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PILOT PERFORMANCE DURING LOW SPEED, LOW LEVEL NAVIGATION

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DEFENCE RESEARCH BOARD
DEPARTMENT OF NATIONAL DEFENCE
CANADA

MEMORANDUM

Stewart Harrison

H/SIC

DE-LIMITING TWO DOCUMENTS

1. With respect to your Memo of 13 January 2005 concerning the de-linmiting of DRML 248-1 and 248-2.

2. This fell through the cracks. I came across it while cleaning up my office recently.

3. I believe these two reports should be made available to the public. I see no reason to restrict distribution.

4. My argument is as follows:

    a. The material is now over 40 years old.
    b. The contents do not describe current operational environments.

Keith Hendy
Head, Human Factors Research and Engineering Section
2074

Abstract

The report considers the problem faced by pilots required to navigate accurately while flying very low. Army pilots flew two-hour low level sorties in quick succession, three times a day for four days. Pilots were instructed to:

(a) reach the target,
(b) stay on track,
(c) fly at approximately 25 feet.

An L19 100 m.p.h. aircraft was instrumented as the test vehicle. Measurements were taken of absolute height and track flown. Pilot's head and eye movements were sampled and recorded cinephotographically. The main findings were that:

(a) whereas a gross score of endpoints reached showed flawless performance, detailed measurement of track maintained revealed a tendency for performance to deteriorate in the second and third sorties of the day. A night's rest restored performance to the first flight level.

(b) performance was in general maintained throughout the fourth day, though it is not certain whether this can be attributed to a training or 'endspurt' effect.

(c) critical errors which were subsidiary to the main task occurred toward the end of the low level section of sorties.

(d) pilots spent 27% of flying time at low level with their heads down looking at the map. The 'looks' contributing to this total ranged in length from 0.2 to 3.9 seconds.

(Cont'd)

Abstract (Cont'd)

It is concluded that:

(a) no more than three consecutive sorties of this kind should be flown in a routine day,

(b) the task could be simplified by the use of automatic navigation equipment,

(c) pilots could be better prepared for the task by considerably more practice in flying and navigating near to the ground during training and operational flying,

(d) regardless of the pilot's skill, aircraft engaged in flying of this nature will sooner or later hit wires, trees and birds.

PILOT PERFORMANCE DURING LOW SPEED, LOW LEVEL NAVIGATION

INTRODUCTION

Can Army pilots navigate accurately over unfamiliar terrain whilst flying very low? Can they maintain performance in repeated sorties? The problems implied in these questions, posed by the Director of Land Air Warfare, Canadian Army, have been investigated by the Defence Research Medical Laboratories with the cooperation of pilots from 1 and 2 Air Observation Flights, Royal Canadian Artillery.

The difficulty of attempting to navigate along a short unfamiliar track when flying very close to the ground was indicated in a preliminary trial. (Appendix 1, page 17). Operational sorties may comprise four such tracks flown in sequence. The present trial was designed to reveal difficulties encountered in typical sorties navigated with no aids other than map, compass, and gyro compass. Pilots participating in this study were required to navigate over unknown ground and fly at an altitude of approximately twenty-five feet at 100 m.p.h. They did this during three successive two-hour sorties on each of four successive days.

Some difficulties which become more severe the nearer the aircraft is to the ground are:

(a) forward vision is limited to the next obstruction,
(b) navigational features come into view and pass out of sight quickly,
(c) the altitude of the aircraft is rarely constant for more than a few seconds,
(d) obstacles must be constantly avoided,
(e) useful topographical features which are elevated to the side are not seen,
(f) turbulent air can cause dramatic attitude changes calling for swift correction.

Factors such as these combine to make the task particularly exacting.

PROCEDURE

The trial required pilots to fly over unknown ground from an unfamiliar airfield. Each pilot came to the airfield to complete twelve two-hour sorties in a four day period. The next pilot was then tested, and so on. Each sortie consisted of an outbound leg flown at 500 feet, followed by four legs flown very near to the ground and finally a return leg at 500 feet.

Aircraft

Two L19 light aircraft were used to obtain performance measurements*. One, the test aircraft, flew low and was instrumented to record continuously absolute altitude (radar) and normal acceleration. Ciné photographs of the pilot's eyes and the view forward were taken simultaneously. The test aircraft also carried the investigator who kept a lookout for telephone wires and operated recording equipment. The second aircraft flew 500 feet above the test aircraft and carried an observer whose sole task was to plot accurately the track of the lower aircraft.

Trial Design

A simple design required each of four pilots to fly twelve different sortie tracks which were randomized. Each sortie was 200 miles long and was flown to a typical operational profile (Figure 1, page 3). The low level section within each sortie was approximately 50 miles long and lasted 30 minutes, but there were differences in duration of as much as 10 minutes.

Terrain

The trial was flown over the relatively flat homogeneous mid-west Canadian Prairies. Track features which are basic to the navigation problem, e.g., terrain contours and endpoint characteristics, were similar for all tracks. Turning points and endpoints were relatively small, e.g., farm buildings, junctions of secondary roads and farm tracks, etc.

The trial was flown from a little-used grass airfield in Virden, Manitoba. Though Virden lacked some services available at larger airfields, use of it facilitated adherence to a rigid timetable.

Maps

Aeronautical editions of the National Topographic Series $\frac{1}{250,000}$:

*It was assumed that results obtained would apply equally to low speed fixed wing aircraft and helicopters fitted with stability augmentation systems.

