MAE - 275

DEFINITIONS

HANDLING QUALITIES

HANDLING QUALITIES (HQ'S) ARE THOSE QUALITIES OR CHARACTERISTICS WHICH DETERMINE THE EASE AND PRECISION WITH WHICH A PILOT CAN COMPLETE A TASK

THE FIRST MILITARY HANDLING QUALITIES SPECIFICATION

BEFORE ACCEPTANCE A TRIAL ENDURANCE FLIGHT WILL BE REQUIRED. . .DURING WHICH TIME THE FLYING MACHINE MUST REMAIN CONTINUOUSLY IN THE AIR WITHOUT LANDING. IT SHALL RETURN TO THE STARTING POINT AND LAND WITHOUT ANY DAMAGE. . .IT MUST BE STEERED IN ALL DIRECTIONS WITHOUT DIFFICULTY AND AT ALL TIME UNDER PERFECT CONTROL AND EQUILIBRIUM.

--- ADVERTISEMENT AND SPECIFICATION FOR A HEAVIER THAN AIR FLYING MACHINE

SIGNAL CORPS SPECIFICATION NO. 486, DEC. 23, 1907

A Succession of Military Handling Qualities Documents

Fixed-Wing Aircraft

1.) MIL-F-8785A

2.) MIL-F-8785B (1969)

3.) MIL-F-8787C (1980)

4.) MIL-STD-1797A (1990)

5.) MIL-STD-1797B (1997)

Fixed-Wing Documents Dropped in 2000 (approx)

V/STOL & Rotary Wing Aircraft

1.) MIL-H-8501A (1961)

2.) MIL-H-83300 (1970)

3.) ADS-33C (1989)

4.) ADS-33E (2000)

NASA TN D-5153

THE USE OF PILOT RATING IN THE EVALUATION OF AIRCRAFT HANDLING QUALITIES

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Moffett Field, Calif.

and

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Buffalo, N.Y.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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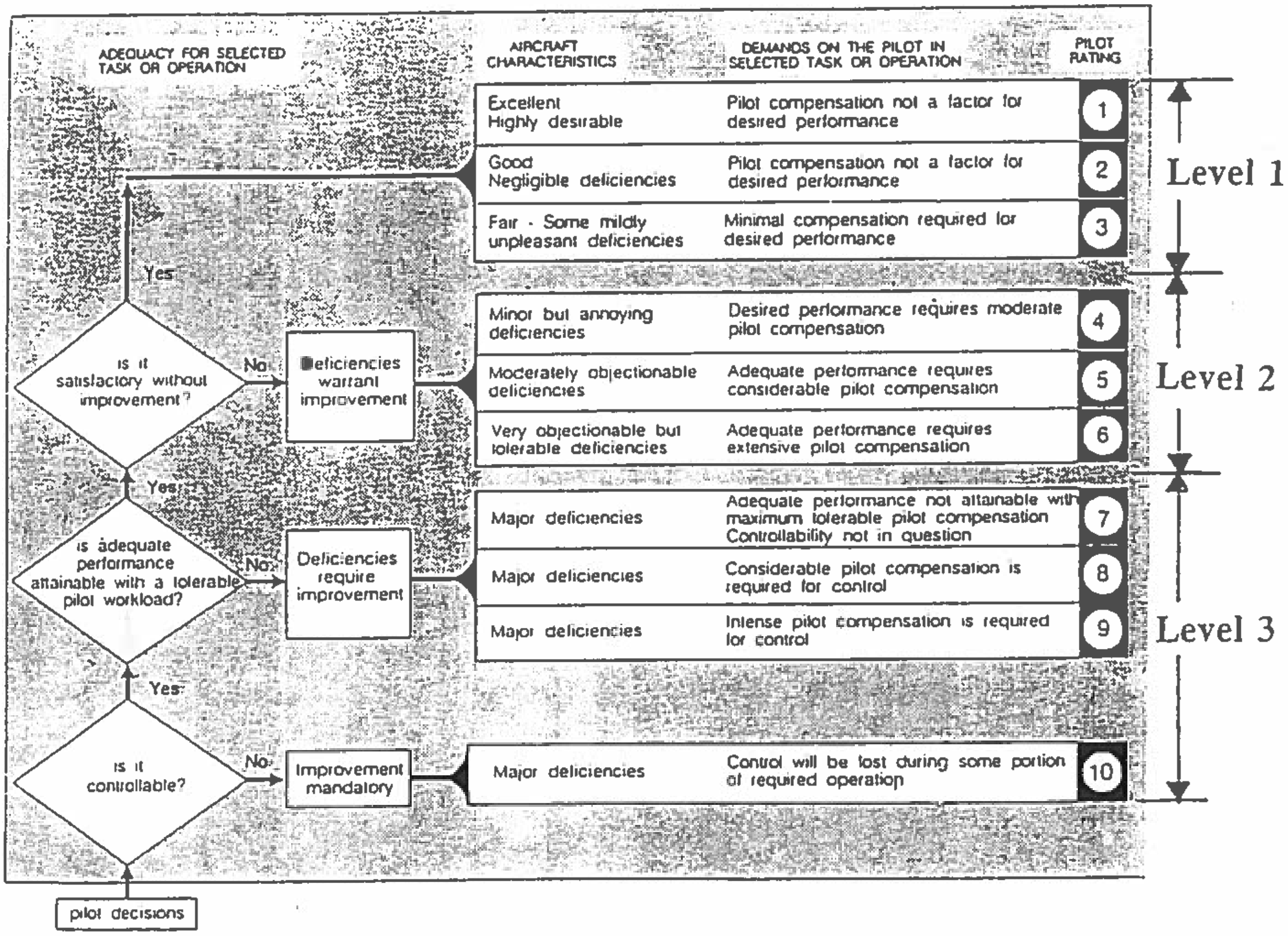


The Cooper-Harper handling qualities rating scale.

HANDLING QUALITIES LEVELS

DEFINITIONS

LEVEL 1:

$$1 < \text{COOPER HARPER} \leq 3.5$$

LEVEL 2:

$$3.5 < \text{COOPER HARPER} \leq 6.5$$

LEVEL 3:

$$6.5 < \text{COOPER HARPER} < 10$$

HANDLING QUALITIES LEVELS FOR AIRPLANE NORMAL STATES

WITHIN OPERATIONAL FLIGHT ENVELOPE: LEVEL 1

WITHIN SERVICE FLIGHT ENVELOPE: LEVEL 2

CLASSIFICATION OF AIRPLANES

Class I: Small light airplanes, such as

light utility

primary trainer

Class II: Medium weight, low-to-medium maneuverability airplanes, such as

light or medium transport

antisubmarine

tactical bomber

Class III: Large, heavy low-to-medium maneuverability airplanes, such as

heavy transport

heavy bomber

Class IV: High-maneuverability airplanes such as

fighter/interceptor

attack

FLIGHT PHASE CATEGORIES

Nonterminal Flight Phases

Category A: Rapid maneuvering, precision tracking and flight path control

a) Air to air combat

b) Ground attack

c) Formation flying

Category B: Gradual maneuvers, without precision tracking

a) Climb

b) Cruise

c) Descent

Terminal Flight Phases

Category C: Gradual maneuvers, with precision flight path control

a) Takeoff

b) Approach

c) Landing

FOR ALL CLASSES OF AIRCRAFT

TABLE 4.9
Longitudinal flying qualities

Phugoid mode	
Level 1	$\zeta > 0.04$
Level 2	$\zeta > 0$
Level 3	$T_2 > 55$ s

Short-period mode

	Categories A & C		Category B	
Level	ζ_{sp} min	ζ_{sp} max	ζ_{sp} min	ζ_{sp} max
1	0.35	1.30	0.3	2.0
2	0.25	2.00	0.2	2.0
3	0.15	—	0.15	—

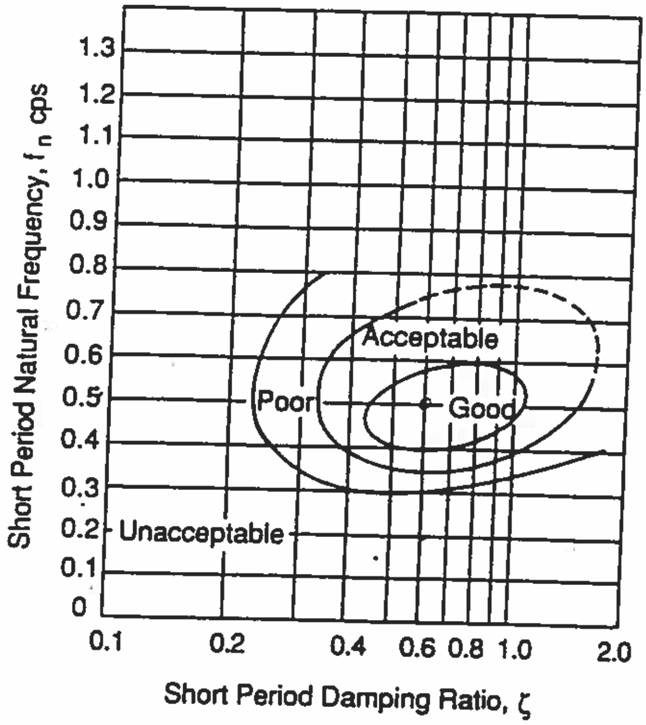


FIGURE 4.14
Short-period flying qualities.

