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IN-FLIGHT RESPONSE TO A NEW NON-GYROSCOPIC BLIND FLIGHT INSTRUMENT

Stanley R. Mohler, M.D.
A. Howard Hasbrook

Approved by

Robert Dille

J. R. DILLE, M.D.
CHIEF, CIVIL AEROMEDICAL INSTITUTE

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In-flight Response to a New Non-Gyroscopic Blind Flight Instrument

STANLEY R. MOHLER, M.D., and A. HOWARD HASBROOK

Pilot responses to a new "geomagnetic" non-gyroscopic blind flight instrument were recorded during flight, utilizing an aircraft typical of those flown by many general aviation pilots.

Data were obtained under induced conditions of loss of control during simulated instrument flight utilizing subjects ranging from student pilots with as little as 6 hours flight time to commercial pilots with up to 10,000 hours experience.

The device used in tests of human response during simulated blind flight is the Kenyon Instrument. This is a small, light weight, self-contained instrument which requires neither electrical power nor vacuum source. It is non-tumbling and is not susceptible to turbulence.

Comparisons of pilot response with the Kenyon Instrument and the conventional "turn and bank" instrument were an integral part of the tests. More positive and smooth control was obtained with the new instrument. Also, there was a marked decrease in onset and severity of vertigo with the Kenyon Instrument.

IN NOVEMBER 1963, a late model popular four-place light aircraft was flying at 5,000 feet under radar control in IFR conditions over Ohio. Soon after a communication with Approach Control, the instrument-rated pilot reported that the turn and bank indicator and the artificial horizon were becoming inoperative, as was the directional gyro.

The pilot requested guidance to the nearest VFR airport and took the directed heading. Shortly thereafter he reported that all of the "gyros" were now lost, and inquired of the radar service "What direction am I turning?" The controller observed the plane enter a tightening right turn and directed the pilot "turning right, stop turn or turn to left." No acknowledgment was received and shortly thereafter radio and radar contact were lost. All four occupants of the aircraft received fatal injuries in the ground impact which followed this "graveyard spiral."

It is not rare that aircraft experience failure in certain portions of their power supply (in the above case the turn and bank indicator was operated electrically). Similiarly, vacuum supply failures are not uncommon (the artificial horizon and directional gyro operated by vacuum in the case at hand). This case of loss of all electrical and vacuum blind flight instruments is described in Civil Aeronautics Board accident docket number 22398. It should be pointed out that total failure of all gyro instruments necessary to blind flight is relatively rare, but sufficient instances have occurred to stimulate interest in the development of a back-up instrument. It is also noted that by virtue of its simplicity of use, the instrument described in this paper is of value to non-instrument rated pilots having limited "blind flight" experience who find themselves in instrument flight conditions.

The role of gyroscopic instruments in enabling attitude control of aircraft under blind flight conditions is defined in early classical papers.[2,3,4] A new non-gyroscopic instrument, requiring no electrical, mechanical or hydrodynamic energy sources, and representing a marked departure from existing attitude instruments, has been described.[1]

This paper describes the results of tests by CARI of this new instrument, known as the "Kenyon Instrument." As will be described, the data indicate that accidents such as the above could be prevented through the availability of the KI as an emergency back-up instrument.

THE KENYON INSTRUMENT

In 1962, Dr. Ross McFarland of the Harvard School of Public Health called to the authors' attention the development of a geomagnetic flight orienter developed by Mr. Ralph Kenyon of Newtonville, Massachusetts. Arrangements were made for the acquisition of an instrument by CARI for testing and evaluation.

The instrument is 3¼" in length, 2 3/16" in diameter. Weight is 0.45 pounds (7.2 ounces). The circular instrument face display consists of a "right-left" needle, a white center index, two small arrows pointing toward the center index mark, and the following printed directions: "Bank toward needle" and "For straight-level-south center needle" (Figure 1). The instrument requires no vacuum or electricity for operation. The instrument uses lines of geomagnetic force for its operation similar to the manner in which a magnetic compass operates. The manufacturer's installation instructions state the instrument should be installed on or near the instrument panel in such a way as to minimize possible effects of magnetic fields generated within the aircraft. Also, the use of copper (rather than steel) mounting screws is stated to be of importance in this regard.

