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A GRAPHICAL SUMMARY OF MILITARY HELICOPTER FLYING AND GROUND HANDLING QUALITIES OF MIL-H-8501A

JOHN M. GRIFFIN
ROBERT G. BELLAIRE

TECHNICAL REPORT ASNF TN 68-3

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DEPUTY FOR ENGINEERING, AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

136

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FOREWORD

The work presented herein was done completely in-house by the Stability and Control Branch, Aeromechanics Division, Directorate of Airframe Subsystems Engineering, Deputy for Engineering, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio. The work was initiated by Mr. Bellaire in early 1965 and was continued and finished by Mr. Griffin in early 1966.

The report is a compendium of figures generated by the Stability and Control Branch to facilitate use of the design requirements in MIL-H-8501A. The graphs were constructed to aid engineers in examining helicopter characteristics from preliminary data and flight test results. The report is not a replacement for MIL-H-8501A, nor is it the official Air Force or DOD position concerning the specification. It is presented solely as an engineering aid.

The authors are indebted to Mr. John Watson for his assistance throughout the preparation of the work.

Mr. John W. Carlson, Supervisor of the Stability and Control Branch is thanked for his guidance and review of the work.

The report was submitted for publication on 1 September 1968.

The report is reviewed and approved.

R H Klepinger

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ABSTRACT

A designer's handbook for helicopter flying and ground handling qualities is presented. It is based on the current Military helicopter design requirements of MIL-H-8501A. The written requirements are interpreted mathematically and presented graphically, along with a discussion of the requirement and the resulting figure. The report is a designer's aid and does not represent an official Air Force or DOD position concerning the interpretation of MIL-H-8501A.

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LIST OF SYMBOLS

a, b, c, d, constants

$C_{1/2}$, cycles to damp to half amplitude

$C_{1/10}$, cycles to damp to 1/10 amplitude

C_2, cycles to double amplitude

C_{10}, cycles to ten times amplitude

D, rate damping, ft-lbs/rad/sec

$D/_I$, damping parameter, per rad-sec

F, force, lbs

G(s), transfer function

g, gravitational constant, 32.174 ft/sec^2

I, inertia, slugs-ft^2

$j\omega$, imaginary axis, $\sqrt{-1}\omega$, rad/sec

L, rolling moment, 1/sec^2

M, pitching moment, 1/sec^2

N, yawing moment, 1/sec^2

n, normal load factor, g's

R_m, ratio of the maximums

s, Laplacian operator

T, period, sec

V, velocity, knots

W, gross weight, lbs

X, Y, Z, reference axis

β, sideslip angle, degrees

δ, control input, inches

ζ , damping ratio

θ , pitch angle, degrees

σ , real axis values of $\zeta\omega$, rad/sec

ϕ , roll angle, degrees

ψ , yaw angle, degrees

ω_n, natural undamped frequency, rad/sec

ω_D, natural damped frequency, rad/sec

Subscripts

coll, collective stick

fc, full control input

max, maximum

1 in, one inch control input

Lat cyc, lateral cyclic stick

Long cyc, longitudinal cyclic stick

ped, pedal deflection

ss, steady state

Abbreviations

ABS, absolute value , |( )|

Att, attainable

FWD, forward

kts, Knots

IFR, instrument flight rules

IGE, in ground effect

SAS, stability augmentation system

VFR, visual flight rules

Superscripts

$(\dot{\ })$, time rate of change of variable; rate

$(\ddot{\ })$, time rate of change of rate; acceleration

$(\ ')$, prime

$|(\ \ )|$, absolute value of

INTRODUCTION

Military specifications are the source of requirements to which items are purchased and designed. Initially, operational requirements are developed, and from these requirements a particular type of vehicle is chosen to fulfill the mission. Once this part of the cycle is completed, the design of the vehicle commences, and the ruling requirements become the Military Specifications. In preparing these mil-specs, it has been the practice to present the requirements in form of the written word. This leads to some obvious disadvantage such as the inability to "see" the requirement in its actual numerical or trend form.

MIL-H-8501A, "Helicopter Flying and Ground Handling Qualities General Requirements for" is one such specification presented in the form of the written word. In an effort to gain insight into the requirements and to compile a designer's handbook based on current Military helicopter design requirements, the paragraphs in the spec were interpreted mathematically and presented in graphical form. This enables the working engineer to quickly examine helicopter designs in terms of the figures.

The report presents figures for all of the requirements of MIL-H-8501A that can be presented graphically. The figures are plotted in several different ways where possible. In addition to the figures, the specification requirement is shown, followed by a discussion of the requirement and the figures.

It will be noted that there are blank paper in the report. These are necessary so the discussion of the figure and the figure itself are on facing pages.

It cannot be overemphasized that this report is only an engineering aid and in no way represents an official Air Force or DOD position concerning MIL-H-8501A. These graphs are presented as the interpretation of the requirements by the Stability and Control Branch. They are meant purely as an aid during design of a helicopter to guide the designer to a configuration based on current Military helicopter design requirements. Once the configuration is designed, the acceptance of it is the responsibility of the purchasing organization.

III GRAPHICAL REQUIREMENTS

3.2.1 It shall be possible to obtain steady, smooth flight over a speed range from at least 30 knots rearward to maximum forward speed as limited either by power available or by roughness due to blade aerodynamic limitations, but not by control power. This speed range shall be construed to include hovering and any other steady state flight condition, including steady climbs and steady descents. Throughout the specified speed range a sufficient margin of control power, and at least adequate control to produce 10 percent of the maximum attainable pitching moment in hovering shall be available at each end to control the effects of longitudinal disturbances. This requirement shall apply not only to powered flight, but also to autorotative flight at forward speeds between zero and the maximum forward speed for autorotation. Within the limits of speed specified in 3.2.1 and during the transitions between hovering and the specified extremes, the controls and the helicopter itself shall be free from objectionable shake, vibration, or roughness, as specified in 3.7.1.

3.2.10 The helicopter shall, at all forward speeds and at all trim and power conditions specified in table I, except as noted below, possess positive, static longitudinal control force, and control position stability with respect to speed. This stability shall be apparent in that at constant throttle and collective pitch-control settings a rearward displacement of and pull force on the longitudinal-control stick shall be required to hold a decreased value of steady, forward speed, and a forward displacement and push force be required to hold an increased value of speed. In the speed range between 15 and 50 knots forward, and 10 to 30 knots rearward, the same characteristics are desired, but a moderate degree of instability may be permitted. However, the magnitude of the change in the unstable direction shall not exceed 0.5 inch for stick position or 1.0 pound for stick force.

3.2.10.1 The stability requirements of 3.2.10 are intended to cover all steady flight conditions in which the helicopter might be operated for more than a short time interval. As a guide for the conditions to be investigated, the tabulation of pertinent conditions in table I may be utilized, all referred to the most critical center of gravity position.

3.3.4 In all normal service loading conditions, including those resulting in asymmetrical lateral center of gravity locations and steady flight under the conditions specified in 3.2.1 (including autorotation) and 3.3.2, a sufficient margin of control effectiveness, and at least adequate control to produce 10 percent of the maximum attainable hovering rolling moment shall remain at each end.

Figure 1 Longitudinal Control Power Limits and Trim Stick Position versus Velocity

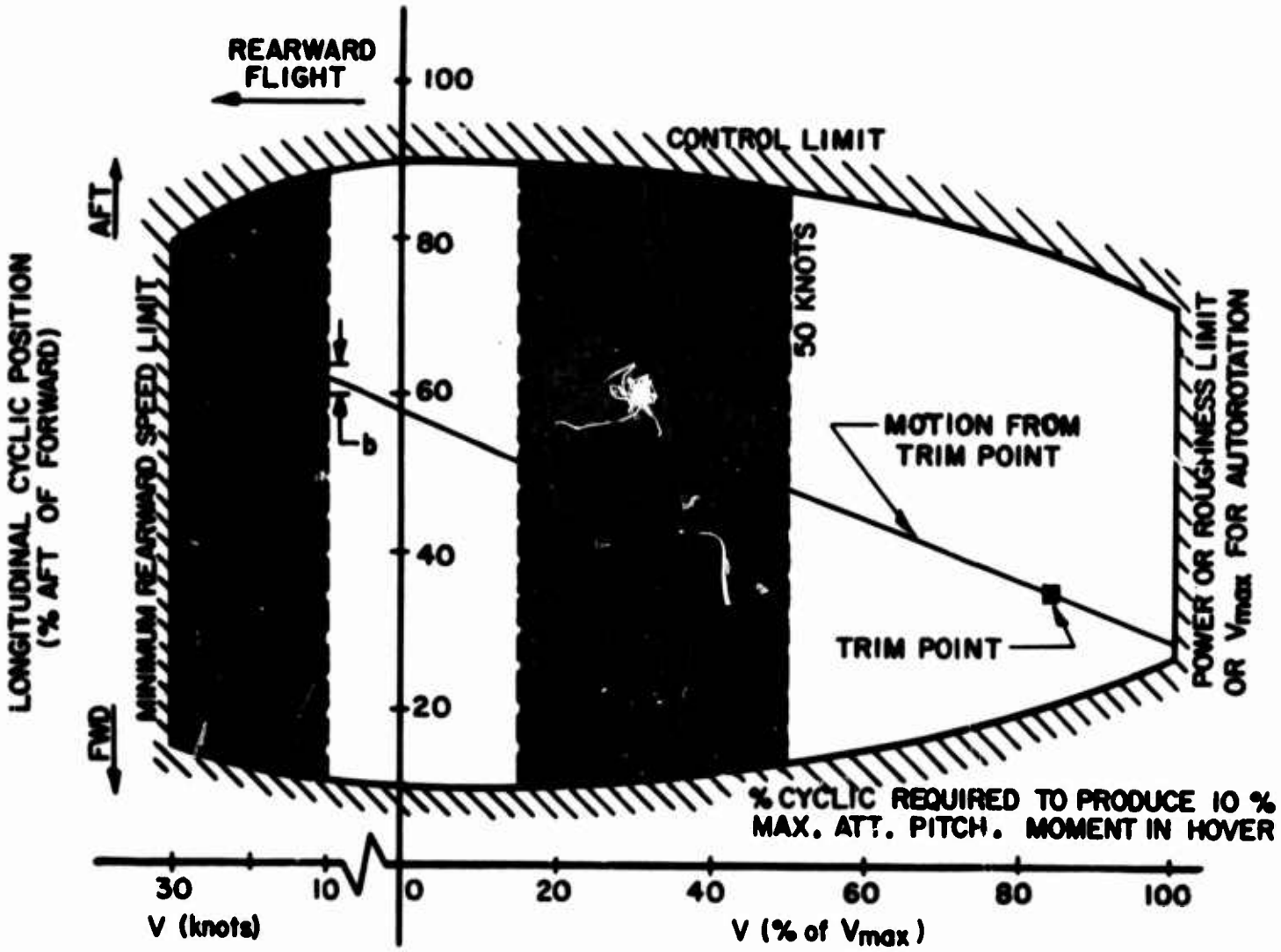
Reference: Paragraphs 3.2.1, 3.2.10, 3.2.10.1, 3.3.4

Figure 1 depicts a general map of the longitudinal stick position, showing the cyclic position limits when 10 percent of the maximum hover pitching moment is available at all flight conditions and also the trend of stick position around a trim velocity. The limit boundaries are shown for stick position rather than the percent of pitching moment in an effort to depict a typical envelope. Such an envelope should be constructed for each helicopter with the stick positions being determined by the requirement that ten percent of the maximum hover pitching moment must remain at the extremes of the flight envelope. It must be remembered that 10 percent of the maximum hover rolling moment must also be available at these stick positions.

The second requirement presented in figure 1 is the slope of stick position around a trim velocity. This is a plot of cyclic position required to accelerate and/or decelerate (and maintain) approximately 10 or 20 knots about a trim velocity with collective fixed. This is not a curve of trim stick position for each velocity as collective is varied in such a curve.

The curve shown is only a trend curve as the trim stick travel may be anywhere within the stick position limits as determined by the 10 percent requirement. The allowable instability in the stick position curve is shown in actual numerical form and the speed range for the instability is denoted by the shaded area. The magnitude of the instability is shown by a and b, which are also the numerical values allowed by the specification.

These stick position limits and trim curves must be constructed for all power conditions, weights, altitudes, et cetera.



NOTES:

1. This envelope applies for steady smooth flight (hover, level flight, climb, and autorotation).

2. During transition (unsteady flight) within this envelope, the controls must be free of objectionable shake vibration or roughness.

3. Must have static longitudinal position stability with respect to speed within the envelope.

4. Stability must be apparent in control motions from trim and for various trim positions.

5. Mild instability is permissible in the shaded area provided that it does not exceed 1/2 inch control travel. (a and b must be less than 1/2 inch or 1 lb. of stick force.)

6. At all times the force gradient should oppose motion of the stick.

7. 10% of max. attain. hover rolling moment must be avail. at all times

Figure 1. Longitudinal Control Power Limits and Trim Stick Position Versus Velocity

MIL H-8501A Requirement

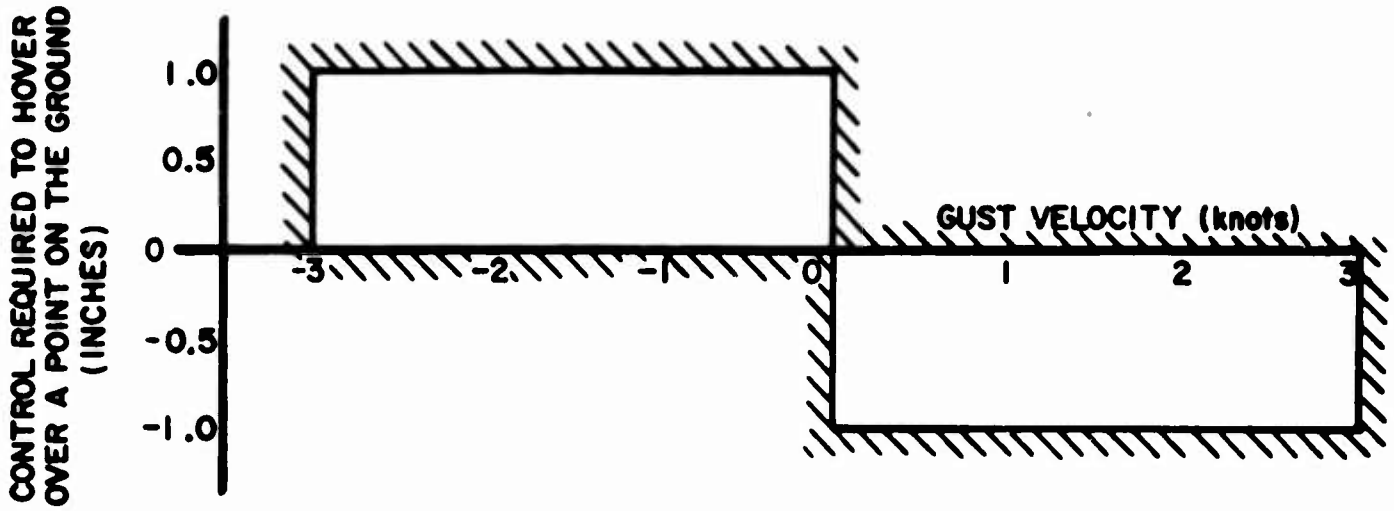
3.2.2 The helicopter shall be reasonably steady while hovering in still air (winds up to 3 knots), requiring a minimum movement of the cyclic controls to keep the machine over a given spot on the ground, for all terrain clearances up to the disappearance of ground effect. In any case, it shall be possible to accomplish this with less than ±1.0-inch movement of the cyclic controls.

3.3.3 The requirements of 3.2.2 shall be applicable to lateral as well as to longitudinal control motions. It shall be possible to meet this requirement with less than ±1-inch movement of the directional control.

Figure 2 Hover in Still Air; Stick Position vs Gust Velocity

Reference: Paragraphs 3.2.2, 3.3.3

This requirement is meant to limit the pilot's activity in still air (which is defined to be ±3 knots or less). It is required that the helicopter hover IGE with less than ±1 inch cyclic and pedal control inputs.



NOTE:

1. This requirement must be met for all terrain clearances up to disappearance of ground effect.

2. This figure is meant to imply that the control motion must be in a direction to oppose the disturbance.

3. This requirement holds for longitudinal and lateral cyclic stick inputs and for directional (pedal) inputs.

Figure 2. Hover in Still Air; Stick Position vs Gust Velocity

MIL H-8501A Requirement

3.2.4 At all trim conditions and speeds specified in 3.2.1, the longitudinal force gradient for the first inch of travel from trim shall be no less than 0.5 pound per inch and no more than 2.0 pounds per inch. In addition, however, the force produced for a 1-inch travel from trim by the gradient chosen shall not be less than the breakout force (including friction) exhibited in flight. There shall be no undesirable discontinuities in the force gradient, and the slope of the curve of stick force versus displacement shall be positive at all times with the slope for the first inch of travel from trim greater than or equal to the slope for the remaining stick travel.

3.2.6 Without retrimming, the longitudinal control forces required to change from any trim and power condition to any other trim and power condition to any other trim and power condition as specified in table I, or for performance of the maneuvers discussed in 3.2.5 and 3.5.4 or any other normal helicopter maneuvers, shall not exceed the values given in table II.

3.2.7 With the control trimmed for zero force, breakout forces, including friction in the longitudinal control system, shall conform with the values given in table II when measured in flight.

3.3.12 From trimmed initial conditions, the lateral and directional control forces required for the performance of the maneuvers discussed in 3.2.6, 3.3.1, 3.3.2, 3.3.4, 3.3.5, 3.3.6, 3.3.8, and 3.3.9.1, shall conform with the values given in table II.

3.3.13 With the controls trimmed for zero force, the breakout forces including friction in the lateral and directional control systems shall conform with the values given in table II when measured in flight.

Figure 3 Longitudinal Cyclic Stick Forces and Gradients; Force vs Position

Reference: Paragraphs 3.2.4 and 3.2.7

Figure 3 presents the specific numerical requirements for the allowable range of breakout forces, the limit control forces, and the gradient of force versus position. The range of breakout forces is shown as the distance between the intersection of the hashed lines and the ordinate axes. The values of a and b are such that b is the particular breakout force of the longitudinal cyclic stick, and a is the force produced in the first inch of travel. Note that a must be greater or equal to b. Slope d is the gradient after the first inch of travel, and it must be less than or equal to slope c but not zero, nor can the extreme of the line d penetrate the upper hash mark for any stick deflection. The gradient characteristics must be identical for the push and pull directions.

NOTES:

1. No undesirable discontinuities in the force gradient.

2. Slope of gradient must be positive at all times

3. Slope d must be less than or at the most equal to slope c, but not zero.

4. Applies for all trim conditions and speeds specified in section 3.2.1

5. Max. slope = 2.0 #/in for first inch of travel.

6. Min. slope = 0.5 #/in for first inch of travel.

7. —··— Nominal gradient.

8. a ≥ b for all cases.

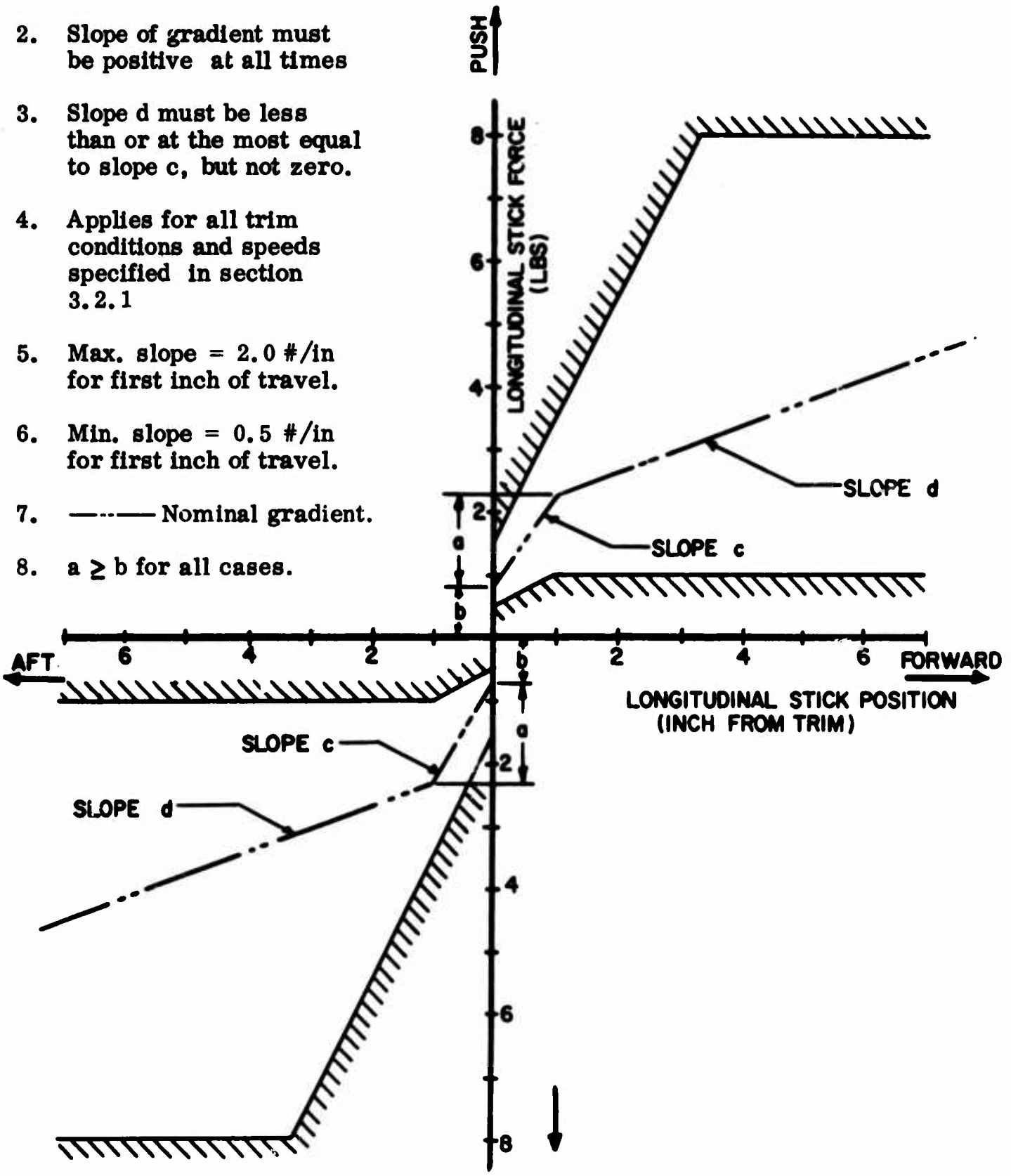


Figure 3. Longitudinal Cyclic Stick Forces and Gradients; Force vs Position

MIL H-8501A Requirement

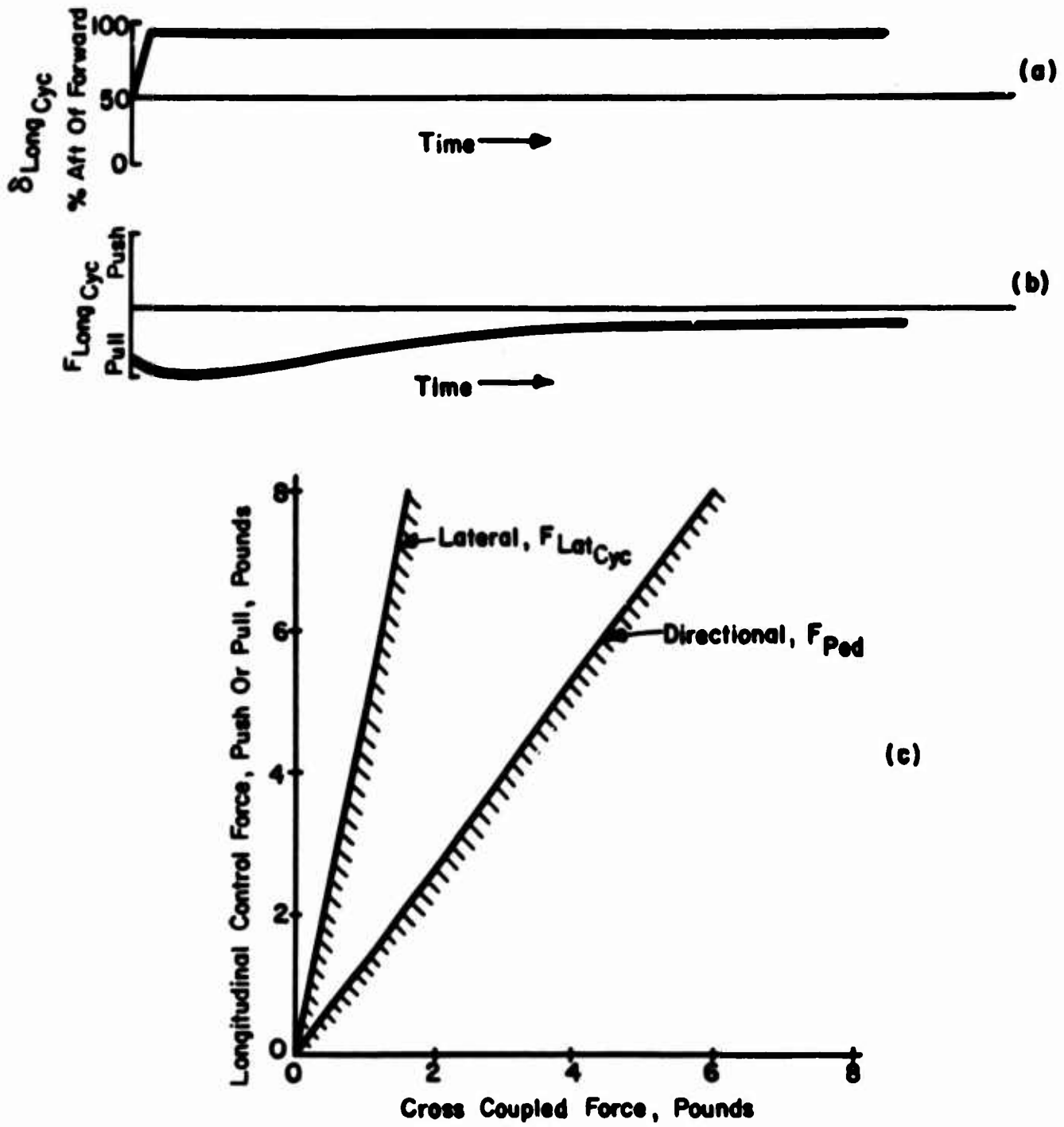
3.2.8 The controls shall be free from objectional transient forces in any direction following rapid longitudinal stick deflections. During and following rapid longitudinal displacement of the control stick from trim, the force acting in a direction to resist the displacement shall not at any time fall to zero. Longitudinal control displacement shall not produce lateral control forces in excess of 20 percent or pedal forces in excess of 75 percent of the associated longitudinal force. For helicopters employing powerboosted or power-operated controls, there shall be no lateral or directional control forces developed.

Figure 4 Longitudinal Control Force Characteristics and Cross Coupling

Reference: Paragraph 3.2.8

Figure 4 depicts the first part of the requirements; (a) shows a typical rapid forward stick displacement and (b) shows that the force characteristics which resist the stick displacement never decreases to zero and is free from objectional transients. (c) shows the allowable cross coupled forces during a rapid longitudinal cyclic input in terms of specific forces. The lateral line shows a 20 percent cross coupling and the directional line depicts the 75 percent pedal force. The forces can be in any direction as only the magnitude is limited.

No cross coupling is allowed for power boosted control systems.



NOTES:

1. Controls shall be free from objectional transient forces

2. Following rapid δ long cyc, the resisting force shall not fall to zero

3. No cross coupling for power boosted controls.

Figure 4. Longitudinal Control Force Characteristics and Cross Coupling

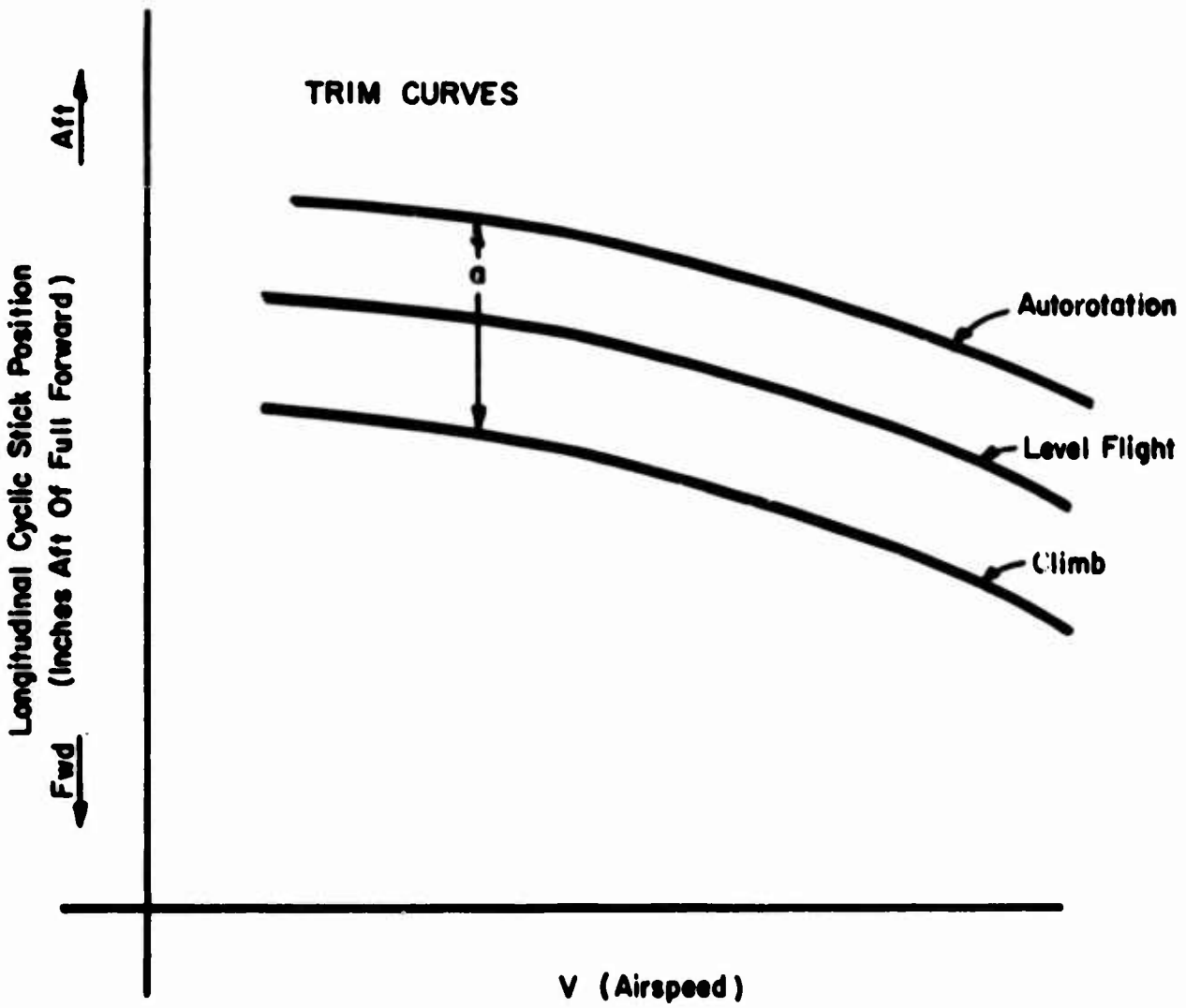
MIL H-8501A Requirement

3.2.10.2 The helicopter shall not exhibit excessive longitudinal trim changes with variations of rate of climb or descent at constant airspeed. Specifically, when starting from trim, at any combination of power and airspeed within the flight envelope, it shall be possible to maintain longitudinal trim with a longitudinal control displacement of no more than 3 inches from the initial trim position as the engine power or collective pitch, or both, are varied throughout the available range. Generally, the airspeeds needing the most specific investigation of the above characteristics include Vmax and the speeds between zero and one-half the speed for minimum power.

Figure 5 Longitudinal Trim Changes with Power and/or Collective Variations; Stick Position vs Airspeed

Reference: Paragraph 3.2.10.2

This is a longitudinal trim requirement stating that power and/or collective pitch changes in their allowable range cannot cause a longitudinal stick position change of more than 3 inches from trim. The curves depict trends only.



NOTE:

At a given gross weight and center of gravity position, the variation of longitudinal trim position with power at a constant airspeed and rotor speed must be less than 3 inches of cyclic ($a \leq 3''$).

Figure 5. Longitudinal Trim Changes with Power and/or Collective Variations; Stick Position vs Airspeed

MIL-H-8501A Requirement

3.2.11 The helicopter shall exhibit satisfactory dynamic stability charactersitics following longitudinal disturbances in forward flight. Specifically, the stability characteristics shall be unacceptable if the following are not met for a single disturbance in smooth air:

(a) Any oscillation having a period of less than 5 seconds shall damp to one-half amplitude in not more than 2 cycles, and there shall be no tendency for undamped small amplitude oscillations to persist.

(b) Any oscillation having a period greater than 5 seconds but less than 10 seconds shall be at least lightly damped.

(c) Any oscillation having a period greater than 10 seconds but less than 20 seconds shall not achieve double amplitude in less than 10 seconds.

Figure 6 Longitudinal Dynamic Stability, VFR; Damping Ratio vs Period

Reference: Paragraph 3.2.11

Figure 6 presents the VFR damping requirement of 3.2.11 in the generalized form of ζ vs the damped period. The helicopter must exhibit sufficient short period damping so as to exclude all points inside the hashed line.

To use this figure, it is necessary that some form of damping be presented, along with the value of the damped period of the oscillation. (The damped period is the time it takes for the oscillation to complete one full cycle.) If the damping is not presented in terms ζ, see part II of this appendix for the methods for obtaining ζ from dynamic traces or $C_{1/2}$, et cetera.

