The *Attitude* Technique in Instrument Flying

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BEFORE the outbreak of the recent war, flight by reference solely to aircraft instruments was little understood and was feared by most pilots, who avoided weather which necessitated such flight whenever possible. In military operations, however, frequent instrument flight was required under conditions which hastened the development of new techniques. These conditions are the following:

1. LONGER FLIGHTS: Flights became longer, with the result that a single pilot was often required to fly by instruments without interruption for as much as eight hours
2. ADVERSE WEATHER: It was often necessary to fly under most hazardous weather conditions. As a result pilots frequently encountered icing and turbulence of a degree rarely met in non-military flying
3. EMERGENCIES: The incidence of emergencies in flight was many times greater in war flying than it was in peace-time flying. Instruments and controls were often damaged or destroyed, with the result that difficult problems in instrument flying were created.

NEW INSTRUMENTS AND NEW TECHNIQUES

Prior to the second world war, the development of instrument flying had been guided and limited by the nature and number of flight instruments which existed. These instruments—the turn indicator, the air speed indicator, the altimeter, the climb indicator, and the magnetic compass—are not helpful in giving the pilot a vivid mental picture of the attitude of his aircraft with respect to the ground. Furthermore, prolonged flying under instrument conditions may create sensory illusions which give the pilot an incorrect impression of his aircraft's attitude.

As a result of these factors, instrument flying came to be regarded as a skill entirely distinct from contact flying. The latter was a process in which the aircraft was kept in the desired attitude by coordinated movements of all controls. Instrument flight, on the other hand, was regarded as a strictly mechanical process. Certain readings of the instruments were known to correspond to certain attitudes of flight. The reading of each instrument could be controlled by manipulation of a specific aircraft control.

For example, in a normal climbing turn the desired instrument readings might be as follows: Air speed indicator, 160 mph; climb indicator, 500 fpm ascent; turn indicator, ball centered and needle deflected half its width in the direction of the turn. These conditions could be maintained by controlling the elevators to yield 160 mph air speed, setting the throttles to give a 500 fpm climb, moving the ailerons to deflect the needle half its width, and moving the rudders to keep the ball centered.

The disadvantages of such a technique of flying are obvious. Flying becomes an uncoordinated process characterized by large-scale manipulations of the controls. Such overcontrolling is at best uncomfortable; it may be dangerous when the stalling speed of the aircraft is approached. In any case this mechanical form of flying is fatiguing, and a fatigued pilot is particularly subject to vertigo, inefficiency, and forgetfulness. Fortunately, before the outbreak of the second world war, pilots were seldom required to fly by instruments longer than two hours without relief, and the "needle, ball, air speed" system of instrument flying described above was generally adequate. In the early stages of the war, however, pilots recognized the need for a less tiresome technique of instrument flying to cope with the demands of military operations.

The first step toward the solution of this problem was the perfection and large-scale production of two new flight instruments, the artificial horizon and the directional gyro. The latter, a direction indicator, was designed to replace the magnetic compass except as a primary standard of reference. For reasons to be discussed later, the dial of the magnetic compass is usually oscillating, with the effect that it can be read only with difficulty. This oscillation was a prime source of pilot fatigue before the more stable directional gyro was introduced. A more fundamental contribution to the pilot's instrument panel was the artificial horizon. This instrument, reproducing in miniature the actual attitude of the airplane with respect to the ground, paved the way for the development of a technique of instrument flying identical with the technique used in ordinary contact flying.

As early as 1942, a number of military pilots reasoned that with the aid of the artificial horizon the attitude of the aircraft could be visualized with sufficient clearness to permit the use of the coordinated technique of contact flying. This idea was accepted slowly at first; most experienced pilots, including most flying instructors, were firmly indoctrinated in the mechanical system of instrument flying. By the end of 1943, however, the "attitude" system of instrument flying had gained universal acceptance in the flying schools of the armed forces of the United States.

