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EVALUATION OF THE FLYING QUALITIES REQUIREMENTS OF MIL-F-8785B (ASG) USING THE C-5A AIRPLANE

Charles L. Silvers, et al

Lockheed-Georgia Company

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20 March 1975

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LOCKHEED—GEORGIA COMPANY

TECHNICAL REPORT AFFDL—TR—75—3

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This study was conducted to validate military specification MIL-F-8785B(ASG), "Flying Qualities of Piloted Airplanes," dated 7 August 1969, Interim Amendment-1 (USAF), dated 31 March 1971, by performing a detail comparison of its requirements with the known characteristics of the Lockheed C-5A and pilot comments on them.

The comparison was based primarily on existing flight test data supplemented by analytical data as required for this evaluation process. Paragraph by paragraph

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validations or discrepancies are noted, resolution attempted if necessary, and any recommendations given.

In addition, recommendations are made enumerating experimental and analytical investigations beyond the scope of this study which will provide data for further validation and updating of the requirements.

FOREWORD

This report was prepared by the Lockheed-Georgia Company, Marietta, Georgia, for the Air Force Systems Command, United States Air Force, Wright-Patterson Air Force Base, Ohio. This study was conducted under Contract F33615-75-C-3012. Captain Jerry Callahan (FGC) was the Project Engineer.

This report was prepared by C. L. Silvers and C. C. Withers with assistance from C. A. Mason, C. E. Houston, and W. B. Southerland.

This report represents the views of the authors, which may not necessarily be the same in all cases as the views of the Air Force or those of the Lockheed-Georgia Company.

SUMMARY

This report presents the results of a study to validate Military Specification MIL-F-8785B(ASG), "Flying Qualities of Piloted Airplanes," dated 7 August 1969, including Interim Amendment-1(USAF), dated 31 March 1971, by performing a detail comparison of its requirements with the known characteristics of the C-5A and pilot comments.

The comparison was based primarily on Category I/II test results supplemented by analytical data and results obtained during the ALDCS development test program. Paragraph by paragraph evaluations or discrepancies are noted and, if necessary, discussions and recommendations given.

Results of the comparison show that the specifications favorably compare with C-5A data except in the sections noted below. The requirements for these sections appear to have been based on an abundance of light and medium weight airplane data with little conflicting data from Class III heavy weight airplane data.

3.2.1.2	Phugoid Stability
3.2.2.1	Short Period Response
3.2.2.2.1	Control Forces in Maneuvering Flight
3.3.1.1	Lateral Directional Oscillations (Dutch Roll)
3.3.1.2	Roll Mode (τ_R)
3.3.2.4	Sideslip Excursions
3.3.4	Roll Control Effectiveness
3.4.2.2.1	Resistance to Loss of Control

From the above list, the most significant difference between the specification and C-5A data appear in the sections related to lateral control. Based on C-5A data, the requirements of Sections 3.3.1.2-Roll Mode, 3.3.2.4-Sideslip Excursions, and 3.3.4-Roll Control Effectiveness are far too stringent for Class III airplanes. Section IV of this report lists additional paragraphs of the specification where recommendations have been made.

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LIST OF SYMBOLS

Symbol	Definition
b	Wing span, ft
$C_{1/2}$	Cycles to damp to half amplitude
$C_{1/10}$	Cycles to damp to 1/10 amplitude
CG	Center of gravity
c.g.	Center of gravity
D	Aerodynamic drag, parallel to flight path, lb
F	Total number of failures
F_s	Elevator control force, applied by pilot, lb
F_s/n	Gradient of steady-state elevator control force versus n at constant speed, lb/g
g	Acceleration of gravity, ft/sec^2
h	Height above ground level (AGL) or above mean sea level (MSL), ft
h_{max}	Maximum service altitude, ft
$h_{o_{max}}$	Maximum operational altitude, ft
$h_{o_{min}}$	Minimum operational altitude, ft
H	Total flight hours, hr
I_x, I_y, I_z	Moments of inertia about x, y, and z axes, respectively, slug-ft^2
I_{xz}	Product of inertia, slug-ft^2
k	Ratio of "commanded roll performance" to applicable roll performance requirement" of 3.3.4 or 3.3.4.1
K	$K = \sqrt{I_y/m}$
KCAS	Airspeed, knots calibrated
L	Aerodynamic lift plus thrust component, normal to the flight path, lb

LIST OF SYMBOLS (Cont.)

Symbol	Definition
L	Rolling moment about the x-axis, including thrust effects, ft-lb
m	Mass of airplane, slugs
M	Mach number
M	Pitching moment about the y-axis, including thrust effects, ft-lb
M_{F_s}	$= \frac{\delta_e}{F_s} M_{\delta_e}$
MAC	Mean aerodynamic chord
n	Normal acceleration of normal load factor, measured at the c.g., g's
n/α	The steady-state normal acceleration change per unit change in angle of attack for an incremental elevator deflection at constant speed (airspeed and Mach number) g's/rad
n_L	Symmetrical flight limit load factor for a given Airplane Normal State, based on structural considerations, g's
n_{max}, n_{min}	Maximum and minimum service load factors, g's
n(+), n(-)	For a given altitude, the upper and lower boundaries of n in the V-n diagrams depicting the Service Flight Envelope, g's
$n_{o_{max}}$, $n_{o_{min}}$	Maximum and minimum operational and load factors, g's
$n_o(+)$, $n_o(-)$	For a given altitude, the upper and lower boundaries of n in the V-n diagrams depicting the Operational Flight Envelope, g's
N	Yawing moment about the z-axis, including thrust effects, ft-lb
p	Roll rate about the x-axis, rad/sec
PACS	Pilot-assist cable servo system
$\frac{p_{osc}}{p_{AV}}$	A measure of the ratio of the oscillatory component of roll rate to the average component of roll rate following a rudder-pedals-free step aileron control command

LIST OF SYMBOLS (Cont.)

Symbol	Definition
$\frac{pb}{2V}$	Wing tip helix angle, rad
$\frac{p}{\hat{\beta}}$	Phase angle between roll rate and sideslip in the free Dutch roll oscillation. Angle is positive when p leads $\hat{\beta}$.
p_{ss}	Steady state roll rate following step aileron command, deg/sec
P	Period, sec
P	Probability of encounter, /flight
PIO	Pilot-induced oscillation
q	Dynamic pressure, lb/ft^2
q	Pitch rate, rad/sec
r	Yaw rate, rad/sec
S	Wing area, ft^2
SAS	Stability Augmentation System
t	Time, sec
t_ϕ	Time to bank angle ϕ, in response to control deflection of the form given in 3.3.4, sec
T	Longest mission, hr
T_d	Damped period of the Dutch roll, sec
T_2	Time to double amplitude, sec
$T_{1/2}$	Time to damp to half amplitude, sec
$T_{1/10}$	Time to damp to 1/10 amplitude, sec
u	Incremental velocity along the x reference axis, ft/sec
v	Incremental velocity along the y reference axis, ft/sec

LIST OF SYMBOLS (Cont.)

Symbol	Definition
V	Airspeed, kt
V_{end}	Speed for maximum endurance
V_{MAT}	High speed, level flight, maximum augmented thrust
V_{max}	Maximum service speed
V_{range}	Speed for maximum range in zero wind conditions
V_{min}	Minimum service speed
V_{MRT}	High speed, level flight, military rated thrust
$V_{R/C}$	Speed for maximum rate of climb
V_S	Stall speed (equivalent airspeed), at 1 g normal to the flight path
V_{trim}	Trim speed
$V_{o_{max}}$	Maximum operational speed
$V_{o_{min}}$	Minimum operational speed
W	Weight of the airplane, lb
w	Incremental velocity along the z reference axis, ft/sec
x	Body-fixed axis of the airplane, along the projection of the undisturbed (trim or operating-point) velocity onto the plane of symmetry, with its origin at the c.g.
X	Force along the x-axis, aerodynamic plus thrust, lb
y	Body-fixed axis of the airplane perpendicular to the plane of symmetry directed out the right wing, with its origin at the c.g.
Y	Force along the y-axis, lb
z	Body-fixed axis of the airplane, directed downward perpendicular to the x and y axes, with its origin at the c.g.
Z	Force along z-axis, lb

LIST OF SYMBOLS (Cont.)

Symbol	Definition
α	Angle of attack, the angle in the plane of symmetry between the fuselage reference line and the tangent to the flight path at the airplane center of gravity
α_s	The stall angle of attack at constant speed for the configuration, weight, center-of-gravity position and external-store combination associated with a given Airplane Normal State
β	Sideslip angle at the center of gravity, angle between undisturbed flow and plane of symmetry. Positive, or right, sideslip corresponds to incident flow approaching from the right side of the plane of symmetry
$\Delta\beta_{max}$	Maximum sideslip excursion at the c.g., occuring within two seconds or one half-period of the Dutch roll, whichever is greater, for a step aileron-control command, deg
γ	climb angle = $\sin^{-1} \frac{\text{vertical speed}}{\text{true airspeed}}$, positive for climb, radians
Δ	Used in combination with other parameters to denote a change from the initial value
δ_a	Aileron surface deflection
δ_e	Elevator surface deflection
δ_r	Rudder surface deflection
ζ_d	Damping ratio of the Dutch roll oscillation
ζ_p	Damping ratio of the phugoid oscillation
ζ_{SP}	Damping ratio of the longitudinal short-period oscillation
θ	Pitch angle, angle between the fuselage reference line and the horizontal, rad
ρ	Air density, slug ft^3
τ_R	First-order roll mode time constant, positive for a stable mode, sec
ϕ	Bank angle measured in the y-z plane, between the y-axis and the horizontal, rad

LIST OF SYMBOLS (Cont.)

Symbol	Definition
ϕ_t	Bank angle change in time t, in response to control deflection of the form given in 3.3.4, rad
$\frac{\phi_{osc}}{\phi_{AV}}$	A measure of the ratio of the oscillatory component of bank angle to the average component of bank angle wollowing a rudder-pedals-free impulse aileron control command
$\frac{\phi_1}{\beta_d}$	At any instant, the ratio of amplitudes of the bank-angle and sideslip-angle envelopes in the Dutch-roll mode
ψ	Phase angle in a cosine representation of the Dutch-roll component of sideslip - negative for a lag
ω	Imaginary part of a complex dynamic root, sec^{-1}
ω_{n_d}, ω_d	Undamped natural frequency of the Dutch-roll oscillation, rad/sec
ω_{n_p}	Phugoid undamped natural frequency, rad/sec
$\omega_{n_{SP}}$	Undamped natural frequency of the short-period oscillation, rad/sec
ω_{RS}	Roll-spiral undamped natural frequency, rad/sec
ω_ϕ	Undamped natural frequency of numerator quadratic of ϕ/δ_{AS} transfer function, rad/sec

NOTICE

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the United States Government thereby incurs no responsibility nor any obligation whatsoever; and the fact that the government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

This report has been reviewed and cleared for open publication and/or public release by the appropriate Office of Information (OI) in accordance with AFR 190-17 and DODD 5230.9. There is no objection to unlimited distribution of this report to the public at large or by DDC to the National Technical Information Service (NTIS).

This Technical Report has been reviewed and is approved for publication.

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Project Engineer/Scientist

FOR THE COMMANDER

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AIR FORCE/56780/4 June 1975 – 400

SECTION I

INTRODUCTION

This report is prepared as part of a continuing effort by Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, to update and improve Military Specification MIL-F-8785B(ASG), "Flying Qualities of Piloted Airplanes." The requirements of the specification were largely prepared on the basis of experimental flying qualities data, and form the criteria for the aircraft industry in design, development, and flight test demonstration of new military airplanes. A detailed comparison of the flying qualities of currently operational airplanes to the specification requirements forms the basis for evaluation of the requirements.

Evaluation of the specification requirements was performed by a paragraph-by-paragraph comparison of the specification requirements to available flight test data, supplemented in certain areas by analytical data. Inevitably, comparison of any airplane with the specification will be less than complete because of data limitations. Although more thorough coverage would be needed to show compliance of a new airplane, this depth of presentation is adequate for an evaluation report.

This report may be considered a critique of MIL-F-8785B(ASG) by one class of specification user. It is hoped that the recommendations of this study will serve as a basis for future specification revision programs, and may also serve as additional guidance for interpretation and application of the specification.

SECTION II

AIRPLANE DESCRIPTION

1.0 GENERAL PHYSICAL CHARACTERISTICS

Airplane Description

The C-5A is a long-range, all weather, high-altitude, high-subsonic, swept-wing, T-tailed airplane designed for use as a heavy logistic transport with relatively short field takeoff and landing capability. The airplane is designed to airlift a wide variety of combat support equipment and personnel at payloads of up to 265,000 pounds. Aircraft gross weight ranges from 319,809 pounds empty to 769,000 pounds maximum design weight. Initial cruise altitude is 30,000 feet with cruise speeds of up to 470 knots true airspeed. It is powered by four General Electric TF-39 turbofan engines equipped with thrust reversers. Inflight reverse thrust is applied to the inboard engines for rapid or emergency descent. A retractable, high-flotation landing gear consisting of four six-wheel, bogie-type, main landing gears and a four-wheel, steerable nose gear enables the airplane to operate from paved or unpaved runways. The landing gear can be set at "crabbed" positions for takeoffs and landings in crosswinds. Some of the other unique design features of the airplane are a forward and aft cargo door system enabling straight through loading and unloading and a landing gear kneeling system. The kneeling system permits the cargo deck to be tilted nose down or tail down or to be lowered in the level position. Aerial delivery of payloads through the aft cargo door is possible. Up to 200,000 pounds of payload may be dropped in multiple packages, and a single package of 86,000 pounds has been dropped in demonstration tests. Two auxiliary power units, one located in each main landing gear pod, are provided to supply electrical, pneumatic, and hydraulic power (through use of air turbine motors) for engine starting and for ground operation and maintenance requirements.

Basic Data

The three-view drawing in Figure 1 (1.0) shows the basic airplane and gives dimension details. Overall dimensions are as follows:

Overall Wing Span:	222.71 feet
Overall Length:	247.86 feet
Overall Height:	65.10 feet

Wing geometry parameters are the following:

Area:	6200 square feet
Span:	219.20 feet

MAC	30.93 feet
Aspect Ratio:	7.75
Taper Ratio (theoretical):	0.371
Dihedral (0.25c):	-3.50 degrees
Incidence - Root:	-3.50 degrees
- Tip:	0.00 degrees

Airplane gross weights are listed below:

Empty Weight:	319,809 pounds
Design Flight Gross Weight (2.5g):	728,000 pounds
Maximum Design Gross Weight:	769,000 pounds

2.0 FLIGHT CONTROLS

Primary flight controls include ailerons, spoilers, rudders, and elevators. All surface hinge homents are provided by hydraulically powered actuators and pilot "feel" is artificial (see Figures 1 through 15(2.0)). Control wheels, columns, and rudder pedals provide pilot or copilot inputs to the control valves through the mechanical linkage and cable systems. Hydraulic power is provided by four independent systems. Secondary flight controls include ground spoilers, leading edge slats, pitch trim, and trailing edge flaps.

STABILITY AUGMENTATION

Pitch and yaw/lateral SAS (Stability Augmentation Subsystem) are provided. Pitch SAS provides short period pitch damping. Yaw/lateral SAS provides yaw damping, roll damping, turn coordination, and spiral divergence control. The C-5 SAS is triple redundant, fail safe/fail operational. The actuator inputs are added in series with pilot inputs to control the surface actuators. The aircraft can be flown safely without SAS. Analytical diagrams are presented in Figures 1(2.0) and 2(2.0).

ROLL CONTROL

The roll control system controls the motion of the aircraft about the longitudinal axis by the use of ten flight spoilers operated differentially in conjunction with two conventional ailerons. The ten flight spoilers serve a dual purpose in that upon command they also function as ground spoilers. The interface is shown on Figure 3(2.0).

A mix box in each wing converts an input signal from the aileron cable system to a proportional output signal to the flight spoilers. This same mix box converts an input signal from the ground spoiler cable system to an output signal to the flight spoilers when they are to function as ground spoilers.

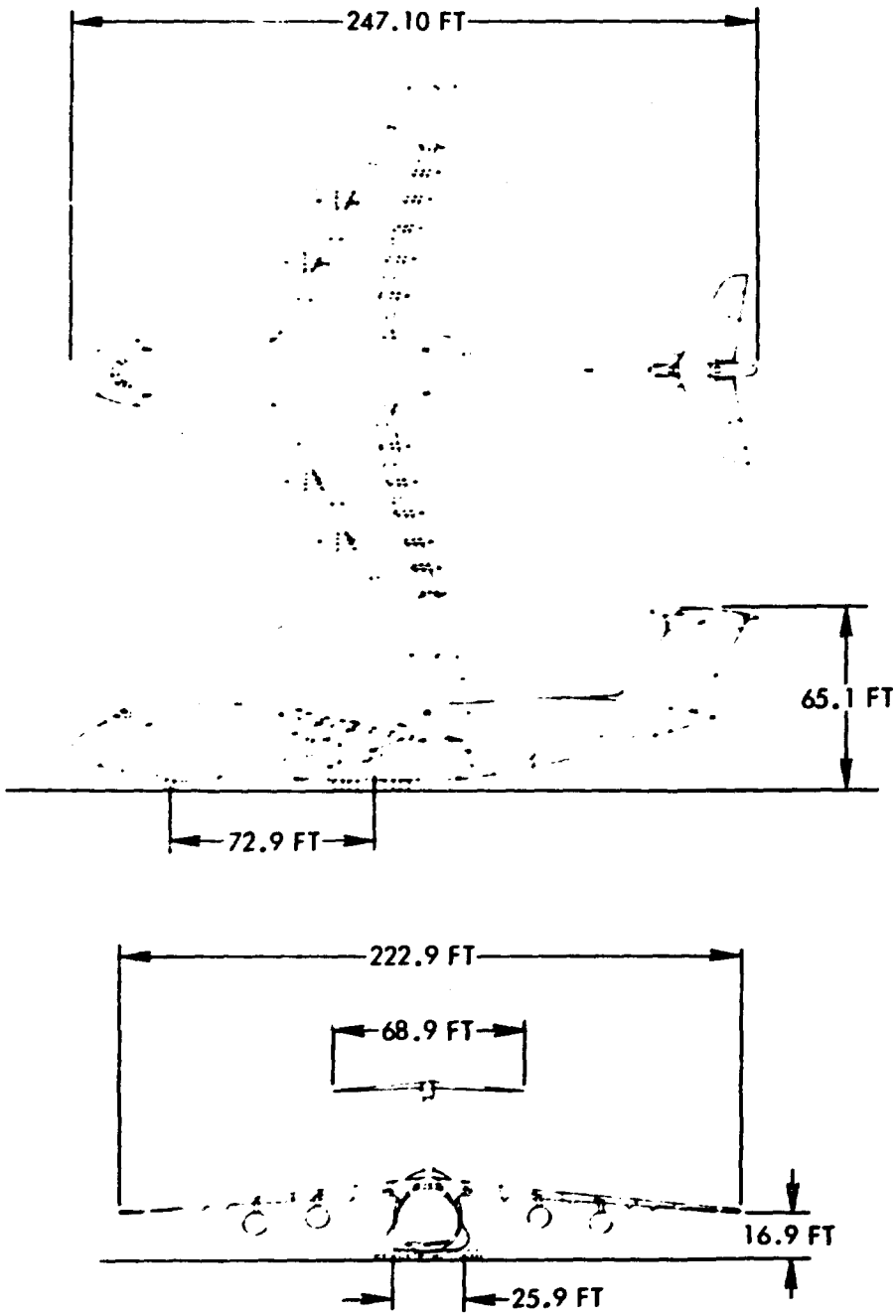
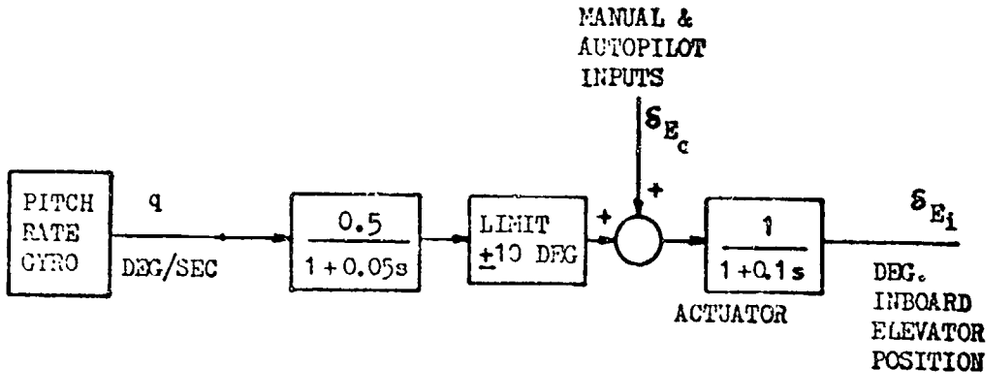
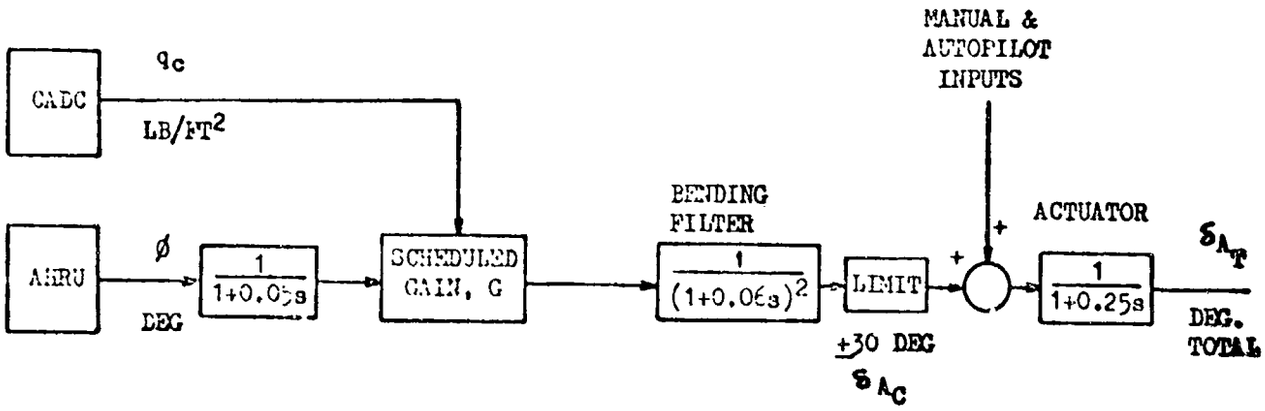
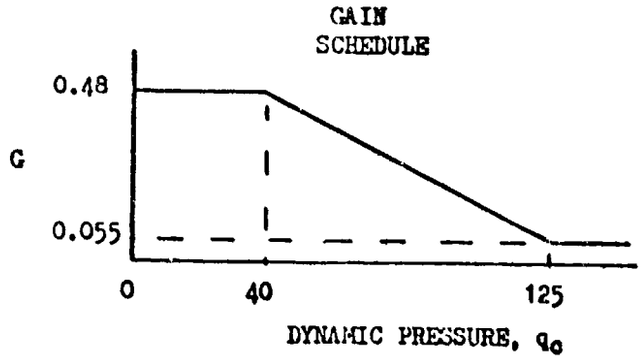


Figure 1(1.0). General Arrangement - Baseline C-5A



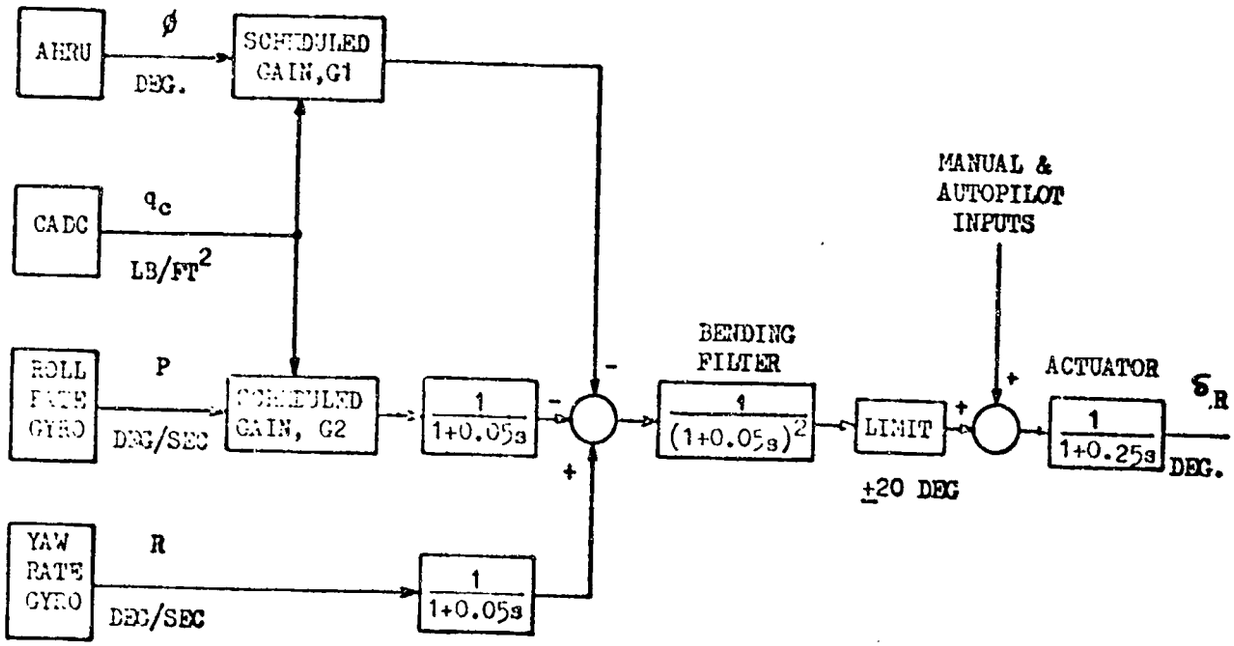
PITCH STABILITY AUGMENTATION SYSTEM





ROLL STABILITY AUGMENTATION SYSTEM

Figure 1(2.0). Analytical Diagrams - Pitch and Roll Stability Augmentation System



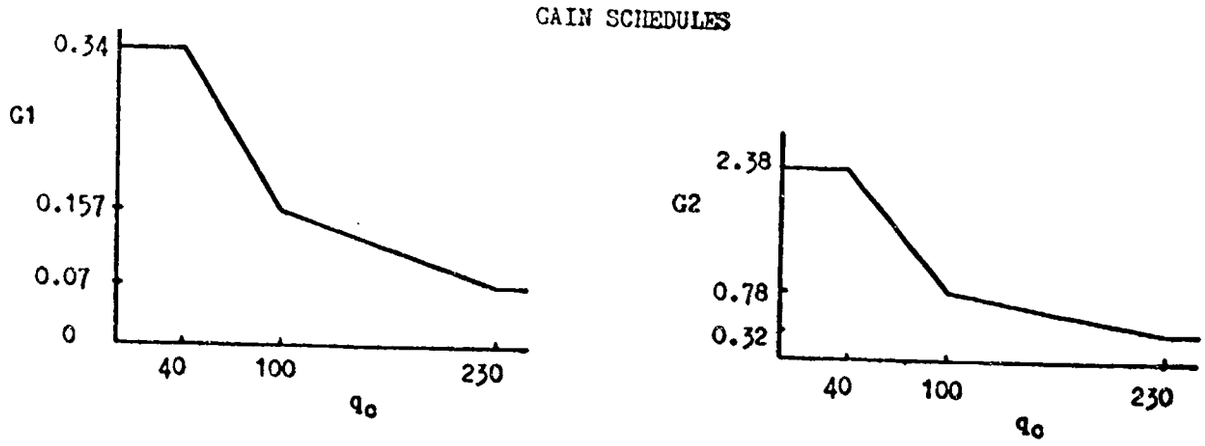


Figure 2(2.0). Analytical Diagram - Yaw Stability Augmentation System

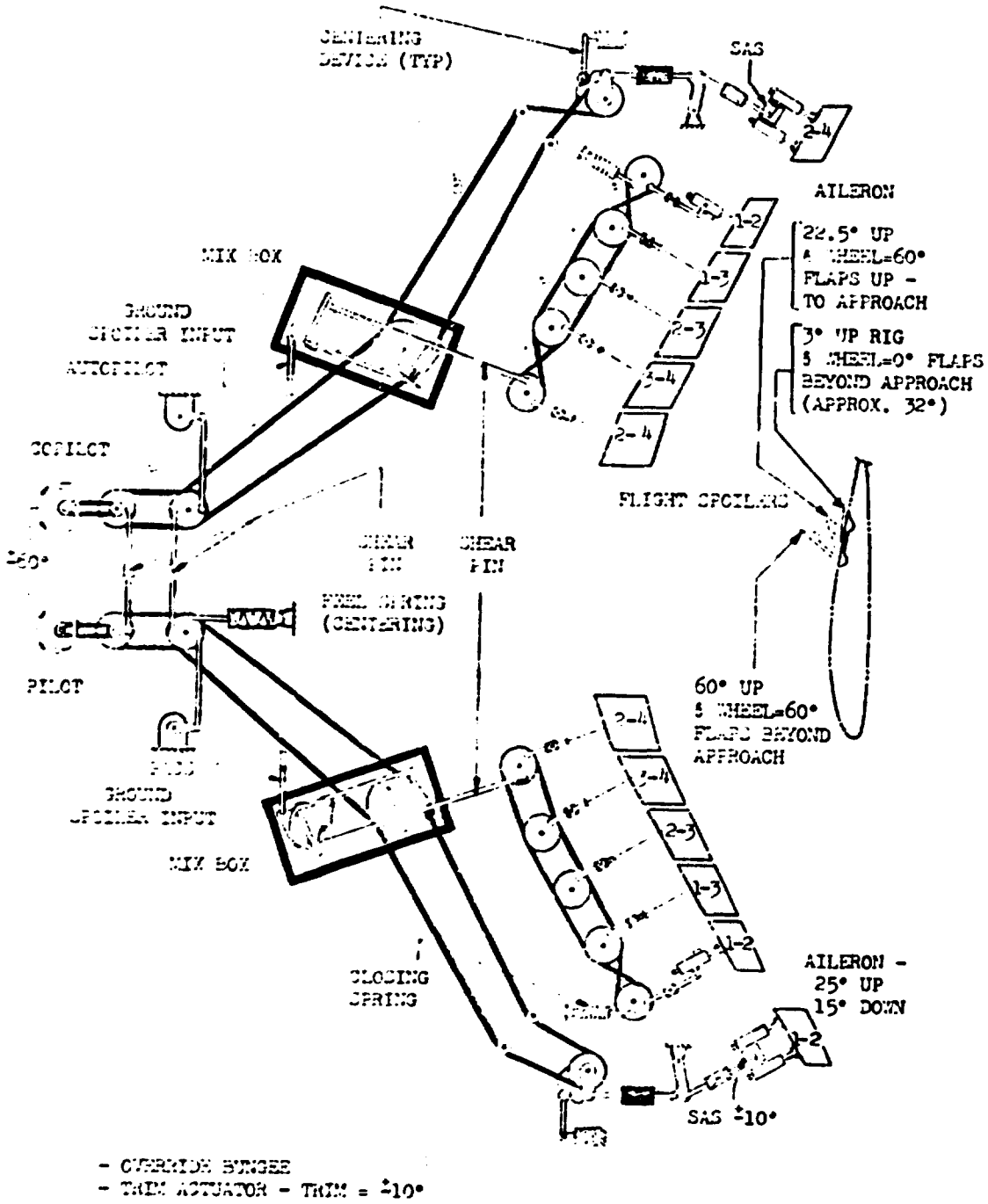


Figure 3(2.0). - Roll Control Systems

Each aileron and flight spoiler panel is operated by a dual hydraulic servo control assembly which responds to manual cable inputs. The aileron control package also responds to electrical inputs from the automatic flight control computer for lateral augmentation, and to mechanical inputs from the aileron trim actuator.

System operation incorporates conventional pilot's and copilot's control wheels with travel from neutral to $\pm 60^{\circ}$. Aileron travel as a function of control wheel rotation is 25° up and 15° down from the faired position. With flaps up, flight spoiler travel as a function of control wheel rotation is 22.5° up from the faired position.

When the trailing edge flaps extend to approximately 32°, an electrical signal is given to the ratio shift actuator which, through the mix box, up-rigs the flight spoilers 3° from the faired position. This is done to minimize the loss of spoiler-flap lift with roll control. The maximum spoiler travel from the 3° up-rigged position is 57° up and 3° down.

Artificial Feel - A combination centering and artificial feel spring is attached to the pilot's rear quadrant. This spring is preloaded to a force which is adequate to overcome system friction, thus ensuring positive system centering with no force applied to the control wheel. Additional artificial feel is obtained from the flight spoiler closing springs attached to the outboard flight spoiler input quadrant.

Autopilot - The autopilot roll control servo is attached by a pushrod to the copilot's rear quadrant and, when engaged, provides an automatic parallel input to the cable system. An emergency disconnect switch on either control wheel allows rapid electrical disengagement with negligible friction remaining on the system. An internal slip clutch gives either pilot an override capability in the event of a runway or jammed roll control servo.

Pilot Assist Cable Servo (PACS) - The PACS is a small output electromechanical torque motor, attached by a pushrod to the pilot's rear quadrant, which assists the pilot in overcoming control wheel breakout force. Electrical sensors in the control wheel detect an initial pilot effort of 3 to 4 pounds of force on the wheel and result in the PACS adding an additional 5 pounds toward overcoming the roll control system breakout force of approximately 9 pounds.

The PACS is intended for full-time use during manual flight control of the aircraft and is interfaced to be compatible with the autopilot for automatic flight control.

Aileron Trim - An electromechanical trim actuator is located in the input linkage of each aileron control servo assembly and is in series with the pilot input system. Operation of the aileron trim knob, which is located on the center console, sends an electrical signal to each trim actuator. The aileron trim actuator in turn gives a mechanical input to the aileron control servo assembly, thus providing the desired aileron deflection to maintain wings level flight and allow the pilot's and copilot's control wheel to center. Each aileron trim actuator may be energized separately by operating a switch located to the side of the aileron trim knob. This will provide roll trim in the event one trim actuator is inoperable. The normal aileron trim range is $\pm 10^{\circ}$ at a rate of 1/2 degree per second per actuator or a total effective roll trim rate of 1 degree per second. A trim actuator with

dual pointers, located in the flight station area, indicates the position of each aileron panel relative to the faired position.

ELEVATOR CONTROL SYSTEM

The elevator control system controls the attitude of the aircraft about the pitch axis by means of four separate elevator surfaces hinged at the rear of the horizontal stabilizer. Pilot control column travel of five inches forward and nine inches aft provides surface deflections of 15 degrees down and 25 degrees up, respectively. Control column motion is transmitted through a cable system to the full power, irreversible-type hydraulic servos which power each surface. The inboard surfaces, which are structurally interconnected by a mechanical linkage, are each powered by a dual actuator servo package, while each outboard surface is powered by both dual and single actuator servo packages. For normal operation, the L.H. inboard elevator is powered by Sys. No. 2 and the R.H. inboard elevator is powered by Sys. No. 3. The pilot can switch on the inactive system after a hydraulic system failure. The elevator control system is shown schematically in Figure 4(2.0).

Pilot Assist Cable Servo - As an aid to the pilots in overcoming input system friction, a pilot assist cable servo (PACS) is incorporated in the cable system. The servo, which is an electromechanical torque motor with a small, variable torque output, is attached to the pilot's aft cable quadrant. The signal for actuation of the PACS is generated by force transducers mounted in each control wheel. This signal is then amplified and transmitted to the PACS for actuation of the cable system.

Elevator Artificial Feel Subsystem - Since a full-power control system provides no feedback of aerodynamic loads, an elevator artificial feel subsystem is required to provide the pilots and autopilot with appropriate "feel" forces to permit safe maneuvering of the aircraft throughout its operational flight envelope. The feel subsystem consists of three force-producing components:

- The system centering spring plus four servo centering springs.
- The bobweight effects of the control columns and the stick shaker mounted on each.
- The system variable feel unit.

The arrangement of these components within the elevator control system is shown in Figures 4(2.0) and 5(2.0).

Centering Springs - Artificial feel proportional to elevator surface position is provided by the system centering spring attached to the pilot's aft quadrant and by the centering springs incorporated in the servo packages. These springs together are preloaded to provide a system force of approximately 7.5 pounds at the column, i.e., 3.5 pounds from the system centering spring, and 1 pound from each of the four servo package centering springs. The centering springs on the servos are to provide a centering force to each servo in the event of a failure anywhere in the servo input system. The pilots' feel force as a function of the centering springs only (beyond breakout) is shown in Figure 6(2.0).

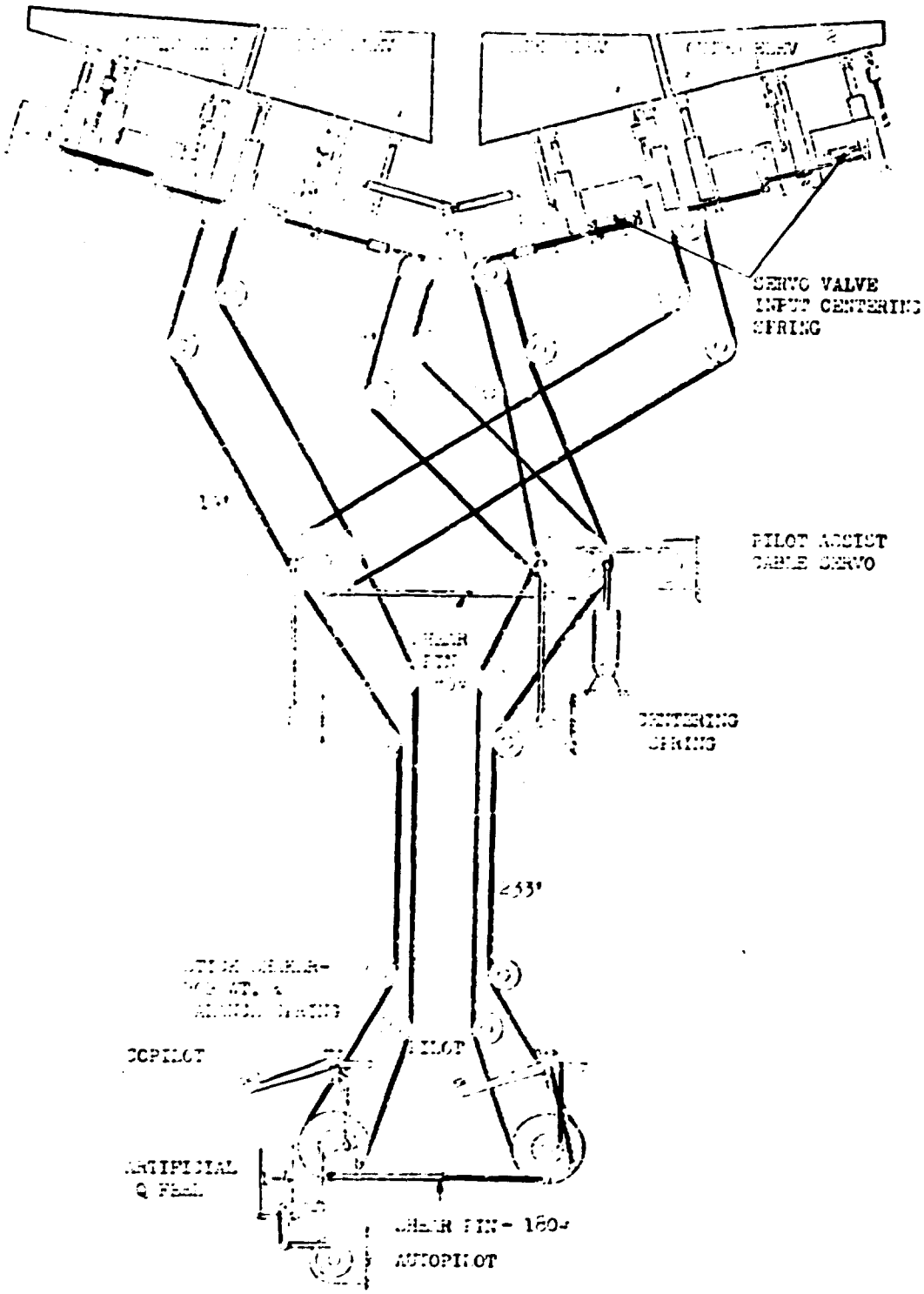


Figure 4(2.0. Elevator Control System

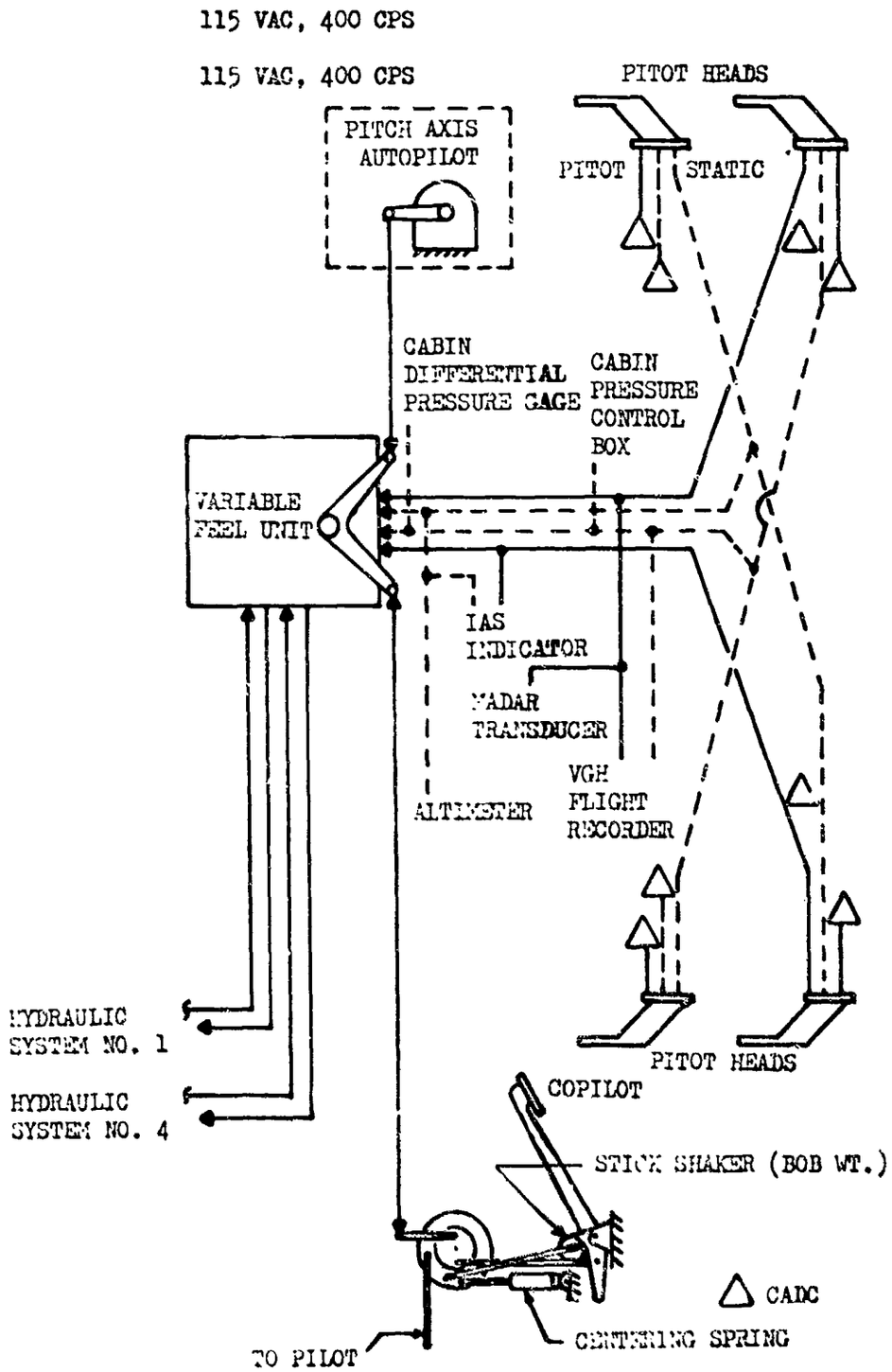


Figure 5(2.0). Elevator Artificial Feel System

Bobweight - The bobweight effects of the elevator manual control subsystem and the stick shaker assembly mounted at the base of each column provide the pilot with feel forces as a function of normal acceleration (load factor). The stick shaker bobweight effect is transmitted to the system via a pushrod connecting each shaker to its respective forward cable quadrant. A flat coiled spring is incorporated in the attachment of each stick shaker to balance the total bobweight effect for one "g" condition. The pilots' feel force as a function of the total bobweight effect only is shown in Figure 7(2.0).

Variable Feel Unit - The variable feel unit (VFU) provides the pilots with feel forces as a function of the impact pressure (q_c) from the Central Air Data Computer. The unit, which is installed below the flight deck floor to the right of the copilot's feet, is connected to the elevator control system by means of a pushrod connected to the VFU output lever and the copilot's forward cable quadrant. Figures 8(2.0) and 9(2.0) show pilot forces.

Stallimiter System - The pitch axis control system incorporates a stall warning subsystem consisting of a stick shaker mounted at the base of each control solumn and an audible signal fed into the cockpit overhead interphone speakers and into the pilot, copilot, and observer headsets. The shaker is an electromechanical device which is actuated by the stallimiter computer. The shakers induce control system vibrations to warn the pilots of an impending stall condition. If the pilots fail to take appropriate action after receiving the stall warning through the stick shaker and a stall is actually entered, the audible warning signal is initiated by the stallimiter computer.

RUDDER CONTROL SYSTEM

Directional control of the air vehicle is accomplished by the rudder control subsystem, including rudder trim. The rudder control consists of an upper and lower rudder surface, each deflected by a dual irreversible hydraulic servo assembly. Normal maneuvering of the aircraft in the yaw axis is accomplished by displacement of the conventional rudder pedals. Movement of the rudder pedals 3.00 inches forward or aft from neutral will produce ±35 degrees of surface travel through a single closed-loop cable system originating from a tension regulator installed on the pilot's side. Superimposed upon the manual input system is the stability augmentation system (SAS), which has the capability of producing 20.5 ±1.0 degrees of surface travel. Rudder trim, pedal feel force gradient, and pedal/surface centering is provided by a trim and feel system which provides parallel inputs to the rudder system. The rudder control system is shown schematically in Figure 10(2.0).

Rudder pedal nose wheel steering allows either pilot to command ±7 degrees of nose wheel deflection with ±3.00 inches of pedal travel. This limited control provides some assistance to the rudder in yaw axis control of the aircraft during landing and takeoff. The steering wheel mounted on the pilot's side panel provides manual control of the full ±80 degrees of nose wheel deflection. A lever forming part of the pilot's tension regulator assembly is attached to a pushrod which connects to the nose wheel steering mechanism. A linear actuator is used to automatically disengage the rudder pedal steering input when the nose gear is retracted

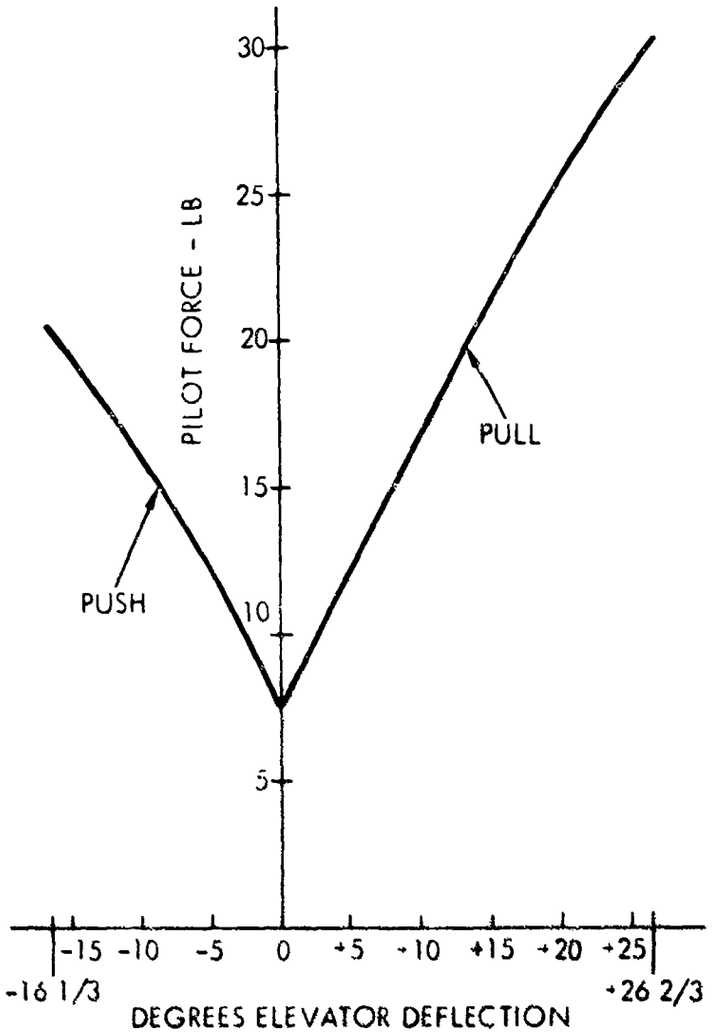


Figure 6(2.0). Pilot Forces Due to Centering Springs

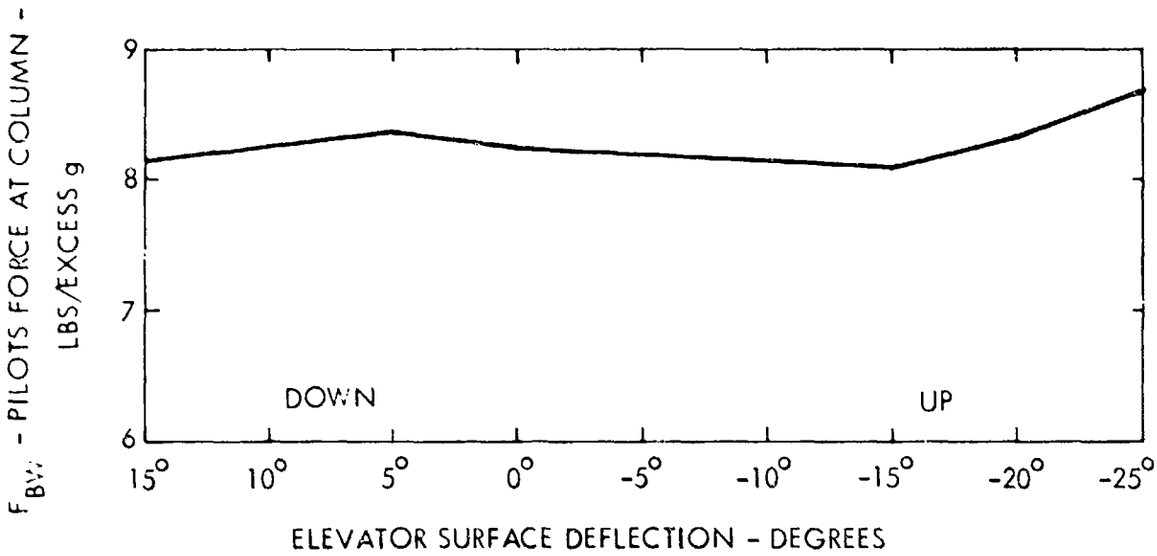


Figure 7(2.0). Elevator Bobweight Force Characteristics

NOTES:

1. NORMAL AERODYNAMIC SIGN CONVENTION SHOULD BE USED.
2. THE STICK FORCE (ΔF_s) IS REPRESENTED AS THE PILOT EFFORT REQUIRED TO DISPLACE THE STICK AT ZERO EXCESS g's. THE FORCE INCLUDES THE ELEVATOR CONTROL SYSTEM CENTERING SPRING (F_k) AND F_q FORCE FROM THE VARIABLE FEEL UNIT, 4Y91063.
3. F_s IS THE PILOT EFFORT FOR EXCESS g LOADINGS.
4. THIS PLOT DOES NOT INCLUDE THE EFFECT OF BREAKOUT, FRICTION, AND HINGE MOMENT LIMITING.

$$F_S = F_q - F_k$$

$$F_S = F_S + F_{BW}$$

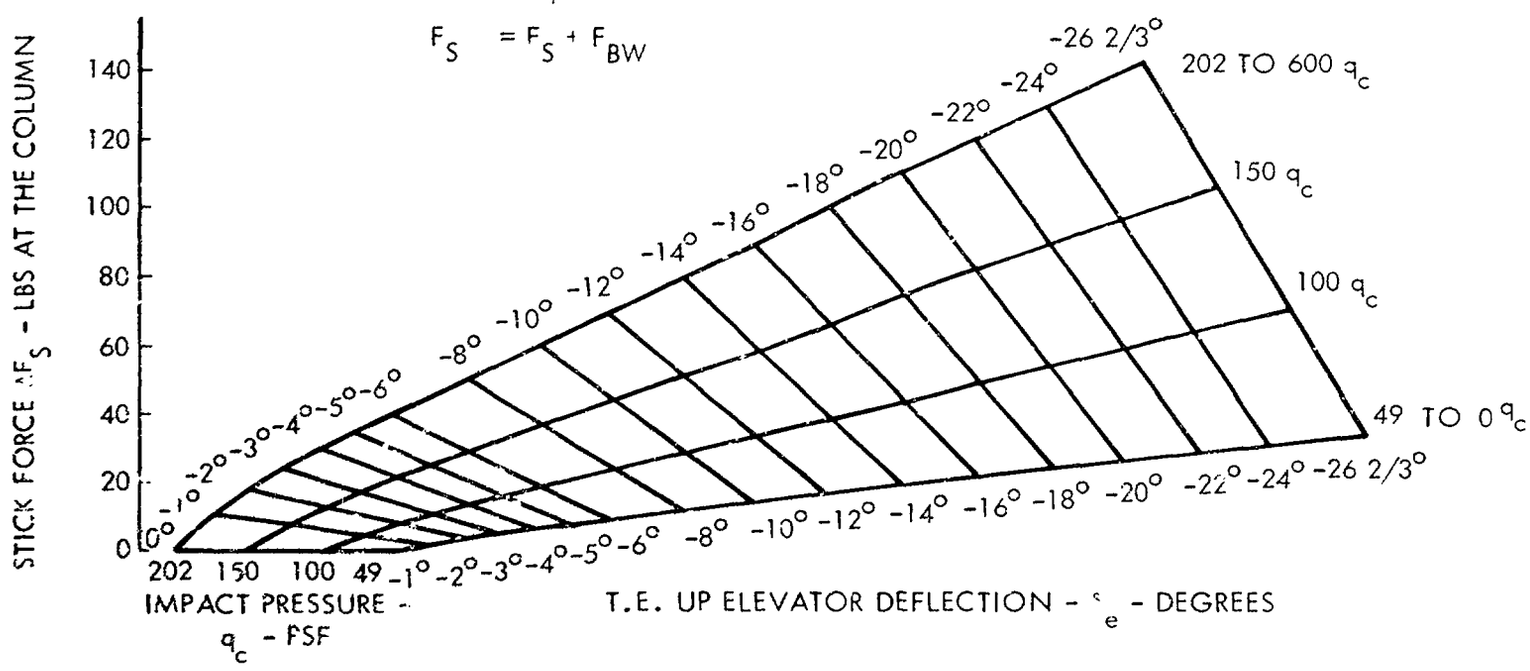


Figure 8(2.0). Elevator Artificial Feel Subsystem

NOTES:

1. NORMAL AERODYNAMIC SIGN CONVENTION SHOULD BE USED.
2. THE STICK FORCE ($'F_s$) IS REPRESENTED AS THE PILOT EFFORT REQUIRED TO DISPLACE THE STICK AT ZERO EXCESS g's. THE FORCE INCLUDES THE ELEVATOR CONTROL SYSTEM CENTERING SPRING (F_k) AND F_q FORCE FROM THE VARIABLE FEEL UNIT, 4Y1063.
3. F_s IS THE PILOT EFFORT FOR EXCESS g LOADINGS
4. THIS PLOT DOES NOT INCLUDE THE EFFECT OF BREAKOUT, FRICTION, AND HINGE MOMENT LIMITING.

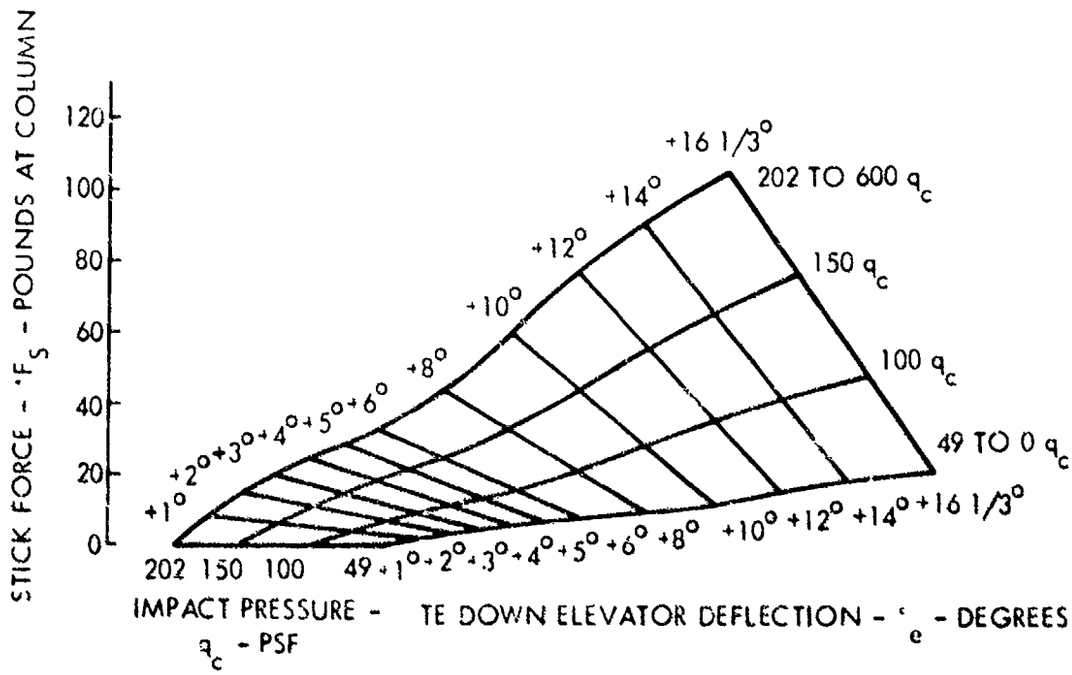


Figure 9(2.0). Elevator Artificial Feel Subsystems

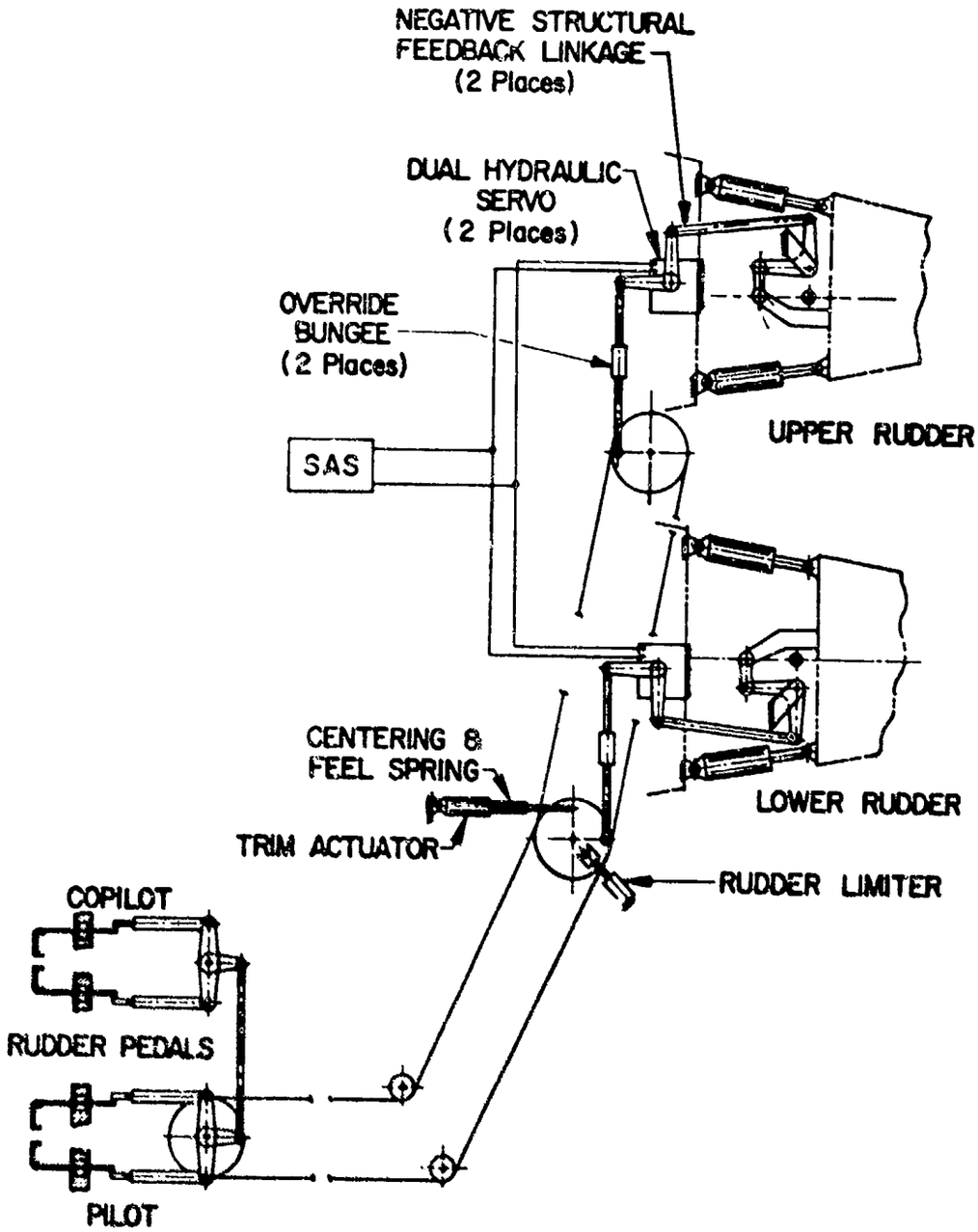


Figure 10(2.0). Rudder System

Feel, Trim, and Autopilot System - Rudder trim, pedal feel force gradient, and pedal/surface centering are provided by a combination feel and centering spring installed in series with an electromechanical trim actuator and attached to the lower rudder input quadrant. The spring is preloaded to a pedal force of approximately 8 pounds, which is adequate to overcome system friction. The preload force also ensures positive system centering with no force applied to the rudder pedals. The pedal feel force gradient is 4.3 pounds per degree for the first 10 degrees and changes to 2.6 pounds per degree from 10 degrees to 35 degrees. The maximum pedal feel force under normal operation is 120 pounds.

The trim actuator for normal operation provides a parallel input to the rudder system. The actuator repositions the neutral point of the preloaded centering spring after the rudder pedals have been displaced to a desired trim position. Trim actuator operation is controlled by two rudder trim control switches located on the copilot's side of the center console. The switches are three position (nose left, off, nose right) toggle switches and are spring loaded to the OFF position. Simultaneous operation of the switches is required to provide power and ground signals to the trim actuator. The upper and lower rudder surfaces are trimmed simultaneously as if the input were due to pedal deflection. The trim actuator provides ±11 degrees trim authority at a rate of one degree per second and trim position is displayed on an indicator located on the center instrument panel.

Emergency Rudder Control - Emergency rudder control provides the pilot with ± 20 degrees of upper and lower rudder authority. A YAW AUG MAN TRIM control knob is provided on the flight augmentation panel to permit control of the rudders through the Yaw Augmentation (Y/A) subsystem in the event of a jam in the single rudder cable system. A guarded switch to the right of the control knob must be moved from the OFF position to the ON position before the emergency mode becomes operational. Signals are not applied to the Y/A subsystem if the control knob is offset from its neutral position when the guarded switch is thrown to ON. Electrical interlocs are provided which require that the control knob must be returned to neutral position before the signals are switched in. In addition, this control may be used to obtain rudder trim in the event of a failure in the rudder trim system.

Rudder Position Limiting - The rudder position and travel are pedal limited by mechanical stops positioned by an electromechanical linear actuator, as shown on Figure 10(2.0). The rudder position limiter assembly is installed at the lower rudder input quadrant. The input actuator responds to step input signals from the Air Data Subsystem (CADC's numbers 1 & 2) which are a function of dynamic pressure and Mach number. Position feedback is provided by limit switches mounted on a cam profile forming part of the mechanical stops. At "Q's" greater than 200 PSF, or Mach numbers in excess of 0.77, whichever occurs first, the stops are positioned to allow a maximum of ±4 degrees of rudder. At intermediate "Q's" between 80 and 200 PSF, the stops are positioned to allow a maximum of ±12 degrees of rudder. When dynamic pressure is below 80 PSF, the stops are completely retracted to allow full rudder travel.

SECONDARY FLIGHT CONTROL SUBSYSTEM DESCRIPTION

Trailing Edge Flaps and Leading Edge Slats - The C-5A employs leading edge slats and trailing edge flaps to change the relatively low-lift wing required for high speed flight to a high-lift wing necessary for short landings and takeoffs. The slats and flaps accomplish this by changing the camber and area of the wing. Actuation of the entire system is accomplished by displacement of a single flap control handle located on the center console. Asymmetry detection with test circuitry is provided for each system. Position indicators for each system are also provided. Major elements of the flap system are shown in Figure 11(2.0).

Trailing edge flaps are slotted Fowler type with six panels on each wing semi-span. The panels are positioned by ball screw actuators which drive the carriage in each straight track. The actuators are driven through a torque tube system by a power package mounted on the aft side of the center wing beam in the mid-fuselage. The power package receives inputs from the flap handle.

There are seven leading edge slat panels, three slotted and four sealed, on each wing semi-span. The actuators are driven through a torque tube system by the trailing edge flaps power package, utilizing a decoupler and clutch/brake assembly. The clutch/brake assembly, mounted on the forward side of the center wing front beam, engages to extend or retract the slat system depending on the direction of flap motion.

Slat and flap motion is initiated simultaneously from the retracted position, and the slats are fully extended when the flap reaches approximately the 15 degree position. At the slats extended position the clutch is disengaged and the brake engaged by means of an electrical signal from proximity switches located at each inboard moving island in each wing semi-span. When the clutch is disengaged at the slats extended position, the T.E. flaps are free to continue to any selected position. At the slats retracted position the clutch is disengaged and the brake engaged by means of an electrical signal from proximity switches on the No.1A slat track in each wing semi-span.

HORIZONTAL STABILIZER TRIM CONTROL SYSTEM

The pitch trim system includes the horizontal stabilizer actuator and an actuator input system. A high degree of safety and reliability is provided since two signals are required from the input system before the actuator can operate.

Trim about the pitch axis is accomplished by movement of the horizontal stabilizer and is independent of the primary pitch control system (elevators). The pitch trim actuating system, shown in Figure 12(2.0), consists of the following:

1. One pitch trim actuator, irreversible linear screwjack.

2. Two pilot or copilot operated electrical command systems.

3. One pilot or copilot operated manual command system.

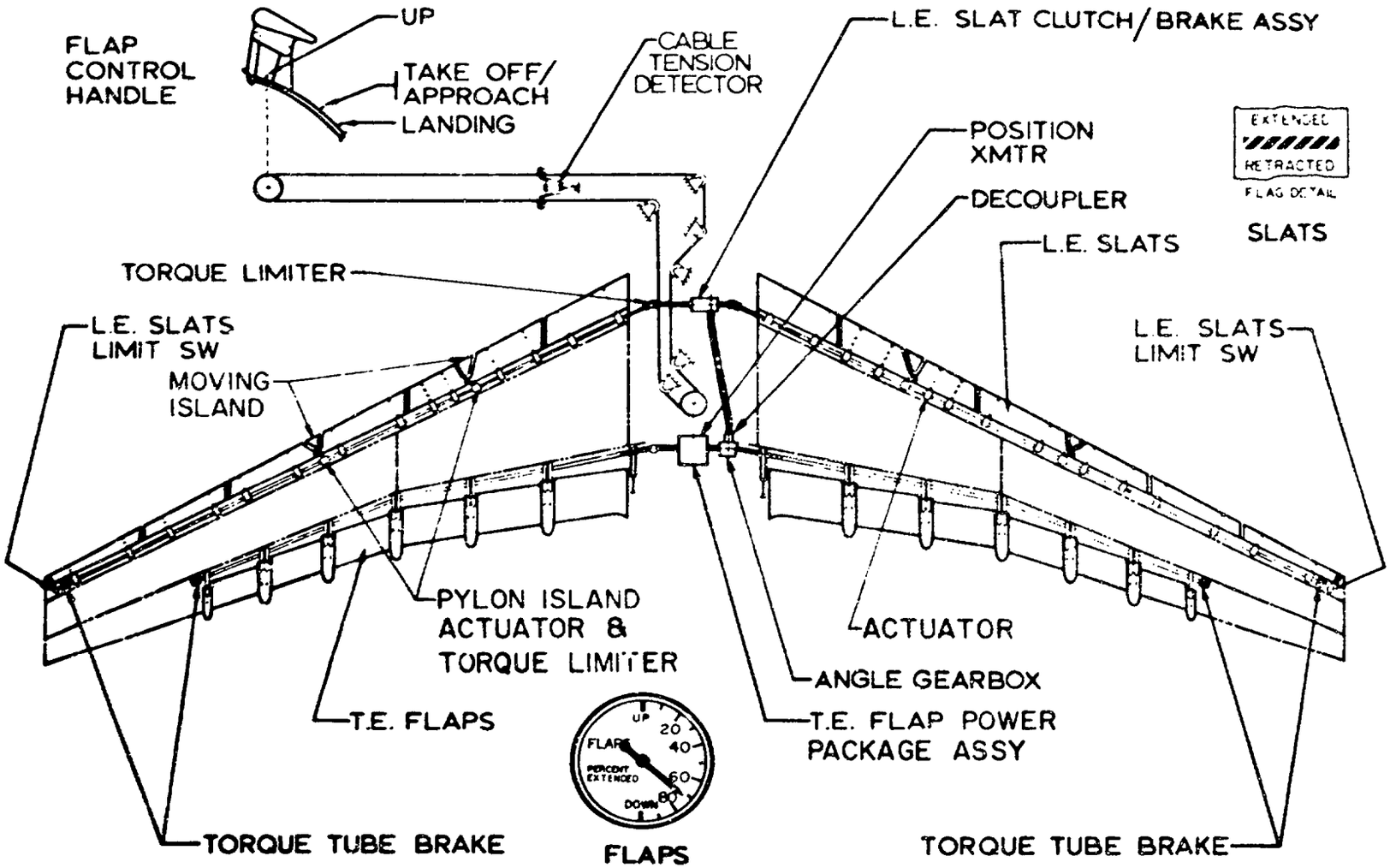


Figure 11(2.0). Flap System

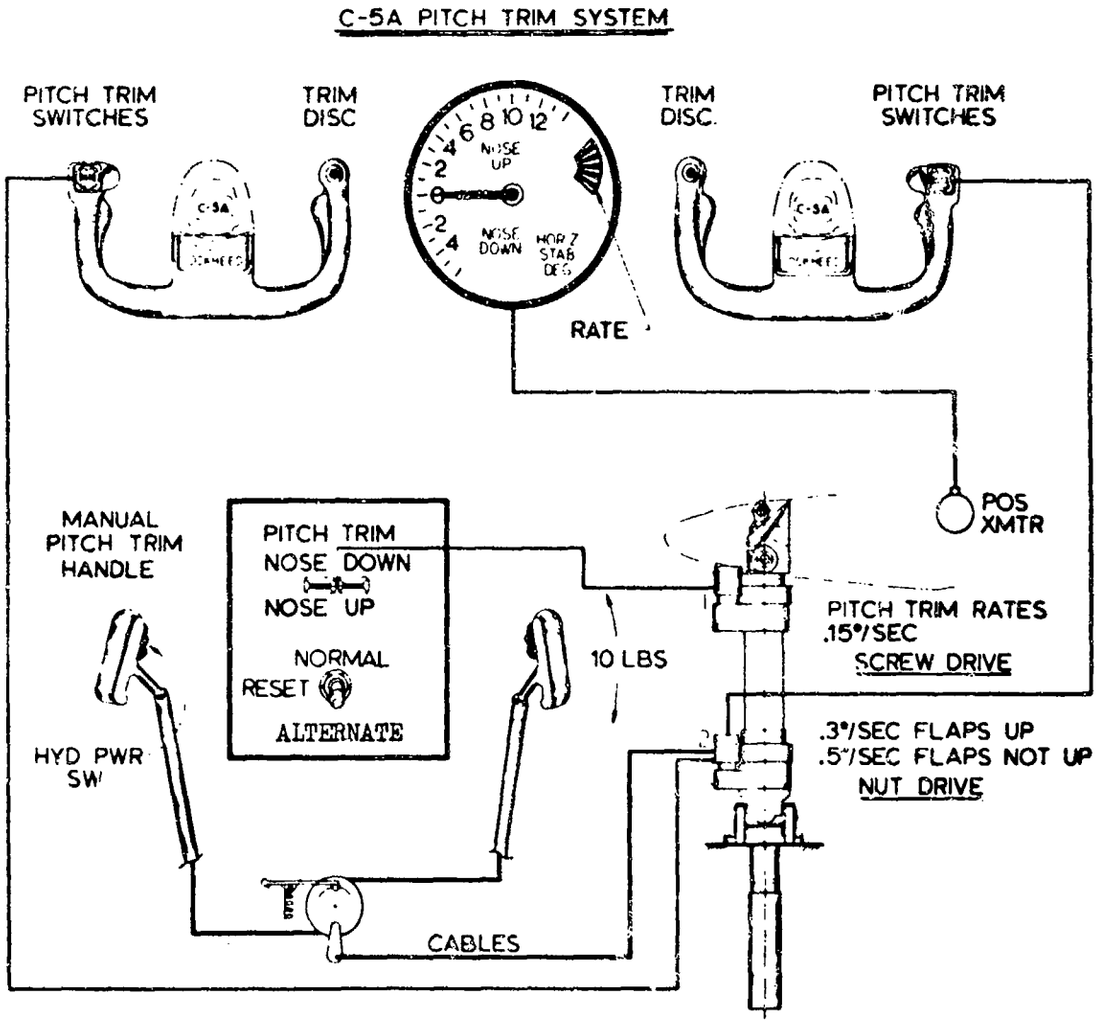


Figure 12(2.0). Pitch Trim Controls

4. One autopilot command system, signal to screw drive.

5. Four horizontal stabilizer position limit switches.

6. Two separate hydraulic system inputs.

7. One horizontal stabilizer position indicator system.

GROUND SPOILER SYSTEM

The ground spoiler system is provided to reduce the aircraft's stopping distance during landing roll-out or a rejected takeoff by destroying wing lift and increasing wing drag. Destroying the wing lift deposits the aircraft weight onto the landing gear more rapidly after touchdown thereby increasing the efficiency of the wheel brakes.

The ground spoilers consist of four inboard panels, which are used as ground spoilers only, and five outboard panels which are used as ground spoilers during landing roll-out and as flight spoilers while airborne to aid in roll control of the aircraft. Figure 13(2.0) presents a schematic of the ground spoiler system.

The ground spoiler system is controlled by either the pilot or copilot. There are dual control handles provided, one on each side of the center console. The two handles are interconnected through a torque tube and have two positions. The most forward position corresponds to spoilers closed and the most aft position corresponds to spoilers fully extended. There are no intermediate positions provided. Spoiler handle travel is 60 degrees. The ground spoiler control input system is presented in Figure 14(2.0).

Four closing springs are used in the spoiler input system -- one at each No. 4 spoiler quadrant and one at each No. 9 spoiler quadrant, shown in Figure 13(2.0). These springs bias the input system in a closing direction and, therefore, oppose the pilot in deploying the spoilers and aid in closing the spoilers.

The spoilers are deployed by hydraulic actuators. Each spoiler panel is provided with an actuator. Spoiler panels No. 1 through No. 4 have two-position actuators which are either fully retracted or fully extended with no position feedback to provide intermediate positions. The spoiler quadrant pushrod operates a valves which ports hydraulic fluid from two individual systems to a dual tandem piston through a bypass and shutoff valve and a pressure switch. A locking device is provided to lock the piston in the retracted (spoilers closed) position. This lock is released when pressure is ported to the opening side of the piston.

Spoiler panels No. 5 through No. 9 have servoactuators. This is necessary since these panels are used during flight and have a feedback mechanism which allows the actuators to stop at intermediate positions. When the console handles are moved to the ground position, however, the actuators are commanded to the full extend position. The spoiler quadrant pushrod operates a control valve which ports fluid from two separate systems to a dual tandem piston through shutoff and bypass valves and pressure switches. No locking device is provided on these actuators since they are used during flight.

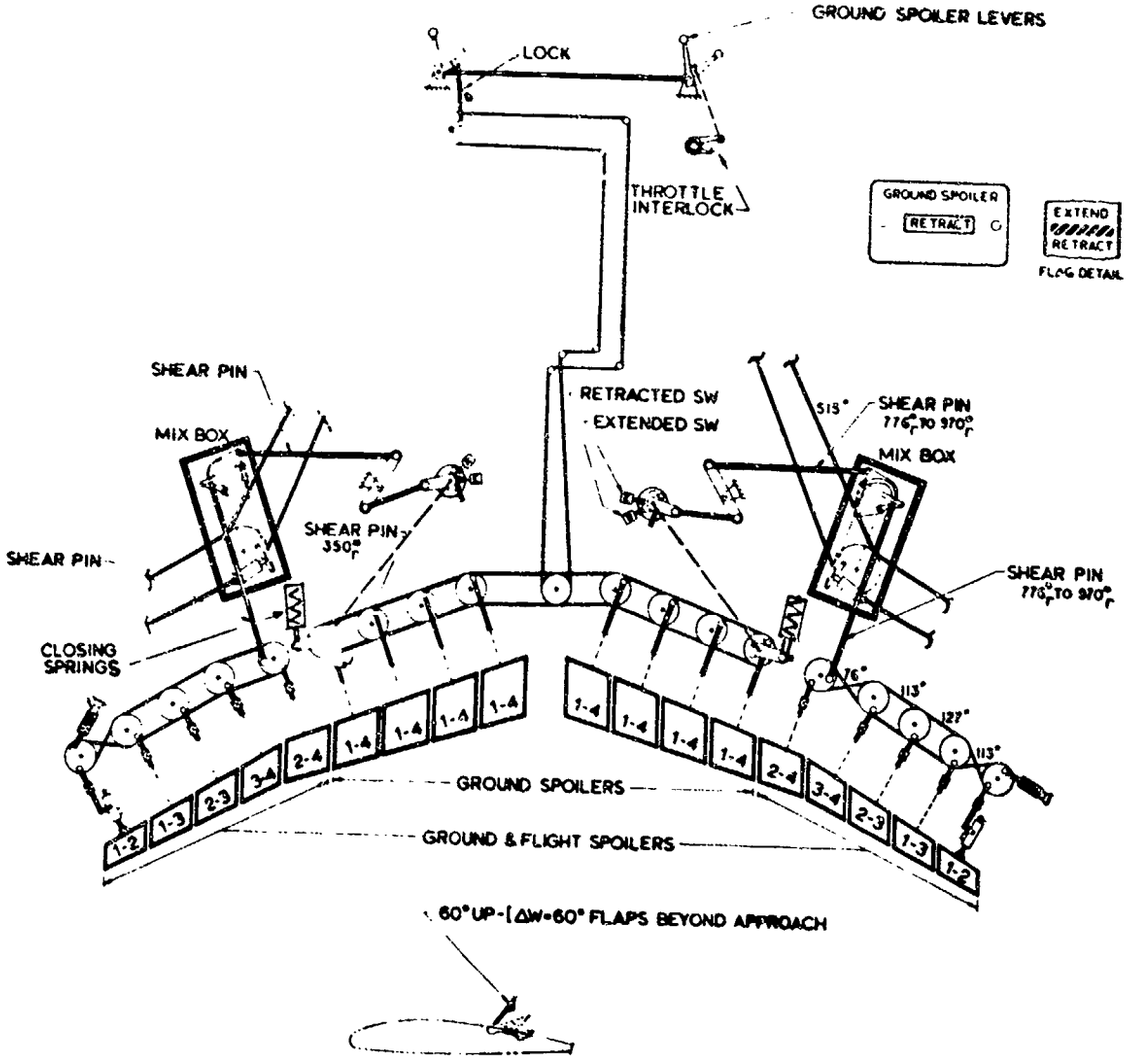


Figure 13(2.0). Ground Spoiler System

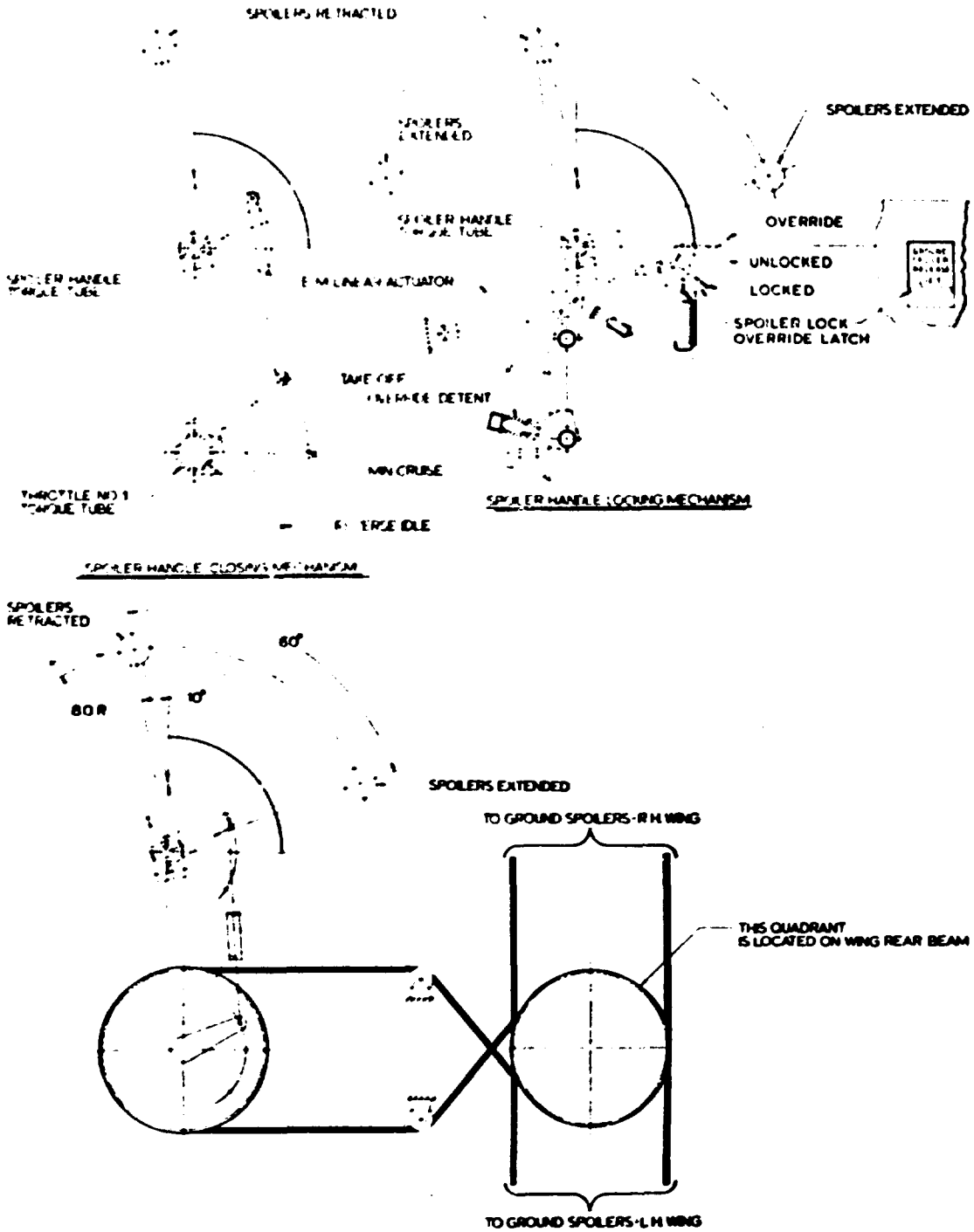


Figure 14(2.0). Ground Spoiler Control System

Located in the center console is a locking mechanism which locks the spoiler control handles while in flight. An electromechanical actuator is energized to the retracted position upon the loss of the wheel spin-up and the touchdown signal. This in turn pulls a stop into the path of an adjustable locking cam which is attached to the spoiler handle torque tube. Upon landing with either the spin-up or the touchdown signal present, the actuator will be given an extend signal which will push the stop out of the path of the locking cam and allow spoiler deployment.

Located on the center instrument panel is a position indicator which will indicate the position status of the spoilers. This indicator is operated by position switches located at the No. 4 spoiler quadrant of each wing. If the closed switch on each wing is contacted the indicator will show "RETRACT." If neither the closed or open switch is contacted, the indicator will show "ENROUTE." If both open switches are contacted, the indicator will show "EXTEND." If one wing open switch is contacted and other wing cam remains on the closed switch, or at some point between the open and closed switch, the indicator will show "ENROUTE." This will indicate to the pilot that one wing's spoilers are open and the other wing's spoilers are at some position other than full open which could result in a dangerous asymmetric condition. The pilot could then close all spoilers.

PASSIVE LDCS (LIFT DISTRIBUTION CONTROL SUBSYSTEM)

The passive LDCS system reduces the wing bending moment by uprigging both aileron. An LDCS control panel on the center console incorporates an "ARM" switch and a three position "rig" switch. The "RIG" switch is wired through the trim actuator so that operation of the switch to the "UPRIG" or "DN RIG" position will move the left hand aileron and the right hand aileron symmetrically up or down simultaneously.

The surface position relationships and capabilities that result from the incorporation of the Passive LDCS System are shown in Figure 15a(2.0). The Pilot Control Wheel position plotted against aileron surface position is shown in Figure 15b(2.0).

CHARACTERISTIC	DURING TAKEOFF	AFTER TAKEOFF	ABOVE 20,000 FT.	DURING TURBULENCE	ENGINE FAIL OR FERRY MISSION
LDCS Command	0°	6° Up	0°	6° Up	6° Dn
Roll Trim Capability	±10°	4° Up 16° Dn	±10°	4° Up 16° Dn	16° Up 4° Dn
Surface Position 0° Man and/or SAS	6°	12°	6°	12°	0°
Manual Capability 0° SAS	19° Up 15° Dn	13° Up 15° Dn	19° Up 15° Dn	13° Up 15° Dn	25° Up 15° Dn

Figure 15a(2.). Passive LDCS Aileron Trim and Deflection

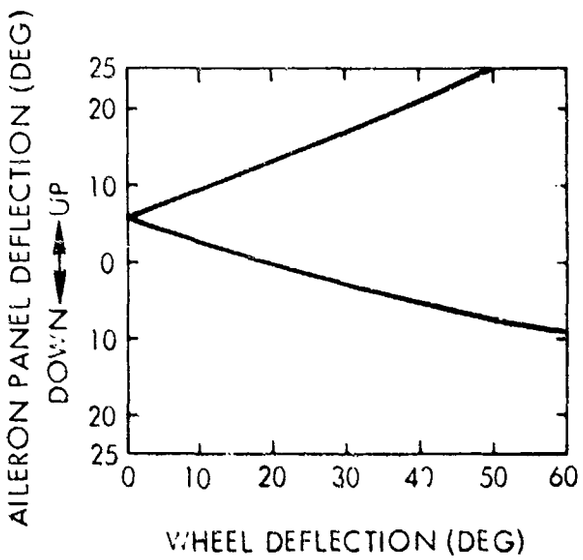


Figure 15b(2.0). Aileron Deflection Vs Wheel Deflection

SECTION III

EVALUATION OF REQUIREMENTS

INTRODUCTION

This section presents the comparison of the flying qualities of the C-5A airplane to the requirements of the current specification, MIL-F-8785B(ASG), including Interim Amendment-1 (USAF), 31 March 1971. Each specification paragraph of Section 3, Requirements, is presented in sequence, either singly or in logical groups, and compared to the characteristics of the airplane. For ease of reference the paragraph numbers of the specification are used here.

