

**APPENDIX A**

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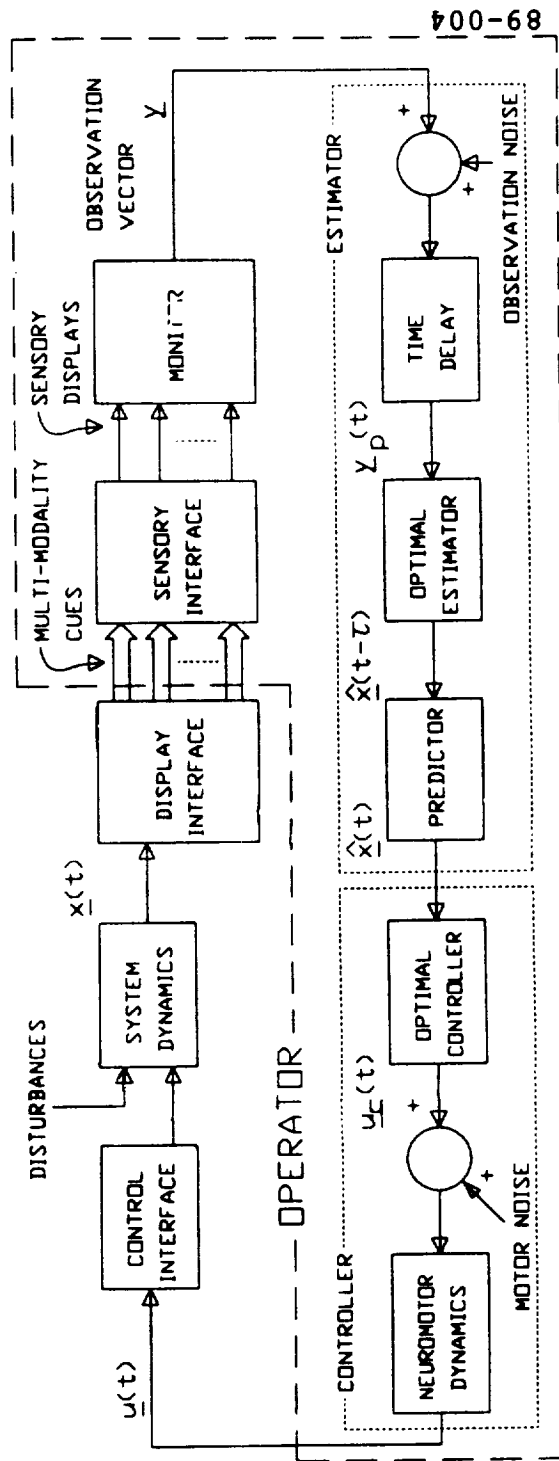
**PILOT/VEHICLE MODEL ANALYSIS OF VISUALLY GUIDED FLIGHT**

Greg L. Zacharias  
Charles River Analytics Inc.  
Cambridge, Massachusetts

**PILOT/VEHICLE MODEL ANALYSIS OF VISUALLY-GUIDED FLIGHT**

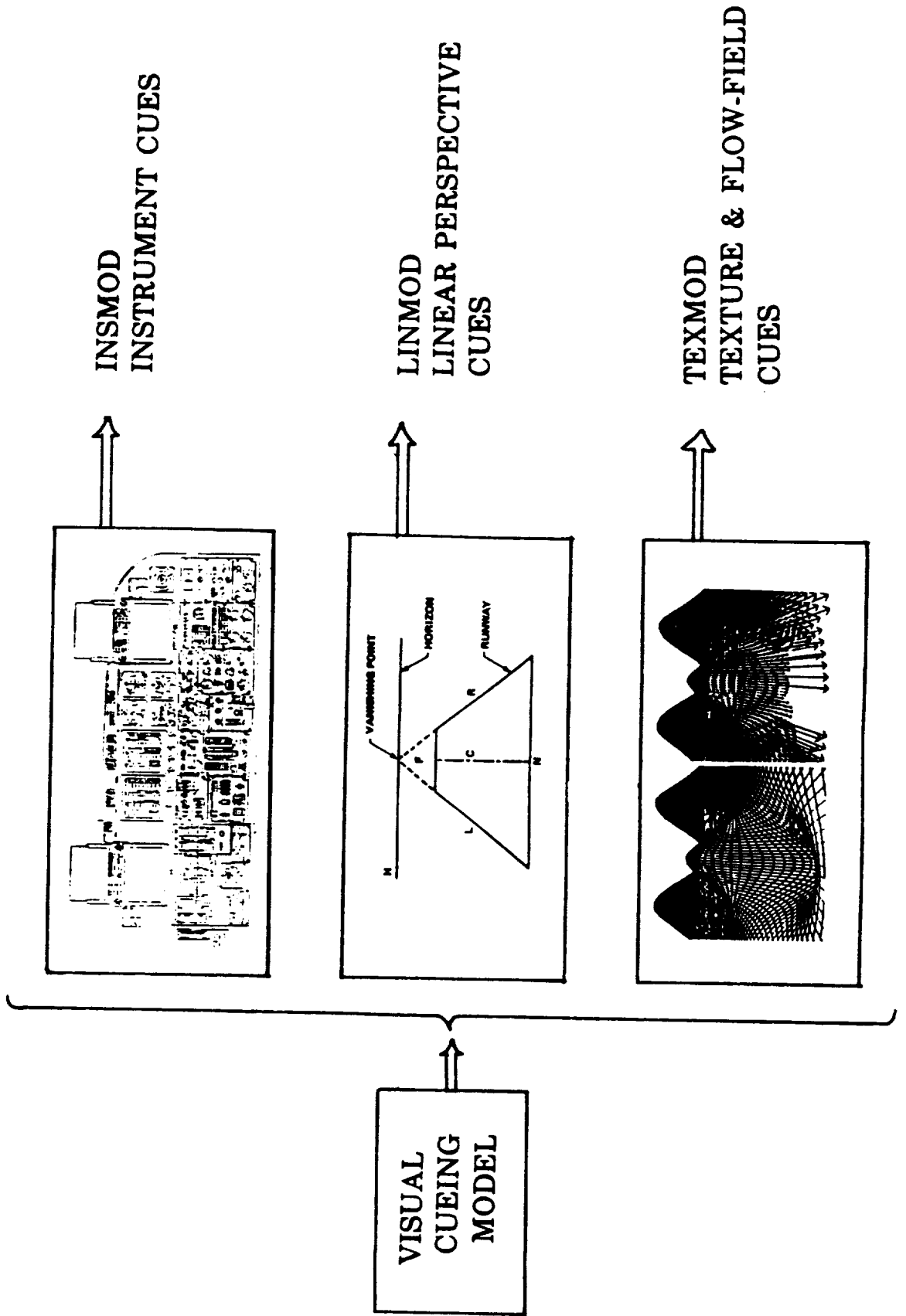
- PILOT/VEHICLE MODEL DESCRIPTION
- CONTROL OF ALTITUDE WITH SIMPLE TERRAIN CUES
- SIMULATED FLIGHT WITH VISUAL SCENE DELAYS
- MODEL-BASED IN-COCKPIT DISPLAY DESIGN
- RANDOM THOUGHTS