TABLE 5.4
Spiral mode flying qualities

Spiral mode—minimum time to double amplitude				
Class	Category	Level 1	Level 2	Level 3
I & IV	A	12 s	12 s	4 s
	B & C	20 s	12 s	4 s
II & III	All	20 s	12 s	4 s

TABLE 5.5
Roll mode flying qualities

Roll mode—maximum roll time constant, seconds				
Class	Category	Level 1	Level 2	Level 3
I, IV	A	1.0	1.4	10
II, III		1.4	3.0	
All	B	1.4	3.0	10
I, IV	C	1.0	1.4	10
II, III		1.4	3.0	

TABLE 5.6
Dutch roll flying qualities

Dutch roll					
Level	Category	Class	Min ζ*	Min $\zeta\omega_n$,* rad/s	Min ω_n, rad/s
1	A	I, IV	0.19	0.35	1.0
		II, III	0.19	0.35	0.4
	B	All	0.08	0.15	0.4
	C	I, II-*C* IV	0.08	0.15	1.0
		II-*L*, III	0.08	0.15	0.4
2	All	All	0.02	0.05	0.4
3	All	All	0.02	—	0.4

Where *C* and *L* denote carrier or land based aircraft.
* The governing damping requirement is that yielding the larger value of ζ.

The Wright Flyer - An Example of an Aircraft With Very Poor Handling Qualities

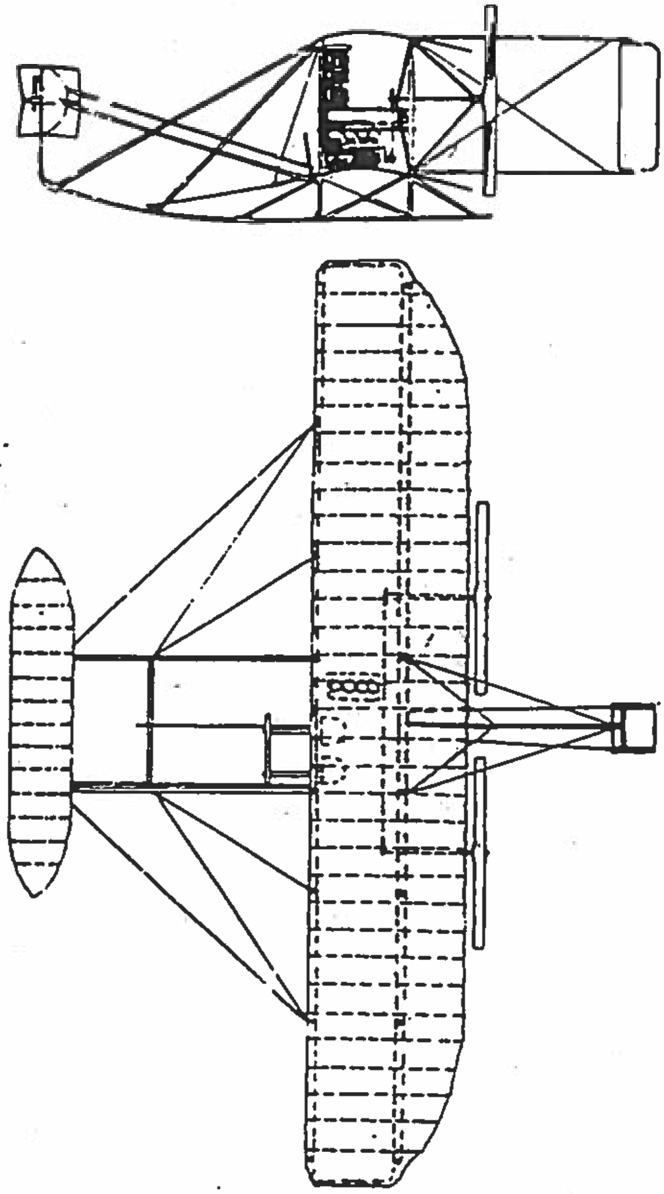


Figure 1.22 A two-view of the Wright type A, 1908.

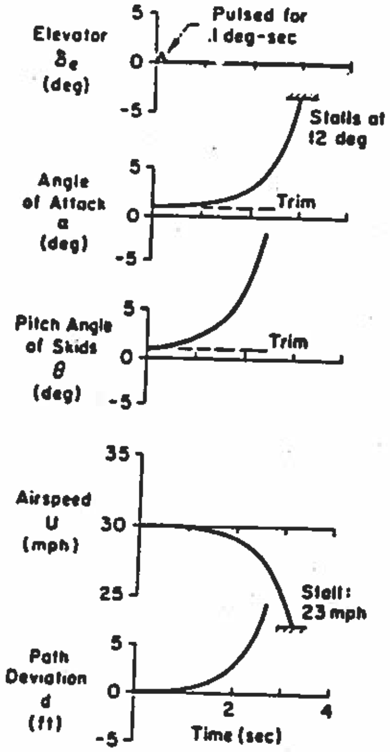


Fig. 11 Open Loop Time Response in Pitch for a Pulsed Canard Deflection

t_2 = 0.5 SECS

!!

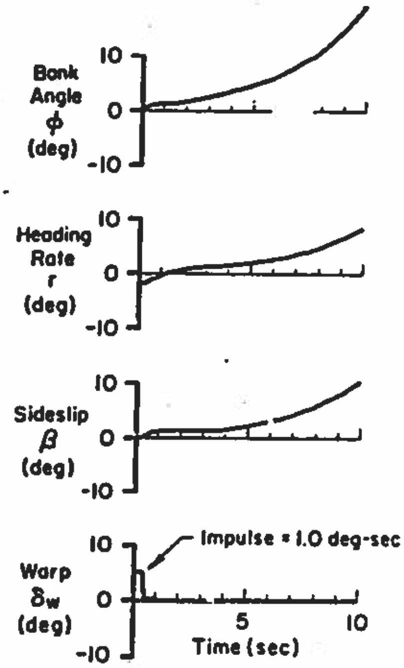


Fig. 14 Open Loop Lateral Responses to a Wing Warp Pulse

t_2 = 2.5 SECS

(SPIRAL MODE)

AIRCRAFT-PILOT SYSTEM & "HANDLING QUALITIES"

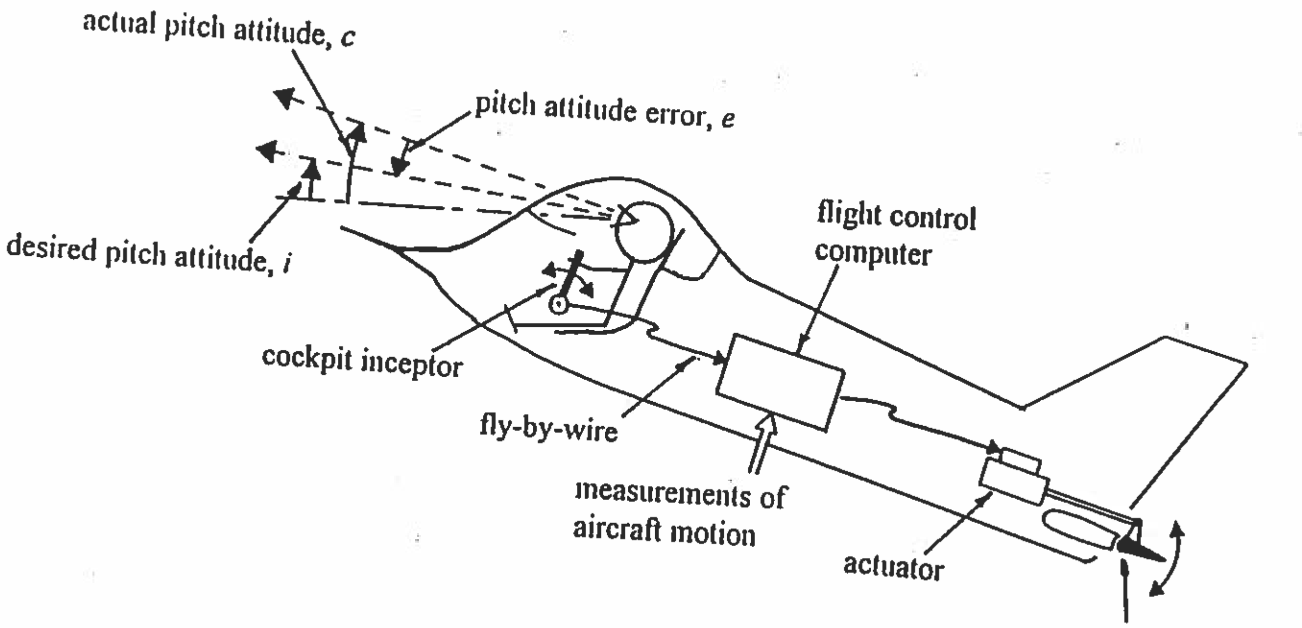


Fig. 5-1 A feedback system involving the human pilot.

