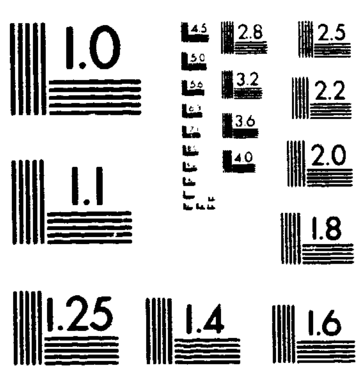
1 OF 1

N90-2[illegible]952 UNCLAS



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

NASA CONTRACTOR REPORT 181967

FLIGHT TEST INVESTIGATION OF CERTIFICATION ISSUES PERTAINING TO GENERAL-AVIATION-TYPE AIRCRAFT WITH NATURAL LAMINAR FLOW

WAYNE A. DOTY

CESSNA AIRCRAFT COMPANY
WICHITA, KANSAS

CONTRACT NAS1-18561
APRIL 1990

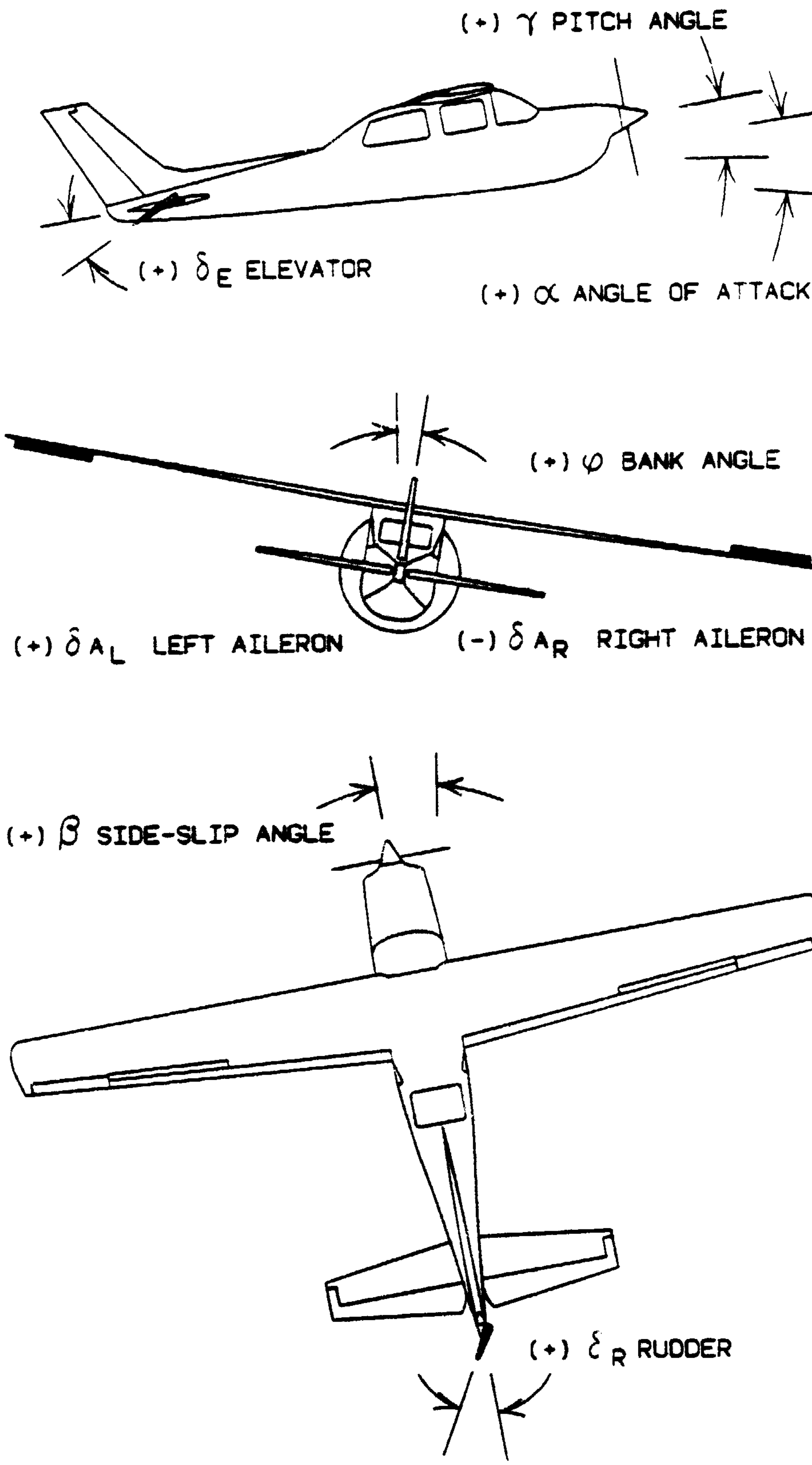
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

NOMENCLATURE

b	=	Wing Span (ft)
BHP	=	Brake Horsepower (550 ft lbs/sec)
C.G.	=	Center of Gravity
$C_{L_{max}}$	=	Maximum Lift Coefficient
g	=	Acceleration (32.2 ft/sec^2)
KCAS	=	Calibrated Airspeed (knots)
LBS	=	Pounds Force
n	=	Normal Acceleration (g's)
P	=	Roll Rate (deg/sec)
q	=	Dynamic Pressure (lbs/ft^2)
RPM	=	Engine Revolutions Per Minute
S	=	Wing Area (ft^2)
V	=	True Airspeed (ft/sec)
V_{S1}	=	Calibrated stalling speed if obtainable, or the minimum steady speed at which the airplane is controllable with 1) engine idling, and 2) propeller in takeoff position (knots)
W	=	Gross Weight (lbs)
ω_d	=	Damped Frequency (rad/sec)
ω_n	=	Natural Frequency (rad/sec)
ζ	=	Damping Ratio

Control surface deflections and forces are defined as follows:



POSITIVE CONTROL FORCES
PRODUCE POSITIVE DEFLECTIONS

ABSTRACT

Development of Natural Laminar Flow (NLF) technology for application to general-aviation-type aircraft has raised some question as to the adequacy of FAR Part 23 for certification of aircraft with significant NLF.

A series of flight tests ~~have been~~ conducted with a modified Cessna T210R to allow quantitative comparison of the aircraft's ability to meet certification requirements with significant NLF and with boundary layer transition fixed near the leading edge.

There were no significant differences between the two conditions except an increase in drag, which resulted in longer takeoff distances and reduced climb performance.

INTRODUCTION

NASA's Flight Research Branch, Flight Applications Division, has undertaken the development of natural laminar flow (NLF) technology for application to business, commuter, and transport aircraft. This research has shown benefits which warrant incorporation in the design of new aircraft. Thus, the adequacy of FAR Part 23 for certification of new aircraft utilizing significant NLF must be determined.

The objective of this program is to determine the adequacy of FAR Part 23 for certification of conventional general-aviation-type aircraft using an NLF airfoil. The aircraft used in this program was a Cessna T210R with a wing incorporating a NASA-designed NLF airfoil section, smoothed NLF horizontal stabilizer, and smoothed vertical stabilizer. See Figure 1.

The scope of this program was to compare the results from a series of tests with fixed transition at 5% chord to those obtained with natural transition on the NLF and smoothed surfaces. Tests and parameters were chosen to allow quantitative comparison of the aircraft's ability to meet certification requirements with changes in boundary layer conditions.

AIRCRAFT MODIFICATIONS

The design goals, analytical methods, and two dimensional wind tunnel tests of the NLF(1)-0414F have been reported in references 1 through 3. Full scale wind tunnel tests of the modified T210R with this section on the wing were reported in reference 4. Earlier flight test results have been reported in reference 5.

The modified T210R wing had a span of 42 feet and aspect ratio of 11. The NLF(1)-0414F airfoil section was used. There was a small 12.5% chord trailing edge cruise flap which was not used during this research program. The leading edge had no sweep and the planform had no twist.

The horizontal stabilizer was modified from the production configuration. Stabilizer area was added forward of the production leading edge. One-half percent camber was added forward of the quarter-chord of the otherwise symmetric sections in an effort to expand the width of the drag bucket and provide a larger range of useful lift coefficient.

Using the existing airfoil sections, the vertical stabilizer and dorsal fin were smoothed. Rivets were recessed below the surface and then all gaps and depressions filled to the 50% chord location.

Because of the additional empennage weight, forward ballast was necessary to move the C.G. within the aft limit of the production T210. Since the pilot, instrumentation, fuel, modifications, and ballast increased the weight of the aircraft above the production T210 gross weight, it was not possible to add more weight to fly at anything besides the aft C.G. limit.

The production engine was replaced with a TSIO-520-CE with dual alternators to provide for the additional electrical needs of the instrumentation package. This engine is rated at 325 BHP at 2700 RPM.

TRANSITION

The chordwise location at which the laminar boundary layer transitioned to a turbulent boundary layer was determined using hot film anemometer gauges. There were twenty-two gauges on the upper and lower surfaces of the wing and twenty-six on the upper and lower surfaces of the horizontal stabilizer. When a hot film gauge is in a laminar boundary layer, there is little heat transfer near the gauge and consequently the voltage required to hold the gauge's temperature constant is almost constant. When a gauge is in a turbulent boundary layer, the voltage required to hold the temperature constant fluctuates rapidly. The boundary layer state at a given gauge was determined by looking at the excitation voltage required to hold the gauge at 200°F. The hot film excitation voltages were recorded on tape in analog form during all flights. See Figure 2.

Transition location and spanwise extent were verified using the sublimating chemical acenaphthene. When acenaphthene is applied uniformly to a surface prior to flight, the transition location may be determined after flying sufficiently long to sublimate the chemical in the turbulent region. Sublimation occurs in less time in turbulent than in laminar regions due to greater mass transfer and viscous shear forces associated with the turbulent boundary layer.

Acenaphthene was sprayed onto the wing, horizontal, and vertical surfaces. The spanwise line of sublimation indicated transition at a constant percent chord starting about one foot outboard of the fuselage and extending to the tip. See Figure 3.

Acenaphthene was also used to determine the most effective way of fixing transition at 5% chord. Two methods were tried. Serrated tape did not yield as repeatable results as trip disks. Several combinations of disk height, diameter, and spacing were tested. Best overall results were obtained using disks which measured 0.013 inches high, 0.070 inches diameter, and had 0.125 inch spacing between them. All fixed transition tests were conducted with these disks located at 5% chord of the upper and lower surfaces of the wing, horizontal tail, and both sides of the vertical fin. See Figure 4.

Laminar flow was achieved to about 70% chord on the upper and lower surface of the wing at and above 100 KCAS. By recontouring the horizontal stabilizer, while still retaining the production straight tapered elevator, laminar flow was achieved to 70% chord on the upper surface at and above 100 KCAS, and about 35% chord on the lower surface at 150 KCAS. Boundary layer transition occurred at 30% chord on the upper half and at about 50% on the lower half of the vertical stabilizer at and above 100 KCAS.

STALL SPEED

Wings level stall tests were conducted such that a quantitative comparison between natural and fixed transition results could be made. The wings level stall requirements are discussed in FAR 23.49. The test procedures in 23.201 were followed except the stall was corrected for 1g in order to determine $C_{L_{max}}$ using the relationship:

$$V_{S1} = V_{S_{test}} \sqrt{\frac{W_{std}}{n_{test} \, W_{test}}}$$

The aircraft was trimmed at 100 KCAS (1.5 V_{S1}) with idle power, and airspeed was reduced with elevator only. Stall speed was the minimum speed with full nose up elevator and a -1 knot per second entry rate. The stall speed was corrected to 1g, 4100 pounds and sea level standard day.

Full scale wind tunnel data was used to give a stall speed for zero entry rate (steady-state). Data was curve fit by using engineering judgement and a theoretical understanding of the physical relationship between the airplane and its environment. The $C_{L_{max}}$ versus stall speed line was from the following relationship:

$$C_{L_{max}} = \frac{295\, W_{std}}{S\, V_{S1}^2}$$

A test with landing gear up and natural transition was conducted to determine the significance of gear position. The change in stall speed due to landing gear position was negligible, and thus was not repeated with 5% transition.

Wings were held level during stall, and the aircraft recovered with normal aileron control. Stall speed remained essentially the same in both natural and 5% transition cases as shown below. See also Figures 5 and 6.

Stall Speed: (KCAS)	Natural Transition	5% Transition
Ge. Down	67.1	67.1

TAKEOFF TO 50 FT

Takeoff tests were conducted as outlined in FAR 23.51. Speeds at 50 feet were varied to bracket 1.3 V_{S1} as defined in 23.53. The flaps on the test aircraft were not designed to be adjustable in flight. They are small chord cruise flaps and were not used for takeoff performance.

Takeoff distance was the distance traveled over the ground from the point where the aircraft began to roll to the point where the aircraft was 50 feet above the ground with an airspeed of 1.3 V_{S1}. Basically, the takeoff ground run was corrected for wind, engine thrust, and aircraft weight. Takeoff air distance was corrected for wind, air density, engine thrust, and aircraft weight. In addition, the lift-off and 50 foot speeds were converted to calibrated airspeed by adding the wind component and multiplying by square root of the density ratio. The airspeeds were further corrected to standard weight by square root of the weight ratio. Additionally, takeoff data reduction required the propeller efficiency, and this was determined in previous Cessna flight tests with this engine and propeller combination where torque and rpm measurements were made. All the relevant theory and equations for these corrections may be found in reference 6.

T.O. Distance To 50 Ft:	Natural Transition	5% Transition
	2060 ft	2620 ft

Takeoff distance increased over 27% with 5% transition. Most of the increase occurred in the air portion of the test where drag was the highest. A review of the results has found the increase in takeoff distance with transition fixed at 5% to be greater than expected when compared to natural transition. Further testing, beyond the scope of this program, may be warranted to investigate these results. See Figure 7.

CLIMB

Continuous climbs were performed from 7000 to 13,000 ft density altitude. Climb performance procedures were followed as described in FAR 23.65. A climb speed between that for best angle and that for maximum rate of climb for the production (non-NLF) T210R was chosen for the climb test. This speed, 100 KCAS, was held constant during the climbs. Climbs were conducted with max continuous power and in air with normal temperature lapse rates (no thermal activity). Rate and gradient data were corrected to standard day and 4100 pounds.

At 10,000 Ft Density Altitude:	Natural Transition	5% Transition
Rate of Climb (ft/min)	1013	912
Climb Gradient (%)	11.8	10.5

Rate of climb and climb gradient at 10,000 ft density altitude decreased approximately 10% with the 5% transition configuration. See Figures 8 and 9.

STATIC LONGITUDINAL

Stick fixed stability was demonstrated by the positive gradient of the elevator angle for trim versus airspeed. There was negligible difference in the trim elevator deflection between natural and 5% transition configurations. Both configurations were stable. See Figure 10.

FAR 23.173 and 23.175 address the stick force versus airspeed curve. The curve must have a stable slope, and airspeed must return to within plus or minus 10 percent of the original trim speed when disturbed. This is an example of positive stick free stability.

There was negligible difference in the elevator stick force curves for natural and 5% transition. Both configurations demonstrated stable gradients, since a pull was required to reduce airspeed and a push to increase it. The free return speeds were within 2 percent of the trim speed. See Figure 11.

STATIC LATERAL

FAR 23.177 describes positive stability as 1) the tendency to recover from a skid with rudder free; 2) the tendency to raise the low wing in a slip (dihedral effect), and 3) the aileron and rudder movements and forces must increase steadily as the angle of slip is increased.