# OPTIMAL CONTROL MODEL OF PILOT/VEHICLE SYSTEM



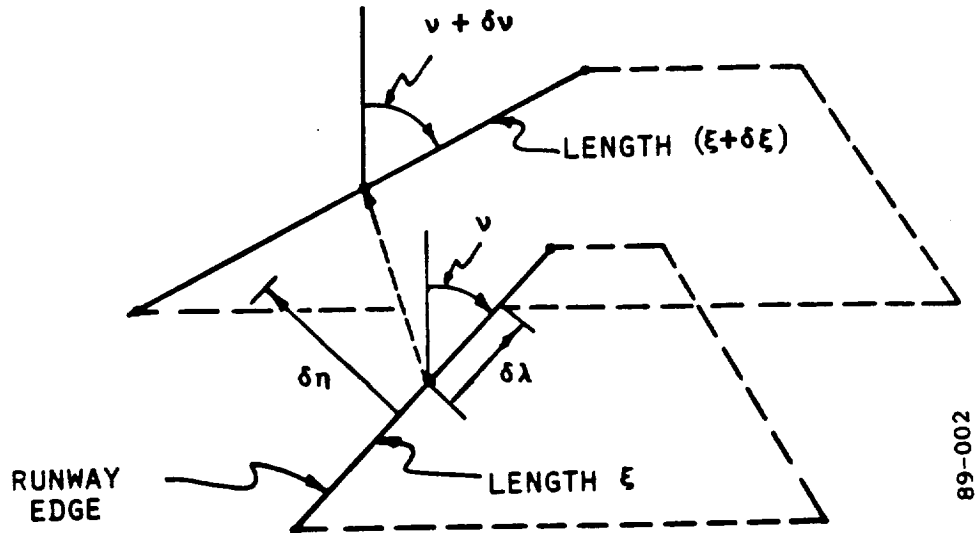
89-004

VISUAL SUBMODELS



## LINMOD: LINEAR PERSPECTIVE CUES

### o PILOT'S VIEW DURING LANDING APPROACH



### o LINEAR PERSPECTIVE CUES

- Length : scalar  $\xi$ , angular units
- Orientation: scalar  $\nu$ , angular units wrt observer reference
- Location : vector  $(\lambda, \eta)$ , angular units specifying midpoint LOS

### o MODELING REQUIREMENTS

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

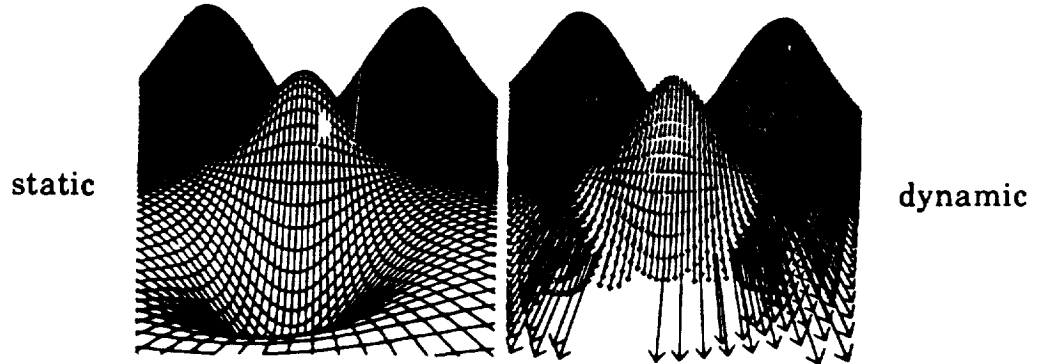
$$\underline{Y}_{vis} \equiv (\xi, \nu, \lambda, \eta) = \underline{f}(\underline{x}) + \underline{v}_y$$

&

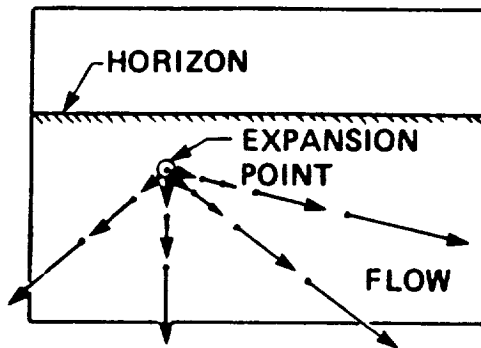
$$\delta \underline{Y}_{vis} = \frac{\partial \underline{f}}{\partial \underline{x}} \delta \underline{x} + \underline{v}_y$$