<u>C</u>ontrol <u>A</u>nticipation <u>P</u>arameter (CAP)

$$N_{z_\alpha} = n/\alpha = \frac{-U_0}{g}\frac{N_\delta^{a_z'}(s)}{N_\delta^w}\Bigg|_{s=0}$$

where $N_\delta^{a_z'}$ = numerator of $\frac{a_z'}{\delta}(s)$ transfer function

and a_z' = acceleration parallel to z-body axis measure at pilot's station

$= a_z - l_x\dot{q}$; a_z = cg acceleration parallel to z-body axis

l_x = distance from cg to pilot's station measured parallel to x-body axis, positive forward

$$\boxed{CAP = \frac{\omega_{n_{sp}}^2}{n/\alpha}}$$

The military specification indicates regions in the $\omega_{n_{sp}}$ vs n/α space for different handling qualities levels.

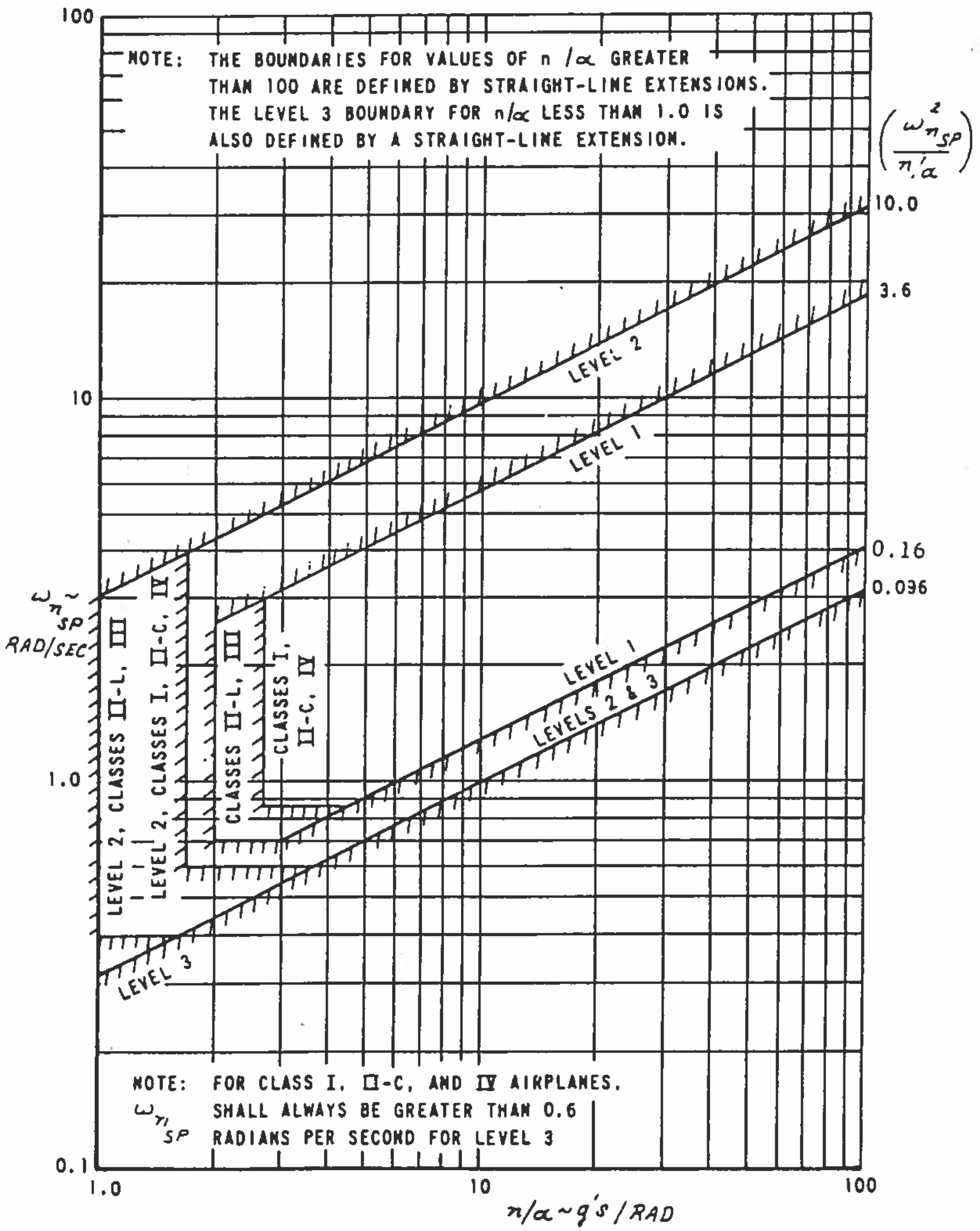
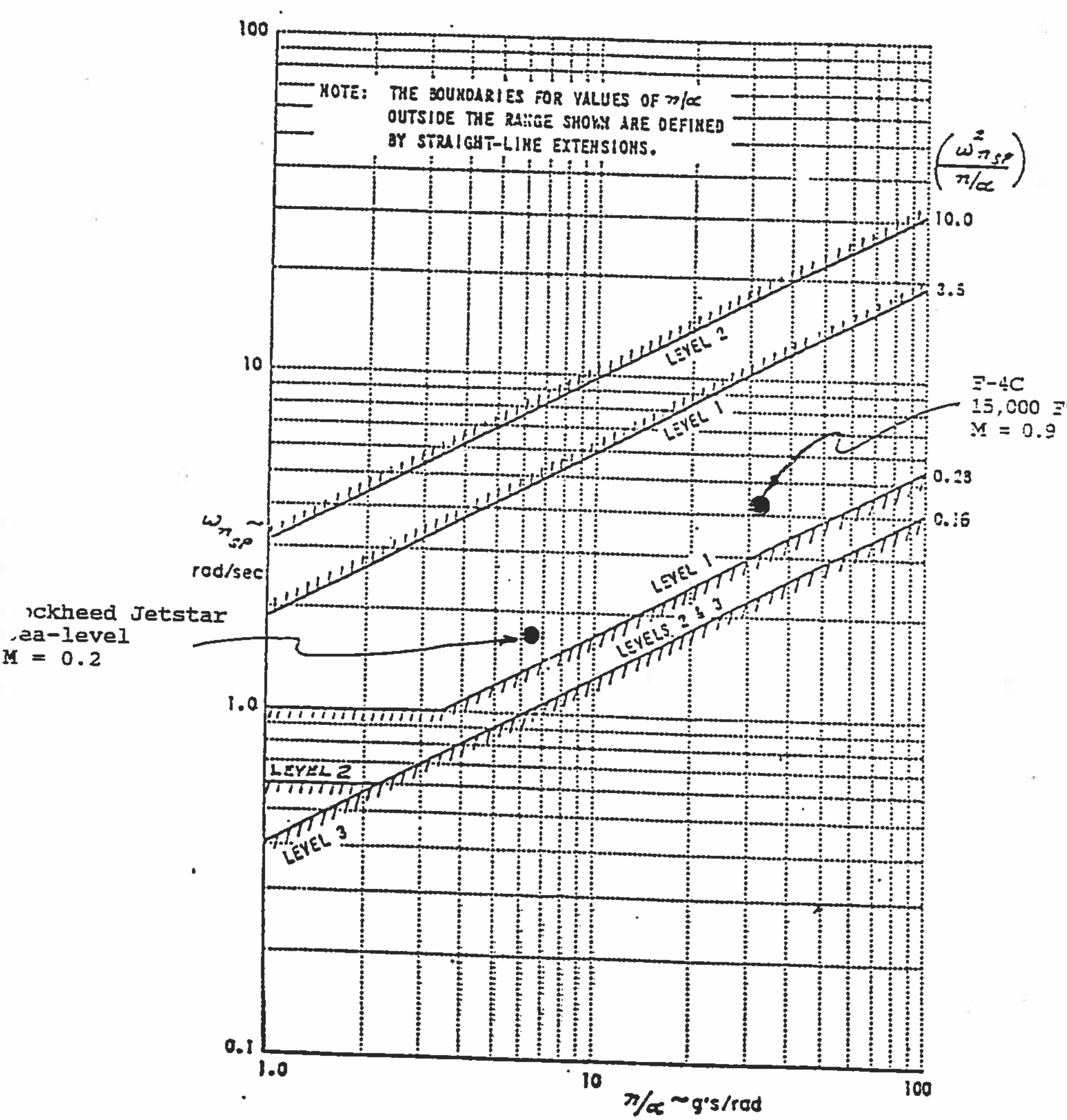


Figure 6. (MIL-F-8785C Figure 3) Short-Period Frequency Requirements - Category C Flight Phases.



