# HUMAN ENGINEERING PROBLEMS IN THE OPERATION OF CONTROLS AND THE DESIGN OF AIRCRAFT INSTRUMENTS

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## ABSTRACT

Speed and accuracy in performance are major considerations in the design of man-machine systems which involve displays for presenting information to the senses, and controls for human use. Sensory capacity, mobility and muscle strength, mental stamina, and capacity for team work are psychological factors which call for appropriate attention.

In the design and selection of control devices, it is important to consider size, shape, location and action of the control devices. These should be compatible with the element to be controlled. Four matters call for attention: firstly, control dimensions should take into consideration the normal hand grasp limitations of the operator. Secondly, knobs of controls should be suitably shape coded so as to forestall inadvertant operation of wrong controls. Thirdly, controls which have to be used most often should be placed within convenient reach of the operator. Fourthly, the human operator cannot be expected to perform at maximum capacity for any great length of time. Correctly positioned power controls are being increasingly used in present day aircraft.

In the design of aircraft instruments and the layout of flying panels, the limitations of the human operator, emergencies which are likely to arise during flight, and imperfections in the indications of instruments need to be taken into account. The design of aircraft instruments such as the altimeter, the air speed indicator, and the artificial horizon, are being improved from time to time so as to meet the new requirements in flying. Single and multiple instrument combinations have effected a saving of time in locating parts of a total picture, e.g. the composite indication of fuel state in modern aircraft. Many unsolved problems still remain with regard to the use of certain items such as the aiming, photographic and oxygen equipments.

## Introduction

When human effort is brought into dynamic interplay with mechanical processes, the achievement of a compromise between the potentialities of the machine and the limitations of man becomes a prerequisite to efficiency.

In the past, this requirement was not fully appreciated, largely because designers of machines tended to regard an instrument as an instrument, and expected men to get along as best as they could with the conditions of work set by the machine. The inevitable outcome of this attitude was an increase in the hazards of machine operation, particularly high performance machines put to industrial or military use. Further, the severe stresses encountered by operators of certain types of machines merely multiplied the already intricate and difficult problems arising from the immense variety of mechanical gadgets adopted for practically every purpose.

Another factor which received scant attention in the days gone by was the scientific evaluation of human characteristics. It was all too tempting to believe that human beings instinctively understand human beings, and that common sense is a safe guide in this matter. Military commanders today realise, however, that modern weapons of war can no longer depend on common sense to provide them the answer to their problems. A gun which is not designed with an eye to human efficiency will inflict grievous injuries on the user before it causes hurt to the enemy. As Col. G. E. Long, an efficiency expert of the USAF remarks, "there are characteristics of human behaviour that are important in equipment design problems; these can be specified, and when they are taken into account, the errors made by the operator decrease and the efficiency of the man-machine system increases significantly"[1]. Human Engineering has thus developed in response to the need for optimum efficiency in man-machine systems involving displays presenting information to the senses and controls for human use. Sensory capacity, mobility and muscle strength, mental stamina, and capacity for team work are all psychological factors which deserve appropriate attention.

In the past, even psychologists paid little heed to problems of the interrelationship between men and machines. The earlier presupposition was that there is a best job for every kind of man, and a best man for every kind of job. It was not till recently that psychologists became aware of the limitations of personnel selection techniques. The assessment of abilities and aptitudes will be profitable only if "there is in any population a fair number of people who have the required capacity for highly specialized types of machine operation but then, machines have become so complex nowadays that none or only a few can work them satisfactorily"[2]. Attention has thus turned from the design of intelligence and personality tests to questions concerning the design and operation of machines. Is the machine designed in such a way that it can be used most efficiently by an operator? Can a better machine, which could be operated with comparatively greater ease, be designed? These are no doubt questions about the machine, but they have to do with the operation of machines by men.

The purpose of this paper is to discuss some human engineering problems in the operation of controls and the design of instrument displays, with special reference to flying.

## Typical Errors in the Operation of Aircraft Controls

*Types of Errors*—Cats have been observed to operate latches in puzzle boxes by hitting them with their tails or bumping them with their heads.

