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FLIGHT RESEARCH EXPERIMENTS TO DETERMINE RIDE QUALITY AND PASSENGER ACCEPTANCE

Memorandum Report 403903

Short-Haul Air Transportation Program

by

Ira D. Jacobson

and

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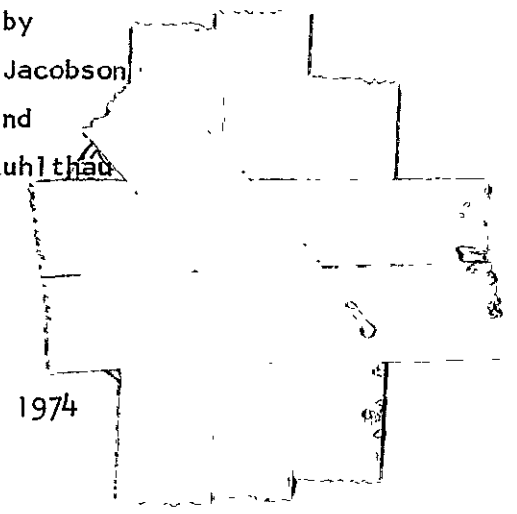

July 1974

Department of Engineering Science and Systems

27

FLIGHT RESEARCH EXPERIMENTS TO DETERMINE RIDE QUALITY AND PASSENGER ACCEPTANCE

Status Report

National Aeronautics and Space Administration
Flight Research Center
Grant No. NGR 47-005-202

Submitted by:

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July 1974

DEPARTMENT OF ENGINEERING SCIENCE AND SYSTEMS
UNIVERSITY OF VIRGINIA

The period covered by this status report runs from June 15, 1973 through June 14, 1974. During this period, progress was made in two areas. First, a preliminary analysis of Jetstar ride-comfort data was completed. This included a study of human reaction to a two-axis motion environment produced by the GPAS system and the gathering of baseline data for ground-based simulator validation. In addition, a preliminary screening of bank angle effects was obtained. These results have been put into report form and submitted to the technical monitor for his comments. These reports are as follows:

- "Effect of Motion Frequency Spectrum on Subjective Comfort Response," Memorandum Report 403901;
- "Flight Simulator Experiments to Determine Human Reaction to Aircraft Motion Environments," Memorandum Report 403902.

The second area in which progress was made is in the design and analysis of a ride-smoothing system for the Jetstar aircraft. Mr. Maris Lapins, a Ph.D. graduate student at the University of Virginia, has been in residence at the Flight Research Center since December 1, 1973. Here he has used the Center's facilities (computer, simulator, and Jetstar aircraft) to accomplish the design, analysis, and implementation of the ride-smoothing system. A status report of his work was presented in a briefing at the Flight Research Center on May 2, 1974.

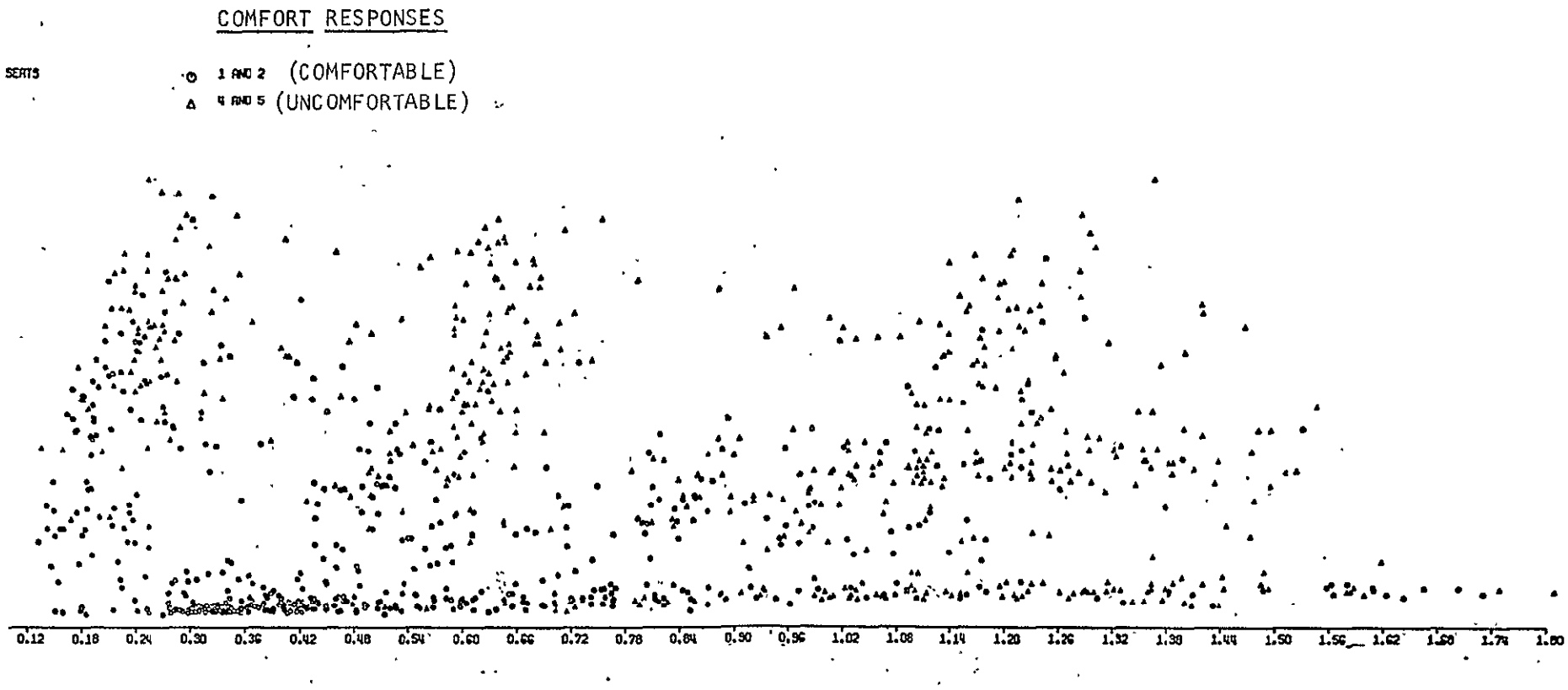
In addition to the above, a briefing of the status of the entire program was given to Mr. Ray Whitten at NASA Headquarters on May 9, 1974. Copies of the slides used in that briefing are attached.