SHORT-PERIOD FREQUENCY REQUIREMENTS - CATEGORY A FLIGHT PHASES

Dept. of Mech. and Aero. Engineering

MAE – 275

Bandwidth/Phase-Delay Handling Qualities Metric

For a thorough discussion of this and other relevant flight control topics, the following text is highly recommended:

Advances in Flight Control, Ed: Mark B. Tischler, Taylor and Francis, London, 1996.

Modified Flight Phase Category Definitions

- Category A: Tasks that are precise and aggressive.
- Category B: Tasks that are non-precise and non-aggressive.
- Category C: Tasks that are precise and non-aggressive.
- Category D: Tasks that are non-precise and aggressive.

Phase Delay:

$$\tau_p = \frac{\Delta\Phi 2\omega_{180}}{57.3\,(2\omega_{180})}$$

Note: if phase is nonlinear between ω_{180} and $2\omega_{180}$, τ_p shall be determined from a linear least squares fit to phase curve between ω_{180} and $2\omega_{180}$

Rate Response-Types:

ω_{BW} is lesser of $\omega_{BW_{gain}}$ and $\omega_{BW_{phase}}$

Attitude Response-Types:

$\omega_{BW} \equiv \omega_{BW_{phase}}$

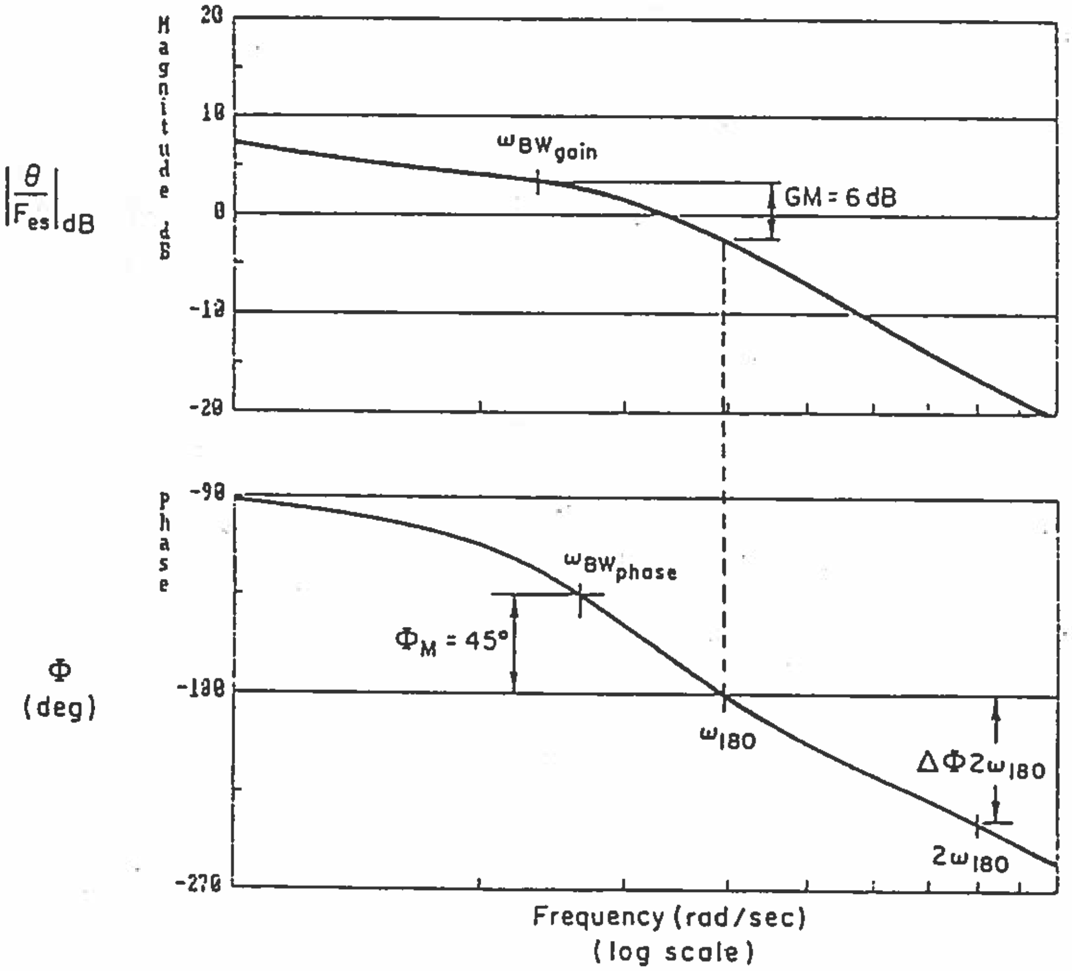


Figure 2(4.2.1.2). Definitions of Bandwidth and Phase Delay

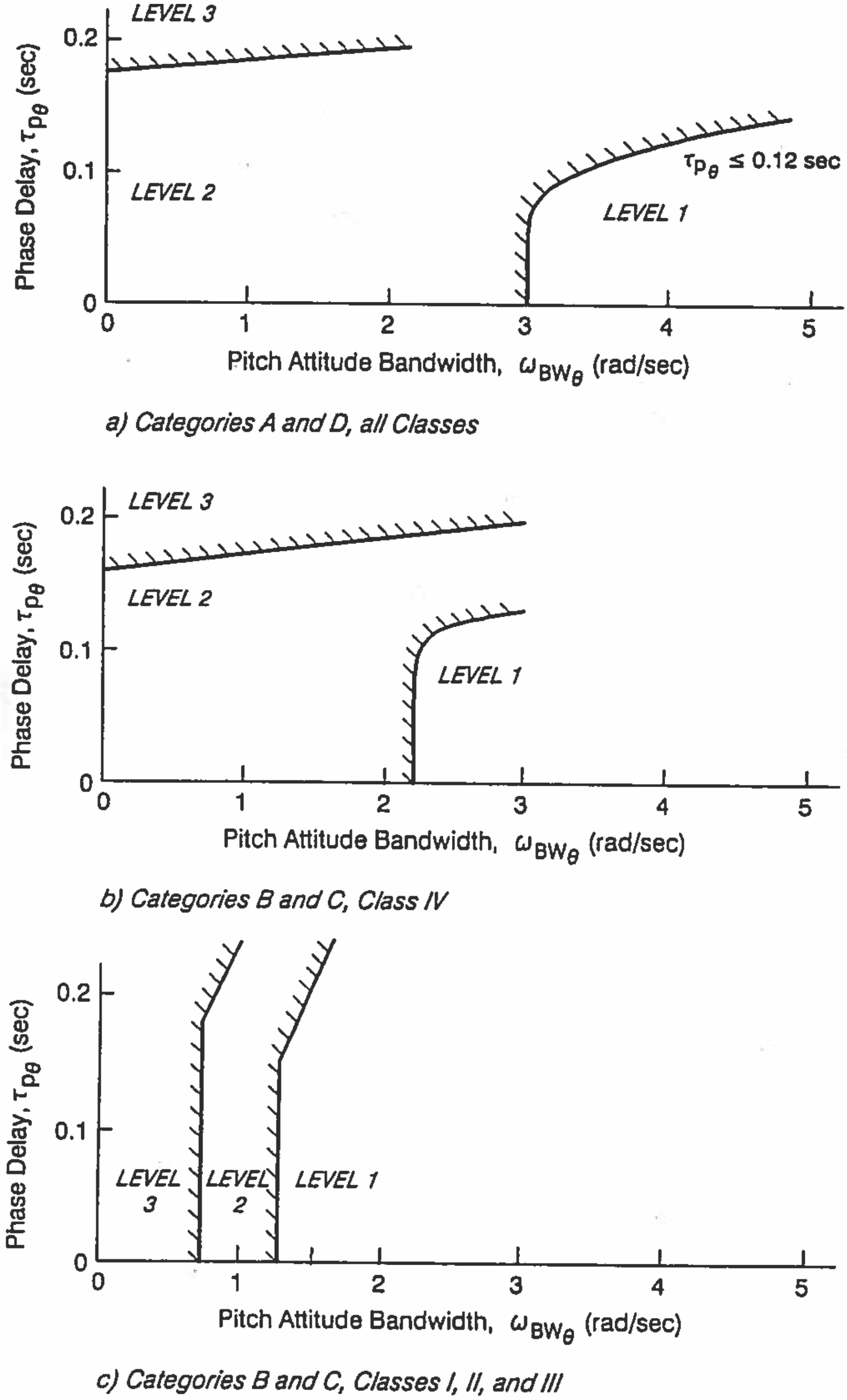
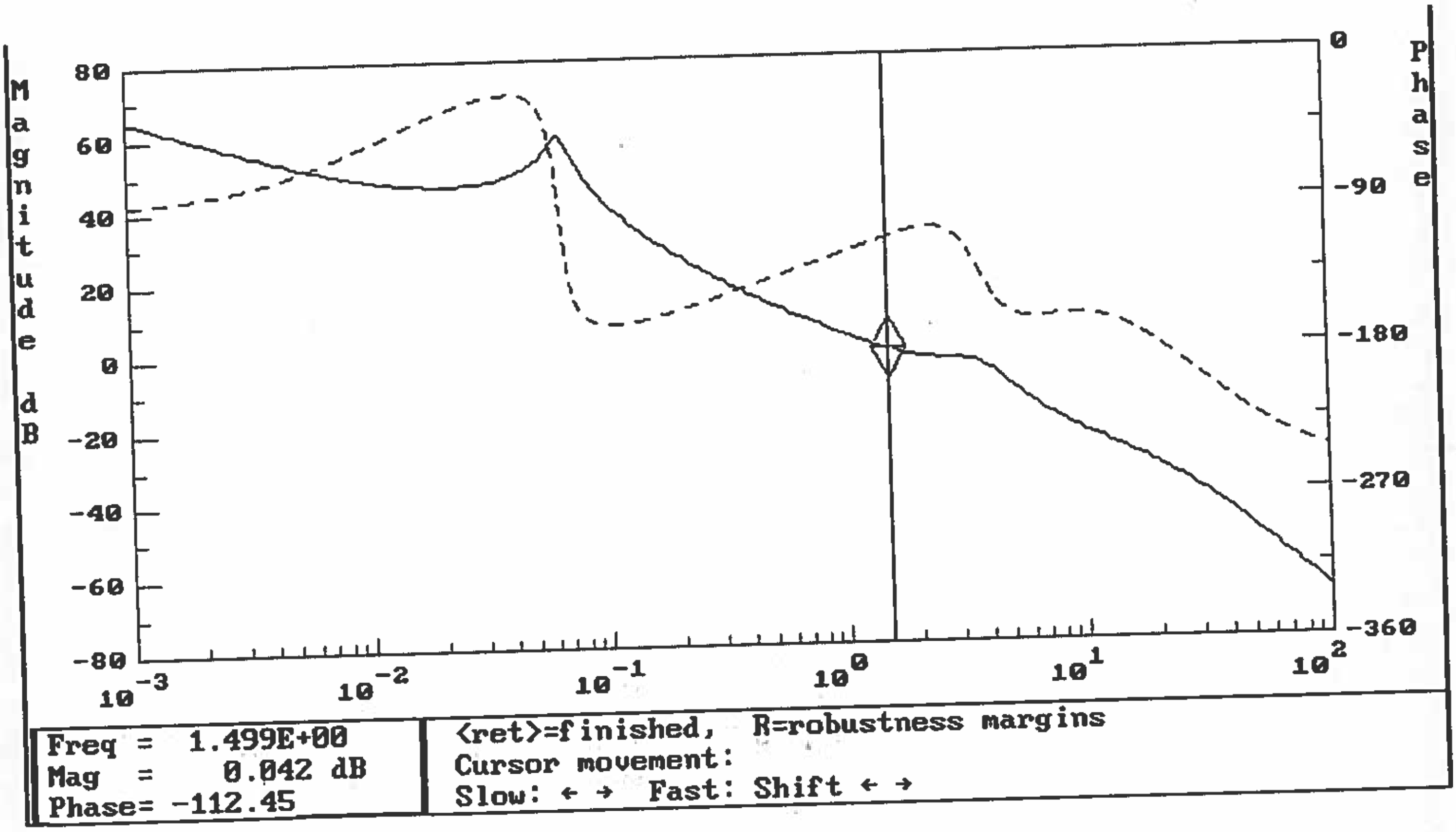


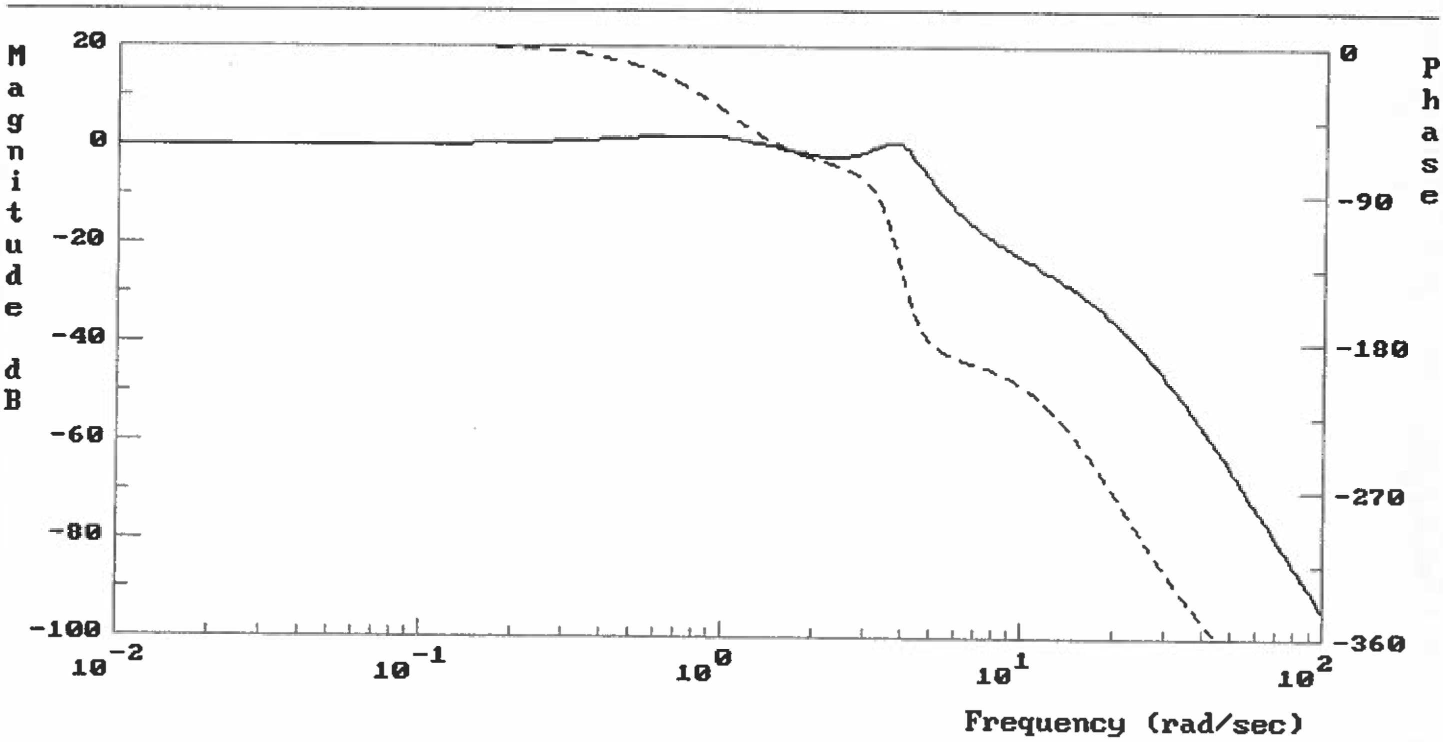
Figure 1(4.2.1.2). Limits on Short-Term, Small-Amplitude Pitch Response to Pitch Controller (Bandwidth)