Monkeys have been trained to pick up things with their tails. Man, not being so versatile, has to use his hands and feet in nearly everything he does—and even so, men tend to do more with their hands than with their feet. Since the aircraft cockpit poses some strange riddles to men who operate the controls, much of this discussion will relate to the types of error in the operation of aircraft controls and the measures necessary in order to forestall those errors. Systematic studies of pilot error indicate six common types of mistakes made in the handling of controls—confusion of controls, adjustment errors, forgetting, reversal errors, unintentional errors, and reaching errors[3].

*Confusion of Controls* is by far the commonest type of error, committed especially by those undergoing flying training. One of the most frequent confusions is operating the wrong control in the throttle control quadrant. Instead of pulling the propeller control, pilots have sometimes changed fuel mixture or have put on more throttle. Part of the reason why this error is committed is that the respective positions of these different controls are not the same in different aircraft. The throttle is on the left in some and in the centre in other types of aircraft. Similarly, gas mixture control is on the right in some and on the left in others. In some aircraft, the control for wing flap and undercarriage are side by sid . Serious accidents occur when the pilot confuses between these controls.

*Errors of Adjustment*—Severe crises in flying have sometimes arisen from incorrect adjustment by the pilot in his manipulation of controls during critical phases of flight. When specific cases of such errors are investigated, it is usually found that errors such as not adjusting flaps at the correct rate, or following the wrong sequence of controls in lowering the undercarriage should never have occurred. When such errors do occur, they are generally attributed to carelessness on the part of the pilot. One possible reason for this may be overfamiliarity of the pilot with cockpit controls, leading to the casual and slipshod operation of controls. A very common error committed by many pilots is incorrect adjustment of the undercarriage at the time of landing, on account of which the undercarriage collapses as the aircraft touches down. Stress is not infrequently a predisposing factor in making faulty adjustments. For instance, if one engine cuts, while the pilot of a multi engined aircraft is taking off, the awkwardness of the situation is worsened by the yawing of the aircraft's nose. The pilot has to restore directional stability to the aircraft, largely by his interpretation of the feel of the engine. In these circumstances, pilots have sometimes feathered the wrong engine, which would only make confusion worse confounded. Past experience has thus shown the usefulness of incorporating in the designs of modern aircraft special devices which ensure that the correct adjustment is made. In the vampire, for instance, the pilot has to execute a 'squeezing' action on the control mechanism which lowers or retracts his undercarriage. The alighting gear is operated hydraulically and locked mechanically in both the up and down positions. Further, there are warning lights, which either come on or go off, indicating whether the respective adjustments have or have not been correctly performed.

*Forgetting Errors*—The pilot who has to carry out a long chain of checks precautionary adjustments and manipulatory actions, is liable under the stress of many actions to be performed in quick succession, to forget some vital operation. Forgetting to lower the undercarriage before landing is a very common type of error. Recently, a vampire pilot, while coming in to land, called "downwind green", and was cleared for finals. He extended his air brakes, lowered his flaps, called for clearance to land, and was cleared to land by the ATC. As the aircraft sank lower than normal, the pilot realised that his undercarriage was not out, and he tried to open throttle to go round, but in the meanwhile the undersurface of the aircraft touched the ground, and the aircraft came to rest after skidding for about 400 yards. Practically every mechanical device which has been tried out in order to keep the pilot's memory alive has its own limitations. The provision of warning devices which come on well before a danger point is reached does, however, serve a useful purpose. One such device is the horn which sounds automatically, warning the pilot that he must lower the undercarriage. Mnemonics are also helpful to trainees in remembering correct sequences of vital actions. For example, the mnemonic BUMPH, standing for Brakes, Undercarriage, Mixture, Pitch, and Hood, help the pupil pilot to remember the vital actions necessary at the time of landing.

