APPENDIX A

N92-21484

PILOT/VEHICLE MODEL ANALYSIS OF VISUALLY GUIDED FLIGHT

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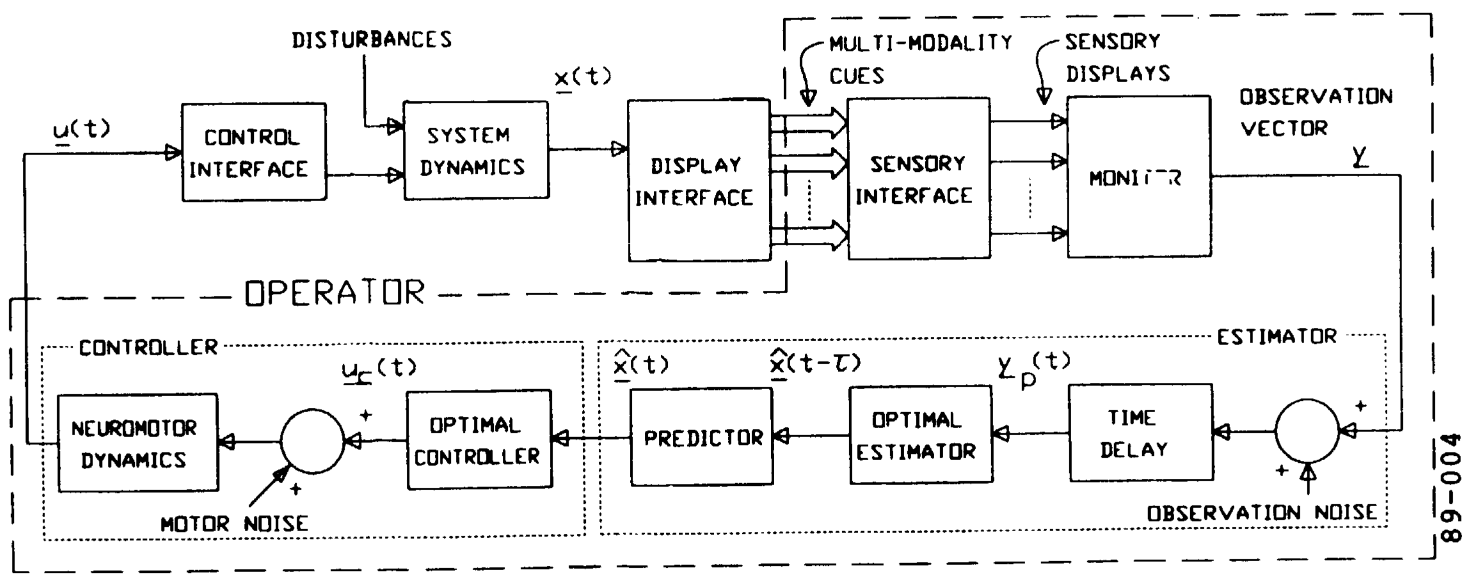
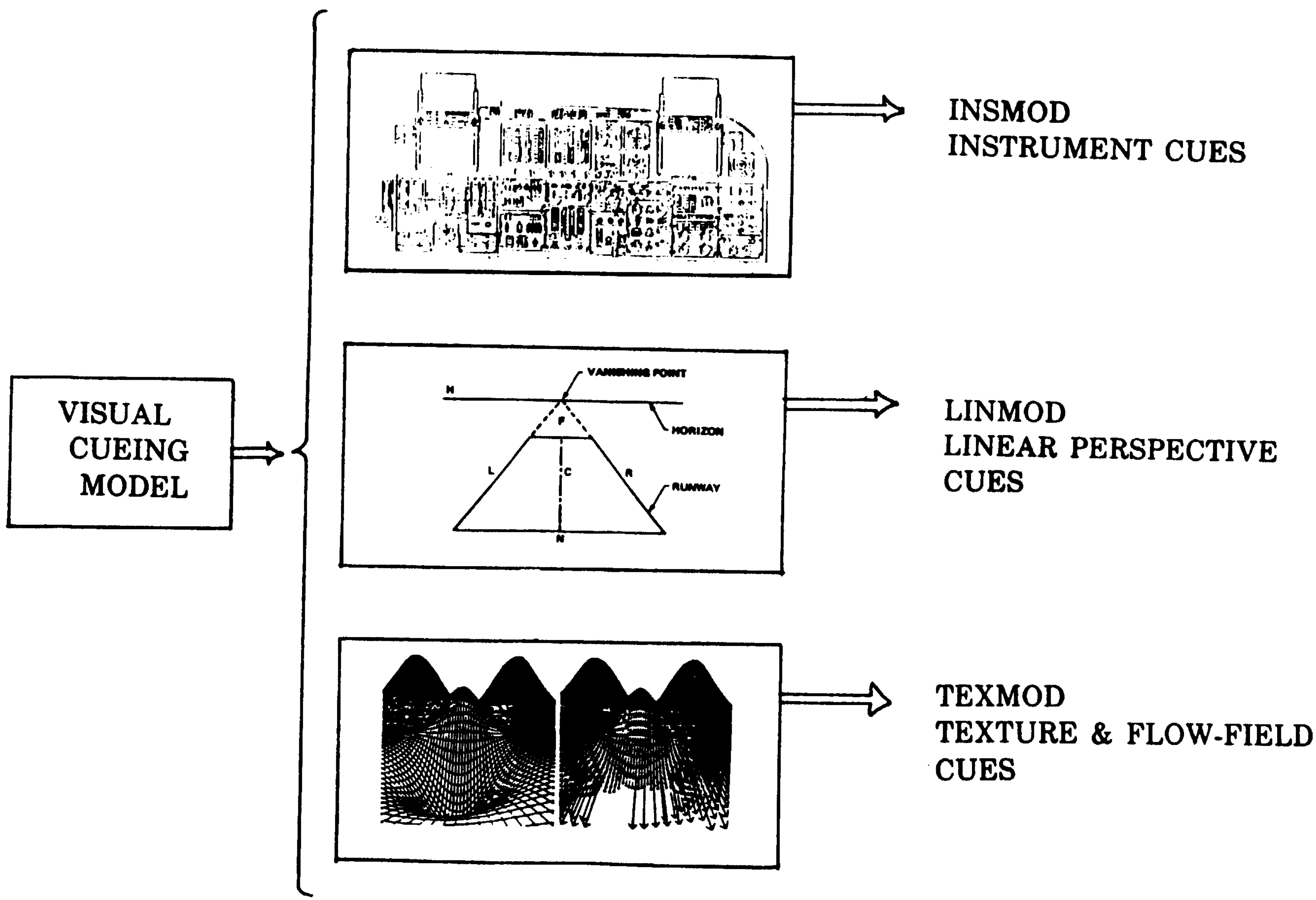
PILOT/VEHICLE MODEL ANALYSIS OF VISUALLY-GUIDED FLIGHT