In order to make a quantitative comparison between the natural and 5% transition configurations, control deflections and bank angle were plotted against side slip angle. Tests were conducted with idle and 75% power, while a steady heading was maintained.

The test aircraft exhibited positive lateral and directional static stability with no difference between natural and 5% transition configurations. The aileron required to hold zero bank angle is due to a weight imbalance of the wing. The right wing is heavier than the left.

See Figures 12 and 13. Aileron and rudder forces are addressed in the "Lateral/Directional Control" section of this report.

SHORT PERIOD

Dynamic stability is discussed in FAR 23.181. Short period oscillations of pitch must be heavily damped with controls free and in a fixed position.

When excited by an elevator pulse, the short period motion was dead beat and no oscillation was detectable with controls fixed or free, in either natural or 5% transition configurations.

PHUGOID

Long period oscillations of pitch and airspeed are not addressed in FAR 23.181. The phugoid motion was excited from trimmed flight with 75% max continuous power by pitching the aircraft down 10° and releasing the elevator control. Airspeed and pitch were lightly damped. There were negligible differences between natural and 5% transition in frequency and damping ratio. In general, there was a slight increase in frequency with 5% transition. See Figures 14 and 15.

Phugoid:		Natural Transition	5% Transition
Airspeed Response	ω_d	0.158 $\frac{rad}{sec}$	0.161 $\frac{rad}{sec}$
	ω_n	0.158 $\frac{rad}{sec}$	0.161 $\frac{rad}{sec}$
	ζ	0.032	0.028
Pitch Response	ω_d	0.158 $\frac{rad}{sec}$	0.160 $\frac{rad}{sec}$
	ω_n	0.159 $\frac{rad}{sec}$	0.161 $\frac{rad}{sec}$
	ζ	0.065	0.062

DUTCH ROLL

The dutch roll response was recorded with controls free and in a fixed position for both natural and 5% transition. FAR 23.181 states any combined lateral-directional oscillations must be damped to 1/10 amplitude in 7 cycles ($\zeta = 0.13$) with both controls free and in a fixed position. The test aircraft was initially trimmed in level flight with 75% max continuous power.

Dutch Roll:		Natural Transition	5% Transition
Sideslip Response Stick Fixed	ω_d	3.01 $\frac{rad}{sec}$	3.24 $\frac{rad}{sec}$
	ω_n	3.10 $\frac{rad}{sec}$	3.34 $\frac{rad}{sec}$
	ζ	0.24	0.25
Side-Slip Response Stick Free	ω_d	3.43 $\frac{rad}{sec}$	2.74 $\frac{rad}{sec}$
	ω_n	3.48 $\frac{rad}{sec}$	2.78 $\frac{rad}{sec}$
	ζ	0.17	0.17
Roll Response Stick Free	ω_d	3.27 $\frac{rad}{sec}$	2.86 $\frac{rad}{sec}$
	ω_n	3.33 $\frac{rad}{sec}$	2.92 $\frac{rad}{sec}$
	ζ	0.18	0.20

Side-slip and roll were sufficiently damped in all tests. There was a small increase in frequency in the controls fixed tests and a small decrease in the stick free tests with 5% transition.

LONGITUDINAL CONTROL

The procedures to determine adequate longitudinal control are discussed in FAR 23.145. Based on these requirements, a landing gear cycle test and a power application test were carried out.

Without the exertion of more control force than can readily be applied with one hand for a short period of time, it must be possible to 1) extend the landing gear and 2) apply max continuous power from a minimum trim speed.

For the landing gear cycle tests, the aircraft was trimmed at 100 KCAS with max continuous power, speed was reduced to 80 KCAS with elevator control, and then the landing gear was extended. The purpose of reducing the speed after trimming the aircraft was to move away from zero control force and the potential instrumentation dead band.

Response to Gear Cycle:	Natural Transition	5% Transition
Max increase in stick force (lbs)	7	3.5
Max increase in pitch (deg)	2.5	2.5

The control forces required were readily applied with one hand for natural and 5% transition configurations. See Figure 16.

For the power application test, the aircraft was trimmed at minimum trim speed (87 KCAS) with idle power, then max continuous power was rapidly applied. Instead of letting the aircraft accelerate, speed was to be held constant and a climb established.

Response to Power Increase:	Natural Transition	5% Transition
Max stick force (lbs)	7	13.5
Max deviation in at airspeed (KCAS)	9	6

The control forces required were readily applied with one hand for natural and 5% transition configurations. See Figure 17.

LATERAL/DIRECTIONAL CONTROL

FAR 23.177(3) describes the requirement for aileron and rudder forces to increase steadily as the angle of slip increases. Control force measurements were recorded at various side-slip angles while a steady heading was maintained in natural and 5% transition configurations. Tests were conducted both with the aircraft trimmed at 100 KCAS with idle power and trimmed at 75% max continuous power in level flight.

The aileron and rudder forces increased steadily with the angle of side-slip in all tests. There were negligible differences between the natural and 5% transition configuration results. See Figures 18 and 19.

DIHEDRAL

The results from tests to determine dihedral affect, the tendency to raise the low wing in a side-slip, are also included in the "Lateral/Directional Control" section of this report. Positive and equal dihedral effect was found in both natural and 5% transition configurations at idle and max continuous power. Dihedral effect was evident on the plots of aileron control force versus side-slip angle, since the force required increased steadily with the side-slip angle. In other words, it took force to hold the low wing down. See Figures 18 and 19.

ELEVATOR STICK FORCES

The elevator control force in maneuvers is discussed in FAR 23.155. For this aircraft, the control force needed to achieve the positive limit maneuvering load factor (3.8 g's) may not be less than 41 pounds. The experimental type certificate for the test aircraft, due to unique construction, specifies a 2g design limit load factor.

Control force measurements were made at several load factors between 1 and 2 g's while the pilot executed coordinated 110 KCAS wind-up turns at the most aft center of gravity. The tests were conducted in natural and 5% transition configurations.

There were negligible differences in the data between natural and 5% transition configurations. The average control force gradient was 70 pounds per g, which extrapolates to 271 pounds at 3.8 g's. The control force required exceeds the minimum control force of 41 pounds. See Figure 20.

ROLL RATE

Rate of roll requirements for takeoff and approach conditions are presented in FAR 23.157. In order to make a quantitative comparison between natural and 5% transition configurations, a series of rolls were performed with several different aileron deflections. Tests were conducted at several speeds with idle power and power for level flight in both natural and 5% transition configurations. Roll rate and aircraft forward speed were reduced to helical angle and plotted against total aileron deflection.

The left roll spoiler deflections were plotted against total aileron deflection to illustrate why the helical angle increased near maximum aileron deflection. This phenomenon is attributed solely to the non-linear relationship between the aileron and spoiler.

There were negligible differences in roll rates between the natural and 5% transition configurations, with either idle or power for level flight. See Figure 21.

LONGITUDINAL TRIM

Longitudinal trim requirements are presented in FAR 23.161(c). The test aircraft was trimmed for level flight at several airspeeds at and above the minimum trim speed. Elevator tab deflections were recorded at each test point for natural and 5% transition configurations.

There was an increase in the amount of tab required to trim the aircraft at speeds below 144 KCAS in the 5% transition configuration. This additional deflection was approximately 2 degrees trailing edge down. See Figure 22.

The tab deflections for natural and 5% transition may merge due to the transition line moving forward with increased trailing-edge-up deflection in the natural transition configuration. In any case, the difference between the configurations was small.

LATERAL TRIM

The test aircraft was not equipped with a device for lateral trim. The aileron deflection required to hold the wings level was presented in the "Static Lateral section of this report.

There was a small amount (1-1½ degrees) of right aileron necessary to hold wings level. This control deflection has been attributed to a "right-wing heaviness", and was the same for natural and 5% transition configurations with idle and 75% max continuous power. See Figures 12 and 13.

DIRECTIONAL TRIM

Directional trim requirements are discussed in FAR 23.161(b). The test aircraft was equipped with a fixed rudder tab (ground adjustable only), which was not changed during the entire program.

To compare the effectiveness of the rudder to directionally trim the aircraft in natural and 5% transition configurations, rudder deflection required for steady heading was plotted against power divided by airspeed. The quantity HP/KCAS is proportional to thrust. By plotting values from the minimum controllable airspeed to the maximum allowable airspeed, the rudder's ability to directionally trim the aircraft over the entire flight envelope was explored. See Figure 23. There was no appreciable difference in rudder required for directionally trimmed conditions in the natural and 5% transition configurations.

WINGS LEVEL STALL TESTS

When the aircraft was stalled there was no prestall buffet. All stalls were done with full nose up elevator. Instead of a sudden pitch break, there was a small oscillation in pitch (about 4 degrees) during the stall, a minimum speed was obtained, and the aircraft would lose altitude. The aircraft remained controllable during the stall. Stalls with fast entry rates ($\leq$ -3 knots/sec) had more of a tendency for one wing to roll off. The pilots reported no noticeable difference in controllability or recovery between the natural and 5% transition configurations.

TURNING STALL TESTS

Turning flight stalls were conducted from a coordinated 30 degree bank by tightening the turn with elevator until the aircraft stalled. Stalls were entered from both left and right turns. To reduce power and speed effects, the aircraft was trimmed at 120 KCAS with power for level flight instead of 1.2 V_{S1} and 75% MCP as outlined in FAR 23.203.

According to FAR 23.203(b), it must be possible to regain level flight without excessive loss of altitude, undue pitchup, uncontrollable tendency to spin, or exceeding 60 degrees of roll in either direction from the established 30 degree bank.

Turning Stalls:	Natural Transition		5% Transition	
	Left	Right	Left	Right
Altitude Loss (Feet)	400	650	400	300
Pitch Up (Yes/No)	No	No	No	No
Spin (Yes/No)	No	No	No	No
Max Dev in Roll (Degrees)	63	38	85	90

The aircraft consistently exceeded the allowable roll from the 30 degrees bank after stall regardless of the transition location. After several turning stalls, it was determined that the tendency to roll off was not significantly different between natural and 5% transition configurations. Nevertheless, these stall characteristics do not satisfy the certification requirement of FAR 23.203(b). It is possible that correction of this deficiency may reduce the beneficial low-drag characteristic of the NLF wing. The tendency to roll off was adversely affected by greater sideslip angles at stall.

STALL WARNING

According to FAR 23.207, there must be a clear and distinctive stall warning. The warning must begin at least five knots above stall speed. As discussed in the "Wings Level Stall Tests" section, there was no prestall buffeting. Furthermore, the test aircraft was not equipped with a device to warn of eminent stall. More importantly, there was no difference between natural and 5% transition configurations.

HIGH SPEED CONTROL FORCES

Control forces in the aircraft's flight envelope were not excessive nor were there appreciable differences between natural and 5% transition. The aircraft was capable of having elevator control forces trimmed to zero from 87 KCAS to 180 KCAS. See Figures 10 and 22.

HIGH SPEED VIBRATION AND BUFFETING

FAR 23.251 states the entire aircraft must be free from excessive vibration under any appropriate speed and power conditions. In addition, there may be no buffeting in any normal flight condition, severe enough to interfere with control of the aircraft.

The test aircraft has been flown with natural and 5% transition, and a qualitative evaluation by the pilot has determined that there was no abnormal vibration or buffeting at any combination of speed and power.

CONCLUSION

This program demonstrated that loss of laminar flow on a well designed NLF airfoil will adversely affect aircraft performance, while the effect on flight characteristics is not significant. A well designed NLF section may be described as an airfoil designed for extensive natural laminar flow with lower cruise drag while maintaining acceptable maximum lift, stall, and moment characteristics. Takeoff distance, rate of climb, and gradient are significantly affected by the increased drag associated with loss of laminar flow. However, stall speeds, stall characteristics, flight stability, and controllability were found to be independent of transition location.

Significant knowledge was gained regarding modification of the design and development of an NLF airfoil for the horizontal stabilizer. This airfoil was designed with the constraint that the stabilizer contours faired into the straight line upper and lower surfaces of the existing T210 elevator. This compromise in airfoil contour results in a drag penalty when compared with the cusped trailing edge of the NASA NLF sections. However, extensive laminar flow was achieved while retaining the same docile response to loss of laminar flow, and improving ease of fabrication. Analytical methods used to derive this airfoil yielded results that agreed well with test data. Therefore, it has been demonstrated that careful design of NLF sections, to meet specific performance and producibility goals, can be accomplished without jeopardizing the desired docile handling qualities characteristics.

In summary, a conventionally configured aircraft with a well designed NLF section exhibits no behavior that could be deemed unusual or outside the scope of current FAR Part 23 requirements. This is true, regardless of the amount of laminar flow achieved. However, since some performance characteristics are affected significantly by the extent of laminar flow, the issues of additional flight testing required for certification, and appropriate presentation of performance to operators will need to be addressed.

REFERENCES

1. Viken, Jeffrey K.; Pfenninger, Werner; and McGhee, Robert J.: Advanced Natural Laminar Flow Airfoil With High Lift to Drag Ratio. Langley Symposium on Aerodynamics, Volume I, pp. 401-414, NASA CP-2397, April 1985.

2. McGhee, Robert G.; Viken, Jeffrey K.; Pfenninger, Werner; and Harvey, W. D.: Experimental Results for a Flapped Natural-Laminar-Flow Airfoil with High Lift/Drag Ratio. NASA TM-85788, May 1984.

3. Viken, J. K.; Campbell, R. L.; Viken, S. A. W.; Pfenninger, W.; and Morgan, H. L., Jr.: Design of the Low Speed NLF(1)-0414F and the High Speed HSNLF(1)-0213 Airfoils with High-Lift Systems. NASA CP 2487, pp. 637-671. Natural Laminar Flow and Laminar-Flow Control Symposium, NASA Langley Research Center, Hampton, Virginia, March 16-19, 1987.

4. Murri, Daniel G. and Jordan, Frank L., Jr.; Wind Tunnel Investigation of a Full Scale General Aviation Airplane Equipped with an Advanced Natural Laminar Flow Wing. NASA-TP-2772, November 1987.

5. Befus, Jack; Nelson, E. Randel; Ellis, David R.; and Latas, Joe: Flight Test Investigations of a Wing Designed for Natural Laminar Flow. SAE 871044, April 1987.

6. AFFTC Office of Information: USAF Test Pilot School, Volume III, Performance Flight Test Technique, Chapter 5. FTC-TIH-70-1001, January 1973.

7. Office of the Federal Register National Archives and Records Administration: Code of Federal Regulations, Title 14, Aeronautics and Space, Part 23, Airworthiness Standards; Normal, Utility, Acrobatic, and Commuter Category Airplanes, pp. 103-246. January 1, 1988.