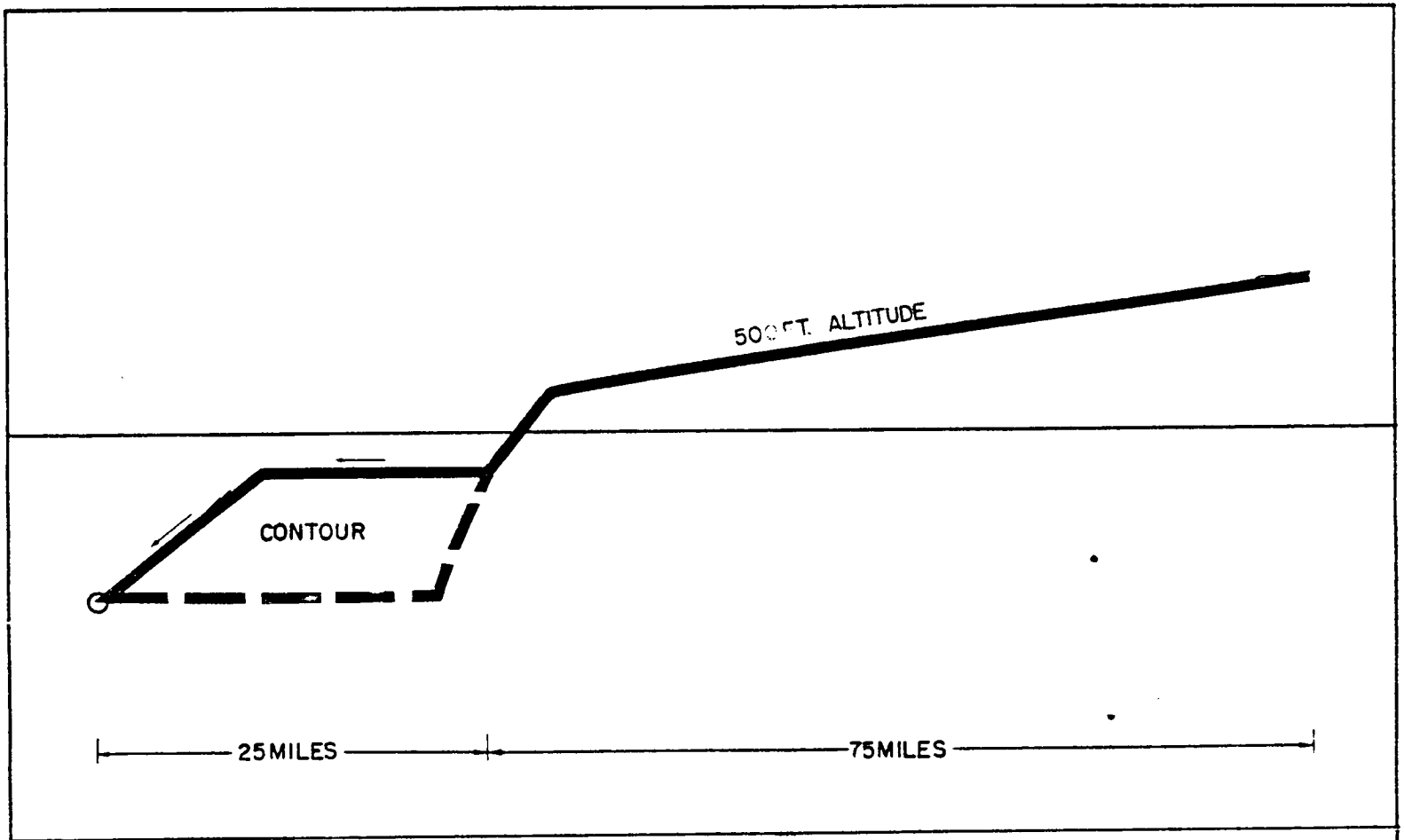


FIG. 1. TYPICAL OPERATIONAL SORTIE

scale 8 miles to the inch, covered the area flown over at 500 feet. National Topographic sheets $\frac{1}{50,000}$: scale 1 mile to one inch and a quarter covered the low level sections.

Pilots

Each of four participating pilots had between 300 and 500 hours flying time on light aircraft. Though practiced in reading large scale maps they were unaccustomed to combining the skills of navigating and piloting near to the ground.

Instructions

On the evening before flying in the trial, each pilot attended a detailed briefing at Virden. He was told the reason for the trial and the methods used to record his performance, and was informed that he had no other duties to perform on the ensuing four days. Instructions were summarized with the following three statements given in order of relative importance:

1. reach the endpoint,
2. stay on track,
3. fly as near to the ground as possible with safety. *

Daily Flying Schedule

The day commenced with a fifteen-minute self-briefing for the pilot at the airfield at 0730 hours. He examined maps, which he had not seen previously, covering the first sortie tracks to be flown. To reduce the likelihood of error, tracks had been drawn in on the maps and true track bearings and distances had been listed. At 0745 hours crews boarded the aircraft, performed checks lasting fifteen minutes, then flew the first sortie. After landing the pilot under test briefed himself with fresh maps in preparation for the second sortie. Coffee was provided while he did so. Meanwhile the aircraft were checked, refueled, and the cameras and flight recorders reloaded. After the briefing was completed, the second sortie was flown. A deviation from this pattern occurred between the second and third flights, when, in addition to coffee, a sandwich lunch awaited the pilot. Three sorties to this pattern, totalling six hours and thirty minutes in the air,

*After the first thirteen flights pilots were instructed to fly no lower than 25 feet.

were flown on each of four consecutive days.* Every effort was made to limit time spent on the ground between sorties 1 and 2 to thirty minutes and between 2 and 3 to fifty minutes.

Performance Scores

Low level navigation was scored in four ways: (a) the number of endpoints reached was noted as a gross score, (b) the length of the tracks flown was compared with the intended track length, (c) corridors were superimposed over intended tracks and where the track actually flown deviated from the corridor the lengths of the deviations along the corridor were summed, and (d) the number of occasions on which the track departed from a corridor was scored.

Procedural Problems Affecting Trial Design

Unforeseen problems were encountered, typical of those which dog complex field studies and which in analysis disturb the balance of an experimental design.

The complications listed below, coupled with the small number of pilots tested, made refined statistical tests inappropriate.

(a) Four flights were flown on the first day---thereafter three.
(b) Subsequent to the thirteenth flight a minimum height restriction of 25 feet was imposed.
(c) Bad weather caused the last day's flying to be postponed one day.
(d) On three occasions tracks which headed into bad weather were changed for the next in order. These changes were made by the investigator before pilot briefing.

RESULTS

Number of Effective Sorties

The ultimate test of sortie effectiveness, namely, the number of endpoints reached, shows that in all 48 sorties the pilot reached the target endpoint.

*Four consecutive sorties were flown on the first day of the trial. This procedure was discontinued on medical grounds. (See Appendix II, page 21).

Low Level Track-Keeping

All tracks were straight lines. Performance in track-keeping appears to be one of the most informative measures available of a pilot's skill in low level navigation. Records of 192 track legs flown are shown in Figure 2, page 7. Errors in maintaining track stem from (a) setting course in the wrong direction---a rare error, (b) searching for the end-point, and (c) losing track and failing through an appreciable distance to make a correct course change. Figure 3, page 9, summarizes performance in terms of distance flown in excess of track length. Table I indicates the percentage of track flown outside corridors of arbitrary width. Figure 4, page 10, indicates the frequency of excursions outside the borders of a corridor 2 miles in width.