STATUS REPORT

FLIGHT RESEARCH EXPERIMENTS TO DETERMINE RIDE QUALITY AND PASSENGER ACCEPTANCE USING NASA JETSTAR AIRCRAFT

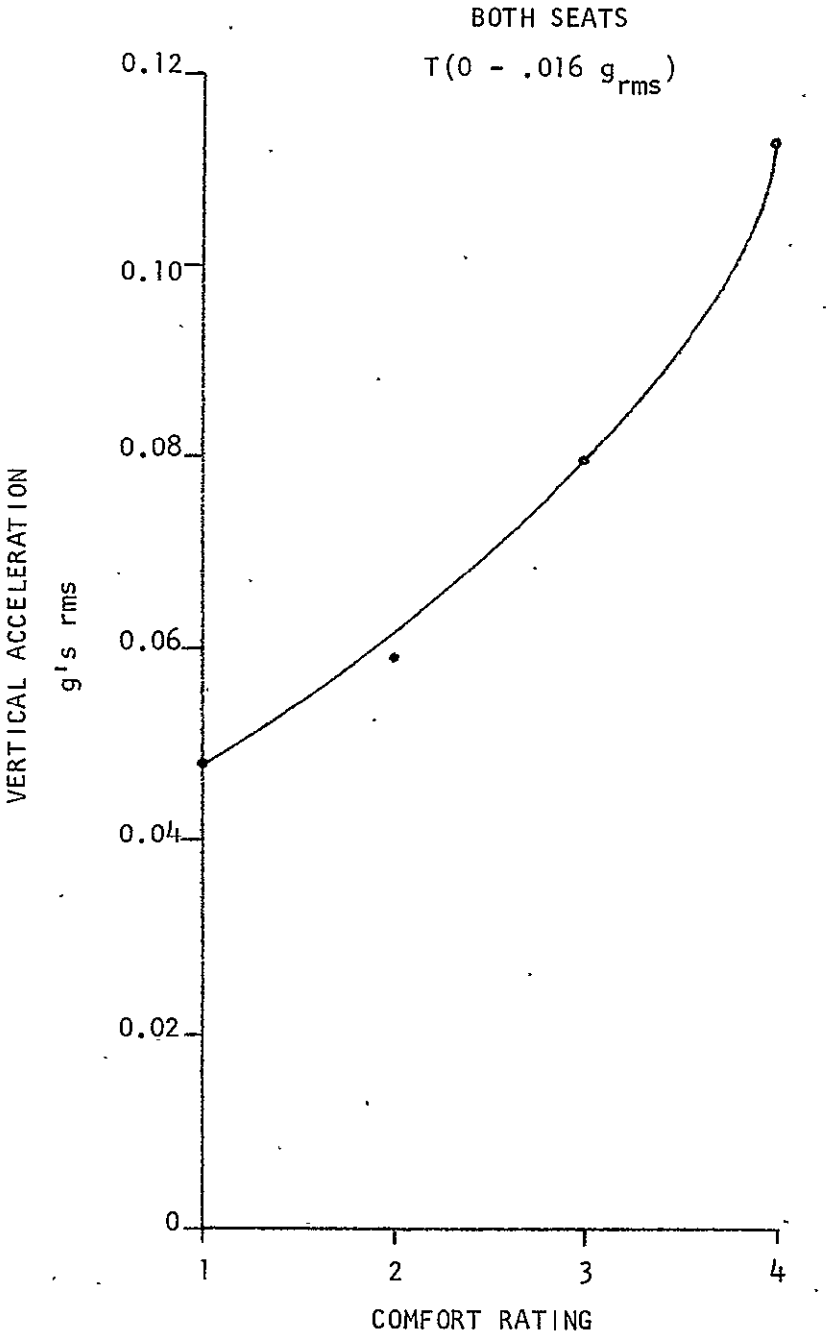
University of Virginia

May 1974