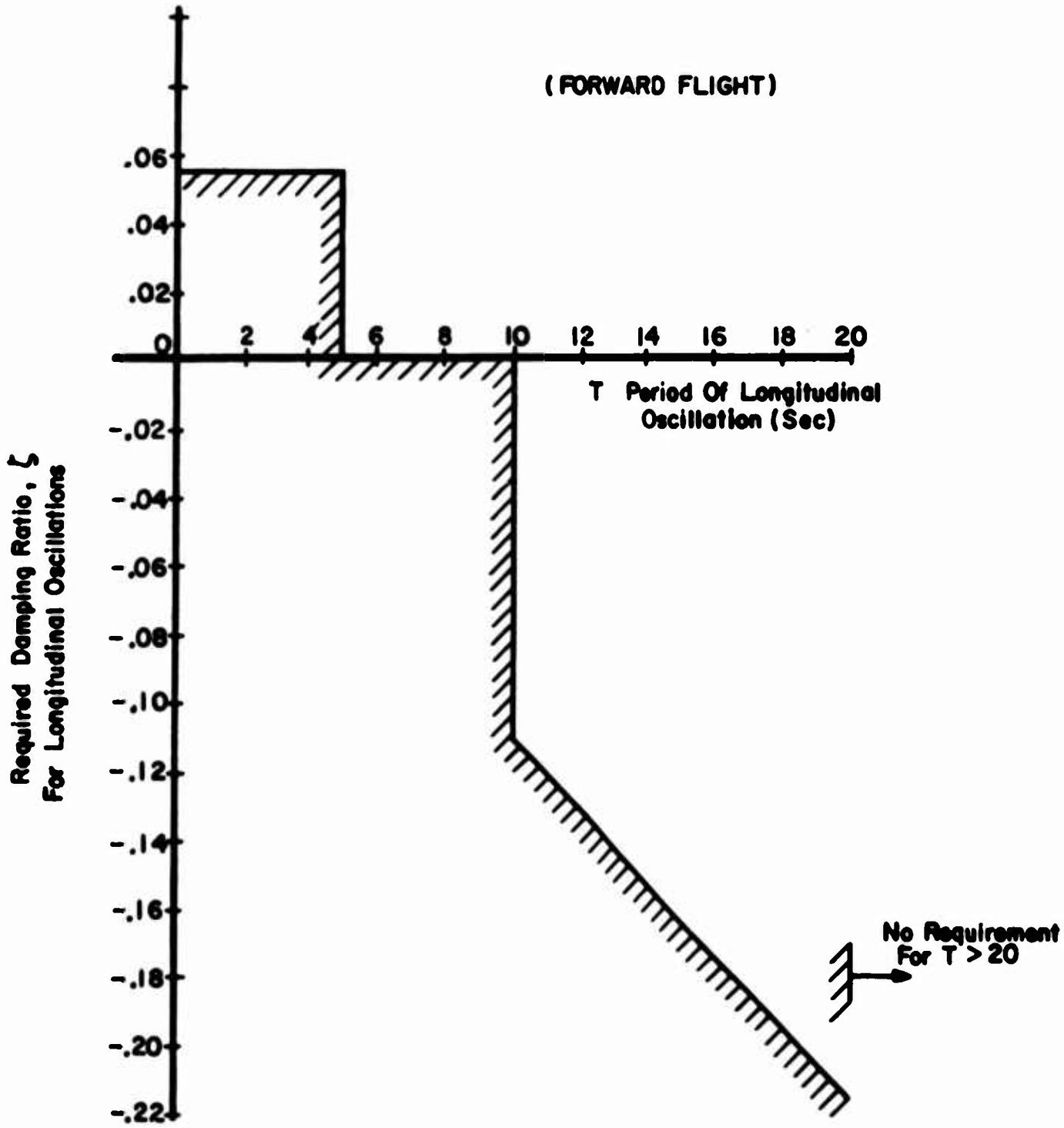


Figure 6. Longitudinal Dynamic Stability, VFR; Damping Ratio vs Period

Figure 7 Longitudinal Dynamic Stability, VFR; Representation in the Complex Plane

Reference: Paragraph 3.2.11

The complex plane (root locus) diagram is presented herein to facilitate examination of helicopters that are in design stages and where the data are presented in root locus form. The poles of the denominator of the longitudinal transfer function are plotted on this figure. If the poles (roots of the equation of the denominator) lie within the hashed lines, the helicopter will meet the requirements of 3.2.11. Note that the poles may be in the shaded area.

The simplified form of the transfer function from which the poles are plotted is the input of response from a unit impulse and the general form of the transfer function is

$$G(s) = \frac{1}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

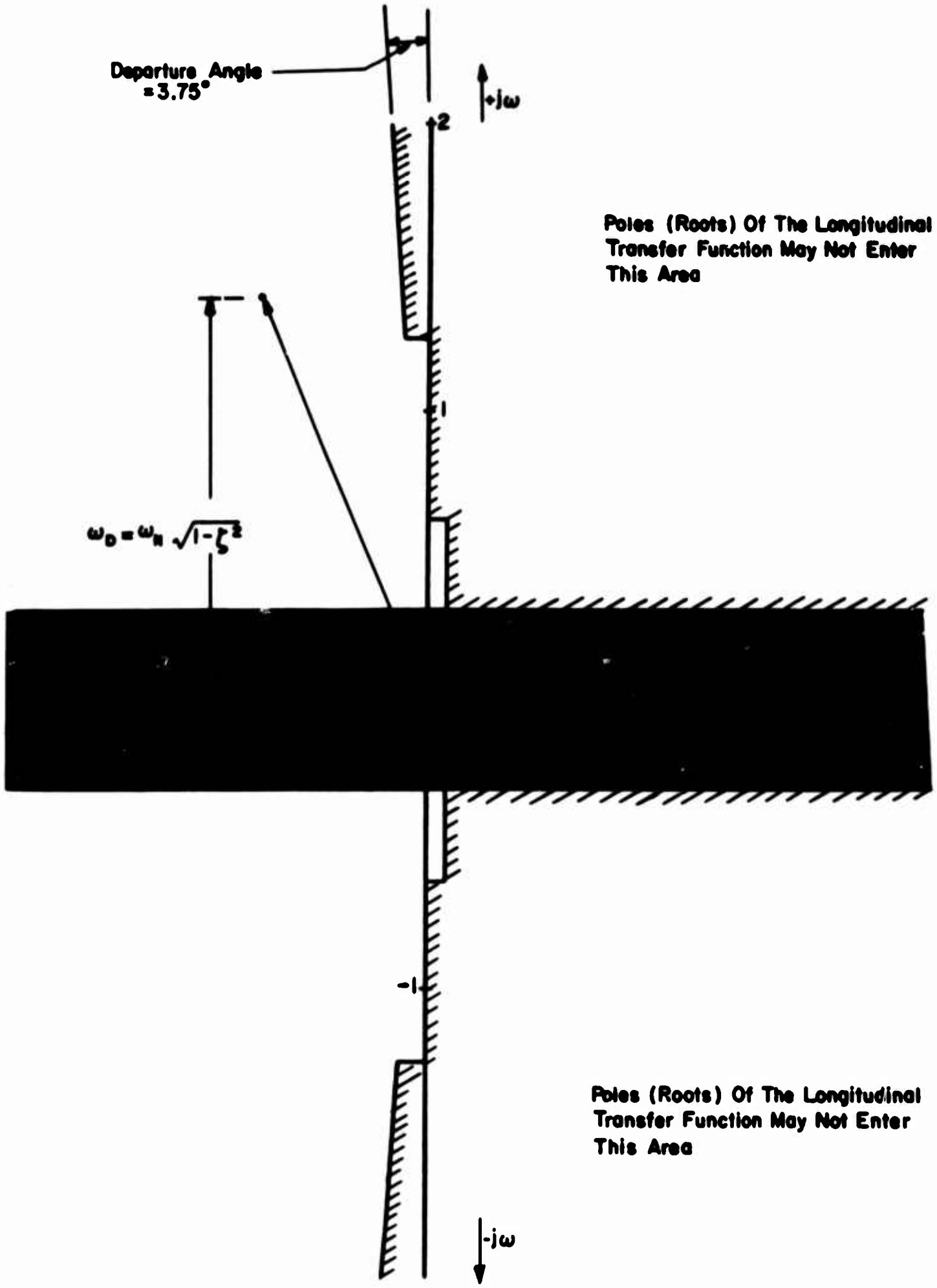


Figure 7. Longitudinal Dynamic Stability; VFR; Representation in the Complex Plane

MIL H-8501A Requirement

3.2.9 There shall be no objectionable or excessive delay in the development of angular velocity in response to control displacement. The angular acceleration shall be in the proper direction within 0.2 second after longitudinal control displacement. This requirement shall apply for the speed range specified in 3.2.1.

3.2.11.1 The following is intended to insure acceptable maneuver stability characteristics. The normal acceleration stipulations are intended to cover all speeds above that for minimum power required; the angular velocity stipulations shall apply at all forward speeds, including hovering.

(a) After the longitudinal control stick is suddenly displaced rearward from trim a sufficient distance to generate a 0.2 radian/sec. pitching rate within 2 seconds, or a sufficient distance to develop a normal acceleration of 1.5 g within 3 seconds, or 1 inch, whichever is less, and then held fixed, the time-history of normal acceleration shall become concave downward within 2 seconds following the start of the maneuver, and remain concave downward until the attainment of maximum acceleration. Preferably, the time-history of normal acceleration shall be concave downward throughout the period between the start of the maneuver and the attainment of maximum acceleration. Figure 1(a) is illustrative of the normal acceleration response considered acceptable.

(b) During this maneuver, the time-history of angular velocity shall become concave downward within 2.0 seconds following the start of the maneuver, and remain concave downward until the attainment of maximum angular velocity; with the exception that for this purpose, a faired curve may be drawn through any oscillations in angular velocity not in themselves objectionable to the pilot. Preferably, the time-history of angular velocity should be distinctly concave downward throughout the period between 0.2 second after the start of the maneuver and the attainment of maximum angular velocity. Figure 1(b) is illustrative of the angular velocity response considered acceptable.

3.2.12 The response of the helicopter to motion of the longitudinal control shall be such that in the maneuver described in 3.2.11.1, the resulting normal acceleration always increases with time until the maximum acceleration is approached, except that a decrease not perceptible to the pilot may be permitted.

Figure 8 Longitudinal Control Response and Maneuver Stability; Pitch Acceleration, Pitch Rate, Normal Load Factor and Longitudinal Cyclic Position versus Time

Reference: Paragraphs 3.2.9, 3.2.11.1 and 3.2.12

These requirements are to insure satisfactory dynamic characteristics during a control input. Figure 8 (a) shows that within two tenths of a second, the acceleration will be in the proper direction. The hashed lines in figure 8 (b), (c) and (d) graphically present the three possible conditions for demonstrating compliance with the maneuver stability requirement and the faired curves show the requirement. The three conditions for demonstrating compliance are stated in 3.2.11.1 (a) and are; for the longitudinal control stick displaced rearward from trim a distance

1. Sufficient to generate 0.2 rad/sec pitch rate in 2 seconds
2. Sufficient to generate a normal load factor of 1.5 g's in 3 seconds
3. Of 1 inch

The easiest condition is the 1-inch displacement if it is sufficiently large to show that the acceleration is in the proper direction in 0.2 second.

These conditions just outline how the control input is applied; the resulting motions of the helicopter can then be compared with the required motions shown in figure 8 (b) and (c) to determine compliance. These curves depict the requirements and also the aforementioned conditions.

In figure 8 (b), the hashed lines show the limits for condition one and the curve shows the requirement in trend form, i.e., $\dot{\theta}$ shall be concave downward within 2 seconds. The specification prefers that $\dot{\theta}$ be concave downward after t = 0.2 second and remain so until $\dot{\theta}_{ss}$ is reached. Figure 8 (c) shows the normal load factor (n) requirement, i.e., n shall be concave downward after t = 2.0 seconds. The specification prefers than n be concave downward from t = 0 until n_{Max} is reached. The requirement stated in 3.2.12 would enter into figure 8 (c), as a decrease in load factor is allowed, as long as it is imperceptable to the pilot.

Figure 8 (d) shows condition three, $\Delta\delta_{Long_{Cycle}}$ = 1 inch. This is not a requirement only a possible condition of control input in an effort to demonstrate that the helicopter complies with the requirements seen in (a), (b) and (c).

Note that figure 8 shows the traces if condition 3 were chosen to demonstrate compliance.

NOTES:

1. Pitch rate curve may be faired and normal acceleration may decrease, provided it isn't objectional to the pilot.

2. Good for the speed range mentioned in 3.2.1.

3. Step must be large enough satisfy at least one of conditions 1. through 3.; usually 3. is the least severe maneuver as this figure indicates.

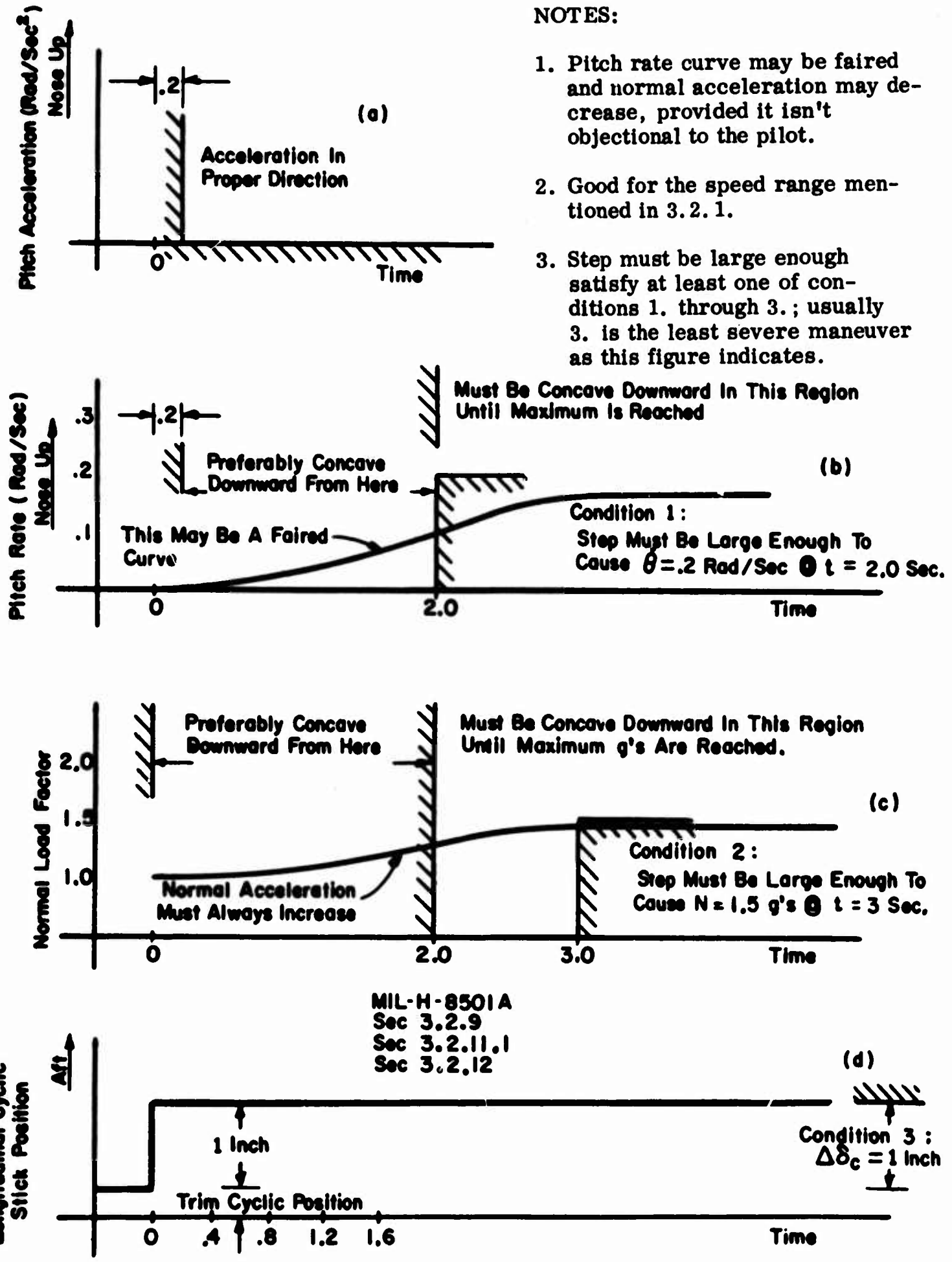


Figure 8. Longitudinal Maneuver Stability

MIL H-8501A Requirement

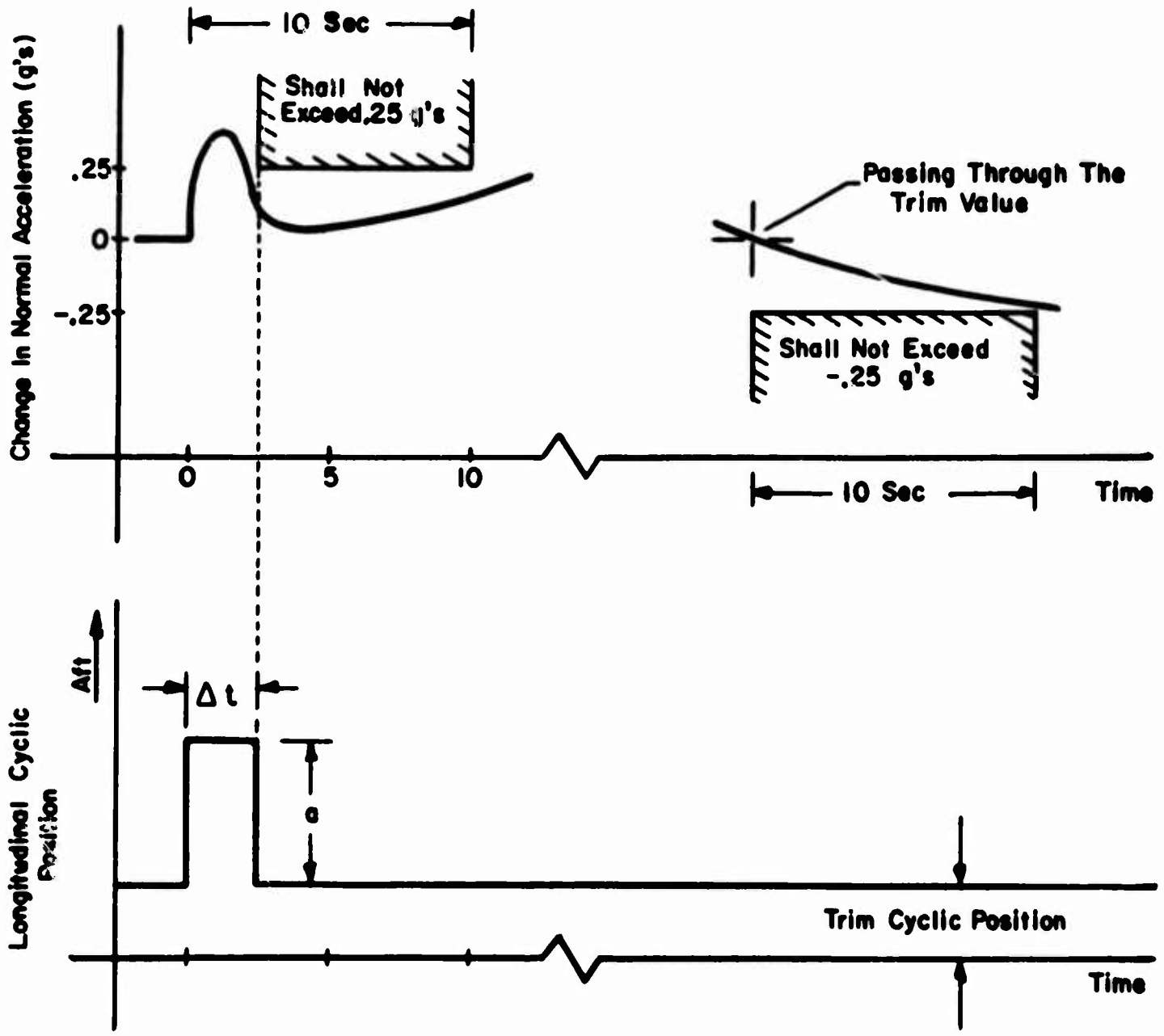
3.2.11.2 To insure that a pilot has reasonable time for corrective action following moderate deviations from trim attitude (as, for example, owing to a gust), the effect of an artificial disturbance shall be determined. When the longitudinal control stick is suddenly displaced rearward from the trim, the distance determined in 3.2.11.1 above, and held for at least 0.5 second, and then returned to and held at the initial trim position, the normal acceleration shall not increase by more than 0.25 g within 10 seconds from the start of the disturbance, except 0.25 g may be exceeded during the period of control application. Further, during the subsequent nosedown motion (with the controls still fixed at trim) any acceleration drop below the trim value shall not exceed 0.25 g within 10 seconds after passing through the initial value.

Figure 9 Effects of a Longitudinal Disturbance; Change in Normal Acceleration and Cyclic Position vs Time

Reference: Paragraph 3.2.11.2

Figure 9 represents the helicopter's behavior following an external disturbance. To test for compliance, the stick is deflected aft and held for 0.5 seconds at sufficient amplitude to comply with figure 8*. The resulting motion is then shown graphically in figure 9. Although the change in normal acceleration (n) may exceed 0.25 g's during the time of control application, it may not again exceed this value until after the tenth second, at which time there is no limiting requirement until, at any time later, when and if the helicopter passes through the value of the initial trim acceleration. Then the change in load factor must not exceed -0.25 g's until 10 seconds after crossing the trim value. There are no requirements after this second 10-second time interval.

* This means that if the stick were held at this amplitude instead of being returned to trim, the resulting motion would be sufficient to meet the requirements of 3.2.11.1 which are shown graphically in figure 8.



NOTES:

1. "a" must be large enough that it would satisfy Sec 3.2.11.1 or Figure 7 if it were held constant.

2. $\Delta t \geq 0.5$ sec

Figure 9. Effects of a Longitudinal Disturbance

MIL H-8501A Requirement

3.2.13 Longitudinal control power shall be such that when the helicopter is hovering in still air at the maximum overload gross weight or at the rated power, a rapid 1.0-inch step displacement from trim of the longitudinal control shall produce an angular displacement at the end of 1.0 second which is at least $\frac{45}{W + 1000}$ degrees. When maximum available displacement from trim of the longitudinal control is rapidly applied, the angular displacement at the end of 1.0 second shall be at least $\frac{180}{W + 1000}$ degrees. In both expressions W represents the maximum overload gross weight of the helicopter in pounds.

Figures 10a and 10b Longitudinal Control Power; Gross weight vs Pitch Angle in the First Second.

Reference: Paragraph 3.2.13

Figures 10a and 10b present the longitudinal control power requirement in two manners; figure 10a shows gross weight (W) vs pitch angle in the first second (θ_1) and figure 10b shows the product of the gross weight parameter $\sqrt[3]{W+1000}$ and maximum pitch acceleration $\frac{M_\delta}{I_{yy}}$ vs the damping parameter $\frac{D_y}{I_{yy}}$. Figure 10a is straight forward as θ_1 is plotted vs W for a 1-inch control input and a full control input, as defined by the requirement of 3.2.13. The point must lie to the right of its associated hashed curve.

Figure 10b is useful when the characteristics of the second order differential equation are known, but the solution is not present. It is then a simple matter to use the values of W, $\frac{M_\delta}{I_{yy}}$ and $\frac{D_y}{I_{yy}}$ to determine if the helicopter is acceptable. $\frac{D_y}{I_{yy}}$ can be calculated from a trace of $\ddot{\theta}$ vs time by use of part II of this appendix. The gross weight parameter, $\sqrt[3]{W+1000}$, is shown graphically in part II of this appendix.

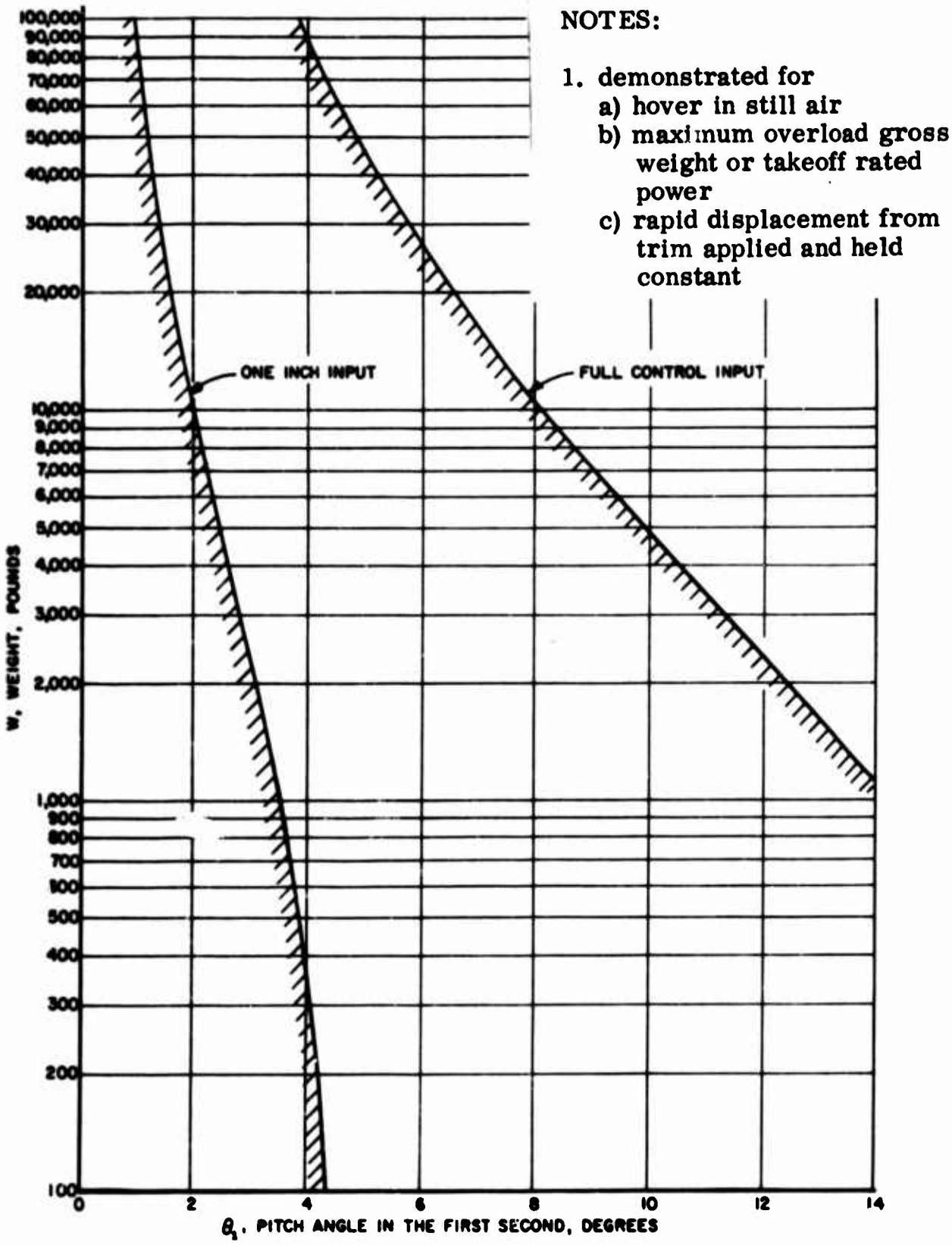
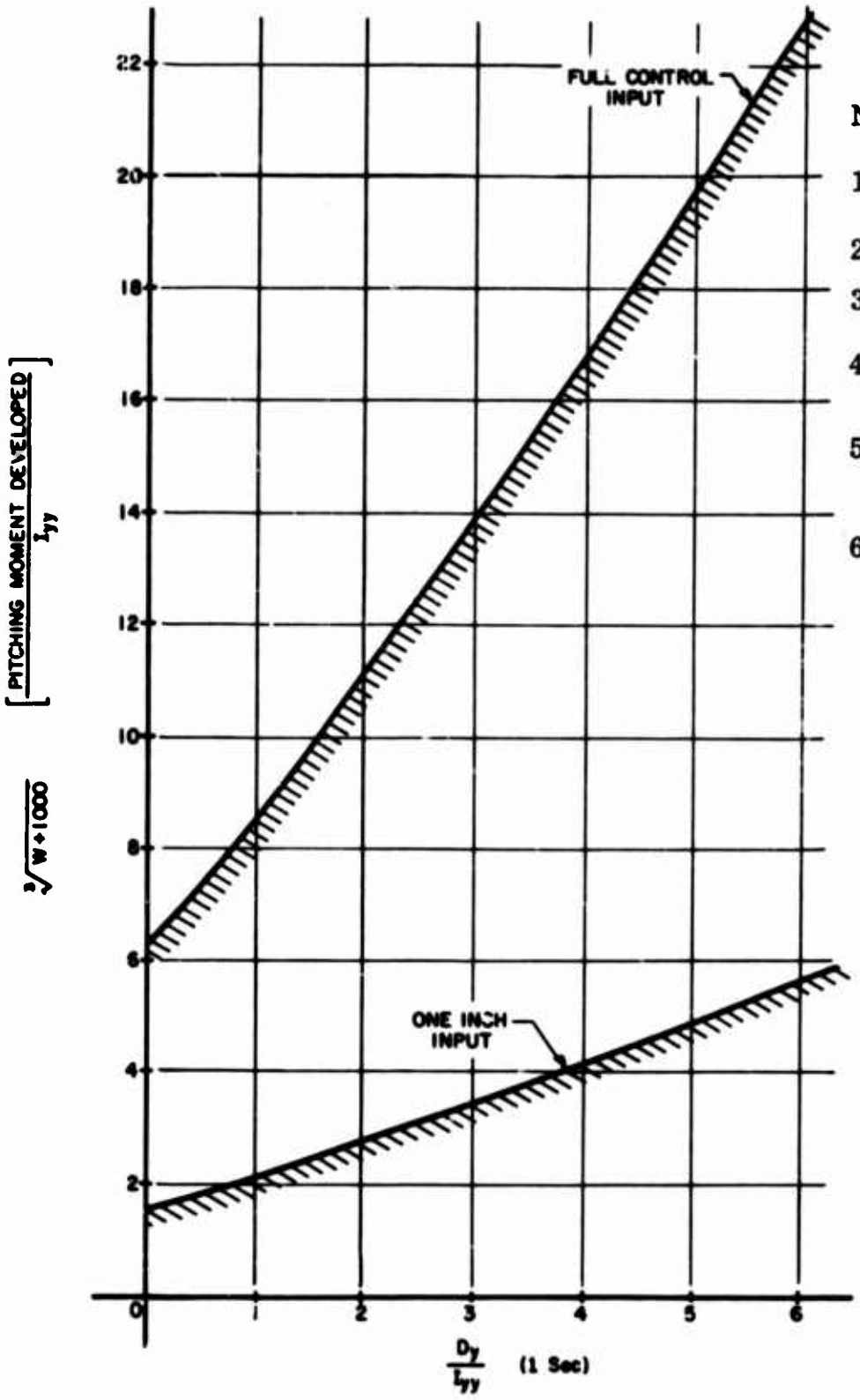


Figure 10a.

Longitudinal Control Power: Gross Weight vs. Pitch Angle in the First Second.



NOTES:

1. Pitching moment is in ft-lbs
2. I_{yy} is in slugs-ft^2
3. W is the maximum over load gross weight
4. D_y is pitch damping in ft-lbs-sec
5. Control is applied rapidly and held constant
6. Demonstrated at max. overload gross weight or rated power

Figure 10b.

Longitudinal Control Power, Acceleration Parameter vs Damping Parameter

MIL H-8501A Requirement

3.2.14 To insure satisfactory initial response characteristics following a longitudinal control input and to minimize the effects of external disturbances, the helicopter in hovering shall exhibit pitch angular velocity damping (that is, a moment tending to oppose the angular motion and proportional magnitude to the angular velocity) of at least $8\ (I_y)^{0.7}$ ft-lb/rad/sec, where I_y is the moment of inertia about the pitch axis expressed in slug-ft^2.

Figure 11 Pitch Damping; Pitch Moment of Inertia vs Damping Parameter

Reference: Paragraph 3.2.14

Figure 11 depicts the hover damping requirement, i.e.,

$$\frac{Dy}{Iyy} = 8(I_{yy})\ 0.7$$

The helicopter must have such damping characteristics in order that the point lies to the right of the hashed line.

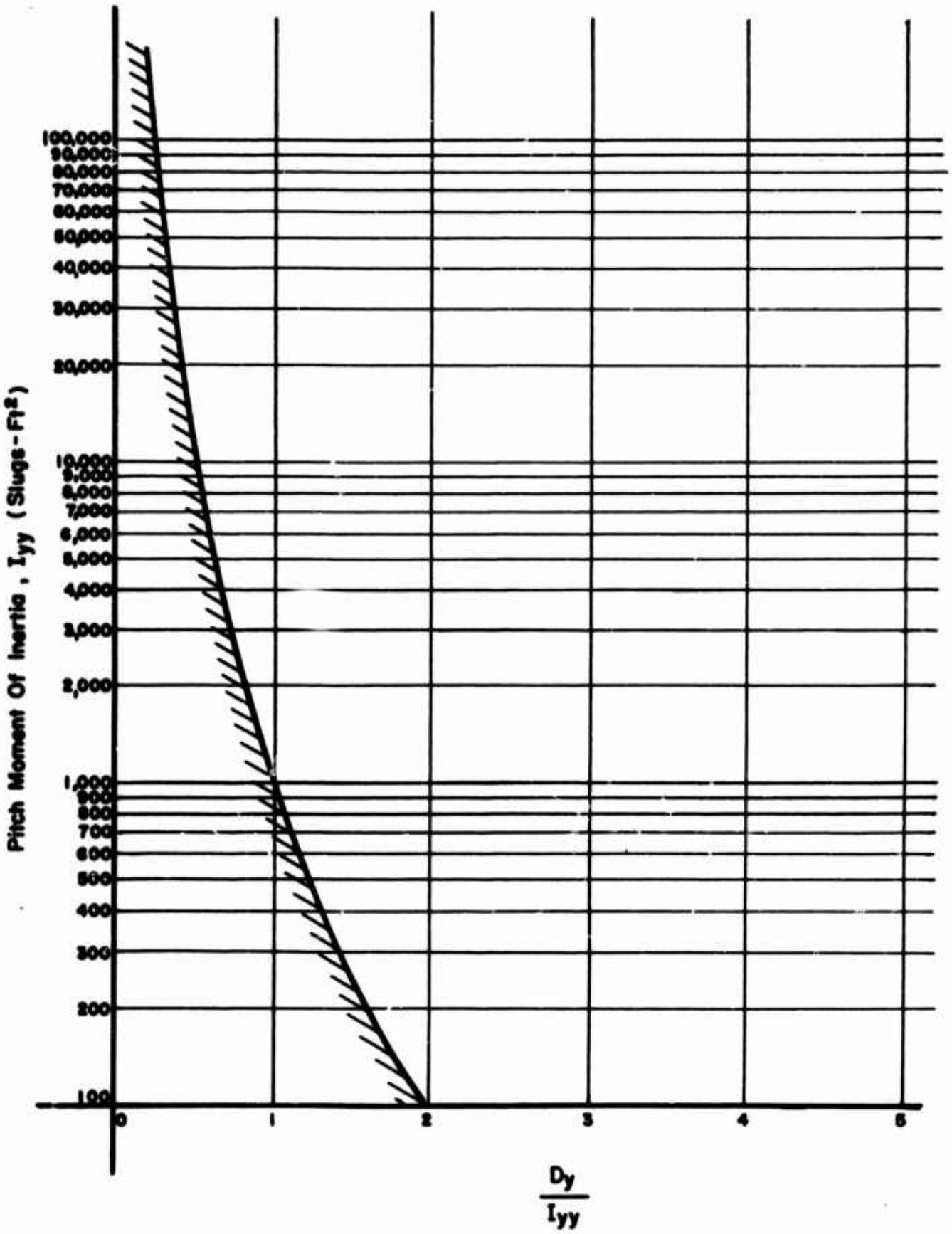


Figure 11. Pitch Damping; Pitch Moment of Inertia vs Damping Parameter

MIL H-8501A Requirement

3.3.2 From the hovering condition, it shall be possible to obtain steady, level, translational flight at a sidewise velocity of 35 knots to both the right and the left. At the specified sidewise velocity and during the transition from hovering, the controls and the helicopter itself shall be free from objectionable shake, vibration, or roughness as specified in 3.7.1.