## TEXMOD: TEXTURAL FLOW-FIELD CUES

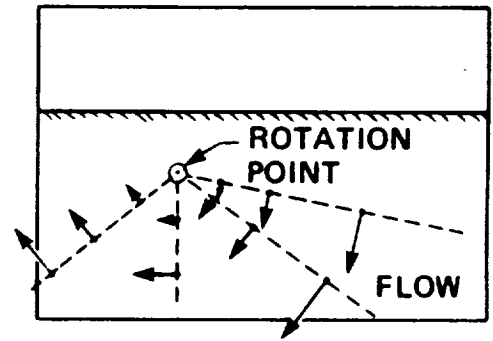
### o PILOT'S VIEW DURING TF/TA



### o AIMPOINT AND SPIN AXIS ESTIMATION



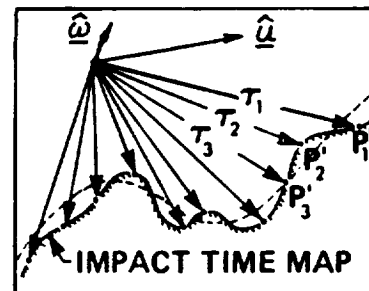
translation



rotation

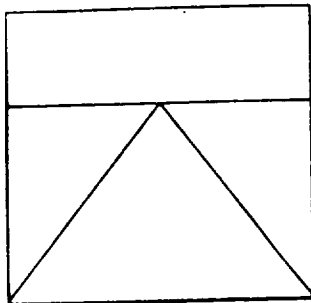
### o MODEL OUTPUTS

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

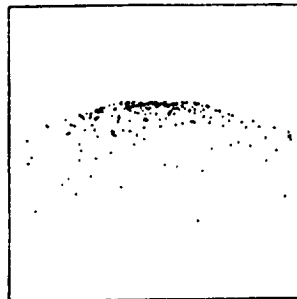


## SIMPLE TERRAIN CUEING: TASK DESCRIPTION

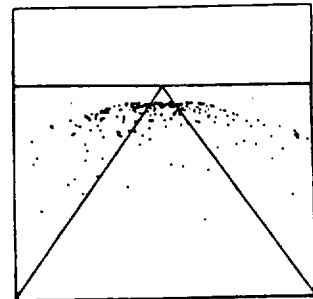
- o TASK: Altitude regulation against vertical gust
- o DYNAMICS:
  - Gust : First Order Dryden, BW = 12 rad/s
  - Vehicle: F-16 at SL, 400 kts, SAS-augmented
- o DISPLAYS:



R: ROADWAY



T: TEXTURE



RT: ROADWAY &  
TEXTURE

86-080

### o DISPLAY VARIABLES

- Roadway-only:  $(\beta, \dot{\beta})$  from roadway  
 $(\theta, q)$  from horizon
- Texture-only:  $(h, \gamma)$  from textural flow  
 $(\theta, q)$  from pseudo-horizon
- Combined RT:  $(\beta, \dot{\beta}, h, \gamma, \theta, q)$

### o VISUAL CUE THRESHOLDS

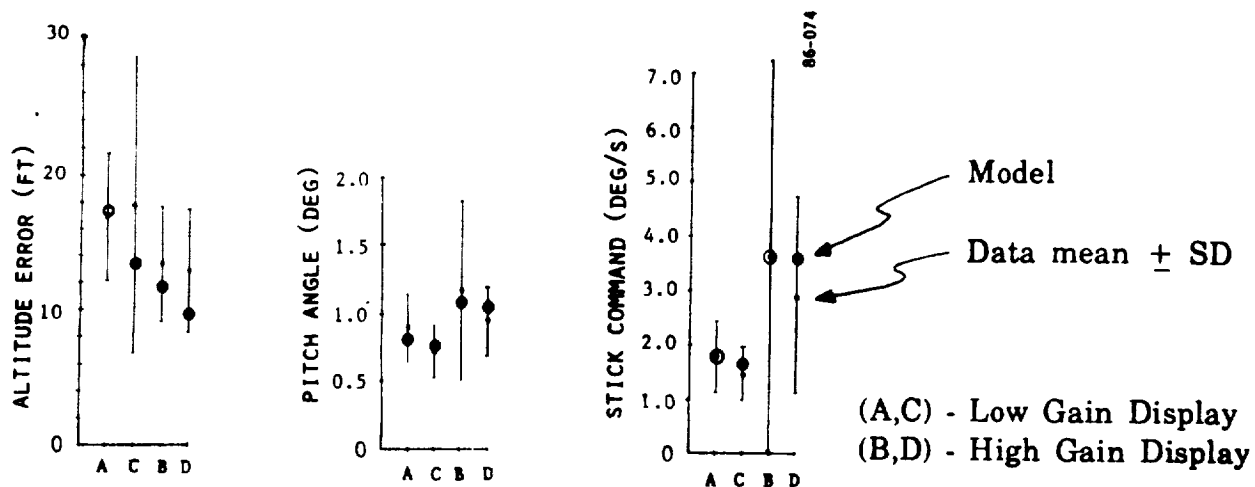
$(\beta, \dot{\beta})_{th}$  &  $(\theta, q)_{th}$  from acuity estimates

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

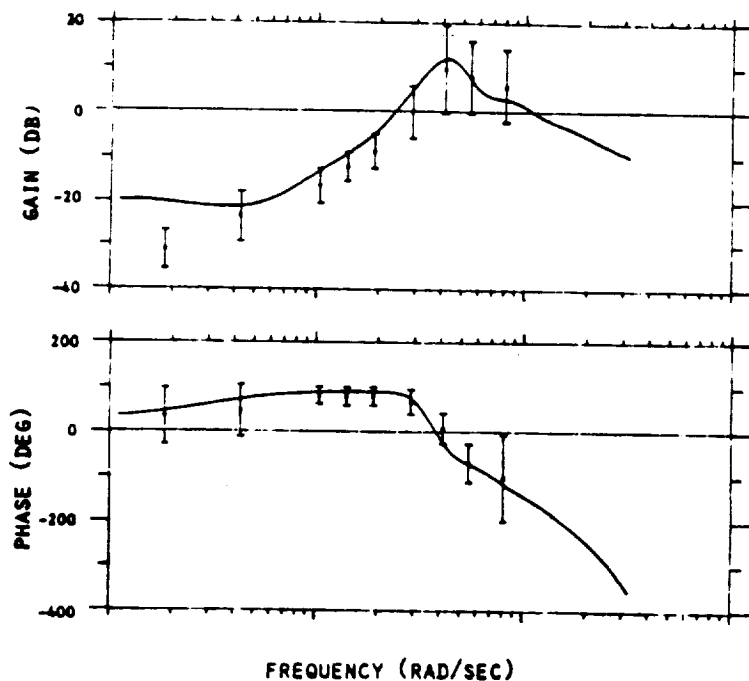
- o REFERENCE: WARREN & RICCIO (85); ZACHARIAS, WARREN & RICCIO (86)