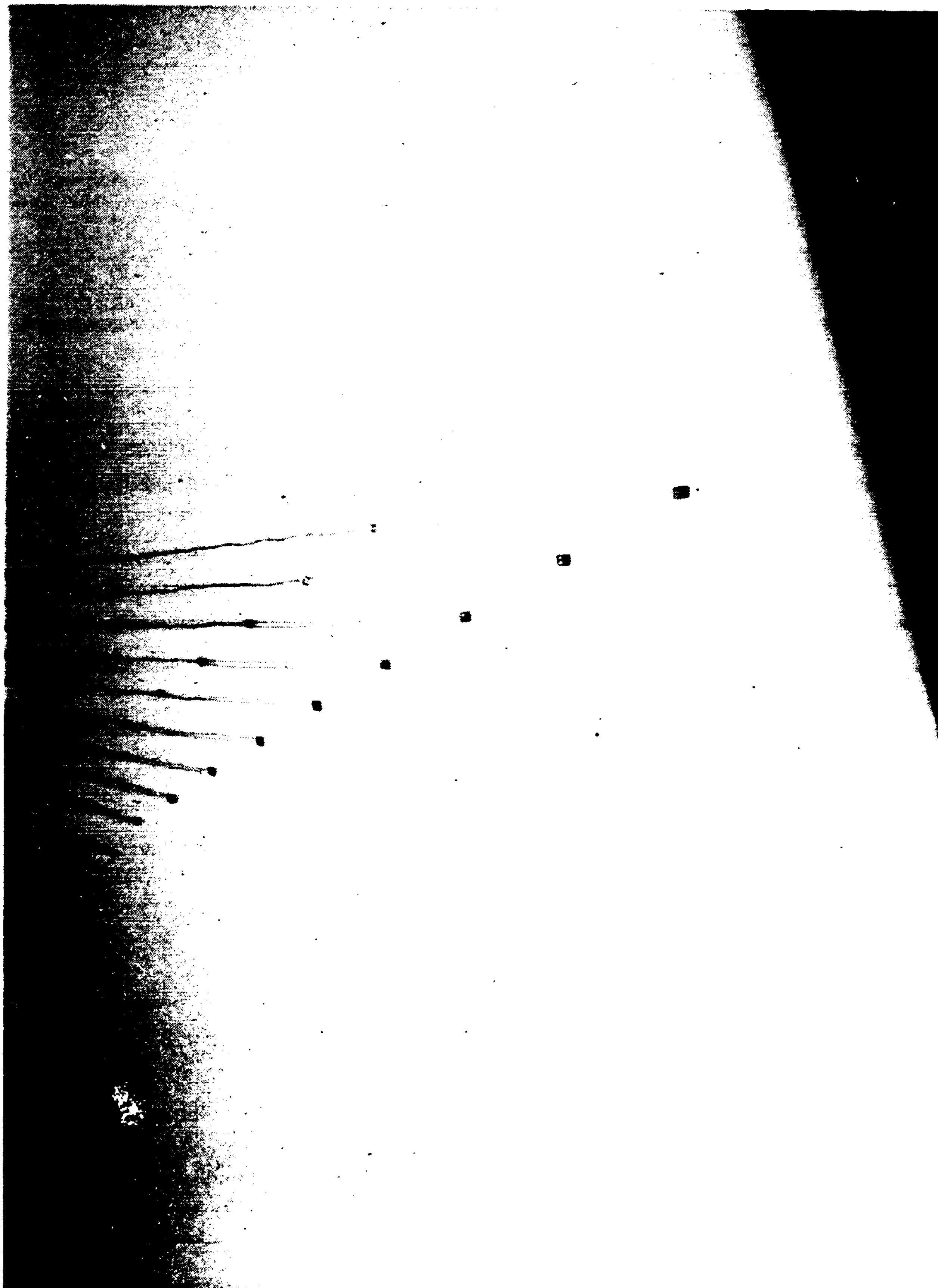
Figure 1

The modified Cessna T210R.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 2

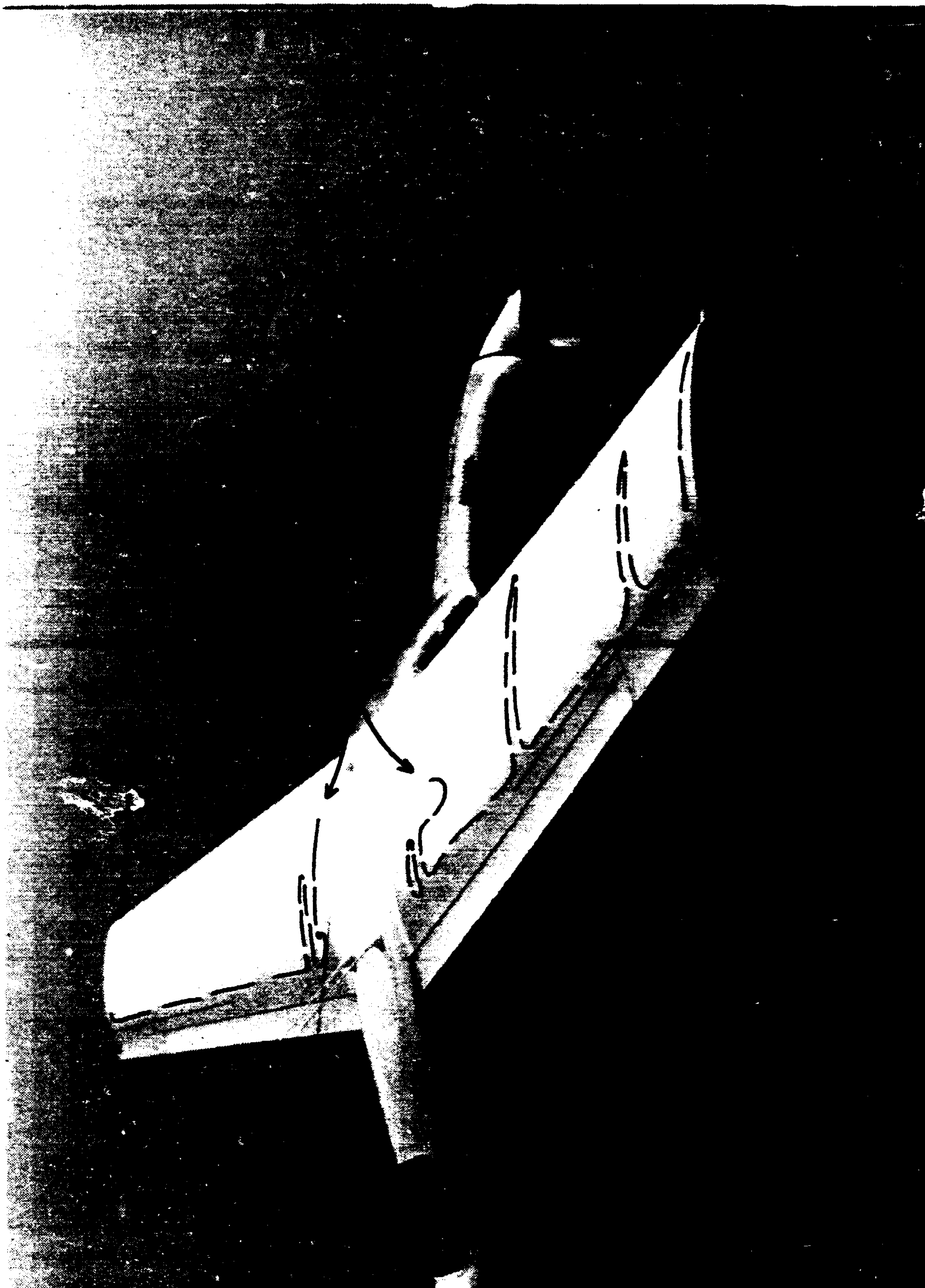


A typical installation of hot film gauges (upper horizontal).

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

ORIGINAL PAGE IS
OF POOR QUALITY

Figure 3

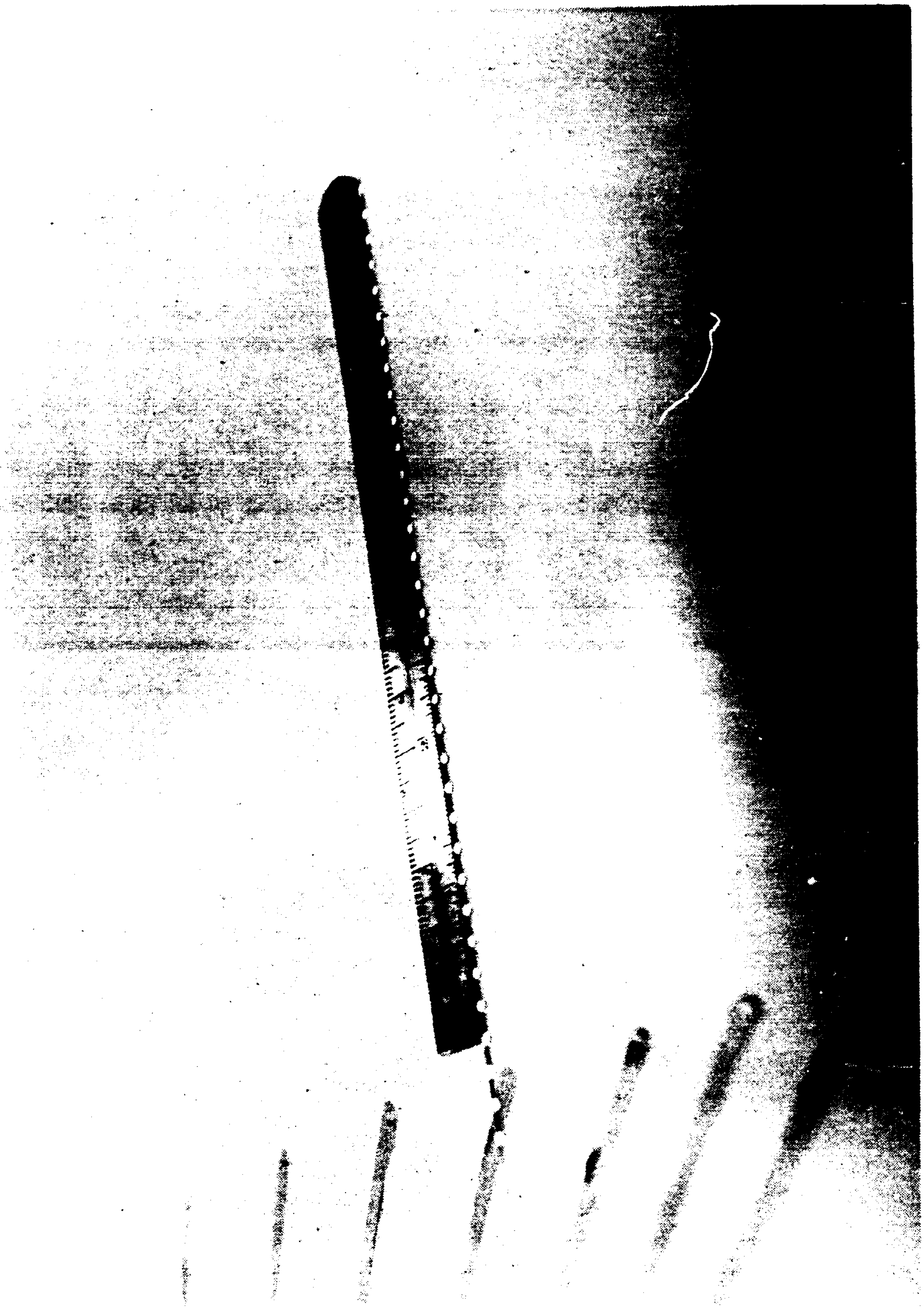


Acenaphthene on the wing indicating transition at 70% chord.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

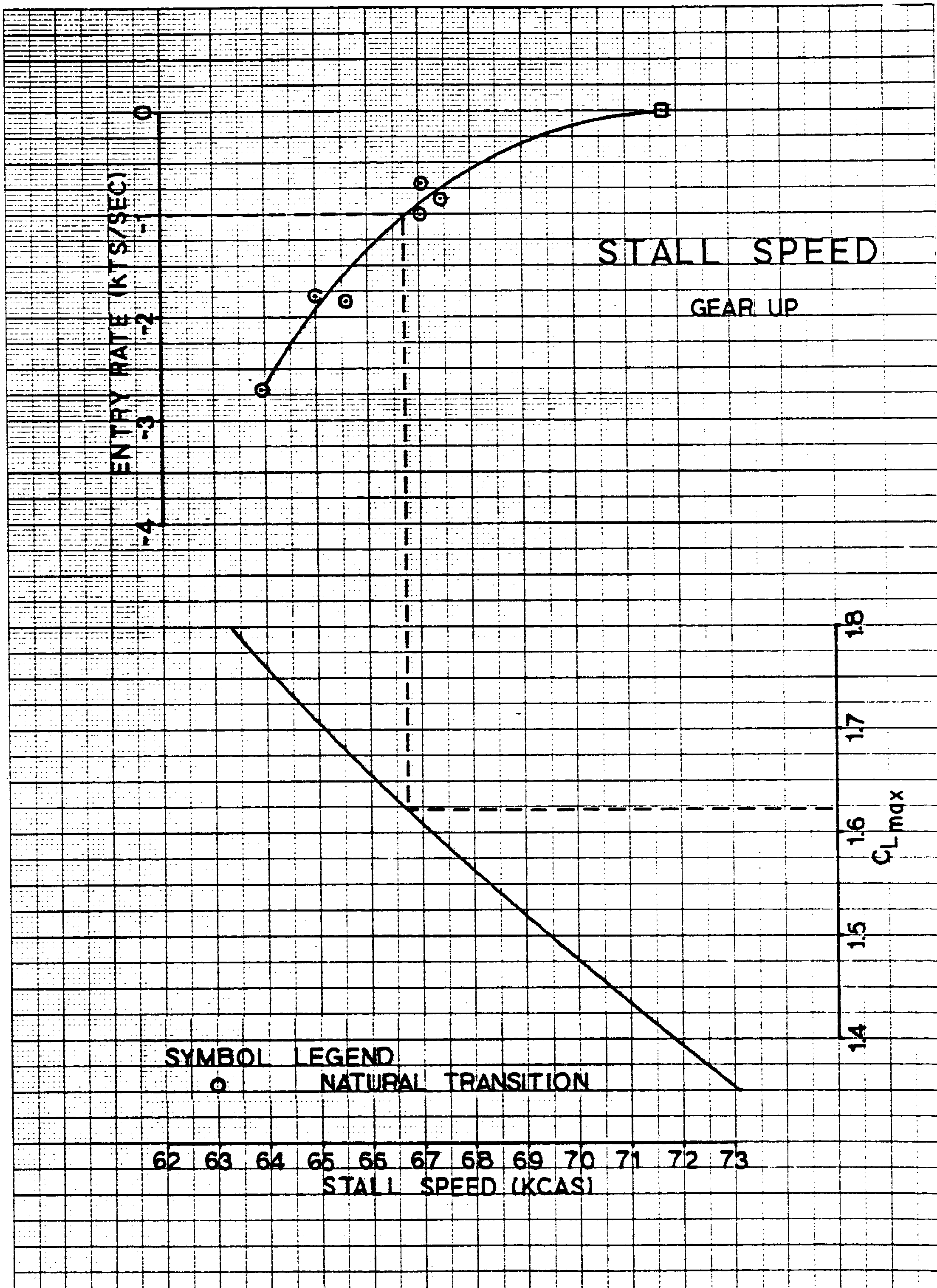
ORIGINAL PAGE IS
OF POOR QUALITY

Figure 4



Trip disks with a scale on the upper surface of the wing.

