AD-757 243

ATC ANGLE OF ATTACK TRAINING

Max L. Odle

Instrument Flight Center
Randolph Air Force Base, Texas

July 1972

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USAF INSTRUMENT FLIGHT CENTER

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IFC-TR-72-3

Major Max L. Odle

July 1972

RESEARCH AND DEVELOPMENT DIVISION
RANDOLPH AIR FORCE BASE, TEXAS

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) USAF INSTRUMENT FLIGHT CENTER	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP NA

3. REPORT TITLE

ATC ANGLE OF ATTACK TRAINING

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Report 3 Sep 1971 - 18 Jul 1972

5. AUTHOR(S) (First name, middle initial, last name)

Major Max L. Odle

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
July 1972	~~83~~ 91	1

8a. CONTRACT OR GRANT NO. NA	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO. IFC TR&D 71-3	IFC-TR-72-3
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	None

10. DISTRIBUTION STATEMENT

Distribution of this Document is Unlimited

11. SUPPLEMENTARY NOTES NA — Details of illustrations in this document may be better studied on microfiche.	12. SPONSORING MILITARY ACTIVITY Research and Development Division USAF Instrument Flight Center

13. ABSTRACT

The Research and Development Division of the United States Air Force Instrument Flight Center conducted an evaluation and study of the Bendix Standardized Angle of Attack (AOA) System for its use in Air Training Command flying training programs. The Bendix AOA System was installed in T-38, S/N 70-1549 for engineering flight test at the Air Force Flight Test Center, Edwards AFB, California. The aircraft was then flown to Randolph AFB for pilot factors evaluation and determination of exactly what flying maneuvers could be flown using AOA as the controlling parameter and how AOA should be used in these maneuvers. Subjective data on the procedures and techniques for AOA use were gathered from twelve T-38 instructor pilots from the Pilot Instructor Training (PIT) and Instrument Pilot Instructor School (IPIS) at Randolph AFB. The conclusions from the study are:

a. Subject pilots felt that the AOA indicator and indexer satisfactorily displayed usable angle of attack information to the pilot. It was determined that a system displaying AOA as a percent of lift available was more meaningful to pilots than the Bendix system displaying AOA as a percent of the available angle of attack or other systems using non-meaning terms such as "units."

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DD FORM 1 NOV 65 1473

Unclassified
Security Classification

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
AOA						
Angle of Attack						
Bendix Standardized Angle of Attack System						
Air Training Command						
Training						
AOA Display						
AOA Vane Sensor						
AOA Probe Sensor						
Flap Compensation						
Mach Compensation						
Alpha						
Stalling Angle of Attack						
AOA Display Symbology						

Security Classification

FOREWORD

This report (IFC-TR-72-3) is the summation of an Air Force Instrument Flight Center (IFC) project, TR&D 71-3, Angle of Attack Training for ATC. This project was conducted at the request of the Flying Training Division, Headquarters, Air Training Command (ATC/DOTF). This project is complete as of 18 July 1972. Special recognition is given to Major William G. Bookout, Major James T. McDaniel, and Captain James R. Spurger, Randolph AFB, Texas, for their assistance as project pilots in conducting the evaluation; Major John P. Kelly for his technical advice; and to Captain Robert J. McCusker for his angle of attack expertise and assistance in preparing the final report.

This technical report has been reviewed and is approved.

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ABSTRACT

The Research and Development Division of the United States Air Force Instrument Flight Center conducted an evaluation and study of the Bendix Standardized Angle of Attack (AOA) System for its use in Air Training Command flying training programs. The Bendix AOA System was installed in T-38, S/N 70-1549 for engineering flight test at the Air Force Flight Test Center, Edwards AFB, California. The aircraft was then flown to Randolph AFB for pilot factors evaluation and determination of exactly what flying maneuvers could be flown using AOA as the controlling parameter and how AOA should be used in these maneuvers. Subjective data on the procedures and techniques for AOA use were gathered from twelve T-38 instructor pilots from the Pilot Instructor Training (PIT) and Instrument Pilot Instructor School (IPIS) at Randolph AFB. The conclusions from the study are:

a. Subject pilots felt that the AOA indicator and indexer satisfactorily displayed usable angle of attack information to the pilot. It was determined that a system displaying AOA as a percent of lift available was more meaningful to pilots than the Bendix system displaying AOA as a percent of the available angle of attack or other systems using non-meaning terms such as "units."

b. The Bendix AOA system accurately depicts the area of stall below 20,000 feet, maximum L/D and the optimum approach angle of attack for full flap, normal approaches. The maximum range index is satisfactory for cruise at altitudes 35,000' to 40,000'.

c. An on-speed AOA indication in the no-flap configuration commands an approach speed equivalent to $1.23V_{stall}$ (approximately 5 Kts above the $1.20V_{stall}$ design speed).

d. Present Flight Manual recommended no-flap approach and touchdown speeds are too slow.

e. The Bendix AOA system provides a satisfactory assessment of angle of attack and aircraft performance relative to the stalling angle of attack at altitudes below 20,000 feet and indicated mach numbers below 0.9. If properly monitored and used it will provide a safe margin above the stall for aircraft control in the traffic pattern and max performance maneuvers.

f. Max L/D (endurance) is accurate for a clean configuration.

g. The Bendix AOA system is very flyable and subject pilots had little difficulty in controlling the aircraft using AOA.

h. The vane angle of attack sensor may cause excessive airflow disruption in front of the right engine inlet at high altitudes and high angles of attack.

i. Angle of attack can be used to effect a safe recovery in event of airspeed indicator failure. For penetration from altitude .18 (max range) will closely approximate 280 KIAS in one G flight. Gear may be lowered at angle of attack indications above 0.4 in one G flight and the approach index will accurately provide final approach airspeed.

j. Reliability of the system could not be determined because a prototype AOA computer was used during the first part of the evaluation and the limited time the system was flown.

TABLE OF CONTENTS

I. PROJECT NUMBER AND TITLE: TR&D 71-3, Angle of Attack Training for ATC.

II. PROJECT OFFICER: Major Max L. Odle, Research and Development Division, USAF Instrument Flight Center, Randolph AFB, Texas 78148. Project pilots were: Major James T. McDaniel (ABEQ), Major William J. Bookout (ATC/DOV), Captain James R. Spurger (DOF), and Captain Robert J. McCusker (IFC/RD), Randolph AFB, Texas 78148.

III. AUTHORITY. AFR 53-12; and letter, ATC/DOTF, 3 September 1971, Subject: T-38 Aircraft Standardized AOA Project.

IV. PURPOSE OF THE PROJECT:

A. To test and evaluate the suitability of the Bendix Angle of Attack instrument presentations.

B. To validate the displayed information.

C. To develop system application and restrictions.

D. To develop operator instructions/guidance.

E. To conduct ATC staff orientation on the T-38 Bendix Angle of Attack system.

F. To orient ATC UPT/PIT/IFC personnel on the angle of attack system.

V. INTRODUCTION:

The Air Training Command has lost 35 T-38s in landing pattern accidents since beginning T-38 operations in 1961. The accidents range from solo students who forgot to lower the flaps, to dual, heavy-weight aircraft that stalled in the final turn. Aircraft have stalled and crashed while executing TACAN non-precision approaches, circling approaches, and precision ILS and radar approaches. An AOA system could have prevented a large percentage of these accidents.

The IFC Research and Development Division was tasked by the Director of Flying Training, Headquarters Air Training Command to conduct this evaluation. Previous AOA studies conducted by Northrop Corporation and the Air Force Flight Test Center were not oriented to ATC usage.

Angle of attack is not new; in fact, the Wright brothers discussed a need for such a system when they first designed their aircraft. What is new is that AOA systems have now been developed that are accurate and reliable. An AOA system can be used by the pilot as a better reference for controlling his aircraft through certain maneuvers than the more traditional airspeed indications.

Angle of attack, or "alpha" as it is commonly called, is nothing more than the angle between the chord of the wing and the flight path of the aircraft. Simplifying it further, it may be considered as the angle between the longitudinal axis of the aircraft and the flight path.

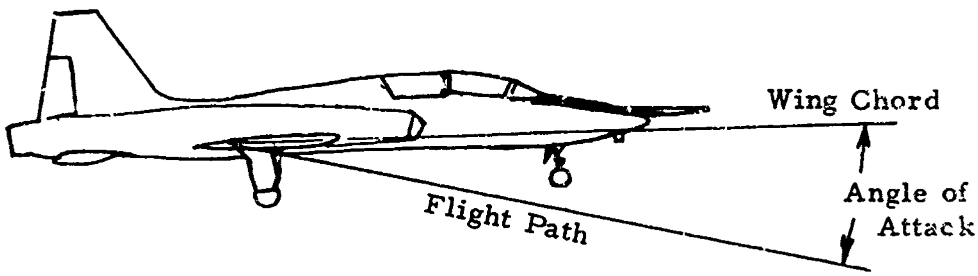


Figure 1.

Each type of aircraft has its own unique angle of attack characteristics. For example: for a given configuration in subsonic flight the stalling angle of attack is always the same regardless of aircraft weight, G-loading, or bank angle. Changing wing configurations by lowering full or partial flaps does change the stalling angle of attack, but as long as the configuration remains unchanged the aircraft will always stall at the same angle of attack. The stall speed is affected by changing weight, G-loading and bank angle, but the stalling angle of attack is not.

It should be noted at the very beginning of this study that angle of attack is not, and was never intended to be, a replacement for airspeed information. There are several flight conditions where airspeed is an easier and better performance parameter than angle of attack. It also must be noted that certain conditions are true with the Bendix T-38 angle of attack system that are not true of other AOA systems. Budget limitations and the need to economize have greatly limited the design capabilities of this system as it applies to the T-38.

It must be emphasized that angle of attack is not a panacea for all that can go wrong with a flight maneuver. For example: in a 360° overhead pattern a pilot can still overshoot or undershoot; land short or long, using angle of attack. The major difference between angle of attack and airspeed/bank limitations is that angle of attack shows the pilot precisely what his aircraft is doing with relation to the aerodynamic limitations. Airspeed/bank limitations as used during final turn and approach are rules of thumb that are oftentimes neither easy to calculate nor particularly accurate.

The conclusions of this investigation with regard to how the parameter of angle of attack is controlled may vary with previously established concepts in use with other aircraft or by other services. The Navy clearly specifies that angle of attack is controlled with pitch and that flight path on final approach is controlled by throttle adjustment. Many Air Force F-4 pilots use this method. However, ex-F-4 pilots used in this study and familiar with the "Navy" method were less successful using it in the T-38 and in most cases reverted to using a combination of pitch and power changes to adjust the angle of attack and the desired flight path angle. The maneuver itself should dictate how angle of attack will be controlled.

IV. THEORY OF OPERATION OF BENDIX ANGLE OF ATTACK SYSTEM: (Reprinted with permission of Bendix).

Any aircraft, for a particular airspeed and configuration of lift and drag surfaces, has a specific lift curve of the coefficient of lift (C_L) versus the true angle of attack (α_T). Figure 2 depicts a typical

T-38 lift curve.

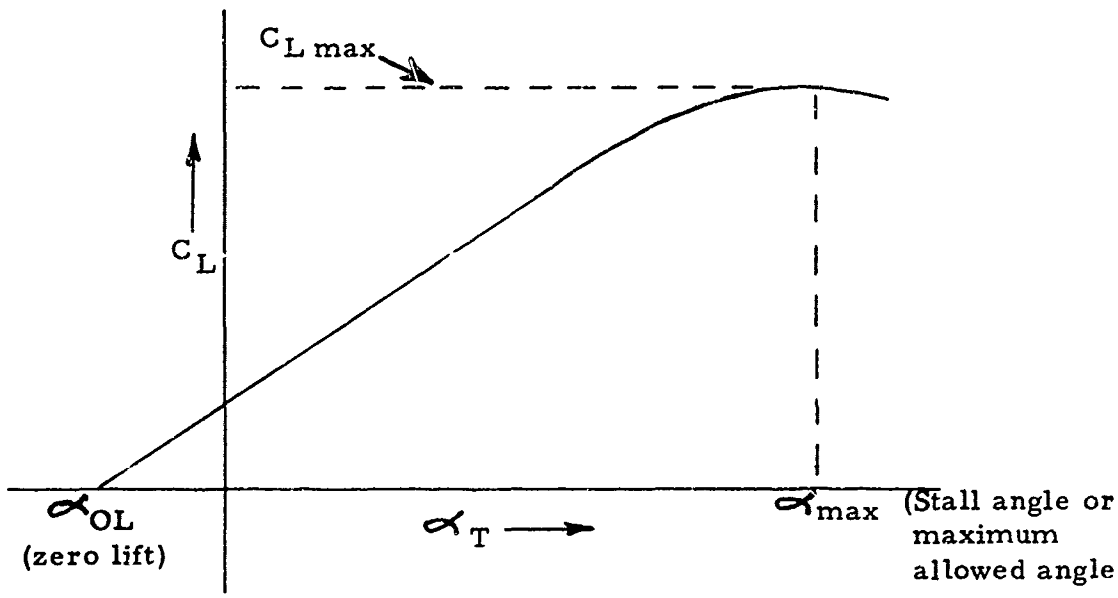


Figure 2.

The Bendix system stores sufficient data in the AOA computer to generate a lift curve for any particular aircraft configuration. The computation performed is:

$$\frac{\alpha_T - \alpha_{OL}}{\alpha_{max} - \alpha_{OL}}$$

where: α_T = true angle of attack

α_{OL} = angle of attack at zero lift

α_{max} = angle of attack at stall

and the true angle of attack is shown as a percentage of the range between zero lift angle and stall angle. Regardless of what criteria is used to define α_{max}, (whether at max stall or max allowed angle of attack) using the above formula will always result in a computed ratio of 1.00. It is also verified empirically that other performance indices such as optimum approach (regardless of wing configuration), stall, maximum range and endurance are obtained at certain values of the computed ratio.

The formula $$\frac{V}{V_S} = \sqrt{\frac{C_{L\,max}}{C_L}}$$

where: V = airspeed

V_S = stall speed

$C_{L\,max}$ = lift coefficient at stall angle

C_L = lift coefficient

describes stall speed margin independentally of gross weight, G-loading or bank angle. With classical lift curves it is also true that

$$\frac{\alpha_T - \alpha_{OL}}{\alpha_{max} - \alpha_{OL}} = \frac{C_L}{C_{Lmax}} = \frac{1}{(V/V_S)^2}$$

The dial reading for $1.2V_S$ approach speed can be calculated to be $1/(1.2)^2 = 0.695$.