- o PILOT/VEHICLE MODEL DESCRIPTION
- o CONTROL OF ALTITUDE WITH SIMPLE TERRAIN CUES
- o SIMULATED FLIGHT WITH VISUAL SCENE DELAYS
- o MODEL-BASED IN-COCKPIT DISPLAY DESIGN
- o RANDOM THOUGHTS

OPTIMAL CONTROL MODEL OF PILOT/VEHICLE SYSTEM

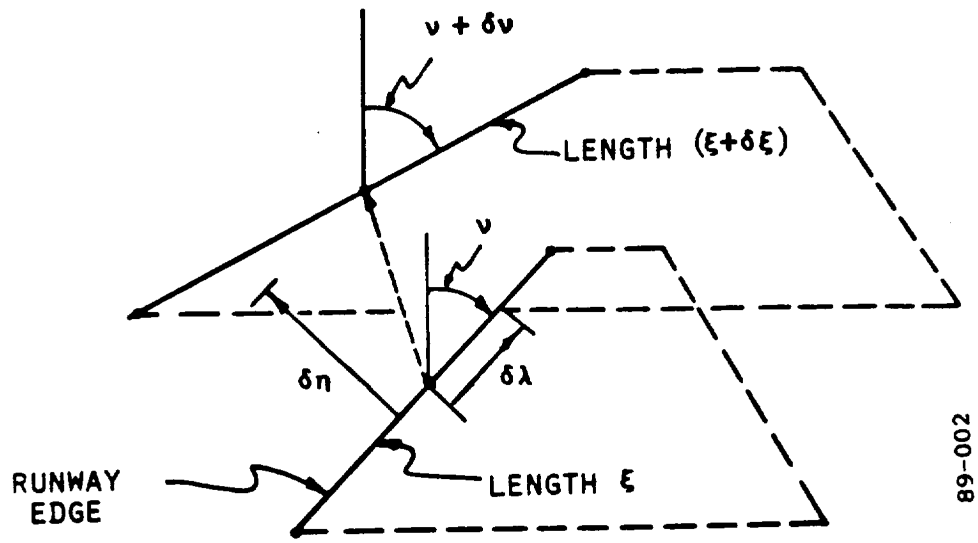


VISUAL SUBMODELS



LINMOD: LINEAR PERSPECTIVE CUES

o PILOT'S VIEW DURING LANDING APPROACH



o LINEAR PERSPECTIVE CUES

- Length : scalar ξ, angular units
- Orientation: scalar ν, angular units wrt observer reference
- Location : vector (λ, η), angular units specifying midpoint LOS

o MODELING REQUIREMENTS

- How does change in vehicle state (position/attitude) relate to change in cues?

- Find

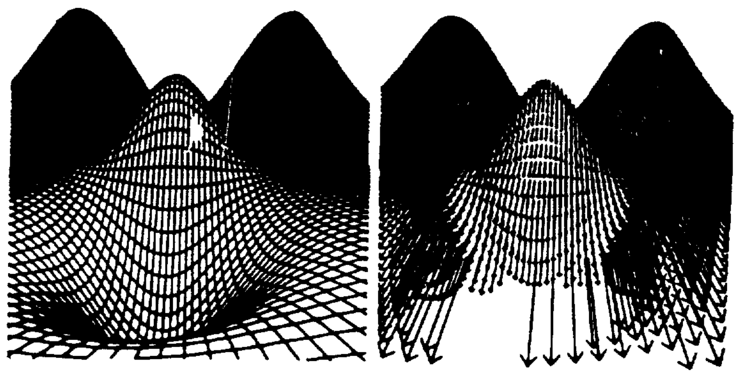
$$\underline{y}_{vis} \equiv (\xi, \nu, \lambda, \eta) = \underline{f}(\underline{x}) + \underline{v}_y$$

&

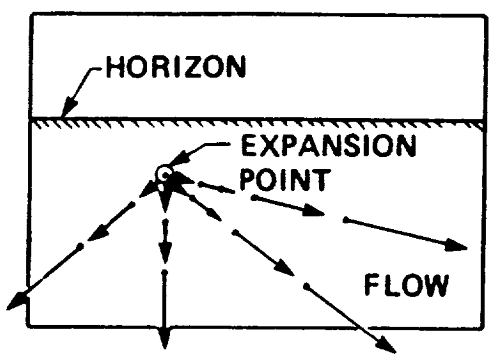
$$\delta \underline{y}_{vis} = \frac{\partial f}{\partial \underline{x}} \delta \underline{x} + \underline{v}_y$$