3.3.4 In all normal service loading conditions, including those resulting in asymmetrical lateral center of gravity locations and steady flight under the conditions specified in 3.2.1 (including autorotation) and 3.3.2, a sufficient margin of control effectiveness, and at least adequate control to produce 10 percent of the maximum attainable hovering rolling moment shall remain at each end.

Figure 12 Sideward Velocity and Lateral Control Power Limits; Lateral Cyclic Position vs Side Velocity

Reference: Paragraphs 3.3.2 and 3.3.4

Figure 12 defines the amount of lateral control power that must remain at the extremes of the velocity envelope, and is similar to figure 1 in this respect. The control limit is shown in terms of stick position, but in actuality, the requirement is that 10 percent of the maximum hover rolling moment must be available, not just some percentage of stick. A plot of the stick position limits, as defined by the 10 percent requirement should be made for each helicopter and include the effects of gross weight, CG, etc. Note that the velocity extreme shown here is 35 knots sideward. A similar plot should be made for the longitudinal speed range so as to determine the lateral stick position limits as defined by the 10 percent requirement, as this applies to longitudinal speeds as well as lateral speed.

Also shown in figure 12 is the lateral cyclic position vs sideward speed. The specification does not explicitly require lateral stick position stability vs side velocity at zero forward speed; however, such a feature is certainly desirable.

NOTES:

1. Controls must be free of objectionable shake, vibration, or roughness
2. Forward velocity is zero
3. Shall be met at all normal service loadings and all longitudinal and lateral c.g. positions

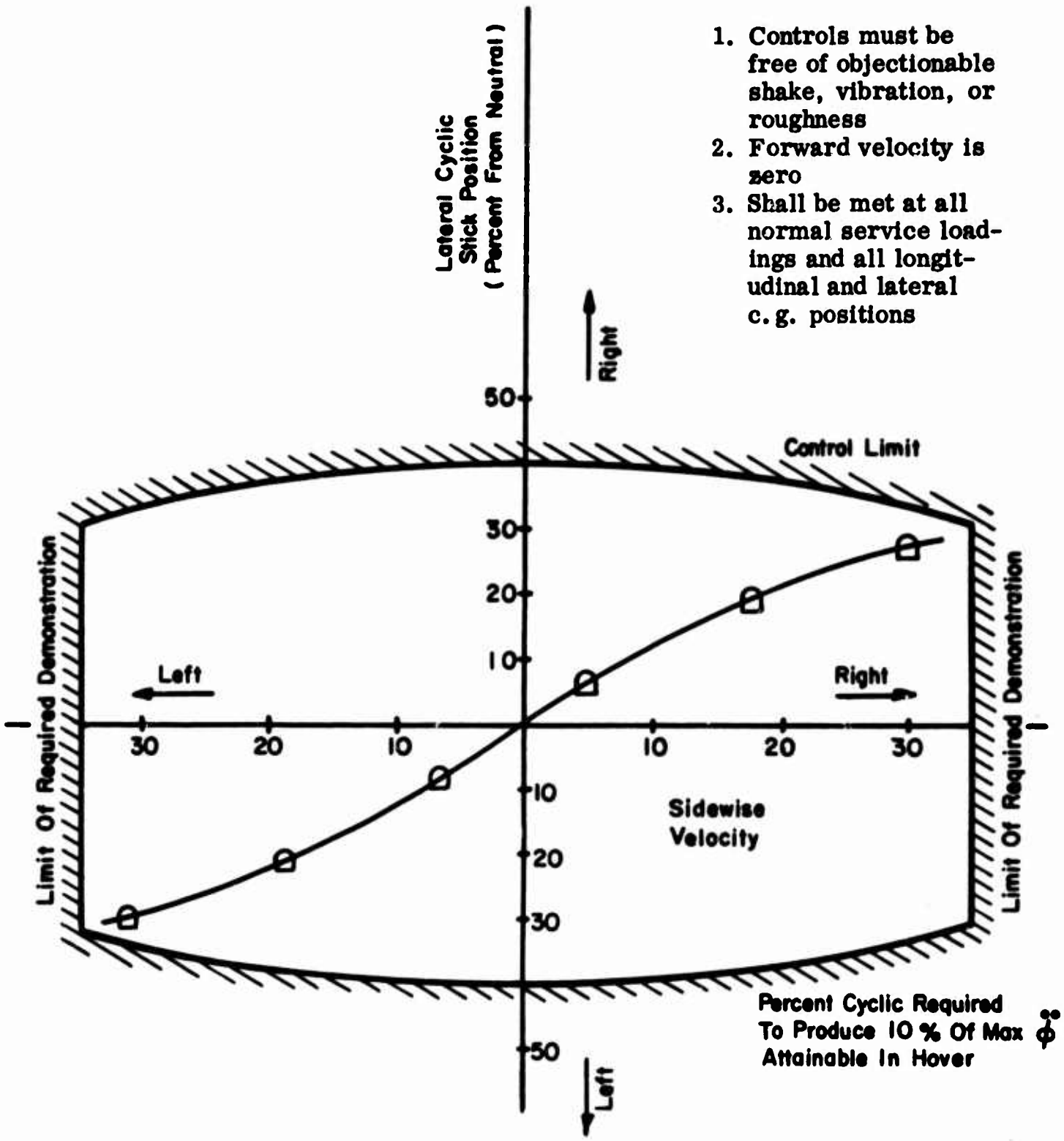


Figure 12. Sideward Velocity and Lateral Control Power Limits; Lateral Cyclic Position vs Side Velocity

MIL H-8501A Requirement

3.3.5 Directional control power shall be such that when the helicopter is hovering in still air at the maximum overload gross weight or at rated takeoff power, a rapid 1.0-inch step displacement from trim of the directional control shall produce a yaw displacement at the end of 1.0 second which is at least $\frac{110}{3\,W + 1000}$ degrees. When maximum available displacement from trim of the directional control is rapidly applied at the conditions specified above, the yaw angular displacement at the end of 1.0 second shall be at least $\frac{330}{3\,W + 1000}$ degrees. In both equations W represents the maximum overload gross weight of the helicopter in pounds.

3.3.6 It shall be possible to execute a complete turn in each direction while hovering over a given spot at the maximum overload gross weight or at takeoff power (in and out of ground effect), in a wind of at least 35 knots. To insure adequate margin of control during these maneuvers, sufficient control shall remain at the most critical azimuth angle relative to the wind, in order that, when starting at zero yawing velocity at this angle, the rapid application of full directional control in the critical direction results in a corresponding yaw displacement of at least $\frac{110}{3\,W + 1000}$ degrees in the first second, where W represents the maximum overload gross weight of the helicopter in pounds.

3.3.7 The response of the helicopter to directional-control deflection, as indicated by the maximum rate of yaw per inch of sudden pedal displacement from trim while hovering shall not be so high as to cause a tendency for the pilot to overcontrol unintentionally. In any case, the sensitivity shall be considered excessive if the yaw displacement is greater than 50 degrees in the first second following a sudden pedal displacement of 1 inch from trim while hovering at the lightest normal service loading.

Figures 13a, 13b and 13c. Directional Control Power

Reference: Paragraphs 3.3.5, 3.3.6 and 3.3.7

Figures 13a, b, and c graphically show the directional control power and sensitivity requirements of the specification. Figures 13a and 13c are similar to figures 10a and 10b, except the former are for the directional control axis. Figure 13a shows the actual yaw angle to be developed for a 1 inch and a full control input. Note, however, that curve B is for both a 1-inch input in still air and a full control input in a 35-knot wind with the helicopter starting at the most critical azimuth angle with respect to the wind. The control power must be such that the W vs ψ_1 point lies to the right of the associated hashed curve. Note, however, that the directional control power must not be so sensitive that a yaw angle of 50 degrees in the first second is developed from a 1-inch input. The limit on sensitivity is seen in figure 13b; the points must be to left of the hashed line.

Figure 13c is useful when the characteristics of the second order differential equation are known, but the solution is not present. It is then a simple matter to use the values of W, $\frac{N\delta}{I_{zz}}$ and $\frac{D_z}{I_{zz}}$ to determine if the helicopter is acceptable. $\frac{D_z}{I_{zz}}$ can be calculated from a trace of $\dot{\psi}$ vs time by use of part II of this appendix. The gross weight parameter is shown graphically in part II of this appendix.

All three requirements for directional control are shown in figure 10b. The lower line corresponds to the 1-inch control input in still air and the full control input in 35 knot winds, the middle curve is for the full control input in still air and the upper curve is the limit on sensitivity. The bottom two curves use the ordinate on the left, while the upper curve is for the ordinate on the right. The two ordinates differ by a factor of $\sqrt[3]{W+1000}$.

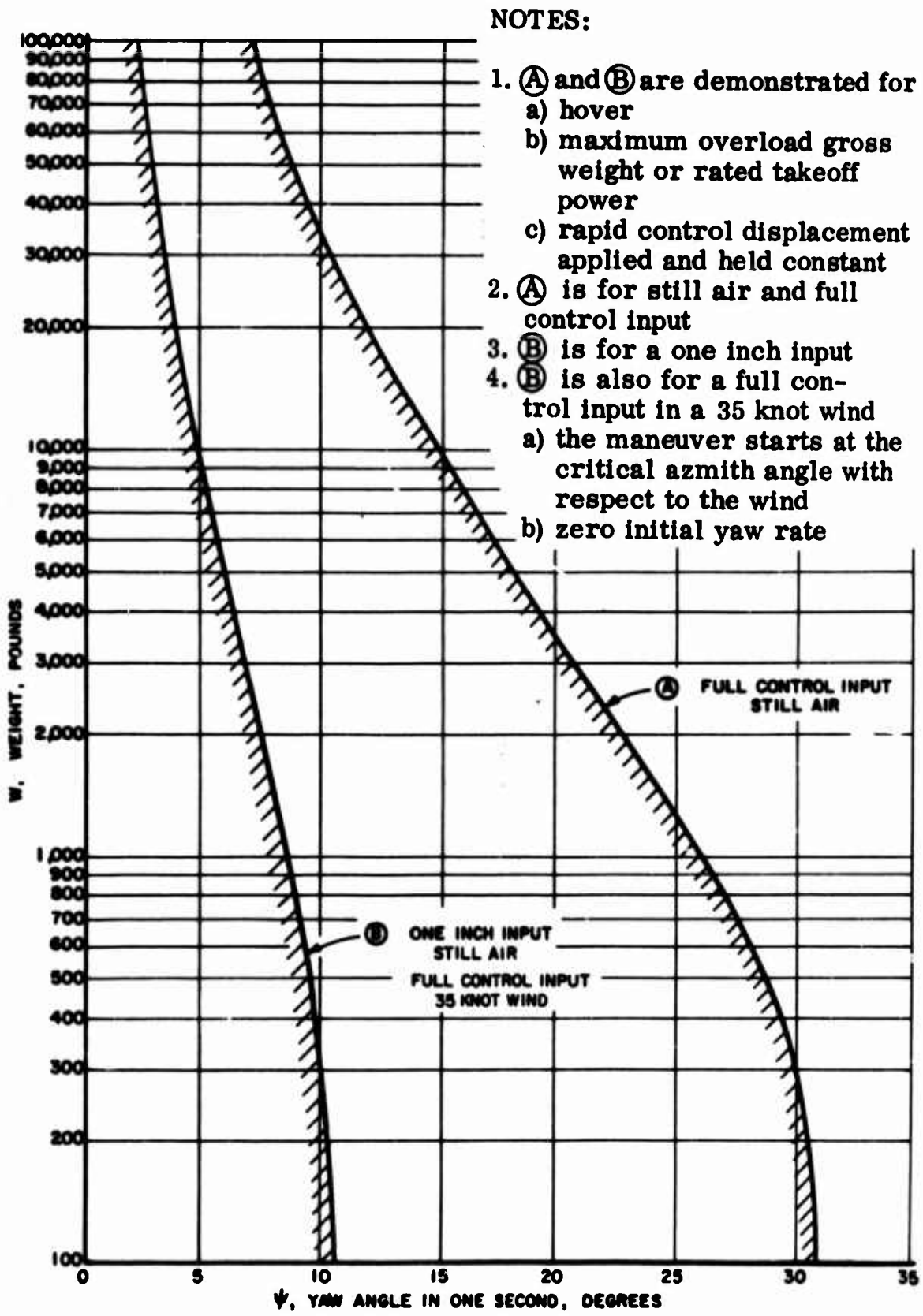


Figure 13a. Directional Control Response: Gross Weight vs. Yaw Angle in the First Second.

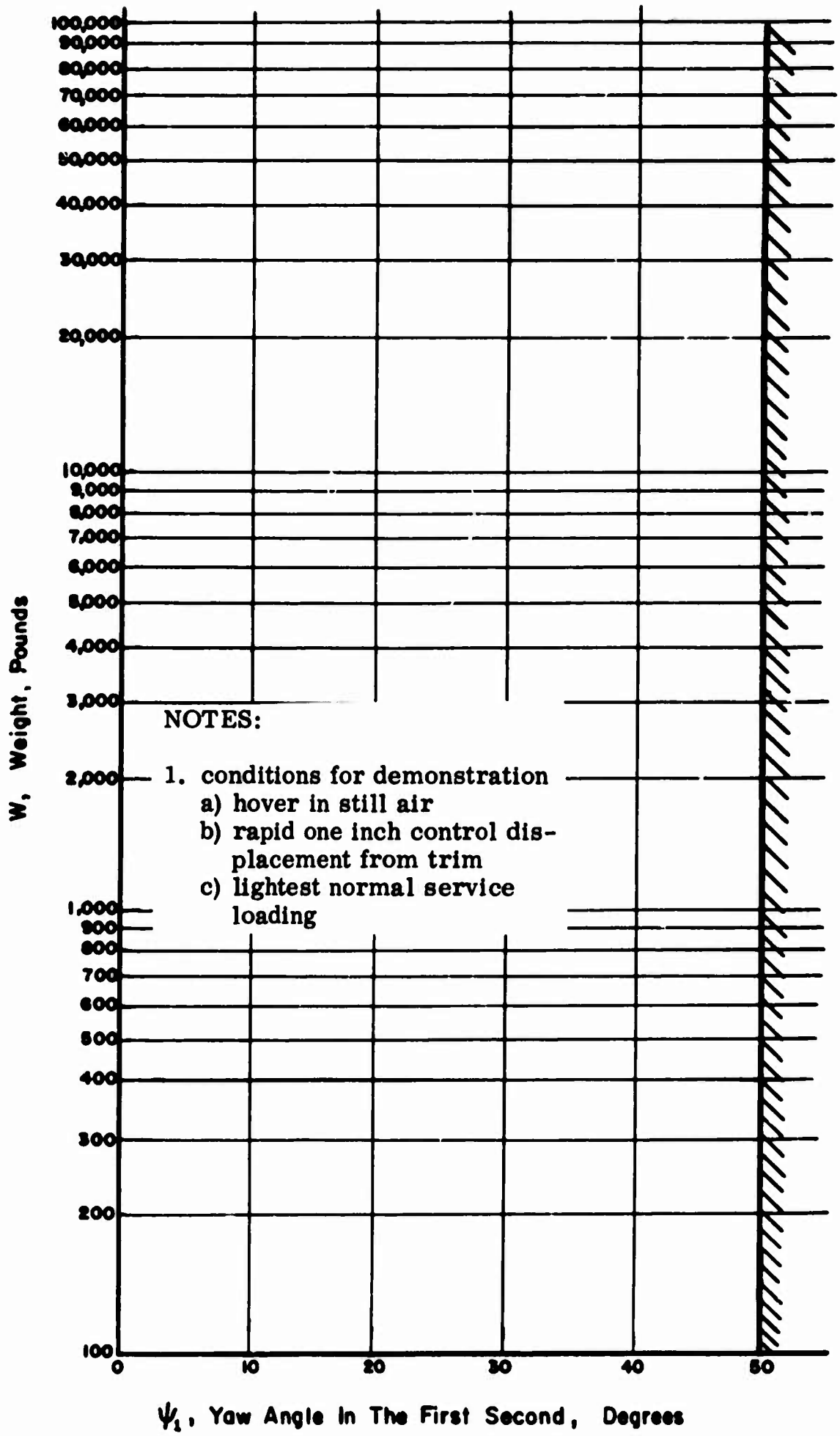
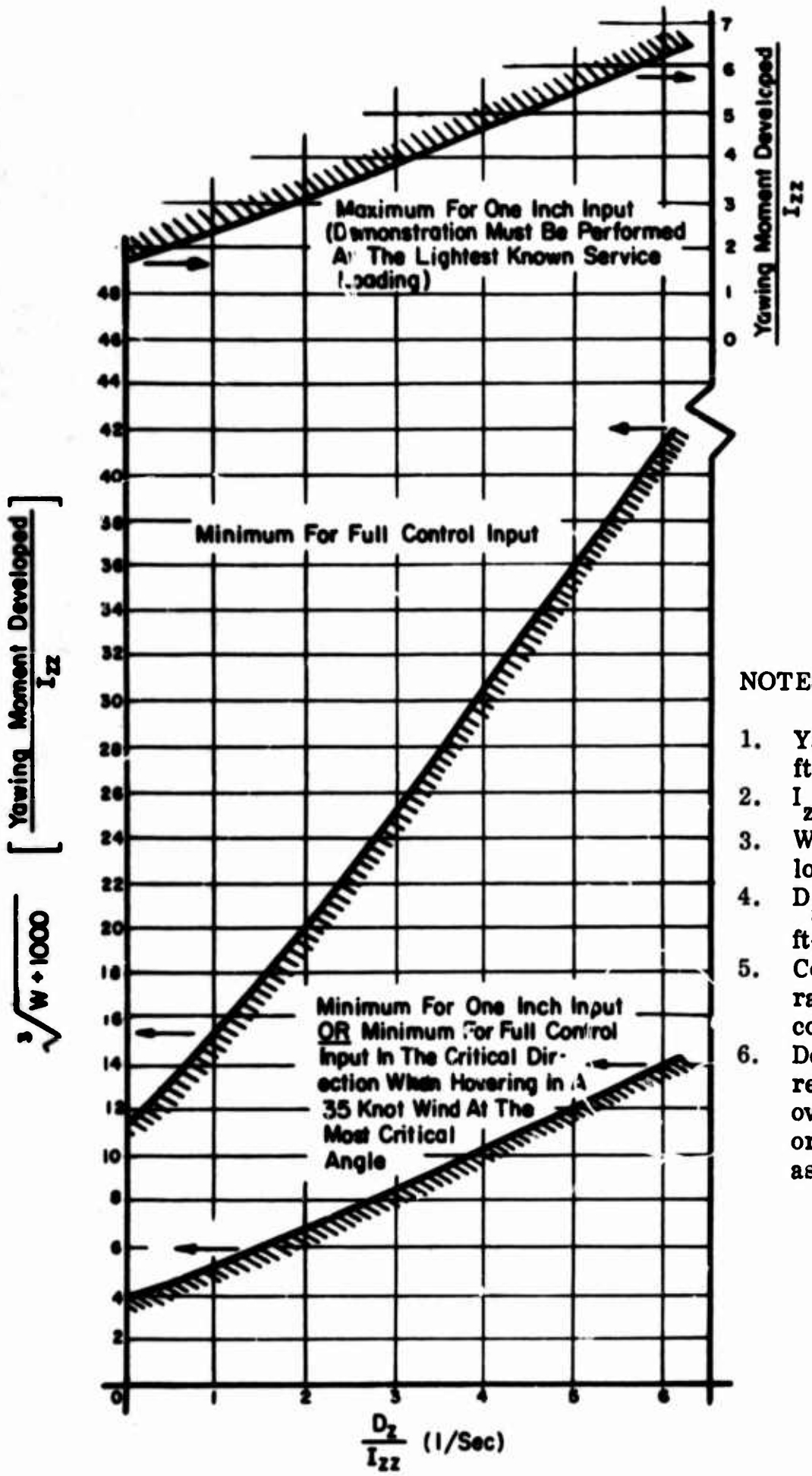


Figure 13b. Directional Control Response Sensitivity; Gross Weight vs. Yaw Angle in the First Second.



NOTES:

1. Yawing moment is in ft-lbs
2. I_{zz} is in slugs-ft^2
3. W is the maximum over load gross weight
4. D_z is yaw damping in ft-lbs-sec
5. Control is applied rapidly and held constant
6. Demonstration is required at maximum overload gross weight or rated power except as noted.

Figure 13c. Directional Control

MIL H-8501A Requirement

3.3.9 The helicopter shall possess positive, control fixed, directional stability, and effective dihedral in both powered and autorotative flight at all forward speeds above 50 knots, 0.5 Vmax, or the speed for maximum rate of climb, whichever is the lowest. At these flight conditions with zero yawing and rolling velocity, the variations of pedal displacement and lateral control displacement with steady sideslip angle shall be stable (left pedal and right stick displacement for right sideslip) up to full pedal displacement in both directions, but not necessarily beyond a sideslip angle of 15 degrees at Vmax, 45 degrees at the low speed determined above, or beyond a sideslip angle determined by a linear variation with speed between these two angles. Between sideslip angles of ± 15 degrees, the curve of pedal displacement and lateral control displacement plotted against sideslip angle shall be approximately linear. In all flight conditions specified above, a 10 percent margin of both lateral and longitudinal control effectiveness (as defined in 3.2.1 and 3.3.4) shall remain.

Figure 14 Sideslip at Forward Speeds; Sideslip Angle vs Forward Velocity

Reference: Paragraph 3.3.9

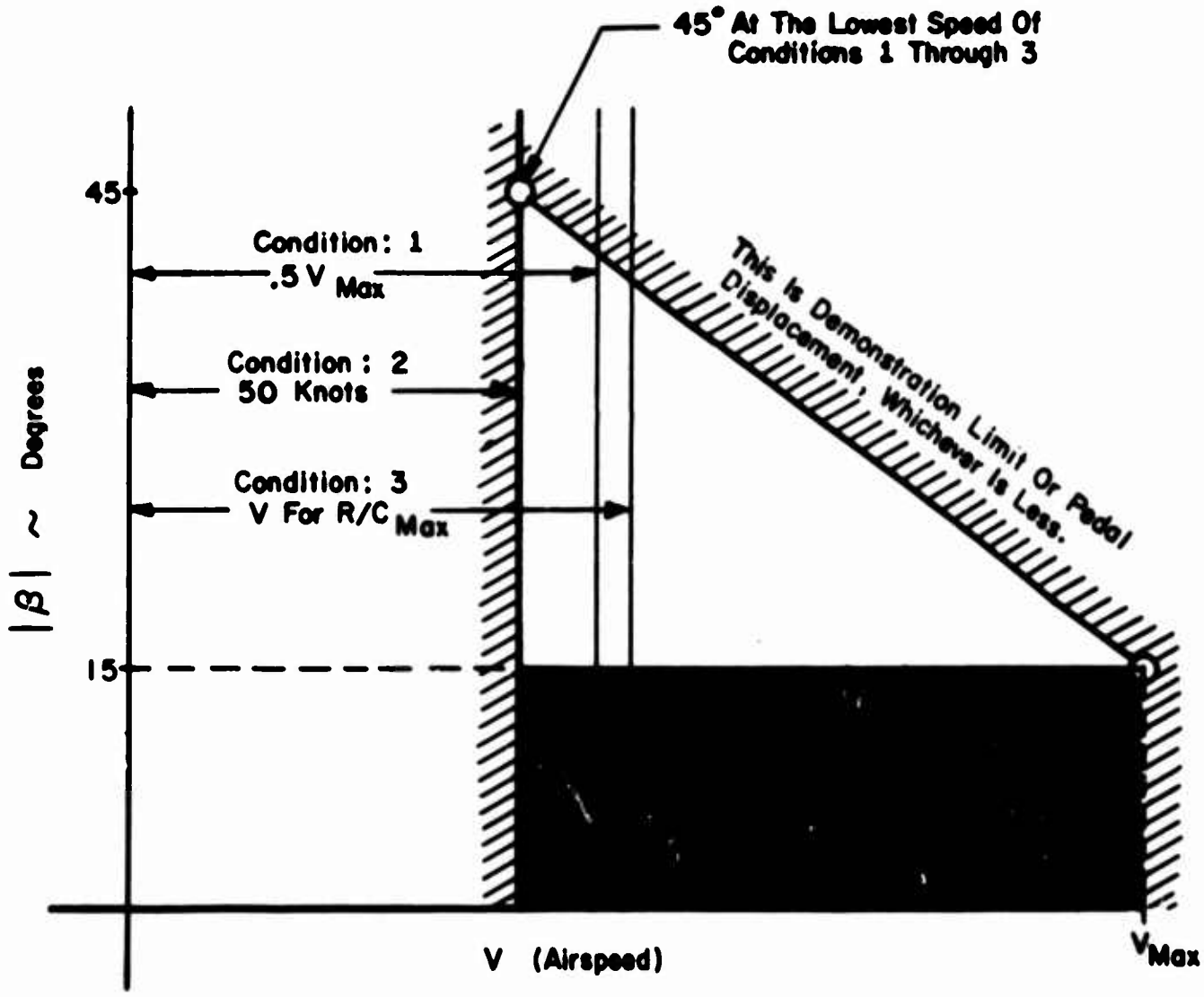
This figure shows the sideslip angles stated in 3.3.9 vs speed, i.e., β=45° at the lowest of the stated speeds. β=15° at V_{max} and the linear variation between them. This curve is not a requirement per se, only the maximum sideslip angles that need be generated while demonstrating the true requirements are shown. Note that the limit of demonstration is either the maximum sideslip angles as outlined in the figure, or full pedal displacement, whichever occurs first. These maximum angles are stated because a helicopter may exist that can exceed them.

To determine the sideslip angles at which the requirements must be met, the particular helicopter is tested (or a mathematical analysis made in the case where the helicopter is still in the initial design stage) to see if the maximum angle will be reached before full pedal is used. This is done from the lowest of the 3 speeds (0.5 V_{max}, 50 knots, or speed for best rate of climb) up to V_{max}. Beginning at this lowest speed condition, determine if

1. β will increase for right $\delta_{Lat\ Cyc}$ and left δ_{Ped} up to the limit sideslip angle, or full δ_{Ped}
2. $\delta_{Lat\ Cyc}$ and δ_{Ped} vs β are essentially linear up to β =15°

At all conditions at least 10 percent of the longitudinal and lateral hover moments will remain simultaneously.

As an example of this requirement, assume a helicopter is flying at a speed half way between the lowest of the three speeds and V_{max}. From figure 13, the maximum sideslip angle is determined to be 30° (a helicopter attains 30° with 75 percent of the pedal). The requirement has been met if increasing right $\delta_{Lat\ Cyc}$ and left δ_{Ped} were used as the sideslip angle increased to 30° and if the control deflections vs β were essentially linear up to β =15°. Another helicopter would also meet the requirement if it attained a β =13° at full pedal deflection, assuming linearity of control deflection vs sideslip angle.



NOTES:

1. Possess positive, control fixed, directional stability, and effective dihedral in powered and autorotative flight within this envelope.

2. Throughout this envelope, sufficient longitudinal and lateral control shall remain to produce at least 10% of the maximum attainable pitching or rolling moments available in hover.

Figure 14. Sideslip at Forward Speeds; Sideslip Angle vs Forward Velocity

MIL H-8501A Requirement

3.3.9.1 At the conditions specified in 3.3.9, it shall be possible to make complete turns in each direction with pedals fixed, by use of cyclic control stick alone. At all speeds specified in 3.3.9, no reversal of rolling velocity (i.e., return through zero) shall occur after a small lateral step displacement of the control stick is made with pedals fixed. The stick deflection chosen shall be such that the maximum angle of bank reached during 6 seconds is approximately 30 degrees. This requirement is intended to apply to angular velocity type controls.

3.3.16 There shall be no objectionable or excessive delay in the development of angular velocity in response to lateral or directional control displacement. The angular acceleration shall be in the proper direction within 0.2 second after control displacement. This requirement shall apply for all flight conditions specified in 3.2.1, including vertical autorotation.

Figure 15 Roll Acceleration Response and Rolling Reversal; Roll Acceleration, Rate and Angle and Lateral Cyclic Position vs Time

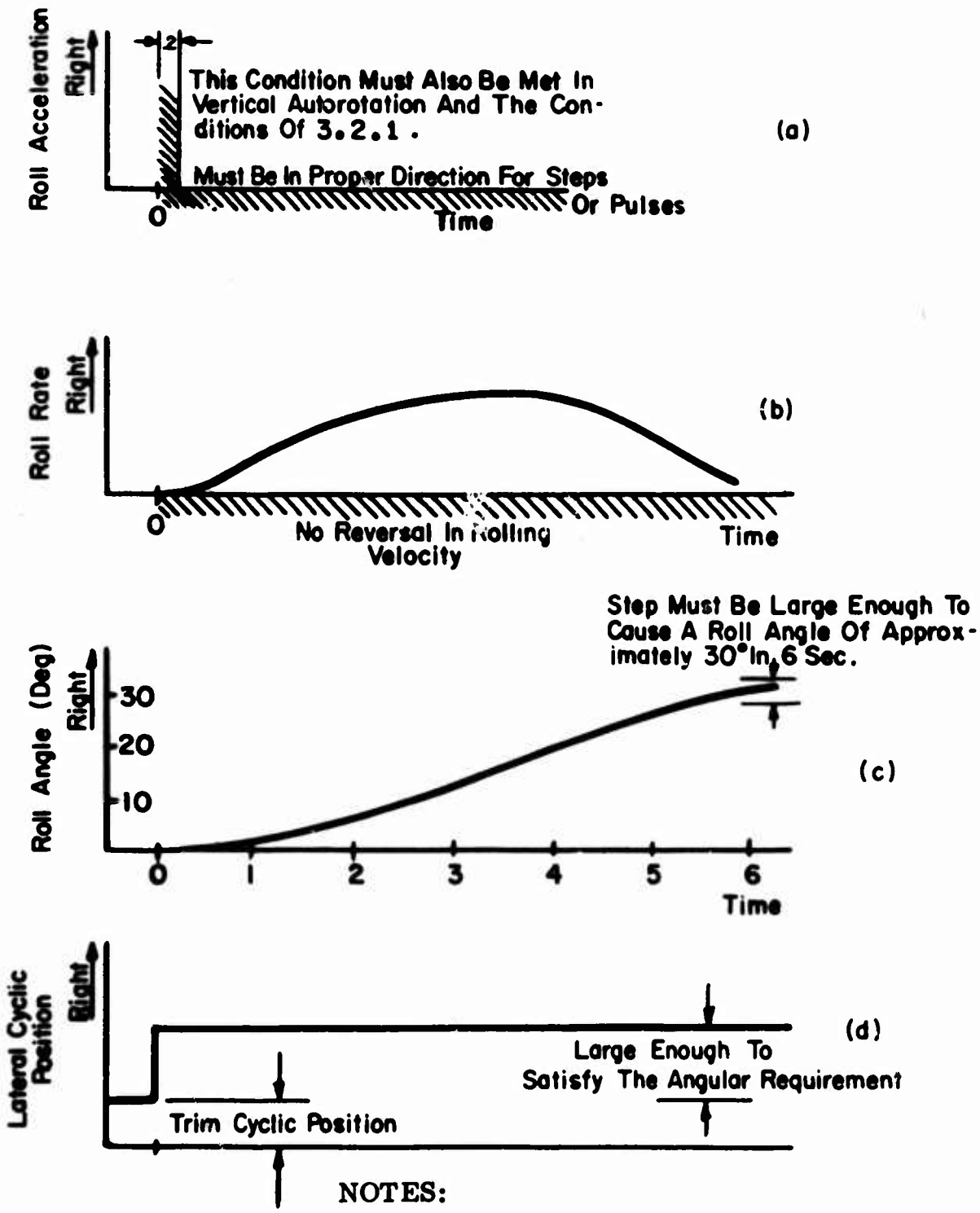
Reference: Paragraphs 3.3.9.1 and 3.3.16

Figure 15 (a) shows the requirement of 3.3.16, i.e., the $\ddot{\phi}$ will be in the proper direction in 0.2 seconds (above and to the right of the hashed lines).

Figure 15 (b) describes the requirement in 3.3.9.1, i.e., there shall be no rolling velocity reversals for small lateral control inputs (pedals fixed).

Figure 15 (c) and (d) define the condition of a "short lateral control input" which is of sufficient magnitude to roll to 30° bank angle in approximately 6 seconds.

All curves are trends only. Note that no rolling velocity zero crossings are allowed at any time, even after 6 seconds.



NOTES:

1. Only the acceleration requirement holds for non-rate command systems.

2. For the flight conditions of 3.3.9.

Figure 15. Roll Acceleration Response and Rolling Reversal.

MIL H-8501A Requirement

3.3.11 At all trim conditions and speeds specified in 3.3.10, the lateral force gradient for the first inch of travel from trim shall be no less than 0.5 pound per inch and no more than 2.0 pounds per inch. In addition, however, the force produced for a 1-inch travel from trim by the gradient chosen shall not be less than the break-out force (including friction) exhibited in flight. The slope of the curve of stick force versus displacement shall be positive at all times and the slope for the first inch of travel from trim shall always be greater than or equal to the slope for the remaining stick travel. The directional control shall have a limit force of 15 pounds at maximum deflection with a linear force gradient from trim position. There shall be no undesirable discontinuities in either the lateral or directional force gradients.