*Reversal Errors*—Pilots sometimes move controls in the direction opposite to what is intended or perform movements which are the reverse of what should have been done in order to produce the correct result. Psychologically, certain bents of movement are natural, and if a control is so operated that it falls in line with a natural bent of movement, errors or reversal will be considerably minimized. This, however, is not fully realisable even in the ideal aircraft cockpit. Nevertheless, it is imperative in designing controls to take note of certain obvious facts of human behaviour. It is natural, for instance, to move a control to the left when the pilot is turning to the left. Again, the pilot of a heavy aircraft, pulling the stick back may lean backwards, or in easing the stick forward, may lean slightly forward, throwing the weight of his body along with his hand. In fact, pilots flying Liberator aircraft, have reported that they virtually wrestle with the controls. This being so, the operation of controls should as far as possible avoid unnatural movements on the part of the pilot.

*Accidental Movement of the Wrong Controls*—Owing to space limitations in the cockpit, designers have not always provided against the possibility of the pilot's hand or arm brushing a control located too close to his body, while he is reaching for another control. In the HT2 aircraft, for instance, many pupil pilots sustained bad scratches on their hands while manipulating certain controls because they brushed against the sharp edges of some other control. Much the same has occurred with pilots of Spitfires. Recently a pilot undergoing conversion to vampires on a trainer inadvertantly knocked the undercarriage lever slightly down, while trying to operate the drive brakes. This inadvertant movement of the lever released the mechanical lock and the port undercarriage lowered slightly. The port undercarriage light came on, and the aircraft pitched very sharply. The instructor took over controls and made a safe landing. Errors of accidentally moving the wrong control could be minimized by preventing controls being crowded together, and by placing them in such a way that the pilot could move freely without knocking them.

*Reaching Errors*—Some aircraft cockpits are so designed that short statured pilots cannot easily reach certain controls. The Harvard, for instance, confronts many pilots with a leg length of 39″, with a problem of reaching for the rudder, or if they do, of not enabling them to give full rudder without considerable strain. The difficulty becomes even greater when the seat cannot be adjusted, and the pilot is firmly strapped. In some aircraft, the mechanism for jettisoning bombs or drop tanks is placed right below the pilot's seat and it has been extremely difficult for many pilots to reach it in an emergency. Pilots who have flown the spitfire have commended the positioning of cockpit controls, particularly rudder, stick and throttle, which are located within easy reach and which can be manipulated without strain. Reaching errors can be minimized by designing cockpits on anthropometric data. These will vary according to population samples. Recently an anthropometric survey was carried out in order to assess the requirements of IAF Pilots[4]. These measurements are quite different from the data available from U.S. or British sources[5]

## Human Engineering Requirements for Aircraft Controls

*Types of Controls*—The most important practical question concerning the use of control systems is the compatibility of the control device with the element to be controlled. Aircraft designers have a wide choice of control mechanisms—pedals, pushbuttons, throttles, toggle switches, selector switches, joysticks, levers and so forth. Exactly what type of control would be appropriate to a specific task is, nevertheless, a matter in which the user's point of view has to be given full consideration. If the pilot needs to turn something on and off, he requires a *contact control*, such as a switch or pushbutton. If, on the other hand, he has to choose one of many alternative conditions, he will have to operate a *selector control*, such as a selector or regulator mechanism, which can be so manipulated as to maintain control action at a desired level. If, however, the pilot has to make continuous adjustments, he must be provided with an *adjustment control*, such as a steering wheel or rudder pedal, which will permit him to maintain action at the correct setting. It is strange but true that designers sometimes consider what may be perfectly logical from the standpoint of the machine, but what is quite unsatisfactory for the job which the pilot has to do, and the circumstances in which he has to do it.

*Accuracy in Control Operation*—Several investigations relating to the efficiency of trained pilots and others, in the operation of controls, have brought to light certain fundamental facts regarding the effects of the position and direction of movement on the accuracy of control by the human operator. The American Scientist, Dr. J. Orlansky, found that hand controls such as stick or wheel are consistently better operated than foot control such as rudder pedal or brake. He also found that pilots are just as efficient with stick as with wheel controls. The advantage of the stick would, however, lie in the fact that it could be operated with one hand, leaving the other free for some other concurrent action. Positioning movements away from the body tend to be executed with greater precision than movements towards the body[6]. The British investigators Hick and Bates found that the duration and force of a movement are less accurately judged than its extent[7]. These and many other studies have made it amply evident that certain natural human limitations curtail the accuracy with which aircraft controls can be operated. Further, a delicately graded action which is easily performed under normal conditions may be difficult when the pilot is under stress. Any facility which will help him to operate faster, more accurately, and with less impediment cannot, therefore, fail to add something to his overall efficiency in varying flight conditions.