TEXMOD: TEXTURAL FLOW-FIELD CUES

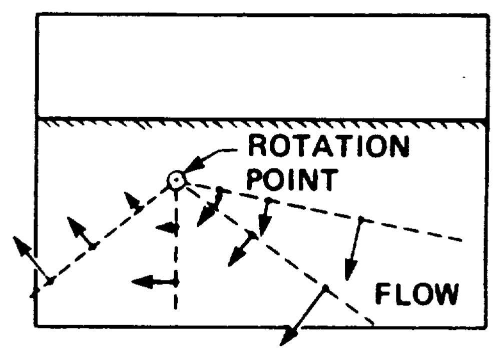
- PILOT'S VIEW DURING TF/TA

static  dynamic

- AIMPOINT AND SPIN AXIS ESTIMATION



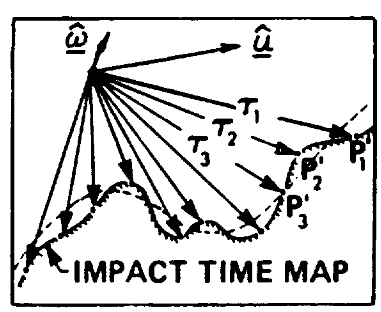
translation



rotation

- MODEL OUTPUTS

  - Aimpoint
  - Angular velocity
  - Impact time map
  - Relative orientation



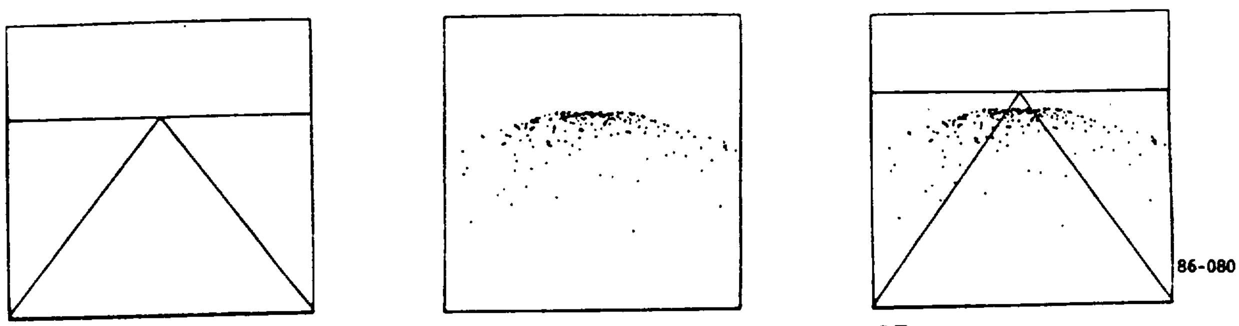
SIMPLE TERRAIN CUEING: TASK DESCRIPTION

- o TASK: Altitude regulation against vertical gust

- o DYNAMICS:

    - Gust : First Order Dryden, BW = 12 rad/s
    - Vehicle: F-16 at SL, 400 kts, SAS-augmented

- o DISPLAYS:



R: ROADWAY T: TEXTURE RT: ROADWAY & TEXTURE

- o DISPLAY VARIABLES

    - Roadway-only: $(\beta, \dot{\beta})$ from roadway
      (θ, q) from horizon

    - Texture-only: (h, γ) from textural flow
      (θ, q) from pseudo-horizon

    - Combined RT: $(\beta, \dot{\beta}, h, \gamma, \theta, q)$

- o VISUAL CUE THRESHOLDS

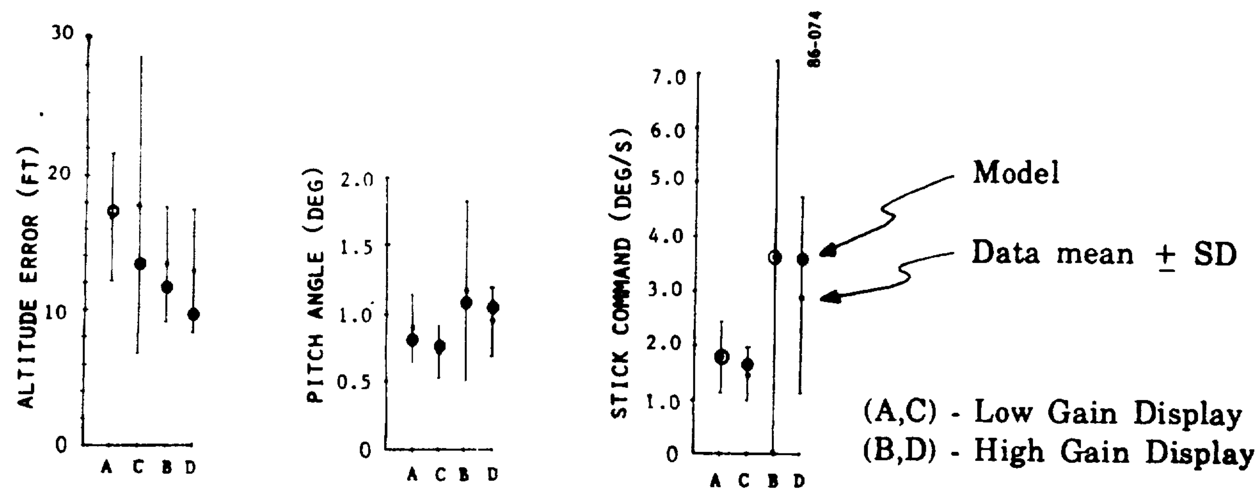
    $(\beta, \dot{\beta})_{th}$ & $(\theta, q)_{th}$ from acuity estimates

    $(h, \gamma)_{th}$ from textural flow model

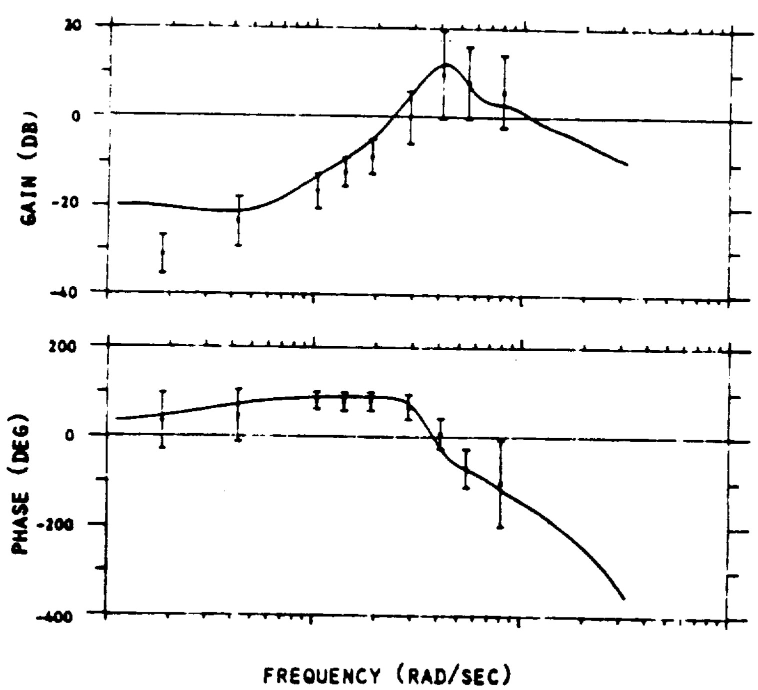
- o REFERENCE: WARREN & RICCIO (85); ZACHARIAS, WARREN & RICCIO (86)

SIMPLE TERRAIN CUEING: DATA & MODEL

o PERFORMANCE SCORES



o PILOT FREQUENCY RESPONSE (stick/error)



Condition B:
High Gain
Small Angle

PILOT MODEL PARAMETERS FROM DATA ANALYSIS

- DISPLAY VARIABLES
  - ROADWAY-ONLY: $(\beta_e, \dot{\beta}_e)$ FROM ROADWAY
    (θ, q) FROM HORIZON
  - TEXTURE-ONLY: (h_e, γ) FROM TEXTURAL FLOW
    (θ, q) FROM PSEUDO-HORIZON
  - COMBINED RT : $(\beta_e, \dot{\beta}_e, h_e, \gamma, \theta, q)$