EVALUATION FORMAT

The evaluation format will comprise four specific parts. The listing and description of possible contents of the parts are as follows:

1. Requirement:

   In this part, the requirement paragraph is written exactly as it appears in the specification.

2. Comparison:

   In this part, the data, flight test and/or analytical, are presented to compare the characteristics of the C-5A with the requirements of the specification. The comparison is analyzed and a discussion presented to exhibit: (a) compliance with the specification, (b) non-compliance, or (c) disagreements (i.e., partial compliance or non-compliance may exist, or quantitatively non-compliance was exhibited but pilot qualitative comments indicate acceptable flying qualities). These conditions, if exhibited, define disagreements which need to be resolved. Other disagreements may be the result of engineering judgment regarding the feasibility, wording, or purpose of the requirements. Resolution of these disagreements is covered in the third part.

3. Discussion:

   In this part, the disagreements presented in the comparison part are resolved. Data, background information, substantiating arguments, and discussion are used in the resolution of the disagreements. The basis for the recommendation is presented in this part.

4. Recommendation:

The recommendations, if any, are given in this part. These recommendations are a result of Parts 2 and 3. If a complete rewrite of the specification paragraph is suggested, it is written in this part. If only a partial rewrite is recommended, either the specification paragraph is rewritten with the partial changes or the changes are just indicated. If the recommendations consist of other relevances such as additional work necessary to obtain resolution, then this work is defined.

Requirement

1. SCOPE AND CLASSIFICATION

1.1 Scope. This specification contains the requirements for the flying qualities of U.S. military-piloted airplanes.

Comparison

The C-5A was designed to meet MIL-F-8785(ASG), Amendment-4, 17 April 1959, FAR 25 and some special requirements added by the procuring activity. Therefore, complete compliance with MIL-F-8785B(ASG) is not possible.

Discussion

None

Recommendation

None

Requirement

1.2 Application. The requirements of this specification shall be applied to assure that no limitations on flight safety or on the capability to perform intended missions will result from deficiencies in flying qualities. The flying qualities for all airplanes proposed or contracted for shall be in accordance with the provisions of this specification unless specific deviations are authorized by the procuring activity. Additional or alternate special requirements may be specified by the procuring activity.

Comparison

As stated in Section 1.1, the C-5A was not designed to comply with MIL-F-8785B(ASG) requirements. Had MIL-F-8785B(ASG) been applicable at the time the C-5A contract was initiated it is felt that some deviations would have been necessary.

Discussion

It has been amply demonstrated through flight test and operational use that the C-5A performs its intended mission with no limitations on flight safety resulting from deficiencies in flying qualities. Although, as pointed out in the report, there are quite a few areas where compliance with MIL-F-8785B(ASG) cannot be shown. Consequently, some means of deviating from these requirements would be necessary to keep contract cost within a reasonable range. Paragraph 1.2 provides this provision in the second sentence by allowing deviations to be authorized by the procuring activity. The C-5A program, therefore, supports the requirements and wording of this paragraph.

Recommendation

None

Requirement

1.3 Classification of airplanes. For the purpose of this specification, an airplane shall be placed in one of the following Classes:

Class I Small, light airplanes such as
- Light utility
- Primary trainer
- Light observation

Class II Medium weight, low-to-medium maneuverability airplanes such as
- Heavy utility/search and rescue
- Light or medium transport/cargo/tanker
- Early warning/electronic countermeasures/airborne command, control, or communications relay
- Antisubmarine
- Assault transport
- Reconnaissance
- Tactical bomber
- Heavy attack
- Trainer for Class II

Class III Large, heavy, low-to-medium maneuverability airplanes such as
- Heavy transport/cargo/tanker
- Heavy bomber
- Patrol/early warning/electronic countermeasures/airborne command, control, or communications relay
- Trainer for Class III

Class IV High-maneuverability airplanes such as
- Fighter/interceptor
- Attack
- Tactical reconnaissance
- Observation
- Trainer for Class IV

The procuring activity will assign an airplane to one of these Classes, and the requirements for that Class shall apply. When no Class is specified in a requirement, the requirement shall apply to all Classes. When operational missions so dictate, an airplane of one Class may be required by the procuring activity to meet selected requirements ordinarily specified for airplanes of another Class.

1.3.1 Land- or carrier-based designation. The letter -L following a Class designation identifies an airplane as land-based; carrier-based airplanes are similarly identified by -C. When no such differentiation is made in a requirement, the requirement shall apply to both land-based and carrier-based airplanes.

Comparison

The Lockheed C-5A is Class III Heavy Transport Airplane with no operational mission requirements which would require complying with any other Class requirements.

Discussion

None

Recommendations

None

Requirement

1.4 Flight Phase Categories. The Flight Phases have been combined into three Categories which are referred to in the requirement statements. These Flight Phases shall be considered in the context of total missions so that there will be no gap between successive Phases of any flight and so that transition will be smooth. When no Flight Phase or Category is stated in a requirement, that requirement shall apply to all three Categories. In certain cases, requirements are directed at specific Flight Phases identified in the requirement. Flight Phases descriptive of most military airplane missions are:

Nonterminal Flight Phases:

Category A - Those nonterminal Flight Phases that require rapid maneuvering, precision tracking, or precise flight-path control. Included in this Category are:

a. Air-to-air combat (CO)

b. Ground attack (GA)

c. Weapon delivery/launch (WD)

d. Aerial recovery (AR)

e. Reconnaissance (RC)

f. In-flight refueling (receiver) (RR)

g. Terrain following (TF)

h. Antisubmarine search (AS)

i. Close formation flying (FF)

Category B - Those nonterminal Flight Phases that are normally accomplished using gradual maneuvers and without precision tracking, although accurate flight-path control may be required. Included in this Category are:

a. Climb (CL)

b. Cruise (CR)

c. Loiter (LO)

d. In-flight refueling (tanker) (RT)

e. Descent (D)

f. Emergency descent (ED)

g. Emergency deceleration (DE)

h. Aerial delivery (AD)

Terminal Flight Phases:

Category C - Terminal Flight Phases are normally accomplished using gradual maneuvers and usually require accurate flight-path control. Included in this Category are:

a. Takeoff (TO)

b. Catapult takeoff (CT)

c. Approach (PA)

d. Wave-off/go-around (WO)

c. Landing (L)

When necessary, recategorization or addition of Flight Phases or delineation of requirements for special situations, e.g., zoom climbs, will be accomplished by the procuring activity.

Comparison

The C-5A total mission requirements correspond primarily with Flight Phase Categories B and C, although in-flight refueling and terrain following missions correspond to Category A Flight Phase.

Comparison of the C-5A airplane flying qualities with the requirements of this Specification will involve the following Flight Phases:

Category A - In-flight refueling (receiver) (RR)

Category B - Climb (CL)
Cruise (CR)
Descent (D)
Aerial delivery (AD)

Category C - Takeoff (TO)
Approach (PA)
Wave-off/go-around (WO)
Landing (L)

Discussion

As noted in the preceding paragraph, flying qualities data are not included in this report for the terrain following (TF) mission. The reasons are as follows:

1 Flying qualities data were not recorded during the flight test development of the Terrain Following/Terrain Avoidance (TF/TA) missions since at that time there were no requirements.

2. If suitable instrumentation had been included on the TF/TA development test vehicle for recording flying qualities type data, the results for either the fully

automatic mode or the manual mode would be more applicable for comparison with MIL-F-9490 and MIL-F-18372 requirements instead of MIL-F-8785B(ASG) requirements. In addition, in order to acquire the necessary data to determine compliance with applicable MIL-F-8785B(ASG) requirements, test maneuvers would have to be performed which are not consistent with normal TF/TA maneuvers.

A change in the requirements is not recommended to cover the C-5A TF/TA mission, since it is felt that a deviation to the specification could be included in the initial contractual requirements for cases similar to the one discussed here.

Recommendation

None

Requirement

1.5 Levels of flying qualities. Where possible, the requirements of section 3 have been stated in terms of three values of the stability or control parameter being specified. Each value is a minimum condition to meet one of three Levels of acceptability related to the ability to complete the operational missions for which the airplane is designed. The Levels are:

Level 1	Flying qualities clearly adequate for the mission Flight Phase
Level 2	Flying qualities adequate to accomplish the mission Flight Phase, but some increase in pilot workload or degradation in mission effectiveness, or both, exists
Level 3	Flying qualities such that the airplane can be controlled safely, but pilot workload is excessive or mission effectiveness is inadequate, or both. Category A Flight Phases can be terminated safely, and Category B and C Flight Phases can be completed.

Comparison

None

Discussion

None

Recommendation

None

Requirement

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on the date of invitation for bids or request for proposal, form a part of this specification to the extent specified herein:

SPECIFICATIONS

Military

MIL-D-8708	Demonstration Requirements for Airplanes
MIL-F-9490	Flight Control Systems - Design, Installation and Test of, Piloted Aircraft, General Specification for
MIL-C-18244	Control and Stabilization Systems, Automatic, Piloted Aircraft, General Specification for
MIL-F-18372	Flight Control Systems, Design, Installation and Test of, Aircraft (General Specification for)
MIL-S-25015	Spinning Requirements for Airplanes
MIL-W-25140	Weight and Balance Control Data (for Airplanes and Rotorcraft)

STANDARDS

MIL-STD-756	Reliability Prediction

(Copies of documents required by suppliers in connection with specific procurement functions should be obtained from the procuring activity or as directed by the contracting officer.)

Comparison

The C-5A airplane design is defined in Lockheed Specification Number CP40002-1B.

Discussion

None

Recommendation

None

Requirement

3. REQUIREMENTS

3.1 General requirements

3.1.1 Operational missions. The procuring activity will specify the operational missions to be considered by the contractor in designing the airplane to meet the flying qualities requirements of this specification. These missions will include the entire spectrum of intended operational usage.

Comparison

The Contract End Item Detail Specification, Reference 1, specifies the following missions or use allocated to the C-5A:

"1.2 Intended Use - The use allocated to the air vehicle by the 410A Heavy Logistic Support Specification, SS40001, is as follows:

a. To provide transportation for the required payloads at high subsonic speeds to objective areas in any region in the world.

b. To provide capability to transport tactical ground vehicles and equipment (including ballistic missiles) which are outsized for the air transport systems now in Government inventory.

c. To provide capability of world-wide, all weather operation into all established air bases and operations on a limited basis into support area airfields. The air vehicle will be employed in inter- and intra-theater operations.

d. To provide capability for aerial delivery of cargo and paratroop drop when fitted with the appropriate special mission kit(s)."

"3.1.1.2.5 In-Flight Refueling - The air vehicle shall have performance characteristics which permit in-flight refueling from the KC-135 tanker system."

Additional missions are specified in terms of performance parameters (payload-range, takeoff distance, etc.) which are not directly applicable to flying qualities requirements.

Discussion

The C-5A design specification(s), relating to flying qualities, is not specified in terms of operational missions or intended usage as defined by this requirement. The specifications dealing with flying qualities were generally extracted from MIL-F-8785(ASG) and FAR Part 25 with a few special requirements added by the procuring activity. These requirements

are, in general, directed to airplane configuration, which probably implies operational mission rather than specifying missions for design purposes.

The following basic airplane configurations were investigated for handling qualities design of the C-5A:

Configuration	Power, gear, flaps
CRUISE (CR)	Power for level flight at trim speed, flaps and gear up.
DIVE (D)	25% normal power, flaps and gear up.
GLIDE (G)	Idle power, gear and flaps up.
POWER (P)	Normal power, gear and flap-up.
POWER APPROACH (PA)	Power for level flight at 1.3Vs, gear down, flaps 25°, slats 22°.
LANDING (L)	Idle power, gear down, flaps 40°, slats 22°, spoilers 3°
WAVE-OFF (WO)	Takeoff power, gear down, flaps 40°, slats 22°, spoilers 3°.
TAKEOFF (TO) - 25°	Power for level flight at 1.3Vs, gear down, flaps 25°, slats 22°.
AERIAL DELIVERY (AD)	Power for level flight at 3° deck angle, gear up, flaps as necessary.

Recommendation

Flying qualities analysis experience on the C-5A, as well as other previous Class III airplanes (C-141 and C-130), supports this requirement. It is considered that good mission definition will be extremely useful to the flying qualities engineer.

Requirement

3.1.2 Loading. The contractor shall define the envelopes of center of gravity and corresponding weights that will exist for each Flight Phase. These envelopes shall include the most forward and aft center-of-gravity positions as defined in MIL-W-25140. In addition, the contractor shall determine the maximum center-of-gravity excursions attainable through failures in systems or components, such as fuel sequencing, hung stores, etc., for each Flight Phase to be considered in the Failure States of 3.1 6.2. Within these envelopes, plus a growth margin to be specified by the procuring activity, and for the excursions cited above, this specification shall apply.

3.1.3 Moments of inertia. The contractor shall define the moments of inertia associated with all loadings of 3.1.2. The requirements of this specification shall apply for all moments of inertia so defined.

Comparison

The design center of gravity limits are presented in Fig. 1(3.1.2) and the associated moments of inertia are presented in Figures 1 (3.1.3) through 6(3.1.3). These data are generally applicable to all flight phases since the cargo loading or placement is adjusted to provide a center of gravity within these limits, for any gross weight, and the inertia data have been defined as boundaries of fuel and cargo combination. It is not clearly indicated that a growth margin was considered when these envelopes were established.

Discussion

These requirements seem to imply that unique and different envelopes always exist for each Flight Phase. When this is the case, it is reasonable to require the definition of representative envelopes, which span the conditions encountered.

The inherent cargo loading capability of large Class III, cargo type airplanes permits the definition of envelopes for design which can be applied to each Flight Phase. From a flying qualities analysis viewpoint, the specified growth margin, as such, would be of little practical interest since the total envelope must be considered for specification compliance.

Recommendation

None (for Class III, cargo-type airplanes)

C-5A DATA

MAC ~ 370.5 IN
L.E. MAC @ F.S. 1346.9

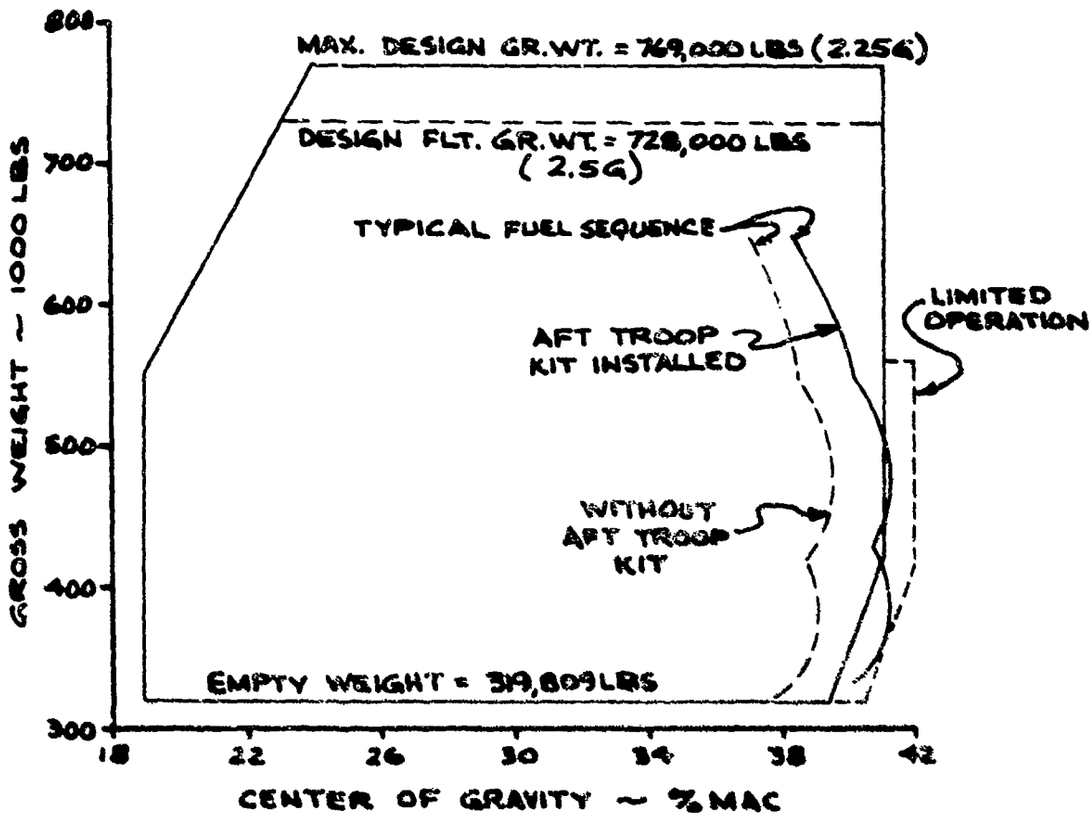


FIGURE NO. 1 (3.1.2) CENTER OF GRAVITY LIMITS

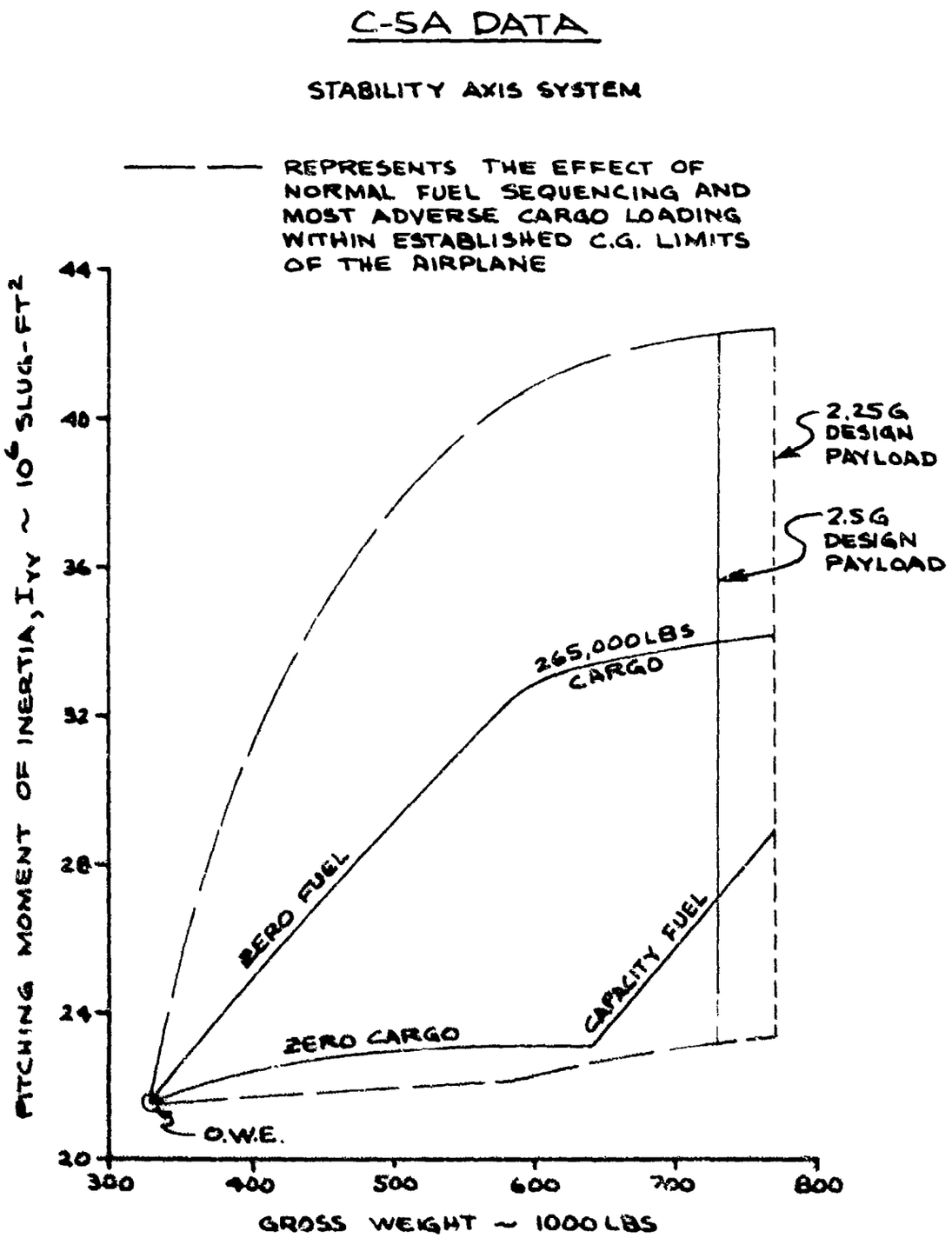


FIGURE NO.1 (3.1.3) EFFECT OF AIRPLANE WEIGHT ON PITCHING MOMENT OF INERTIA

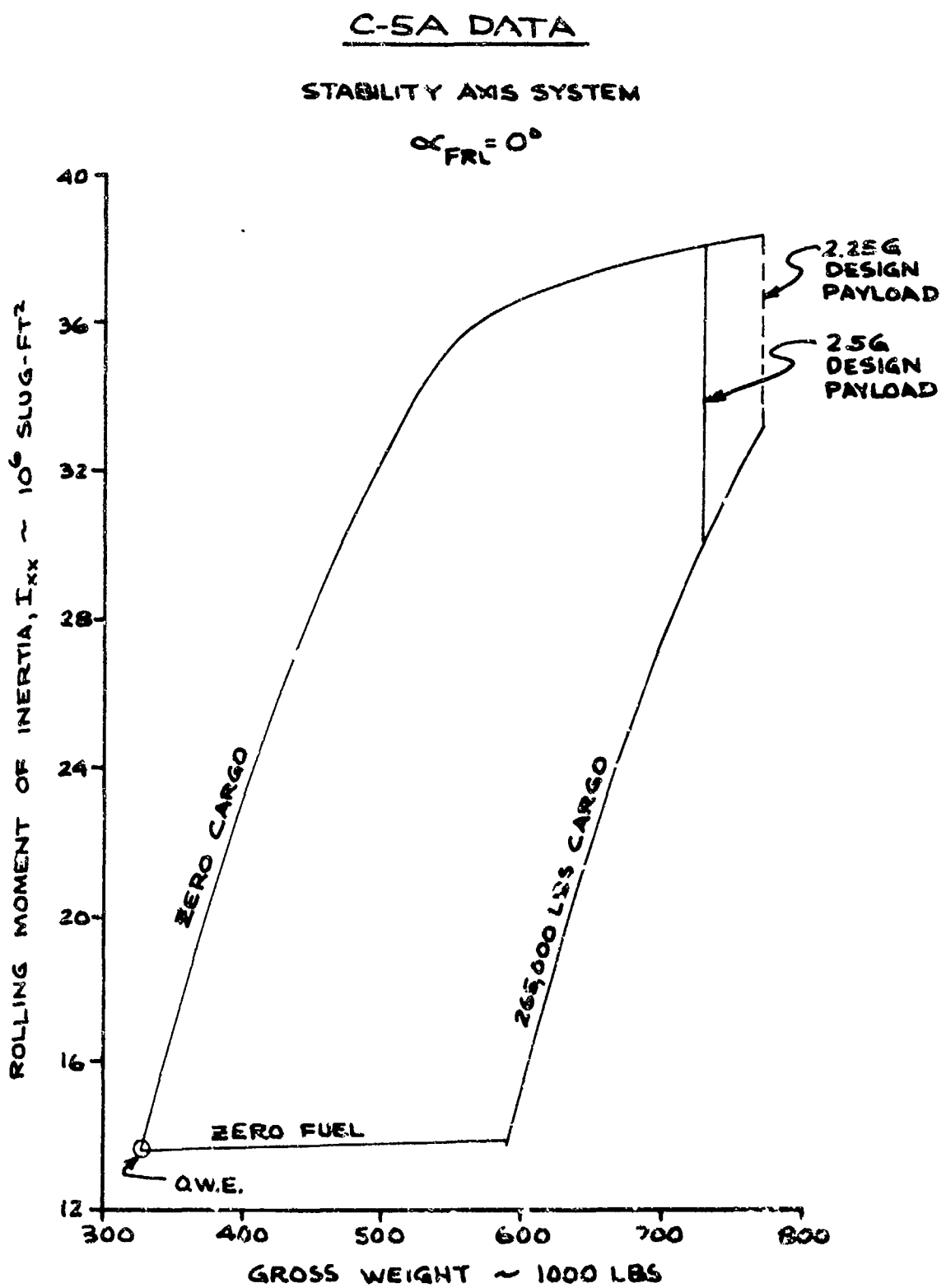


FIGURE NO.2(3.1.3) EFFECT OF AIRPLANE WEIGHT ON ROLLING MOMENT OF INERTIA

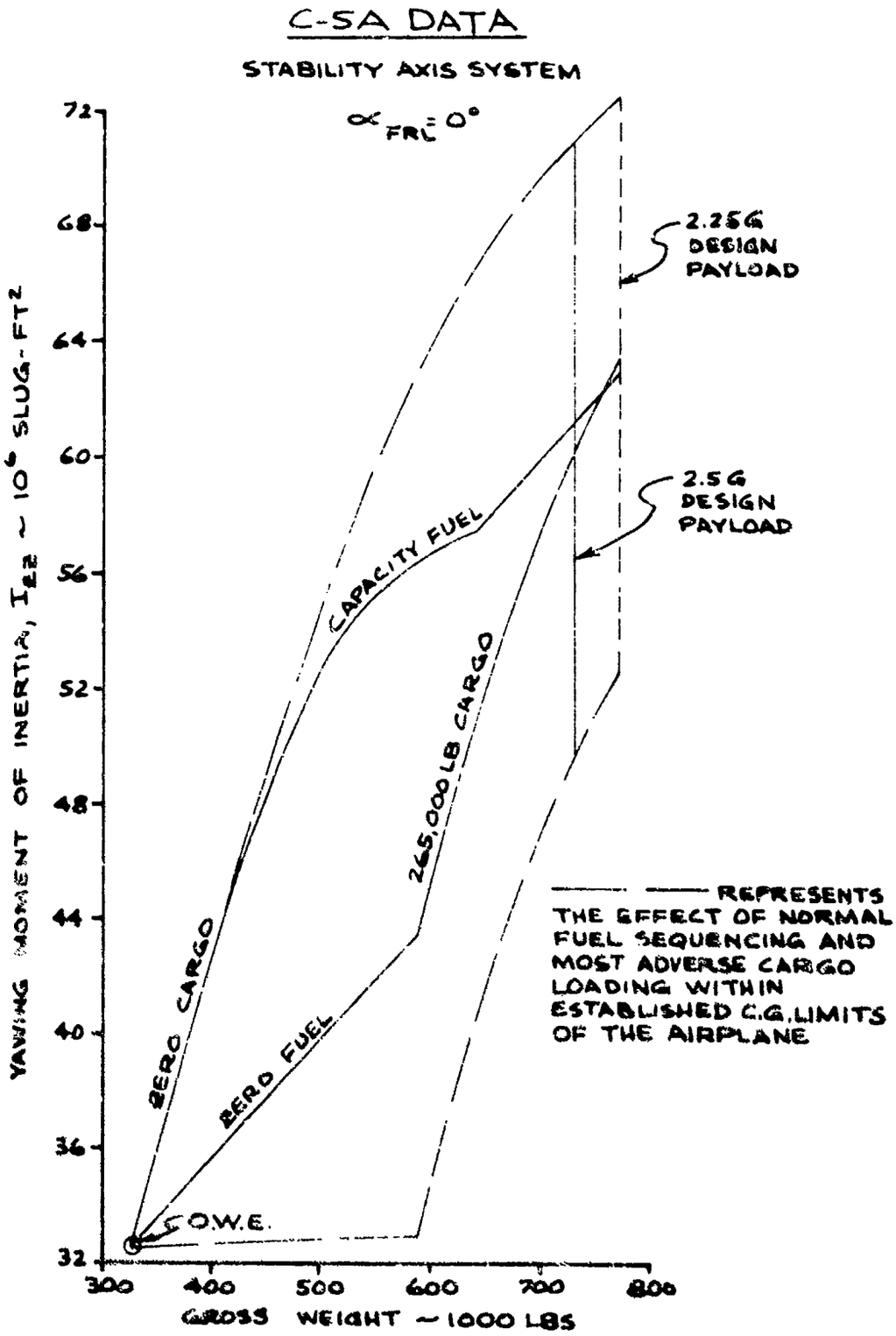


FIGURE NO.3(3.1.3) EFFECT OF AIRPLANE WEIGHT ON YAWING MOMENT OF INERTIA

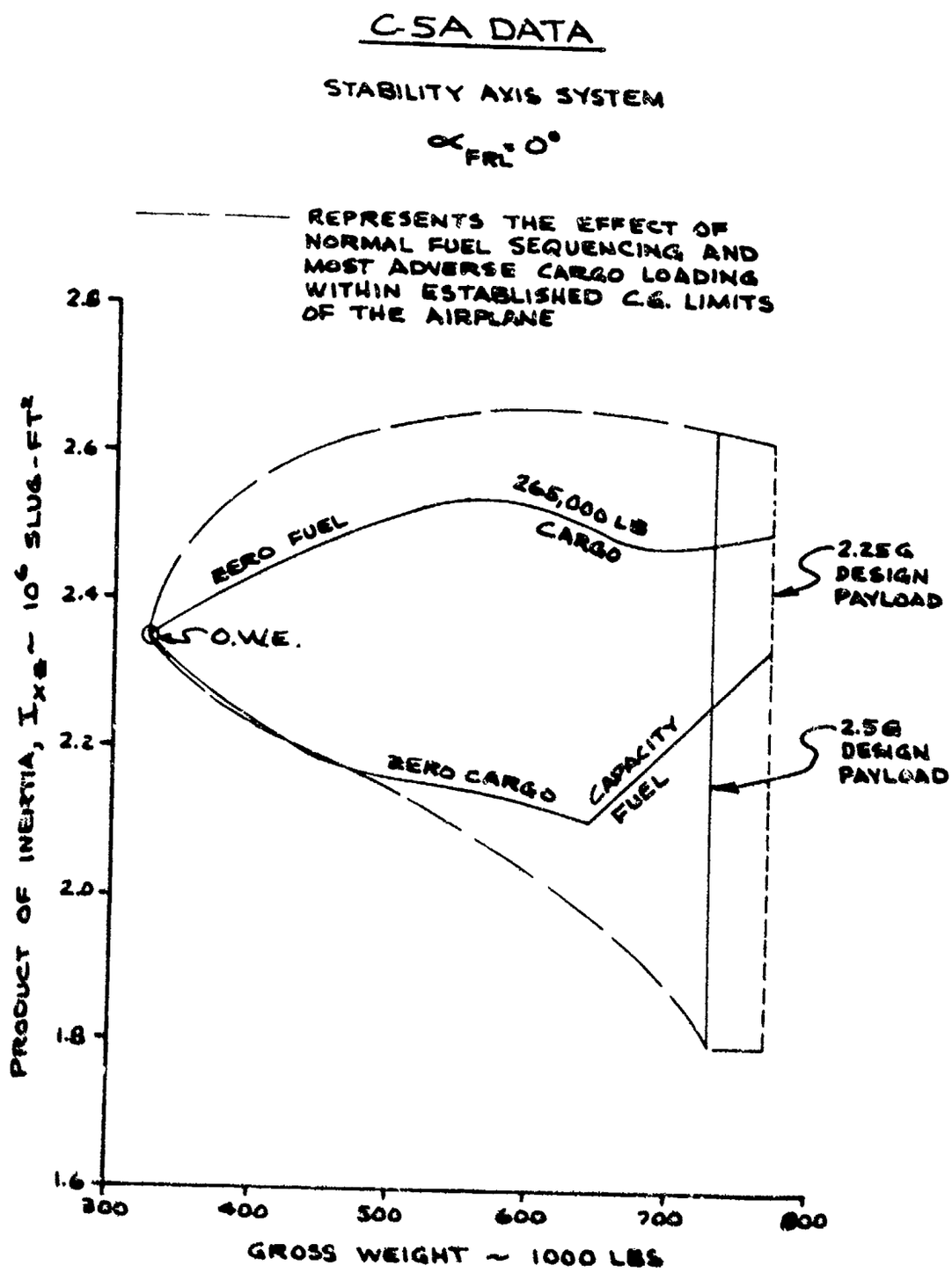


FIGURE NO.4(3.1.3) EFFECT OF AIRPLANE WEIGHT ON ROLL-YAW PRODUCT OF INERTIA

C-5A DATA

STABILITY AXIS SYSTEM

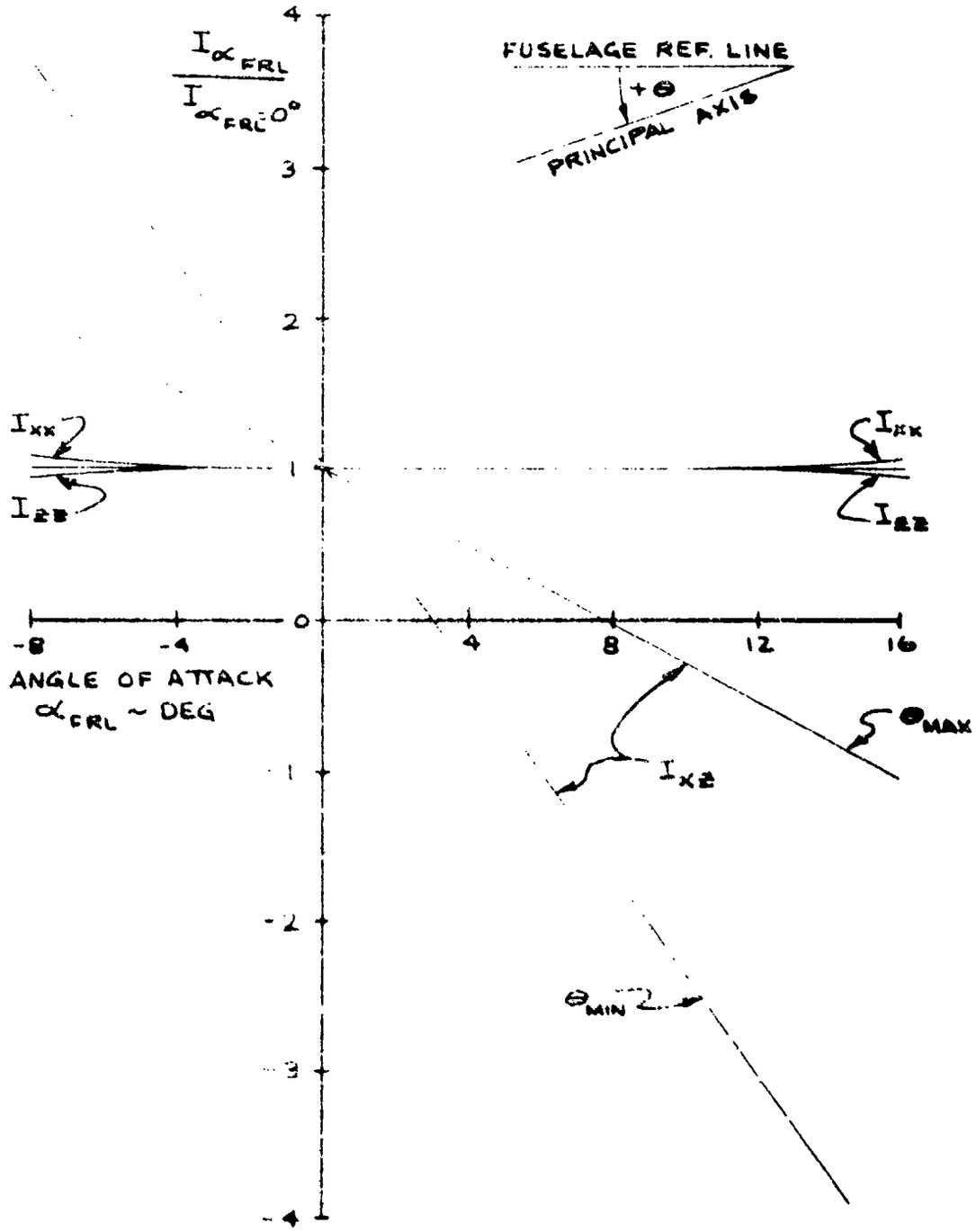


FIGURE NO.5(3.13) EFFECT OF ANGLE OF ATTACK ON INERTIA CHARACTERISTICS

C-5A DATA

STABILITY AXIS SYSTEM

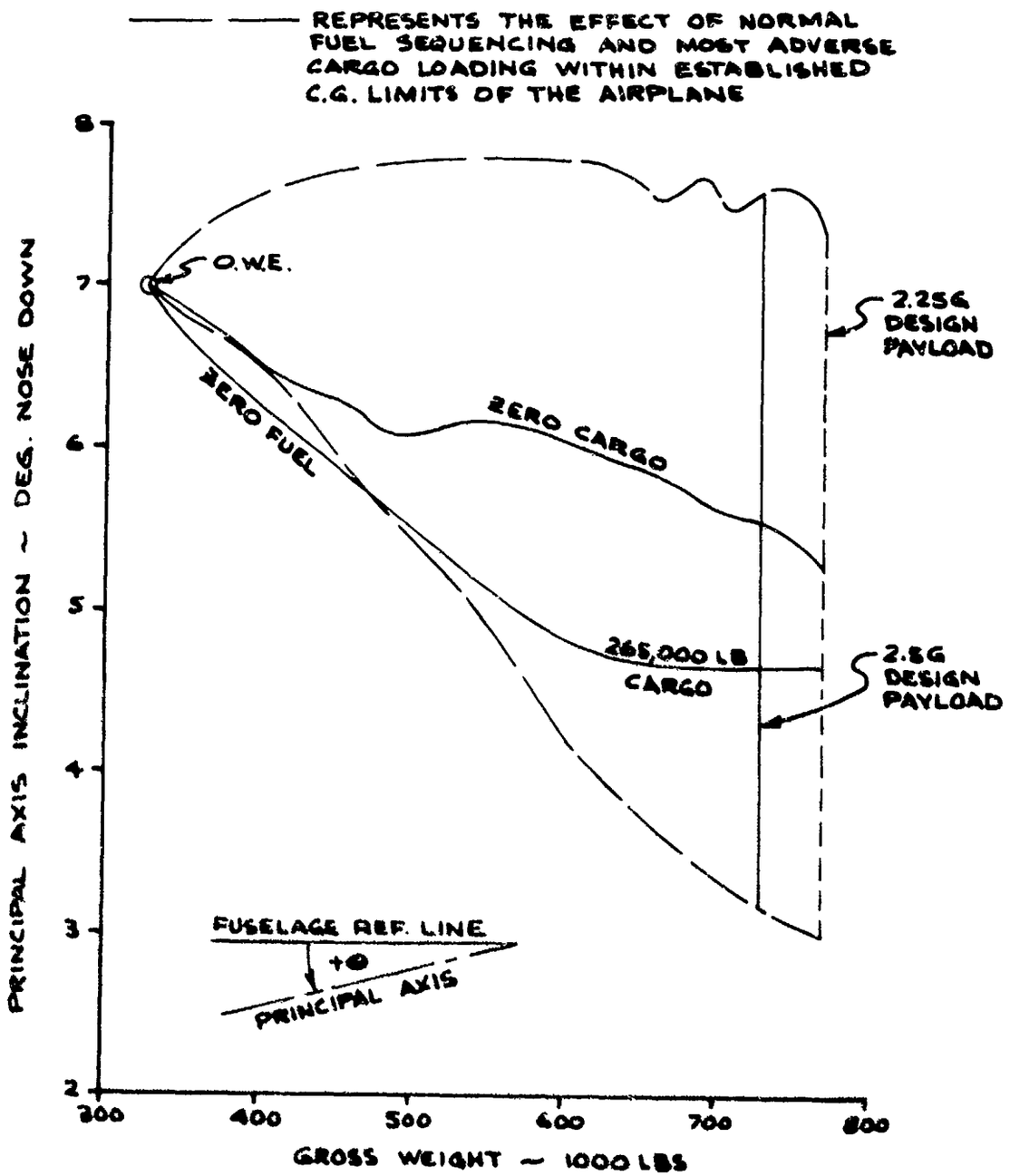


FIGURE NO.6(3.1.3) PRINCIPAL AXIS INCLINATION

Requirement

3.1.4 External stores. The requirements of this specification shall apply for all combinations of external stores required by the operational missions. The effects of external stores on the weight, moments of inertia, center-of-gravity position, and aerodynamic characteristics of the airplane shall be considered for each mission Flight Phase. When the stores contain expendable loads, the requirements of this specification apply throughout the range of store loadings. The external stores and store combinations to be considered for flying qualities design will be specified by the procuring activity. In establishing external store combinations to be investigated, consideration shall be given to asymmetric as well as to symmetric combinations.

Comparison

The C-5A is not equipped to carry external stores.

Discussion

None

Recommendation

None

Requirement

3.1.5 Configurations. The requirements of this specification shall apply for all configurations required or encountered in the applicable Flight Phases of 1.4. A (crew-) selected configuration is defined by the positions and adjustments of the various selectors and controls available to the crew except for rudder, aileron, elevator, throttle, and trim controls. Examples are: the flap control setting and the yaw damper ON or OFF. The selected configurations to be examined must consist of those required for performance and mission accomplishment. Additional configurations to be investigated may be defined by the procuring activity.

Comparison

None

Discussion

None

Recommendation

None

Requirement

3.1.6 State of the Airplane. The state of the airplane is defined by the selected configuration together with the functional status of each of the airplane components or systems, throttle setting, weight, moments of inertia, center-of-gravity position, and external store complement. The trim setting and the positions of the rudder, aileron, and elevator controls are not included in the definition of Airplane State since they are often specified in the requirements.

Certain items, such as weight, moments of inertia, center-of-gravity position, wing sweep, or thrust setting may vary continuously over a range of values during a Flight Phase. The contractor shall replace this continuous variation by a limited number of values of the parameter in question which will be treated as specific states, and which include the most critical values and the extremes encountered during the Flight Phase in question.

3.1.6.1 Airplane Normal States. The contractor shall define and tabulate all pertinent items to describe the Airplane Normal (no component or system failure) State(s) associated with each of the applicable Flight Phases. This tabulation shall be in the format and shall use the nomenclature shown in 6.2.

Comparison

Table 1 lists the airplane normal states.

Discussion

None

Recommendation

None

Table 1. Airplane Normal States

FLIGHT PHASE		WEIGHT LB	CG % MAC	THRUST	FLAPS DEG.	SLATS	LANDING GEAR	THRUST REVERSERS	CARGO DOORS	STAB. AUGM.
Takeoff	TO	769,000	24 -41.	TRT	16 '25	Down	Down	Stowed	Closed	On
Climb	CL	732,500	23.1-41.	MRT	0	Up	Up	Stowed	Closed	On
Cruise	CR	732,500	23.1-41.	NRT	0	Up	Up	Stowed	Closed	On
Loiter	LO	732,500	23.1-41.	NRT	0	Up	Up	Stowed	Closed	On
Descent	D	732,500	23.1-41.	Idle	0	Up	Up	Stowed	Closed	On
Emerg. Desc.	ED	732,500	23.1-41.	2 Idle 2 Rev. Idle	0	Up	Down	2 Inbd. Rev.	Closed	On
Approach	PA	732,500	23.1-41.	TRT	16	Down	Up	Stowed	Closed	On
Wave-Off Go Around	W.O	732,500	23.1-41.	TRT	16	Down	Up	Stowed	Closed	On
Landing	L	635,000	20.9-41.	NRT	40	Down	Down	4 Rev.	Closed	On
Aerial Delivery	AD	732,500	23.1-41.	MRT	Optional	Down	Up	Stowed	Open	On
Refuel Receiver	RR	732,500	23.1-41.	MRT	0	Up	Up	Stowed	Closed	On
Terrain Following	TF	732,500	23.1-41.	MRT	0	Up	Up	Stowed	Closed	On

Requirement

3.1.6.2 Airplane Failure States. The contractor shall define and tabulate all Airplane Failure States, which consist of Airplane Normal States modified by one or more malfunctions in airplane components or systems; for example, a discrepancy between a selected configuration and an actual configuration. These malfunctions that result in center-of-gravity positions outside the center-of-gravity envelope defined in 3.1.2 shall be included. Each mode of failure shall be considered. Failures occurring in any Flight Phase shall be considered in all subsequent Flight Phases.

Comparison

A complete list of the Airplane Failure States for an airplane as complex as the C-5A is not considered within the scope of this study. However, the following summary is provided which list the Failure States that were evaluated as a part of the Category I/II test program. Results from a majority of these tests are presented in Reference 2.

SUMMARY OF FAILURE STATES

1. Flaps Up Landing:	Simulated failure in flap system that prevented flap movement from full up position
2. Slat Retracted Operation:	Failure of slats to fully extend when flaps moved from retracted to approach position. Evaluated throughout envelope from stall to landing.
3. Failed Stabilizer:	Stabilizer failed in most adverse position. Remaining flight phase missions accomplished including landing.
4. Outboard Engine Inoperative:	Entire mission from ground handling, takeoff, climb, cruise, and landing with engine out.
5. Two Engines Inoperative on Same Side:	Controllability evaluated in flight.
6. One Hydraulic System (#2) Inoperative:	Failure in #2 hydraulic system. Remaining mission and landing accomplished.
7. Two hydraulic systems (#2 & #3) Inoperative:	Failures in two hydraulic systems with resulting floating control surfaces (inboard elevator, lower rudder and spoiler panels). Reduced flight envelope. Landing accomplished.
8. Runaway Stabilizer Trim:	Failure within system that resulted in stabilizer movement to nose up and to nose down limits in cruise configuration. Sufficient elevator to counteract runaway.

9. Failed Inboard Thrust Reverser:	Failure of inboard thrust reverser to retract to stowed position in flight. Limited flight envelope Landing accomplished. Failure also evaluated during takeoff abort.
10. SAS Inoperative:	Complete SAS failure. No affect upon operational limitations.
11. Failed Spoiler Panel Connecting Rod:	Failure in connecting rod that resulted in floating panel. No resulting limitations.
12. Autopilot Hardovers:	Simulated failure in AFCS that resulted in control surface hardover in pitch, yaw, and roll axes. Operation restricted in that AFCS must be disengaged.

Discussion

Insufficient comparison data for complete specification validation.

Recommendation

None

Requirement

3.1.6.2.1 Airplane Special Failure States - Certain components, systems, or combinations thereof may have extremely remote probability of failure during a given flight. These failure probabilities may, in turn, be very difficult to predict with any degree of accuracy. Special Failure States of this type need not be considered in complying with the requirements of Section 3 if justification for considering the Failure States as Special is submitted by the contractor and approved by the procuring activity.

Comparison

No special Failure State data are submitted herein.

Discussion

None

Recommendation

None

Requirement

3.1.7 Operational Flight Envelopes. The Operational Flight Envelopes define the boundaries in terms of speed, altitude, and load factor within which the airplane must be capable of operating in order to accomplish the missions of 3.1.1. Envelopes for each applicable Flight Phase shall be established with the guidance and approval of the procuring activity. In the absence of specific guidance, the contractor shall use the representative conditions of Table I for the applicable Flight Phases.

Comparison

The flight envelopes for the C-5A were specified for the various airplane configurations and structural design conditions rather than for specific mission accomplishment and flight phase, as currently required. As mentioned previously (3.1.1) the applicable Flight Phase(s) has to be assigned by implication of configuration. Table 2, along with Figures 1(3.1.7) and 2(3.1.7) summarize the operational envelopes for Flight Phase Categories A and B. Figure 1(3.1.7) presents the cruise (CR) and climb (CL) configuration snd Figure 2(3.1.7) presents the three descent configurations.

The ENROUTE descent is accomplished in the CR configuration with engines retarded to flight idle power. The GEAR DOWN descent uses gear down, engines 1 and 4 in flight idle and engines 2 and 3 in reverse idle. These descents would be associated with Flight Phase D. The third descent schedule (RAPID) is used for flight phase (ED) and is accomplished with the gear up, engines 1 and 4 in flight idle and engines 2 and 3 in reverse idle. Figure 3(3.1 7) presents the operational flight envelopes for the Flight Phase Category C configurations.

Discussion

C-5A data supports this requirement.

Recommendation

None

TABLE I. Operational Flight Envelope

FLIGHT PHASE CATEGORY	FLIGHT PHASE	AIRSPEED		ALTITUDE		LOAD FACTOR	
		$V_{o_{min}}$ ($M_{o_{min}}$)	$V_{o_{max}}$ ($M_{o_{max}}$)	$h_{c_{min}}$	$h_{o_{max}}$	$n_{o_{min}}$	$n_{o_{max}}$
A	AIR-TO-AIR COMBAT (AC)	1.4 V_S	V_{MAT}	MSL	Combat Ceiling	-1.0	n_L
	GROUND ATTACK (GA)	1.3 V_S	V_{MAT}	MSL	Medium	-1.0	n_L
	WEAPON DELIVERY/LAUNCH (WD)	V_{range}	V_{MAT}	MSL	Combat Ceiling	.5	*
	AERIAL RECOVERY (AR)	1.2 V_S	V_{MAT}	MSL	Combat Ceiling	.5	n_L
	RECONNAISSANCE (RC)	1.3 V_S	V_{MAT}	MSL	Combat Ceiling	*	*
	IN-FLIGHT REFUEL (RECEIVER) (FR)	1.2 V_S	V_{MAT}	MSL	Combat Ceiling	.5	2.0
	TERRAIN FOLLOWING (TF)	V_{range}	V_{MAT}	MSL	10,000 ft.	0	3.5
	ANTISUBMARINE SEARCH (AS)	1.2 V_S	V_{MAT}	MSL	Medium	0	2.0
	CLOSE FORMATION FLYING (FF)	1.4 V_S	V_{MAT}	MSL	Combat Ceiling	-1.0	n_L
B	CLIMB (CL)	.85 $V_{R/C}$	1.3 $V_{R/C}$	MSL	Cruising Ceiling	.5	2.0
	CRUISE (CR)	V_{range}	V_{MAT}	MSL	Cruising Ceiling	.5	2.0
	LOITER (LO)	.85 V_{end}	1.3 V_{end}	MSL	Cruising Ceiling	.5	2.0
	IN-FLIGHT REFUEL (TANKER) (FT)	1.4 V_S	V_{MAT}	MSL	Cruising Ceiling	.5	2.0
	DESCENT (D)	1.4 V_S	V_{MAT}	MSL	Cruising Ceiling	.5	2.0
	EMERGENCY DESCENT (ED)	1.4 V_S	V_{max}	MSL	Cruising Ceiling	.5	2.0
	EMERGENCY DECELERATION (ED)	1.4 V_S	V_{max}	MSL	Cruising Ceiling	.5	2.0
	AERIAL DELIVERY (AD)	1.2 V_S	200 kt	MSL	10,000 ft	0	2.0
C	TAKEOFF (TO)	Minimum Normal Takeoff Speed	V_{max}	MSL	10,000 ft.	.5	2.0
	CATAPULT TAKEOFF (CT)	Minimum Catapult End Airspeed	$V_{o_{min}}$ +30 kt	MSL	—	.5	n_L
	APPROACH (PA)	Minimum Normal Approach Speed	V_{max}	MSL	10,000 ft.	.5	2.0
	WAVE-OFF/GO-AROUND (WO)	Minimum Normal Approach Speed	V_{max}	MSL	10,000 ft.	.5	2.0
	LANDING (L)	Minimum Normal Landing Speed	V_{max}	MSL	10,000 ft.	.5	2.0

*Appropriate to the operational mission.

C-5A DATA

FLIGHT CATEGORY B

FLAPS/SLATS AND GEAR UP

FLIGHT PHASES: CL & CR

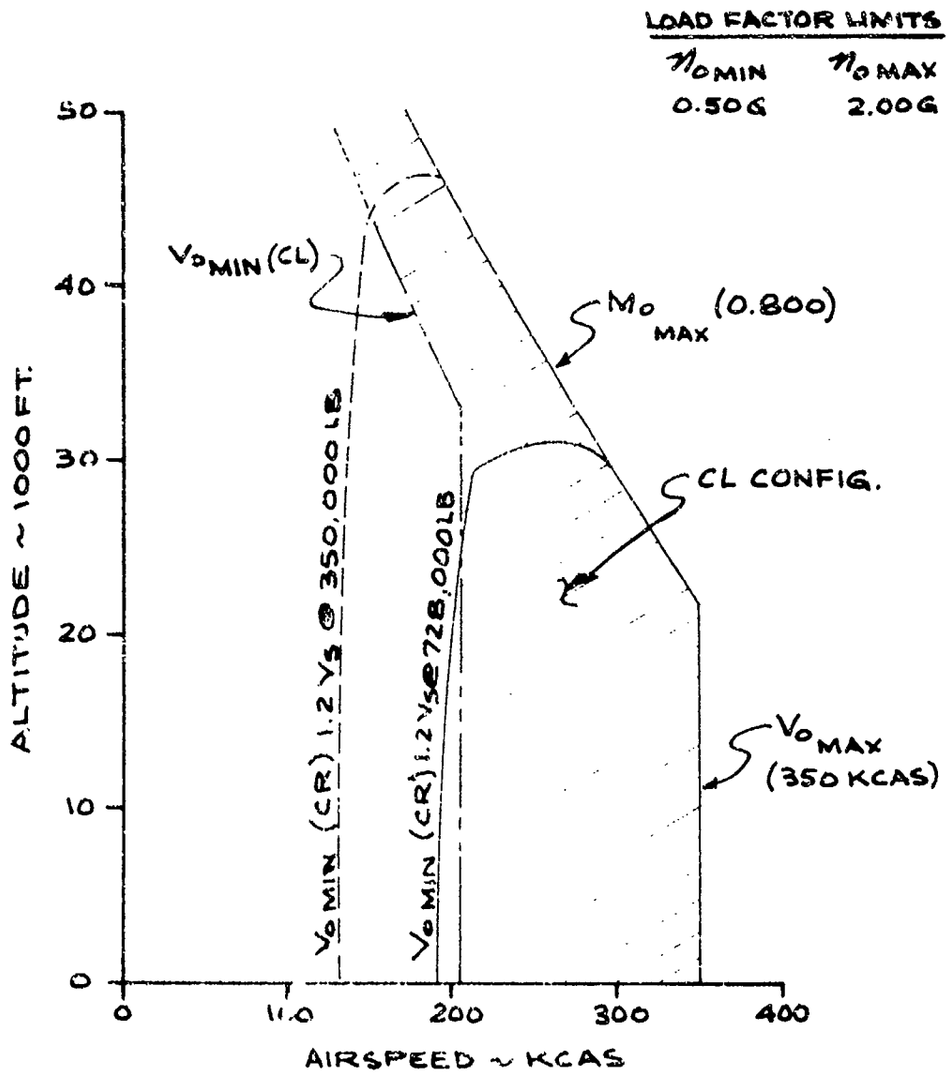


FIGURE NO.1 (3.1.7) OPERATIONAL FLIGHT ENVELOPE

C-5A DATA

FLIGHT CATEGORY B

FLIGHT PHASES: DESCENT (D, ED)

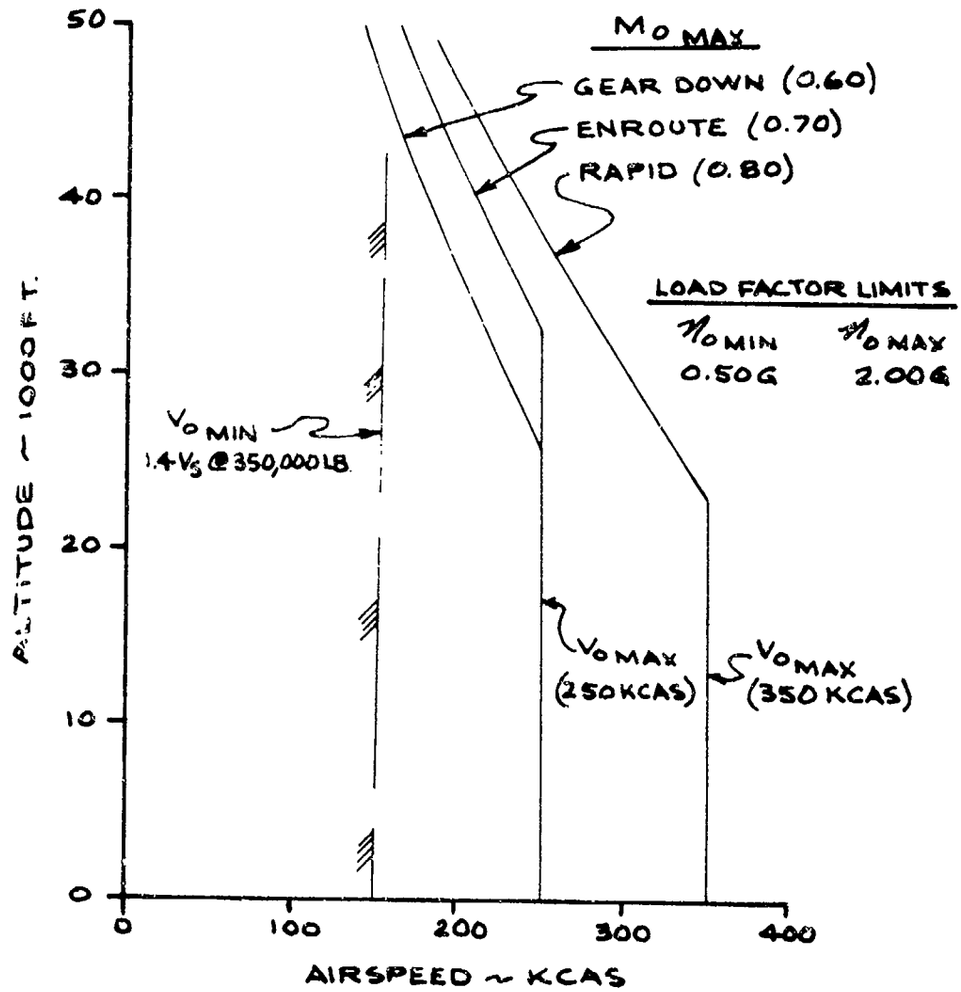


FIGURE NO. 2 (3.17) OPERATIONAL FLIGHT ENVELOPE

C-5A DATA

FLIGHT CATEGORY C

FLIGHT PHASES: TO, PA, WO, L, AD

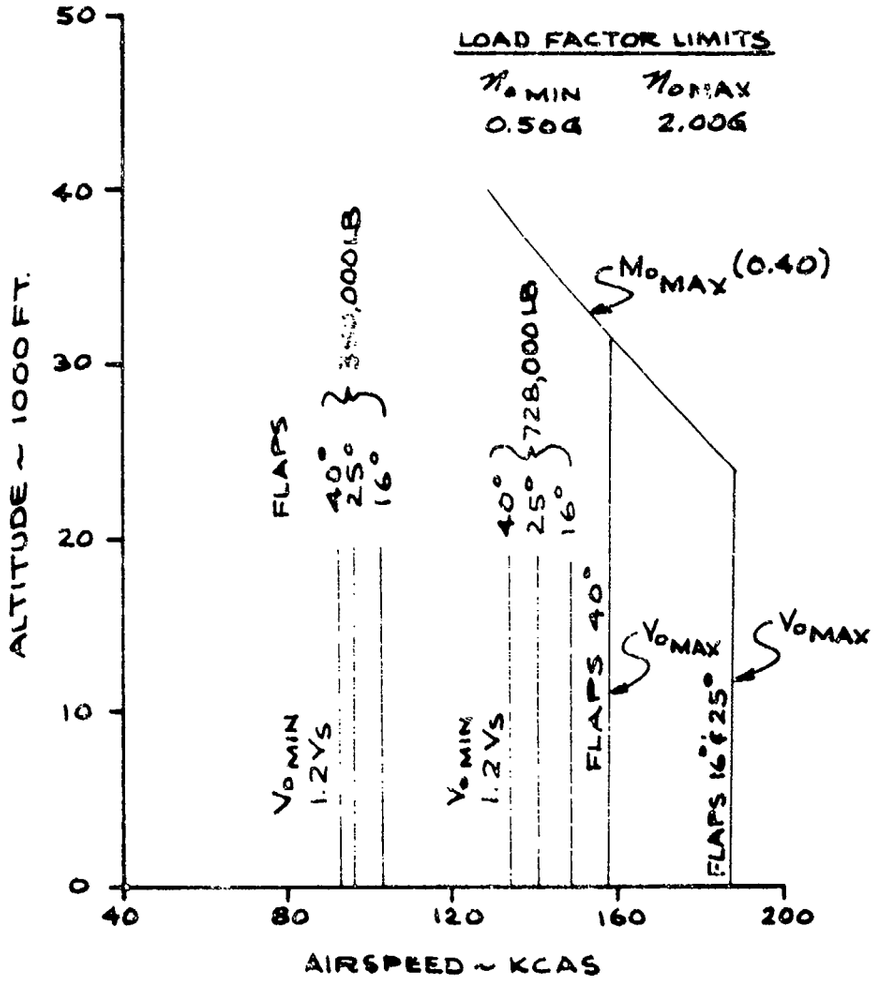


FIGURE NO.3(3.1.7) OPERATIONAL FLIGHT ENVELOPE

Table 2. Operational Flight Envelope

FLIGHT PHASE	AIRSPEED (KCAS)		ALTITUDE (FT)		LOAD FACTOR	
	$V_{o_{min}}$	$V_{o_{max}}$	$h_{o_{min}}$	$h_{o_{max}}$	$n_{o_{min}}$	$n_{o_{max}}$
FLIGHT PHASE CATEGORY A						
Inflight Refuel (RR)	240	270	25,000	30,000	0.50	2.0
Terrain Following (TF)	200	350	MSL	10,000	0	2.5
FLIGHT PHASE CATEGORY B						
Climb (CL)	See Figure 1(3.1.7)					
Cruise (CR)	See Figure 1(3.1.7)					
Loiter (LO)	145	300	5,000	20,000	0.50	2.0
Descent (D)	See Figure 2(3.1.7)					
Emer. Descent (ED)	See Figure 2(3.1.7)					
Aerial Delivery (AD)	130	200	MSL	20,000	0	2.0
FLIGHT PHASE CATEGORY C						
See Figure 3(3.1.7)						

Requirement

3.1.8 Service Flight Envelopes. For each Airplane Normal State the contractor shall establish, subject to the approval of the procuring activity, Service Flight Envelopes showing combinations of speed, altitude, and normal acceleration derived from airplane limits as distinguished from mission requirements. For each applicable Flight Phase and Airplane Normal State, the boundaries of the Service Flight Envelopes can be coincident with or lie outside the corresponding Operational Flight Envelopes, but in no case shall they fall inside those Operational boundaries. The boundaries of the Service Flight Envelopes shall be based on considerations discussed in 3.1.8.1, 3.1.8.2, 3.1.8.3, and 3.1.8.4.

3.1.8.1 Maximum service speed. The maximum service speed, V_{max} or M_{max}, for each altitude is the lowest of:

a. The maximum permissible speed

b. A speed which is a safe margin below the speed at which intolerable buffet or structural vibration is encountered

c. The maximum airspeed at MAT, for each altitude, for dives (at all angles) from V_{MAT} at all altitudes, from which recovery can be made at 2,000 feet above MSL or higher without penetrating a safe margin from loss of control, other dangerous behavior, or intolerable buffet, and without exceeding structural limits.

3.1.8.2 Minimum service speed. The minimum service speed, V_{min} or M_{min}, for each altitude, is the highest of:

a. $1.1\ V_S$

b. V_S + 10 knots equivalent airspeed

c. The speed below which full airplane-nose-up elevator control power and trim are insufficient to maintain straight, steady flight

d. The lowest speed at which level flight can be maintained with MRT

and, for Category C Flight Phases:

e. A speed limited by reduced visibility or an extreme pitch attitude that would result in the tail or aft fuselage contacting the ground.

3.1.8.3 Maximum service altitude. The maximum service altitude, h_{max}, for a given speed is the maximum altitude at which a rate of climb of 100 feet per minute can be maintained in unaccelerated flight with MAT.

3.1.8.4 Service load factors. Maximum and minimum service load factors, n(+)[n(-)], shall be established as a function of speed for several significant altitudes. The maximum

minimum service load factor, when trimmed for 1g flight at a particular speed and altitude, is the lowest highest algebraically of:

a. The positive negative structural limit load factor

b. The steady load factor corresponding to the minimum allowable stall warning angle of attack (3.4.2.2.2)

c. The steady load factor at which the elevator control is in the full airplane-nose-up nose-down position

d. A safe margin below above the load factor at which intolerable buffet or structural vibration is encountered.

Comparison

The service flight envelopes are presented in Figure 1(3.1.8) through 5(3.1.8) for each airplane configuration and applicable (implied) flight phase. Structural design limits establish the maximum service or permissible speed. The minimum service speed is limited by the highest of 1.1 V_s or V_s + 10 knots (defined by the stall indication system) except for the L configuration (Category C), which is limited to 1.3 V_s by geometry considerations. The maximum service altitude is limited by power or thrust available and the maximum service load factors (n+), n(-) are limited by structural considerations and the shaker onset schedule.

Discussion

The present structural design limit conditions were utilized to establish the Service Flight Envelopes. The C-5A data favorably compares with these requirements.

Recommendation

None

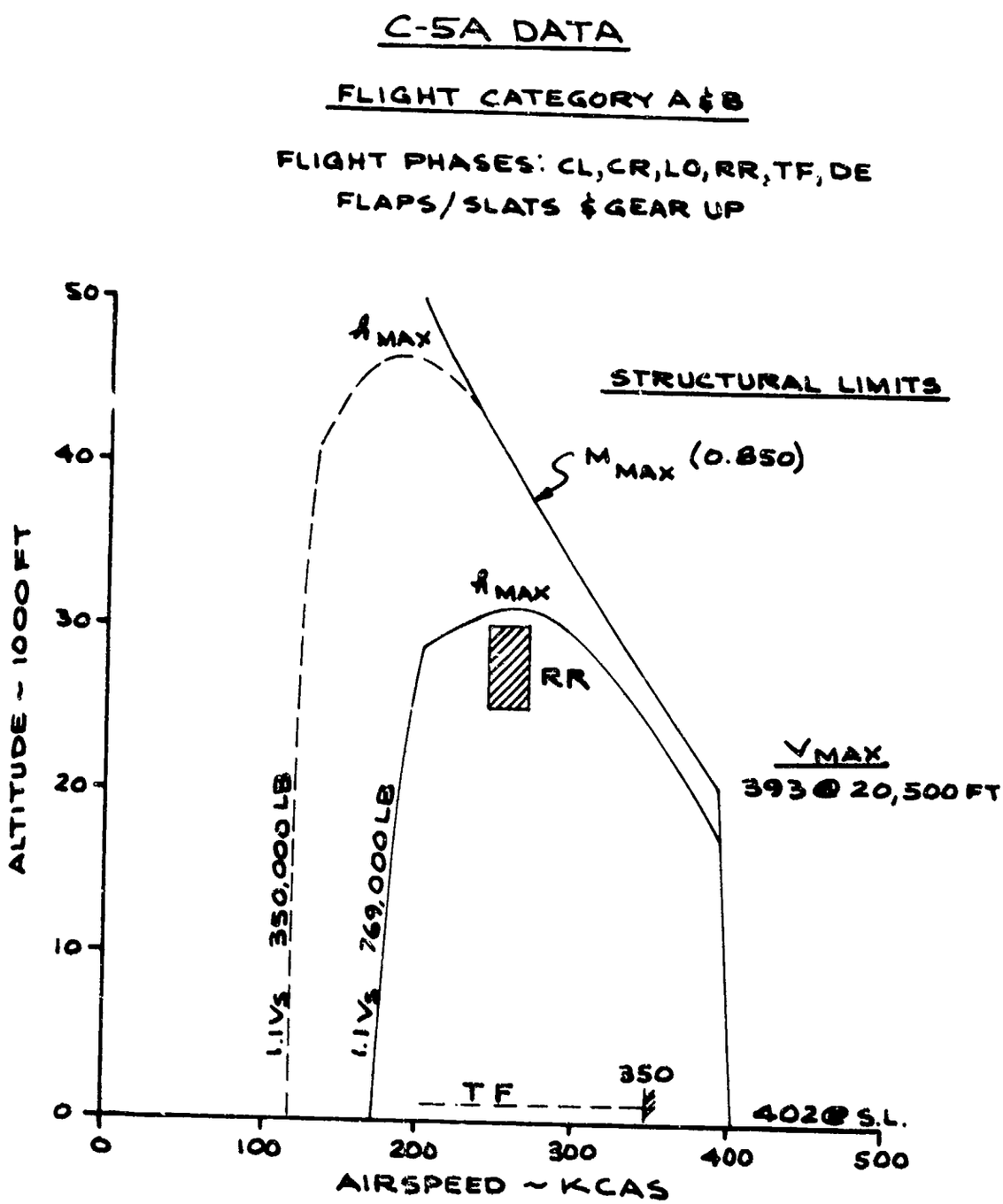


FIGURE NO.1 (3.1.8) SERVICE FLIGHT ENVELOPE

C-5A DATA

FLIGHT CATEGORY C

FLIGHT PHASES: TO, PA, WO, L, AD

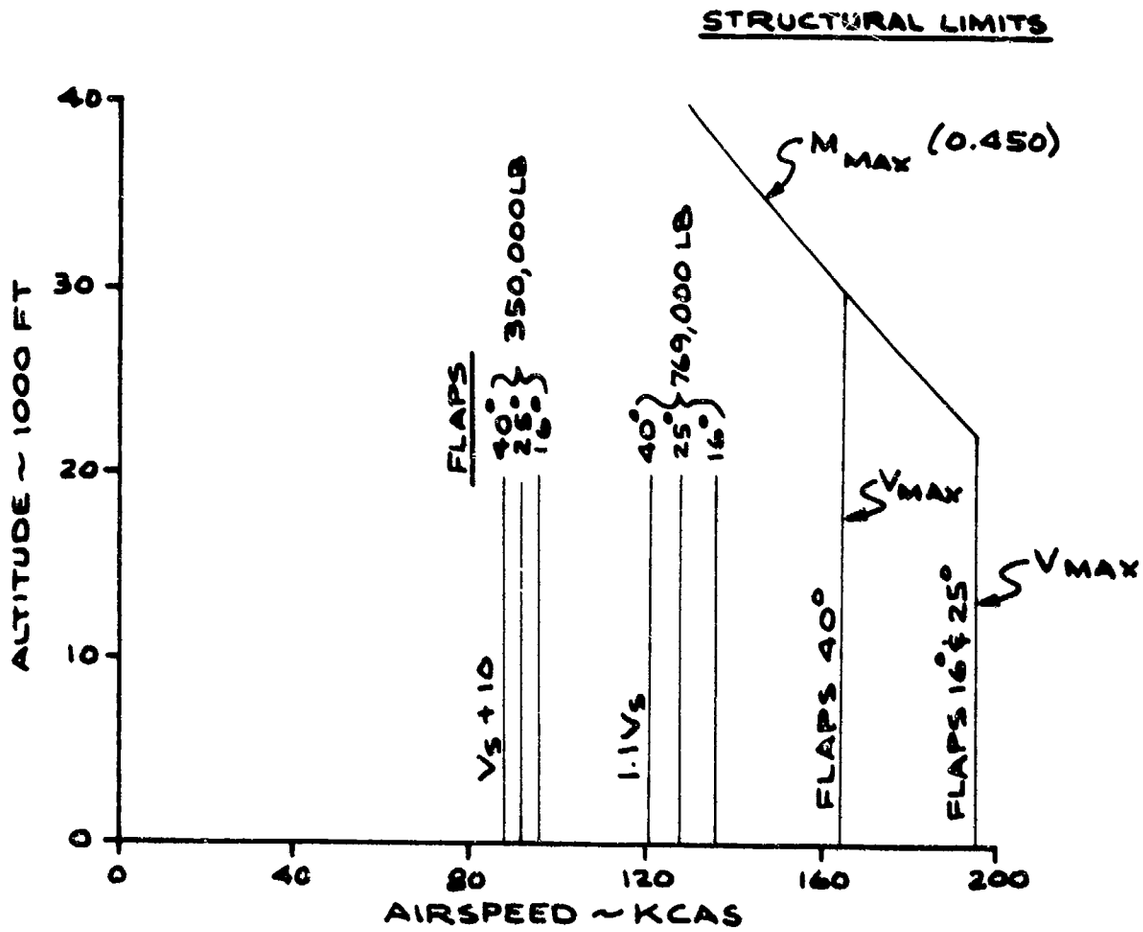


FIGURE NO. 2 (3.1.8) SERVICE FLIGHT ENVELOPE

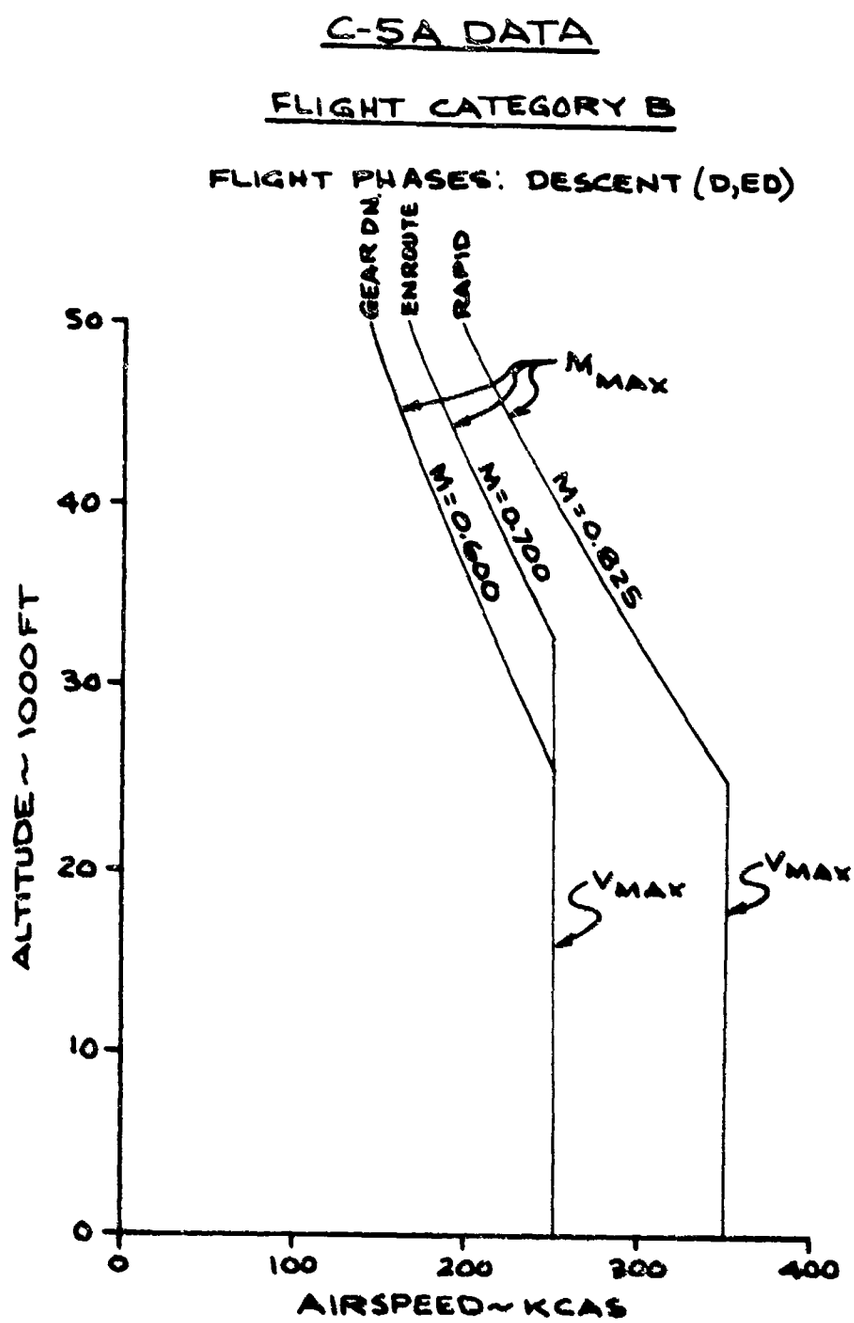


FIGURE NO.3(3.1.8) SERVICE FLIGHT ENVELOPE

C-5A DATA

FLIGHT CATEGORY A&B

FLIGHT PHASES: CL, CR, LO, RR, TF, DE

FLAP/SLAT AND GEAR UP

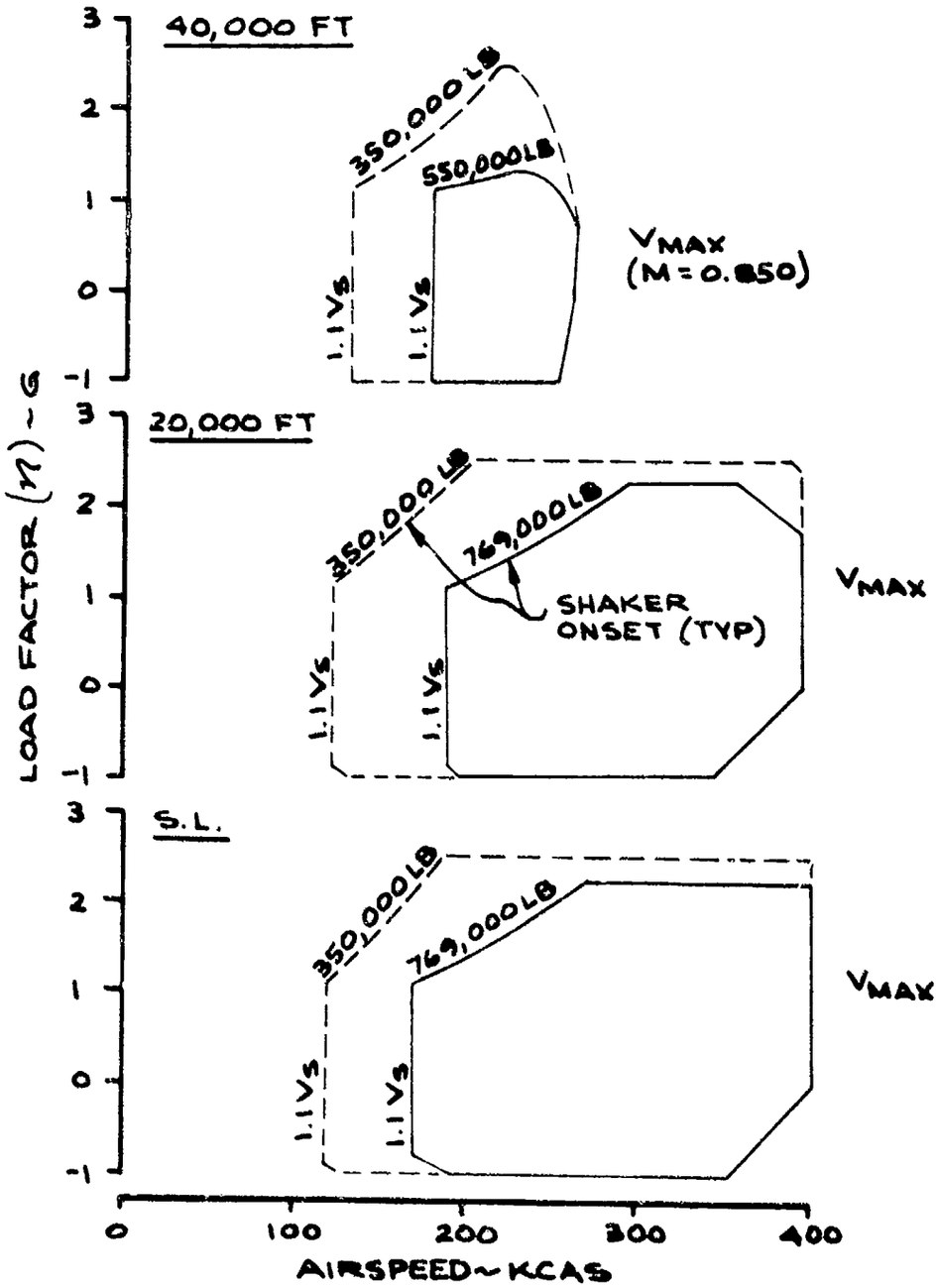


FIGURE NO.4 (3.1.8) SERVICE FLIGHT ENVELOPE

C-5A DATA

FLIGHT CATEGORY C

FLIGHT PHASES: TO, PA, WO, L, AD

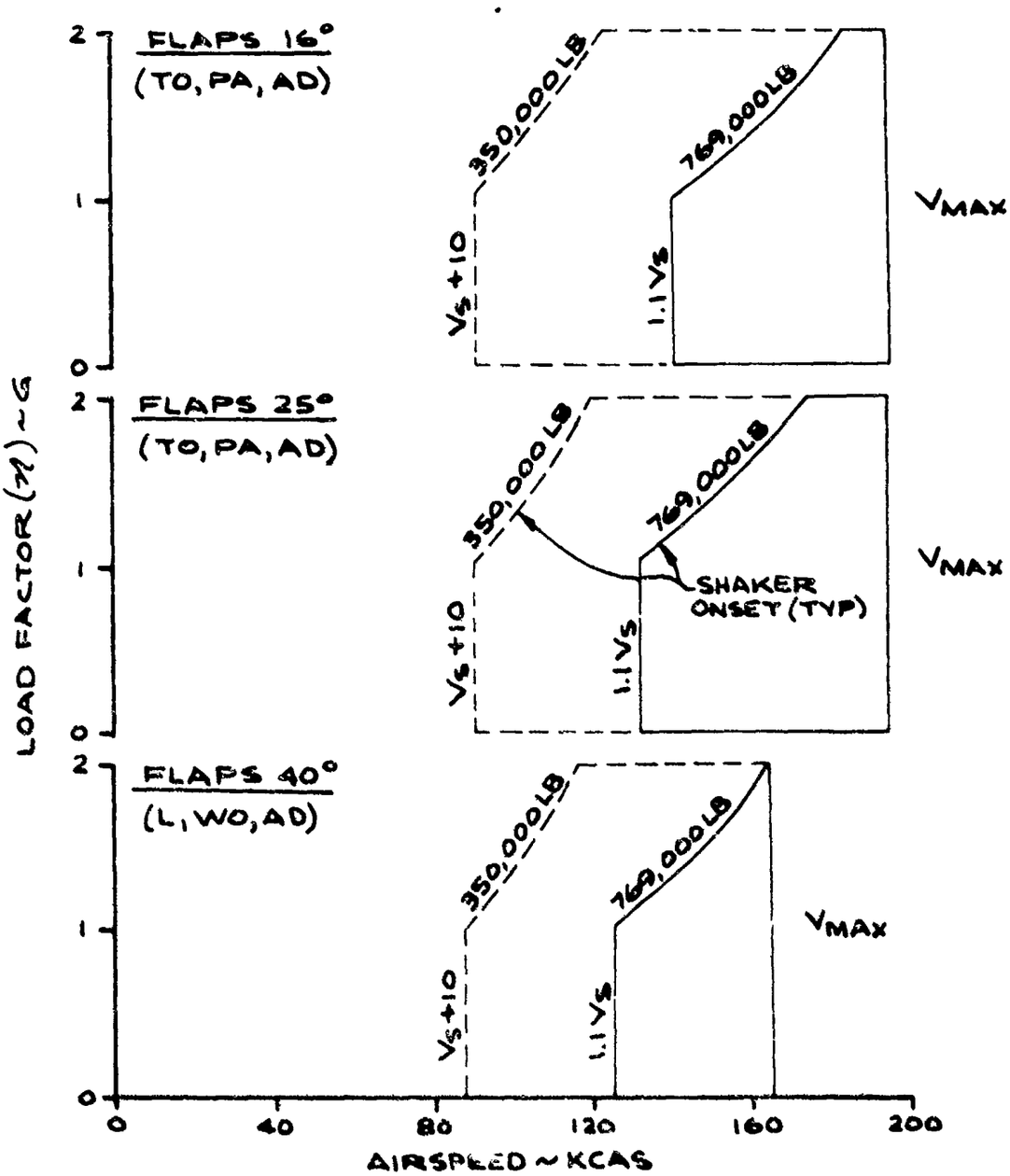


FIGURE NO.5 (3.1.8) SERVICE FLIGHT ENVELOPE

Requirement

3.1.9 Permissible Flight Envelopes. The Permissible Flight Envelopes encompass all regions in which operation of the airplane is both allowable and possible. These are the boundaries of flight conditions outside the Service Flight Envelope which the airplane is capable of safely encountering. Stalls, post stall gyrations, spins, zooms, and some dives may be representative of such conditions. The Permissible Flight Envelopes define the boundaries of these areas in terms of speed, altitude, and load factor

3.1.9.1 Maximum permissible speed. The maximum permissible speed for each altitude shall be the lowest of:

a. Limit speed based on structural considerations.

b. Limit speed based on engine considerations

c. The speed at which intolerable buffet or structural vibration is encountered

d. Maximum dive speed at MAT for each altitude, for dives (at all angles) from V_{MAT} at all altitudes from which dive recovery at 2000 feet above MSL or higher is possible without encountering loss of control or other dangerous behavior, intolerable buffet or structural vibration, and without exceeding structural limits.

3.1.9.2 Minimum permissible speed. The minimum permissible speed in 1g flight is V_s as defined in 6.2.2 or 3.1.9.2.1.

3.1.9.2.1 Minimum permissible speed other than stall speed. For some airplanes, considerations other than maximum lift determine the minimum permissible speed in 1g flight (e.g., ability to perform altitude corrections, excessive sinking speed, ability to execute a wave-off (go-around), etc.). In such cases, an arbitrary angle-of-attack limit, or similar minimum speed and maximum load factor limits, shall be established for the Permissible Flight Envelope, subject to the approval of the procuring activity. This defined minimum permissible speed shall be used as V_S in all applicable requirements.

Comparison

The permissible flight envelopes are presented in Figures 1(3.1.9) through 5(3.1.9). The comparison and discussion of Requirement (3.1.8) will generally apply to this requirement.