## 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  
 $(\theta, q)$  FROM HORIZON
- TEXTURE-ONLY:  $(h_e, \gamma)$  FROM TEXTURAL FLOW  
 $(\theta, q)$  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  $\rightarrow$  0.4s
- MOTOR NOISE : -40dB  $\rightarrow$  -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 $\tau_N$				
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 $\tau_D$	SEC	0.15	0.15	0.15
PERCEPTUAL NOISE LEVEL $P_0$	DB	-18	-18	-18
ATTENTION ALLOCATION				
HORIZON ( $\theta, \rho$ )	--	0.70	0.70	0.70
ROADWAY ( $\beta_e, \dot{\beta}_e$ )	--	0.30		0.15
TEXTURE ( $h_e, \gamma$ )	--		0.30	0.15
VISUAL CUE THRESHOLDS				
HORIZON ( $\theta_{th}, \rho_{th}$ )	( $^\circ, ^\circ/s$ )	(1, .28)	(2, .56)	(1, .28)
ROADWAY ( $\beta_{th}, \dot{\beta}_{th}$ )	( $^\circ, ^\circ/s$ )	(* , 1)		(* , 1)
TEXTURE ( $h_{th}, \gamma_{th}$ )	(FT, $^\circ$ )		(** , 2)	(** , 2)

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

$$**h_{th} = 0.3h_a$$

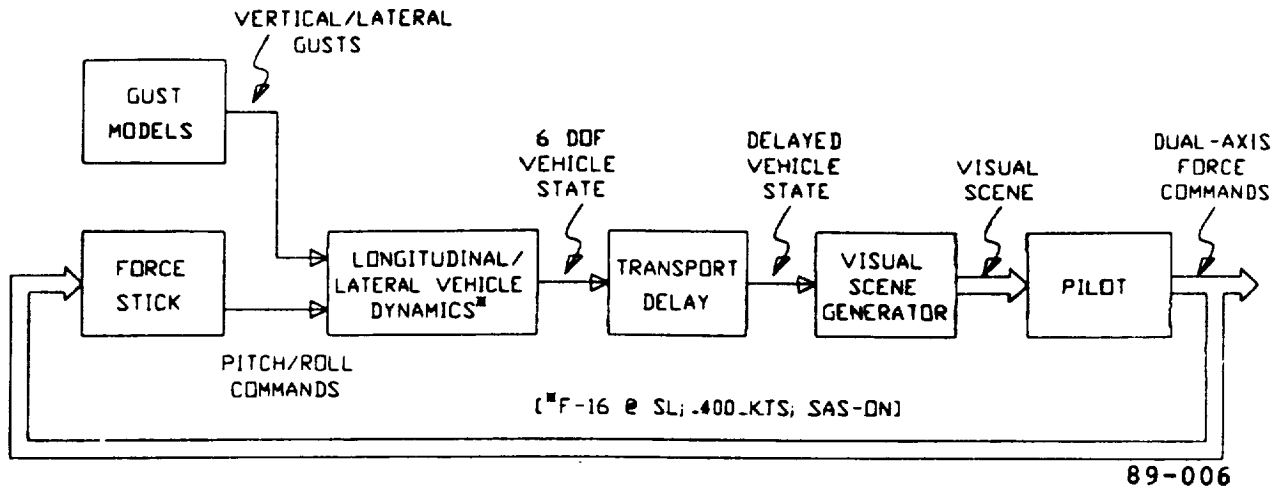
## SIMPLE TERRAIN CUEING: EXPERIMENTAL RESULTS & MODEL FINDINGS

- o 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
  
- o 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
  
- o 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

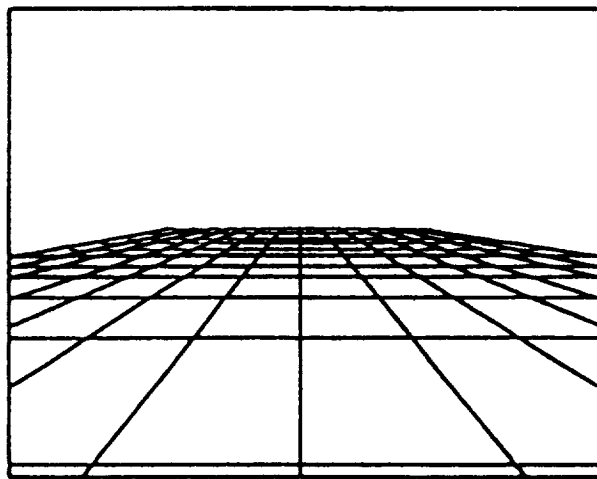
- o TASK: FLY STRAIGHT & LEVEL AGAINST VERTICAL/LATERAL GUSTS

- o OVERALL PILOT/VEHICLE BLOCK DIAGRAM



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

- o VISUAL SCENE



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

## SCENE GENERATOR DELAYS: MODEL ANALYSIS

### o TASK OBJECTIVE

- Longitudinal subtask: minimize  $\sigma_h^2$
- 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

