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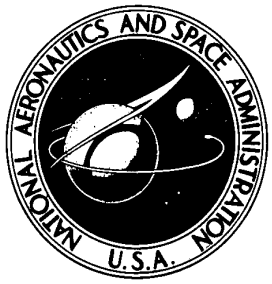


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# FLIGHT EVALUATION OF ANGLE OF ATTACK AS A CONTROL PARAMETER IN GENERAL-AVIATION AIRCRAFT

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16. Abstract

The use of angle-of-attack information for a pilot's display in a general-aviation airplane was investigated to determine whether this form of information would improve performance and flight safety. An angle-of-attack system consisting of a wing-mounted vane, an electronic computer unit, and a display instrument was installed and flight tested in a typical twin-engine, general-aviation airplane. The flight-test maneuvers were limited to the low-speed flight region where the benefits of angle-of-attack presentation were likely to be greatest. Some of the expected advantages of this parameter, such as visual indication of stall margin and its independence of gross weight and flap position, were realized; however, certain aerodynamic characteristics of the airplane, such as the phugoid and directional-control capability, were found to limit and tended to negate some of the expected advantages. As a result, this use of angle of attack did not show a significant improvement in performance and flight safety.

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Flight Research Center

## INTRODUCTION

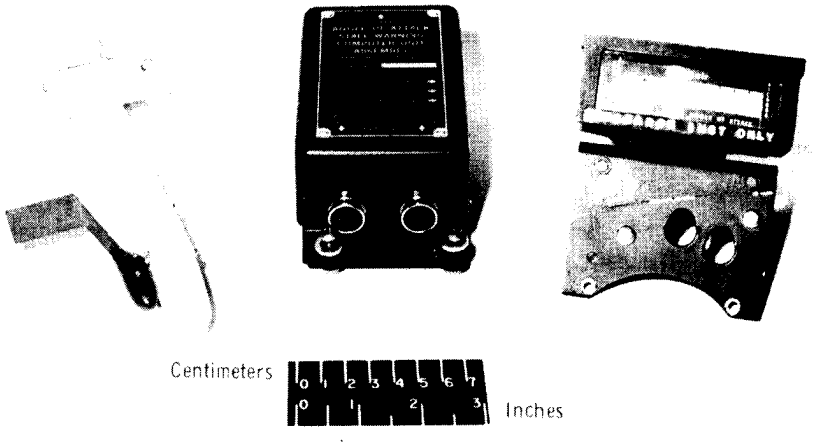
Over the years, general-aviation airplanes have been improved so that they now achieve performance levels comparable to those of World War II fighter aircraft. The greater power, high wing loading, and vehicle complexity have resulted in increased demands on the pilot's ability. In consideration of this problem and the continued growth of general-aviation activity, the NASA Flight Research Center has undertaken a program to provide the technology upon which continued improvements in safety, utility, and economics of this class of aircraft may be based. As one part of this program, the use of a vane-type angle-of-attack system for a pilot's display was investigated. The results of this investigation are discussed in this report.

Numerous studies have been conducted and articles written on angle-of-attack displays for high-performance fighter, transport, and general-aviation aircraft (for example, refs. 1 to 6). The results of these studies show that angle-of-attack information is a usable parameter, but not necessarily a superior one. The expected advantages of angle-of-attack information as a primary flight parameter are generally based on two considerations: (1) angle of attack is a direct measure of stall margin independent of aircraft weight, and (2) angle of attack responds earlier than airspeed to the pilot's control stick and throttle inputs and to other variables which may change the equilibrium flight condition.

For use as a piloting aid, angle of attack was displayed on a horizontal indicator mounted above the instrument panel on the left side of the cockpit of a light, twin-engine, general-aviation airplane. Angle-of-attack information was obtained from a sensor mounted immediately in front of the leading edge of the left wing. Since the angle-of-attack indicator was not considered to be a replacement for other flight instruments, the primary question was whether this form of information, as displayed, enhanced pilot performance and safety to justify its presence in the cockpit. Appropriate piloting tasks, including takeoffs and climbs, low-speed maneuvering, approaches and landings, and instrument approaches, were performed at the NASA Flight Research Center by pilots with widely varied experience. Pilot opinion, onboard recorded data, and previously obtained full-scale wind-tunnel data for the airplane were used in the study.

## DESCRIPTION OF APPARATUS

The commercially available angle-of-attack system consisted of a wing-mounted angle-of-attack vane, an electronic computer unit, and a display instrument, as shown in figure 1. The system components were installed in the test airplane, which was considered representative of a typical light, twin-engine, general-aviation airplane.




E-21485

*Figure 1. Components of angle-of-attack system.*

### Wing-Mounted Vane

A photograph of the vane installation is shown in figure 2. A high-resolution potentiometer was mechanically connected to the wedge-shaped vane to provide an electrical

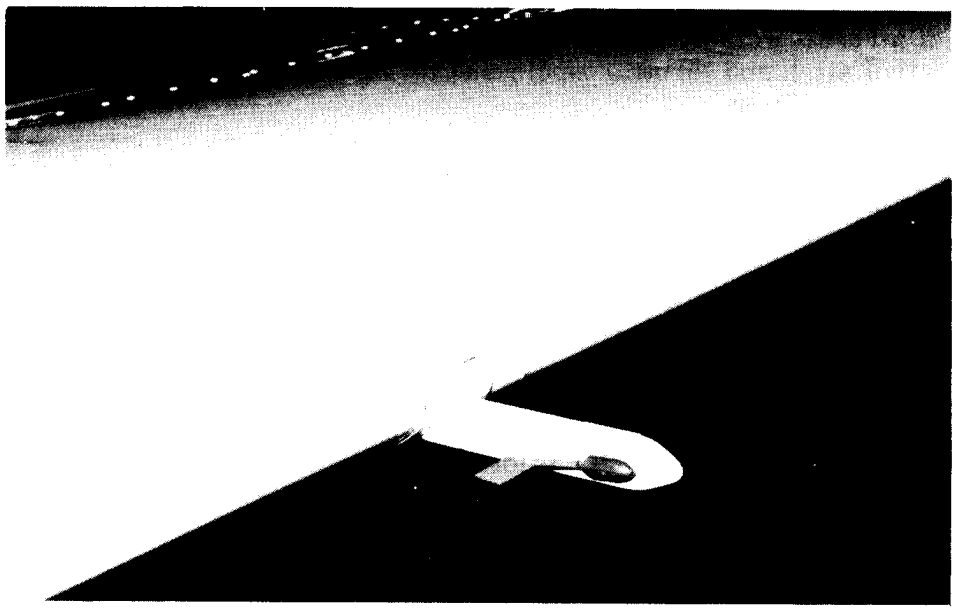


*Figure 2. Wing-mounted-vane installation.* E-21114

signal as a function of vane position. Because of the proximity of the vane to the leading edge of the wing, the inflight vane deflection was not in true degrees of angle of attack but had a nonlinear magnification factor.