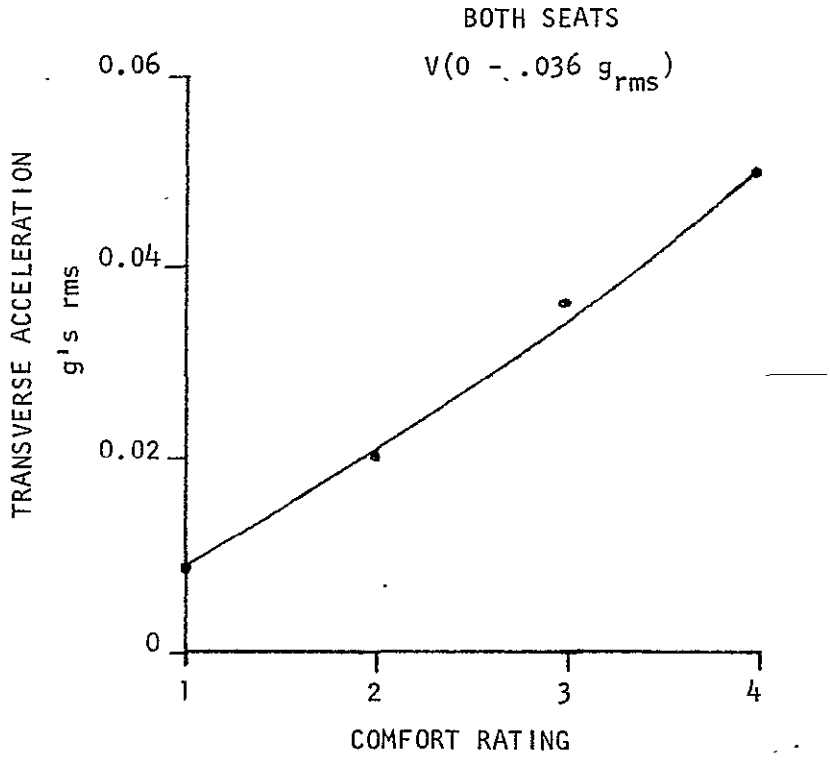


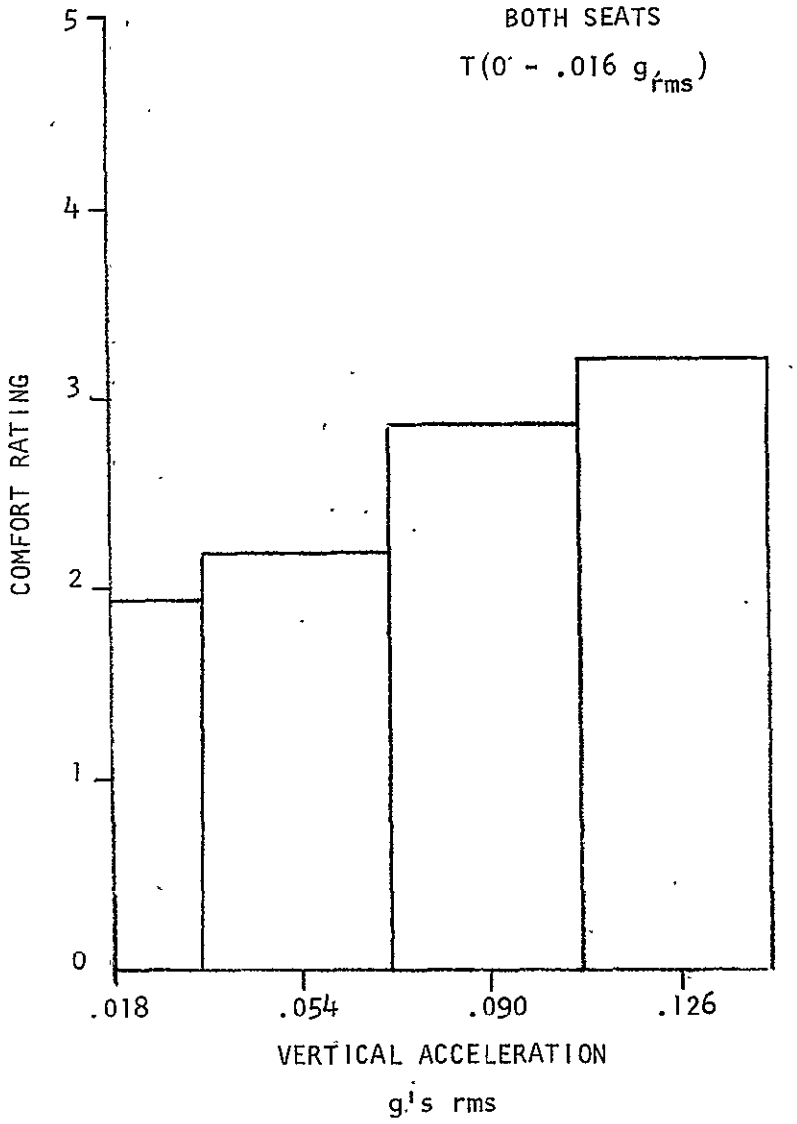
VERTICAL ACCELERATION, g's rms x 10

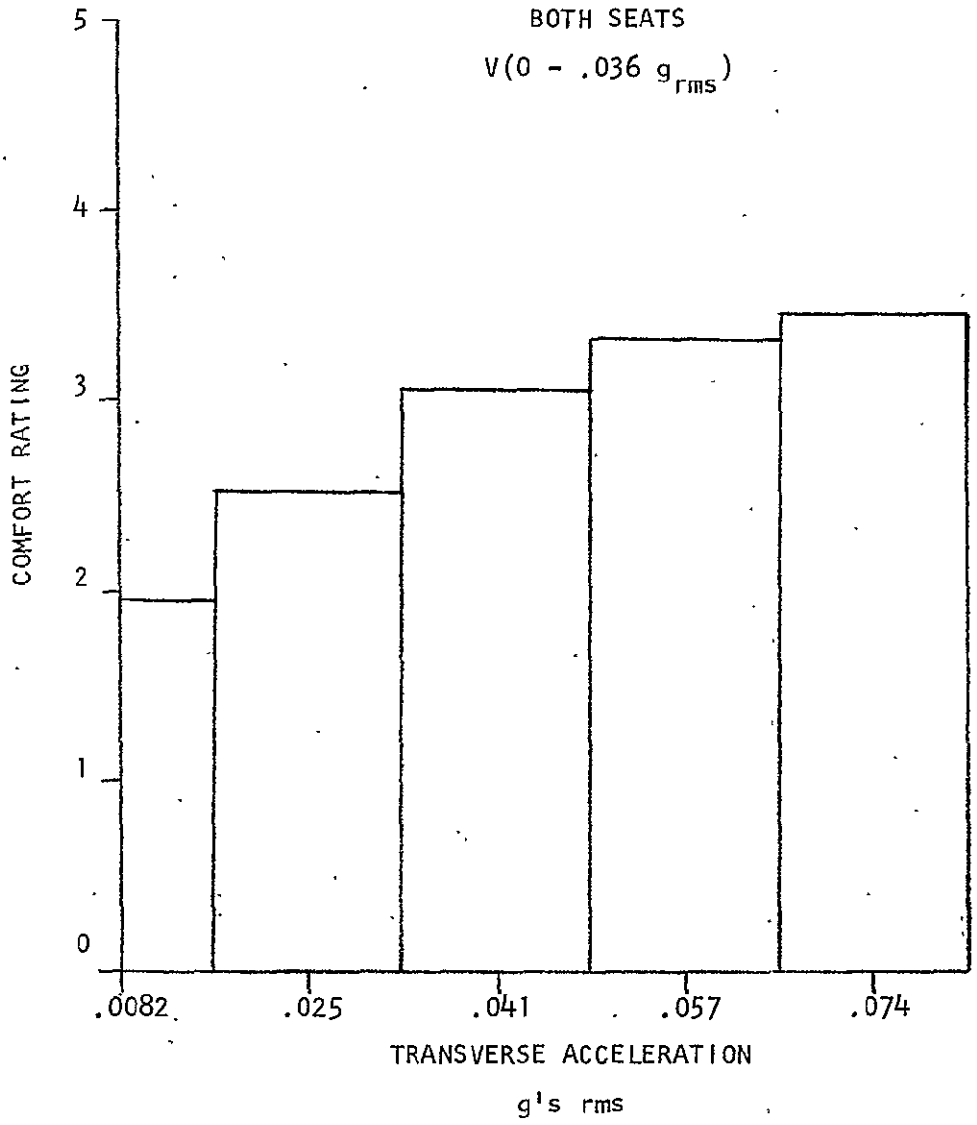
JETSTAR FLIGHT DATA (GPAS System)