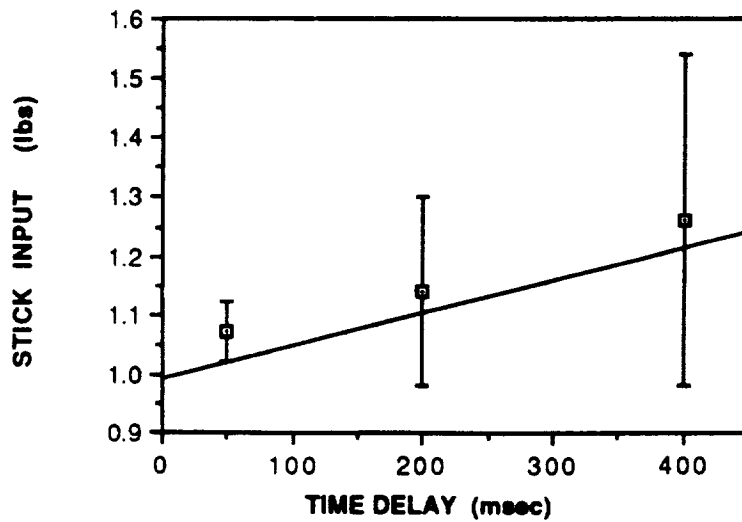
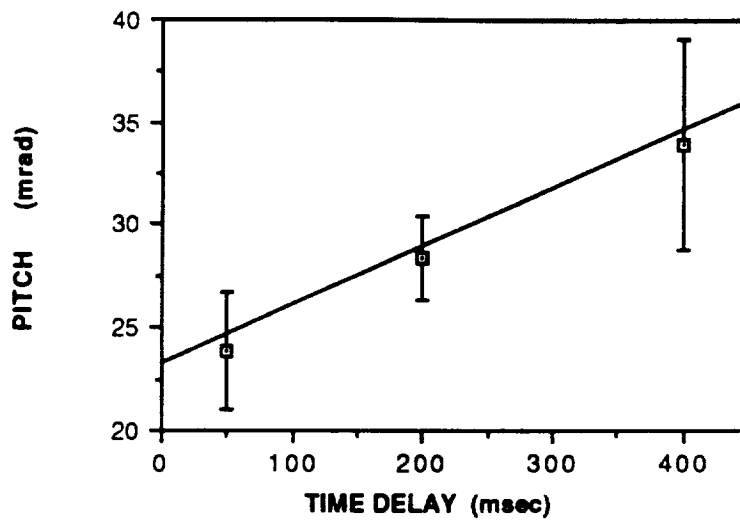
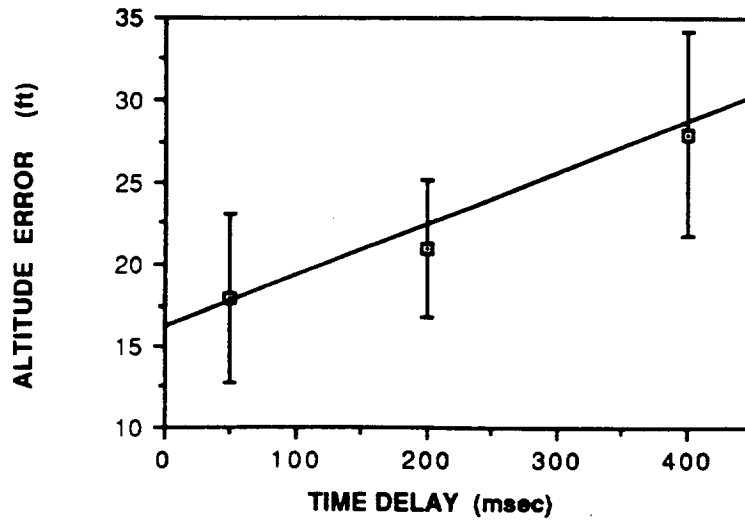
### o DISPLAY ANALYSIS

- Meridian texture:  $(\theta, h)$  &  $(\phi, \psi, Y)$
- Latitude texture:  $(\theta, h)$  &  $(\phi, \psi^*)$
- 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

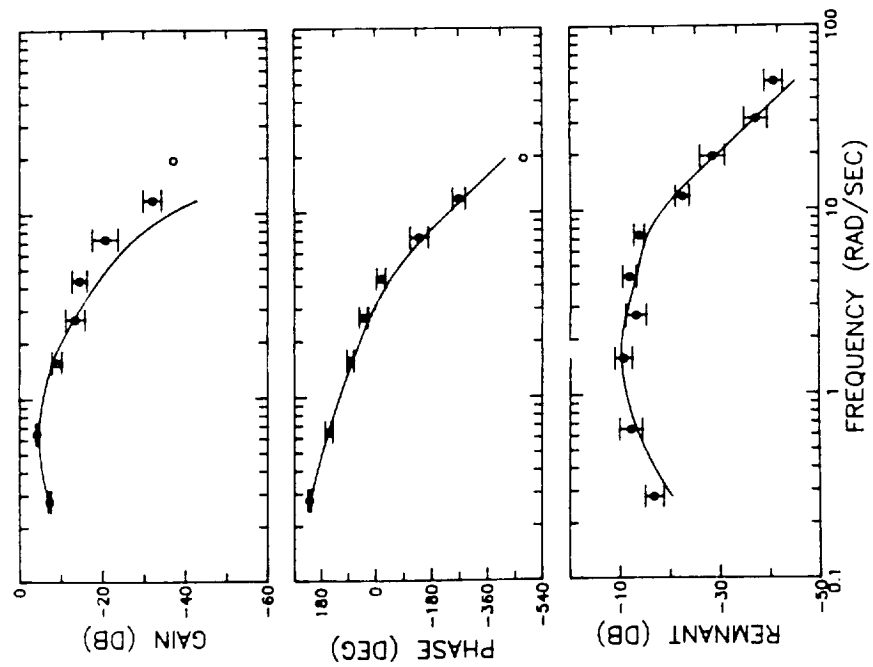
# DELAY EFFECTS ON PERFORMANCE: DATA & MODEL



