CHANGES IN THE TIMING OF RESPONSES FOLLOWING SPELLS OF HIGH SPEED FLYING

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ABSTRACT

One of the important signs of fatigue in pilots is prolongation of the time taken to respond to signals for action. Since promptness in action is essential in high-speed flying, it was of interest to see whether any changes occur in the timing of responses of IAF pilots after routine flying sorties. This study was carried out on a group of IAF jet fighter pilots stationed at Palam, New Delhi during the Summer months of 1954. The pilots were tested immediately before and after their flying exercises by measuring their response times to three arrangements of stimuli presented in rapid succession, so as to determine the time required for an immediate response, a discrimination and a choice. Analysis of results showed that there was slight prolongation in the post-flight response times of pilots as compared with pre-flight values. This difference was most marked after 'hard' sorties, but very slight after 'easy' and 'slightly difficult' sorties. Of the various alternative explanations considered in order to account for this difference, 'transient' fatigue appears to be most plausible.

Introduction

Modern aircraft, flying at high speeds and high altitudes, impose on flying personnel strains of a character hitherto unknown. High levels of tolerance are demanded of the man in the cockpit. He is required to exercise finely developed powers of mind and brain. His safety is undermined if he is slow in sensing minute changes, or if he fails to think up the right action without delay. His efficiency depends on his success in spotting errors promptly and applying corrective adjustments instantly. Operational requirements such as these point to the need for high standards of flying fitness. It is, however, necessary first of all to focus the spotlights of scientific research on the operation of high speed flying itself, and to gain some idea as to what high speed flying costs the human operator in terms of bodily and mental effort.

Skill in Flying—High speed flying is a skilled operation. When put to military use, it has to be combined with tactical ingenuity, as a result of which, it assumes an even more specialized character. In general, the skill of the aircraft pilot consists of a series of "accurately graded action" [1], in which "receptor and effector processes are closely interlinked" [10]. Mechanical and human efficiency must come into an interplay, so as to facilitate performance of the task which is served by the skill. In practice, the wide variability of human performance makes the analysis of human factors a matter of vital concern. This paper therefore discusses the findings of a recent Field Study carried out on a group of Fighter Pilots of the Indian Air Force, immediately before and after different types of sorties on Vampire Aircraft.

The Time Factor—In the last analysis, excellence in flying depends on the accurate timing of the various items which constitute the skill of the pilot. The unmistakable sign of skill impairment is ragged performance, resulting from distortions in the timing of constituent items. In this connection, it is appropriate to quote the view of Professor Sir Frederic Bartlett of Cambridge University: "Each component of the coordinated effort must come in exactly when it is required..........If it finishes too soon, there will be irritating and disordering gaps. If it finishes too late, there will be interference. Either way, there will be clumsiness" [2]. These remarks have a special bearing on high speed flying. The pilot of any aircraft, flying at high speed, has to keep track of rapidly occurring changes. It would thus follow that timing assumes a primary role in high speed flying. The purpose of this paper is to indicate the association between high speed flying and changes in the timing of responses.

Study of Indian Air Force Pilots

Purpose of the Study—It is a matter of common knowledge that the fighter pilot is required to direct his undivided attention to several tasks, *continuously*, from the moment he takes off till the time he lands. The pilot of a transport aircraft on the other hand, can afford to relax once he gets airborne and sets the auto pilot on the course of his flight. An hour's flying on a high speed jet fighter would thus call for greater effort from the pilot, as compared with the same duration of flying on a transport aircraft. Since flying fighter aircraft involves continuous exercise of the pilot's skill, it is important to know whether a 45-minute spell of high speed flying on jet fighter aircraft is likely to cause changes in the timing of the pilot's response patterns; and also whether the changes, if any, are liable to vary with difficulty in flying, as felt or reported by the pilot.

Test Situation—A group of ten fighter pilots who volunteered to participate in this field study was given a simple psychomotor test on the airfield, immediately before and after each spell of high speed flying. They were also asked to say whether flying conditions in the cockpit and outside were found to be easy or difficult. The test display consisted of signals in the form of small arrow marks, appearing at intervals of 1·5 seconds. The operator's task consisted in moving a stylus up or down, according to instructions, in response to the signals. This action was recorded on a strip of moving paper where the responses assumed the pattern shown in figure 1, indicating the upward or downward movement of the stylus and its return to the 'ready' position.