Discussion

None

Recommendation

None

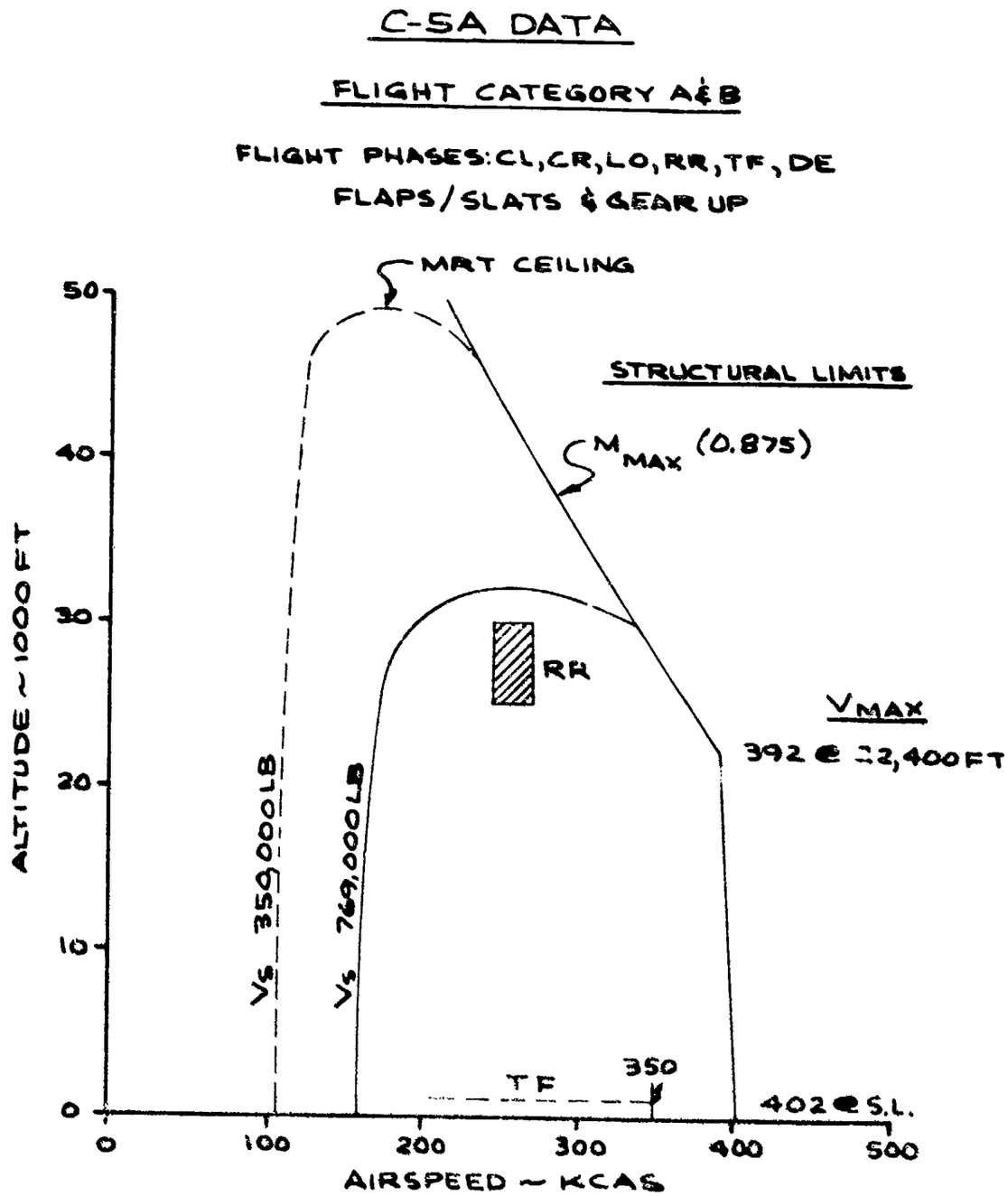


FIGURE NO.1 (3.1.9) PERMISSIBLE FLIGHT ENVELOPE

C-5A DATA

FLIGHT CATEGORY C

FLIGHT PHASES: TO, PA, WO, L, AD

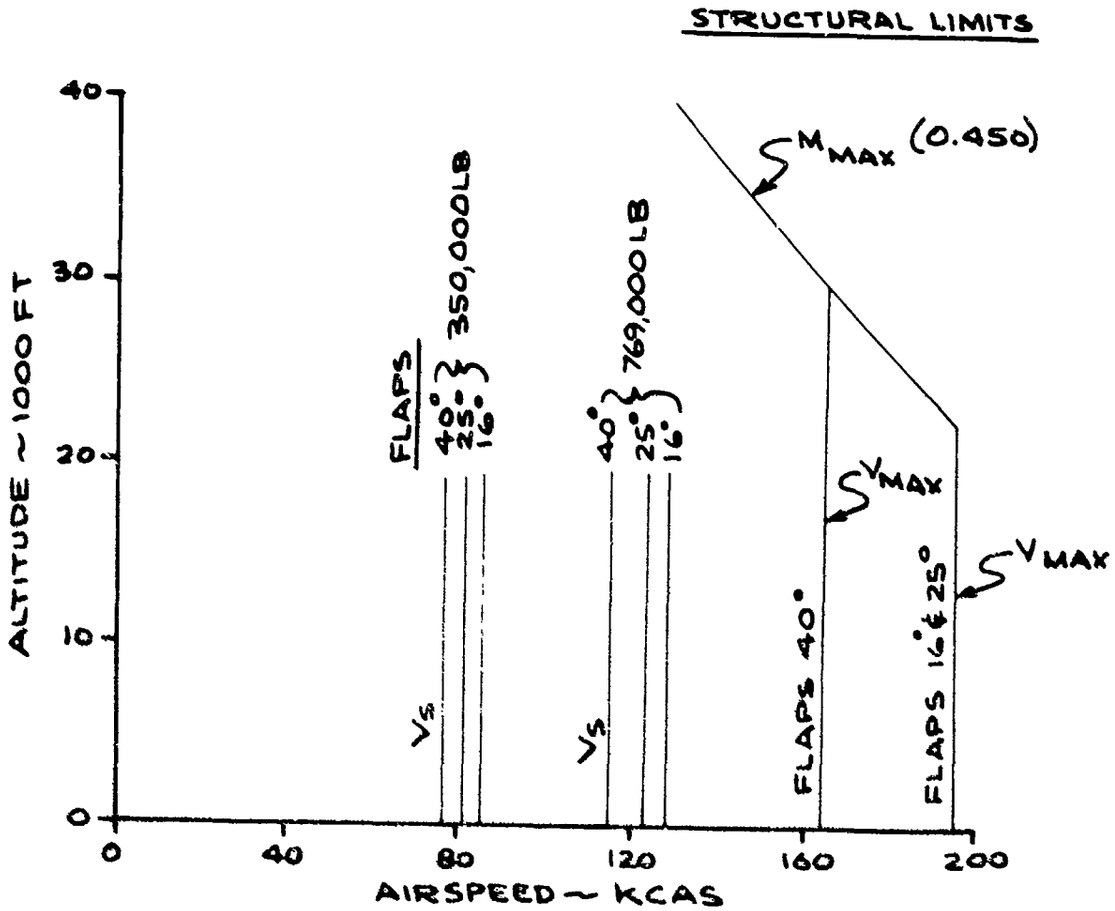


FIGURE NO.2 (3.1.9) PERMISSIBLE FLIGHT ENVELOPE

C-5A DATA

FLIGHT CATEGORY B

FLIGHT PHASES: DESCENT (D, ED)

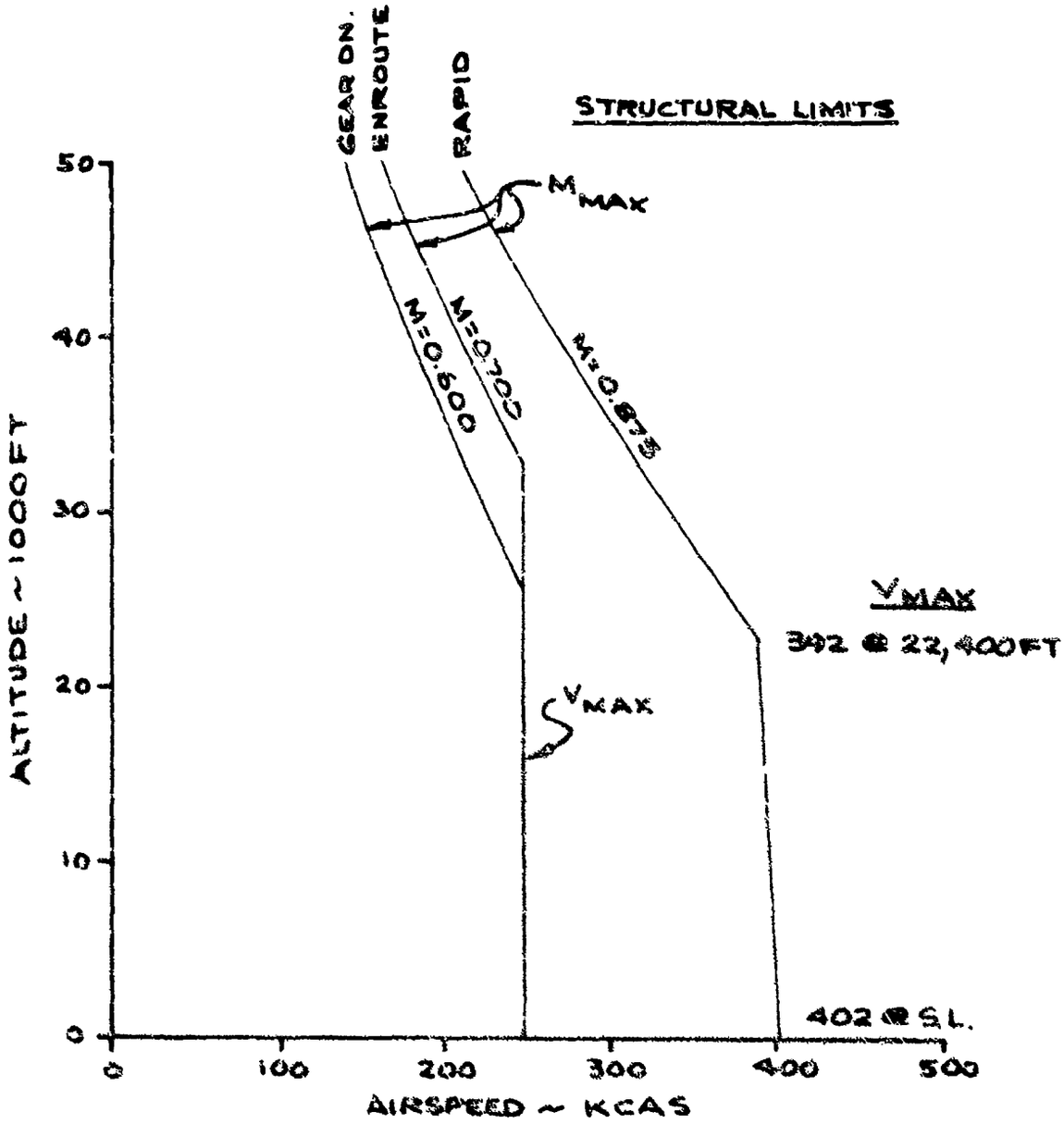


FIGURE NO.3 (3.1.9) PERMISSIBLE FLIGHT ENVELOPE

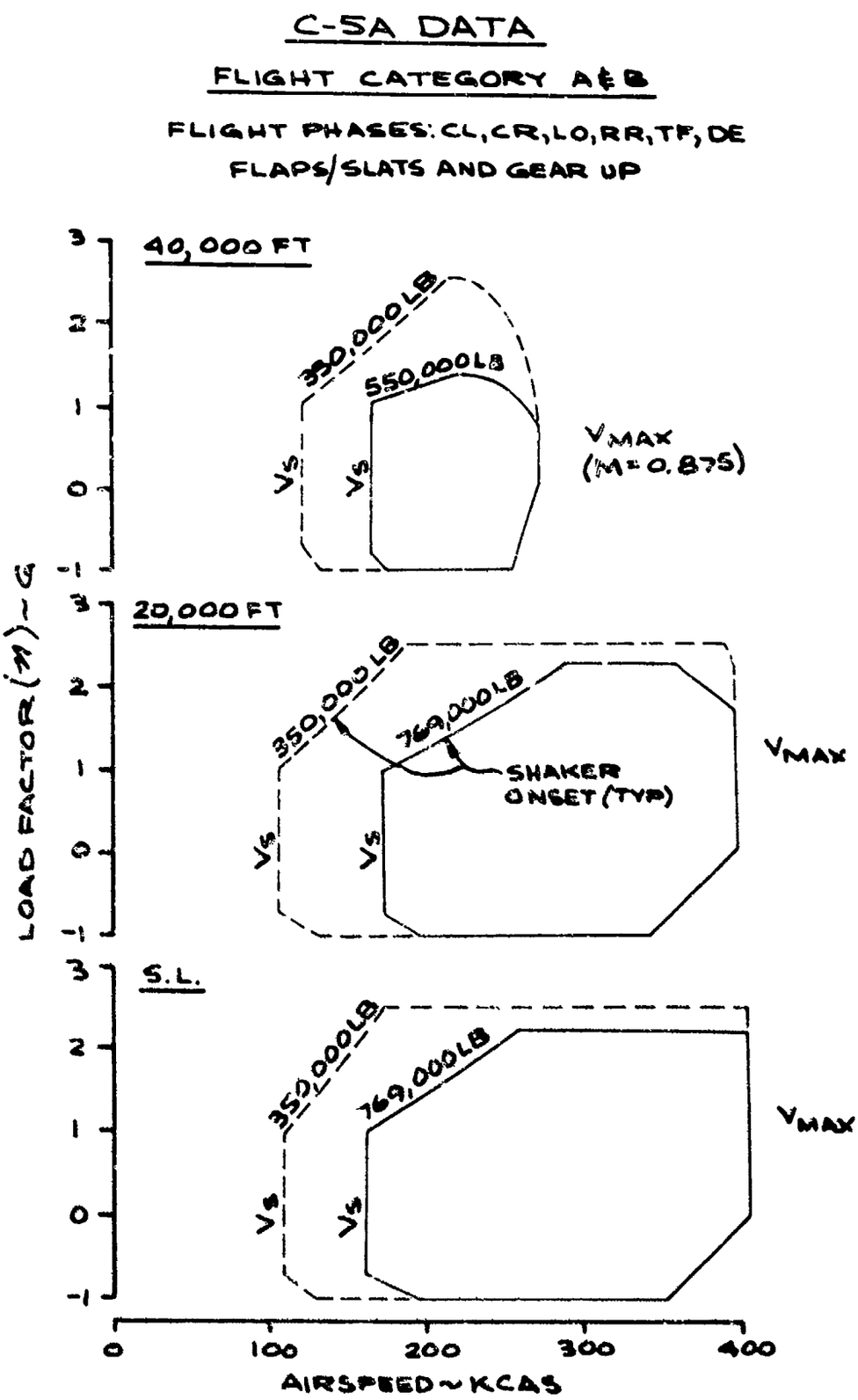


FIGURE NO.4 (3.1.9) PERMISSIBLE FLIGHT ENVELOPE

C-5A DATA

FLIGHT CATEGORY C

FLIGHT PHASES: TO, PA, WO, L, AD

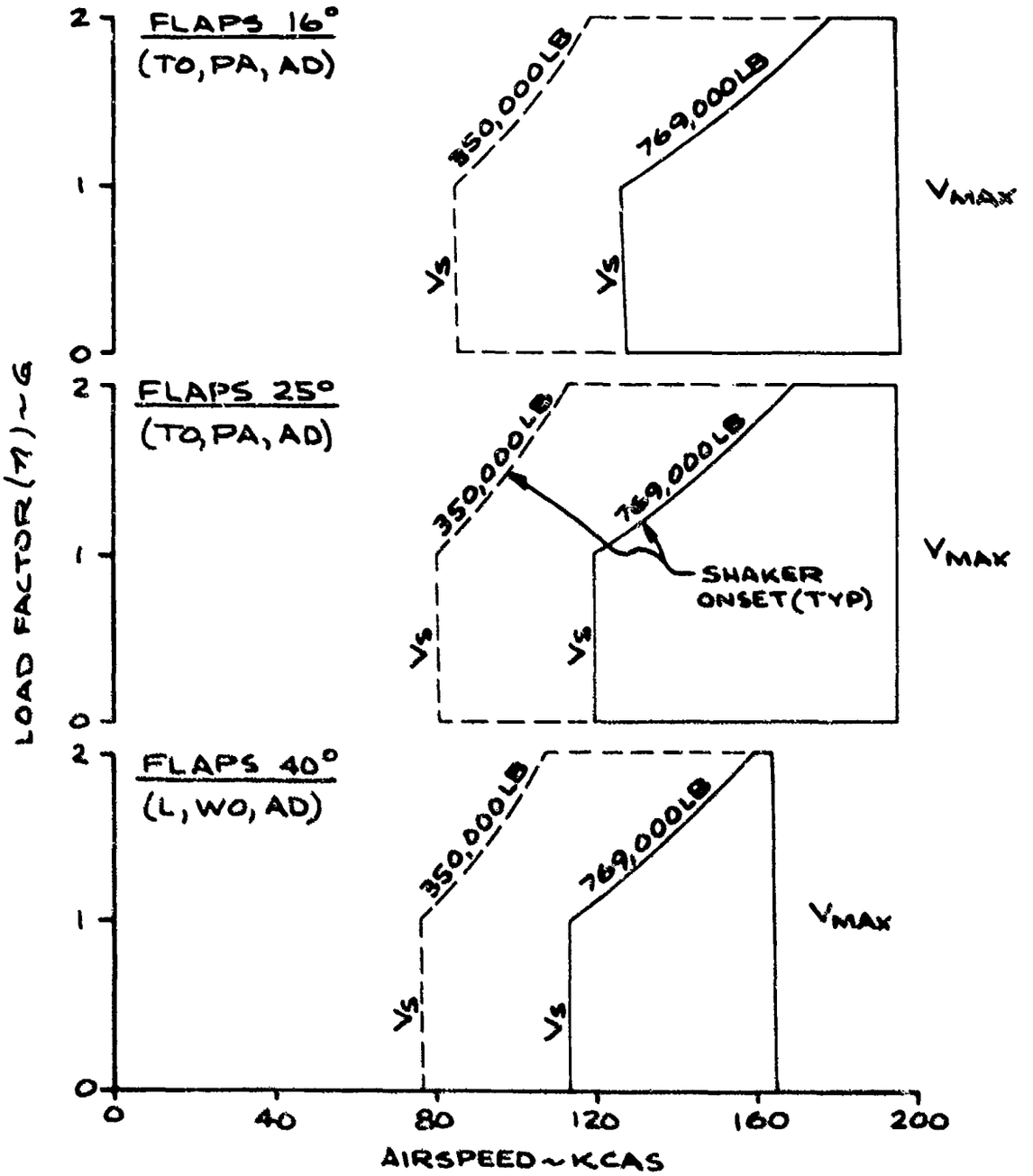


FIGURE NO.5 (3.1.9) PERMISSIBLE FLIGHT ENVELOPE

Requirement

3.1.10 Applications of Levels. Levels of flying qualities as indicated in 1.5 are employed in this specification in realization of the possiblity that the airplane may be required to operate under abnormal conditions. Such abnormalities that may occur as a result of either flight outside the Operational Flight Envelope or the failure of airplane components, or both, are permitted to comply with a degraded level of flying qualities as specified in 3.1.10.1 through 3.1.10.3.3.

3.1.10.1 Requirements for Airplane Normal States. The minimum required flying qualities for Airplane Normal States (3.1.6.1) are as shown in table II.

TABLE II. Levels for Airplane Normal States

Within Operational Flight Envelope	Within Service Flight Envelope
Level 1	Level 2

Comparison

None

Discussion

None

Recommendation

None

Requirement

3.1.10.2 Requirements for Airplane Failure States. When Airplane Failure States exist (3.1.6.2), a degradation in flying qualities is permitted only if the probability of encountering a lower Level than specified in 3.1.10.1 is sufficiently small. At intervals established by the procuring activity, the contractor shall determine, based on the most accurate available data, the probability of occurrence of each Airplane Failure State per flight and the effect of that Failure State on the flying qualities within the Operational and Service Flight Envelopes. These determinations shall be based on MIL-STD-756 except that (a) all airplane components and systems are assumed to be operating for a time period, per flight, equal to the longest operational mission time to be considered by the contractor in designing the airplane, and (b) each specific failure is assumed to be present at whichever point in the Flight Envelope being considered is most critical (in the flying qualities sense). From these Failure State probabilities and effects, the contractor shall determine the overall probability, per flight, that one or more flying qualities are degraded to Level 2 because of one or more failures. The contractor shall also determine the probability that one or more flying qualities are degraded to Level 3. These probabilities shall be less than the values shown in table III.

TABLE III Levels for Airplane Failure States

Probability of Encountering	Within Operational Flight Envelope	Within Service Flight Envelope
Level 2 after failure	$\cdot 10^{-2}$ per flight	
Level 3 after failure	$\cdot 10^{-4}$ per flight	$\cdot 10^{-2}$ per flight

In no case shall a Failure State (except an approved Special Failure State) degrade any flying quality outside the Level 3 limit.

Comparison

The basis for the initial design of the C-5A was that no single failure would degrade handling characteristics; and the effect of a second failure should not preclude completion of the mission, with some degradation in handling characteristics, and performing a safe landing. At this point it is evident that ample conservatism was included in the initial design. The fact is borne out in the test results presented herein. In some sections of the specification compliance with Level 1 requirements can be shown with SAS inoperative. However, some Level 2 requirements cannot be met with SAS operative. During the conduct of the Category I/II flight test program, ample tests were conducted with the SAS intentionally disengaged. These were conducted with one engine inoperative and with two engines inoperative on the same side. Results were also obtained with a single and with two hydraulic system(s) depressurized. For the purpose of this report SAS inoperative results have been compared with Level 2 requirements. Although, the SAS is triple redundant. Accurate failure rate data, which is not available, could possibly alter some assignment of failure test results presented in this report. Results obtained with a single hydraulic system depressurized have been compared with Level 2 requirements, while results with two

hydraulic systems depressurized have been related to Level 3 conditions. Here again accurate failure rate data could change this. Due to reasons summarized here, a meaningful comparison of C-5A data with the requirements of this paragraph is not feasible.

Discussion

Due to insufficient C-5A failure effects data and the reasons stated above, the validity of this requirement cannot be substantiated.

Recommendation

None

Requirement

3.1.10.2.1 Requirements for specific failures. The requirements on the effects of specific types of failures, e.g., propulsion or flight control system, shall be met on the basis that the specific type of failure has occurred, regardless of its probability of occurrence.

3.1.10.3 Exceptions

3.1.10.3.1 Ground operation and terminal Flight Phases. Some requirements pertaining to takeoff, landing, and taxiing involve operation outside the Operational, Service and Permissible Flight Envelopes, as at V_S or on the ground. When requirements are stated at conditions such as these, the Levels shall be applied as if the conditions were in the Operational Flight Envelope.

3.1.10.3.2 When Levels are not specified. Within the Operational and Service Flight Envelopes, all requirements that are not identified with specific Levels shall be met under all conditions of component and system failure except approved Airplane Special Failure States (3.1.6.2.1).

3.1.10.3.3 Flight outside the Service Flight Envelope. From all points in the Permissible Flight Envelopes, it shall be possible readily and safely to return to the Service Flight Envelope without exceptional pilot skill or technique, regardless of component or system failures. The requirements on flight at high angle of attack, dive characteristics, dive recovery devices, and on approach to dangerous flight conditions shall also apply.

Comparison

None

Discussion

None

Recommendation

None

Requirement

3.2 Longitudinal flying qualities

3.2.1 Longitudinal stability with respect to speed

3.2.1.1 Longitudinal static stability There shall be no tendency for the airspeed to diverge aperiodically when the airplane is disturbed from trim with the cockpit controls fixed and with them free. This requirement will be considered satisfied if the variations of elevator control force and elevator control position with airspeed are smooth and the local gradients stable, with:

Trimmer and throttle controls not moved from the trim settings by the crew, and

1g acceleration normal to the flight path, and

constant altitude

over a range about the trim speed of ±15 percent or ± 50 knots equivalent airspeed, whichever is less (except where limited by the boundaries of the Service Flight Envelope). Stable gradients mean incremental pull forces and aft displacement of the elevator control to maintain slower airspeeds and the opposite to maintain faster airspeeds. The term gradient does not include that portion of the control force or control position versus airspeed curve within the preloaded breakout force or friction range.

Comparison

Static longitudinal stability tests were conducted on the C-5A in each of the takeoff, approach, landing, cruise, dive, aerial delivery, glide and wave-off configurations throughout the appropriate speed range. Each flight test was conducted using the following procedure. The airplane was trimmed "hands off" at the appropriate trim speed. Without changing power setting or trim setting, the airplane was stabilized at speeds below and above the trim speed within the range of ±15 percent or ± 50 KIAS, whichever was less. Typical results from these tests, presented in Figures 1(3.2.1.1) through 6(3.2.1.1), show that in order to stabilize at speeds less than the trim airspeed an aft movement of the control column displacement was required along with an increase in pull control forces. In order to stabilize at speeds above the trim speed a push forward on the control column was required. Since power was not changed during any of these runs the airplane climbed slightly at speeds less than the trim value and descended at speeds greater than trim. The variation in altitude experienced during any run was kept within ± 2,000 feet of the trim altitude. Test results presented in Figures 1(3.2.1.1) through 6(3.2.1.1) show smooth variation of stick position and force with airspeed along with stable local gradients. It is, therefore, concluded that the C-5A comply with requirements of this paragraph. In addition, pilot comments indicated no adverse characteristics.

Discussion

The portion of the second paragraph which states "constant altitude" is incompatible with the first portion which states "trimmer and throttle controls not moved from the trim settings by the crew." There is no way to conduct these tests at a constant altitude unless power is varied. It is not recommended to alter the trim power setting during the subject tests since a variation in thrust has more of an effect on airplane pitching moment than a slight variation in altitude. Therefore, the requirement should be changed to permit a variation in altitude during the conduct of these tests.

Recommendation

It is recommended that "constant altitude" be replaced by "altitude within ±2,000 feet from trim altitude."

C-5A FLIGHT TEST DATA

(L) CONFIGURATION
540,000 LBS 10,000 FT.
PITCH SAS OFF

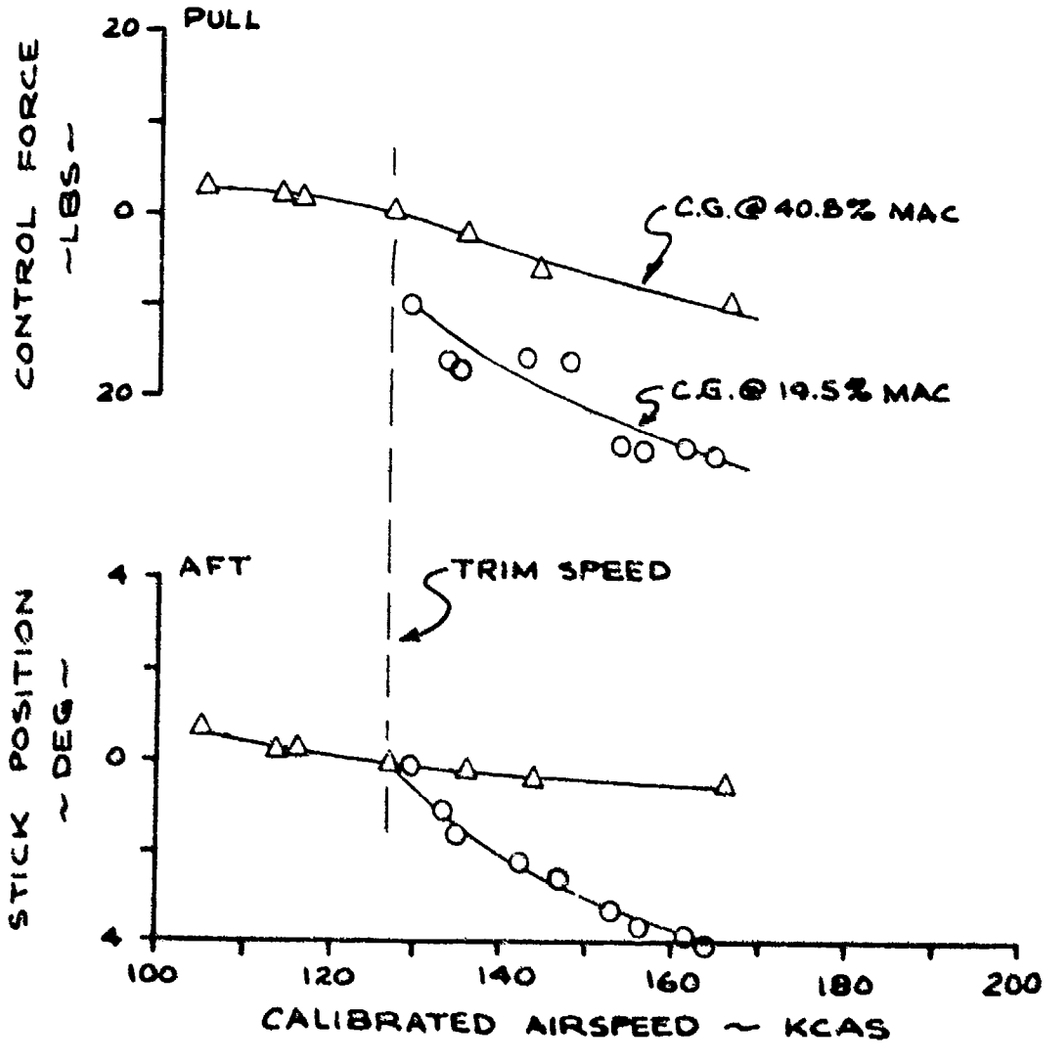


FIGURE NO. 1 (3.2.1.1) STATIC LONGITUDINAL STABILITY

C-5A FLIGHT TEST DATA

(PA) CONFIGURATION

600,000 LBS 10,000 FT.

PITCH SAS OFF

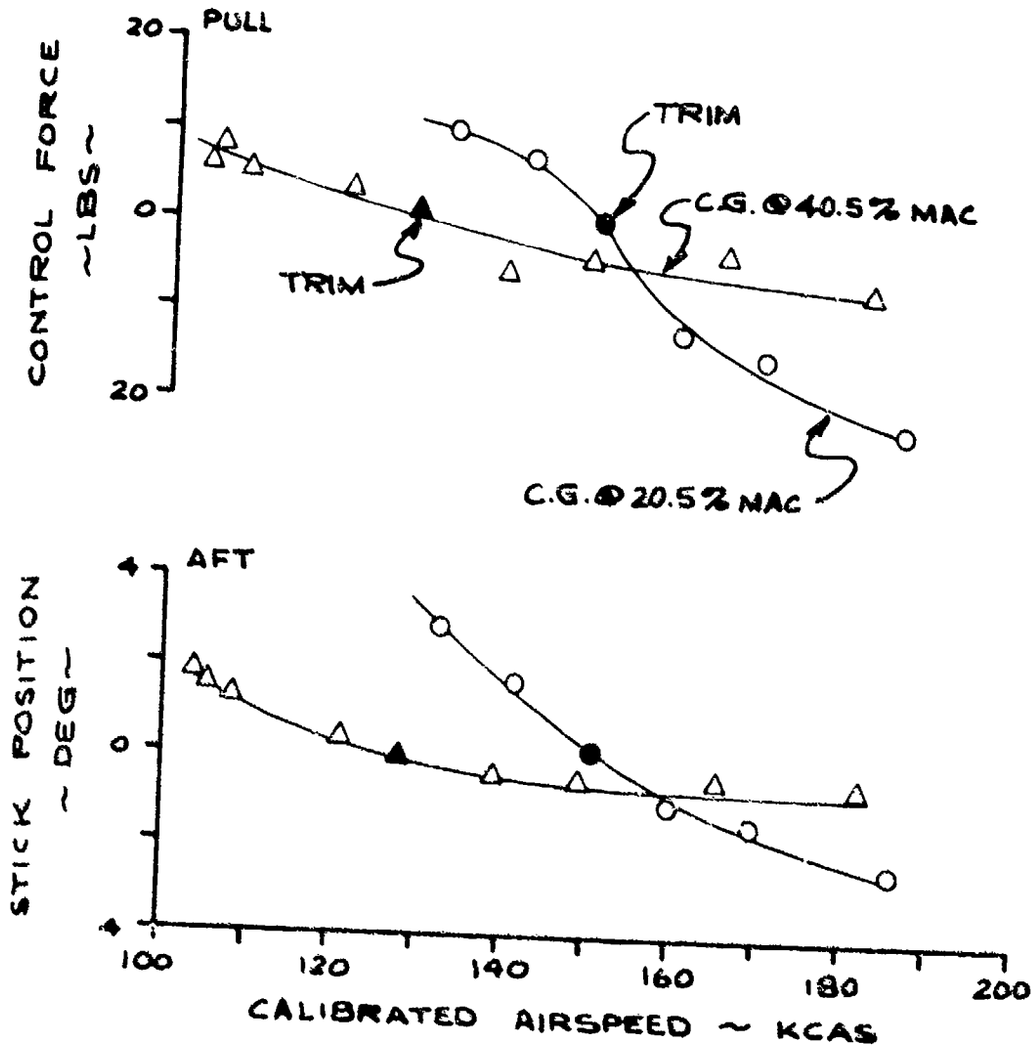


FIGURE NO. 2 (3.2.1.1) STATIC LONGITUDINAL STABILITY

C-5A FLIGHT TEST DATA

(CR) CONFIGURATION

486,000 LBS 10,500 FT.

PITCH SAS OFF

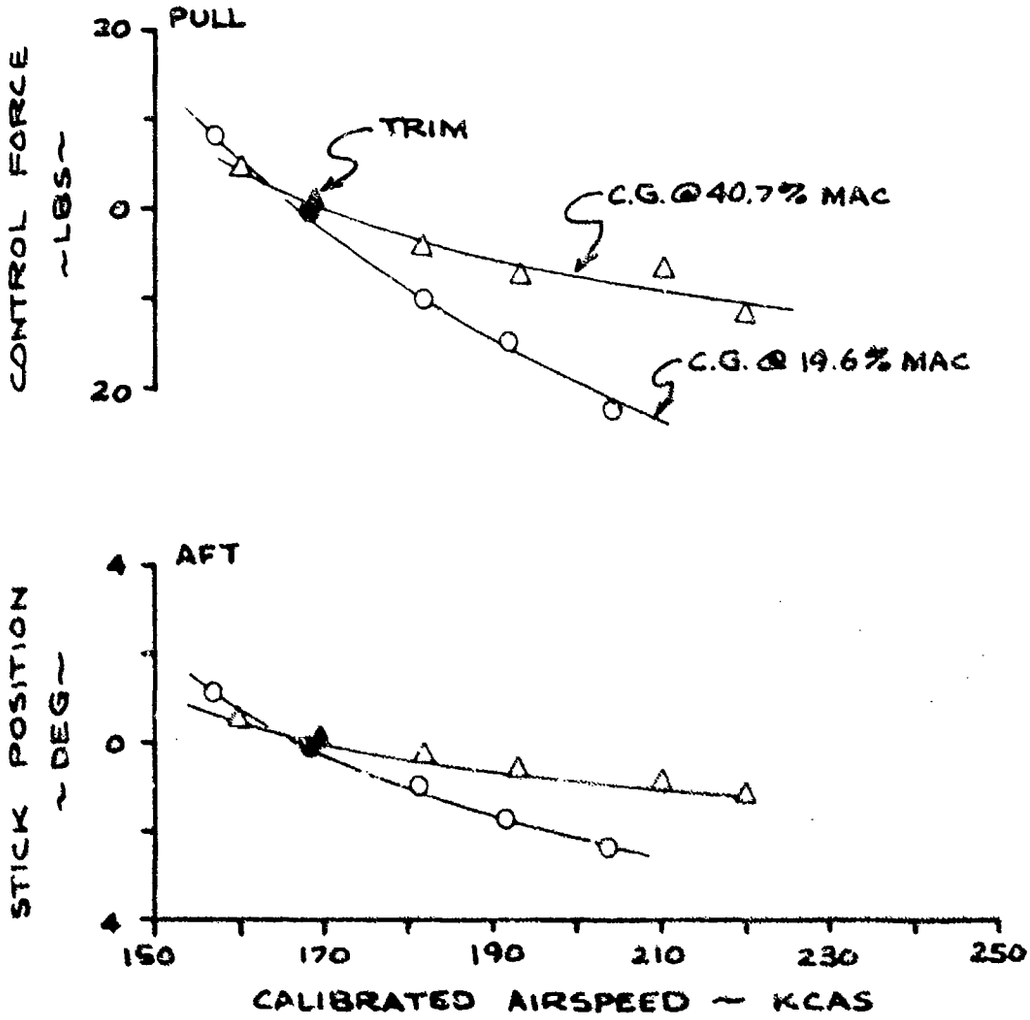


FIGURE NO. 3 (3.2.1.1) STATIC LONGITUDINAL STABILITY

C-5A FLIGHT TEST DATA

(CR) CONFIGURATION

485,000 LBS 11,100 FT.

PITCH SAS OFF

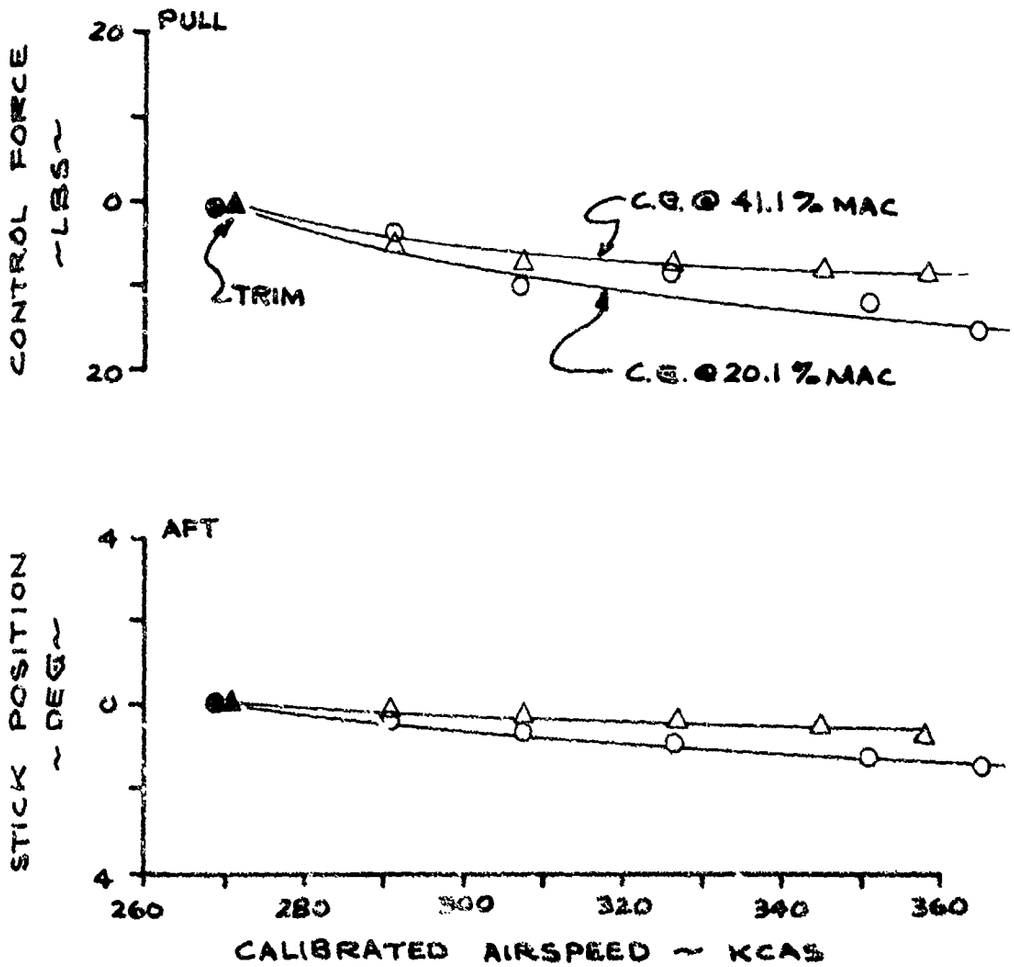


FIGURE NO. 4 (3.2.1.1) STATIC LONGITUDINAL STABILITY

C-5A FLIGHT TEST DATA

(CR) CONFIGURATION

497,000 LBS 36,000 FT.

PITCH SAS OFF

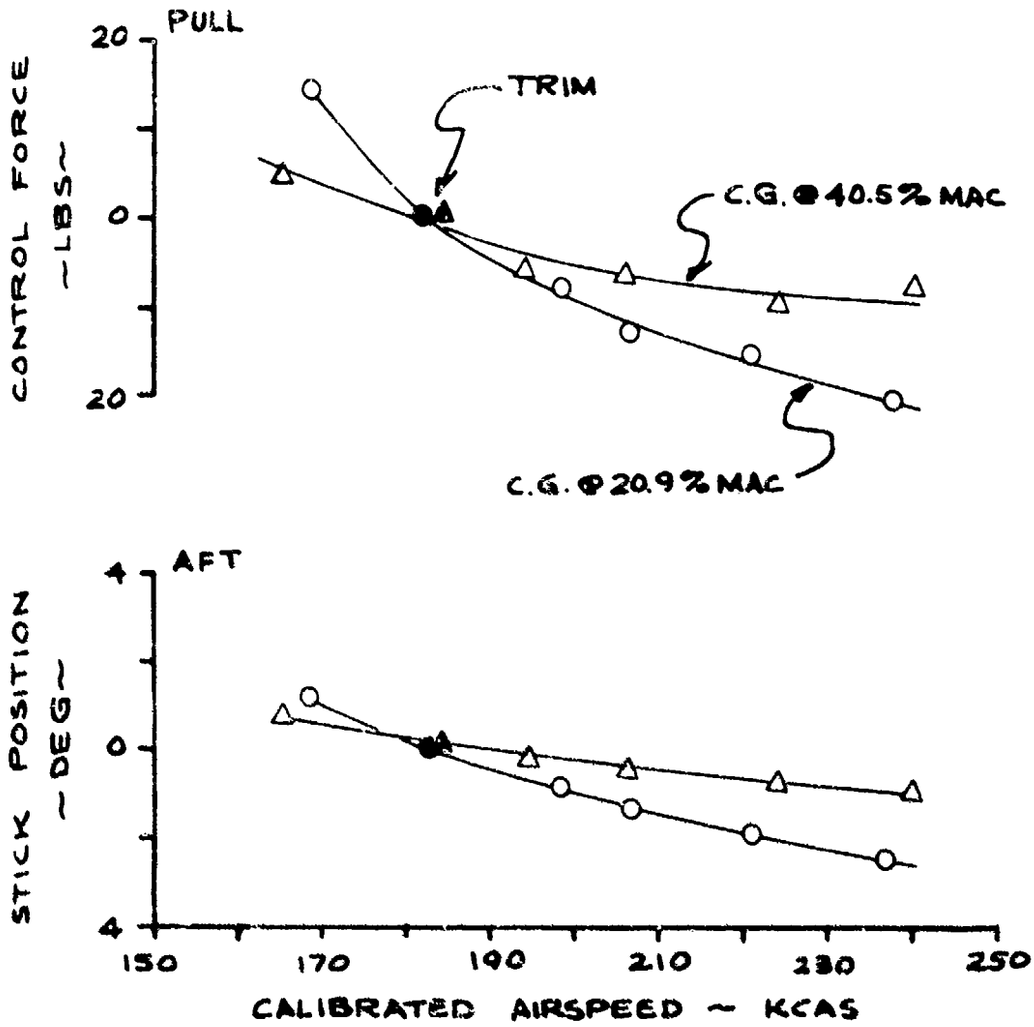


FIGURE NO. 5 (3.2.1.1) STATIC LONGITUDINAL STABILITY

C-5A FLIGHT TEST DATA

(CR) CONFIGURATION

483,000 LBS 35,800 FT

PITCH SAS OFF

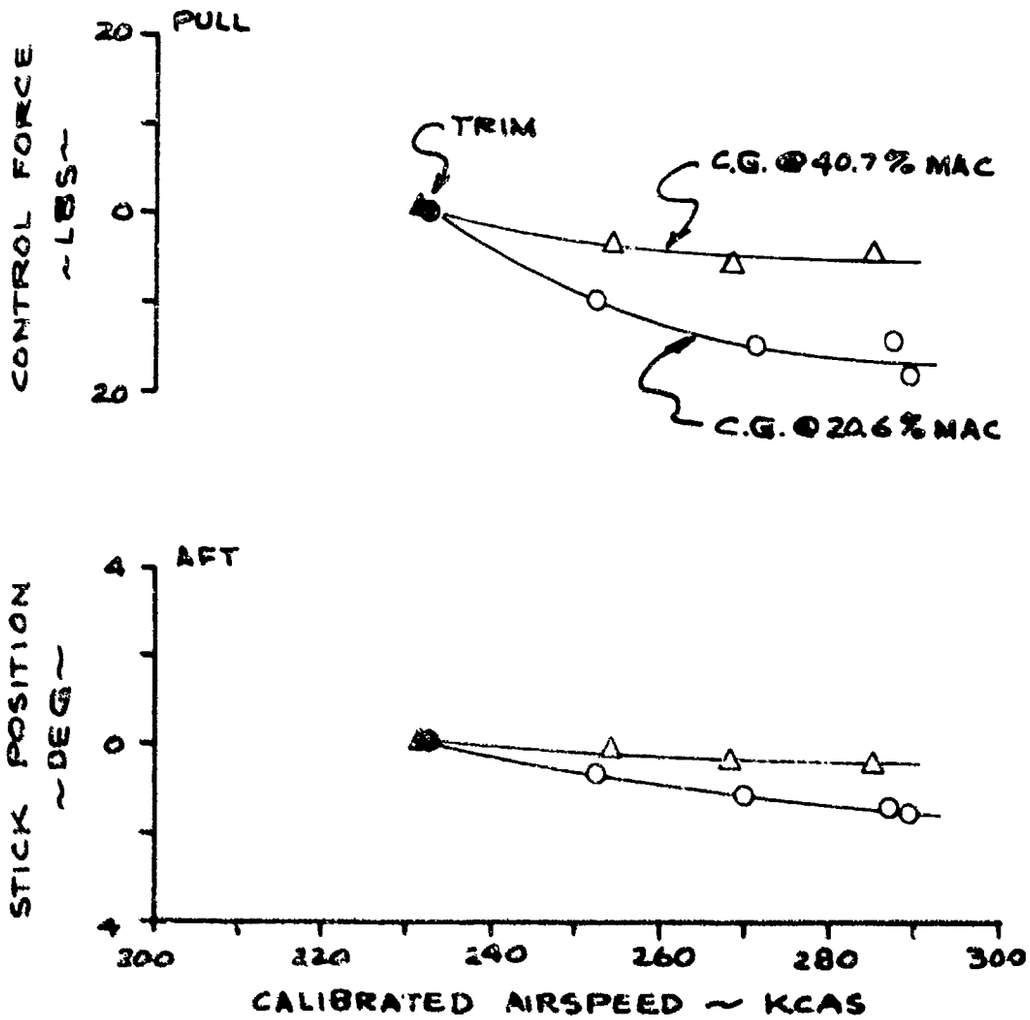


FIGURE NO. 6 (3.2.1.1) STATIC LONGITUDINAL STABILITY

Requirement

3.2.1.1.1 Relaxation in transonic flight. The requirements of 3.2.1.1 may be relaxed in the transonic speed range provided any divergent airplane motions or reversals in slope of elevator control force and elevator control position with speed are gradual and not objectionable to the pilot. In no case, however, shall the requirements of 3.2.1.1 be relaxed more than the following:

a. Levels 1 and 2 - For center-stick controllers, no local force gradient shall be more unstable than 3 pounds per 0.01 M nor shall the force change exceed 10 pounds in the unstable direction. The corresponding limits for wheel controllers are 5 pounds per 0.01 M and 15 pounds, respectively.

b. Level 3 - For center-stick controllers, no local force gradient shall be more unstable than 6 pounds per 0.01 M nor shall the force ever exceed 20 pounds in the unstable direction. The corresponding limits for wheel controllers are 10 pounds per 0.01 M and 30 pounds, respectively.

This relaxation does not apply to Level 1 for any Flight Phase which requires prolonged transonic operation.

Comparison

Results presented in Figure 1(3.2.1.1.1) show that the C-5A longitudinal control characteristics comply with the transonic flight requirements of this paragraph. In addition, pilot comments noted no unusual handling characteristics. It was also concluded by the joint Air Force/Company Test Team that Mach trim compensation was not required. It is, therefore, concluded that the C-5A characteristics compare favorably with this requirement.

Discussion

The C-5A characteristics compare favorably with this requirement.

Recommendation

None

C-5A FLIGHT TEST DATA

534,000 LBS 32,300 FT

C.G. @ 18.7% MAC

M_D : 0.875

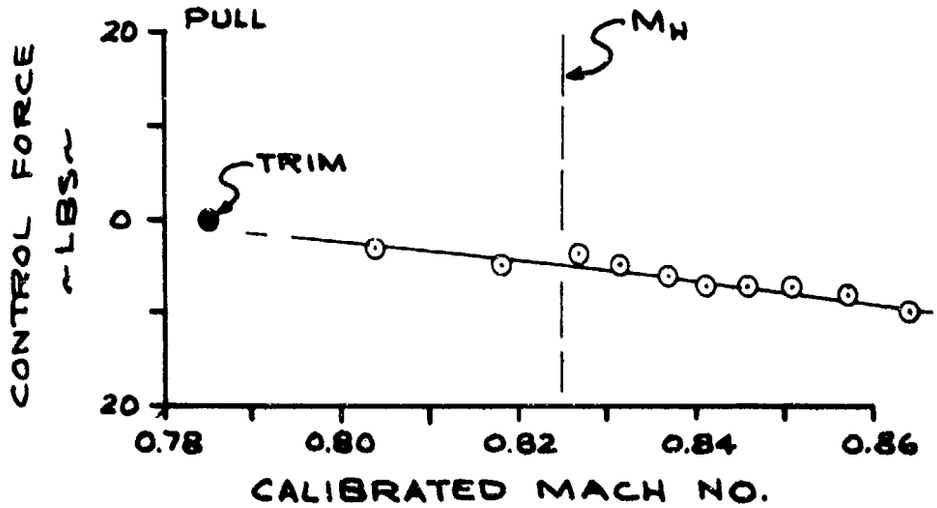


FIGURE NO. 1 (3.2.1.1.1) LONGITUDINAL CHARACTERISTICS DURING DIVE

Requirement

3.2.1.1.2 Elevator control force variations during rapid speed changes. When the airplane is accelerated and decelerated rapidly through the operational speed range and through the transonic speed range by the most critical combination of changes in power, actuation of deceleration devices, steep turns and pullups, the magnitude and rate of the associated trim change shall not be so great as to cause difficulty in maintaining the desired load factor by normal pilot techniques.

Comparison

Flight test maneuvers consisting of thrust reverser extensions, rapid power changes, landing gear extension and retraction, flap extension and retractions and cargo door opening and closing were conducted to evaluate C-5A longitudinal trim change characteristics. Results of these tests are presented in Section 3.6.3.1 and show that there are no adverse control force characteristics associated with rapid speed changes. It is, therefore, concluded that the C-5A characteristics comply favorably with this requirement.

Discussion

C-5A test results support this requirement.

Recommendation

None

Requirement

3.2.1.2 Phugoid Stability. The long-period airspeed oscillations which occur when the airplane seeks a stabilized airspeed following a disturbance shall meet the following requirements:

a. Level 1 - ζ at least 0.04

b. Level 2 - ζ at least 0

c. Level 3 - T_2 at least 55 seconds

These requirments apply with the elevator control free and alwo with it fixed. They need not be met transonically in cases where 3.2.1.1.1 permits relaxation of the static stability requirements.

Comparison

Dynamic longitudinal stability tests were conducted on the C-5A to determine the frequency and damping characteristics of the long period (phugoid) oscillatory modes resulting from short duration longitudinal control deflections. Results from the flight tests are presented in Figure 1 (3.2.1.2) in the form of phugoid frequency (ω_{np}) versus damping ratio (ζ). These data are for the clean configuration and represent results obtained at gross weights ranging from approximately 500,000 lb to 700,000 lb, altitudes ranging from 10,000 ft to 35,000 ft, Mach numbers ranging from approximately 0.33 to 0.825 (M_h) and at center of gravity conditions ranging from the forward limit (19.0%) to the aft limit (41.0%). A tabulation of the rest results are presented in Table 3.

Table 3. Phugoid Stability Summary - Cruise Configuration

Altitude (ft)	Mach No.	ω_{np}	ζ	Required ζ Level	C.G. (% MAC)
10,000	0.64	0.056	0.062	0.04	22
10,000	0.64	0.056	0.044	0.04	41
10,000	0.64	0.056	0.058	0.04	22
26,000	0.77	0.058	0.096	0.04	41
35,000	0.825	0.026	0.149	0.04	41
10,000	0.33	0.105	0.106	0.04	22
35,000	0.54	0.105	0.048	0.04	22
10,000	0.39	0.080	0.028	0.04	41
10,000	0.39	0.091	0.027	0.04	22
35,000	0.70	0.075	0.025	0.04	41
35,000	0.70	0.088	0.042	0.04	22
26,000	0.60	0.070	0.024	0.04	41
26,000	0.60	0.070	0.030	0.04	22
26,000	0.66	0.065	0.045	0.04	22
26,000	0.66	0.096	0.030	0.04	41

A review of the test results show that the higher damping data were obtained at Mach number conditions in excess of 0.75 M where drag rise due to speed (C_{DU}) is the primary contributor to higher damping. Normal cruise for the C-5A is 0.76 M to 0.79 M. It should also be noted that the conditions under which the 0.04 damping requirement for Level 1 is not met are other than normal cruise. Herein, the period ranged from one minute to two minutes and pilot reports do not indicate any annoyance due to trim difficulty or any control problem associated with the longitudinal phugoid.

Tests were conducted at 1.3 V_s in the takeoff/approach configuration and the results tabulated in Table 4 show a wide variation in damping characteristics.

Table 4. Phugoid Stability Summary
Takeoff/Approach Configuration

Altitude (ft)	Gross Weight (lb)	C.G. (% MAC)	ζ_{np}	ζ	Required Level
2,000	700,000	Aft	0.065	0.0525	0.04
2,000	500,000	Aft	0.087	0.165	0.04
2,000	675,000	Fwd	0.116	0.029	0.04

The flaps down data, like the cruise results, show that the period (54 to 74 seconds) is easily controllable with no adverse pilot comments. However, the results obtained at the forward C.G. position show noncompliance with the 0.04 minimum damping ratio requirements.

Discussion

Results of longitudinal phugoid tests conducted on the C-5A show that the damping ratio ζ varied from about 0.024 to 0.165 for Level 1 conditions, not completely complying with the 0.04 requirements of this section. Pilot comments corresponding to these results averaged about 3.5 which are for Level 1 conditions. For Level 2 test conditions the damping ratio is permitted to drop to zero with a corresponding degradation in pilot rating. Here the inconsistency appears to exist in the specification requirements for a Class III type airplane. Test results correspond to Level 2 requirements, but the pilot ratings correspond to Level 1 requirements. This inconsistency is considered to exist because the Period τ_{np} has not been taken into consideration. The C-5A results which fell below the 0.04 damping requirement had a period of at least one minute, which probably affected pilot ratings considerably. It is, therefore, concluded that the 0.04 damping requirement for Level 1 should be relaxed provided that the frequency of the oscillation is low enough not to affect trimmability or longitudinal control. It is also evident from these data that the application of MIL-F-8785B(ASG) longitudinal phugoid requirements to the C-5A initial design, in lieu of MIL-F-8785(ASG) requirements, would have had an insignificant effect on overall pilot ratings but would have had a significant effect on the initial design and resulting cost.

Recommendations

It is recommended that the following note be added to the last paragraph:

"Subject to approval of the procuring activity, relaxation of the Level 1 requirements is permitted for conditions where it can be shown that the period of the oscillation is greater than 30 seconds."

C-5A FLIGHT TEST DATA

CRUISE CONFIGURATION
FWD AND AFT C.G.

□ TRIM ABOVE M=.75
○ TRIM BELOW M=.75

LEVEL 3 $T_2 \geq 55$ SEC

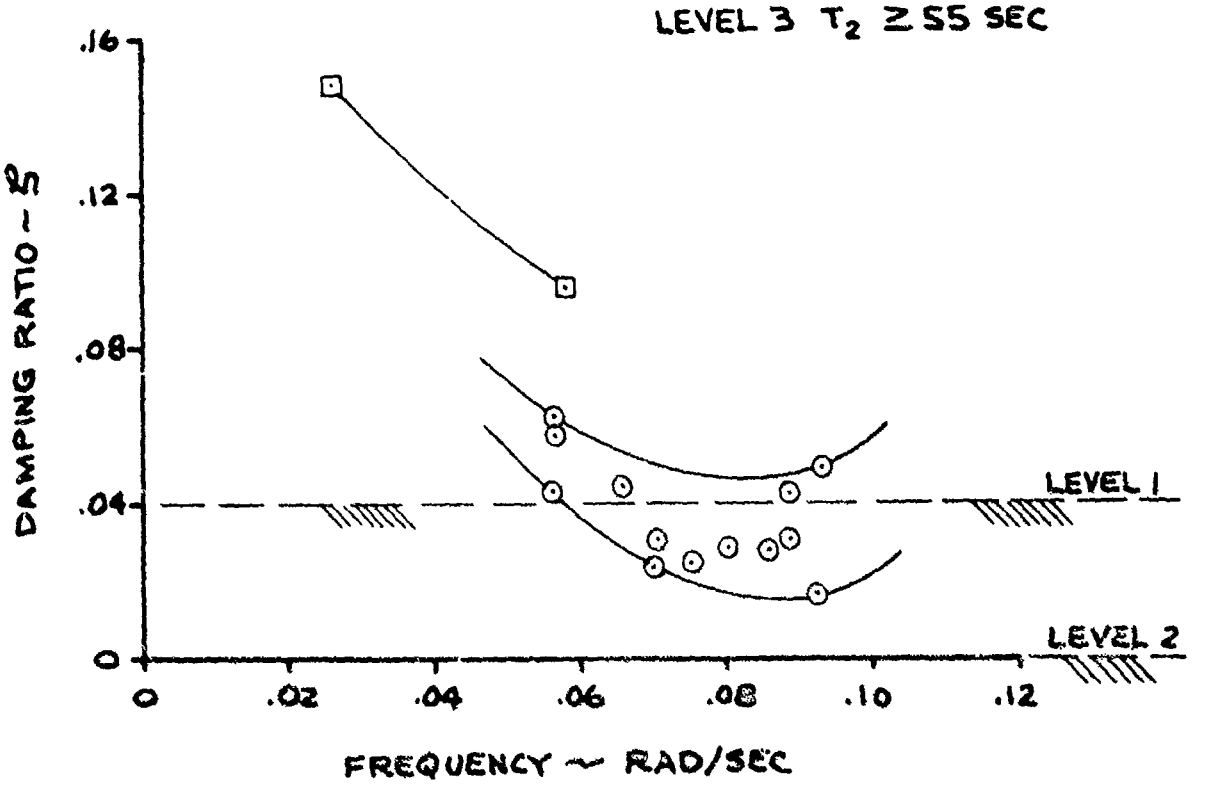


FIGURE NO. 1 (3.2.1.2) PHUGOID STABILITY

Requirement

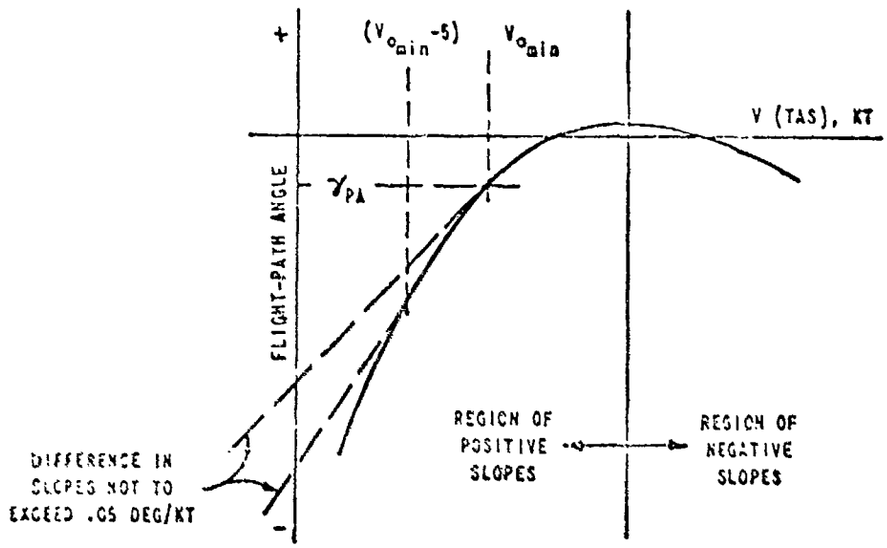
3.2.1.3 Flight-Path Stability. Flight-path stability is defined in terms of flight-path-angle change where the airspeed is changed by the use of the elevator control only (throttle setting not changed by the crew). For the landing approach Flight Phase, the flight-path-angle versus true-airspeed curve shall have a local slope at $V_{o_{min}}$ which is negative or less positive than:

a. Level 1 ---------- 0.06 degrees/knot

b. Level 2 ---------- 0.15 degrees/knot

c. Level 3 ---------- 0.24 degrees/knot

The thrust setting shall be that required for the normal approach glide path at $V_{o_{min}}$. The slope of the flight-path angle versus airspeed curve at 5 knots slower than $V_{o_{min}}$ shall not be more than 0.05 degrees per knot more positive than the slope at $V_{o_{min}}$ as illustrated by:



Comparison

Flight-path stability tests were conducted on the C-5A during a simulated landing approach at an altitude of 6,000 feet. The airplane was trimmed at 1.3V_{s_1} ($V_{o_{min}}$) in the landing configuration with thrust required for a rate of sink of approximately 800 ft/min. Without changing power setting or trim setting, data were recorded at stabilized speed conditions of ($V_{o_{min}}$ + 5), ($V_{o_{min}}$ - 5), and ($V_{o_{min}}$ - 10). Results of the tests are presented in Figure No. 1(3.2.1.3) in the form of flight path angle (γ) versus true airspeed. Flight path angle was obtained by the equation,

$$\gamma = \sin^{-1} \frac{\text{Vertical Speed}}{\text{True Airspeed}}$$

Vertical speed was obtained by differentiating pressure altitude with respect to time. Radar altimeter data were not available. Presented along with the flight test data are analytical results computed from thrust required and thrust available data obtained from flight test performance tests These data show that at the normal approach speed of $1.3\ V_{s_1}$ ($V_{o_{min}}$) the local slope of flight-path-angle versus true airspeed is -0.0020 deg/kt, thus complying with the requirement that the slope should not be more positive than 0.06 deg/kt. In addition, the data also show that the change in slope from $V_{o_{min}}$ to ($V_{o_{min}}$ - 5) is +0.0064 deg/kt which also complies with the requirement of not exceeding +0.05 deg/kt. Based on the 0.06 deg/kt requirement and Figure 1(3.2.1.3) data, the C-5A landing approach speed could be as low as $1.2\ V_s$.

Discussion

The second sentence of the first paragraph which states, "For the landing approach...," is not clear. The sentence should be revised to state the acceptable range of slope of flight-path-angle versus true airspeed

Reference 3 suggests that a radar altimeter be utilized to determine vertical speed for calculating flight-path-angle. This imposes an additional requirement on test instrumentation along with a requirement that the test be conducted over a smooth terrain. The most straightforward method is to obtain stable airspeed, altitude and free air temperature data and then calculate the flight path angle from vertical speed and true airspeed. As an aid in fairing the flight test results, it is also recommended that analytical data from power required flight test results be utilized for computing flight path angle versus true airspeed.

Recommendation

It is recommended that the second sentence of the first paragraph be revised as follows:

"For the landing approach flight phase, the flight-path-angle versus true airspeed shall have a local slope at $V_{o_{min}}$ which is within the following ranges:

a. Level 1 - From Positive 0.060 DEG/KT to negative slope

b. Level 2 - From positive 0.15 DEG/KT to negative slope

c. Level 3 - From positive 0.24 DEG/KT to negative slope

C-5A FLIGHT TEST DATA

LANDING CONFIGURATION

592,000 LBS 6,000 FT.

$d\gamma/dV$ ~ SLOPE AT

(a) $V_{o_{MIN}}$: -0.0020

(b) $V_{o_{MIN}}$ - 5KTS : +0.0044

SLOPE DIFFERENCE BETWEEN (a) & (b): +0.0064

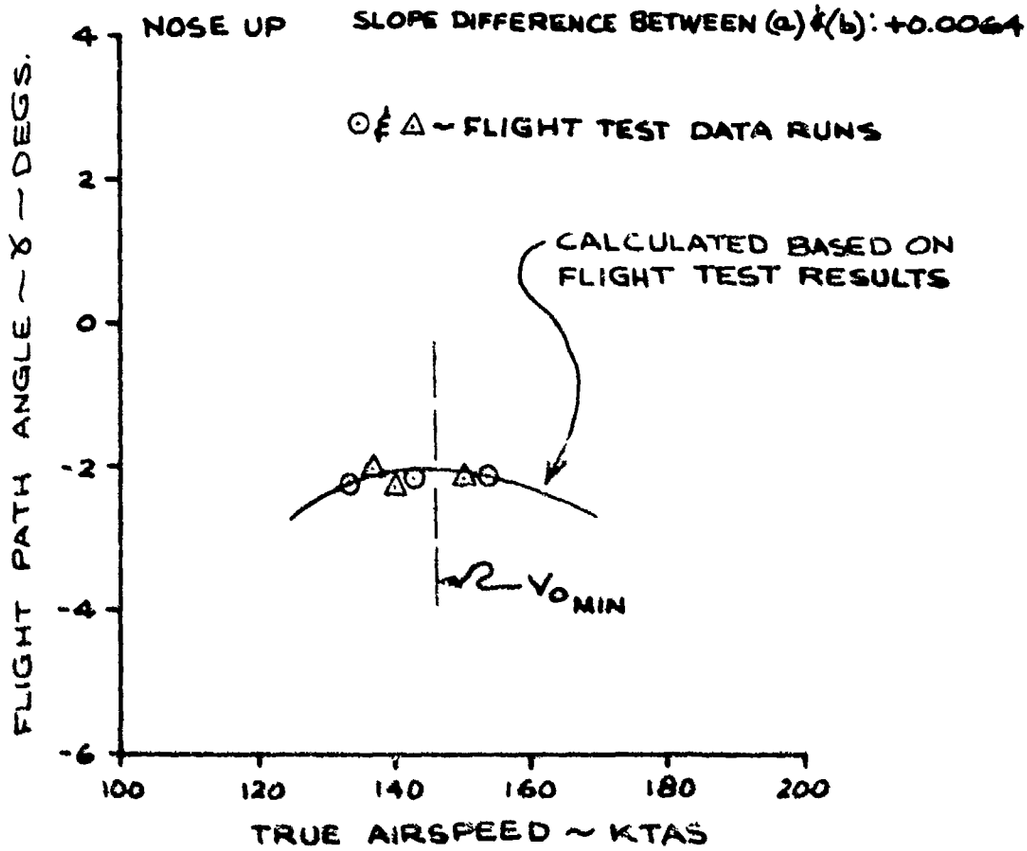


FIGURE NO.1 (3.2.1.3) FLIGHT PATH STABILITY

Requirement

3.2.2 Longitudinal maneuvering characteristics.

3.2.2.1 Short-period response. The short-period response of angle of attack which occurs at approximately constant speed, and which may be produced by abrupt elevator control inputs, shall meet the requirements of 3.2.2.1.1 and 3.2.2.1.2. These requirements apply, with the cockpit control free and with it fixed, for responses of any magnitude that might be experienced in service use. If oscillations are nonlinear with amplitude, the requirements shall apply to each cycle of the oscillation. In addition to meeting the numerical requirements of 3.2.2.1.1 and 3.2.2.1.2, the contractor shall show that the airplane has acceptable response characteristics in atmospheric disturbances.

3.2.2.1.1 Short-period frequency and acceleration sensitivity. The short-period undamped natural frequency, $\omega_{n_{sp}}$, shall be within the limits shown in figures 1, 2, and 3. If suitable means of directly controlling normal force are provided, the lower bounds on $\omega_{n_{sp}}$ and n/α of figure 3 may be relaxed if approved by the procuring activity.

3.2.2.1.2 Short-period damping. The short-period damping ratio, ζ_{sp}, shall be within the limits of table IV.

TABLE IV. Short-period damping Ratio Limits

Level	Category A and C Flight Phases		Category B Flight Phases	
	Minimum	Maximum	Minimum	Maximum
1	0.35	1.30	0.30	2.00
2	0.25	2.00	0.20	2.00
3	0.15*	-	0.15*	-

*May be reduced at altitudes above 20,000 feet if approved by the procuring activity.

Comparison

The short-period response characteristics were investigated with the pitch SAS inoperative at the flight conditions listed in Tables 5 and 6 by both the elevator pulse and the elevator doublet methods. Either procedure produced essentially the same results. The short period is well damped with no residual oscillations and is rated by the Joint Air Force/Lockheed Test Team pilots as good for all Flight Phases.

As stated in Reference 2, the short period oscillations were essentially deadbeat throughout the flight envelope; consequently, frequency and damping ratio data were not extracted from the time history plots. In order to compare analytical data with these requirements, a "curve-fit" technique of flight test data with a theoretical short period shape of known frequency and damping was employed. Table 7 lists the flight conditions

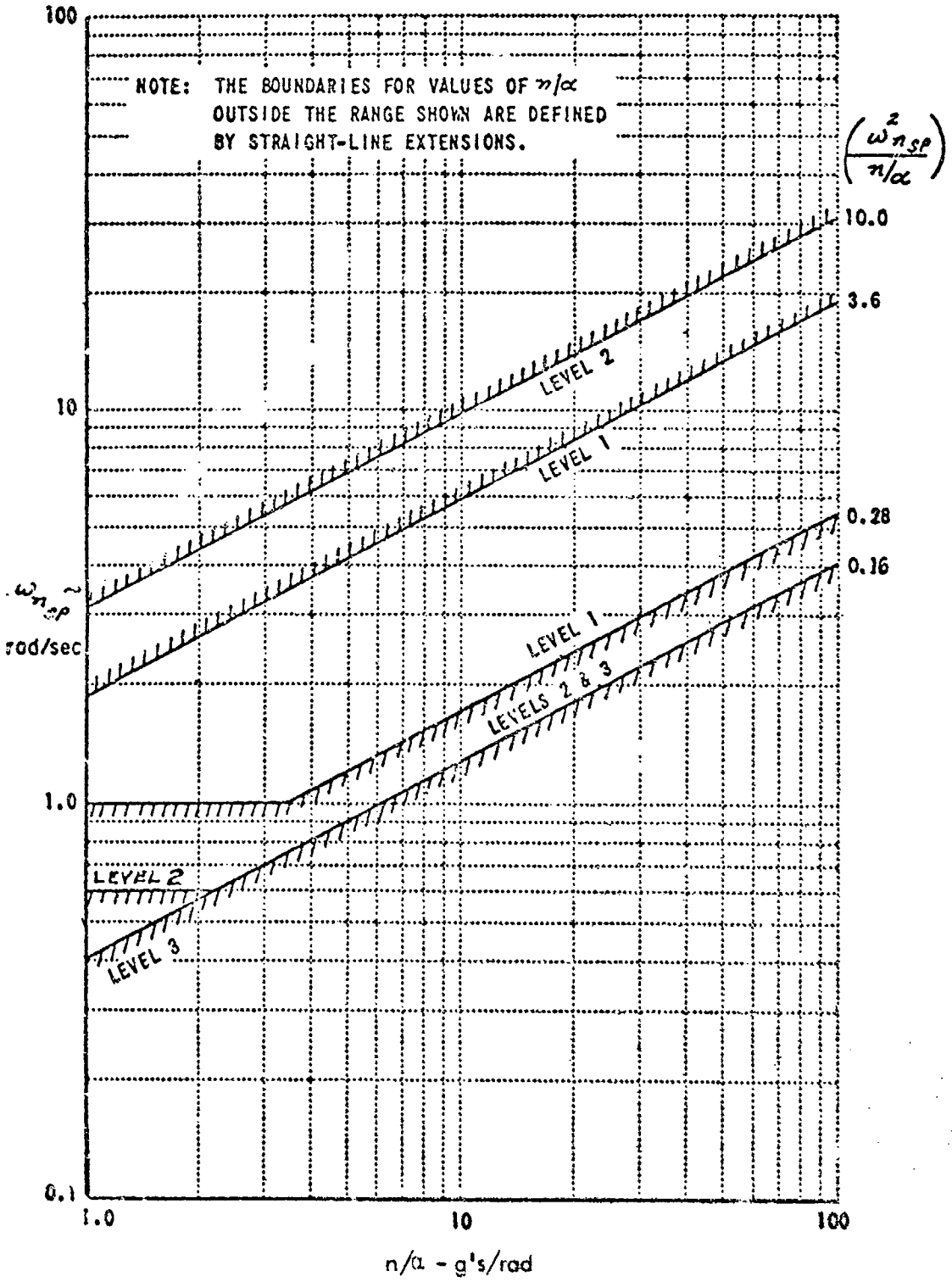


Figure 1. Short-Period Frequency Requirements - Category A Flight Phases

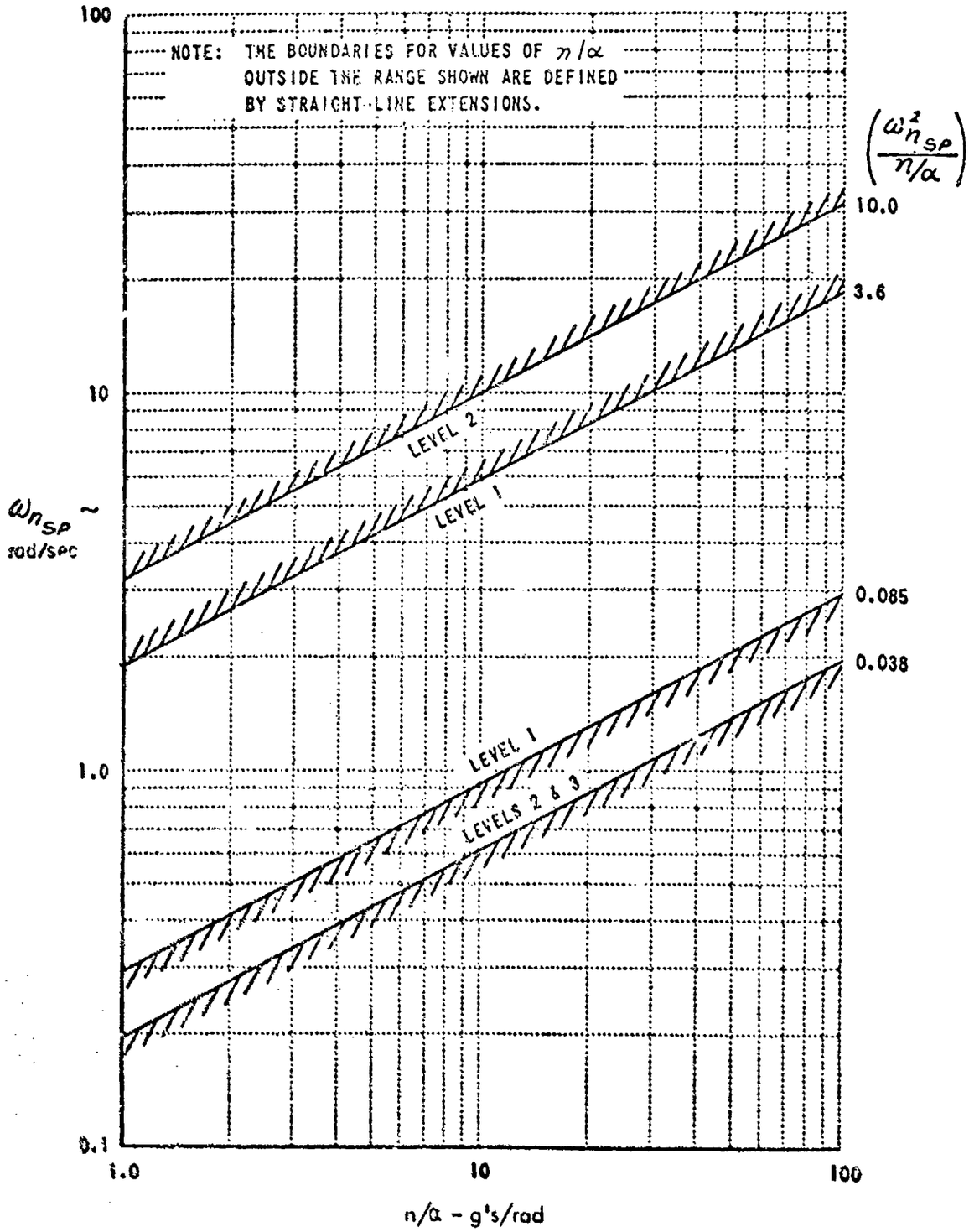


Figure 2. Short-Period Frequency Requirements - Category B Flight Phases

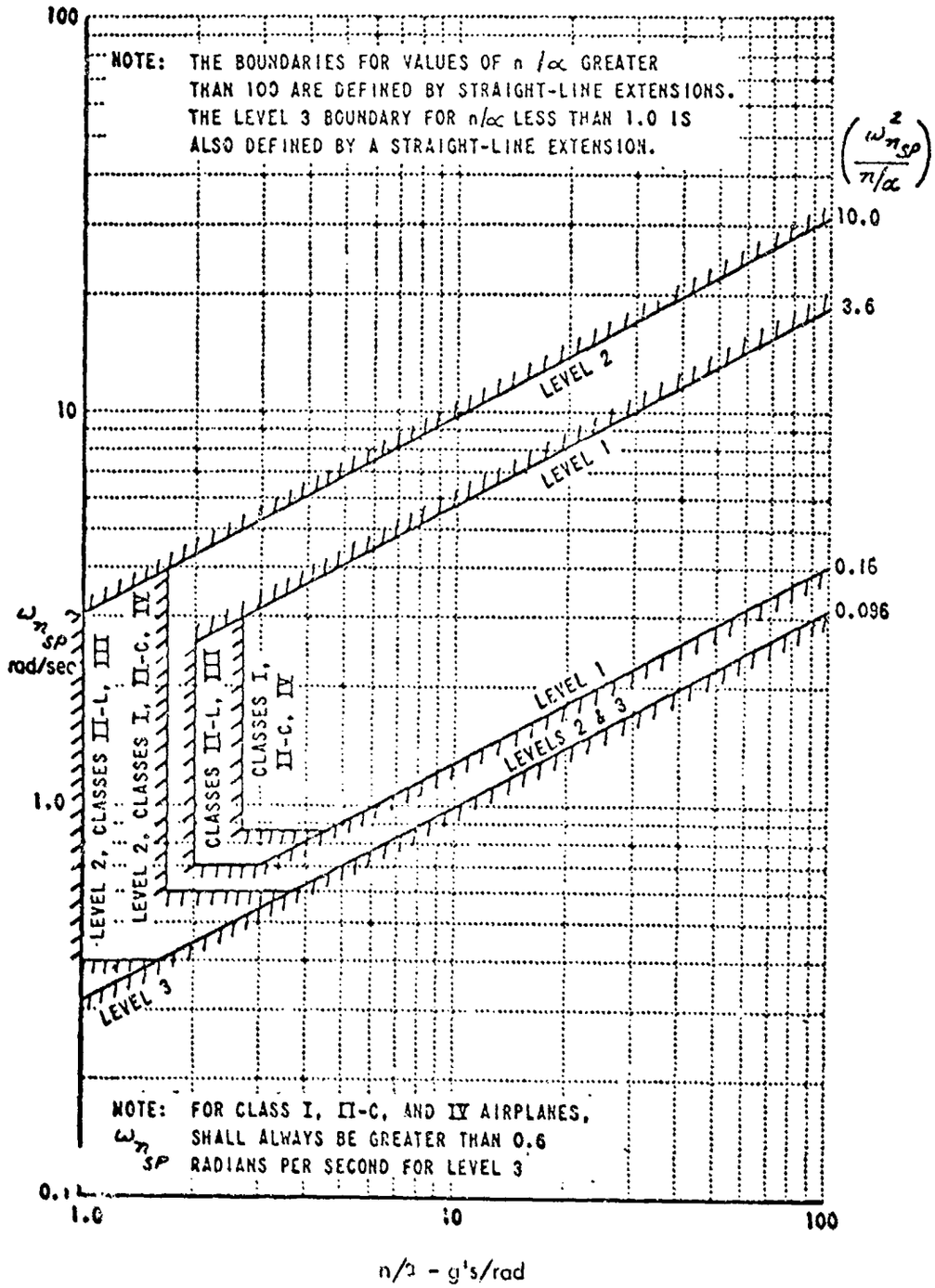


Figure 3. Short-Period Frequency Requirements - Category C Flight Phases

investigated and Figures 1(3.2.2.1), 2(3.2.2.1), and 3(3.2.2.1) present the results in the required format for flight phases A, B, and C, respectively. It should be noted that low altitude cruise data (Category B) is also applicable for the terrain following flight phase (Category A) and medium altitude (approximately 25,000 ft) cruise data (Category B) corresponds to the in-flight refueling flight phase (Category A).

The data presented in Table 7 complies with the damping ratio requirements. Although, neither of the Flight Phase A, B, or C results completely comply with the frequency requirements. For Category A, only one test condition satisfies the Level 1 requirements and only three conditions satisfy the Level 2 and 3 requirements. For Category B Flight Phase, all the data except the high altitude (35,000 ft) satisfy the Level 1 requirements. For Category C, three test conditions fall below the Level 1 minimum frequency requirements.

Discussion

Pitch SAS inoperative data are used for comparison with Level 1 requirements because the joint Air Force/Lockheed test team concluded that short and long period characteristics were good without any pitch damping. Short period damping and frequency was not noticeably affected by operation of the pitch SAS. Pitch SAS operates as a function of pitch rate only; consequently, its operation affects primarily the long period mode.

Based on the C-5A short period data discussed herein, the Level 1 and Level 2 frequency requirement envelopes appear to be too high for all Flight Phase categories for a Class III airplane. Pilot comments indicate that the short period response corresponds to Level 1 conditions. However, test results do not completely agree with specification requirements. Although the terrain following flight phase is not utilized on C-5A fleet aircraft yet, the in-flight refueling phase has been used with very satisfactory results. It, therefore, appears that as an interim measure, the minimum frequency requirements should be lowered for Class III aircraft for Flight Phases A and C. For Flight Phase B, the lower limit need to be reduced for altitudes above approximately 20,000 ft.

Recommendations

(a) Additional data needs to be obtained for other Class III airplanes to support or revise the Category A flight phase requirements.

(b) Relative to Category B, the lower bounds of Figure 2 Level 1 should be relaxed for Class III airplanes contingent upon procuring activity approval.

(c) Reduce the lower bounds of Figure 3 Level 1 by ten percent.