Figure 16 Lateral Cyclic Stick Forces and Gradients; Force vs Position

Reference: Paragraph 3.3.11

Presented in figure 16 are the specific numerical requirements for the allowable range of breakout forces, the limit control forces and the gradient of force versus position. The range of breakout forces is shown as the distance between the intersection of the hashed lines and ordinate axes. The values of a and b are such that b is the particular breakout force of the lateral cyclic stick and a, the force produced in the first inch of travel, is equal to b. Note that a must be greater than or equal to b. Slope d is the gradient after the first inch of travel, and it must be less than or equal to slope c but not zero, nor can the extreme of the line d penetrate the upper hash mark (limit forces from table II of MIL-H-8501A) for any stick deflection. The gradient characteristics must be identical for right and left inputs.

NOTES:

1. for all conditions and' speeds in 3.3.1 and 3.3.2.
2. $a \geq b$
3. $c \geq d > 0$
4. max. slope = 2.0 #/in for first inch of travel
5. min. slope = 0.5 #/in for first inch of travel
6. no undesirable discontinuties
7. — — —nominal gradient

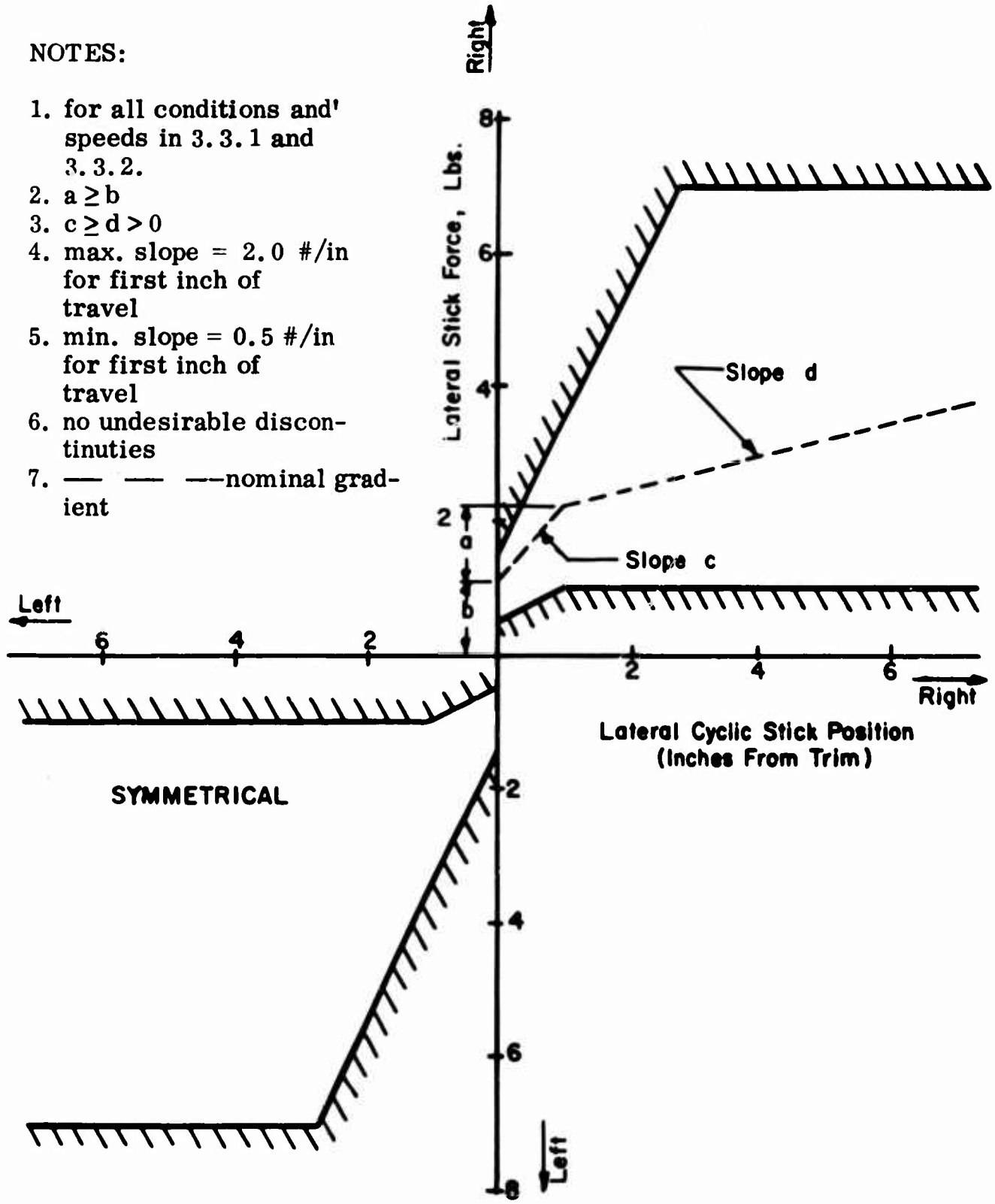


Figure 16. Lateral Cyclic Force Gradients.

MIL H-8501A Requirement

3.3.11 At all trim conditions and speeds specified in 3.3.10, the lateral force gradient for the first inch of travel from trim shall be no less than 0.5 pound per inch and no more than 2.0 pounds per inch. In addition, however, the force produced for a 1-inch travel from trim by the gradient chosen shall not be less than the breakout force (including friction) exhibited in flight. The slope of the curve of stick force versus displacement shall be positive at all times and the slope for the first inch of travel from trim shall always be greater than or equal to the slope for the remaining stick travel. The directional control shall have a limit force of 15 pounds at maximum deflection with a linear force gradient from trim position. There shall be no undesirable discontinuities in either the lateral or directional force gradients.

3.3.14 The controls shall be free from objectionable transient forces in any direction following rapid lateral stick or pedal deflections. During and following a rapid lateral displacement of the control stick from trim or a rapid pedal displacement from trim, the force acting in a direction to resist the displacement shall not at any time fall to zero. Lateral control displacement shall not produce longitudinal control forces in excess of 40 percent or pedal forces in excess of 100 percent of the associated lateral force. Pedal displacement shall not produce longitudinal control forces in excess of 8 percent or lateral control forces in excess of 6 percent of the associated pedal force. For helicopter employing power-boosted or power-operated controls, there shall be no longitudinal control forces developed in conjunction with lateral or directional control displacement.

Figure 17 Pedal Forces and Gradients; Force vs Percent Pedal Deflection

Reference: Paragraphs 3.3.11 and 3.3.14

The requirement states that the limit pedal force is 15 pounds and table II of the specification states the permissible break out force range is from 3 to 7 pounds. If one pedal fully deflected is defined as 50 percent of the total deflection, the limit seen in figure 17 results. The upper sloping line can be constructed knowing that if the maximum breakout force is chosen, the limit force for a fully deflected pedal cannot be greater than 15 pounds. Since the gradient has to be essentially linear, the two points are connected. The line with a slope of infinity is obvious, because full deflection is defined as 50 percent of one pedal. The lower line of slope zero results from the minimum breakout force and the minimum force gradient. The slope can never be zero, but can approach a small value. Right and left pedal deflections are symmetrical.

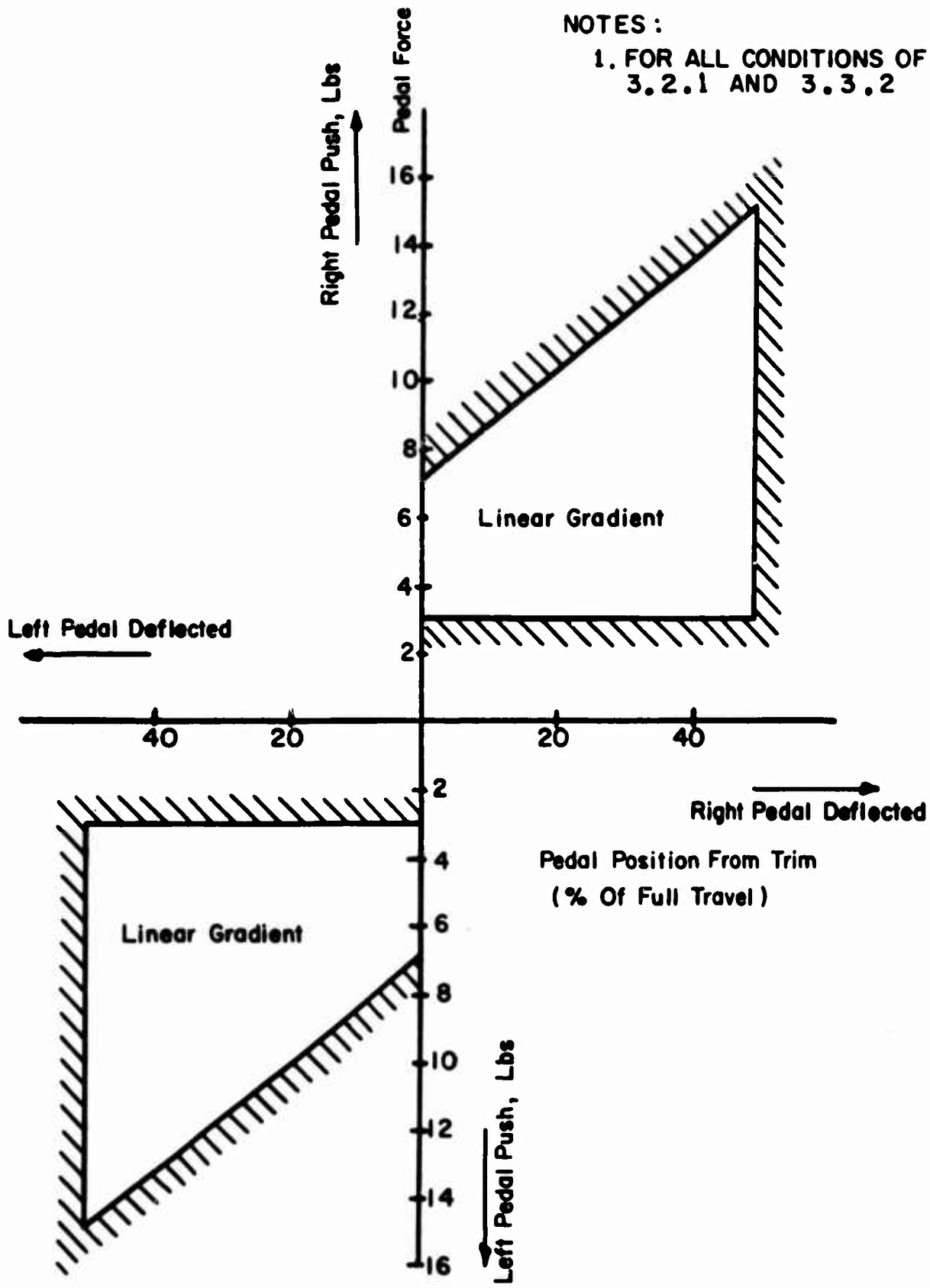


Figure 17. Pedal Forces and Gradients; Force vs Percent Pedal Deflection

MIL H-8501A Requirement

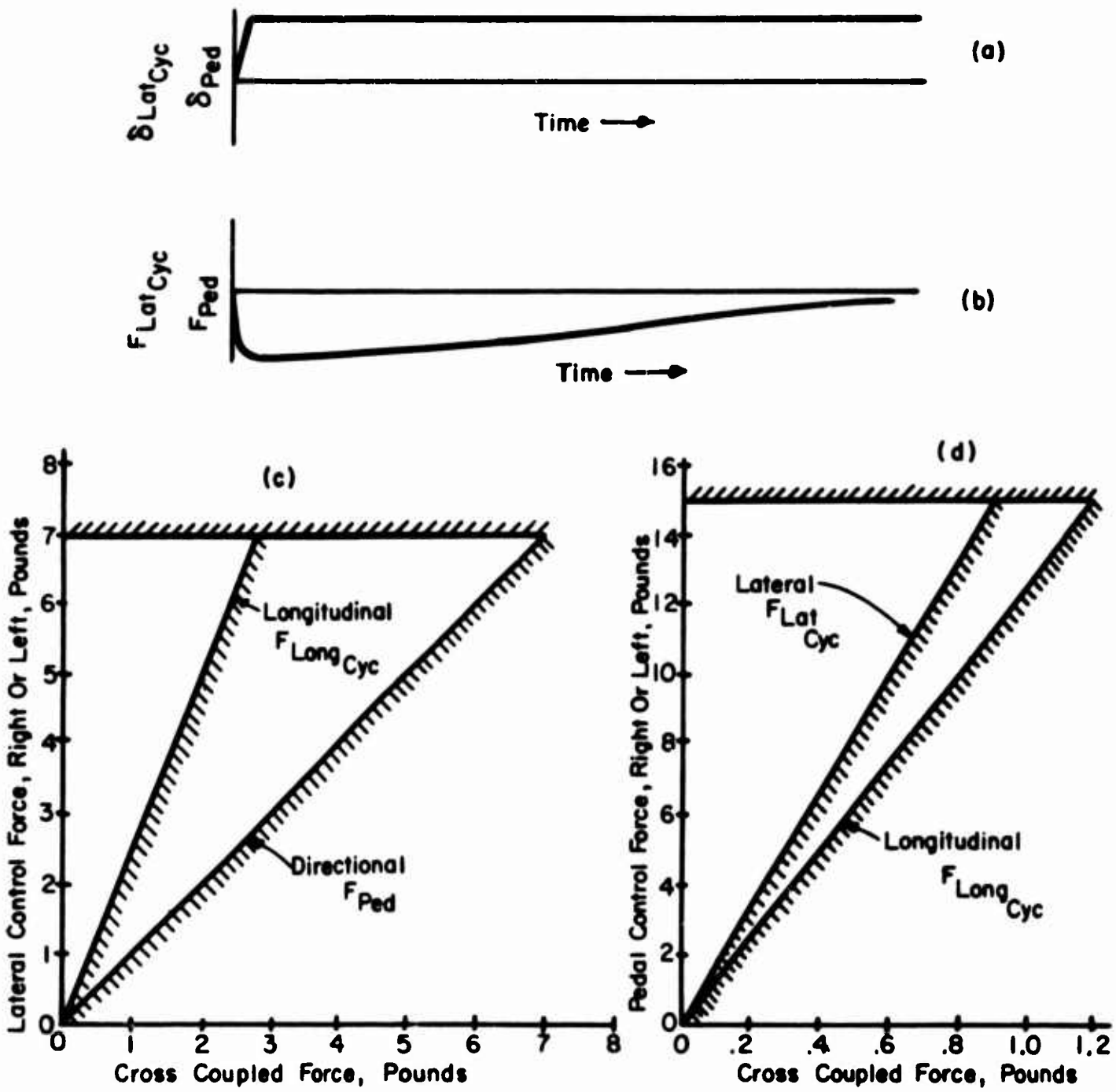
3.3.14 The controls shall be free from objectionable transient forces in any direction following rapid lateral stick or pedal deflections. During and following a rapid lateral displacement of the control stick from trim or a rapid pedal displacement from trim, the force acting in a direction to resist the displacement shall not at any time fall to zero. Lateral control displacement shall not produce longitudinal control forces in excess of 40 percent or pedal forces in excess of 100 percent of the associated lateral force. Pedal displacement shall not produce longitudinal control forces in excess of 8 percent or lateral control forces in excess of 6 percent of the associated pedal force. For helicopters employing power-boosted or power-operated controls, there shall be no longitudinal control forces developed in conjunction with lateral or directional control displacement.

Figure 18 Lateral Cyclic and Pedal Control Force Characteristics and Cross Coupling

Reference: Paragraph 3.3.14

This figure is similar to figure 4, which depicts longitudinal characteristics. Figure 18 (a) depicts a rapid lateral cyclic or pedal control input and (b) shows the force generated by the input shall resist the stick (or pedal) displacement, shall never fall to zero and is free from objectional transient forces.

Figure 18 (c) shows the allowable cross coupled forces during a rapid lateral cyclic stick input in terms of the specific forces. The LONGITUDINAL line shows the 40 percent cross coupling and the DIRECTIONAL line depicts the 100 percent pedal force. Figure 18 (d) is similar, except the amount of cross coupling from a pedal input is shown. The cross coupling has to be less than or equal to the associated force of the hashed line.



NOTES:

1. Controls shall be free from objectional transient forces
2. Following a rapid $\delta_{lat\ cyc}$ or δ_{ped}, the respective forces shall not fall to zero
3. No cross coupling for power boosted controls

Figure 18. Lateral Cyclic and Pedal Control Force Characteristics and Cross Coupling

MIL H-8501A Requirement

3.3.15 The response of the helicopter to lateral-control deflection, as indicated by the maximum rate of roll per inch of sudden control deflection from the trim setting, shall not be so high as to cause a tendency for the pilot to overcontrol unintentionally. In any case, at all level flight speeds, including hovering, the control effectiveness shall be considered excessive if the maximum rate of roll per inch of stick displacement is greater than 20 degrees per second.

Figure 19 Lateral Control Sensitivity; Roll Rate Parameter vs Lateral Cyclic Displacement

Reference: Paragraph 3.3.15

The requirement for lateral control sensitivity states that the maximum roll rate per inch of stick shall not exceed 20°/sec. The second order differential equation

$$\ddot{\phi} + \frac{D_x}{I_{xx}} \dot{\phi} = \frac{L\delta_{Lat_{Cyc}} \delta_{Lat_{Cyc}}}{I_{xx}} = \frac{L\delta}{I_{xx}}$$

is solved and the limit of $d\dot{\phi}/d\,\delta_{Lat_{Cyc}} = 20$ is substituted into the result. This yields figure 19.

To calculate the roll parameter

$$\frac{\frac{1}{D_x}}{I_{xx}} \times \frac{1}{I_{xx}} - \frac{d}{d\,\delta_{Lat_{Cyc}}} (L\delta)$$

the dynamic trace data for several sizes of step inputs are required. Measure $\ddot{\phi}_{Max}$ for these traces and plot $\ddot{\phi}_{Max}$ vs $\delta_{Lat_{Cyc}}$.

The slope of this line at any point can be calculated and $dL\delta/d\delta_{Lat_{Cyc}}$ is obtained from

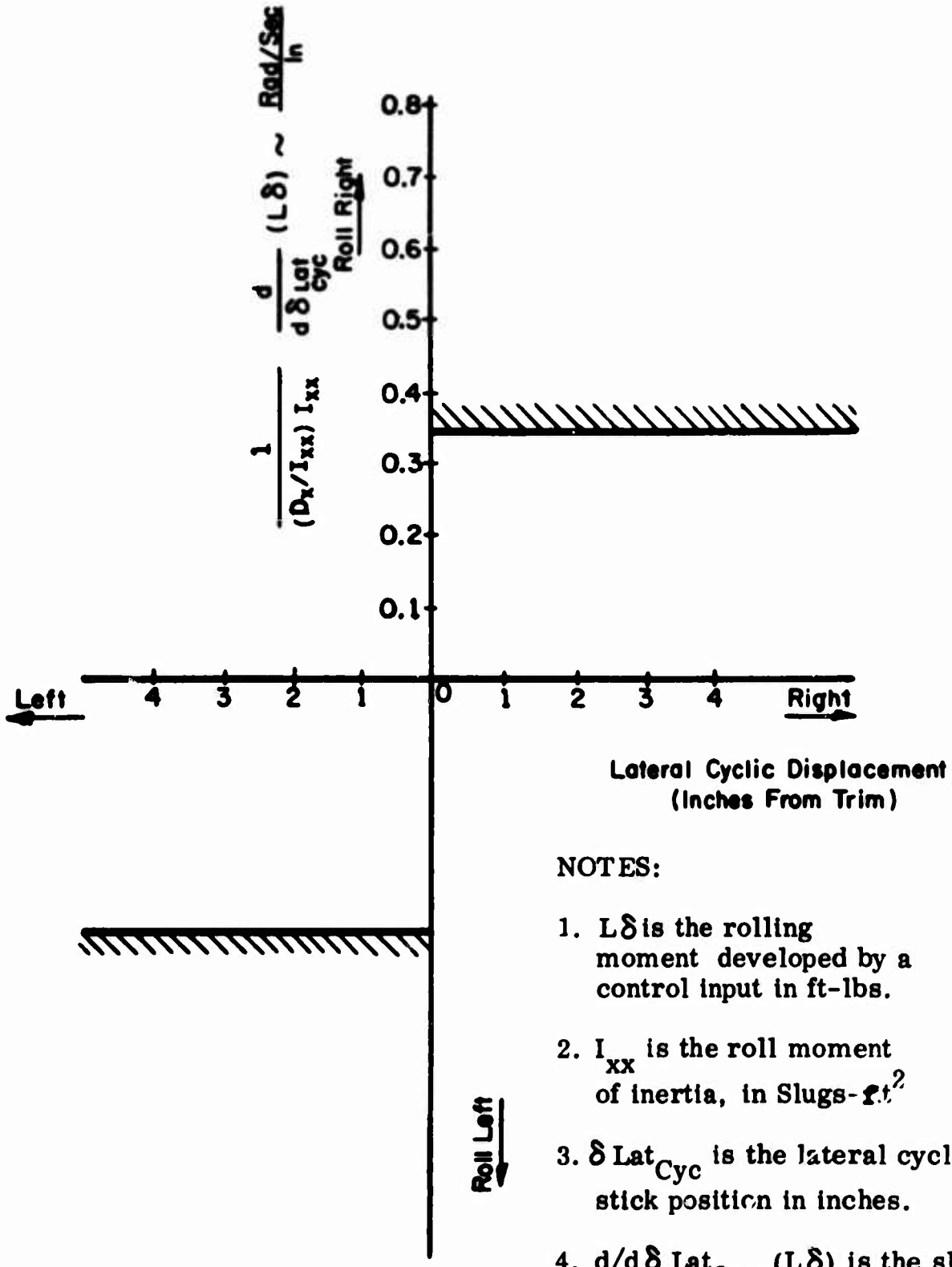
$$\frac{d\ddot{\phi}}{d\delta_{Lat_{Cyc}}} = \frac{d(L\delta/I_{xx}}{d\,\delta_{Lat_{Cyc}}} = \frac{1}{I_{xx}} \frac{dL\delta}{d\,\delta_{Lat_{Cyc}}}$$

thus, the roll parameter can be expressed as

$$\frac{\frac{1}{D_x}}{I_{xx}} \cdot \frac{d\ddot{\phi}}{d\,\delta_{Lat_{Cyc}}} = \frac{\frac{1}{D_x}}{I_{xx}} \cdot \frac{1}{I_{xx}} \cdot \frac{dL\delta}{d\,\delta_{Lat_{Cyc}}}$$

To check for compliance with figure 19, the maximum slope of $d\ddot{\phi}/d\,\delta_{Lat_{Cyc}}$ divided by the damping parameter cannot exceed 0.35 rad/sec/in. $\frac{D_x}{I_{xx}}$ can be determined by the method outlined in part II of the appendix.

If the data of roll date per inch of stick are given, determining compliance is a relatively simple task.



NOTES:

1. $L\delta$ is the rolling moment developed by a control input in ft-lbs.

2. I_{xx} is the roll moment of inertia, in Slugs-ft^2

3. $\delta\, Lat_{Cyc}$ is the lateral cyclic stick position in inches.

4. $d/d\delta\, Lat_{Cyc}\, (L\delta)$ is the slope of the curve relating rolling moment developed to lateral cyclic displacement.

Figure 19. Lateral Control Sensitivity; Roll Rate Parameter vs Lateral Cyclic Displacement.

MIL H-8501A Requirement

3.3.16 There shall be no objectionable or excessive delay in the development of angular velocity in response to lateral or directional control displacement. The angular acceleration shall be in the proper direction within 0.2 second after control displacement. This requirement shall apply for all flight conditions specified in 3.2.1, including vertical autorotation.

Figure 20 Yaw Acceleration Response; Yaw Acceleration and Pedal Displacement vs Time

Reference: Paragraph 3.3.16

The directional acceleration response requirement is shown and is the same as for the pitch and roll axes. (Figures 8 and 14 respectively).

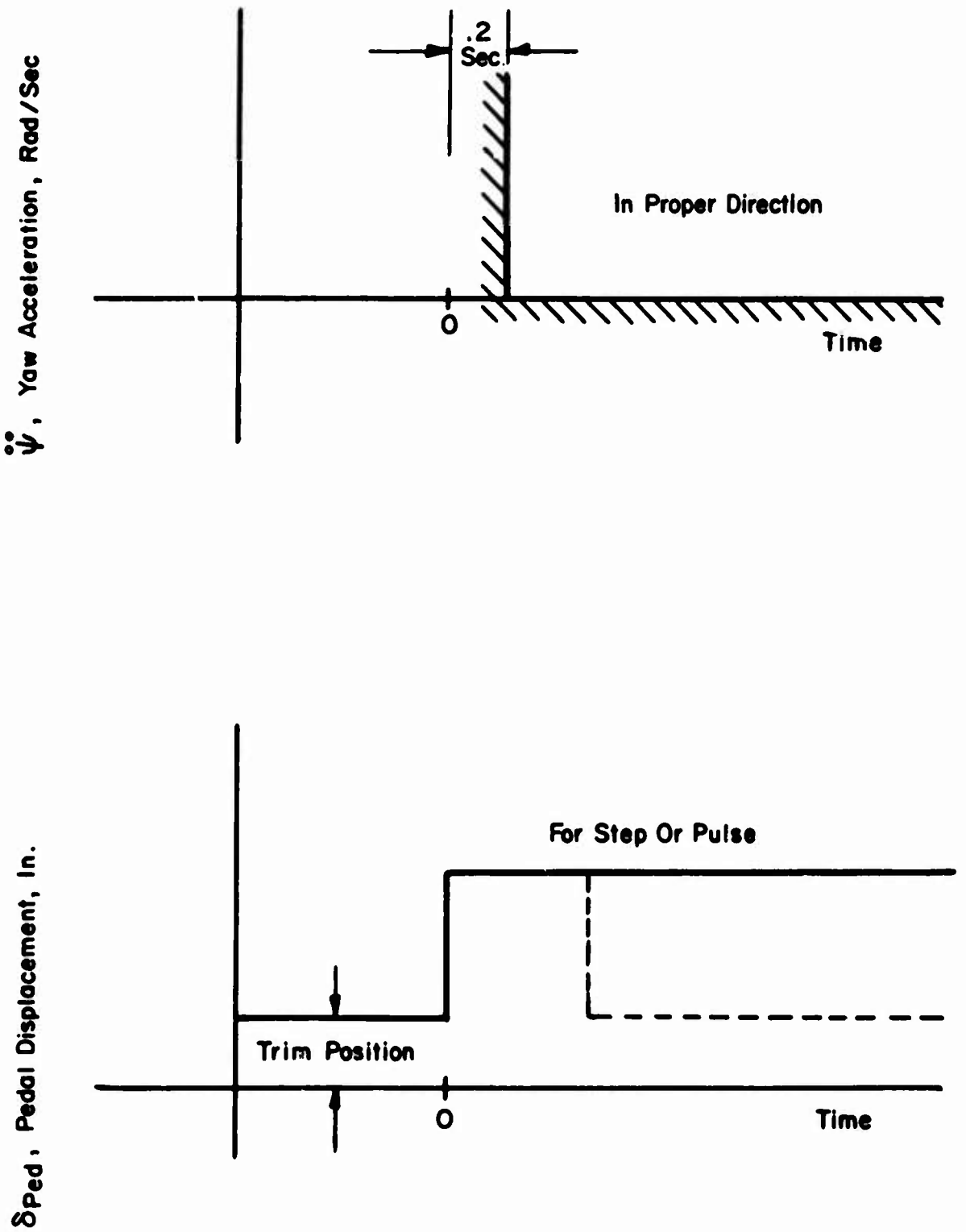


Figure 20. Yaw Acceleration Response; Yaw Acceleration and Pedal Displacement vs Time.

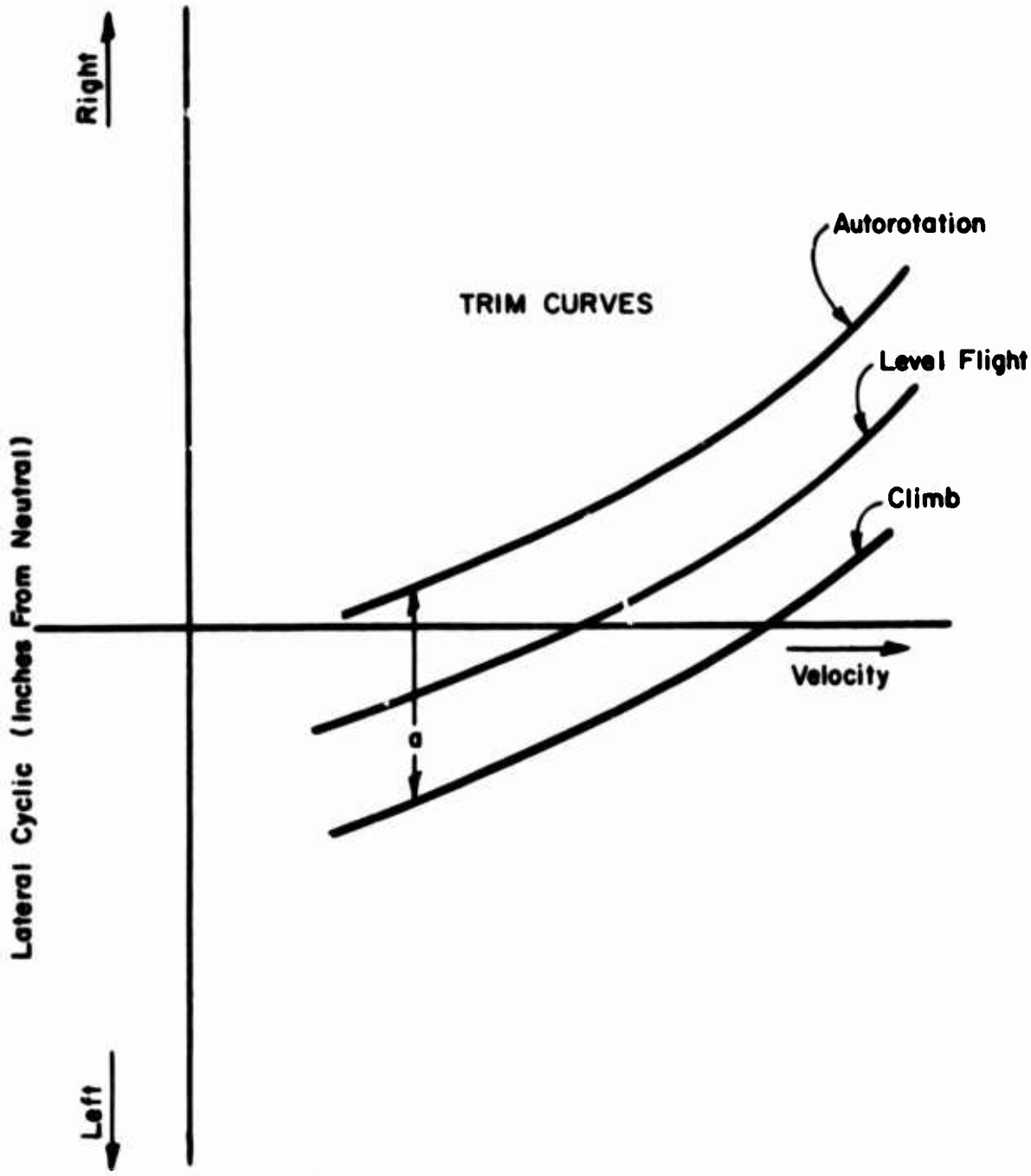
MIL H-8501A Requirement

3.3.17 The helicopter shall not exhibit excessive lateral trim changes with changes in power or collective pitch, or both. Specifically, when starting from trim at any combination of power and airspeed within the flight envelope of the helicopter, it shall be possible to maintain lateral trim with a control displacement amounting to no more than 2 inches from the initial trim position as the engine power or collective pitch, or both, are varied either slowly or rapidly in either direction throughout the available range.

Figure 21 Lateral Trim Changes with Power and/or Collective Variations; Stick Position vs Airspeed

Reference: Paragraph 3.3.17

This is a lateral trim requirement stating that power and/or collective pitch changes in their allowable range cannot cause a lateral stick position of more than 2 inches from trim. This requirement is similar to the longitudinal; however, longitudinal trim changes can be as large as a 3-inch stick movement. (See figure 5.)



NOTES:

1. At a constant gross weight and C.G., the trim changes with power (a) shall be no greater than 2 inches. ($a \leq 2$ inches)

Figure 21. Lateral Trim Changes with Power and/or Collective Variations; Stick Postion vs Airspeed

MIL H-8501A Requirement

3.3.18 Lateral control power shall be such that when the helicopter is hovering in still air at the maximum overload gross weight or at the rated power, a rapid 1-inch step displacement from trim of the lateral control shall produce an angular displacement at the end of one-half second of at least $\frac{27}{3\,W + 1000}$ degrees. When maximum available displacement from trim of the lateral control is rapidly applied at the conditions specified above, the resulting angular displacement at the end of one-half second shall be at least $\frac{81}{3\,W + 1000}$ degrees. In both expressions W represents the maximum overload gross weight of the helicopter in pounds.

Figures 22a and 22b. Lateral Control Power

Reference: Paragraph 3.3.18

Figure 22a shows the requirement for bank angle in the first half second (as opposed to the displacement angle in the first second for longitudinal and directional axes) vs gross weight. Curve A is for a full control input and B is for the 1-inch control input. The points must be to the right of the associated hashed curve.

Figure 22b shows the bank angle requirement in terms of the solution to the second order differential equation. To use this figure, a dynamic trace of roll acceleration is needed, and then the $\left[\frac{\text{Rolling Moment Developed}}{I_{xx}}\right]$ and $\frac{D_x}{I_{xx}}$ are found via Part II of the appendix. The calculated point must be above its associated hashed curve.

Figures 22a and 22b do not have the limit of lateral control sensitivity represented. The sensitivity limit is seen in figure 19, and is stated in MIL-H-8501A, paragraph 3.3.15.