Figure 3 shows typical data stored in the Bendix AOA computer. The displayed ratio of angle of attack is by definition equal to A/B. In the example the empirical value of angle of attack for $1.2V_S$ corresponds to a ratio of 0.6 rather than the ideal 0.69. The example also illustrates that the same 0.6 ratio is still approximately correct for all flap configurations.

VII. DESCRIPTION OF TEST ITEMS:

The Bendix Corporation angle of attack system consists of the following components:

A. Angle of Attack Transmitter Vane (Figure 4). The transmitter vane is mounted on the right side of the fuselage just ahead of the front cockpit (fuselage station 154.55, water line zero). The

FOR 1.2 V_S $$\frac{\alpha_T - \alpha_{OL}}{\alpha_{MAX.} - \alpha_{OL}} = \frac{A}{B}$$

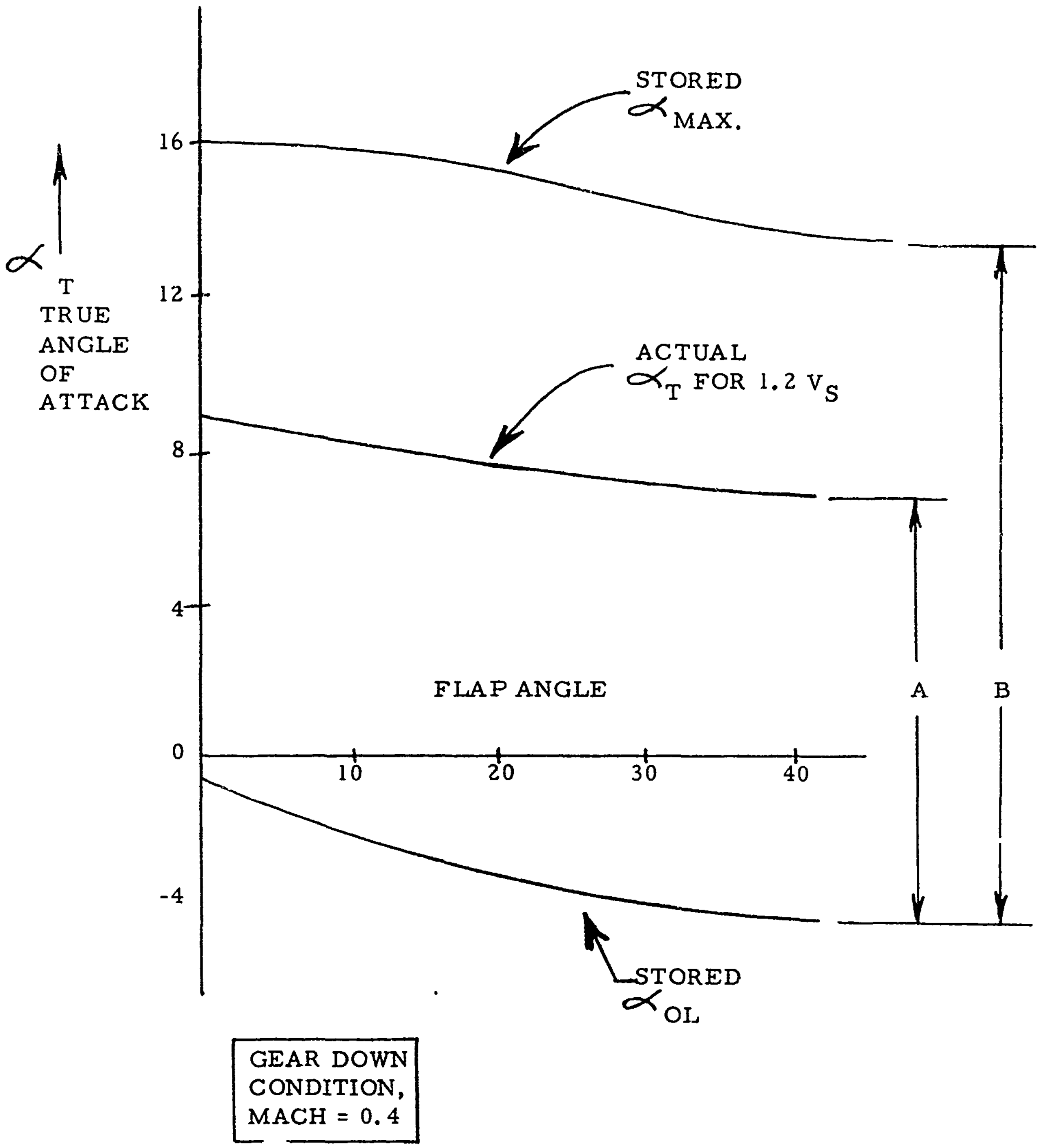


Figure 3. Typical Data Stored in Computer Memory

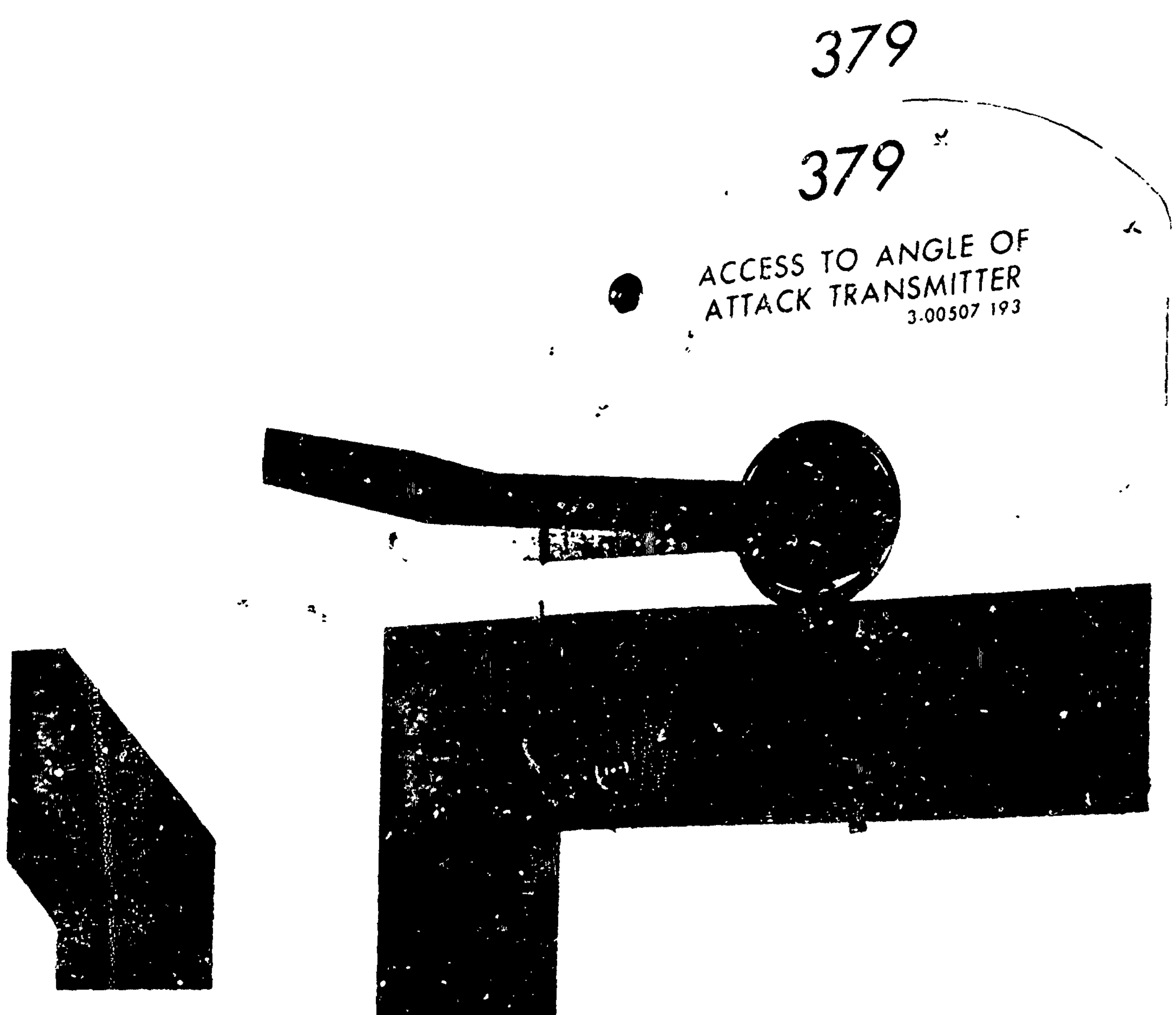


Figure 4. Angle of Attack Transmitter Vane

wedge-shaped vane aligns itself with local airflow and transmits this signal to the CPU-115A computer. The vane has an internal electric heating element powered through the aircraft's pitot heat circuit to provide de-icing capability.

B. CPU-115A Computer (Figure 5). The computer is mounted in the right-hand communications/navigation equipment bay. Data is stored in the computer so that accurate angle of attack information displayed to the pilot is corrected for all gear and flap configurations.

C. Angle of Attack Indicator (Figure 6). Angle of attack information is presented in both cockpits on a round dial indicator located to the left of the mach/airspeed indicator. The dial presents angle of attack information as a percentage of available angle of attack being used. The scale is from 0 (0%) to 1.1 (110%). 0 equates to the angle of attack for zero lift and 1.0 represents the stall. A max range index is set at .18, max endurance (L/D max) is set at .30, and the approach index is centered at .60. The approach index is set at the three o'clock position. The approach to stall area is color coded amber beginning at .90 and the stall area is colored red beginning at 1.0. A red "OFF" flag is visible under certain electrical power malfunctions within the system.

D. Angle of Attack Indexer (Figure 6). A head-up type of AOA indexer is mounted on the anti-glare shield directly in front of each pilot. Angle of attack trend information is supplied to the pilots by the following light combinations:

Light		Meaning
	Red	High AOA, low airspeed
	Red Green	Slightly high AOA, slightly low airspeed
	Green	On approach AOA, on approach speed
	Green Amber	Slightly low AOA, slightly high airspeed
	Amber	Low AOA, high airspeed