Table 5. Short Period Response - Category A & B Flight Conditions

CATEGORY	CONFIG.	WEIGHT	C G	V_{KCAS}	ALT. FT.	PITCH CONTROL INPUT (+), (-) PULSE, DOUBLET		
A & B	CR	495,850	22.3	180	9,941	X	X	
A & B	CR	644,056	22.6	211	9,943		X	X
A & B	CR	691,925	22.9	268	10,178	X	X	
A & B	CR	503,200	22.5	269	9,941	X	X	
B	CR	711,725	23.0	352	10,016			X
B	CR	521,000	19.6	351	9,993	X	X	
A & B	CR	489,050	40.8	168	10,384	X	X	X
A & B	CR	636,900	39.7	213	10,499		X	X
A & B	CR	682,700	40.1	270	9,978	X	X	X
A & B	CR	507,991	40.7	265	9,826			X
B	CR	699,600	39.8	351	9,961	X	X	
B	CR	545,900	19.7	197	29,321			X
A & B	CR	679,945	23.0	240	26,000			X
B	CR	536,100	19.3	257	30,249			X
A & B	CR	664,334	22.9	269	26,010	X	X	
B	CR	557,209	21.5	335	26,345			X
B	CR	555,050	40.2	196	31,185			X
A & B	CR	665,700	40.7	244	26,083	X	X	
B	CR	564,400	40.1	256	29,981			X
A & B	CR	698,400	40.1	270	26,000	X	X	
B	CR	680,400	40.4	315	26,145	X		
B	CR	451,000	40.8	348	20,615			X
B	CR	507,945	20.2	186	35,175		X	X
B	CR	496,734	19.8	238	35,134			X
B	CR	467,200	40.8	193	34,709	X	X	
B	CR	475,724	40.7	231	36,320	X	X	X
B	CR	499,200	40.7	235	35,045	X	X	
B	CR	513,400	40.5	272	35,175	X	X	
B	D	690,200	22.9	246	12,559			X
B	D	505,643	40.7	245	14,150	X	X	X
B	D	671,728	40.9	250	26,270	X	X	X
B	D	475,724	40.8	231	34,700	X	X	X
B	AD	624,060	20.3	135	7,815	X	X	
B	AD	683,263	22.4	150	9,046	X	X	
B	AD	514,301	39.9	131	6,203	X	X	
B	AD	688,690	40.6	150	9,100	X		
B	AD	668,890	40.6	153	9,100	X	X	X

Table 6. Short Period Response - Category C Flight Conditions

CONFIG.	WEIGHT	C.G.	V_{KCAS}	ALT. FT.	PITCH CONTROL INPUT (+),	(-) PULSE,	DOUBLET
T.O. (16)	704,600	22.9	156	10,876		X	X
T.O. (16)	720,900	23.2	183	9,569		X	X
T.O. (16)	710,750	40.5	156	10,959		X	X
T.O. (16)	706,550	40.6	185	11,319		X	X
T.O. (25)	489,450	22.2	132	11,183	X	X	
T.O. (25)	670,900	22.6	149	9,178	X	X	X
T.O. (25)	674,750	22.8	150	9,704	X	X	
T.O. (25)	715,800	23.2	183	11,073	X	X	X
T.O. (25)	498,150	40.7	129	9,630		X	X
T.O. (25)	684,000	40.4	148	11,513			X
T.O. (25)	661,800	40.6	151	10,470	X	X	
T.O. (25)	679,150	40.6	186	11,186			X
T.O. (25)	489,500	40.5	183	10,107	X	X	X
L	468,400	19.3	107	9,980			X
L	482,900	21.9	124	11,270	X	X	
L	661,500	22.8	145	10,187	X	X	
L	707,200	23.0	163	11,793	X		
L	457,116	40.9	111	10,227	X	X	X
L	487,750	40.4	126	10,679	X	X	X
L	636,100	39.6	145	11,704	X	X	
L	700,150	40.7	165	8,611	X	X	
L	489,600	40.4	166	10,703	X	X	X

NOTE: (+) Pulse - Pull Force on Control
(-) Pulse - Push Force on Control
Doublet - Rapid Force Reversal, Approx. Symmetric

Table 7. Short Period Response Summary

Flight Data - Curve Fit

CATEGORY	CONFIG.	WEIGHT	C. G.	V_{KCAS}	ALT.	ζ	ω_{nsp}	τ_{sp}	n/α
C	T.O. (25)	670,900	22.6	149	9,178	.65	1.06	.81	4.03
C	T.O. (25)	661,800	40.6	151	10,470	.93	.71	.26	4.15
C	T.O. (25)	489,500	40.5	183	10,107	.93	1.05	.39	8.40
C	L	661,500	22.8	145	10,187	.65	1.01	.77	3.87
C	L	636,100	39.6	145	11,704	.84	.76	.41	3.98
C	L	700,150	40.7	165	8,611	.89	.77	.35	4.70
A & B	CR	495,850	22.3	180	9,941	.63	1.29	1.00	6.50
A & B	CR	691,925	22.3	268	10,178	.57	1.81	1.49	10.70
A & B	CR	503,200	22.5	269	9,941	.61	1.86	1.47	14.80
A & B	CR	682,700	40.1	270	9,978	.76	1.27	.83	10.90
A & B	CR	699,600	39.8	351	9,961	.76	1.55	1.01	18.40
A & B	CR	698,400	40.1	270	26,000	.61	1.08	.86	11.80
B	CR	499,200	40.7	235	35,045	.85	.80	.42	13.00
B	CR	513,400	40.5	272	35,175	.78	1.08	.68	18.70
B	D	505,643	40.7	245	14,150	.79	1.22	.75	11.70
B	D	475,724	40.8	231	34,700	.85	.83	.44	11.40

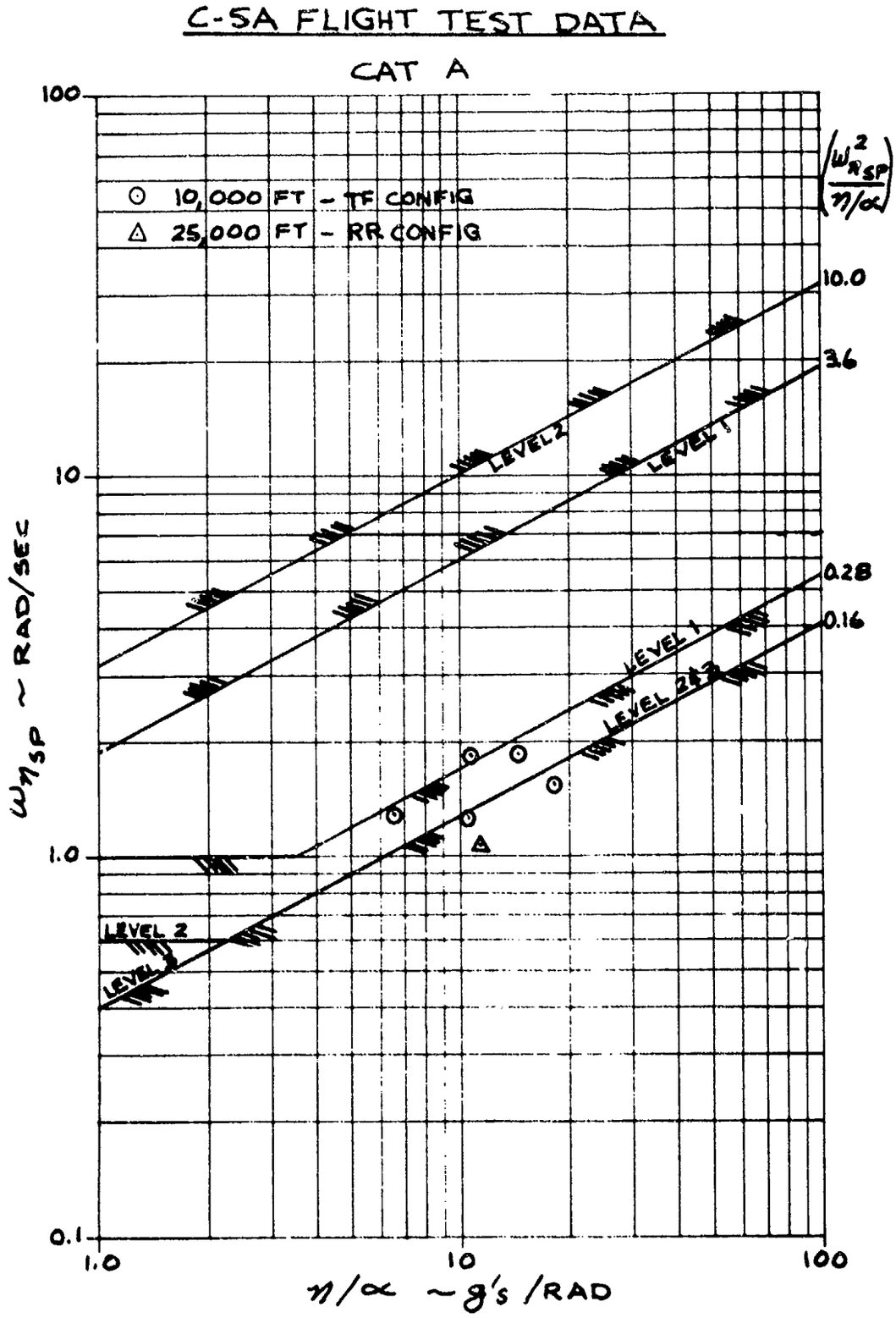


FIGURE NO. 1 (3.2.2) SHORT-PERIOD FREQUENCY

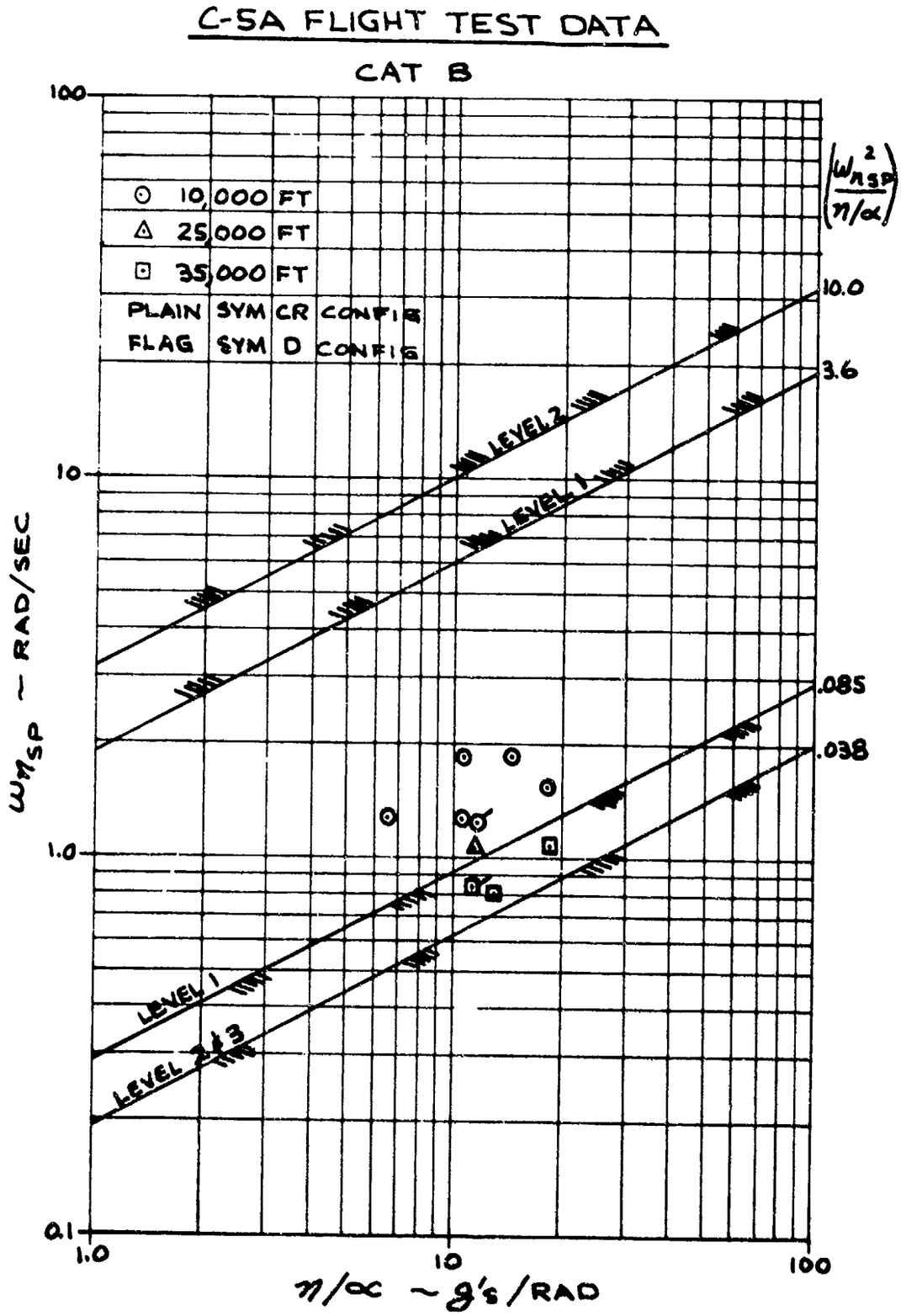


FIGURE NO. 2 (3.2.2) SHORT-PERIOD FREQUENCY

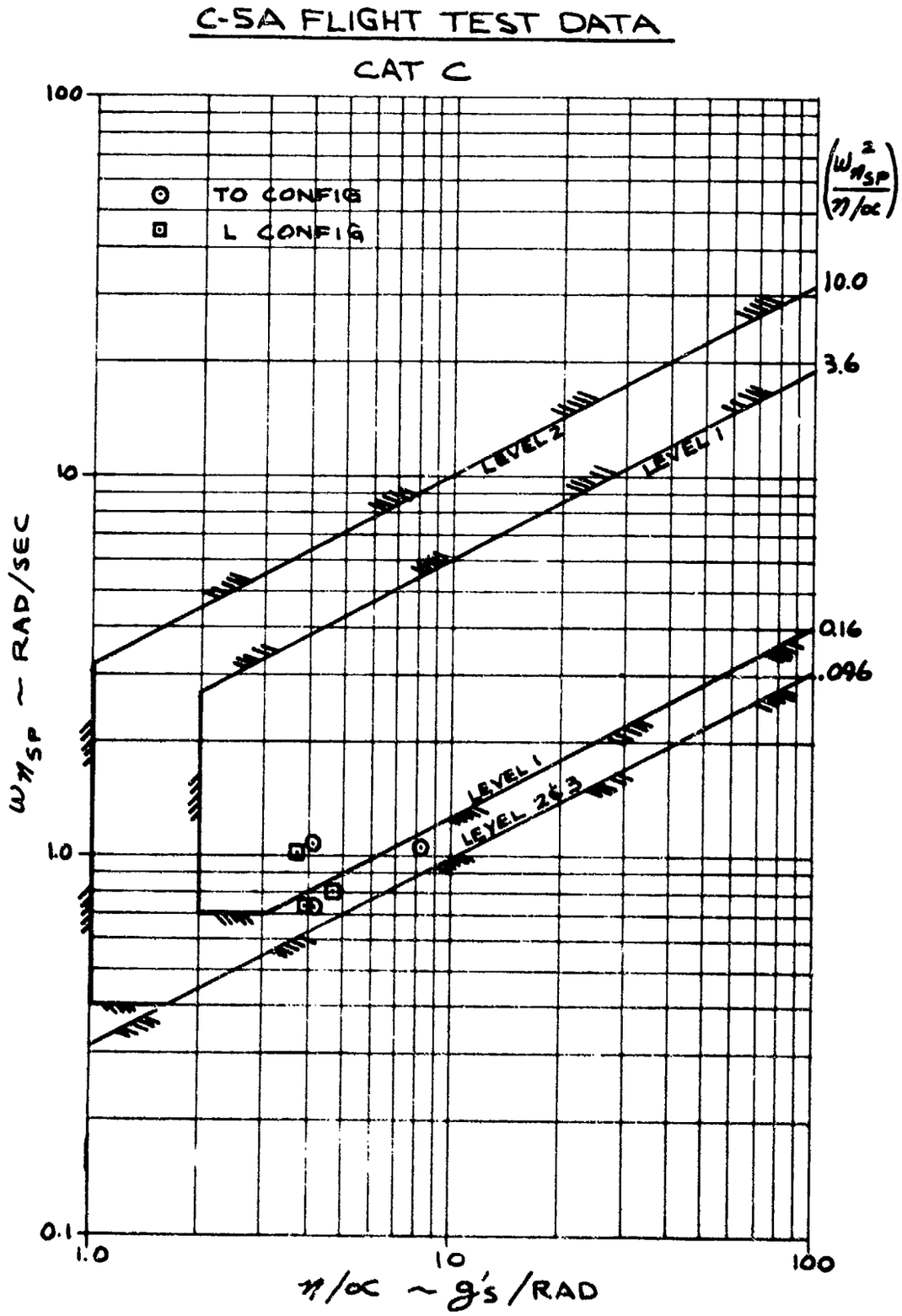


FIGURE NO.3 (3.2.2) SHORT-PERIOD FREQUENCY

Requirement

3.2.2.1.3 Residual oscillations. Any sustained residual oscillations shall not interfere with the pilot's ability to perform the tasks required in service use of the airplane. For Levels 1 and 2, oscillations in normal acceleration at the pilot's station greater than ±0.05g will be considered excessive for any Flight Phase, as will pitch attitude oscillations greater than ±3 mils for Category A Flight Phases requiring precision control of attitude. These requirements shall apply with the elevator control fixed and with it free.

Comparison

There are no test data availble for comparison with this requirement; however, it is reported that the airplane response is well damped with no residual oscillations.

Discussion

None

Recommendation

None

Requirement

3.2.2.2 Control Feel and Stability in Maneuvering Flight. In steady turning flight and in pullups at constant speed, increasing pull forces and aft motion of the elevator control and airplane-nose-up deflection of the elevator surface are required to maintain increases in normal acceleration throughout the range of service load factors defined in 3.1.8.4. Increases in push force, forward control motion, and airplane-nose-down deflection of the elevator surface are required to maintain reductions of normal acceleration in pushovers.

Comparison

Tables 8a through 8c presents a summary of maneuvering flight test results obtained on the C-5A throughout the operational speed envelope and in all configurations. Figures 1(3.2.2.2) through 5(3.2.2.2) present time history data from typical normal and abrupt symmetrical pull-up and push-down maneuvers. These data, along with the maneuvering flight summary, show that increasing pull forces along with airplane-nose-up deflection of the elevator surface are required to maintain increases in normal acceleration and vice versa. Consequently, a favorable comparison of the C-5A control feel and stability characteristics with the requirements of this paragraph is demonstrated.

Discussion

C-5A flight test results compare favorably with this requirement.

Recommendation

None

Table 8a. Maneuvering Longitudinal Stability Summary

CONFIG.	GROSS WEIGHT LBS.	ALTITUDE FT.	KCAS	MACH NO.	C_L	C.G. % MAC	δ_e n	MANEUVER POINT % MAC	Fs/n AV.	
									MAX.	MIN.
TO	700,000	10,000	150	.273	1.51	22.6	33.2	66.4	85	69*
TO	700,000	10,000	150	.273	1.51	40.5	19.6	66.4	61	47
TO	700,000	10,000	185	.336	1.00	22.8	18.9	67.0	80	65*
TO	700,000	10,000	185	.336	1.00	40.6	11.5	67.0	59	46
PA	700,000	10,000	150	.273	1.51	22.8	24.0	75.2	71	54
PA	700,000	10,000	150	.273	1.51	40.7	15.8	75.2	47	38
PA	700,000	10,000	185	.336	1.00	22.5	19.4	66.3	83	65*
PA	700,000	10,000	185	.336	1.00	40.6	11.5	66.3	48	41
PA	480,000	10,000	125	.228	1.48	22.1	31.4	85.8	63	47
PA	480,000	10,000	125	.228	1.48	40.5	22.4	85.8	50	38
PA	480,000	10,000	185	.336	.69	19.9	15.2	86.9	58	52
PA	480,000	10,000	185	.336	.69	40.5	10.6	86.9	53	40
Land	700,000	10,000	145	.263	1.62	22.8	28.8	72.0	75	56
Land	700,000	10,000	145	.263	1.62	39.8	18.9	72.0	56	42
Land	700,000	10,000	165	.300	1.26	22.4	26.2	66.0	50	39
Land	700,000	10,000	165	.300	1.26	40.7	15.2	66.0	55	45
Land	480,000	10,000	120	.219	1.61	21.7	30.4	77.7	58	43
Land	480,000	10,000	120	.219	1.61	40.7	20.1	77.7	43	33
Land	480,000	10,000	165	.300	.86	19.4	18.6	72.4	65	53
Land	480,000	10,000	165	.300	.86	41.0	11.05	72.4	48	36
CR	700,000	10,000	210	.381	.78	22.9	15.6	66.0	84	69*
CR	700,000	10,000	210	.381	.78	39.8	9.5	66.0	57	49
CR	700,000	10,000	270	.488	.47	23.0	9.8	62.8	79	63*
CR	700,000	10,000	270	.488	.47	40.3	5.56	62.8	48	41
CR	700,000	26,000	225	.557	.70	23.0	12.5	61.5	76	67*
CR	700,000	26,000	225	.557	.70	40.8	6.8	61.5	52	43
CR	700,000	26,000	285	.697	.45	22.8	8.0	61.0	65	54
CR	700,000	26,000	285	.697	.45	40.2	4.35	61.0	42	33

Table 51. Maneuvering Longitudinal Stability Summary

CONFIG.	GROSS WEIGHT LBS.	ALTITUDE FT.	KCAS	MACH NO.	C_L	C.G. % MAC	e/n	MANEUVER POINT % MAC	Fs/n AV.	
									MAX.	MIN.
CR	480,000	10,000	173	.314	.78	22.3	19.6	80.0	69	58
CR	480,000	10,000	173	.314	.78	40.9	13.4	80.0	52	45
CR	480,000	10,000	270	.488	.33	22.5	7.5	72.0	58	52
CR	280,000	10,000	270	.488	.33	40.8	4.7	72.0	42	35
CR	480,000	35,000	185	.560	.71	20.1	13.25	61.0	52	47
CR	480,000	35,000	185	.560	.71	40.8	6.5	61.0	35	30
CR	480,000	35,000	235	.700	.46	19.8	8.2	48.2	59	48
CR	480,000	35,000	235	.700	.46	40.7	3.8	58.2	38	29
CR	550,000	30,000	200	.542	.69	19.4	12.4	64.5	43	40
CR	550,000	30,000	200	.542	.69	40.2	6.7	64.5	37	33
CR	550,000	30,000	260	.694	.42	19.2	8.1	61.2	64	55
CR	550,000	30,000	260	.694	.42	40.1	4.1	61.2	41	32
CR	700,000	10,000	350	.629	.28	23.1	5.9	61.0	50	43
CR	700,000	10,000	350	.629	.28	40.0	3.3	61.0	39	29
CR	700,000	26,000	315	.765	.37	23.0	6.2	64.0	54	42
CR	700,000	26,000	315	.765	.37	40.6	3.6	64.0	39	29
CR	480,000	10,000	350	.629	.20	22.6	4.7	66.3	43	36
CR	480,000	10,000	350	.629	.20	40.6	2.8	66.3	34	25
CR	480,000	35,000	275	.807	.34	20.5	6.0	57.8	48	43
CR	480,000	35,000	275	.807	.34	40.6	2.8	57.8	35	24
C	700,000	10,000	210	.381	.78	22.7	17.8	A	84	79*
C	700,000	26,000	225	.557	70	23.1	14.2	A	85	76*
C	480,000	10,000	173	.314	.78	19.5	20.7	80.0	78	64*
C	480,000	10,000	173	.314	.78	40.9	13.3	80.0	59	45
C	480,000	35,000	185	.560	.71	20.6	13.2	69.2	57	52
C	480,000	35,000	185	.560	.71	40.5	7.8	69.2	39	33
D	700,000	10,000	250	.452	.55	23.0	14.7	A	99	87*
D	700,000	26,000	250	.616	.57	22.7	13.2	A	93	80*

Table 8c Maneuvering Longitudinal Stability Summary

CONFIG.	GROSS WEIGHT LBS.	ALTITUDE FT.	KCAS	MACH NO.	C_L	C.G. % MAC	δ_e/n	MANEUVER POINT % MAC	Fs/n AV.	
									MAX.	MIN.
D	480,000	10,000	250	.452	.38	19.8	10.5	77.0	80	66*
D	480,000	10,000	250	.452	.38	40.7	6.7	77.0	57	48
D	480,000	35,000	235	.700	.46	20.4	8.4	58.4	62	56
D	480,000	35,000	235	.700	.46	40.8	3.9	58.4	38	30
AD	700,000	10,000	150	.273	1.51	22.5	25.6	71.7	71	48
AD	700,000	10,000	150	.273	1.51	40.6	16.2	71.7	45	36
AD	480,000	10,000	130	.237	1.37	20.1	28.5	70.2	58	46
AD	480,000	10,000	130	.237	1.37	39.9	17.2	70.2	40	32
CR	700,000	10,000	350	.629	.28	23.1	6.5		51	46
CR	480,000	10,000	350	.629	.20	19.6	4.8	69.0	42	36
CR	480,000	10,000	350	.629	.20	40.6	2.8	69.0	35	25
ATO+	700,000	10,000	150	.273	1.51	22.9	26.0	66.7	74	58
ATO	700,000	10,000	150	.273	1.51	40.5	15.6	66.7	46	39
ATO	700,000	10,000	185	.336	1.00	22.8	19.5	67.1	74	67*
ATO	700,000	10,000	185	.336	1.00	40.6	11.1	67.1	49	43

* - Specification allows 90 lb/g.

+ - ATO - Alternate Takeoff (16° Flap)

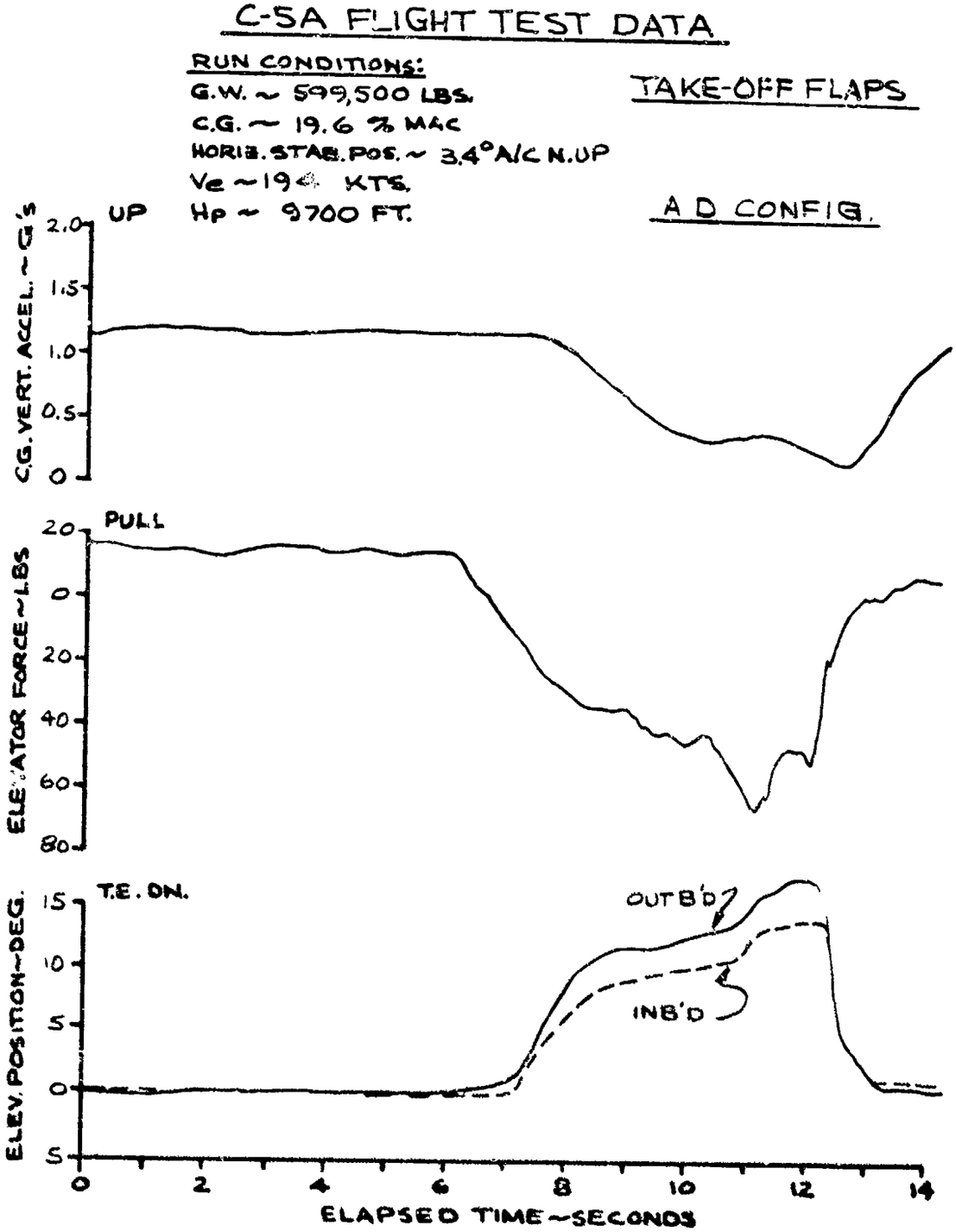


FIGURE NO. 1 (3.2.2.2) NORMAL SYMMETRICAL PUSH-DOWN

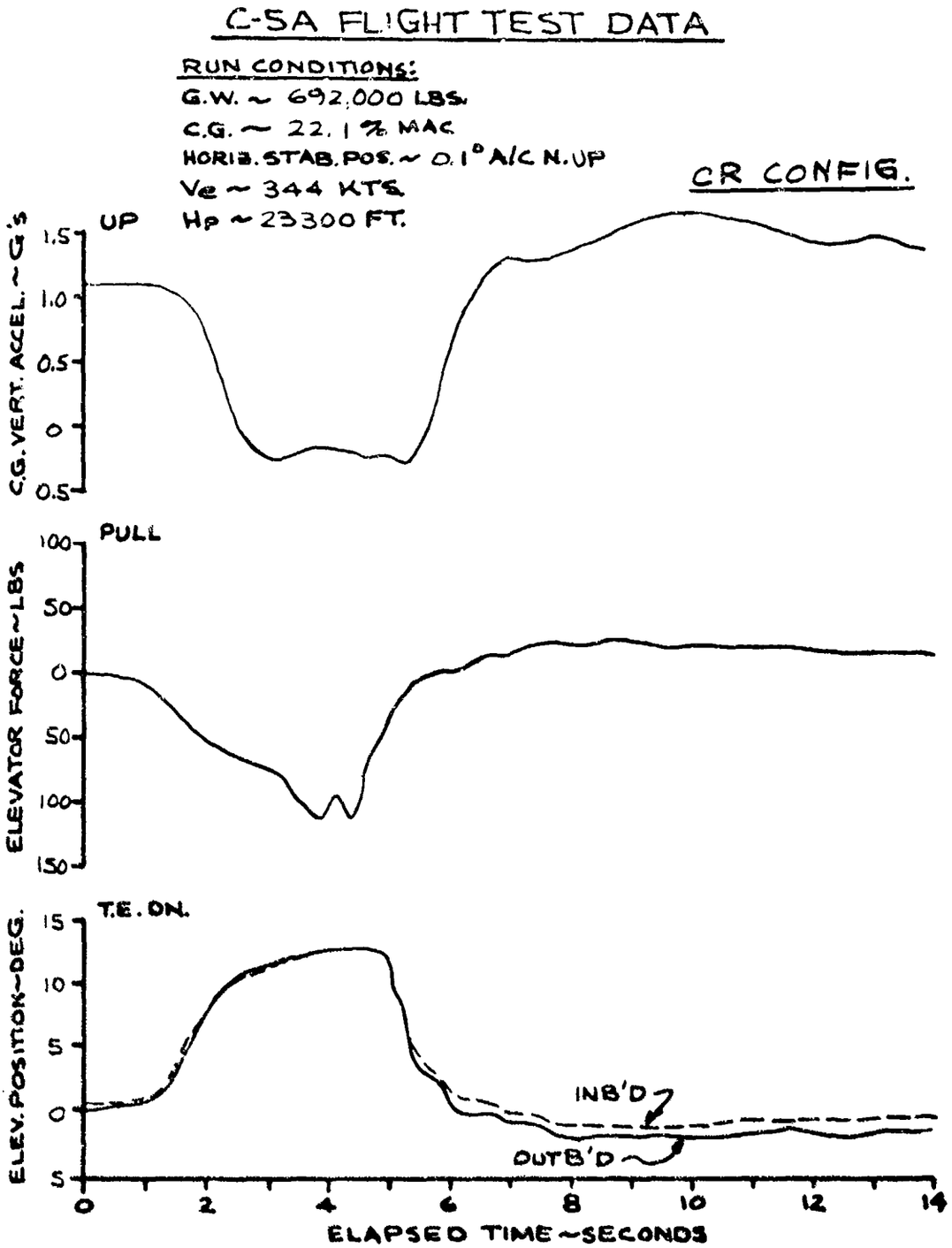


FIGURE NO. 2 (3.2.2.2) NORMAL SYMMETRICAL PUSH-DOWN

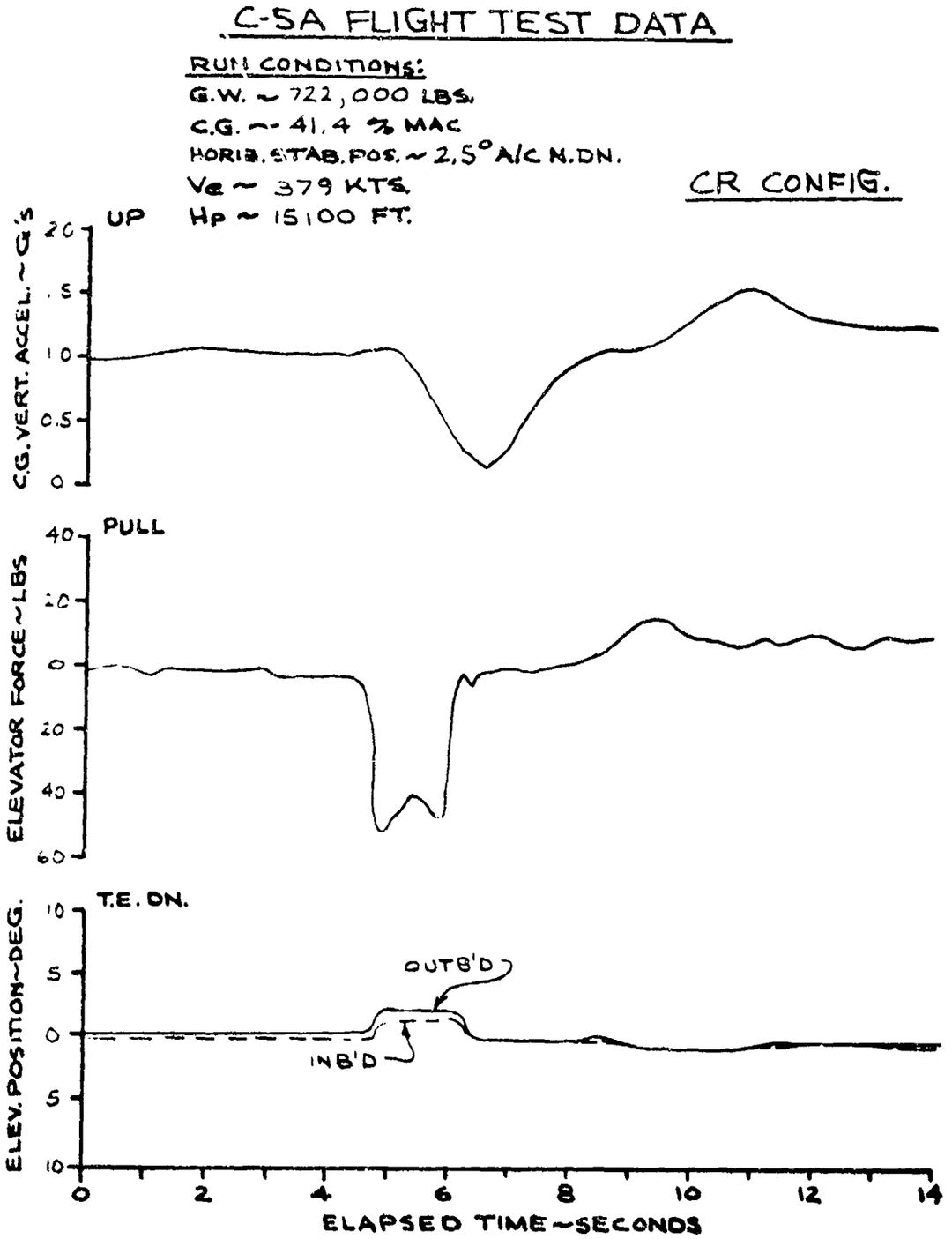


FIGURE NO. 3 (3.2.2.2) ABRUPT SYMMETRICAL PUSH-DOWN

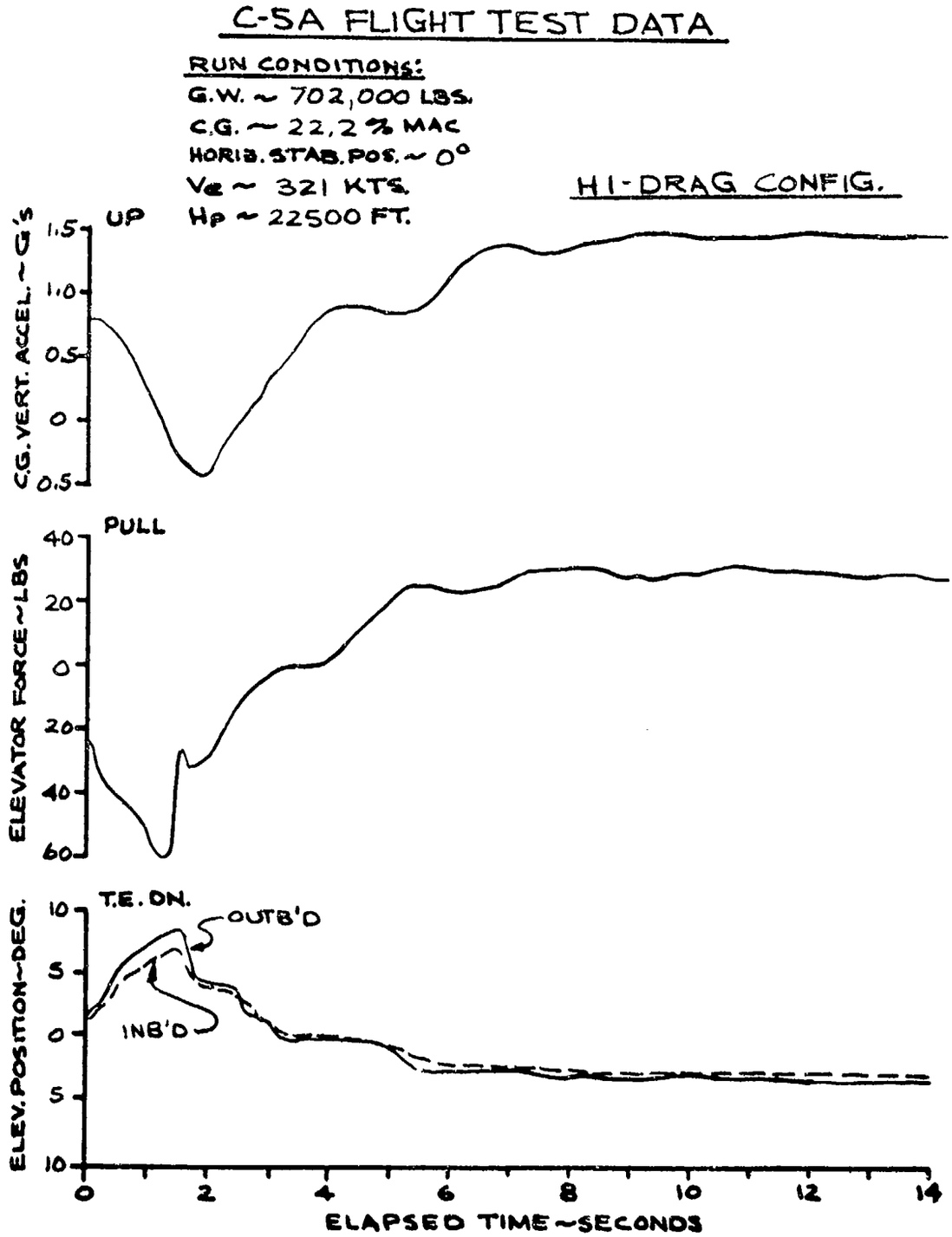


FIGURE NO. 4 (3.2.2.2) NORMAL SYMMETRICAL PUSH-DOWN

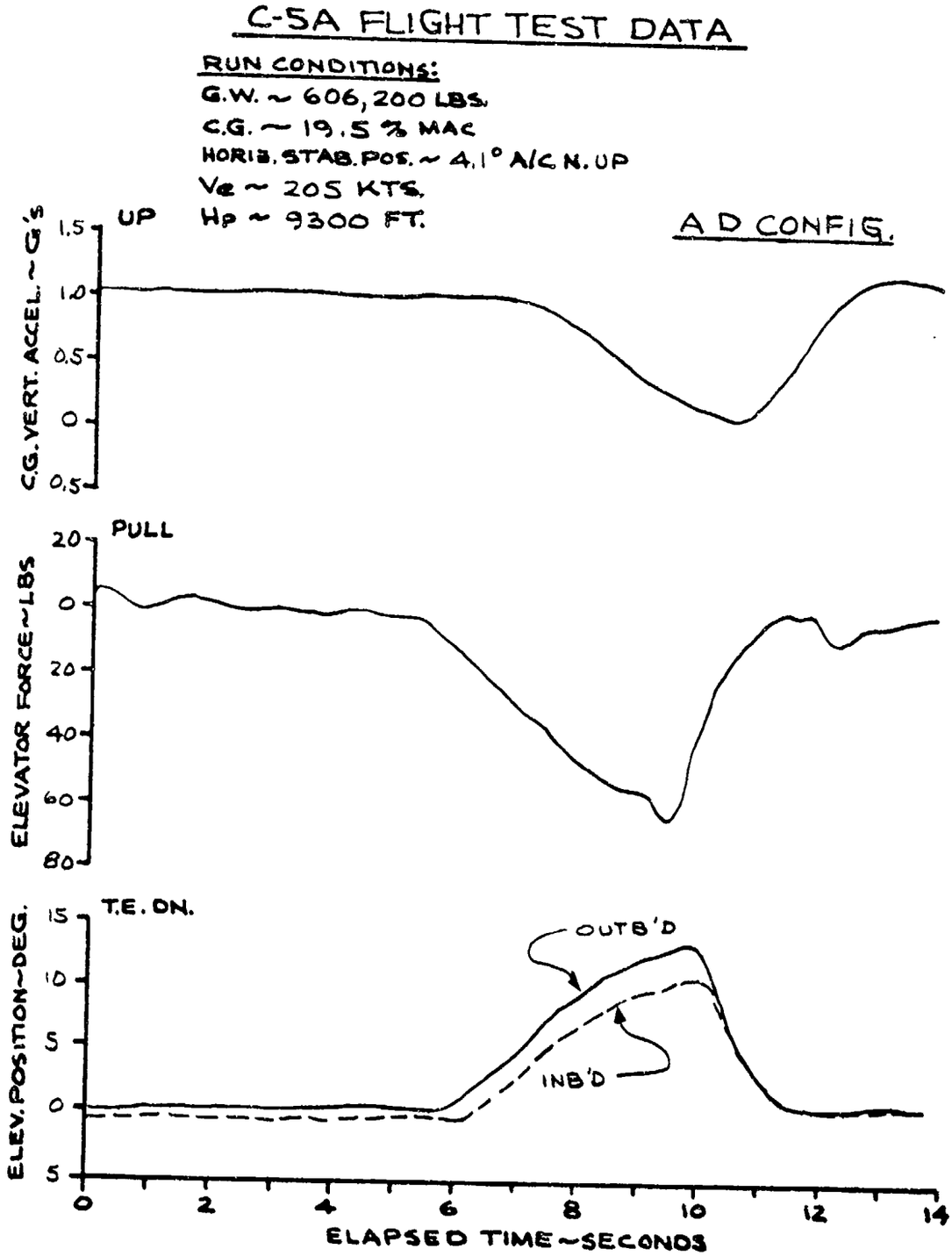


FIGURE NO. 5 (3.2.2.2) NORMAL SYMMETRICAL PUSH-DOWN

Requirement

3.2.2.2.1 Control forces in maneuvering flight. At constant speed in steady turning flight, pullups, and pushovers, the variations in elevator-control force with steady-state normal acceleration shall be approximately linear. In general, departure from linearity resulting in a local gradient which differs from the average gradient for the maneuver by more than 50 percent is considered excessive. All local force gradients shall be within the limits of Table V. In addition, whenever the short-period frequency is near the upper boundaries of Figure 1, F_s/n should be near the Level 1 upper boundaries of Table V. This may be necessary to avoid abrupt response, sensitivity, or tendencies toward pilot-induced oscillations. The term gradient does not include that portion of the force versus n curve within the preloaded breakout force or friction band.

Comparison

A summary of the elevator control force gradient at forward C.G. is presented in Figure 1(3.2.2.2.1) which are used to evaluate the maximum values of the requirement. Figure 2(3.2.2.2.1) presents a summary of the elevator control force gradient at aft C.G.

The force per load factor gradients at forward C.G. compare favorably with the Level 1 maximum values; however, the gradients at aft C.G. are below the Level 1 boundary for five conditions and below the Level 2 boundary for two conditions.

Discussion

The C-5A control force gradients are rated satisfactory and acceptable, which would tend to substantiate the Level 1 maximum requirements and tend to question the validity of the Level 1 minimum requirements.

The minimum boundary of the Level 1 requirement appears to be too high.

Recommendation

Reduce the minimum boundary of the Level 1 requirement to $35/n_L - 1$ and Level 2 requirement to $30/n_L - 1$ for a Class III Airplane which has an n_L equal to 2.5.

TABLE V. Elevator Maneuvering Force Gradient Limits

Center Stick Controllers		
Level	Maximum Gradient, $(F_s/n)_{max}$, pounds per g	Minimum Gradient, $(F_s/n)_{min}$, pounds per g
1	$\frac{240}{n/\alpha}$ but not more than 28.0 nor less than $\frac{56}{n_L-1}$ *	The higher of $\frac{21}{n_L-1}$ and 3.0
2	$\frac{360}{n/\alpha}$ but not more than 42.5 nor less than $\frac{85}{n_L-1}$ *	The higher of $\frac{18}{n_L-1}$ and 3.0
3	56.0	3.0

*For $n_L < 3$, $(F_s/n)_{max}$ is 28.0 for Level 1, 42.5 for Level 2.

Wheel Controllers		
Level	Maximum Gradient, $(F_s/n)_{max}$, pounds per g	Minimum Gradient, $(F_s/n)_{min}$, pounds per g
1	$\frac{500}{n/\alpha}$ but not more than 120.0 nor less than $\frac{120}{n_L-1}$	The higher of $\frac{45}{n_L-1}$ and 6.0
2	$\frac{775}{n/\alpha}$ but not more than 182.0 nor less than $\frac{182}{n_L-1}$	The higher of $\frac{38}{n_L-1}$ and 6.0
3	240.0	6.0

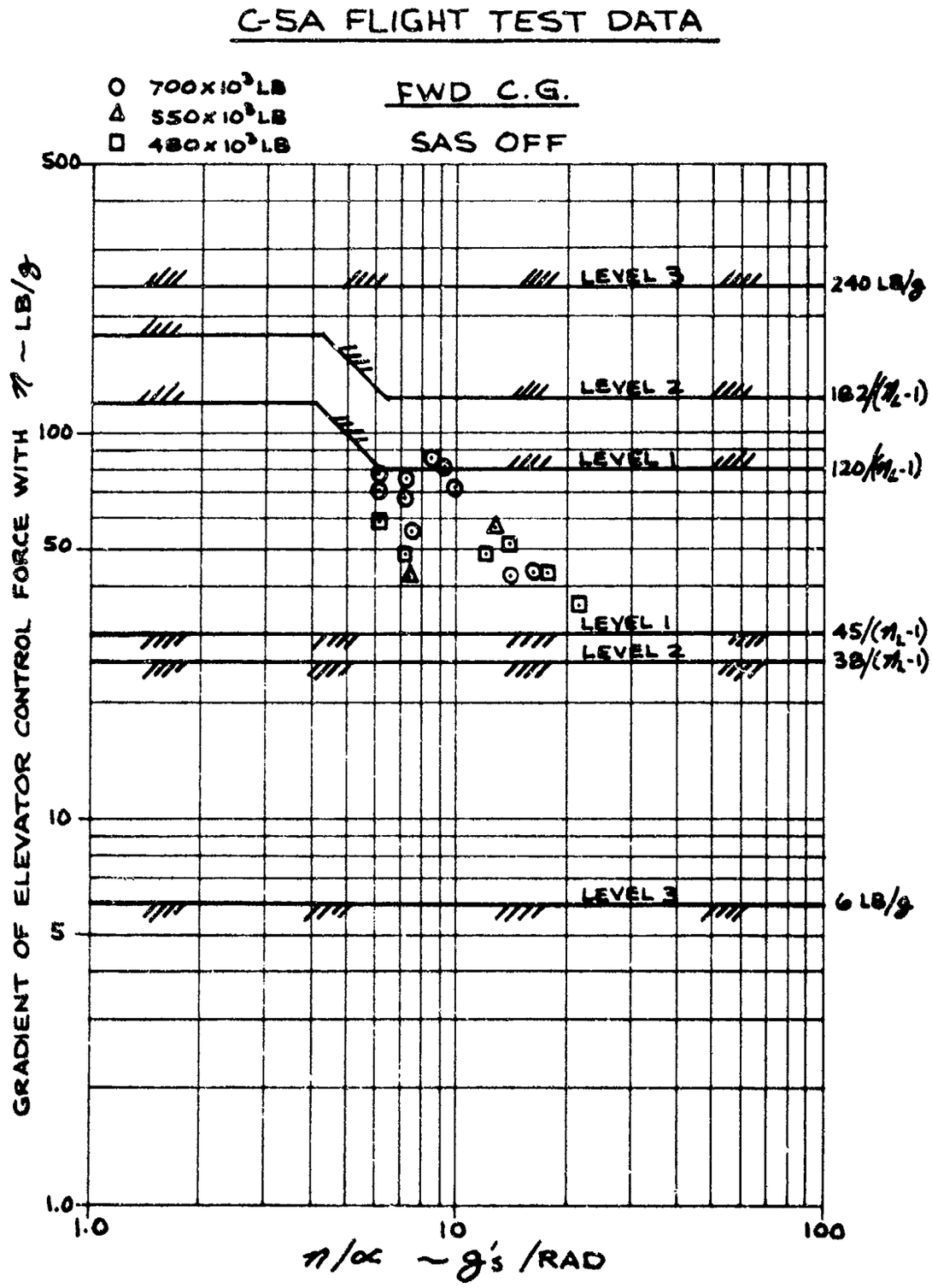


FIGURE NO. 1 (3.2.2.2.1) ELEVATOR CONTROL FORCE GRADIENT SUMMARY

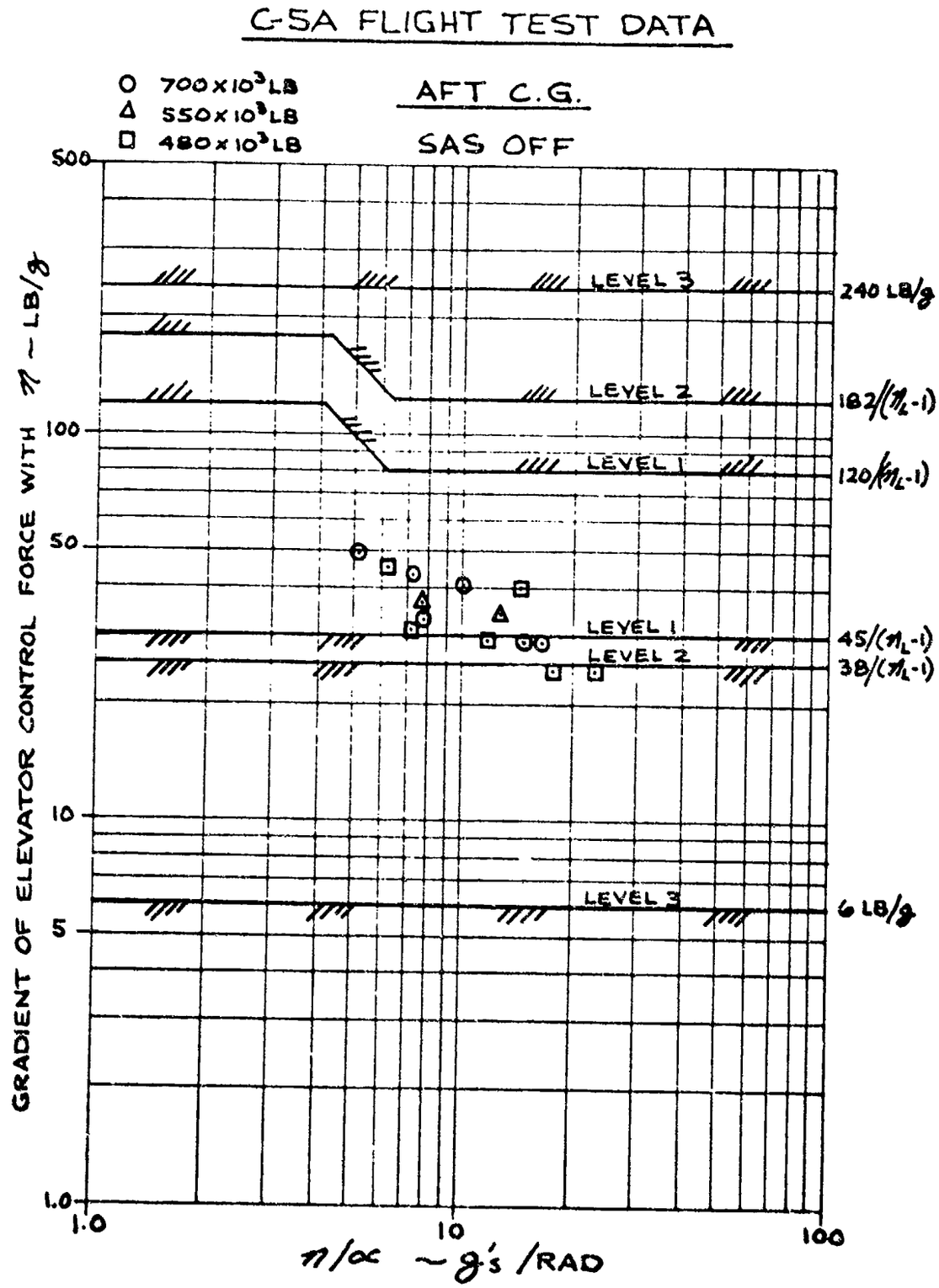


FIGURE NO. 2 (3.2.2.2.1) ELEVATOR CONTROL FORCE GRADIENT SUMMARY

Requirement

3.2.2.2.2 Control motions in maneuvering flight. The elevator-control motions in maneuvering flight shall not be so large or so small as to be objectionable. For Category A Flight Phases, the average gradient of elevator-control force per inch of elevator-control deflection at constant speed shall be not less than 5 pounds for Levels 1 and 2.

Comparison

Since the C-5A uses a full-power control system, an elevator artificial feel subsystem is utilized to provide the pilot with appropriate "feel" forces. Based on flight test data, the subsystem provides the column with a force per inch of travel ranging from a minimum of 5 pounds per inch to a maximum of 15 for both push and pull motions. Therefore, it is concluded that the C-5A agrees with this requirement.

Discussion

C-5A design and test data compare favorably with this requirement.

Recommendation

None

Requirement

3.2.2.3 Longitudinal Pilot-Induced Oscillation - There shall be no tendency for pilot-induced oscillations, that is, sustained or uncontrolled oscillations resulting from the efforts of the pilot to control the airplane.

Comparison

Throughout the conduct of the C-5A Category I/II Flight Test Program which accumulated a total of approximately 7,000 flight hours consisting of performance, flying qualities, loads and systems tests, there was only one condition in which a tendency toward a pilot-induced oscillation occurred. This condition occurred early in the Flight Test Program during air refueling tests with a KC-135 tanker. As Figure 1(3.2.2.3) shows, the condition occurred in the precontact position at an altitude of approximately 22,000 feet and an airspeed of 237 KIAS. The gross weight and center of gravity position were 480,700 lb and 30% MAC, respectively. At the time these tests were conducted, the longitudinal control feel system (Pilot-Assist Cable Servo System - PACS) and the pitch axis stability augmentation system were not in final configuration. It was later concluded that the PIO tendency was due to a faulty pitch PACS (elevator break-out force was 18 lb) aggrevated by an out of trim condition existing at the start of the test. Since the time the above test was conducted, approximately 150 additional air refueling test runs have been conducted with final production PACS and SAS configurations with no reported tendency toward PIO. It is, therefore, concluded that the C-5A agrees with the requirements of this section.

Discussion

The C-5A results agree with this requirement.

Recommendation

None

C-5A FLIGHT TEST DATA

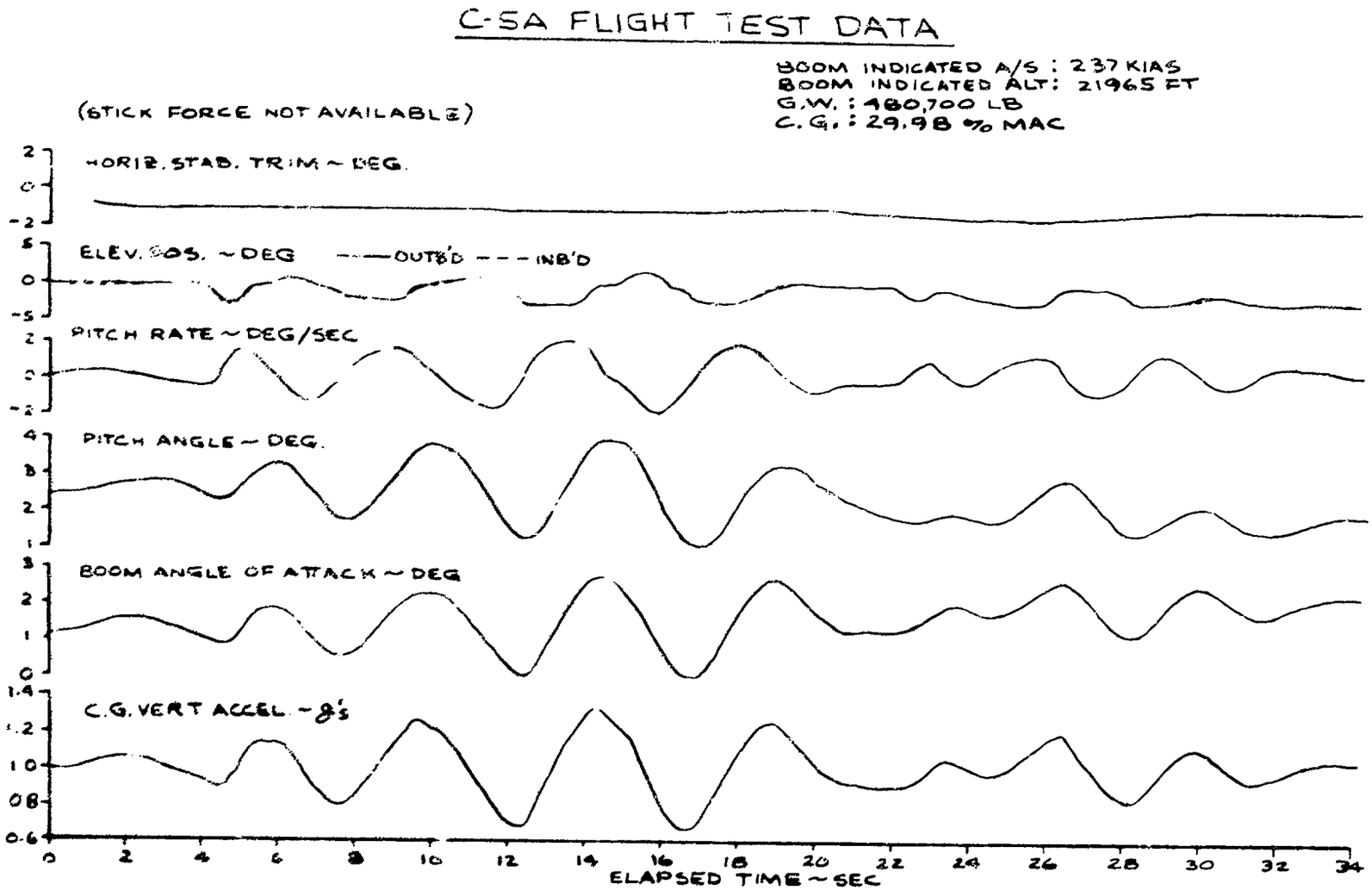


FIGURE NO.1(3.2.2.3) INFLIGHT REFUELING CHARACTERISTICS

Requirement

3.2.2.3.1 Transient Control Forces. The peak elevator-control forces developed during abrupt maneuvers shall not be objectionably light, and the buildup of control force during the maneuver entry shall lead the buildup of normal acceleration. Specifically, the following requirement shall be met when the elevator control is pumped sinusoidally. For all input frequencies, the ratio of the peak force amplitude to the peak normal load factor amplitude at the c.g. measured from the steady oscillation, shall be greater than:

Center-Stick Controllers ---------- 3.0 pounds per g

Wheel Controllers ---------- 6.0 pounds per g

Comparison

Although tests were not conducted on the C-5A to specifically evaluate the longitudinal control force gradient during sinusoidal type inputs, sufficient data were obtained from other tests to show that the intent of this requirement is met. Figures 1(3.2.2.3.1) and 2(3.2.2.3.1) present results obtained during dynamic longitudinal stability and airload survey tests in which the elevator control was pumped rapidly and slowly, respectively. During the dynamic longitudinal tests the input frequency was approximately 1.25 Hz and during the airload survey tests the input frequency was approximately .08 Hz. These data show that in each case the buildup of control force preceded the buildup of acceleration and the control force gradient was far in excess of the 6.0 lb/g minimum limit. It is, therefore, concluded that results from the C-5A tests agree with this requirement.

Discussion

None

Recommendation

None

C-5A FLIGHT TEST DATA

LANDING CONFIG

AIRSPEED: 110 KCAS
ALTITUDE: 13,000 FT.
G.W.: 457,000 LB
C.G.: 40.9% MAC

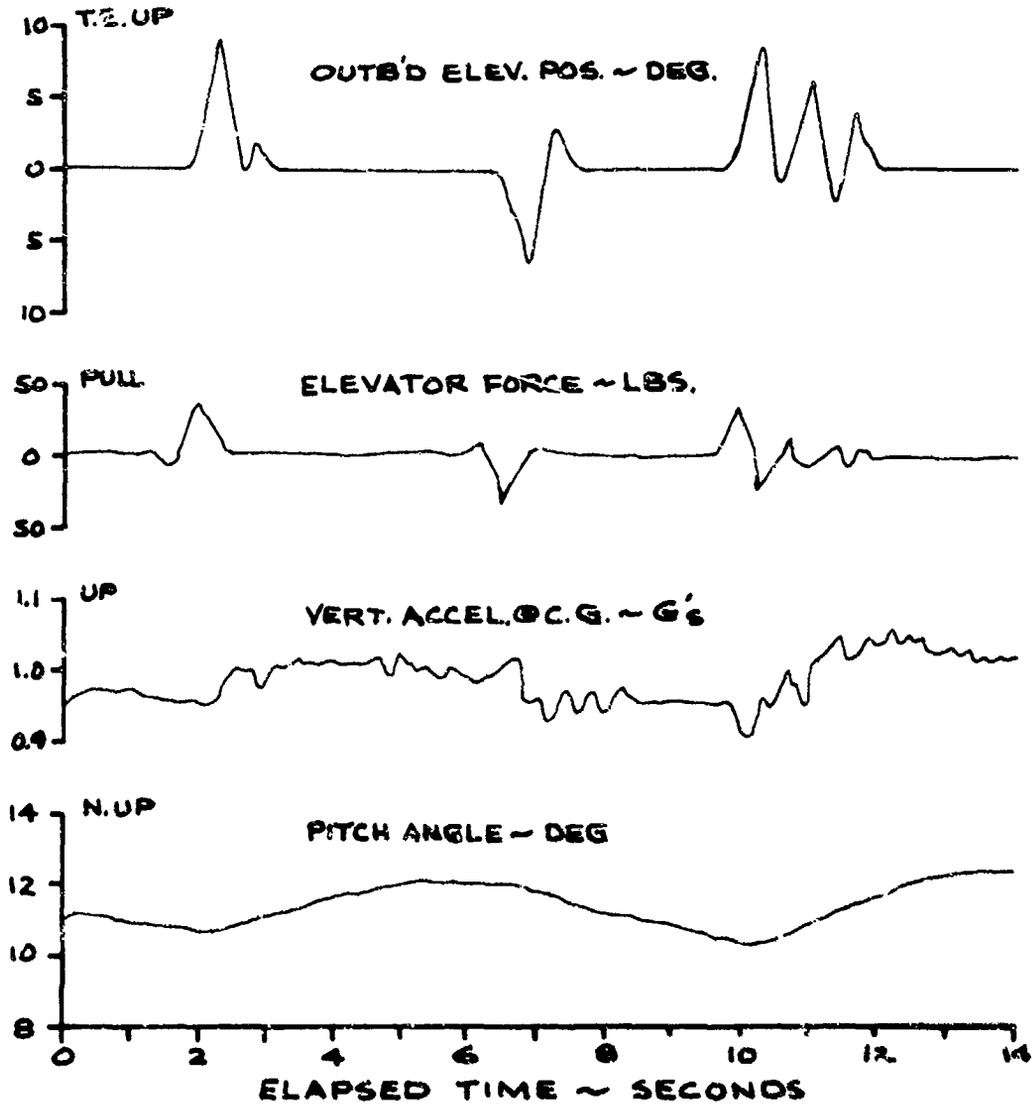


FIGURE NO. 1 (3.2.2.3.1) DYNAMIC LONGITUDINAL STABILITY

C-5A FLIGHT TEST DATA

CR CONFIG

AIRSPEED: 295 KCAS
ALTITUDE: 30,000 FT.
G.W.: 604,000 LB.
C.G.: 20.7 % MAC

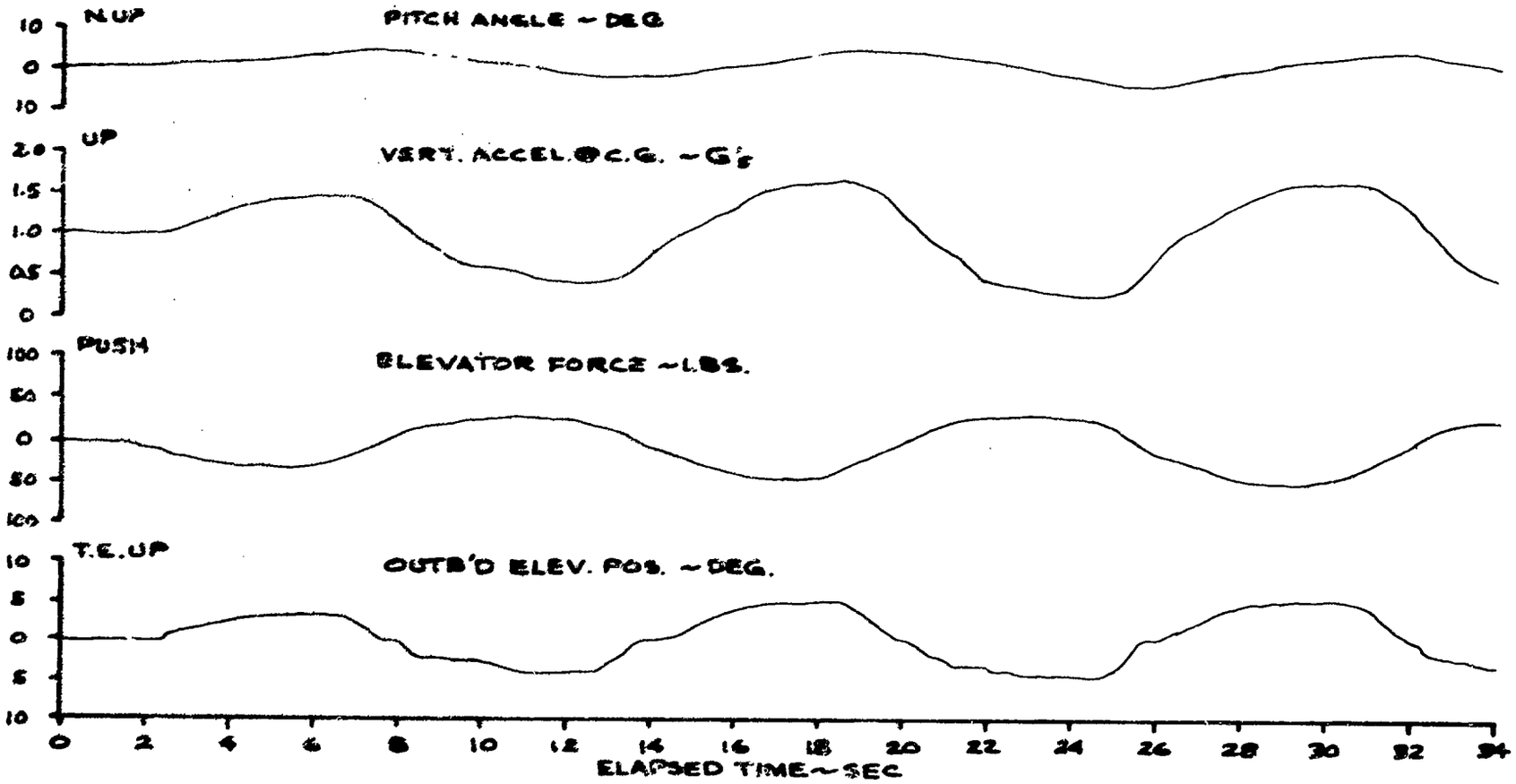


FIGURE NO. 2 (3.2.2.3.1) ROLLERCOASTER MANEUVER

Requirement

3.2.3 Longitudinal Control

3.2.3.1 Longitudinal Control in Unaccelerated Flight. In erect unaccelerated flight at all service altitudes, the attainment of all speeds between V_S and V_{MAX} shall not be limited by the effectiveness of the longitudinal control or controls.

Comparison

Results from trim capability, stall characteristics and dive to V_D/M_D tests are used to compare C-5A longitudinal control effectiveness with this requirement. Figures 1(3.2.3.1) through 4(3.2.3.1) present results of trim capability tests conducted with the center of gravity at the forward limit and at the aft limit in each of the landing, takeoff/approach, alternate takeoff and cruise configurations. Figure 5(3.2.3.1) presents stall characteristics test results obtained with the center of gravity at the forward limit and Figure 6(3.2.3.1) presents results of dive tests to V_D/M_D. The center of gravity for these tests was also at the forward limit. These data show that the attainment of all speeds between V_S and V_{MAX} is not limited by longitudinal control effectiveness in conjunction with stabilizer trim.

Discussion

C-5A results substantiate validity of the requirement.

Recommendation

None

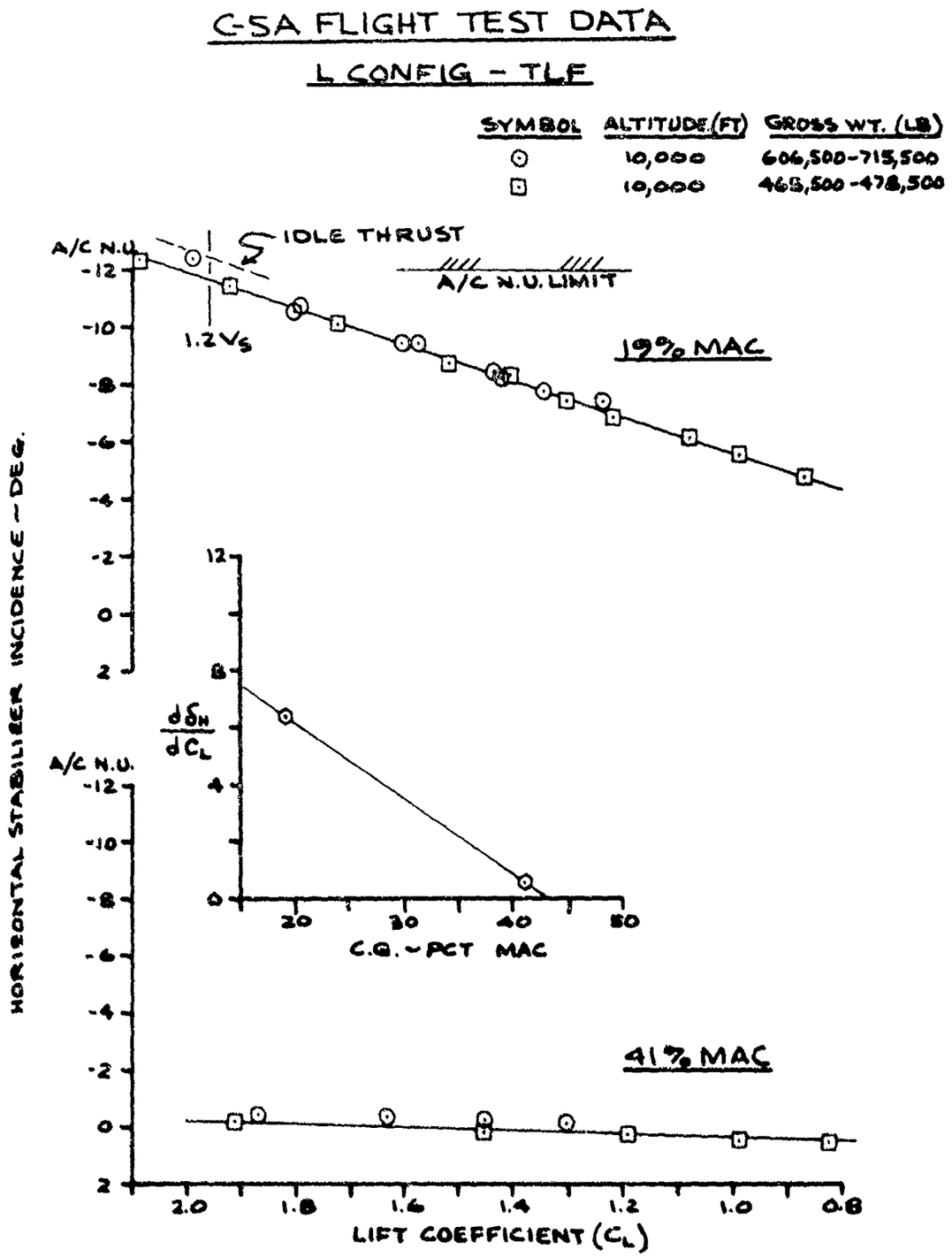


FIGURE NO. 1 (3.2.3.1) TRIM CAPABILITY

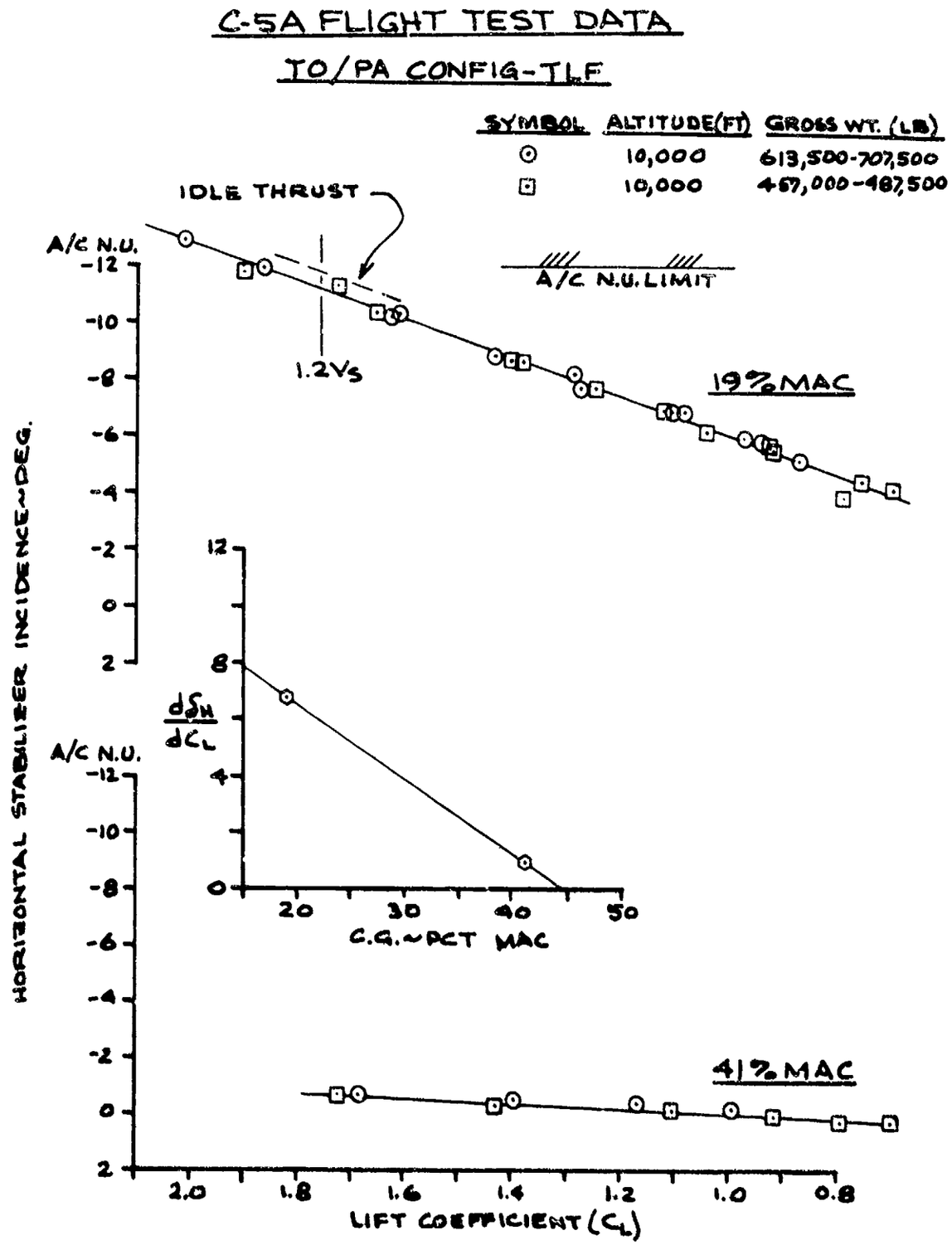


FIGURE NO.2 (3.2.3.1) TRIM CAPABILITY

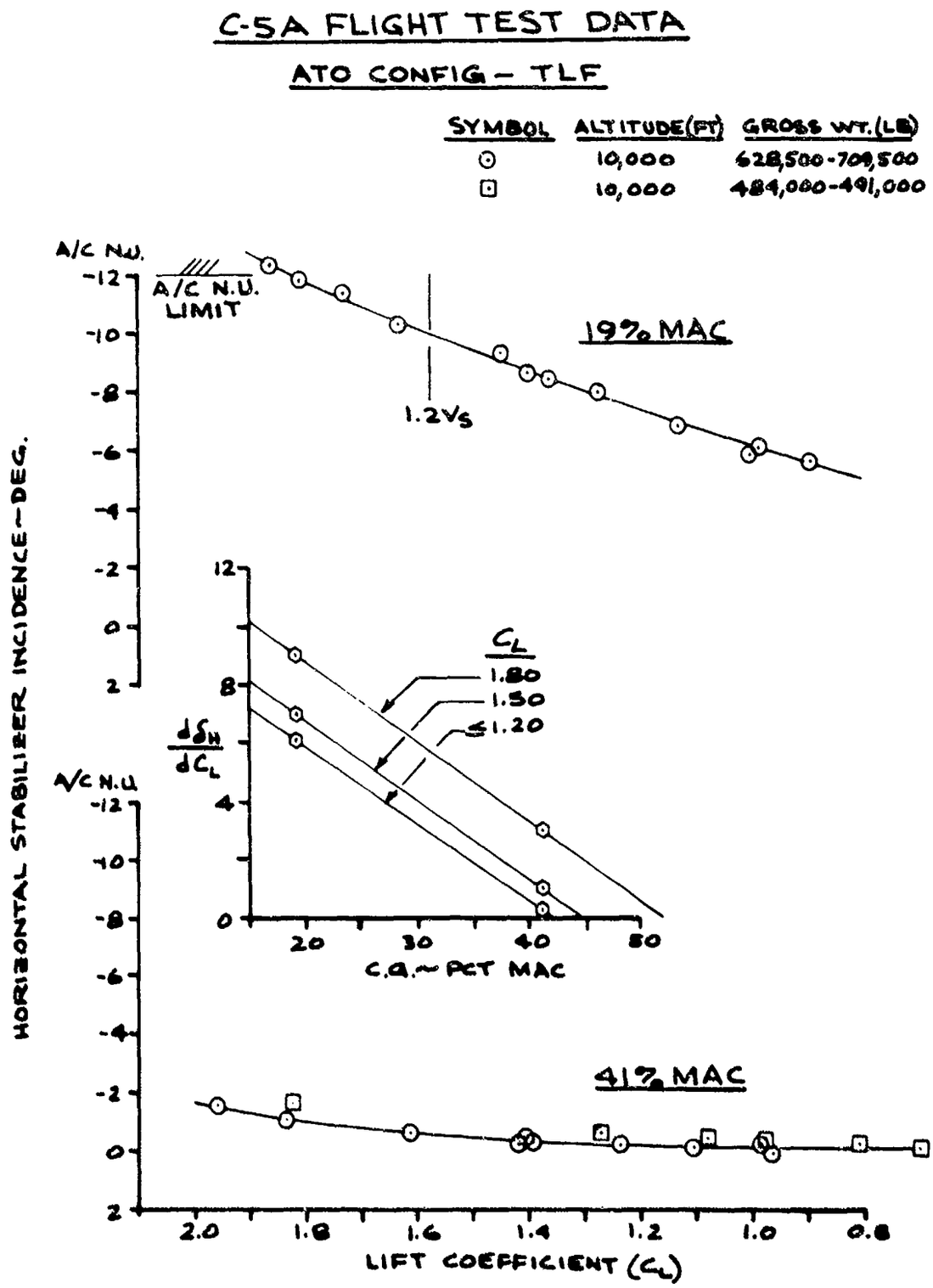


FIGURE NO.3 (3.2.3.1) TRIM CAPABILITY

C-5A FLIGHT TEST DATA

CR CONFIG - TLF

SYMBOL	ALTITUDE(FT)	GROSS WT.(LB)
⊙	10,000	615,500-654,000
△	26,000	650,000-698,500
⊡	10,000	464,000-537,000
◇	35,000	481,500-517,500

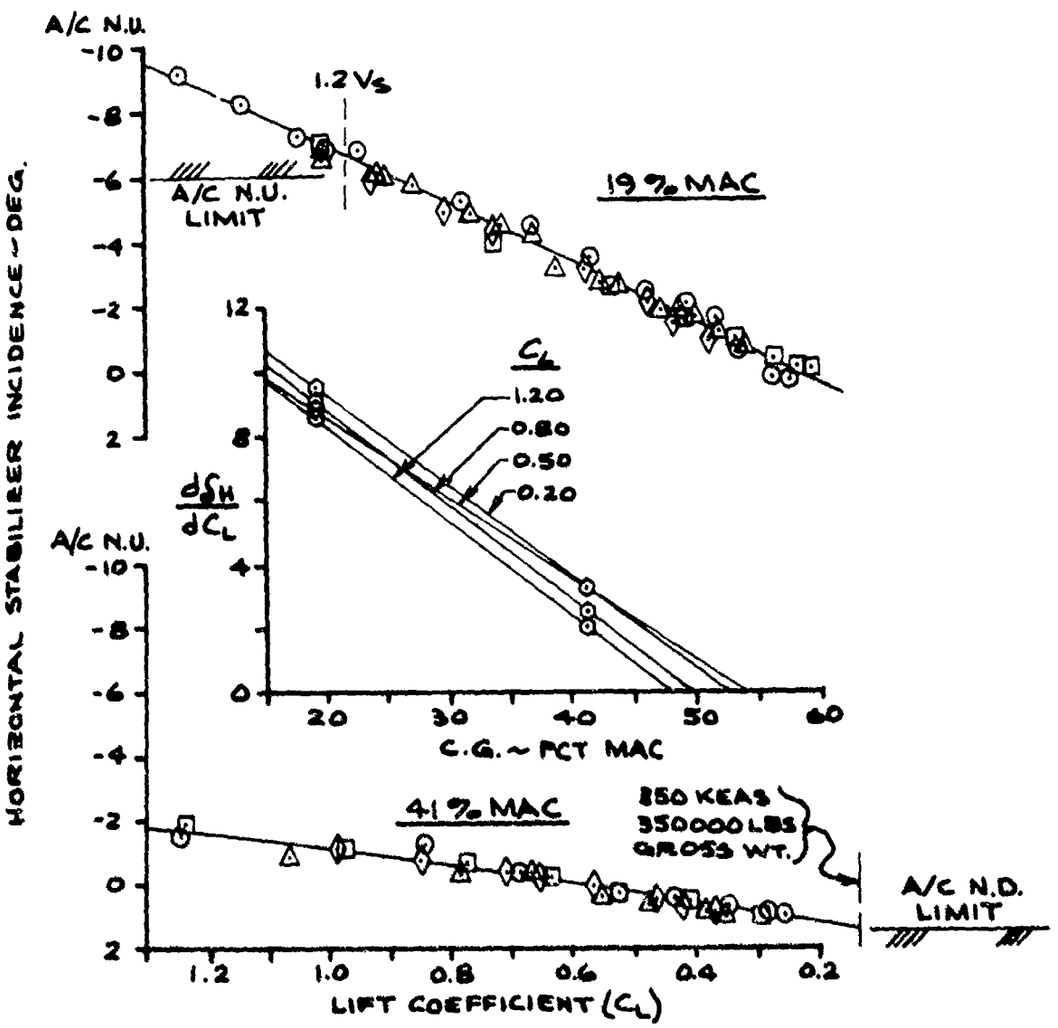


FIGURE NO.4 (3.2.3.1) TRIM CAPABILITY

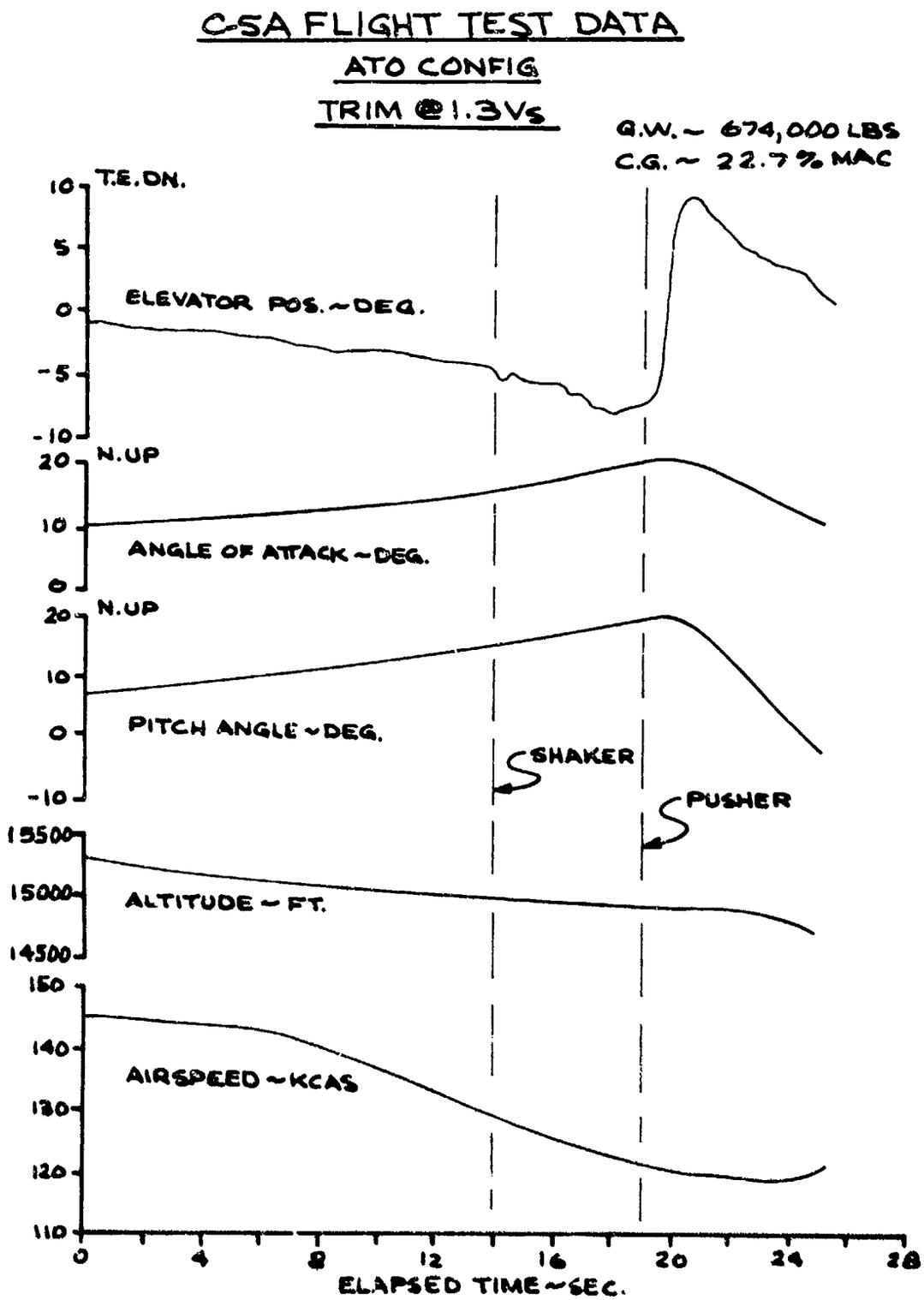


FIGURE NO. 5 (3.2.3.1) STALL CHARACTERISTICS

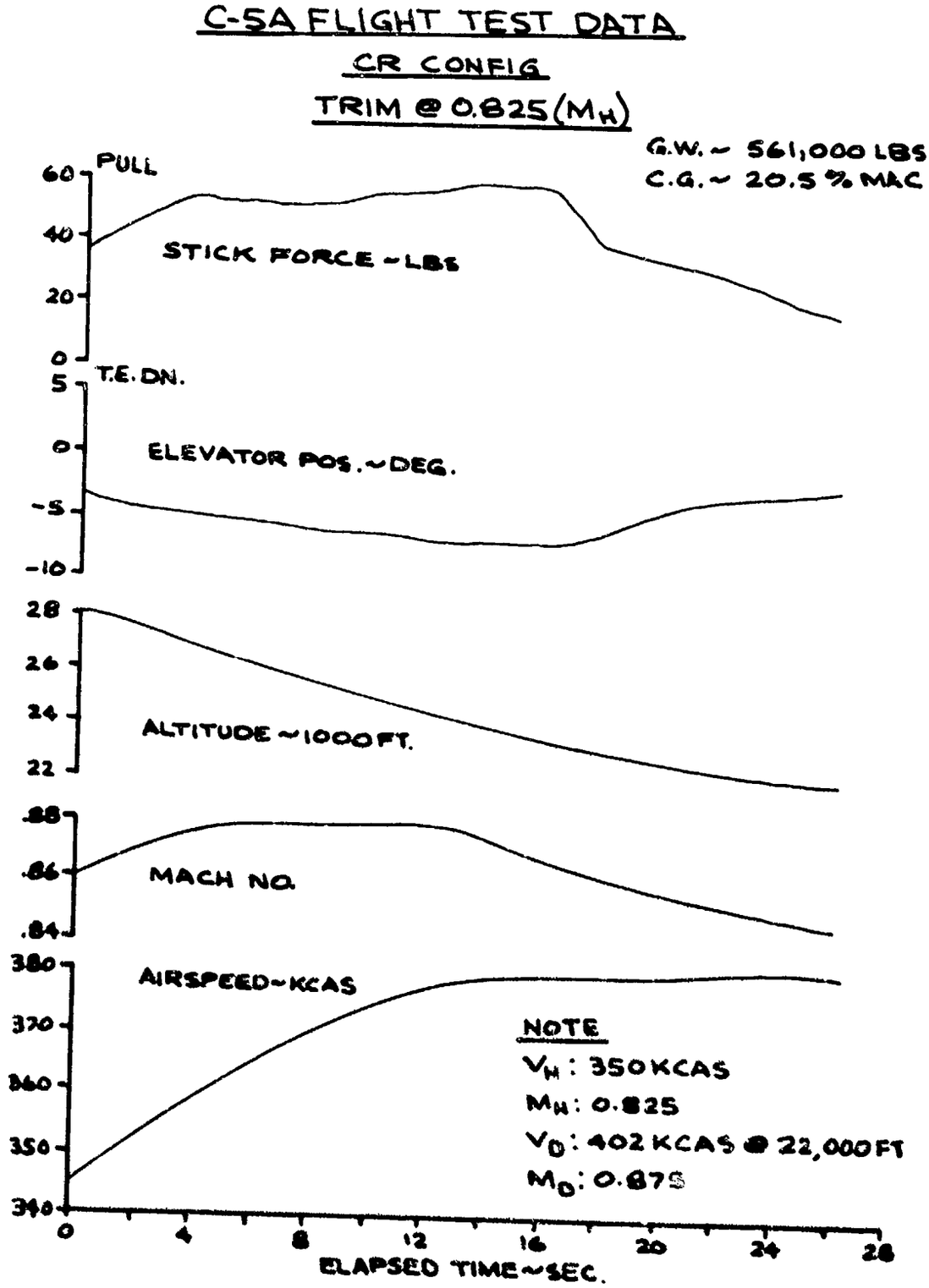


FIGURE NO.6(3.2.3.1) DIVE CHARACTERISTICS

Requirement

3.2.3.2 Longitudinal Control in Maneuvering Flight. Within the Operational Flight Envelope, it shall be possible to develop, by use of the elevator control alone, the following ranges of load factors:

Levels 1 and 2 ---- $n_o(-)$ to $n_o(+)$

Level 3 ---------- $n = 0.5g$ to the lower of:

a) $n_o(+)$

b) $n = \begin{cases} 2.0 \text{ for } n_o(+) \leq 3g \\ 0.5[n_o(+) + 1] \text{ for } n_o(+) > 3g \end{cases}$

This maneuvering capability is required at the 1g trim speed and, with trim and throttle settings not changed by the crew, over a range about the trim speed the lesser of ±15 percent or ±50 knots equivalent airspeed (except where limited by the boundaries of the Operational Flight Envelope). Within the Service and Permissible Flight Envelopes, the dive-recovery requirements of 3.2.3.5 and 3.2.3.6, respectively, shall be met.