Figure 5



STALL SPEED
GEAR UP
ENTRY RATE (KTS/SEC)
0
-1
-2
-3
-4
$C_{L_{max}}$
1.4
1.5
1.6
1.7
1.8
SYMBOL LEGEND
NATURAL TRANSITION
62 63 64 65 66 67 68 69 70 71 72 73
STALL SPEED (KCAS)

Figure 6

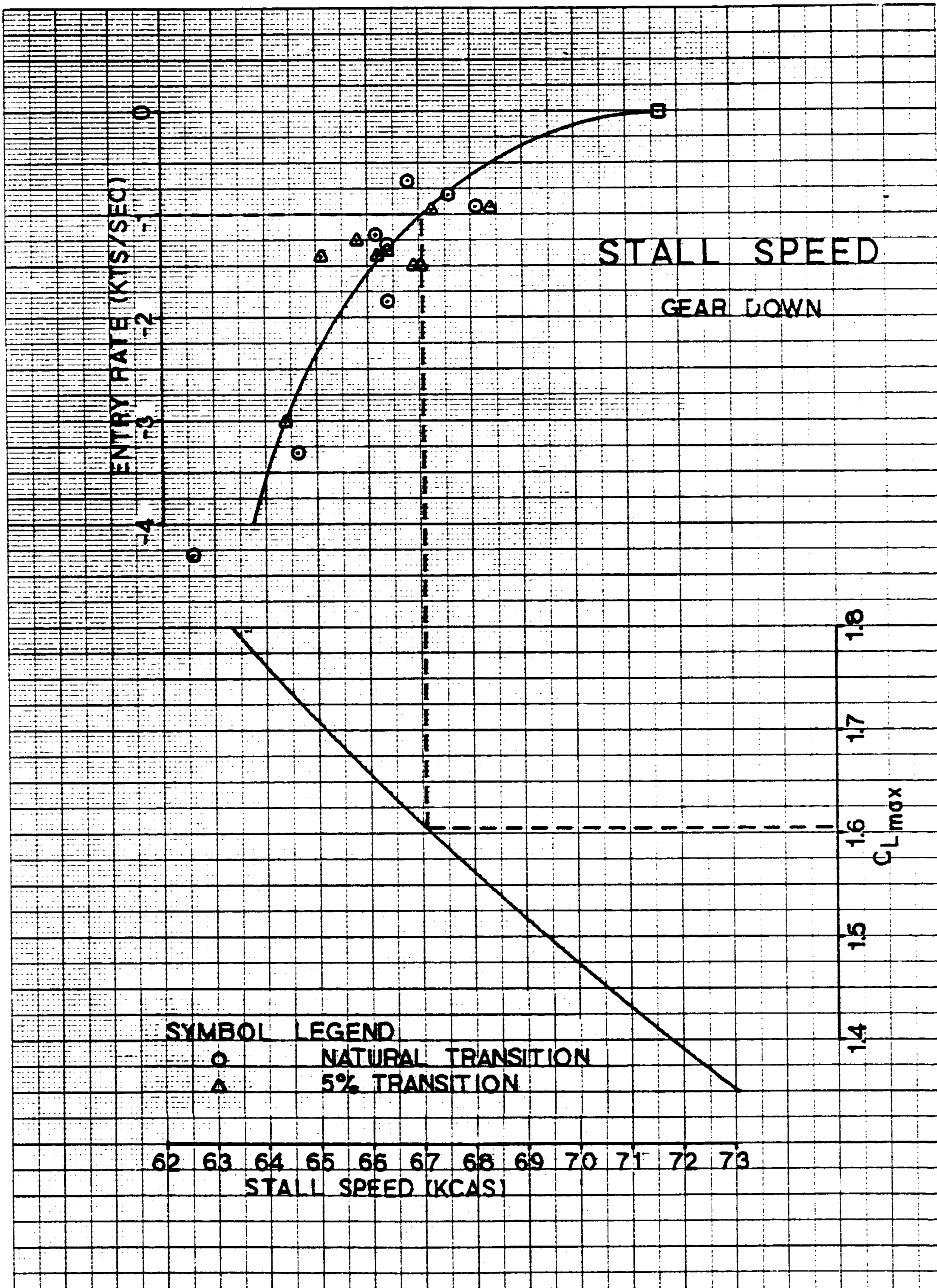
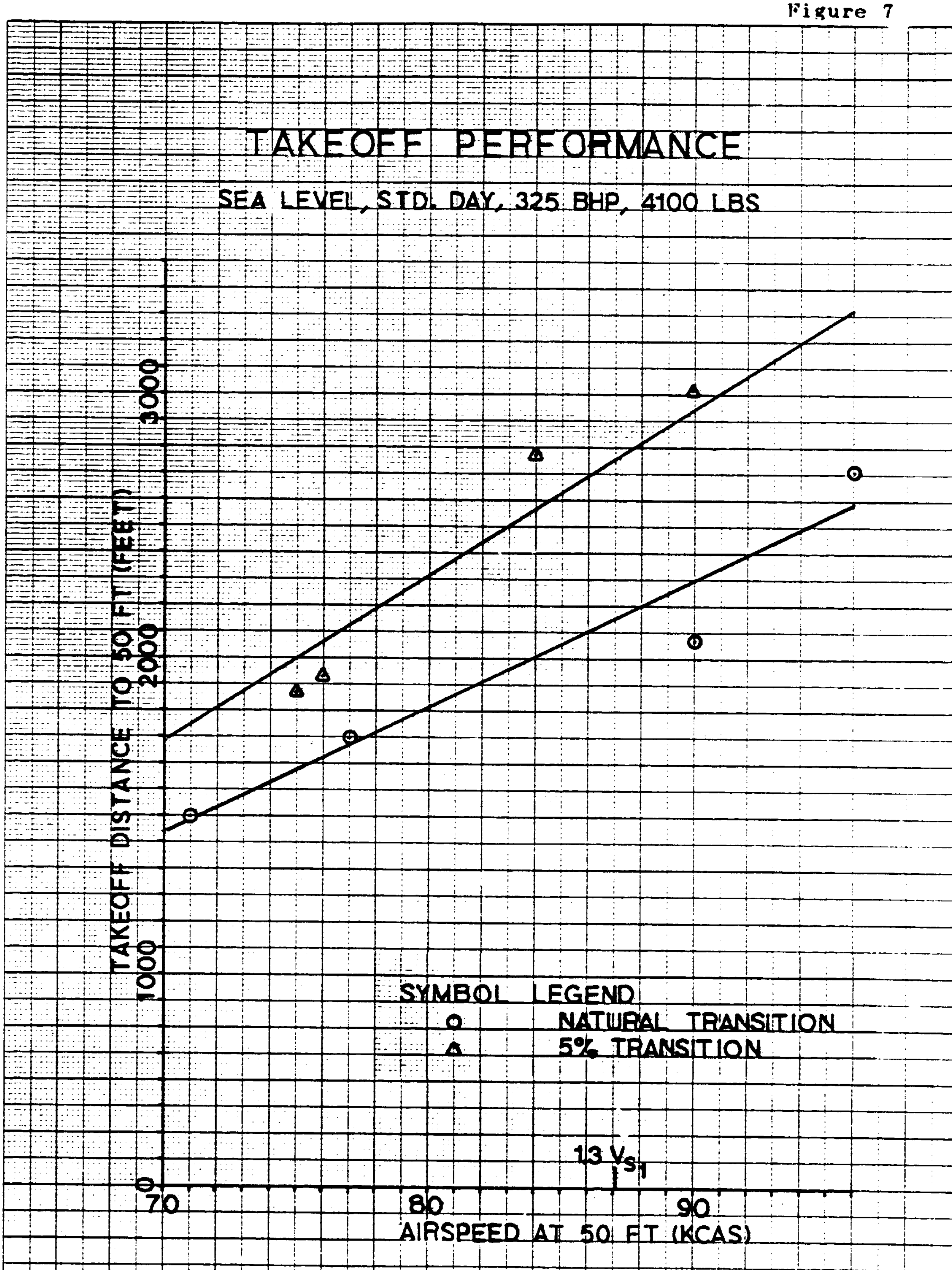

STALL SPEED
GEAR DOWN
ENTRY RATE (KTS/SEC)
0
-1
-2
-3
-4
$C_{L max}$
1.8
1.7
1.6
1.5
1.4
SYMBOL LEGEND
NATURAL TRANSITION
5% TRANSITION
62 63 64 65 66 67 68 69 70 71 72 73
STALL SPEED (KCAS)

Figure 7


TAKEOFF PERFORMANCE
SEA LEVEL, STD. DAY, 325 BHP, 4100 LBS
TAKEOFF DISTANCE TO 50 FT (FEET)
0
1000
2000
3000
70
80
90
AIRSPEED AT 50 FT (KCAS)
1.3 V_{S_1}
SYMBOL LEGEND
NATURAL TRANSITION
5% TRANSITION

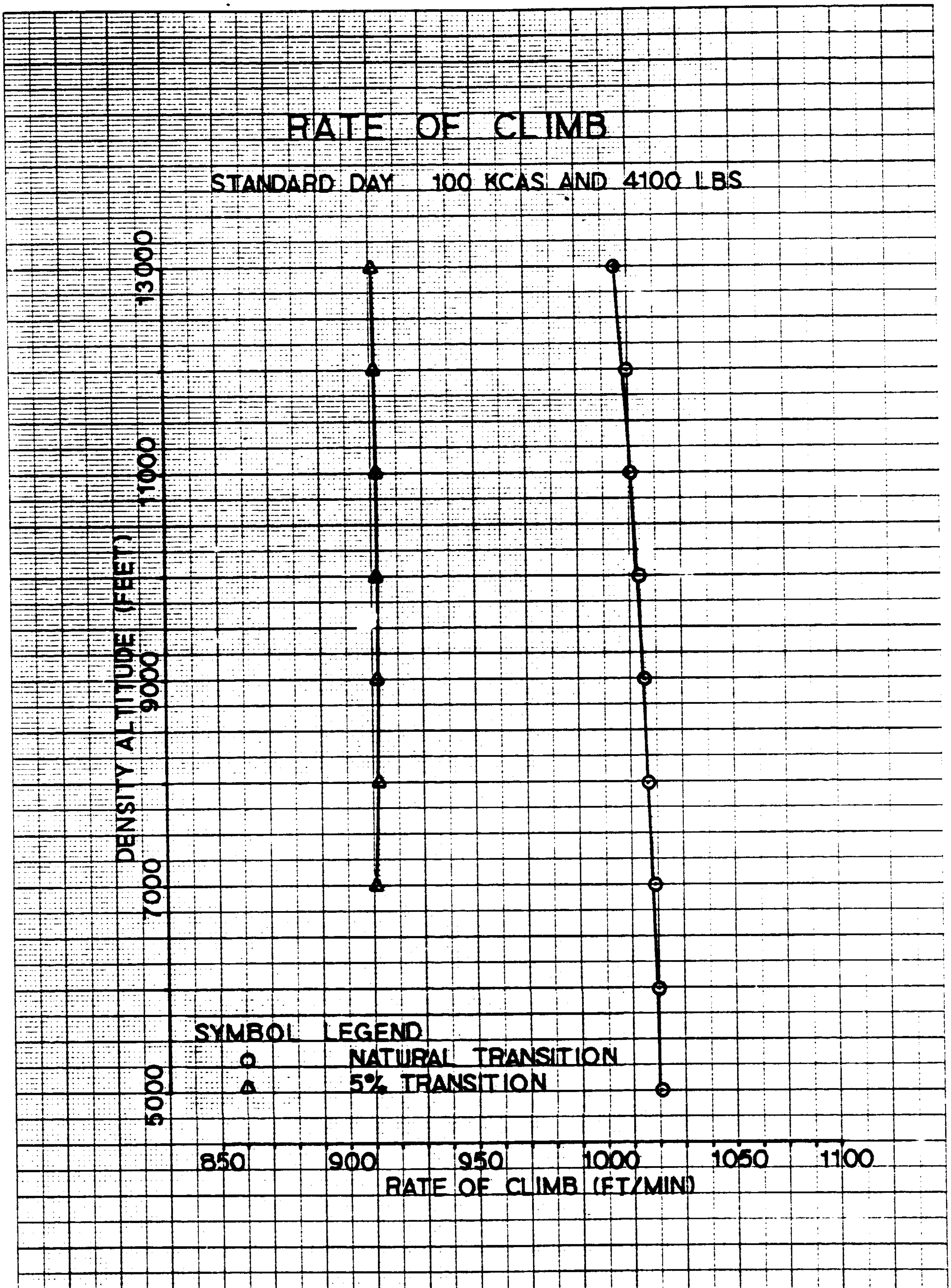

RATE OF CLIMB
STANDARD DAY 100 KCAS AND 4100 LBS
DENSITY ALTITUDE (FEET)
13000
11000
9000
7000
5000
SYMBOL LEGEND
NATURAL TRANSITION
5% TRANSITION
850
900
950
1000
1050
1100
RATE OF CLIMB (FT/MIN)