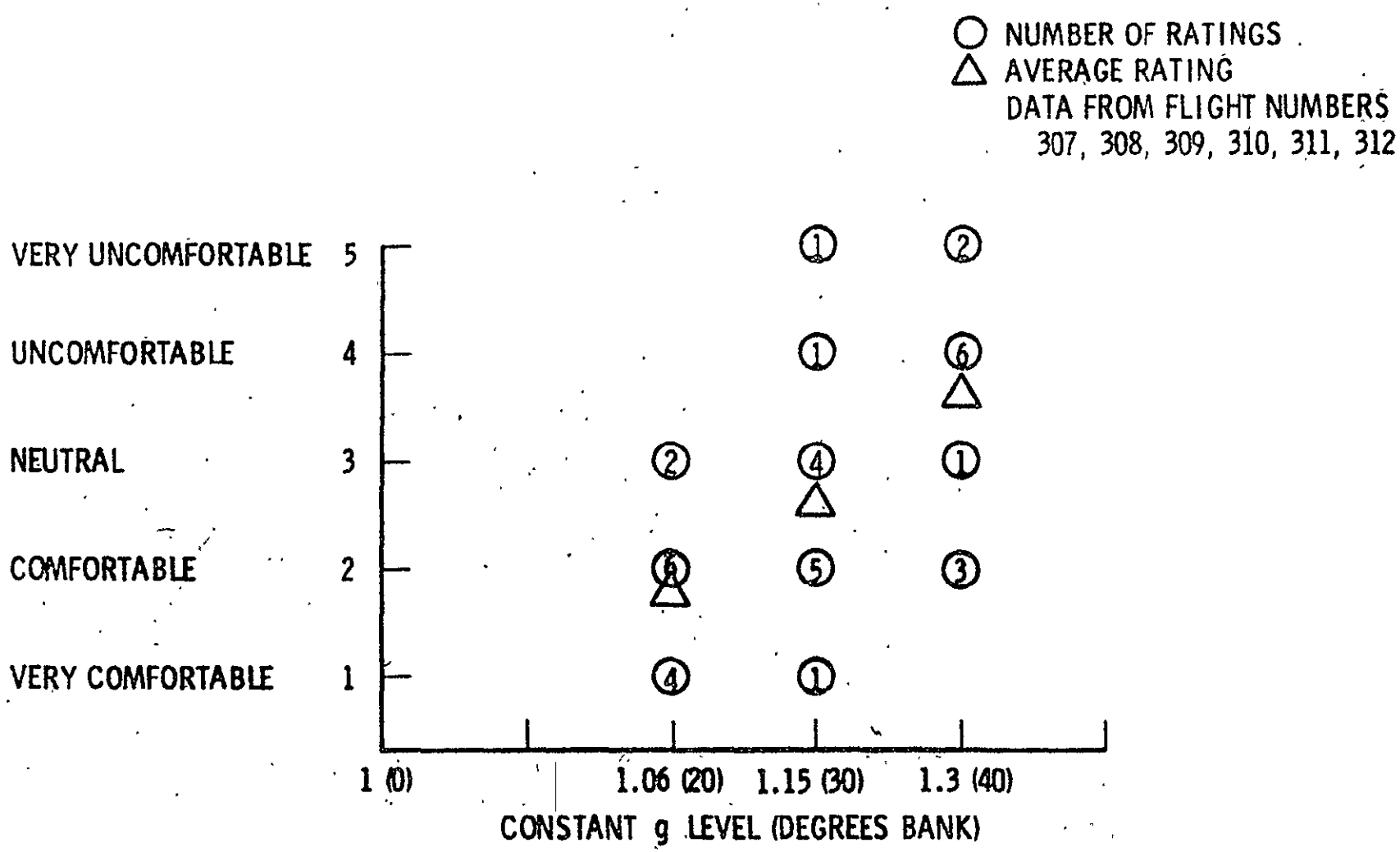
University of Virginia
April 1974


BOTH SEATS
V(0 - .036 g_{rms})
TRANSVERSE ACCELERATION
g's rms
0.06
0.04
0.02
0
1
2
3
4
COMFORT RATING


BOTH SEATS
T(0 - .016 g rms)
COMFORT RATING
5
4
3
2
1
0
.018
.054
.090
.126
VERTICAL ACCELERATION
g's rms


BOTH SEATS
V(0 - .036 g rms)
COMFORT RATING
5
4
3
2
1
0
.0082
.025
.041
.057
.074
TRANSVERSE ACCELERATION
g's rms

PASSENGER RESPONSES TO CONSTANT g LEVELS (BANK ANGLES)



PSYCHOPHYSICAL/BIODYNAMIC COMFORT MODEL

$$C = C_0 + C_1 \text{ Log}_{10} (S_V^2 + S_T^2 + S_L^2) + C_2 \text{ Log}_{10} (S_R^2 + S_P^2 + S_Y^2) + \sum_{i=1}^{6} \left[b_1 \left(\frac{\delta_i}{\delta_{ref_i}} \right)^2 + d_i \left(\frac{v_i}{v_{ref_i}} \right)^2 \right]$$

Psychophysical — Biodynamic

where i = 1 to 6 refers to V, T, L, R, P, Y (Vertical, Transverse, Longitudinal, Roll, Pitch, Yaw)

$S_i = \frac{a_i}{a_{ref_i}}$ $\quad \delta_i$ = rms displacement (weighted) $\quad v_i$ = rms velocity (weighted)

a_i = rms acceleration

a_{ref}, δ_{ref}, v_{ref} - reference acceleration, displacement, velocity

C_0, C_1, C_2, b_i, d_i - weighting constants

$$\delta_i = \int_0^F \phi_{\delta_i} (f)\, W(f)\, df \qquad v_i = \int_0^F \phi_{v_i} (f)\, W(f)\, df$$

$W(f)$ = body sensitivity weighting function

ϕ_δ, ϕ_v = power spectra for displacement, velocity

MOTIVATION

ANTICIPATE UNACCEPTABLE RIDE ENVIRONMENT ABOARD AIRCRAFT OPERATING IN THE PRESENCE OF ATMOSPHERIC TURBULENCE

- OPERATIONAL ENVIRONMENT
- AERODYNAMIC CHARACTERISTICS
- DYNAMIC CHARACTERISTICS

CONCEPT

- SENSE AIRCRAFT MOTION INTERNALLY
  - ACCELEROMETERS
  - RATE GYROS
  - ATTITUDE GYROS
- DRIVE AIRCRAFT CONTROL SURFACES SO AS TO COUNTERACT UNDESIRED RESPONSE TO DISTRUBANCES
  - ELEVATOR
  - RUDDER
  - DIRECT LIFT FLAPS
  - SIDE FORCE GENERATORS
- TREAT PROBLEM AS SEPARABLE
  - LONGITUDINAL
  - LATERAL

CRITERIA

- COMFORT MODEL BASED ON MOTION:

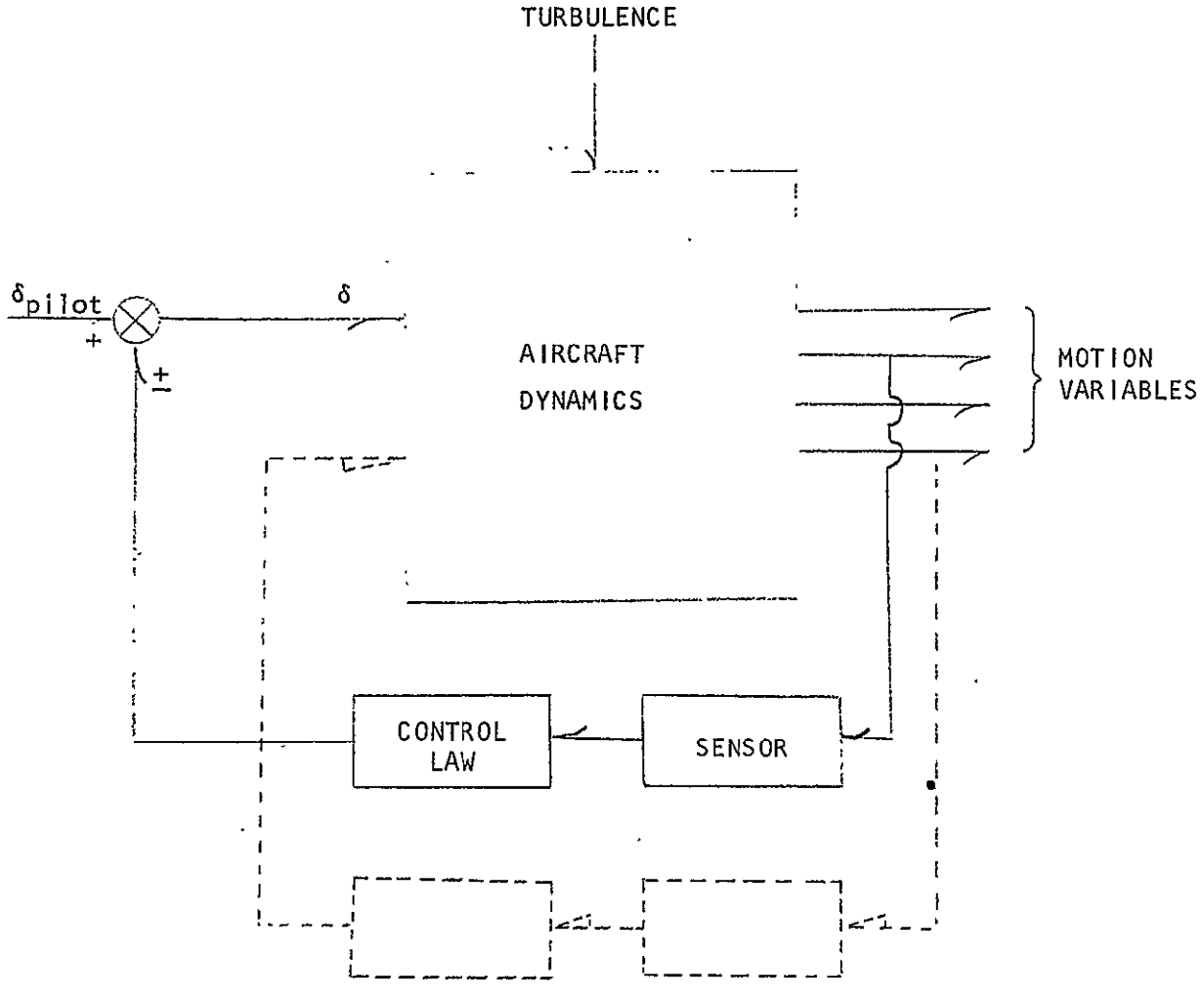
$$C = 2 + 11.9\, a_{V_{rms}} + 7.5\, a_{T_{rms}}$$