Comparison

Specific tests to satisfy this requirement were not conducted on the C-5A; however, there are sufficient data available from maneuvering flight, static longitudinal and stall tests to show that the C-5A can comply with the Level 1 and 2 requirements. Figure 1(3.2.3.2) presents a summary of longitudinal maneuver capability showing the variation of lift coefficient versus Mach number for trim at 480,000 lb with the center of gravity at the forward limit and sea level. Based on test results these conditions are the most critical for accomplishing the required test. The Figure 1(3.2.3.2) data shows that the C-5A has sufficient longitudinal control to mistrim 50 kts and then maneuver to $n_{o_{max}}(2.0g)$ within the speed range of Mach numbers 0.29 to 0.600 (V_D @ S.L.). Below the speed condition 0.29 MN full up elevator restricts the attainment of 2.0g. At a Mach number condition of 0.25 MN, full up elevator will result in an acceleration value of 1.65g. These data, therefore, show that the C-5A could not completely comply with this requirement.

Discussion

Based on the information presented in Reference 3, the intent of this requirement is to ensure that control surface-fixed stability or longitudinal instability characteristics will not unduly limit maneuver capability. The intent of this requirement for a Class III airplane is understandable, although the conduct of this type test is not consistent with normal operation. For the conditions shown in Figure 1(3.2.3.2), approximately 25 percent of full up elevator with a corresponding pull force of about 30 pounds is necessary to

change the speed 50 knots at a trim speed of 0.35 Mach number. Imposing an additional maneuver requirement to 2.0g is not considered realistic for Class III operation. A more realistic requirement for Class III operation is the following which was applied to the C-5A design specification. "The elevator shall be capable of providing a load factor of 1.5 against the most adverse stabilizer trim position at the design dive speed."

Recommendation

It is recommended that for Class III type aircraft, the following requirement apply: "The elevator shall be capable of providing a load factor of 1.5 against the most adverse stabilizer trim position at the design dive speed."

C-5A FLIGHT TEST DATA

CR CONFIG

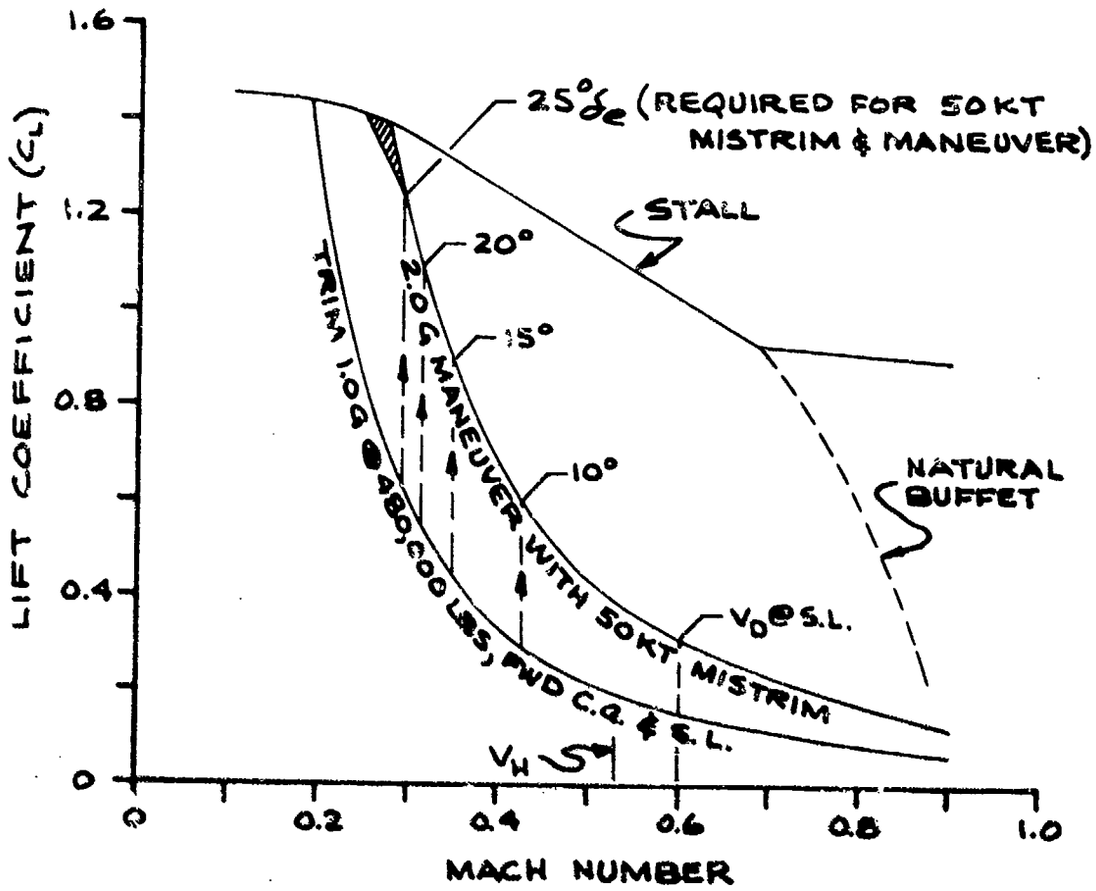


FIGURE NO.1(3.2.3.2) LONGITUDINAL MANEUVER CAPABILITY

Requirement

3.2.3.3 Longitudinal Control in Takeoff. The effectiveness of the elevator control shall not restrict the takeoff performance of the airplane and shall be sufficient to prevent over-rotation to undesirable attitudes during takeoffs. Satisfactory takeoffs shall not be dependent upon use of the trimmer control during takeoff or on complicated control manipulation by the pilot. For nose-wheel airplanes it shall be possible to obtain, at 0.9 V_{min}, the pitch attitude which will result in takeoff at V_{min}. For tail-wheel airplanes, it shall be possible to maintain any pitch attitude up to that for a level thrust-line at 0.5 V_S for Class I airplanes at at V_S for Class II, III, and IV airplanes. These requirements shall be met on hard-surfaced runways. In the event that an airplane has a mission requirement for operation from unprepared fields, these requirements shall be met on such fields.

Comparison

C-5A data used for comparison with this requirement were obtained from airplane performance tests. For the C-5A, the establishment of rotation and lift-off speeds was based on attaining 1.2 V_S at the 50 ft obstacle point with three engines operating. For the four-engine case the obstacle clearance speed is slightly in excess of 1.2 V_S at heavy gross weight conditions. C-5A rotation and lift-off speeds were established at various gross weight conditions so that the proper obstacle clearance speed would be attained without violating other performance limitations such as $V_{MC_{AIR}}$ or pitch attitude as limited by the maximum ground angle to prevent dragging the aft fuselage. Table 9 summarizes the four-engine rotation and lift-off speeds in percent stall speed. These data are independent of center of gravity position.

Table 9. C-5A Rotation and Lift-Off Speed Summary

Gross Weight (lbs.)	V Rotation	V Lift-Off
	(Percent Stall Speed)	
360,000	1.07	1.19
400,000	1.09	1.19
440,000	1.10	1.20
480,000	1.11	1.20
520,000	1.11	1.21
560,000	1.12	1.21
600,000	1.13	1.21
640,000	1.14	1.22
680,000	1.15	1.23
720,000	1.15	1.23

A typical takeoff run is presented in Figures 1a(3.2.3.3), 1b(3.2.3.3), and 1c(3.2.3.3) which show that the lift-off attitude is approximately 8.0 degrees nose up. Maximum

allowable is about 10 degrees. The requirement states that this attitude (8.0 degrees) should be attained at 0.9 V_{min} which corresponds to V_S according to paragraph 3.1.8.2. Although, Table I of MIL-F-8785B(ASG) states that $V_{o_{min}}$ is "Minimum Normal Takeoff Speed." The requirements of 3.2.3.3 would be vague and meaningless for a Class III airplane if V_{min} definition is "minimum normal takeoff speed." Assuming that V_{min} definition is according to paragraph 3.1.8.2, rotation would have to be initiated at approximately 0.9 V_S. At 0.9 V_S in the takeoff configuration, the attitude would be about 14 degrees which is in excess of the maximum allowable ground angle. Based on the definition of V_{min} given in paragraph 3.1.8.2e, it appears that the C-5A complies with the intent of this requirement.

Discussion

Compliance with this paragraph is based on the definition of V_{min} which is not clearly defined. For a Class III airplane the requirement should be relative to a reasonable takeoff absue from flight test established rotation speeds.

Recommendations

It is recommended that the third sentence, "For nose-wheel airplanes ...," be replaced with the following:

> For nose-wheel airplanes it shall be possible to rotate at published V_R speed minus 5 knots without exceeding the published obstacle clearance speed. For multi-engine airplanes this requirement shall be met with an engine failed at the critical engine failure speed.

C-5A FLIGHT TEST DATA

BASIC PARAMETERS

GROSS WEIGHT: 728150 LB
C.G.: 23.36 % MAC
FLAPS: 25 DEG.
STABILIZER: 6.7° A/C N.UP
FAT: 8.6 °C

AVG. EPR: 5.15
CROSS WIND: N/A
V_c @ LIFT-OFF: 157.0 KT.
SAS: OFF
PACS: ON

SH. 1 OF 3

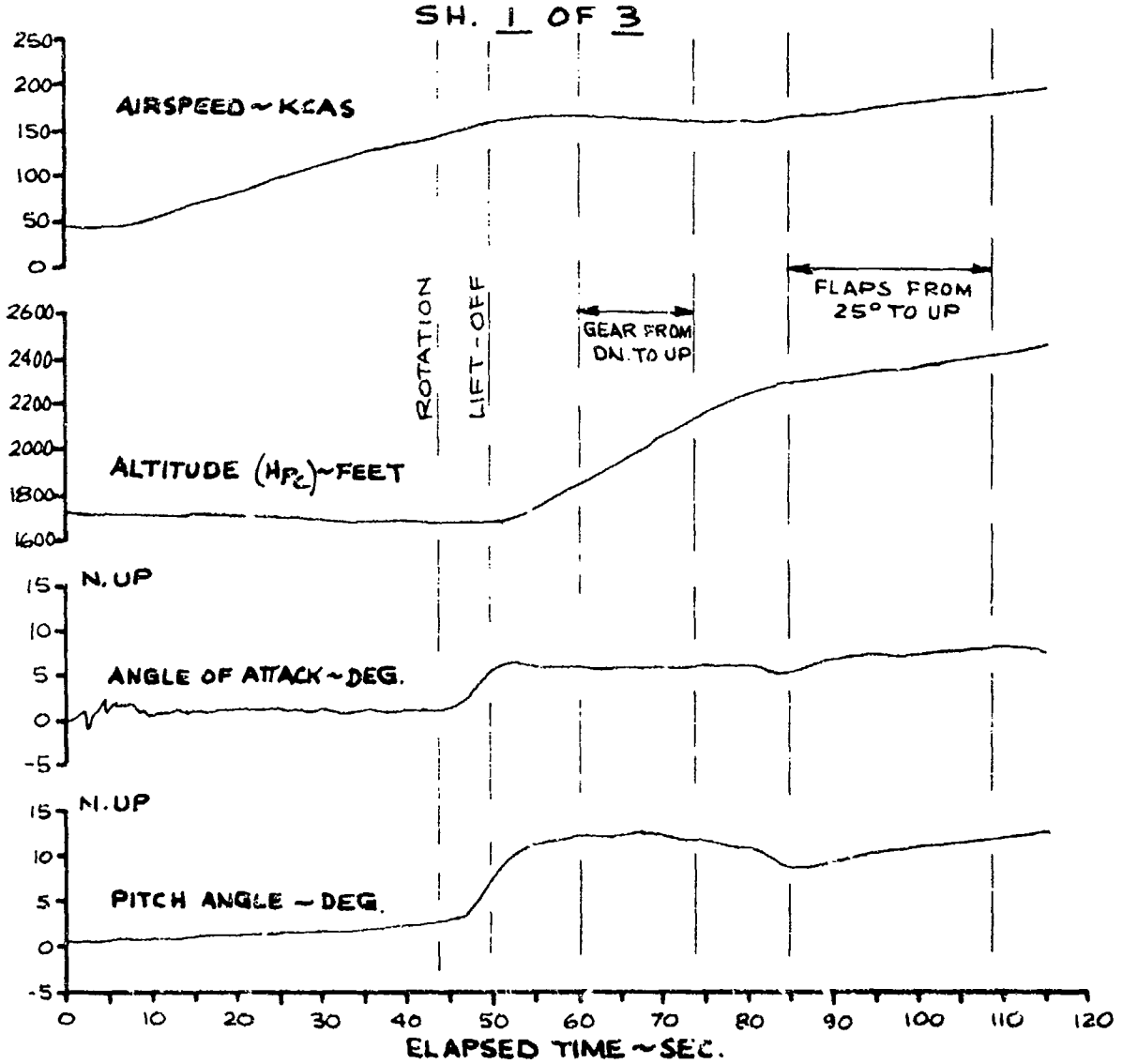


FIGURE NO. 1a (3.2.3.3) TAKE-OFF ASSESSMENT

C-5A FLIGHT TEST DATA

BASIC PARAMETERS

GROSS WEIGHT: 728150 LB
C.G.: 23.36 % MAC
FLAPS: 25 DEG.
STABILIZER: 6.7° A/C N.UP
FAT: 8.6 °C

AVG. EPR: 5.15
CROSS WIND: N/A
Vc @ LIFT-OFF: 157.0 KT.
SAS: OFF
PACS: ON

SH. 2 OF 3

(LONG. ACCEL. ~ N/A)

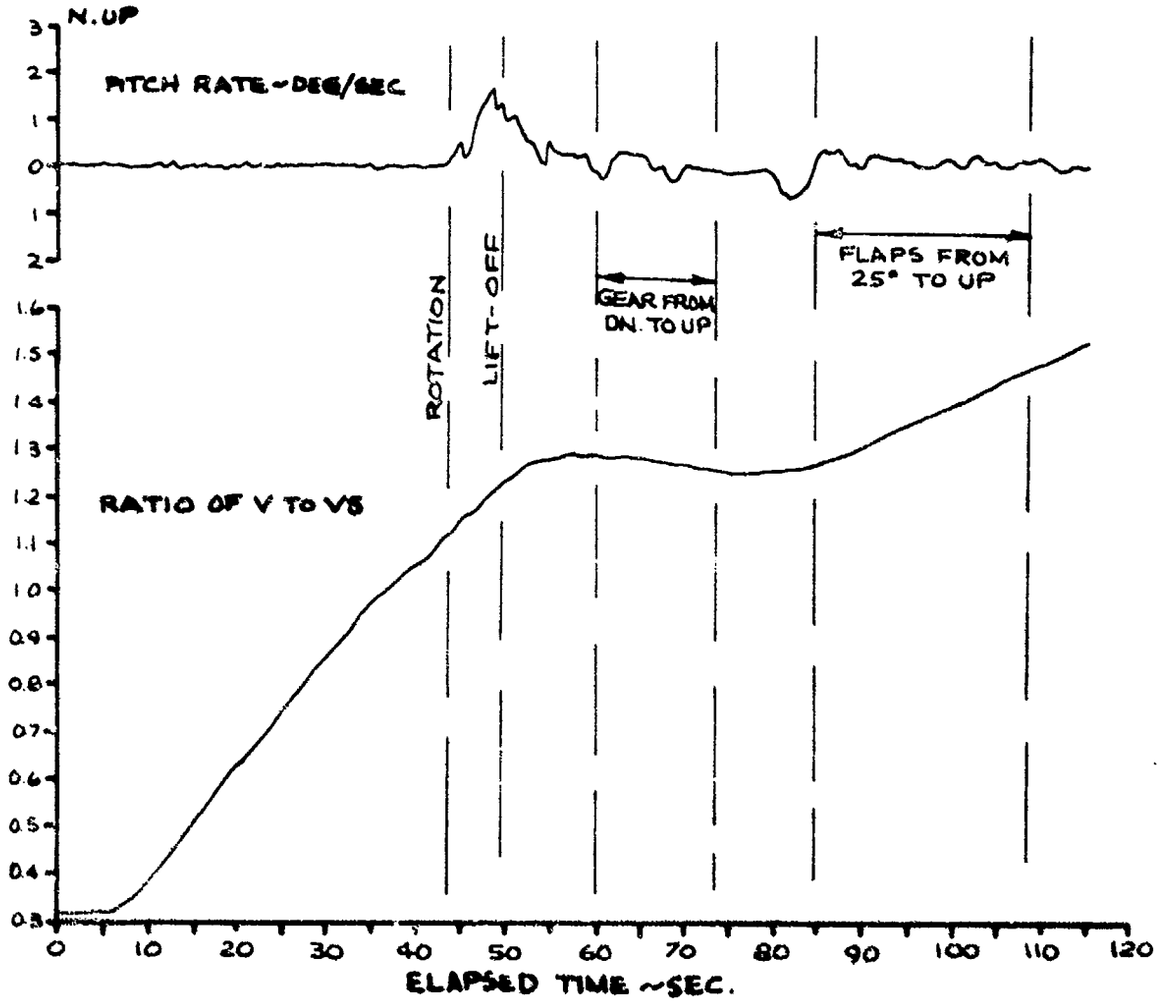


FIGURE NO. 16 (3.2.3.3) TAKE-OFF ASSESSMENT

C-5A FLIGHT TEST DATA

LONGITUDINAL CONTROL

GROSS WEIGHT: 728150 LB
C.G.: 23.36% MAC
FLAPS: 25 DEG.
STABILIZER: 6.7° A/C N.UP
FAT: 8.6°C

AVG. EPR: 5.15
CROSS WIND: N/A
V_c @ LIFT-OFF: 157.0 KT
SAS: OFF
PACS: ON

SH. 3 OF 3

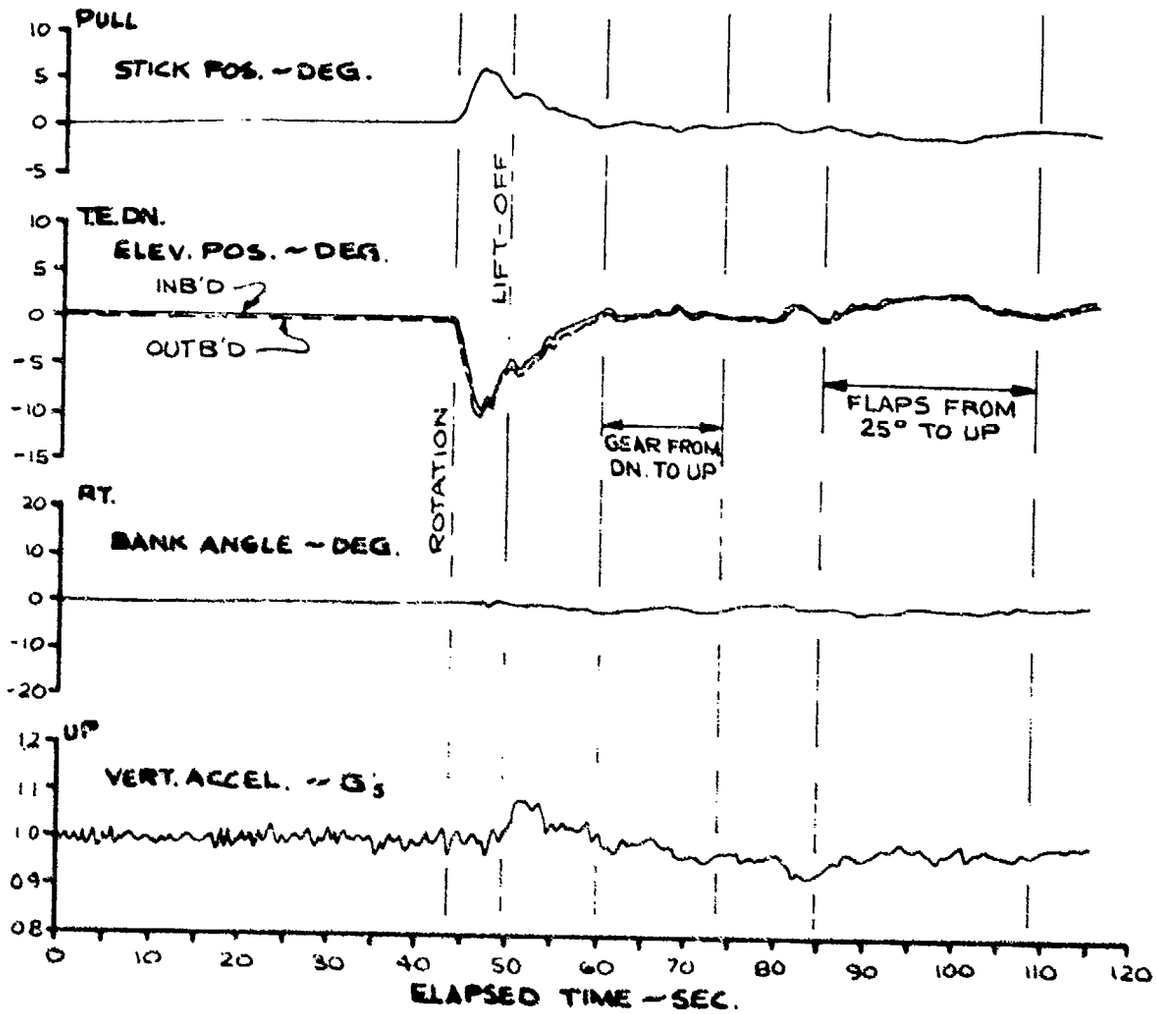


FIGURE NO. 1c (3.2.3.3) TAKE-OFF ASSESSMENT

Requirement

3.2.3.3.1 Longitudinal Control in Catapult Takeoff - On airplanes designed for catapult takeoff, the effectiveness of the elevator control shall be sufficient to prevent the airplane from pitching up or down to undesirable attitudes in catapult takeoffs at speeds ranging from the minimum safe launching speed to a launching speed 30 knots higher than the minimum. Satisfactory catapult takeoffs shall not depend upon complicated control manipulation by the pilot.

Comparison

None. Not applicable to the C-5A.

Discussion

None

Recommendation

None

Requirement

3.2.3.3.2 Longitudinal Control Force and Travel in Takeoff - With the trim setting optional but fixed, the elevator-control forces required during all types of takeoffs for which the airplane is designed, including short-field takeoffs and assisted takeoffs such as catapult or rocket-augmented, shall be within the following limits:

Nose-Wheel and Bicycle-Gear Airplanes

Classes I, IV-C ---------- 20 pounds pull to 10 pounds push

Classes II-C, IV-L ---------- 30 pounds pull to 10 pounds push

Classes II-L, III ---------- 50 pounds pull to 20 pounds push

Tail-Wheel Airplanes

Classes I, II-C, IV ---------- 20 pounds push to 10 pounds pull

Classes II-L, III ---------- 35 pounds push to 15 pounds pull

The elevator-control travel during these takeoffs shall not exceed 75 percent of the total travel, stop-to-stop. For purposes of this requirement, the term takeoff includes the ground run, rotation and lift-off, the ensuring acceleration to V_{max} (TO), and the transient caused by assist cessation. Takeoff power shall be maintained until V_{max} (TO) is reached, with the landing gear and high-lift devices retracted in the normal manner at speeds from Vo_{min} (TO) to V_{max} (TO)

Comparison

The C-5A test data used for comparison with this requirement are presented in Figures 1(3.2.3.3) through 12(3 2.3.3) along with Figures 1(3 2.3 3.2) and 2(3.2.3.3.2). Elevator control force was not recorded on the time history plots presented in Figures 1(3.2.3.3) through 12(3.2.3.3) but control column position and elevator position was recorded. With these data, along with the results of ground control cycle tests presented in Figures 1(3.2.3.3.2) and 2(3.2.3.3.2), elevator control force can be determined at any point during the takeoff run. These data show that the maximum elevator control force encounter during any of the takeoff runs presented in Figures 1(3.2.3.3) through 12(3.2 3.3) was approximately 35 pounds pull and 15 pounds push which comply with the 50 pounds pull and 20 pounds push requirement of this section. In addition, these data also show compliance with the requirement that the control travel should not exceed the 75 percent total travel limit. The C-5A favorably compares with this requirement.

Discussion

None

Recommendation

None

C-5A FLIGHT TEST DATA

PACS ON ~ WITH INCREASING STICK FORCE

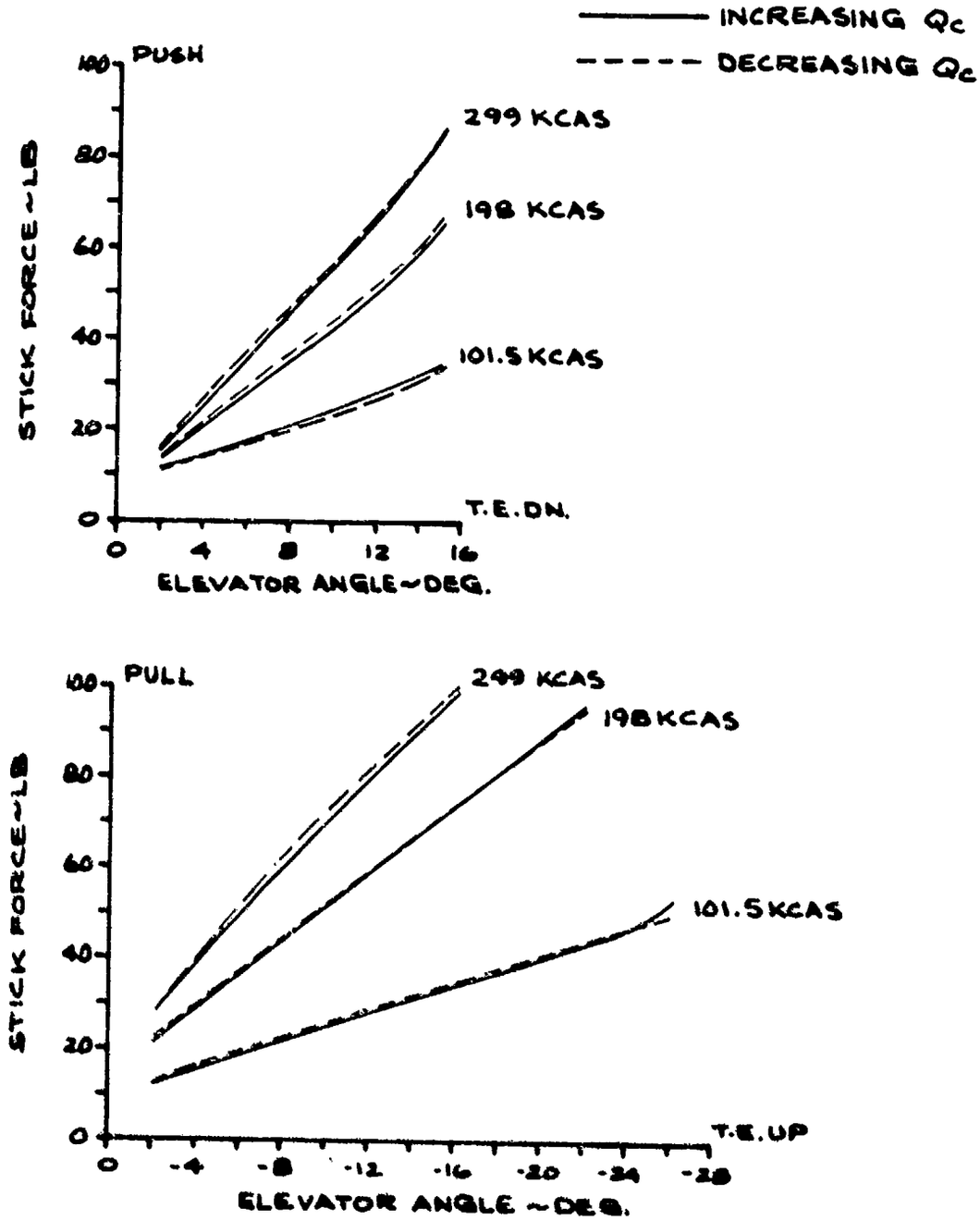


FIGURE NO. 1 (3.2.3.3.2) LONGITUDINAL FEEL SYSTEM

C-5A FLIGHT TEST DATA

T.E. UP δ_e INCREASING FORCE
PACS ON

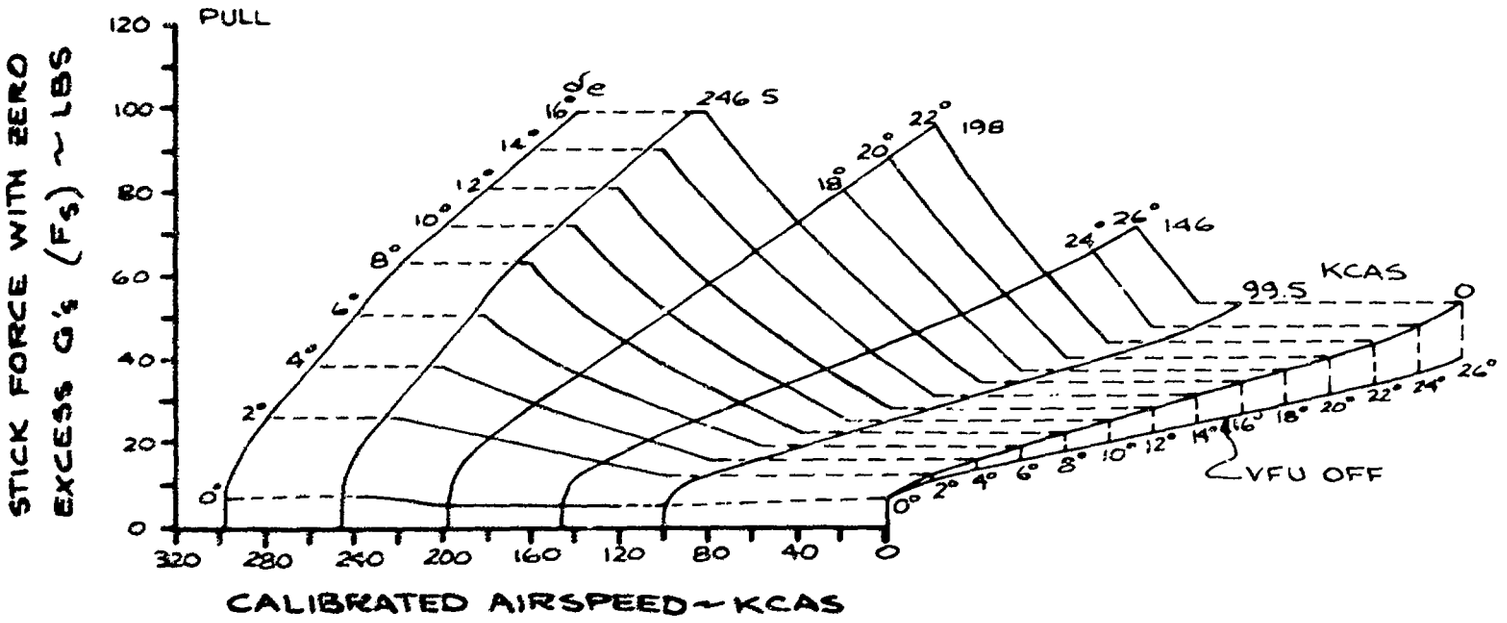


FIGURE NO.2 (3.2.3.3.2) LONGITUDINAL FEEL SYSTEM

Requirement

3.2.3.4 Longitudinal Control in Landing - The elev tor control shall be sufficiently effective in the landing flight phase in close proximity to the ground, that:

a. The geometry-limited touchdown attitude can be maintained in the level flight, or

b. The lower of V_S (L) or the guaranteed landing speed can be obtained.

This requirement shall be met with the airplane trimmed fro the approach flight phase at the recommended approach speed The requirements of 3.2.3.4 and 3.2.3.4.1 define Levels 1 and 2. For Level 3, it shall be possible to execute safe approaches and landings in the presence of atmospheric disturbances.

Comparison

Figures 1a(3.2.3.4) and 1b(3.2.3.4) present pertinent time data of a landing test conducted on the C-5A at a gross weight of 537,000 lb and a center of gravity position of 18 78% MAC. The airplane was trimmed at $1.3V_{SL}$, which is the handbook recommended approach speed, and the trim setting was not changed throughout the run. Touchdown was accomplished at $1.13V_{SL}$ with an attitude angle of 6.5 degrees nose up. The maximum allowable ground angle for the C-5A is 7.4 degrees. The data show that approximately 15 degrees trailing edge up elevator (full travel 25 degrees) was required at touchdown. These data, therefore, compare favorably with the Level 1 requirement.

Relative to Level 2 requirements, two landings were made on the C-5A with the Number 2 hydraulic system deactivated which reduces the available hinge moment capability to about half on the inboard elevators, one-third on the outboard elevators and to about half on the lower rudder. Time history plots of these tests are presented in Reference 2.

The first landing was made at heavy weight and forward c.g. with an actual hydraulic failure of the No. 2 system. A normal approach and landing was made. and a maximum elevator control force of 28 pounds occurred at touchdown. The second landing was made at medium weight and forward c.g. and with the aircraft trimmed at $1.4V_S$ in the PA configuration and not retrimmed thereafter. A maximum elevator control force of 37 pounds occurred at touchdown. With a simulated failure of the No. 2 hydraulic system, there was no noticeable degradation in control available during landing.

Relative to Level 3 conditions, simulated landing approaches were made with both the Number 2 and Number 3 hydraulic systems deactivated. Results of these tests are presented in Reference 2. The tests were performed at medium weight and forward c.g. With these two hydraulic systems inoperative, the inboard elevators were unpowered and consequently drooped to about 3 to 5 degrees, which reduced the available elevator power. Pitch

control was very limited, however, it was possible to maneuver and safely land the airplane provided that longitudinal trim was closely maintained and no large attitude changes were attempted. It was necessary to anticipate any trim change requirements including the nose-up trim change with the addition of power and lead this trim change with the stabilizer trim. It should also be noted that the lower rudder was unpowered, and even though the test indicated that a landing could be accomplished the directional control was limited.

Discussion

C-5A results agree with the requirements of this section.

Recommendation

None

C-5A FLIGHT TEST DATA

BASIC PARAMETERS

GROSS WEIGHT: 537000 LB
C.G.: 18.78% MAC
FLAPS: 40 DEG.
STABILIZER: 8.1° A/C N.UP
FAT: 30.1°C

AVG. EPR: 2.69
CROSS WIND: N/A
V_c @ TOUCH-DOWN: 122 KT.
SAS: ON
PACS: ON

SH. 1 OF 2

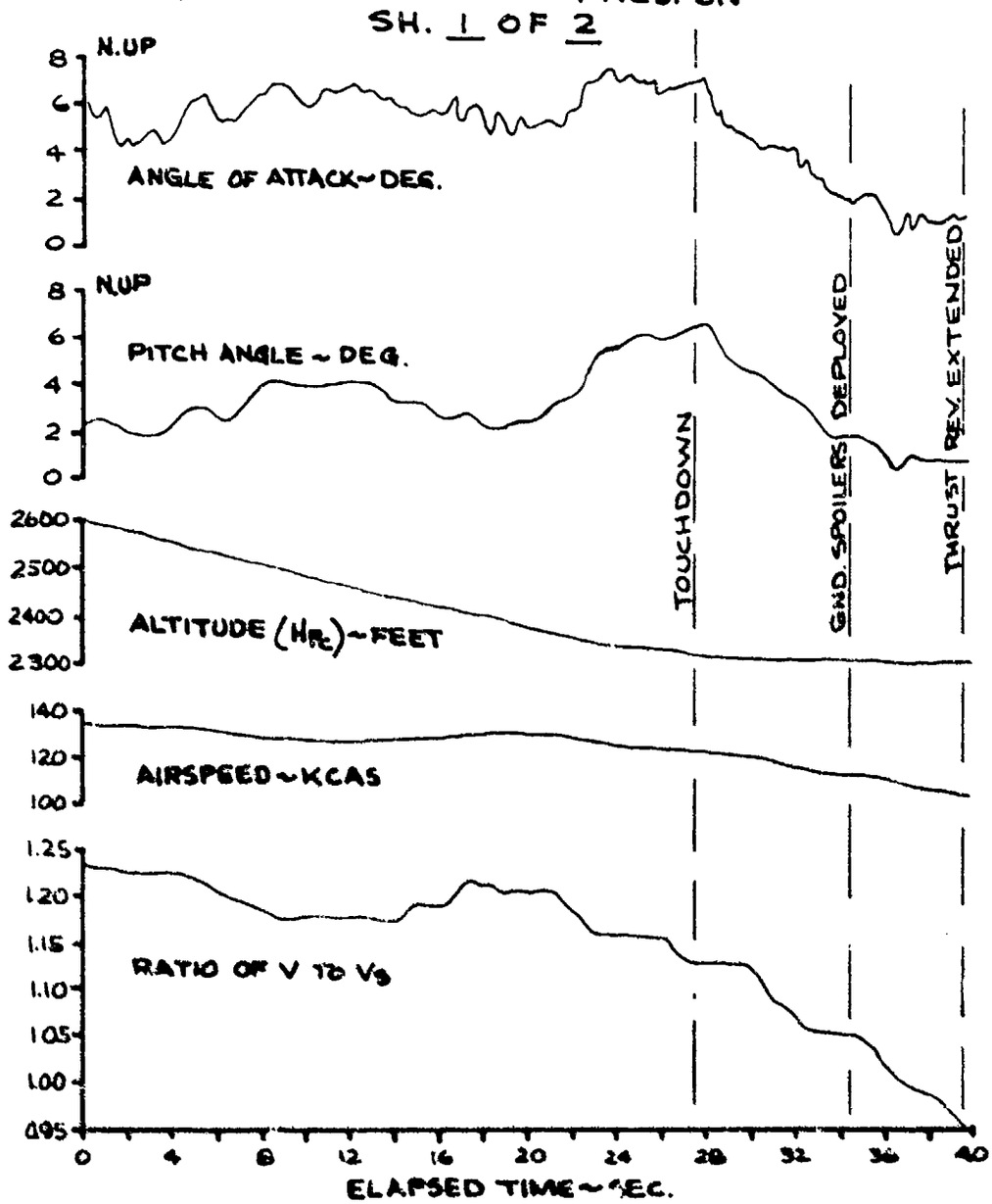


FIGURE NO. 1a (3.2.3.4) LANDING ASSESSMENT

C-5A FLIGHT TEST DATA

LONGITUDINAL CONTROL

GROSS WEIGHT: 537000 LB
C.G.: 18.78% MAC
FLAPS: 40 DEG.
STABILIZER: 8.1° A/C NUP
FAT: 30.1 °C

AVG. EPR: 2.69
CROSS WIND: N/A
V_C @ TOUCH-DOWN: 122 KT.
SAS: ON
PACS: ON

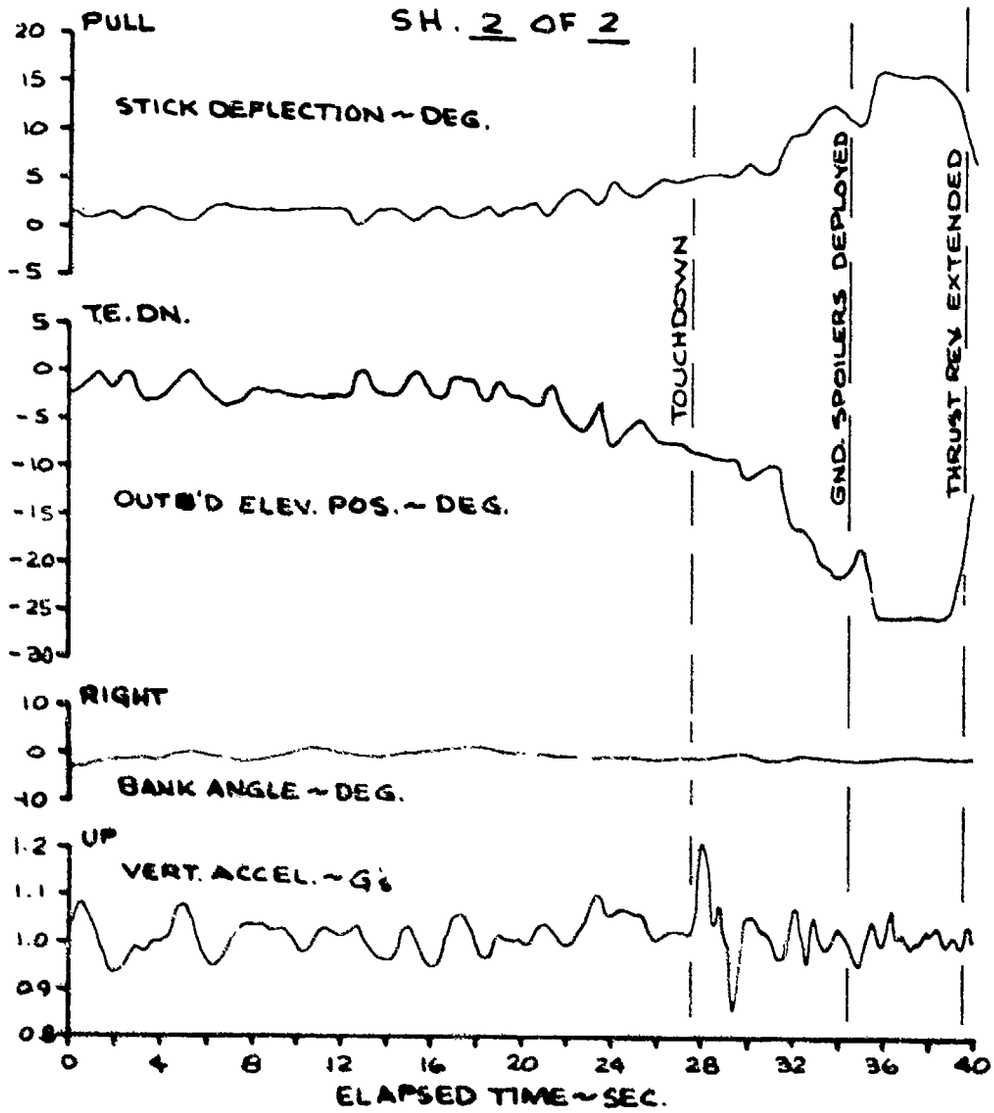


FIGURE NO. 1b (3.2.3.4) LANDING ASSESSMENT

Requirement

3.2.3.4.1 Longitudinal Control Forces in Landing. The elevator-control forces required to meet the requirements of 3.2.3.4 shall be pull forces and shall not exceed:

Classes I, II-C, IV ---------- 35 pounds

Classes II-L, III ---------- 50 pounds

Comparison

Data presented in Sections 3.2.3.3.2 and 3.2.3.4 are used for comparison with this requirement. Elevator control force was not presented with the time history plots of landing assessment results shown in Section 3.2.3.4. However, by use of the ground control cycle test results, presented in Section 3.2.3.3.2, elevator control forces were determined at various conditions throughout the landing run. These data show that approximately 35 pounds pull force was required during flare and about 50 pounds pull force was necessary just following extension of ground spoilers. The increase in control forces following main gear touchdown was due to the deployment of ground spoilers prior to nose wheel touchdown, which is an acceptable procedure for short field landings.

Discussion

C-5A test results support the requirements of this section.

Recommendation

None

Requirement

3.2.3.5 Longitudinal Control Forces in Dives - Service Flight Envelope. With the airplane trimmed for level flight at speeds throughout the Service Flight Envelope, the elevator control forces in dives to all attainable speeds within the Service Flight Envelope shall not exceed 50 pounds push or ten pounds pull for airplanes with center-stick controllers, nor 75 pounds push or 15 pounds pull for airplanes with wheel controllers. In similar dives, but with trim optional following the dive entry, it shall be possible with normal piloting techniques to maintain the forces within the limits of 10 pounds push or pull for airplanes with center-stick controllers, and 20 pounds push or pull for airplanes with wheel controllers. The forces required for recovery from these dives shall be in accordance with the gradients specified in 3.2.2.2.1 although speed may vary during the pullout.

Comparison

Results of a dive test conducted in the emergency descent configuration are used for comparison with the first portion of this requirement. These data are the only results which fall within the requirements for the service flight envelope specified in paragraph 3.1.8. The emergency descent configuration test was conducted through the altitude range of 35,000 feet to 10,000 feet. The airplane was trimmed at Mach 0.825 at 35,000 feet with normal rated thrust at a gross weight of 490,000 pounds with forward center-of-gravity. The power on engines 1 and 4 was reduced to flight idle, and the power on engines 2 and 3 was reduced to reverse idle. The trim setting was not altered during the dive and subsequent recovery at 10,000 feet. Figure 1(3.2.3.5) shows that the control forces did not exceed 20 pounds push or 12 pounds pull which comply with the maximum allowable of 75 pounds push or 15 pounds pull. No unusual control characteristics were encountered during the test.

Relative to the second portion of this requirement, which permits use of trim, dive tests were not conducted according to the specific requirements of this paragraph. Instead, the results of a dive test which was conducted at speeds in excess of the service flight envelope are used for comparison here. The test was conducted in the clean configuration to evaluate longitudinal trimmability at speeds up to V_D (permissible flight envelope). Gross weight was 571,000 pounds with the center of gravity at 19.2% MAC. Figure 2(3.2.3.5) presents the results of the dive and show that a speed of 404 KCAS was attained at 10,000 feet (V_D = 398 KCAS 10,000 ft). During the dive the airplane was trimmed at 403 KCAS where an elevator pulse was accomplished.

These data show that the trim system was capable of reducing all control forces to zero and that there were no unusual control characteristics at speeds up to V_D.

These C-5A dive test results, therefore, compare favorably with this requirement.

Discussion

For the emergency descent configuration, the service flight speed envelope is from 175 KCAS or shaker activation whichever is greater to 0 825 MN/350 KIAS. A literal interpretation of this requirement means that during a descent within the above speed range up until recovery is initiated, the control forces should be within 75 pounds push or 15 pounds pull. Lockheed's interpretation of this requirement has been that either Mach number or airspeed is held constant during a run, unless some limitation is reached, until recovery is initiated. MIL-F-8785B(ASG) has requirements concerning trim change, force gradients and static longitudinal stability. Consequently, there is no need for duplication. A speed range in terms of percent of initial trim should be specified.

Recommendation

Insert the following after the first sentence: "Speed variation during a dive should be consistent with handbook procedures; however, it need not exceed ±25% of initial trim."

C-5A FLIGHT TEST DATA

TRIM CONDITIONS:

GROSS WEIGHT: 490015 LB
C.G.: 19.94% MAC
FLAPS: UP
GEAR: UP
STABILIZER: 0.5° A/C N.UP
TCS: ON

FAT: -27.9°C
AVG. EPR: 5.6
AIRSPEED: 283 KCAS
ALTITUDE: 34530 FEET
MACH NO: 0.825
DYN. PRESS.: 241.4 PSF

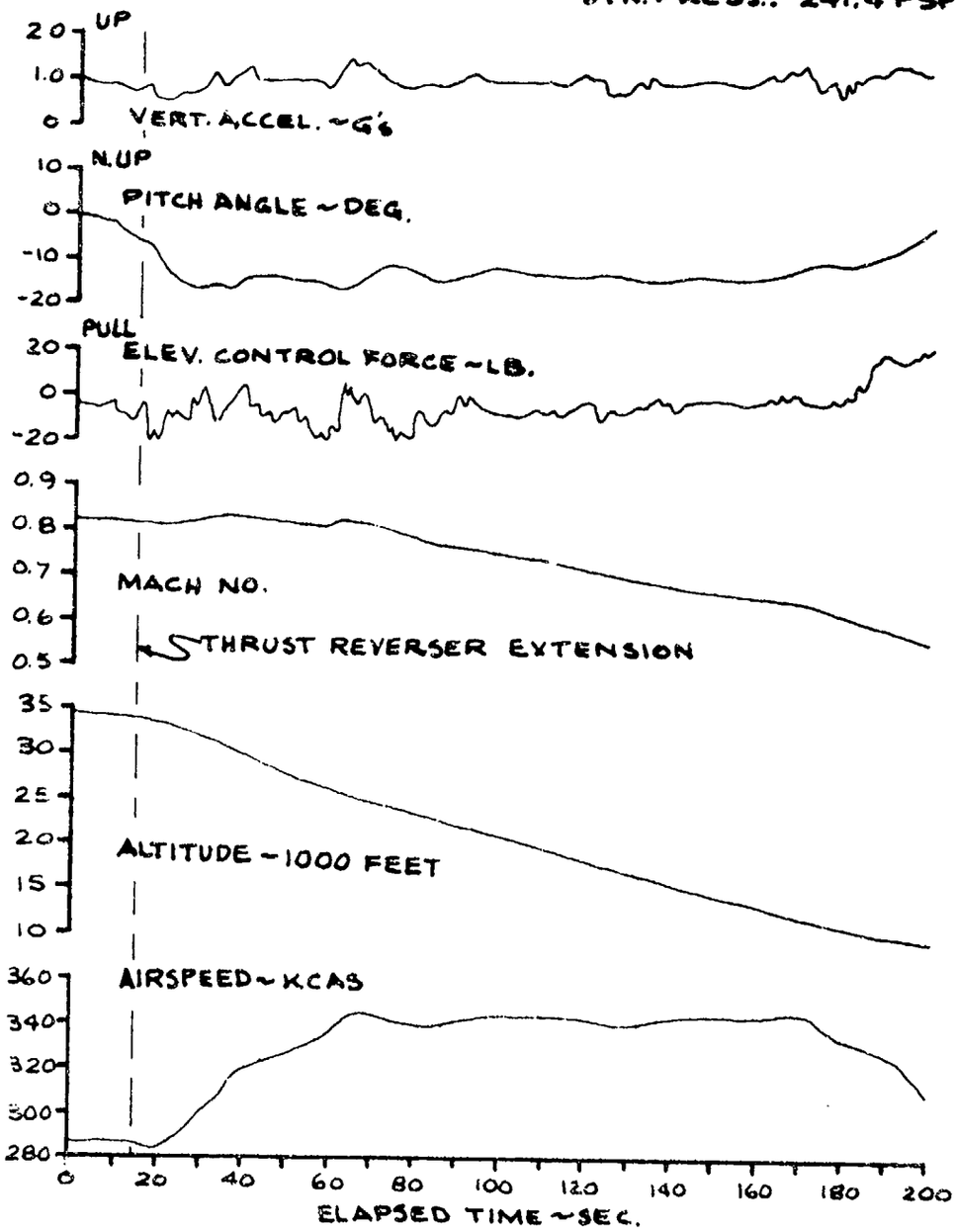


FIGURE NO. 1 (3.2.3.5) DESCENT CHARACTERISTICS

C-5A FLIGHT TEST DATA

V_D/M_D

TRIM CONDITIONS:
GROSS WEIGHT: 571,600 LB.
C.G.: 19.2% MAC
AIRSPEED: 405 KCAS
ALTITUDE: 10235 FEET
MACH NO.: 0.724
STABILIZER: 0.2° A/C N. UP
AVG. EPR: 4.4

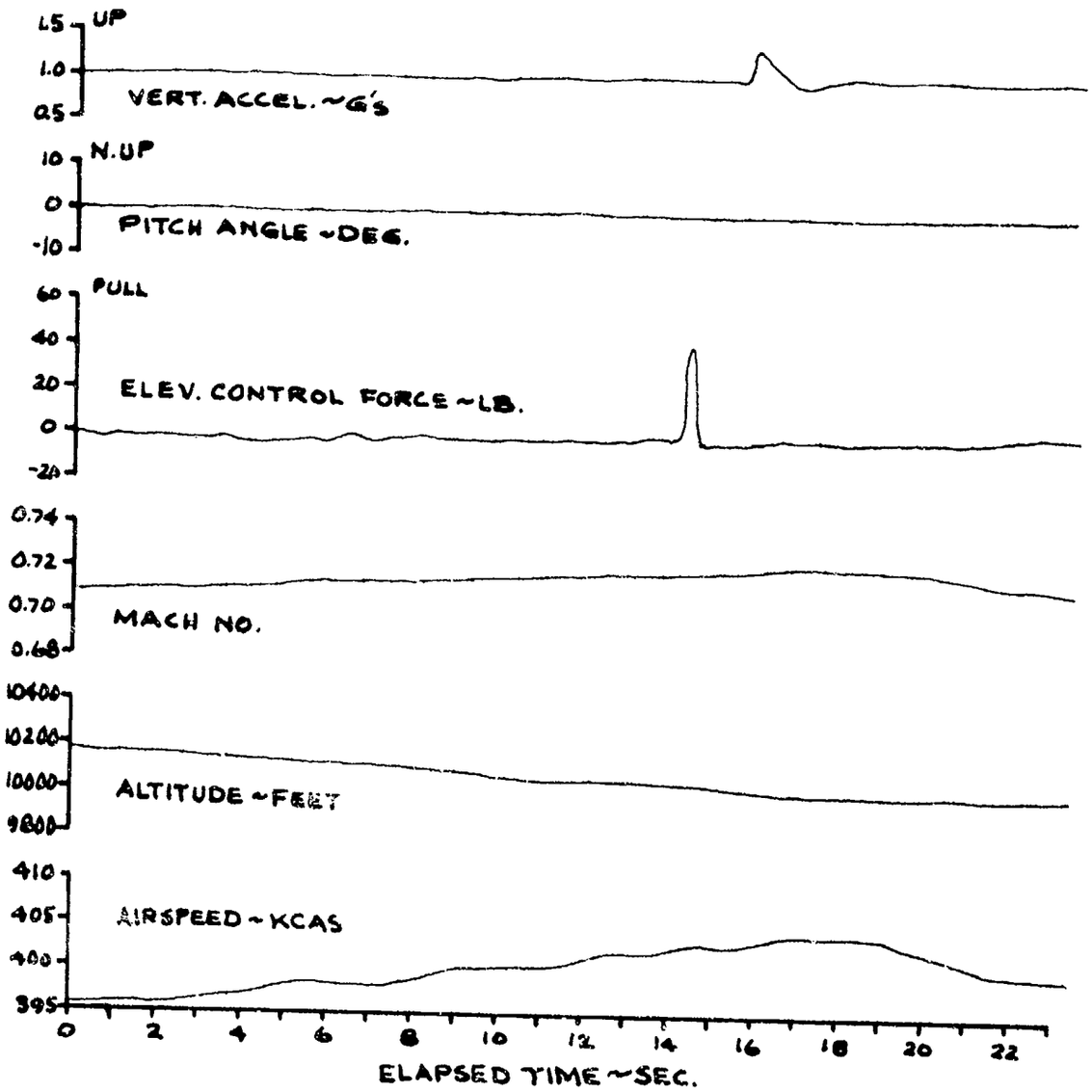


FIGURE NO. 2 (3.2.3.5) DIVE CHARACTERISTICS

Requirement

3.2.3.6 Longitudinal Control Forces in Dives - Permissible Flight Envelope. With the airplane trimmed for level flight at V_{MAT} but with trim optional in the dive, it shall be possible to maintain the elevator control force within the limits of 50 pounds push or 35 pounds pull in dives to all attainable speeds within the Permissible Flight Envelope. The force required for recovery from these dives shall not exceed 120 pounds. Trim and deceleration devices, etc., may be used to assist in recovery if no unusual pilot technique is required.

Comparison

Figures 1a(3.2.3.6) and 1b(3.2.3.6) present the results of a dive to Mach 0.875 at 30,000 feet and a subsequent recovery with the airplane trimmed initially at M_H (Mach 0.825). Thee data show that during the dive the control forces varied from zero at 0.825 M to 20 pounds push at 0.86M and during the recovery the control force reached a maximum of 60 pounds pull for an acceleration value of 1.80 g at 0.875M. These data, therefore, compare favorably with the requirements of this section.

Discussion

Results from tests conducted to satisfy the requirements of this section along with Section 3.2.3.5 are dependent upon the establishment of the service flight envelope and the permissible flight envelope. According to Paragraph 3.1.8.1, the contractor is provided the option of establishing a speed limitation between the operational flight envelope and the permissible flight envelope relative to maximum speeds. For some aircraft the maximum service speed and the maximum permissible speed may be the same, as in the case of the C-141A and the C-5A. When this occurs, the specification should provide some guidance as to which paragraph, 3.2.3.5 or 3.2.3.6, should be complied with. Tests for both paragraphs, in this case, should not have to be conducted.

Recommendation

Add the following note to either paragraph 3.2.3.5 or 3.2.3.6:

> When the maximum service speed and the maximum permissible speed envelopes are coincident, the trim operable tests defined in paragraph 3.2.3.5 need not be complied with.

C-5A FLIGHT TEST DATA

V_D/M_D

TRIM CONDITIONS:
GROSS WEIGHT: 534000 LB
C.G.: 18.7 % MAC
AIRSPEED: 297 KCAS
ALTITUDE: 32700 FEET
MACH NO.: 0.827
STABILIZER: 0.6° A/C N.UP
AVG. EPR: 5.4

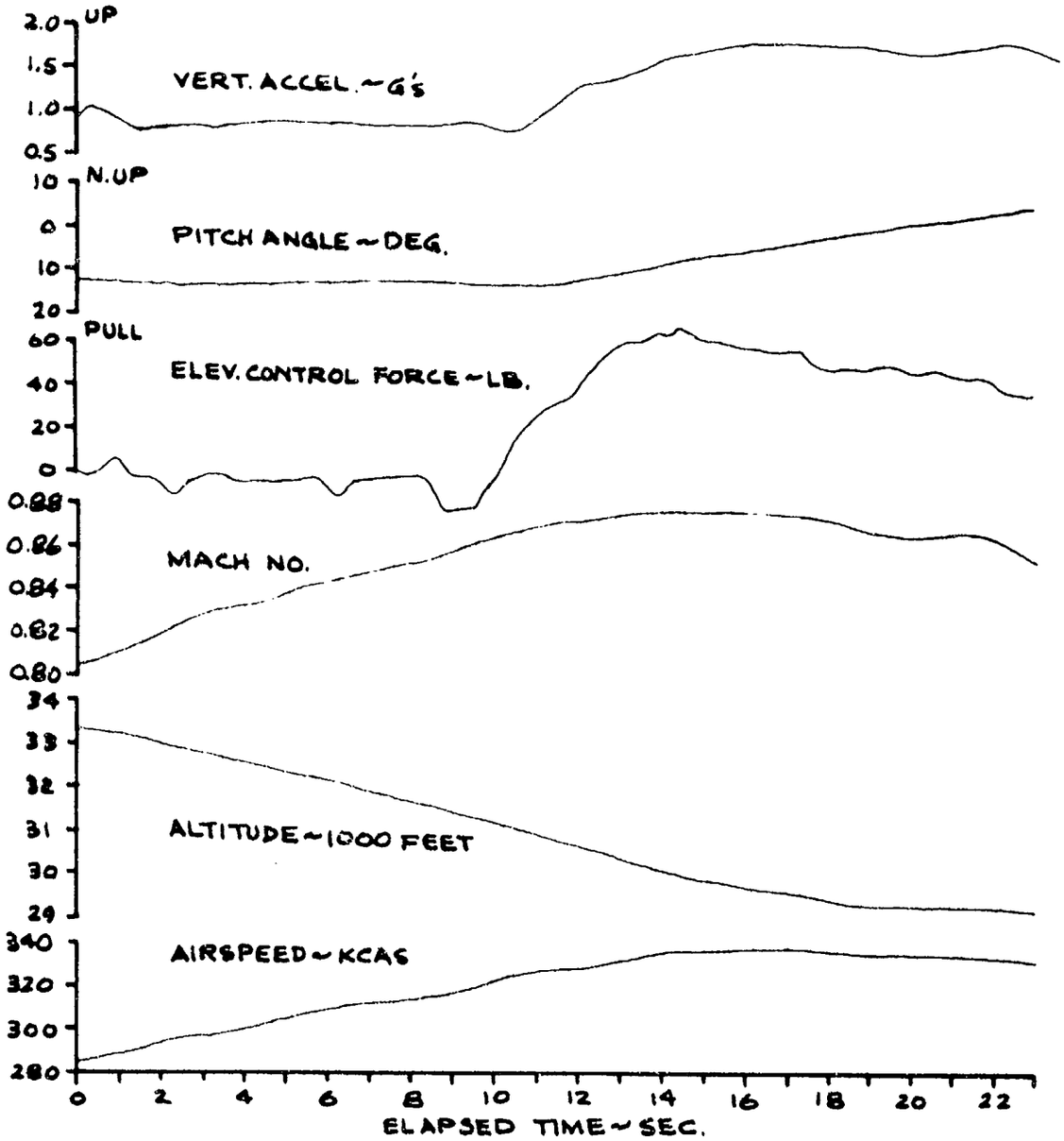


FIGURE NO. 1 (3.2.3.6) DIVE CHARACTERISTICS

Requirement

3.2.3.7 Longitudinal Control in Sideslips. With the airplane trimmed for straight, level flight with zero sideslip, the elevator-control force required to maintain constant speed in steady sideslips with up to 50 pounds of rudder pedal force in either direction shall not exceed the elevator-control force that would result in a 1g change in normal acceleration. In no case, however, shall the elevator-control force exceed:

Center-stick controllers --------- 10 pounds pull to 3 pounds push

Wheel controllers ---------- 15 pounds pull to 10 pounds push

If a variation of elevator-control force with sideslip does exist, it is preferred that increasing pull force accompany increasing sideslip, and that the magnitude and direction of the force change be similar for right and left sideslips These requirements define Levels 1 and 2. For Level 3, there shall be no uncontrollable pitching motions associated with the sideslips discussed above.

Comparison

Static lateral directional stability tests were conducted on the C-5A throughout the operational speed range in the landing, takeoff/approach, cruise, descent, and aerial delivery configurations. Results from these tests are discussed in Section 3.3.6 of this report As stated in Reference 2, "longitudinal trim changes during steady heading, constant airspeed sideslips were mild. Stick Forces were positive and less than 10 pounds in all cases." The C-5A elevator control force characteristics during sideslips, therefore, agree with this requirement.

Discussion

None

Recommendation

None

Requirement

3.3 Lateral-directional flying qualities

3.3.1 Lateral-directional mode characteristics

3.3.1.1 Lateral-directional oscillations (Dutch roll). The frequency, ω_{n_d}, and damping ration, ζ_d, of the lateral-directional oscillations following a rudder disturbance input shall exceed the minimums in table VI. The requirements shall be met with cockpit controls fixed and with them free, in oscillations of any magnitude that might be experienced in operational use. If the oscillation is nonlinear with amplitude, the requirement shall apply to each cycle of the oscillation. Residual oscillations may be tolerated only if the amplitude is sufficiently small that the motions are not objectionable and do not impair mission performance. For Category A Flight Phases, angular deviations shall be less than $\pm$ 3 mils. With the control surfaces fixed, ω_{n_d} shall always be greater than zero.

Table VI. Minimum Dutch Roll Frequency and Damping

Level	Flight Phase Category	Class	Min ζ_d	Min $\zeta_d\omega_{n_d}$,* rad/sec.	Min ω_{n_d}, rad/sec.
1	A	I, IV	0.19	0.35	1.0
		II, III	0.19	0.35	0.4 **
	B	All	0.08	0.15	0.4 **
	C	I, II-C, IV	0.08	0.15	1.0
		II-L, III	0.08	0.15	0.4 **
2	All	All	0.02	0.05	0.4 **
3	All	All	0.02	-	0.4 **

* The governing damping requirement is that yielding the larger value of ζ_d.

** Class III airplanes may be excepted from the minimum ω_{n_d} requirement, subject to approval by the procuring activity, if the requirements of 3.3.2 through 3.3.2.4.1, 3.3.5 and 3.3.9.4 are met.

When $\omega_{n_d}^2 |\phi/\beta|_d$ is greater than 20 (rad/sec)^2, the minimum $\zeta_d\omega_{n_d}$ shall be increased above the $\zeta_d\omega_{n_d}$ minimums listed above by:

$$\text{Level 1} - \Delta\zeta_d\omega_{n_d} = .014\,(\omega_{n_d}^2 |\phi/\beta|_d - 20)$$

$$\text{Level 2} - \Delta\zeta_d\omega_{n_d} = .009\,(\omega_{n_d}^2 |\phi/\beta|_d - 20)$$

$$\text{Level 3} - \Delta\zeta_d\omega_{n_d} = .005\,(\omega_{n_d}^2 |\phi/\beta|_d - 20)$$

with ω_{n_d} in rad/sec.

Comparison

Dynamic lateral-directional stability tests were conducted on the C-5A throughout the operational speed-altitude envelope with the center of gravity at the aft limit (41% MAC). These tests were conducted by exciting the Dutch roll frequency by rudder doublets with the stability augmentation system off. After exciting the basic airplane mode, the SAS was turned on in an attempt to determine the SAS effect on damping. Some representative time history plots are presented in Figures 1(3.3.1) through 8(3.3.1) and show that the effect of SAS operation is to suppress basic airplane modes. These data, therefore, show that the C-5A agree with the Level 1 requirements for flight phase categories B and C. For the C-5A, flight phases for Category A are the same as for Category B. Consequently, requirements for Category A are also in agreement with C-5A results. With respect to the requirement that the angular deviations shall be less than ± 3 mils for the Category A flight phase, instrumentation accuracy limitations prevent complete substantiation of this requirement. Figure 9(3.3.1) summarizes test results obtained with the SAS inoperative which are applicable to the Level 2 requirements. These data show that the minimum damping requirement of 0.02 and the minimum undamped natural frequency requirement of 0.40 are complied with, although the minimum product ($\omega_{n_d}\zeta_d$) requirement of 0.05 is not met. Test results presented in reference 2 show that operation with SAS off does not present any operational problems due mainly to the fact that the period (10 seconds) is sufficiently long. Table 10 tabulates plotted SAS inoperative test data.

Discussion

Based on the Category I/II test results which are discussed above, the C-5A flight manual (T O. 1C-5A-1) does not restrict operation with the SAS inoperative. In addition, evaluating pilots do not rate operation with the SAS inoperative below Level 2 suggested guide lines (.65 Harper-Cooper scale). For these reasons, the Level 2 requirement that $\zeta_d\omega_{n_d}$ be no less than 0.05 appears to be too stringent.

Recommendation

It is recommended that additional Class III airplane data be obtained to substantiate the Level 2 requirement of minimum $\zeta_d\omega_{n_d}$ value of 0.05.

Table 10. Dynamic Lateral Directional Stability Summary
SAS Inoperative

CONFIGURATION	WEIGHT (Lbs)	ALTITUDE (Ft)	C_L	ζ	PERIOD (Sec)	$1/C_{1/2}$	ω_{n_d} (Rad/Sec)
(CR)	HEAVY	10,000	.81	.10	10.4	0.90	.601
(CR)	HEAVY	10,000	.28	.13	7.8	1.17	.793
(CR)	HEAVY	26,000	.43	.055	8.5	0.50	.732
(CR)	HEAVY	26,000	.245	.110	6.5	1.0	.954
(CR)	HEAVY	26,000	.73	.03	10.0	.25	.624
(CR)	LIGHT	10,000	.20	.195	6.8	1.8	.899
(CR)	LIGHT	25,000	.73	.080	10.2	.75	.610
(CR)	LIGHT	25,000	.205	.12	6.0	1.05	1.03
(CR)	LIGHT	35,000	.73	.030	11.0	.30	.567
(CR)	LIGHT	35,000	.32	.10	7.0	.90	.885
(D)	HEAVY	10,000	.58	.155	10.0	1.45	.616
(D)	HEAVY	26,000	.55	.05	10.0	.50	.623
(L)	HEAVY	10,000	.89	.14	8.5	1.25	.726
(L)	HEAVY	10,000	1.56	.10	10.0	.94	.621
(L)	HEAVY	10,000	1.72	.10	10.5	.90	.591
(L)	LIGHT	10,000	1.35	.095	9.0	.85	.689
(L)	LIGHT	10,000	1.67	.105	8.0	.98	.775
(TO)	HEAVY	10,000	.78	.055	7.0	.50	.889
(TO)	HEAVY	10,000	1.49	.085	9.5	.75	.653
(TO)	MEDIUM	10,000	1.72	.110	10.2	.95	.608
(TO)	MEDIUM	10,000	1.035	.055	8.5	.50	.732
(TO)	MEDIUM	10,000	1.53	.09	9.0	.80	.690
(TO)	MEDIUM	10,000	1.53	.105	11.0	.95	.563

C-5A FLIGHT TEST DATA

CR CONFIG.

AIRSPEED: 231 KCAS
ALTITUDE: 35,910 FT
G.W.: 475,050 LB
C.G.: 40.7 % MAC
M: 0.70

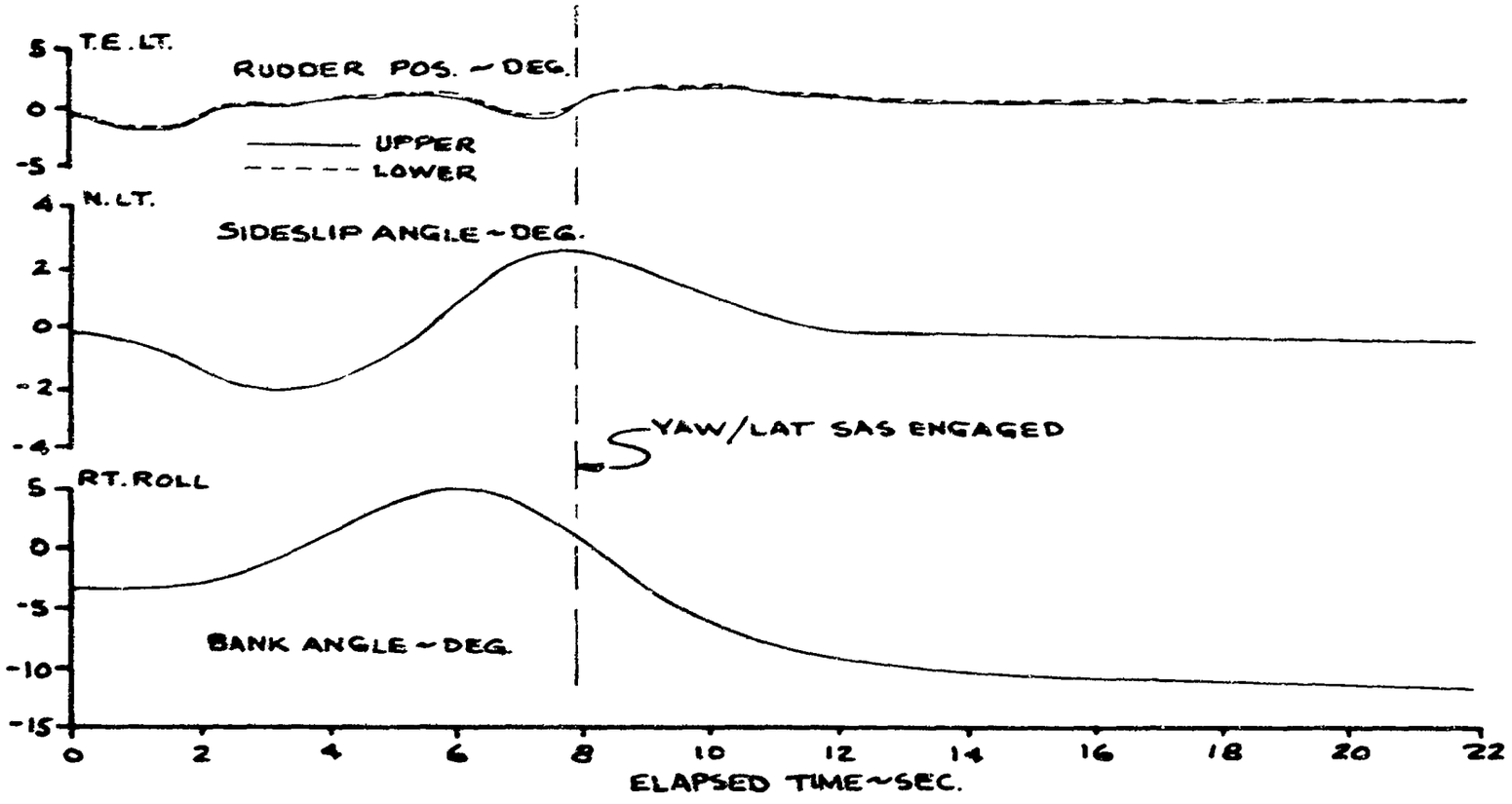


FIGURE NO. 1 (3.3.1) DYNAMIC LAT-DIR STABILITY

C-5A FLIGHT TEST DATA

CR CONFIG.

AIRSPEED: 207 KCAS
ALTITUDE: 8300 FT.
G.W.: 712,350 LB.
C.G.: 40.9 % MAC

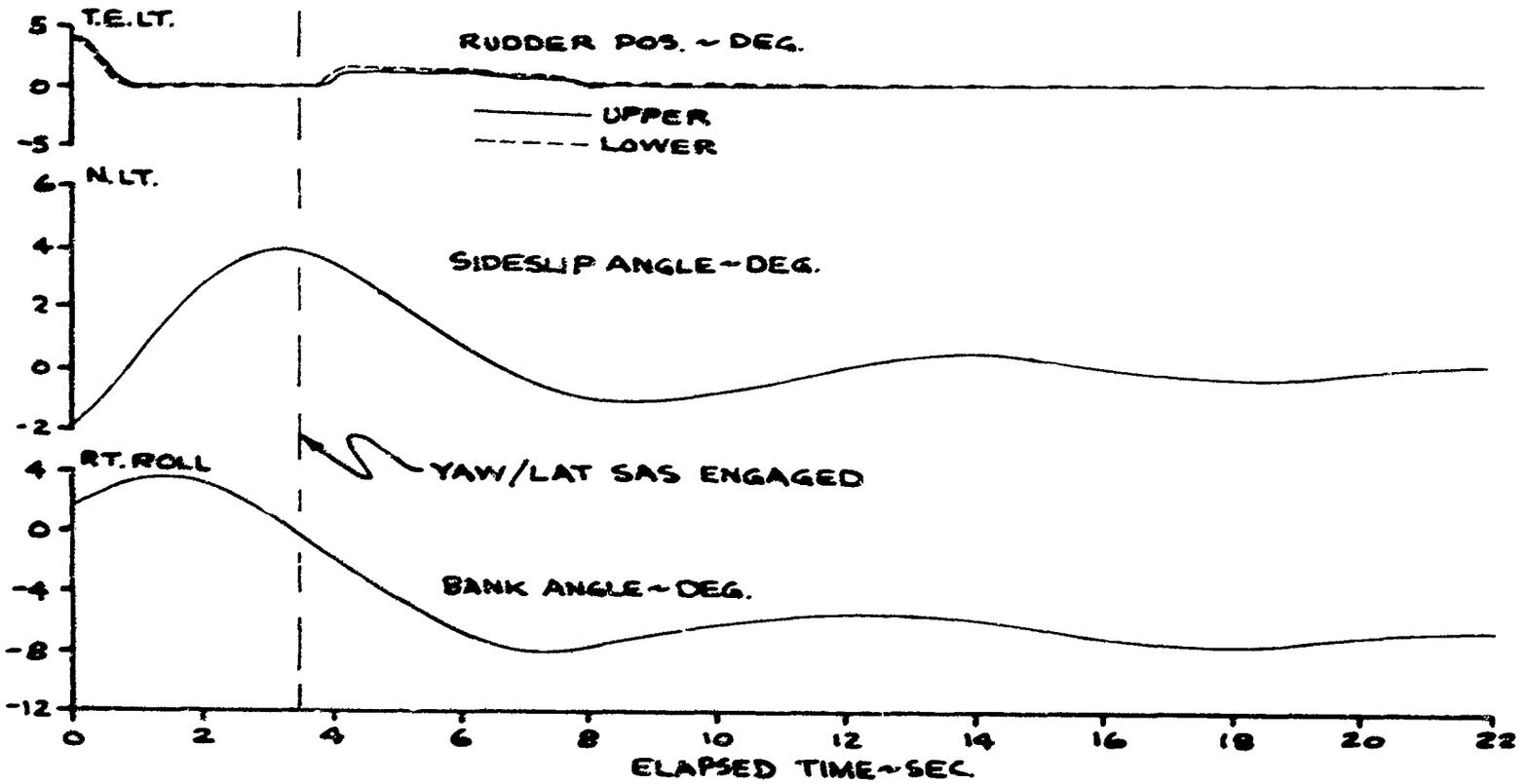


FIGURE NO. 3 (3.3.1) DYNAMIC LAT-DIR STABILITY

C-5A FLIGHT TEST DATA

CR CONFIG.

AIRSPEED: 355 KCAS
ALTITUDE: 11,450 FT.
G.W.: 710,550 LB
C.G.: 40.4% MAC

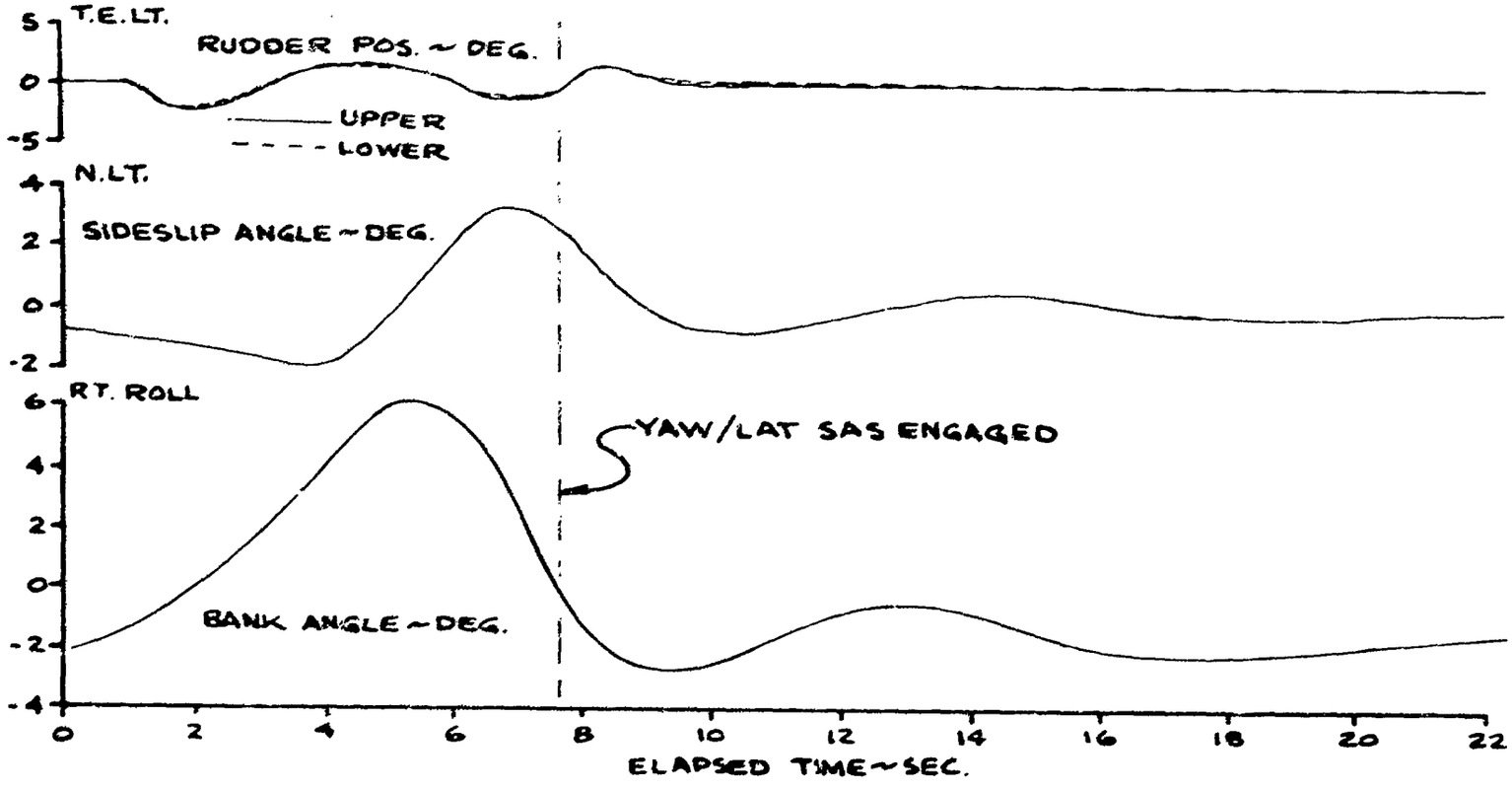


FIGURE NO. 2 (3.3.1) DYNAMIC LAT-DIR STABILITY

C-5A FLIGHT TEST DATA

T.O. CONFIG.

AIRSPEED: 151 KCAS
ALTITUDE: 10,360 FT.
G.W.: 697,000 LB.
C.G.: 40.9% MAC

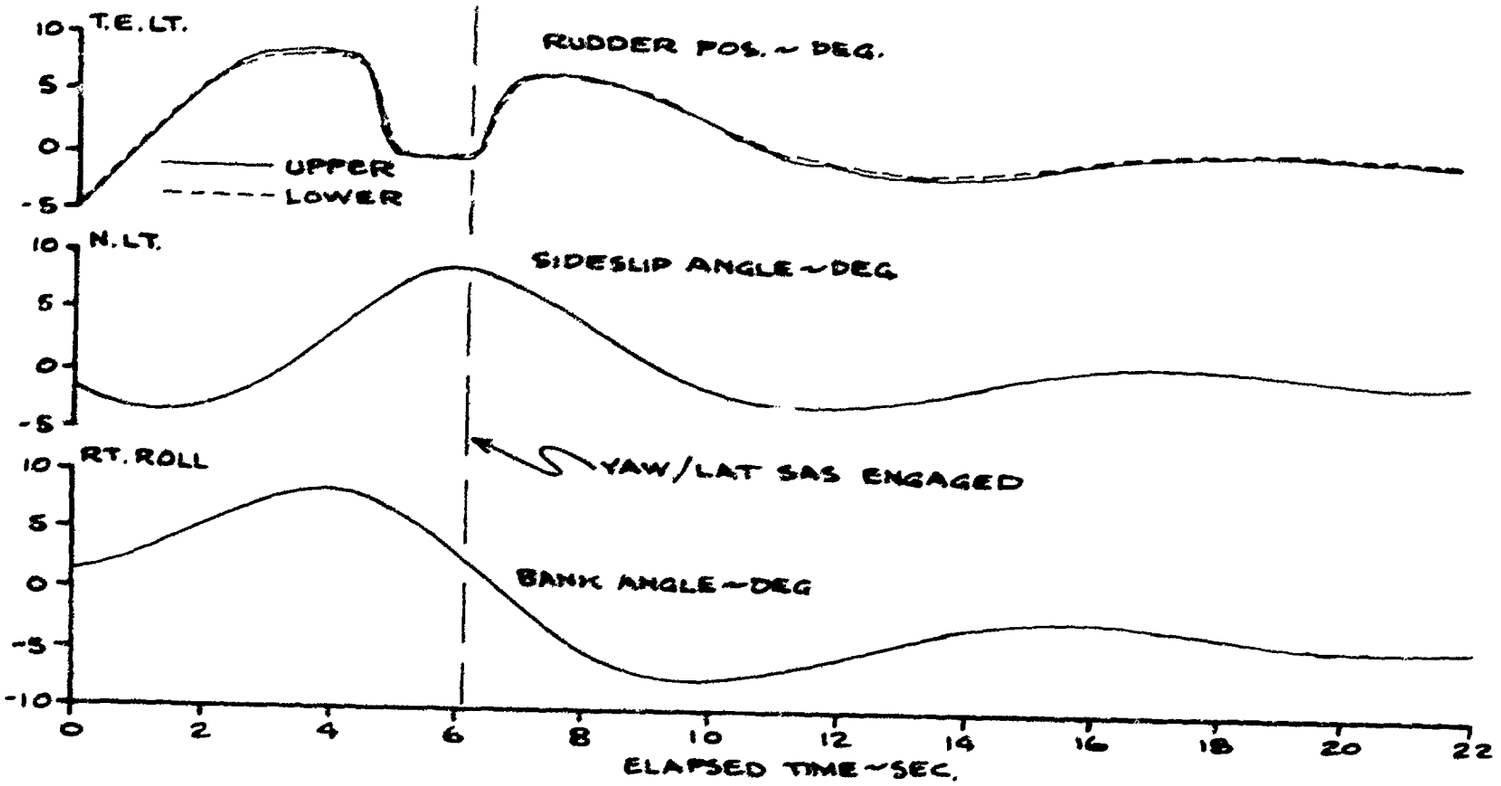


FIGURE NO. 4 (3.3.1) DYNAMIC LAT-DIR STABILITY

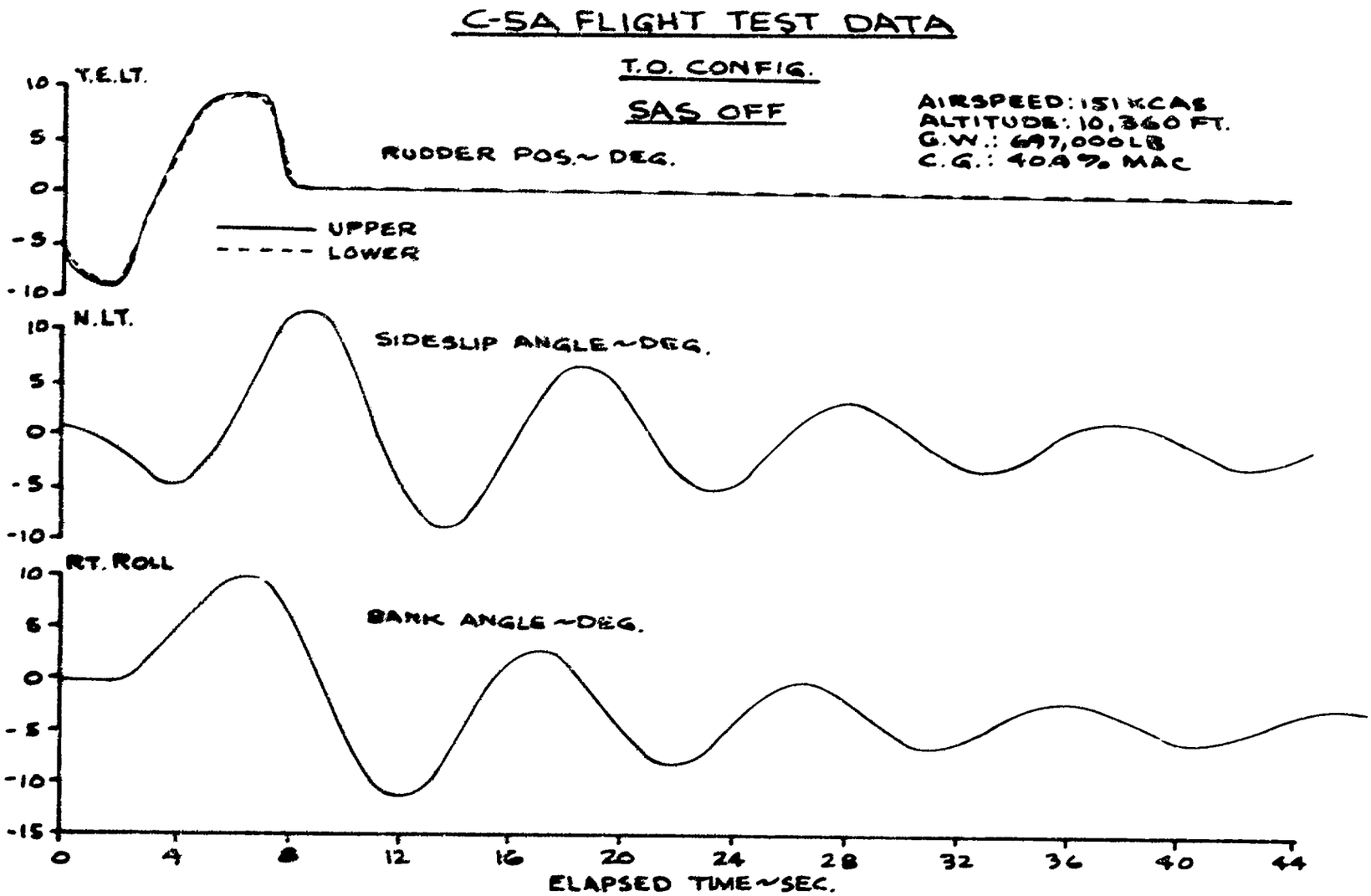


FIGURE NO. 5 (3.3.1) DYNAMIC LAT-DIR STABILITY

C-5A FLIGHT TEST DATA

L CONFIG.