Figure 9

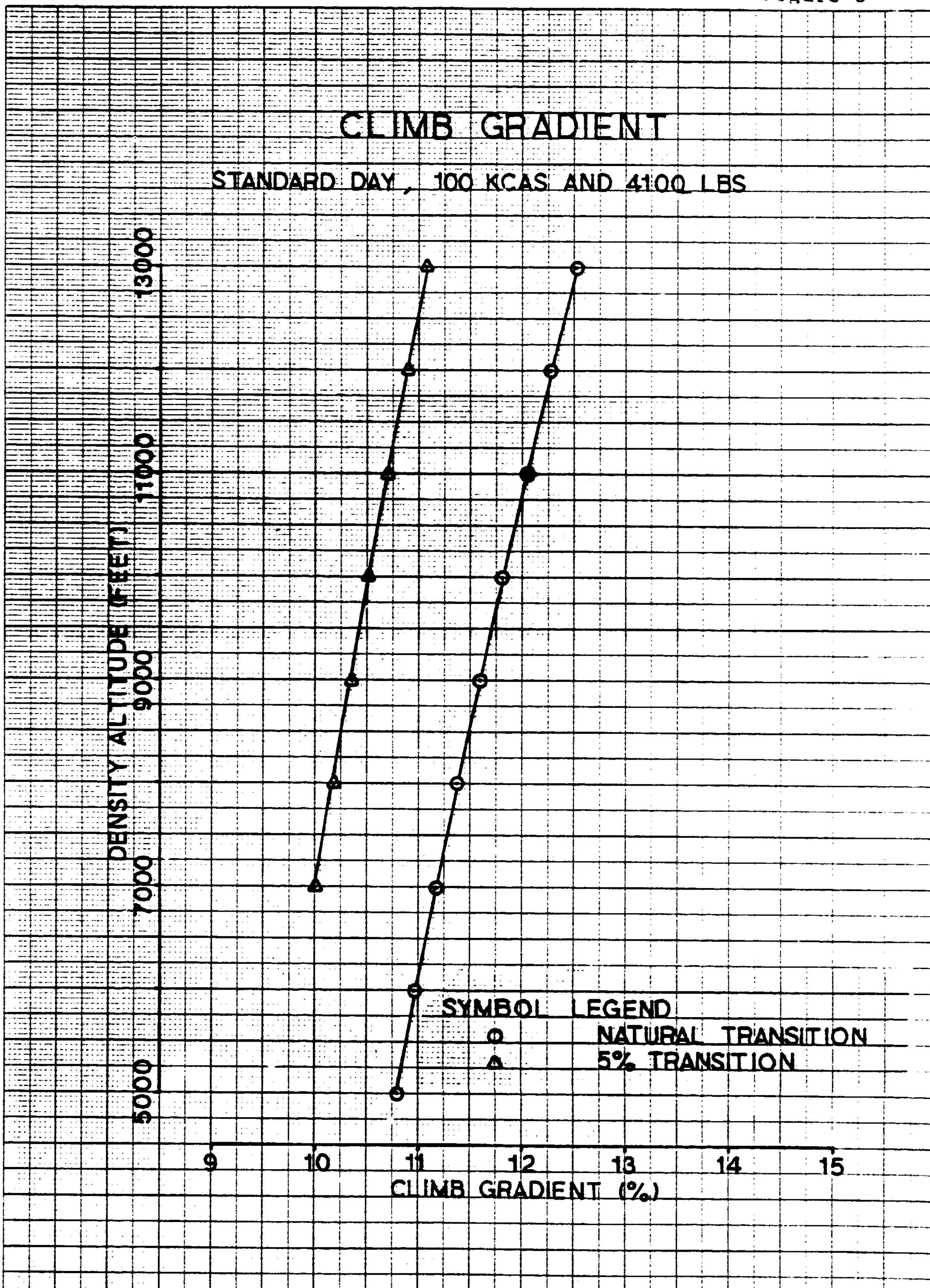
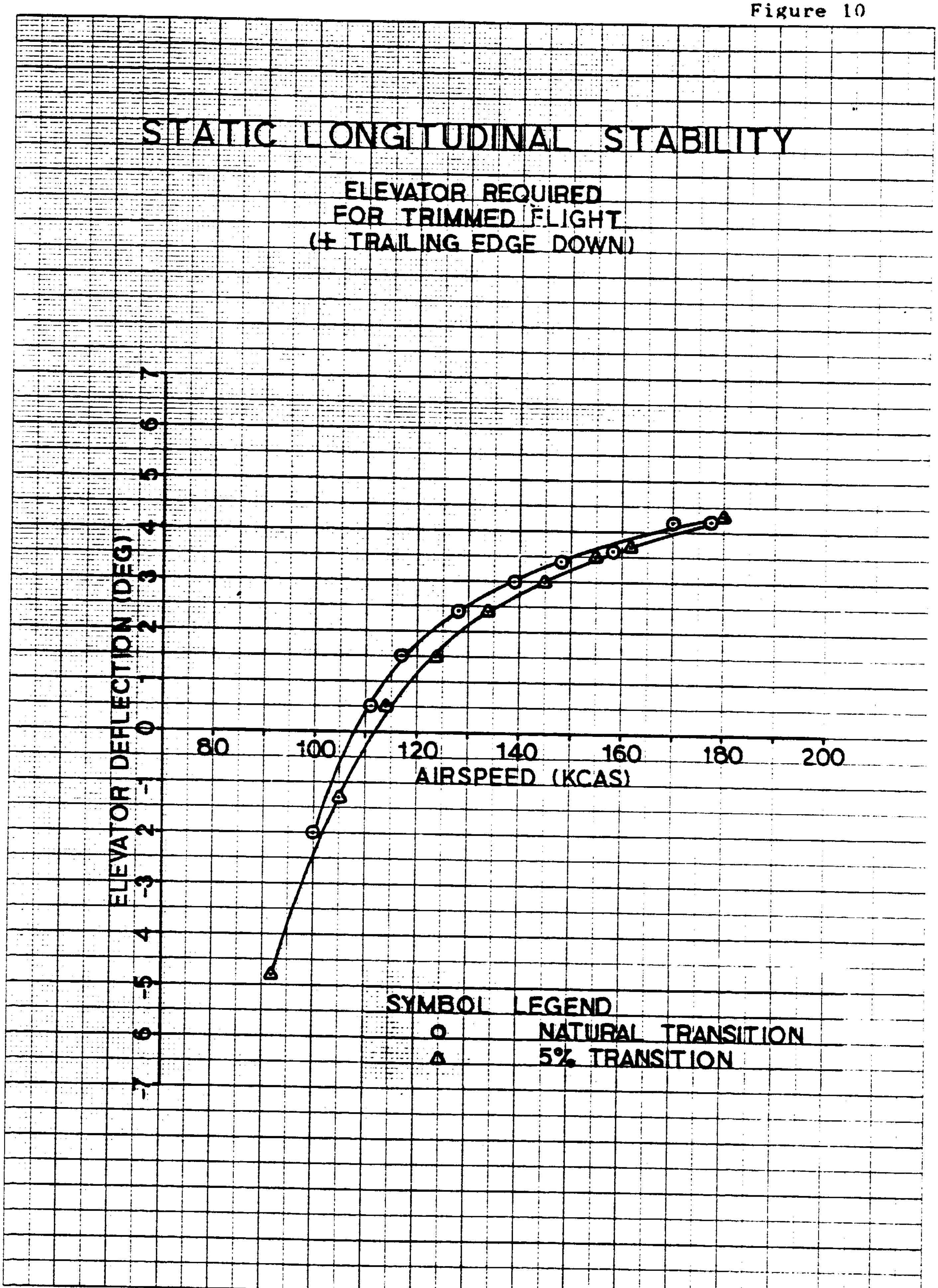
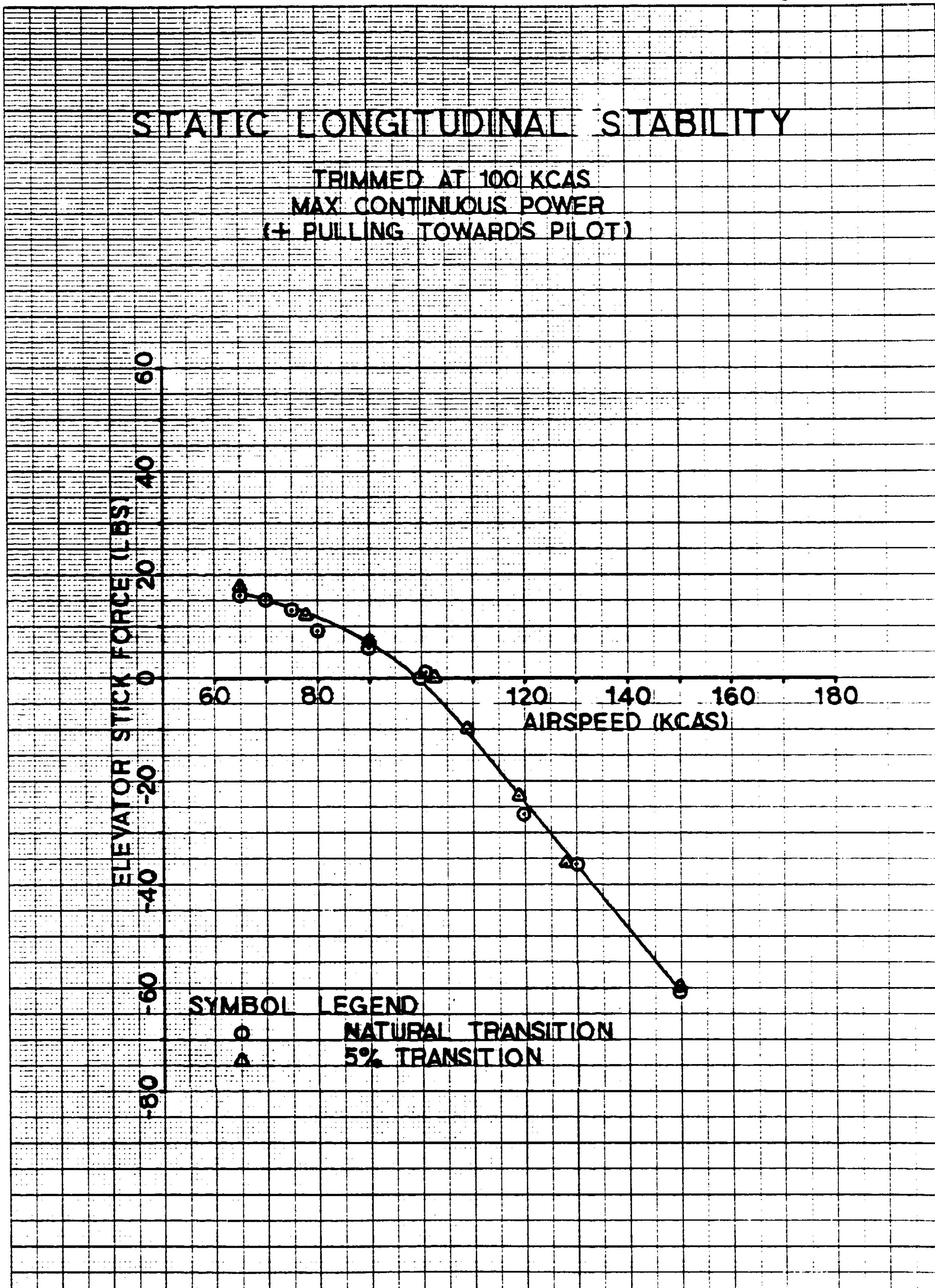

CLIMB GRADIENT
STANDARD DAY, 100 KCAS AND 4100 LBS
DENSITY ALTITUDE (FEET)
5000
7000
9000
11000
13000
9
10
11
12
13
14
15
CLIMB GRADIENT (%)
SYMBOL LEGEND
NATURAL TRANSITION
5% TRANSITION

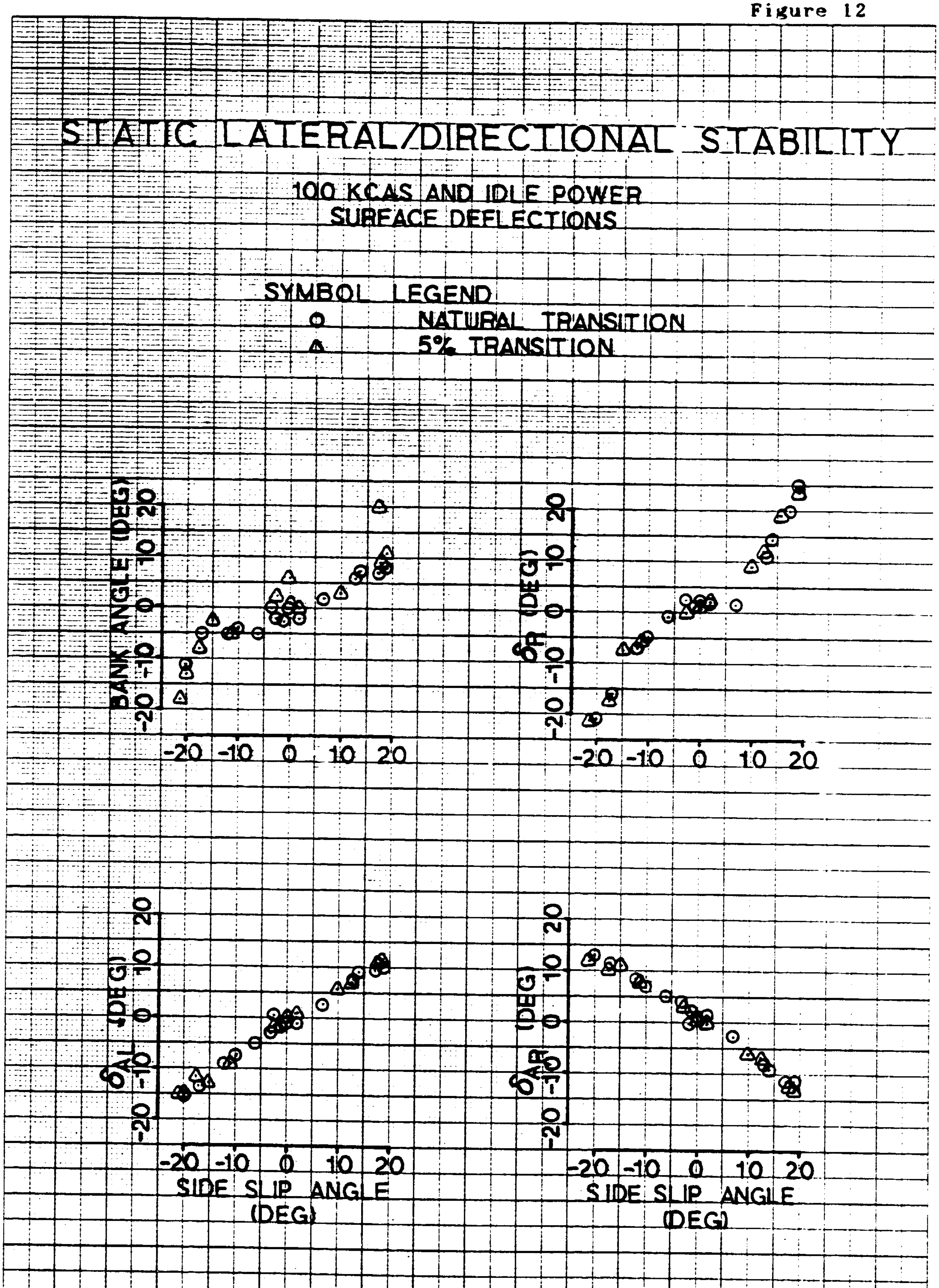
Figure 10



STATIC LONGITUDINAL STABILITY
ELEVATOR REQUIRED
FOR TRIMMED FLIGHT
(+ TRAILING EDGE DOWN)
ELEVATOR DEFLECTION (DEG)
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
80
100
120
140
160
180
200
AIRSPEED (KCAS)
SYMBOL LEGEND
O NATURAL TRANSITION
Δ 5% TRANSITION

Figure 11


STATIC LONGITUDINAL STABILITY
TRIMMED AT 100 KCAS
MAX CONTINUOUS POWER
(+ PULLING TOWARDS PILOT)
ELEVATOR STICK FORCE (LBS)
60
40
20
0
-20
-40
-60
-80
60
80
120
140
160
180
AIRSPEED (KCAS)
SYMBOL LEGEND
NATURAL TRANSITION
5% TRANSITION


STATIC LATERAL/DIRECTIONAL STABILITY
100 KCAS AND IDLE POWER
SURFACE DEFLECTIONS
SYMBOL LEGEND
NATURAL TRANSITION
5% TRANSITION
BANK ANGLE (DEG)
-20 -10 0 10 20
δ_R (DEG)
δ_{AL} (DEG)
δ_{AR} (DEG)
SIDE SLIP ANGLE
(DEG)