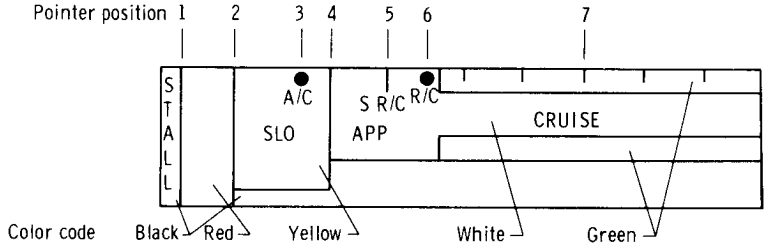
## Electronic Computer Unit

The electronic computer unit was mounted in the nose section of the airplane. The unit contained the electronics for signal stabilization and conditioning for display and stall warning. A 6-volt dc regulated referenced voltage was used for the wing-mounted vane and the computer unit. Two adjustments were available for setting the stall point and scale factor for the display indicator. A balanced bridge circuit was used to insure stability and minimize drift near the stall point. Indicator damping was electronically provided in the circuitry.

## Display Instrument

The display instrument used was basically a milliammeter with a milliampere range of 0 to 100. The horizontal movement minimized mechanical needle deflection caused by pitch or normal-acceleration forces. Figure 3 shows the indicator markings and briefly describes them. The regions were color-coded to facilitate interpretation of the displayed information.

The display instrument was mounted in the airplane above the instrument panel on the left side of the cockpit so that it would be in the pilot's field of view when he was looking through the windscreen and would not affect the arrangement of the instrument-panel display.




| Pointer position | Flight condition | Indicated airspeed, knots (1) |
|---|---|---|
| 1 | Stall | 66 |
| 2 | Stall warning | 70 |
| 3 | A/C (best angle of climb) | 73 (half flaps) |
| 4 | Slow approach | 73 (full flaps) |
| 5 | SR/C (single-engine climb) or normal approach | 93<br>80 (full flaps) |
| 6 | R/C (best rate of climb) | 97.5 |
| 7 | IFR approach | 100 (full flaps) |

[1] Based on maximum gross weight.

*Figure 3. Cockpit-indicator faceplate for display of angle-of-attack information.*

## SYSTEM CHARACTERISTICS

### Single-Point Display for Approaches

The desired approach velocities for most aircraft are generally 1.3 times the stall velocity $V_{stall}$. Because the $V_{stall}$ differs with flap position and aircraft weight conditions, the desired approach velocity may vary as much as 25 knots for the test airplane. Two extreme conditions are shown in figure 4, which was derived from full-scale wind-tunnel data on the test airplane. It is also shown that the desired approach velocities occur at different angles of attack with different flap settings. Therefore,

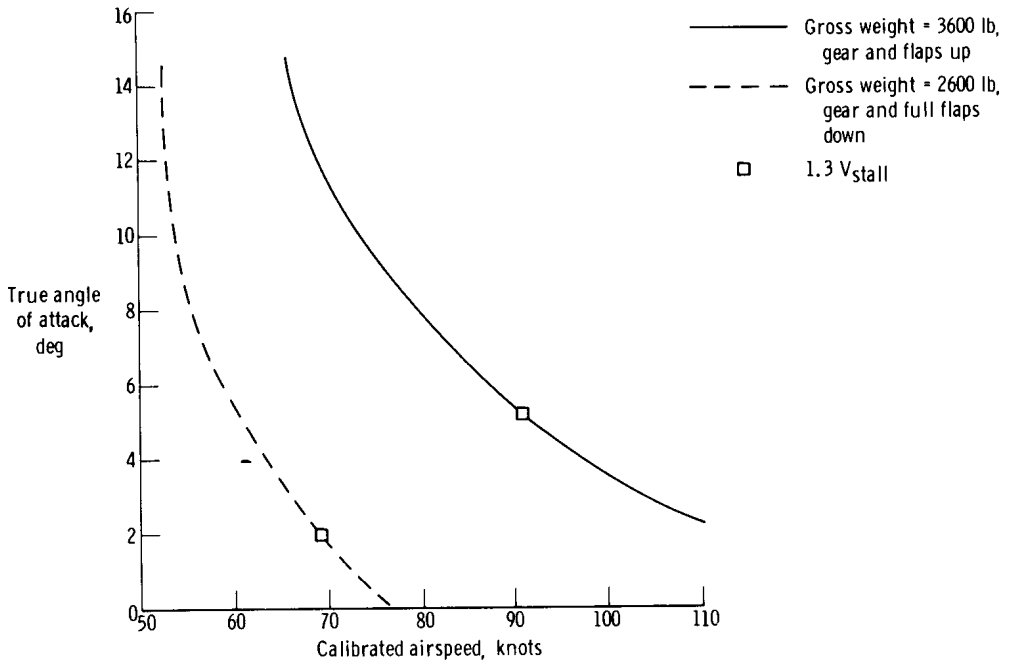



*Figure 4. Variation of angle of attack with airspeed for the test airplane with power off, as determined from full-scale wind-tunnel test data.*

to provide a single approach index for all configurations, the manufacturer, through flight tests, found a location within the upwash field near the wing leading edge where the vane deflection at 1.3 $V_{stall}$ was nearly the same for all flap settings. Compensation for flap setting could have been achieved electrically if a suitable vane location had not been found. The correspondence of vane position to stall margin in the $V_{stall}$ range of 1.0 to 1.5 was found to be satisfactorily insensitive to flap position.