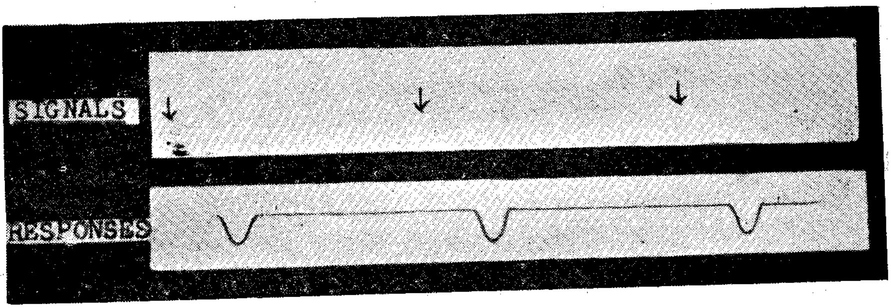

Fig. 1 Sample of Recorded Responses to Signals

Test Conditions—The psychomotor tests were given to the pilots under three conditions:

(a) *Immediate Response*—Ten signals were presented in succession, in response to each of which, the subject was instructed to move the stylus upwards, to return the stylus immediately back to the ready position, and to get set for the next signal.

(b) *Discrimination Response*—Ten signals—five red, and five green—were presented one after another, in random order. The subject was instructed to move the stylus on seeing the green signal, and to hold it still on seeing the red.

(c) *Discrimination-cum-Choice*—Ten signals, consisting of five arrows pointing downwards and five pointing upwards, were presented one after the other, in random order. The subject was instructed to move the stylus in the direction in which the arrow was pointing, to return it to the 'ready' position, and to await the next signal.

The results of an earlier study indicated that the time allowance necessary for seeing a signal of this type and completing a response to it was about 0·5 second. It was found also that a margin of 1 second between the end of a response and the appearance of the next signal would be adequate. The signals were therefore spaced at 1·5 second intervals.

Timing of Response Patterns

Inadequacy of the Classical Method—Considering that skilled performance consists of action and reaction between receptor and effector processes, it has been a common practice to measure the time elapsing between some simple stimulus such as a flash of light or the sound of a buzzer and an equally simple muscle response such as pushing a button or lifting the finger off a morse key. Recent research on skilled performance has made it abundantly clear that such simple measurements say little or nothing regarding the timing of constituent elements in a skill. The criticism levelled against the classical method has been summed up by Professor Bartlett in the following way: "The finger lifted from a morse key may rise an inch or a mile, it makes no difference. In any conceivable form of skill, however, circumstances of this kind do make a tremendous amount of difference. This is because a given movement has to be followed by another, and the second has to be spaced correctly in regard to the first. The time we need is the total reaction time, including that required for the full completion of a given movement, and the recovery time which the organism must have in order that a successive movement should be efficiently performed" (3). From this it would follow that three types of time measurements are necessary for an appreciation of the timing of constituent actions in the continued exercise of a skill:

(*a*) The time elapsing between the appearance of a signal on the display and the initiation of action on the control;

(*b*) the time taken to complete action on the control;

(*c*) recovery time, or the time needed for the organism to get set to deal with the next signal, so that the succeeding movement may be effective.

The design of the test apparatus incorporated arrangements for recording the first two time measures mentioned above; but owing to certain practical limitations, it was not possible to incorporate any device for the measurement of recovery time.

Time Measurements—From various test records, the following types of measurements were extracted:

(*a*) *Immediate Response Time*—This was calculated by averaging in each case, ten readings from the first test condition already described. This measure represents the time for the sensory-motor circuit to be completed; *i.e.*, for the formulation of action in response to the signal.

(*b*) *Composite Response Time*—This was calculated by averaging in each case, ten readings from the third test condition already described. This measure represents the time taken by the sensory-motor circuit involved, to initiate action appropriate to the signal, and comprises also the time required for sensory discrimination and for choice. From this one may calculate the time required respectively for discrimination and for choice.