The instrument was tested in several aircraft over a three-year period. No change in operation has been noted, and it appears that the instrument can be expected to function indefinitely.

Prepared for the April 26-29, 1965, meeting of the Aerospace Medical Association, New York, New York. This paper relates to the portion of the meeting sponsored by the Flying Physicians Association. The opinions or conclusions contained in this report are those of the authors, and are not to be construed as necessarily reflecting the views of the Federal Aviation Agency.
Dr. Mohler is Director of the Civil Aeromedical Research Institute and Mr. Hasbrook is Chief, Flight Research Operations, CARI. Effective December, 1965, Dr. Mohler became Chief, Aeromedical Applications Division, Office of Aviation Medicine, FAA, Washington, D. C.

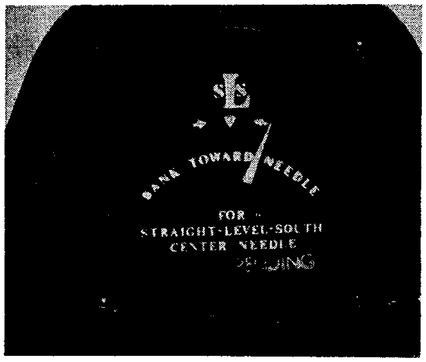

Fig. 1. Face surface of the Kenyon instrument.

When the needle is centered (by banking toward the needle), the aircraft will assume a bank angle ranging from zero to approximately 30°, depending on the magnetic heading of the aircraft. A maximum bank angle of about 30° occurs as the aircraft turns to the left through a heading of 270° magnetic. Similarly, an approximate 30° bank to the right occurs when turning to the right through a heading of about 90° magnetic. Turns through other headings, either toward magnetic north or south, result in bank angles of less than 30°, with the bank angle decreasing in relation to the nearness of the aircraft's heading to a north or south direction. A centered needle on a north heading results in a minor bank angle of about 3°-5°; this causes the aircraft to turn toward the south. The airplane assumes a no turn attitude only on a south heading.

Since the instrument is designed as a "blind flight" safety device, tests were made to determine its performance during inverted flight. Tests showed that full scale deflection of the needle (70° movement to either side of vertical) occurs at different bank angles depending on heading and direction of turn. In all cases the needle moves to the "high" side of the bank during a roll until an inverted attitude is reached. Therefore, moving the stick (or wheel) toward the needle will tend to stop the roll and return the aircraft to an "upright" attitude.

However, if the inadvertent roll continues past an inverted attitude (similar to progressing through a slow roll), the needle does not immediately shift its position to the new "high" side. After passing an inverted attitude, full scale shift, either from right to left or from left to right, occurs at various bank angles depending on the direction of roll and the heading. The centered turn and bank needle during inverted flight does not readily aid in rolling the aircraft to an upright attitude, but rather, can lead to a "split-S" maneuver and extreme vertical dive speeds.

MATERIALS AND METHODS

Subjects—Eleven male pilot subjects representing a spectrum of flight skill were utilized in the test program. Five held commercial pilot licenses (one with an ATR), three were private pilots, and the remaining three were student pilots. Total flying time of the subjects ranged from a low of six hours to a high of 10,000+ hours, with an average of approximately 1984 hours.

Instrument flying experience of the subjects in simulated and/or actual instrument conditions varied between 1.5 hours to over 5,000 hours. Ages of the subjects ranged from 21 years up to and including 49 years.