Figure 5 shows the vane and display variations as a function of velocity for different flap settings on the test airplane. The single line on the display for approach resulted in an airspeed of 91 knots at flaps up, 81 knots at one-half flaps, and 76 knots at full flaps at an average gross weight of 3425 pounds.

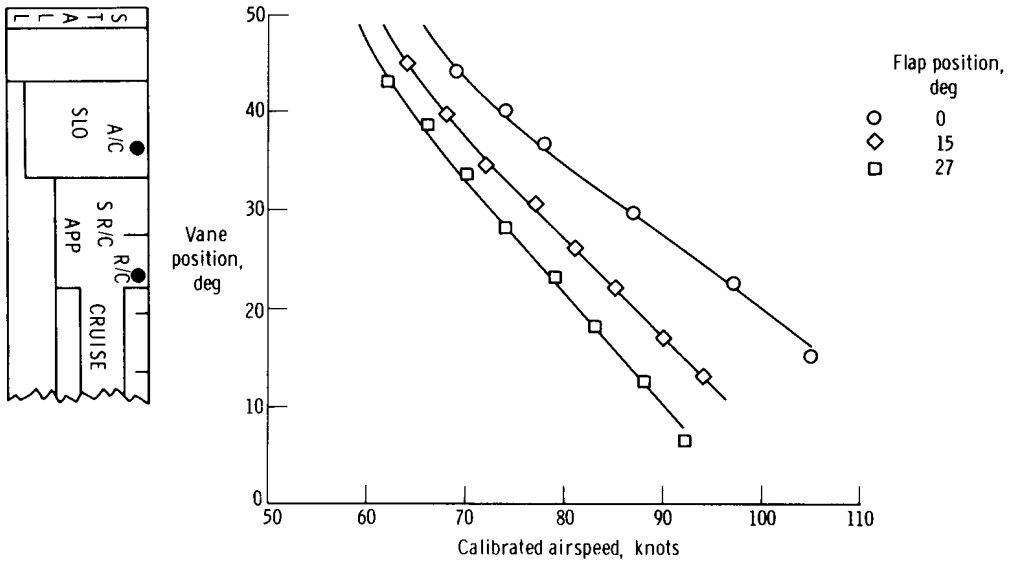



*Figure 5. Position and display variations of wing-mounted vane as a function of velocity on the test airplane at an average gross weight of 3425 pounds.*

## Vane Friction and Balance

The torque required to overcome friction was measured at 0.140 inch-ounce for the combined vane and potentiometer assembly, and recordings of the vane output at takeoff indicated that friction was overcome at about 45 knots. The torque due to static mass unbalance of the vane-potentiometer assembly was less than that required to overcome friction.

## Indicator Damping

After several trial flights, it became apparent that the display instrument needle was inadequately damped. By modifying the electronic circuitry to the indicator, the damping time constant was increased from 0.8 second to 2 seconds. This signal, used on all subsequent evaluation flights, can be compared with the undamped output from the vane potentiometer shown in figure 6. (The high-frequency noise on the display signal channel was not from the system output and did not appear on the display needle.) The 2-second time constant provided adequate stability for the needle under all flight conditions encountered in this study and did not result in an excessive response lag time to pilot inputs.

## Indicator Calibration

To calibrate the display system the display had to be tailored to the vehicle. Recent wind-tunnel data from reference 7 and data from the aircraft owner's handbook were used to examine performance characteristics of the airplane. From preliminary flight tests, vane positions were determined for displaying stall, stall warning, best climb angle, slow and normal approach, and best climb rate. A short preliminary flight-test program was conducted to validate these data. A ground calibration

*Figure 6. Time history of position and display signal of wing-mounted vane during a landing approach.*

procedure was established in which the vane was manually positioned and the display indication recorded. For normal preflight operations a two-point display check of stall and maximum rate of climb was established, and the vane and display were operationally checked before each flight.

## DATA ACQUISITION

A pulse code modulated (PCM) digital data-acquisition system was used during the flight-test program. Flight data were telemetered from the airplane and recorded on tape at the ground station. Angle-of-attack measurements were taken from two vanes installed on two 6-foot booms, one mounted on each wing tip, and were corrected to true angles. Airspeed and altitude measurements were taken from transducers connected to pressure sources located on the left wing-tip boom. The instrumentation parameters used were:

| Parameter | Range | Frequency, Hz |
|---|---|---|
| Airspeed | 0 to 250 knots | 4 |
| Altitude | 0 to 10,000 feet | 4 |
| Angle of attack (right boom) | -2.5° to 17.5° | 40 |
| Angle of attack (left boom) | -2.5° to 17.5° | 40 |
| Normal acceleration | 0 to 4 g | 10 |
| Wing-mounted-vane position | 0 to 50° | 10 |
| Display signal | - - - - - - - - | 4 |
| Timer | - - - - - - - - | 1 |

Data from flight notes and pilot readings of cockpit instruments were also used.

## EVALUATION PROCEDURE

The evaluation was designed to investigate the expected advantages and disadvantages of using angle-of-attack information. The expected advantages were:

(1) Visual presentation of the stall margin under all flight conditions.

(2) Approximate independence of performance points with respect to gross weight, load factor, velocity, and altitude of nonturning flight.

(3) Better resolution than for an airspeed indicator when flight at specific points on the lift curve is required, such as for slow flight or maximum performance maneuvers.

(4) Faster response to pilot control inputs than airspeed system when a departure from equilibrium flight is effected.

The expected disadvantages of using angle-of-attack information were:

(1) Systems must be tailored for the particular aircraft.

(2) Pilots must understand the characteristics, limitations, and operational techniques for using the display in order to interpret it.

(3) An additional display in the cockpit because the system is not a replacement for airspeed.

(4) A mechanical-electrical system requires extra care and maintenance.

(5) The system's operation is dependent on the aircraft's electrical system.