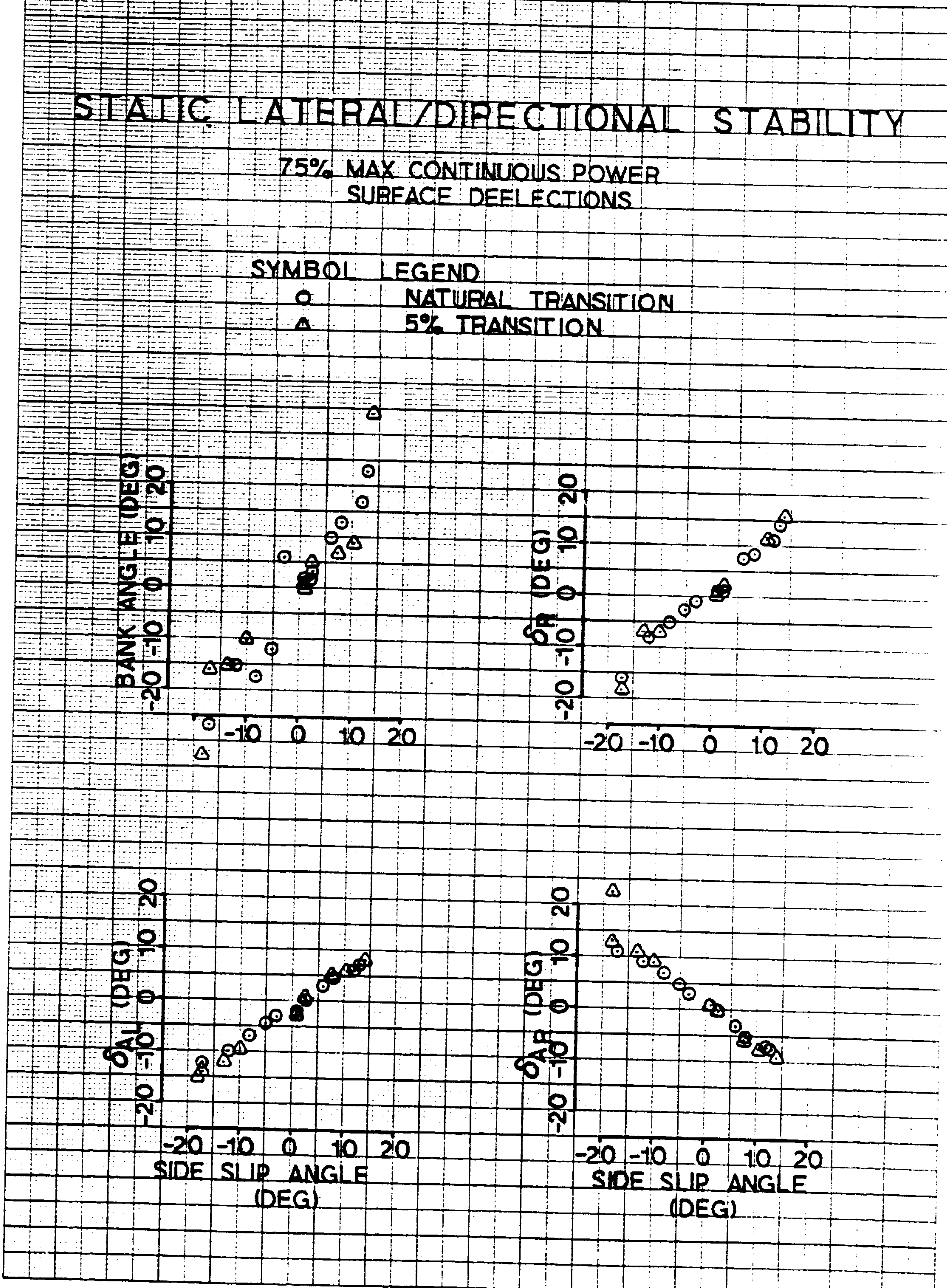
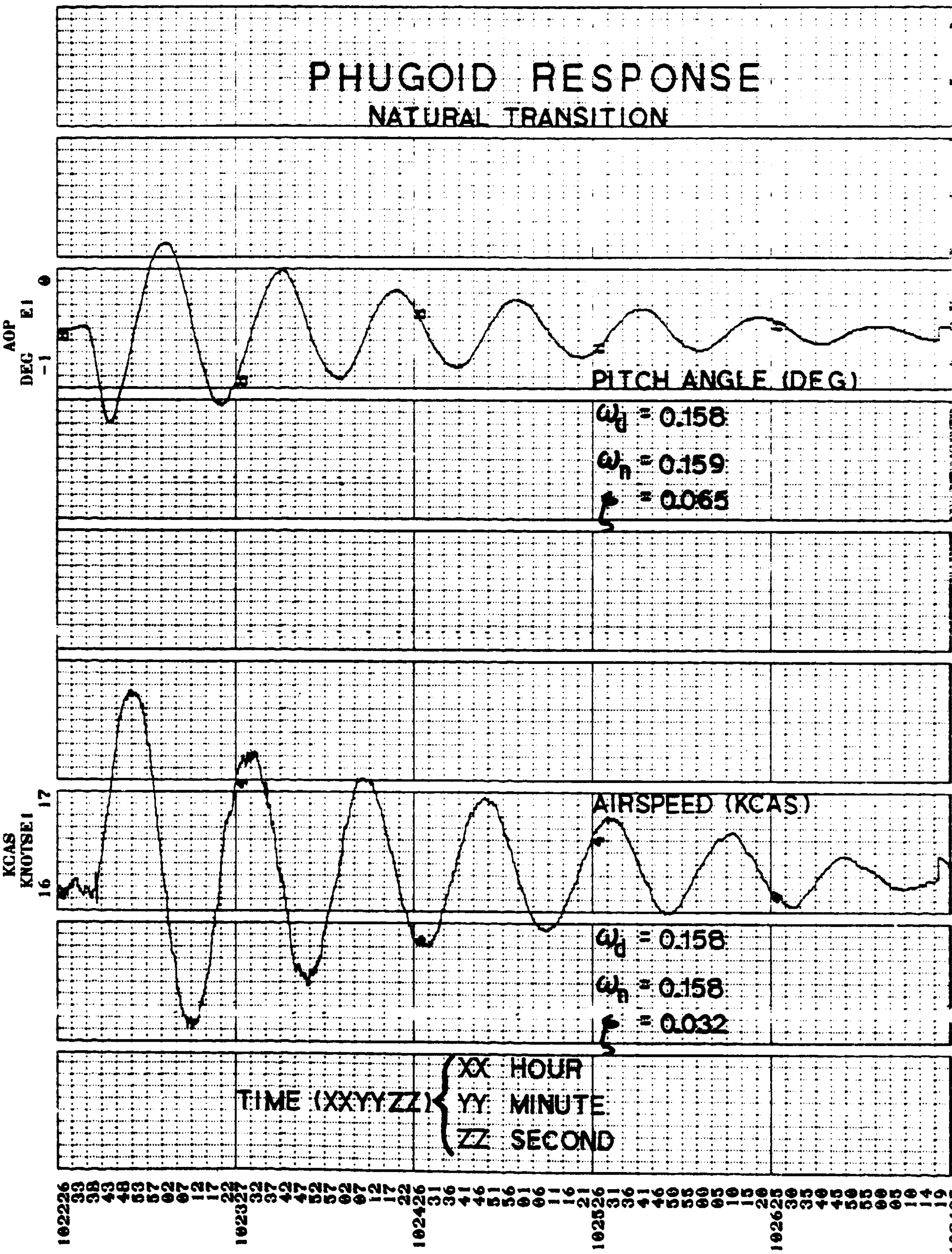

STATIC LATERAL/DIRECTIONAL STABILITY
75% MAX CONTINUOUS POWER
SURFACE DEFLECTIONS
SYMBOL LEGEND
○ NATURAL TRANSITION
△ 5% TRANSITION
BANK ANGLE (DEG)
δR (DEG)
δAL (DEG)
δAR (DEG)
-20 -10 0 10 20
SIDE SLIP ANGLE (DEG)
SIDE SLIP ANGLE (DEG)

Figure 14


PHUGOID RESPONSE
NATURAL TRANSITION
AOP DEG E1
0
-1
PITCH ANGLE (DEG)
ω_d = 0.158
ω_n = 0.159
ζ = 0.065
KCAS KNOTSE1
17
16
AIRSPEED (KCAS)
ω_d = 0.158
ω_n = 0.158
ζ = 0.032
TIME (XXYYZZ)
XX HOUR
YY MINUTE
ZZ SECOND
102226
102326
102426
102526
102626

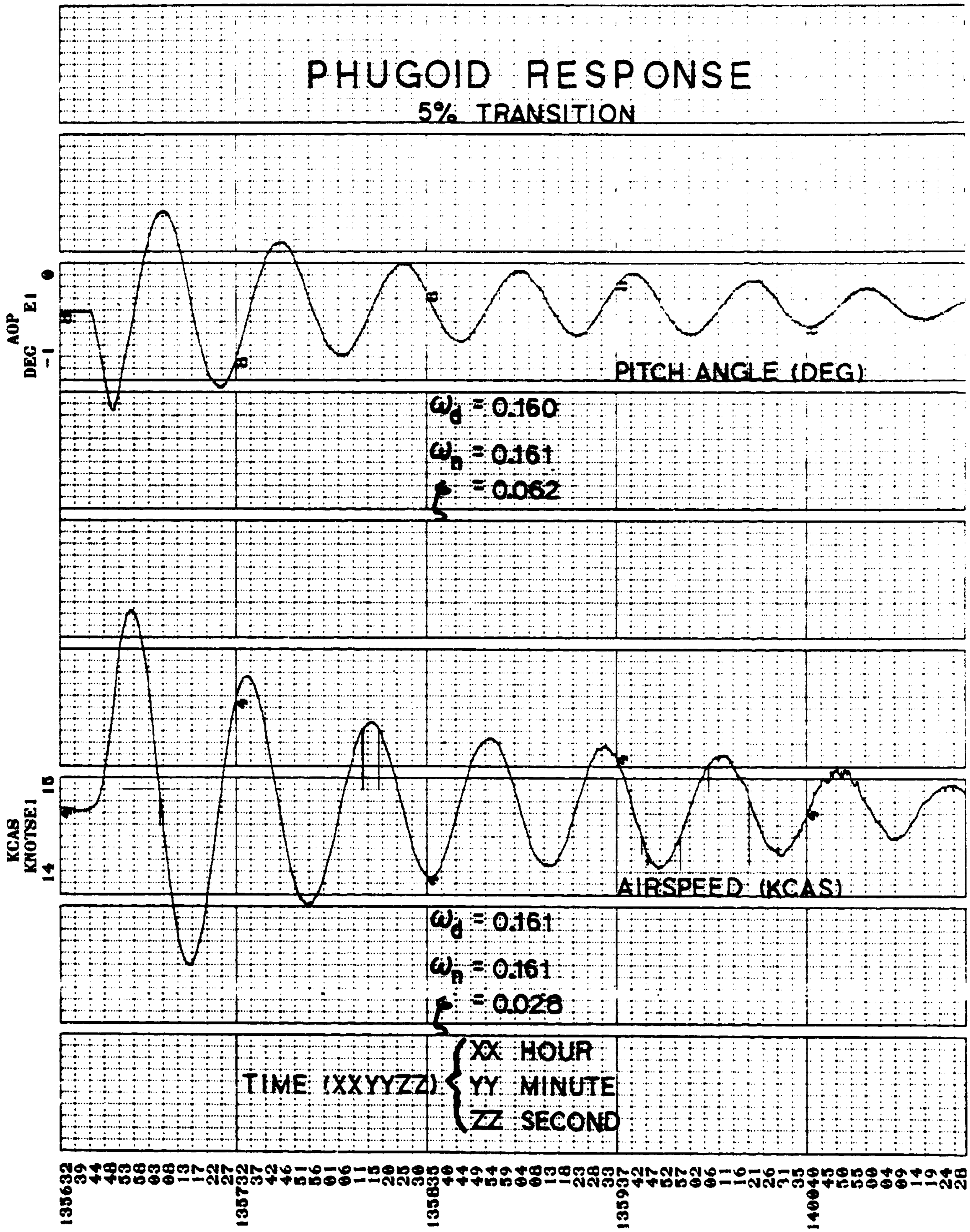
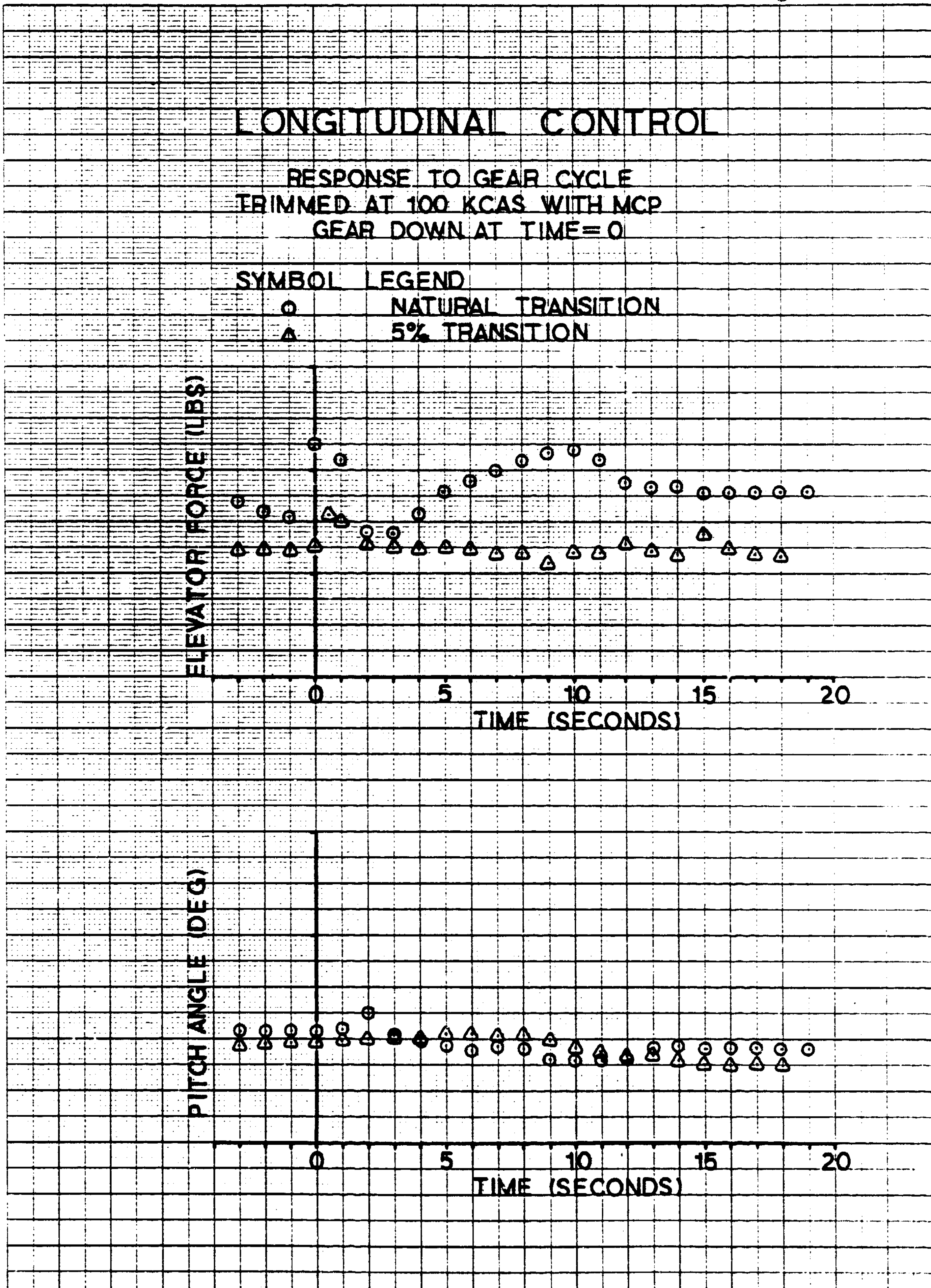
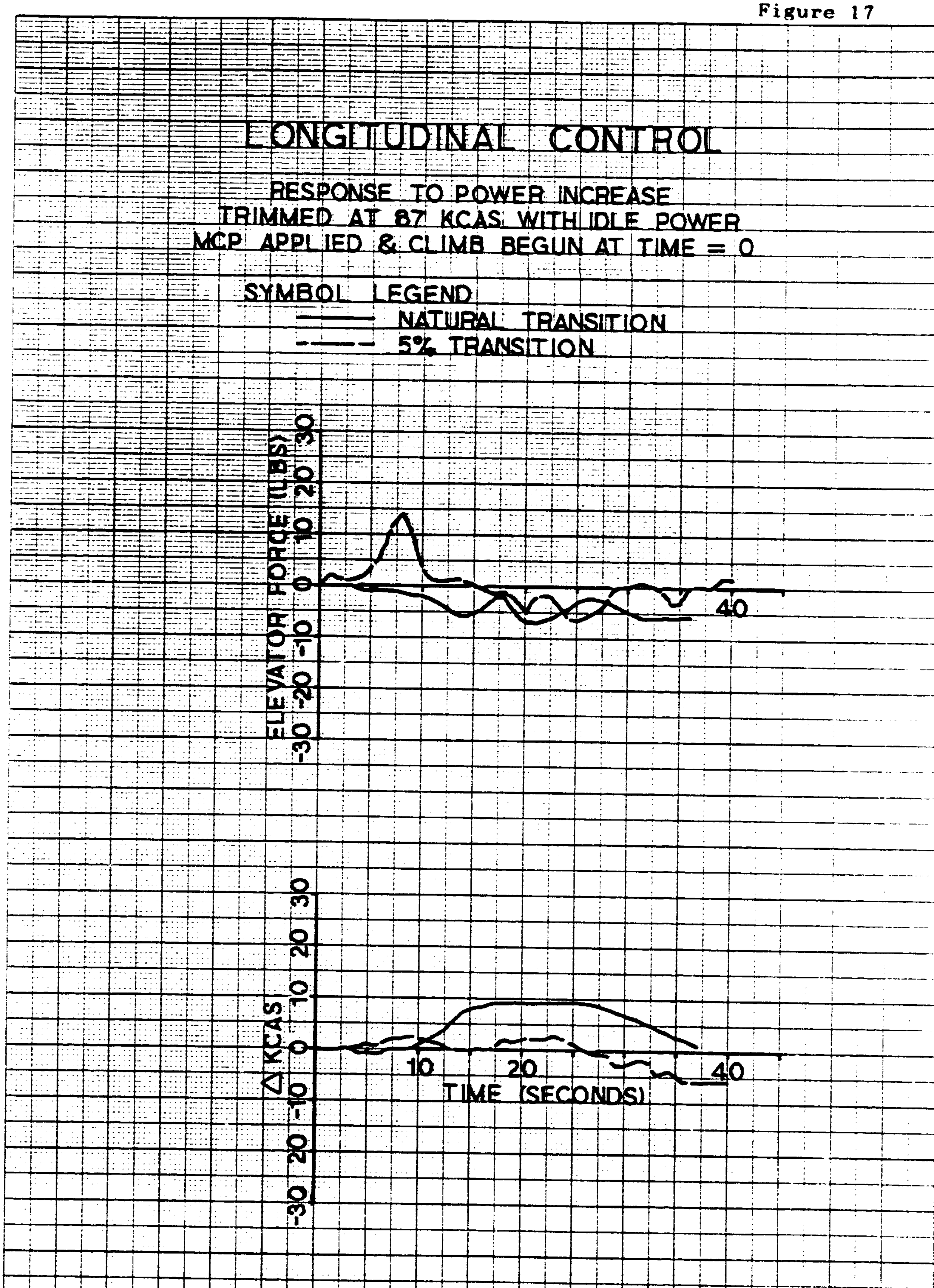