AIRSPEED: 163 KCAS
ALTITUDE: 10,500 FT.
G.W.: 705,550 LB
C.G.: 40.5 % MAC

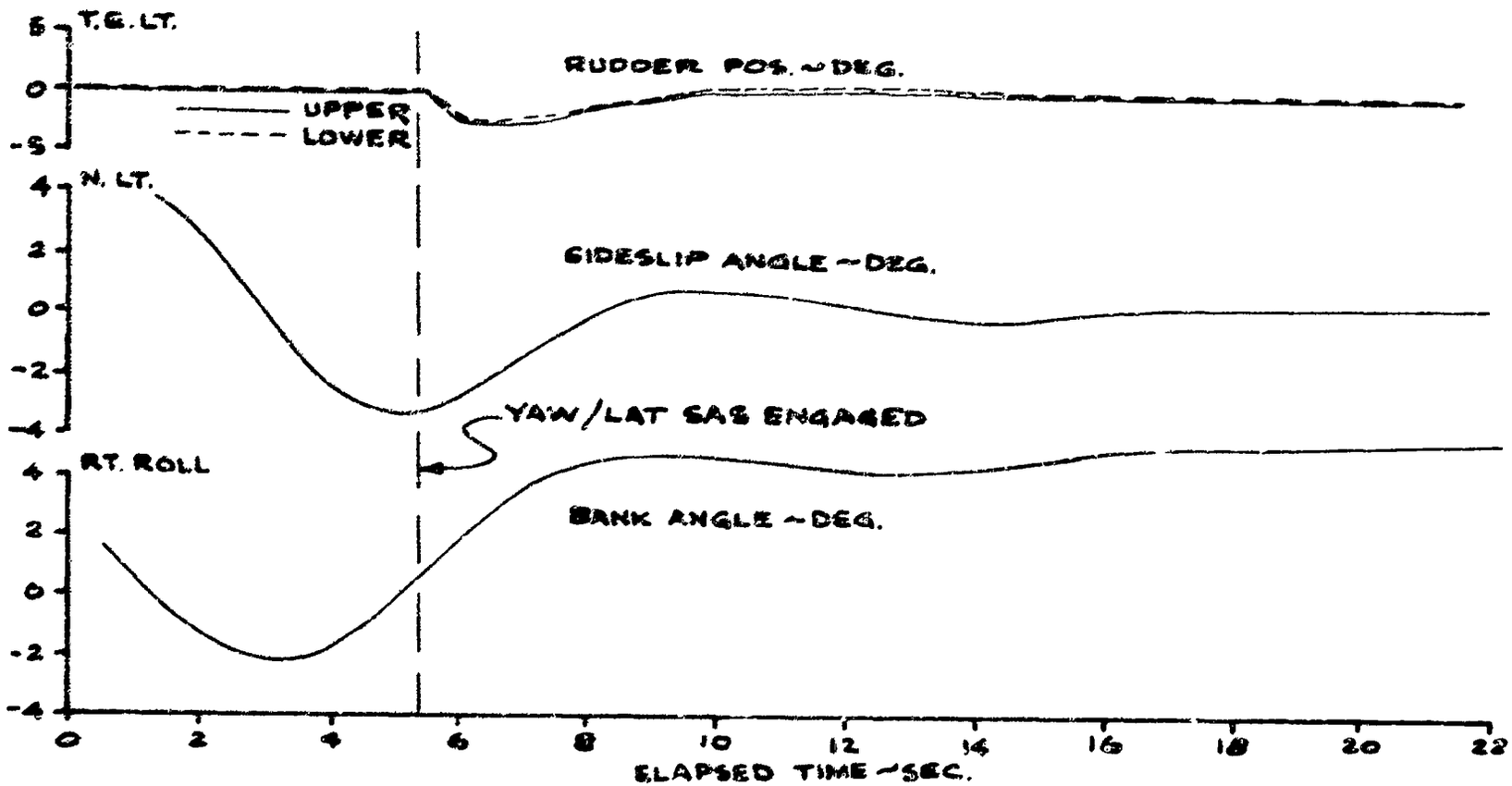


FIGURE NO. 6 (3.3.1) DYNAMIC LAT-DIR STABILITY

C-5A FLIGHT TEST DATA

L CONFIG.

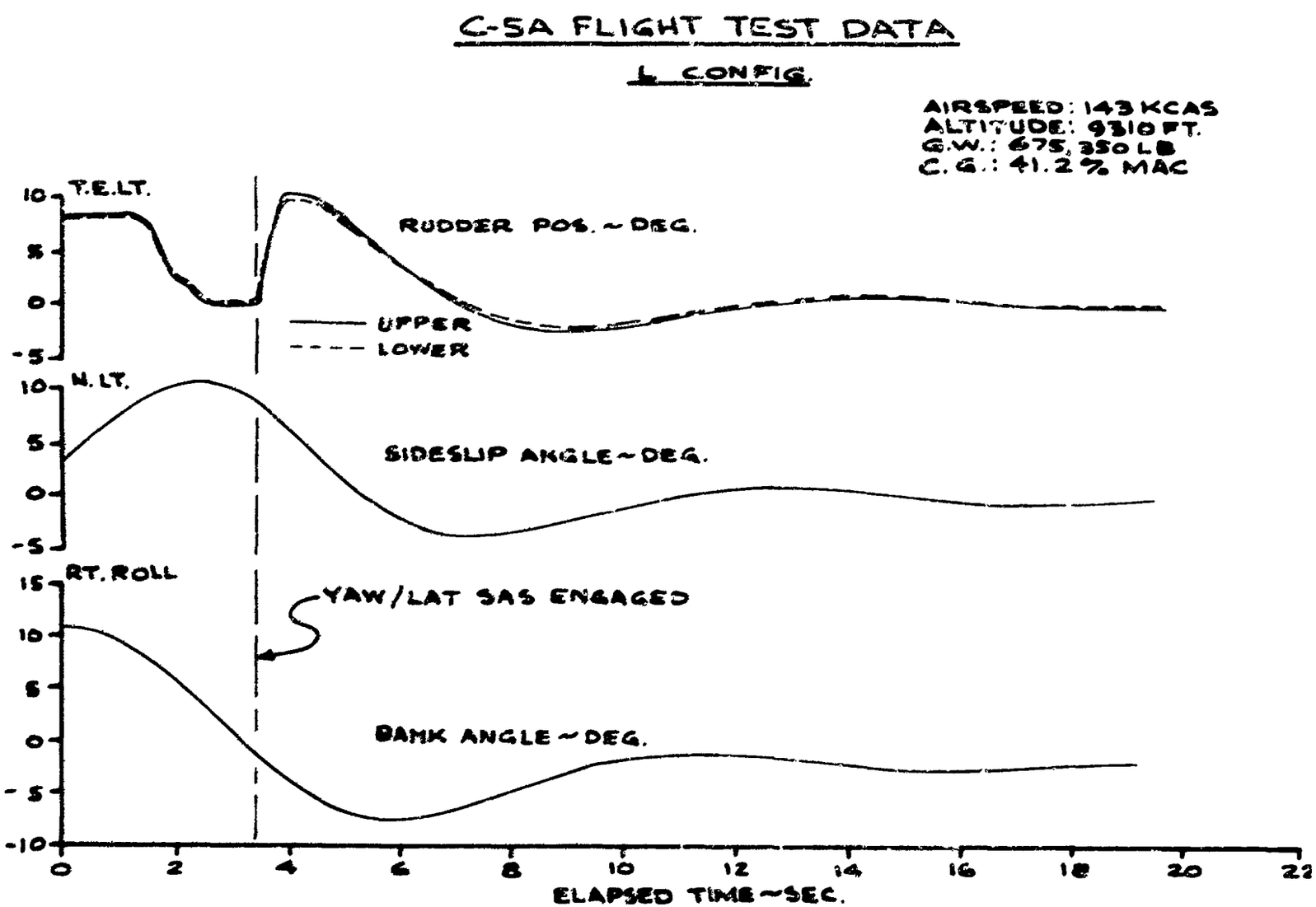


FIGURE NO. 7 (3.3.1) DYNAMIC LAT-DIR STABILITY

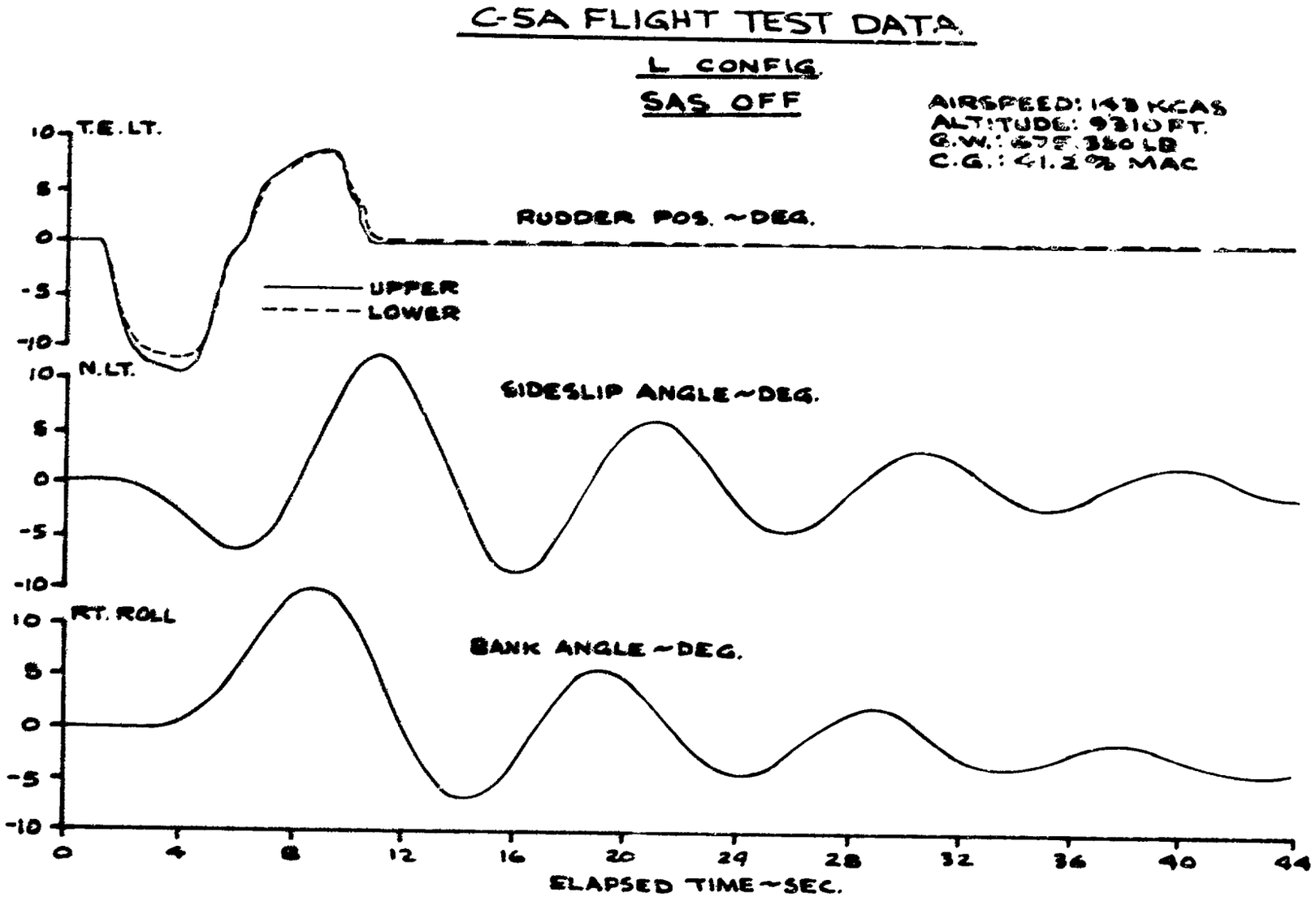


FIGURE NO. 8 (3.3.1) DYNAMIC LAT- DIR STABILITY

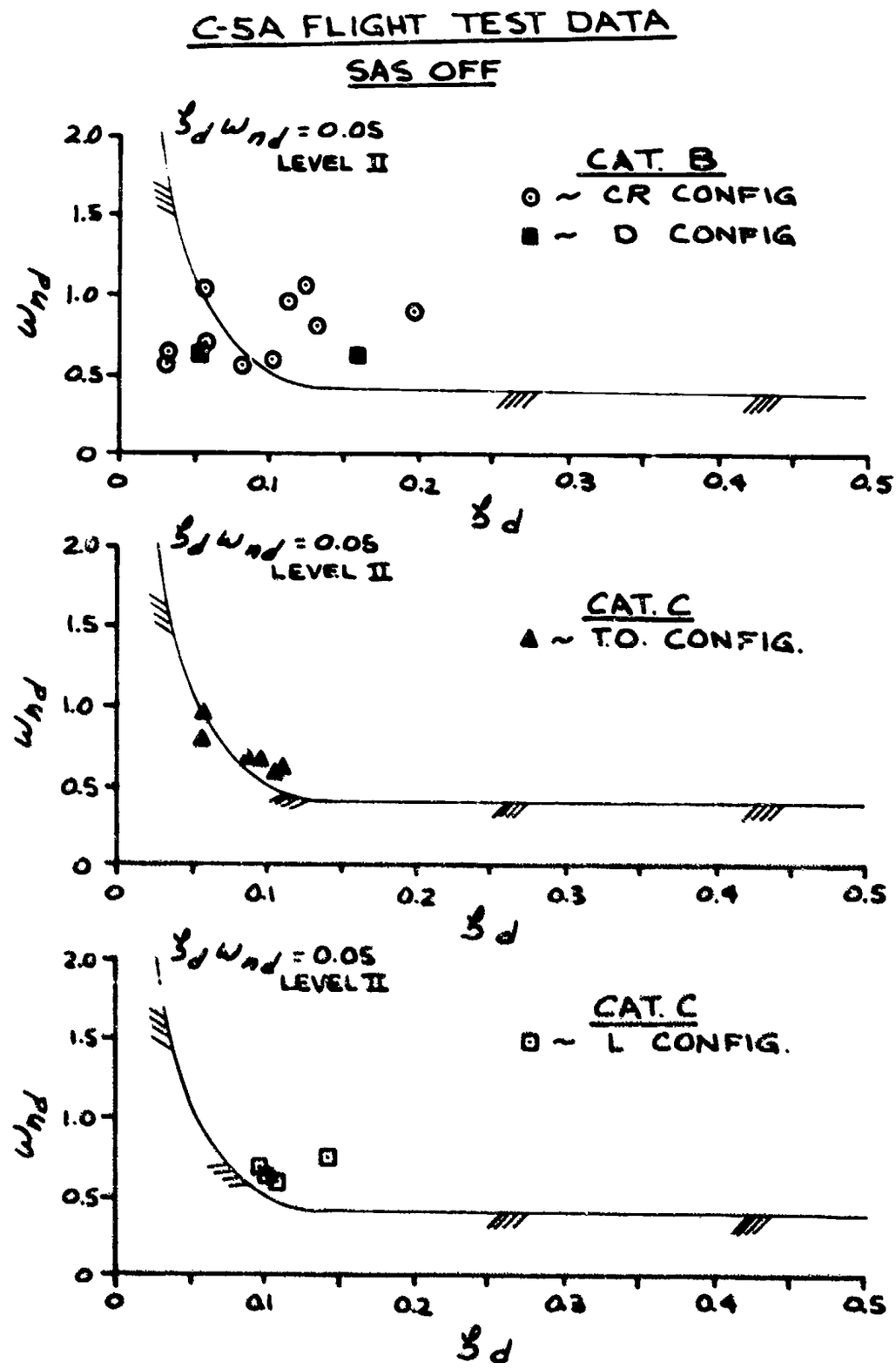


FIGURE NO.9 (3.3.1) LATERAL DIRECTIONAL DAMPING

Requirement

3.3.1.2 Roll Mode. The roll-mode time constant, τ_R, shall be no greater than the appropriate value in Table VII.

Table VII. Maximum Roll-Mode Time Constant

Flight Phase Category	Class	Level 1	Level 2	Level 3
A	I, IV	1.0	1.4	10
	II, III	1.4	3.0	
B	All	1.4	3.0	
C	I, II-C, IV	1.0	1.4	
	II-L, III	1.4	3.0	

Comparison

The extraction of the roll-mode time constants from the C-5A data was done determining the logarithmic time constant from the roll rate buildup by solving for the time from P_i to .632 P_i. P_i is defined as the roll rate existing at t_i following a step input of lateral control. This method is in accordance with Appendix V of reference 3. This approach closely approximates the time constant for the C-5A determined by the more rigorous methods because of the magnitude of the spiral-mode and Dutch-roll-mode time constants. The spiral-mode time constant for the C-5A is large: sometimes divergent, sometimes convergent. This, coupled with an operative SAS which virtually eliminates any Dutch-roll, produces a nearly pure roll rate buildup that is influenced only by roll damping and rolling inertia.

Figures 1, 2, and 3 (3.3.1.2) present the results of the analysis for the takeoff, landing and cruise configurations, respectively. The roll-mode time constant for the C-5A exceeds Level 1 in all three cases. The landing configuration data remain well within Level 2. The takeoff configuration is at the maximum (3.0) for Level 2 at 1.3 V_{STO}. In the cruise configuration, the roll-mode time constant is within Level 3 at the higher Mach numbers. The higher Mach numbers are less than M_H.

Discussion

One of the significant characteristics following the input of rapid full lateral control on the C-5A is that the initial rolling acceleration produces a very noticeable "side kick" or lateral acceleration component in the cockpit and in the troop compartment, since the cockpit and troop compartment are located considerably above the principal roll axis of the airplane. For normal operation, this characteristic can be avoided by initially using slow lateral control input and then increasing the rate of input until the desired airplane response is obtained. In situations requiring abrupt full control input, this characteristic will be noticed; however, it will not unduly restrict the use of full control when required.

The purpose of the roll-mode requirement is to describe the shape of the roll rate trace which is essentially defining the average rolling acceleration. The C-5A does not meet the Level 1 requirements, with most of the data showing Level 2 and, in some cases, Level 3. The C-5A exhibits this objectionable "side kick" characteristic. To achieve the Level 1 roll-mode time constant on the C-5A would produce an even more objectionable condition.

As previously stated, the "side kick" condition is caused by the cockpit location being considerably above the principal roll axis, not by the heavier gross weight or larger airplane size. It is, however, difficult to divorce the weight and size from the cockpit location because the design requirements essentially dictated the high cockpit for drive-through capability and the low CG position because of the 265,000-pound cargo located near the truck bed height. It is felt that this condition will exist for all heavy transports and may exist for other classes of airplane. This problem should be recognized in the roll-mode time constant requirements.

Recommendation

For airplanes where the personnel are located at a considerable distance from the principal roll axis, the requirements of paragraph 3.3.1.2 may be reasonably relaxed. Additional information is needed to support Class III requirements.

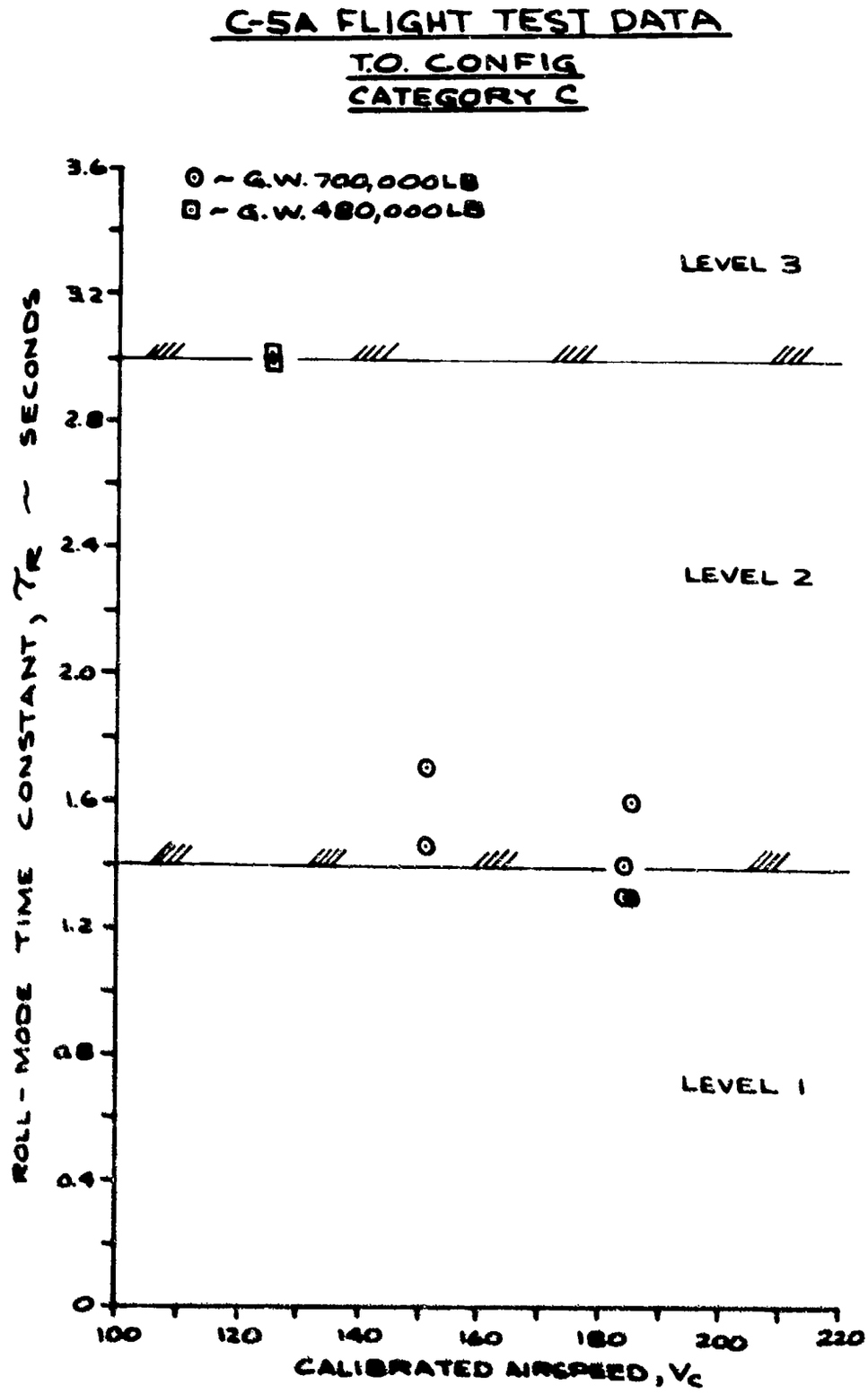


FIGURE NO. 1 (3.3.1.2) ROLL-MODE TIME CONSTANT

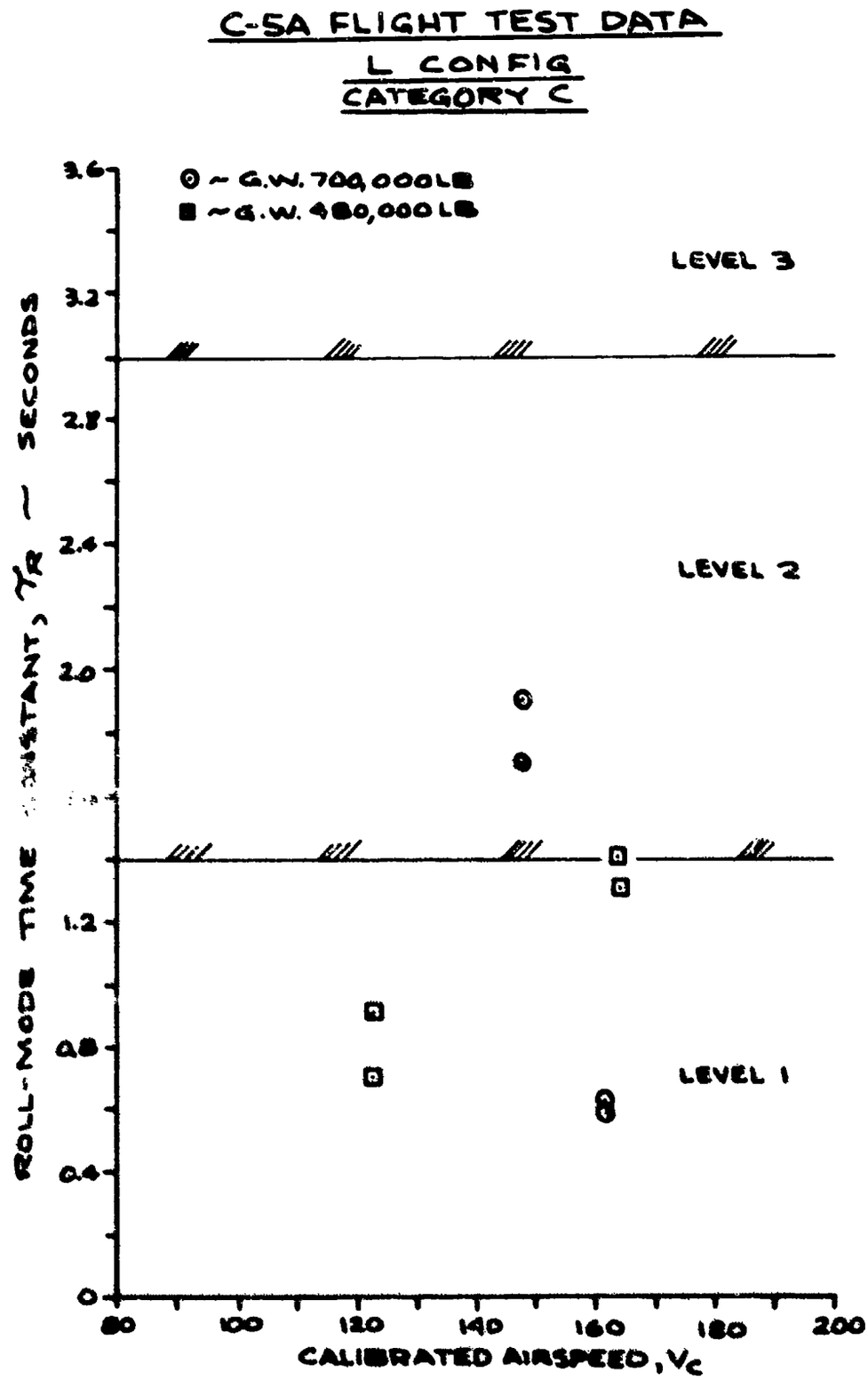


FIGURE NO.2(3.3.1.2) ROLL-MODE TIME CONSTANT

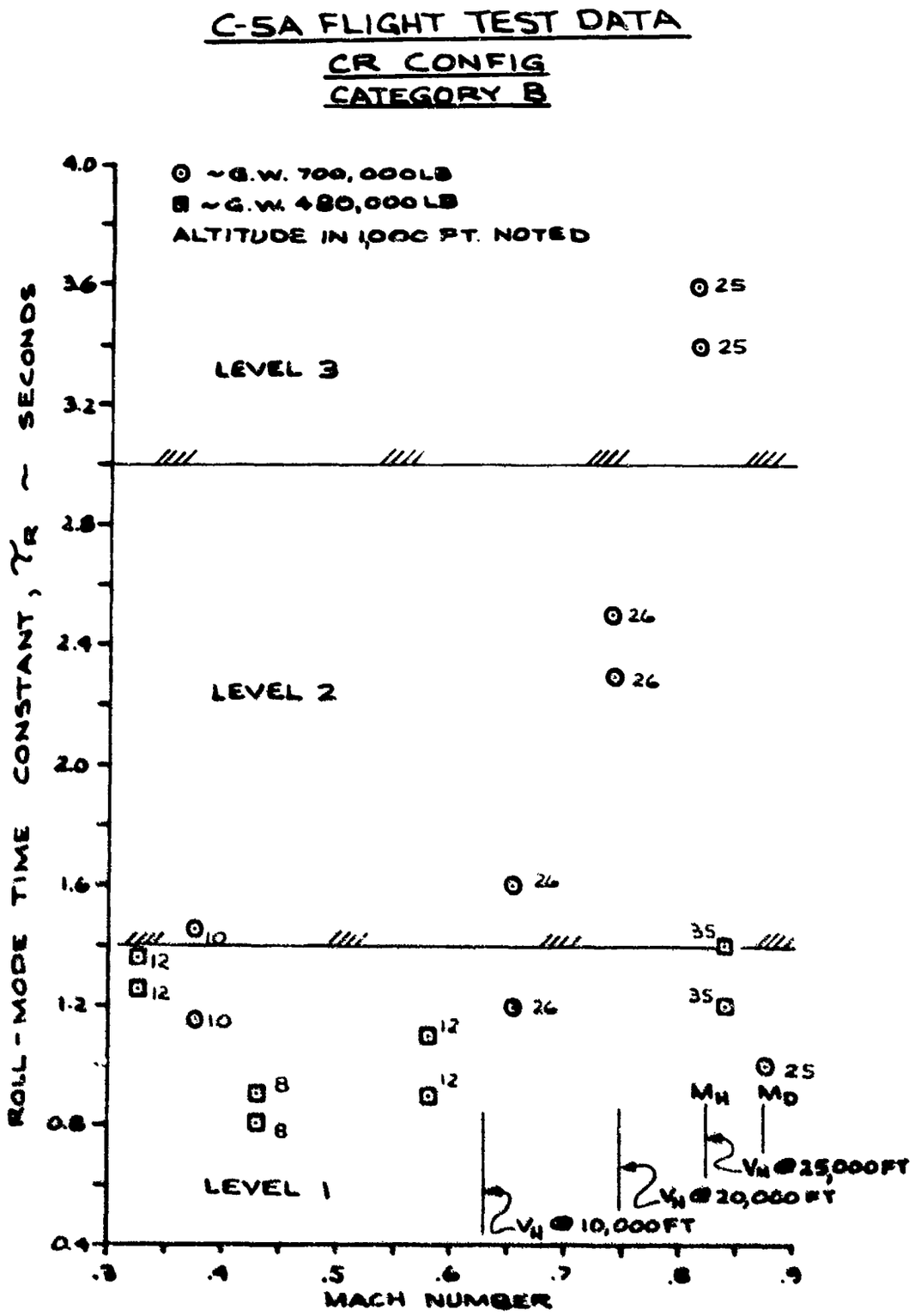


FIGURE NO.3 (3.3.1.2) ROLL-MODE TIME CONSTANT

Requirement

3.3.1.3 Spiral stability. The combined effects of spiral stability, flight-control system characteristics, and trim change with speed shall be such that following a disturbance in bank of up to 20 degrees, the time for the bank angle to double will be greater than the values in table VIII. This requirement shall be met with the airplane trimmed for wings-level, zero-yaw-rate flight with the cockpit controls free.

Table VIII. Spiral Stability - Minimum Time to Double Amplitude

Class	Flight Phase Category	Level		
		1	2	3
I & IV	A	12 sec	12 sec	4 sec
	B & C	20 sec	12 sec	4 sec
II & III	All	20 sec	12 sec	4 sec

Comparison

Flight test evaluation of the spiral stability determined that the spiral mode is basically neutral for most conditions and does not approach the allowable time to double amplitude for the few conditions which are divergent.

Discussion

None

Recommendation

None

Requirement

3.3.1.4 Coupled Roll-Spiral Oscillation. A coupled roll-spiral mode will not be permitted.

Comparison

There is no indication in the C-5A data that a coupled roll-spiral mode exists.

Discussion

None

Recommendation

None

Requirement

3.3.2 Lateral-directional dynamic response characteristics. Lateral-directional dynamic response characteristics are stated in terms of response to atmospheric disturbances and in terms of allowable roll rate and bank oscillations, sideship excursions, aileron stick or wheel forces, and rudder pedal forces that occur during specified rolling and turning maneuvers. The requirements of 3.3.2.2, 3.3.2.3, and 3.3.2.4 apply for both right and left aileron commands of all magnitudes up to the magnitude required to meet the roll performance requirements of 3.3.4 and 3.3.4.1.

Comparison

None

Discussion

None

Recommendation

None

Requirement

3.3.2.1 Lateral-directional response to atmospheric disturbances. Although no numerical requirements are specified, the combined effect of ω_{n_d}, ζ_d, τ_R, $\measuredangle P/\beta$, $|\phi/\beta|_d$, gust sensitivity, and flight-control-system nonlinearities shall be such that the airplane will have acceptable response and controllability characteristics in atmospheric disturbances. In particular, the roll acceleration, rate, and displacement responses to side gusts shall be investigated for airplanes with large rolling moment due to sideslip.

Comparison

Relative to the last sentence of the subject requirement, test data are presented in Section 3.3.6.3.2 which show that the C-5A does not have large rolling moments due to sideslip. In fact, these data show that at a speed of 100 KCAS, less than 75 percent wheel throw is required to balance a side gust of 46 ft/sec. In addition, test data are presented in Section 3.7.1 showing pilot workload and control characteristics in turbulence.

Discussion

None

Recommendation

None

Requirement

3.3.2.2 Roll rate oscillations. Following a rudder-pedals-free step aileron control command, the roll rate at the first minimum following the first peak shall be of the same sign and not less than the following percentages of the roll rate at the first peak:

Level	Flight Phase Category	Percent
1	A & C	60
	B	25
2	A & C	25
	B	0

For all levels, the change in bank angle shall always be in the direction of the aileron control command. The aileron command shall be held fixed until the bank angle has changed at least 90 degrees.

Comparison

Full wheel throw rolls performed with the C-5A show full compliance with the requirements of the paragraph. Table 11 summarizes these uncoordinated roll data for the normal operating mode and table 12 summarizes the SAS off operating mode.

For the C-5A, the SAS produces sufficient roll entry coordination to eliminate roll rate oscillation on full wheel throw rolls. In the tables, this is termed "flat," which inherently means a roll rate valley-to-peak ratio of 100%. With the SAS off, which can be considered as a single failure, the level of natural roll damping produces a slight oscillatory characteristic. Oscillations are well within the paragraph minimum for Level 1 for SAS on or off, for all flight categories.

All of these data were obtained with the aileron command held fixed less than the specified 90 degrees of bank. The C-5A is limited to 45 degrees of bank. Since a finite time is necessary to accelerate and decelerate the roll, the full 90 degrees of roll is not available.

Discussion

None

Recommendation

The 90 degrees of required bank should be adjusted to 60 degrees to recognize the larger airplanes with 45 degree bank limitations.

Table 11. C-5A Roll Rate Summary
SAS On

FLIGHT CATEGORY	CONF	SAS	GW LB	V_C KCAS	ALTITUDE 1000 FT	ROLL RATE AT FIRST PEAK, P1 DEG/SEC	ROLL RATE AT SECOND PEAK, P2 DEG/SEC	(P2/P1) %	MINIMUM SPECIFICATION (P2/P1) %
C	L	ON	708,000	148	10	23.0	FLAT	100	60
C	L	ON	480,000	123	12	21.5	FLAT	100	60
C	L	ON	690,000	162	12	25.3	FLAT	100	60
C	L	ON	476,000	162	11	30.0	FLAT	100	60
C	TO	ON	694,000	161	10	14.8	FLAT	100	60
C	TO	ON	490,000	125	12	13.6	FLAT	100	60
C	TO	ON	675,000	142	10	18.8	FLAT	100	60
C	TO	ON	490,000	180	10	20.0	FLAT	100	60
B	CR	ON	708,000	207	10	14.8	FLAT	100	25
B	CR	ON	722,000	263	11	16.9	FLAT	100	25
B	CR	ON	712,000	358	12	13.5	FLAT	100	25
B	CR	ON	500,000	170	12	14.5	FLAT	100	25
B	CR	ON	500,000	346	12	15.7	FLAT	100	25
B	CR	ON	700,000	268	26	17.7	FLAT	100	25
B	CR	ON	690,000	305	26	20.8	FLAT	100	25
B	CR	ON	675,000	355	25	14.5	FLAT	100	25
B	CR	ON	450,000	267	27	21.0	FLAT	100	25
B	CR	ON	450,000	342	25	13.0	FLAT	100	25
B	CR	ON	470,000	216	35	19.3	FLAT	100	25
B	CR	ON	480,000	284	35	21.8	FLAT	100	25

Table 12. C-5A Roll Rate Summary
SAS Off

FLIGHT CATEGORY	CONF	SAS	GW LB	V_C KCAS	ALTITUDE 1000 FT	ROLL RATE AT FIRST PEAK, P1 DEG/SEC	ROLL RATE AT SECOND PEAK, P2 DEG/SEC	(P2/P1) %	MINIMUM SPECIFICATION (P2/P1) %
C	L	OFF	683,000	145	9	23.1	FLAT	100	60
C	L	OFF	700,000	162	12	23.7	FLAT	100	60
C	TO	OFF	684,000	151	11	8.7	8.0	92	60
C	TO	OFF	488,000	126	12	12.9	9.7	75	60
C	TO	OFF	660,000	186	10	18.3	FLAT	100	60
B	CR	OFF	705,000	207	10	15.2	9.6	63	25
B	CR	OFF	500,000	170	10	13.7	10.9	80	25

Requirement

3.3.2.2.1 Additional roll rate requirement for small inputs. The value of the parameter P_{osc}/P_{av} following a rudder-pedals-free step aileron command shall be within the limits shown on figure 4 for Levels 1 and 2. This requirement applies for step aileron control commands up to the magnitude which causes a 60 degree bank angle change in $1.7T_d$ seconds.

Comparison

The value of T_d varies from 6 to 11 seconds, which implies a roll rate of 3 to 6 degrees/second for the above 60 degree bank angle. Approximately 1/3 wheel deflection produces this roll rate. Test data performed at this condition with the SAS operative show low roll rate oscillation which is within the Level 1 envelope. This is due to the SAS rudder coordination input. Tests performed with the SAS inoperative show somewhat larger roll rate oscillation. This, too, is within the Level 1 allowable The magnitudes of these oscillations are shown in figures 1 and 2 (3.3.2.2.1).

Discussion

None

Recommendation

None

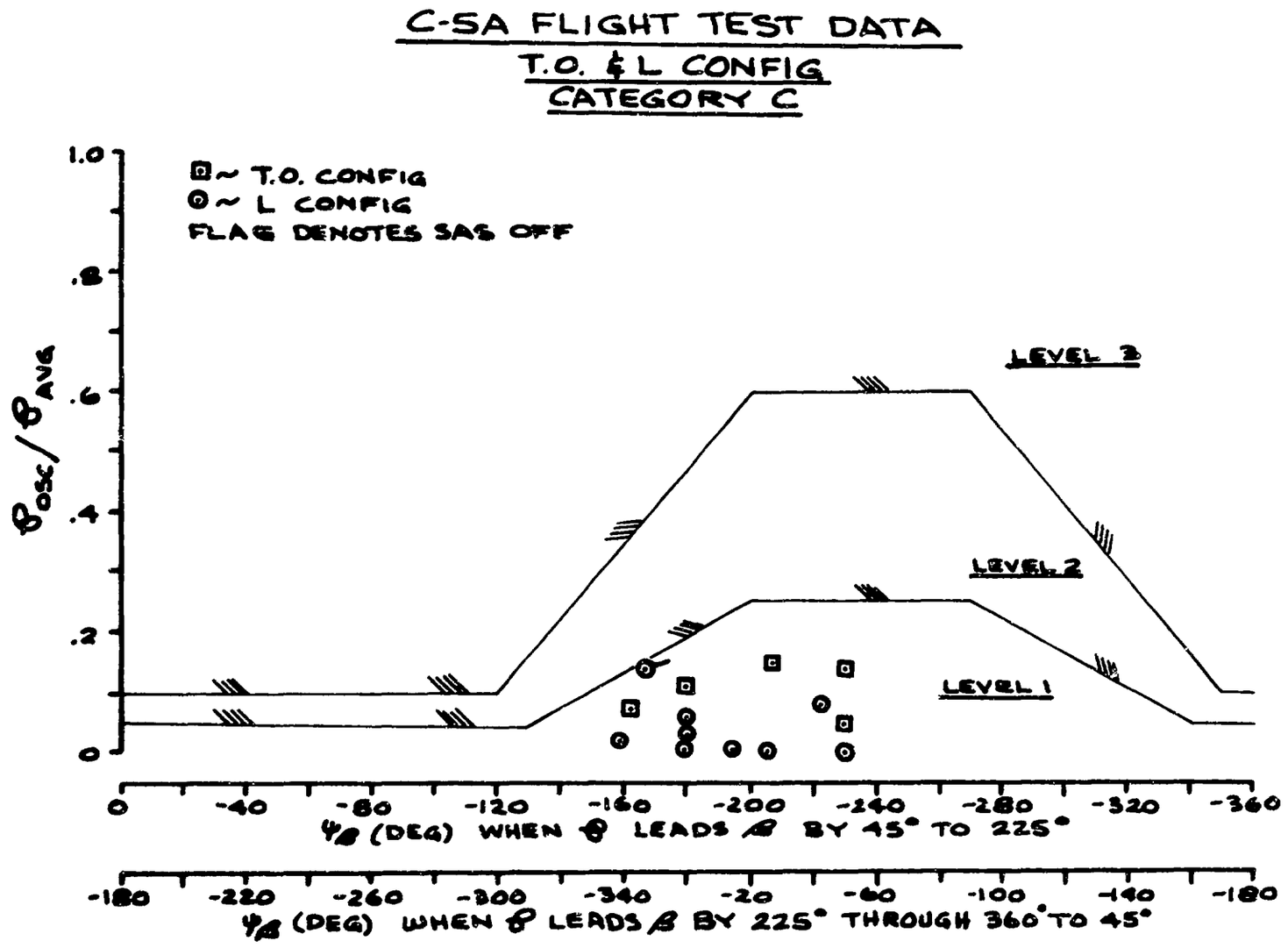


FIGURE NO. 2 (3.3.2.2.1) ROLL RATE OSCILLATION

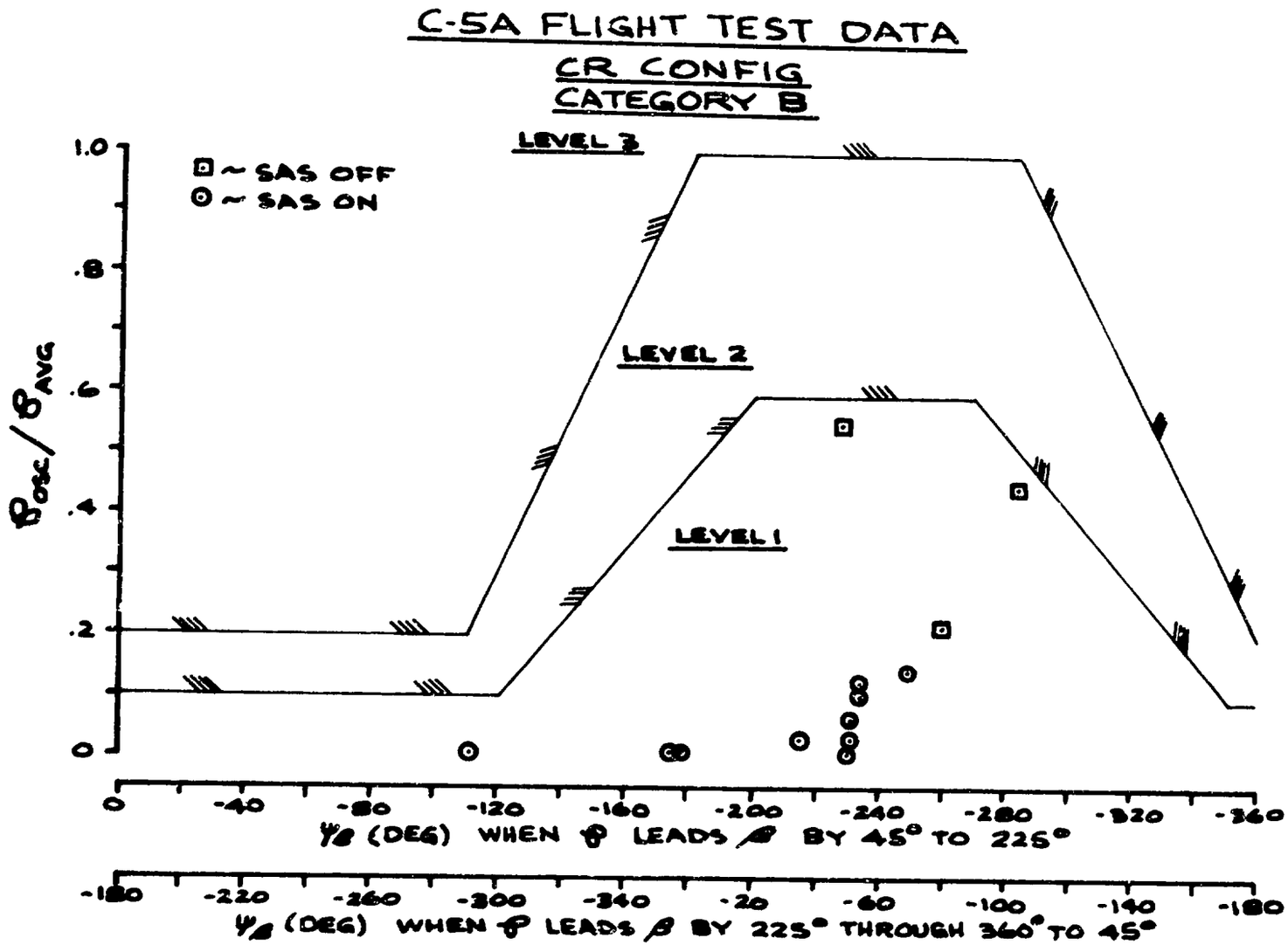


FIGURE NO. 1 (3.3.2.2.1) ROLL RATE OSCILLATION

Requirement

3.3.2.3 Bank angle oscillations. The value of the parameter ϕ_{OSC}/ϕ_{AV} following a rudder pedals-free impulse aileron control command shall be within the limits in figure 5 for Levels 1 and 2. The impulse shall be as abrupt as practical within the strength limits of the pilot and the rate limits of the aileron control system.

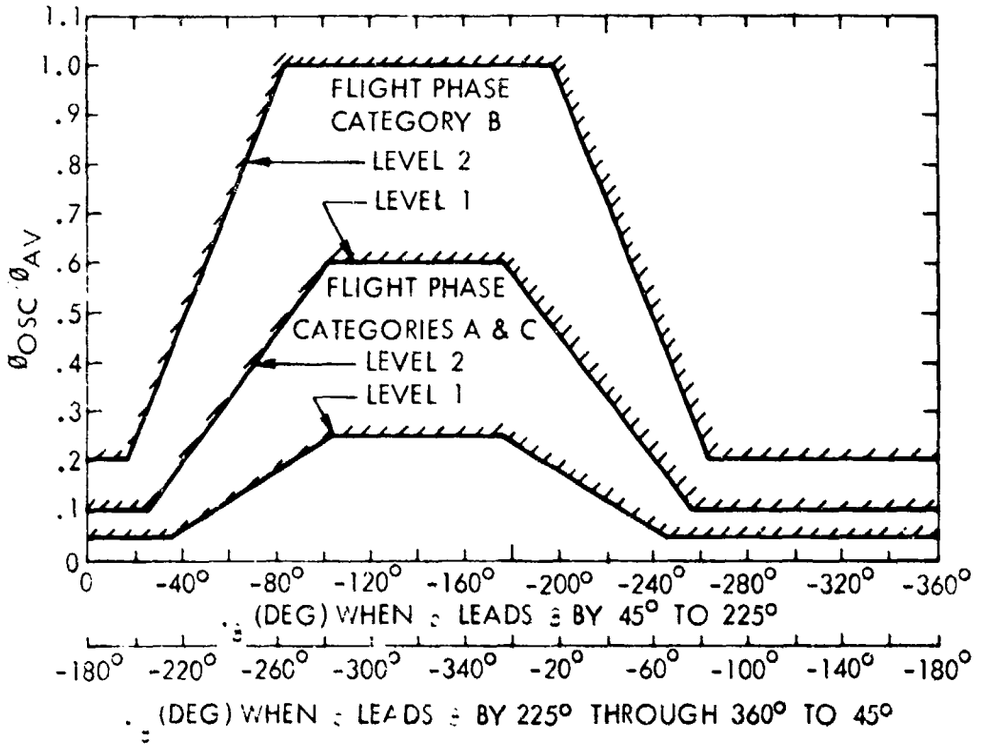


Figure 5. Bank Angle Oscillation Limitations

Comparison

Data are not presented for comparison with this requirement.

Discussion

None

Recommendation

None

Requirement

3.3.2.4 Sideslip excursions. Following a rudder-pedals-free step aileron control command, the ratio of the sideslip increment, $\Delta\beta$, to the parameter k (6.2.6) shall be less than the values specified herein. The aileron command shall be held fixed until the bank angle has changed at least 90 degrees.

Level	Flight Phase Category	Adverse Side (Right roll command causes right sideslip)	Proverse Sideslip (Right roll command causes left sideslip)
1	A	6 degrees	2 degrees
	B & C	10 degrees	3 degrees
2	All	15 degrees	4 degrees

Comparison

The $\Delta\beta/K$ results are presented in figures 1 (3.3.2.4) through 4 (3.3.2.4) for configurations falling within Flight Phase Categories B and C. One half of the Dutch roll period has been used to obtain the $\Delta\beta$ parameter for all flight cases, since the Dutch roll period varies from approximately 6 seconds to 11 seconds.

The data indicate that the C-5A airplane with the SAS off, which is applicable to Level 2, does not meet Level 1 requirements and meets Level 2 requirements only above certain airspeeds. With SAS on, which is the normal operating condition, the C-5A meets Level 2 requirements at all airspeeds and Level 1 requirements at most airspeeds. Comments in reference 2 state that the variations in sideslip do not affect roll performance during uncoordinated rolls.

Discussion

Although the C-5A does not meet this specification at certain conditions, the sideslip excursions are not considered undesirable. Hence, the uniform applicability of the requirements to all classes of aircraft is questioned.

The definitions of $\Delta\beta$ and k as given in paragraph 6.2.6 are not clear. It has been assumed that the $\Delta\beta$ parameter referred to in 3.3.2.4 is identical to the defined parameter $\Delta\beta$ max. The definition of k could be more clearly stated to precisely define k for the various levels.

The requirement to hold the aileron command fixed until the bank angle has changed at least 90 degrees is unnecessary for Class III aircraft. The aileron command should be held long enough to establish the parameters, $(\phi_t)_{command}$ and $\Delta\beta$, which depend on the time stated in paragraphs 3.3.4 and 3.3.4.1 and on one half the Dutch roll period or 2.0 seconds, whichever is greater.

Recommendation

It is recommended that the definition of the parameter k in 6.2.6 be changed to read:

(a) "Applicable roll performance requirement," $(\phi_t)_{req.}$, is the bank angle determined from 3.3.4 and 3.3.4.1 for the class, Flight Phase Category, and Level under consideration.

(b) "Commanded roll performance," $(\phi_t)_{command}$, is the bank angle attained in the time stated for the Class, Flight Phase Category, and Level under consideration for a given step aileron command with rudders employed as specified in 3.3.4 and 3.3.4.1.

It is also recommended that the sentence, "The aileron command shall be held fixed until the bank angle has changed at least 90 degrees," be replaced with the following:

"The aileron command shall be held fixed for a period of time sufficient to establish the parameters $\Delta\xi$ and $(\phi_t)_{command}$ (6.2.6)."

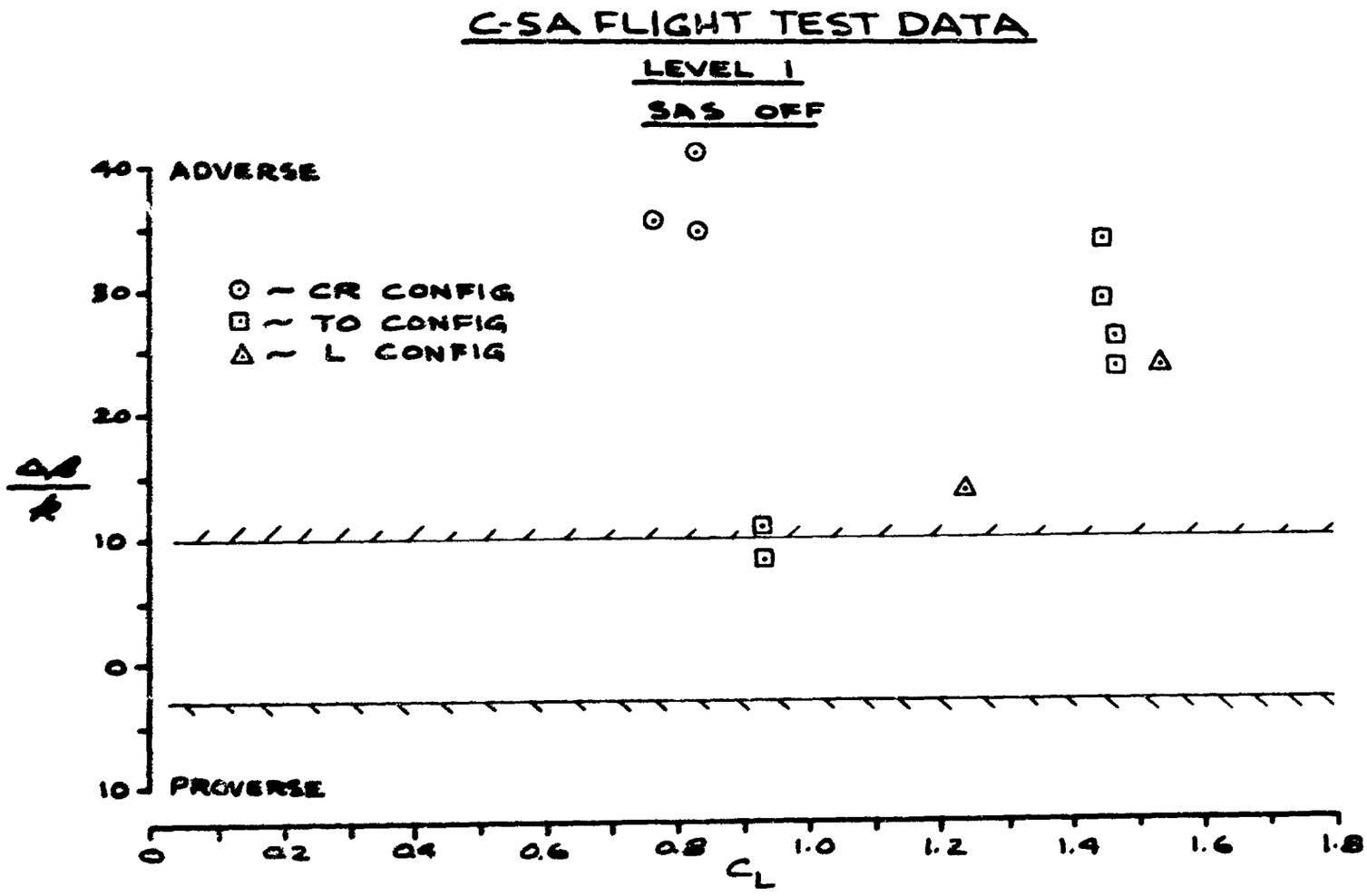


FIGURE NO. 1 (3.3.2.4) SIDESLIP EXCURSION SPECIFICATIONS

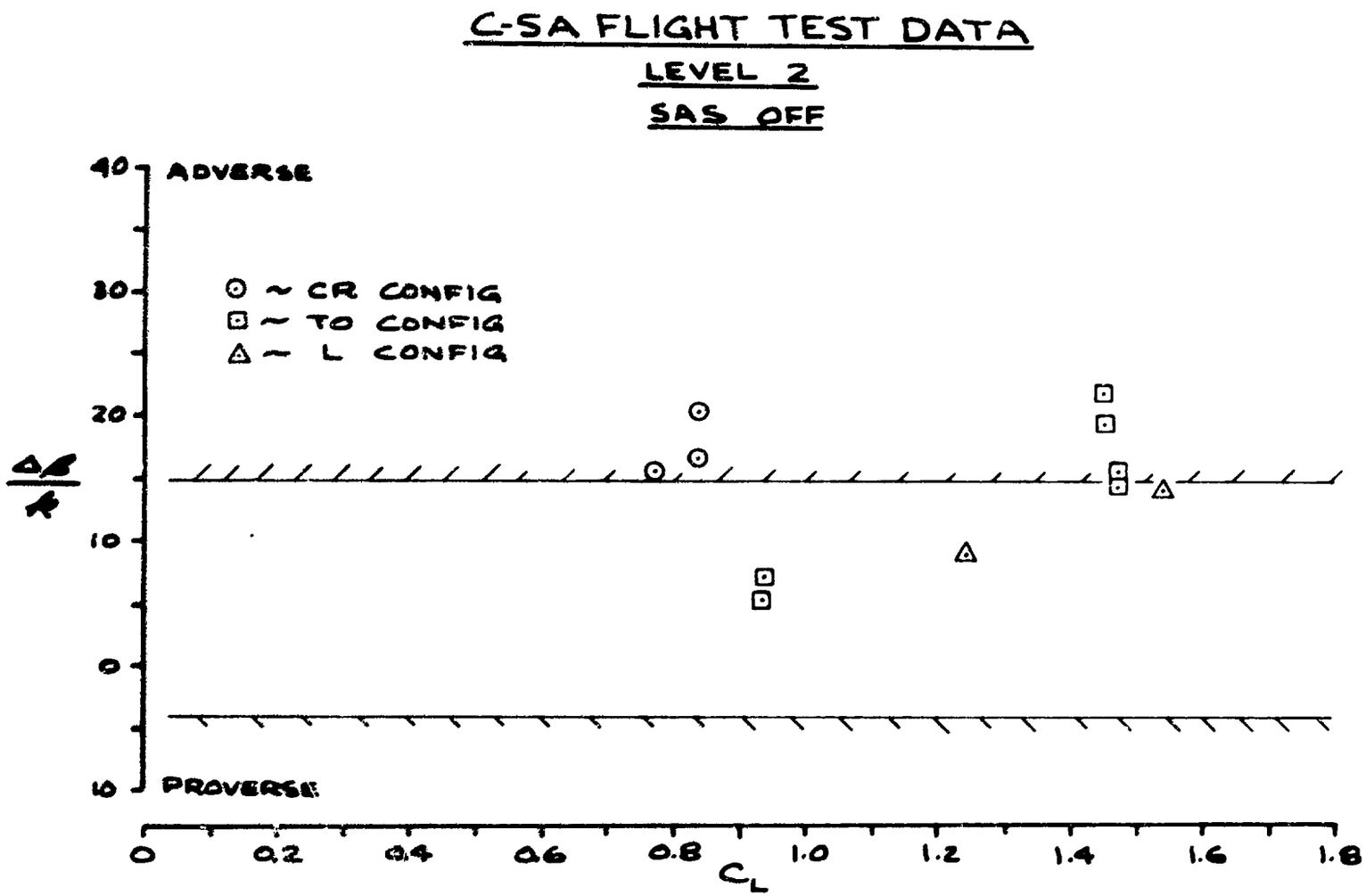


FIGURE NO. 2 (3.3.2.4) SIDESLIP EXCURSION SPECIFICATIONS

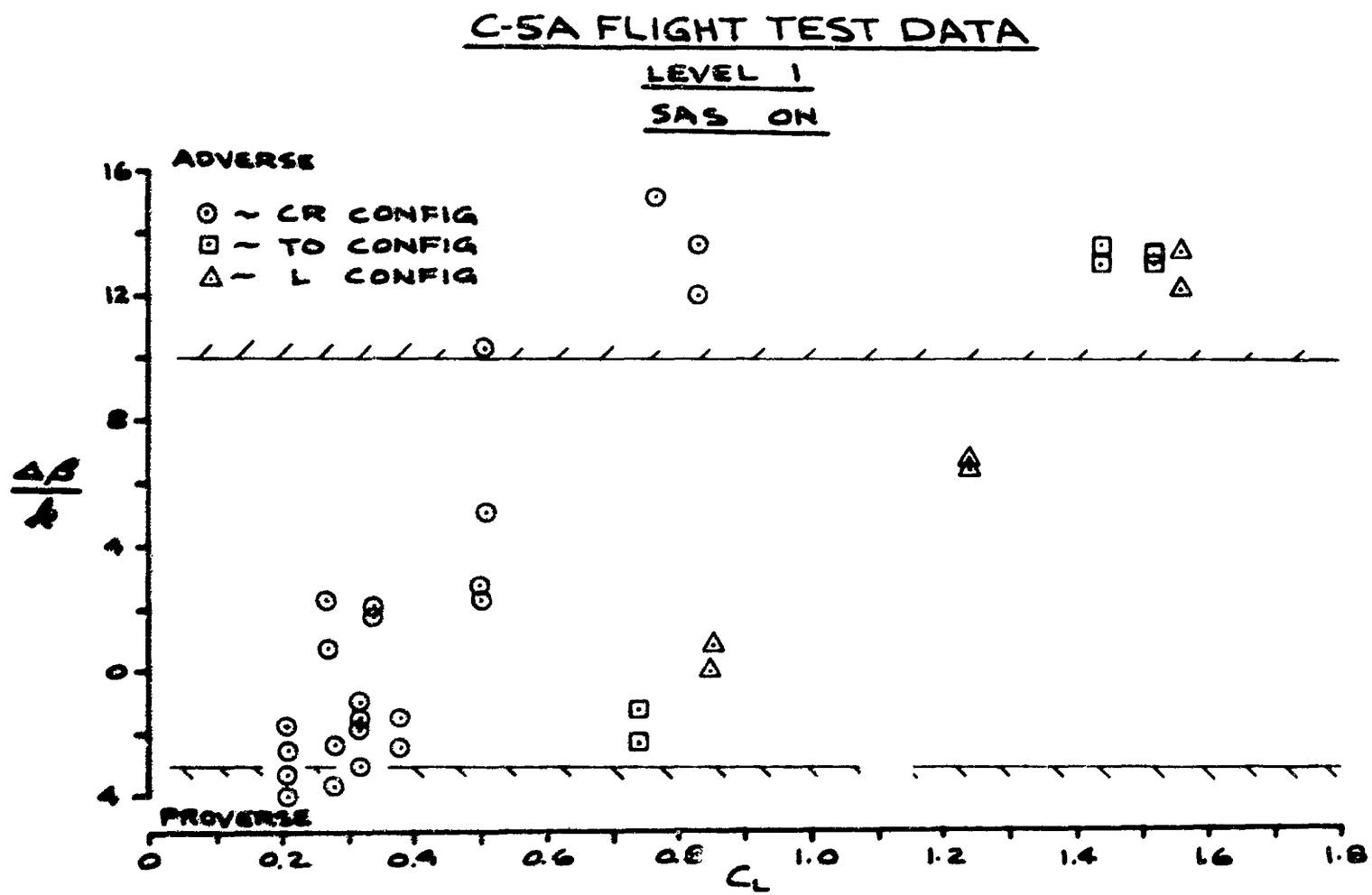


FIGURE NO. 3 (3.3.2.4) SIDESLIP EXCURSION SPECIFICATIONS

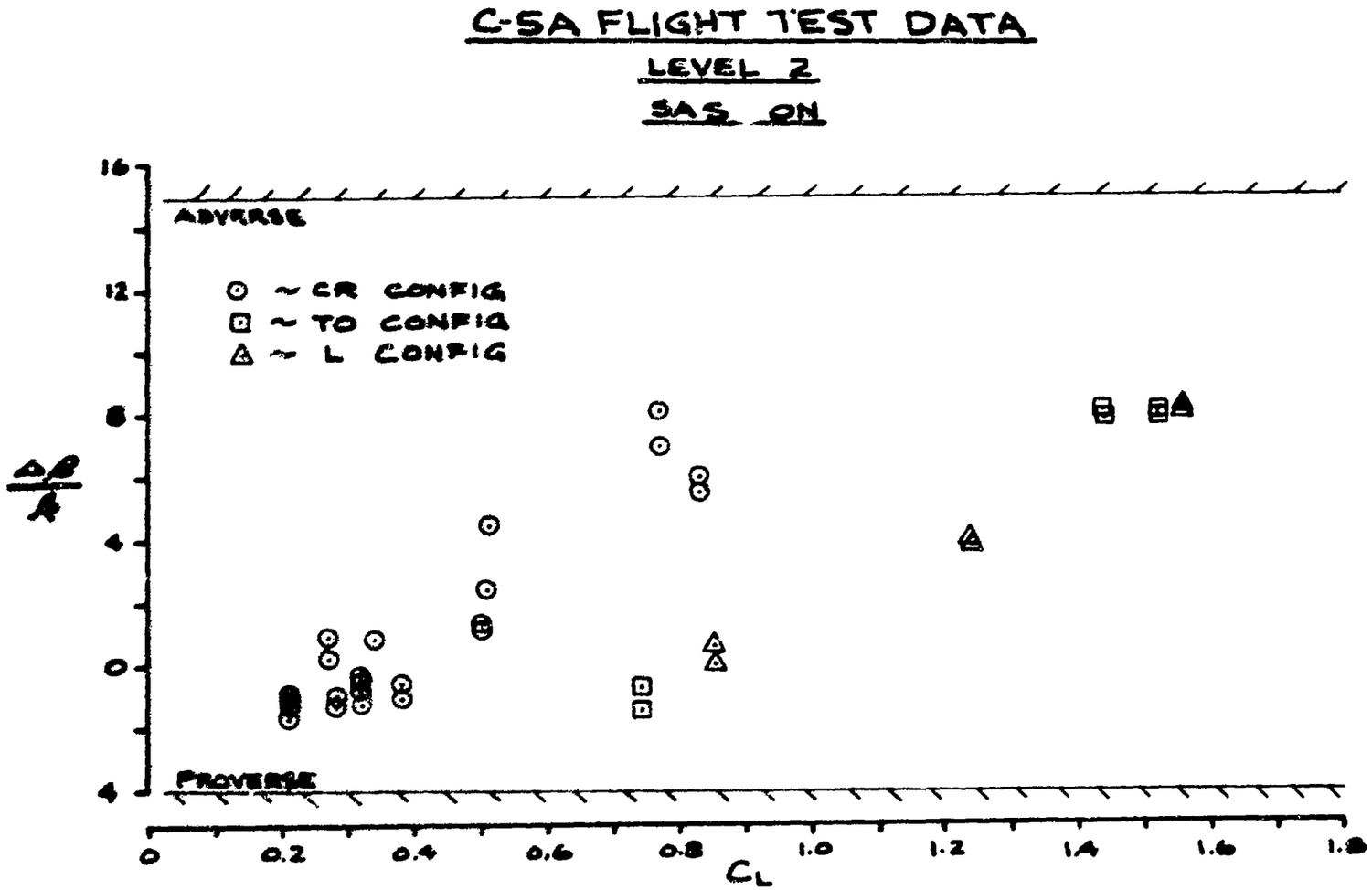


FIGURE No. 4 (3.3.2.4) SIDESLIP EXCURSION SPECIFICATIONS

Requirement

3.3.2.4.1 Additional sideslip requirement for small inputs. The amount of sideslip following a rudder-pedals-free step aileron control command shall be within the limits shown on figure 6 for Levels 1 and 2. This requirement shall apply for step aileron control commands up to the magnitude which causes a 60-degree bank angle change within T_d or two seconds, whichever is longer.

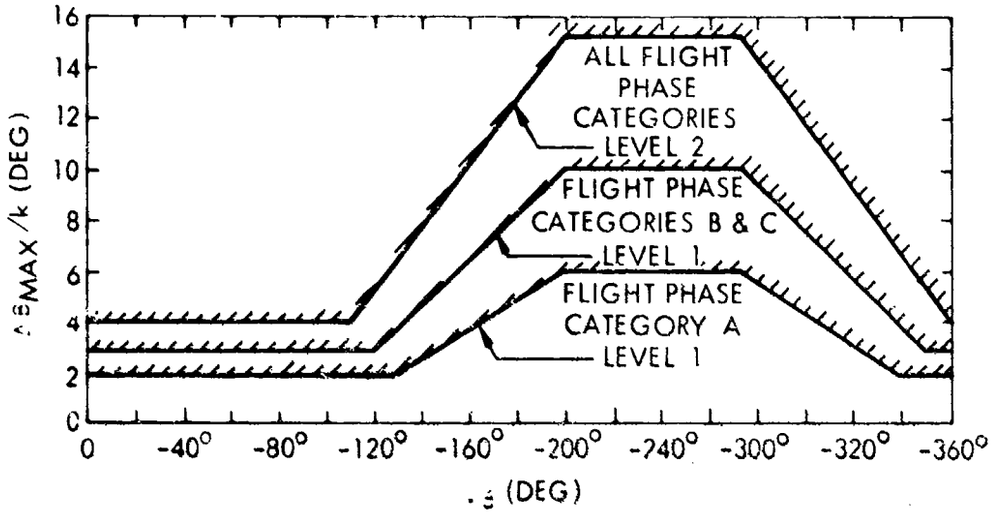


Figure 6. Sideslip Excursion Limitations

Comparison

Data are not presented for comparison with this requirement.

Discussion

None

Recommendation

None

Requirement

3.3.2.5 Control of sideslip in rolls. In the rolling maneuvers described in 3.3.4, but with the rudder pedals used for coordination for all Classes, directional-control effectiveness shall be adequate to maintain zero sideslip with a rudder pedal force not greater than 50 pounds for Class IV airplanes in Flight Phase Category A, Level 1, and 100 pounds for all other combinations of Class, Flight Phase Category and Level.

Comparison

Zero sideslip can be maintained during an abrupt, full-wheel roll with less than the specified limit of 100 pounds of rudder pedal force. Figure 1 (3.3.2.5) presents a pilot-coordinated abrupt roll. Pedal force to maintain zero sideslip does not exceed 40 pounds for this particular maneuver.

Discussion

None

Recommendation

None

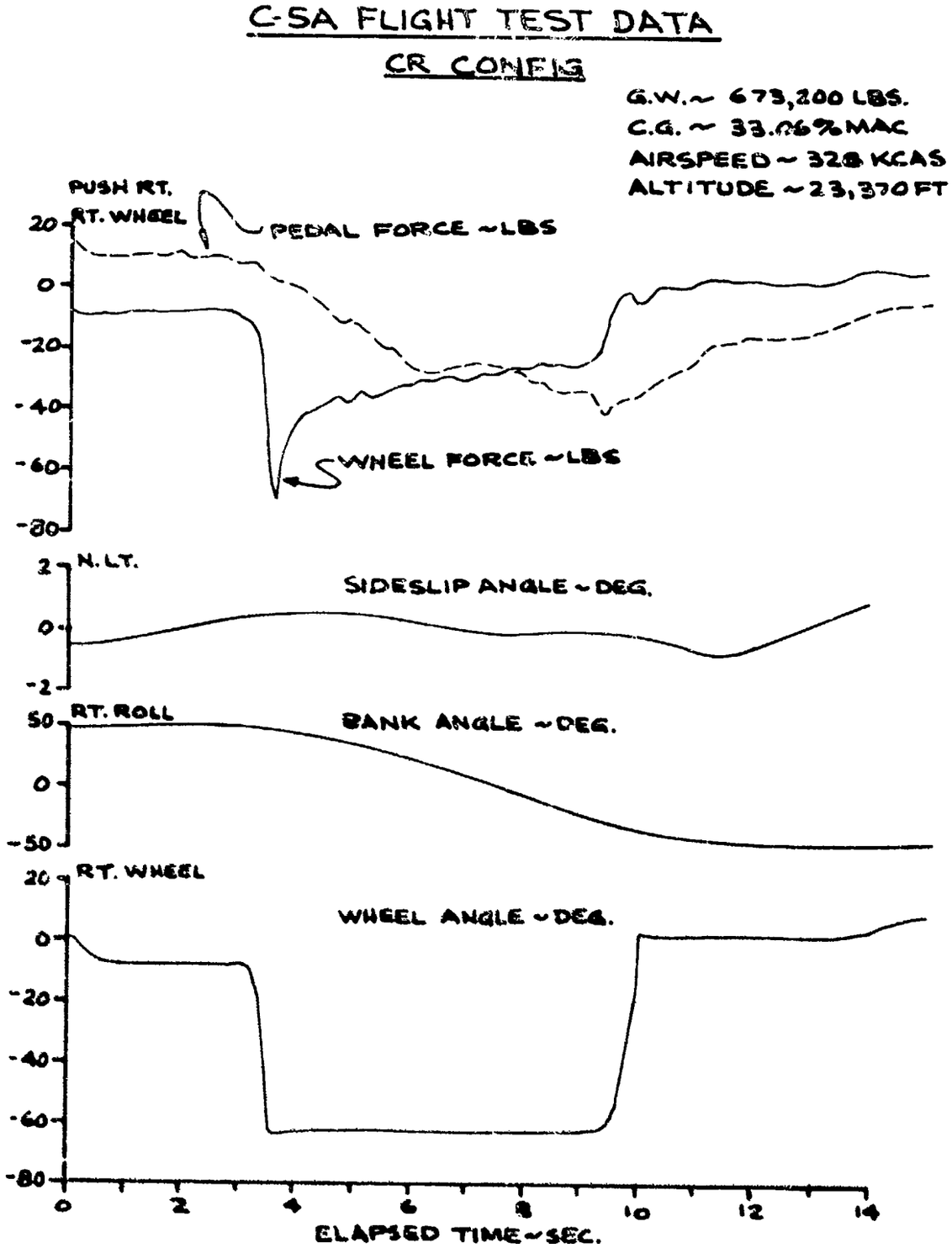


FIGURE NO.1 (3.3.2.5) PILOT-COORDINATED ABRUPT TURNS

Requirement

3.3.2.6 Turn coordination. It shall be possible to maintain steady coordinated turns in either direction, using 60 degrees of bank for Class IV airplanes, 45 degrees of bank for Class I and II airplanes, and 30 degrees of bank for Class III airplanes, with a rudder pedal force not exceeding 40 pounds. It shall be possible to perform steady turns at the same bank angles with rudder pedals free, with an aileron stick force not exceeding 5 pounds or an aileron wheel force not exceeding 10 pounds. These requirements constitute Levels 1 and 2 with the airplane trimmed for wings-level straight flight.

Comparison

The C-5 meets the turn coordination specifications for a Class III aircraft. A steady bank angle of 30° can be maintained with less than 40 pounds of rudder pedal force. The same bank angle can also be maintained with rudder pedals free using a maximum aileron wheel force of 10 pounds. Typical coordinated rolls are shown in figures 1 (3.3.2.6) and 2 (3.3.2.6) for the TO and CR configurations. Uncoordinated rolls for the TO and CR configurations are presented in figure 3 (3.3.2.6) and 4 (3.3.2.6).

Discussion

C-5A results agree with this requirement.

Recommendations

None

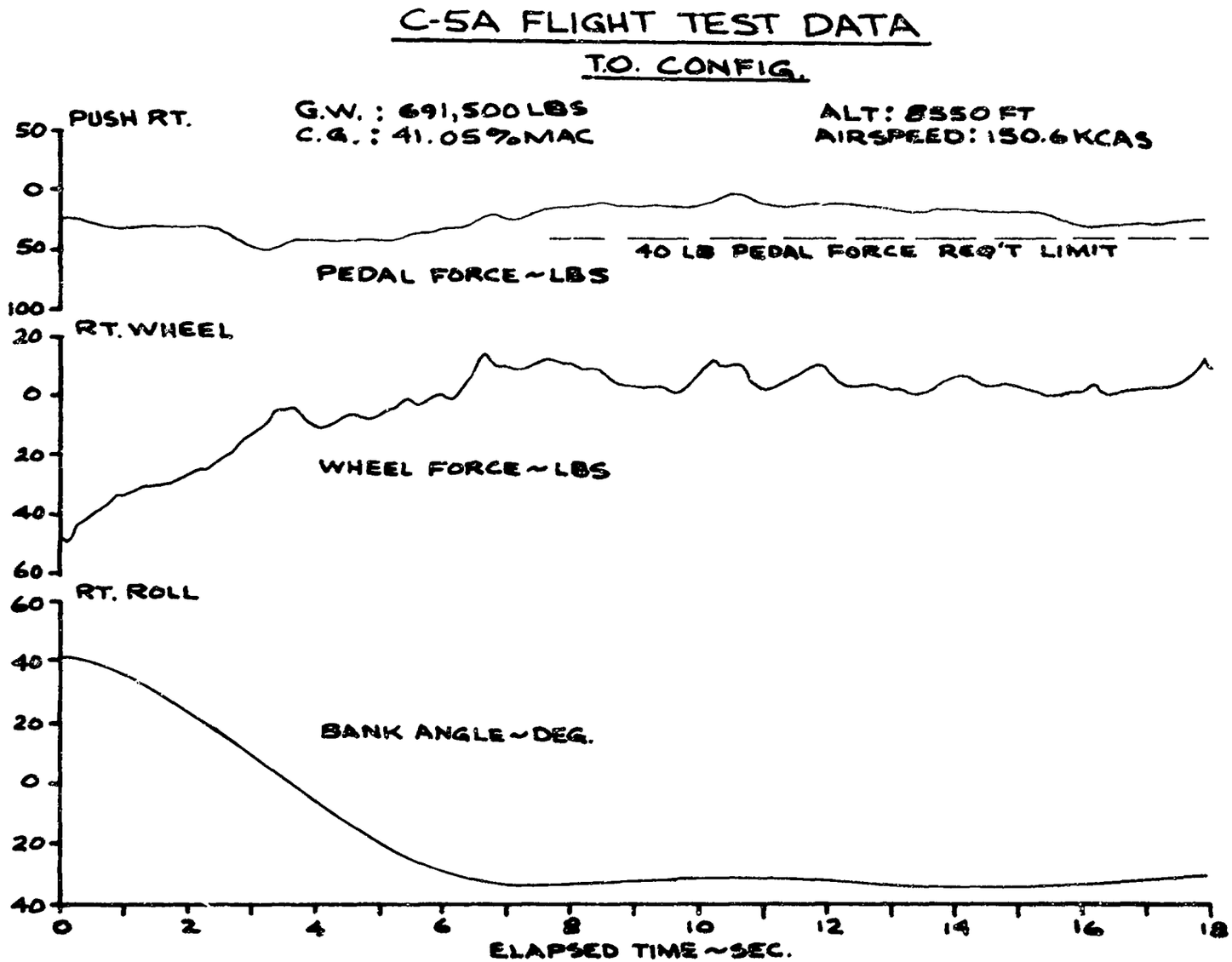


FIGURE NO. 1 (3.3.2.6) PILOT-COORDINATED ABRUPT ROLLS

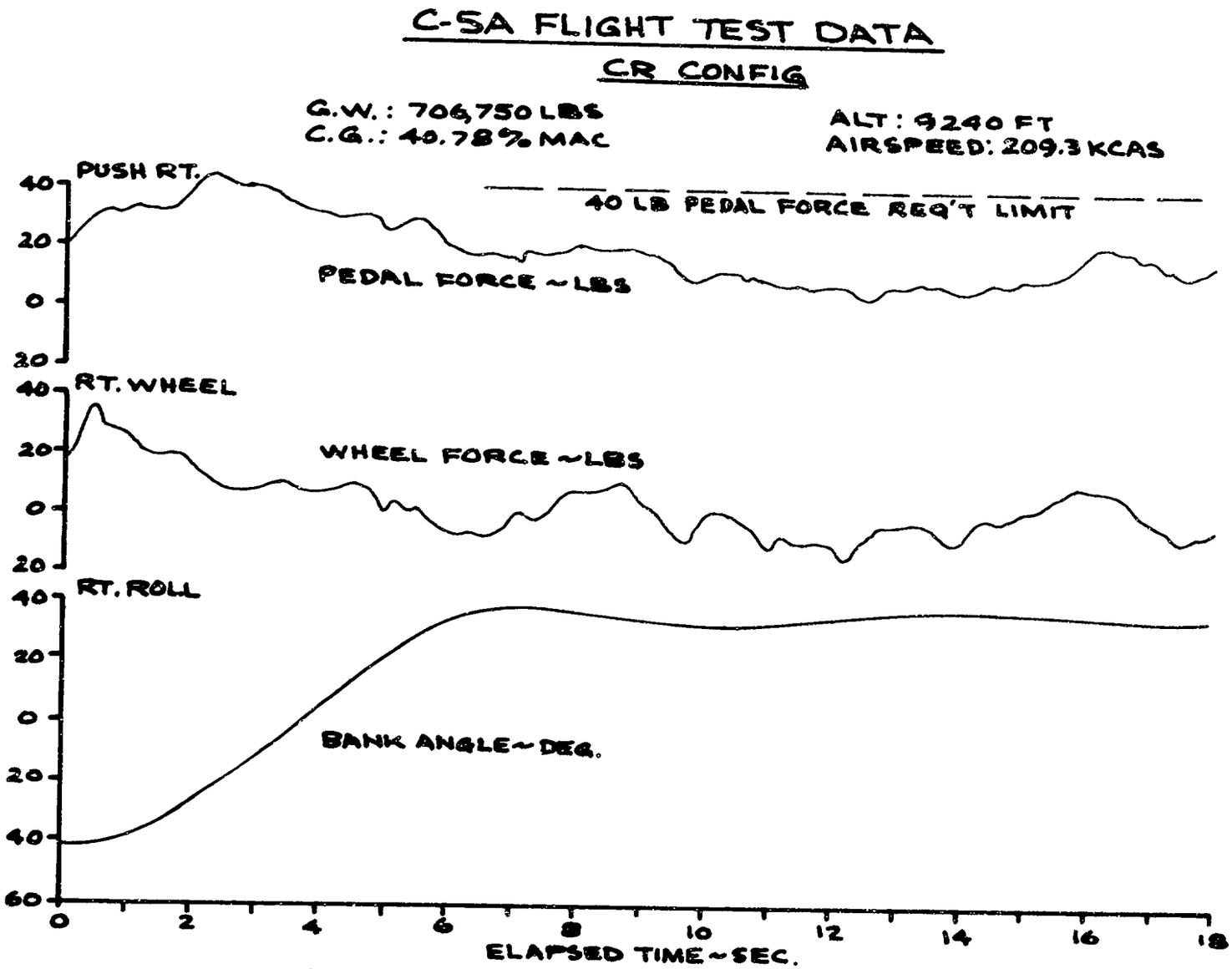


FIGURE NO. 2 (3.3.2.6) PILOT-COORDINATED ABRUPT ROLLS

C-5A FLIGHT TEST DATA

CR CONFIG

G.W.: 704,950 LBS
C.G.: 40.81 % MAC

ALT: 8520 FT
AIRSPEED: 206.7 KCAS

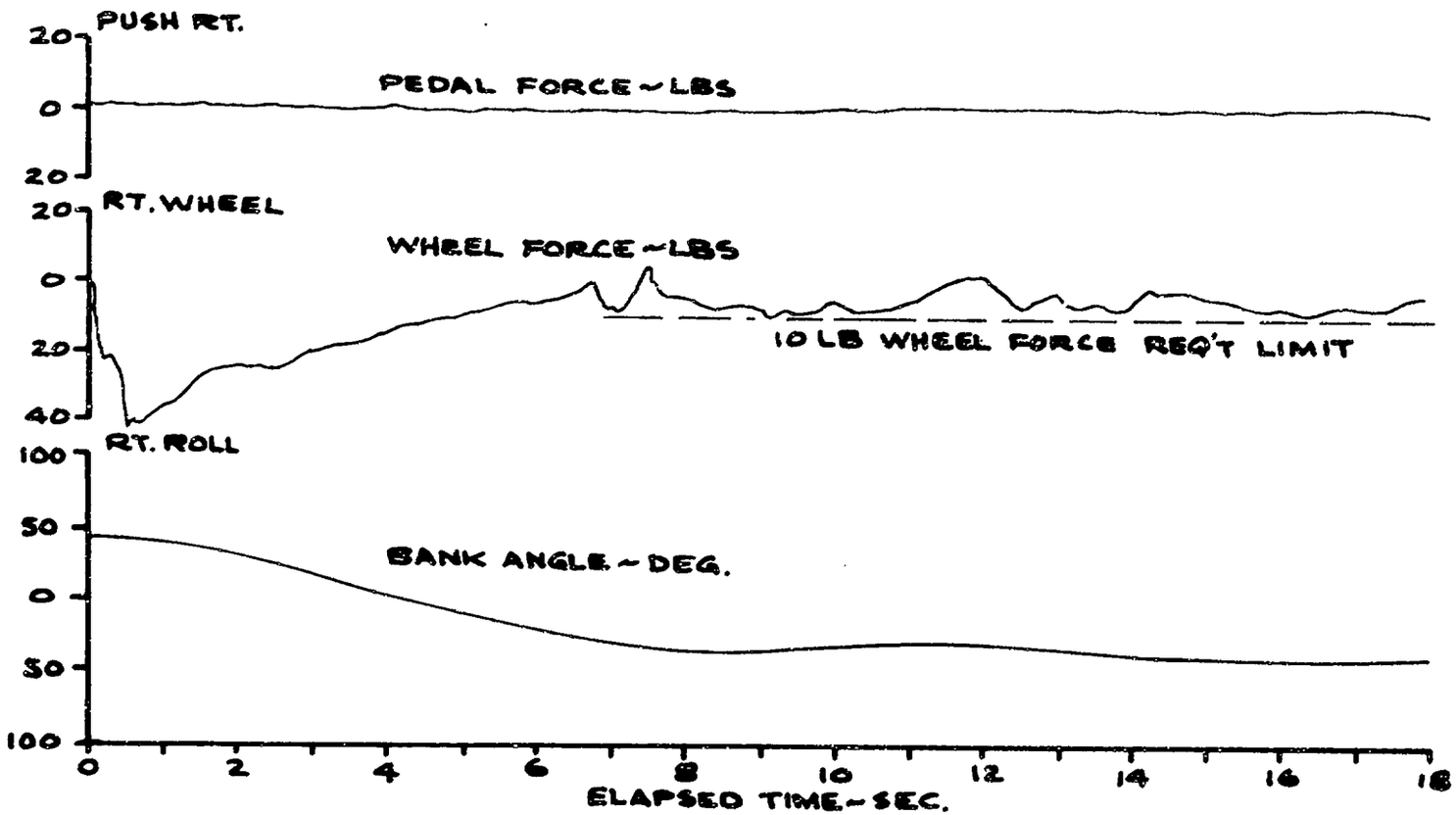


FIGURE NO. 3 (3.3.2.6) UNCOORDINATED ABRUPT ROLLS

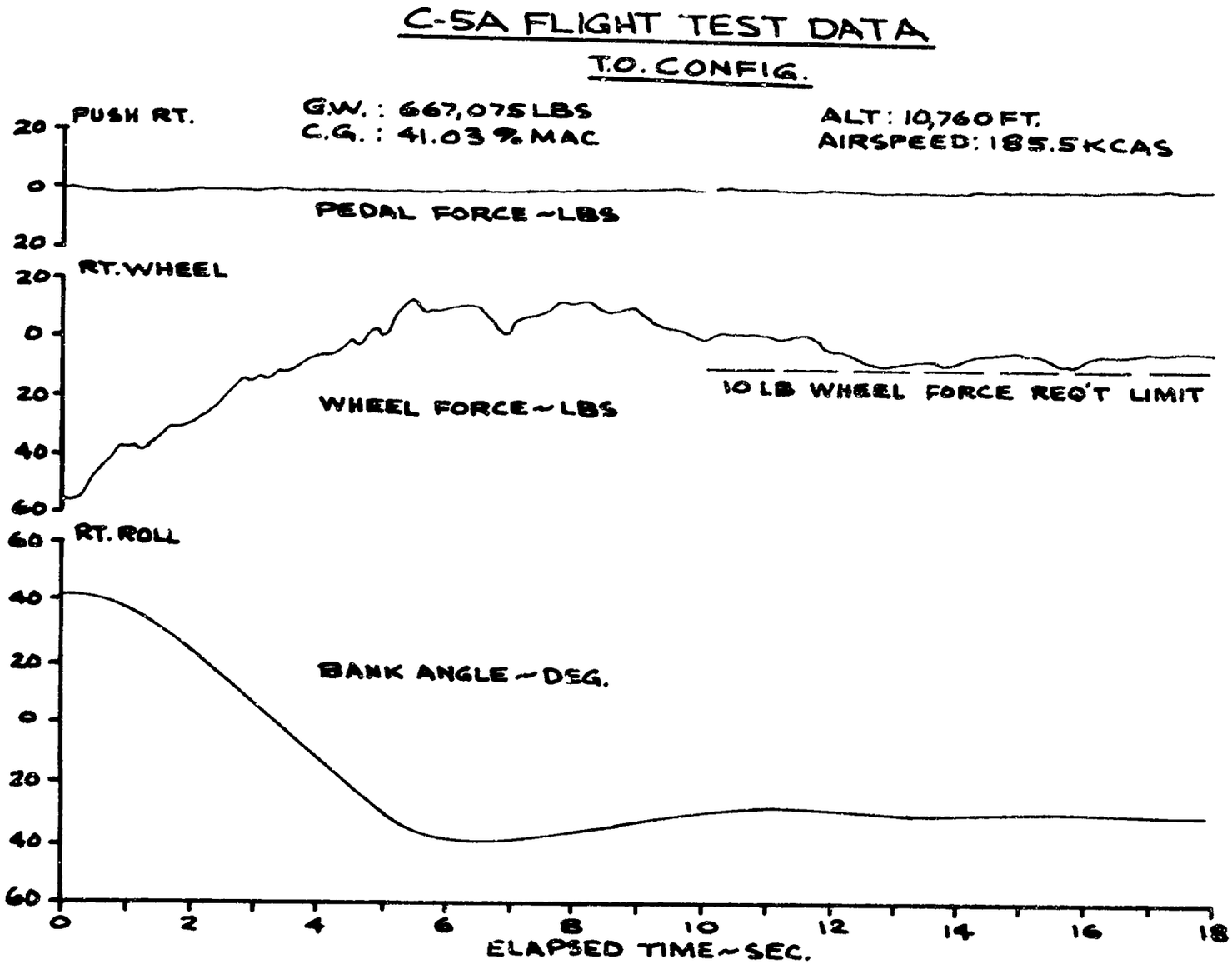


FIGURE NO.4 (3.3.2.6) UNCOORDINATED ABRUPT ROLLS

Requirement

3.3.3 Pilot-induced oscillations. There shall be no tendency for sustained or uncontrollable lateral-directional oscillations resulting from effort of the pilot to control the airplane.

