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

[ Diagram of a control system with blocks labeled as Control Interface, System Dynamics, Display Interface, Sensory Interface, Monitor, Observer, Controller, NeuroMotor Dynamics, Optimal Controller, Predictor, Optimal Estimator, Time Delay, and Observation Noise.]
LINMOD: LINEAR PERSPECTIVE CUES

0 PILOT'S VIEW DURING LANDING APPROACH

0 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

0 MODELING REQUIREMENTS

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

Find

$$Y_{vis} = (\xi, \nu, \lambda, \eta) = f(x) + v_y$$

&

$$\delta Y_{vis} = \frac{\partial f}{\partial x} \delta x + v_y$$
TEXMOD: TEXTURAL FLOW-FIELD CUES

0 PILOT'S VIEW DURING TF/TA

0 AIMPOINT AND SPIN AXIS ESTIMATION

0 MODEL OUTPUTS

- Aimpoint
- Angular velocity
- Impact time map
- Relative orientation
SIMPLE TERRAIN CUEING: TASK DESCRIPTION

- TASK: Altitude regulation against vertical gust

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

- DISPLAYS:

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

- VISUAL CUE THRESHOLDS

  \((\beta, \dot{\beta})_{th} \& (\theta, q)_{th}\) from acuity estimates
  \((h, \gamma)_{th}\) from textural flow model

- REFERENCE: WARREN & RICCIO (85); ZACHARIAS, WARREN & RICCIO (86)
SIMPLE TERRAIN CUEING: DATA & MODEL

0 PERFORMANCE SCORES

- ALTIMETER ERROR (FT)
- PITCH ANGLE (DEG)
- STICK COMMAND (DEG/S)

Model
Data mean ± SD

(A,C) - Low Gain Display
(B,D) - High Gain Display

0 PILOT FREQUENCY RESPONSE (stick/error)

Condition B:
High Gain
Small Angle
PILOT MODEL PARAMETERS FROM DATA ANALYSIS

**DISPLAY VARIABLES**

- ROADWAY-ONLY: \((\beta_e, \hat{\beta}_e)\) FROM ROADWAY
  \((\theta, q)\) FROM HORIZON

- TEXTURE-ONLY: \((h_e, \gamma)\) FROM TEXTURAL FLOW
  \((\theta, q)\) FROM PSEUDO-HORIZON

- COMBINED RT: \((\beta_e, \hat{\beta}_e, h_e, \gamma, \theta, q)\)

**ATTENTION ALLOCATION**

70% ON HORIZON; 30% ON ROADWAY/TEXTURE

**VISUAL CUE THRESHOLDS**

\((\beta_e, \hat{\beta}_e)_\text{th} \quad \& \quad (\theta, q)_\text{th}\) FROM ACUITY ESTIMATES

\((h_e, \gamma)_\text{th}\) FROM TEXMOD SIMULATIONS

**OBSERVATION NOISE RATIO:** \(-18\text{dB}\)

**MOTOR PARAMETERS**

- TIME CONSTANT: \(0.2s \rightarrow 0.4s\)

- MOTOR NOISE: \(-40\text{dB} \rightarrow -50\text{dB}\)