- HANDLING QUALITIES SPECIFICATIONS

- PILOT OPINION RATINGS

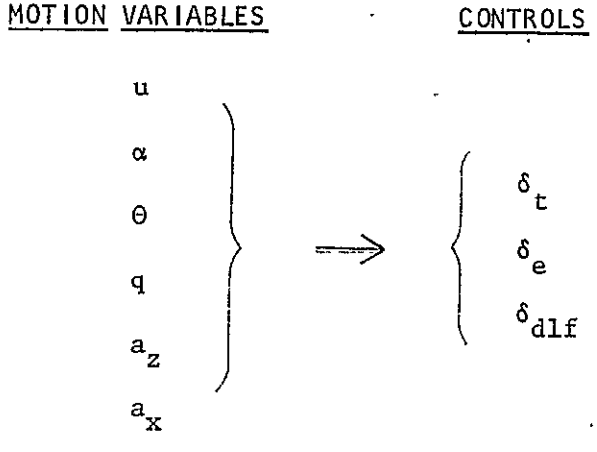
CONTROL LAWS

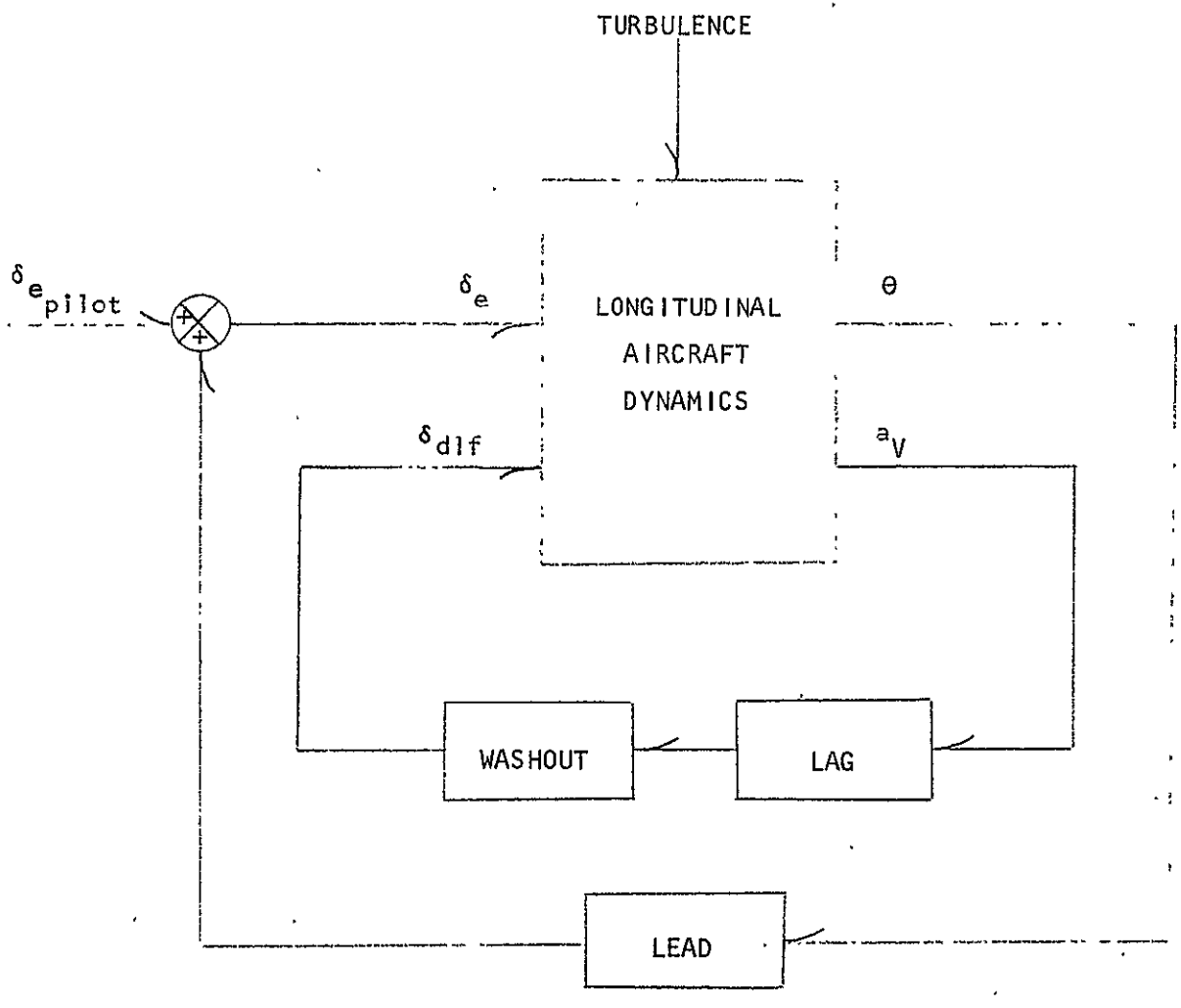
- PURE GAIN
- LEAD EQUALIZATION
- LAG EQUALIZATION
- NOTCH FILTER
- WASHOUT
- QUADRATIC FILTER