Test Aircraft—A Beechcraft T-34B Mentor was utilized for the tests because its weight, performance and flight characteristics closely resemble those of the general aviation airplanes flown by a large percentage of private pilots. The rear cockpit of the plane was equipped with a "blind flight" hood (Figure 2). The hood covers the pilot-subject during the tests, and prevents outside reference to the terrain. The test instrument was installed on the top center of the rear instrument panel and cover plates were placed over all flight instruments on the panel (including the magnetic compass) with the exception of the air speed indicator. The air speed indicator provides airplane pitch information.

Photographic Coverage of Front Cockpit Instruments for Data Recording—An Auto-Max-G-1 data recording camera was installed on a special camera mount between the two cockpits. The camera was located behind and to the upper right of the safety pilot (in the front cockpit) and recorded all pertinent readings on the front instrument panel. Natural light in the cockpit was augmented with a continuous light supplied by a Sylvania "Sun-Gun" with a quartz iodide lamp. Results of the tests were recorded on 35 mm Eastman Plus-X motion picture film exposed at a rate of one frame per second at f8 with a shutter speed of 1/65th second.

Flight test data recorded photographically included the following: airspeed, heading, attitude in roll and pitch, altitude, rate of turn, slip and/or skid, vertical acceleration (positive and negative) and time in hours, minutes, and seconds.

Weather Conditions—All filmed flights were conducted in VFR weather with clear and/or scattered cloud conditions. Flight altitudes for the various tests ranged between 5,500 ft. and 10,000 ft. MSL, depending on the existence and height of clouds. The flights took place in an area northwest of Oklahoma City, Oklahoma. Certain flights were made in moderate

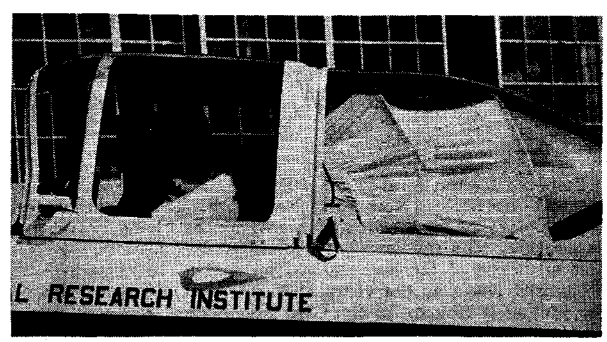

Fig. 2. Rear cockpit of plane equipped with "blind flight" hood.

turbulence conditions with no effect upon the operation of the instrument. Due to its damped needle, turbulence had no adverse effect on the instrument.

Flight Test Maneuvers—The flight maneuvers used to test the subject's ability to maintain control of the aircraft consisted of "level" turns, climbing turns, diving turns, and spirals. All turns, with the exception of spirals, involved a 30° bank at the time control of the aircraft was assumed by the subject. Initial bank angles utilized in the spirals ranged between a minimum of 60° to a maximum of 105°. Control of the aircraft was transferred to the subject on specific headings in relation to the direction of these turns; left turns at 360° and 270°, respectively, and right turns at 90° and 180°, respectively. No initial, specific heading was used during entry into spirals.

Test Procedure—Prior to flight each subject was informed: (1) the test objective was to provide data for evaluation of a new type of safety instrument; (2) it was supposed to provide the pilot with enough information so that he could maintain the aircraft in a safe level attitude while extricating himself from instrument weather conditions; (3) the test would be divided into two parts: flying the aircraft under the hood while (a) using the Kenyon instrument with the airspeed only and (b) using the "turn and bank" indicator with the air speed indicator; (4) they would be given approximately 10 minutes to familiarize themselves with the "feel" of the plane during (a) climb to altitude and (b) during several 360° changes of direction in shallow "level" turns—while flying with visual reference to the ground and natural horizon; (5) the aircraft would be trimmed for approximate level flight at a speed of 120 knots by the safety pilot; (6) the subject was *not* to change the throttle or propeller settings during the test, and (7) any further instructions would be given to the subject over the "hot" intercom system in the aircraft (the safety pilot and the subject were equipped with headsets and lip microphones that operated continuously without requiring use of any manual controls, switches, etc.