*Control Dimensions*—It is simple commonsense to expect that controls such as adjustment knobs or handles for cranks are appropriate to the kinds of operation to be performed, to the normal hand grasp limitations of the operators, and to the position in which they are mounted relative to the operator. Otherwise, they are bound to be a hindrance rather than a help. For example, control knobs should be round if the action required is a continuous turn, but bar shaped if it is a stepwise turn. Adjustment knobs ought to be limited in diameter to 2″ or less for the most convenient hand grasp. Again, the size of crank handles should depend on the type of operation required. Operations involving fast wrist and finger movements would be best performed on crank handles about 1½″ long and ½″ thick, whereas operations involving arm movement of heavy loads need crank handles about twice that length and thickness. Wheel and crank diameters should bear some relationship with the mounting position, the torque expected, and the speed of turning required. For high speed cranking, the diameter may vary from 3—9″, but that would depend on other relevant factors. Thus, a wheel mounted at a height of 36″, centered in front of the operator, ought to have an optimum diameter of 3—8″ at a torque of '00″/lb, of 10-16″ at 40″/lb, and 16″ at 90″/lb, provided that the control is set in only one rotation of the wheel. Scientific research on these aspects of control design has emphasised the importance of a clear understanding of what a pilot has to do whilst flying, and the consequent need to evaluate the usefulness of every little element of the control system which he operates[8].

*Differentiation of Controls*—Considering that the aircraft cockpit contains a bewildering variety of instruments and controls, it is an essential principle that everything possible should be done in order to make controls easily distinguishable. Coding techniques are thus highly important in the layout of aircraft control panels. Let us take shape and colour coding first. Shape coding is most helpful to the pilot in conditions of subdued cockpit illumination. Several studies have been carried out in order to discover what kinds of shapes are readily distinguishable by touch. A turntable arrangement presenting 22 different shapes was used on blindfolded pilots who were asked to identify from amongst knobs presented one after another, the various shapes they were earlier made to feel with their fingers. The results showed that certain shapes were liable to be confused with others, and that only 8 of the 22 shapes were never confused with each other. Further investigations using paired knobs showed that three more shapes were suitable for coding purposes. In this way, 11 shapes eventually came into use. Colour coding has also been useful in making knobs visually distinguishable. Since, however, some colours are variously affected by lower light levels, it is important to use colours which are recognisable under the expected light conditions. Experiments have shown that colour coding of controls helps pilots to operate controls correctly, even when they are considerably changed in position[9]. As regards size coding, it must be remembered that discrimination of *relative* size, i.e., of a particular knob handled immediately before or after another knob, can be made with ease. On the other hand, an *absolute* judgment of size is rather difficult to make. Another important factor is the serration of knobs. This should be such as to give the best gripping characteristics, that is, point contacts rather than rounded one; and evenly spaced serrations rather than uneven or widely spaced ones.

*Positioning of Controls*—Several control movements have to be performed by pilots without the aid of direct vision. The pilot has to move his hands without seeing, where they are going, because his eyes are busy elsewhere, or because the spot is not visible at the moment. Such blind positioning reactions call for considerable accuracy. They may occur either in a *restricted* manner, as when a pilot has to move a lever or a knob along a straight line, or in a comparatively *free* way, as when he moves the hand from one position to another. Studies of positioning movements have shown that the ability to distinguish location, all at arm's reach, varied from one region to another; that about 6—8" of separation was necessary for the best area, and about twice this amount in poorer regions[10]. The important consideration appears to be that controls should be positioned in groups far enough apart to establish a position habit pattern. The more definite spacing one gives a pilot, the sooner will he establish accurate habit patterns. In placing controls, it is essential to remember that they should be placed close to the display they affect, that they ought to be arranged sequentially with respect to the expected order of operation, and at the optimum position of manipulability for the control which is to be used most frequently. There should be an equitable distribution of work for both hands. Right hand operation should of course be reserved for operations requiring fine adjustments.