PHUGOID RESPONSE
5% TRANSITION
AOP
DEC E1
0
-1
PITCH ANGLE (DEG)
ω_d = 0.160
ω_n = 0.161
ζ = 0.062
KCAS
KNOTSE1
15
14
AIRSPEED (KCAS)
ω_d = 0.161
ω_n = 0.161
ζ = 0.028
TIME (XXYYZZ)
XX HOUR
YY MINUTE
ZZ SECOND
135632
135732
135835
135937
140040

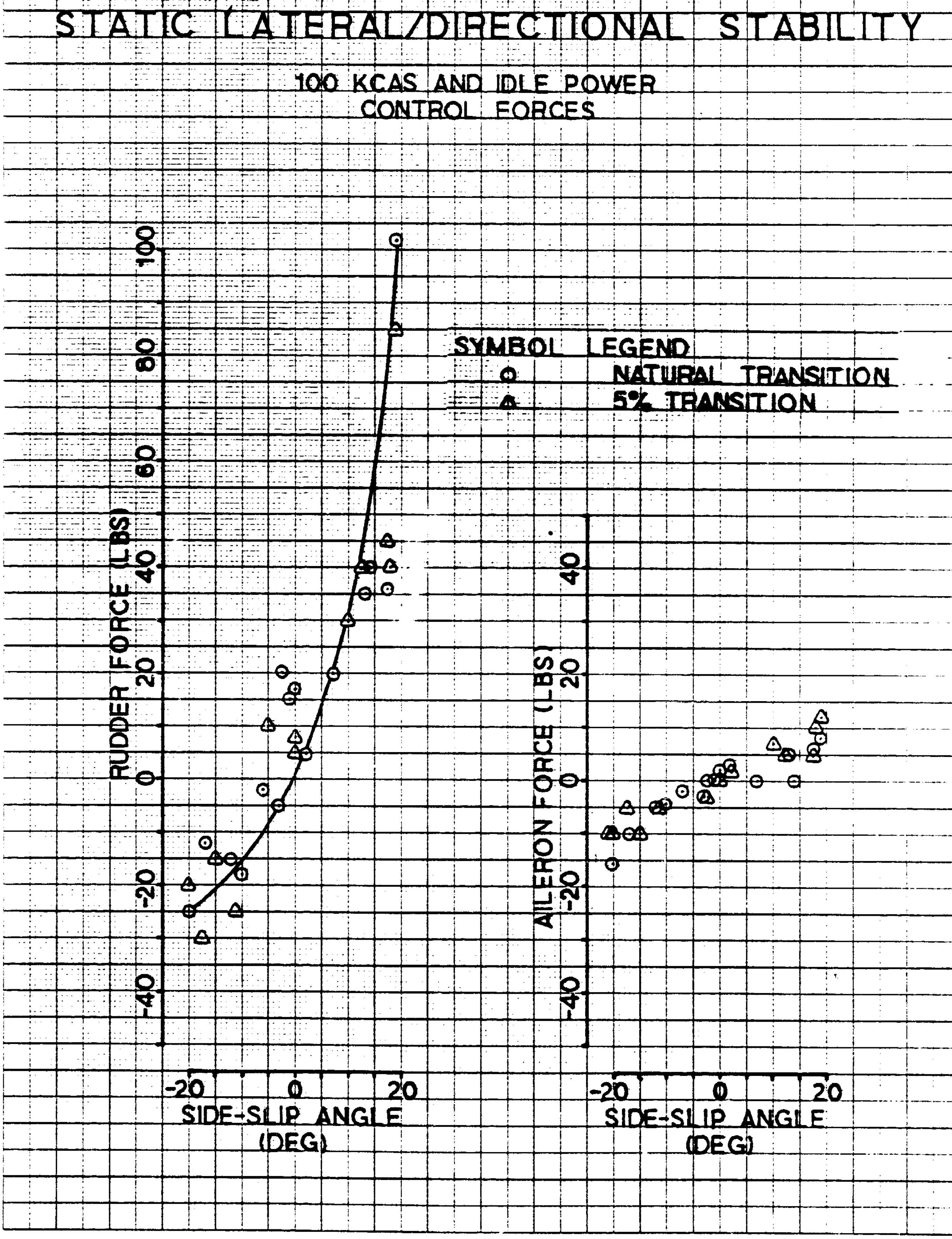
Figure 16



LONGITUDINAL CONTROL
RESPONSE TO GEAR CYCLE
TRIMMED AT 100 KCAS WITH MCP
GEAR DOWN AT TIME=0
SYMBOL LEGEND
NATURAL TRANSITION
5% TRANSITION
ELEVATOR FORCE (LBS)
0
5
10
15
20
TIME (SECONDS)
PITCH ANGLE (DEG)
0
5
10
15
20
TIME (SECONDS)

Figure 17


LONGITUDINAL CONTROL
RESPONSE TO POWER INCREASE
TRIMMED AT 87 KCAS WITH IDLE POWER
MCP APPLIED & CLIMB BEGUN AT TIME = 0
SYMBOL LEGEND
NATURAL TRANSITION
5% TRANSITION
ELEVATOR FORCE (LBS)
-30 -20 -10 0 10 20 30
40
Δ KCAS
-30 -20 -10 0 10 20 30
10 20 40
TIME (SECONDS)


STATIC LATERAL/DIRECTIONAL STABILITY
100 KCAS AND IDLE POWER
CONTROL FORCES
SYMBOL LEGEND
NATURAL TRANSITION
5% TRANSITION
RUDDER FORCE (LBS)
100
80
60
40
20
0
-20
-40
-20
0
20
SIDE-SLIP ANGLE
(DEG)
AILERON FORCE (LBS)
40
20
0
-20
-40
-20
0
20
SIDE-SLIP ANGLE
(DEG)

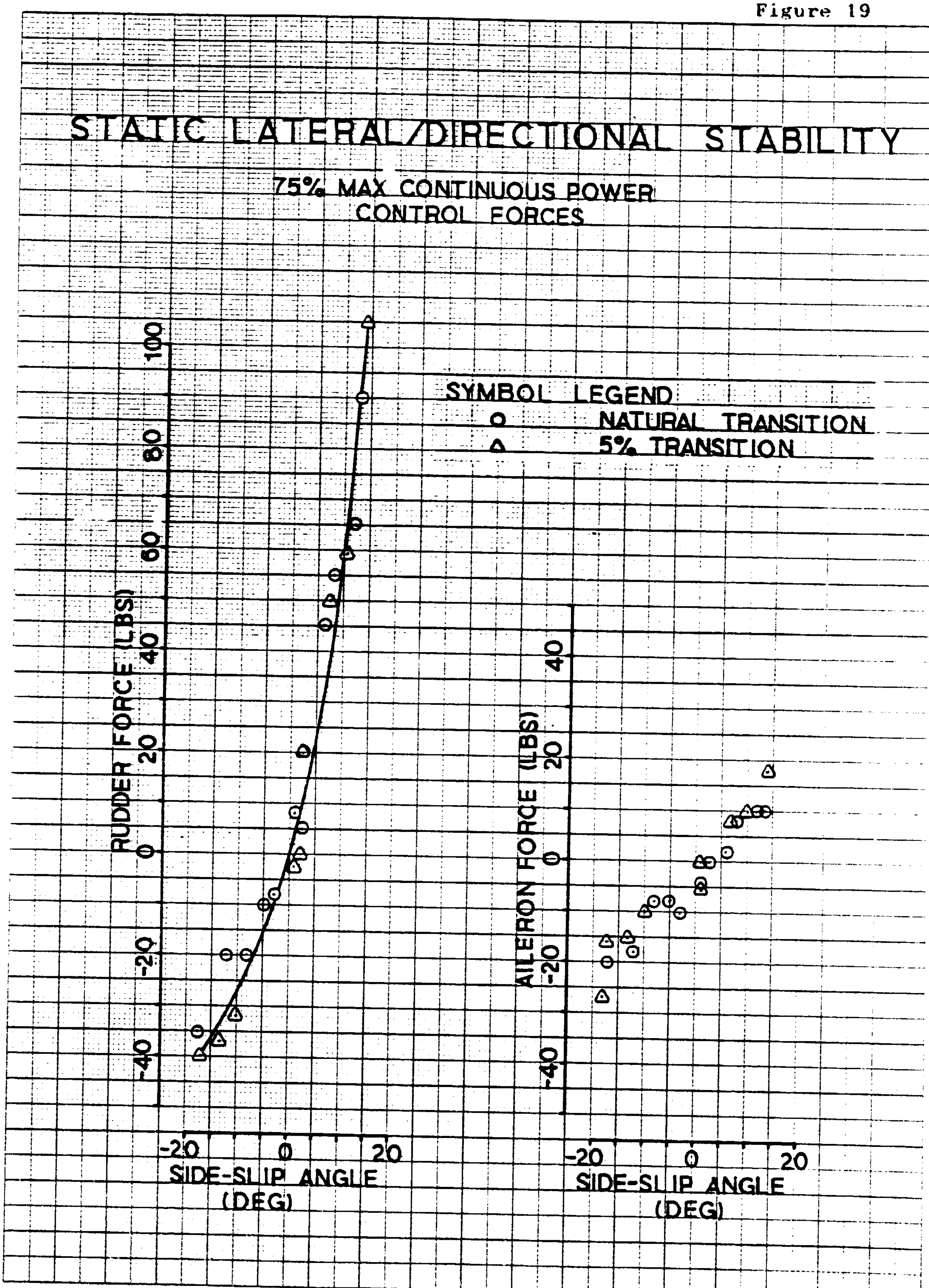
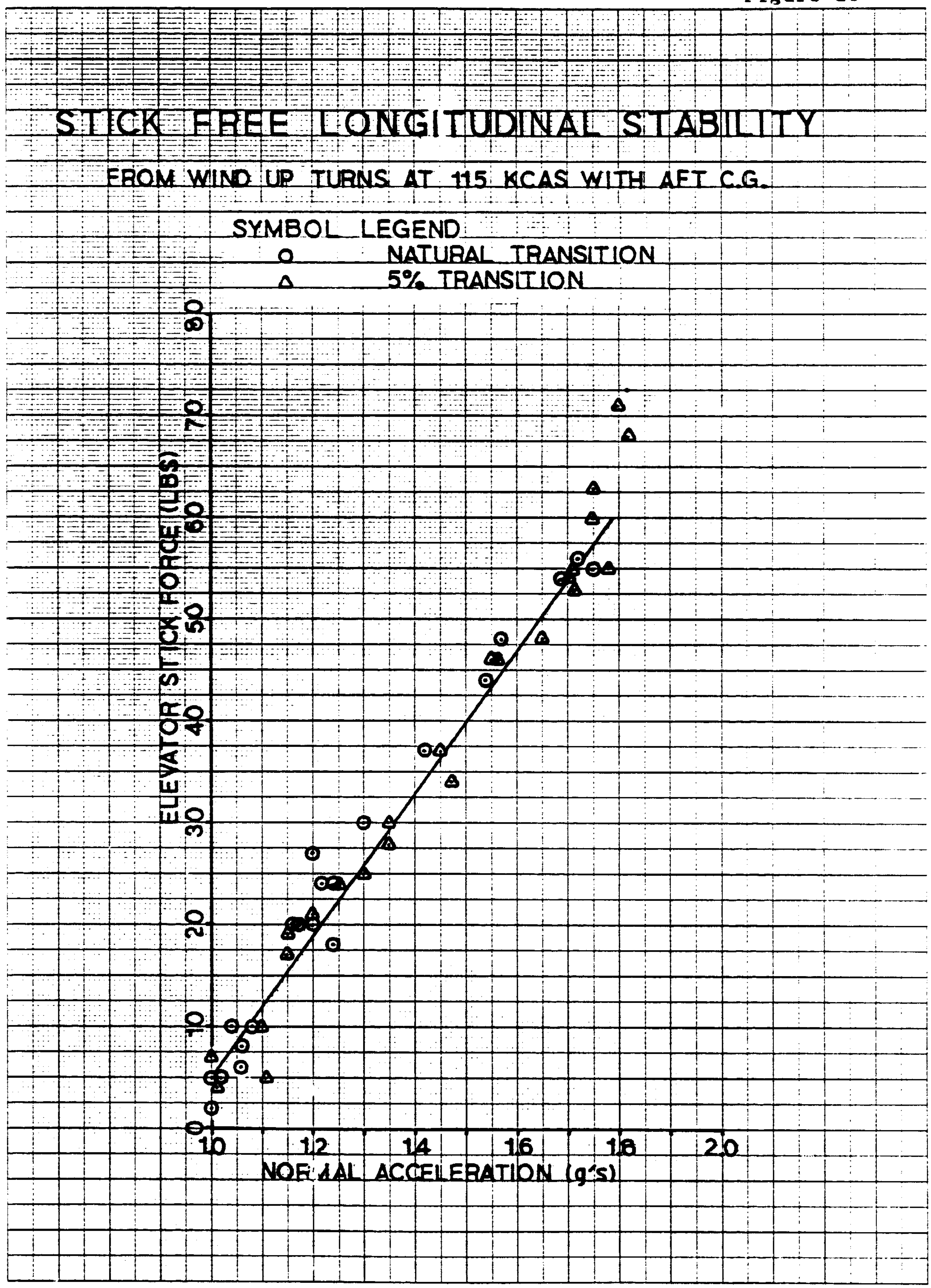