The safety pilot operated the aircraft during the following phases: starting the engine, taxiing, take-off, descent (after completion of the tests), landing, and return to flight line. In addition, he trimmed the aircraft for level flight prior to initiation of the tests and also placed the aircraft in the desired condition of bank, speed, and magnetic heading (prescribed by the test program) prior to turning over control of the aircraft to the subject.

During the climb to altitude the subject was instructed to make climbing turns to the left and to the right involving 90° change of direction, respectively, using approximately 15° of bank and a speed of 90 knots. After reaching the desired altitude the safety pilot again took control of the aircraft and set the manifold pressure, rpm and trim for 120 knots cruising flight. The subject was then instructed to make two medium banked turns involving 360° change of direction to the left and right, respectively. Upon completion of these familiarization turns, control of the aircraft was again assumed by the safety pilot while the "blind flight" hood was placed in position over the subject. Upon affirmative response from the subject that he was ready for the test to begin, the safety pilot placed the aircraft in the appropriate maneuver, switched on the recording camera and turned over control of the aircraft to the subject by a voice command. Upon completion of the maneuver (recovery to a straight and level attitude within a maximum of two minutes—or loss of control), the safety pilot again took control of the aircraft, placed it in the next appropriate maneuver and instructed the subject to again take control. Each succeeding maneuver was handled in a similar manner.

After completion of the 14 prescribed maneuvers using the Kenyon instrument (in combination with the air speed indicator), the subject was given a five-minute rest with the "blind flight" hood open and the aircraft under control of the safety pilot. At the end of this time the cover plate was removed from the "turn and bank" instrument and placed over the Kenyon instrument. The hood was again put in place and the subject was tested on his ability to control the aircraft by use of the turn and bank instrument (in combination with the air speed indicator only) by repeating a representative sample of the maneuvers previously used in testing his response to the Kenyon instrument. Upon completion of this set of maneuvers, the test portion of the flight was terminated, the hood was raised and the aircraft was flown back to the field and landed by the safety pilot. Immediately after the flight the subject was queried on his subjective reactions to the use of the Kenyon and T & B instruments, as well as to any difference in ease of use of either one. His responses were noted for future use in the analysis and reporting of the testing of the Kenyon instrument.

RESULTS

The flight test data shows that the subjects were able to make consistently smooth recoveries to a wings level attitude without any tendency to lose control of the aircraft and without regard to the subject's flying experience, while using the Kenyon instrument. In addition, while using this instrument, roll and yaw control was smooth with a high degree of coordination; speed control was surprisingly smooth among the "low time" subjects who had only a few hours of previous "simulated instrument" time; after achieving straight and level flight, bank angle and heading were usually maintained within ±3° for periods up to 8 minutes. Also, average positive acceleration imposed on the aircraft during recoveries from high speed spirals using the Kenyon instrument was 2.24 g; average for the turn and bank instrument was 2.75 g. Maximum positive acceleration for the Kenyon instrument was 3.6 g; maximum for the turn and bank instrument was 4.0 g. Maximum negative acceleration for the Kenyon instrument was 0.5 g; maximum negative acceleration for the turn and bank was 0.8 g.

Recoveries to straight and level were as smooth or smoother with the Kenyon instrument than with the turn and bank with the exception of three subjects who had recent and extensive instrument flying experience (Figure 3).

Speed control was approximately the same for both instruments (Kenyon and T&B), with the first effect of corrective action taking place between 4 and 9 seconds after the subject took over control of the aircraft (Figure 4).

Continued maintenance of a wings-level attitude—once achieved—over extended periods of time was generally better with the Kenyon instrument than with the turn and bank.

Pitch control during recovery and return to straight and level was generally the same for both instruments (Figure 5).

Subjective comments (after the flights) of various subjects included:

"I had no difficulty in knowing which way to turn to recover" (while using Kenyon instrument).

"I used no rudder—just banked toward the needle—" (Kenyon instrument).