This is the $\frac{\theta}{\theta_c}$ open-loop transfer function for the A-4D "low bandwidth" attitude-command/attitude-hold SCAS that we discussed in the handout entitled: "Sample Loop-Shaping Design". In shorthand notation, The compensator was given by

$$G_\theta = \frac{24.8(0.3)(4)^2(5)(6)}{(0)(0.5)(1.5)(20)^3}$$



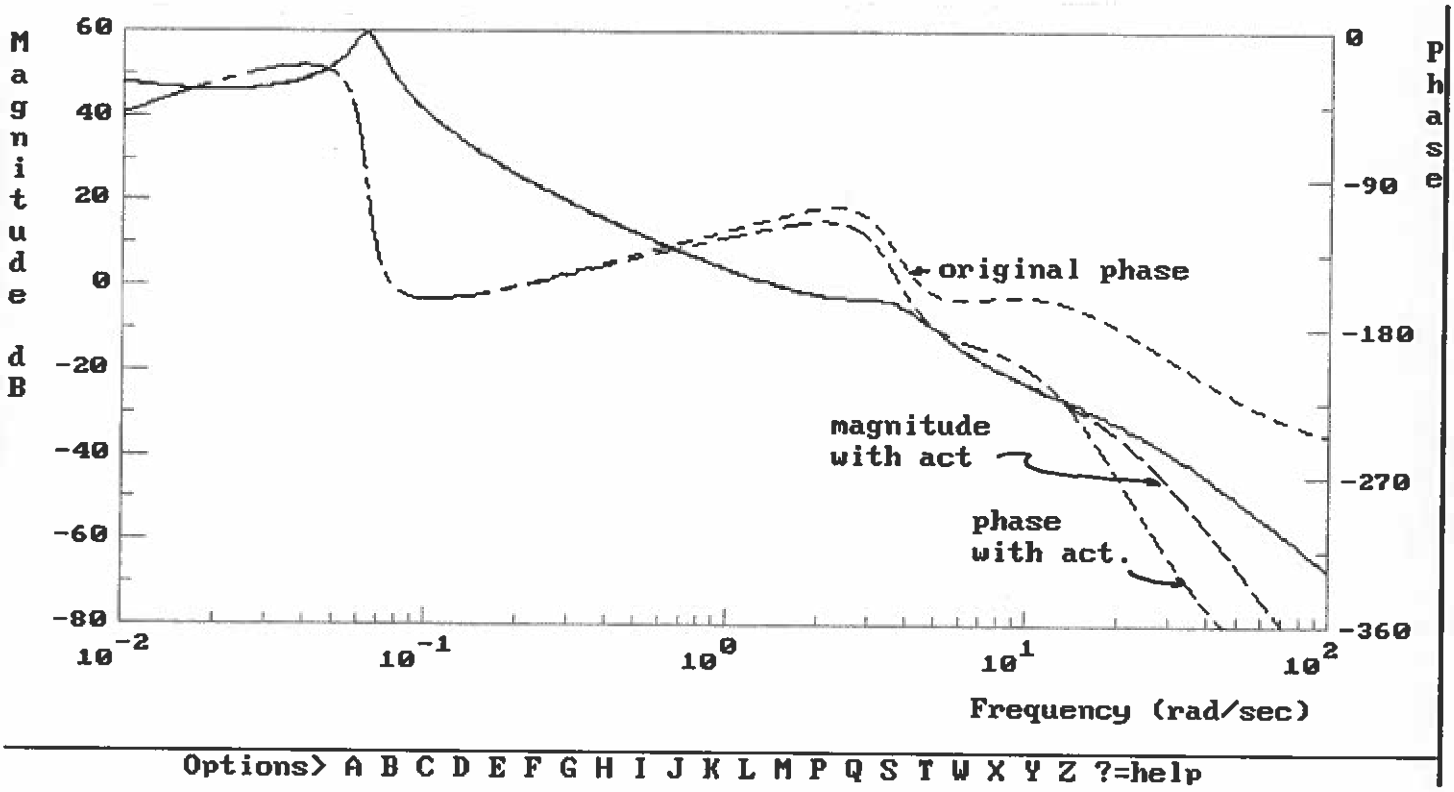
Closed-loop $\frac{\theta}{\theta_c}$ transfer function with actuator



Options> A B C D E F G H I J K L M P Q S T W X Y Z ?=help

This plot shows the effect of adding an elevator actuator to the open-loop system transfer function. The actuator was not included in the design. In shorthand notation, the actuator dynamics are given by

$$G_{act} = \frac{20^2}{(20)^2}$$



Handling Qualities Analysis of Low-Bandwidth Attitude Command/Attitude Hold A4-D Flight Control System

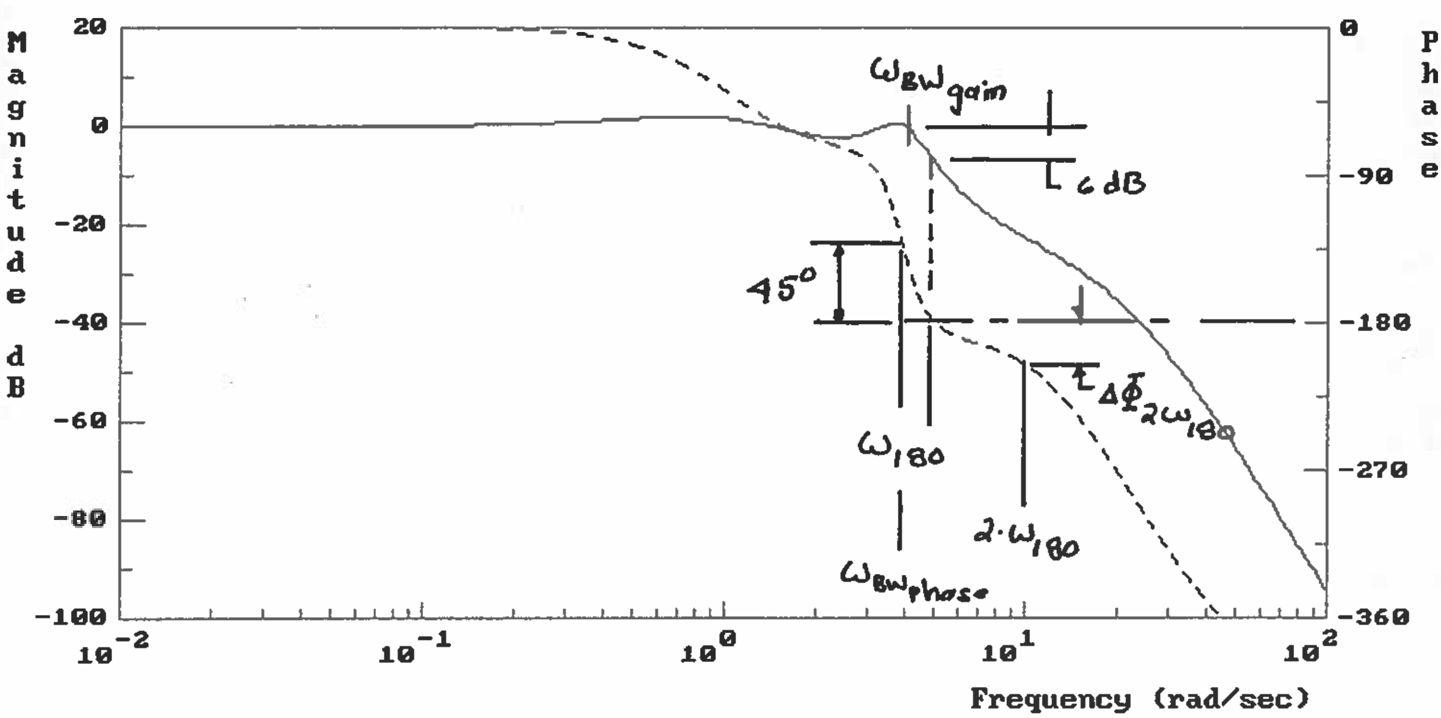
$$\omega_{180} = 4.96 \ rad/\text{sec}$$

