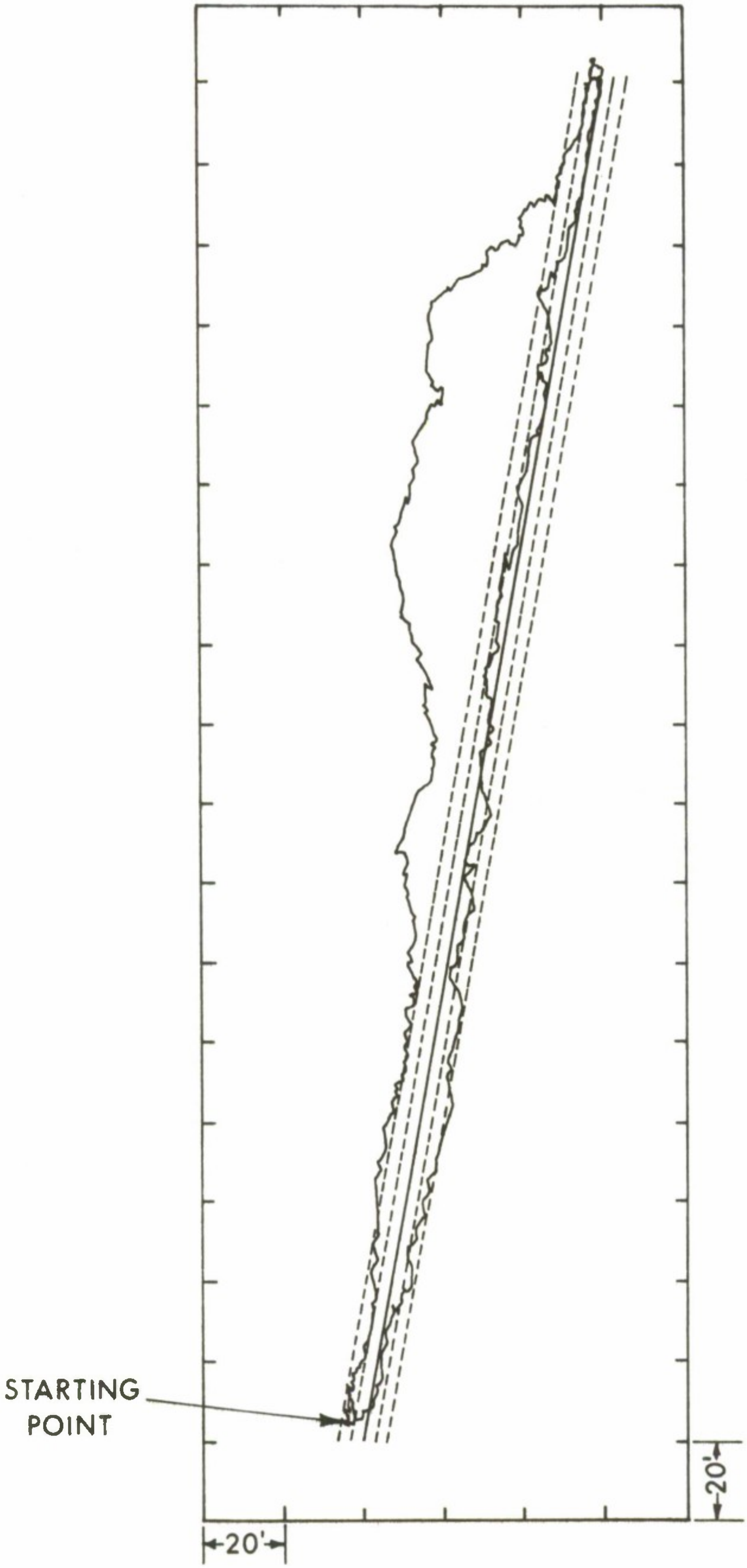


Fig. 12. Flight path of subject 10, right arm restrained.

REFERENCES

1. Cochran, W.G., & Cox, G.M.; Experimental designs. (2nd ed.), New York: John Wiley & Sons, 1957.

2. Dember, W.N. The psychology of perception. New York: Holt, Rinehart, & Winston, 1960.

3. Doss, N.W. Influence of pilot limb incapacitation on rotary-wing flight. Technical Note 9-72, U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD 1972.

4. Kopitzke, R.W. 9830A Stat Pac Manual and Program for HP Model 30 Calculator. Hewlitt Packard Corporation.

5. Lindquist, E. F. Design and analysis of experiments in psychology and education. Boston: Houghton Miffin Company, 1953.

6. Snedecor, G.W., & Cochran, W.G. Statistical methods. (6th ed), Ames, Iowa: Iowa State University Press, 1967.

APPENDIX

MEASUREMENT ERROR

With respect to the coarse azimuth data, some representative calibration readings are given below:

$T_1 \quad -907 \pm 8 \qquad -227 \pm 8 \quad \rightarrow \quad \Delta T_1 = 680 \pm 8$

$T_2 \quad -617 \pm 12 \qquad 1348 \pm 12 \quad \rightarrow \quad \Delta T_2 = 1965 \pm 12$

Where E_2 and B_{19} are the beginning and ending points of the flight path (Fig 8). Since the flight path is 345.3 feet in length, there are approximately .164 units/ inch with respect to T_1 and .474 units/inch with respect to T_2. The noise generated in the signal was found to be +8 units at T_1 and +12 units at T_2. These noise levels correspond to conservative errors of 2.4 percent from T_1 and 1.2 percent from T_2 ; i.e., the error inherent using the coarse azimuth readings only is 1.8 percent.

DEPARTMENT OF THE ARMY

US Army Human Engineering Laboratory
Aberdeen Proving Ground, MD 21005

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

POSTAGE AND FEES PAID
DEPARTMENT OF THE ARMY
DOD-314

U.S.MAIL

THIRD CLASS