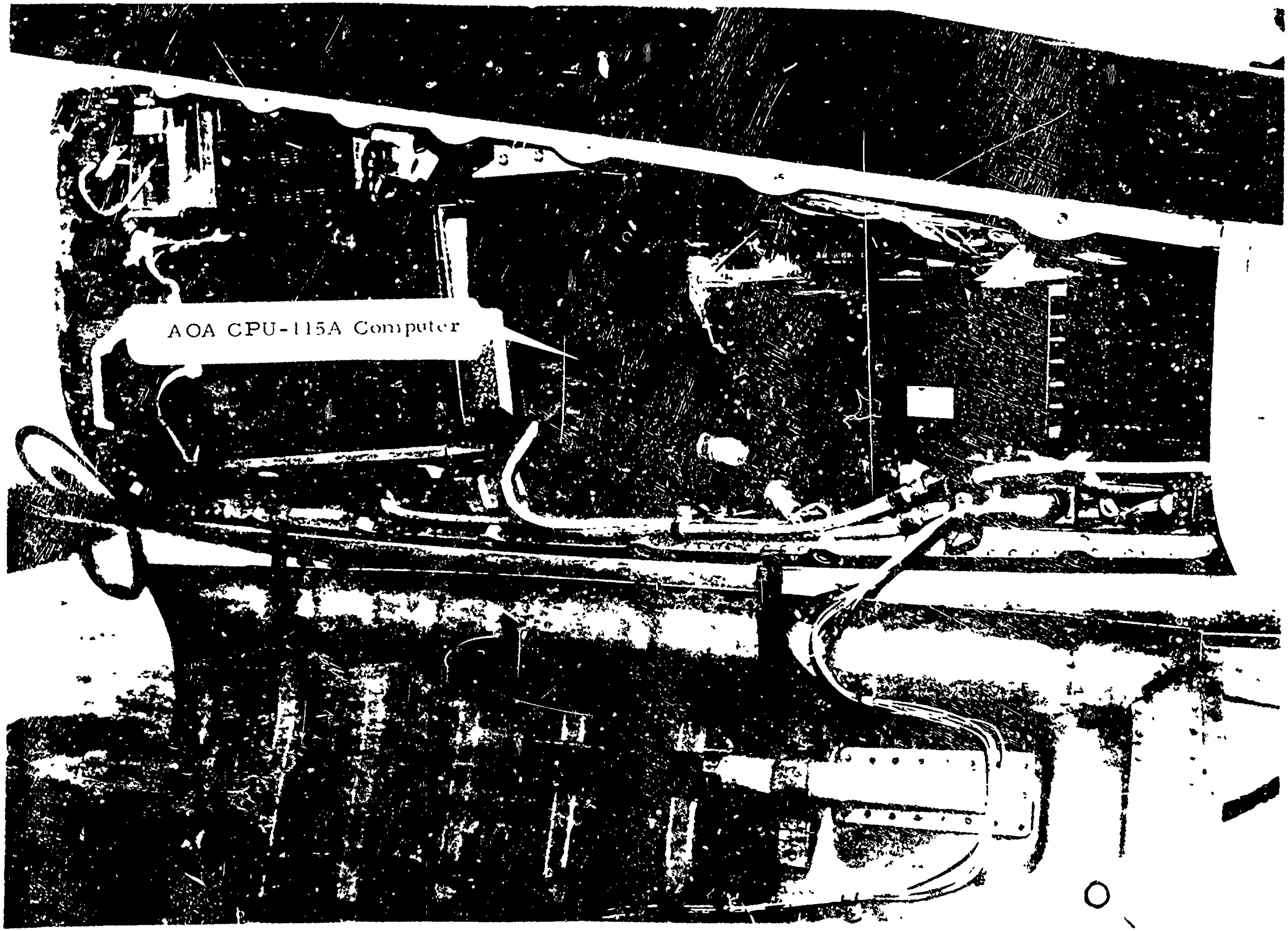


Figure 5. Angle of Attack CPU-115A Computer

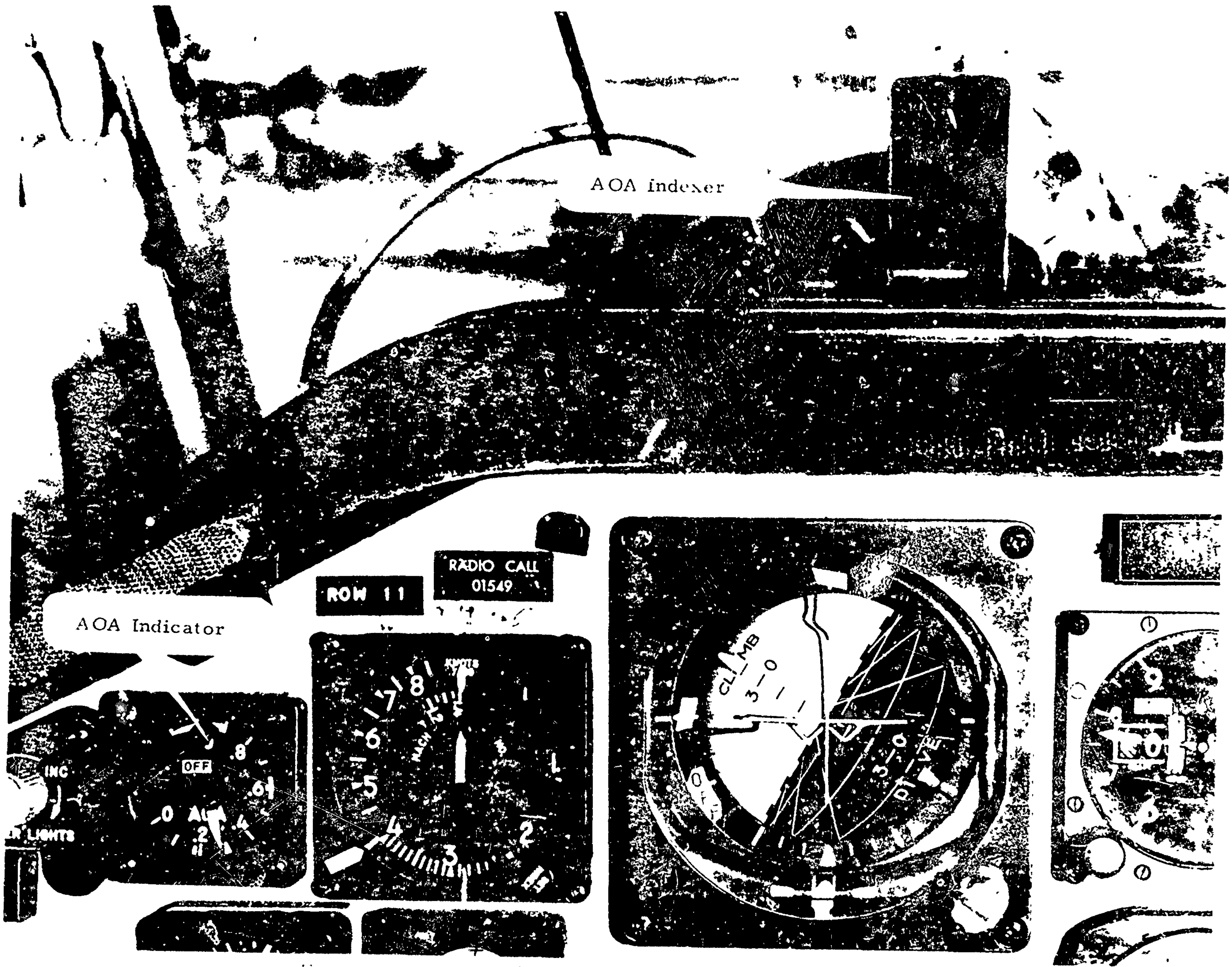
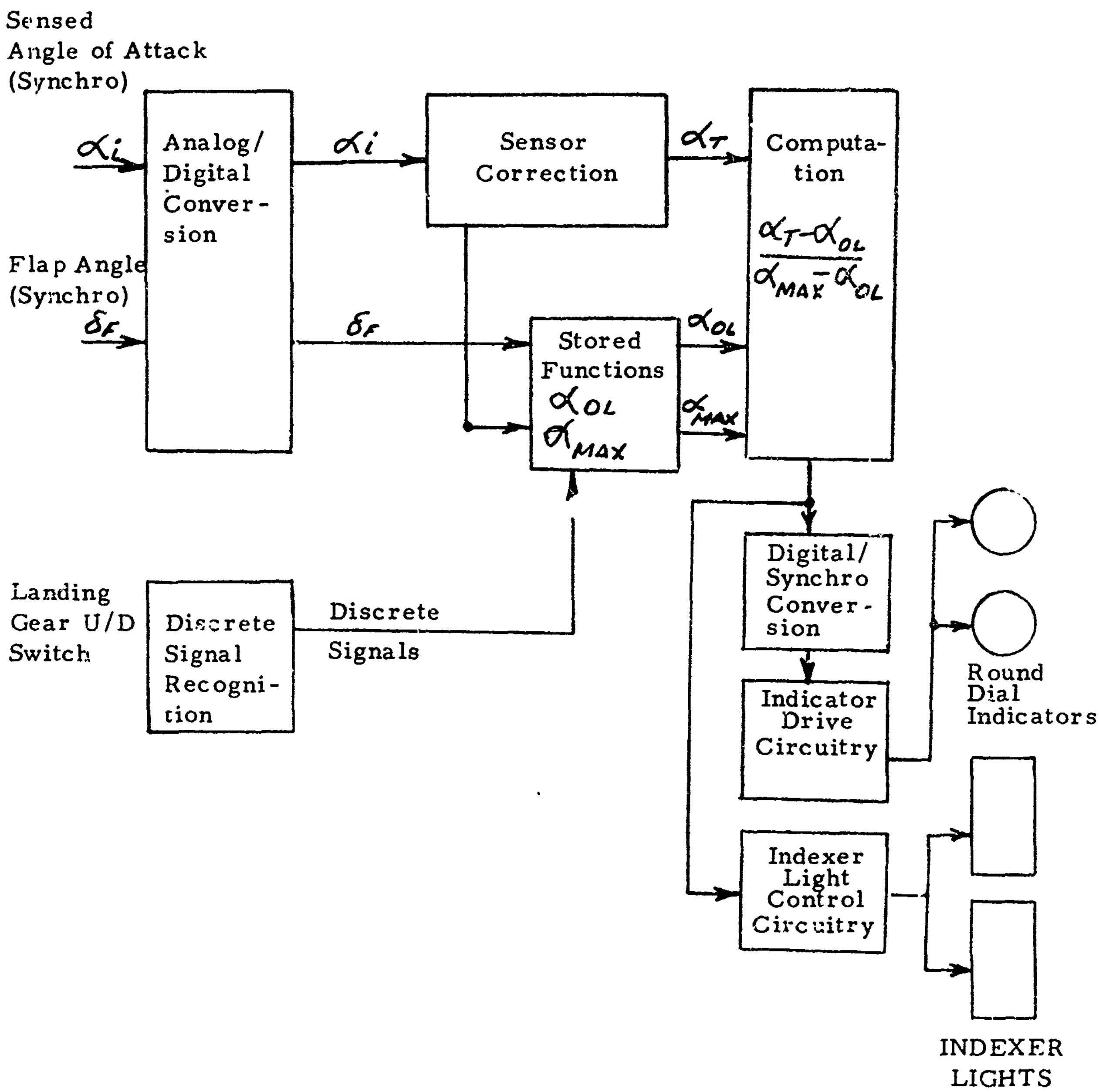


Figure [illegible]. Angle of Attack Indicator and Indexer Rear Seat

E. Flap Position Synchrotransmitter: Flap position is sensed by a synchrotransmitter located in the lower fuselage near the right trailing edge flap inboard hinge support. Flap position is sent to the computer which then computes and applies the flap compensation.

F. Gear Switch: Gear position information is supplied to the computer by a switch located on the aft bulkhead panel in the nose gear well. The switch is connected to the nose gear down lock indicator relay.



System Block Diagram. Bendix Angle of Attack System

G. <u>System Monitoring</u>. A feature of the Bendix AOA system is an automatic self-test every 40 milliseconds. If an individual AOA indicator develops excessive error an OFF flag is displayed on the indicator dial, or all three indexer lights will illuminate simultaneously. Failure of the computer computations or storage system produces output to system warning lamps on the computer and to the AOA indicators and indexers. Failure of the vane sensor heater or synchro produces the same failure indications plus triggering a warning sensor flag on the computer box. In case of a single failure of a display unit, the failure can be identified by observation of the failed unit.

VIII. METHOD OF CONDUCTING THE EVALUATION:

Twelve highly-qualified T-38 instructor pilots were used for validation purposes. These IPs were selected from the Undergraduate Pilot Training, Pilot Instructor Training and Instrument Pilot Instructor School at Randolph AFB. Additional pilots were flown for orientation and staff familiarization.

Flight profiles were designed to insure exposure to as many uses of angle of attack as possible. Two missions were transition oriented (one front, one rear cockpit) and one mission was instrument flight oriented. The profiles were:

A. <u>Mission Profile</u> -- <u>1st Flight</u> -- <u>Subject in Front Seat</u>

1. Takeoff
2. Airspeed climb transitioning to max L/D climb
3. Best cruise to area
4. Standardized concept demonstration -- 1 & 2 G
5. Stall series demonstration
6. Flap compensation demonstration
7. Maneuvering air work
8. Max L/D descent

9. Normal traffic pattern demonstration

10. Subject traffic patterns

    a. Normal

    b. No flap

    c. Single engine (go-around and landing)

    d. Full stop

11. Debrief -- Hand out questionnaires

B. Second Flight -- Subject in Rear Seat

1. Takeoff

2. Low level

3. Heavy weight single engine

4. Heavy weight normal

5. Proceed to area

6. Repeat area work

7. Return to field

8. Demonstration -- pushover final turn with overshoot

9. Subject traffic patterns -- full stop

10. Debrief

C. Third Flight -- Instruments -- Subject in Rear Seat

1. Takeoff

2. Combination A/S and angle of attack climb

3. Cruise	)	
4. Holding	)	
5. Penetration	)	Angle of attack augmenting airspeed
6. TACAN approach	)	
7. PAR	)	

8. PAR -- A/S covered

9. ILS -- A/S covered

10. PAR full stop

11. Debrief

Experimental Design and Data Measurement: Each subject pilot completed three (3) data flights as outlined previously. A thorough briefing was given prior to flight to insure familiarity with the system, test objectives and angle of attack uses. A comprehensive debriefing was conducted by the project pilot and significant comments and observations recorded. A two-part questionnaire (Atch 1) was completed by each subject pilot following the final sortie.

IX. DISCUSSION:

A. DISPLAY SUITABILITY.

Subject pilots were unanimous on the necessity of establishing an Air Force standard for both angle of attack indicator and indexer displays. There was general agreement that a system presenting angle of attack information in terms of percentage of lift being used would be more desirable than the present display of percentage of available AOA. Pilot understanding and application of this parameter to maneuvering flight was felt to be more direct and readily transferrable from one aircraft to another.

The difference between displaying percentage of AOA versus percentage of lift is felt to be significant. For example, an indication of

.8 on the lift percentage system tells the pilot that he has a 20% lift reserve. An indication of .8 on the AOA percentage system will not result in 20% of lift remaining, although there is 20% of AOA remaining, due to characteristic flattening of the lift curve approaching maximum angles of attack. The Bendix concept of display, therefore, is not completely satisfactory. However, due to close approximation of the two presentations it is felt to be adequate for ATC training purposes. Future systems should display AOA as a percentage of available lift being used.

Presently there is no AF standard dealing with AOA display symbology. Subject pilots all stated that a standard should be established as to symbology. It is recommended that a triangular symbol be adopted for the maximum range index and a rectangular symbol be standardized for L/D max.

△ .... Maximum range

□ .... L/D maximum

 .... Approach index (located at three o'clock position on dial)

Subject pilots were generally pleased with the AOA indicator. Location, adjacent to the mach/airspeed indicator, afforded ready comparison and correlation of the two into a comfortable cross-check. However, it was felt that the color coding needed to be changed. The amber shading on the indicator between .9 and 1.0 is intended to warn of high AOA, impending stall. The amber colored indexer chevron denotes low angle--high airspeed. It is therefore recommended that to avoid possible confusion the area signifying an approach to a stall be color coded with red and black stripes.

The AOA indexers were unanimously accepted. In general, it was felt that the indexers allowed the pilot to fly "heads up" in the traffic pattern. This allowed better clearing and more precise patterns with smoother aircraft control. The red chevron provided a much more effective cue "to do something" than a corresponding 5-6 knot low airspeed deviation. Two modifications to the indexers were suggested. The most urgent related to adding additional shielding to the indexers to shade them. Under certain lighting conditions, the ambient light overpowers that from the indexer rendering the lights invisible. In at least one instance in high ambient light the subject pilot believed himself to be "on speed" when actually he was getting a red chevron (slow) indication. To correct this deficiency, the indexer hood (particularly in the front cockpit installation) should be lengthened. The second modification suggested by numerous subject pilots was that two indexers be installed, one in each lower corner of the windscreen rather than the single center location. Aircraft mission and design considerations (i.e., gun sight location) may dictate the "two indexer" installation. All subject pilots were basically satisfied with the existing Bendix centerline indexer location and felt that it was completely adequate for the ATC training mission.

Subject pilots were questioned pertaining to their desires to have the high speed light on the indexer to function at all times with the gear retracted or only with the gear extended. Response was evenly divided with one half desiring the present configuration in which the high speed light is deactivated with gear retraction. The other half expressed a desire to have the high speed light operative at all times in which case it would be on at all times except when operating at angles of attack equal to, or greater than, those corresponding to $1.2_{V_{stall}}$. If the high speed light is to be of use during all phases of flight, it should be modified to go out as speed increases (AOA decreases) beyond the final approach range (possibly 10 knots). In this way, trend information would be available from the indexer. As AOA was increased, the amber high speed light would illuminate indicating that $1.2_{V_{stall}}$ AOA was being approached. It would thus serve as an advanced warning prior to the green "on-speed" light.

The majority of subject pilots (10 of 12) felt that system dynamics and response were "just about right." The remaining pilots felt that the system was over-dampened and responded too slowly. Overall, the system is very flyable. It is significant that those pilots who felt that they used power to control AOA and elevator to control flight path considered system dynamics to be satisfactory. Pilots who thought they were using the elevator to control AOA and power for flight path consistently found system dampening to be excessive.