Table I

PERCENTAGE OF TRACK FLOWN OUTSIDE OF CORRIDORS

Corridor Width	First Flight	Second Flight	Third Flight
1/4 mile	29%	39%	39%
1/2 mile	16%	25%	22%
1 mile	6%	11%	9%

Maintaining Performance

From inspection of Figures 2, 3, 4, and Table I, it can be seen that low level track-keeping tends to deteriorate in the second or third sorties of each day. Large differences appear among pilots. On the fourth day a marked trend was observed toward overall improvement which may represent either an effect of training, or 'endspurt'. No differences appear among sorties or days during outbound and inbound legs flown at 500 feet.

Critical Incidents

On five occasions pilots were warned by the investigator that they were about to fly through wires, and on another occasion did (Figure 5, page 11). Missed turning points, though non-critical errors, tended to occur in

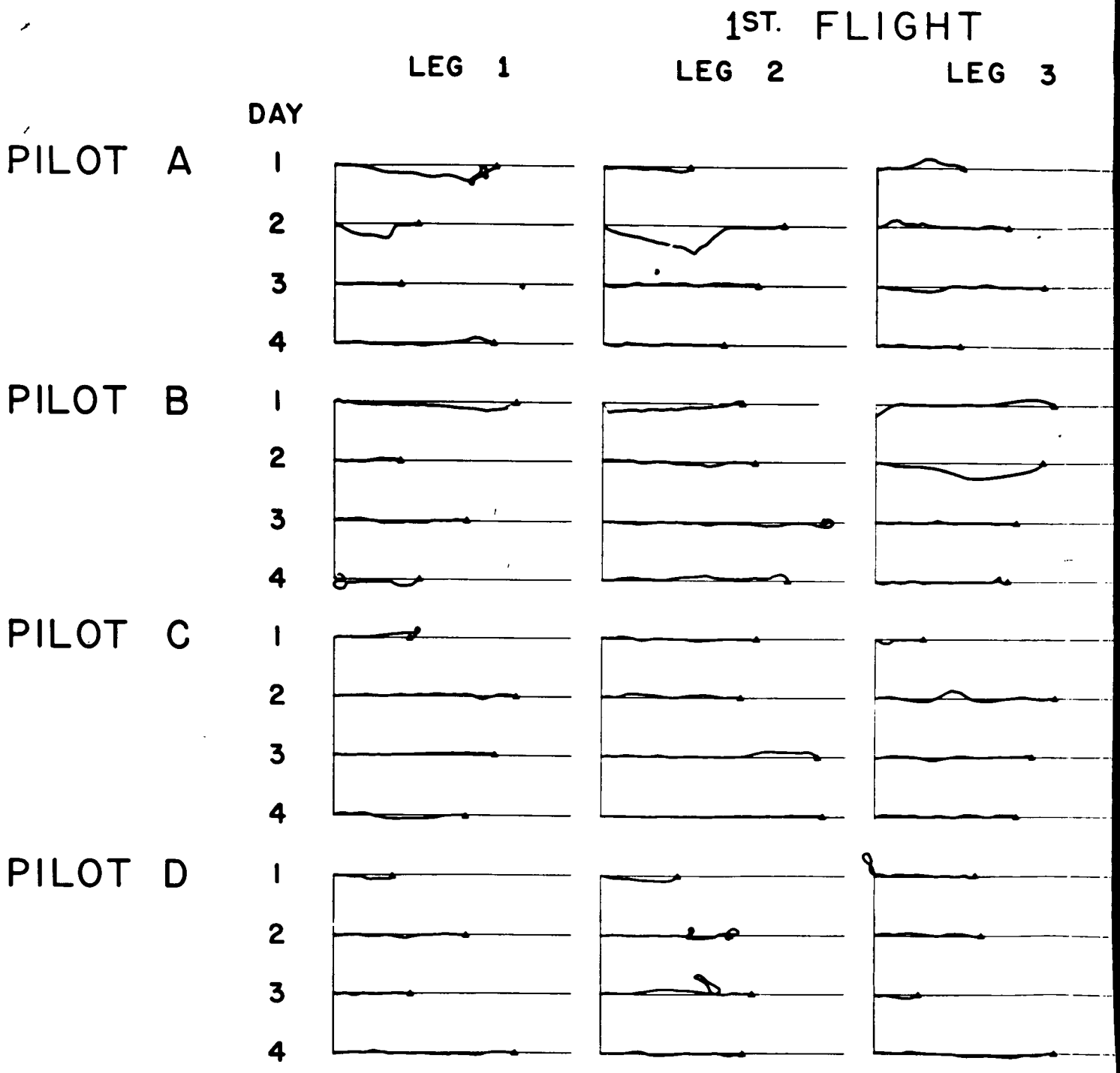
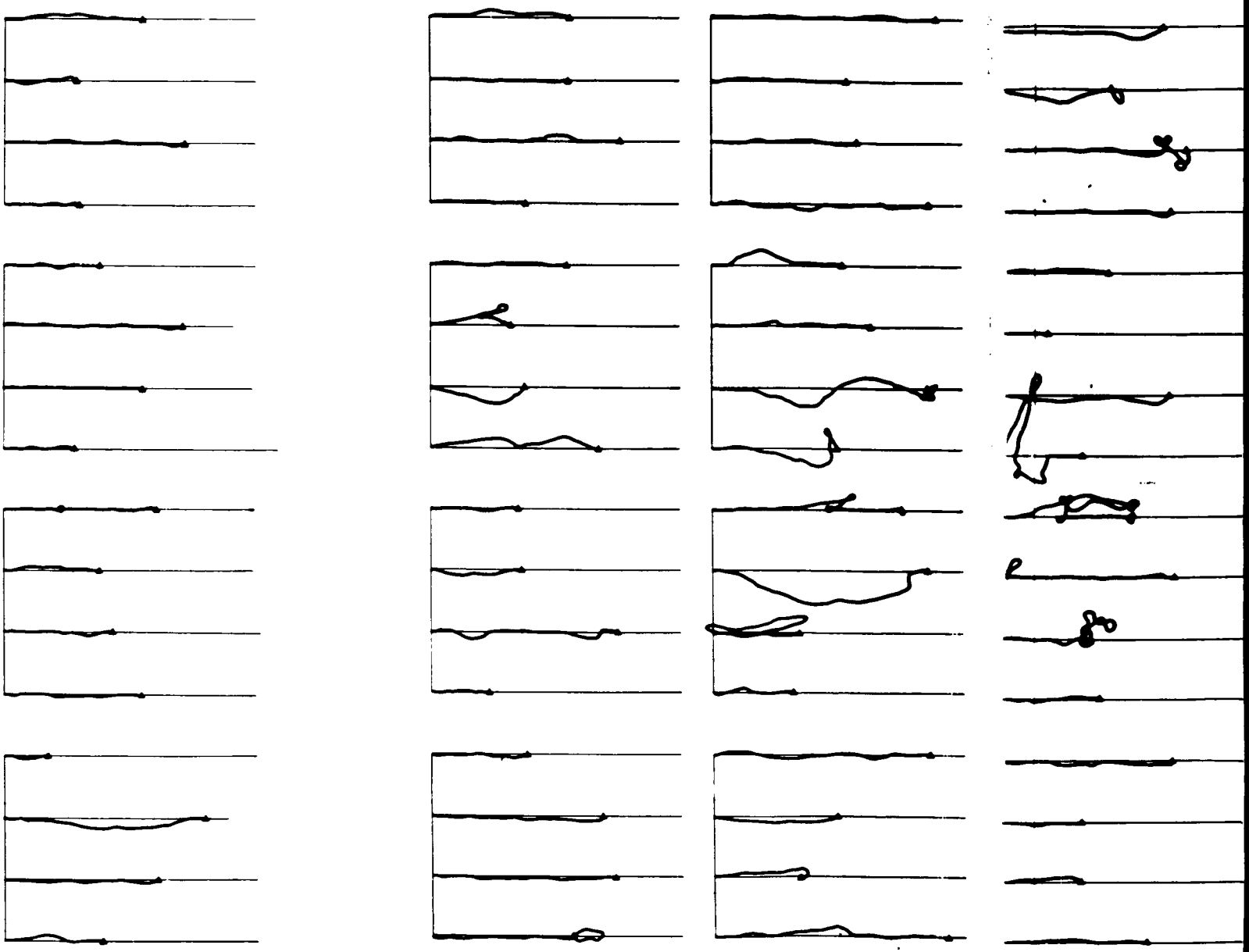