$$\Delta\Phi_{2\omega_{180}} = 25 \ deg$$

$$\omega_{BW_{gain}} = 4.19 \ rad/\text{sec}$$

$$\omega_{BW_{phase}} = 3.91 \ rad/\text{sec} \checkmark$$

$$\tau_p = \frac{25}{57.3(2*4.96)} = 0.044 \text{ sec} \checkmark$$



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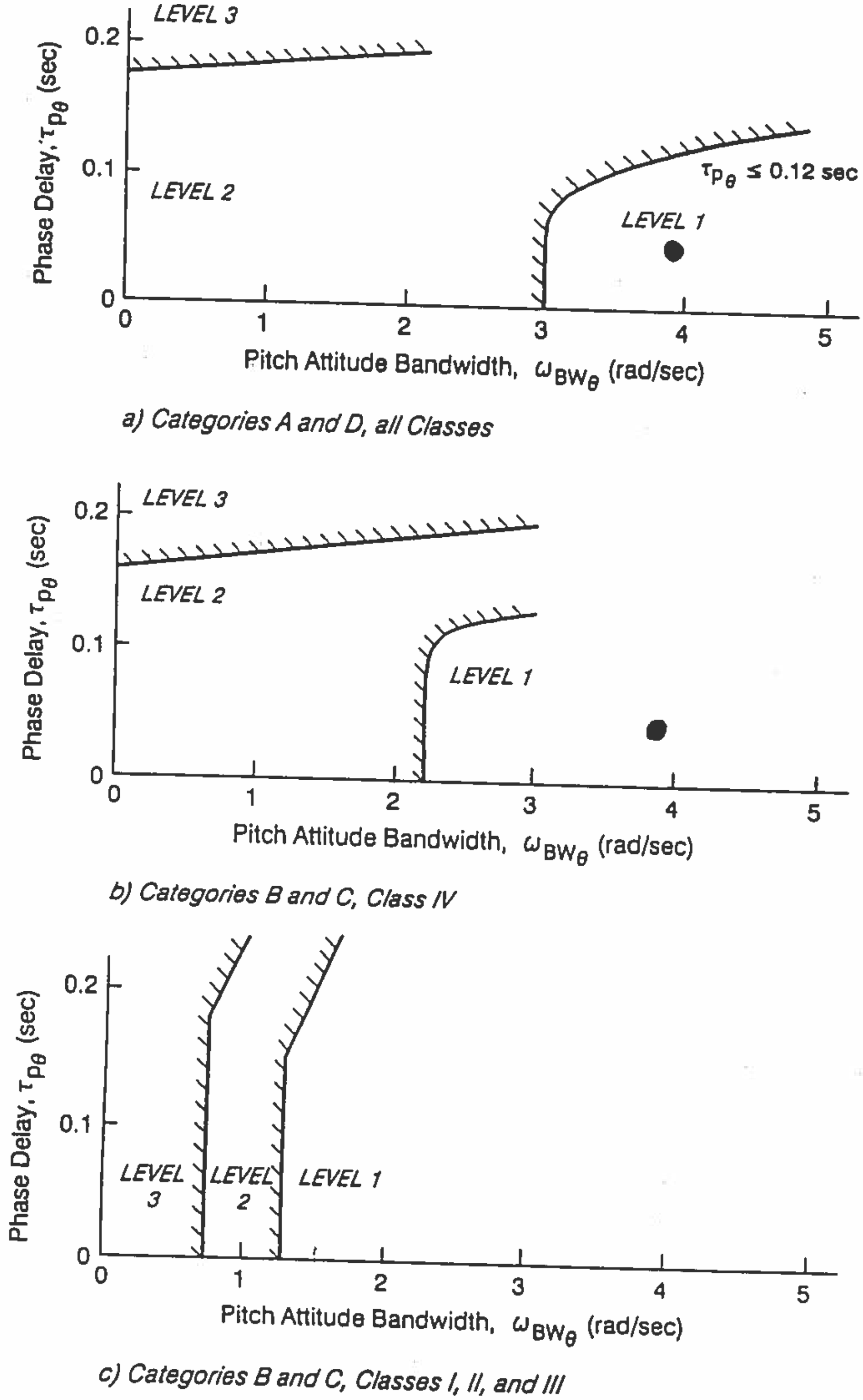
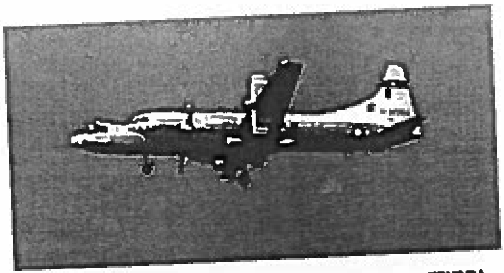


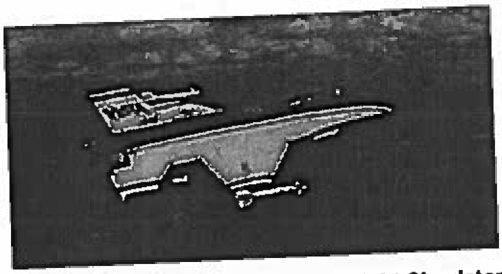
Figure 1(4.2.1.2). Limits on Short-Term, Small-Amplitude Pitch Response to Pitch Controller (Bandwidth)

Experimental Evaluation of Aircraft Handling Qualities

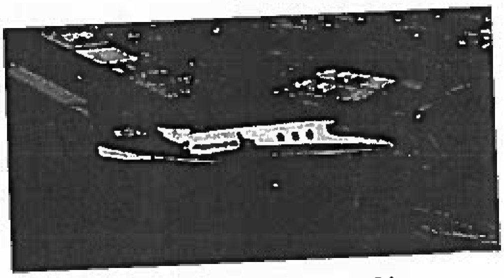
Ground-based and in-flight simulators are often used to evaluate the handling qualities of proposed aircraft. Enclosed are examples of the ground-based NASA Ames Vertical Motion Simulator (VMS) and the Total In-Flight Simulator (TIFS). The latter is basically a variable-stability aircraft based upon an Air Force C-154.



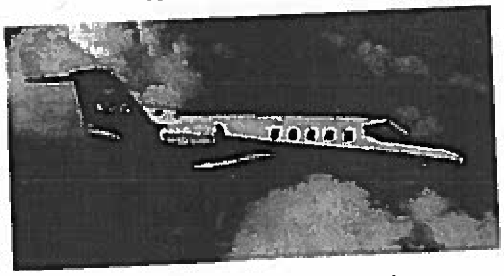
USAF NC-131 Total In-Flight Simulator (TIFS)



USAF NF-16 Variable Stability In-Flight Simulator Test Aircraft (VISTA)