B. SYSTEM VALIDATION.

The Air Force Flight Test Center, Edwards Air Force Base, California, conducted an engineering evaluation of the pre-production angle of attack system installed in T-38, S/N 70-1549. The results of this evaluation are published in Technical Letter Report T-38 Angle of Attack Evaluation, September 1971. The evaluation disclosed several potential problem areas that should be corrected or noted prior to beginning angle of attack operations in ATC. Some of these problem areas affected specific syllabus maneuvers. The decision was therefore made to further validate the angle of attack system. However, even if the Edwards evaluation had shown the system to be flawless, validation was still necessary to satisfy the pilot factors objectives.

1. Stalls and Stall Warnings: Traffic pattern stall series and full aft stick stalls were accomplished with each subject pilot. It should be noted that stalls were conducted below 20,000' in accordance with ATCM 51-38 and high altitude/mach stalls were not explored. Because the system is not mach compensated the adequacy of proper angle of attack stall indications at high altitude and high mach number flight is questionable. (See discussion of High Speed Flight.)

The T-38 stall is extremely hard to define and leads to some problems in locating the approach to stall area on the angle of attack indicator. The stall, as defined by the T-38 Flight Manual and ATCM 51-38, is characterized by airframe buffet and high sink rate rather than by a clean nose down pitch motion. The actual stall is normally not accompanied by any abrupt aircraft attitude change, but only by a very high sink rate. The stall condition is immediately preceded by a heavy low-speed buffet and wing rock.

Using these parameters for identifying the stall, the Bendix angle of attack satisfactorily identifies the stall at 1.0 on the indicator. The approach to stall area between 0.9 and 1.0 on the indicator corresponds with the definition of the pre-stall condition; however, aerodynamic buffet is detected prior to the .9 indication. Since the stall curve is rather nebulous and difficult to define precisely, it appears that .8 on the angle of attack indicator would define the approach to stall point better than .9. There is good aerodynamic buffet in all flap configurations at .8 angle of attack indicated.

2. Landing Patterns: In early T-38 flight testing a safe approach speed for a normal full flap approach was determined to be approximately $1.2_{V_{stall}}$. This speed provided a safe margin above the stall (approximately 30 Kts at the 155 KIAS basic approach speed) and provided adequate handling characteristics and downward cockpit visibility angles necessary to land the aircraft. The no-flap approach speed was established at $1.16_{V_{stall}}$. The Bendix angle of attack system was designed to command a $1.2_{V_{stall}}$ for all approaches regardless of flap setting.

During the study it was noted that the angle of attack system indicated "on-speed" for full-flap approaches at normal approach speeds, but commanded a much higher approach speed than normal for a no-flap approach. The stall speed charts in the T-38 Flight Manual reveal that with 45° of bank during the final turn and holding the recommended final turn airspeed (175 Kt basic plus 10 Kts for no-flap plus fuel), the aircraft is actually flying at $1.10V_{stall}$. On final approach, wings level, the approach speed is $1.16V_{stall}$. It was common to see the angle of attack command final turn airspeeds as much as 30 knots above normal--particularly if the no-flap pattern were flown tight, but still within bank angle limitations of 45° during the final turn.

Further research revealed that present recommended no-flap touchdown speeds are actually 2 knots below the stalling speed with 1000 pounds fuel remaining. This explains why many pilots are unwilling (or unable) to hold the aircraft off during the flare and landing to get to the recommended no-flap touchdown airspeed (Ref Figure 8). It is recognized that stall speed is affected by ground effect; however, landing at the recommended handbook touchdown speed leaves no margin for error which is very critical in the event of gusts, jet wash, high flare, etc.

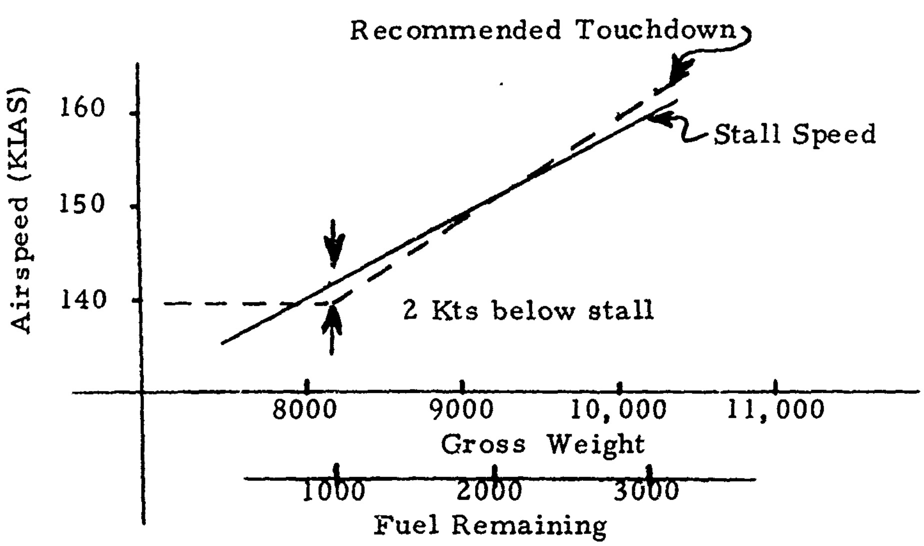


Figure 8. No Flap Recommended Touchdown Speeds vs Stall Speeds

The Bendix angle of attack system has an apparent error in the no-flap compensation. Angle of attack commanded no-flap approach speeds were consistently high throughout the study. While some of the higher than normal no-flap final approach speeds can be accounted for by the discrepancy between the flight manual $1.16_{V_{stall}}$ final approach speed and the design $1.2_{V_{stall}}$ angle of attack approach speed, there were still some cases of unaccountable excess airspeed (Ref Figure 9).

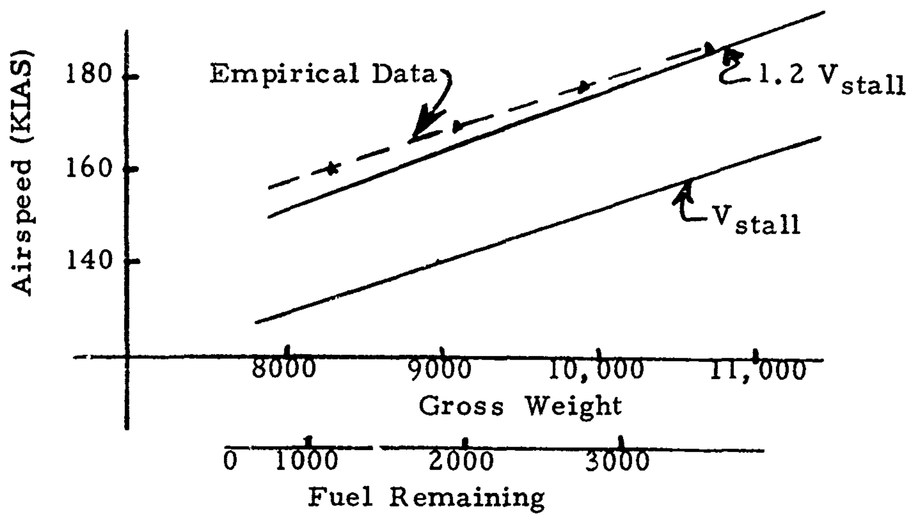


Figure 9. No Flap Approach T-38 SN 1549

The no-flap angle of attack on-speed indication commands an airspeed that is approximately 10 knots higher than the recommended handbook no-flap approach speed and 5 knots higher than $1.2_{V_{stall}}$. It was extremely difficult to dissipate this extra airspeed and achieve the recommended no-flap touchdown speed. In an attempt to achieve recommended touchdown speeds, subject pilots were reducing the throttle to idle prior to the overrun. This was far outside the normal ground effect and resulted in a very high sink rate and necessitated rapid pitch and power increases to preclude touchdown in the overrun.

It is recommended that the AOA system be adjusted to command $1.2_{V_{stall}}$ for all approach configurations and recommended flight manual no-flap touchdown airspeed be increased 5 knots for all weights. The flight manual no-flap approach speed should be increased 5 Kts to give a $1.2_{V_{stall}}$ final approach and final turn.

3. Maximum Range: Max range is a function of both engine and aircraft performance characteristics and varies depending on the altitude (air density). To maintain a constant angle of attack for max range the indicated mach number must be increased for higher gross weights. As fuel is used, the indicated mach number (IMN) must be reduced to keep the same indicated angle of attack for max cruise control.

Cruise control tests were conducted at various altitudes to verify the max range indication of .18 on the AOA indicator. The aircraft was trimmed and stabilized for hands-off flight at .18 indicated AOA and the resultant IMN and fuel on board recorded (Figure 10). The observed data indicates that the max range index is usable in the 35,000' to 40,000 feet range (Figure 11).

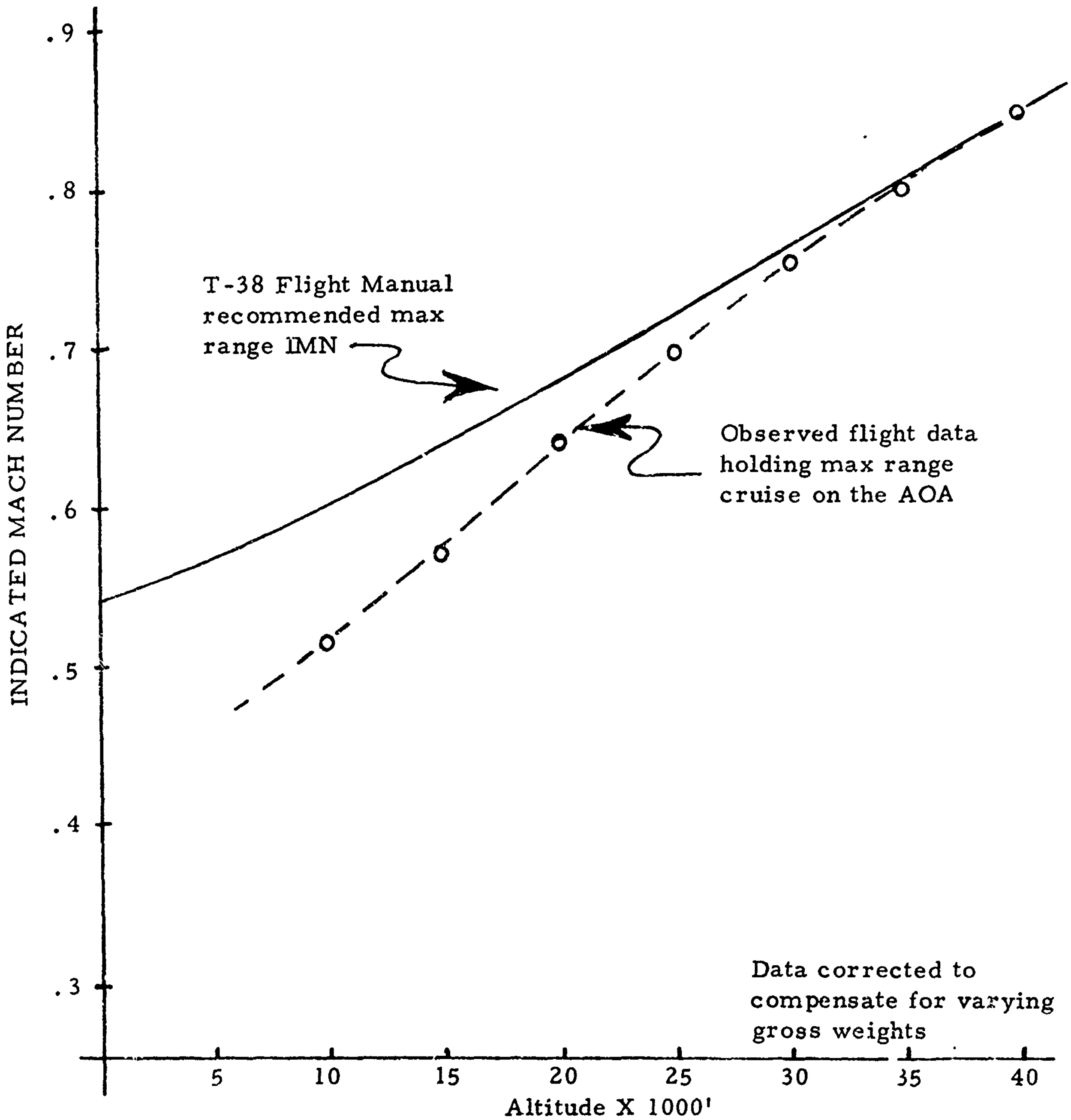
At altitudes above 40,000 feet the recommended max range IMN approaches .9 and the AOA becomes increasingly less reliable because of lack of mach compensation. At lower altitudes there is a continually increasing divergence between IMN while maintaining max range AOA indications and the IMN recommended in the T-38 Flight Manual. For example, at altitudes below 35,000 feet the AOA commands an IMN that is less than optimum. At 20,000 feet max range AOA is .65 IMN vs the Flight Manual .68 IMN. At the lower altitudes IMN commanded by the AOA could be used as a "point-to-go-to" until optimum diversion cruise speeds could be determined from the Flight Crew Checklist.

4. Max L/D: Several evaluations of Max L/D were conducted at various altitudes and gross weights. Aircraft was trimmed hands off at the recommended AOA indication of .3 and the airspeed and fuel weight recorded. Close correlation of Max L/D and T-38 Flight Manual airspeed was observed in both loiter and simulated flamed out conditions.

5. High Speed Flight: The high-speed, low-angle-of-attack condition is not adequately defined. As airspeed increases above .9 IMN the angle of attack becomes increasingly unreliable. At .93 IMN the AOA indicator was observed at .0, implying the aircraft was using none of the available angle of attack. This condition was expected of this AOA system because it is not mach compensated.