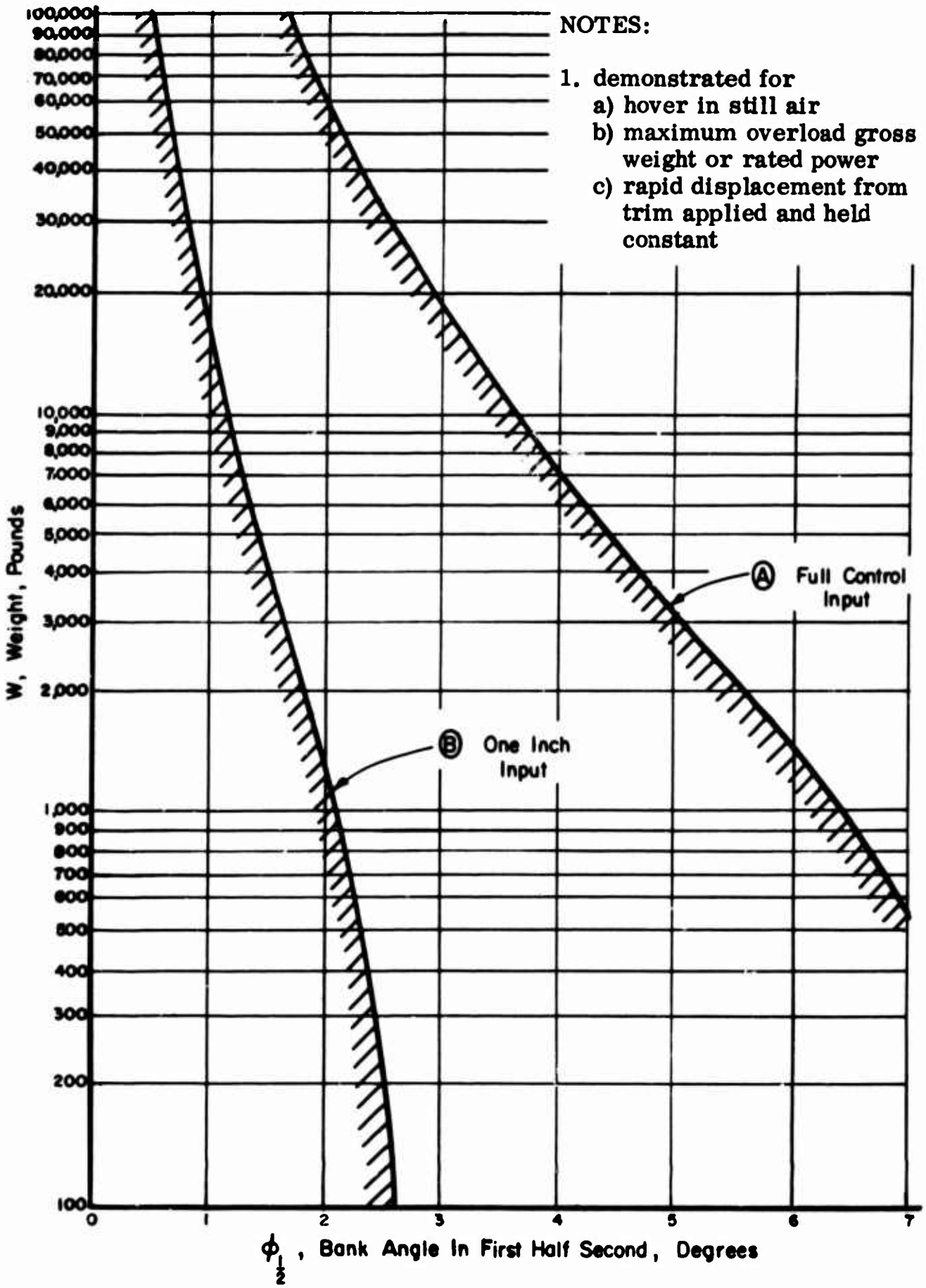
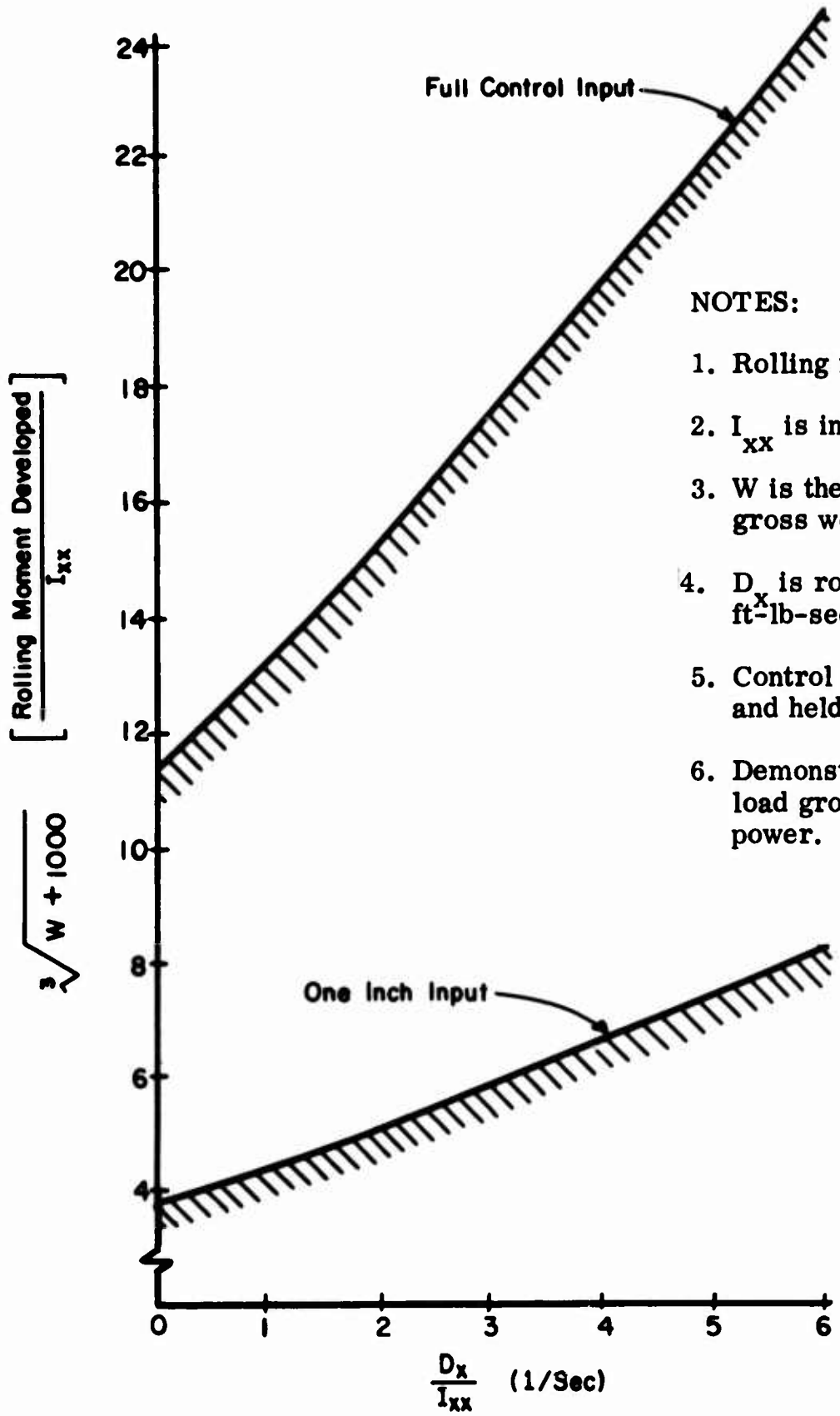


Figure 22a. Lateral Control Power; Gross Weight vs Bank Angle in the First Half Second



NOTES:

1. Rolling moment is in ft-lbs.
2. I_{xx} is in slugs-ft^2.
3. W is the maximum overload gross weight.
4. D_x is roll damping in ft-lb-sec.
5. Control is applied rapidly and held constant.
6. Demonstrated at maximum overload gross weight or rated power.

Figure 22b. Lateral Control Power

MIL H-8501A Requirement

3.3.19 To insure satisfactory initial response characteristics following either a lateral or directional control input and to minimize the effect of external disturbances, the helicopter, in hovering, shall exhibit roll angular velocity damping (that is, a moment tending to oppose the angular motion and proportional in magnitude to the rolling angular velocity) of at least 18 $(I_x)^{0.7}$ ft-lb/rad/sec., where I_x is the moment of inertia about the roll axis expressed in slug-ft^2. The yaw angular velocity damping should preferably be at least 27 $(I_z)^{0.7}$ ft-lb/rad/sec., where I_z is the moment of inertia about the yaw axis expressed in slug-ft^2.

Figures 23a and 23b Lateral and Directional Hover Rate Damping; Inertia vs Damping Parameter

Reference: Paragraph 3.3.19

Figure 23a shows the hover damping in roll required by the equation

$$\frac{D_x}{I_{xx}} = 18\,(I_{xx})^{0.7}$$

as given in the specification. The inertia-damping relationship must be such as to create values to the right of the curve.

Figure 23b shows the hover yaw rate damping as per the equation

$$\frac{P_z}{I_{zz}} = 27\,(I_{zz})^{0.7}$$

The values of $\frac{D}{I}$ must lie to the right of the hashed lines.

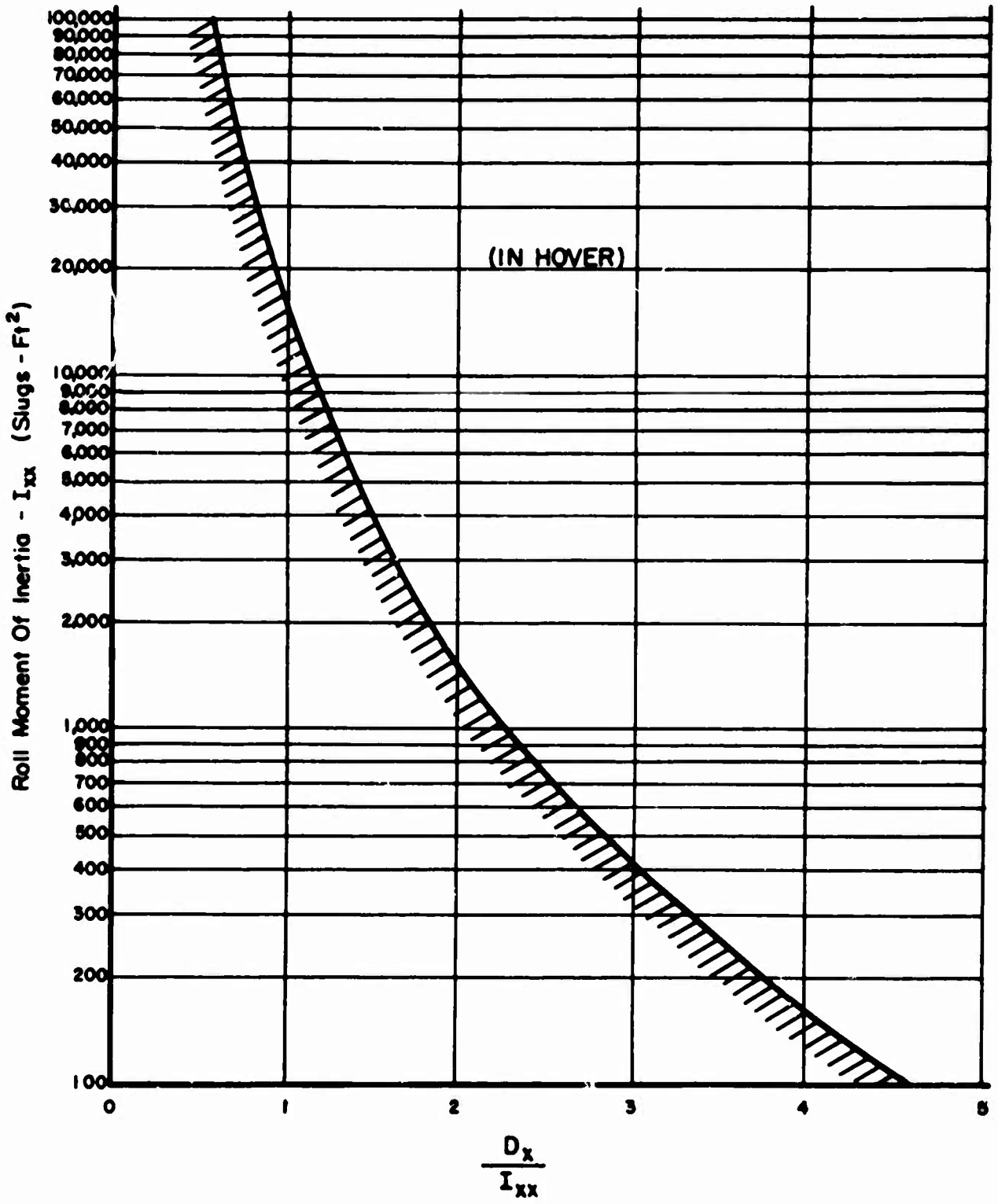


Figure 23a. Lateral and Directional Hover Rate Damping; Inertia vs Damping Parameter

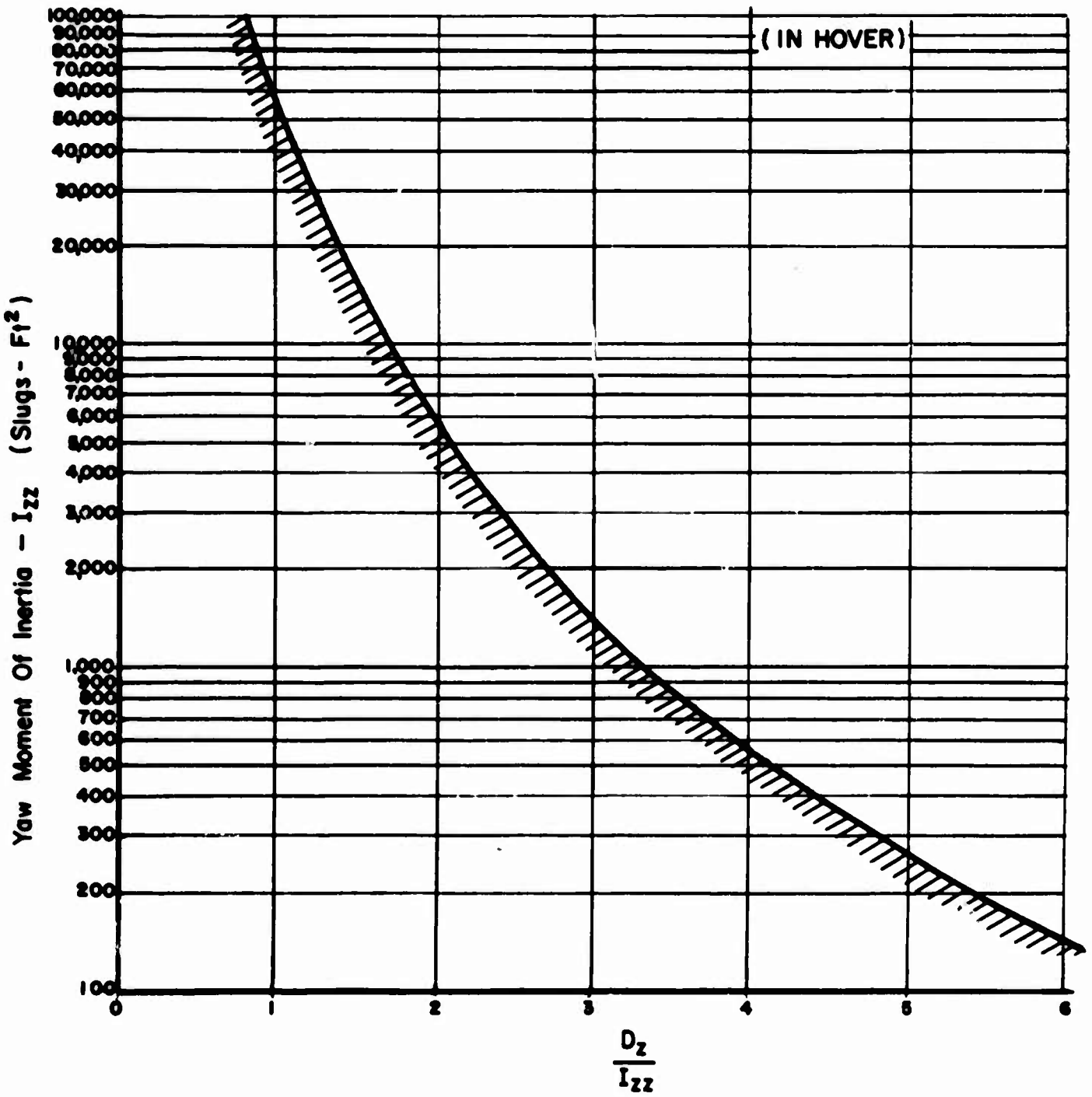


Figure 23b. Lateral and Directional Hover Rate Damping

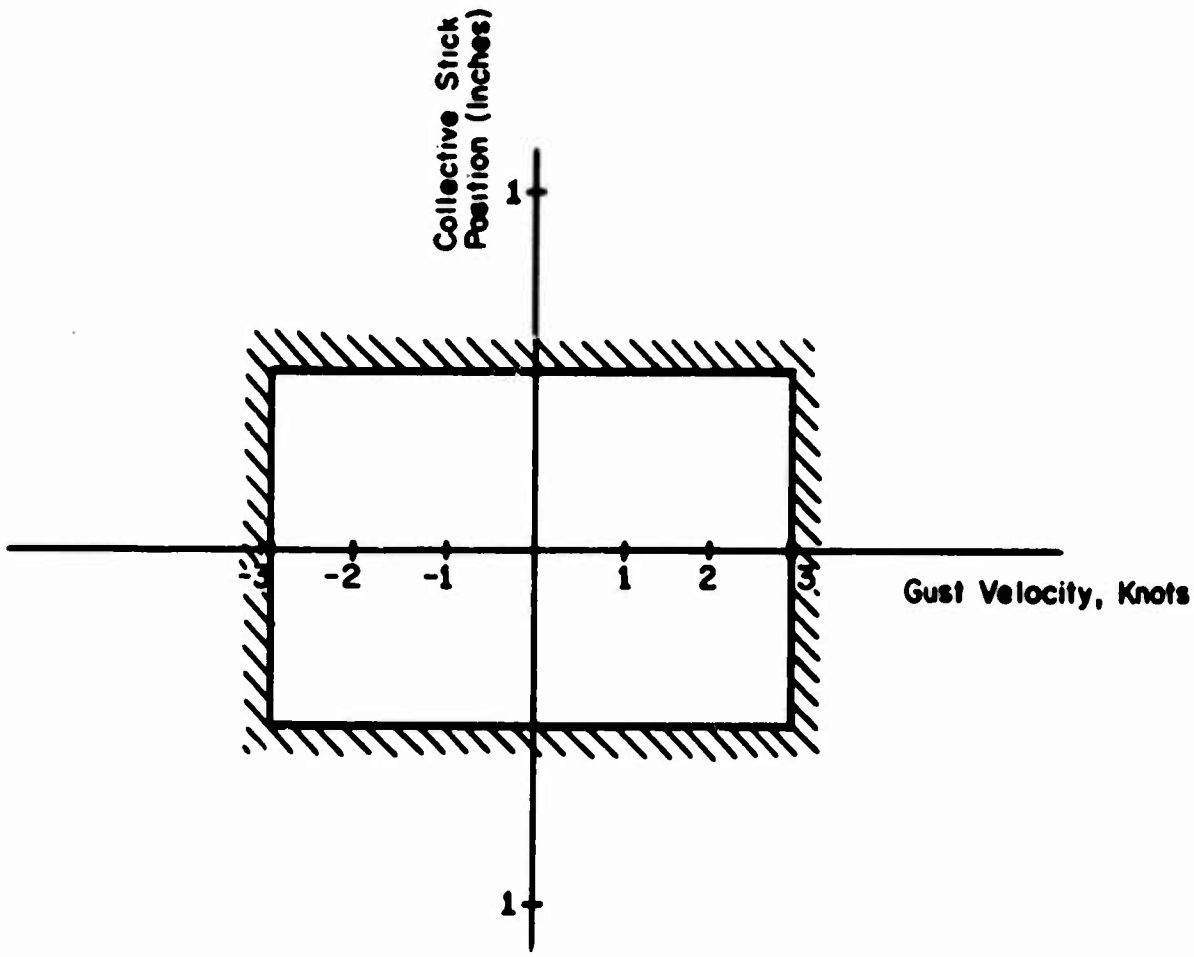
MIL H-8501A Requirement

3.4.1 It shall be possible to maintain positive control of altitude within ± 1.0 foot by use of the collective-pitch control while hovering at constant rotor rpm under the conditions of 3.2.2. This shall be accomplished with a minimum amount of collective stick motion required, and in any case it shall be possible to accomplish this with less than ± ½ inch movement of the collective stick. When a governor is employed, there shall be no objectional vertical oscillation resulting from lag in governor response.

Figure 24 Collective Movement in Still Air; Collective Position vs Gust Velocity

Reference: Paragraph 3.4.1

This requirement is similar to 3.2.2, figure 2, only for collective movement. Still air is again defined as ±3 knot gusts, and hovering in these gusts shall not require more than ±1/2 inch of $\delta_{Coll.}$. Requirements of 3.4.1 and 3.2.2 are written in MIL-H-8501A in an effort to limit the pilot activity in still air hover tasks.



NOTES:

1. This requirement must be met while hovering over a point for all terrain clearances up to disappearance of ground effect while maintaining altitude within one foot.

2. This is to be done at constant rotor RPM. If a governor is employed, there shall be no objectionable vertical oscillations resulting from lag in governor response.

Figure 24. Collective Movement in Still Air; Collective Position vs Gust Velocity

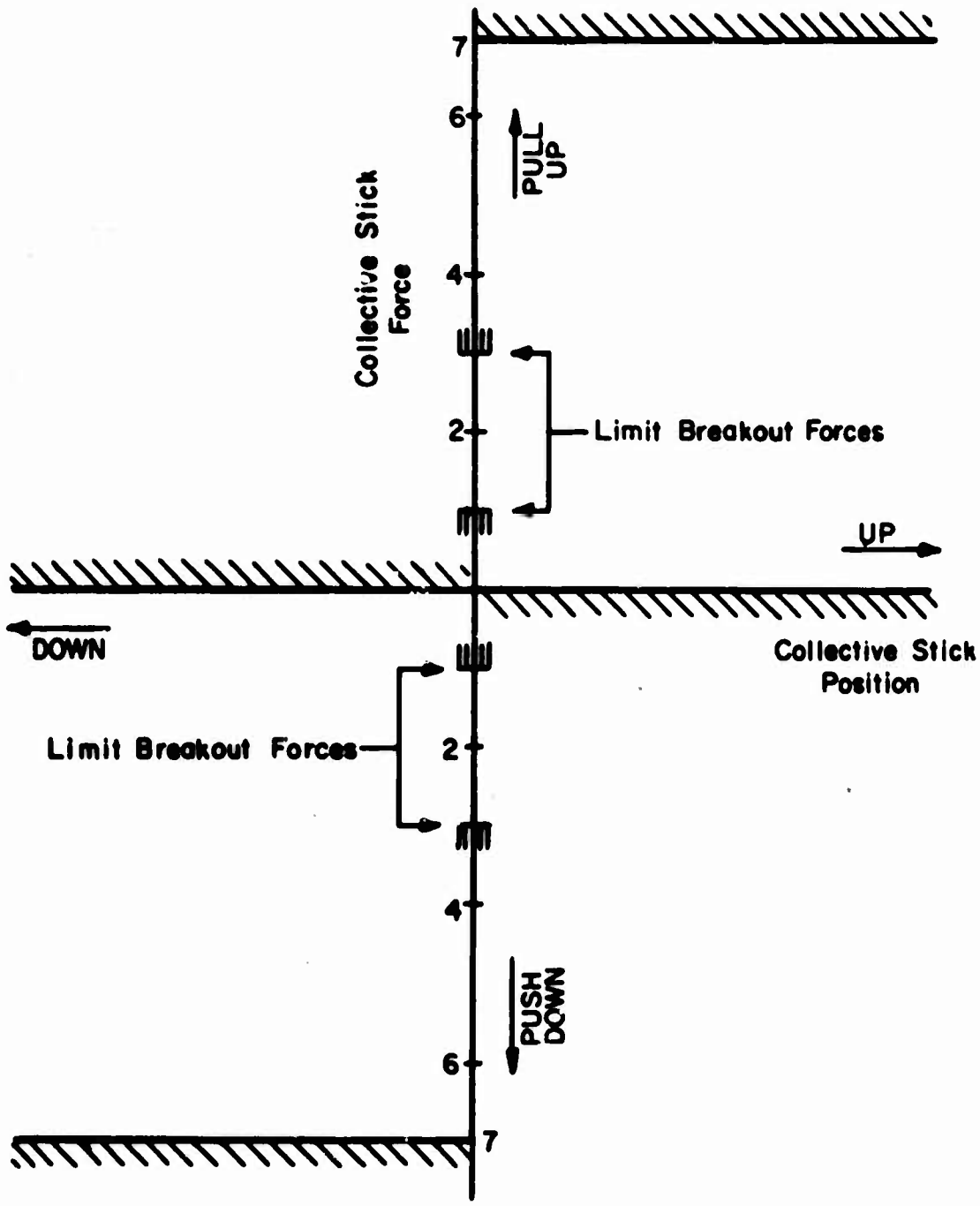
MIL H-8501A Requirement

3.4.2 The collective-pitch control shall remain fixed at all times unless moved by the pilot and shall not tend to creep, whether or not cyclic or directional controls are moved. The maximum effort required for the collective control shall not exceed the values specified in table II. The breakout force (including friction) shall be within the acceptable limits as specified in table II.

Figure 25 Collective Breakout and Limit Forces; Collective Stick Force vs Position

Reference: Paragraph 3.4.2

Figure 25 shows the collective stick force characteristics as outlined in table II of MIL-H-8501A. The hashed line segments on the ordinate depict the range of breakout forces and the upper hashed line is drawn through the limit force of 7 pounds. No force gradient or position stability is shown on the figure, as none are required by MIL-H-8501A.



NOTE: The collective control shall not move unless moved by the pilot regardless of any other control input

Figure 25. Collective Breakout and Limit Forces; Collective Stick Force vs Position

MIL H-8501A Requirement

3.5.1 It shall be possible while on the ground to start and stop the rotor blades in winds up to at least 45 knots. For helicopters with a gross weight of less than 1,000 pounds, this requirement shall be at least 35 knots. For all ship-based helicopters, this requirement shall be at least 60 knots while headed into the wind.

3.2.2 It shall be possible without the use of wheel chocks to maintain a fixed position on a level paved surface with takeoff rotor speed while power is being increased to takeoff power in winds as specified in 3.5.4.1.

3.5.4.1 It shall be possible to make satisfactory, safe vertical takeoffs and landings in steady winds up to 45 knots and winds with gusts up to 45 knots. This shall apply to all helicopters, except those with a gross weight less than 1,000 pounds, which shall be capable of the foregoing in winds and gusts up to 35 knots.

Figure 26 Characteristics in Winds, Longitudinal Wind Velocity vs Lateral Wind Velocity

Reference: Paragraph 3.5.1, 3.5.2, 3.5.4.1

Figure 26 shows the operational envelope for a helicopter in winds. A helicopter of gross weight greater than or equal to 1000 pounds must be capable of the following maneuvers in steady winds of 45 kts or winds with 45 kt gusts:

a. While on the ground, start and stop the rotor blades.

b. Maintain a fixed position on a level paved surface without the use of wheel chocks.

   1. With take-off rotor speed

   2. Power increased from idle to take-off power

c. Taxi

d. Pivot

e. Land vertically

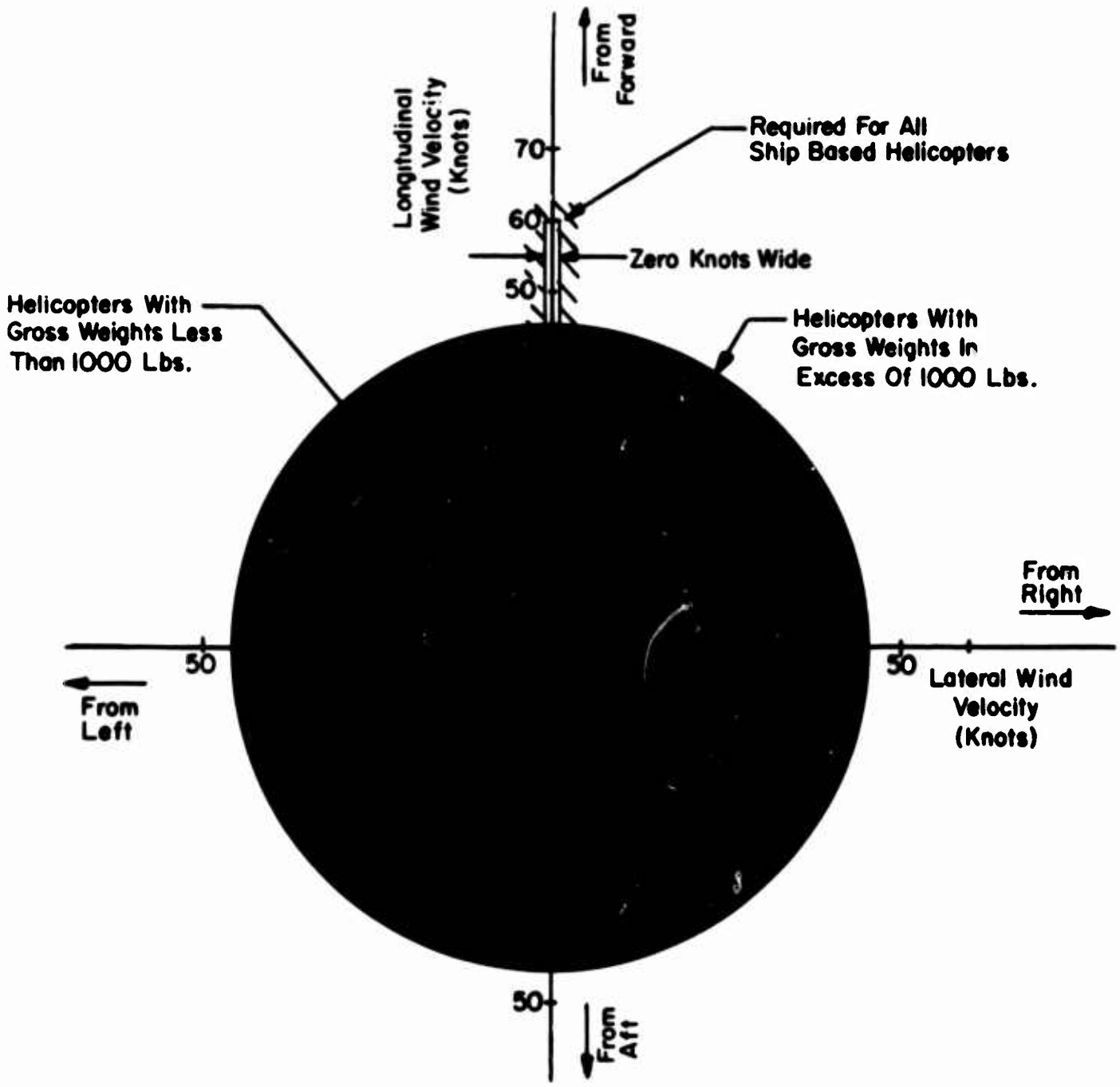
f. Take-off vertically

These requirements shall also apply to helicopters with a gross weight of less than 1000 pounds, only the wind velocity at which the requirements shall be met is relaxed to 35 kts.

In addition, all ship based helicopters shall be capable of starting and stopping the rotor blades in a 60 kt headwind.

Thus, in figure 26, a helicopter must lie on or outside its associated hashed circle.

Also note that although the helicopter must meet these requirements, no wind direction is specified except for ship based helicopters; this is why the curves come out in circular form.



NOTES:

1. Winds include steady winds and steady winds with gusts

2. Rotor starting and stopping must be demonstrated through out the appropriate portion of the envelope

3. Must be able to maintain a fixed point on a level paved surface with take off rotor speed as power is increased to take off power through out the appropriate shaded portion of the envelope.

4. Through out the appropriate shaded portion of the envelope it must be possible to make safe, satisfactory power on vertical landings and take offs.

Figure 26. Characteristics in Winds, Longitudinal Wind Velocity vs Lateral Wind Velocity

MIL H-8501A Requirement

3.5.4.2 From a level paved surface, it shall be possible to make satisfactory, safe running takeoffs with wheel-type gear, up to ground speeds of at least 35 knots.

3.5.4.3 For both power-on and autorotative conditions, it shall be possible to make satisfactory, safe landings on a level paved surface, with wheel and skid gear, up to ground speeds of at least 35 knots. This shall be construed to cover landings with 3 knots ground speed in any direction and up to a side drift of at least 6 knots when landing with a ground speed of 35 knots.

3.5.4.4 In autorotation at a touchdown ground speed of 35 knots on a level paved surface, with wheel and skid gear, it shall be possible to bring the helicopter to a stop within 200 feet.