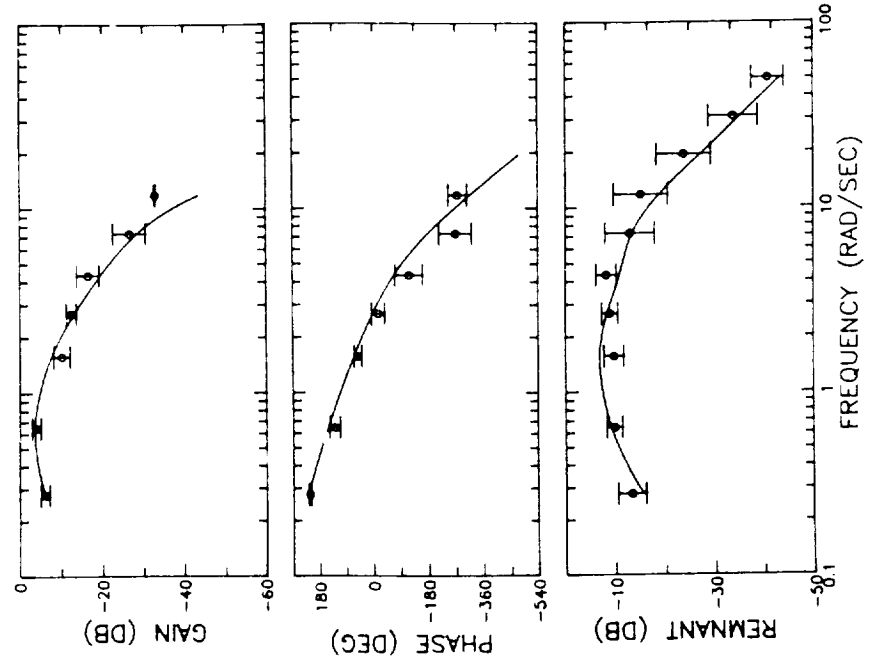
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DELAY EFFECTS ON PILOT FREQUENCY RESPONSE: DATA & MODEL

o SHORT DELAY RESPONSE (50 msec)



o LONG DELAY RESPONSE (400 msec)



o stable gain  
 o increased lag  
 o increased remnant

↑

**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**



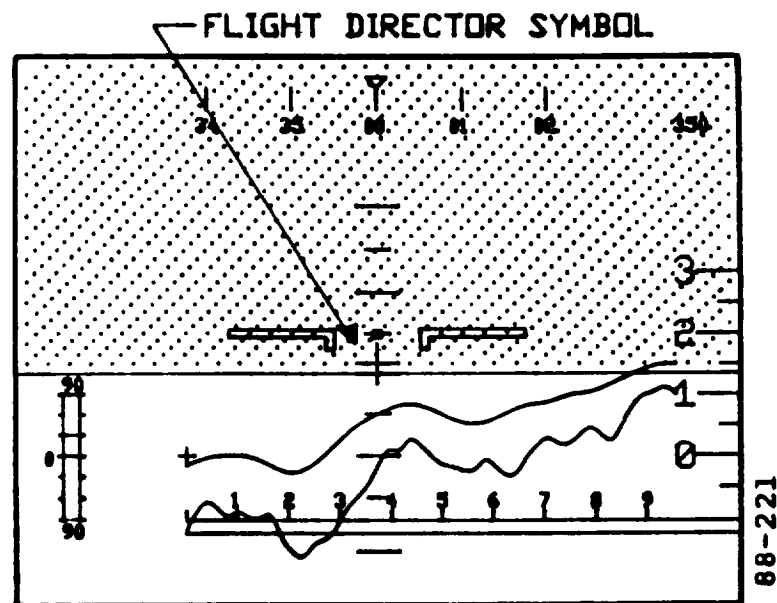
## COCKPIT DISPLAY DESIGN: TASK DESCRIPTION

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

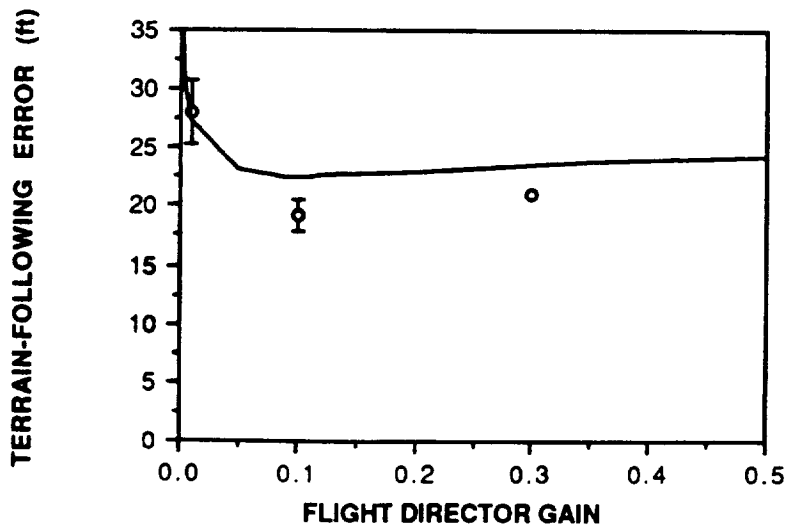


o DIRECTOR LAW

- Law:  $\theta_{fd} = a + \gamma_{dfp} - k * h_{error}$
- Optimize director gain k

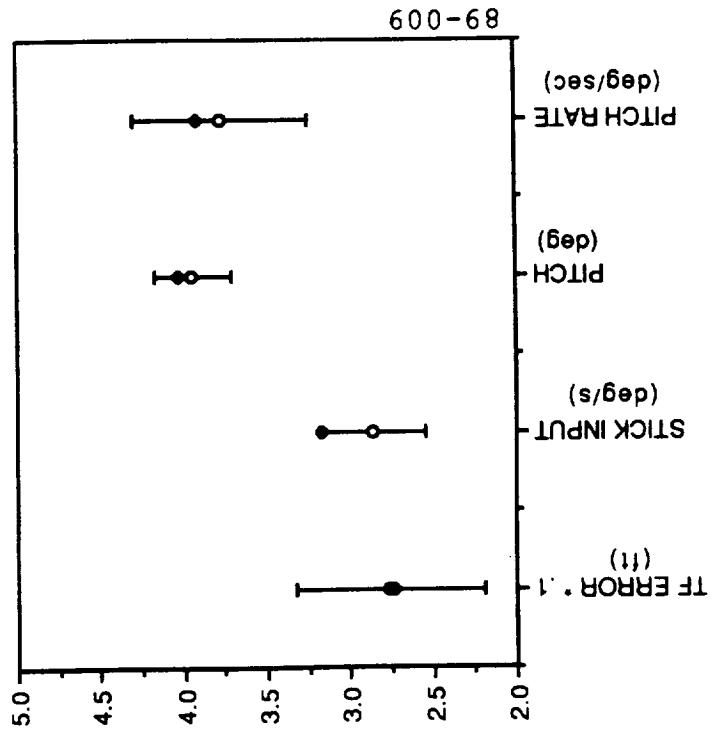
## COCKPIT DISPLAY DESIGN: MODEL-BASED PROCEDURE