"More work with the turn and bank; the needle (T&B) jumps around too much".

"Kenyon needle has large deflection—makes it easier to recover (to know which direction to turn)."

"Kenyon instrument easier to fly".

"Had to use two thought processes when flying the T&B to

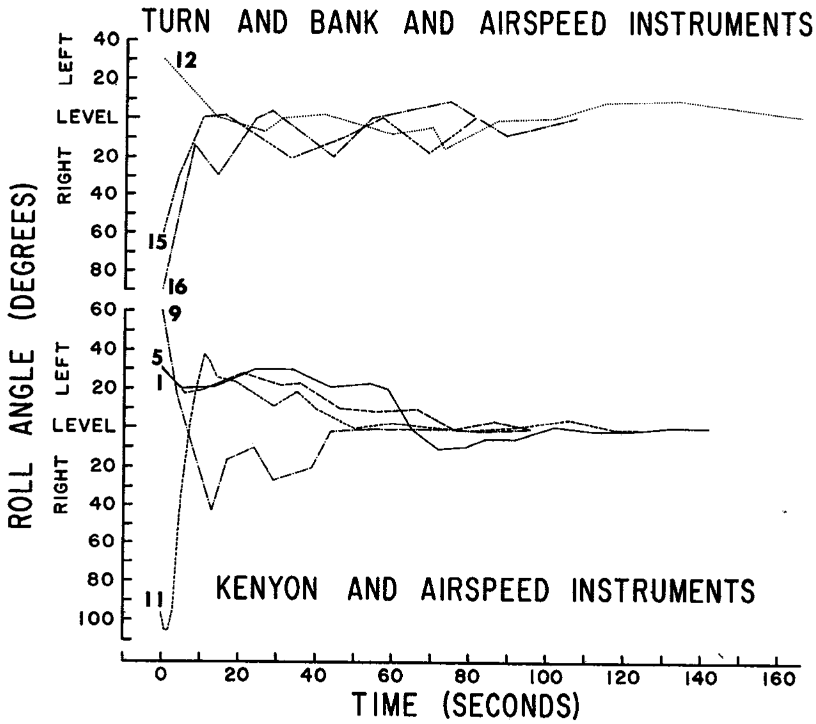

Fig. 3. Comparison of recoveries to straight and level flight between Kenyon and conventional turn and bank instrument.

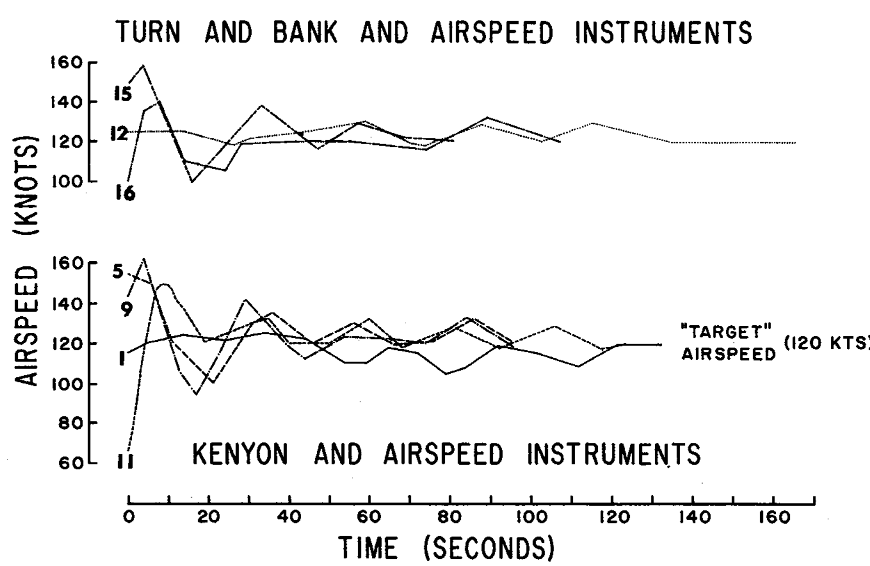

Fig. 4. Speed control comparisons with Kenyon and T and B instrument.