Pres Alt	Gross Wgt	Recommended Flt Man IMN	Indicated AOA	IMN with Aircraft at Recommended AOA	Date
SL		.54			
5M	1900	.56		.47	7-9 Jan 72
8	2150		.18	.50	7 Oct 71
10	2050		.13	.52	7-9 Jan 72
	3100	.60	.18	.53	7 Oct 71
15	2100	.64	.14	.58	7-9 Jan 72
20	2300		.16	.65	7-9 Jan 72
	2200	.68	.15	.64	7-9 Jan 72
25	2950		.16	.70	7-9 Jan 72
	2390	.73	.20	.70	7-9 Jan 72
26	2820		.18	.70	
30	2725		.18	.77	7-9 Jan 72
	2400	.77	.17	.76	7-9 Jan 72
33	2660		.18	.79	
35	2400		.18	.81	7-9 Jan 72
	2700	.81	.17	.80	7-9 Jan 72
	2400		.18	.81	7 Oct 71
40		.85			
41	2600		.18	.87	7 Oct 71
43	2400		.18	.90	7 Oct 71
45		.87			

Figure 10. Max Range Inflight Data
7 Oct 71 and 7-9 Jan 72



MAXIMUM RANGE AOA DATA
T-38 1549
7 October 1971/7-9 January 1972
Figure 11

6. Reliability: Reliability of the Bendix AOA system could not be determined accurately during the test for two reasons: (1) The AOA computer used during the first part of the evaluation was a prototype computer and not a production model. The prototype computer began experiencing intermittent failure after 27 sorties and 43.6 hours of evaluation. The first failures were of short duration occurring while taxiing out or shortly after takeoff. These intermittent failures gradually became more frequent and lasted for longer periods. After replacing the computer with a production model no further failures were observed. (2) The period of evaluation is considered too short to be an indication of reliability.

There is some question as to the reliability of the AOA system's self-test feature. Several times the OFF flag appeared on the AOA indicator, but never did the system indicate any malfunctions on the indexer by illuminating all three lights. Also, it was observed that an OFF flag would be observed in one cockpit and not the other. Replacing these individual components did not correct the malfunction. Only after the AOA computer was replaced did the AOA system operate properly.

All of the pilots felt the AOA system was very flyable; however, system reversal was observed during the pre-experimental phase of the evaluation. If the aircraft is abruptly loaded up in a tight turn, the ACA indicator momentarily lags or reverses. This is not a problem while performing normal flight maneuvers.

7. AOA Transmitter Vane: The T-38 has had a history of engine flameouts at high altitude while changing throttle positions and/or angle of attack. During one orientation-demonstration flight a flameout was experienced at 35,000 feet gear down, 0° flaps and 175 KIAS in stabilized, level flight. The airstart was successful and a thorough maintenance check and engine teardown could disclose no reason for flameout.

It is felt that this situation may have been aggravated by the location and type of AOA sensor installed. Further evaluation should be conducted comparing the slotted conical probe with the vane type AOA sensor and its effect on disrupting airflow in front of the engine at high angles of attack at high altitude.

It may be possible to use wind tunnel smoke tests to determine if airflow disruption around a vane is more severe than around a probe. Considering past flameout history it appears advisable to explore this area further to determine if AOA is going to aggravate the problem.

System dampening during gusty landing conditions could not be adequately evaluated during the test period. There was only one day of extremely gusty crosswind conditions and the subject pilots that day felt the system to be at least as flyable or more so than using airspeed. Flying a slightly fast indication (slightly low AOA) would provide adequate airspeed compensation for an 8-12 knot gust.

C. SYSTEM APPLICATION/RESTRICTION.

Requestors of this study were primarily concerned with AOA application in the traffic pattern and landing phases. Experience during the evaluation indicated that AOA will be beneficial in numerous other areas. Subject pilots' confidence throughout the flight profile increased as they gained understanding of the AOA system. It must be emphasized, however, that angle of attack is not a panacea and blind application to certain maneuvers could have undesirable effects. The following comments relate to applicability of AOA during various phases of flight:

1. Stalls -- The Bendix AOA system accurately relates aerodynamic performance of the wing. It provides the pilot with a visual means of determining how close his aircraft is to stalling. This is vastly superior to the present pilot "feel" system as was graphically discovered during this evaluation. Subject instructor pilots were requested to demonstrate a traffic pattern stall series as they normally would with a student. Recovery was to be initiated at the onset of "increased buffet" as is currently taught. No reference to AOA was to be used. Repeatedly, highly qualified instructors initiated the recovery at .7 to .75 indicated AOA, using only the increase in buffet as an indication of the approaching stall. These same individuals would then execute final turns in the traffic pattern with up to .75 indicated AOA and rationalize the resulting buffet as a normal condition in T-38 traffic patterns. The significance is the total lack of learning transfer between the traffic pattern stall series at altitude and the maneuver it is intended to simulate. The anomolism becomes immediately evident with AOA equipment which would provide an invaluable aid in teaching stall recoveries and preventing traffic pattern stalls.

2. Final turn/final approach -- The Bendix AOA system

presents a significant additional parameter for controlling an aircraft during the final turn and approach. It accurately displays aircraft performance in relation to the aerodynamic stall and therefore has two immediate applications. Most critically, it will immediately aid in preventing the situation encountered with a miscomputed final turn airspeed or neglected flap extension. Although the cause of this "rather frequent" type of accident can only be surmised, an "on-speed" AOA indication would maintain safe flying speed. Again, it is necessary to emphasize that AOA is not a panacea -- the pilot must still control the flight path of the aircraft. A second major advantage is the ability to begin slowing to final approach airspeed during the rollout onto final. Because AOA accurately displays aircraft performance, power reduction may be safely initiated during the rollout on final, due to the fact that bank angle, and therefore lift requirements, decreases. This permits an earlier, smoother transition to final approach airspeed and encourages better throttle technique.

3. Cruise control -- AOA proved to be of only limited value for cruise control. Without mach compensation the maximum range index is optimized for a maximum range cruise altitude of 35,000' to 40,000'. At other altitudes, significant errors were encountered. This, coupled with the fact that at high indicated mach numbers (.93 IMN and above) the AOA indicator falsely presents a zero reading dictates that airspeed/mach are more satisfactory cruise parameters.

4. Best glide or loiter -- The max L/D index accurately defined the max L/D angle of attack. This provides a rapid means of establishing best glide speed in the event of two engine flameout provided engine windmilling RPM is sufficient to maintain A/C generator operation. The index also provides the pilot with his most efficient loiter speed. This speed has to be determined during wings level flight and the indicated airspeed maintained during turns to preclude large throttle movement that would be required if the pilot attempted to maintain the specific AOA as illustrated in the following equation:

$$L = 1/2 \rho V S C_L$$

Increase lift in turn — Velocity must increase — Constants

5. Aerobatics -- AOA is of only limited value during aerobatic maneuvers. Presently, specific "G" values are used for over-the-top maneuvers. The on-speed indication could be used to maintain

a $1.2V_{stall}$ airspeed during the latter portion of these maneuvers; however, extreme caution must be exercised. If the aircraft were pulled "into the green" at higher airspeeds, an overstress could result. At lower airspeeds, the on-speed indication does not yield maximum turn performance. For example, maintaining an on-speed AOA during Split-S maneuvers resulted in greater altitude loss than a Split-S without AOA. In view of these factors, it is recommended that AOA not be used as a control parameter during aerobatic flight except for stall warning and recovery.

6. Takeoff/go-around -- The Bendix AOA system was found to be of only limited value during the takeoff or go-around maneuvers. The on-speed indication is set for $1.2V_{stall}$. The T-38 takes off fully fueled at 155 KIAS which is well below the $1.2V_{stall}$ speed of 178 KIAS. If the on-speed is maintained, once the aircraft accelerates to $1.2V_{stall}$, an excessively steep pitch attitude results. The go-around condition is similar. AOA does provide the pilot with aerodynamic performance during these phases of flight and presents an excellent stall warning cue. However, it should not be used as a control parameter.

7. Alternate application -- The Bendix angle of attack system will provide a usable indication of speed for the recovery of an aircraft in the event of pitot static system failure.

D. OPERATOR TECHNIQUES.

As has been mentioned, the need for angle of attack equipment has been realized and discussed since the days of the Wright brothers. For almost as long, methods of using angle of attack have occurred with frequent confusion existing between the two separate subjects of "when to use angle of attack" and when using angle of attack, "how to use it." This study indicated that the Bendix angle of attack system would be of great value during stall and stall recovery training and during portions of traffic pattern instruction. It would be of limited value to the Air Training Command for navigation cruise control, aerobatics, best glide/loiter flight, and during takeoff or go-around maneuvers. The system would also provide an alternate for the airspeed indicator in the event of a malfunction of this instrument or system.

The "how to use" question becomes rather complex and has been clouded with a great amount of rhetoric and debate. Two factors should be considered in deciding upon a proper control technique relating to angle of attack; lifting force demanded from the wing and lift available. Essentially this means that both elevator force and airspeed have an effect on indicated AOA and both are used to control it, depending upon the particular set of circumstances. The most immediate and direct effect upon AOA can be obtained through use of the elevator. It must be remembered that if maintaining a given AOA were the only task of the pilot, the stick (elevator) would be the only logical choice of control. However, this is not the case because controlling the aircraft through a prescribed flight profile while maintaining a sufficient margin of safety involves numerous complex tasks. Subject pilot responses indicate that use and control of AOA is dependent upon the existing circumstances. To illustrate this relationship, various maneuvers will be discussed and the interaction of AOA, airspeed and elevator force discussed.

1. Navigation cruise control: The preferred parameter for obtaining optimum cruise control is mach number or airspeed. Although, in theory, optimum thrust drag relationships will occur at a specific AOA, at cruise airspeeds AOA is too coarse a parameter on the Bendix display. A very small change in AOA corresponds to large airspeed changes. The maximum range index will provide a quick reference of "place to start" while consulting the checklist for optimum cruise control in the event of an emergency divert. In this event, normal control-performance techniques apply, i.e., maintain altitude with pitch (elevator control) and AOA (airspeed) with power. Pilots reported that attempting to control AOA with pitch and altitude with power, during the cruise realm, resulted in an almost constant ocsillation in altitude and required continual power adjustment.

2. Aerobatics: AOA can be of value during aerobatic maneuvers as a performance indicator, not a control instrument. During most aerobatic maneuvers power setting is constant and therefore the only control input affecting AOA is elevator. Attempting to establish a set AOA at high speed could exceed structural limitations. Adjustments to this to prevent high speed overstress would result in less than optimum performance at low speed, as was indicated during Split "S" maneuvers. Using traditional aerobatic techniques, the AOA system will continuously display aircraft performance in relation to the stall and therefore help the pilot to avoid critical areas of flight.

3. Takeoff and Go-Around: AOA is of only limited value. Due to the excellent acceleration of the T-38, AOA rapidly decreases

through takeoff and into the high speed range. Attempting to maintain the on-speed indication would require a rapid pitch increase resulting in an excessively steep climb attitude. A similar situation exists during a go-around. During a single-engine go-around, power is fixed at maximum Attempting to obtain an on-speed indication by relaxing back-pressure would probably result in development of a sink rate. The primary benefit of AOA equipment during a go-around may be as a performance indicator reflecting the maximum angle of attack (or lift) available to the pilot.

4. Traffic Patterns and Landings: The Bendix angle of attack system finds its most fruitful application during the pattern and landing phase. To illustrate these applications, various portions of the traffic pattern will be discussed. It will be evident that emphasis will shift from "elevator" as the AOA control to "power" for control of AOA. On initial approach, conventional techniques of aircraft control apply with airspeed being the most significant parameter for traffic separation considerations. During the pitchout, "G" loading is increased to maintain altitude. The increase in "G" loading coupled with a decreasing airspeed will result in ever-increasing angles of attack. The pilot can use AOA information to insure that an adequate margin is maintained above the stalling angle of attack or the angle of attack where undesirable aircraft characteristics may be encountered (pitch up -- instability -- etc). If AOA approaches the maximum value for the particular aircraft, the pilot has two alternatives, increase airspeed and/or reduce "G" loading. Since it is usually necessary to decrease airspeed to below configuration speed, the logical choice is to reduce bank angle thereby reducing "G" requirement and thereby safely reducing AOA.

As the aircraft rolls out on downwind, airspeed decreases further. If the desired angle of attack is to be maintained (while holding altitude), thrust must be added. During the turn to final, angle of attack becomes a critical parameter. The pilot is controlling the aircraft ground track and rate of descent using a combination of elevator, aileron, rudder and throttle. During this phase, angle of attack may be controlled with either thrust or elevator forces, depending upon circumstances. If the aircraft is on the desired ground track but descending too rapidly, bank angle must be maintained to prevent overshooting final approach. In this instance, the nose of the aircraft must be raised using elevator force to slow the rate of descent and thrust added to maintain a safe AOA. If desired ground track or safe AOA cannot be maintained, angle of bank should be decreased and a go-around executed.

If the aircraft were undershooting final approach with a slightly high AOA indication, simply reducing bank angle and relaxing elevator pressure would result in desired flight path and AOA indication. It therefore becomes evident that a coordinated application of both elevator force and thrust is necessary to maintain control of the aircraft and to insure that the stalling AOA is not reached. If the desired flight path cannot be maintained using this technique, the pilot must execute a go-around. On final approach, aircraft flight path and AOA is controlled with a coordinated combination of elevator forces and power.

For instrument approaches, AOA can be used in a very similar fashion. Prior to final approach descent, the aircraft is configured for landing and slowed to desired final approach angle of attack. The airspeed, at this point, should correspond to computed final approach airspeed. Altitude is then maintained using elevator forces and angle of attack maintained with thrust. On final approach descent, establish and maintain the desired flight path and AOA with a coordinated combination of configuration, elevator forces and thrust.

NOTE: Because angle of attack is directly related to elevator forces, momentary deviations from desired AOA may occur during pitch changes or during turbulent conditions.

It is important to note that a large majority of the subject pilots felt increased confidence in their ability to control the aircraft properly using a combination of angle of attack and airspeed in both traffic patterns and max performance maneuvers. They were equally enthusiastic about using angle of attack for a wide range of other maneuvers that later proved unfeasible with the Bendix system. An example of this is using angle of attack for max range cruise control. The lack of mach compensation made angle of attack usable only at an optimum altitude of approximately 40,000 feet. At all other altitudes it was not accurate.

It must also be emphasized that the test aircraft was not instrumented adequately for meaningful objective data. Many times it was observed that subject pilots said they were controlling angle of attack one way when it appeared to the project pilot that just the opposite was occurring. A flight recorder with capabilities of measuring pilot control inputs and aircraft outputs is mandatory for objective data but was not available for this study.