The information analyzed was obtained from questionnaires (see appendix) and discussions with (1) the research project pilot who performed the critical maneuvers not included in the evaluation piloting tasks such as low-weight, short-field takeoffs and landings, and normal and accelerated stalls, and (2) a group of three additional research pilots and five general-aviation commercial instrument-rated pilots who performed the evaluation piloting tasks under high-gross-weight conditions. All pilots flew one or two familiarization flights in the test airplane before evaluating the angle-of-attack display system. The project pilot who obtained extensive individual experience with the system acted as safety pilot for all flights by other pilots.

The evaluation tasks were divided into the categories of takeoffs and climbs, low-speed maneuvers and speed changes in level flight, short-field and normal approaches and landings, and ILS approaches. No set procedure was followed in briefing the participating pilots on angle-of-attack properties before or during test flights. Each pilot used his own flight technique and ingenuity in adapting the angle-of-attack information to the tasks but was advised by the safety pilot in developing a satisfactory technique. Tasks were performed by using angle-of-attack and airspeed information

alternately for comparison purposes. The airspeed indicator was covered when the angle-of-attack display was used, and vice versa. Tasks and practice maneuvers were also performed using both instruments together. Pilots answered a questionnaire and discussed their results after completing their flights.

## RESULTS AND DISCUSSION

### Takeoff and Initial Climbout

Tests of the pilot's ability to take off and climb in a minimum distance from a standing start showed grossly inferior performance when the angle-of-attack system was used compared to that attained when airspeed was used. The reason for this surprising result was found in the slower pullup to the best climb angle that resulted from maintaining the best climb angle of attack after takeoff. It was observed on takeoffs in which airspeed was used that, for a short interval immediately after lift-off, angles of attack near the stall were used in order to rotate the flight-path vector to the best climb angle as the airspeed reached the best climb airspeed. When the angle-of-attack indicator was used, the airspeed increased above the best climb airspeed before the best climb angle was reached.

The climb path after lift-off was usually oscillatory, with the aircraft following a constant angle-of-attack phugoid when the angle-of-attack display was used. Typically, the airspeed varied ±15 knots about its mean value, which for best angle climbs, periodically brought the speed below $V_{mc}$. The phugoid had a period of about 20 seconds and an amplitude dependent upon the initial displacement from the equilibrium flight path. The oscillation was lightly damped. Carefully holding constant angle of attack resulted in prolonging the oscillation. There was a strong tendency for pilots to fly the angle of attack carefully, thus inadvertently sustaining the oscillation. It puzzled the subject pilots that to apparently accomplish the required task--holding constant angle of attack--did not result in the desired steady, optimum flight path. In this characteristic, angle of attack flying was believed to be basically less satisfactory than airspeed flying, where constant airspeed directly implies a stabilized flight path.

Additionaly, it is noted that an angle-of-attack display provides no cue when the correct takeoff speed has been reached.

The characteristics described in the above paragraphs are not peculiar to the test aircraft and angle-of-attack system but would apply to almost any contemporary airplane and simple angle-of-attack indicator.

Figure 7 is a time history of airspeed and angle of attack for a typical short-field takeoff in which the pilot used airspeed for a rotation cue and maintained angle of attack for climb. As can be seen, the airspeed at lift-off (70 knots desired) was approximately correct, but flying constant angle of attack did not prevent further acceleration and the airspeed continued to increase beyond the best angle-of-climb speed of 73 knots. The induced phugoid oscillation in airspeed of over 10 knots variation eventually resulted in the airplane falling below the $V_{mc}$ speed of 70 knots. From both pilot and ground observation, the flight path and pitch angles changed from being too shallow immediately after takeoff to too steep about 10 seconds later.

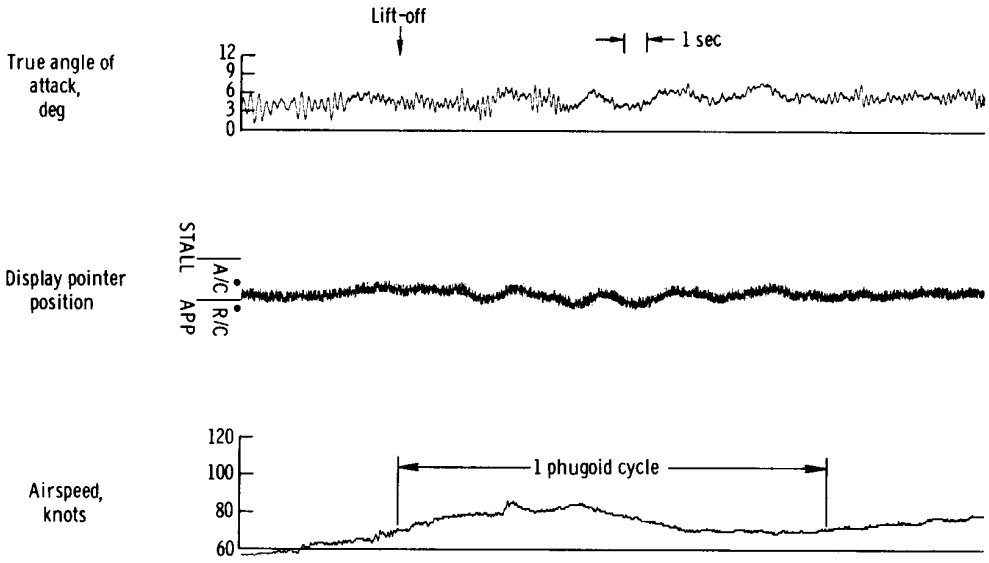



*Figure 7. Time history of a short-field takeoff when pilot used angle-of-attack display instrument.*

Although the best climb angle (A/C), best climb rate (R/C), and best single-engine climb rate (SR/C) are more closely determined by angle of attack than by airspeed, the curves for these quantities for the test airplane were so flat near the optimum values that the performance gained by defining the quantities in terms of angle of attack was insignificant. However, this may not be true for higher performance aircraft with greater weight variance or more sharply peaked performance curves than those of the test airplane. As seen from figure 8, the best climb rate was obtained at 92 knots or