**CENTRAL DELAY:** \(0.15s\)
## Pilot Model Parameter Values from Data Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>Roadway (R)</th>
<th>Texture (T)</th>
<th>Combined (RT)</th>
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</thead>
<tbody>
<tr>
<td><strong>Motor Time Constant</strong> $\tau_N$</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>L'W Gain $(A,C)$</td>
<td>SEC</td>
<td>0.30</td>
<td>0.40</td>
<td>0.30</td>
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<tr>
<td>High Gain $(B,D)$</td>
<td>SEC</td>
<td>0.20</td>
<td>0.35</td>
<td>0.20</td>
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<tr>
<td><strong>Motor Noise</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motor Noise, MN</td>
<td>DB</td>
<td>-50</td>
<td>-50</td>
<td>-50</td>
</tr>
<tr>
<td>Perceived Motor Noise, PMN</td>
<td>DB</td>
<td>-50</td>
<td>-40</td>
<td>-50</td>
</tr>
<tr>
<td><strong>Processing Time Delay</strong> $\tau_D$</td>
<td>SEC</td>
<td>0.15</td>
<td>0.15</td>
<td>0.15</td>
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<tr>
<td><strong>Perceptual Noise Level</strong> $P_o$</td>
<td>DB</td>
<td>-18</td>
<td>-18</td>
<td>-18</td>
</tr>
<tr>
<td><strong>Attention Allocation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizon $(\theta, q)$</td>
<td></td>
<td>--</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td>Roadway $(\beta_e, \beta_e)$</td>
<td></td>
<td>--</td>
<td>0.30</td>
<td>0.15</td>
</tr>
<tr>
<td>Texture $(h_e, \gamma)$</td>
<td></td>
<td>--</td>
<td>0.30</td>
<td>0.15</td>
</tr>
<tr>
<td><strong>Visual Cue Thresholds</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Horizon $(\theta_{th}, q_{th})$ $(^\circ, ^\circ/s)$</td>
<td>(1, 28)</td>
<td>(2, 56)</td>
<td>(1, 28)</td>
<td></td>
</tr>
<tr>
<td>Roadway $(\beta_{th}, \beta_{th})$ $(^\circ, ^\circ/s)$</td>
<td>(*, 1)</td>
<td>(*, 1)</td>
<td>(*, 1)</td>
<td></td>
</tr>
<tr>
<td>Texture $(h_{th}, \gamma_{th})$ $(ft, ^\circ)$</td>
<td>(**, 2)</td>
<td>(**, 2)</td>
<td>(**, 2)</td>
<td></td>
</tr>
</tbody>
</table>

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

$^{**}h_{th} = 0.3h_a$
SIMPLE TERRAIN CUEING: EXPERIMENTAL RESULTS & MODEL FINDINGS

0 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

0 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

0 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

0 TASK OBJECTIVE

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

0 DYNAMICS MODEL

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

0 DELAY MODEL

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

0 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

0 NON-DISPLAY PILOT PARAMETERS

Fixed across conditions, except for increasing delay
DELAY EFFECTS ON PERFORMANCE: DATA & MODEL

![Graphs showing the relationship between time delay and altitude error, pitch, and stick input.](image)
DELAY EFFECTS ON PILOT FREQUENCY RESPONSE: DATA & MODEL

- SHORT DELAY RESPONSE (50 msec)
  - stable gain
  - increased lag
  - increased remnant

- 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

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

- **DYNAMICS**:
  - Terrain: Second order matched terrain spectra
  - Terrain-following guidance: Low order predictor
  - Vehicle: B-1B at SL, Mach 0.85, SAS-augmented

- **DISPLAY**

- **DIRECTOR LAW**
  - Law: \( \theta_{fd} = a + \gamma_{dFP} - k \times h_{error} \)
  - Optimize director gain \( k \)
COCKPIT DISPLAY DESIGN: MODEL-BASED PROCEDURE

- CONDUCT PILOTED SIMULATION TO IDENTIFY BASELINE PILOT PARAMETERS

- SWEEP THRU DIRECTOR GAINS TO IDENTIFY OPTIMUM CHOICE

- CONFIRM CHOICE WITH SIMULATION USING OPTIMIZED DIRECTOR

- PRELIMINARY MODEL/DATA COMPARISONS (SINGLE SUBJECT)
COCKPIT DISPLAY DESIGN: DATA AND MODEL

o PERFORMANCE SCORES

o FREQUENCY RESPONSE

![Graphs showing performance scores and frequency response](image-url)
BASELINE PICTORIAL GUIDANCE DISPLAY

DISPLAY FORMAT

- 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

- H ERROR (FT)
- PITCH (DEG)
- Q (DEG/SEC)
- STICK (D/S)

Nominal, Gamma Track, Flight Director, Predictor, Picture Guided Display
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

- DOES THE STRUCTURE GAINED BY MODELING OVERLY CONSTRAIN THE RESEARCH?
  - New experimental directions
  - New model development

- CAN EXCESSIVE COMPRESSION LEAD TO MISSED DATA TRENDS?

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

- 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
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.