An angle of attack education program for pilots is necessary to insure rapid acceptance and proper use of the Bendix system. This program could entail both an individual checkout program conducted by ATC or local stan/eval groups and a film or slide presentation. Increased emphasis should be placed on angle of attack during formal courses of instruction such as Undergraduate Pilot Training and Pilot Instructor Training.

Additional uses of angle of attack will undoubtedly be discovered as the pilots obtain more familiarity with the system. Continuing studies of the system should be conducted to realize optimum benefits from the system for both ATC and the Air Force.

X. CONCLUSIONS:

A. Subject pilots felt that the AOA indicator and indexer satisfactorily displayed usable angle of attack information to the pilot It was determined that a system displaying AOA as a percent of lift available was more meaningful to pilots than the Bendix system displaying AOA as a percent of the available angle of attack or other systems using non-meaning terms such as "units."

B. The Bendix AOA system accurately depicts the area of stall below 20,000 feet maximum L/D and the optimum approach angle of attack for full flap, normal approaches. The maximum range index is satisfactory for cruise at altitudes 35,000' to 40,000 feet.

C. An on-speed AOA indication in the no-flap configuration commands an approach speed equivalent to $1.23V_{stall}$ (approximately 5 Kts above the $1.20V_{stall}$ design speed).

D. Present Flight Manual recommended no-flap approach and touchdown speeds are too slow.

E. The Bendix AOA system provides a satisfactory assessment of angle of attack and aircraft performance relative to the stalling angle of attack at altitudes below 20,000 feet and indicated mach numbers below 0.9. If properly monitored and used it will provide a safe margin above the stall for aircraft control in the traffic pattern and max performance maneuvers.

F. Max L/D (endurance) is accurate for a clean configuration.

G. The Bendix AOA system is very flyable and subject pilots had little difficulty in controlling the aircraft using AOA.

H. The vane angle of attack sensor may cause excessive airflow disruption in front of the right engine inlet at high altitudes and high angles of attack.

I. Angle of attack can be used to effect a safe recovery in event of airspeed indicator failure. For penetration from altitude .18 (max range) will closely approximate 280 KIAS in one G flight. Gear may be lowered at angle of attack indications above 0.4 in one G flight and the approach index will accurately provide final approach airspeed.

J. Reliability of the system could not be determined because a prototype AOA computer was used during the first part of the evaluation and the limited time the system was flown.

XI. RECOMMENDATIONS:

A. The approach to the stall warning range on the AOA indicator should be increased from 0.9-1.0 to 0.8-1.0.

B. The amber color coding denoting the approach to the stall area on the AOA indicator should be changed to a red and black hash mark to avoid confusing the present amber approach to stall (high AOA) color coding with the amber high speed chevron (low AOA) on the indexer light.

C. A light shield similar to the rear seat indexer or some sort of filtering device should be used to make the front seat indexer visible in all cockpit lighting conditions.

D. The no-flap compensation should be corrected to command $1.2V_{stall}$.

E. The T-38 Flight Manual no-flap approach and touchdown speeds should be increased 5 Kts to provide a $1.2V_{stall}$ approach speed and to permit the aircraft to touch down above the no-flap stall speed.

F. Angle of attack systems should display angle of attack in terms of percent of usable lift.

G. Angle of attack systems should be mach compensated so as to allow accurate depiction of angle of attack information throughout the entire aircraft performance envelope.

H. Further flight test evaluations should be conducted in the T-38 to determine the airflow patterns around the AOA vane sensor at high altitude and high angles of attack and its effect on engine operation. Studies should be made comparing vane vs conical probe in this and turbulent flight regions.

I. A training film on the uses, techniques and procedures of angle of attack should be made. Angle of attack training for instructor pilots should be commenced as soon as aircraft equipped with angle of attack become available at each base. Pilots must be made aware that AOA is not a panacea for poor aircraft control but a superior way of displaying aircraft performance to the pilot when compared to placing sometimes erroneous minimum airspeeds and bank limitations on him.

J. A continuing study of angle of attack should be conducted to establish other uses of angle of attack such as single-engine go-arounds, etc, and to provide pilots with state-of-the-art angle of attack information.

K. Angle of attack symbology should be standardized for all Air Force aircraft.

L. Amber high speed chevron should not illuminate with gear up until approaching an on-speed angle of attack. This would provide usable AOA trend information.

M. A Mean Time Before Failure study should be conducted to determine Bendix AOA system reliability and improve overall system reliability.

SUMMARY OF QUESTIONNAIRES

Angle of Attack Training for ATC (TR&D 71-3)
Part I

1. Total flying time as a pilot (approx)
Aircraft types flown:

Subj #	
1	2100 -- T-41, T-37, T-38, A-1
2	1500 -- T-41, T-37, T-38
3	1900 -- T-38
4	1875 -- T-41, T-37, T-38
5	2000 -- T-41, T-37, T-38
6	4100 -- B-50, T-37, F-4
7	2900 -- T-37, T-33, T-38, T-39, F-104, F-4, C/D/E
8	5100 -- T-33, T-37, T-38, '-39, F-100, O-1
9	2950 -- T-37, T-38, T-39. F-4
10	2300 -- B-52, F-100, T-38
11	1500 -- T-41, T-37, T-38, F-100
12	3200 -- T-37, T-38, F-4D

2. Total Instructor Pilot Time:

Subj #	
1	1000 hours
2	1200 hours
3	1500 hours
4	1500 hours
5	1600 hours
6	1125 hours
7	1900 hours
8	3800 hours
9	1800 hours
10	200 hours
11.	800 hours
12	2350 hours

3. Have you flown angle of attack equipped aircraft before? If so, please list the type aircraft and flying time.

Subj #	
1	No Except 1.0 F-4, 1.0 F-105
2	No
3	No
4	No
5	No

3. (Continued)

Subj #

6	Yes, RF-4C, 400 hours
7	Yes, F-4 C/D/E 750 HRS
8	No
9	Yes, F-4, 450 hours
10	No
11	No
12	Yes

4. How well do you feel you understood angle of attack prior to flying it?

   a. Good -- Subjects 4, 6, 7, 9, 12

   b. Fair -- Subjects 1, 5, 8, 10

   c. Poor -- Subjects 2, 3, 11

5. How well do you feel you understand angle of attack now?

   a. Good -- Subjects 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12

   b. Fair -- Subject 11

   c. Poor -- None

6. Do you feel more confident, less confident or about the same when using a combination of angle of attack and airspeed for the following maneuvers?

a. Turn to final

	More	Less	Same
Subj # 1	X		
2			X
3	X		
4			X
5			X
6	X		
7	X		
8			X
9	X		
10	X		
11			
12	X		

b. Final approach

	More	Less	Same
Subj # 1	X		
2	X		
3	X		
4	X		
5	X		
6	X		
7	X		
8	X		
9	X		
10	X		
11			
12	X		

c. Stall Prevention

	More	Less	Same
Subj # 1	X		
2	X		
3	X		
4	X		
5	X		
6	X		
7			X
8	X		

6.c. (Continued)

	More	Less	Same
Subj # 9	X		
10	X		
11			
12	X		

d. Vertical Recovery

	More	Less	Same
Subj # 1	X		
2	X		
3	X		
4	X		
5	X		
6	X		
7			X
8			X
9	X		
10	X		
11			
12	X		

e. Unusual attitude recovery

	More	Less	Same
Subj # 1	X		
2	X		
3	X		
4			X
5			X
6	X		
7			X
8			X
9	X		
10			X
11			
12	X		

7. Indicate which parameter you feel is the more meaningful for each of the following:

		Angle of Attack	Airspeed
a.	Turn to final	Subj # 3, 5, 6, 7, 9, 10, 11, 12	1, 2, 4, 8
b.	Final approach	Subj # 1, 3, 5, 6, 7, 8, 9, 11, 12	2, 3, 10, 4
	(Comment by Subj 3 -- Possibly for a no-flap, checks airspeed.)		
c.	Stall prevention	Subj # 1 through 12	
d.	Flare to touchdown	Subj # 2, 7, 11, 12	1, 3, 6, 8, 9, 10
	(Comments: Subj 4 and 5--neither)		
e.	Single engine takeoff/ go-around	Subj # 2, 3, 11, 12	1, 4, 5, 6, 7, 8, 9, 10
f.	Holding patterns	Subj # 1, 5, 9	2, 3, 4, 6, 7, 8, 10, 11, 12
	(Comments: Subj 3. Because of turns.)		
g.	Max angle climbs	Subj # 1, 3, 4, 5, 6, 8, 10, 11, 12	2, 7, 9
*h.	Minimum roll landing	Subj # 2, 3, 4, 5, 6, 9 11, 12	1, 7, 10
i.	Max range cruise	Subj # 1 through 12	
j.	Max endurance	Subj # 1 through 12	
k.	Stall recovery	Subj # 1, 2, 3, 4, 5, 6, 8, 9, 10, 11, 12	7
*l.	Acceleration (as loiter to max speed)	Subj # 5, 9, 10, 11, 12	1, 2, 3, 4, 6, 7

* Subject #8 no answer

7. (Continued)

		Angle of Attack	Airspeed
*m.	Avoidance of undesirable flight characteristics (pitch-up, etc)	Subj # 1, 2, 3, 4, 9, 11, 12	5, 6, 7, 10
	(Comment: Subj 5 -- Lag.)		
n.	Max range glide	Subj # 1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12	2
o.	Takeoff	Subj #12	1, 2, 3, 4. 5, 6, 7, 8, 9, 10, 11
p.	Single engine climb/ cruise	Subj # 1, 2, 3, 4, 5, 9, 10, 11, 12	6, 7, 8
q.	Diversion cruise	Subj # 1 through 12	

* Subject #8 no answer

8. Can you think of other maneuvers in which angle of attack might be of assistance? How?

Subj #

1 All instrument approaches, extended trail.

2 Traffic pattern stall series, full aft stick stall and slow flight. In the pilot training situations the α system will be much less vague than "increased buffet etc." and will show exactly when the aircraft approaches to and finally does stall. These areas are now open for a great deal of personal interpretation -- such as when to initiate a stall recovery. General maneuvering -- improve and extend the envelope such as during formation trail work.

8. (Continued)

Subj #

3 Pitchouts -- 6 units works well for a normal pitchout
Closed patterns -- 6 units makes a nice tight closed
Emergency procedure -- for loss of airspeed indicator
Contact maneuvers -- slow flight, Split-S, etc.

4 High Speed Dive -- would provide a definite angle of attack for recovery with minimum loss of altitude but without getting an accelerated stall.
Chandelle -- provide guidance on how hard to pull for max performance.

5 Demonstration of max performance "G", i.e., Split-S, high speed dive.

6 Aerobatics: by computing best α for min. radius of turn.

7 Yes, ACM maneuvering requiring maximum performance of aircraft. Compensator to show max performance turn and "G" to allow pilot to keep his head out of cockpit.

8 No.

9 Optimum turn capability, out of control recovery.

10 None at the moment.

11 Chandelle -- max performance, trail, closed pattern, Split-S.

12 Any maneuver which requires you to maneuver the aircraft in a slow airspeed, max performance environment, Split-S, clover leaf, Chandelle, pitchout for landing, trail maneuvering, pulling up for closed--especially heavy weight.

9. What advantages do you feel angle of attack offers over airspeed in the traffic pattern?

Subj #

1 Shows, without lag, exactly how much lift is available over what is presently being used. Shows excellent bank to airspeed relationship. Compensates for fuel load.

2 Shows that the aircraft can stall during the final turn even though on final turn airspeed by measuring bank angle and load factor. It also shows the exact stall margin for any deviation from the desired airspeed, particularly useful for slightly low airspeeds from computed final turn and approach airspeeds on no-flap patterns. Most useful however during flare and touchdown.

3 Tells you exactly how much more of the aircraft you can bank and yank. Sensitivity of the gauge was smoother when flying patterns in turbulence. Somewhat more heads-up than airspeed. A more accurate aerodynamic input during closed patterns and pitchouts.

4 It provides a visual indication of your stall margin on final. This is particularly useful on no-flap and min run finals. The color code head-up display eliminates cross-check inside the cockpit on final.

5 Automatically compensates for fuel weight and bank angle.

6 Safety primarily. The aircraft will stall at α stall regardless of airspeed and G loading.

7 Serves as an additional reference for determining best final approach and turn speeds. Primary advantage is to give pilot an immediate indication of a desired correction on final or in the turn. Allows pilot to concentrate on outside references by referring to indexer lights.

8 On final approach the red chevron stimulates a reaction more than just airspeed.

9. (Continued)

Subj #

9 Simplifies computation, constant reference to some optimum performance (limit how tight you attempt to turn).

10. Mainly, the ability to spend more time "outside the cockpit" and use visual cues to a greater extent.

111 Something that seems more positive in indicating a stall than A/S -- you have the indication as well as the indexer which seems to sink in more when you see them.

12 Angle of attack indications offer a very precise way of telling what the airplane is doing besides just the "feel" of the airplane.

10. During final turn and final approach, what percent of the time did you devote to:

a. Airspeed indicator:

Subj #		
1	60%	
2	45%	
3	0%	Only as an occasional cross-check of the system.
4	80%	Final turn, 40% final approach
5	5%	
6	40%	
7	20%	
8	10%	
9	20%	

10. a. (Continued)

Subj #	
10	50%
11	15%
12	10%

b. Panel angle of attack indicator

Subj #		
1	20%	
2	45%	
3	80%	
4	15%	Final turn, 5% Final approach
5	5%	
6	40%	
7	20%	
8	0%	
9	40%	
10	20%	
11	40%	
12	40%	

10. (Continued)

c. Head-Up Angle of Attack Indicator

Subj #		
1	20%	
2	45%	
3	0%	
4	5%	Final turn, 55% Final approach
5	20%	
6	20%	
7	60%	
8	15%	
9	40%	
10	30%	
11	45%	
12	50%	

Subject 4: This question is difficult to answer because of the nature of the rides. Patterns were flown on airspeed while studying AOA or on AOA while seeing what airspeed it gave. My response is my best guess at a normal pattern.