(*i*) *Discrimination Time*—An approximate measure of this is the difference between the respective averages of the second and the first of the three test conditions described.

(*ii*) *Choice Time*—*i. e.*, the approximate time taken by the subject to make a simple choice between two alternatives. This is represented by the difference between the respective averages of the third and second of the three test conditions already described.

(c) *Response Completion Time*—In this study, time for completion of response means the time taken to move the stylus up or down, as the case may be, and to return it to the 'ready' position. The calculation in every case was made by averaging ten readings of the time interval between the beginning and the end of the response movement.

Psychological Significance of Recovery Time—Recovery time, or 'change over' time, as it is sometimes called, is liable to variation, depending on the overall required speed of performance, combined with the special conditions of display and control. Recent studies have led to the postulation of the 'psychological refractory phase'. Telford showed that when the human-being has to make discrete responses to two stimuli, an interval of 0·5 second between any two stimuli is necessary (8). In her experiments at the Cambridge Psychological Laboratory, Miss Margaret Vince showed that although rates of responses much higher than 2 per second could be obtained from her subjects when a series of discrete responses was presented at an accelerating rate, errors per second increased (9). On the psychological significance of recovery time, Professor Bartlett has commented as follows: "There is some evidence that most people are more intolerant to marked increase in change over or resting time, than marked decrease. If this is really the case, the reasons which are not yet known must be of great interest. It is, however, quite certain that overall speeding up of performance can alter the timing relations of the successive phases of serial response. It seems likely that it does this principally by a forced reduction of change over time, and when this passes a certain limit, the performance becomes ragged and uneven, and if it has to be continued, the performer will inevitably suffer from fatigue and strain" (4). Recently, Welford has suggested that "the data from a stimulus which arrives while the central mechanisms are dealing with data from a previous stimulus, have to be 'held in store' until the mechanisms have been cleared". According to Welford's estimates, the time between the onset of a stimulus and the beginning of a response movement is of the order of 0·2 second. The time for organising sensory data fed back from either the beginning or the end of the response movement is 0·15 second. This would imply that when stimuli arrive at intervals of less than 0·5 second, as they occurred in some of Welford's Tracking Experiments at the Cambridge Laboratory, there has to be "overlapping of organising time, thus making it theoretically pos ble for an operator to cope with rapid acceleration of movement" (11). Details of these and other studies point to the importance which Experimental Psychologists, attach to the Psychological Refractory period. Unfortunately, it was not possible in the present study of IAF pilots to incorporate any device for the measurement of Recovery time; but since this is the initial set of a series of such studies, the measurement of 'change over' time will receive due attention in future studies.

Preflight and Postflight Response Times

The overall picture—When response times, measured after a spell of high speed flying are compared with preflight readings, one would expect to find a difference. Since high speed flying requires constant mental alertness, brisk action, ready appreciation of rapid changes, and foresight, it is but natural that the response mechanisms should be tuned up to a level of action higher than normal in a period of high speed flying. Where this is the case, one may expect a retraction in postflight response times. On the other hand, when one has to keep up a super normal level of action continuously for long periods, or to maintain operational efficiency in spite of environmental stresses, one may expect protraction of postflight response times. The overall picture of the present study is shown in Table I.

TABLE I

Mean values of Preflight and Postflight Response Times of IAF Fighter Pilots (in milliseconds)

Response	Preflight	Postflight	Percentage of increase
			%
1. Immediate Response Time	254	276	8·6
2. Composite Response Time	456	479	5·0
3. Response Completion Time	244	266	9·1

In all the above three test situations, postflight response times are higher than preflight times, and the difference is most marked as regards the time required for completion of the response movement. Mean values of the Composite Response are about 200 milliseconds in excess of mean values of Immediate Response. This is accounted for by the extra time needed for discrimination and choice, which enter into the composite response.

Discrimination and Choice—Analysis of test records revealed the following mean values for discrimination and choice.

TABLE II

Mean values of Preflight and Postflight Response Times for Sensory Discrimination and Simple Choice (in milliseconds)

Process	Preflight	Postflight	Percentage of increase or decrease
			%
Sensory Discrimination	142	133	—6·3
Simple Choice	60	70	+16·6
Total ..	202	203	..