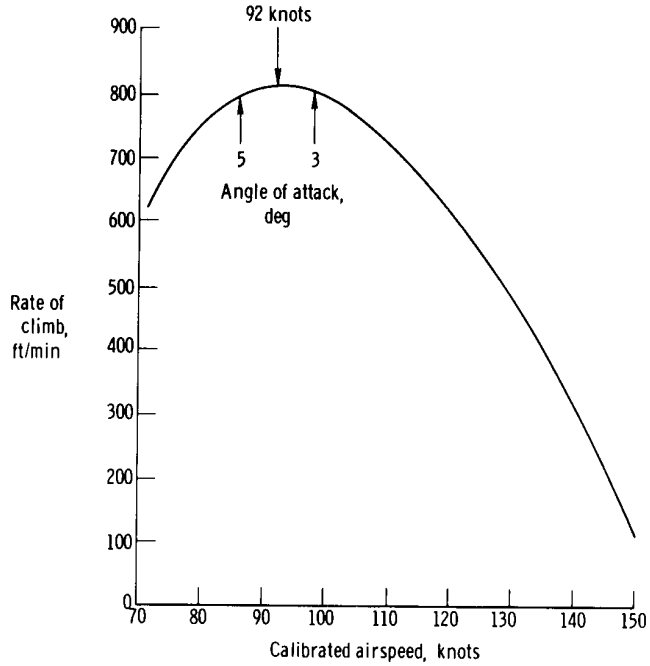



*Figure 8. Rate-of-climb performance as a function of airspeed of the test airplane. Gross weight, 3450 pounds; gear and flaps up; 6000 feet altitude; 64° F.*

3.8° angle of attack. For a variation of ±5 knots in airspeed or ±1° in angle of attack, the change in performance was only 20 feet per minute, which is about 2.5 percent.

## Low-Speed Maneuvering

Performance in low-speed maneuvers was roughly equivalent whether angle-of-attack or airspeed information was used. Maneuvers are normally performed primarily by using attitude control, with reference to airspeed or angle of attack as a secondary control parameter. Although angle of attack responds faster to the pilot's pitch or throttle inputs, this expected advantage is more or less negated by the necessity of compensating for any induced phugoid, or, stated another way, angle of attack does not necessarily command the correct control inputs. At a given instant of time the correct input to maintain a desired stall margin may be in the opposite direction to the input required to achieve stabilized flight. Thus, the solution of the control problem is a compromise between objectives which cannot be directed by angle of attack alone. Because angle of attack represents the desired solution to the control problem only under stabilized conditions, it has no obvious advantage over airspeed as a control parameter for low-speed maneuvering. The main limitation on performance in this area is believed to be the pilot's ability to monitor attitude, altitude, heading, and either airspeed or angle of attack from different visual references. The substitution of angle of attack for airspeed did not materially reduce the workload; however, the pilots expressed no doubt that the visual indication of stall margin provided by the angle-of-attack indicator was desirable.

## Approach and Landing

For approaches and landings, the angle-of-attack display was found to be of benefit when used properly in conjunction with other parameters, but it led to hazardous procedures and poor control techniques when used without the necessary understanding of how to use the display.

The major benefit derived from the angle-of-attack display was the convenience of having a single reference point for straight-in approaches which enabled the pilot to select an approach trim condition. This provided a constant stall margin before flare and therefore resulted in consistent flare and float characteristics regardless of weight and flap setting. Both normal and short-field approaches were evaluated, and the evaluation pilots found the flare and float characteristics to be consistent, predictable, and appropriate. However, during the full-flap, lightweight approaches, it was noted that the airspeed was slow enough to cause undesirable, low lateral-control response. In addition, the airspeed was below $V_{mc}$, and, although directional response was adequate for the landing task, the use of speeds below $V_{mc}$ was believed to be an unnecessary exposure to hazard. Therefore, it was concluded that the low-speed lateral- and directional-control capability of the test airplane limited the advantages of using angle-of attack information in that portion of the flight envelope.

A further benefit from the angle-of-attack display was the ability to establish the longitudinal trim setting for straight flight when not in that flight condition. Trim

settings for final approach were made before or during the turn to the final approach. Thereafter, stick force was a useful indication of stall margin. This was practical because of the close relationship between trim setting and angle of attack. On the test airplane the resulting trim was sufficiently accurate except when large power changes were made.

The use of angle of attack as a control parameter, independent of airspeed or attitude control, was found to be unsatisfactory. When a constant angle of attack was flown, the characteristic phugoid path was encountered following any displacement from equilibrium conditions. This was particularly noticeable on the entry to or rollout from the turn to final approach. An extreme example of this characteristic is shown in figure 9, a time history of a landing approach in which a 45° banked turn was used and the resulting airspeed variation was 40 knots. The airspeed for stabilized banked flight is higher than that for stabilized wings-level flight for the same angle of attack. When the transition was made from one condition to another, the stabilized airspeed difference was the amplitude of the phugoid which was excited by the maneuver.