PHYSICAL TECHNIQUES

The attitude system of instrument flying, as has been indicated, rests upon the formation of a mental image of the attitude of the aircraft. When this image is adequately formed, instrument flying becomes essentially the same as contact flying. Unfortunately, the mental picture does not serve as well as the real visual picture in directing those control movements which seem automatic to the pilot in contact flight.

An illustration of this fact can be found in the simple maneuver of entering a turn from level flight. When an aircraft is banked for a turn, the lift of its wings is no longer directed vertically upward. This partial loss of lift causes the airplane to begin a descent. Under contact flight conditions the experienced pilot compensates for this tendency unconsciously, exerting enough back pressure on the elevator control to avoid a descent as he enters a turn. This action is not, however, completely automatic; it is stimulated by the very slight change in attitude of the airplane as it begins to nose down. One would expect that the artificial horizon would give the pilot such a stimulating indication under instrument conditions; however, this instrument is so small that an appreciable indication does not appear until a significant descent has begun.

It is evident, then, that conscious effort must sometimes be exerted by the pilot to compensate for the imperfect nature of the mental picture formed in instrument flight. Some control movements which seem instinctive to the pilot in contact flight are actually stimulated by minute variations of the visual picture of attitude, variations which are imperceptible when transmitted via the instruments.

Control movements which seem instinctive in contact flight but which must be executed deliberately in instrument flight may be listed as follows:

1. When entering a turn, the pilot must apply back pressure on the elevator control to avoid descending
2. When resuming level flight from a turn, he must apply forward pressure on the elevator control to avoid climbing
3. When making a prolonged turn, he must increase power slightly to compensate for loss of lift if he is to maintain altitude and air speed
4. When resuming level flight after a climb or descent, he must anticipate the desired altitude by an amount depending upon the size of the airplane. In heavy aircraft the leveling action must be begun 100 feet before the desired altitude is attained.

SENSORY ILLUSIONS AND PSYCHOLOGICAL EFFECTS

A more serious difficulty met by students of the attitude system of instrument flying is the disturbing influence of sensory illusions and related effects. To fly competently under instrument conditions, the pilot must reject all such illusions and rely solely upon the indications of his instruments. These illusions, which are always present in flight, are contradicted by the pilot's visual or mental picture of the attitude of his airplane. The visual picture which the pilot has in contact flight is so compelling that any sensory illusions are disregarded and usually pass unnoticed. Under instrument conditions this is not the case. The pilot has exerted considerable effort to form a mental picture of his attitude, while a physical illusion may appear spontaneously. Of the two impressions the illusion, being the more natural, is dominant, and the pilot is led to discard the correct mental picture in favor of the illusion.

Thus it is seen that instrument flying is primarily a discipline of the mind over the natural reactions of the nervous system. The pilot must remind himself continuously to act in accordance with a mental impression of attitude formed solely by reference to the flight instruments. All other impressions, however compelling they may be, must be rejected.

A description of the illusions attending flight will clarify the foregoing discussion.

1. When the pilot initiates a climb he is forced downward in his seat; he experiences a sensation of heaviness. Similarly, when he begins a dive he experiences a sensation of lightness. Consequently a feeling of heaviness or lightness, whatever its cause may be, is associated with climbing or diving.
2. If a change in attitude is sufficiently slow it is not noticed by senses other than vision. Consequently a pilot may enter a turn or a bank so slowly that he will think he is still in straight and level flight. If he then returns rapidly to straight and level flight he will experience a sensation of turning or banking in the opposite direction.
3. If a pilot makes a coordinated turn he will experience a force directed straight down into his seat. If he maintains the turn longer than a few seconds he will associate the force with gravity and will receive an illusion of straight flight. As a result, when he recovers from the turn he will experience a sensation of entering a turn in the opposite direction.

If the pilot understands and recognizes these illusions he should not find it difficult to disregard them and to rely solely upon the mental picture imparted by his instruments. He will then find instrument flying to be a safe and relatively simple procedure. If, however, he yields to the illusions, the pilot is likely to encounter serious difficulty.