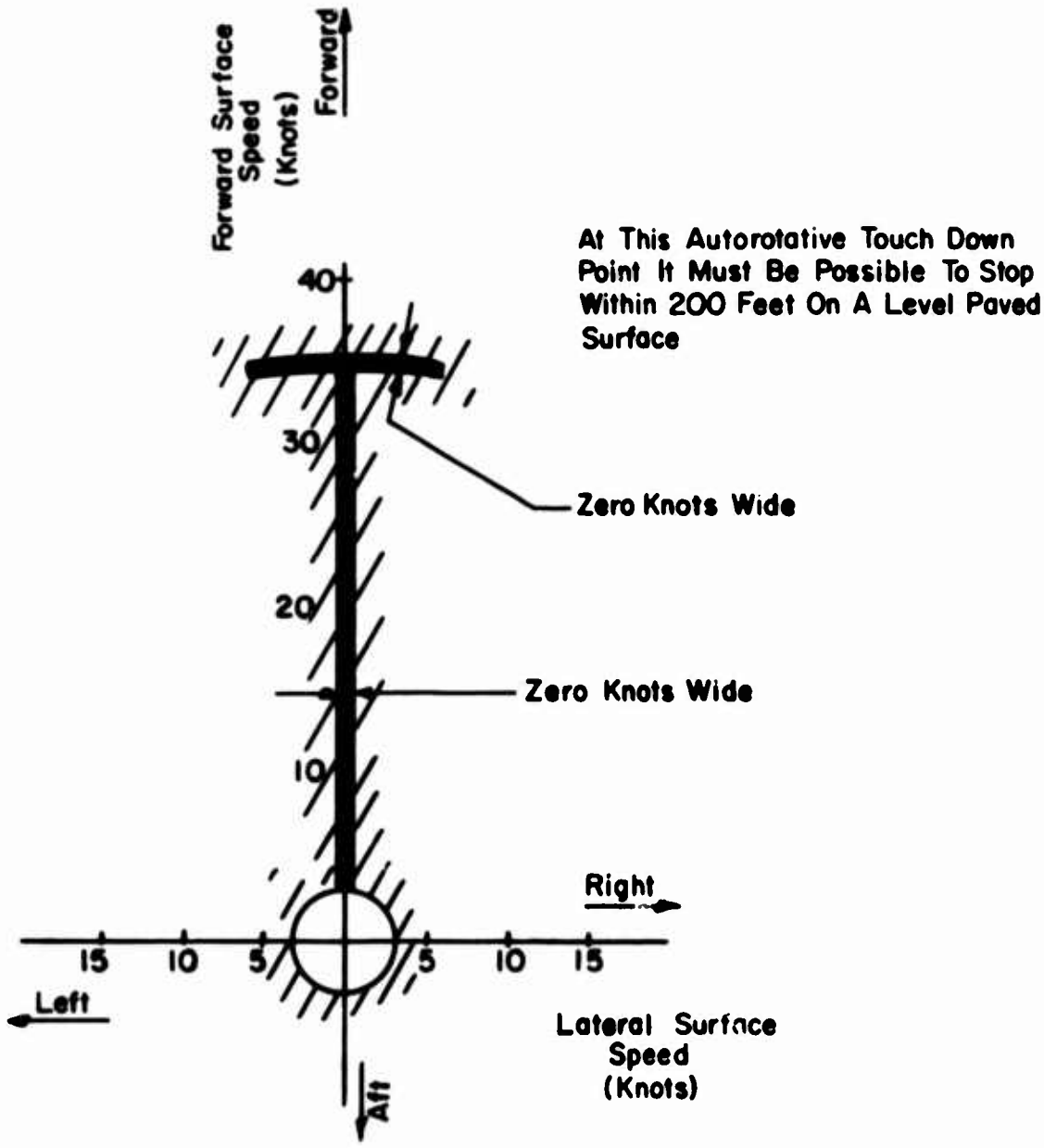
Figure 27 Landing Speed Envelope, Forward Surface Speed vs Lateral Surface Speed

Reference: Paragraphs 3.5.4.2, 3.5.4.3 and 3.5.4.4

This figure depicts the landing requirement for both power on and autorotational landings. The requirement states that the helicopter must execute a safe landing at 35 kts ground speed with at least 6 kts side velocity. It is interpreted herein that the 6 kt sideward velocity vector is included in the calculation of the ground speed. This corresponds to a steady sideslip angle of 9.74°. The requirement also includes landing with a 3 kt ground speed in any direction. This is depicted as the 3 kt circle around zero in the figure.

There is no requirement in the MIL-H-8501A that specifies a side drift in the range of speeds between 3 kts and 35 kts. It is assumed that the extremes stated should assure safe landings in this speed range.

Also shown in figure 27 is the requirement that the helicopter should take off safely up to ground speeds of 35 kts.



NOTES:

1. Through out the entire envelope it must be possible to make satisfactory, safe landings in power on and autorotative descents on a level paved surface, regardless of landing gear type

2. Through out the shaded portion those with wheel-type gear must be capable of take-offs from a level paved surface

Figure 27. Landing Speed Envelope, Forward Surface Speed vs Lateral Surface Speed

MIL H-8501A Requirement

3.5.5 The helicopter shall be capable of entering into power-off autorotation at all speeds from hover to maximum forward speed. The transition from powered flight to autorotative flight shall be established smoothly, with adequate controllability and with a minimum loss of altitude. It shall be possible to make this transition safely when initiation of the necessary manual cellective-pitch control motion has been delayed for at least 2 seconds following loss of power. At no time during this maneuver shall the rotor speed fall below a safe minimum transient autorotative value (as distinct from power-on or steady-state autorotative values). This shall be construed to cover both single and multiengine helicopters.

3.5.5.1 Sudden power reduction, power application, or loss of power with collective control fixed, shall not produce pitch, roll, or yaw attitude changes in excess of 10 degrees in 2 seconds, except that, at speeds below that for best climb, a 20-degree yaw in 2 seconds will be accepted.

Figure 28 Characteristics for Entering Autorotation

Reference: Paragraphs 3.5.5 and 3.5.5.1

The requirement for entering autorotation following a sudden loss in power is that it shall be done smoothly and with adequate control margin regaining. The figures show the definition of smooth and adequate.

Figure 28(a) shows a typical trend of torque loss; the trend could depict a step or a more gradual ramp. Figure 28(b) shows the rotor rpm decay. As before this is only a trend curve, but is shows that the rpm must never fall below the design minimum transient autorotative rpm.

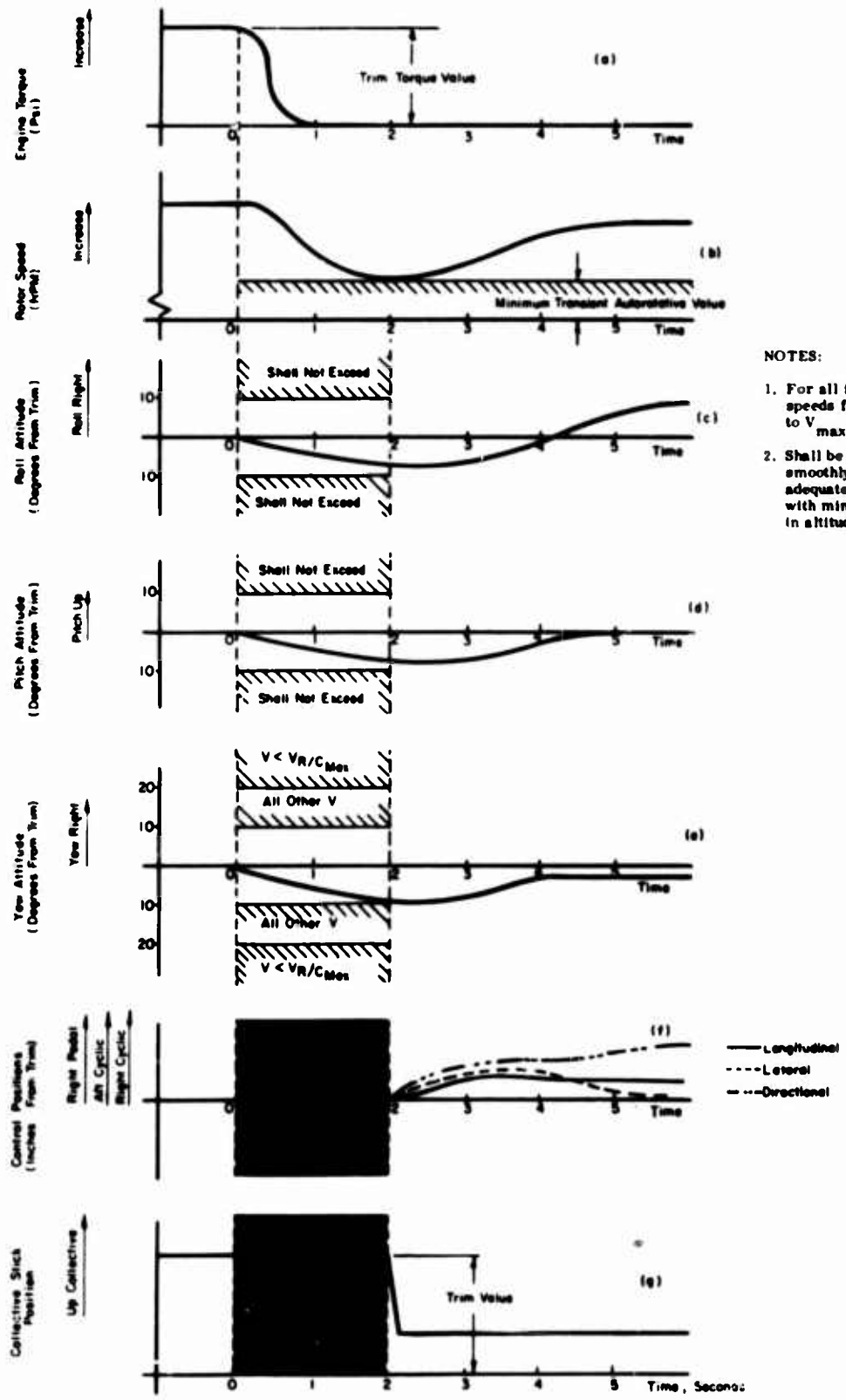
Figure 28(c), (d), and (e) show the allowable attitude excursions (as limited by MIL-H-8501A) in roll, pitch and yaw respectively. For any speed from hover to the maximum speed, no more than a 10-degree pitch and/or roll excursion in 2 seconds is allowed. An exception is made for the yaw axis which allows a 20° yaw angle in 2 seconds for speed below the speed for the maximum rate of climb.

It is worth noting that an angle in excess of these are allowed after 2 seconds. This situation could exist in the case where the roll angle (roll is chosen for the sake of discussion) is increasing as a function of e^{kt} and at 2 seconds is 10 degrees. Even if the pilot applied full opposite lateral cyclic at 2 seconds, the inertia of the roll would not force a roll angle reversal for at least a few more degrees, thus exceeding the 10° but not until about 2 1/4 seconds.

Figure 28(f) shows the control inputs starting after the required 2-second delay. Note that the inputs are in the normal sense of opposing the motion, showing that no control reversal is allowed. The control forces during autorotational entry must not exceed the limit force seen in table II of MIL-H-8501A.

Note that the figure depicts a helicopter that, following a sudden power loss, rolls left, pitches down and yaws left. While this may be the usual sequence, it is not a required sequence. It the sequence is changed, the control input direction must also be changed to correspond to the standard convention dictated by the specification.

At the bottom of figure 28, (g) shows the 2-second delay before application of collective stick as dictated by the requirement.



NOTES:

1. For all initial speeds from Hover to V_{max}
2. Shall be performed smoothly with adequate control with minimum loss in altitude

Figure 28. Characterestics For Entering Autorotation

MIL H-8501A Requirement

3.5.8 For helicopters equipped with power-boosted or power-operated controls, the following conditions shall be met:

(a) In trimmed level flight at any speed, out-of-trim conditions resulting from abrupt power-operated control system failure shall be such that:

(1) With controls free for at least 3 seconds, the resulting rates of yaw, roll, and pitch shall not exceed 10 degrees per second, and the change in normal acceleration shall not exceed $\pm\frac{1}{2}$ g.

(2) It shall be possible to continue level flight with zero sideslip with forces to operate the controls not exceeding 80 pounds for the directional control, 25 pounds for the collective and longitudinal controls, and 15 pounds for the lateral control.

(b) With power-operated control system off, it shall be possible to trim steady longitudinal, lateral, and directional control forces to zero under all the conditions and speeds specified in 3.2.1 and 3.3.2.

(c) With power-operated control system off, the collective-pitch control shall not tend to creep, whether or not cyclic or directional controls are moved.

(d) With the helicopter trimmed in steady level flight at 40 knots under power-operated control system failure conditions, it shall be possible without retrimming to make a normal landing approach and landing with control forces not exceeding the limits given in 3.5.8 (a)(2).

(e) Engine failure or electrical system failure, or both, shall not result in primary power-operated control system failure.

(f) Power-operated control system failure shall not result in failure of the trim systems.

(g) For helicopters having two or more completely independent power-operated control systems, the requirements of 3.5.8(a) shall be met upon failure of one of the complete systems during the period of transfer from one system to another. With the remaining system or systems, 3.5.8(b) shall apply and the rates of control motion attainable shall be such that safe operation of the helicopter is in no way compromised, and shall in no case be less than 50 percent of the normal rates. In such operations, including the approach and landing specified in 3.5.8(d), the control forces stated in 3.5.8(a)(2) shall be considered an absolute maximum, and it is desired that these forces be considerably lower.

MIL H-8501A Requirement

3.5.9 Automatic stabilization and control or stability augmentation equipment, or both, may be employed to meet all of the above requirements of section 3, provided that suitable separate requirements for system reliability are met. If such equipment is employed, the following conditions shall be met:

(a) With the automatic stabilization and control or stability augmentation equipment or both engaged, and from steady level flight for a period greater than 30 seconds, out-of-trim conditions resulting from abrupt complete disengagement or from abrupt complete failure of the equipment shall be such that with controls free for 3 seconds following the disengagement or failure, the resulting rates of yaw, roll, and pitch shall not exceed 10 degrees per second and the change in normal acceleration shall not exceed $\pm \frac{1}{2}$ g. When engaging the automatic stabilization and control or stability augmentation equipment, there shall be no apparent switching transients.

(b) For helicopters employing completely independent dual automatic stabilization and control or dual stability augmentation equipment, or a completely independent combination of both, the requirements of 3.5.9(a) shall be met upon the failure of one complete system during the period of transfer from one system to another, but need not be met for a simultaneous failure of both.

(c) It shall be possible on the ground, with the automatic stabilization and control or stability augmentation equipment or both operating and engaged to move the controls manually to all limits without exceeding the forces of table II. For helicopters with power-operated controls, this requirement shall apply also with rotor stopped.

(d) Helicopters employing automatic stabilization and control or stability augmentation equipment or both shall possess a sufficient degree of stability and control with all the equipment disengaged to allow continuation of normal level flight and the manuevering necessary to permit a safe landing under visual flight conditions.

(e) In cases where automatic stabilization and control or stability augmentation devices, or both, are used to compensate for divergent tendencies of the basic airframe, a considerable margin of control power beyond that needed to overcome airframe instability under simple flight conditions shall be provided. For this purpose, sufficient control margin over the amount required to perform maneuvers and to accomplish stability augmentation shall be provided. Specifically for pitch, roll, and yaw control, the augmentation system in combination with pilot controlled inputs shall not utilize more than 50 percent of the available control moment in the unstable direction from the trim position for straight level flight at a given speed when performing the following maneuvers:

MIL H-8501A Requirement

(1) Steady level-flight turn at cruise speed to maximum load factor attainable in actual operation, or the design or placard load factor, whichever occurs first.

(2) Steady sideslips in both powered and autorotative flight at the combinations of speed and sideslip angle set forth in 3.3.9.

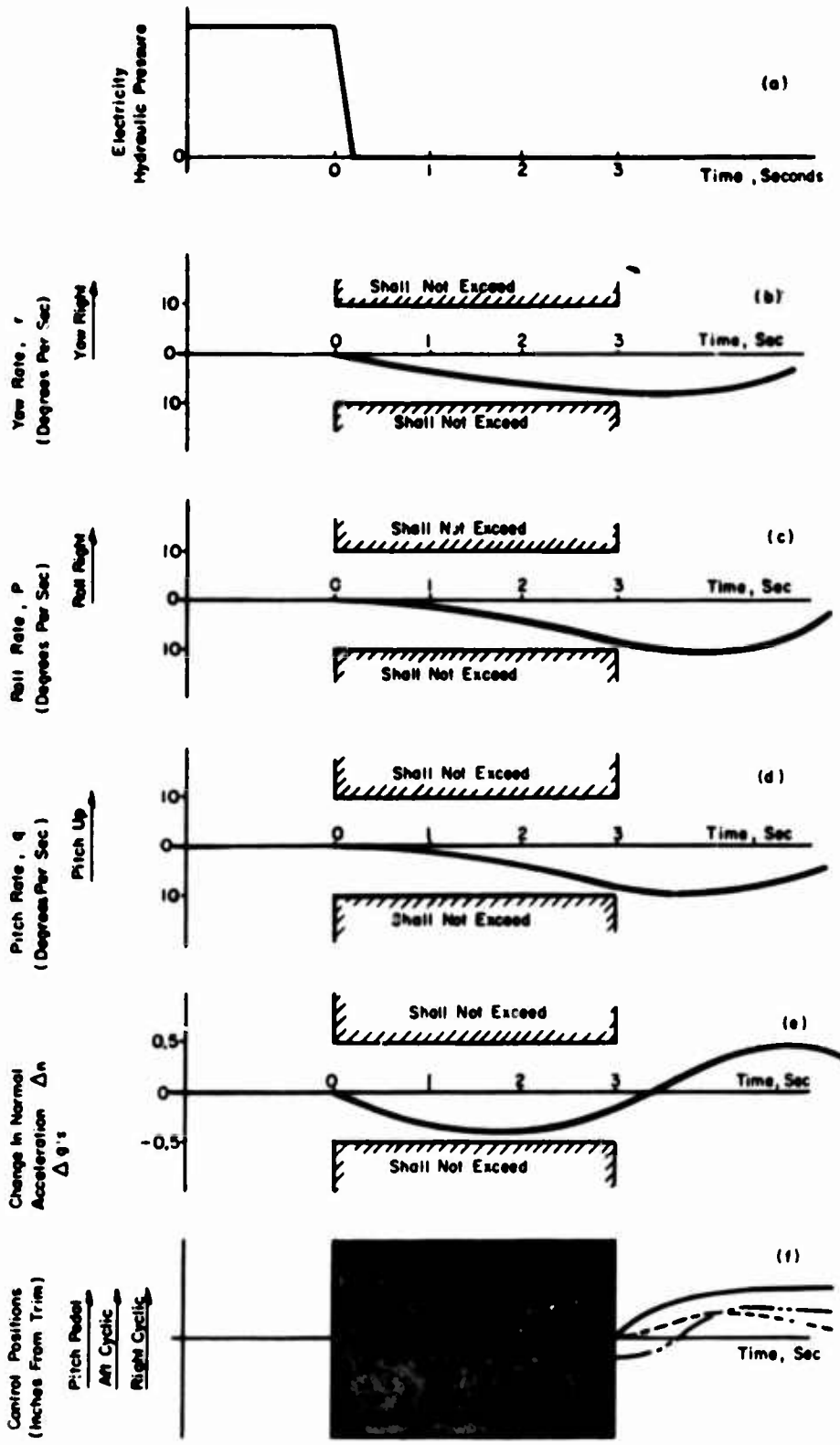
Figure 29 Power Boosted Control and Automatic Stabilization System Failures

Reference: Paragraphs 3.5.8(a)(1), 3.5.8(f), 3.5.8(g) and 3.5.9

This set of figures depicts the characteristics of the helicopter following a sudden power boosted control system failure and a failure or disengagement of the automatic stabilization equipment (Stability Augmentation System, SAS).

For helicopters employing power boosted control systems, a sudden power failure, shown in (a) may not create yaw, pitch or roll rates greater than 10 degrees per second for 3 seconds; the rates are shown in (b), (c) and (d). Furthermore, the normal acceleration is limited to ±1/2 g's, which is shown in (e). During the 3-second time interval, the controls must remain free; this is pictured in (f). Note that the rudder pedals are shown to be wandering during the 3 seconds; if this occurs, the controls must still remain free.

The same limits of excursions are set for a SAS failure, only the a priori condition is to maintain trimmed level flight for at least 30 seconds, whereas the initial condition for the control system boost failure is just trimmed level flight. Trimmed level flight at any speed includes the extreme rearward and sideward speed and hovering.



NOTES:

1. For single power boost system failure
2. For transfer to altenate power boost system
3. Trimmed level flight at any speed
4. Trim system shall not fail when boost fails
5. For automatic stabilization and/or control failure or disengagement
   a. From trimmed level flight of at least 30 seconds.
   b. For transfer to alternate automatic system

Figure 29 Power Boosted Control and Automatic Stabilization System

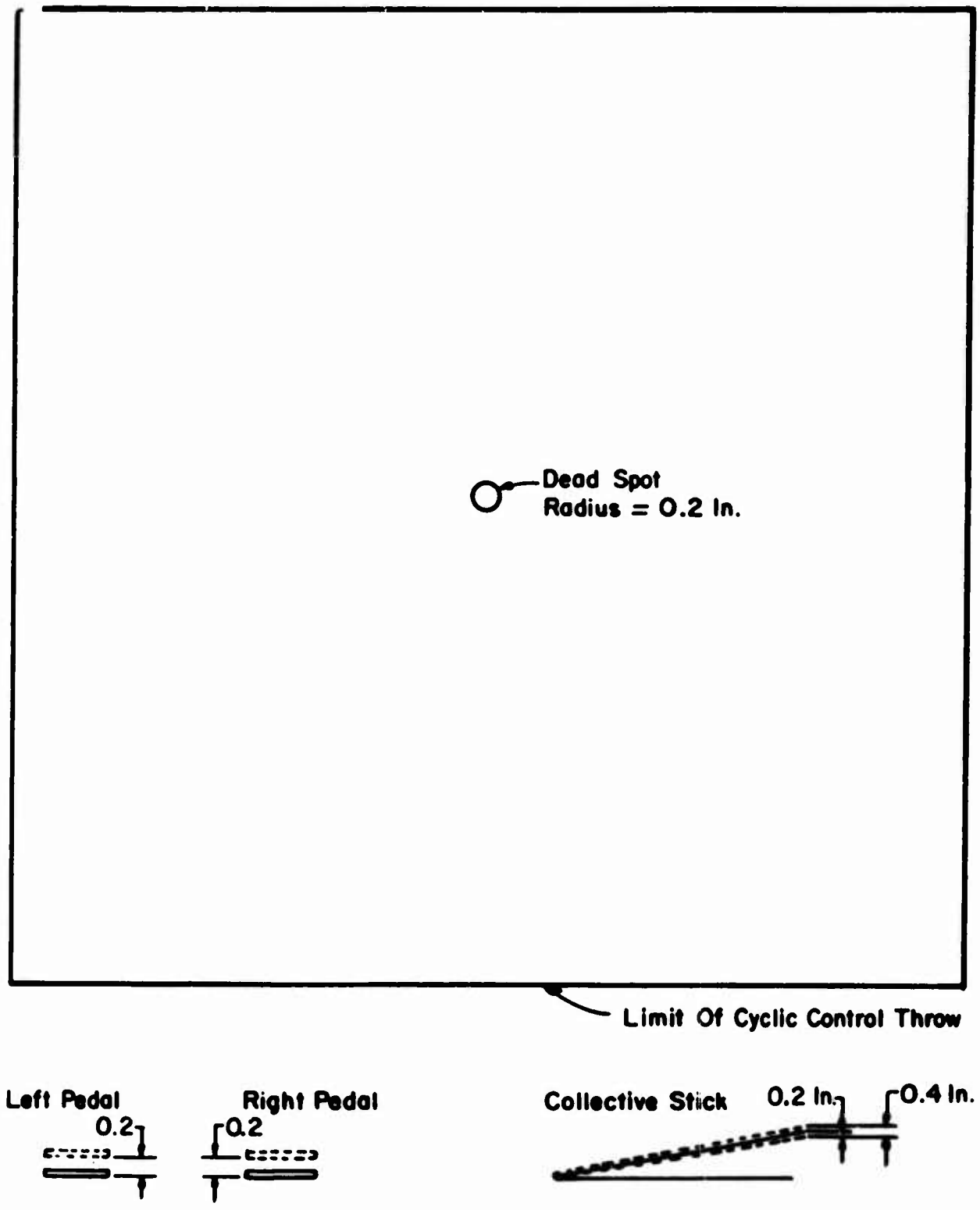
MIL H-8501A Requirement

3.5.10 For all operating conditions, there shall be no dead spots in any of the control systems which permit more than ± 0.2-inch motion of the cockpit control without corresponding motion of the rotor blades, control surfaces, etc.

Figure 30 Control System Dead Spots

Reference: Paragraph 3.5.10

A pictorial representation of MIL-H-8501A requirements shows the dead spots in the control stick and pedals. These dead spots can occur from any reference point throughout the total throw of the control. For a definition of how these spots are measured, see the Rotorcraft section of AFSCM 80-1 HIAD.



NOTES:

1. Dead spot no larger than ±0.2 inches
   a. For all operating conditions

Figure 30. Control System Dead Spots

MIL H-8501A Requirement

3.6.1.1 For any helicopter required to operate under instrument or all-weather conditions, the following control power and angular velocity damping requirements shall apply in hovering:

	Angular displacement at end of 1 sec. for a rapid 1-inch control displacement-degrees	Angular velocity damping ft-lbs/rad/sec.
Longitudinal	$\frac{73}{3\,W + 1000}$	$15\,(I_y)^{0.7}$
Directional	$\frac{110}{3\,W + 1000}$	$27\,(I_z)^{0.7}$
Lateral	([1])	$25\,(I_x)^{0.7}$

[1] The lateral requirement is based on the angular displacement at the end of one-half second following a control displacement and for a 1-inch control displacement shall be at least $\frac{32}{3\,W + 1000}$ degrees displacement in the first one-half second. For full available displacement of the controls from trim, the values of angular displacement specified above shall be multiplied by 4 for longitudinal and 3 for lateral and for directional values.

Figures 31a, 31b, 31c and 31d Longitudinal, Lateral and Directional Hover Control Powers (IFR)

Reference: Paragraph 3.6.1.1

These figures are the requirements for IFR hover control powers for one inch and full control inputs. Figure 31(a) shows the helicopter gross weight versus angular displacement for a 1-inch control input for the longitudinal, lateral and directional axes. The absissa is for the pitch and yaw angles in the first second and roll angle in the first half second. The helicopter must exhibit angular displacement characteristics such that the angle is equal to or greater than the associated hashed curve. Angular displacements resulting from a full control input are not shown in this figure; however, it is a relatively simple task to calculate them by use of the following relationships:

$$(\theta_1)_{fc} = 4.0\ (\theta_1)_{1\ in.}$$

$$(\phi_{\frac{1}{2}})_{fc} = 3.0\ (\phi_{\frac{1}{2}})_{1\ in.}$$

$$(\psi_1)_{fc} = 3.0\ (\psi_1)_{1\ in.}$$

where fc stands for full control input and 1 in. means one inch control input. The value of a displacement from a one inch input is found from figure 31 (a) and multiplied by the appropriate integer.

Figure 31 (b), (c) and (d) are the relationships between the control power and the damping that yield the required angular displacement. These figures are useful when the characteristics of the second order equation are presented. but the solution is not shown. It is then a simple matter to use the control powers ($\frac{M_\delta}{I_{yy}}$, $\frac{L_\delta}{I_{xx}}$ And $\frac{N_\delta}{I_{zz}}$) damping ($\frac{D_y}{I_{yy}}$, $\frac{D_x}{I_{xx}}$ And $\frac{D_z}{I_{zz}}$) and gross weight parameter $\sqrt[3]{W+1000}$ seee appendix II).

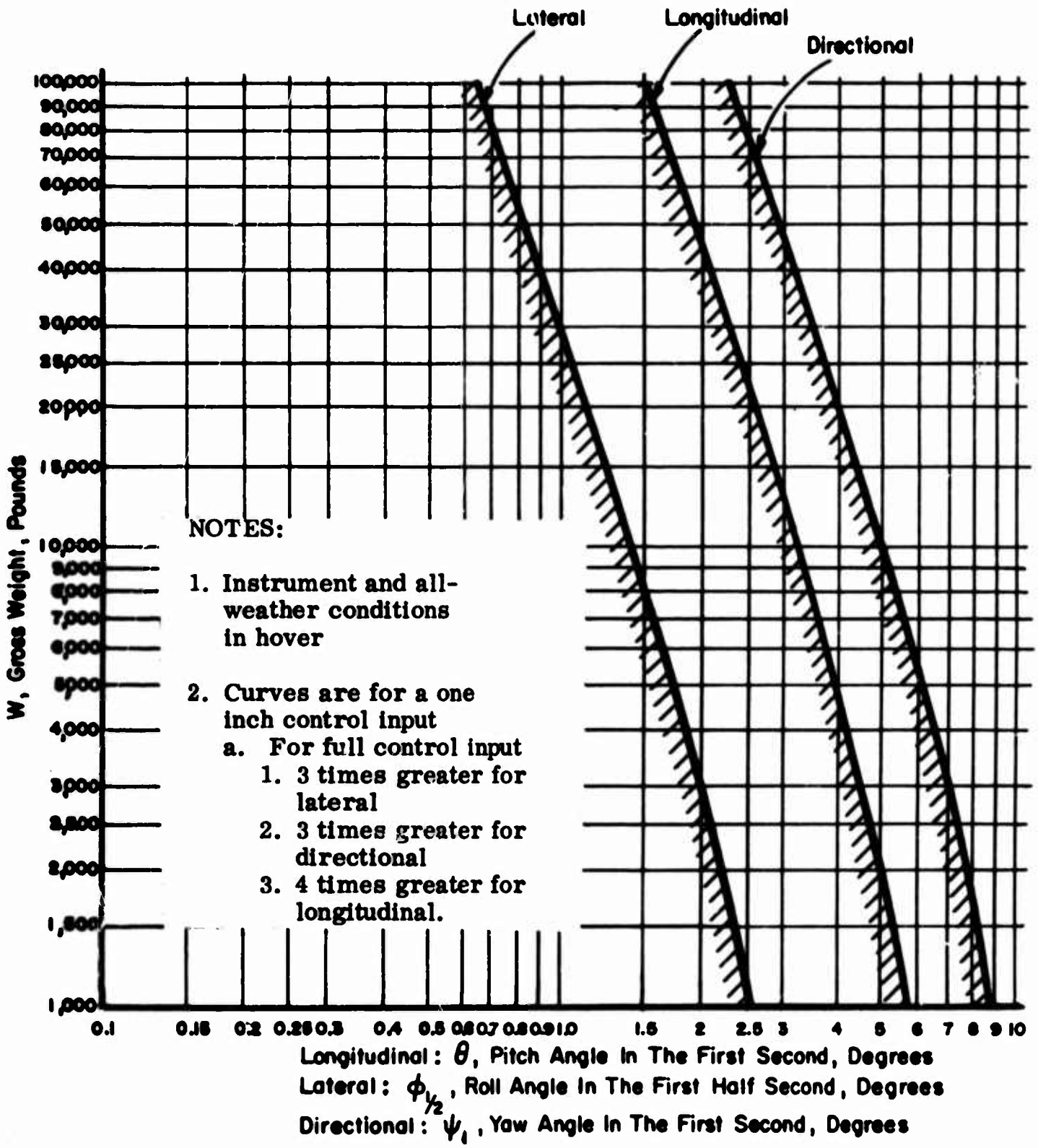


Figure 31a. Longitudinal, Lateral and Directional Control Powers (IFR)

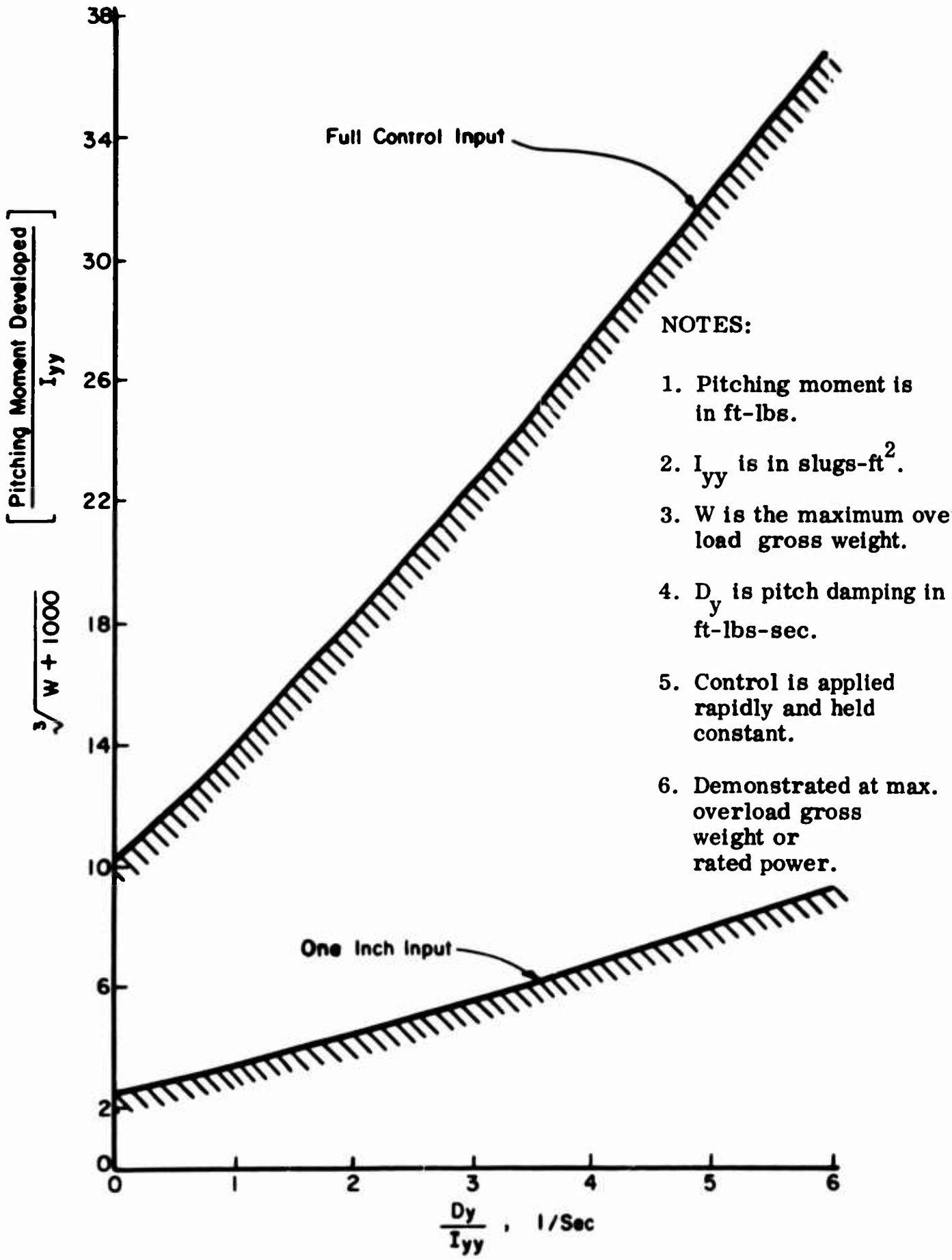
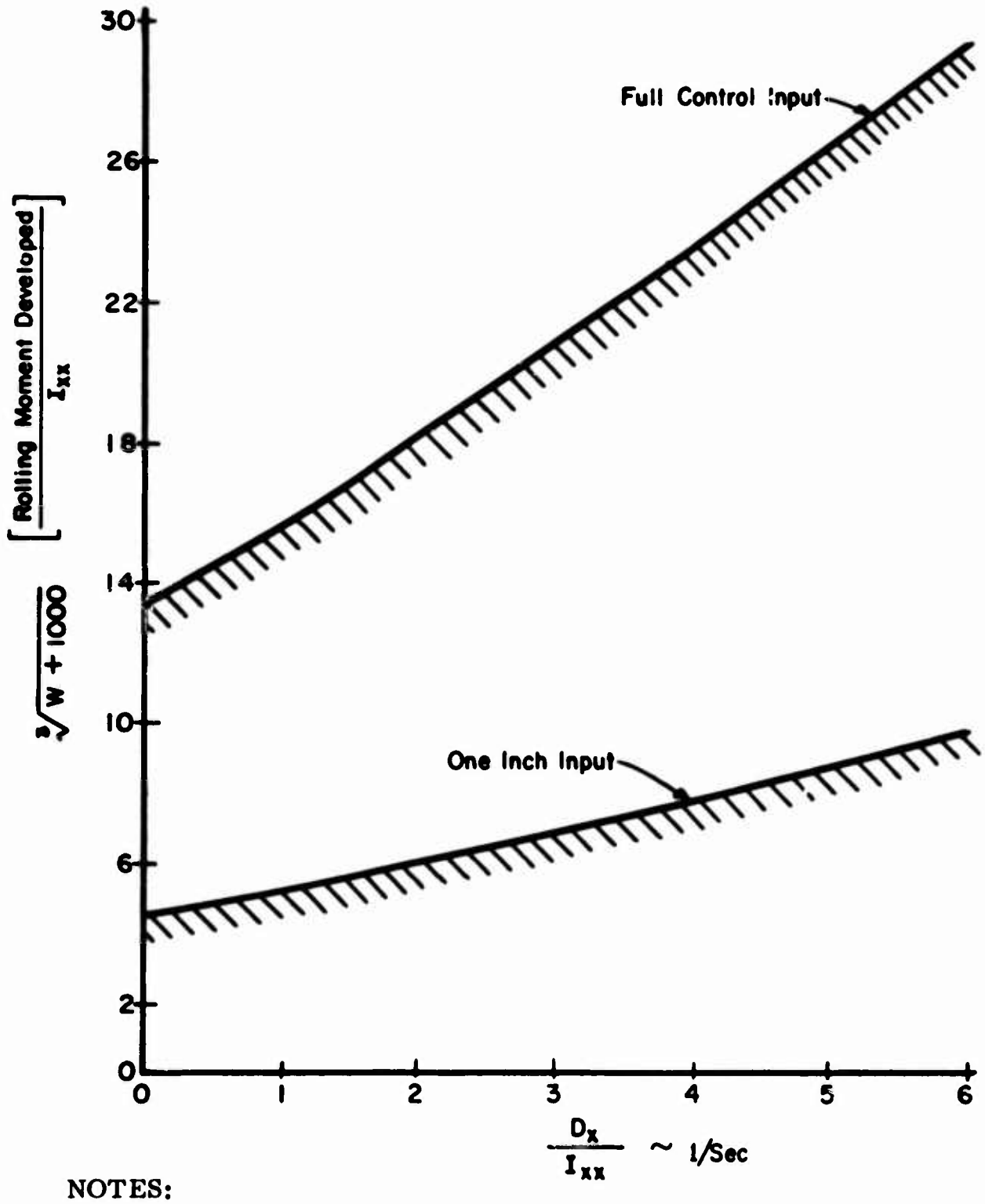