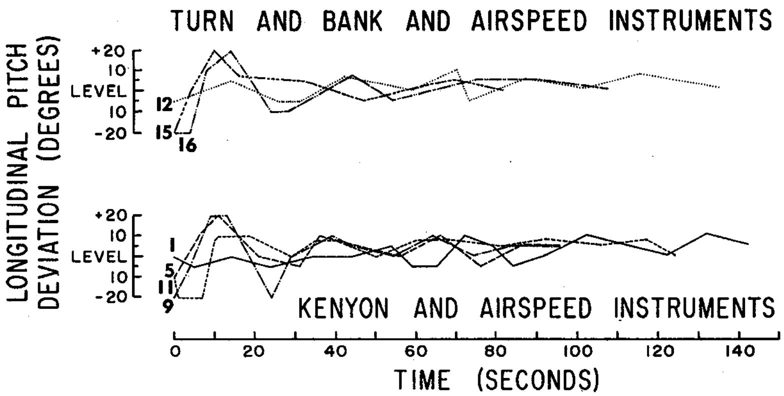

Fig. 5. Pitch control comparisons with Kenyon and T and B instrument.

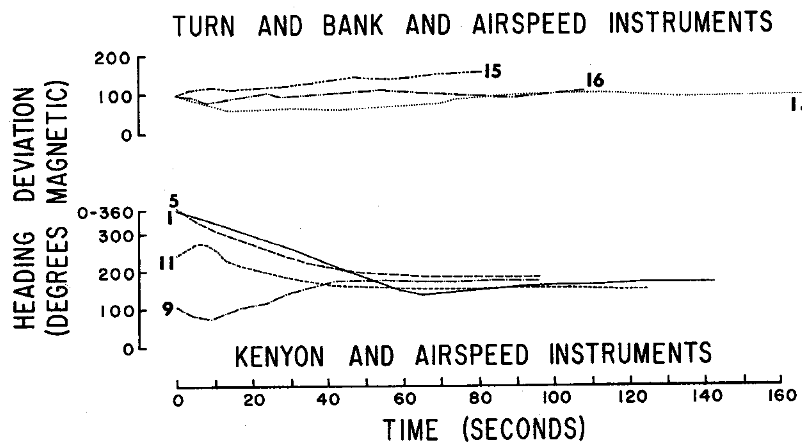

Fig. 6. Heading comparisons between the turn-and-bank and Kenyon instrument.

figure out what to do—only one thought process to know what to do with the Kenyon Instrument". (The T&B has a needle and ball which operate independently of one another—the Kenyon instrument has only a needle.)

"Could spend more time on (looking at) the airspeed when using the Kenyon Instrument".

"Felt more confidence with Kenyon Instrument".

"Had confidence that Kenyon Instrument would keep me on heading".

"Kenyon Instrument not as sensitive to rudder inputs".

"Kenyon Instrument has one less 'cue' to worry about—ball of T&B adds to confusion".

"Kenyon Instrument did not incite panic by rapid movement of controls".

"Kenyon Instrument reassuring—like mother-hen saying 'Don't get excited, we'll get there' ".

"Once needle (Kenyon) centered, knew bank was decreasing and could spend more time checking air speed".

"It feels normal to bank toward needle (of Kenyon Instrument)".

"Ball (of T&B) all over the place—had to ignore it".

"I liked Kenyon needle".

"Speed control better with Kenyon Instrument—could do better scanning".

"Have to concentrate too much when using turn-and-bank—uneven scanning with turn-and-bank and air speed goes to pot".

"Flying without a care in the world" (with Kenyon instrument).

"I'm used to flying 'steer needle' in simulator which caused me to turn toward the needle when using the turn-and-bank".

"T&B required more work than Kenyon".