The serious nature of such difficulty is well illustrated by a description of a maneuver common among student instrument pilots. The pilot is initially in straight and level flight; slowly and imperceptibly he slips into a turn. The loss of lift caused by his banked attitude induces a descent; soon the airplane is descending rapidly in a moderately banked turn. At this point the pilot, still thinking he is in straight and level flight, begins to notice that his air speed is somewhat higher than it should be. Checking his other instruments, he finds to his surprise that they indicate a turn. Obeying the instruments, he recovers from the turn and immediately feels a strong sensation of turning in the opposite direction and of diving suddenly. Disregarding the instruments, which he thinks are out of order, he re-enters his original turn and applies strong back pressure to the elevators. This action serves to increase the degree of bank and rate of turn; the airplane dives more steeply and the air speed increases still more. Alarmed, the pilot increases his back elevator pressure more and more as the air speed increases and the bank becomes steeper; the pilot still thinks that he is trying to recover from a straight dive. The airplane is now virtually out of control.

Unfortunately, this maneuver, popularly known as the "screaming spiral" is not confined to practice flights in which the student is saved by the intervention of his instructor.

The pilot is subject to the following various illusions and mental conditions in addition to those described above:

1. If the clouds surrounding the airplane are lighter in color to the left than to the right, the pilot will associate the left side with "up" and will tend to bank his airplane or lean his body to the left.
2. When flying at night, the pilot will often seek visual reference outside the aircraft instead of relying upon his instruments. He will tend to confuse stars with lights on the ground and vice versa, and will think that lights are moving past him when he is actually turning about the lights
3. The pilot who has flown for more than an hour without rest will become hypnotized very readily by the combination of monotonous engine sound, steady radio signals, and fixed attention.

The pilot can alleviate these three effects by moving about in his seat, shaking his head, and smoking or eating something from time to time.

In summary, the instrument pilot is subject to numerous illusions which obstruct his task of creating a correct mental image of the attitude of his airplane. These illusions can be combatted only by familiarity with them and by unceasing mental discipline against them, aided by as complete a state of physical relaxation as can be attained.

FLIGHT WITH A LIMITED NUMBER OF INSTRUMENTS

The technique of forming a mental picture of attitude during instrument flight was evolved primarily as a result of the development of the artificial horizon. After the technique was established, however, it was found that it could be used advantageously even when the recently developed instruments were absent. The attitude system is now recognized as superior to the old mechanical system of instrument flying under all circumstances, regardless of the number or type of instruments available.

If the pilot must rely solely upon his altimeter and turn indicator, he will still find it possible to picture the attitude of his aircraft and to fly in a coordinated manner. It is only necessary that he know the characteristics of performance of the type of airplane he is flying. For example, if the altimeter reading is constant, the turn needle and ball are centered, and the power is set for cruising, the pilot can assume that he is in level flight at a certain air speed. If the altitude increases uniformly 500 feet each minute, the turn needle is deflected by its own width, the ball is centered, and the power is set for a normal climb, the pilot can visualize himself as executing a climbing turn at a safe air speed. He also knows that he is turning at a rate of three degrees per second (if the turn needle is so calibrated) so that if his compass is inoperative he can make any desired turn by reference to the time.

In order to fly successfully with a reduced number of instruments, the pilot must learn to extract as much information as he can from the few instruments which are operating. The most important source of "hidden information" lies in the fact that instruments show rates of change as well as actual readings. Much can be learned about the attitude of an airplane from the rate at which air speed is changing; a safe air speed which is decreasing rapidly indicates a more dangerous attitude than does a dangerously low air speed which remains constant.