- ATTENTION ALLOCATION

  70% ON HORIZON; 30% ON ROADWAY/TEXTURE

- VISUAL CUE THRESHOLDS

  $(\beta_e, \dot{\beta}_e)_{th}$ & $(\theta, q)_{th}$ FROM ACUITY ESTIMATES
  $(h_e, \gamma)_{th}$ FROM TEXMOD SIMULATIONS

- OBSERVATION NOISE RATIO: - 18dB

- MOTOR PARAMETERS
  - TIME CONSTANT: 0.2s → 0.4s
  - MOTOR NOISE : -40dB → -50dB

- CENTRAL DELAY: 0.15s

PILOT MODEL PARAMETER VALUES FROM DATA ANALYSIS

PARAMETER		UNITS	DISPLAY TYPE: ROADWAY (R)	TEXTURE (T)	COMBINED (RT)
MOTOR TIME CONSTANT τ_N					
LOW GAIN	(A,C)	SEC	0.30	0.40	0.30
HIGH GAIN	(B,D)	SEC	0.20	0.35	0.20
MOTOR NOISE					
MOTOR NOISE, MN		dB	-50	-50	-50
PERCEIVED MOTOR NOISE, PMN		dB	-50	-40	-50
PROCESSING TIME DELAY τ_D		SEC	0.15	0.15	0.15
PERCEPTUAL NOISE LEVEL P_O		dB	-18	-18	-18
ATTENTION ALLOCATION					
HORIZON	(θ, q)	--	0.70	0.70	0.70
ROADWAY	$(\beta_e, \dot{\beta}_e)$	--	0.30		0.15
TEXTURE	(h_e, γ)	--		0.30	0.15
VISUAL CUE THRESHOLDS					
HORIZON	(θ_{th}, q_{th})	$(^\circ, ^\circ/s)$	(1, .28)	(2, .56)	(1, .28)
ROADWAY	$(\beta_{th}, \dot{\beta}_{th})$	$(^\circ, ^\circ/s)$	(*,1)		(*,1)
TEXTURE	(h_{th}, γ_{th})	(FT, $^\circ$)		(**,2)	(**,2)

$*\beta_{th} = (90^\circ - \beta_a)/6$ $\qquad$ $**h_{th} = 0.3h_a$

SIMPLE TERRAIN CUEING: EXPERIMENTAL RESULTS & MODEL FINDINGS

- EFFECTS DUE TO DISPLAY TYPE:
  - Roadway-only provides adequate cues for task
  - Texture-only does also, but yields larger tracking errors, lower gains, greater lags, more remnant
  - Combined roadway-texture looks like roadway-only

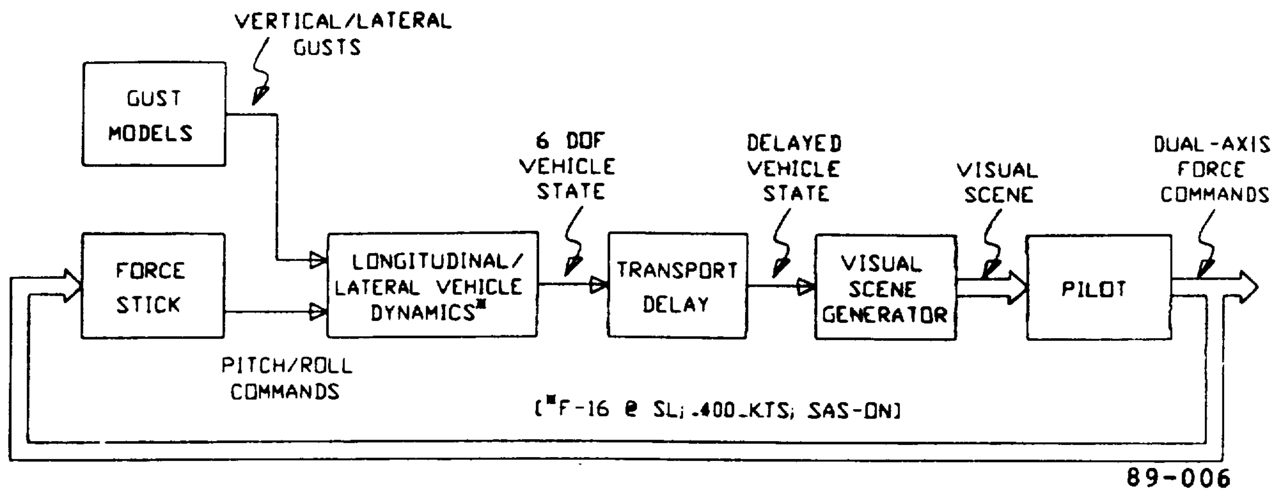
- MODEL ANALYSIS FOLLOWED PERFORMANCE & FREQUENCY RESPONSE TRENDS ACROSS 3 DISPLAYS AND 4 FLIGHT CONDITIONS
  - Scores: Almost all within one SD
  - Gains/Phases: Almost all within one SD, but some gain mismatch at low frequencies
  - Remnant: Most within fraction of SD, but mid-frequency "plateau" missed

- DISPLAY EFFECTS MODELING
  - Roadway-only well-modeled by simple linear cue model
  - Texture-only modeled by TEXMOD-generated thresholds & increased motor time constant
  - Combined roadway-texture is dominated by roadway cues

SCENE GENERATOR DELAYS: TASK DESCRIPTION

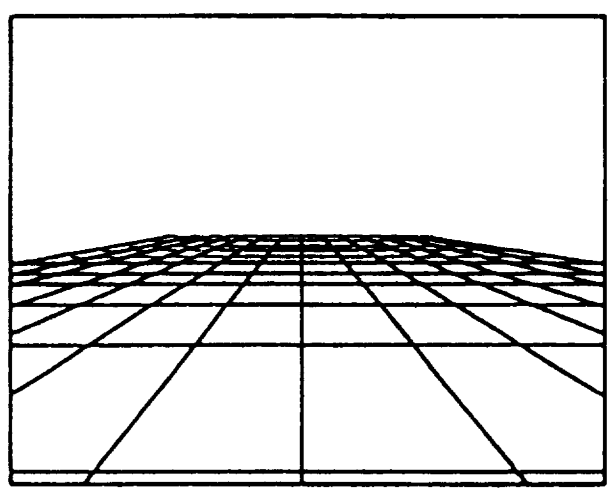
- TASK: FLY STRAIGHT & LEVEL AGAINST VERTICAL/LATERAL GUSTS

- OVERALL PILOT/VEHICLE BLOCK DIAGRAM



- DELAY FACTORS: 50, 100, 200, 400 msec

- VISUAL SCENE



- REFERENCE: RICCIO, CRESS, AND JOHNSON (87)