11. Could you observe the head-up angle of attack indicator without removing your eyes from the runway?

a. Turn to final

Subj #	YES	NO
1		X
2		X
3		X (Only the last part of the turn)
4	X	
5	X	
6	X	
7	X Could suggest moving indexers to side of glare shield rather than center.	
8		X
9		X
10		X
11		X
12		X

b. Final approach

Subj #	YES	NO
1	X	
2		X
3	X	
4	X	
5	X	
6	X	
7	X	
8	X	
9	X	
10	X	
11	X	
12	X	

12. What difficulties, if any, did you experience in using angle of attack or integrating angle of attack and airspeed?

Subj #

1 At first there is a definite tendency to disregard the basic pattern and ground track to concentrate on the AOA.

2 It was mostly a matter of difficulty in adapting to a different cross-check to include the angle of attack as well as airspeed and also a little extra time at first trying to determine exactly what a given angle of attack actually meant, and what to do about it. This difficulty I feel was due mainly to old habits and should not present much of a problem to someone learning the patterns in the first place with no habit pattern cross-check yet developed.

3 At first I misinterpreted the direction of the AOA needle and would pull up when the needle went up as if following a pitch steering bar. After first ride -- no problem.

4 The margin given for slightly high or low is too small. The Head-Up display could not be seen from under the hood.

5 Understanding the chevrons initially.

6 AOA system in this installation appears to be sluggish at times, i.e., too large a range for on-speed indications.

7 AOA gives an immediate trend but one can't determine the magnitude or rate of trend without cross-checking α and confirming with A/S.

8 None

9 AOA panel indicator is too far from the ADI. Recommend swapping AOA and standby attitude.

10 Just the normal problem of understanding how the system worked initially -- figuring out exactly what the indications meant.

12. (Continued)

Subj #

11 My biggest problem was looking through the indexer. I tended to fix on it at times and lose perspective of the RW. I had most luck using the indicator perhaps because I'm used to flying A/S and the indicator is very similar.

12 The only difficulty that I had was due to the placement of the gauge in relation to the rest of the instruments. In my opinion it would be better placed where the present "G" meter is and place the "G" meter where the present clock is.

13. What part of the VFR traffic pattern did you find angle of attack to be the most useful? Least useful?

Subj #

1 Most useful in final approach -- least useful in takeoff.

2 Most useful during final approach and touchdown -- least useful going around the pattern.

3 Most -- turn to final and final approach
Least -- flare and touchdown.

4 Final approach -- the only place where I found it <u>really</u> useful.

5 Final turn and final approach -- most; overhead and pitchout -- least.

6 Final turn, most and pitchout, least.

7 Final approach -- most, expecially straight-ins.
Final turn -- close second.

8 Final most useful; pitchout least useful.

9 Most -- Final turn, final approach, flare.
Least -- 280 knots around the pattern.

13. (Continued)

Subj #

10 Most useful in final turn; least useful in flare.

11 Final turn and final approach most along with max endurance and max range. Least useful to me in flare as it tended to distract me.

12 Turn to final and final approach most useful. Other areas useful to a lesser degree, but it would be very difficult to say what was least useful.

14. Did you control angle of attack with the throttle or elevator in

a. Turn to final:

Subj #	Throttle	Stick
1	X	X
2		X
3	X	X
4	70%	30%
5	X	
6		X
7	X	X
8		X
9		X
10	X	
11		X
12		X

Comment, Subj 7: Depends on AC flight path in relation to ground or runway.

14. (Continued):

b. Final approach?

Subj #	Throttle	Stick
1	X	X
2	X	
3	X	X
4	90%	10%
5	X	
6		X
7	X	X
8	X	
9		X
10	X	
11		X
12		X

c. Stall prevention:

Subj #	Throttle	Stick
1	X	X
2	X	
3	X	X
4		100%
5	X	
6		X
7	X	X
8	X	X
9		X
10	X	X
11		X
12		X

Comment, Subj 5: Stall prevention 30% throttle 70% stick.

15. Were your normal pitch/power techniques satisfactory for instrument work?

Subj #

1 Yes, if during glide slope I felt my rate of descent was proper, and AOA was showing fast or slow, I would adjust power. If AOA was off and VV was not as desired, I would return to ADI and adjust pitch.

2 Yes, Generally -- Throttle controls airspeed, low airspeed -- add power, high on glide path -- lower nose, pitch controls descent rate. During my IP experience with UPT students this method seemed the safest and easiest for them to comprehend and accomplish although not necessarily aerodynamically correct. Example -- it was difficult in some cases for the student to accurately determine the aircraft response from a given reduction in power and how this would change his descent rate or glide path as one example.

3 Yes, on successive patterns I let the sink rate develop and corrected one by increasing the AOA, and the second time by adding power and holding 6 units. By increasing AOA to 6.5 to 7 units the sink rate corrected quickly without too much buffet. When power was advanced and 6 units held, no increase in buffet was encountered but the correction was slower.

4 Yes, I find that in the pattern (VFR and IFR) I used the AOA very much like I used airspeed. I flew the airplane with the stick to put it where I want it and then fix AOA with power.

5 Yes.

6 Yes, treat the AOA like an airspeed indicator and make power changes accordingly.

7 Yes.

8 Yes, control performance.

9 Yes.

15. (Continued):

Subj #

10 Yes, I used the technique of making adjustments on the ADI then cross-check other instruments, including A/S and angle of attack, to see if power adjustments were required.

11 Yes, controlling angle of attack with stick and rate with A/S. In one ride, however, I did not become acquainted enough to develop any sound techniques.

12 Yes. In instructing and demonstrating maneuvers, accuracy is very important and in most cases, a constant airspeed is desired. So, with that in mind, my technique is to trim the airplane for the desired airspeed and through cross-checking the altimeter and VVI, determine whether a power change is required which will also necessitate a pitch change but not a trim change. This enables me to trim the aircraft not only in pitch, but also with power. This technique works very well with angle of attack by substituting AOA for airspeed.

16. Did angle of attack assist you in terms of controlling the glide path and touchdown point? Please explain.

Subj #

1 It was another AID in controlling glide path. It had no effect on touchdown point except to help keep a/c on glide path and airspeed.

2 Yes, particularly from back seat patterns on short final when minimum visibility straight ahead made it difficult to make immediate decisions and corrections to a deviation from glide slope and touchdown flares. Students learning the pattern experience this same difficulty in the front seat when they have the visibility but little experience.

3 Only once the glide path was established visually. If you always rolled out at the same altitude and distance, it could be used. However, with the AOA slowing you up as you roll out on final, it is much easier to establish a glide path.

16. (Continued):

Subj #

4 Did not help with glide slope/path. Proper AOA obviously does not (necessarily) give proper glide path or aim point. On a min run landing or no flap (small stall margin) it did help with touchdown point.

5 Not really. I put the aircraft where I wanted it then went after the angle of attack as appropriate.

6 Yes, by holding a constant on-speed indication and a constant rate of descent you insure a proper glide path and touchdown point.

7 No, AOA alone doesn't control either G/S or touchdown point, could fly optimum AOA and crash in any attitude. The pilot must still establish the desired flight path and then use AOA to maintain what you have established.

8 No.

9 Yes, I feel that it gave me more accurate control of my airspeed in the high AOA, high drag, low airspeed situation. Smaller throttle inputs required.

10 Not really. I establish an angle that would drive me in to the aim point and then used angle of attack to help control A/S not really to control the glide path.

11 Yes, it was easy to set the angle of attack and control the descent with A/S.

12 Yes, because in general, fewer and smaller pitch changes are required if you set the angle of attack first and then use enough power to get to the touchdown zone.

17. Do you feel you had (more), (less), (same) time to visually plan your approaches with the head-up angle of attack display?

Subj #

1 There was less time at first, until I became more familiar with the system.

2 Same. Probably would have more time after using the system a little more.

3 More. On final.

4 More. MORE!! The color code allows constant distant focus.

5 Initially -- less, but as I became more familiar with the equipment it looks less.

6 Same.

7 More -- allows pilot to pay more attention to outside reference.

8 More.

9 More.

10 More.

11 More. As I mentioned before; however, at first I tended to fix too much on display.

12 More.

18. Was the method of displaying angle of attack satisfactory?

Subj #

1 Yes.

2 Yes.

18. (Continued):

Subj #

3 Yes.

4 Yes, I would suggest a repeater of the head-up display vertically between the airspeed indicator and main ADI in the rear cockpit for use while flying approaches under the hood. I would also question somewhat the scale on the AOA indicator. I would rather see a scale from 0 to 1.0 where .0 is the maximum useful lift, i.e., the scale should be such that recovery from a stall series or actual stall should be made at 1.0 on the scale. As it is now 1.0 should be at .85 on the present scale.

5 Yes, might consider a blue chevron for fast indication instead of amber.

6 No, the front cockpit indexer lights should be shielded like the rear cockpit to eliminate the glare on the mounted indexer.

7 Yes, move indexer lights to one side of glare shield. Consider using two indexer lights one on each edge of glare shield as in F-4.

8 No.

9 No. The marks on the AOA indicator are too far apart -- too few. AOA can be flown much more precisely than to the closest 10%.

10 No. Head-up display needs a shield or higher lighting capacity. It was difficult to read with the sun shining directly on it.

11 Yes. None -- but I don't discount with more experience in it I would have recommendations.

12 No. My comment concerning placement of the gauge is contained in item #12. The gauge itself is fine, except for one thing, standardization in going from one aircraft to another is totally lacking throughout the USAF, and I question the advisability of making another non-standard contribution.

19. Was the location of the head-up display satisfactory?

Subj #

1 Yes.

2 Yes, in that I don't know where else it could be properly set up to be useful. It was a bit of a distraction in the front seat with it sticking up into your line of sight outside to the horizon.

3 Yes, during a late evening flight turning final into the sun, the head-up indexer was impossible to see through the windscreen. This was of course in the rear cockpit.

4 Yes.

5 Yes.

6 No answer.

7 Yes, see answer to 18. Minor problem visualizing indexer depending on sun glare.

8 No; for final yes, base turn no.

9 No. Two indexers are needed, one on either side of the glare shield. Present location requires a triangular cross-check during turn to final. At side of panel the cross-check would be closer to a straight line.

10 Yes.

11 Yes.

12 Yes.

20. Was the location of the instrument panel mounted display satisfactory?

Subj #

1 Yes.

2 Yes.

3 Yes.

4 Yes.

5 Yes.

6 No answer

7 Yes

8 Yes

9 No, should be closer to the ADI. Swap the AOA and standby attitude!

10 Yes

11 Yes

12 No. See item #12.

21. Was the sensitivity of the angle of attack pointer too sensitive, not sensitive enough, or about right?

Subj #

1 About right.

2 About right.

3 About right.

4 About right.

21. (Continued):

Subj #

5 About right, occasionally too slow.

6 Not sensitive enough on speed should be $^{-2}_{+4}$

7 About right.

8 About right.

9 About right.

10 About right.

11 About right.

12 Not sensitive enough. It seemed to lag more than is really necessary. However, the lag also contributes to slower changes if you want them to be more accurate.

22. Would you recommend that angle of attack be installed in the ATC T-38 fleet?

Subj #

1 Yes.

2 Yes, it can be an extremely useful tool. I hope that too many procedures and restrictions do not develop from its installation which would cause even more time spent "in the cockpit" in refence to instruments. This is already a recognized problem in the ATC training environment.

3 ASAP. I have been instructing in the T-38 for three years and feel that angle of attack is a much needed and valuable piece of aerodynamic information both for the instructor and student.

22. (Continued):

4 YES. It adds greatly to a student pilot's understanding of aerodynamics. (One of the more difficult courses to really understand in academics.) I'll take this space to list the rest of my recommendations:

I think a new student should be taught to fly the T-38 using airspeed only initially. AOA is much more meaningful when the airplane is handled properly, not by a T-37 student. So my first suggestion is to put an on/off switch on the system so it can be used when you want to use it, but have the ability to turn it off to avoid confusion initially.

I really liked the opportunity to fly AOA while the airspeed was covered. A device should be mass produced for use in this way. (in advanced phases of training).

5 Yes, only change would be a shroud to cover F/C/P indicator also.

6 Definitely! Let's start teaching and using the basic fundamentals of aircraft flight, i.e., angle of attack and its influence on aircraft performance.

7 Yes and no. AOA should only be taught as an aid to maintaining the desired lift relationship while maneuvering. It provides excellent trend information and can be an excellent aid in the traffic pattern if used properly. The pilot must learn that simply flying an "on-speed" indication will not insure him of landing at a desired aim point. The pilot still has to establish his desired flight path and then use pitch and power as required to maintain the necessary AOA.

8 Yes, for two reasons -- indoctrination in angle of attack and final approach.

9 YES!!

10 Yes.

11 A conditional yes. I don't feel in 3 rides qualified to make such a recommendation. The rides give you mixed feelings

22. Subj #11 (continued):

in that you're not sure if the fact that you were becoming more confident in flying the angle of attack tended to make you feel it is a good system.

12 Yes.

SUMMARY OF QUESTIONNAIRES

Angle of Attack Training for ATC (TR&D 71-3)
Part II

NOTE: Questions 1-4 pertain to personal data of Part I.

5. Panel Mounted Instrument Evaluation.

a. Is dial size adequate?

Subj #	
1	Yes
2	Yes
3	Yes, ve-y easy to read
4	Yes
5	Yes
6	No
7	Yes
8	Yes
9	Yes
10	Yes
11	Yes
12	Yes

b. Is dial design (pointer moving against a fixed scale) compatible with information presented?

5. b. (Continued):

Subjects #1-12 -- Yes.

c. Comment on markings.

(1) Scaling

Subj #

1 OK.

2 OK.

3 Very good -- I like the onspeed reading at 3 o'clock.

4 See Part I, question #18.

5 Good.

6 The scaling is irrelevant if the pilot can correlate the numbers.

7 OK.

8 Need a color coding from .6 to 1.0.

9 Too few marks.

10 OK.

11 Good

12 My only comment in this area is on standardization which is contained in Part I, #18.

(2) Number Size

Subj #

1 OK

5. c. (2) (continued):

Subj #

2 OK

3 Fine -- after a while you don't even look at the numbers.

4 OK.

5 Good.

6 Slightly longer.

7 OK.

8 No answer.

9 Too big.

10 OK.

11 Good.

12 No answer.

(3) Pointer Size

1 OK.

2 OK.

3 Good.

4 OK.

5 Check.

6 Slightly longer.

7 OK.

8 No answer.

5. c. (3) (continued):

Subj #

9 OK.

10 OK.

11 Good

12 NA

(4) Indices Configuration

1 OK.

2 OK.

3 Good -- possibly close the gap between 0 and 1.1 to give more space and accuracy between digits.

4 I would add one more -- on second thought I would leave them the same but make the slightly high/low scale wider.

5 Check.

6 Slightly longer -- Should be standardized with all AOA systems in Air Force.

7 OK.

8 Need a color coding from .6 to 1.0.

9 Recommend mark every 5% or so.

10 OK.

11 Good.

12 NA.

5. (Continued):

d. Is instrument location in the panel satisfactory?