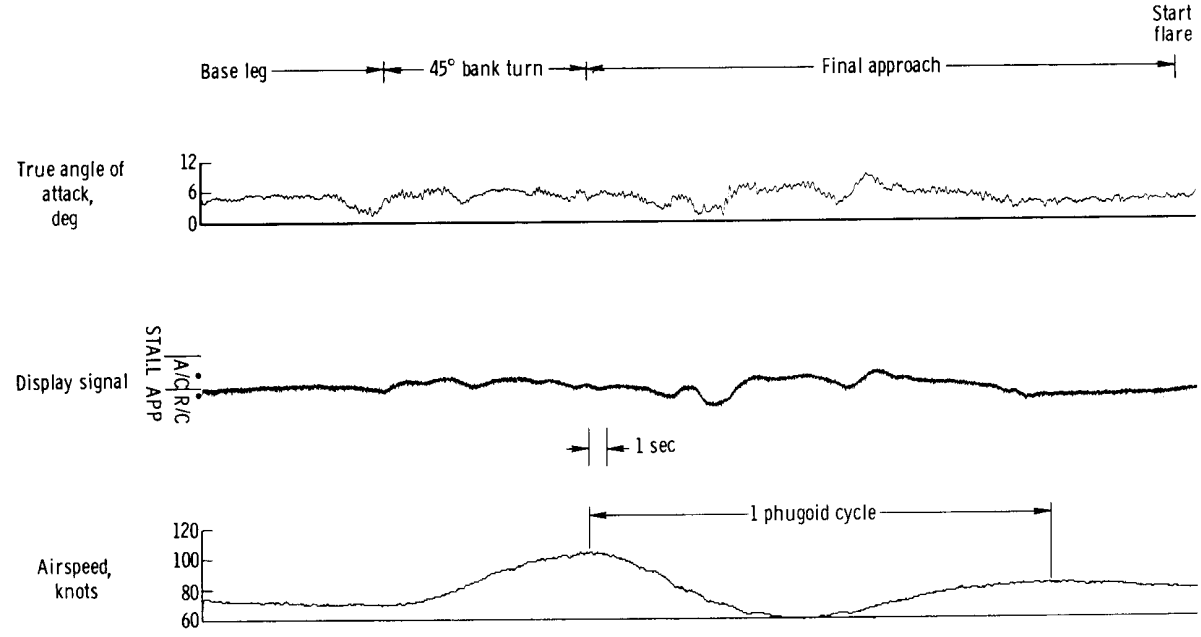



*Figure 9. Time history of landing approach when pilot used angle-of-attack display instrument.*

Three successful techniques for using angle-of-attack information on the final approach were observed. The first was to maintain a flight path by visual reference to the airport and its vicinity. Angle of attack was monitored occasionally, with pitch and power adjustments made to keep a large but decreasing margin from the target angle of attack in order to reach the target angle of attack at the flare point. This technique was used consistently and accurately by a pilot with only general-aviation experience. The second technique was to maneuver to a flare point using elevator control to stabilize the flight path while controlling angle of attack with power. This technique was used by several pilots with heavy aircraft experience. A third technique, successful when only small displacements from equilibrium were encountered, involved controlling

angle of attack with the elevator, and controlling the flight path with power. Combinations of these techniques were also used; however, to recover from any moderate displacement from equilibrium, it was always necessary to first resort to attitude stabilization using the elevator, then to establish control of flight path, and finally to adjust the angle of attack. To conscientiously maintain angle of attack following any departure from equilibrium only sustained the induced characteristic phugoid and delayed regaining stabilized flight; thus, the pilot was required to compensate for the nonstabilizing nature of angle of attack because it was not a reasonable control parameter except in combination with airspeed, attitude, or other information.

### ILS Approach

In the ILS approach, use of the angle-of-attack system did not provide a significant advantage over the airspeed system. The pilot needed to spend nearly all the time monitoring attitude and course deviation. According to pilot opinion, the use of angle-of-attack in place of airspeed information did not significantly alter the workload or degree of accuracy with which the task could be performed. Because the ILS approach is a difficult task at best, excitation of the phugoid characteristics caused by using the angle-of-attack system was possibly more bothersome than it would be under VFR conditions. Again, the necessity for monitoring many instruments is thought to be the limiting performance factor.

## CONCLUDING REMARKS

An investigation of the use of angle-of-attack information for the pilot's display in a light, twin-engine, general-aviation aircraft resulted in exposing certain fundamental complications which tended to negate some expected advantages of this parameter. As a result, the improvement in performance and flight safety was thought to be insignificant for the following reasons:

(1) The pilot was required to compensate for the nonstabilizing nature of angle of attack because it was not a reasonable control parameter except in combination with airspeed, attitude, or other information.

(2) The low-speed directional-control capability of the test airplane limited the advantages of using angle-of-attack information in that portion of the flight envelope, which led to undesirably low approach velocities (below minimum control speed) under low-weight conditions.

(3) The maximum performance curves for the test airplane were so flat near optimum values that expected climb performance gains were insignificant.

(4) Angle of attack was of no value as a cue when the correct speed for takeoff was reached.

Pilot acceptance of angle of attack was found to be highly dependent on a clear understanding of its meaning and limitations and the degree to which he combined it with other types of information. This understanding became important when angle of attack was used as a primary control parameter rather than as a stall margin displayed parameter.

Some of the characteristics of the angle-of-attack system were not adversely affected by vehicle aerodynamics and were considered to be desirable by the pilots. These were:

(1) The visual indication of stall margin.

(2) A single display point for straight-in approaches regardless of flap setting and gross weight, except for extremely lightweight conditions.

(3) The ease of obtaining trim and power settings when using the angle-of-attack indicator as a reference.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., September 18, 1970.

## APPENDIX

## ANGLE-OF-ATTACK EVALUATION - PILOT QUESTIONNAIRE

A. Display factors

1. Was the meter face readable at all times?

Pilot

(A) Yes.
(B) Yes.
(C) Yes.
(D) Yes. I would have preferred a vertical meter.
(E) Yes.
(F) Yes.
(G) Yes.
(H) Yes.

2. Did the scale seem adequately expanded?

Pilot

(A) Yes.
(B) Yes.
(C) Yes, although the cruise portion is greater than needed.
(D) Yes.
(E) No. Since angle of attack is useless near cruise (low angle of attack), eliminating the right half and doubling the left half would be desirable.
(F) No, not in the cruise portion. Scale was adequate in high-angle-of-attack region.
(G) Yes.
(H) Yes.

3. Were the markings readily understandable?

Pilot

(A) Only after explanation.
(B) Yes.
(C) Yes, after being prebriefed.
(D) Yes.
(E) Yes.
(F) Yes.
(G) Yes.
(H) Yes, but some simplification may be needed.

4. Did the horizontal needle deflection cause any confusion?

Pilot

(A) No.
(B) No.
(C) No. It seemed natural.
(D) Yes. Some ambiguity repeatedly throughout the flight.
(E) No.

(F) During the first several approaches, it seemed like there was too much horizontal movement of the needle with no apparent action by the pilot. At first, because of this, there was a tendency to chase the needle. After the first several approaches, the fluctuations were integrated and there was no further tendency to chase the needle.

(G) Yes, due to unfamiliarity. Once trimmed the wrong way to bring the needle to a new position.

(H) No, but vertical needle deflection would be more appropriate.

5. Would you have preferred a circular indicator?

Pilot

(A) No preference.

(B) No.

(C) No preference.

(D) Yes, if the needle were nearly horizontal for approach speed range.

(E) Can't say, since I haven't flown a circular one. Suspect I would not have any preference one way or the other.