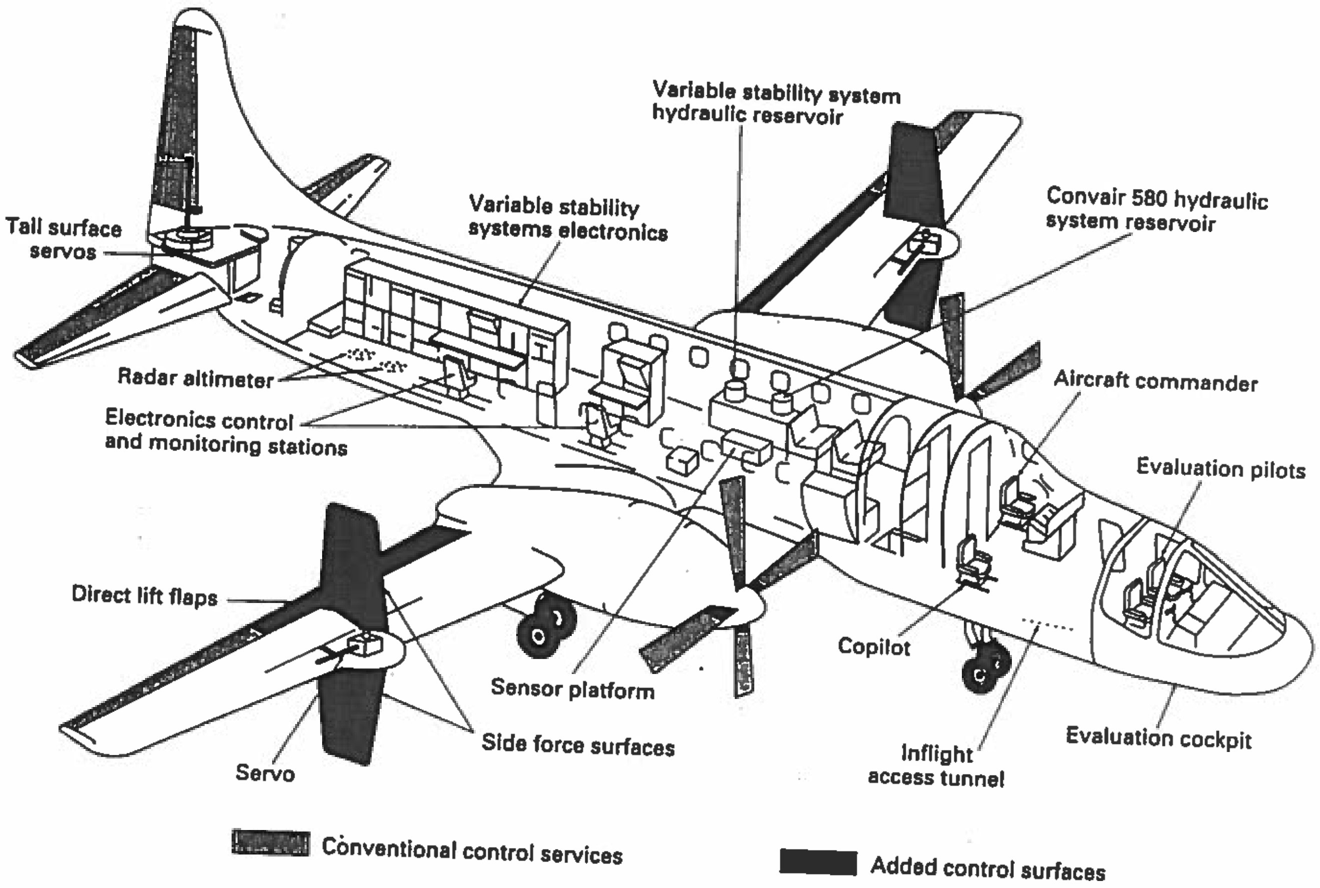


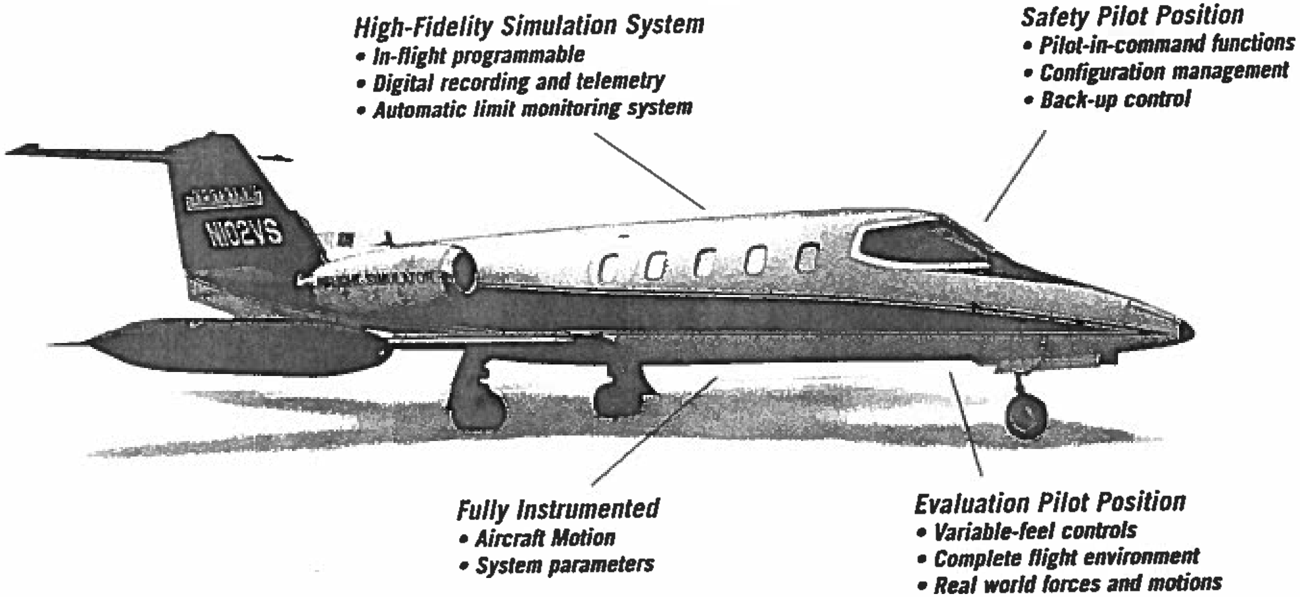
Variable Stability Learjet 24



Variable Stability Learjet 25

Variable Stability Research Aircraft
USAF/CALSPAN Total In-Flight Simulator (TIFS)

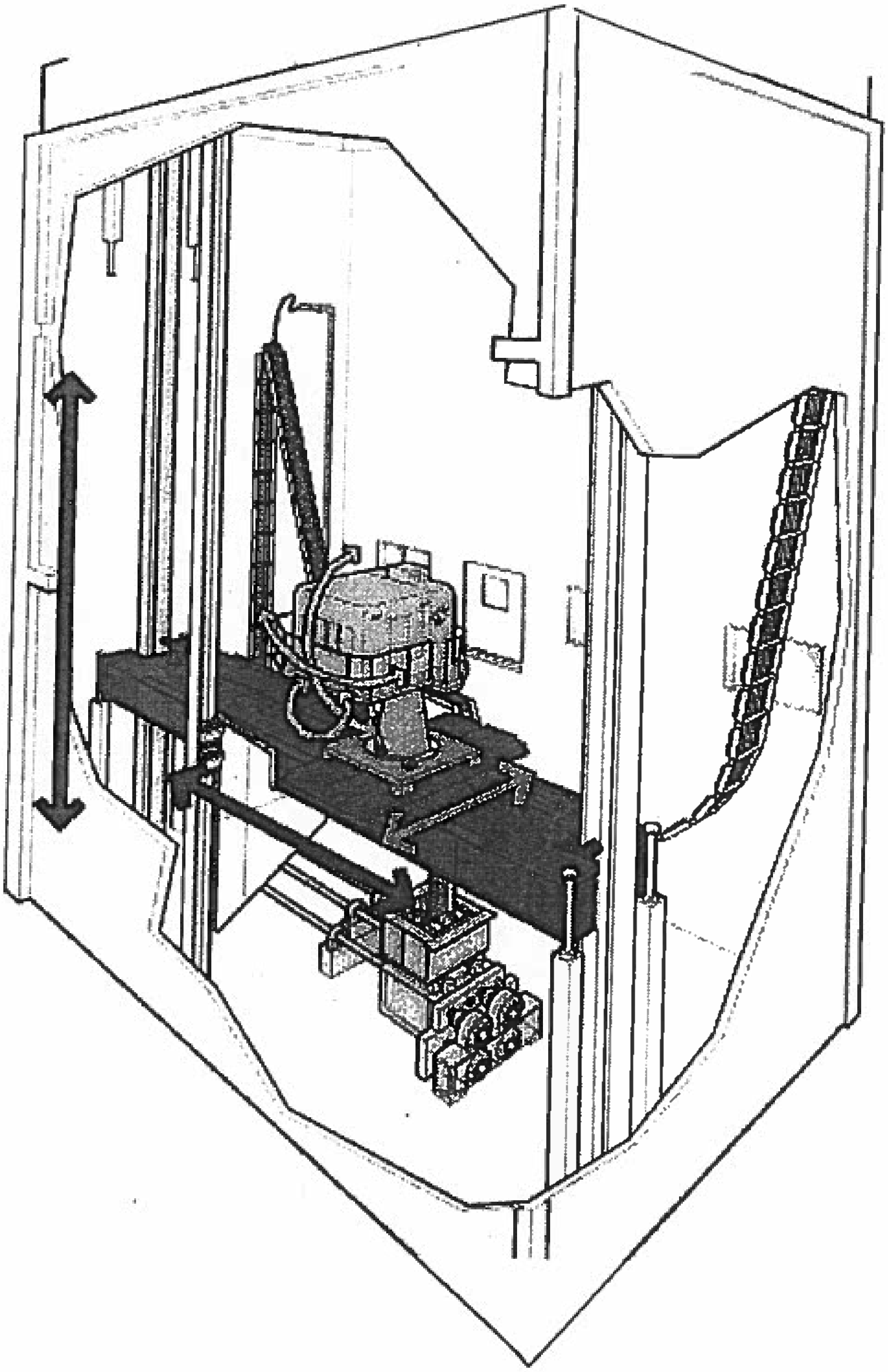


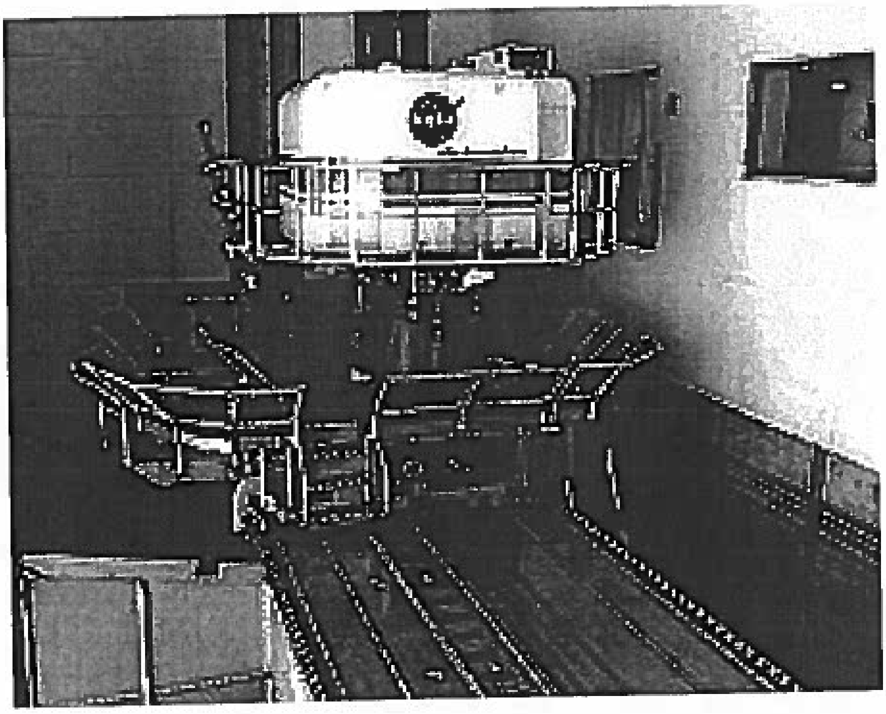


Flight Research Group
150 North Airport Drive
Buffalo, NY 14225
(716) 631-6750

VERIDIAN

NASA Ames Vertical Motion Simulator





NASA Ames Vertical Motion Simulator (VMS)