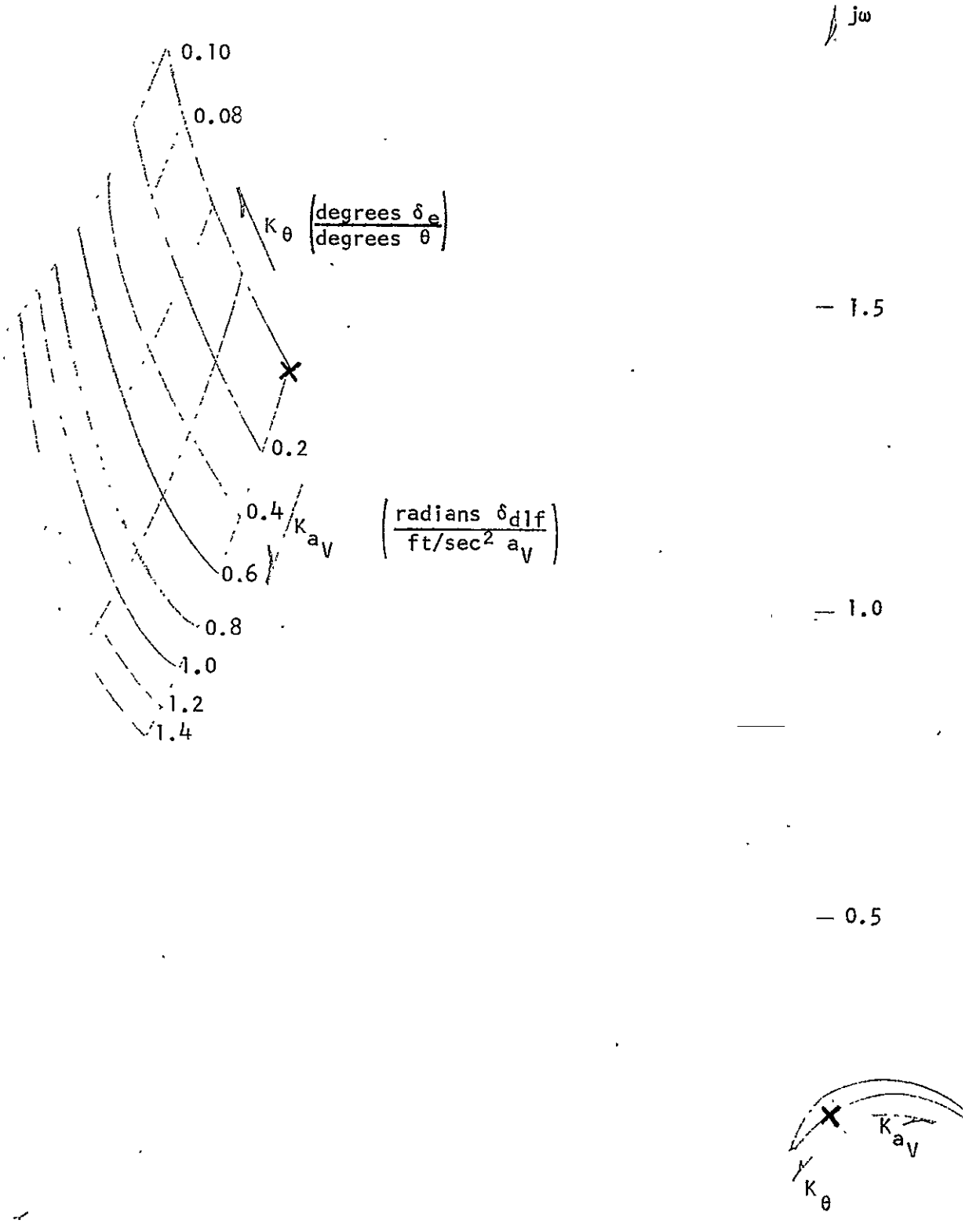
SINGLE & MULTILOOP
CONTROL SYSTEMS

LONGITUDINAL CASE

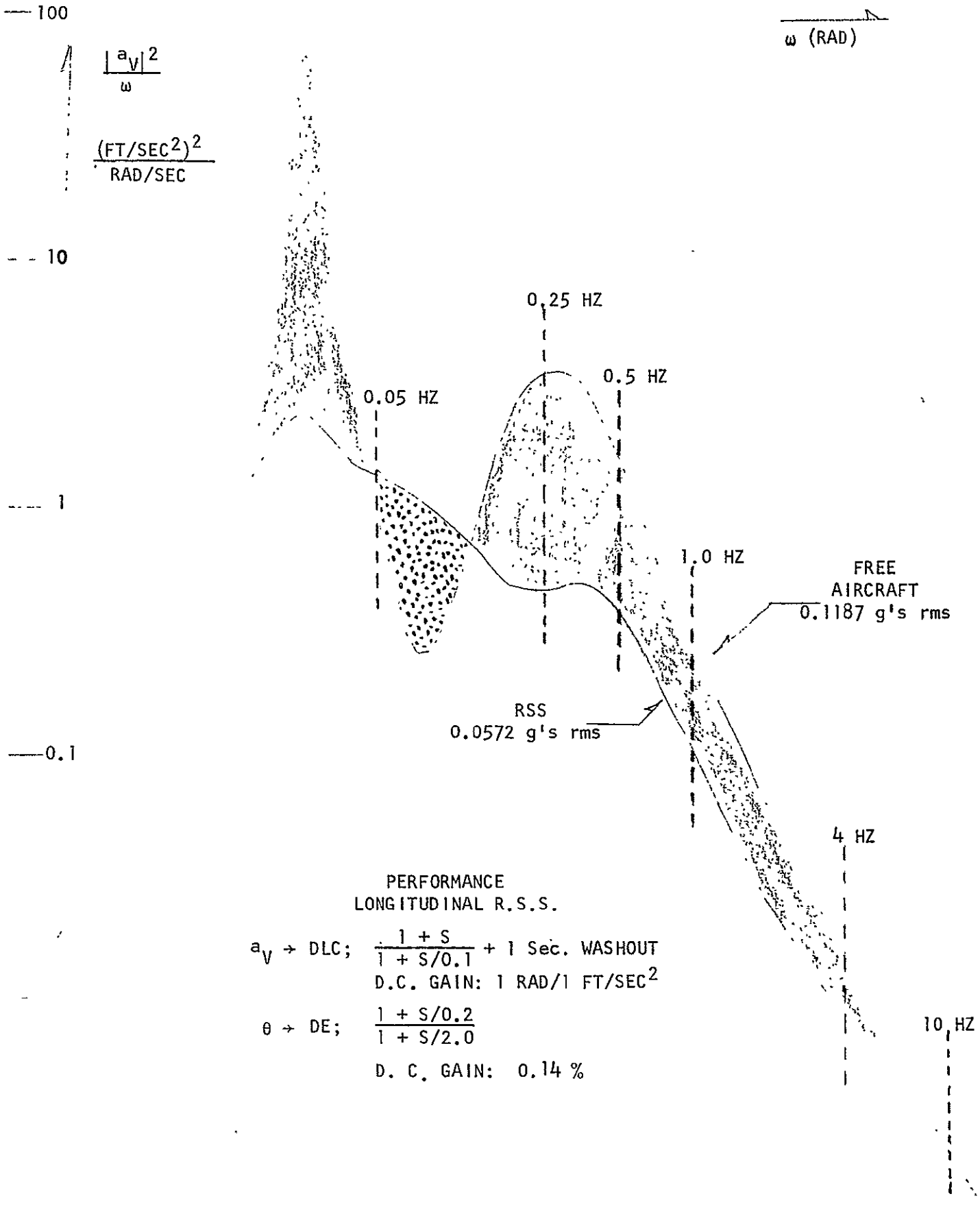




CANDIDATE
SYSTEM

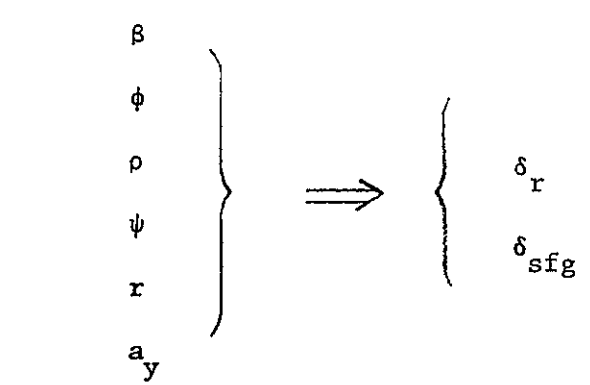

jω
0.10
0.08
K_θ $\left(\frac{\text{degrees } \delta_e}{\text{degrees } \theta}\right)$
0.2
0.4
K_{a_V}
$\left(\frac{\text{radians } \delta_{dlf}}{\text{ft/sec}^2 \ a_V}\right)$
0.6
0.8
1.0
1.2
1.4
1.5
1.0
0.5
K_{a_V}
K_θ
-1.0
-0.5