SCENE GENERATOR DELAYS: MODEL ANALYSIS

o TASK OBJECTIVE

- Longitudinal subtask: minimize σ_h^2
- Lateral subtask: minimize $(\sigma_\psi^2 + k\sigma_y^2)$

o DYNAMICS MODEL

- Linearized F16 6 DOF dynamics
- Sea level, 400 kts, SAS-on

o DELAY MODEL

Pade approximations to: 50, 100, 200, 400 msec delays

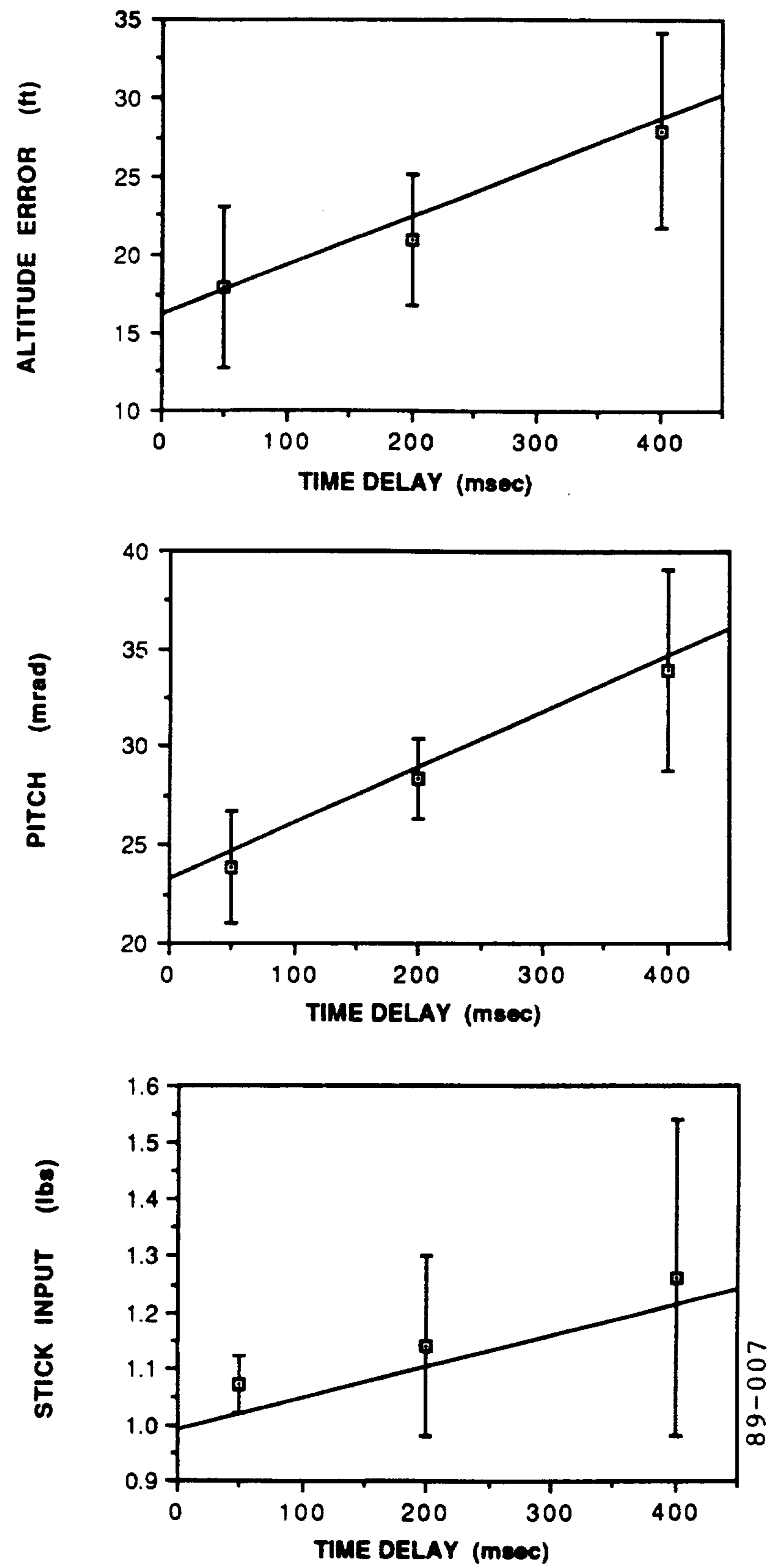
o DISPLAY ANALYSIS

- Meridian texture: (θ, h) & (ϕ, ψ, y)
- Latitude texture: (θ, h) & (ϕ, ψ^*)
- Flow-field cues: rates of above
- Attention allocation set to optimize performance
- Thresholds set to zero

o NON-DISPLAY PILOT PARAMETERS

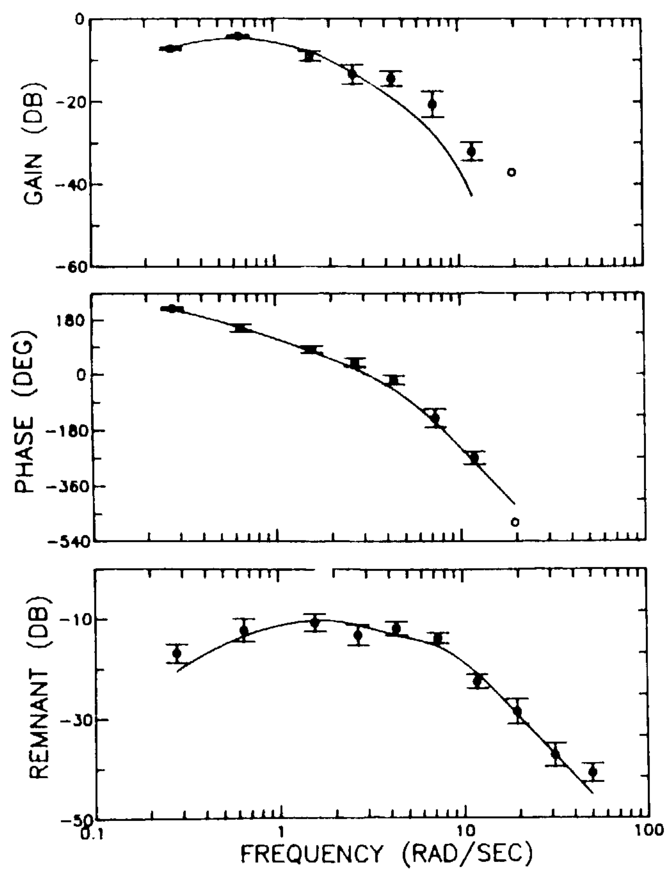
Fixed across conditions, except for increasing delay