- 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)

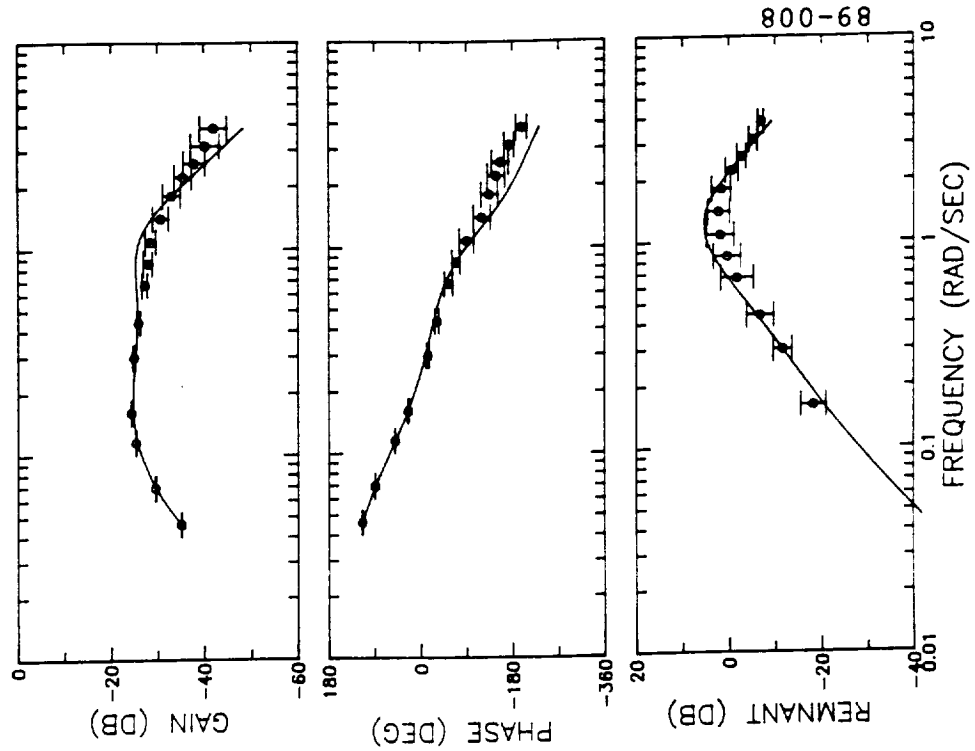


COCKPIT DISPLAY DESIGN: DATA AND MODEL

o PERFORMANCE SCORES

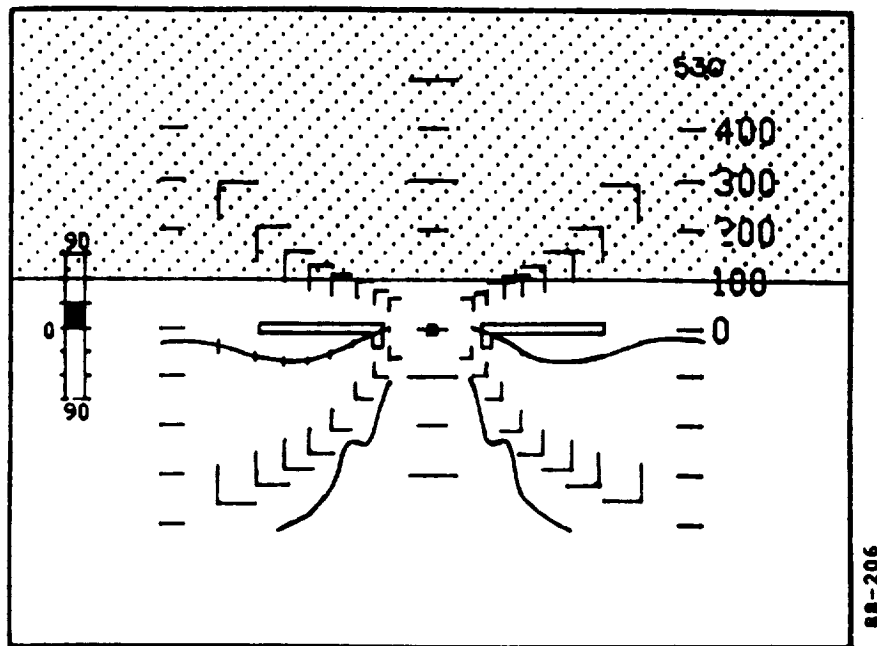


o FREQUENCY RESPONSE



## BASELINE PICTORIAL GUIDANCE DISPLAY

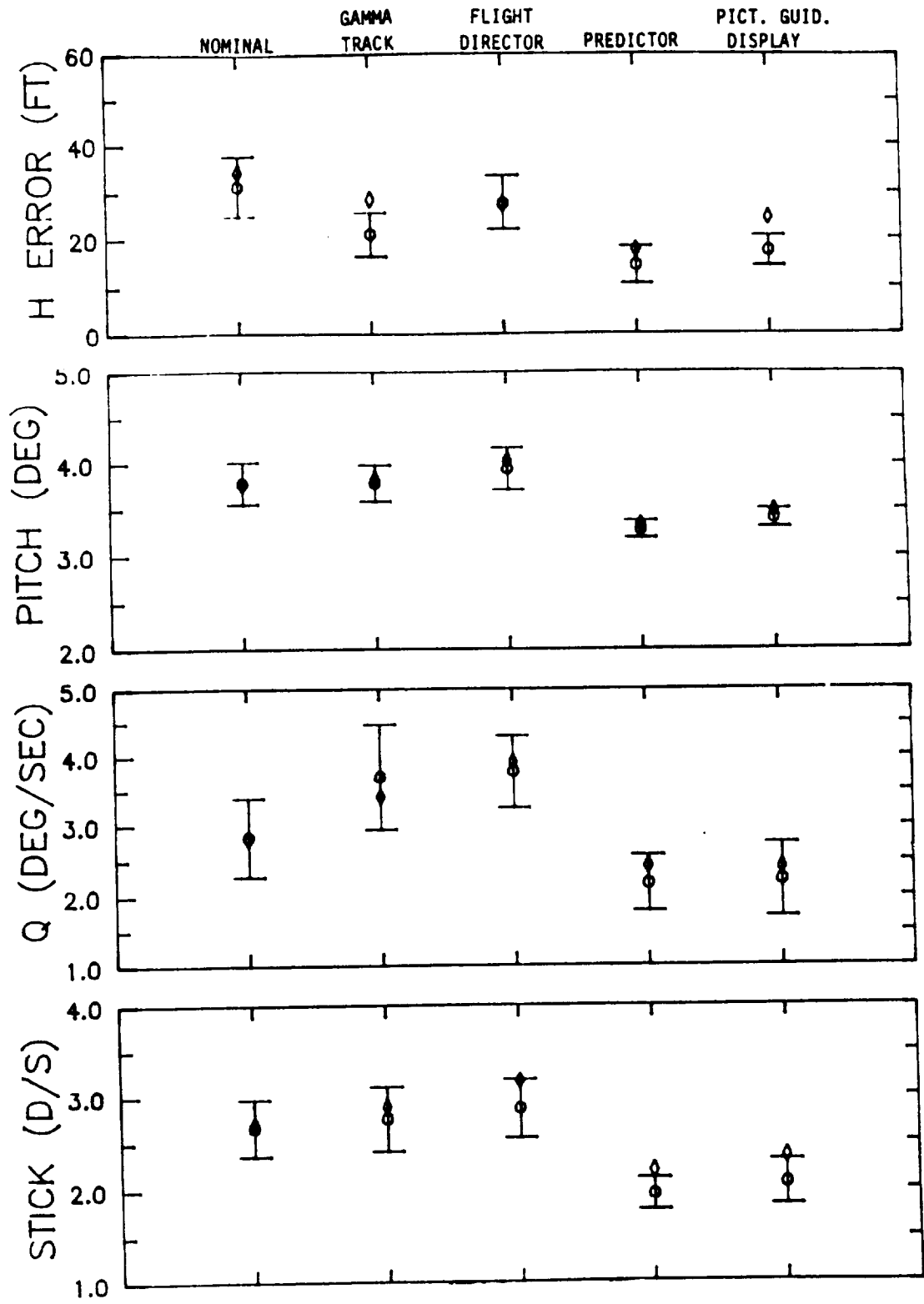
### o DISPLAY FORMAT



### 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



89-311

## SUMMARY AND CONCLUSIONS

- o SIMPLE TERRAIN CUEING DEMONSTRATES MODEL MATCH OF DOMINANCE EFFECTS
- o SCENE GENERATOR DELAY TRENDS FOLLOWED VIA MODEL ANALYSIS
- o MODEL-BASED DISPLAY DESIGN SUPPORTS DIRECTOR OPTIMIZATION
- o 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

### LIST OF PARTICIPANTS

Dr. George J. Andersen  
Department of Psychology  
University of California  
Riverside, CA 92507

Dr. James Cutting  
Department of Psychology  
Uris Hall  
Cornell University  
Ithaca, NY 14853-7601

Dr. John Flach  
Department of Psychology  
Wright State University  
Dayton, OH 45435

Dr. Ronald Hess  
Department of Mechanical, Aeronautical, and  
Materials Engineering  
University of California  
Davis, CA 95616

Dr. Larry Hettinger  
Logicon Technical Services, Inc.  
P.O. Box 317258  
Dayton, OH 45431-7258

Dr. Ian Howard  
Department of Psychology and Institute for Space  
and Terrestrial Science  
York University  