Comparison

No pilot-induced oscillations occur on the C-5A.

Discussion

None

Recommendation

None

Requirement

3.3.4 Roll control effectiveness. Roll performance in terms of bank angle change in a given time, ϕ_t, is specified in table IX and in 3.3 4.1 Aileron control commands shall be initiated from zero roll rate in the form of abrupt inputs, with time measured from the initiation of control-force application. Rudder pedals shall remain free for Class IV airplanes for Level 1, and for all carrier-based airplanes in Category C Flight Phases for Levels 1 and 2; but otherwise, rudder pedals may be used to reduce sideslip that retards roll rate (not to produce sideslip that augments roll rate) if rudder pedal inputs are simple, easily coordinated with aileron-control inputs, and consistent with piloting techniques for the airplane Class and mission. Roll control shall be sufficiently effective to balance the airplane in roll throughout the Service Flight Envelope in the atmospheric disturbances of 3.7.3 and 3.7.4.

Comparison

Roll performance data are presented in figures 1 (3.3.4) and 2 (3.3.4) for Flight Phase Categories B and C. In Category B, the AD configuration meets Level 2 requirements and the CR configuration meets Level 3 requirements. In Category C, the L configuration meets Level 2 requirements, and the TO configuration meets Level 3 requirements.

Discussion

The C-5A was designed to meet the specifications of CP40002. In the L configuration, the design requirement of 1.0 second elapsed time for an 8.0 degree bank angle change at the normal approach speed was not achieved. However, the roll acceleration available was considered satisfactory by the Joint Test Team on the basis of the offset landing maneuver, which was considered a practical test of lateral directional maneuver ability. The offset landing maneuver consists of approaching the runway with a 200 foot lateral misalignment on a 3 degree glideslope. At an altitude of 200 feet, the airplane is aligned with the runway centerline prior to touchdown. In the CR configuration, the specifications that pertain to time to change bank angle and time to attain peak roll rate with symmetric thrust were not satisfied. However, lateral control capability was still considered to be acceptable by the Joint Test Team.

From the Background Information and User Guide for Mil-F-8785B (ASG), it appears that Requirement 3.3.4 levels have been arbitrarily selected for lack of conflicting data. Results from the C-5A airplane demonstrate that a heavy transport airplane can have satisfactory roll performance without meeting the Level 1 limits of Requirement 3.3.4.

In order to meet the Level 1 requirements, the lateral control system would have to be improved to attain a higher bank angle change in the first second of roll. On an aircraft with a very large rolling moment of inertia, this would be difficult to accomplish. Increasing the initial roll response of the C-5A would further aggravate the very noticeable side kick, or lateral acceleration component, in the cockpit and troop compartment that is experienced during full abrupt control input. The side kick occurs since the cockpit and troop compartment are located considerably above the principal roll axis of the airplane.

Table IX. Roll Performance Requirements

CLASS	FLIGHT PHASE CATEGORY	LEVEL 1	LEVEL 2**	LEVEL 3
I	A	$\phi_t = 60^\circ$ in 1.3 sec	$\phi_t = 60^\circ$ in 1.7 sec	$\phi_t = 60^\circ$ in 2.6 sec
	B	$\phi_t = 60^\circ$ in 1.7 sec	$\phi_t = 60^\circ$ in 2.5 sec	$\phi_t = 60^\circ$ in 3.4 sec
	C+	$\phi_t = 30^\circ$ in 1.3 sec	$\phi_t = 30^\circ$ in 1.8 sec	$\phi_t = 30^\circ$ in 2.6 sec
II	A	$\phi_t = 45^\circ$ in 1.4 sec	$\phi_t = 45^\circ$ in 1.9 sec	$\phi_t = 45^\circ$ in 2.8 sec
II	B	$\phi_t = 45^\circ$ in 1.9 sec	$\phi_t = 45^\circ$ in 2.8 sec	$\phi_t = 45^\circ$ in 3.8 sec
II-L	C+	$\phi_t = 30^\circ$ in 1.8 sec	$\phi_t = 30^\circ$ in 2.5 sec	$\phi_t = 30^\circ$ in 3.6 sec
II-C	C+	$\phi_t = 25^\circ$ in 1.0 sec	$\phi_t = 25^\circ$ in 1.5 sec	$\phi_t = 25^\circ$ in 2.0 sec
III	A	$\phi_t = 30^\circ$ in 1.5 sec	$\phi_t = 30^\circ$ in 2.0 sec	$\phi_t = 30^\circ$ in 3.0 sec
	B	$\phi_t = 30^\circ$ in 2.0 sec	$\phi_t = 30^\circ$ in 3.0 sec	$\phi_t = 30^\circ$ in 4.0 sec
	C+	$\phi_t = 30^\circ$ in 2.5 sec	$\phi_t = 30^\circ$ in 3.2 sec	$\phi_t = 30^\circ$ in 4.0 sec
IV	A*	$\phi_t = 90^\circ$ in 1.3 sec	$\phi_t = 90^\circ$ in 1.7 sec	$\phi_t = 90^\circ$ in 2.6 sec
	B	$\phi_t = 90^\circ$ in 1.7 sec	$\phi_t = 90^\circ$ in 2.5 sec	$\phi_t = 90^\circ$ in 3.4 sec
	C+	$\phi_t = 30^\circ$ in 1.0 sec	$\phi_t = 30^\circ$ in 1.3 sec	$\phi_t = 30^\circ$ in 2.0 sec

* Except as the requirements are modified in 3.3.4.1.

** At altitudes below 20,000 feet at the high-speed boundary of the Service Flight Envelope, the Level 3 requirements may be substituted for the Level 2 requirements with all systems functioning normally.

\+ For takeoff, the required bank angle can be reduced proportional to the ratio of the maximum rolling moment of inertia for the maximum authorized landing weight to the rolling moment of inertia at takeoff, but the Level 1 requirement shall not be reduced below the listed value for Level 3.

Recommendations

The Class III roll control effectiveness requirements appear to be too stringent for Class III airplanes. These requirements should be further investigated and reevaluated with additional Class III data.

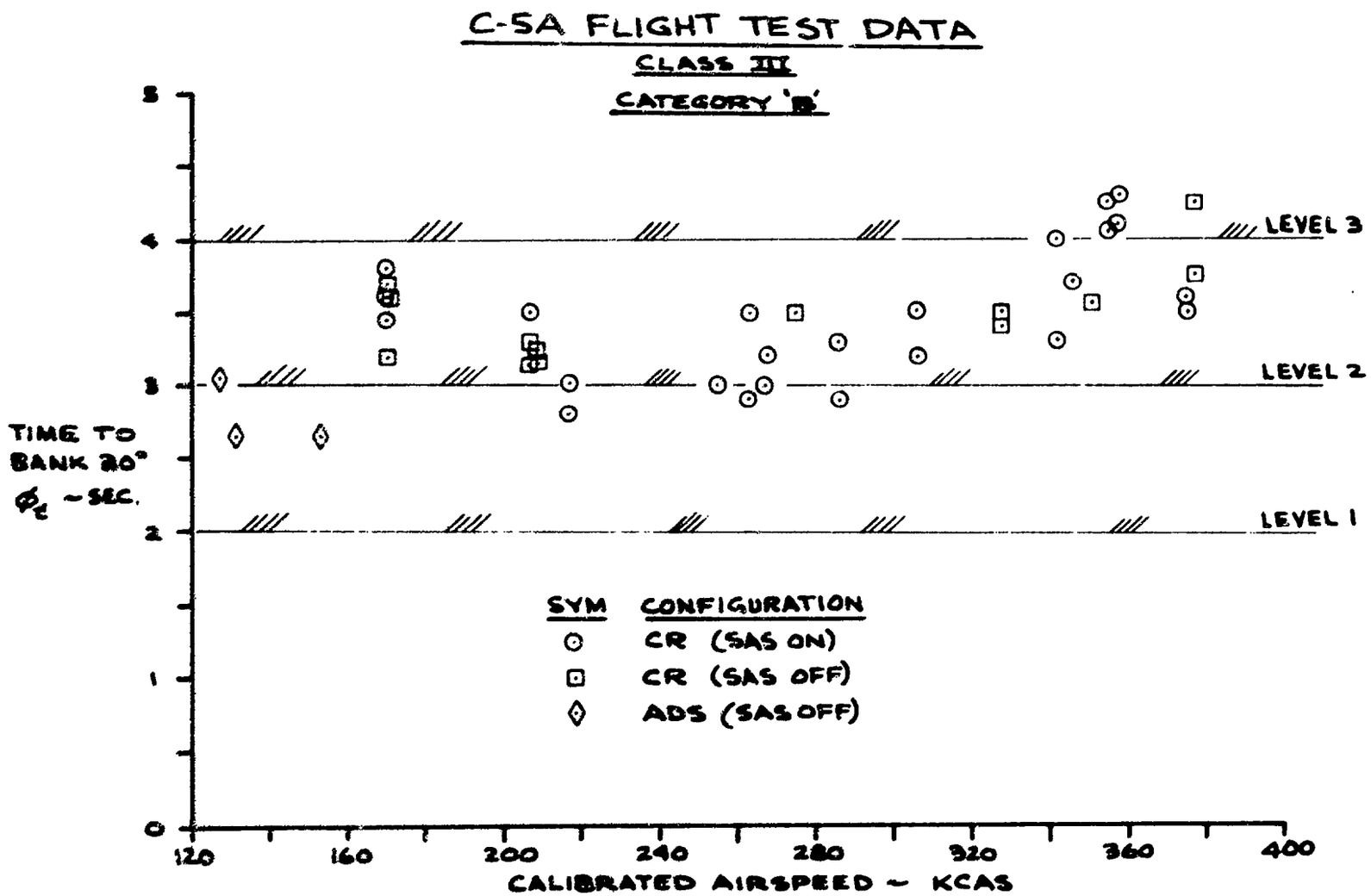


FIGURE NO. 1 (3.3.4) ROLL PERFORMANCE

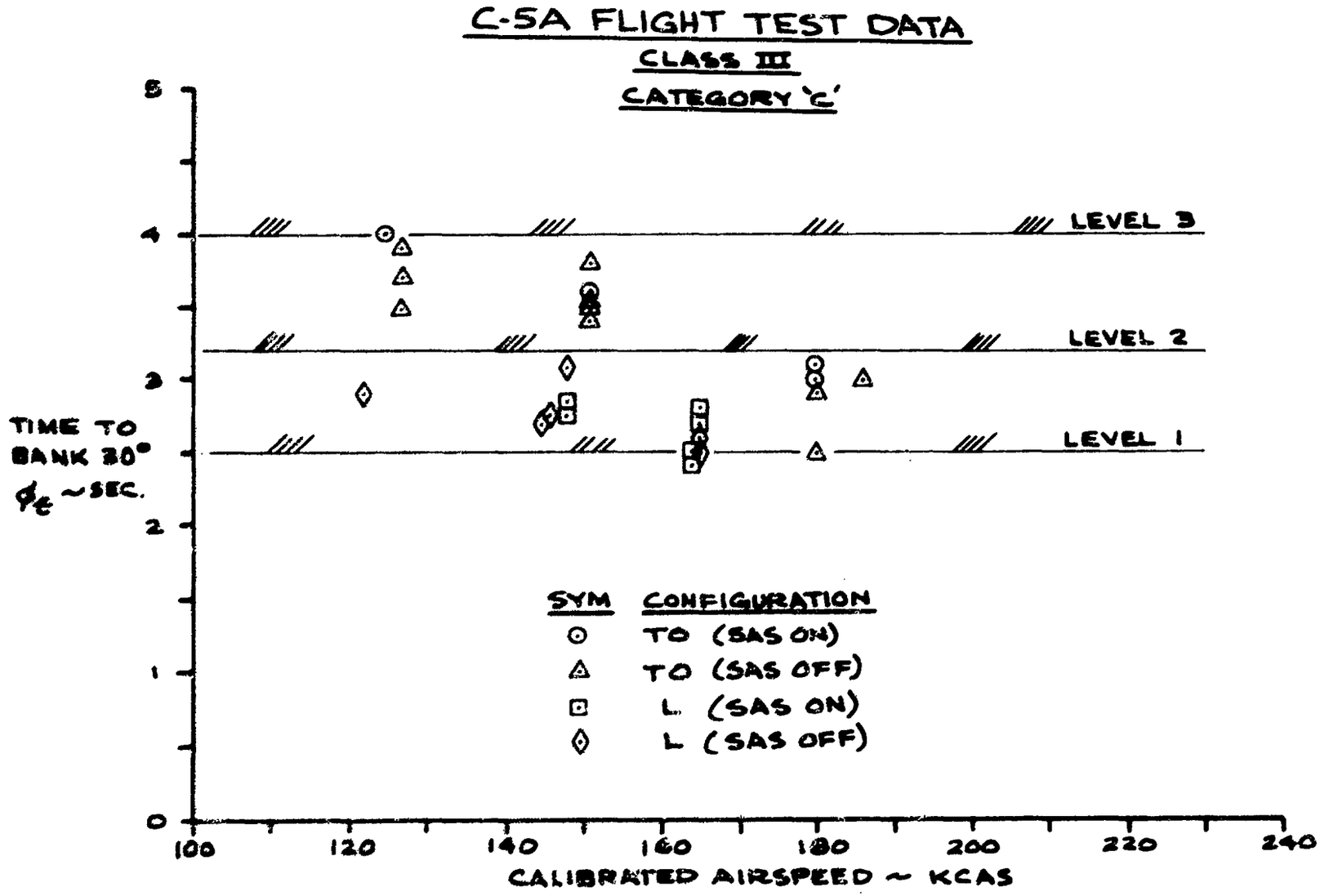


FIGURE NO.2 (3.3.4) ROLL PERFORMANCE

Requirement

3.3.4.1 Roll performance for Class IV airplanes. Additional or alternate roll performance requirements are specified for Class IV airplanes in 3.3.4.1.1 through 3.3.4.1.4. These requirements take precedence over table IX.

3.3.4.1.1 Air-to-air combat. For Class IV airplanes in Flight Phase CO, the roll performance requirements are:

	Time to roll through	
	90 degrees	360 degrees
a. Level 1	1.0 second	2.8 seconds
b. Level 2	1.3 seconds	3.3 seconds
c. Level 3	1.7 seconds	4.4 seconds

3.3.4.1.2 Ground attack with external stores. The roll performance requirements for Class IV airplanes in Flight Phase GA, with large complements of external stores, may be relaxed from those specified in table IX, subject to approval by the procuring activity. For any external loading specified in the contract, however, the roll performance shall not be less than:

a. Level 1 . . . . . 90 degrees in 1.7 seconds

b. Level 2 . . . . . 90 degrees in 2.6 seconds

c. Level 3 . . . . . 90 degrees in 3.4 seconds

For any asymmetric loading specified in the contract, aileron control power shall be sufficient to hold the wings level at the maximum load factors specified in 3.2.3.2 in the atmospheric disturbances of 3.7.3.

3.3.4.1.3 Roll rate characteristics for ground attack. Class IV airplanes in Flight Phase GA shall be able to roll through 180 degrees in not more than twice the time to roll through 90 degrees. This requirement specifies Level 1 with the rudder pedals remaining free throughout the maneuver and Levels 2 and 3 with the rudder pedals employed to reduce sideslip in the manner described in 3.3.4.

3.3.4.1.4 Roll response. Stick-controlled Class IV airplanes in Category A Flight Phases shall have a roll response to aileron control force not greater than 15 degrees in 1 second per pound for Level 1, and not greater than 25 degrees in 1 second per pound for Level 2. For Category C Flight Phases, the roll sensitivity shall be not greater than 7.5 degrees in 1 second per pound for Level 1, and not greater than 12.5 degrees in 1 second per pound for Level 2. In case of conflict between the requirements of 3.3.4.1.4 and 3.3.4.2, the requirements of 3.3.4.1.4 shall govern.

Comparison

Not applicable

Discussion

None

Recommendation

None

Requirement

3.3.4.2 Aileron control forces. The stick or wheel force requirement to obtain the rolling performance specified in 3.3.4 and 3.3.4.1 shall be neither greater than the maximum in table X nor less than the breakout force plus:

a. Level 1 - one-fourth the values in table X

b. Level 2 - one-eighth the values in table X

c. Level 3 - zero

Table X. Maximum Aileron Control Force

Level	Class	Flight Phase Category	Maximum Stick Force (lb)	Maximum Wheel Force (lb)
1	I, II-C, IV	A, B	20	40
		C	20	20
	II-L, III	A, B	25	50
		C	25	25
2	I, II-C, IV	A, B	30	60
		C	20	20
	II-L, III	A, B	30	60
		C	30	30
3	All	All	35	70

Comparison

For the C-5A airplane, this requirement translates into the following:

Level	Category	Maximum Wheel Force	Minimum Wheel Force
1	A, B	50	18
	C	25	11
2	A, B	60	13
	C	30	9
3	A, B, C	70	0

The C-5 lateral flight control system consists of an irreversible artificial feel system which meets the Level 1 requirements for all Flight Phase Categories. The maximum wheel force is approximately 20 to 25 pounds. Figure 1 (3.3.4.2) presents the control wheel forces for the L and CR configurations.

Lateral control breakout forces obtained from ground tests and substantiated by inflight testing complied with the CP 40002 specification allowable limit of 6.0 pounds. From reference 2, the breakout forces are the following:

Direction	Breakout Force	PACS	Flaps	Spoilers
RT	4.4	On	0°	Retracted
LT	5.4	On	0°	Retracted
RT	5.5	On	40°	Retracted
LT	5.2	On	40°	Retracted

Discussion

None

Recommendation

None

C-5A FLIGHT TEST DATA

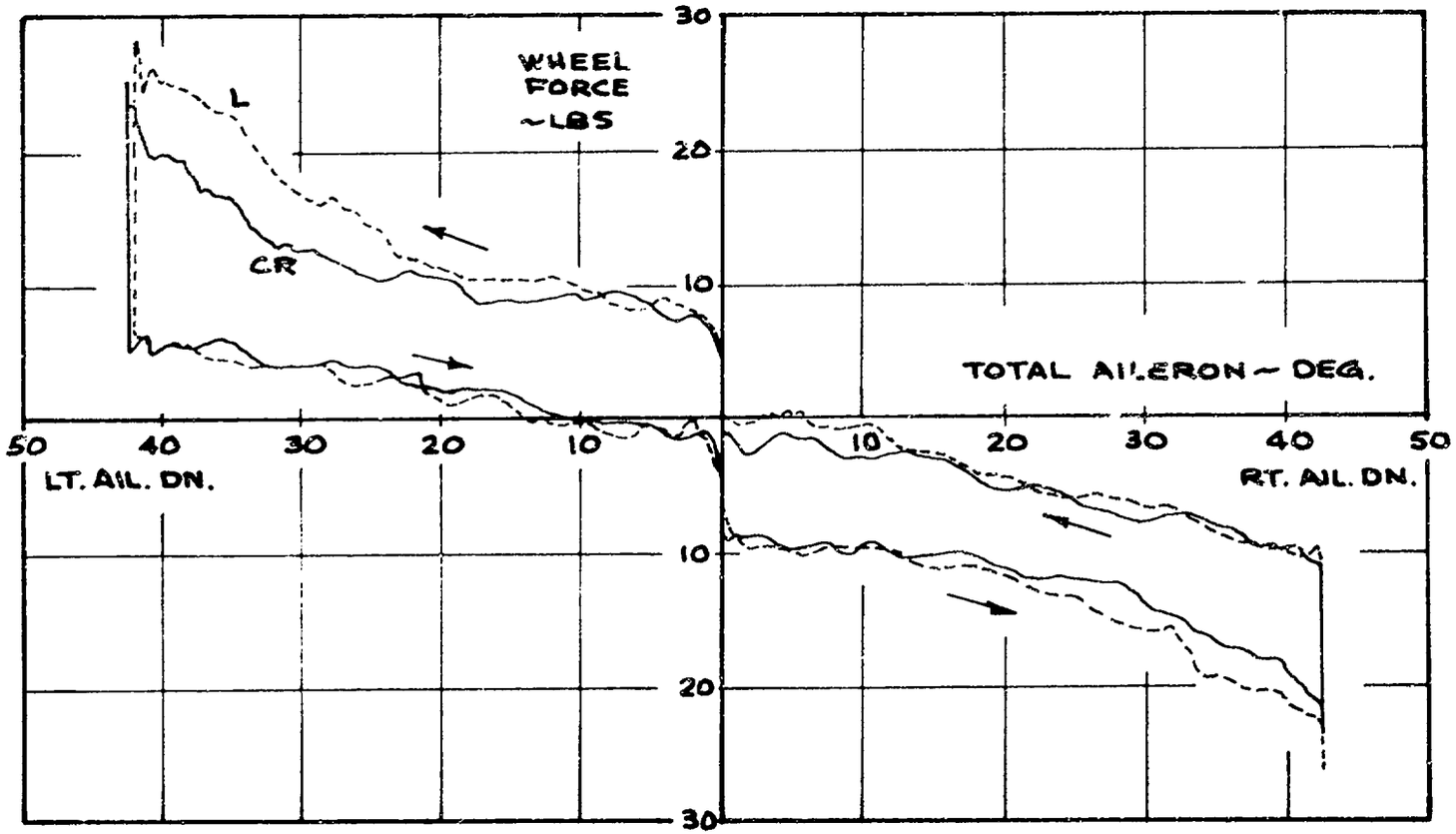


FIGURE NO.1 (3.3.4.2) AILERON CONTROL WHEEL FORCES

Requirement

3.3.4.3 Linearity of roll response. There shall be no objectionable nonlinearities n the variation of rolling response with aileron control deflection or force. Sensitivity or sluggishness in response to small aileron control deflections or forces shall be avoided.

Comparison

The variation of roll rate with wheel deflection was found to be essentially linear with a slight increase in roll-rate to wheel-deflection ratio with increasing wheel deflection for all configurations tested. Figure 1 (3.3.4.3) presents roll response for three flight conditions.

Discussion

None

Recommendations

None

C-5A FLIGHT TEST DATA

	FLAPS UP	25° FLAPS	40° FLAPS
G.W.:	707,000 LBS	667,000 LBS	709,000 LB
AIRSPEED:	205 KCAS	182 KCAS	148 KCAS
ALTITUDE:	9300 FT	10800 FT	10800 FT
SAS:	OFF	OFF	ON

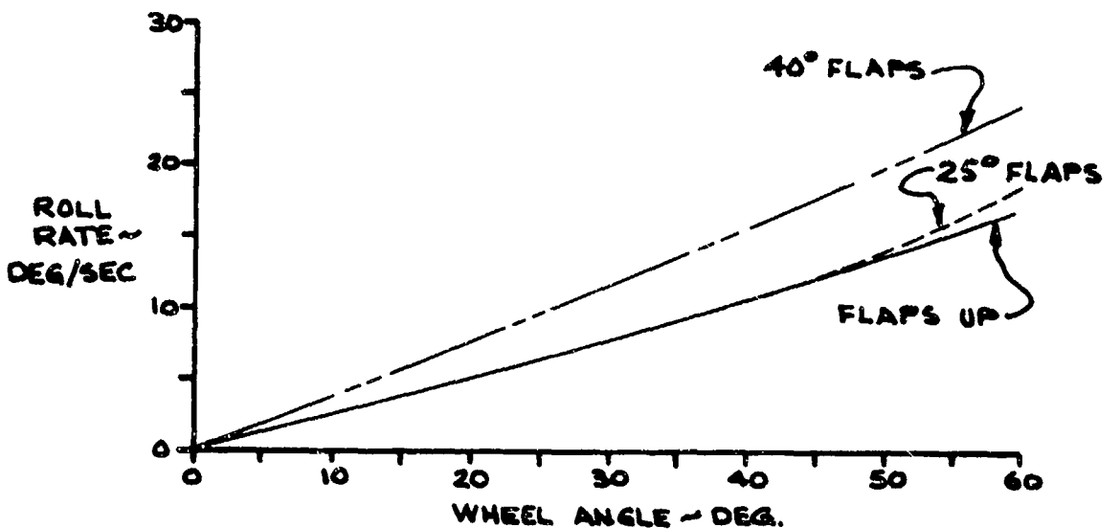


FIGURE NO. 1 (3.3.4.3) ROLL RESPONSE

Requirement

3.3.4.4 Wheel control throw. For airplanes with wheel controllers, the wheel throw necessary to meet the roll performance requirements specified in 3.3.4 shall not exceed 60 degrees in either direction. For completely mechanical systems, the requirement may be relaxed to 80 degrees.

Comparison

The nominal wheel deflection for full lateral control is 60 degrees. This has been considered more desirable than the 90 or 120 degrees used on earlier cargo aircraft.

Discussion

Recommendation

None

Requirement

3.3.4.5 Rudder-pedal-induced rolls. For Levels 1 and 2, it shall be possible to raise a wing by use of rudder pedal alone, with right rudder pedal force required for right rolls and left rudder pedal force required for left rolls. For Level 1, with the aileron control free, it shall be possible to produce a roll rate of 3 degrees per second with an incremental rudder pedal force of 50 pounds or less. The specified roll rate shall be attainable from coordinated turns at up to ± 30 degrees bank angle with the airplane trimmed for wings-level, zero-yaw-rate flight.

Comparison

None

Discussion

Class III aircraft are not normally flown in this manner.

Recommendation

None

Requirement

3.3.5 Directional control characteristics. Directional stability and control characteristics shall enable the pilot to balance yawing moments and control yaw and sideslip. Sensitivity to rudder pedal forces shall be sufficiently high that directional control and force requirements can be met and satisfactory coordination can be achieved without unduly high rudder pedal forces, yet sufficiently low that occasional improperly coordinated control inputs will not seriously degrade the flying qualities.

Comparison

The C-5A possesses sufficient directional control, with symmetric thrust, to maintain wings-level straight flight with a minimum of rudder or aileron control input throughout the speed envelope for each airplane configuration. In no case did the pedal force exceed 70 pounds. The ability to generate sideslip is discussed under paragraph 3.3.6 on static lateral-directional stability.

Discussion

None

Recommendations

None

Requirement

3.3.5.1 Directional control with speed change. When initially trimmed directionally with symmetric power, the trim changes of propeller-driven airplanes with speed shall be such that wings-level straight flight can be maintained over a speed range of ± 30 percent of the trim speed or ± 100 knots equivalent airspeed, whichever is less (except where limited by boundaries of the Service Flight Envelope), with rudder pedal forces not greater than 100 pounds for Levels 1 and 2 and not greater than 180 pounds for Level 3, without re-trimming. For other airplanes, rudder pedal forces shall not exceed 40 pounds at the specified conditions for Levels 1 and 2 nor 180 pounds for Level 3.

Comparison

The C-5A does not experience directional control forces introduced by speed changes.

Discussion

None

Recommendations

None

Requirement

3.3.5.1.1 Directional control with asymmetric loading. When initially trimmed directionally with each asymmetric loading specified in the contract at any speed in the Operational Flight Envelope, it shall be possible to maintain a straight flight path throughout the Operational Flight Envelope with rudder pedal forces not greater than 100 pounds for Levels 1 and 2 and not greater than 180 pounds for Level 3, without retrimming.

Comparison

This requirement is not applicable to the C-5A.

Discussion

None

Recommendations

None

Requirement

3.3.5.2 Directional control in wave-off (go-around). For propeller-driven Class IV and all propeller-driven carrier based airplanes, the response to thrust, configuration, and airspeed change shall be such that the pilot can maintain straight flight during wave-off (go-around) initiated at speeds down to V_S (PA) with rudder pedal forces not exceeding 100 pounds when trimmed at V_{omin} (PA). For other airplanes, rudder pedal forces shall not exceed 40 pounds for the specified conditions. The preceding requirements apply for Levels 1 and 2. For all airplanes, the Level 3 requirement is to maintain straight flight in these conditions with rudder pedal forces not exceeding 180 pounds. For all levels, bank angles up to 5 degrees are permitted.

Comparison

No directional control forces are introduced as the result of power charges.

Discussion

None

Recommendation

None

Requirement

3.3.6 Lateral-directional characteristics in steady sideslips. The requirements of 3.3.6.1 through 3.3.6.3.1 and 3.3.7.1 are expressed in terms of characteristics in rudder-pedal-induced steady, zero-yaw-rate sideslips with the airplane trimmed for wings-level straight flight. Paragraph 3.3.6.1 through 3.3.6.2 apply at sideslip angles up to those produced or limited by:

a. Full rudder pedal deflection, or

b. 250 pounds of rudder pedal force, or

c. Maximum aileron control or surface deflection,

except that for single-propeller-driven airplanes during wave-off (go-around), rudder pedal deflection in the direction opposite to that required for wings-level straight flight need not be considered beyond the deflection for a 10-degree change in sideslip from the wings-level straight flight condition.

3.3.6.1 Yawing moments in steady sideslips. For the sideslips in 3.3.6, right rudder pedal deflection and force shall produce left sideslips, and left rudder pedal deflection and force shall produce right sideslips. For Levels 1 and 2, the following requirements shall apply. The variation of sideslip angle with rudder pedal deflection shall be essentially linear for sideslip angles between + 15 degrees and - 15 degrees. For larger sideslip angles, an increase in rudder pedal deflection shall always be required for an increase in sideslip. The variation of sideslip angle with rudder pedal force shall be essentially linear for sideslip angles between + 10 degrees and - 10 degrees. Although a lightening of rudder pedal force is acceptable for sideslip angles outside this range, the rudder pedal force shall never reduce to zero.

3.3.6.2 Side forces in steady sideslips. For the sideslips of 3.3.6, an increase in right bank angle shall accompany an increase in right sideslip, and an increase in left bank angle shall accompany an increase in left sideslip.

3.3.6.3 Rolling moments in steady sideslips. For the sideslips of 3.3.6, left aileron-control deflection and force shall accompany left sideslips, and right aileron-control deflection and force shall accompany right sideslips. For Levels 1 and 2, the variation of aileron-control deflection and force with sideslip angle shall be essentially linear.

3.3.6.3.1 Exception for wave-off (go-around). The requirement of 3.3.6.3 may, if necessary, be excepted for wave-off (go-around) if task performance is not impaired and no more than 50 percent of roll control power available to the pilot, and no more than 10 pounds of aileron-control force are required in a direction opposite to that specified in 3.3.6.3.

3.3.6.3.2 Positive effective dihedral limit. For Levels 1 and 2, positive effective dihedral (right aileron control for right sideslip and left aileron control for left sideslip) shall never be so great that more than 75 percent of roll control power available to the pilot, and no more than 10 pounds of aileron stick force or 20 pounds of aileron-wheel force,

are required for sideslip angles which might be experienced in service employment.

Comparison

Static lateral-directional stability characteristics were evaluated by performing stabilized sideslips of increasing magnitude to the right and left up to 15 degrees of sideslip or to maximum control authority. Lateral control was used to obtain sufficient bank angle to maintain a constant heading and airspeed was kept close to trim. Power remained constant and altitude varied slightly. Tests were conducted in the CR, TO, PA, L, ADS, and D configurations.

Static lateral-directional stability was positive and linear for all conditions tested, and no significant change in the aircraft stability was produced by the stability augmentation system.

Right rudder pedal position and force were required for left sideslip and, conversely, for right sideslip. The variation of pedal force and rudder displacement with sideslip angle was essentially linear for angles of sideslip between $\pm$ 15 degrees. No rudder pedal force reduction was encountered.

Side force characteristics were such that an increase in right bank angle accompanies an increase in right sideslip, and the same applies to left bank angle and sideslip. The dihedral effect of the C-5A was positive (left aileron position and force for left sideslip, and conversely), and no more than 75 percent of full aileron control was used in the sideslips flown.

The C-5A meets all the static lateral-directional stability specifications. A full spectrum of test data is presented in reference 2. Summary data are shown in Figure 1 (3.3.6).

Discussion

The C-5A results favorably compare with this requirement.

Recommendations

None

C-5A FLIGHT TEST DATA

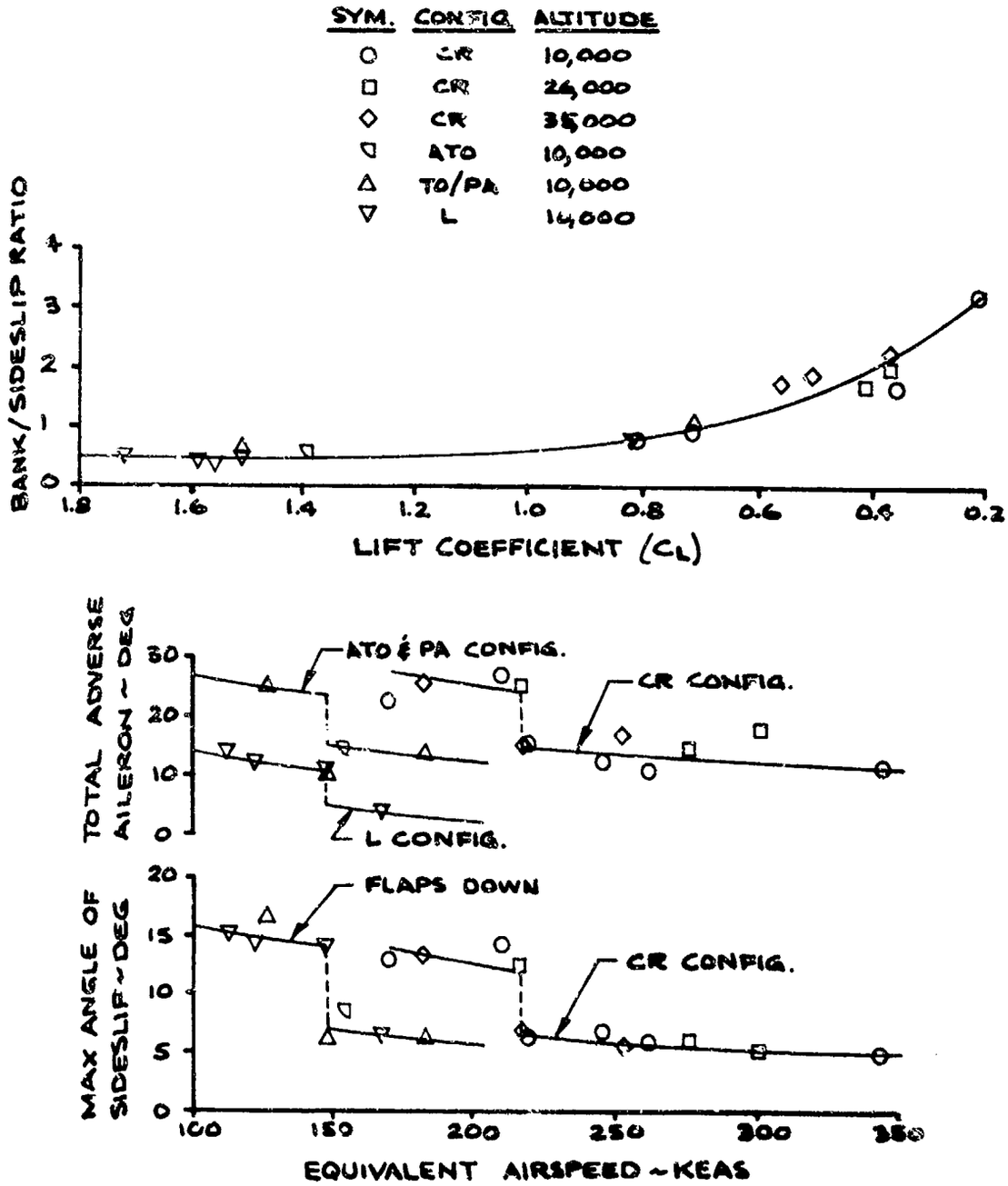


FIGURE NO.1(3.3.6) STATIC LATERAL-DIRECTIONAL STABILITY

Requirement

3.3.7 Lateral-directional control in crosswinds. It shall be possible to take off and land with normal pilot skill and technique in 90-degree crosswinds, from either side, of velocities up to those specified in table XI. Aileron-control forces shall be within the limits specified in 3.3.4.2, and rudder pedal forces shall not exceed 100 pounds for Level 1 nor 180 pounds for Levels 2 and 3. This requirement can normally be met through compliance with 3.3.7.1 and 3.3.7.2.

Table XI. Crosswind Velocity

Level	Class	Crosswind
1 & 2	I	20 knots
	II, III, & IV	30 knots
	Water-based Airplanes	20 knots
3	All	One-half the values for Levels 1 & 2

3.3.7.1 Final approach in crosswinds. For all airplanes except land-based airplanes equipped with crosswind landing gear or otherwise constructed to land in a large crabbed attitude, rudder and aileron-control power shall be adequate to develop at least 10 degrees of sideslip (3.3.6) in the power approach with rudder pedal forces not exceeding the values specified in 3.3.7. For Level 1, aileron control shall not exceed either 10 pounds of force or 75 percent of control power available to the pilot. For Levels 2 and 3, aileron-control force shall not exceed 20 pounds.

3.3.7.2 Takeoff Run and Landing Rollout in Crosswinds. Rudder and aileron-control power, in conjunction with other normal means of control, shall be adequate to maintain a straight path on the ground or other landing surface. This requirement applies in calm air and in crosswinds up to the values specified in table XI with cockpit control forces not exceeding the values in 3.3.7.

Comparison

The C-5A is equipped with a crosswind gear to facilitate takeoffs and landings in crosswinds. Flight test demonstrations of takeoffs and landings were conducted in crosswinds with the gear at zero setting, at undersetting, at the recommended setting, and at an oversetting.

With the crosswind gear set at zero, all handling qualities during takeoffs and landings made in crosswinds up to 29.5 knots and 26 knots, respectively, were judged satisfactory. The wing-down crab technique and recommended threshold speeds were used in landings

with no difficulty in control. For the takeoff at the crosswind condition of 29.5 knots with gusts to 34 knots, a considerable amount of rudder and approximately 3/4 of full wheel throw were required during rotation, lift-off, and initial climbout. Rudder pedal nosewheel steering provided ample control during these takeoffs, and no unusual handling techniques were required.

With the crosswind gear operative, landings were performed at crosswinds up to 30 knots with no unusual characteristics experienced during the landing and rollout. The crosswind gear system washout rate of two degrees per second at speeds below 50 KCAS was smooth and completely satisfactory. Takeoffs were performed at crosswinds up to 30 knots. Using the chart values for crosswind gear setting, takeoffs from brake release through lift-off were smooth and very satisfactory from a controllability standpoint. On takeoffs where the gear was underset 5.0 degrees from the chart angle, approximately 2 to 3 degrees of bank angle was required to maintain a straight flight path climbout. The automatic landing system has demonstrated a capability to easily accommodate crosswinds of 15 knots.

Discussion

The C-5A results support this requirement.

Recommendations

None

Requirement

3.3.7.2.1 Cold- and wet-weather operation. The requirements of 3.3.7.2 apply on wet runways for all airplanes and on snow-packed and icy runways for airplanes intended to operate under such conditions. If compliance is not demonstrated under these adverse runway conditions, directional control shall be maintained by use of aerodynamic controls alone at all airspeeds above 50 knots for Class IV airplanes and above 30 knots for all others. For very slippery runways, the requirement need not apply for crosswind components at which the force tending to blow the airplane off the runway exceeds the opposing tire-runway frictional force with the tires supporting all of the airplane's weight.

Comparison

Flight test data for cold and wet weather operation in crosswinds are not available. Figure 1 (3.3.7.2.1) presents crosswind limitations on the C-5 for various runway condition readings (RCR). An RCR value of 5 corresponds to an icy runway, a value of 12 corresponds to a medium wet runway, and an RCR of 23 indicates a dry runway.

Pilot comments indicate that directional control is effective at airspeeds above 50 knots.

Discussion

Paragraph 3.3.7.2.1 requires identical crosswind capability for dry, wet, and icy runways for all airplanes capable of operating under those conditions. Such capability may not be necessary or desirable for aircraft which might only occasionally experience such adverse weather conditions. Allowable crosswind components with adverse runway conditions are often based on runway condition reading. As RCR decreases, the maximum allowable crosswind also decreases. Whereas the requirements of 3.3.7.2.1 are quite specific regarding magnitudes of crosswinds, they are vague concerning runway slipperiness. Perhaps the procuring office should specify crosswind capability under adverse weather conditions.

Recommendations

None

TAKEOFF GR WT (1000 LB)	LANDING GR WT (1000 LB)	REPORTED RCR										
		12 & ABOVE	11	10	9	8	7	6	5	4	3	2
630 & ABOVE	565 & ABOVE	30	27	24	21	18	15	12	9	6	3	0
610	540	29	26	23	20	17	15	12	9	6	3	0
585	510	28	25	22	20	17	14	11	8	6	3	0
560	480	27	24	22	19	16	14	11	8	5	3	0
540	450	26	23	21	18	16	13	10	8	5	3	0
510	420	25	22	20	17	15	13	10	8	5	3	0
490	395	24	22	19	17	14	12	10	7	5	2	0
470	370	23	21	18	16	14	12	9	7	5	2	0
450	345	22	20	18	15	13	11	9	7	4	2	0
430	320	21	19	17	15	13	11	8	6	4	2	0
405 & BELOW		20	18	16	14	12	10	8	6	4	2	0

NOTE: 1. Takeoff gross weights are based on the use of 40 percent flaps.

2. The crosswind component values are based upon non-use of landing gear crosswind positioning.

3. Data are computed for normal procedures. Increase of rotation speed or approach speed in accordance with T.O. 1C-5A-1-1 may allow increase in maximum crosswind component.

Figure 1 (3.3.7.2.1). C-5 Maximum Takeoff and Landing Crosswind Component

Requirement

3.3.7.2.2 Carrier-based airplanes. All carrier-based airplanes shall be capable of maintaining a straight path on the ground without the use of wheel brakes, at airspeeds of 30 knots and above, during takeoffs and landings in a 90-degree crosswind of at least 10 percent V_S (L). Cockpit control forces shall be as specified in 3.3.7.

Comparison

Not applicable.

Discussion

None

Recommendation

None

Requirement

3.3.7.3 Taxiing wind speed limits. It shall be possible to taxi at any angle to a 35-knot wind for Class I airplanes and to a 45-knot wind for Class II, III, and IV airplanes.

Comparison

The C-5A engine operating limitations in crosswind and tailwind conditions, presented in Figure 1 (3.3.7.3), allow unrestricted operation in winds up to 30 knots. Reduced power settings must be observed above 30 knots; and, at 45 knots, sufficient power would not be available to taxi the airplane.

Discussion

It appears that this flying-qualities requirement could impose an engine design penalty, which was probably not the intent of the requirement. It is considered reasonable that the airplane have taxi capability which exceeds the required crosswind component (30 knot) by some margin which needs to be established on the basis of operational experience.

Recommendation

Conduct a review of the impact of this requirement on other currently operating airplanes which employ large, high-power fan engines. Establish the taxi wind requirements as a margin above the required crosswind component on the basis of operational experience, if possible.

C-5A FLIGHT TEST DATA

FORWARD THRUST

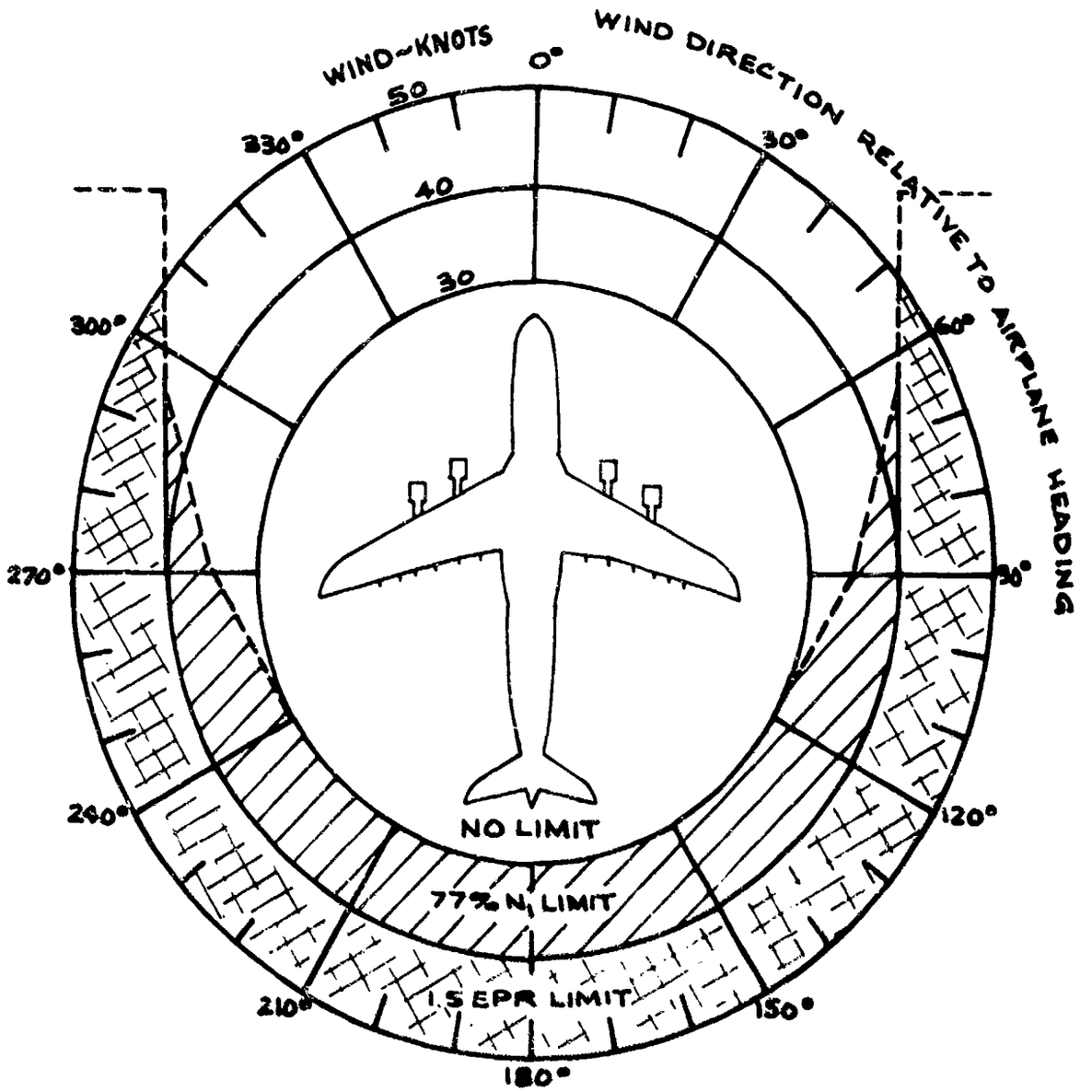


FIGURE NO. 1 (3.3.7.3) ENGINE LIMITATIONS IN CROSSWIND AND TAILWIND

Requirement

3.3.8 Lateral-directional control in dives. Rudder and aileron control power shall be adequate to maintain wings level and sideslip zero without retrimming, throughout the dives and pullouts of 3.2.3.5 and 3.3.3.6. In the Service Flight Envelope, aileron control forces shall not exceed 20 pounds for propeller-driven airplanes nor 10 pounds for other airplanes. Rudder pedal forces shall not exceed 180 pounds for propeller-driven airplanes nor 50 pounds for other airplanes.

Comparison

Evaluation of directional control capabilities during dive tests has shown that wings-level straight flight can be easily maintained with a minimum of rudder or aileron control input throughout the speed envelope for each airplane configuration.

Discussion

None

Recommendations

None

Requirement

3.3.9 Lateral-directional control with asymmetric thrust. Asymmetric loss of thrust may be caused by many factors, including engine failure, inlet unstart, propeller failure, or propeller-drive failure. Following sudden asymmetric loss of thrust from any factor, the airplane shall be safely controllable. The requirements of 3.3.9.1 through 3.3.9.4 apply for the appropriate Flight Phases when any single failure or malperformance of the propulsive system, including inlet or exhaust, causes loss of thrust on one or more engines or propellers, considering also the effect of the failure or malperformance on all subsystems powered or driven by the failed propulsive system.

Comparison

In the takeoff configuration with the most critical outboard engine inoperative and takeoff thrust on the remaining engines, it is possible to control the aircraft and maintain it in straight flight at all speeds above 94 KCAS (1.16Vs at 350,000 pounds) with a bank angle not in excess of 5 degrees. During the air minimum control speed tests, the aircraft does not attain any dangerous attitude nor does it require any exceptional piloting skill to maintain heading.

In the P configuration with the number 1 engine inoperative and the remaining engine/engines developing normal rated thrust, the aircraft is capable of straight flight at 1.3Vs without the application of rudder, using only bank angle and sideslip as control.

With two critical engines inoperative, sufficient directional control is available to hold steady heading with a bank angle of no more than 5 degrees while trimmed at speeds of 1.4Vs or more in the P configuration. It is also possible to make reasonable, sudden 15-degree heading changes in either direction.

Discussion

None

Recommendations

None

Requirement

3.3.9.1 Thrust loss during takeoff run. It shall be possible for the pilot to maintain control of an airplane on the takeoff surface following sudden loss of thrust from the most critical factor. Thereafter, it shall be possible to achieve and maintain a straight path on the takeoff surface without a deviation of more than 30 feet from the path originally intended, with rudder pedal forces not exceeding 180 pounds. For the continued takeoff, the requirement shall be met when thrust is lost at speeds from the refusal speed (based on the shortest runway from which the airplane is designed to operate) to the maximum takeoff speed, with takeoff thrust maintained on the operative engine(s), using only elevator, aileron, and rudder controls. For the aborted takeoff, the requirement shall be met at all speeds below the maximum takeoff speed; however, additional controls such as nosewheel steering and differential braking may be used. Automatic devices which normally operate in the event of a thrust failure may be used in either case.

Comparison

The C-5A has been designed to meet a deviation of 25 feet due to a sudden loss of thrust during takeoff.

Discussion

None

Recommendations

None

Requirement

3.3.9.2 Thrust loss after takeoff. During takeoff, it shall be possible without a change in selected configuration to achieve straight flight following sudden asymmetric loss of thrust from the most critical factor at speeds from V_{min} (TO) to V_{max} (TO), and thereafter to maintain straight flight throughout the climb-out. The rudder pedal force required to maintain straight flight with asymmetric thrust shall not exceed 180 pounds. Aileron control shall not exceed either the force limits specified in 3.3.4.2 or 75 percent of available control power, with takeoff thrust maintained on the operative engine(s) and trim at normal settings for takeoff with symmetric thrust. Automatic devices which normally operate in the event of a thrust failure may be used, and the airplane may be banked up to 5 degrees away from the inoperative engine.

Comparison

Results of the dynamic air minimum control speed tests demonstrate that straight flight can be maintained without requiring undue pilot effort or exceptional pilot skill. Rudder pedal force at full rudder control is approximately 120 pounds. Lateral control is less than 75 percent of the available control power.

Discussion

None

Recommendations

None

Requirement

3.3.9.3 Transient effects. The airplane motions following sudden asymmetric loss of thrust shall be such that dangerous conditions can be avoided by pilot corrective action. A realistic time delay (3.4.9) of at least one second shall be considered.

Comparison

Results from dynamic air minimum control speed tests, ground minimum control speed tests, and cruise configuration asymmetric thrust tests indicate that no adverse effects or dangerous motions occur following sudden asymmetric loss of thrust. The C-5A motions after such a loss are easily controllable.

Discussion

None

Recommendations

None

Requirement

3.3.9.4 Asymmetric thrust - rudder pedals free. The static directional stability shall be such that all speeds above $1.4V_{min}$, with asymmetric loss of thrust from the most critical factor while the other engine(s) develop normal rated thrust, the airplane with rudder pedals free may be balanced directionally in steady straight flight. The trim settings shall be those required for wings-level straight flight prior to the failure. Aileron-control forces shall not exceed the Level 2 upper limits specified in 3.3.4.2 for Levels 1 and 2 and shall not exceed the Level 3 upper limits for Level 3.

Comparison

In the clean configuration with the number 1 engine inoperative and the remaining engines developing normal rated thrust, the C-5A is capable of straight flight at $1.3\ V_{S_G}$ without application of rudder, using only bank angle and sideslip as control. Any speed above that demonstrated is less critical from a controllability standpoint for the conditions tested. The aileron control force required for the maneuver is about 10 pounds, much less than the Level 1 maximum. The specification requirements are, therefore, considered satisfied.

Discussion

None

Recommendations

None

Requirement

3.3.9.5 Two engines inoperative. With any engine initially failed, it shall be possible upon failure of the most critical remaining engine to stop the transient motion at the one-engine-out speed for maximum range and, thereafter, to maintain straight flight from that speed to the speed for maximum range with both engines failed. In addition, it shall be possible to effect a safe recovery at any service speed above $V_{o_{min}}$ (CL) following sudden simultaneous failure of the two critical failing engines.

Comparison

The C-5A possesses adequate handling characteristics to control the airplane following loss of thrust from the two critical engines.

Discussion

None

Recommendations

None

Requirement

3.4 Miscellaneous flying qualities.

3.4.1 Approach to dangerous flight conditions. Dangerous conditions may exist where the airplane should not be flown. When approaching these flight conditions, it shall be possible by clearly discernible means for the pilot to recognize the impending dangers and take preventive action. Final determination of the adequacy of all warning of impending dangerous flight conditions will be made by the procuring activity, considering functional effectiveness and reliability. Devices may be used to prevent entry to dangerous conditions only if the criteria for their design, and the specific devices, are approved by the procuring activity.

3.4.1.1 Warning and indication. Warning or indication of approach to a dangerous condition shall be clear and unambiguous. For example, a pilot must be able to distinguish readily among stall warning (which requires pitching down or increasing speed), Mach buffet (which may indicate a need to decrease speed), and normal airplane vibration (which indicates no need for pilot action). If a warning or indication device is required, functional failure of the device shall be indicated to the pilot.

3.4.1.2 Prevention. As a minimum, dangerous-condition-prevention devices shall perform their function whenever needed, but shall not limit flight within the Operational Flight Envelope. Neither normal nor inadvertent operation of such devices shall create a hazard to the aircraft. For Levels 1 and 2, nuisance operation shall not be possible. Functional failure of the device shall be indicated to the pilot.

Comparison

The T-tail configuration of the C-5A provides longitudinal control capability that is sufficient to drive the airplane to angles of attack conditions far in excess of normal stall conditions. However, more than adequate elevator is available for recovery. The C-5A stall is characterized by light airframe buffet, which is difficult to distinguish from light turbulence, with no classic G-break or roll-off. For these reasons, the C-5A is equipped with a stallimiter system which consists of a stall warning function and a stall limiting function. The stall warning function warns of an approach to a stall condition by means of a control column shaker. The stall limiting function provides an audible warning through the interphone system and overhead speakers that the airplane is entering an excessive stall penetration regime. The following description of the stallimiter system is provided not only for the purpose of satisfying the requirements of this section but also for the following sections concerning stall warning and stall characteristics.

Stallimiter System

The stallimiter subsystem has two channels which separately operate the pilot's and copilot's shaker and stall horn event. Each channel is dual within itself and has its own input sensors. Monitoring is provided by a system of comparators which can detect a difference in a pair of channels and light the stallimiter malfunction warning on the annunciator panel.

For each channel, the primary input parameters into the stallimiter computer include angle-of-attack, Mach number, horizontal stabilizer position, engine thrust reversers, and slat position. Output signals include preshaker, shaker, and stall event. The preshaker function is introduced by a thrust reverser relay when inflight thrust reversers are deployed. The preshaker signal activates the pilot and copilot shakers on a schedule which is 2 degrees vane angle of attack below the cruise configuration shaker schedule.

The Mach signal from the CADC is fed through a function generator which provides the basic shape of the stallimiter schedules presented in figure 1 (3.4.1). The angle-of-attack signal for each channel is provided by two servo-positioned angle-of-attack vanes, one located on each side of the forward fuselage at F.S. 610. The signals from the vanes are averaged and scaled to convert from vane angle to angle-of-attack referenced to the fuselage reference line (FRL) as presented in figure 2 (3.4.1). The slat position signal operates to select the cruise or slats/flap-extended schedule in the stallimiter. When in the slats/flaps extended configuration, the slat position signal introduces the stall event suppression schedule which is a function of horizontal stabilizer position as shown in figure 1 (3.4.1).

Ground test of the stallimiter system is accomplished by a combination of built-in test equipment (BITE) and ground operation of the stallimiter input sensors to provide shaker and stall event output signals from the stallimiter computer.

Discussion

The C-5A stallimiter system has proven to be a safe and dependable means of providing stall warning and stall limiting. There have been no adverse comments received from the operational fleet. C-5A results support this requirement.

Recommendation

None

C-5A FLIGHT TEST DATA

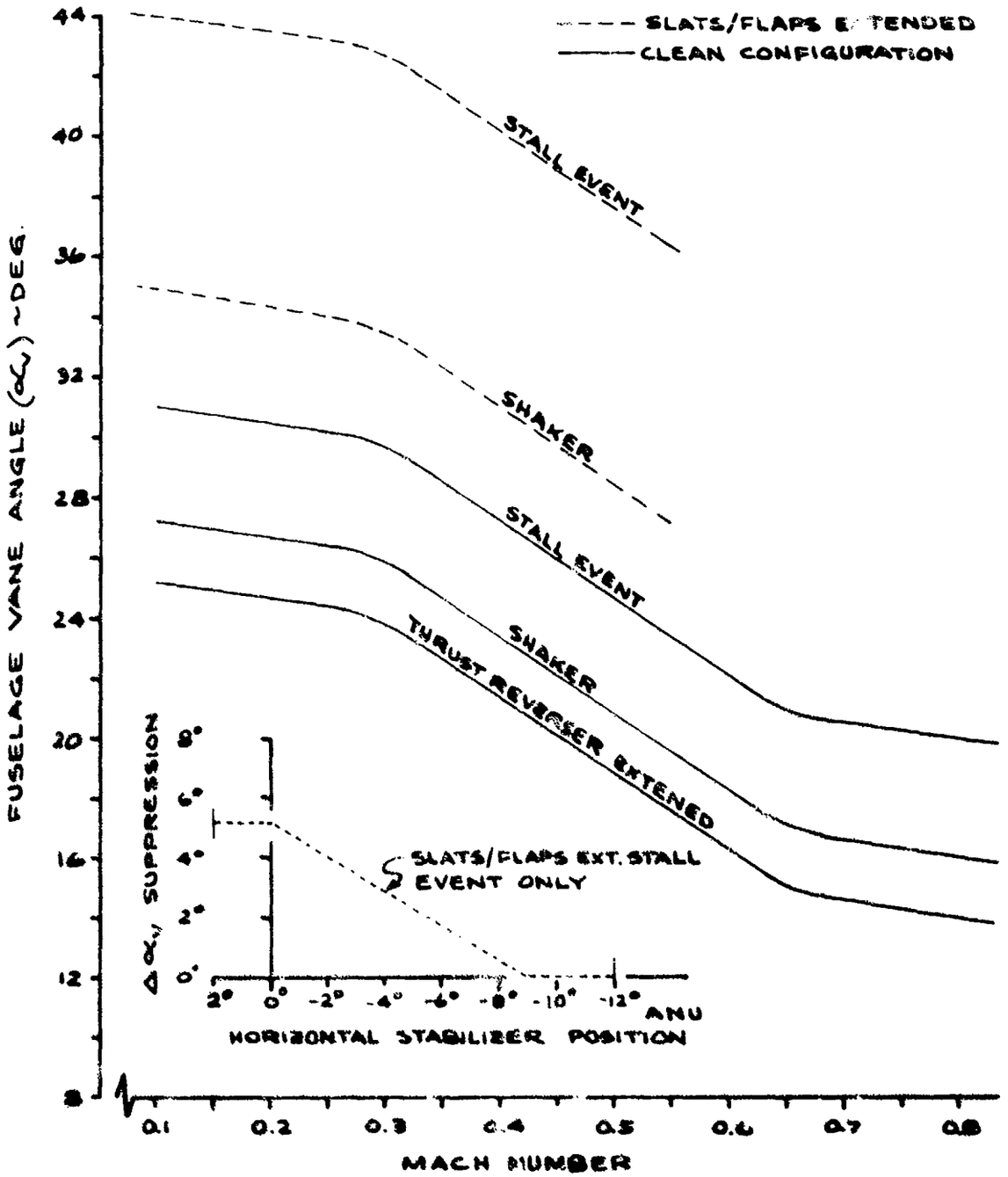


FIGURE NO. 1(3.4.1) STALLIMITER SCHEDULE

C-5A FLIGHT TEST DATA

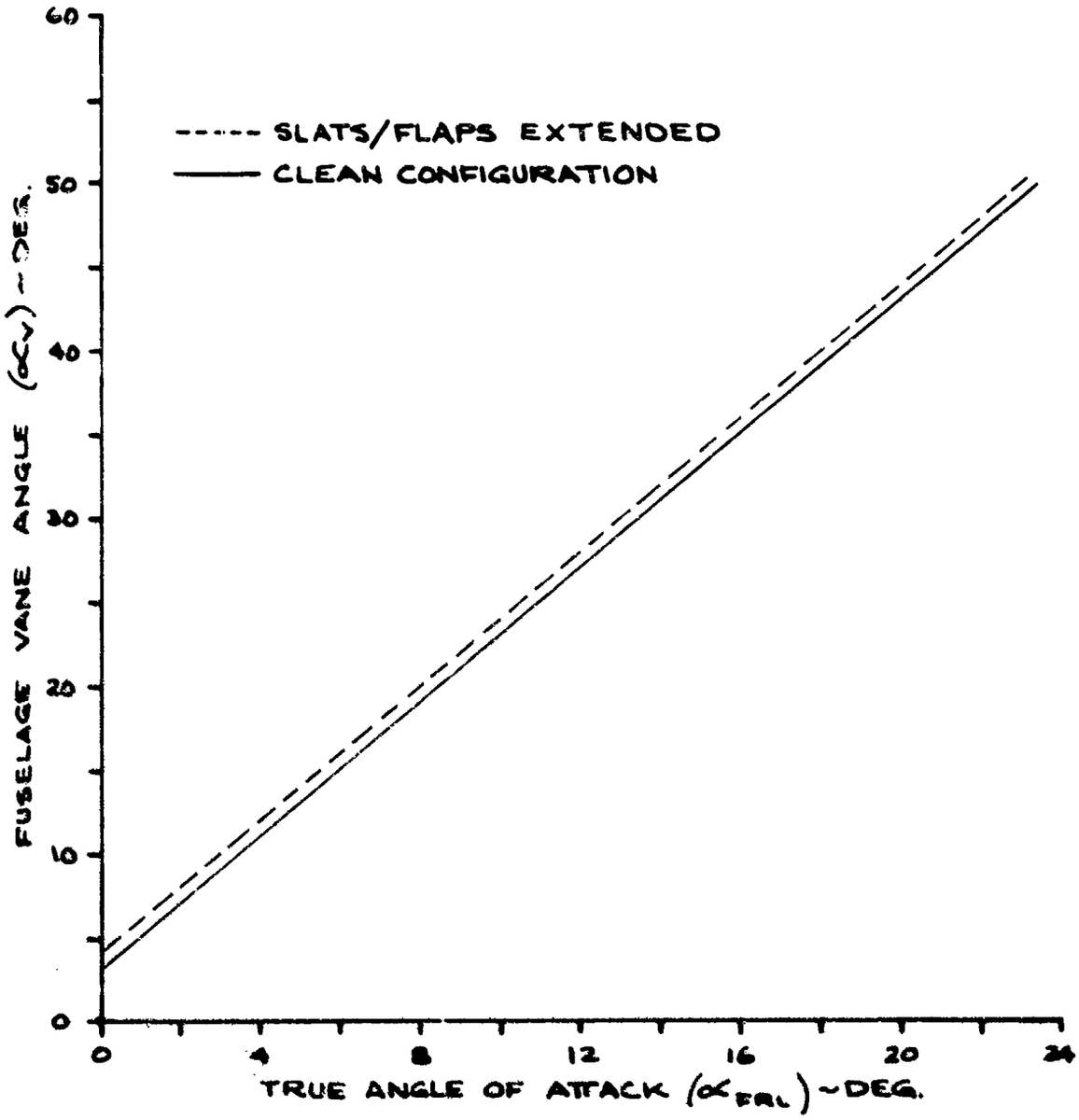


FIGURE NO. 2 (3.4.1) ANGLE OF ATTACK CALIBRATION

Requirement

3.4.2 Flight at high angle of attack. The requirements at 3.4.2 through 3.4.2.2.2 concern stalls, loss of control, post stall gyration, spin and related characteristics. They apply at speeds and angles of attack which, in general, are outside the Service Flight Envelope (although in some instances, warning is allowed to commence slightly inside that envelope). They are intended to assure safety and the absence of mission limitations due to stall and post-stall situations. These requirements may be met with the aid of certain special devices only if it can be shown that appropriate aerodynamic design and mass distribution are not feasible.

3.4.2.1 Stalls. The stall is defined in terms of airspeed and angle of attack in 6.2.2 and 6.2.5 respectively. It usually is a phenomenon caused by airflow separation induced by high angle of attack, but it may instead (3.1.9.2.1) be determined by some limit on unusable angle of attack. The stall requirements apply to all Airplane Normal States in straight unaccelerated flight and in turns and pullups with normal acceleration up to $n_{o_{max}}$. Specifically, the Airplane Normal States, in straight unaccelerated flight and in throttle settings, and trim settings of 6.2.2 shall be investigated; also, the requirements apply to Airplane Failure States that affect stall characteristics.

Comparison

Stall characteristics and stall performance tests were conducted on the C-5A concurrent with stallimiter development tests. Straight and turning flight stall tests were conducted in the landing, takeoff approach, alternate takeoff, descent, aerial delivery, and cruise configurations throughout the operational weight-center-of-gravity and altitude envelope. Stall tests also included slow flight demonstration, stalls with the stabilizer mistrimmed and stalls with the stability augmentation system deactivated. A complete discussion of these results is presented in reference 2. These data show compliance with the subject requirements in every respect except that stall tests were not conducted at normal acceleration values up to $n_{o_{max}}$ as specified in 3.4.2.1. Turning flight stalls were conducted at an acceleration value of 1.5 g's (46 degree bank angle) in all configurations. However, during the 100 percent structural demonstration test program, a maneuver was conducted at $n_{o_{max}}$ and stall warning (stick activation) in the cruise configuration only.

Discussion

The C-5A results favorably compare with this requirement.

Recommendation

None

Requirement

3.4.2.1.1 Stall approach. The stall approach shall be accompanied by an easily perceptible warning. Acceptable stall warning for all types of stalls consists of shaking of the cockpit controls, buffeting or shaking of the airplane, or a combination of both. The onset of this warning shall occur within the ranges specified in 3.4.2.1.1.1 and 3.4.2.1.1.2 but not within the Operational Flight Envelope. The increase in buffeting intensity with further increase in angle of attack shall be sufficiently marked to be noted by the pilot. The warning shall continue until angle of attack is reduced to a value less than that for warning onset. This warning may be provided artificially only if it can be shown that natural stall warning is not feasible. At all angles of attack up to the stall, the cockpit controls shall remain effective in their normal sense, and small control inputs shall not result in complete loss of control. Prior to the stall, uncommanded oscillations shall not exceed $\pm 10^{\circ}$ bank, $\pm 2^{\circ}$ sideslip, $\pm 2^{\circ}$ pitch attitude. These requirements apply whether V_S is as defined in 6.2.2 or as allowed in 3.1.9.2.1.

3.4.2.1.1.1 Warning speed for stalls at 1g normal to the flight path. Warning onset for stalls at 1g normal to the flight path shall occur between the following limits:

Flight Phase	Minimum Speed for Onset	Maximum Speed for Onset
Approach	Higher of $1.05V_S$ or $V_S + 5$ knots	Higher of $1.10V_S$ or $V_S + 10$ knots
All Other	Higher of $1.05V_S$ or $V_S + 5$ knots	Higher of $1.10V_S$ or $V_S + 15$ knots

3.4.2.1.1.2 Warning range for accelerated stalls. Onset of stall warning shall occur outside the Operational Flight Envelope associated with the Airplane Normal State and with the following angle-of-attack ranges:

Flight Phase	Minimum Angle of Attack for Onset	Maximum Angle of Attack for Onset
Approach	$\alpha_0 + 0.82\ (\alpha_S - \alpha_0)$	$\alpha_0 + 0.90\ (\alpha_S - \alpha_0)$
All Other	$\alpha_0 + 0.75\ (\alpha_S - \alpha_0)$	$\alpha_0 + 0.90\ (\alpha_S - \alpha_0)$

where α_S is the stall angle of attack and α_0 is the angle of attack for zero lift (α_S is defined in 6.2.5; α_0 may be estimated from wind tunnel tests).

Comparison

As stated in Section 3.4.1, stall warning for the C-5A is provided by the stallimiter system as a function of angle of attack and Mach number for the flaps up and flaps extended configurations. The basis for use of the stallimiter system is covered in Section 3.4.2.1.2. The stallimiter system was optimized to provide stall warning in the form of shaking the elevator control at approximately $1.07V_S$. Figure 1 (3.4.2.1.1) presents a summary of

the clean configuration stall warning and stall test results in the form of lift coefficient versus Mach number. These data show that stall warning occurs at approximately $1.06V_S$ at low Mach number conditions and at approximately $1.05V_S$ at the higher Mach number conditions. Figure 2 (3.4.2.1.1) presents a summary of stall performance test results in the form of lift coefficient versus flap position for shaker onset and for stall. These data show that stall warning occurs at approximately $1.07V_S$ for each of the flaps down configurations (16 degrees through 40 degrees). These data, therefore, show that the C-5A favorably compares with the requirement concerning stall warning speeds.

With respect to the requirements concerning stall warning angle of attack range, Figure 3 (3.4.2.1.1) presents Flight Test results in the form of lift coefficient versus true angle of attack for the various configurations. Utilizing these data and Figure 4 (3.4.2.1.1), the following angle of attack data are provided for showing compliance with paragraph 3.4.2.1.1.2.

Configuration	α_0	α_W	$\alpha_{W_{MIN}}$*	$\alpha_{W_{MAX}}$*	α_S
Cruise	- 3.2	11.5	9.3	11.8	13.5
Alt. Takeoff	- 6.2	15.0	14.9	16.9	19.5
Takeoff Appr.	- 7.2	15.0	14.7	16.9	19.5
Land	- 9.3	15.0	14.3	16.6	19.5

* $\alpha_{W_{MIN}}$ - Minimum angle of attack for warning per equation in 3.4.2.1.1.2

$\alpha_{W_{MAX}}$ - Maximum angle of attack for warning per equation in 3.4.2.1.1.2

These data, therefore, comply with the requirement of this section.

Discussion

The requirements of Section 3.4.2.1.1.2 for stall warning angle of attack range do not specify the form of the angle of attack information. Since α_0 may be estimated from wind tunnel data, it is implied that the data should be in the form of true angle of attack in lieu of some local angle of attack. A requirement which is based on true angle of attack will necessitate an accurate angle of attack calibration at conditions up to stall. Any angle of attack calibration data that is obtained at speeds below approximately $1.2V_S$ is highly questionable due to the inability to stabilize at a given rate of sink, pitch attitude or rate of pitch and airspeed. At the best, any angle of attack calibration curve depends a lot on engineering judgment for the range between $1.2V_S$ and stall. Consequently, the final proof of compliance with a requirement such as this is highly questionable.

Recommendation

A recommendation is not necessary since, subsequent to this draft, amendment 2 of the subject specification was issued with which we concur.

C-5A FLIGHT TEST DATA

CR CONFIG

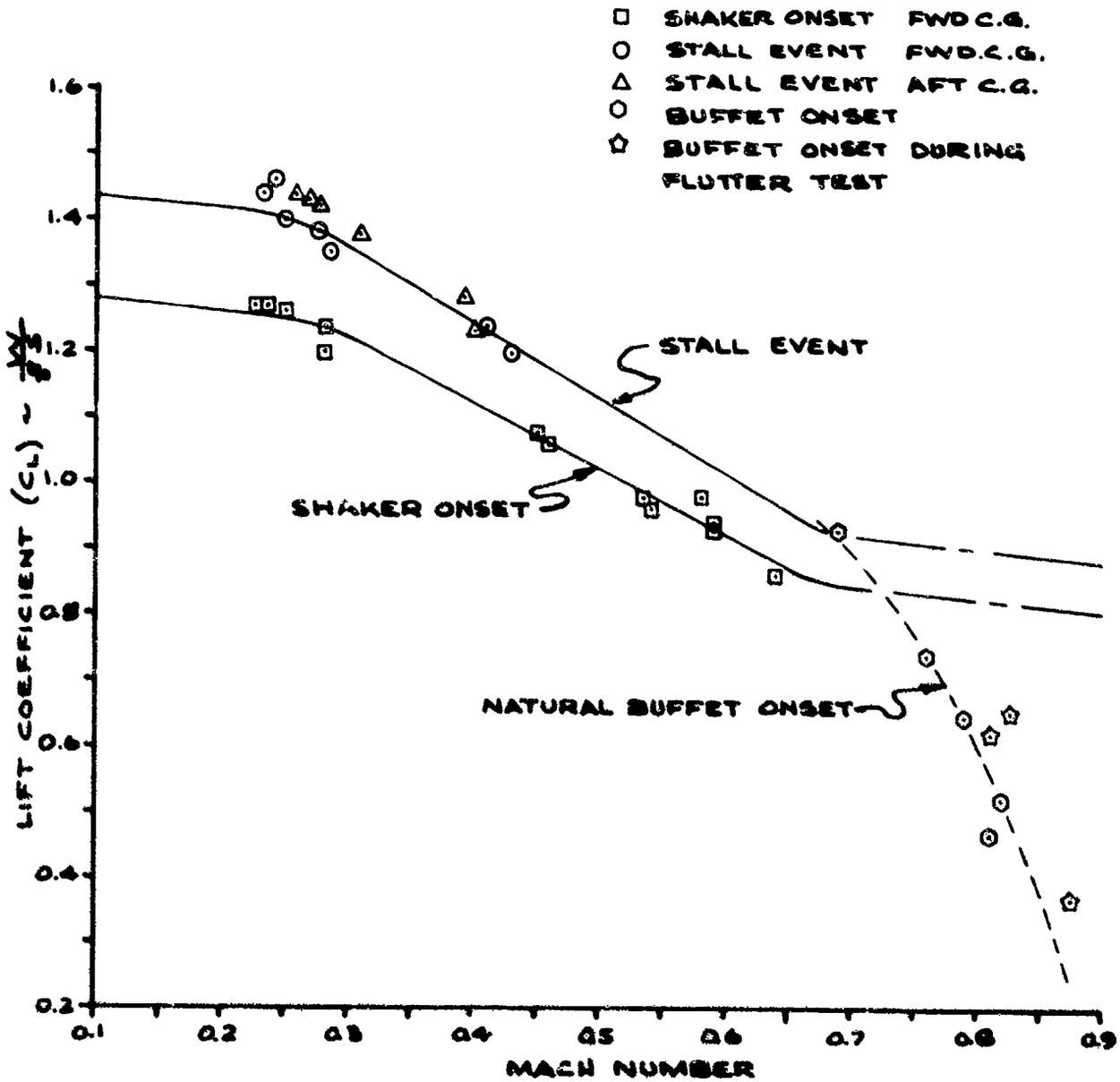


FIGURE NO. 1 (3.4.2.1.1) REFERENCE LIFT COEFFICIENTS

C-5A FLIGHT TEST DATA

L.E. SLATS EXTENDED

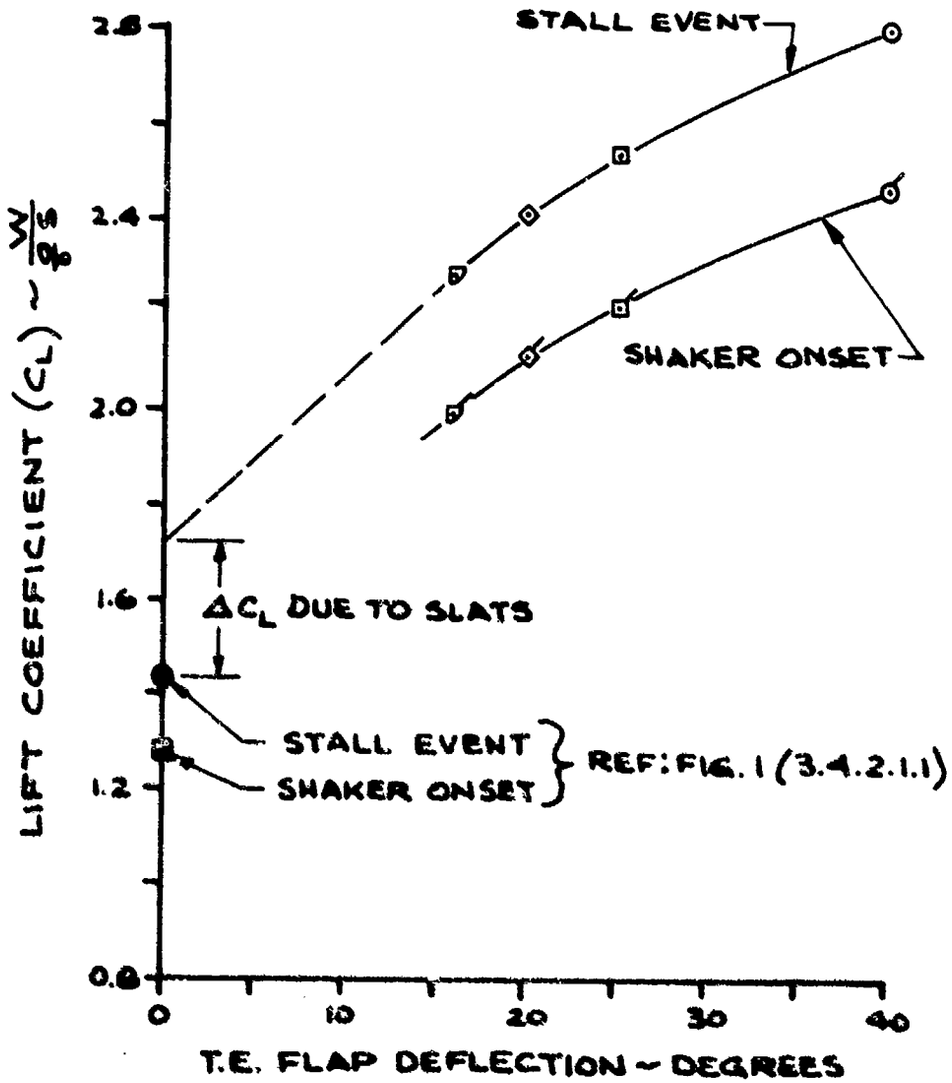


FIGURE NO 2 (3.4.2.1.1) REFERENCE LIFT COEFFICIENTS

C-5A FLIGHT TEST DATA

C.G. AT 30 % MAC

STALL DATA CORRECTED TO ZERO dv/dt

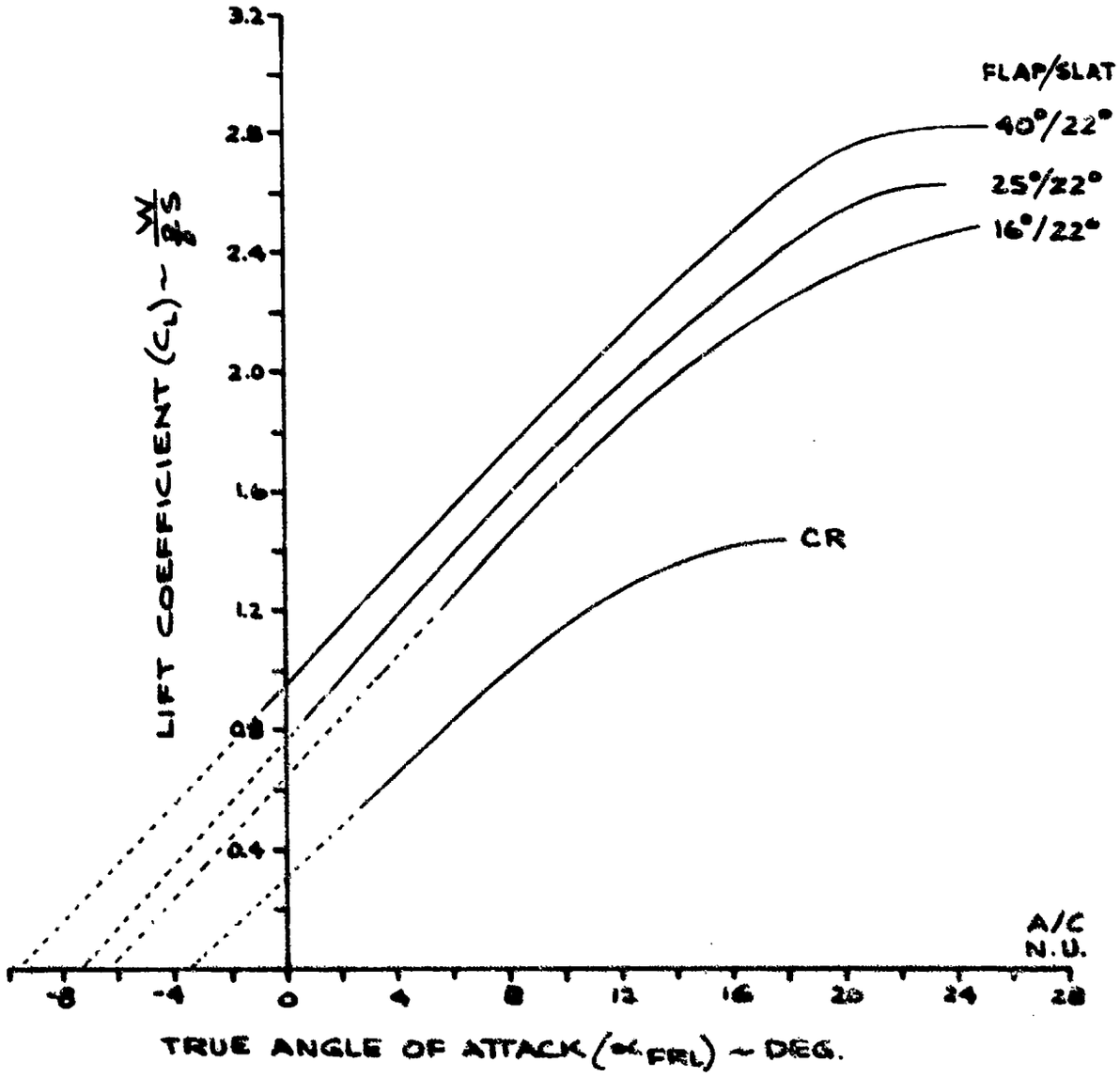


FIGURE NO. 3(3.4.2.1.1) LIFT CHARACTERISTICS

C-5A FLIGHT TEST DATA

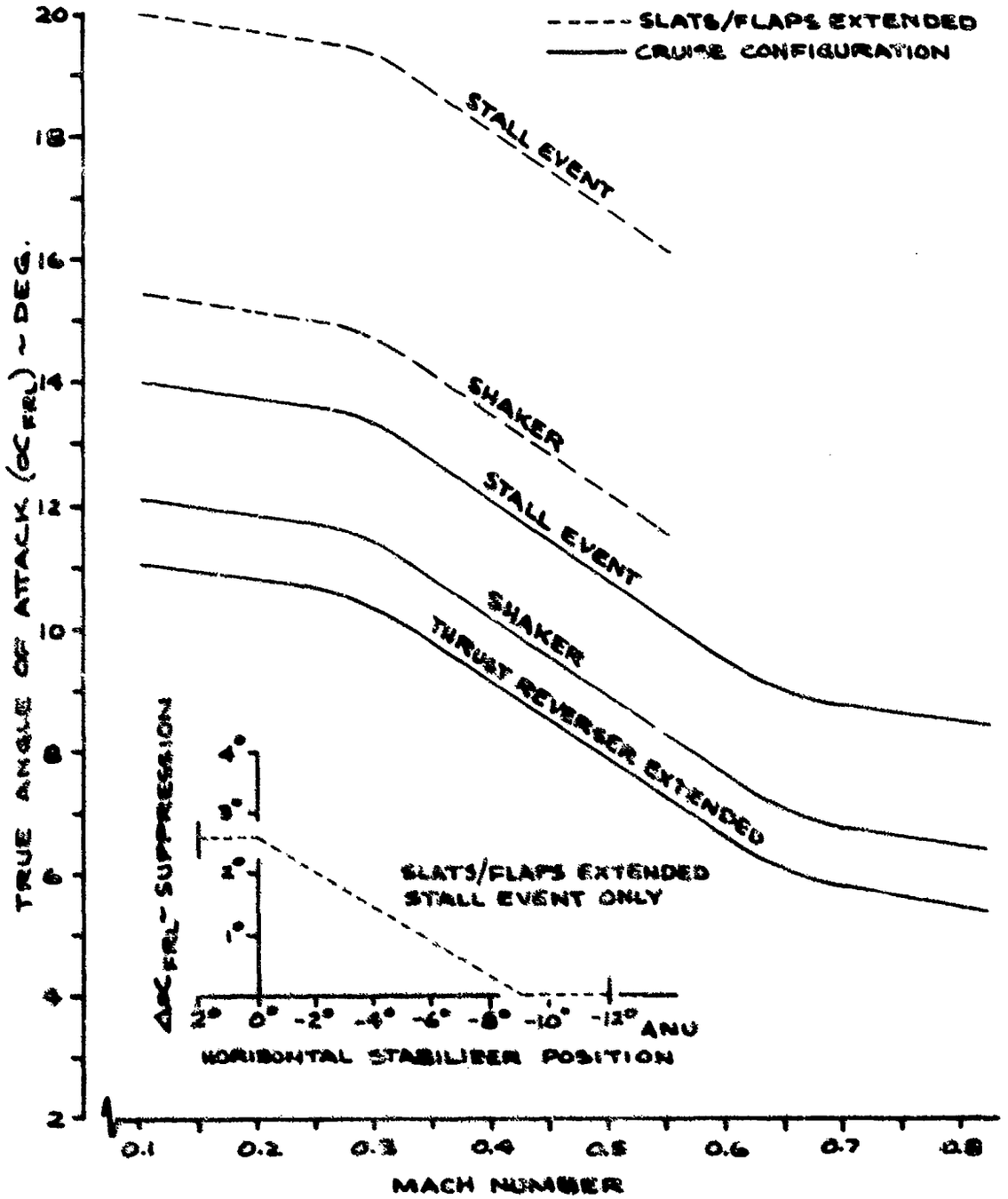


FIGURE NO4(3.4.2.1.1) STALLIMITER SCHEDULE

Requirement

3.4.2.1.2 Stall characteristics. In the unaccelerated stalls of 3.4.2.1, the airplane shall not exhibit uncontrollable rolling, yawing, or downward pitching at the stall in excess of 20 degrees for Classes I, II and III, or 30 degrees for Class IV airplanes. It is desired that no pitch-up tendencies occur in unaccelerated or accelerated stalls. In unaccelerated stalls, mild nose-up pitch may be acceptable if no elevator control force reversal occurs and if no dangerous, unrecoverable, or objectionable flight conditions result.