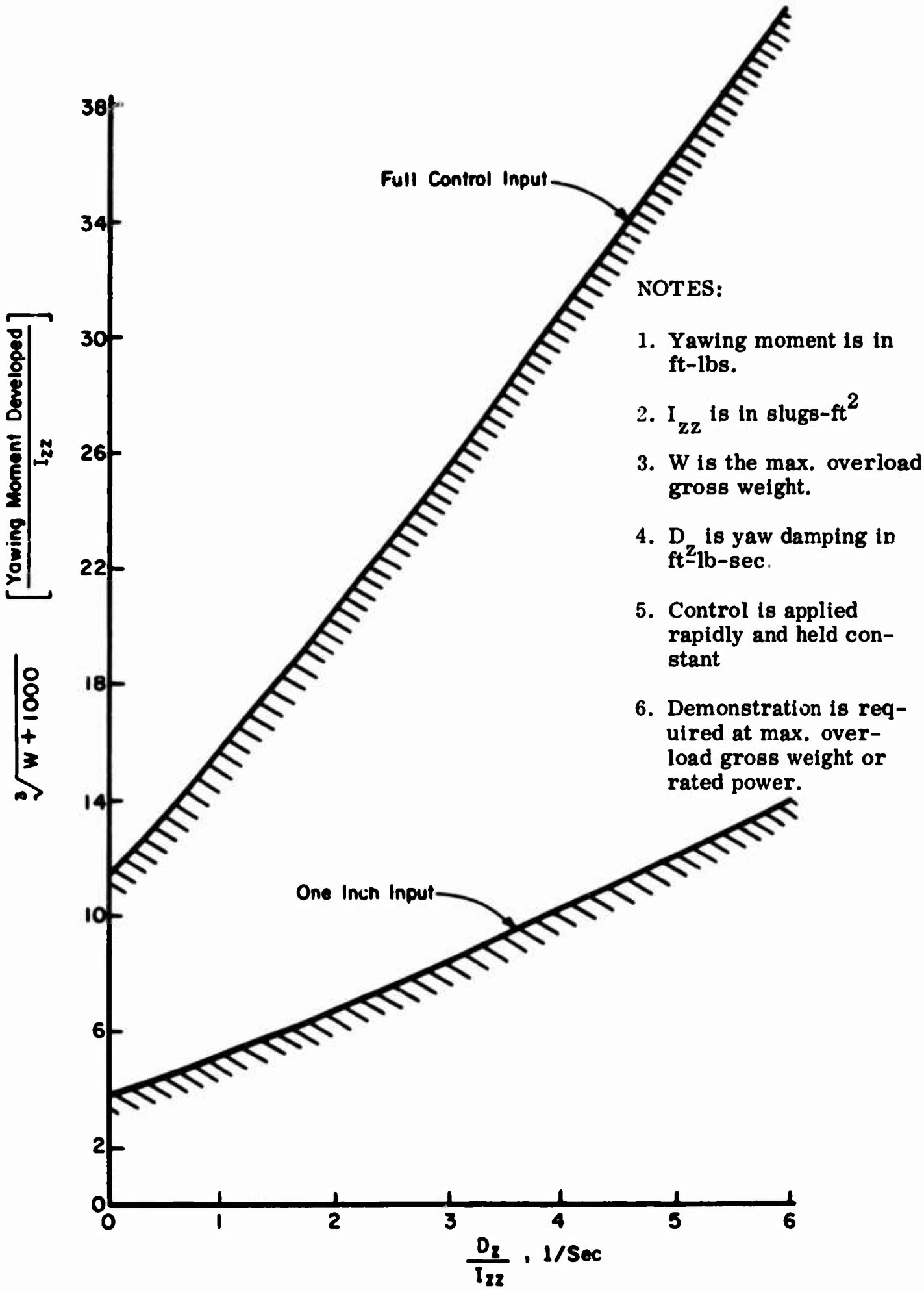
Figure 31b. Longitudinal, Lateral and Directional Control Powers (IFR)



NOTES:

1. Rolling moment is in ft-lbs.
2. I_{xx} is in slugs-ft^2.
3. W is the max. overload gross weight.
4. D_x is roll damping in ft-lb-sec.
5. Control is applied rapidly and held constant.
6. Demonstrated at max. overload gross weight or rated power.

Figure 31c. Longitudinal, Lateral and Directional Control Powers (IFR)



NOTES:

1. Yawing moment is in ft-lbs.
2. I_{zz} is in slugs-ft^2
3. W is the max. overload gross weight.
4. D_z is yaw damping in ft-lb-sec.
5. Control is applied rapidly and held constant
6. Demonstration is required at max. overload gross weight or rated power.

Figure 31d. Longitudinal, Lateral and Directional Control Powers (IFR)

Figures 32a, 32b and 32c Longitudinal, Lateral and Directional Moment of Inertia vs Damping; Hover

Reference: Paragraph 3.6.1.1

Plotted on figures 32 (a), (b) and (c) is a form of the damping seen in the table of paragraph 3.6.1.1. The actual value of the damping is not presented, but rather it is presented in a form unique to a second order differential equation, $\frac{D}{I}$, because this is the usual form in which the damping parameter is shown. If the actual value of the damping D is desired, simply multiply $\frac{D}{I}$ by the appropriate value of the inertia. As an example, assume the roll inertia of a helicopter is I_{xx} = 10,000 Slug-Ft. From figure 32(c),

$$\frac{D_x}{I_{xx}} = 1.572 \text{ / Rad-Sec}\,\theta$$

And

$$\frac{D_x}{I_{xx}} \cdot I_{xx} = D_x = 15{,}720 \frac{\text{Ft-Lbs}}{\text{Rad/Sec}}$$

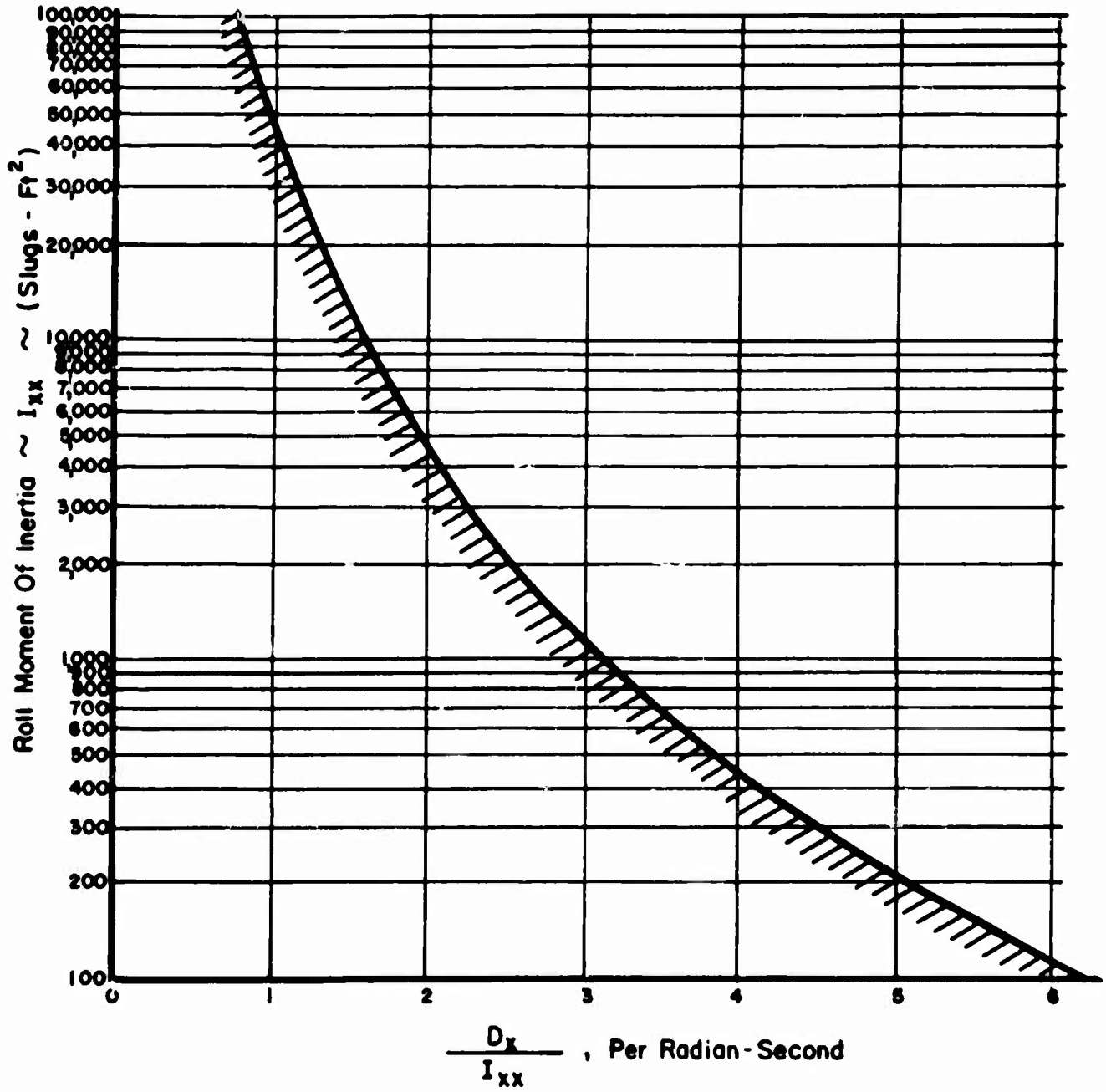


Figure 32a. Lateral Hover Damping

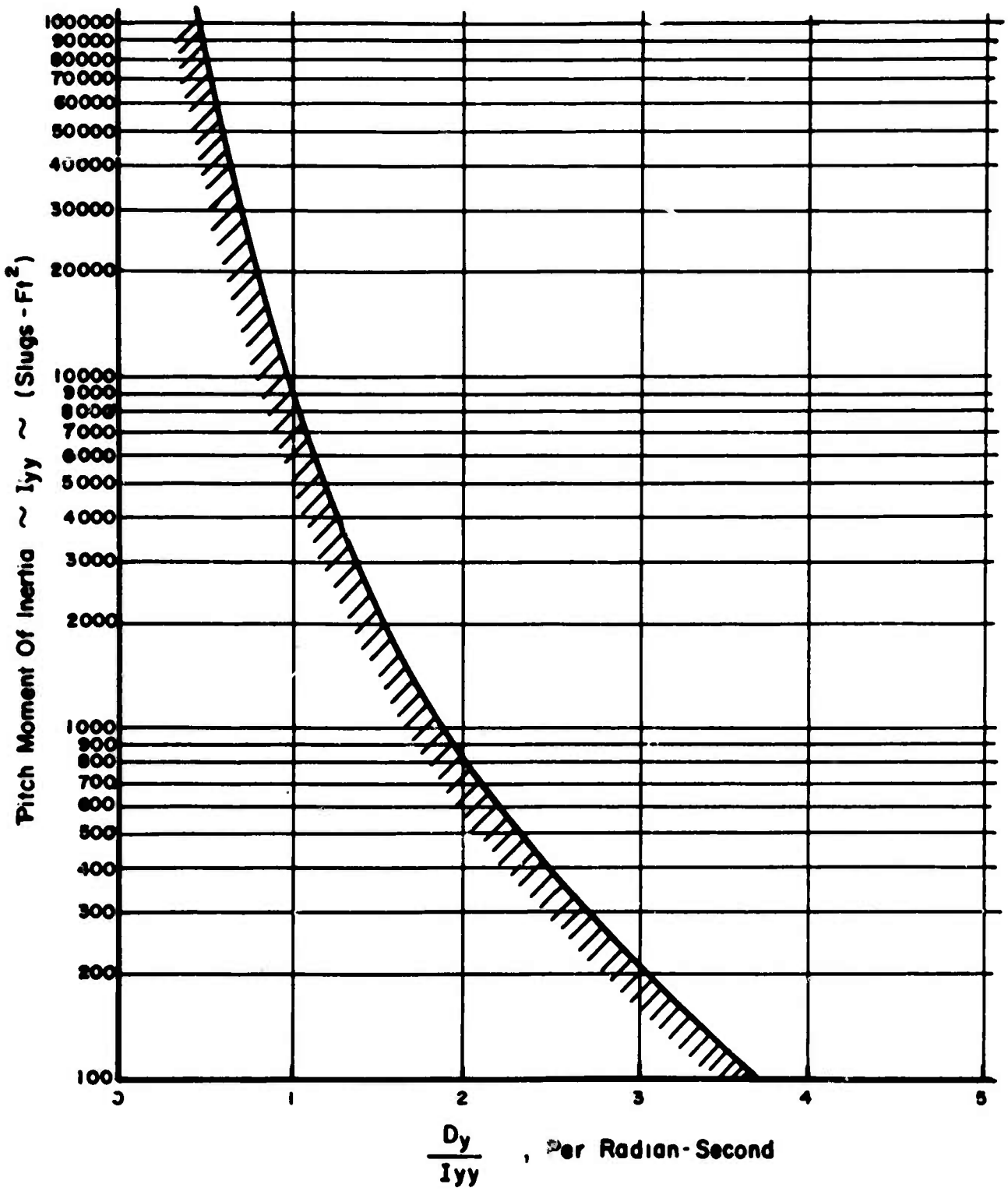


Figure 32b. Longitudinal Hover Damping

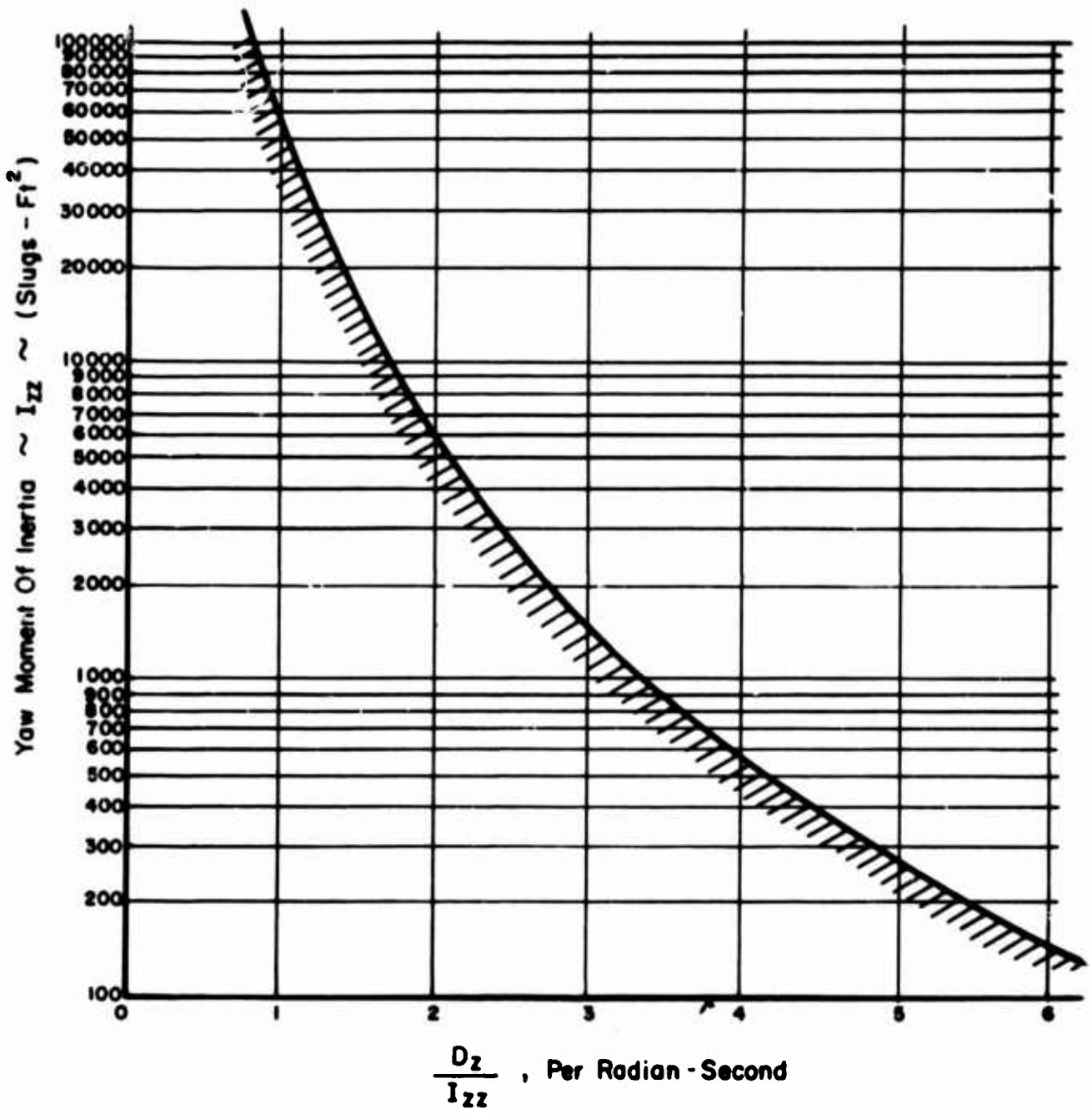


Figure 32c. Directional Hover Damping

MIL H-8501A Requirement

3.6.1.2 Longitudinal- and lateral-directional oscillations with controls fixed following a single disturbance in smooth air shall exhibit the following characteristics:

(a) Any oscillation having a period of less than 5 seconds shall damp to one-half amplitude in not more than one cycle. There shall be no tendency for undamped small amplitude oscillations to persist.

(b) Any oscillation having a period of less than 10 seconds shall damp to one-half amplitude in not more than 2 cycles. There shall be no tendency for undamped small oscillations to persist.

(c) Any oscillation having a period greater than 10 seconds but less than 20 seconds shall be at least lightly damped.

(d) Any oscillation having a period greater than 20 seconds shall not achieve double amplitude in less than 20 seconds.

Figures 33a, 33b and 33c Longitudinal and Lateral Directional Oscillatory Mode Damping in Forward Flight (IFR)

Reference: Paragraph 3.6.1.2

These figures depict the required damping of any dynamic oscillatory modes during forward flight. The requirement stated in terms of cycles to damp to a specified amplitude is broken down to show damping ratio versus the damped period of the oscillation. Figure 33 (a) is for oscillations with periods less than 30 seconds and (b) is for periods greater than 20 seconds.

If the data are presented in terms of cycles to half amplitude, it is a relatively simple task to determine if the helicopter complies just by checking the numerical value of the requirement in paragraph 3.6.1.2 of MIL-H-8501A. If the data are presented in terms of ζ , figures 33(a) and (b) can be used. If the data are presented as dynamic traces of the mode, the damping can be determined by use of part II of this appendix. Part II can also be used to convert $C_{1/2}$ to ζ if it is desired to plot the helicopter's damping on figure 33.

Figure 33(c) presents the requirement in terms of the complex plane.

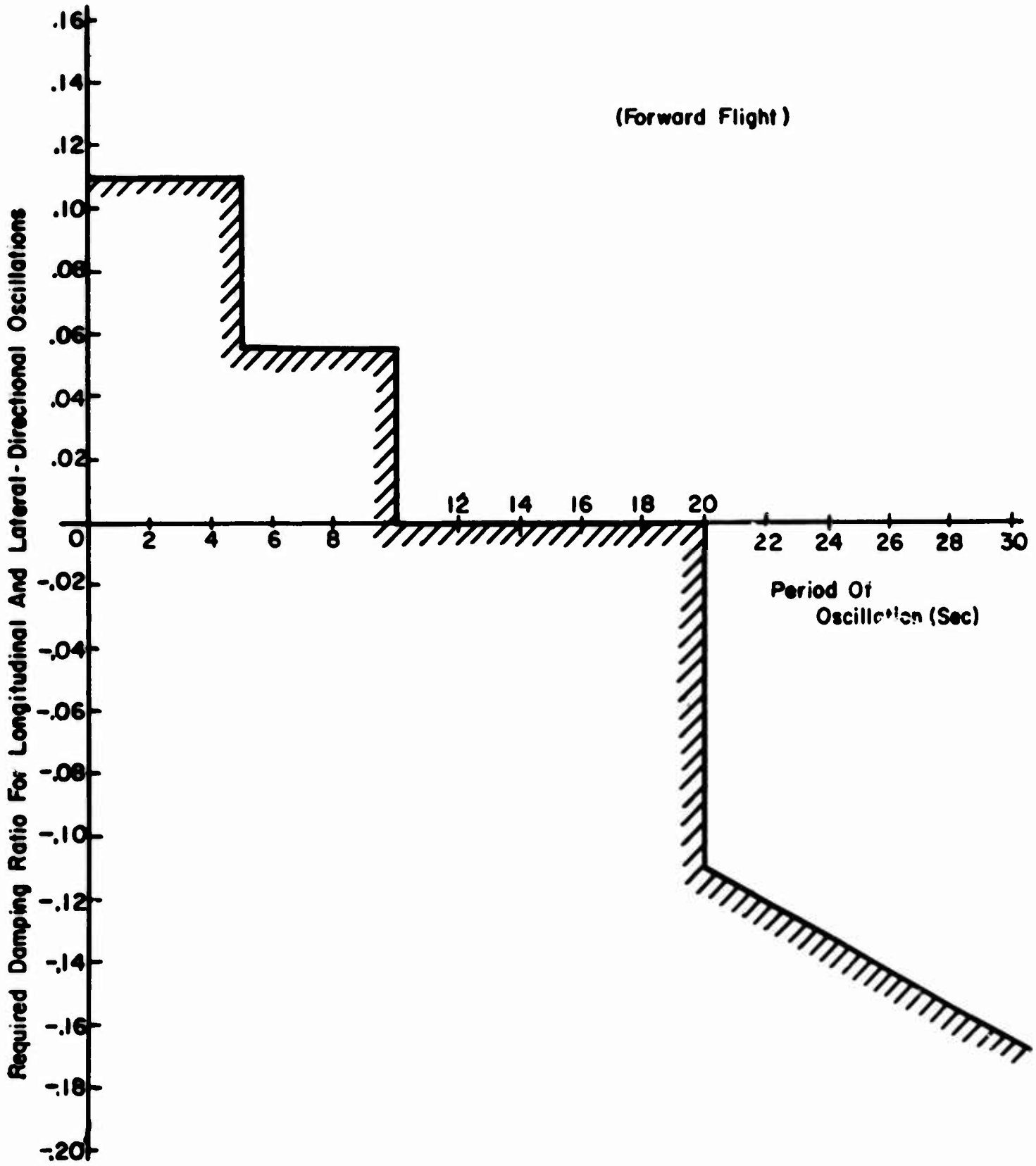


Figure 33a. Damping in Forward Flight, Damping Ratio vs Period

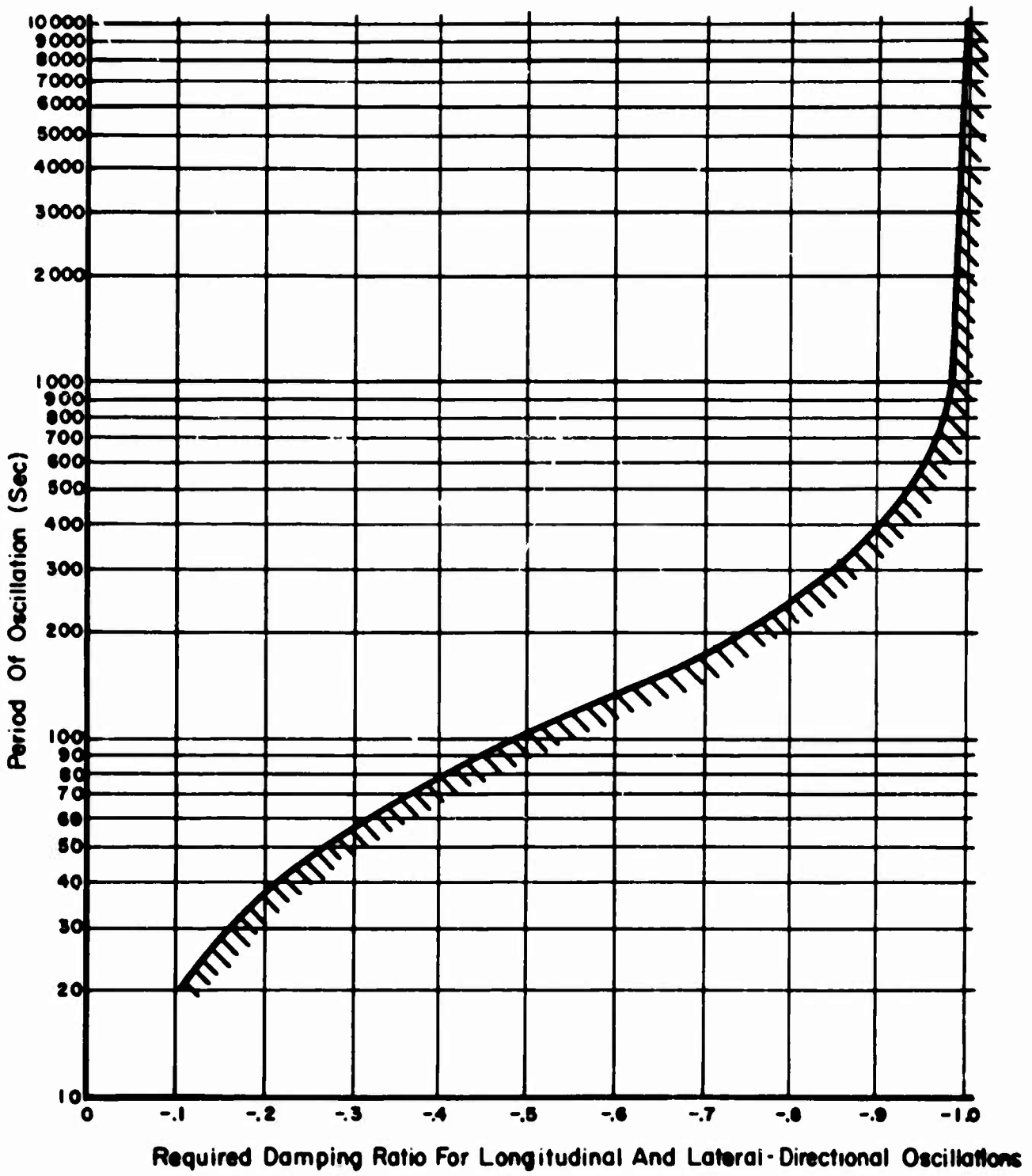


Figure 33b. Damping in Forward Flight, Period vs Damping Ratio

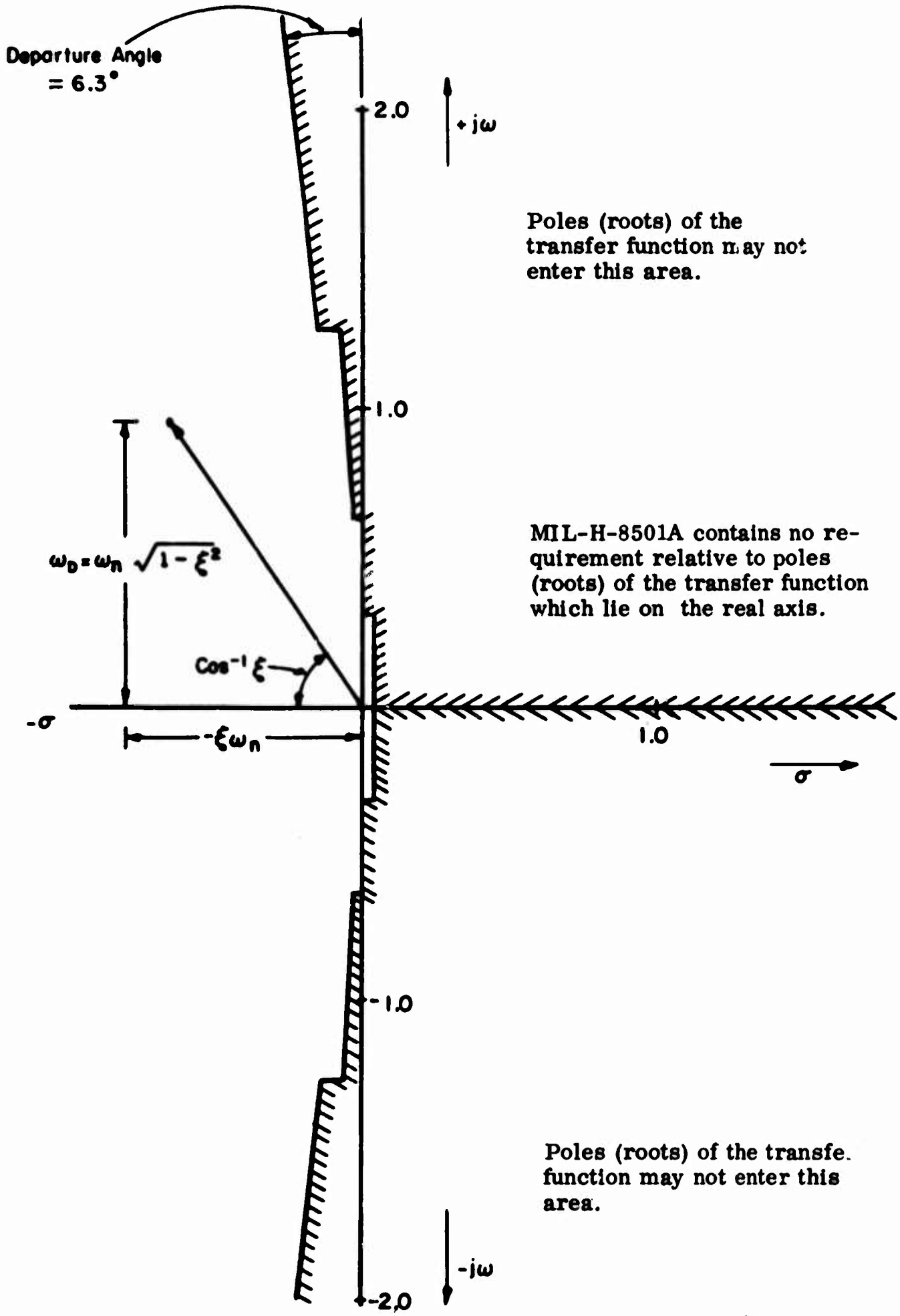


Figure 33c. Root Locus Representation of Longitudinal and Lateral Directional/Damping in Forward Flight IFR.

Appendix I

Forward Flight Damping Ratio

20. Figures 34(a), (b), (c) and (d) are not graphical representations of the requirements of MIL-H-8501A but are used to reduce data to check if the helicopter complies with the dynamic stability requirements, both VFR and IFR. The dynamic stability requirements are seen in 3.2.11 and 3.6.1.2 and are represented by figures 6 and 33 respectively.

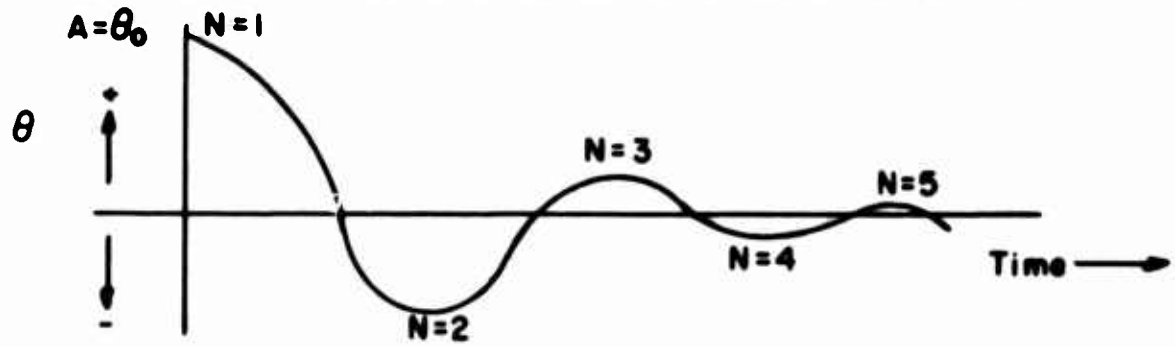
20.1 Figures 34a, 34b, 34c and 34d present R_m vs ζ

20.1.1 If dynamic trace data are available, the damping ratio of the mode of motion can be obtained by figures 34a through 34d. The method entails calculating the ratio of the amplitudes (R_m) of the peaks and by use of

$$R_m = \frac{A_{n+2}}{A_n}$$

where A is the amplitude of a particular peak and n is the peak number. The aforementioned figures are entered and the damping ratio (ζ) is found.