STATIC LATERAL/DIRECTIONAL STABILITY
75% MAX CONTINUOUS POWER
CONTROL FORCES
SYMBOL LEGEND
o NATURAL TRANSITION
Δ 5% TRANSITION
RUDDER FORCE (LBS)
100
80
60
40
20
0
-20
-40
SIDE-SLIP ANGLE
(DEG)
-20
0
20
AILERON FORCE (LBS)
40
20
0
-20
-40
SIDE-SLIP ANGLE
(DEG)
-20
0
20

Figure 20


STICK FREE LONGITUDINAL STABILITY
FROM WIND UP TURNS AT 115 KCAS WITH AFT C.G.
SYMBOL LEGEND
o NATURAL TRANSITION
Δ 5% TRANSITION
ELEVATOR STICK FORCE (LBS)
0
10
20
30
40
50
60
70
80
1.0
1.2
1.4
1.6
1.8
2.0
NORMAL ACCELERATION (g's)

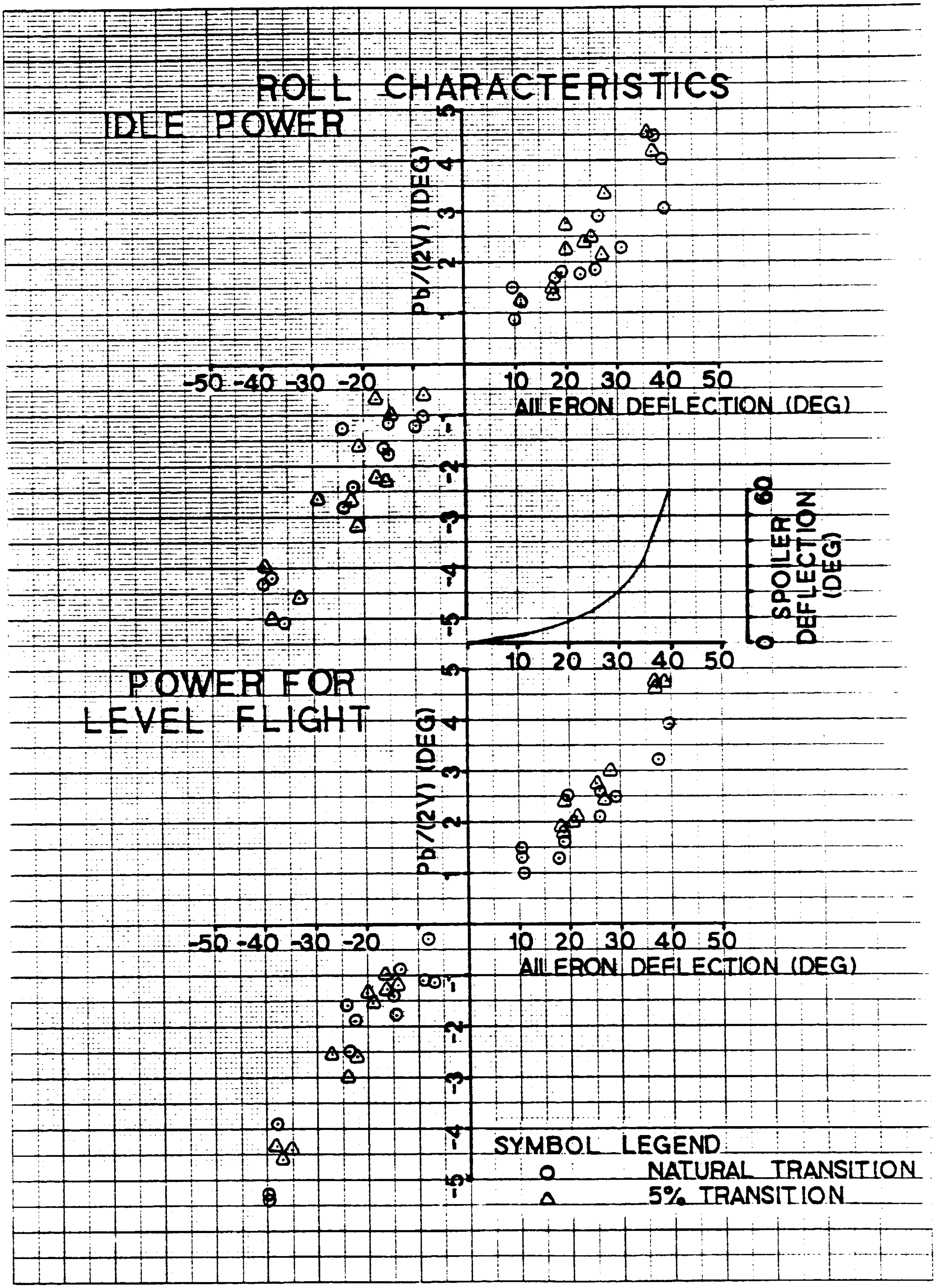
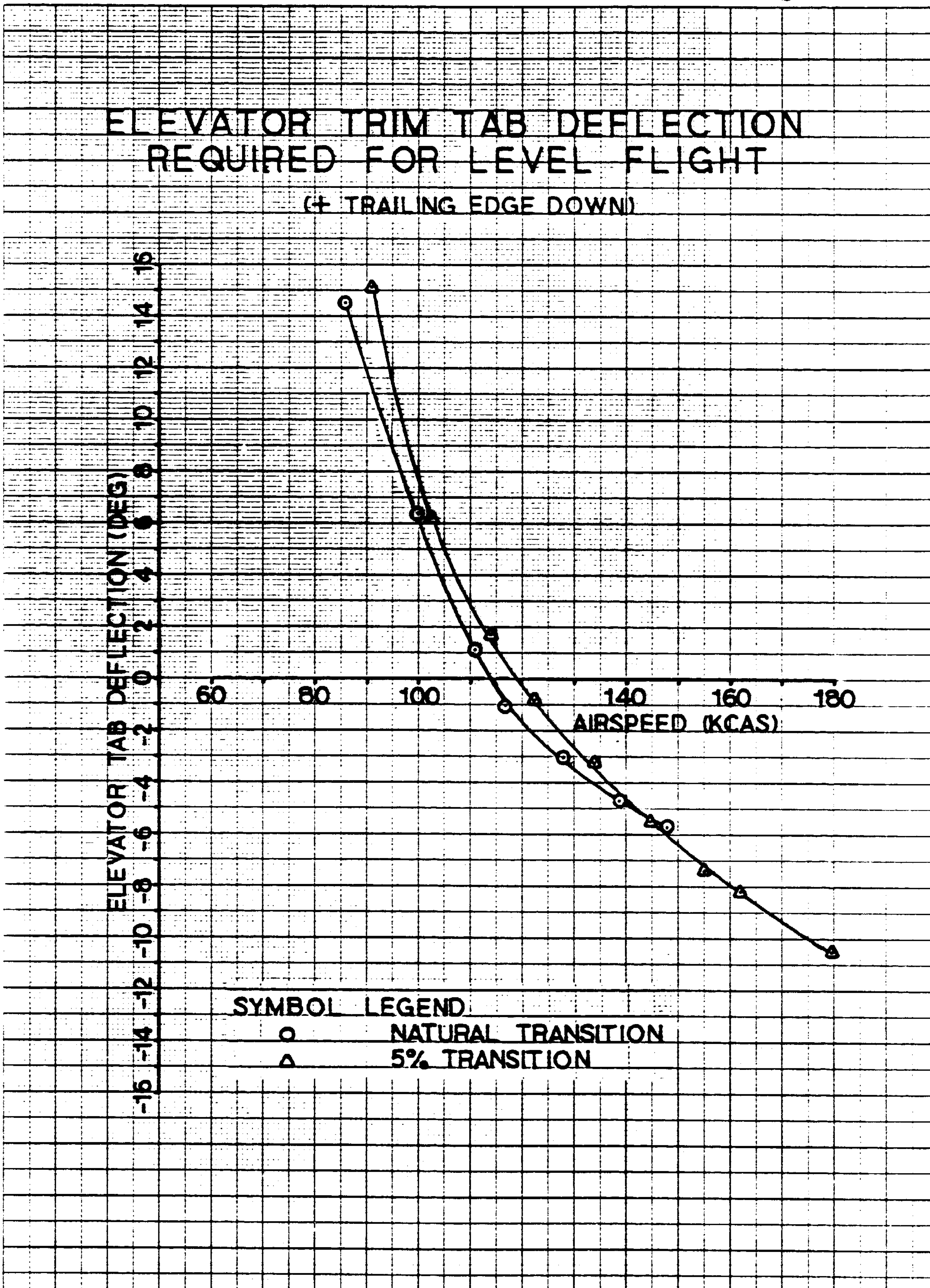
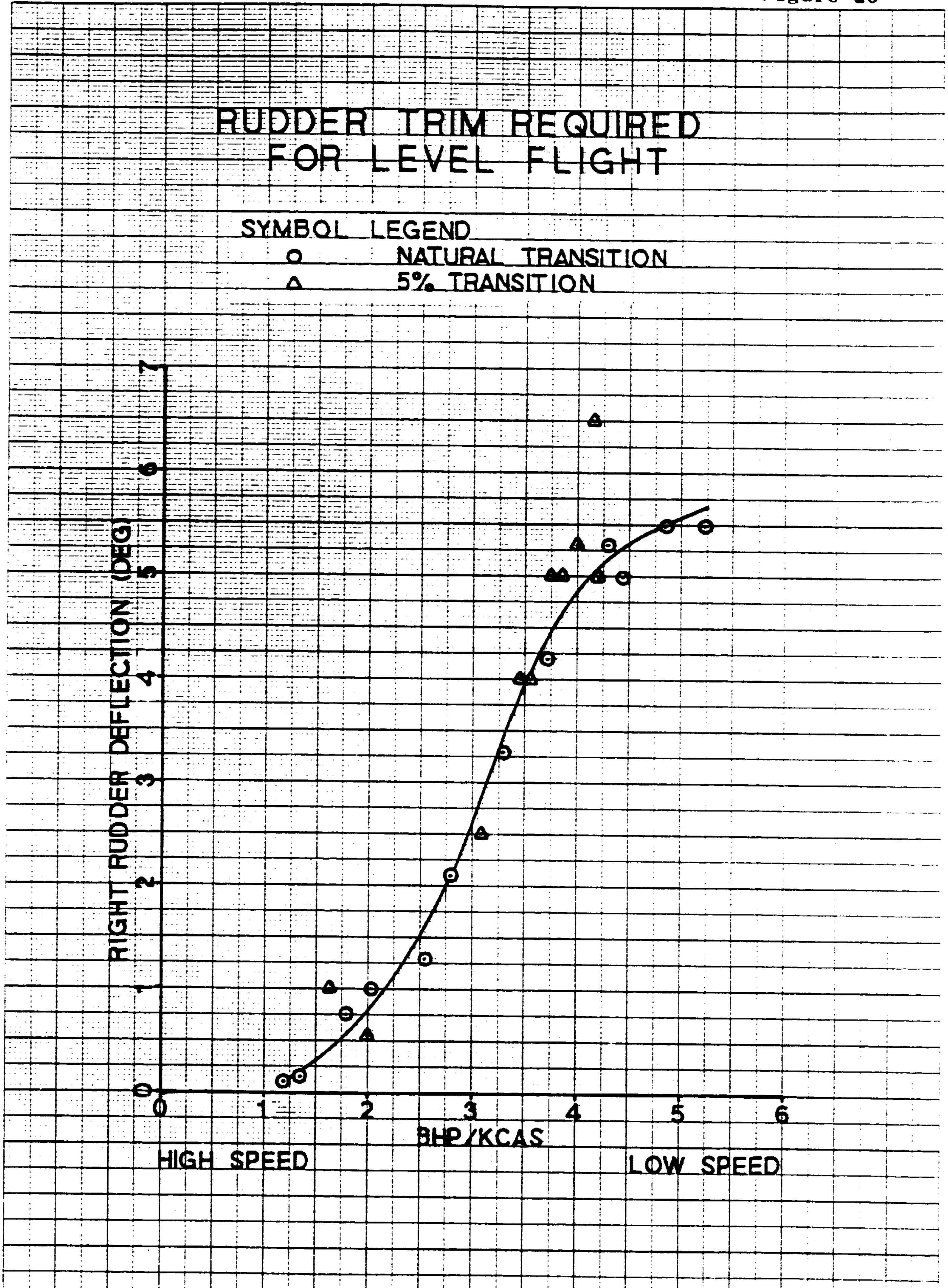

ROLL CHARACTERISTICS
IDLE POWER
Pb/(2V) (DEG)
AILERON DEFLECTION (DEG)
SPOILER DEFLECTION (DEG)
POWER FOR LEVEL FLIGHT
Pb/(2V) (DEG)
AILERON DEFLECTION (DEG)
SYMBOL LEGEND
NATURAL TRANSITION
5% TRANSITION

Figure 22



ELEVATOR TRIM TAB DEFLECTION
REQUIRED FOR LEVEL FLIGHT
(+ TRAILING EDGE DOWN)
ELEVATOR TAB DEFLECTION (DEG)
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
60
80
100
140
160
180
AIRSPEED (KCAS)
SYMBOL LEGEND
○ NATURAL TRANSITION
△ 5% TRANSITION


RUDDER TRIM REQUIRED
FOR LEVEL FLIGHT
SYMBOL LEGEND
o NATURAL TRANSITION
Δ 5% TRANSITION
RIGHT RUDDER DEFLECTION (DEG)
0
1
2
3
4
5
6
7
0
1
2
3
4
5
6
BHP/KCAS
HIGH SPEED
LOW SPEED

NASA National Aeronautics and Space Administration	Report Documentation Page	
1. Report No. NASA CR-181967	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Flight Test Investigation of Certification Issues Pertaining to General-Aviation-Type Aircraft with Natural Laminar Flow		5. Report Date April 1990
		6. Performing Organization Code
7. Author(s) Wayne A. Doty		8. Performing Organization Report No.
		10. Work Unit No. 505-45-33-64
9. Performing Organization Name and Address Cessna Aircraft Company P.O. Box 7704 Wichita, KS 67277		11. Contract or Grant No. NAS1-18561
		13. Type of Report and Period Covered Contractor Report
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Langley Research Center Hampton, VA 23665-5225		14. Sponsoring Agency Code
15. Supplementary Notes Langley Technical Monitor: Gregory S. Manuel		

16. Abstract

Development of Natural Laminar Flow (NLF) technology for application to general-aviation-type aircraft has raised some question as to the adequacy of FAR Part 23 for certification of aircraft with significant NLF.

A series of flight tests have been conducted with a modified Cessna T210 to allow quantitative comparison of the aircraft's ability to meet certification requirements with significant NLF and with boundary layer transition fixed near the leading edge.

There were no significant differences between the two conditions except an increase in drag, which resulted in longer takeoff distances and reduced climb performance.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Flight Test Certification Natural Laminar Flow General Aviation	Unclassified - Unlimited Subject Category 02

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	47	

NASA FORM 1626 OCT 86

END

DATE

FILMED

JUN 19 1990