FIG. 2. PILOT PERFORMANCE DU

2ND. FLIGHT

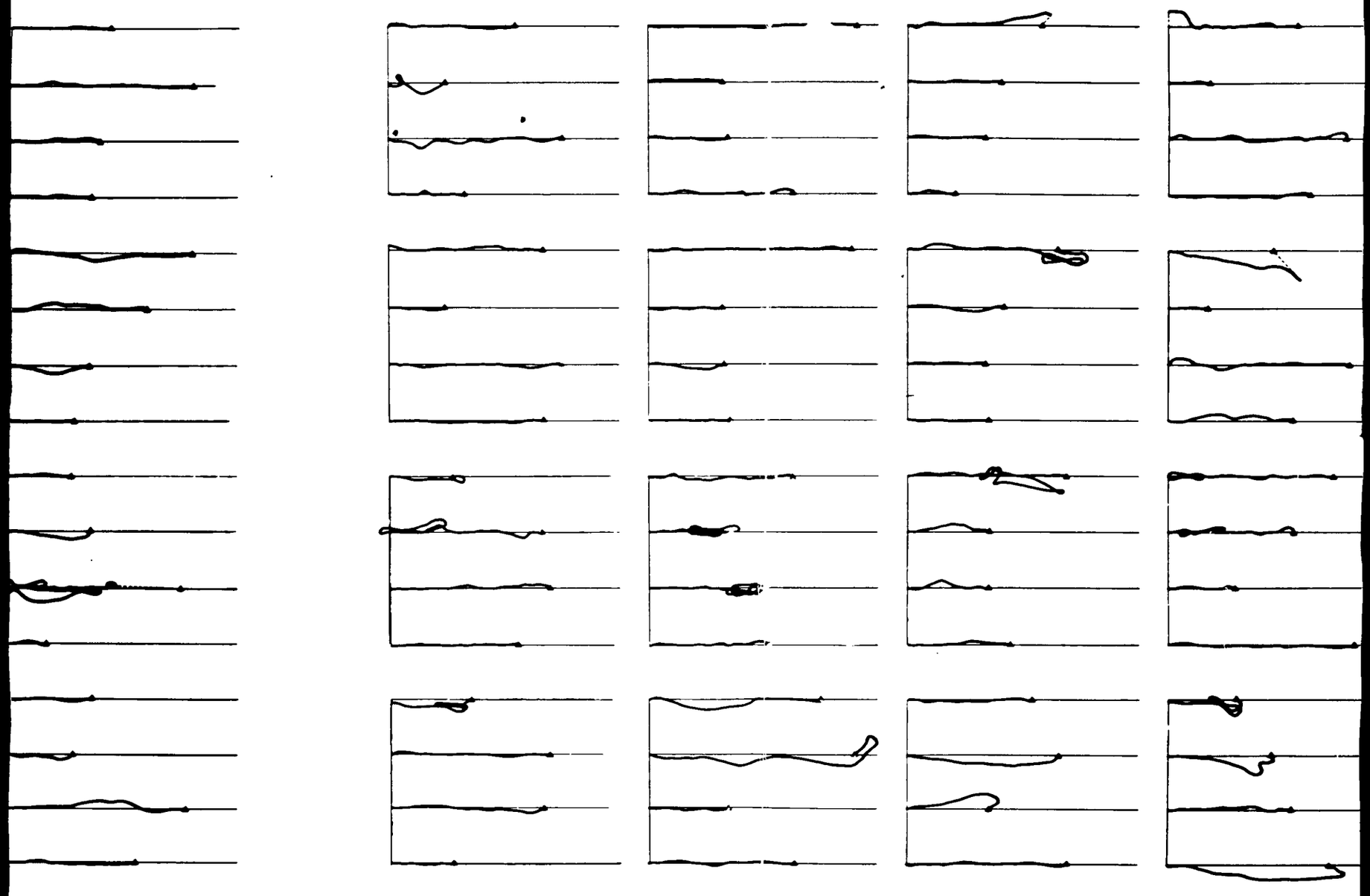
LEG 4 LEG 1 LEG 2 LEG 3



RING LOW LEVEL NAVIGATION

3RD. FLIGHT

LEG 4 | LEG 1 | LEG 2 | LEG 3 | LEG 4



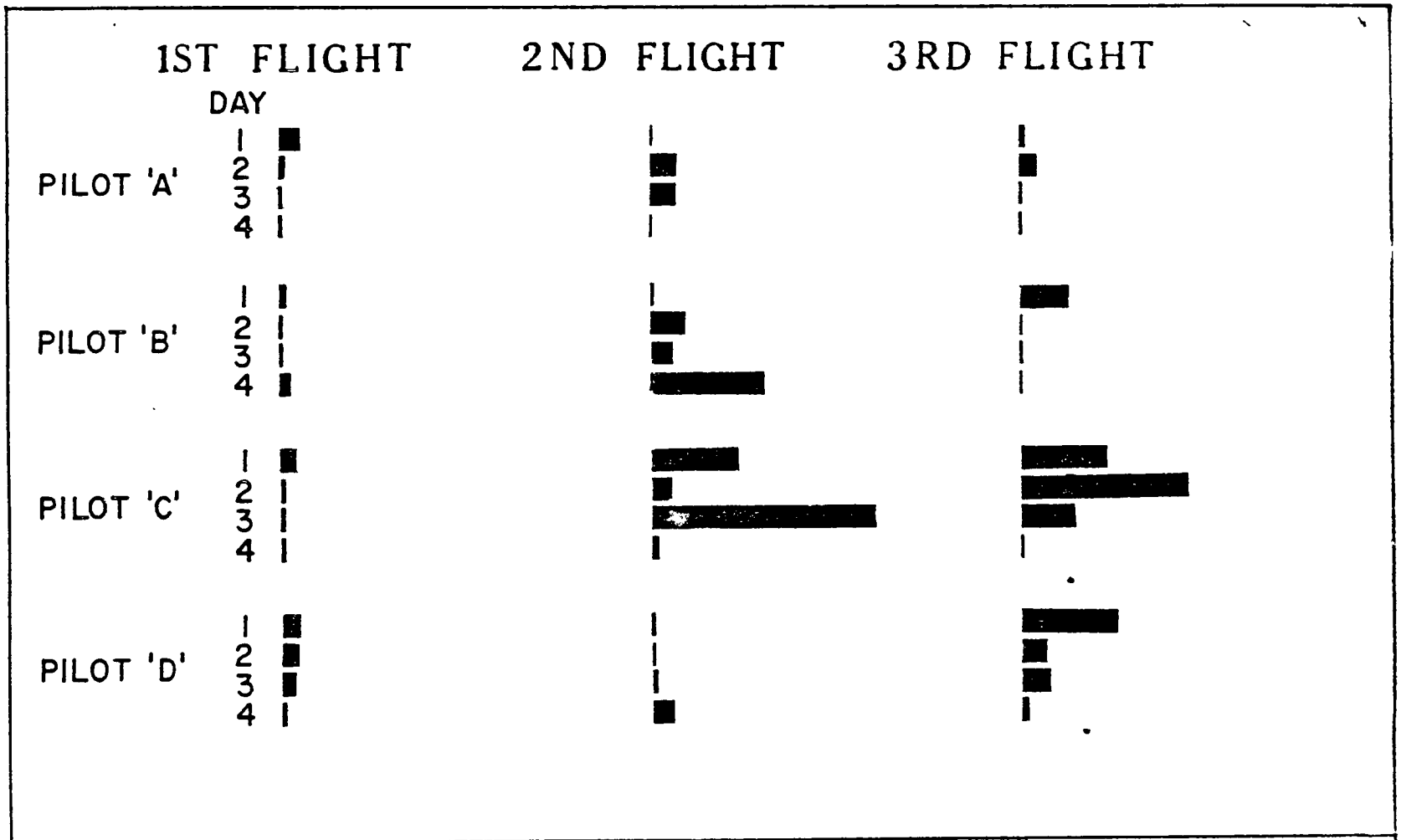


FIG. 3. DISTANCE FLOWN BEYOND TRACK LENGTH

100% =

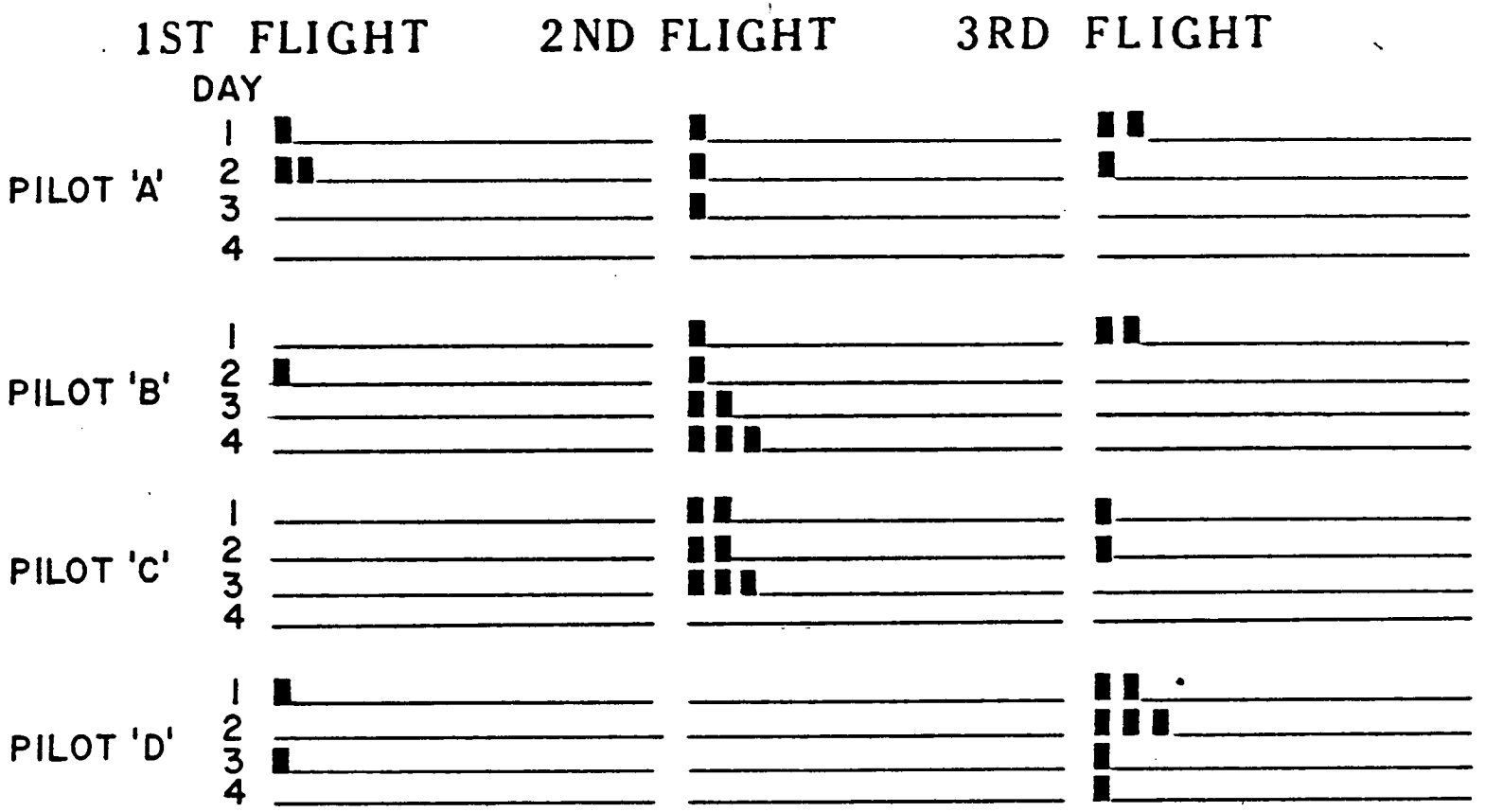


FIG. 4. OCCASIONS OUTSIDE OF A 2 MILE CORRIDOR

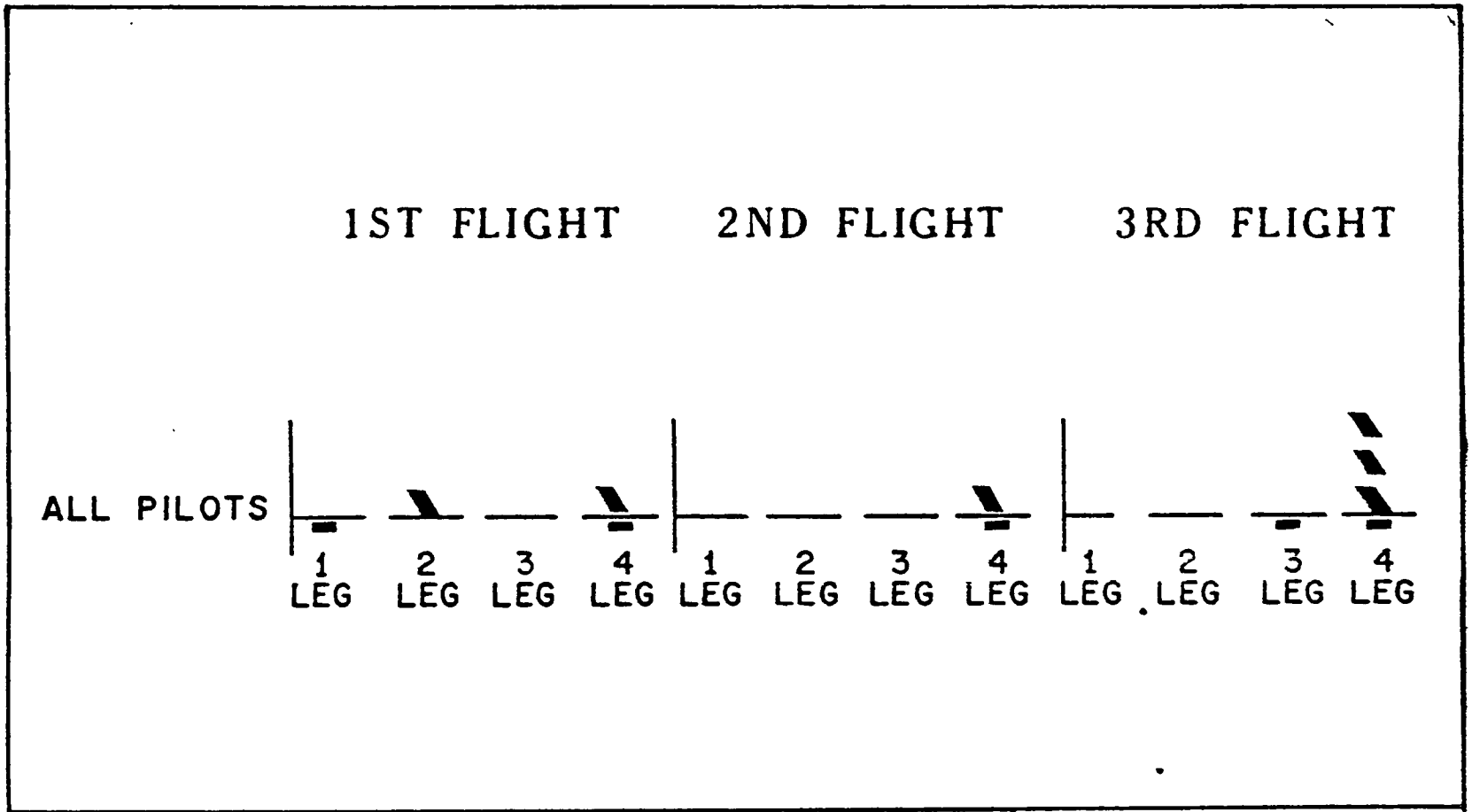


FIG. 5. TURNING POINT AND WIRE ERRORS

the same pattern in time as the wire incidents. On three occasions fuel tank switching was neglected until well after the safe time which was just after the low level section. This pattern, based on very few incidents, tends to suggest deterioration in subsidiary aspects of the skill[1] towards the end of the low level portion of the sortie.

Eye Movements During Map Reading

Random ciné-film samples of eye movements to and from the map during low level map reading were analyzed by the single-frame method. Samples totalled twenty-five minutes and were obtained for two pilots only. Maps were held or clipped on the pilot's left knee and an eye movement to the map was clearly identifiable and often was accompanied by a gross downward head movement. Each sample film strip was analyzed from the end of the first 'look' to the end of the last 'look' at the map. During low flying the eyes were occupied with map reading through 27 per cent of the sampled film time. Three wire incidents occurred during map-reading intervals.