*The Strength of Body Components*—As an actuator of the aircraft controls the pilot has to exert pressure to deflect a stick, or wheel or a pedal. In this sense, he is a free producer, and acts like an actuator. This, however, is dependent on proprioceptive and tactual clues which he gets as he operates the controls. When a pilot executes a manoeuvre, he controls it by applying forces to the stick and to the rudder pedals, and perhaps by moving the throttle. He relies on his senses to control the forces he applies, to recognise when the aircraft is satisfactorily performing the manoeuvre, and how or when to bring the manoeuvre to an end. The importance of the feel of the controls cannot be exaggerated. "In a banking turn, the pilot expects from experience a certain stick force to accompany a certain rolling velocity. He associates changes in air speed with push or pull forces which vary in magnitude with the amount of air speed change. In pulling out of a dive, or entering a climb, he associates stick forces with changes in normal acceleration involved, and he associates various rudder pedal forces with side slip angles" [11]. This factor has been effectively summed up by Orlansky, who points out that jet aircraft pilots 'regard stick feel as a particularly valuable cue because it is always available without distracting the pilot's attention from his target....... For such a man, a stick with feel is equivalent to a host of flight instruments" [12]. All this would make it evident that controls need to be designed on certain criteria of control forces, with a scientifically established maximum and minimum, allowing for a safety factor in the force required. Thus, hand levers of the gear shift type should not require more than 30 lbs of applied force. According to Orlansky, the rate on control stick motion decreases as the load against which the stick is being moved increases. For a 35 lb load, the maximum rate of stick movement can be taken as 50" per second. The range is from 10—75" per sec. Pushing a stick can be approximately 25 per cent faster than pulling. As regards the minimum, the consensus is that no movement of hand control should require less than 2 lbs of force, and that no pedal movement should require less than 7 lbs of force.

*Power Operated Controls*—In the past, power supplied by the pilot's muscles was all that was available to operate the control surfaces of the aircraft. The response of the pilot in controlling the aircraft, therefore, had to involve the application of sheer bodily force to a stick, wheel or pedal, so as to produce a deflection of these controls. In fact, pilots learned to fly by associating certain aircraft responses with the application of certain amounts of bodily force. In recent years, greater and greater speeds have increased the aerodynamic loads on control surfaces. This has made it virtually impossible for the pilot to supply all the power required to move these controls. Consequently, power boosted or fully powered control systems have come into use. In Hunter aircraft, for instance, the controls are electrically operated, and as such the pilot does not have to apply any of the power required in the operation of the controls. When, however, the powered control system fails, the pilot may have to exert tremendous force in order to operate the controls and ensure that the aircraft returns safe to the ground.

**Problems regarding the Design of Aircraft Instruments and Equipment**

The efficiency and usefulness of any man-aircraft combination can be described as the product of two factors—aircraft efficiency and human proficiency. If either factor is low, the product will be low, and if either factor is zero, the product will inevitably be zero. Human engineering aims at providing the pilot with the best available mechanical aids, so as to enable him to overcome the limitations which prevent him from acting with speed and with force. It is therefore appropriate in this connection to consider a few problems which arise in connection with the design of aircraft instruments and ancillary equipment. Although the problems are many and varied, a select number of them are discussed in this paper, so as to give a general indication of the scope of human engineering research, as it applies to aviation.

*The Instrument Flying Panel*—In determining the presentation details for an informational display in the aircraft cockpit, designers nowadays include visibility, legibility and interpretability as important considerations. Nevertheless, the basic purpose in all the efforts to improve the layout of the flying panel is task simplification, consistent with increased flying safety. The requirements of high preformance aircraft are making changes in the conventional design and layout of flight instruments necessary. Recent experiments carried out on USAF pilots have shown that certain changes are necessary and desirable. The rate of climb indicator, turn and slip indicator and certain engine instruments are being reduced to two inches in diameter. A new instrument, called the directional horizon, is being introduced. The purpose of this instrument is to present by natural cues, aircraft attitude and direction information. It has a good display configuration, which makes integration of information and a direct interpretability of data possible. The counter-pointer altimeter replaces the conventional three pointer altimeter, thereby reducing the chances of errors in reading. The Mach number air speed indicator shows both speed notations on one instrument. Another new instrument is the distance bearing indicator, a highly accurate dead reckoning device giving navigation data which is not dependent on external radio signals. "There is good evidence from the performance measures employed that the newer displays, after a period of familiarization, allow the pilot to perform his tasks more easily and accurately and with fewer demands upon his psychological and physiological capacities"[13].