In this connection, two points call for attention.

(*a*) The absolute values for discrimination are nearly twice as much as those for choice. The reason for this is that the stimuli to be discriminated in this test were arrows moving at a speed of 180 centimeters per minute, each visible for 500 milli-seconds. Under these conditions, a time lag of about 60 milliseconds for a correct appreciation of the direction in which the arrow is pointing ought not to be considered excessive. If the stimulus objects had been presented on a static display, and if they had been simpler, *e.g.* 'red' and 'green' lights instead of moving arrows, a time lag of this extent would not in all probability have occurred. The display of stimulus objects in motion was, however, considered to simulate the conditions of the cockpit better than a static display.

(*b*) There is an overall retraction to the extent of 6·3 per cent. in the mean preflight time for sensory discrimination. When a closer analysis of the test records was made, it was found that this overall retraction was not consistently in evidence.

These conditions make it abundantly clear that it is unsafe to base generalization regarding human performance on overall measures alone, although it might be quite legitimate to maintain that overall measures are capable of serving as interesting pointers to significant trends in performance. Indeed, as Professor Sir Frederic Bartlett says ; " Scoring must yield some measure of overall performance, but also some measures of the incidence and especially the timing of contributory items of performance. The criteria will have to do with the relation of overall measures to the number and timing of internal items or moves of manipulation. Whatever the form such measures may take in particular cases, fatigue will always be indicated by some reduction in the internal economy of performance relative to the final level of achievement " (5).

Response Times in Relation to Difficulty of Sortie

' Hard ' and ' Easy ' Sorties—It is only too well known that any operation which is hard to perform causes greater strain than one which is comparatively easy (12). The IAF pilots who were tested in this study had to carry out different flying exercises and their verbal reports of these exercises were recorded during postflight testing, so as to grade the various exercises in order of difficulty, according to the testimony of the pilots themselves. The classification thus made is shown, along with the typical comments of pilots, in Table III.

TABLE III

Classification of Degrees of Difficulty (Based on Pilots' Comments)

Degree of Difficulty	Exercise	Typical Comments
1. ' Easy ' ..	Dry RP. and Front gun attack ..	"Not tired" "quite refreshing".
	Low level Flying	"quite easy to carry out, though one had to be more watchful".
	Parallel quarter attacks ..	"A little strenuous as compared with dry R.P., but not really hard".

TABLE III—contd.

Degree of Difficulty	Exercise	Typical Comments
2. 'Somewhat difficult'.	Rapid climb and Descent ..	"The weather was fine but the work wasn't easy". "felt hot and uncomfortable in the cockpit"
	Cloud Flying	"Strenuous" "Bad visibility mounted up my difficulties".
2. '*Hard*' ..	Snake climb and Descent ..	"a really hard exercise, made worse by uncomfortable cockpit." "tough, to say the very least".
	Formation Flying	"Difficulty increased by bumpy weather". "feeling exhausted and irritable".

In order to secure objective confirmation of this classification, Relative values of Postflight Response Times were calculated, on the basis of a preflight value of 100 milliseconds. These values are shown in table IV.

TABLE IV

Relative Values of Postflight Response Times of IAF Pilots, classified according to degree of difficulty of Flying Sortie (Preflight Value 100 • milliseconds)

Degree of Difficulty	Immediate Response	Composite Response			Response Completion
		Overall	Discrimination	Choice	
1. 'Easy' Sorties	106	101	94	98	109
2. 'Somewhat Difficult' Sorties ..	107	105	97	107	108
3. 'Hard' Sorties	112	109	106	111	110

It will be seen here that although in three cases postflight values drop slightly below 100, in the majority of cases, postflight response times tend to exceed preflight values by anything up to about 10 per cent.

Factors Associated with Variations in Response Times

In order to gain some understanding of the factors associated with the protraction and retraction of postflight response times, it is necessary to study the graphs appearing in figure 2.

One of these represents variations in relative postflight response times for the Immediate Response, the Composite Response, and Response Completion. The other graph represents Postflight time values for discrimination and choice, at varying degrees of difficulty in flying conditions.