A frequency distribution of map-reading times for the two pilots (Figure 6, page 13) shows that a surprising percentage of 'looks' were less than one second in duration. Whether these 'looks' were long enough to be useful[2], or completed, remains uncertain.

Ground Turbulence

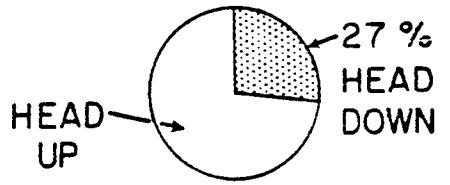
Normal acceleration peaks were assumed to show the effects of ground turbulence rather than corrective accelerations imposed by pilot control movements. These were analyzed through the first, middle, and last minute of each low level sortie to determine whether differences in pilot performance in navigation could be attributed to difference in exposure to turbulence. There were no obvious differences among or within daily sorties. Turbulence peaks ranged from $\pm$ 0.29 to $\pm$ 0.4g at the relatively slow frequency of 12 to 20 cycles per minute. Turbulence of this nature, though startling to the novice, is accepted as a routine source of minor irritation by the experienced light aircraft pilot.

Height

The radar altimeter recorded ground to aircraft height---not tree-top to aircraft height. Therefore, since the prairies were wooded along approximately 17 per cent of the tracks flown, it was impossible to utilize the altimeter record as a measure of pilot performance in height flown above terrain or obstructions. Secondly, the imposition of a 25' minimum compelled three pilots to fly higher at times than they otherwise would have.

TIME	CHECKS
0·0 — 0·4 SEC.	11
0·5 — 0·9 SEC.	74
1·0 — 1·4 SEC.	74
1·5 — 1·9 SEC.	50
2·0 — 2·4 SEC.	25
2·5 — 2·9 SEC.	4
3·0 — 3·4 SEC.	3
3·5 — 3·9 SEC.	6
	247

FIG. 6. FREQUENCY DISTRIBUTION OF MAP READING CHECKS



The recorded altitudes showed that in spite of these restrictions (a) 80 per cent of track was flown beneath 100', (b) 33 per cent of track beneath 50', and (c) two per cent of track beneath 25'.

DISCUSSION AND CONCLUSIONS

Performance at Low Level

The trials revealed a number of difficulties likely to be encountered by pilots flying and navigating close to the ground. Though performance appeared flawless when measured by a gross score, more detailed measurement revealed the effects of flying consecutive sorties separated by a relatively short interval.

Ability to stay on track appeared to be the most informative measure of performance; track-keeping errors tended to increase during the second and third sorties of the day. A night's rest, however, returned performance to the level observed in the first sortie. On the last day this level of performance was maintained throughout the day. Whether this was a true effect of training or, alternatively, an example of endspurt is uncertain.

Errors in subsidiary aspects of the skill followed a pattern observed in the classic pilot error studies performed twenty years earlier with the Cambridge cockpit[3]. These critical errors could in practice be limiting factors since a single incident could terminate a sortie abruptly. From observation in flight it can be concluded that in flying of this nature, no matter how skillful the pilot, the risk of the aircraft striking wires, trees or birds must be recognized.

Simplifying the Task

Several remedial steps could be taken to ease the load on the pilot or better prepare him for this task.

1. 'Heads-up' displays of navigation, flight instrument, and failure warning information would reduce the time that the pilot has his 'head in the cockpit'. Similarly, aircraft navigation systems providing continuous positional information, ground beacons providing endpoint bearings, and maps emphasizing topographical and other details important to low level navigation would each reduce the problem of navigation.

2. Training and practice in flying and navigating near the ground should be given special emphasis because the Army pilot, unlike pilots in the other services, must fly close to the ground in most of his operational roles.

3. Dividing the task between a pilot and observer would permit the pilot to attend solely to flying. Whether this arrangement would result in greater navigational accuracy en route is, however, a moot point.

4. Obviously, the cockpit of an aircraft to be used in this role should be specially designed. There should be, for example, no requirement for the pilot to switch fuel tanks---such an arrangement is archaic. Similarly, if the pilot spends a quarter of his low level flight with his head in the cockpit he will sooner or later hit obstructions.

It is concluded that within the terrain limits of these trials the Army pilot can navigate to an endpoint whilst flying very low and can do this on three consecutive occasions in one day. He may, however, (a) experience greater difficulty in keeping to track in the later sorties of the day, and (b) commit critical errors in subsidiary aspects of the skill.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge the support given to the project by Lt. Col. D.R. Ely, Director of Land/Air Warfare.

Substantial assistance was given by the Flight Section of the National Aeronautical Establishment who instrumented the Aircraft with a flight recorder and special equipment.

The assistance of the Surgeon General's office through the services of Major F.R. Cullen, R.C.A.M.C., of the Institute of Aviation Medicine is gratefully acknowledged.

The Commanding Officers of Camp Shilo and CJATC Rivers provided maintenance support. The technicians who were unstinting in their efforts are gratefully acknowledged.

Mr. J. Tunney of DRML who was responsible for special equipment installations was invaluable throughout the trial.

The pilots who flew the test and chase aircraft deserve special thanks. Needless to say, order of pilot participation has been masked in this report.

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2. Byrnes, Victor A. "Visual Problems of Supersonic Speeds". Amer. J. Ophthal., Vol. 34, pp. 169-177. (February, 1951).

3. Drew, G.C. "An Experimental Study of Mental Fatigue". FPRC 227, (1940). Re-issued 1960.

APPENDIX I

PRELIMINARY TRIALS

INTRODUCTION

As a means of determining performance problems which might be amenable to detailed study, preliminary trials were flown from Camp Petawawa, Province of Ontario, with the pilots and aircraft at 1 Air Observer Flight, Royal Canadian Artillery.

PROCEDURE

A briefing was held initially at which the four participating pilots were told the purpose of the trials. The pilots were then tested singly. Each pilot flew to Bonnechère, an air strip twenty-three miles from Petawawa which was chosen as a relatively unfamiliar starting point for each of four test tracks. These were straight tracks, 1, 5, 15, and 30 miles long. The tracks covered open country and terminated at inconspicuous topographical features, e.g., farm buildings or tips of small lakes.