*Study of Prototypes of HT2*—When the HT2, which is now being used as the basic trainer aircraft in the Indian Air Force was at the prototype stage, many of the problems discussed here arose in connection with the layout of controls and the placing of instruments in the cockpit. For some years, there was a good deal of correspondence with the producers of this aircraft and protracted discussions between the designer and the prospective user. For instance, the altimeter, at one stage of the production of this aircraft was placed at the left top corner and the ASI at the right top corner. After much discussion it was agreed that the ASI, Gyro and Turn & Bank indicator should be placed on the horizontal upper line, and that the Altimeter, Directional Gyro and RCDI should be placed on the lower line. Similarly, it was noticed that the throttle and mixture controls were of the same size and shape. After some discussion with the designer, these two controls were made distinguishably different[14].

*Study of the Altimeter*—In 1955 a field study was carried out on a sample of more than 100 pilots and navigators drawn from the various squadrons of the Indian Air Force, and the Aviation Branch of the Indian Navy, in order to assess efficiency in reading a modified design of the three pointer altimeter. Photographs of different settings of the conventional and modified designs were shown to each pilot and navigator, and the time as well as the accuracy in reading these settings were measured. It was found that the modified design was interpreted with 30% greater efficiency on the criteria of speed and accuracy in reading the altimeter displays. It was noticed, however, that the most serious type of reading error, namely, misreading the altimeter by a thousand feet was not reduced in the modified design. This makes it look as if the modification serves only one useful purpose, namely to render clear visibility of all the three pointers in any setting; and this appeared to be its only advantage over the conventional design of the three pointer altimeter[15].

*Integrated Instrumentation systems*—Apart from the design and improvement of individual instruments, there is the problem of developing integrated instrument systems. A good example of an integrated instrument system is the zero reader, developed by Sperry Gyroscope Company. The purpose of this instrument is to present the pilot the information he needs in a simplified form, so that he can respond to it without lag or confusion. The zero reader, which is different in concept from all previous flight instruments, became the first of a new class that may be called the flight director type of instrument. Its special advantage lies in that it can be used as a ready reference at the time of landing, for then the pilot may use the zero reader more than the altimeter, the ASI, or the ILS. In this way, a considerable amount of looking around may be avoided, eye movement cut down to the minimum, and the pilot's task may be reduced to the simple process of flying the aircraft continuously to maintain the two needles crossed in the centre of the dial. The zero reader has in fact come into use in the informational displays of certain types of modern aircraft[16].

*Fuel, Contents Gauges in Modern Aircraft*—In the older types of aircraft, pilots had to take readings on each of two or four fuel gauges, and add up the readings before they could find out the exact fuel state of the aircraft, This task generally takes about 2·5 seconds for two and nearly 4 seconds for 4 readings to be made and added. In some of the older aircraft, there is a device which adds up the readings and presents them to the pilot as a total, but this device is mechanically operated and is subject to many limitations. In high performance aircraft, time spent over adding several readings, would merely increase the hazards of flight. High performance aircraft have therefore been fitted with electronic fuel contents gauges. These devices have radiometer type instruments which record the electrical capacitance changes of tank units in terms of direct current readings, recorded with a high degree of accuracy on a large scale indicator. On Hunter aircraft, for instance, the di-electrical type fuel contents gauge provides a continuous indication of a group of tanks, which is independent of the attitude or movement of the aircraft tank units. In this way, pilots of high performance aircraft could, at a glance obtain the information they need regarding fuel state.