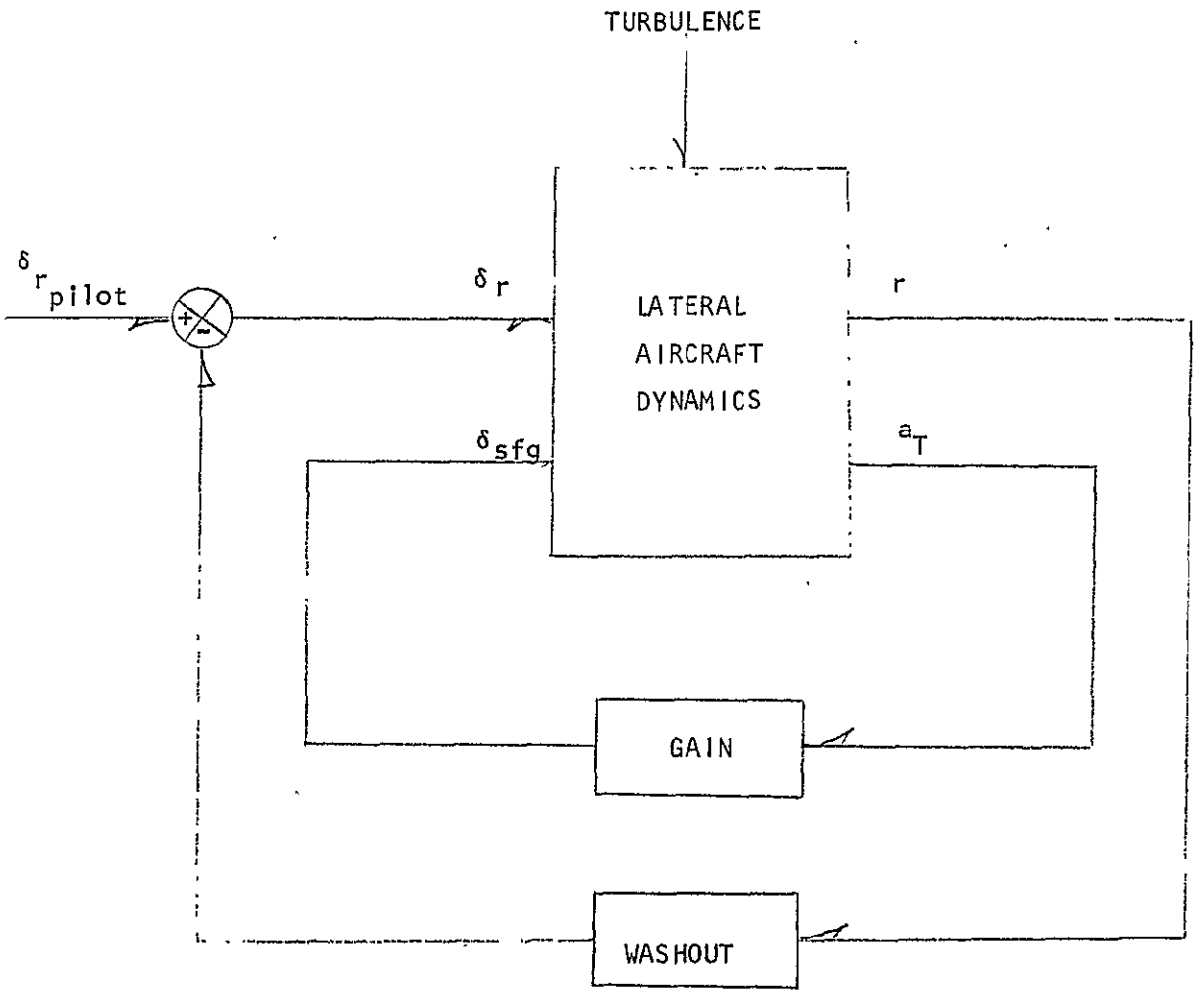
ROOT LOCUS


100
10
1
0.1
$\frac{|a_V|^2}{\omega}$
$\frac{(FT/SEC^2)^2}{RAD/SEC}$
ω (RAD)
0.25 HZ
0.5 HZ
0.05 HZ
1.0 HZ
4 HZ
10 HZ
FREE AIRCRAFT
0.1187 g's rms
RSS
0.0572 g's rms
PERFORMANCE
LONGITUDINAL R.S.S.
$a_V \rightarrow$ DLC; $\frac{1 + S}{1 + S/0.1}$ + 1 Sec. WASHOUT
D.C. GAIN: 1 RAD/1 FT/SEC^2
$\theta \rightarrow$ DE; $\frac{1 + S/0.2}{1 + S/2.0}$
D. C. GAIN: 0.14 %

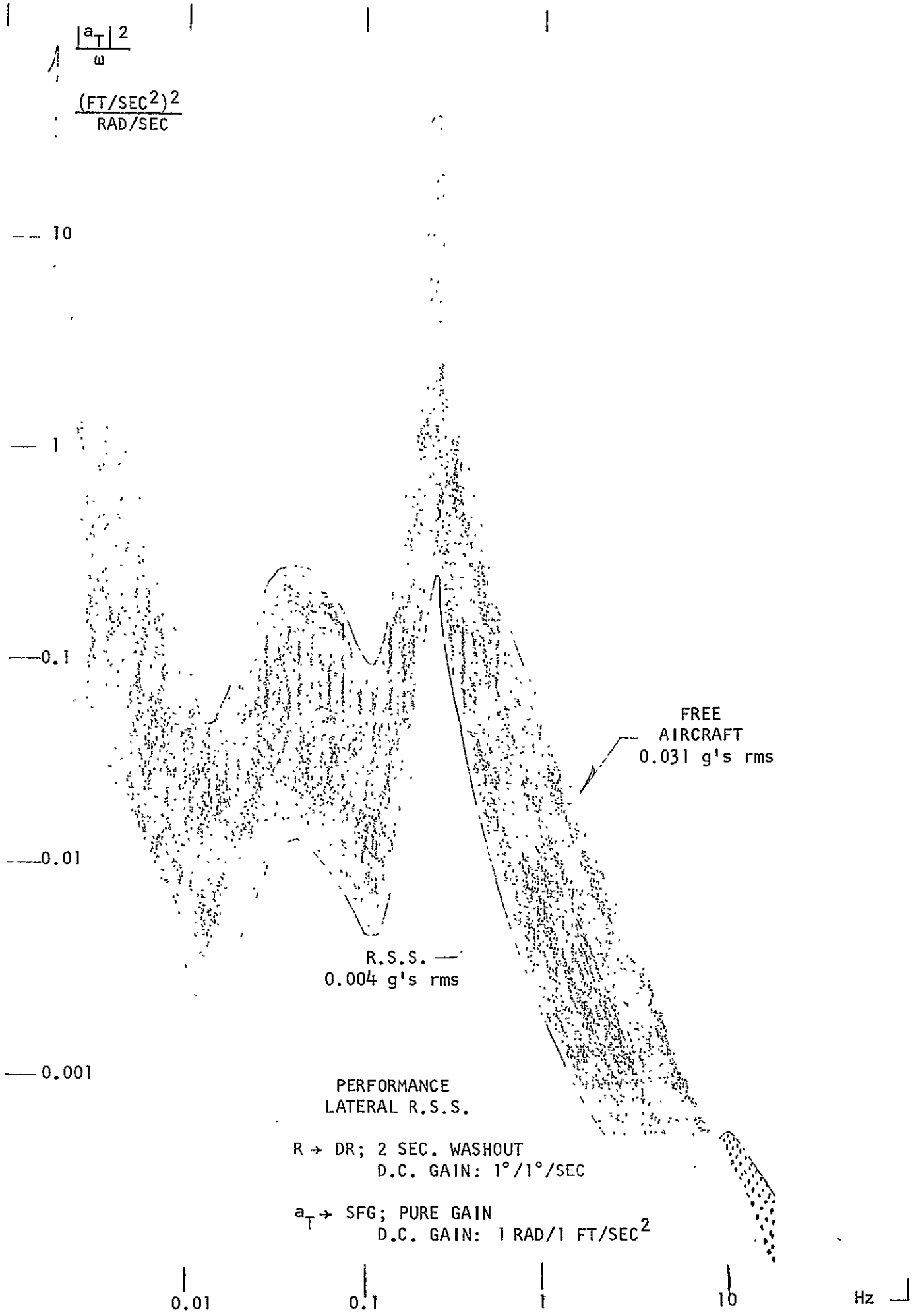
	BASIC JETSTAR	JETSTAR & R.S.S.
• a_V IN RESPONSE TO 7 FT/SEC (rms) GUST FIELD	0.1187 g's	0.0572 g's
• % REDUCTION a_V		54.2%
• SHORT PERIOD MODE		
- PERIOD	4.5 sec.	3.4 sec.
- TIME TO $\frac{1}{2}$ AMPLITUDE	0.76 sec.	0.55 sec.
• PHUGOID MODE		
- PERIOD	36.6 sec.	53.2 sec.
- TIME TO $\frac{1}{2}$ AMPLITUDE	74.8 sec.	9.6 sec.
• DIRECT LIFT FLAP ACTIVITY (rms)		9.9°
• ELEVATOR ACTIVITY (rms)		0.4°