At Bonnechère the aircraft was parked. The investigator who flew on each flight then handed the pilot an envelope containing one or more folded maps on which the first track to be flown was drawn.

INSTRUCTIONS

Each pilot was then slowly briefed as follows: "We want you to fly to the point at the end of the track drawn from Bonnechère. The track bearing is . . . True, and . . . nautical miles long. Take any route you wish to get there, time is not important. Remember, the most important thing is to get there. As you know, we want you to fly as low as you can with safety. Fly at any air speed. Take as long as you wish to think about it. Shut down the engine if you want to---it's quieter then. One more thing, let me know the route you're taking. Any questions?"

Each pilot considered the problem for about three minutes, then described the route to be taken, which was noted. The pilot then took off and flew at about 100 m.p.h. at relative heights varying between 5 and 50

feet approximately* above the ground or tree tops.

TRACK TERRAIN

The tracks crossed forests which undulated steeply between 595 and 1250 feet above sea level. Lakes were ice covered and the ground snow covered. Roads, cart-tracks, and railroads were clear.

SUBJECTS

The four pilots who flew in the preliminary trial were experienced artillery officers who had, as qualified light aircraft pilots, accumulated flying experience ranging between 400 (the near modal figure) and 900 hours. It must be noted that as artillery officers they were experienced in reading large-scale maps. A proportion of their flying had been spent in routine low flying, e.g., concealed approaches and take-offs, etc., but they were relatively unaccustomed to very low navigational flights of this kind over unfamiliar terrain.

TRIAL DESIGN

The four tracks were flown in random order by each pilot. The series was then repeated in different order so that each pilot completed eight flights in all. As stated above, the route for the first four tracks was left to the discretion of the pilot. On the second (repeated) series it was required that the tracks be flown direct.

No practice in map-reading or low flying was provided since these skills are essential to the Army pilot's role.

WEATHER CONDITIONS

Ground turbulence, although moderate, was sufficient to add to the difficulty of the flying task for twenty-four of the tracks flown. The remaining tracks were flown in relatively smooth air.

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*The investigator, an ex-flying instructor on light aircraft, found height near to the ground or tree tops relatively easy to judge, whereas the higher the aircraft flew the more difficult and less reliable the estimate. However, there is no doubt that the aircraft spent more time at 20 feet above tree tops than at 50 feet.

MAPS

The maps used were 1:50,000 topographic; scale 1.25 inches to the mile, and 1:250,000 provisional topographic; scale 1 inch to 8 miles.

RESULTS

In the first series of sixteen flights in which the pilots chose their own routes, only one error was made. The pilot flew past the endpoint, missing it by very few yards, and continued for 1-1/2 miles before commencing a search turn. This was the first track flown by the pilot in his series. On two other occasions the pilots circled once within a 1/4 mile of the endpoint before indicating the precise location.

In the second (direct) series only one scoreable error was made. The pilot again flew more than 1-1/2 miles beyond the endpoint. This again was the first flight of the series for this pilot. For one track in the second series the aircraft circled in the immediate vicinity of the endpoint before positive identification was claimed.

At no time did the pilots climb to determine their position.

CONCLUSIONS

1. Errors occurred only in the first flights in each series. This suggests that during briefing pilots should give particular attention to the run-in to the endpoint. The provision of a larger scale map covering the endpoint should be helpful in this regard.

2. In the first series flown, pilots made great use of main topographical features (railroads, rivers, etc.). Flying a greater distance in order to utilize these features seemed worthwhile in that pilots were certain of their position when they reached each feature and less concerned with map-reading whilst flying between features. In contrast, when flying 'direct' the pilots appeared to work harder at map-reading, and judging from their repeated glances at minor topographical features they seemed less certain of their position. It is concluded that the use of main topographical features even at the expense of additional distance flown, is justified by the advantage gained in regard to the navigational task.

APPENDIX II

Medical Officer's Report

DRML Low Level Pilot Navigation Trials

Author: Major F.R. Cullen,
Royal Canadian Army Medical Corps,
Institute of Aviation Medicine.

INTRODUCTION

The Medical Officer attended the first week (September 5-12) of the trial at Virden, Manitoba.

ROLE

(a) To observe pilots before and after each flight.
(b) To comment and advise on the degree of fatigue.

METHOD

The M.O. interviewed the first pilot when he arrived at Virden on the evening prior to the commencement of the trial. Thereafter the pilot was interviewed at breakfast prior to the first flight of each day and after each subsequent flight.

Good control was maintained on all pilots as they were housed in a motel away from their parent unit, and thus were away from routine responsibilities, both Service and family.

ROUTINE IN DAY 1

Breakfast between 0630 and 0645 hrs.

Self-briefing on arrival at airport at 0730 hrs.

Two flights in the morning and afternoon with approximately 20 minutes between flights. Coffee was available during preflight self-briefing.

Lunch allowed approximately 50 minutes on the ground. It consisted of coffee and sandwiches delivered from a local restaurant.

Dinner followed the final flight of the day, around 1800 hours. Hour of retirement was left to the pilot's discretion.

DISCUSSION

Day one for the first pilot consisted of four flights of approximately two hours and ten minutes duration. This pilot had been advised that the trial would require him to fly five similar days consecutively. Following day one, he was extremely fatigued but stated the task was not as difficult as he had anticipated. This subject was somewhat of a perfectionist, with a strong desire to complete the exercise as skilfully as possible.

On pre-flight interview the next morning he admitted to great difficulty getting to sleep, and still appeared very tired. Following a discussion with the investigator, it was mutually decided to limit the number of flights to three daily for a four day period. With this modification of the original routine, the pilot continued the exercise without undue fatigue and the trials appeared to be well within the bounds of safety. The low level section of the trial did, however, involve considerable physiological and psychological effort.

The poorer performance on the second flight of each day by most pilots is of interest. This may in part be due to fatigue following the first flight, with the functional overlay of realization that there remained two more flights to perform. Also blood sugar may have been lowered during the first flight and not raised to a sufficient level by coffee alone.

The fact that performance was in general maintained through day four may be due to increased ability after practice, together with some psychological release, in the realization that this was the final day, leading to a final burst of incentive to finish the task well.

CONCLUSIONS

It is the opinion of the observer that three two hour and ten minute sorties of this nature, i.e., low level, are within normal tolerance, but increasing this to four may exceed the bounds of safety for training or a routine operational role. In an emergency, however, four successive flights a day may be possible with justifiable risk.