(F) Yes. I say this because I used the circular indicator in the Navy. Also, with the desired approach angle of attack at the 3 o'clock position, the instrument is easier to interpret.

(G) Not particularly.

(H) No.

6. Was the location of the meter adequate?

Pilot

(A) Yes.

(B) Yes.

(C) No. For IFR work I would like it below the attitude gyro or near the top center (like a head-up display) of the panel.

(D) Yes.

(E) Yes.

(F) Yes.

(G) OK for temporary test installation but not for actual IFR.

(H) Yes.

B. Takeoffs, approaches, and landings

1. Is the takeoff procedure acceptable?

Pilot

(A) Procedure not acceptable when using angle of attack only.

(B) No.

(C) Yes, although I feel it's unsafe in high-density traffic; visibility over the nose is nonexistent. The task is acceptable.

(D) [No comment. ]

(E) No. In fact it was ridiculous to try to take off on angle of attack alone.

(F) No. I did not feel that the instrument could be interpreted quickly and accurately enough to use for a takeoff.

(G) No. Requires gentle touch and familiarity with aircraft.

(H) Yes.

2. Would you suggest a better procedure?

Pilot

(A) 1. Use airspeed $V_{mc}$ for rotation.
2. Establish attitude using attitude indicator after rotation.
3. Use airspeed or angle of attack thereafter.

(B) No.
(C) No. The results are as desired.
(D) [No comment.]
(E) Yes. Rotate on airspeed the way we always have.
(F) No.
(G) Prefer airspeed on takeoff. Did not try combination, but that might be best.
(H) No.

3. Was there any tendency to overrotate?

Pilot

(A) There was a tendency to underrotate because of the oscillatory nature of the angle-of-attack indication.
(B) No.
(C) Not initially, but if the pilot initially underrotates, it leads to a tendency to overcorrect.
(D) [No comment.]
(E) No.
(F) Yes. However, it could easily be corrected.
(G) Not initially, since I had been briefed, but reached an abnormal (I felt) nose-high attitude on climbout.
(H) No.

4. After rotation, were airspeed and/or pitch oscillations induced?

Pilot

(A) Some.
(B) Yes.
(C) Yes. This can happen at nearly constant angle of attack like a phugoid.
(D) [No comment.]
(E) No, since I fly primarily attitude and then just cross-check angle of attack or airspeed.
(F) No.
(G) Airspeed was covered. See preceding comment (B-3).
(H) No.

5. Could you trim adequately on angle of attack?

Pilot

(A) Yes.
(B) Yes.
(C) Yes, quite well.
(D) Yes.
(E) Yes.
(F) Yes, at least as well as when using airspeed.
(G) Yes, because I normally do not trim at cruise for airspeed. However, for slow flight, angle of attack and airspeed were about the same.

(H) Yes.

6. In trying to fly on set values, were pitch oscillations induced?

Pilot

(A) Yes. Had tendency to chase needle at first.

(B) Not in steady flight, but following any turn or change in speed.

(C) Yes. See comment, B-4. I would not fly constant angle-of-attack cruise flight.

(D) More flight-path oscillations than pitch angle. This was the feeling, although pitch attitude and flight-path angle are the same if angle of attack is constant.

(E) No, for same reasons as in question B-4.

(F) None that were noticeable to the pilot.

(G) Not in stabilized flight - VFR.

(H) No.

7. During flare and touchdown, did aircraft response seem right for those maneuvers?

Pilot

(A) Yes.

(B) Yes.

(C) Yes.

(D) Short period, yes; flight path, no.

(E) Yes.

(F) Yes.

(G) Yes, because the aircraft was flown visually from threshold.

(H) Yes.

8. Did the glide time between flare and touchdown seem right?

Pilot

(A) Yes.

(B) Yes.

(C) It floats a bit if any power is left on.

(D) Yes.

(E) Yes.

(F) Yes.

(G) Yes, but this factor was somewhat distorted due to shifting wind. At least one landing was downwind.

(H) Yes.

9. On short-field takeoffs and landings, did angle of attack seem to provide better control feel and response?

Pilot

(A) No.

(B) Takeoff, no; landing, yes. Except at light weight, [where] roll control was inadequate.

(C) No, but it quickly indicates a deviation from a desired condition.

(D) [No comment.]

(E) Landings, yes. Takeoff on angle of attack was absurd.

(F) Yes.

(G) Not good for takeoff. Equal or better than airspeed on landings.
(H) Same.

C. Slow flight and maneuvering

1. Was angle of attack useful as a stall-warning reference?

Pilot
(A) Yes.
(B) Yes.
(C) Not done.
(D) Yes.
(E) Very. Primary. It's great.
(F) Yes, very much so.
(G) Yes, but aircraft has good buffet warning.
(H) Yes.

2. Was there any noticeable lag time in the needle?

Pilot
(A) No.
(B) No.
(C) [No comment.]
(D) No.
(E) No.
(F) No. I would say that there was too much response if anything.
(G) No.
(H) No.

3. Did the needle seem to respond faster or slower than airspeed?

Pilot
(A) About same.
(B) Both systems adequate.
(C) [No comment.]
(D) Faster, too fast. Produced a tendency to chase it or ignore it completely.
(E) It responded to wheel motion; airspeed then lagged.
(F) Faster.
(G) About same.
(H) Did not notice.

4. Using angle of attack, was less throttle jockeying required to maintain altitude?

Pilot
(A) About same.
(B) Not significantly or consistently true.
(C) [No comment.]
(D) Yes, plenty.
(E) No, mainly because I don't jockey the throttles. I set them and jockey the wheel.
(F) It appeared that less throttle jockeying was required.
(G) No.
(H) Did not notice.

5. You held altitude best using which system, airspeed or angle of attack?

Pilot
(A) About same.
(B) No difference.
(C) [No comment.]
(D) Airspeed.
(E) Neither. I was sloppy either way.
(F) There appeared to be no difference.
(G) About same; probably held low speed more accurately with angle of attack.
(H) Did not notice.

D. ILS approaches

1. Your better performance was with which system, airspeed or angle of attack?

Pilot
(A) Did not do.
(B) No difference.
(C) Angle of attack.
(D) [No comment.]
(E) Not applicable.
(F) Could not tell any difference.
(G) Not performed.
(H) [No comment.]