DELAY EFFECTS ON PERFORMANCE: DATA & MODEL



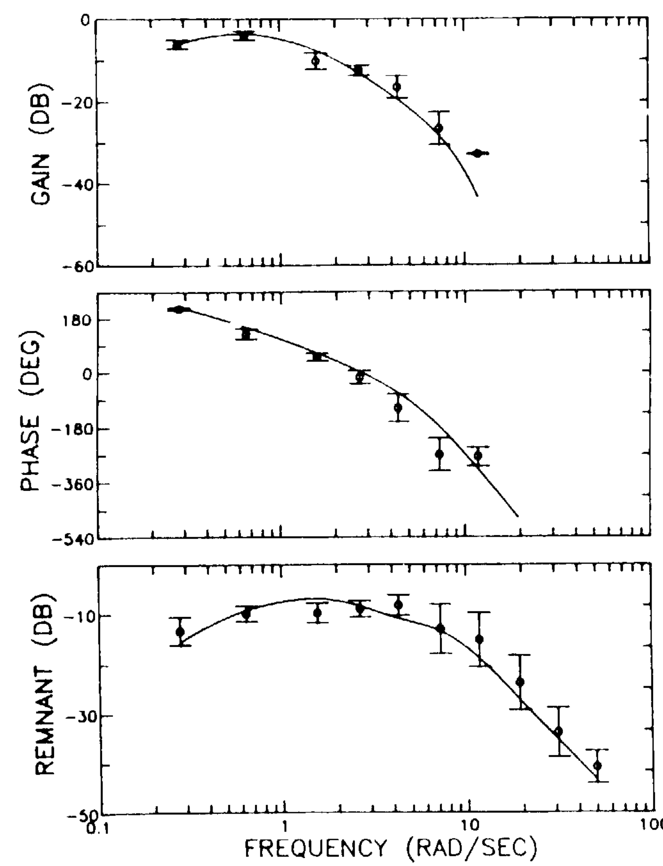
DELAY EFFECTS ON PILOT FREQUENCY RESPONSE: DATA & MODEL

o SHORT DELAY RESPONSE (50 msec)



o stable gain
o increased lag
o increased remnant

o LONG DELAY RESPONSE (400 msec)



SCENE GENERATOR DELAYS: EXPERIMENTAL RESULTS & MODEL FINDINGS

- o EFFECTS DUE TO INCREASING DELAYS
  - More stick activity & poorer performance
  - Increased response lags
  - Increased remnant (more random)

- o MODEL ANALYSIS MATCH TO PERFORMANCE & FREQUENCY TRENDS
  - Performance trends with delays closely matched
  - Gain, phase, & remnant trends with frequency also well-matched
  - Obtained with fixed model parameters, except for increasing pilot delays

COCKPIT DISPLAY DESIGN: TASK DESCRIPTION

- o TASK: LOW-LEVEL TERRAIN-FOLLOWING AT CONSTANT HEADING

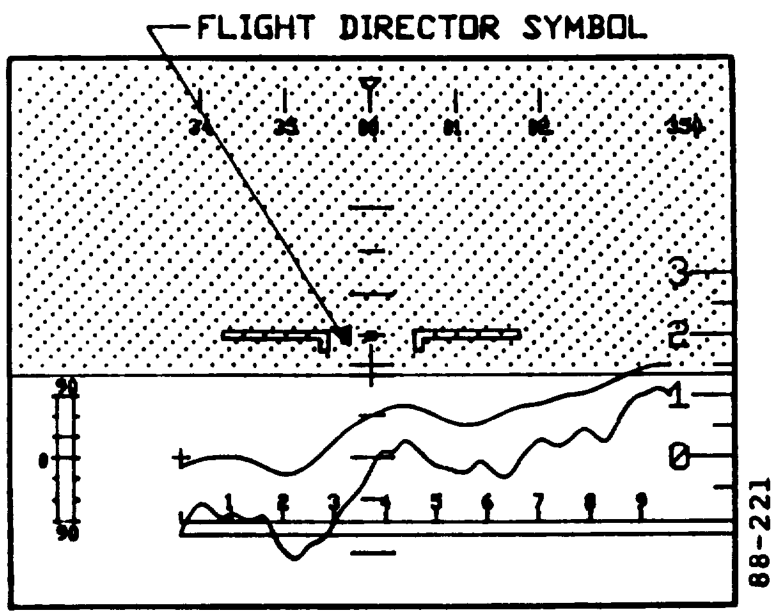
- o DYNAMICS:

  - Terrain: Second order matched terrain spectra

  - Terrain-following guidance: Low order predictor

  - Vehicle: B-1B at SL, Mach 0.85, SAS-augmented

- o DISPLAY



- o DIRECTOR LAW

  - Law: $\theta_{fd} = \alpha + \gamma_{dfp} - k * h_{error}$

  - Optimize director gain k

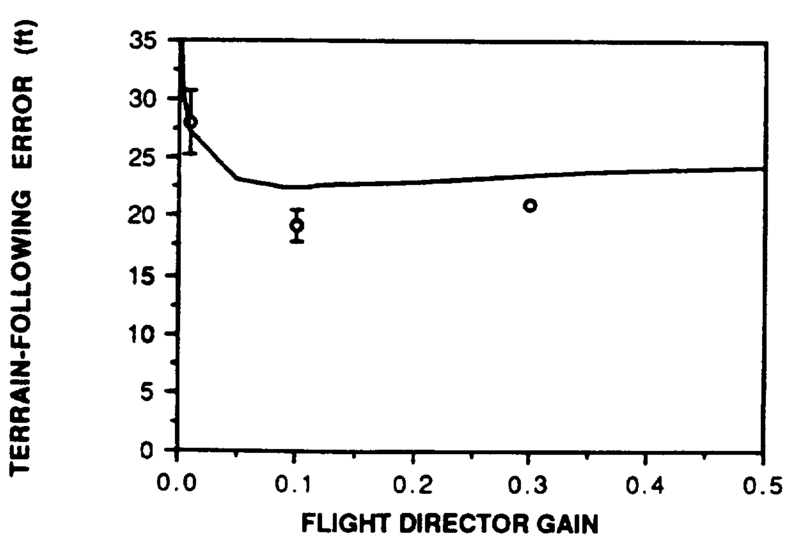
COCKPIT DISPLAY DESIGN: MODEL-BASED PROCEDURE