*Aircraft Oxygen Equipment*—The problem of providing an adequate supply of oxygen for use by aircrews during high altitude flying sorties has assumed considerable importance now-a-days in view of the fact that high performance aircraft generally operate at heights above 25,000 feet. In most of these aircraft, the space occupied by oxygen equipment, and its weight have imposed serious limitations on the endurance of aircraft. Modern aircraft are therefore being fitted with liquid oxygen converters which provide a continuous supply of gaseous oxygen at the required pressure. Since a gaseous supply is 800 times the volume of the original liquid, this effects a saving of the order of 68% in weight and 86% in space. There are, however, serious risks in the use of liquid oxygen, but these are being overcome by improvements in the design of the liquid oxygen carrying equipment.

*Gun Sights in Fighter Aircraft*—The role of fighter aircraft in frustrating enemy attacks is widely recognised as a vital one. The sting of the fighter in fact depends on the types and quantities of the armaments it carries. The conventional type of fighter had four 20 mm guns, mounted on it; but before the pilot could use them to any effect, he had to carry out elaborate preparatory actions such as ranging, tracking and so on, which involved a considerable time lag between the spotting of a target and the action of the guns. The high operating speeds of modern fighter aircraft have made the elimination of these time lags an inescapable necessity. No longer does the fighter pilot have sufficient time to think out the appropriate sighting technique to be applied in firing rockets, guns, or bombs, as previously. Present day high performance fighter aircraft are therefore fitted with better designed armament and aiming instruments, which make aiming easier, and fire power more effective. For instance, the modern fighter is fitted with two 30 mm instead of four 20 mm guns. The sting of the fighter has not been reduced by 50% as a result of this change, but has rather increased considerably. Further, improved designs of gunsights now employ radar in place of the pilot to work out automatically the distance of the target from the gun. Another improvement in design is the incorporation of special gyros which enable pilots to fire at any aircraft, even while they are engaged in violent manoeuvres, without the gunsights toppling and becoming ineffective. Whereas formerly every type of armament had to be operated by the application of a different sighting technique, high performance aircraft today are fitted with selector switch arrangements which automatically change the parameters of the gunsight, to suit the particular preselected armament, thereby reducing the pilot's effort and saving much of his time. There are, however, still a few more improvements possible, which would facilitate the fighter pilot's combative effectiveness while he is flying at high speed. In order to release his projectiles, the pilot still has to press a button. This involves a sensori motor delay which may range from four tenths of a second to a few seconds. Experience shows that pilots tend to open fire too late because of the fact that modern aircraft flying at supersonic speed give only a fraction of a second when they are vulnerable from the aiming point of view, even though the actual dogfight may last for a few minutes. The provision of an electronically operated gunsight which would lock on to the target and fire automatically and instantaneously would obviously be the answer to this problem. It will not be long before such a device, similar to what is already incorporated on new types of anti aircraft guns will also be available to the fighter pilot of the future.

## Conclusion

To sum up, recent advances in psychological research have brought to the forefront several new problems regarding the human factor in man-machine systems. On the one hand, achievements which lie beyond the range of human capabilities on account of such limitations as sensory lags and errors of judgement can be realised only by better designed mechanical devices. On the other hand, the best elements of the human factor must be harnessed with the machine system by an intelligent planning of the man-machine relationship. High performance aviation raises problems of far reaching importance to the aircraft pilot, the human engineer, and the aviation physiologist alike.

Efficient operation of aircraft controls depends, in the first instance, on error free performance. Errors due to confusions, improper adjustment, forgetting, disorientation, inadvertant mishandling, and poor reach, lead to serious crises in flying. Accuracy in action over aircraft controls needs to be ensured by designing them to suit the body limitations of pilots, by making them ostensibly distinguishable, by positioning them in conformity with the natural reactions of pilots, and above all by considering the maximum and minimum bodily forces which it is humanly possible for pilots to apply.

Since effectiveness in the control of service aircraft demands among other things meticulous accuracy in the interpretation of instruments, and frequent cross checking of instrument indications, questions such as instrument design, the layout of visual displays in the cockpits, and the adaptation of ancillary equipment to changing service requirements are all matters of practical concern. Conventional psychological interest in aptitude and personality testing has thus found its sequel in problems regarding the wherewithal for efficient operation and success in battle.

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