"Have to pay too much attention to turn-and-bank".

"No sweat with Kenyon".

"Easy to fly (Kenyon)".

"Kenyon doesn't require much attention".

"I over control with turn-and-bank".

"Kenyon easiest to use—didn't have to worry about the ball (T&B)".

"Kenyon easier to fly in rough air—turn-and-bank needle moves too much".

Figures 6, 7, and 8 show heading and altitude comparisons between the turn-and-bank and Kenyon instruments. The fifth maneuver (curve #5) consisted of a recovery from a 30° banked diving turn to the left; control of the aircraft was given over to the subject at an air speed of 154 knots, and in a nose-down attitude of approximately 10°. Air speed corrective action was immediately instituted with some over-control resulting in air speed decaying to 100 knots; air speed was then bracketed between 120 knots (target speed) and 132 knots. The rate of turn to a constant heading was uniform and roll angle gradually decreased to zero. Pitch changes after the first excursion to 10° up + varied between a maximum of 10° up and 5° down. Maximum altitude excursion involved approximately 700 feet (during the initial air speed reduction phase) and then remained within 170 feet.

The ninth maneuver consisted of a recovery from a 60° banked diving spiral to the left with the air speed at 142 knots and a pitch-down angle in excess of 10° at the time control was given to the subject. By the time action was initiated to reduce air speed (4 seconds after taking control of the aircraft) speed had increased to 162 knots (maximum in this maneuver) and a 3 g positive load was applied to the aircraft. Speed reduction then followed almost a straight line to 94 knots (minimum); speed then varied between 142 and 112 knots, finally settling down to 118 knots after one minute and 32 seconds from the time the subject took over control of the aircraft.

The bank angle of 60° to the left was reduced almost linearly to zero and then progressed to a 43° bank to the right, prior to recovery to a constant level flight attitude. Original altitude excursion during the first 17 seconds of recovery involved approximately 450 feet ± or a total of 900 feet; excursions thereafter involved approximately 260 feet during the time interval of 44 to 96 seconds.

The eleventh maneuver consisted of recovery from nose-high attitude in a partially inverted lazy-eight with a bank of 107° to the right. The subject allowed air speed to increase to 149 knots while reducing the bank evenly from 107° to level flight and thence to a bank of 37° to the left as the aircraft turned through a westerly heading toward the south (a bank of 30° to the left would be normal during this heading change; the extra 7° recorded at this time probably was the result of over control and/or lack of attention to the Kenyon needle). Control of air speed, heading, bank angle, pitch angle, and altitude was smooth and within safe limits.

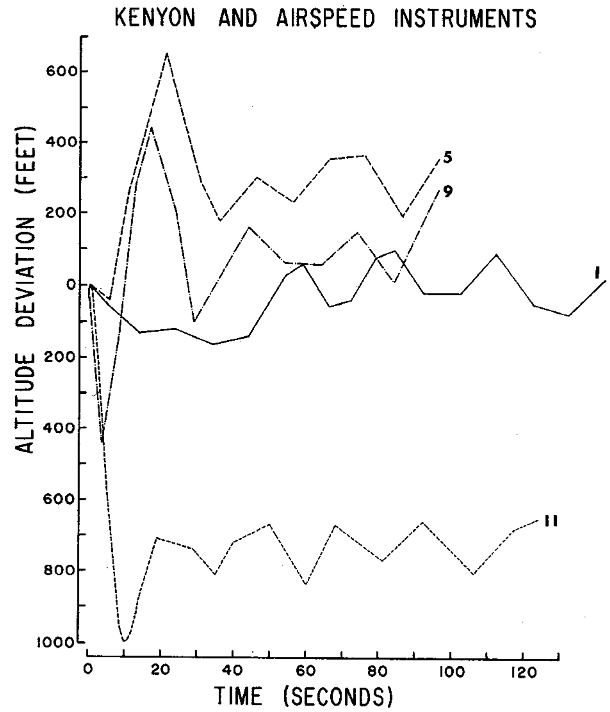

Fig. 7. Altitude deviation with Kenyon instrument.