- o CONDUCT PILOTED SIMULATION TO IDENTIFY BASELINE PILOT PARAMETERS

- o SWEEP THRU DIRECTOR GAINS TO IDENTIFY OPTIMUM CHOICE

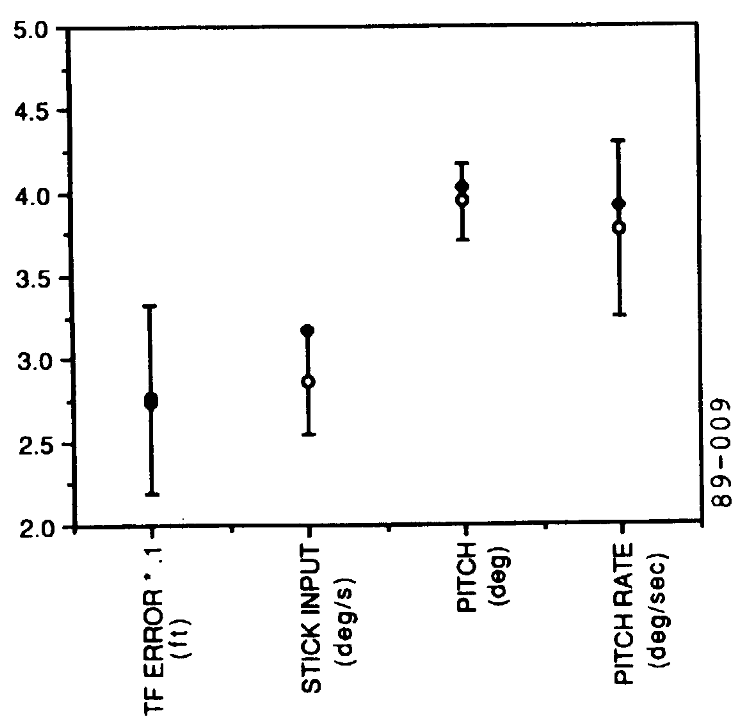
- o CONFIRM CHOICE WITH SIMULATION USING OPTIMIZED DIRECTOR

- o PRELIMINARY MODEL/DATA COMPARISONS (SINGLE SUBJECT)