Subj #

1 Yes.

2 Yes -- Should definitely be readily comparable to air-speed indicator in a cross-check.

3 Yes -- It would probably be difficult to enlarge the dial without major modification to the instrument panel, but it is rather small.

4 Yes.

5 Yes.

6 Yes.

7 Yes.

8 No -- Angle of attack and airspeed should be displayed on the same instrument.

9 No, closer to ADI, where standby attitude is now would be my recommendation.

10 Yes.

11 Yes.

12 No.

e. Is the 0 to 100% concept of display meaningful to you?

Subj #

1 Yes.

2 Yes -- That method seems to assess aircraft position and performance very clearly.

5. e. (Continued):

Subj #

3 Yes -- The 0 to 100% is by far the easiest to read at a glance. The exact relationship to a stall is known without interpretation.

4 Yes.

5 Yes.

6 Yes.

7 Yes, if I can equate .60 AOA.

8 No, get away from decimals.

9 Yes, it's no more meaningful than any other system. Just something to gauge corrections by.

10 Yes, I interpret the percentages as amount of total lift available which is currently being used.

11 Yes.

12 Yes.

f. Would you prefer angle of attack displayed in units, degrees, percent of lift, or other?

Subj #

1 It makes no difference.

2 Percent of lift. Prefer the present setup but have no experience with other types.

3 Negative.

4 Percent of lift.

5 Percent of lift -- easier to relate to students.

5. f. (Continued):

Subj #

6 Percent of lift.

7 Percent of lift.

8 Units.

9 Units ! !

10 Percent of lift.

11 Percent of lift.

12 I like this one.

g. Is the direction of pointer movement compatible with data presented and in its relationship to other instruments, i.e., airspeed, altimeter, etc. ?

Subj #

1 Yes.

2 Yes, but in any case I think it is a question of just getting familiar with the system.

3 The relationship to the needle is good -- they both go the same direction. However, on the very first few patterns, I would use the needle as a pitch steering bar and pull up when it went up. It didn't take long to correct the error.

4 Yes.

5 Yes.

6 Yes, if taught properly.

7 Yes.

8 Yes.

5. g. (Continued):

Subj #

9 Yes.

10 Yes.

11 Yes.

12 Yes.

h. Could you suggest a better method of displaying angle of attack, i.e., vertical or horizontal scale, speed command, etc?

Subj #

1 No.

2 Might be easier to get a full understanding with an indicator where miniature aircraft rotates around a fixed scale with indices for α stall, best final and etc. This is essentially what we have with just a little different display.

3 Vertical tapes would be nice but probably expensive.

4 Part I, Question 18.

5 Only to shield F/C/P display.

6 None -- just keep it simple -- don't clutter it up with colors and numbers. Remember it is only an aid and used primarily in the pattern.

7 Having AOA displayed with the flight director components would be nice for low visibility approaches.

8 No.

9 I like the round dial.

5. h. (Continued):

Subj #

10 No.

11 No.

12 No.

i. Other comments:

Subjects 1-12 -- None.

6. Head-Up Instrument Evaluation (front cockpit):

a. Was the location satisfactory?

Subj #

1 Yes.

2 Yes.

3 Yes, very good.

4 Yes.

5 Yes.

6 Yes.

7 Yes, would prefer it offset to both sides.

8 No.

9 No.

10 Yes.

11 Yes.

12 Yes.

6. (Continued):

b. Was light/glare a problem?

<u>Subj #</u>

1 No.

2 No.

3 No.

4 No, only with sun shining in the shadow box.

5 Yes, with sun behind you.

6 Yes.

7 Yes, depending on sun.

8 Yes.

9 No.

10 Yes -- not in direct sunlight.

11 No, occasionally in the sun.

12 No.

c. Were the chevrons readily visible?

<u>Subj #</u>

1 Yes.

2 Yes.

3 Yes.

4 Yes.

5 Yes.

6. (Continued):

b. Was light/glare a problem?

Subj #

1 No.

2 No.

3 No.

4 No, only with sun shining in the shadow box.

5 Yes, with sun behind you.

6 Yes.

7 Yes, depending on sun.

8 Yes.

9 No.

10 Yes -- not in direct sunlight.

11 No, occasionally in the sun.

12 No.

c. Were the chevrons readily visible?

Subj #

1 Yes.

2 Yes.

3 Yes.

4 Yes.

5 Yes.

6. c. (Continued):

Subj #

6 No, because of glare.

7 Yes, except for sun glare.

8 Yes.

9 Yes.

10 No, not in direct sunlight

11 Yes.

12 Yes

d. Were the chevrons and on-speed symbols meaningful to you?

Subj #

1 Yes.

2 Yes.

3 Yes.

4 Yes, but took some time for adjustment to interpret them rapidly. Particularly the amber far too fast.

5 Yes.

6 Yes.

7 Yes.

8 Yes.

9 Yes.

10 Yes.

6. d. (Continued):

Subj #

11 Yes.

12 Yes.

e. State your preference with respect to the speed lights.

Subj #

1 Functional only with gear extended.

2 Functional regardless of gear position -- would like to see this

3 Functional only with gear extended.

4 Low speed chevron only functional with gear up.

5 Low speed chevron only functional with gear up.

6 High speed chevron only functional with gear down.

7 Functional regardless of gear position -- definitely!

8 No preference.

9 Functional regardless of gear position.

10 Functional regardless of gear position.

11 Functional regardless of gear position.

12 Functional regardless of gear position.

6. (Continued):

f. Did you use: pointer only, pointer and speed lights, speed lights only?

Subj #

1 Pointer and speed lights.

2 Pointer only -- Pointer and speed lights during final approach and touchdown mostly.

3 Pointer and speed lights -- comment in g.

4 Pointer and speed lights.

5 Pointer and speed lights.

6 Pointer and speed lights.

7 Pointer and speed lights.

8 Speed lights only.

9 Pointer and speed lights.

10 Pointer and speed lights.

11 Pointer and speed lights -- I tend to use pointer more though.

12 Pointer and speed lights.

g. Other comments:

Subj #

1 None.

2 None

6. g. (Continued):

Subj #

3 Front Cockpit:
Righthand pattern
Turn:
Pointer 80%
Lights 20%
Final:
Pointer 10%
Lights 90%
Lefthand pattern
Turn:
Pointer 100%

Difference in the turn to final is due to the cross-check from the runway to the AOA gauges.

Rear Cockpit:
Turn:
Pointer 80%
Lights 20%
Lefthand pattern
Turn:
Pointer 100%
Final: Lights 50%
Pointer 50%
From an IP standpoint student patterns aren't normally stable enough to watch the light or get trend information.

Possible problem areas: No gust factor considered -- possibly fly green over amber on gusty days. Difficult to get no-flap touchdown speed with the higher approach speeds -- practice may improve this area.

4 No comment.

5 No comment.

6 No comment.

7 Found AOA speed lights to be an excellent aid in the traffic on outside references and know if a change was required. Using AOA indications makes for a much more comfortable no-flap pattern.

8 The red chevron on final approach gives a more meaningful display to take some sort of action than just airspeed does.

9 No comment.

6. g. (Continued):

Subj #

10 No comments.

11 No comments.

12 No comments.

7. Rear Cockpit Indexer Evaluation:

a. Was the location satisfactory?

Subj #

1 Yes.

2 Yes.

3 No -- comment below.

4 Yes.

5 Yes.

6 Yes.

7 No.

8 Yes.

9 No.

10 Yes.

11 Yes.

12 Yes.

7. (Continued):

b. Was the indexer usable?

Subjects 1-8, 10-12 -- Yes.
Subject 9 -- No.

c. Do you consider the indexer as necessary?

Necessary: Subjects 1, 2, 4-12
Unnecessary: Subject 3

d. Any additional comments:

<u>Subj #</u>

1 None.

2 None.

3 Early morning or late evening glare renders the indexer unusable through the center windscreen. The indexer is usable, but not necessary from an IP standpoint. Normal student patterns are not stable enough to watch the lights or to see trend information that the pointer gives.

4 With large deviations from .6 the indexer was necessary to see how far off you were.

5 None.

6 None.

7 Makes a super aid for rear seat IPs when making VFR patterns and to transition from IFR to VFR landing out of approaches. Suggest putting speed lights side of glare shield.

8 See 5.d.

9 Covered by hood during instrument flight. Same comments about turn to final.

10, 11, 12 -- no comments.

8. System Performance:

a. Is the instrument response compatible with aircraft characteristics? Front Indicator, Rear Indicator.

Subj #

1 Yes on both

2 Yes on both

3 Yes on both -- when it says it's going to stall, it stalls.

4 Yes on both.

5 Yes on both.

6 No answer.

7 Yes as far as trend is concerned but not for determining magnitude of rate.

8 Yes on both

9 Yes on both

10 Yes on both

11 Yes on both

12 NA

b. Is the instrument response/sensitivity compatible with pilot control responses?

Subj #

1 Yes.

2 Yes, but depends on experience of pilot.

3 Yes -- on one gusty, turbulent pattern ride, the pointer was more stable than the airspeed

8. b. (Continued):

Subj #

4 Yes.

5 Yes.

6 Slightly sluggish.

7 Yes.

8 Yes.

9 Yes.

10 Yes.

11 Yes.

12 No. It tends to lag a little.

c. Is the instrument smooth and flyable?

Subj #

1 Yes, during configuration changes and rough air.

2 Yes, during configuration changes and rough air, but no experience.

3 Yes, during configuration changes -- hardly notice the little jump and yes on rough air.

4 Yes, during configuration changes and rough air.

5 Yes, during configuration changes and rough air.

6 No answer

7 Yes, during configuration changes and no answer on rough air.

8. c. (Continued):

Subj #

8 Yes, during configuration changes, but you better know power setting. Question on rough air.

9 Yes, during configuration changes and rough air.

10 Yes, during configuration changes and as much as would seem possible in rough air.

11 Yes on both.

12 Yes on both.

d. Was the approach index valid for all configurations?

Subj #

1 No, no-flap approaches according to our procedures did not agree.

2 Yes.

3 Yes, the higher speed no-flap was more comfortable, but hard to get touchdown speed. This instrument may save someone's life who tries an unintentional no-flap.

4 Yes.

5 Yes.

6 No, no-flap configuration should be investigated.

7 Yes. Why does ATC insist on flying no-flap patterns too slow?

8 Yes.

9 No. Slightly faster for no-flaps.

10 Yes.

8. d. (Continued):

Subj #

11 Yes.

12 Yes, based on the $1.2V_{stall}$ data.

e. Could you maintain the approach index smoothly and safely during the landing?

Subj #

1 No, indexers should be dropped for visual flare and landings.

2 Yes.

3 No, it worked well to get red over green in the overrun, but the flare and TD was visual and with an AS check on TD.

4 Yes.

5 Yes.

6 Yes.

7 Yes.

8 Question mark on yes.

9 Yes.

10 Yes.

11 No, I had trouble using it in flare portion.

12 Yes.

8. (Continued):

f. Was the max range index valid?

Subjects 1-3, 5-11 -- Yes.

Subject 4 -- Yes at high altitude.

Subject 12 -- Yes, seemed to be but didn't practice thoroughly.

g. Was the max L/D index usable and valid for max endurance or glide speeds?

Subjects 1-3, 5-11 -- Yes

Subject 4 -- Yes. except at low altitude.

Subject 12 -- Glide speeds, yes, but didn't practice max endurance enough to get a feel for it.

9. Operational Validity:

a. Did the 0 - 100% scaling provide you with lift ratio, i.e., lift being used vs available?

Subj #

1 Yes.

2 Yes.

3 Yes, probably the greatest feature of the system -- you know how much of the aircraft you have left.

4 No. See Part I, Question 18.

5 Yes.

6 Yes

7 Yes.

9. a. (Continued):

Subj #

8 Yes.

9 Only if you believe it.

10 Yes.

11 Yes.

12 Yes, at 1.1 you don't have enough lift to fly the aircraft.

b. If 1 "G" flight were being conducted and was requiring a .55 indication on the angle of attack instrument, do you think a 2"G" turn could be accomplished?

Subj #

1 No.

2 No.

3 No, it appeared that it took double the indication to double the Gs.

4 Yes.

5 No.

6 As your indexer system defines it, no. Since you define 100% lift at C stall and L=nw; n=2 hence if L=.55 2n=1.1 or 110%.

7 Not if the AOA doubles perhaps on lift curve!?

8 No.

9 No.

10 No.

9. b. (Continued):

<u>Subj #</u>

11 No.

12 Don't know.

c. Do you think the 0-100% lift concept is valid for all aircraft?

Subjects 1-7, 10, 11 -- Yes.

Subject 8 -- Question mark on yes.

Subject 9 -- No, some aircraft reach max lift well after flight is no longer possible due to extreme drag or controllability problems. Even max lift will only give an instantaneous max performance. What's needed is an optimum max sustainable lift. I'd be willing to discuss this further at your leisure. This whole concept has great potential. I'd like to see it become as good as is possible within the state-of-the-art and become a model for all further AOA flying a guy does after he leaves ATC. Let's not set an ATC AOA program that is totally different from that of the <u>using commands</u>!

Subject 12 -- No, I do think that 0-100% of the usable angle of attack would be.

d. Would the 0-100% lift concept expedite or ease transition from one aircraft to another, i.e., would this concept be desirable as a standardized system across all aircraft?

<u>Subj #</u>

1 Yes.

2 Yes

3 Yes, definitely. It could be the cause of a major aircraft accident, if a pilot misread the AOA transitioning from one aircraft to another.

9. d. (Continued):

Subj #

4 Yes -- expedite.

5 Yes.

6 Yes. This whole concept of angle of attack flying must be coupled with a thorough understanding of angle of attack and AOA interpretation. Control inputs based solely on gauge readings can be as deadly as a total neglect.

7 Yes.

8 Not sure, but we better get all angles of attack saying the same thing.

9 No.

10 Yes.

11 Yes.

12 No. I do think that 0-100% of the usable angle of attack would be.