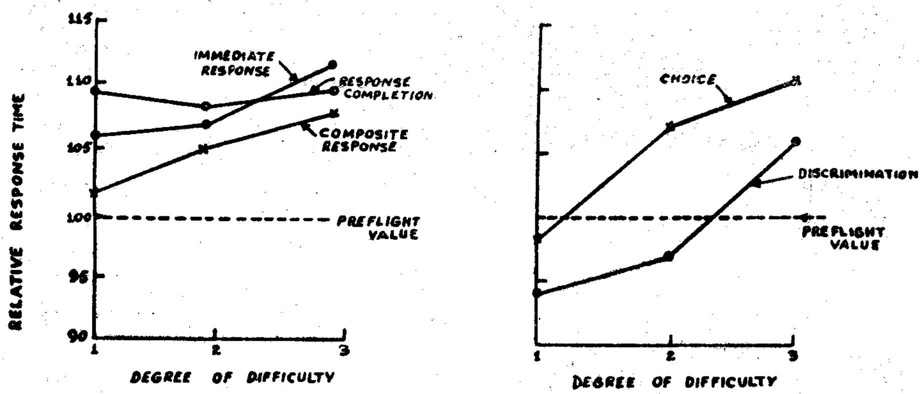

FIGURE 2—*Relative Postflight Response Times of IAF Pilots, according to degree of difficulty in flying sorties. (Preflight level 100 milliseconds).*

The graph on the left, representing overall measures, shows that post-flight responses are above the preflight level. The graph on the right which represents timing of internal items such as the mental processes of discrimination and choice, tells a different story. Where the degree of strain is negligible or low, as in the case of 'easy' sorties, there is a retraction of postflight response times. 'Hard' sorties, on the other hand, are followed by responses which take a longer time. It may thus be concluded that higher mental processes are invigorated by high speed flying if the task is 'easy'. Postflight response times are capable of a 10 per cent increase in the case of 'hard' sorties.

Improvement of Response Times by Practice

In all human performance, particularly actions involving the coordination of sense organs and muscular responses, repetition of a task ought to result in a saving of time or effort. Since each of the pilots in this study took the psychomotor test five times, with an interval of a week between trials, it is of interest to know what improvement occurred as a result of repeated testing of the same group. The following table shows the mean values of Immediate Response time and Response Completion time in preflight and postflight conditions, over a five week period :—

TABLE IV

Preflight and Postflight Values of Immediate Response and Response Completion Times, shown week by week.

Weeks	Immediate Response		Response Completion	
	Preflight	Postflight	Preflight	Postflight
1st	292	316	314	307
2nd	222	270	265	298
3rd	246	268	221	244
4th	248	276	219	244
5th	242	250	201	237
Mean	254	276	244	266

From the above figures it will be apparent that there is a progressive retraction of response time corresponding with increasing practice. This trend is all the more clearly seen in the following graphs.

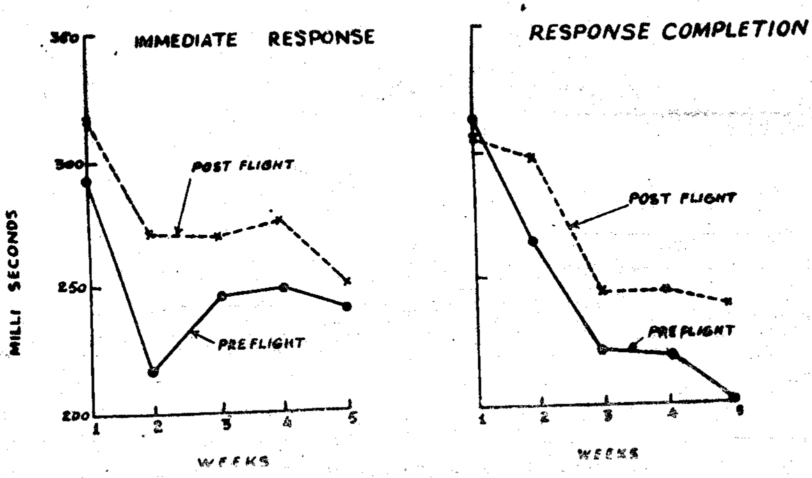

FIGURE 3—*Effects of practice on Immediate Response and Response Completion.*

In both these graphs, two trends are evident:—

(*a*) Immediate Response Time and Response Completion Time tend to drop from above the 300 millisecond level in the first week to the 200 millisecond level in the fifth, thereby indicating a saving of 33·3 per cent due to practice.