A mild nose-up tendency may be acceptable in accelerated stalls if the operational effectiveness of the airplane is not compromised and:

a. The airplane has adequate stall warning

b. Elevator effectiveness is such that it is possible to stop the pitch-up promptly and reduce the angle of attack, and

c. At no point during the stall, stall approach, or recovery does any portion of the airplane exceed structural limit loads.

Comparison

Straight and turning flight stall tests were conducted on the C-5A at the forward and aft center of gravity limits, at low altitude for the flaps down configurations, and at low and high altitude for the flaps up configurations. As stated in Section 3.4.1, operation at high angle of attack is limited by operation of the stallimiter system. The stallimiter system was included in the initial design per reference 4, as agreed between Lockheed and the procuring activity.

A complete discussion of the test results, which is too lengthly for inclusion here, is presented in reference 2. These data show that, based on operation of the stallimiter, the C-5A stall characteristics are in complete agreement with the subject requirements.

Discussion

C-5A results support this requirement.

Recommendation

None

Requirement

3.4.2.1.3 Stall prevention and recovery. It shall be possible to prevent the stall by moderate use of the elevator control alone at the onset of the stall warning. It shall be possible to recover from a stall by simple use of the elevator, aileron, and rudder controls after a brief delay, with reasonable forces, and to regain level flight without excessive loss of altitude or buildup of speed. Throttles shall remain fixed until speed has begun to increase when an angle of attack below the stall has been regained. In the straight-flight stalls of 3.4.2.1, with the airplane trimmed at a speed not greater than $1.4V_S$ and with a speed reduction rate of at least 4.0 knots per second for Class I, II and III airplanes, and an angle-of-attack rate of 2 degrees per second for Class IV airplanes, elevator control power shall be sufficient to recover from any attainable angle of attack: that is, to preclude inability to recover from a deep stall.

3.4.2.1.3.1 One-engine-out stalls. On multi-engine airplanes, it shall be possible to recover safely from stalls with the critical engine inoperative. This requirement applies with the remaining engines at up to thrust setting for level flight, but these engines may be throttled back during recovery.

Comparison

Evaluation of stall recovery techniques on the C-5A show that, in general, a standard technique is adequate. The recovery is satisfactorily accomplished with a positive, although not rapid, airplane nose down elevator control input. If recovery is initiated at any angle up through stall event plus approximately 4.0 degrees (true α), a slow smooth elevator application will result in a normal stall recovery.

With respect to the requirements of Section 3.4.2.1.3.1, one-engine-out stalls were not conducted on the C-5A. However, steady-state and dynamic minimum-air control speed tests were conducted with the number one engine inoperative and engines 2,3, and 4 developing military rated thrust. These tests were conducted at a gross weight of 460,000 pounds and at speeds down to the stick shaker ($1.07V_S$). Although tests were not conducted with an engine inoperative at speeds down to stall, the results discussed above are considered adequate to show that there are not control problems, directionally or laterally, with an engine inoperative down to the stall.

Discussion

The requirement should provide a conditional statement to the effect that the amount of thrust employed for these tests should not exceed that which would require more than full control to maintain wings level during approach to stall.

Recommendation

Add the following sentence to paragraph 3.4.2.1.3.1:

"Thrust setting for these tests not to exceed 75 percent normal rated thrust or the thrust at which the use of maximum control travel just holds the wings laterally level in the approach to stall, whichever is lesser."

Requirement

3.4.2.2 Post-stall gyrations and spins. The post-stall gyration and spin requirements apply to all modes of motion that can be entered from upsets, deceleration, and extreme maneuvers appropriate to the Class and Flight Phase Category. For Class IV airplanes, this includes air combat, ground attack, and other tactical and training maneuvers. For Class I and IV airplanes, entries from inverted flight shall be included. Less extreme entry conditions are also included for all classes. Entry angles of attack and sideslip up to maximum control capability and those obtained under dynamic flight conditions are to be included, except as limited by structural considerations. For all Classes, thrust settings up to and including MAT shall be included, with and without one critical engine inoperative at entry. At the critical time, the elevator, aileron and rudder controls are to be misapplied abruptly: for Class I and IV airplanes, full deflection; for Class II and III, gross deflection changes. MIL-S-83691 contains more detailed guidance on entry conditions and techniques. The requirements hold for all Airplane Normal States and for all States of Stability and Control Augmentation systems except approved Special Failure States. Store release shall not be allowed during entry, spin or gyration, recovery, or subsequent dive pullout. Automatic disengagement of augmentation systems, however, is permissible if it is necessary and does not prevent meeting any other requirements; reengagement shall be possible in flight. A spin/post-stall-gyration recovery system initiated by pilot action or an automatic prevention device may be accepted only if it can be shown (3.4.1) that the requirements of 3.4.2.2 through 3.4.2.2.2 cannot be met by normal means and the device meets the requirements of 3.4.1.2.

3.4.2.2.1 Resistance to loss of control. Nether post-stall gyrations not spins shall be readily attainable from the entry conditions specified in 3.4.2.2 except by prolonged gross misapplication of controls. With the control misapplications of 3.4.2.2 held for at least three seconds, or longer if there is no clear indication, the airplane shall exhibit no uncommanded motion which cannot be arrested promptly by application of elevator control to reduce the magnitude of the angle of attack (neutralizing the aileron and rudder controls is allowed). In addition, Class I training airplanes shall be capable of a developed spin, such that the pilot can identify the spin mode.

Comparison

The stall development program for the C-5A did not include tests to evaluate the resistance to loss of control during stall recovery. However, during the stallimiter optimization program, stall tests were conducted at angle of attack conditions of approximately 4.0 degrees excess of the maximum boundary as defined by the stallimiter system. The airplane exhibited no unusual handling characteristics at these higher angles. These data are discussed in more detail in reference 2.

Discussion

For a Class III airplane like the C-5A, operation at speeds down to the stall is not frequent enough to warrant an evaluation to determine susceptibility of entering a spin. Intentional operation at speeds down to the stall on the C-5A is made during the flight test program and during crew training flights only, and during these phases, control inputs are

planned and rather precise. Consequently, gross misapplication of the controls is not consistent with flight test maneuvers or with training flight maneuvers. Instead, a requirement relating to a reasonable angle of attack range beyond stall would be more realistic for Class II and III operation.

Recommendation

It is recommended that the requirement relative to misapplication of controls be deleted from paragraphs 3.4.2.2 and 3.4.2.2.1 for Class II and III airplanes and be replaced with the following:

> "For Class II and III airplanes, stall characteristics (straight and turning flight) shall be evaluated at an angle of attack range beyond the stall angle. The angle of attack range shall be negotiated between the contractor and the procuring activity prior to the start of the stall test program."

Requirement

3.4.2.2.2 Recovery from post-stall gyrations and spins. For Class I and IV airplanes, the following requirements apply. For any loss of control that can occur with the control misapplications of 3.4.2.2 held for as long as 15 seconds, the start of recovery shall be apparent to the pilot within three seconds, or one spin turn, of the instant he initiates recovery. The proper recovery technique must be readily ascertainable by the pilot, and all techniques must be simple and easy to apply under the motions encountered. Whatever the motions, safe, consistent recovery and pullout shall be possible without exceeding the control forces of 3.4.5.1, and without danger of violating airplane limits or of excessive altitude loss. A single technique shall provide recovery from all post-stall gyrations and incipient spins, without tendency to develop a spin; prompt recovery is required using only the elevator control (neutralizing the aileron and rudder controls is allowed). The same technique used to recover from post-stall gyrations and incipient spins, or at least a compatible one, is also desired for spin recovery. For all modes of spin that can occur, recoveries shall be attainable within:

Class	Flight Phase	Turns for Recovery	Altitude Loss in Recovery *
I	Category A, B	1 1/2	1000 ft.
I	PA	1	800 ft.
IV	Category A, B	2	5000 ft.

* Not including dive pullout

Avoidance of a spin reversal or an adverse mode change shall not depend upon precise control timing or deflection.

Comparison

None - Not applicable to Class III.

Discussion

None

Recommendation

None

Requirement

3.4.4 Roll-pitch-yaw coupling. For Class I and IV airplanes in rudder-pedal-free, elevator-control-fixed, maximum-performance rolls through 360 degrees, entered from straight flight or from turns, pushovers, or pullups ranging from 0g to 0.8 n_L, the resulting yaw or pitch motions and sideslip or angle of attack changes shall neither exceed structural limits nor cause other dangerous flight conditions such as uncontrollable motions or roll auto-rotation.

During combat-type maneuvers involving rolls through angles up to 360 degrees, the yawing and pitching shall not be so severe as to impair the tactical effectiveness of the maneuver. These requirements define Level 1 and Level 2 operation. For Class II and Class III airplanes, these requirements apply in rolls through 120 degrees.

Comparison

The C-5A has successfully performed an abrupt, uncoordinated rolling pullout at 1.67g, which constitutes a 100 percent demonstration. Other maneuvers specified in this paragraph are not required. The C-5A has a bank angle limitation of approximately 45 degrees. Rolls of 120 degrees specified for Class II and III cannot, therefore, be attained.

Discussion

This paragraph does not seem to be a definitive requirement. The inclusion of 100 percent structural demonstration requirements into handling qualities requirements is somewhat incompatible. The handling qualities demonstrations are generally performed while the airplane is limited to 80 percent of its structural capability.

Class II and III aircraft appear to be added as an afterthought. Some heavy transport airplanes, such as the C-5, may not have the capability of rolling through 120 degrees. Therefore, a roll of 90 degrees may be more applicable to Class III airplanes. Abrupt, uncoordinated rolls from pushovers or pullups ranging from 0g to 0.8 n_L may not be possible for some large Class III airplanes.

Recommendations

The entire paragraph needs to be reworded while retaining the central idea of preventing undesirable roll-pitch-yaw coupling conditions.

> "For Class I and IV airplanes in rudder-pedal-free, elevator-control-fixed, maximum-performance rolls through 360 degrees, entered from straight flight or from turns, pushovers, or pullups ranging from 0g to 0.8 n_L, the resulting yaw or pitch motions and sideslip or angle of attack changes shall not cause dangerous flight conditions or motions. During combat-type maneuvers involving rolls through angles up to 360 degrees, the yawing and pitching shall not be so severe as to impair the tactical effectiveness of the maneuver. These requirements define Level 1 and Level 2 operation. For Class II airplanes, these requirements apply in rolls through 120 degrees.

For Class III airplanes in rudder-pedal-free, elevator-control-fixed, maximum performance rolls through 90 degrees entered from straight flight, turns, pushovers, or pullups, the resulting yaw or pitch motions and sideslip or angle of attack changes shall not cause dangerous flight conditions or motions."

Requirement

3.4.5 Control harmony. The elevator and aileron force and displacement sensitivities and breakout forces shall be compatible so that intentional inputs to one control axis will not cause inadvertent inputs to the other.

3.4.5.1 Control force coordination. The cockpit control forces required to perform maneuvers which are normal for the airplane should have magnitudes which are related to the pilot's capability to produce such forces in combination. The following control force levels are considered to be limiting values compatible with the pilot's capability to apply simultaneous forces:

Type Control	Elevator	Aileron	Rudder
Center-Stick	50 pounds	25 pounds	175 pounds
Wheel	75 pounds	40 pounds	175 pounds

Comparison

The overall control system of the C-5A is rated as excellent. Relative magnitudes of elevator, rudder, and aileron forces to produce coordinated maneuvers are within the pilot's capability and meet the requirements of paragraph 3.4.5.1. Figure 1 (3.4.5) summarizes the results of rolling pullout maneuvers and also lateral control and maneuvering flight tests. Rudder pedal forces are low and are not critical.

Discussion

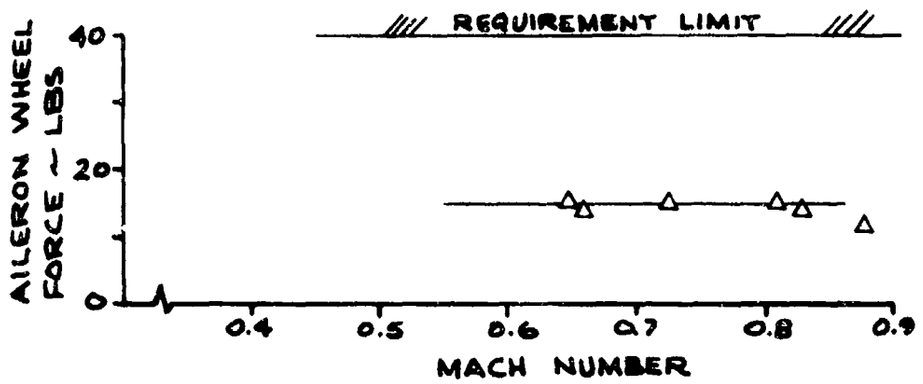
None

Recommendations

None

C-5A FLIGHT TEST DATA

CR CONFIG



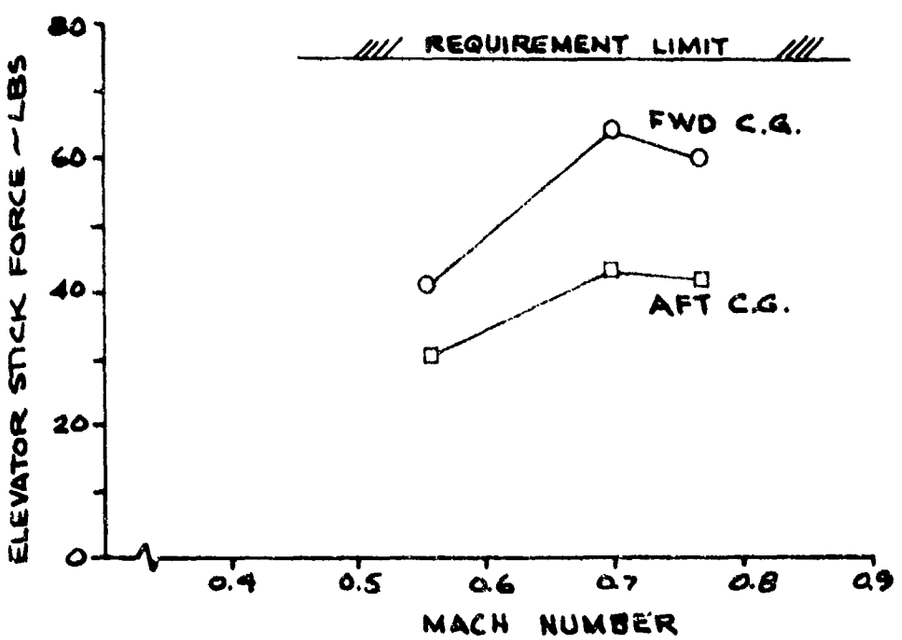


FIGURE NO.1(3.4.5) CONTROLLABILITY DURING ROLLING PULL-OUT

Requirement

3.4.6 Buffet. Within the boundaries of the Operational Flight Envelope, there shall be no objectionable buffet which might detract from the effectiveness of the airplane in executing its intended missions.

Comparison

Buffet does not occur in any region that would affect mission effectiveness. Natural buffet onset at high Mach numbers is shown in Figure 1 (3.4.2.1.1). It is this natural buffet onset at high Mach numbers which somewhat defines a portion of the operational flight envelope. At low speeds, a light natural buffet coincides with stall shaker onset.

Discussion

C-5A results compare favorably with this requirement.

Recommendations

None

Requirement

3.4.7 Release of stores. The intentional release of any stores shall not result in objectionable flight characteristics for Levels 1 and 2. However, the intentional release of stores shall never result in dangerous or intolerable flight characteristics. This requirement applies for all flight conditions and store loadings at which normal or emergency store release is structurally permissible.

Comparison

None. Not applicable.

Discussion

None

Recommendations

None

Requirement

3.4.8 Effects of armament delivery and special equipment. Operation of movable parts such as bomb bay doors, cargo doors, armament pods, refueling devices, and rescue equipment, or firing of weapons, release of bombs, or delivery or pickup of cargo shall not cause buffet, trim changes, or other characteristics which impair the tactical effectiveness of the airplane under any pertinent flight condition. These requirements shall be met for Levels 1 and 2.

Comparison

The C-5A has a mission of aerial delivery of cargo. Operation of the aft cargo doors produces no adverse handling characteristics. Longitudinal trim changes due to opening and closing of the aerial delivery door are light or nonexistent, requiring no more than five pounds of elevator column force to counteract The transient motions resulting from single or multiple package airdrops do not reach dangerous flight conditions and are easily controllable by normal pilot technique. A maximum of 200,000 pounds of cargo may be dropped in packages of 50,000 pounds each. A demonstration drop of a single package weighing 86,000 pounds has been accomplished without adversely affecting the airplane's attitude or heading.

Discussion

None

Recommendation

None

Requirement

3.4.9 Transients following failures. The airplane motions following sudden airplane system or component failures shall be such that dangerous conditions can be avoided by pilot corrective action. A realistic time delay between the failure and initiation of pilot corrective action shall be incorporated when determining compliance. This time delay should include an interval between the occurrence of the failure and the occurrence of a cue such as acceleration, rate, displacement, or sound that will definitely indicate to the pilot that a failure has occurred, plus an additional interval which represents the time required for the pilot to diagnose the situation and initiate corrective action.

3.4.10 Failures. No single failure of any component or system shall result in dangerous or intolerable flying qualities; Special Failure States (3.1.6.2.1) are excepted. The crew member concerned shall be provided with immediate and easily interpreted indications whenever failures occur that require or limit any flight crew action or decision.

Comparison

The sudden loss of the critical engine while operating at high power has been demonstrated during the dynamic air minimum control speed flight tests. No undue pilot efforts or special techniques are required to control motions produced by critical engine failures.

Other failures of concern are autopilot hardovers and stabilizer runaways. The aircraft can be stabilized in level flight up to 280 KCAS in the cruise configuration at any c.g. position after a stabilizer runaway to the 6 degree ANU or the 2.5 degree AND stop. In the flaps down configuration, a stabilizer runaway to the 1.8 degree aircraft nose down stop is fully controllable at any c.g. position. With a c.g. aft of 33 percent, there is not sufficient longitudinal control to prevent the airplane from decelerating into stall following a stabilizer runaway to the 12 degree ANU stop. However, since the stabilizer travels at a rate of 0.15 degrees per second, sufficient time exists after a failure for a pilot to recognize the failure and to actuate the pitch trim disconnect. Consequently, no special warning to the crew is necessary. Autopilot hardover failures have been demonstrated during flight testing to verify that autopilot inputs following a failure in the autopilot are incapable of causing airplane maneuver loads to be exceeded or placing the airplane in an adverse attitude. The hardover, or runaway failure, is simulated by a voltage step input of sufficient magnitude to cause the affected autopilot surface servo to drive at maximum rate to maximum deflection or motor stall. Normal time delay for these tests from pilot recognition of failure to initiation of recovery is three seconds for the CR configuration and one second for the PA and L configurations. Results of tests on the most critical elevator axis configuration, presented in Figures 1 (3.4.10) and 2 (3.4.10), show that airplane response is a fairly smooth change in altitude and buildup in vertical acceleration which is easily recognized and controlled by the pilot. Vertical acceleration values are well within the required 0 to 2.0g envelope when recovery is delayed by three seconds. Tests for aileron axis hardover failures at 280 KCAS and 20,000 feet altitude show that the airplane rolls smoothly to about 30 to 34 degrees of bank when recovery is delayed by three seconds and peaks at about 39 degrees during the recovery. Failures are easily recognized and controlled by the pilot.

Discussion

None

Recommendation

None

C-5A FLIGHT TEST DATA

CR CONFIG

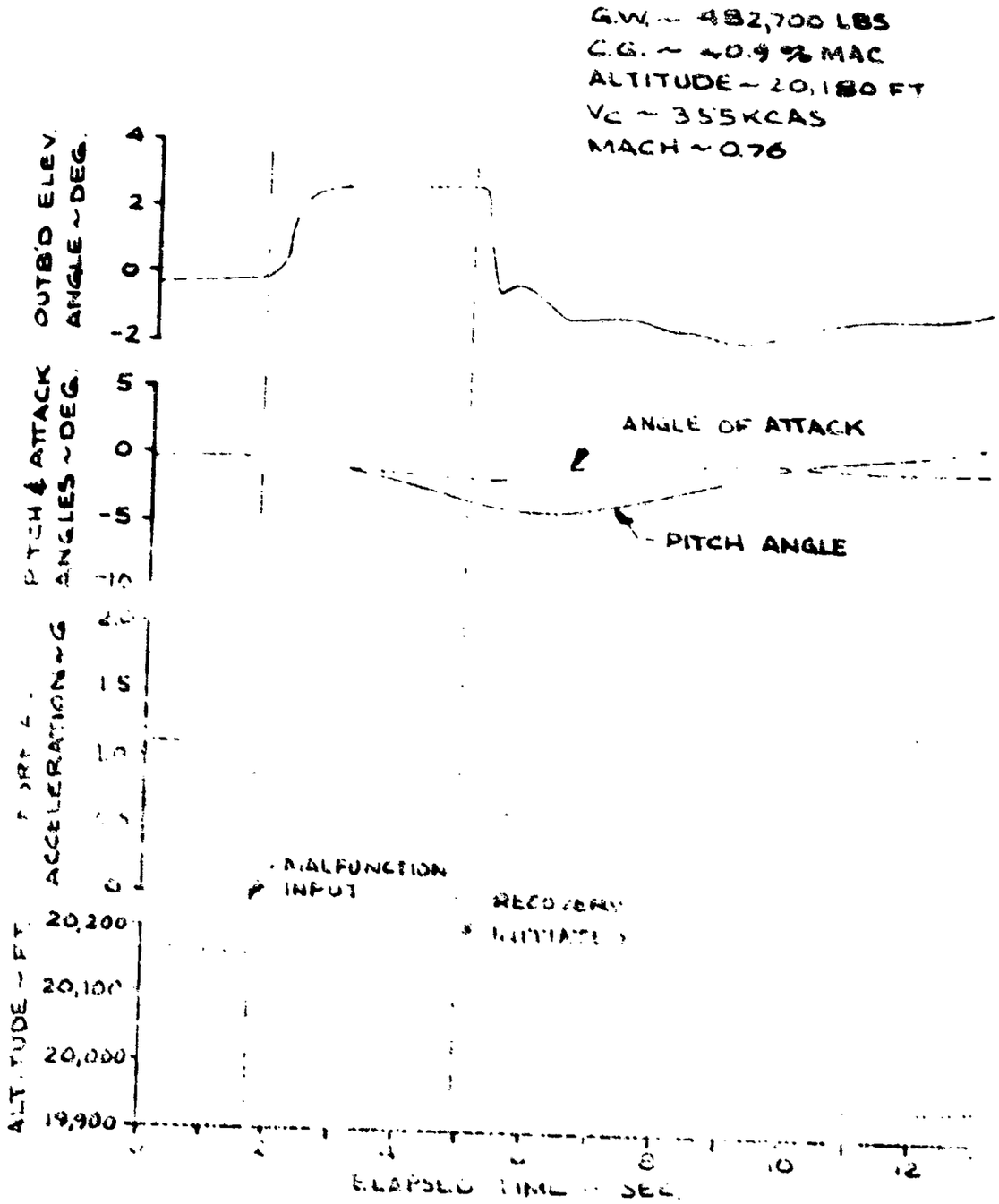


FIGURE NO.1 (3.4.10) PITCH AUTOPILOT HARDOVER FAILURE

C-5A FLIGHT TEST DATA

CR CONFIG

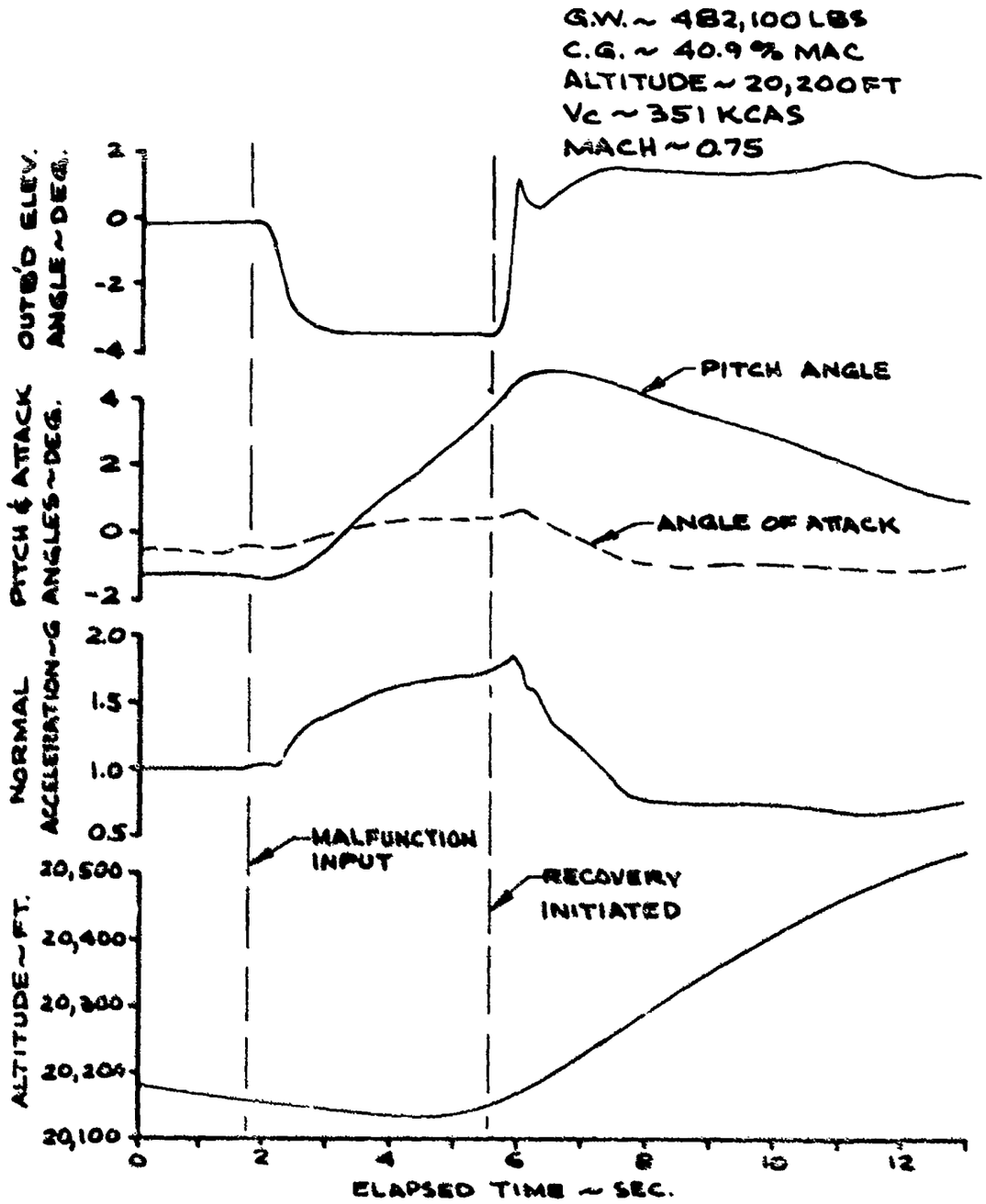


FIGURE NO.2 (3.4.10) PITCH AUTOPILOT HARDOVER FAILURE

Requirement

3.5 Characteristics of the primary flight control system.

3.5.1 General characteristics. As used in this specification, the term primary flight control system includes the elevator, aileron and rudder controls, stability augmentation systems, and all mechanisms and devices that they operate. The requirements of this section are concerned with those aspects of the primary flight control system which are directly related to flying qualities. These requirements are in addition to the requirements of the applicable control system design specification, e.g., MIL-F-9490 or MIL-C-18244.

3.5.2 Mechanical characteristics. Some of the important mechanical characteristics of control systems (including servo valves and actuators) are: friction and preload, lost motion, flexibility, mass imbalance and inertia, nonlinear gearing, and rate limiting. Requirements for some of these characteristics are contained in 3.5.2.1 through 3.5.2.4. Meeting these separate requirements, however, will not necessarily ensure that the overall system will be satisfactory; the mechanical characteristics must be compatible with the nonmechanical portions of the control system and with the airframe dynamic characteristics.

Comparison

None

Discussion

None

Recommendation

None

Requirement

3.5.2.1 Control centering and breakout forces. Longitudinal, lateral, and directional controls should exhibit positive centering in flight at any normal trim setting. Although absolute centering is not required, the combined effects of centering, breakout force, stability, and force gradient shall not produce objectionable flight characteristics, such as poor precision-tracking ability, or permit large departures from trim conditions with controls free. Breakout forces, including friction, preload, etc., shall be within the limits of table XII. The values in table XII refer to the cockpit control force required to start movement of the control surface in flight for Levels 1 and 2; the upper limits are doubled for Level 3.

Table XII. Allowable Breakout Forces, Pounds

CONTROL		Classes I, II-C, IV		Classes II-L, III	
		min	max	min	max
Elevator	Stick	1/2	3	1/2	5
	Wheel	1/2	4	1/2	7
Aileron	Stick	1/2	2	1/2	4
	Wheel	1/2	3	1/2	6
Rudder		1	7	1	14

Measurement of breakout forces on the ground will ordinarily suffice in lieu of actual flight measurement, provided that qualitative agreement between ground measurement and flight observation can be established.

Comparison

The C-5 is a Class III heavy transport aircraft. The Control System breakout forces were measured on the ground and substantiated in flight.

Elevator	Push	5 lbs.
	Pull	6 lbs.
Aileron		6 lbs.
Rudder	Right	13 lbs.
	Left	10 lbs.

Discussion

None. The C-5 control systems meet the requirement.

Recommendation

1. Flight test pilots recommended a lower breakout force for the rudder system and the resulting lower force gradient. The C-5 elevator and aileron systems are able to

meet the requirements by using Pilot Assist Cable Servos (PACS). The rudder system could be required to meet less than 14 pounds and be able to meet it by using PACS.

C-5 and larger aircraft have cable systems so long that they need PACS or similar devices It is recommended that lower rudder breakout forces be considered since a lower breakout and the same spring gradient will result in lower maximum forces.

2. The C-5 Joint Test Team used "the first significant movement of the control surface" in flight as the breakout point since it agreed with the ground test breakout force. It is recommended that the specification be revised to describe a specific technique to be used for measuring breakout.

Requirement

3.5.2.2 Cockpit control free play. The free play in each cockpit control, that is, any motion of the cockpit control which does not move the control surface in flight, shall not result in objectionable flight characteristics, particularly for small-amplitude control inputs.

Comparison

The C-5 complies with this requirement.

Discussion

None

Recommendation

None

Requirement

3.5.2.3 Rate of control displacement. The ability of the airplane to perform the operational maneuvers required of it shall not be limited in the atmospheric disturbances specified in 3.7 by control surface deflection rates. For powered or boosted controls, the effect of engine speed and the duty cycle of both primary and secondary controls together with the pilot control techniques shall be included when establishing compliance with this requirement.

Comparison

The C-5 no-load surface rates are:

Elevator	29°/sec	UP
	24°/sec	DOWN
Rudder	49°/sec	L.
	49°/sec	R.
Aileron	31°/sec	UP
	42°/sec	DOWN
Flight Spoiler	61°/sec	UP
	69°/sec	DOWN

The hydraulic system flow rates for the C-5 are capable of supporting maximum surface rates at engine idle so that duty cycle pilot control techniques need not be evaluated.

Discussion

None

Recommendation

None

Requirement

3.5.2.4 Adjustable controls. When a cockpit control is adjustable for pilot physical dimensions or comfort, the control forces defined in 6.2 refer to the mean adjustment. A force referred to any other adjustment shall not differ by more than 10 percent from the force referred to the mean adjustment.

Comparison

The C-5 rudder pedal adjust mechanism does not change the rudder pedal kinematics or rudder pedal forces and, therefore, meets this requirement.

Discussion

None

Recommendation

None

Requirement

3.5.3 Dynamic characteristics. The response of the control surfaces in flight shall not lag the cockpit control force inputs by more than the angles shown in table XIII, for frequencies equal to or less than the frequencies shown in table XIII.

Table XIII. Allowable Control Surface Labs

Level	Allowable Lag - deg	
	Category A & C Flight Phases	Category B Flight Phases
1 & 2	30	45
3	60	

Control	Upper Frequency - rad/sec
Elevator	$\omega_{n_{SP}}$
Rudder & Aileron	ω_{n_d} or $1/\tau_R$ (whichever is larger)

The lags referred to are the phase angles obtained from steady-state frequency responses, for reasonably large-amplitude force inputs. The lags for very small control-force amplitudes shall be small enough that they do not interfere with the pilot's ability to perform any precision tasks required in normal operation.

Comparison

No tests or analysis were performed to establish proof of compliance. The following information was generated in ground and flight tests.

1. See Figure 1 (3.5.3) for phase lag plot for elevator. The pitch autopilot servo is located underneath the flight station floor and, therefore, the input includes most of the mechanical input system. The elevator system is considered to meet the requirement since the plot shows phase lag is approximately 10 degrees less than the allowable limit at $\omega_{n_{SP}}$, for Categories A, B, and C as well as a low frequency point derived from flight test data.

2. See Figure 2 (3.5.3) for phase lag plot for aileron. The roll autopilot servo is located on the centerline of the wing rear beam, which means that a large portion of the mechanical input system is not included. The plot shows that the Category B requirement is met, but the Category A and C requirements are not met since the phase plot shows 35 degrees is available for the phase lag of the mechanical controls input system from the pilot's wheel to the wing rear beam.

3. See Figure 3 (3.5.3) for a phase lag plot of the hydraulic servo to the rudder surface. Using the phase lag due to the mechanical portion for the elevator system as a guide (and the elevator cable system is a longer run) the rudder system is assumed to meet the requirement.

Discussion

Results presented here support this requirement.

Recommendation

None

C-5A FLIGHT TEST DATA

NOTE:

1. TEST RESULTS FROM "IRON BIRD" SIMULATOR
2. REF: LGIT 20-1-19 P-11.4-86-88
3. PHASE LAG FROM PITCH AUTOPILOT TO ELEVATOR SURFACE.
4. PHASE LAG HYDRAULIC SERVO TO SURFACE (INPUT THROUGH SAS SYSTEM)

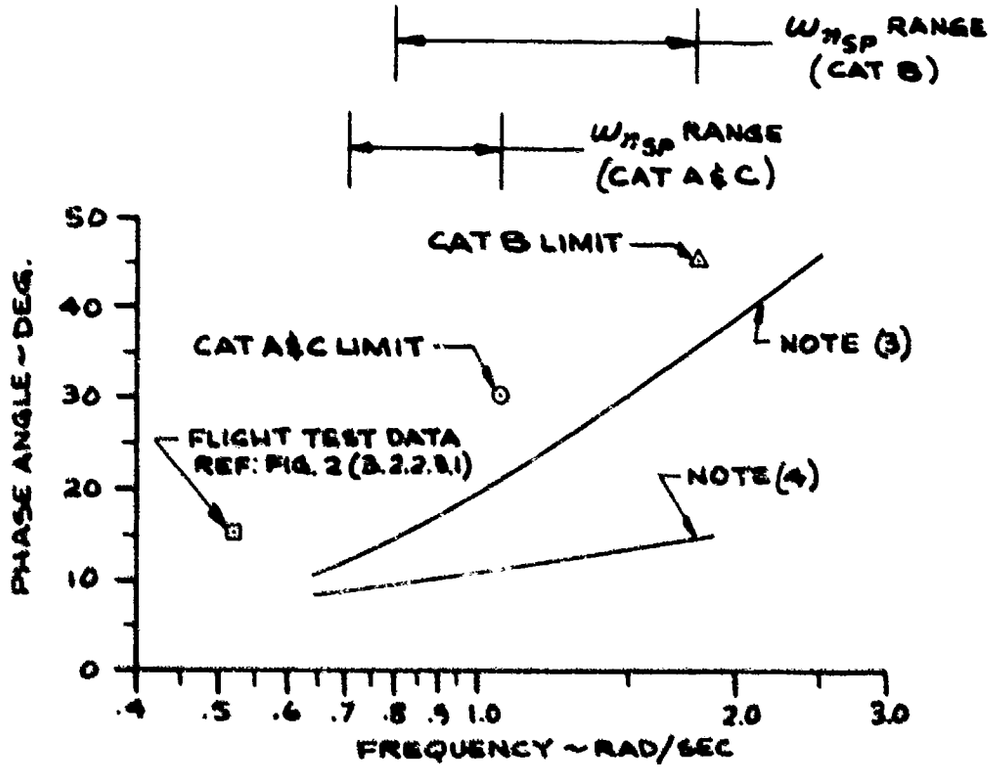


FIGURE NO. 1 (3.5.3) ELEVATOR FREQUENCY RESPONCE

C-5A FLIGHT TEST DATA

NOTE:

1. TEST RESULTS FROM "IRON BIRD" SIMULATOR (EXTRAPOLATED)
2. REF: LGIT 20-1-19 P-104-65-67
3. PHASE LAG FROM AILERON AUTOPILOT TO AILERON SURFACE.
4. PHASE LAG HYDRAULIC SERVO TO SURFACE (INPUT THROUGH SAS SYSTEM)

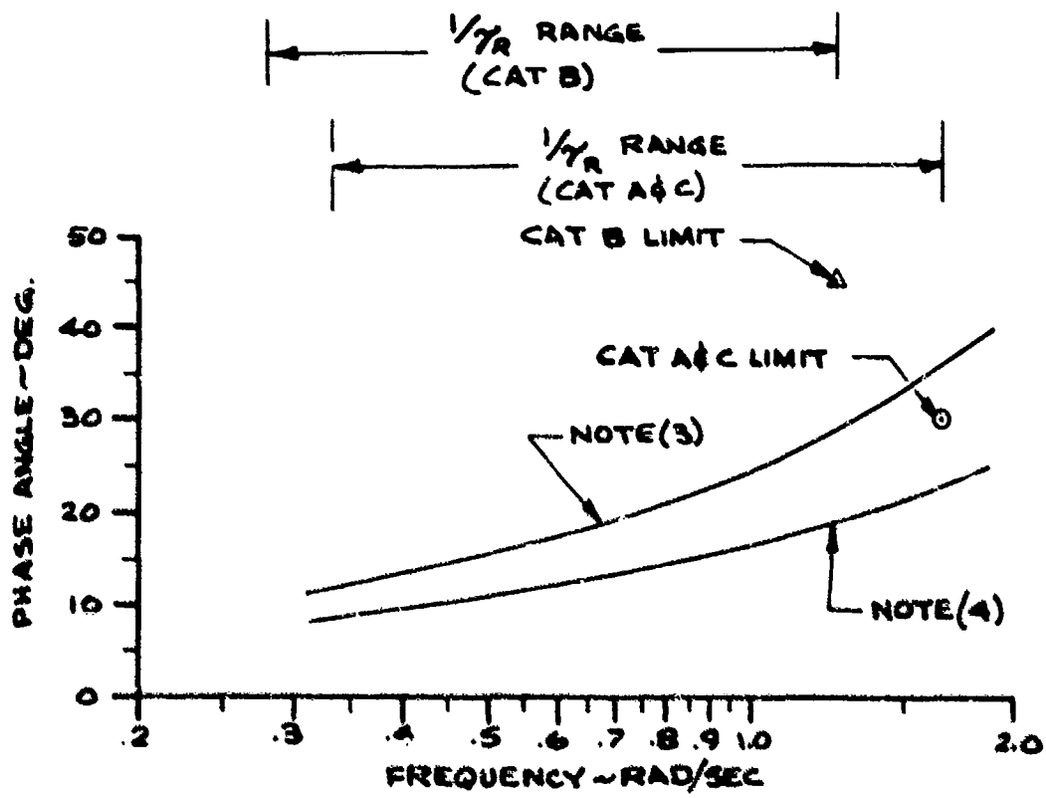


FIGURE NO.2 (3.5.3) AILERON FREQUENCY RESPONCE

C-5A FLIGHT TEST DATA

NOTE:

1. TEST RESULTS FROM "IRON BIRD" SIMULATOR
2. REF: LGIT 20-1-19 P-12.4-49
3. PHASE LAG FROM HYDRAULIC SERVO TO SURFACE (INPUT THROUGH SAS SYSTEM)

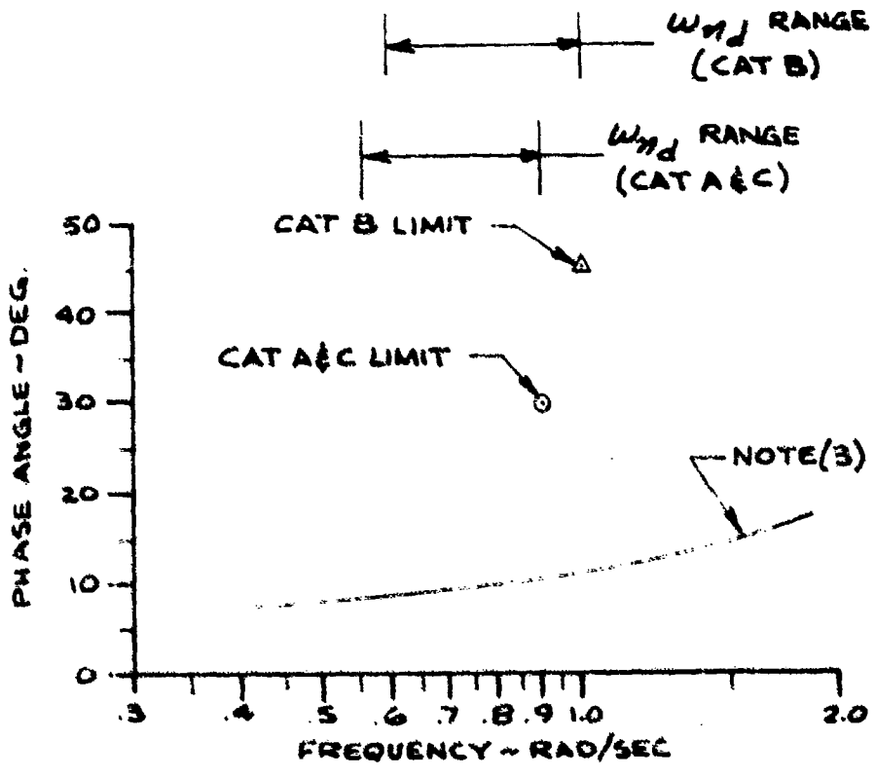


FIGURE NO.3 (3.5.3) RUDDER FREQUENCY RESPONCE

Requirement

3.5.3.1 Control feel. In flight, the cockpit-control deflection shall not lead the cockpit-control force for any frequency or force amplitude. This requirement applies to the elevator, aileron, and rudder controls. In flight, the cockpit-control deflection shall not lag the cockpit-control force by more than the angles listed in 3.5.3, for frequencies equal to or less than those listed in 3.5.3, for reasonably large force inputs. The lags for very small control-force amplitudes shall not interfere with the pilot's ability to perform precision tasks required in normal operation.

Comparison

All frequency response tests conducted on the C-5 primary control systems show that the aileron, rudder and elevator surfaces always lag the input. The phase lag for reasonably large inputs indicate that phase lags probably are close to the limits of 3.5.3 (reference Figures 1, 2, & 3 (3.5.3). The pilot is able to perform all normal operations requiring small inputs.

Discussion

None

Recommendation

None

Requirement

3.5.3.2 Damping. All control system oscillations shall be well damped unless they are of such an amplitude, frequency, and phasing that they do not result in objectionable oscillations of the cockpit controls or the airframe during abrupt maneuvers and during flight in the atmospheric disturbances specified in 3.7.3 and 3.7.4.

Comparison

All C-5 primary control systems are well damped, and there are no objectionable oscillations as a result of abrupt maneuvers.

Discussion

None

Recommendation

None

Requirement

3.5.4 Augmentation systems. Normal operation of stability augmentation and control augmentation systems and devices shall not introduce any objectionable flight or ground handling characteristics.

3.5.4.1 Performance of augmentation systems. Performance degradation of augmentation systems caused by the atmospheric disturbances of 3.7.3 and 3.7.4 and by structural vibrations shall be considered when such systems are used.

3.5.4.2 Saturation of augmentation systems. Limits on the authority of augmentation systems or saturation of equipment shall not result in objectionable flying qualities. In particular, this requirement shall be met during rapid large-amplitude maneuvers, during operation at high angle of attack (3.4.2 through 3.4.2.2.2), and during flight in the atmospheric disturbances of 3.7.3 and 3.7.4.

Comparison

The C-5 with SAS (Stability Augmentation System) operational, under all flight conditions, has exhibited no objectionable flying qualities.

Discussion

None

Recommendation

None

Requirement

3.5.5 Failures. If the flying qualities with any or all of the augmentation devices inoperative are dangerous or intolerable, special provisions shall be incorporated to preclude a critical single failure. Failure-induced transient motions and trim changes resulting either immediately after failure or upon subsequent transfer to alternate control modes shall be small and gradual enough that dangerous flying qualities never result.

Comparison

The C-5 can be safely flown with SAS (Stability Augmentation Subsystem) inoperative. Pilot work load is increased with SAS "off" in both pitch and yaw/lateral systems. The SAS is triply redundant and will automatically switch to the standby channel in the event of a failure and switch "off" after a second failure. Trim changes resulting from an SAS failure are small and are not dangerous.

Discussion

None

Recommendation

None

Requirement

3.5.5.1 Failure transients. With controls free, the airplane motions due to failures described in 3.5.5 shall not exceed the following limits for at least two seconds following the failure, as a function of the level of flying qualities after the failure transient has subsided.

Level 1 (after failure)	± 0.05g normal or lateral acceleration at the pilot's station and ± 1 degree per second in roll
Level 2 (after failure)	± 0.05g at the pilot's station, ± 5 degrees per second roll, and the lesser of ± 5 degrees sideslip or the structural limits
Level 3 (after failure	No dangerous attitude or structural limit is reached, and no dangerous alteration of the flight path results from which recovery is impossible.

Comparison

The C-5 SAS (Stability Augmentation Subsystem) is a triply redundant system that switches automatically to a standby channel after a failure. The time from a failure to switchover is on the order of 60 milliseconds and, therefore, the resulting n_z change is small. Failure tests were not conducted, but pilot comments about an SAS failure that occurred during the Flight Test program indicated that no significant airplane motions resulted.

Discussion

None

Recommendation

None

Requirement

3.5.5.2 Trim changes due to failures. The change in control forces required to maintain attitude and sideslip for the failures described in 3.5.5 shall not exceed the following limits for at least five seconds following the failure.

Elevator.	20 pounds
Aileron	10 pounds
Rudder	50 pounds

Comparison

Pilot force changes as a result of an SAS (Stability Augmentation Subsystem) failure were not measured during the failure experienced in Flight Test. The estimated pilot force change was not significant and was well below the limits stated. The limits stated are considered to be reasonable.

Discussion

None

Recommendation

None

Requirement

3.5.6 Transfer to alternate control modes. The transient motions and trim changes resulting from the intentional engagement or disengagement of any portion of the primary flight control system by the pilot shall be small and gradual enough that dangerous flying qualities never result.

3.5.6.1 Transients. With controls free, the transients resulting from the situations described in 3.5.6 shall not exceed the following limits for at least 2 seconds following the transfer.

Within the Operational Flight Envelope	± 0.05g normal or lateral acceleration at the pilot's station and ± 1 degree per second roll
Within the Service Flight Envelope	± 0.5g at the pilot's station, ± 5 degrees per second roll, and the lesser of ± 5 degrees sideslip or the structural limit

These requirements apply only for Airplane Normal States.

Comparison

Engaging the alternate control system which involved switching off Hydraulic System No. 2 resulted in essentially no change in trim or attitude (reference Figure 1 (3.6.3.1).

During flight test, the SAS was switched "on" many times, and the transients did not exceed ± .05g and there was no change in roll rate or sideslip. It is assumed that the same changes would take place when the SAS is switched "off." Although no specific test analysis or simulation was performed, the flight test records indicate that the C-5 meets this requirement.

Discussion

None

Recommendation

None

Requirement

3.5.6.2 Trim changes. The change in control forces required to maintain attitude and sideslip for the situations described in 3.5.6 shall not exceed the following limits for at least five seconds following the transfer.

Elevator.	20 pounds
Aileron	10 pounds
Rudder	50 pounds

These requirements apply only for Airplane Normal States.

Comparison

SAS was switched "on" a number of times during flight tests, and the pilot forces did not change. It is assumed that the same results would be seen for switching SAS "off." The C-5 meets this requirement.

Discussion

None

Recommendation

None

Requirement

3.6 Characteristics of secondary control systems

3.6.1 Trim system. In straight flight, throughout the Operational Flight Envelope, the trimming devices shall be capable of reducing the elevator, rudder, and aileron control forces to zero for Levels 1 and 2. For Level 3, the untrimmed cockpit control forces shall not exceed 10 pounds elevator, 5 pounds aileron, and 20 pounds rudder. The failures to be considered in applying the Level 2 and 3 requirements shall include trim sticking and runaway in either direction. It is permissible to meet the Level 2 and 3 requirements by providing the pilot with alternate trim mechanisms or override capability. Additional requirements on trim rate and authority are contained in MIL-F-9490 and MIL-F-18372.

Comparison

The C-5 pitch trim system is capable of maintaining zero control force except:

a) longitudinally in the cruise configuration at a forward center-of-gravity within the weighr-altitude envelope described in Figure 1 (3.6.1), and

b) longitudinally in the landing configuration with idle power at the extremely low speed conditions (below $1.22V_S$). The inability to trim at $1.2V_S$ in the cruise configuration with a forward center-of-gravity-low weight condition should not limit the C-5A operational capability. In the landing configuration with idle power, it was not possible to trim down to $1.2V_S$; but, since the recommended landing approach speed was $1.3V_S$ (where idle power trim was possible), there should never be an operational requirement to trim the aircraft to $1.2V_S$.

The pitch trim system is designed so that no single failure will result in a runaway trim. There are single failures that could result in loss of trim (trim sticking) so that after failure, the failed trim position would be maintained. The pilot must use elevator to maintain control of the aircraft. In a simulated failure (at cruise trim), the pilot maintained aircraft trim by using elevator. In this mistrim condition, the elevator required for approach was 12.5 degrees, and pilot force was 30 pounds. The C-5 rudder trim system is capable of reducing control forces to zero for normal operation. For any trim failure, the pilot can trim the aircraft to zero control force using the emergency control knob that inputs a signal through the SAS components to reposition the rudders.

The C-5 aileron trim system is capable of reducing control forces to zero for normal operation. The trim system utilizes two actuators (one in each wing) so that if one fails the remaining actuator is used for trim. Pilot force would exceed five pounds if any is required because breakout is six pounds.

Discussion

The elevator force (10 pounds) allowed for Level 3 trim after a failure would seem to be insufficient for the C-5 because of the change in trim required between cruise and approach speeds. The aileron force (5 pounds) allowed for Level 3 trim is also too low, because the allowable breakout is six pounds. If any force at all is required, it would

have to be greater than breakout.

Recommendation

The allowable elevator force for Level 3 after failure should be increased for Class II and Class III aircraft.

The allowable aileron force for Level 3 after failure should be increased above the allowable breakout.

The requirement as written is not clear in that trim must provide zero control force for Levels 1 and 2, but a later sentence defines the same type failures be considered for Level 2 and 3.

C-5A FLIGHT TEST DATA

CRUISE CONFIGURATION
FORWARD C.G. LIMIT

NOTE:
THE AIRPLANE CAN BE TRIMMED FLAPS UP AT 1.25 V_S WITH THE MOST FORWARD CENTER OF GRAVITY AT ALL GROSS WEIGHT AND ALTITUDE CONDITIONS.

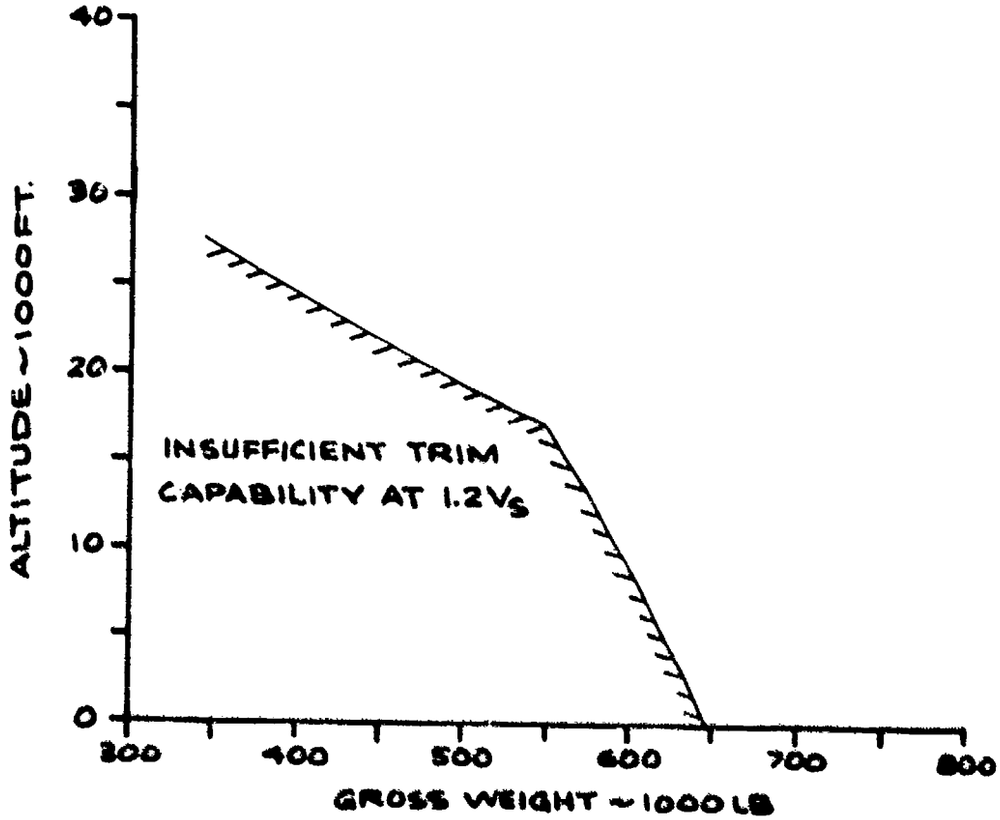


FIGURE NO.1(3.6.1) TRIM CAPABILITY

Requirement

3.6.1.1 Trim for asymmetric thrust. For all multi-engine airplanes, it shall be possible to trim the elevator, rudder, and aileron control forces to zero in straight flight with up to two engines inoperative following asymmetric loss of thrust from the most critical factors (3.3.9). This requirement defines Level 1 in level-flight cruise at speeds from the maximum-range speed for the engine(s) out configuration to the speed obtainable with normal rated thrust on the functioning engine(s). Systems completely dependent on the failed engines shall also be considered failed.

Comparison

The C-5 meets the requirement as demonstrated during Category I/II test program.

Discussion

None

Recommendation

None

Requirement

3.6.1.2 Rate of trim operation. Trim devices shall operate rapidly enough to enable the pilot to maintain low control forces under changing conditions normally encountered in service, yet not so rapidly as to cause over sensitivity or trim precision difficulties under any conditions. Specifically, it shall be possible to trim the elevator control forces to less than ± 10 pounds for center-stick airplanes and ± 20 pounds for wheel control airplanes throughout (a) dives and ground attack maneuvers required in normal service operation, and (b) level-flight accelerations at maximum augmented thrust from 250 knots or $V_{R/C}$, whichever is less, to V_{max} at any altitude when the airplane is trimmed for level flight prior to initiation of the maneuver.

Comparison

C-5 trim rates are:

Horizontal Stabilizer - nut drive .3°/sec, flaps up
.5°/sec, flaps not up

Range: 12° nose up
2.5° nose down - screw drive .15°/sec

Aileron - 1°/sec total
Range: ± 10°

Rudder - 1°/sec
Range: ± 11°

During all normal flight operations, the trim rates were adequate without being excessive. The C-5 is considered to meet the requirement that the elevator force not exceed 20 pounds, although in retarding throttles there was a momentary average push force of 22 pounds. Reference Figure 1 (3.6.3.1).

Discussion

None

Recommendation

During aerial delivery, a normal operation for C-5, there is a large c.g. shift. There should be included in this specification an item approval to momentarily exceed 20 pounds elevator force which the aircraft is being trimmed for this change.

Requirement

3.6.1.3 Stalling of trim systems. Stalling of a trim system due to aerodynamic loads during maneuvers shall not result in an unsafe condition. Specifically, the longitudinal trim system shall be capable of operating during the dive recoveries of 3.2.3.6 at any attainable permissible n, at any possible position of the trimming device.

Comparison

The C-5 trim systems are capable of trimming the aircraft to zero force under all normal flight conditions.

Discussion

None

Recommendation

None

Requirement

3.6.1.4 Trim system irreversibility. All trimming devices shall maintain a given setting indefinitely, unless changed by the pilot, by a special automatic interconnect such as to the landing flaps, or by the operation of an augmentation device. If an automatic interconnect or augmentation device is used in conjunction with a trim device, provision shall be made to ensure the accurate return of the device to its initial trim position on completion of each interconnect or augmentation operation.

Comparison

All C-5 trim devices are irreversible and will maintain a given trim setting indefinitely.

Discussion

None

Recommendation

None

Requirement

3.6.2 Speed and flight-path control devices. The effectiveness and response times of the fore-and-aft force controls, in combination with the other longitudinal controls, shall be sufficient to provide adequate control of flight path and airspeed at any flight condition within the Operational Flight Envelope. This requirement may be met by use of devices such as throttles, thrust reversers, auxiliary drag devices, and flaps.

Comparison

C-5 devices used are throttles, thrust reversers, L.E. slats, and T.E. flaps. Flight tests were conducted on all these devices, and the test results show that they provide adequate flight path and airspeed control of the aircraft.

Discussion

None

Comparison

None

Requirement

3.6.3 Transients and trim changes. The transients and steady-state trim changes for normal operation of secondary control devices (such as throttle, flaps, slats, speed brakes, deceleration devices, dive recovery devices, wing sweep, and landing gear) shall not impose excessive control forces to maintain the desired heading, altitude, attitude, rate of climb, speed or load factor without use of the trimmer control. This requirement applies to all in-flight configuration changes and combinations of changes made under service conditions, including the effects of asymmetric operations such as unequal operation of landing gear, speed brakes, slats, or flaps. In no case shall there by any objectionable buffeting or oscillation of such devices. More specific requirements on secondary control devices are contained in 3.6.3.1, 3.6.4 and 3.6.5 and in MIL-F-9490 and MIL-F-18372.

Comparison

The transients and steady-state trim changes created by operation of such control devices as throttles, flaps, landing gear and thrust reversers are negligible. Longitudinal trim changes are tabulated in Figure 1 (3.6.3.1). The C-5A favorably compares with this requirement.

Discussion

None

Recommendation

None

Requirement

3.6.3.1 Pitch trim changes. The pitch trim changes caused by operation of secondary control devices shall not be so large that a peak elevator control force in excess of 10 pounds for center-stick controllers or 20 pounds for wheel controllers is required when such configuration changes are made in flight under conditions representative of operational procedure. Generally, the conditions listed in table XIV will suffice for determination of compliance with this requirement. (For airplanes with variable-sweep wings, additional requirements will be imposed consistent with operational employment of the vehicle). With the airplane trimmed for each specified initial condition, the peak force required to maintain the specified parameter constant following the specified configuration change shall not exceed the stated value for a time interval of at least five seconds following the completion of the pilot action initiating the configuration change. The magnitude and rate of trim change subsequent to this time period shall be such that the forces are easily trimmable by use of the normal trimming devices. These requirements define Level 1. For Levels 2 and 3, the allowable forces are increased by 50 percent.

Comparison

The conditions tested and results in Figure 1 (3.6.3.1) were considered to be representative of the operation of secondary control devices. Test 10 shows a control force of 22 pounds push, which exceeds the allowable 20 pounds.

Discussion

The 22-pound force exceeded the allowable by only 2 pounds and was only momentary. The C-5 is considered as meeting this requirement.

Recommendation

None

TABLE XIV. Pitch Trim Change Conditions

	Flight Phase	Initial Trim Condition: Altitude	Speed	Landing Gear	High-lift Devices & Wing Flaps	Thrust	Configuration Change	Parameter to be held constant
1	Approach	$h_{o_{min}}$	Normal pattern entry speed	Up	Up	TLF	Gear down	Altitude and airspeed*
2				Up	Up	TLF	Gear down	Altitude
3				Down	Up	TLF	Extend high-lift devices and wing flaps	Altitude and airspeed*
4				Down	Up	TLF	Extend high-lift devices and wing flaps	Altitude
5				Down	Down	TLF	Idle thrust	Airspeed
6			$V_{o_{min}}$	Down	Down	TLF	Extend approach drag device	Airspeed
7				Down	Down	TLF	Takeoff thrust	Airspeed
8	Approach		$V_{o_{min}}$	Down	Down	TLF	Takeoff thrust plus normal clean-up for wave-off (go-around)	Airspeed
9	Takeoff			Down	Take-off	Take-off thrust	Gear up	Pitch attitude
10			Minimum flap-retract speed	Up	Take-off	Take-off thrust	Retract high-lift devices and wing flaps	Airspeed
11	Cruise and air-to-air combat	$h_{o_{min}}$ and $h_{o_{max}}$	Speed for level flight	Up	Up	MRT	Idle thrust	Pitch attitude
12				Up	Up	MRT	Actuate deceleration device	
13				Up	Up	MRT	Maximum augmented thrust	
14			Speed for best range	Up	Up	TLF	Actuate deceleration device	

*Throttle setting may be changed during the maneuver

Notes: • Auxiliary drag devices are initially retracted, and all details of configuration not specifically mentioned are normal for the Flight Phase.

• If power reduction is permitted in meeting the deceleration requirements established for the mission, actuation of the deceleration device in #12 and #14 shall be accompanied by the allowable power reduction.

C-5A FLIGHT TEST DATA

Cond. No.	Initial Trim Conditions: [illegible]	Altitude (Ft)	[illegible]	[illegible]	Gear	Flaps Deg.	Thrust	Configuration Change	Parameter Held Constant	Max. Effective Stick Force During First 5 Seconds (Lb)	Mean Stick Force After Configuration Change (Lb)
1	173	9,9[illegible]	[illegible]	2[illegible]	Up	Up	[illegible]	Gear Down	Altitude	9 Pull	5 Pull
2	22[illegible]	[illegible]	[illegible]	22[illegible]	Up	Up	[illegible]	Gear Down	Altitude	13 Pull	9 Pull *
3	12[illegible]	[illegible]	[illegible]	[illegible]	Dn	[illegible]	[illegible]	Gear Up	Rate of Climb	13 Push	8 Push
4	[illegible]	[illegible]	[illegible]	[illegible]	Up	[illegible]	[illegible]	Gear Down	Airspeed	6 Pull	0
5	1[illegible]	[illegible]	[illegible]	[illegible]	Dn	[illegible]	[illegible]	Gear Up	Airspeed	3 Push	0
6	[illegible]	[illegible]	[illegible]	[illegible]	Dn	Up	[illegible]	Flaps Down	Altitude	20 Push	15 Pull *
7	[illegible]	[illegible]	[illegible]	[illegible]	Up	Up	[illegible]	Flaps Down	Altitude	12 Push	12 Pull *
8	143	[illegible]	[illegible]	[illegible]	Up	Dn	[illegible]	Flaps Up	Rate of Climb	20 Push	25 Push *
9	144	[illegible]	[illegible]	[illegible]	Dn	[illegible]	[illegible]	Flaps Up	Rate of Climb	11 Push	8 Push
10	132	[illegible]	[illegible]	[illegible]	Dn	Dn	[illegible]	Thrust to Idle	Airspeed	22 Push (Avg.)	14 Pull
11	313	[illegible]	[illegible]	[illegible]	Up	Up	[illegible]	Thrust to Idle	Altitude	20 Pull	20 Pull
12	34[illegible]	[illegible]	[illegible]	[illegible]	Up	Up	[illegible]	Thrust to Idle	Altitude	16 Pull	17 Pull *
13	[illegible]	[illegible]	[illegible]	[illegible]	Dn	Dn	[illegible]	Thrust to MRT	Altitude	17 Push	20 Push
14	122	[illegible]	[illegible]	[illegible]	Dn	Dn	[illegible]	Thrust to MRT & Flaps 40° to 25°	Altitude	19 Push	20 Push
15	348	[illegible]	[illegible]	22[illegible]	Up	Up	[illegible]	Thrust Rev. Ext'd	Point of Aim	10 Pull	20 Pull *
16	[illegible]	[illegible]	[illegible]	[illegible]	Up	Up	[illegible]	Thrust Rev. Ext'd	Point of Aim	6 Pull	12 Pull *
17	[illegible]	[illegible]	[illegible]	[illegible]	Up	Up	[illegible]	Thrust Rev. Ext'd	Point of Aim	20 Push	10 Pull *
18	[illegible]	[illegible]	[illegible]	[illegible]	Up	Up	[illegible]	Thrust Rev. Ext'd	Altitude	17 Pull	32 Pull *
19	[illegible]	[illegible]	[illegible]	[illegible]	Up	Up	[illegible]	Thrust Rev. Ext'd	Altitude	20 Pull	20 Pull *
20	[illegible]	[illegible]	[illegible]	[illegible]	Up	Up	[illegible]	Thrust Rev. Ext'd	Altitude	1[illegible] Pull	12 Pull *
21	[illegible]	[illegible]	[illegible]	[illegible]	Up	[illegible]	[illegible]	Open Aft Doors	Altitude	0	0
22	[illegible]	[illegible]	[illegible]	[illegible]	Up	Dn	[illegible]	Close Aft Doors	Altitude	5 Push	5 Push
23	[illegible]	[illegible]	[illegible]	[illegible]	Up	Up	[illegible]	No. 2 Hyd. Sys. Off	Airspeed	0	0
24	[illegible]	[illegible]	[illegible]	[illegible]	Up	Up	[illegible]	No. 2 Hyd. Sys. Off	Airspeed	0	0
25	[illegible]	[illegible]	[illegible]	[illegible]	Dn	Dn	[illegible]	No. 2 Hyd. Sys. Off	Airspeed	0	0
26	[illegible]	[illegible]	[illegible]	[illegible]	Up	Up	[illegible]	No. 2 Hyd. Sys. Off	Airspeed	0	0 *

* Denotes TCS On

Figure 1 (3.6.3.1) Longitudinal Trim Changes

Requirement

3.6.4 Auxiliary dive recovery devices. Operation of any auxiliary device intended solely for dive recovery shall always produce a positive increment of normal acceleration, but the total normal load factor shall never exceed $0.8\ n_L$, control free.

Comparison

The C-5 has no auxiliary dive devices.

Discussion

None

Recommendation

None

Requirement

3.6.5 Direct normal-force control. Use of devices for direct normal-force control shall not produce objectionable changes in attitude for any amount of control up to the maximum available. This requirement shall be met for Levels 1 and 2.

Comparison

The Ground Spoiler System is used to increase aircraft weight on the landing gear and make the brakes more effective at landing. No objectionable attitude changes have been experienced.

Discussion

None

Recommendation

None

Requirements

3.7 Atmospheric dusturbances

3.7.1 Use of turbulence models. Paragraphs 3.7.2 tnrough 3.7.5 specify a continuous random turbulence model and a discrete turbulence model that shall be used in analyses to determine compliance with those requirements of this specification that refer to 3.7 explicitly, to assess:

a. The effect of turbulence on the flying qualities of the airplane;
b. The ability of a pilot to recover from the effects of discrete gusts.

Comparison

Specific analytical studies pertaining to C-5A flying qualities in turbulence using the methods defined in paragraph 3.7 were not performed. A major dynamic analysis was performed in the design phase, however, with the effort tailored to the response of structural components in turbulence. This analysis, performed as an outgrowth of MIL-A-00-8861A, "Airplane Strength and Rigidity, Flight Loads," reflected linearized airplane flying qualities in turbulence. Though this analysis did not completely evaluate controllability, the basic airplane response appeared satisfactory. In the course of fixed and moving base flight simulator tests random turbulence and discrete gust functions were generated to evaluate airplane/pilot combinations. These simulator tests, which incorporated only a quasi-flexible airplane model, showed the C-5A to have reasonable handling characteristics in turbulence.

Since no significant problems were discovered in the early design phase, no extensive effort was performed; and, hence, no large amount of documentation exists at this time.

Early in the development test program, it was demonstrated that the C-5A exhibited no undesirable handling qualities in the light turbulence.

Following completion of the 100 percent structural demonstration program, dynamic response tests were conducted on the C-5A in moderate to heavy turbulence. Dynamic response tests were also conducted during the ALDCS development test program. These tests were conducted to determine primarily the response of structural components in turbulence, with pilot work load and controllability data as secondary. These data are too voluminous for inclusion here, although the results show good airplane control with low pilot work load in gusts conditions up to 33 feet per second. Analyses of the flight test results are presented in references 5 and 6.

Discussion

None

Recommendation

None

Requirement

3.7.2 Turbulence models. Where feasible, the von Karman form shall be used for the continuous random turbulence model, so that the flying qualities analyses will be consistent with the comparable structural analyses. When no comparable structural analysis is performed or when it is not feasible to use the von Karman form, use of the Dryden form will be permissible. In general, both the continuous random model and the discrete model shall be used. The scales and intensities used in determining the gust magnitudes for the discrete model shall be the same as those used in the Dryden continuous random model.

Comparison

None

Discussion

None

Recommendations

None

Requirement

3.7.2.1 Continuous random model (von Karman form). The von Karman form of the spectra for the turbulence velocities is:

$$\Phi_{u_g}(\Omega) = \sigma_u^2 \frac{2L_u}{\pi} \frac{1}{\left[1 + (1.339L_u\Omega)^2\right]^{5/6}}$$

$$\Phi_{v_g}(\Omega) = \sigma_v^2 \frac{L_v}{\pi} \frac{1 + \frac{8}{3}(1.339L_v\Omega)^2}{\left[1 + 1.339L_v\Omega)^2\right]^{11/6}}$$

$$\Phi_{w_g}(\Omega) = \sigma_w^2 \frac{L_w}{\pi} \frac{1 + \frac{8}{3}(1.339L_w\Omega)^2}{\left[1 + (1.339L_w\Omega)^2\right]^{11/6}}$$

3.7.2.2 Continuous random model (Dryden form). The Dryden form of the spectra for the turbulence velocities is:

$$\Phi_{u_g}(\Omega) = \sigma_u^2 \frac{2L_u}{\pi} \frac{1}{1 + (L_u\Omega)^2}$$

$$\Phi_{v_g}(\Omega) = \sigma_v^2 \frac{L_v}{\pi} \frac{1 + 3(L_v\Omega)^2}{\left[1 + (L_v\Omega)^2\right]^2}$$

$$\Phi_{w_g}(\Omega) = \sigma_w^2 \frac{L_w}{\pi} \frac{1 + 3(L_w\Omega)^2}{\left[1 + (L_w\Omega)^2\right]^2}$$

Comparison

None

Discussion

None

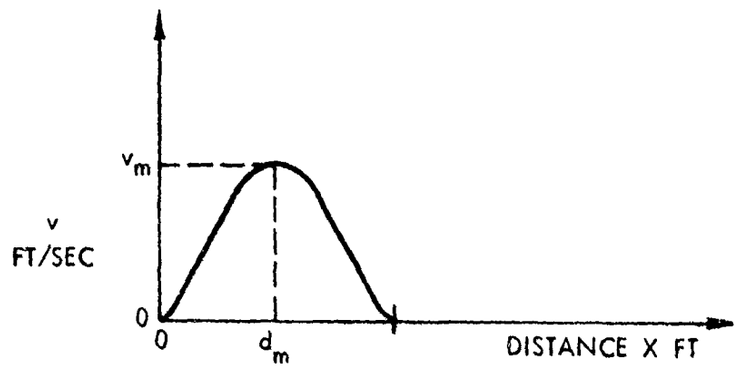
Recommendation

None

Requirement

3.7.2.3 Discrete model. The discrete turbulence model may be used for any of the three gust-velocity components. The discrete gust has the "1 - cosine" shape:

$$
\begin{aligned}
v &= 0 && , x < 0 \\
&= \frac{v_m}{2}\left(1 - \cos\frac{\pi x}{d_m}\right) && , 0 \le x \le 2d_m \\
&= 0 && , x > 2d_m
\end{aligned}
$$



Several values of d_m shall be used, each chosen so that the gust is tuned to each of the natural frequencies of the airplane and its flight control system (higher-frequencies of the airplane and its flight control system (higher-frequency structural modes may be excepted). The magnitude v_m shall then be chosen from Figure 7. The parameters L and σ to be used within Figure 7 are the Dryden scales and intensities from 3.7.3 or 3.7.4 for the velocity component under consideration.

Comparison

None

Discussion

None

Recommendation

None

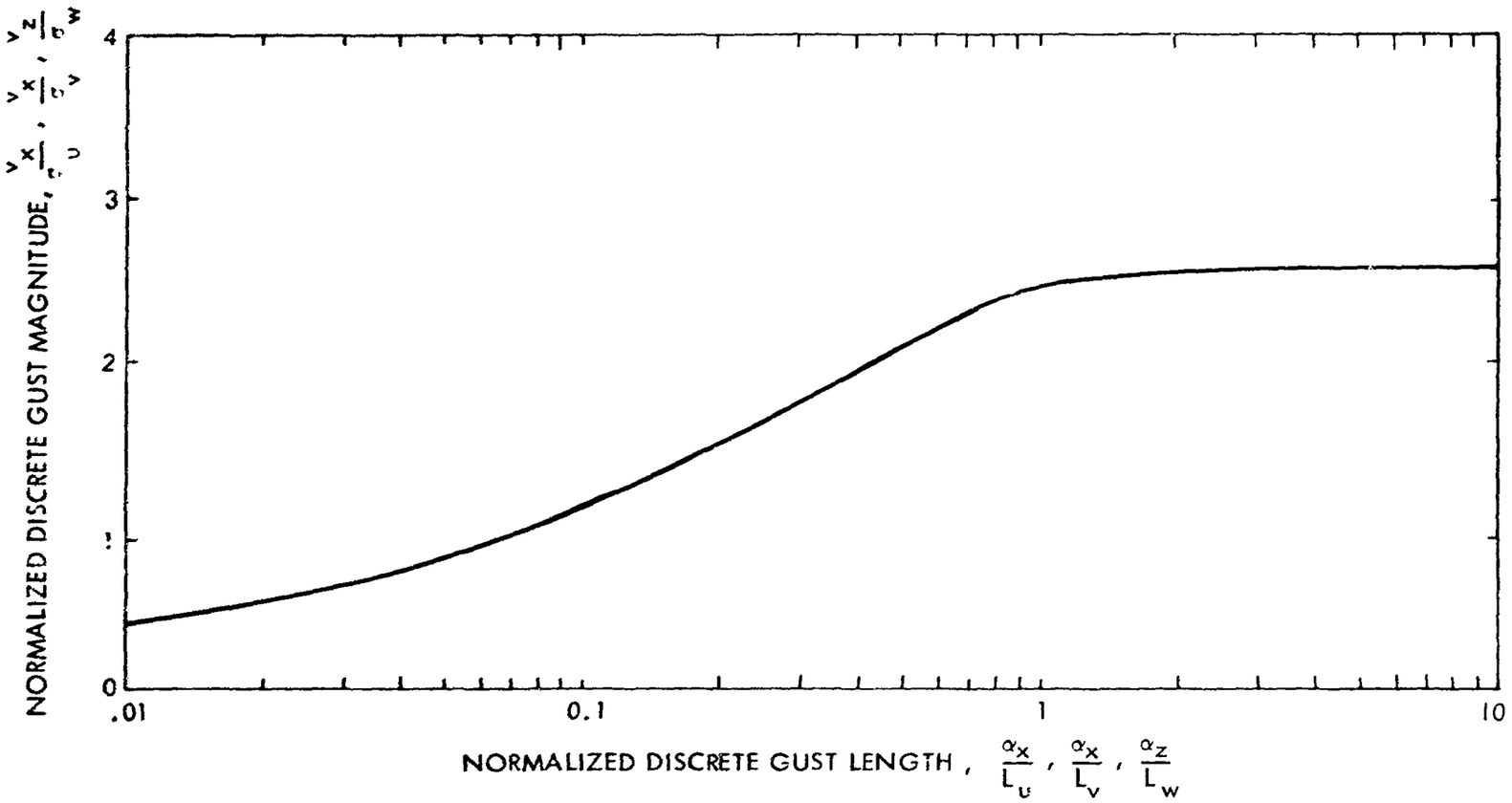


Figure 7. Magnitude of Discrete Gusts

Requirement

3.7.3 Scales and intensities (clear air turbulence). The root-mean-square intensity σ_w for clear air turbulence is defined on Figure 8 as a function of altitude. The intensities σ_u and σ_v may be obtained using the relationships

$$\frac{\sigma_u^2}{L_u^{2/3}} = \frac{\sigma_v^2}{L_v^{2/3}} = \frac{\sigma_w^2}{L_w^{2/3}} \quad \text{(von Karman form)}$$

$$\frac{\sigma_u^2}{L_u} = \frac{\sigma_v^2}{L_v} = \frac{\sigma_w^2}{L_w} \quad \text{(Dryden form)}$$

The scales for clear air turbulence are defined in 3.7.3.1 and 3.7.3.2 as a function of altitude. The altitude shall be defined consistently with any applicable terrain models specified in the contract. For those flight phases involving climbs and descents, a single set of scales and intensities based on an average altitude may be used. If an average set of scales and intensities is used for Category C Flight Phases, it shall be based on an altitude of 500 feet.

3.7.3.1 Clear air turbulence (von Karman scales). The scales for clear air turbulence using the von Karman form are:

Above $h = 2500$ feet: $L_u = L_v = L_w = 2500$ feet

Below $h = 2500$ feet: $L_w = h$ feet

$L_u = L_v = 184\ h^{1/3}$ feet

3.7.3.2 Clear air turbulence (Dryden scales). The scales for clear air turbulence using the Dryden form are:

Above $h = 1750$ feet: $L_u = L_v = L_w = 1750$ feet

Below $h = 1750$ feet: $L_w = h$ feet

$L_u = L_v = 145\ h^{1/3}$ feet

3.7.4 Scales and intensities (thunderstorm turbulence). The root-mean-square intensities σ_u, σ_v, and σ_w are all equal to 21 feet per second for thunderstorm turbulence. The scales for thunderstorm turbulence are defined in 3.7.4.1 and 3.7.4.2. These values are to be used when evaluating the airplane's controllability in severe turbulence but need not be considered for altitudes above 40,000 feet.

3.7.4.1 Thunderstorm turbulence (von Karman scale). The scales for thunderstorm turbu-

lence using the von Karman form are $L_u = L_v = L_w = 2500$ feet.

3.7.4.2 Thunderstorm turbulence (Dryden scales). The scales for thunderstorm turbulence using the Dryden form are $L_u = L_v = L_w = 1750$ feet.

Comparison

None

Discussion

None

Recommendation

None

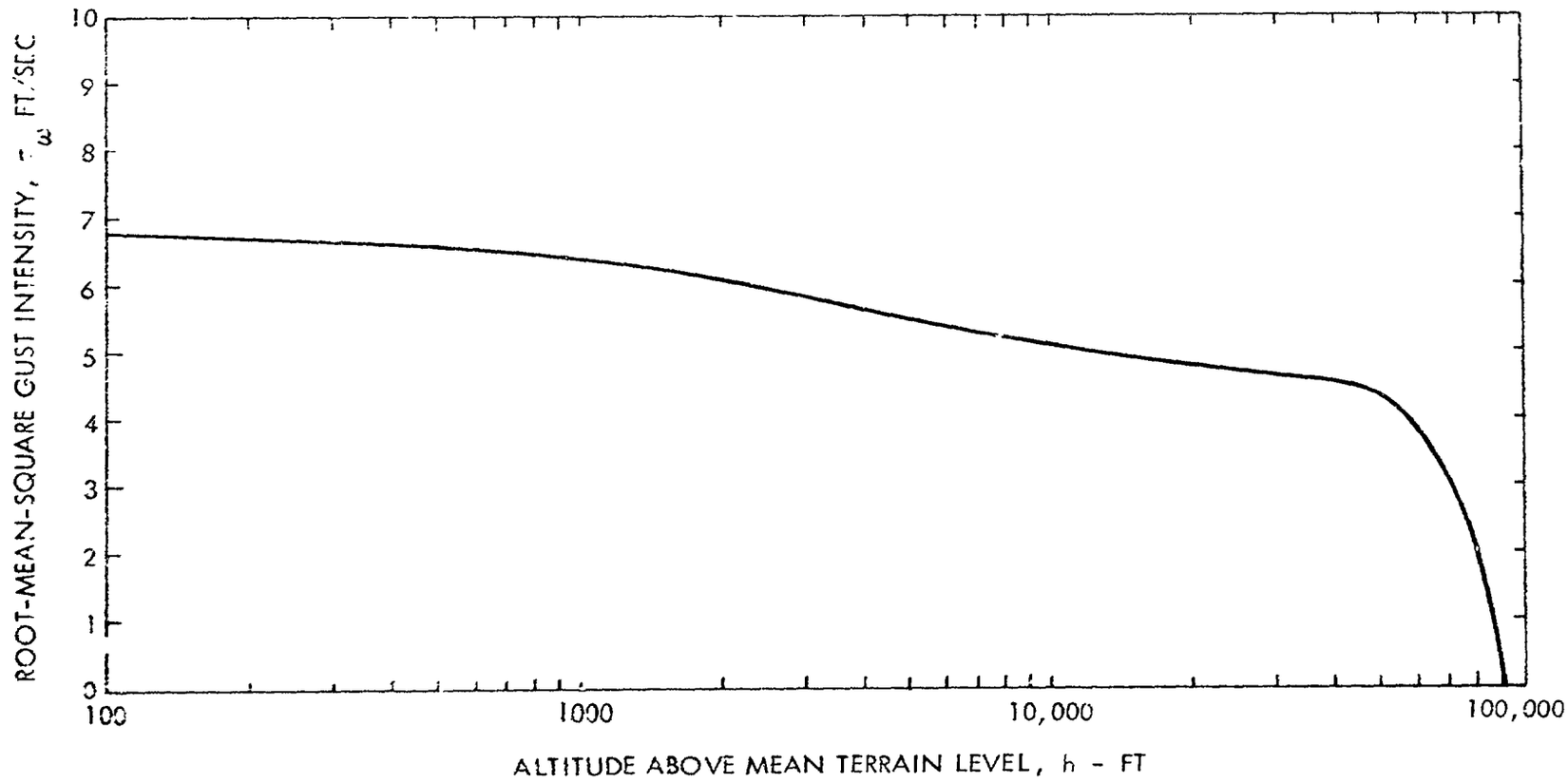


Figure 8. Intensity for Clear Air Turbulence

3.7.5 Application of the turbulence models in analyses. The gust velocities shall be applied to the airplane equations of motion through the aerodynamic terms only, and the direct effect of the gust on the aerodynamic sensors shall be included when such sensors are part of the airplane augmentation system. When using the discrete model, all significant aspects of the penetration of the gust by the airplane shall be incorporated in the analyses. Application of the continuous random model depends on the range of frequencies of concern in the analyses of the airframe. When structural modes are significant, the exact distribution of the gust velocities over the airframe should be considered. For this purpose, it is acceptable to consider u_g and v_g as being one-dimensional functions only of x, but w_g shall be considered two-dimensional, a function of both x and y, for the evaluation of aerodynamic forces and moments.

When structural modes are not significant, airframe rigid-body responses may be evaluated by considering uniform gust immersion along with linear gradients of the gust velocities. The uniform immersion is accounted for by u_g, v_g, and w_g defined at the airplane center of gravity. The angular velocities due to the turbulence are equivalent in effect to the airplane angular velocities. These angular velocities are defined (precisely at very low frequencies only) as follows:

$$p_g = -\frac{\partial w_g}{\partial y}$$

$$-\dot{\alpha}_g = q_g = +\frac{\partial w_g}{\partial x}$$

$$v_g = -\frac{\partial v_g}{\partial x}$$

$$\phi_{p_g}(\Omega) = \frac{\sigma_w^2}{L_w} \frac{0.8\left(\frac{\pi L_w}{4b}\right)^{1/3}}{1+\left(\frac{4b}{\pi}\Omega\right)^2}$$

$$\phi_{q_g}(\Omega) = \frac{\Omega^2}{1+\left(\frac{4b}{\pi}\Omega\right)^2} \quad \phi_{w_g}(\Omega)$$

$$\phi_{r_g}(\Omega) = \frac{\Omega^2}{1+\left(\frac{3b}{\pi}\Omega\right)^2} \quad \phi_{v_g}(\Omega) \quad \text{where } b = \text{wing span}$$

The turbulence velocities u_g, v_g, w_g, p_g, q_g, and r_g are then applied to the airplane equations of motion through the aerodynamic terms. For longitudinal analyses, u_g, w_g, and q_g gusts should be employed. For lateral-directional analyses v_g, p_g, and r_g should be used. The gust velocity components, u_g, v_g, and w_g shall be considered

mutually independent (uncorrelated) in a statistical sense. However, q_g is correlated with w_g, and r_g is correlated with v_g. The rolling velocity gust p_g is statistically independent of all the other gust components.

Comparison

None

Discussion

None

Recommendation

None

4. QUALITY ASSURANCE

This section of the specification has been reviewed and is considered satisfactory.

5. PREPARATION FOR DELIVERY

Since this section is not applicable to this specification, it is suggested that it be deleted.

6. NOTES

This section of the specification has been reviewed and is considered satisfactory.

SECTION IV

CONCLUSIONS AND RECOMMENDATIONS

The results of comparing the C-5A airplane flying qualities with the requirements of this specification yield the following conclusions and recommendations.

CONCLUSIONS

1. The specification represents a substantial improvement over specifications with respect to requirement definition, format and overall clarity.

2. Generally, the C-5A data compare favorably with the specification except in certain sections where the requirements appear to have been based primarily on medium and light weight airplane data.

3. Based on the C-5A data, the following sections of the specification are far too stringent for Class III airplanes.

   3.3.1.2 - Roll mode (τ_R)

   3.3.2.4 - Sideslip excursions

   3.3.4 - Roll control effectiveness

RECOMMENDATIONS

1. Additional data from Class III heavy aircraft be gathered to substantiate or revise the requirements in the following sections.

   3.2.1.2 Phugoid stability

   3.2.2.1 Short period response

   3.2.2.2.1 Control forces in maneuvering flight

   3.3.1.1 Lateral directional oscillations (Dutch roll)

   3.3.1.2 Roll mode (τ_R)

   3.3.2.4 Sideslip excursions

   3.3.4 Roll control effectiveness

   3.4.2.2.1 Resistance to loss of control

INDEX OF RECOMMENDATIONS

The following lists the paragraphs of the specification, indicating by page number where recommendations have been made. The most significant recommendations are marked by an asterisk.

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3.2.1.3	Flight path stability	93
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SECTION V

REFERENCES

1. Contract End Item Detail Specification (Prime Equipment), CEI Number MA0001A, Specification Number CP40002-1B, C-5A Air Vehicle, 10 April 1968.

2. C-5A Category I/II Engineering Flight Test Flying Qualities Test Results, LG1T19-1-10, 19 June 1970.

3. Chalk, C. R., et al, Background Information and User Guide for MIL-F-8785B(ASG), Military Specification - Flying Qualities of Piloted Airplanes, August 1969.

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