2. Did angle of attack seem to alter your technique for any task?

Pilot
(A) Did not do.
(B) Turn to final done at lower bank angle and lower airspeed with angle-of-attack system.
(C) Yes. Power manipulations were fewer and generally in one direction only (i.e., reduction).
(D) [No comment.]
(E) [No comment.]
(F) I did not notice any change in technique.
(G) [No comment.]
(H) [No comment.]

E. General

1. Would you prefer angle of attack to airspeed for some maneuvers in this aircraft?

Pilot
(A) Would rather see both.
(B) No.
(C) Yes. Approaches, tight turns, steep climbs, and some IFR work.
(D) Airspeed for all.
(E) Yes, on landing approach - particularly the very slow approaches. Other phases of flight such as takeoff and cruise are not suited to angle of attack.

(F) Yes. During approaches I think that this instrument would be very useful.
(G) For low-speed approaches it might be better, but it would take some getting used to. Possibly both would be best.
(H) Yes.

2. Was there a noticeable decrease in pilot workload using angle of attack?

Pilot
(A) No.
(B) No.
(C) Yes. I felt it was a substantial decrease (especially considering the panel layout).
(D) More workload.
(E) On the approaches, yes; also much less nerve-racking on the approaches with angle of attack. Takeoff and cruise, no.
(F) Yes. I felt that it is somewhat easier to make approaches using angle of attack.
(G) Not significant.
(H) No.

3. Did angle of attack seem easier to fly?

Pilot
(A) No.
(B) No.
(C) Yes.
(D) No, harder.
(E) On the approach, yes; otherwise, no.
(F) Yes.
(G) Possibly at low speed.
(H) Seemed more secure on short-field approaches.

4. Did you notice any significant advantages in using angle of attack?

Pilot
(A) Very good indication of stall margin.
(B) Good indication of stall margin.
(C) Yes. Reduces number of gages to scan.
(D) Trim reference.
(E) Yes, it made the approach less hairy.
(F) Automatically compensates for changes in gross weight.
(G) [No comment.]
(H) Angle of attack will provide best reference in climbs or descents with changes of weight, etc.

5. Disadvantages?

Pilot
(A) The oscillatory nature of the parameter.
(B) Tendency to concentrate excessively on angle of attack. This did not decrease much with familiarity.
(C) Yes. If one is fast to very fast, it is difficult to know exactly how fast (assuming no airspeed indicator).

(D) If there were any advantages, these were marked by phugoid and power effects on trim and control and it all seemed more disadvantageous than advantageous. I would like to try using angle of attack with an aircraft which had a pitch rate command system, free of aerodynamic trim changes and power effects.

(E) No.

(F) I evaluated the instrument as an additional cockpit instrument and not as a replacement. Under these circumstances, I found no disadvantages.

(G) [No comment.]

(H) Short-field approaches in strong, gusty winds could be a problem due to wind gradient and gusts.

6. Suggestions or miscellaneous comments?

Pilot

(A) First exposure to angle of attack resulted in "chasing" the needle because it was the center of my attention; angle of attack, like airspeed, is best controlled by controlling attitude.

(B) [No comment.]

(C) None, except that the task would be easier in a single-engine airplane. Whether you want it easier is not known, perhaps it is desired to nearly saturate the pilot.

(D) [No comment.]

(E) The angle of attack is a useful indicator for the approach and landing phase and, as such, could be a significant contribution to safety. During the other phases of flight, it is essentially useless, since airspeed or angle of attack are not primary. (For example, in cruise, power and rate of climb are primary.)

(F) On the ILS flight there was light-to-moderate turbulence encountered. With this amount of turbulence, I could not tell any difference in the performance of flying the ILS approach. With any turbulence, I would prefer to fly airspeed. It appeared that I was better able to determine when turbulence was changing airspeed than I was able to determine changes in angle of attack due to turbulence.

(G) After some postflight thought and some discussion, I feel that the major advantage of the angle-of-attack meter would be for low-speed approaches at varying gross weights, particularly in an airplane in which the pilot was not highly experienced. Since the evaluation was flown at essentially constant gross weight, this could not be evaluated. I did not like the angle-of-attack meter on the initial phase of the climbout and I would question its sole use for short-field or obstacle-clearance takeoff. With the airspeed for the initial phases it might be useful, but this was not evaluated. For either high-speed or low-speed cruise, including holding, I use power setting and altitude with the airspeed as a reference only. Therefore, it is doubtful if either the airspeed or angle of attack would be useful here. I didn't really evaluate it completely (I use power and airspeed for stabilized climb), so maybe the angle of attack would be an improvement, particularly for varying gross weights. However, since engine cooling is a consideration here, airspeed would also be required.

(H) [No comment.]

## REFERENCES


1. Gilbert, James: What's your angle? FLYING, April 1969, pp. 82-83.

2. Taylor, L. ; and Hutchinson, J.: Angle of attack - A Proposal. Shell Aviation News, no. 359, 1968, pp. 2-9.

3. Gandelman, Julius H.: Evaluation of Angle of Attack Instrumentation in the Training of Student Pilots to Private Pilot Certification. Rep. No. FAA DS-68-19, FAA, Aug. 1968.

4. LaPlant, Porter II; and Johnson, Alvinus P.: Evaluation of the Giannini Dual Stall Warning System and Stall Margin Indicators Installed in a C-133B. FTC-TR-67-5, U.S. Air Force, May 1967.

5. Bahns, Eugene L. ; and Bock, Charles C., Jr.: Evaluation of the Monitair Angle of Attack/Stall Warning System Installed in a C-130E Aircraft. FTC-TDR-65-23, U. S. Air Force, Aug. 1965.

6. Tuomela, C. H.: Angle of Attack as an Aid to Flying. Tech. Rev., vol. 8, no. 1, Soc. Exp. Test Pilots, 1966, pp. 44-55.

7. Fink, Marvin P. ; and Freeman, Delma C., Jr.: Full-Scale Wind-Tunnel Investigation of Static Longitudinal and Lateral Characteristics of a Light Twin-Engine Airplane. NASA TN D-4983, 1969.

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