20.1.2 To illustrate the symbols and method, consult the sketch:



It can be seen that θ_0 is an amplitude, A, of a peak, n, which is the first peak; thus $A_n = A_1$, where n = 1. Now n + 2 = 1 + 2 = 3 so $A_{n+2}=A_3$, or the amplitude of the third peak; thus

$$Rm = \frac{A3}{A1}$$

for this case. Note that any peak could have been numbered 1, as long as the numerator is the n + 2 peak.

20.1.3 The above sketch depicts a dynamically stable mode, i.e., $\zeta > 0$, so figure 34a or 34b will yield the correct damping ratio. If the motion is dynamically unstable oscillatory motion with amplitude increasing with time). $\zeta < 0$ and figures 34c or 34d will yield the correct damping ratio.

20.2 Figures 35a and 35b present $C_{1/2}$ or C_2 vs ζ

20.2.1 In certain instances the dynamic stability data may be presented in the form of a number of cycles to some fraction of the amplitude. The damping data then takes the form $C_{1/2}$, C_2, $C_{1/10}$ or C_{10}.

$C_{1/2}$ = Cycles to 1/2 amplitude

C_2 = Cycles to double amplitude

$C_{1/10}$ = Cycles to 1/10 amplitude

C_{10} = Cycles to ten times the amplitude

If the data are presented in this form figures 35a and 35b facilitate calculation of the damping ratio, ζ, for use in figures 6 and 33, which are the damping ratio vs period representation of the dynamic stability requirements of the specification

20.2.2 To illustrate the use of the figures, suppose the data are presented as:

$$C_{1/10} = 0.48$$

so, from the noted relationship on the figures,

$$C_{1/10} = 3.322\, C_{1/2}$$

thus

$$C_{1/2} = \frac{0.48}{3.322} = 0.1445$$

and from figure 35a,

$$\zeta = 0.61$$

Note that if the cyclic data are in C_2, or C_{10}, the same relationship holds as for $C_{1/2}$ and $C_{1/10}$, except that the damping ratio is negative.

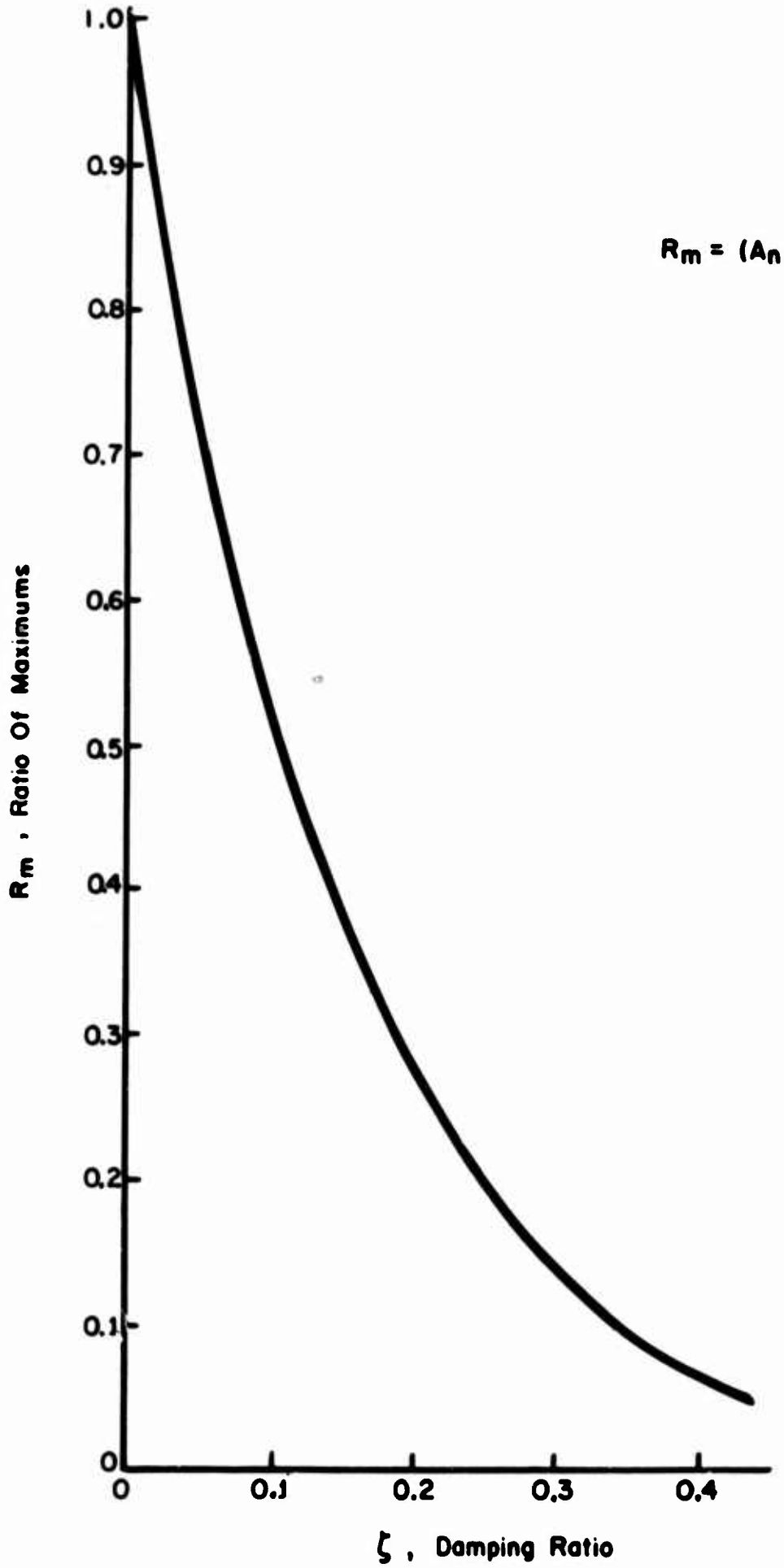


Figure 34a. Damping Ratio vs Ratio of the Maximums

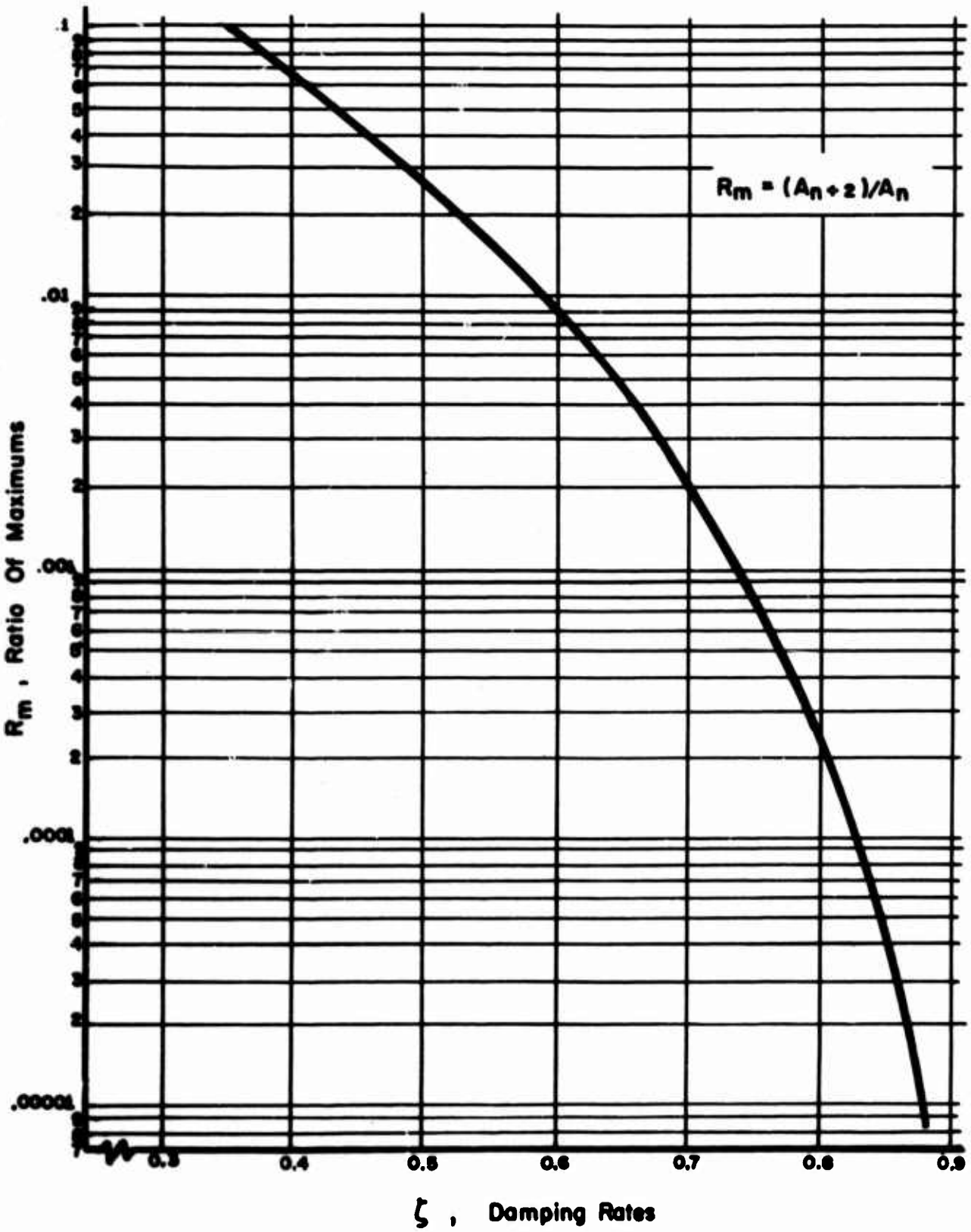


Figure 34b. Damping Ratio vs Ratio of the Maximums

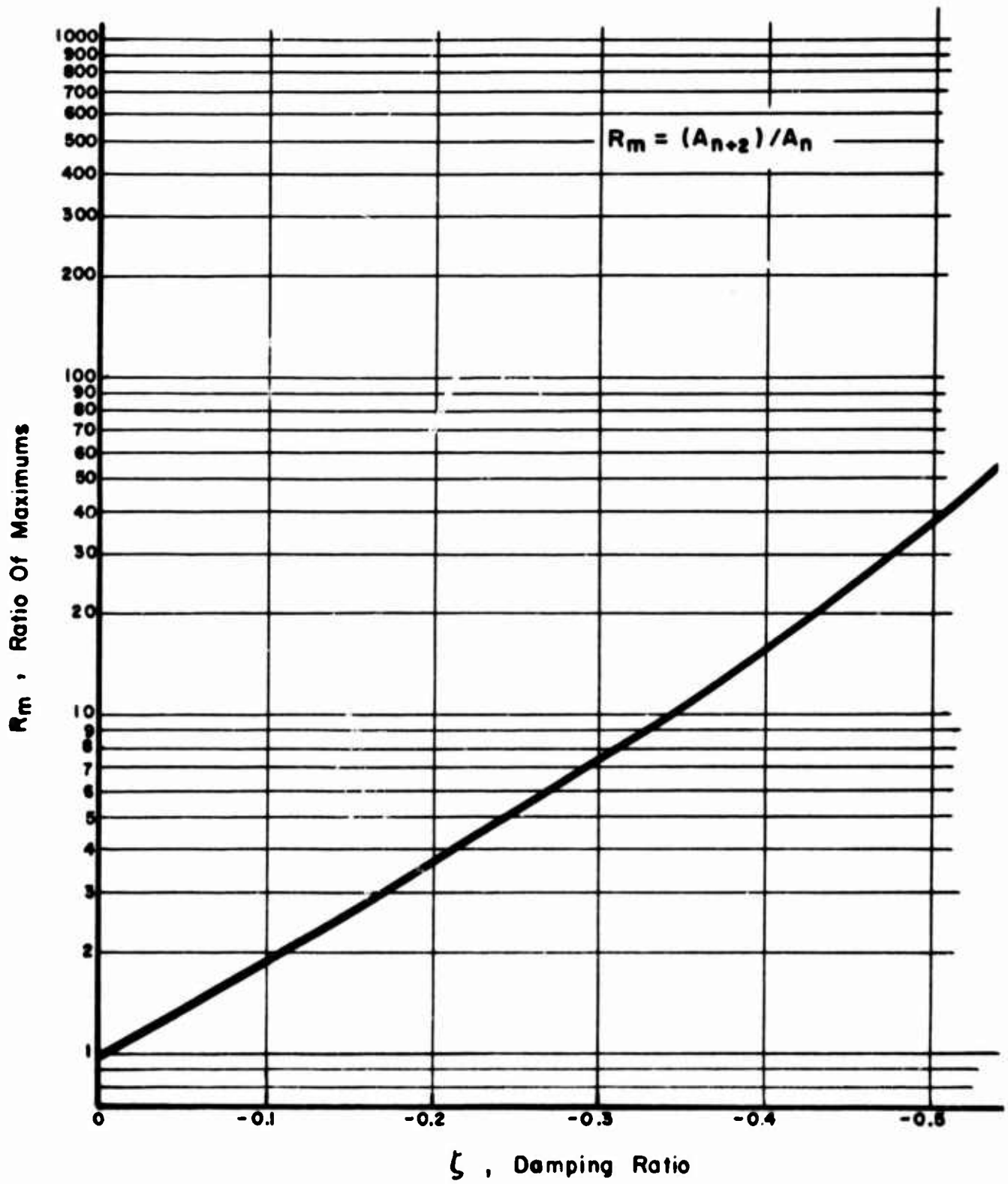


Figure 34c. Damping Ratio vs Ratio of the Maximums

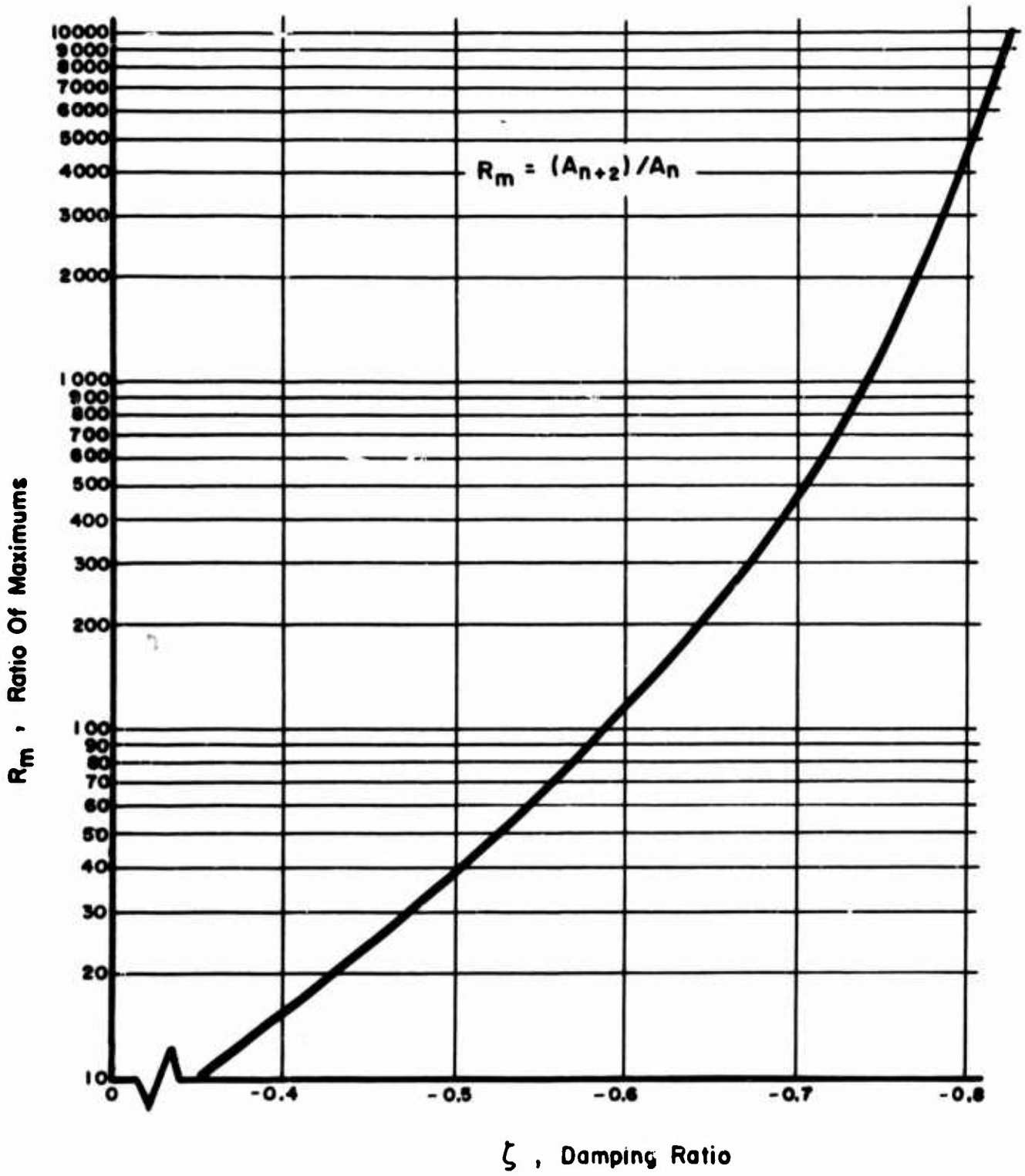
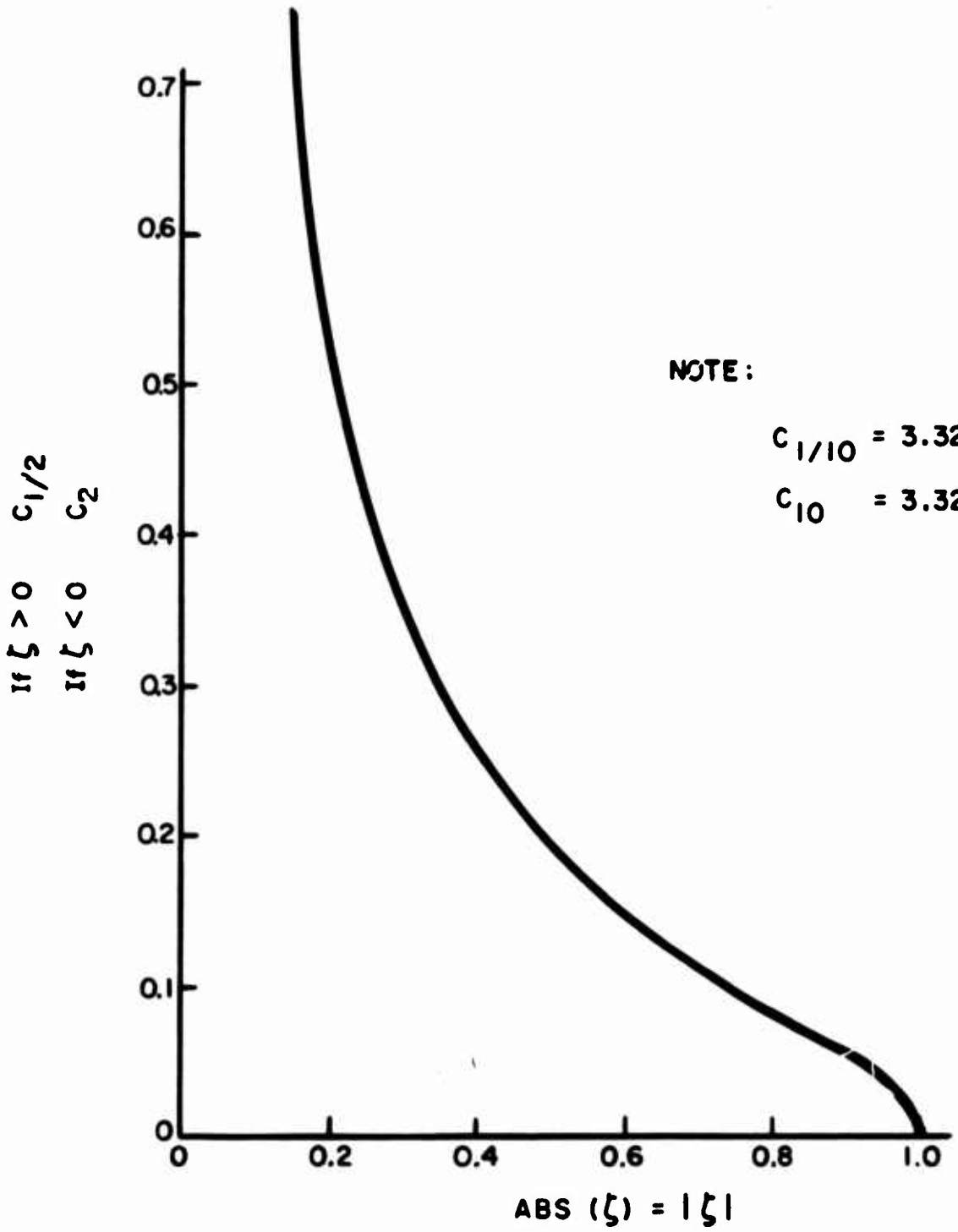


Figure 34d. Damping Ratio vs Ratio of the Maximums



NOTE:

$C_{1/10} = 3.322\ C_{1/2}$

$C_{10} = 3.322\ C_2$

Figure 35a. Damping Ratio vs Cycles to One Half or Double Amplitude

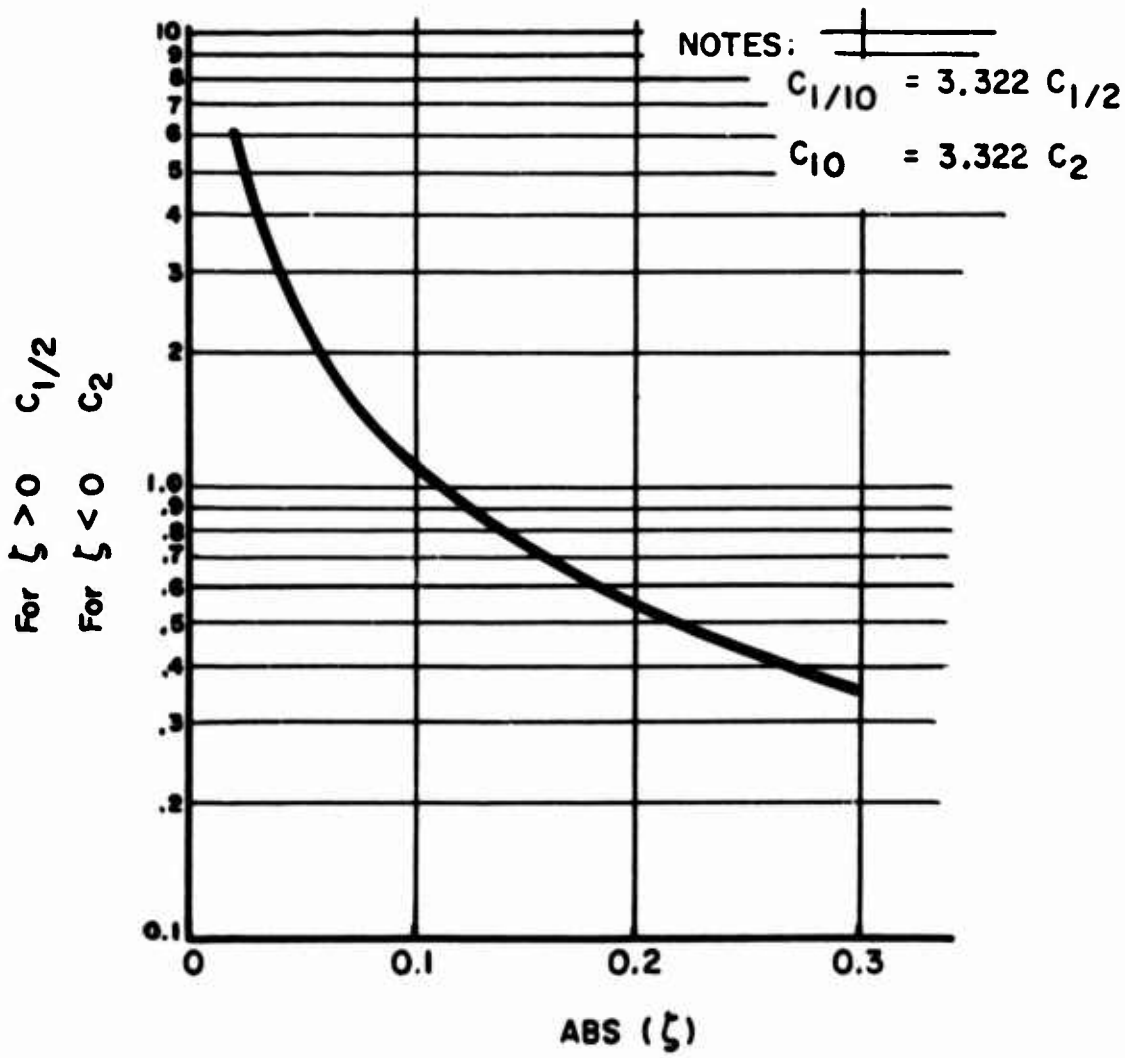


Figure 35b. Damping Ratio vs Cycles to One Half or Double Amplitude

Calculation of Hover Damping and Gross Weight Parameter

30. The figures in this section are to aid in determining the damping of a particular mode during hover and aid calculation of the gross weight parameter, $\sqrt[3]{W+1000}$ To calculate the hover damping, the required data are a trace of the mode acceleration from a rapid step type input. From this dynamic trace, two values are needed, the maximum acceleration and the acceleration 1 second after the maximum. The ratio of the latter to the former is calculated and this value is entered on the ordinate axis of figure 36a. This value is extended across to the line and then projected down to yield the value of the damping parameter, $\frac{D}{I}$

This figure can be used for any axis; it is shown for the longitudinal axis only to illustrate the symbols and usage.

30.1 Figure 36a is based on the solution to a second order differential equation responding to a step input. No artificial attitude stabilization is included in the solution as the amount and type of such stabilization is a function of the stability augmentation system employed on a helicopter.

30.2 Figure 36b is for calculating $\sqrt[3]{W+1000}$; enter with the actual weight plus 1000 and read the gross weight parameter off the abscissa.

$$\frac{M_P}{I_{yy}} = \frac{\text{Pitching Moment Developed (ft-lbs)}}{\text{Pitching Moment of Inertia (slug-ft}^2)} = \ddot{\theta} \text{ max developed } (\text{rad/sec}^2)$$

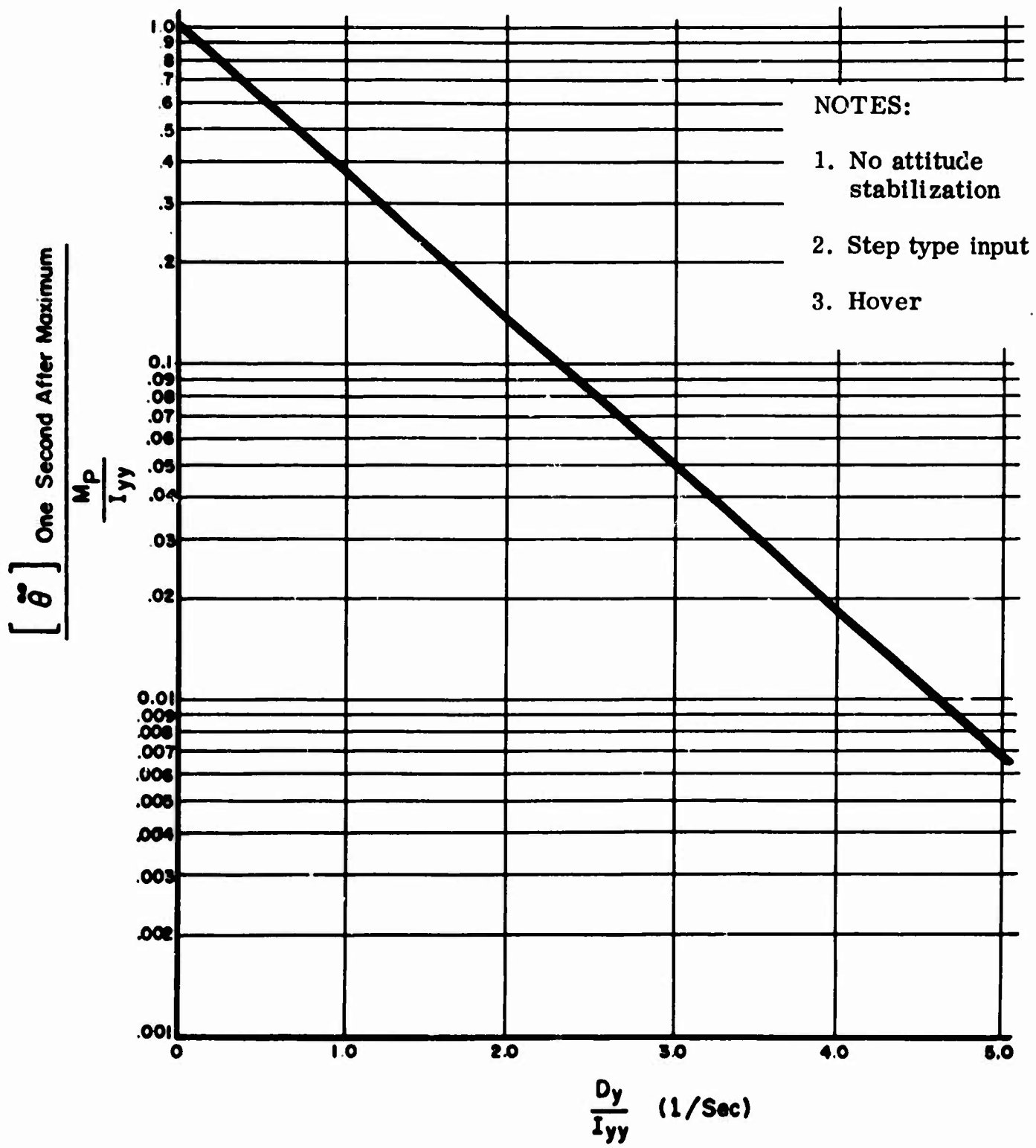


Figure 36a. Calculating of Hover Damping and Gross Weight Parameter

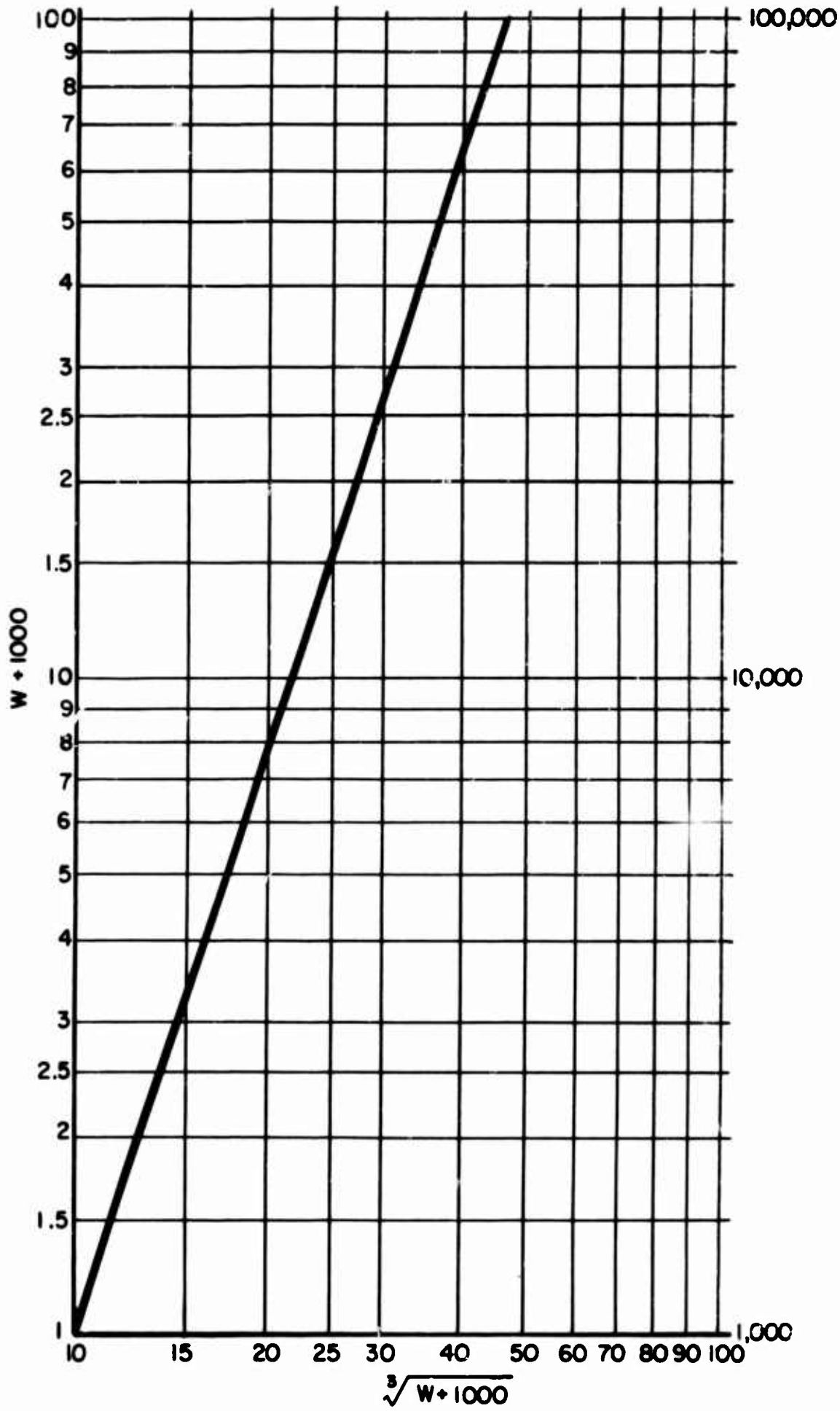


Figure 36b. Calculation of Hover Damping and Gross Weight Parameter