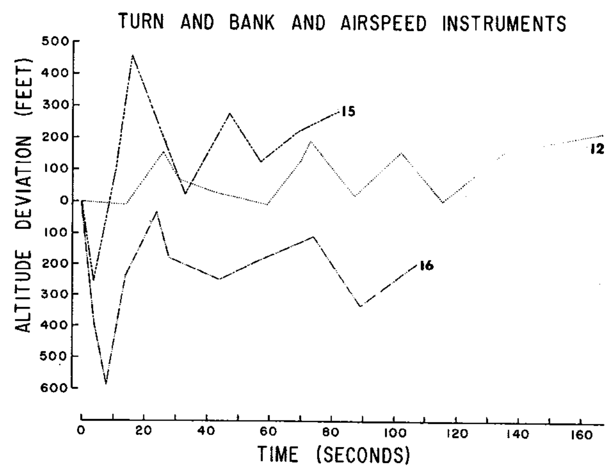

Fig. 8. Altitude deviation with the turn-and-bank instrument.

CONCLUSIONS

Analysis of the data results in the following general conclusions:

The Kenyon Instrument is a "safe" instrument for use in recovering from abnormal (or normal) attitudes to level flight condition.

The Kenyon Instrument can be considered a "back-up" safety instrument during IFR flight should all "normal" flight instrument displays malfunction due to total loss of vacuum and/or electrical power. This applies in principle to all types and sizes of aircraft.

Level flight with the Kenyon Instrument (while in IFR conditions) is possible on a pre-selected heading (built into the instrument); on all other headings, some degree of bank (up to 30°) and turn will occur (unless a specific deflection of the needle is maintained).

Coordination during recovery from normal and/or abnormal attitudes can be expected to be better (in most cases) when using the Kenyon instrument (as compared to using the turn-and-bank) due to the pilot's tendency to fly the aircraft with his "feet on the floor."

The Kenyon instrument will continue to operate when the aircraft is in an inverted attitude but in some cases may cause the pilot to attempt return to level flight the "long way around" (when rolling to the left on a west heading or to the right on an east heading).

The highly damped action of the Kenyon needle appears to be more desirable than the relatively undamped movement of most turn-and-bank needles.

The Kenyon Instrument apparently reduces psychological tension as well as tendencies toward vertigo, as evidenced during the flights and by remarks of the subjects after the flight tests.

Use of the Kenyon Instrument should permit a pilot with little or no instrument flying experience to maintain lateral control of his aircraft while extricating himself from inadvertent IFR flight. This can be of value to "pinch hitter" pilots, as advocated by Aircraft Owners and Pilots Association and other groups.

SUMMARY

Human responses to a new "geomagnetic" non-gyroscopic blind flight instrument have been recorded during flight utilizing an aircraft typical of those flown by general aviation pilots.

Recordings were made under induced conditions of loss of control during simulated instrument flight.

Subjects used in the program ranged from student pilots with 6 flight hours minimum experience to commercial pilots with up to 10,000 hours experience.

The device, known as the Kenyon instrument, is self-contained, weighs 7.2 ounces, requires no vacuum source, no electrical power, and no connection with any moving part of the aircraft. It is non-tumbling and not susceptible to turbulence oscillation.

The series of tests included comparisons under similar conditions of pilot responses to a conventional blind flight instrument display with their responses to the new type display.

Results demonstrate a more positive and smooth control of the aircraft with the new instrument as objectively measured by photographic recordings of the flight instruments. Also, subjective measures indicate a decreased tendency to the onset of vertigo with the new instrument.

It is concluded that the instrument would be of material benefit in reducing the annual toll of fatal light plane accidents which result from loss of control by non-instrument trained pilots who lose visual reference to the natural horizon. It will also be of value to instrument trained pilots whose conventional flight instruments fail under IFR circumstances.

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