North York, Ontario M3J 1P3  
Canada

Dr. Joe Lappin  
134 Wesley Hall  
Department of Psychology  
Vanderbilt University  
Nashville, TN 37240

Dr. Dean Owen  
Department of Psychology  
University of Canterbury  
Christchurch 1, New Zealand

Dr. Dennis Proffitt  
Department of Psychology  
Gilmer Hall  
University of Virginia  
Charlottesville, VA 22903-2477

Dr. Gary Riccio  
Department of Kinesiology  
Rm 231 Freer Hall  
University of Illinois  
Urbana-Champaign, IL 61801

Dr. Rik Warren  
Armstrong Aeromedical Research Laboratory  
Human Engineering Facility  
Wright Patterson AFB, OH 45433  
(informal presentation only — no paper)

Dr. Lawrence Wolpert  
Logicon Technical Services, Inc.  
P.O. Box 317258  
Dayton, OH 45431-7258

Dr. Greg Zacharias  
Charles River Analytics, Inc.  
55 Wheeler St.  
Cambridge, MA 02138  
(viewgraph presentation only — no paper.  
see Appendix)

NASA Ames Research Center  
Aerospace Human Factors Research Division  
Moffett Field, CA 94035-1000

Vernol Battiste  
Dr. C. Thomas Bennett  
Dr. Stephen Ellis  
Sandra G. Hart  
Dr. Walter W. Johnson  
Dr. Mary Kaiser  
Dr. John Perrone



# Report Documentation Page

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16. Abstract <p>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.</p>					
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