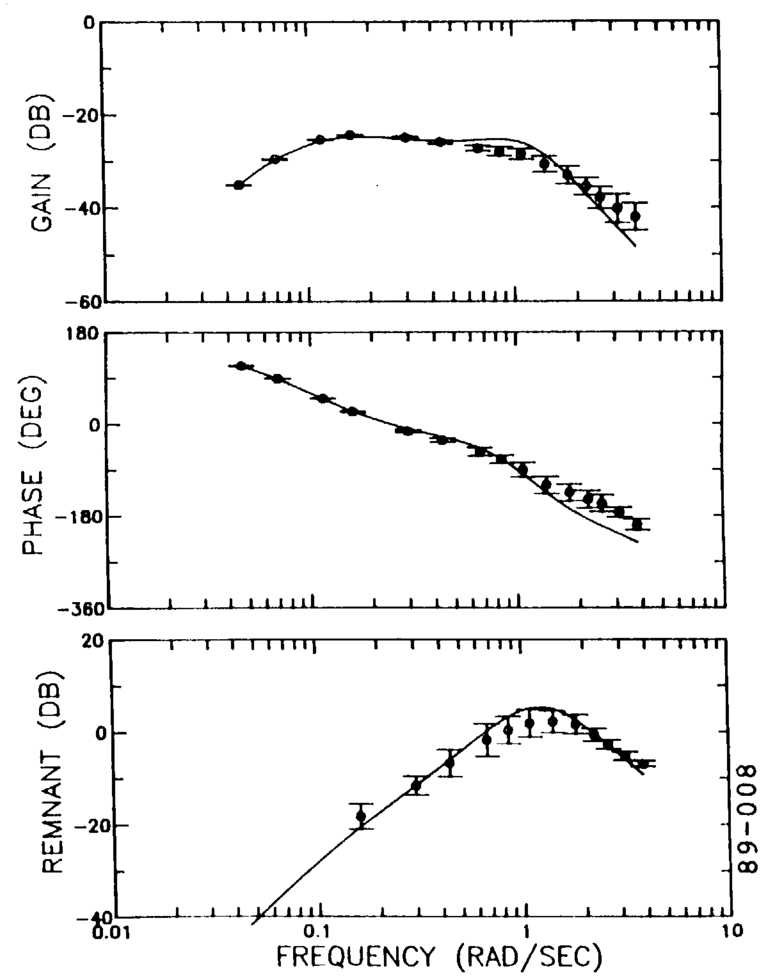


COCKPIT DISPLAY DESIGN: DATA AND MODEL

o PERFORMANCE SCORES

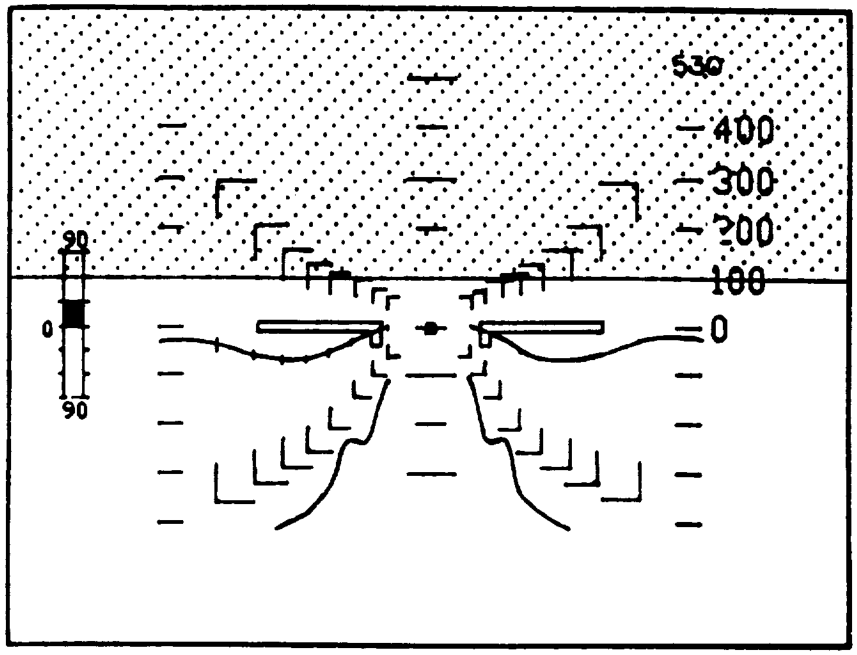


o FREQUENCY RESPONSE



BASELINE PICTORIAL GUIDANCE DISPLAY

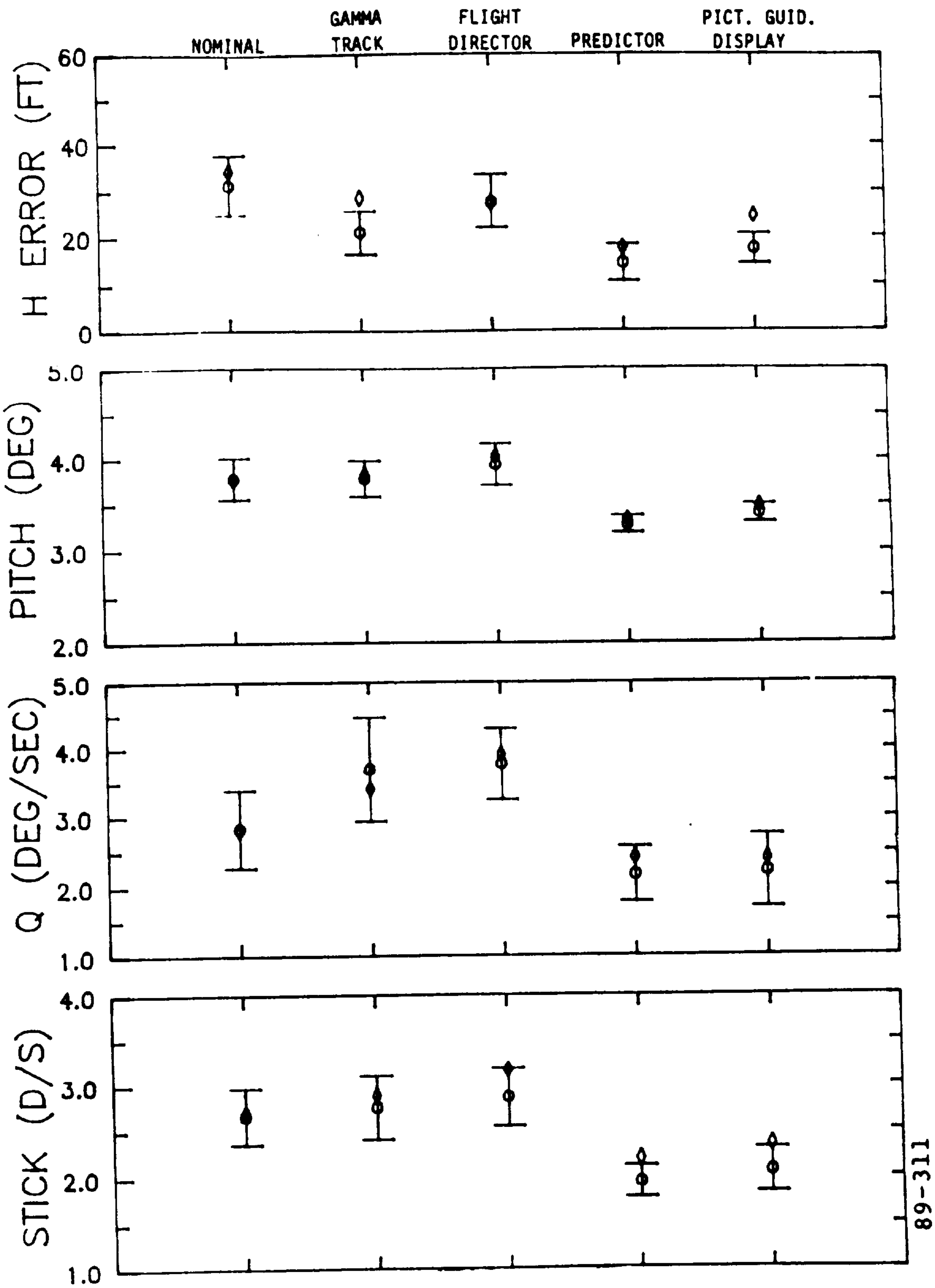
o DISPLAY FORMAT



o KEY FEATURES

- Perspective view of TP & DFP overlaid on artificial horizon
- Artificial horizon gives attitude
- DFP-centered tunnel gives vertical/lateral path errors
- Tunnel dimensions indicate desired TF performance
- ADP gives high-gain TF error via indicator
- Path preview supports situational awareness
- Display integration minimizes attention-sharing

OPERATOR PERFORMANCE SCORES: VSD & PGD



SUMMARY AND CONCLUSIONS

- SIMPLE TERRAIN CUEING DEMONSTRATES MODEL MATCH OF DOMINANCE EFFECTS
- SCENE GENERATOR DELAY TRENDS FOLLOWED VIA MODEL ANALYSIS
- MODEL-BASED DISPLAY DESIGN SUPPORTS DIRECTOR OPTIMIZATION
- GENERAL ROLE OF MODELING
  - Provide structure and insight to multi-dimensional problem
  - Provide means of data compression, interpolation, extrapolation
  - Support design of focused (non-shotgun) experiments
  - Support rational design of new displays

RANDOM THOUGHTS ON ROLE OF PILOT/VEHICLE MODELING

o DOES THE STRUCTURE GAINED BY MODELING OVERLY CONSTRAIN THE RESEARCH?

- New experimental directions
- New model development

o CAN EXCESSIVE COMPRESSION LEAD TO MISSED DATA TRENDS?

o ARE THE TECHNIQUES ADEQUATE TO ACCOUNT FOR OBSERVED BEHAVIOR? OR ARE THEY TOO LIMITED (e.g., LINEAR SYSTEMS)?

o DOES FUNCTIONAL EQUIVALENCE MISLEAD US REGARDING "TRUE" UNDERSTANDING OF THE PERCEPTION/CONTROL PROCESS?

APPENDIX B

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16. Abstract

The papers in this volume were presented at an intensive, three-week workshop on visually guided control of movement. The participants were researchers from academia, industry, and government, with backgrounds in visual perception, control theory, and rotorcraft operations. The papers included invited lectures and preliminary reports of research initiated during the workshop. Three major topics are addressed: extraction of environmental structure from motion; perception and control of self motion; and spatial orientation. Each topic is considered from both theoretical and applied perspectives. Implications for control and display design are suggested.

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