The possibility of prolonged flight solely by reference to the magnetic compass affords an extreme example of the usefulness of a single instrument. The magnetic compass is subject to two effects which are ordinarily objectionable but which can be used in emergencies to yield information not usually associated with a compass. These effects arise from the fact that whenever the compass is tilted to the eastward or westward it is acted upon by the vertical component of the earth's magnetic force and is caused to turn to a new position of equilibrium. Such a tilting occurs when an aircraft headed north or south begins to turn; this "northerly turning error," the first of the two effects, vanishes when the aircraft is headed east or west. The tilting also arises when an aircraft headed east or west gains or loses speed; the inertia of the freely suspended compass causes it to tilt to the eastward or westward. This second effect, the "acceleration error" vanishes when the aircraft is headed north or south.

If all instruments except the magnetic compass should become inoperative (the magnetic compass is the most rugged of the instruments and the least susceptible to failure), the pilot should first turn to a heading midway between north or south and east or west. At one of these headings both northerly turning error and acceleration error will be appreciable. The pilot is then warned of any tendency to turn by the very sensitive northerly turning error, and he is apprised of any rapid climbs or dives by the less sensitive but adequate acceleration error. He can detect a gradual gain or loss of speed by increasing or decreasing responsiveness of the airplane to pressures upon the controls. Thus the pilot can maintain controlled flight until he has flown clear of the instrument weather area.

THE IMPORTANCE OF SELF-CONFIDENCE

The greatest asset to competent instrument flying is self-confidence, gained through constant practice in flying by means of a limited number of instruments and under actual instrument weather conditions. The self-confident pilot is able to think clearly and constructively; his thoughts are not diverted by fear and doubt.

Practice under an instrument flying hood is a prerequisite to flying in actual instrument weather, but it is not a perfect substitute. Every pilot is tense and apprehensive when he first finds himself "in the soup," and it is not until he has flown many times under actual instrument conditions that he acquires the full assurance which enables him to fly well by instruments and to deal efficiently with emergencies.

CONCLUSIONS

In summary the following conclusions may be drawn:

1. When flying by instruments the pilot must form a mental picture of the attitude of his aircraft from the indications of his instruments
2. In instrument flight, the pilot must make deliberately some control movements which seem instinctive in contact flight. These movements are stimulated by small changes in attitude under contact conditions; the instruments are too insensitive to produce these stimuli
3. The pilot must disregard all sensory illusions in flight and must determine his attitude solely from the indications of his instruments
4. The pilot must be physically relaxed to fly well and to avoid hypnosis and illusions of leaning
5. When some instruments are inoperative, the pilot can usually derive enough information from the remaining instruments to continue normal flight under instrument conditions
6. The pilot must have complete confidence in himself, gained only through frequent practice in actual instrument weather, if he is to fly efficiently by instruments and avoid accidents in emergencies.

The 200-Inch Mirror is Moved to Palomar Mountain

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would provide a basin large enough to hold approximately 256 gallons of water. Approximately 24 inches thick at the edges and 20¼ inches at the center, the mirror has a solid face approximately four inches thick. Ribbing on the back accounts for the much greater actual dimension. In its center is a hole 40 inches in diameter, which incidentally is exactly the same diameter as the largest refracting telescope lens at Yerkes Observatory. During grinding and polishing this hole was plugged. Installing the big glass plug, a much greater engineering problem than its removal, was accomplished by the simple method of placing the plug on a cake of ice which protruded above the surface the disc. As the ice melted, the plug sank slowly into position.

Although work on the mirror started 11 years ago, World War II brought a halt for four years. Those working on the mirror turned to war projects, and in the same room where the mirror awaited the end of hostilities, critically needed optical work was done. A number of mirrors, some of them 36 inches in diameter, were ground and polished for the armed forces and sent to such places as the Aberdeen Proving Ground, Wright Field and Langley Field. Approximately 1100 right-angle prisms were made for the armed forces in adition to other optical work.

Work was resumed on the 200-inch mirror on December 17, 1945 and continued until October 3, 1947. Approximately 180,000 man-hours were required to grind and polish it.