(*b*) Although week-to-week retraction of response time occurs progressively, the curves for postflight response times in both graphs are well above the preflight level, which is contrary to expectation, considering that practice ought to effect a reduction in postflight over preflight time on the same day, if retraction occurs between one week and the next.

Possible Influences—As to the nature of the influences underlying the difference between preflight and postflight response times, three possibilities appear to deserve consideration:

(*a*) *Build-up of Tensions*—High speed flying is a task that sets up tensions, which, combined with anticipated fear of mishaps, mount up and become acute as the sortie progresses. This continues till the pilot lands in safety. It is thus argued that the state of tension built up during the sortie lingers on and acts as a retarding influence on the pilots postflight responses.

(*b*) *Level of Care and Effort*—Before flying the pilot is cautious, agile, keyed up and in a state of mental preparedness for the sortie. Consequently his test performance is influenced by a favourable set up of circumstances. After flight, however, he feels relief and satisfaction on having accomplished his task. This feeling influences his approach to the postflight test, which he tackles in a carefree nonchalant, "devil may care" attitude, as a result of which he records a longer response time.

(c) *Transient Fatigue*—Occurs in the normal and healthy person after a period of strenuous effort [7]. With good weather and easy flying to back him, the pilot's postflight response time is not distinguishably lengthened. Under adverse meteorological conditions, combining with strenuous flying, on the other hand, the pilot's responses are delayed; and his errors, markedly on the increase.

The first explanation appears to be rather far fetched. Tensions do not, as a rule, mount up in ordinary peace-time flying as acutely and readily as they do in wartime undertakings. Further, the normal tendency is for tensions to build up during the pre-flight period, during the initial phases of sorties, or when the pilot's safety is gravely threatened. In the Cambridge Cockpit experiments, Davis found that Anticipatory tension occurred before flight, but was rapidly reduced by success. "Generally speaking", says Davis, "the degree of tension and impairment of skill are determined by the apparent difficulty of being successful" [6]. In none of the cases in this study did a minor accident nor even an 'incident' occur. Hence, the 'tension' theory has little weight, as far as this study goes. From what was observed of the attitude and behaviour of the pilots, it can be said that on the whole, they seemed 'sluggish' at time of the preflight test, and considerably more 'wide awake' during the postflight test. This is probably due to the fact that they took the preflight test not very long after waking up in the morning; and they came for the postflight test after nearly an hour's flying. It is not difficult to see that exercise of flying skill invigorates the senses and the mind. At the same time, it is not improbable that some pilots may have taken the postflight test more light heartedly than they did the preflight; but there is insufficient objective evidence in support of this. The third possibility appears to fit in with the test evidence most satisfactorily. In a preponderating majority of cases, it was found that postflight response times after 'hard' sorties increased up to about 10 per cent above the preflight level. Further, it was noticed that after 'easy' sorties, the time for the discrimination and choice dropped by about 5 per cent below the preflight level. It seems legitimate to infer that the lengthening of postflight response times after 'somewhat difficult' and 'hard' sorties, is an indication of the early signs of transient fatigue.

Conclusion

In general, this study of the response times of IAF Fighter Pilots shows that after 'somewhat difficult' and 'hard' flying sorties, there is a noticeable increase in the time required for the initiation and execution of immediate muscular responses to simple visual signals. Postflight response times have been observed to rise by anything upto 10 per cent above the preflight level. Under preflight conditions, sensory discrimination required 142 milliseconds, and simple choice required 60. After 'hard' sorties, these values went up by about 5 per cent and 10 per cent respectively. Absolute values of these increases were not, however, significant. This was so because the test situation was extremely simple and the stresses to which flying personnel were exposed, very moderate. All the same the changes in timing which occurred under these experimental conditions should be regarded as pointers to the nature of skill impairment in operational conditions involving rigorous flying strain. Under battle stresses, or pitched against complex, highly ambiguous and perplexing flying situations, even competent pilots may record increases in response times of a much wider range.

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