LATERAL CASE

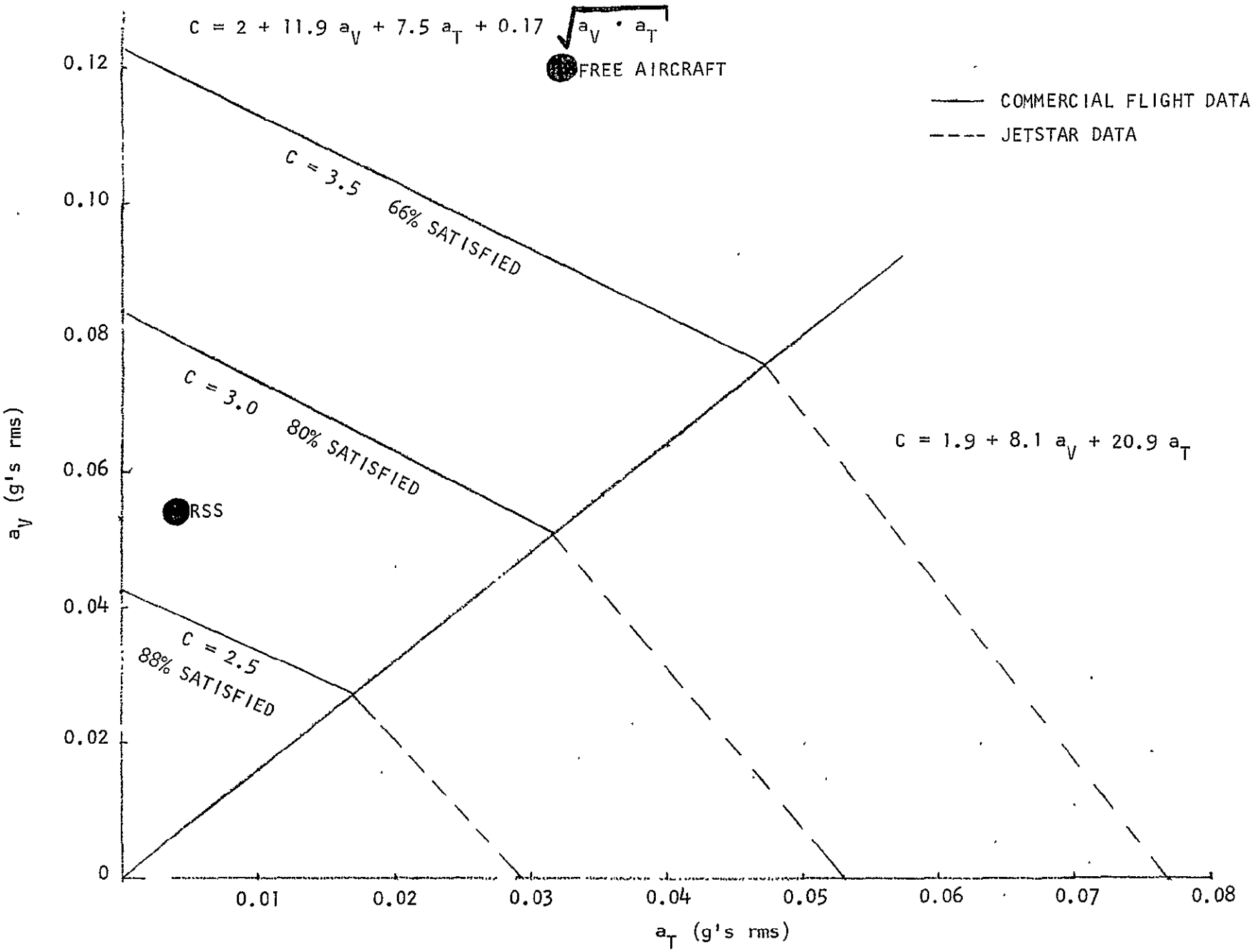




CANDIDATE
SYSTEM


$\frac{|a_T|^2}{\omega}$
$\frac{(FT/SEC^2)^2}{RAD/SEC}$
10
1
0.1
0.01
0.001
FREE
AIRCRAFT
0.031 g's rms
R.S.S.
0.004 g's rms
PERFORMANCE
LATERAL R.S.S.
R → DR; 2 SEC. WASHOUT
D.C. GAIN: 1°/1°/SEC
a_T → SFG; PURE GAIN
D.C. GAIN: 1 RAD/1 FT/SEC^2
0.01
0.1
1
10
Hz

	BASIC JETSTAR	JETSTAR & R.S.S.
• a_T IN RESPONSE TO 7 FT/SEC (rms) GUST FIELD	0.031 g's	0.004 g's
• % REDUCTION IN a_T		88%
• DUTCH ROLL MODE		
- PERIOD	4.6 sec.	5.3 sec.
- TIME TO $\frac{1}{2}$ AMPLITUDE	11.2 sec.	2.6 sec.
• ROLL MODE		
- TIME TO $\frac{1}{2}$ AMPLITUDE	0.62 sec.	0.61 sec.
• SPIRAL MODE		
- TIME TO $\frac{1}{2}$ (DOUBLE) AMPLITUDE	418 sec.	(42) sec.
• SIDE FORCE GENERATOR ACTIVITY (rms)		6.2°
• RUDDER ACTIVITY (rms)		0.9°



PRELIMINARY RIDE COMFORT CRITERIA

University of Virginia
April 1974

UNCERTAINTIES	EVALUATION
● AIRCRAFT AERODYNAMICS	FLIGHT
● SYSTEM NON-LINEARITY	FLIGHT
● HANDLING QUALITIES	SIMULATION/FLIGHT
● FAILURE MODES	SIMULATION