Multi-Axis Pilot Modeling

Models and Methods for Wake Vortex Encounter Simulations

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Outline

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- Modification for Proprioceptive and Vestibular Cues
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- Task Interference in Multi-Axis Tasks
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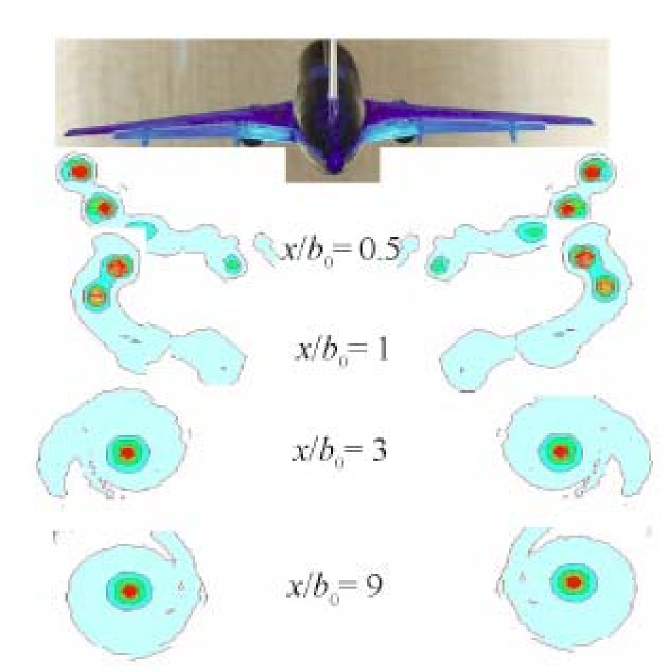
  - Rotorcraft (UH-60)
  - Transport Aircraft (Convair 880)
- Conclusions



Introduction

- Goal: Develop pilot modeling procedure that should
  - be able to provide predictions of task performance (i.e., be able to fly the vehicle)
  - be able to simulate varying levels of visual cue quality
  - be able to simulate varying levels of pilot aggression
  - be amenable to multi-axis tasks
  - be able to provide estimates of handling qualities levels
  - be reasonably tractable to use
- All the while remembering that

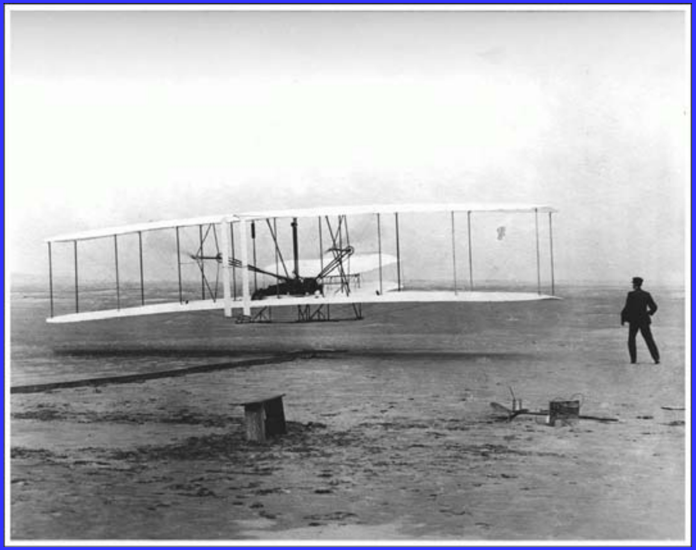
"The human central nervous system is the most complex structure in the known universe,"

- anonymous neurophysiologist

Introduction

107 Years of Pilot/Vehicle Interaction

From Orville Wright in 1903 — to — a Reaper Pilot in 2010



For at least 60 of these 107 years, there has been an interest in pilot modeling

Introduction

There appears to be no reason why a complete closed-loop stability analysis of the manually controlled airplane could not be made…The pilot would be represented by a servo system with particular reactions and time constants to signals such as changes in air speed normal and lateral acceleration, etc. By making a reasonable representation of an "average" pilot …behaviors could be calculated and used to describe the "flying qualities" of the airplane.

– William Bollay *Fourteenth Wright Brothers Lecture*

Dec. 16, 1950

Introduction

"On the basis of these correlations and explanations it appears possible to define mathematically, within limits, the dynamic behavior of the operator (pilot) for the class of tasks considered."

- D.T. McRuer,
- E. S. Krendel

"Dynamic Response of Human Operators,"

WADC TR 56-524, Oct. 1957

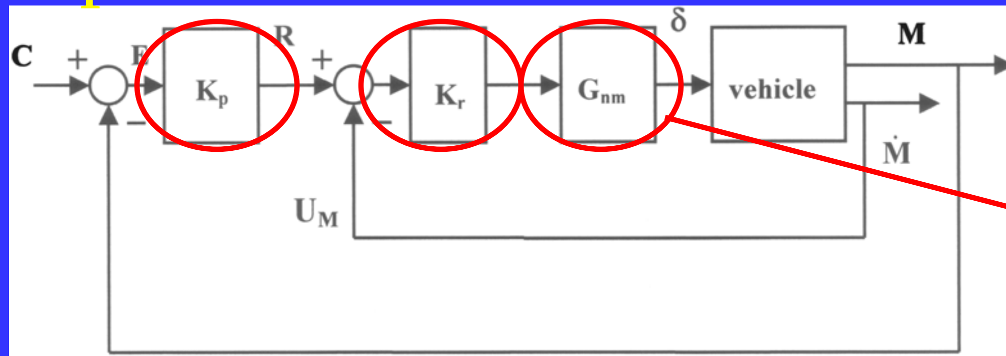
Introduction

Why model the pilot?

The proposed model of the human pilot controlling dynamic systems is offered as a tool that has the potential "…*to summarize behavioral data, to provide a basis for rationalization and understanding of pilot control actions, and, most important of all, to be used in conjunction with vehicle dynamics in forming predictions or in explaining behavior of pilot-vehicle systems*"

McRuer, D. T., and Jex, H. R., "A Review of Quasi-Linear Pilot Models," IEEE Transactions on Human Factors in Electronics, Vol. HFE-8, No. 3, 1967, pp. 181-249.

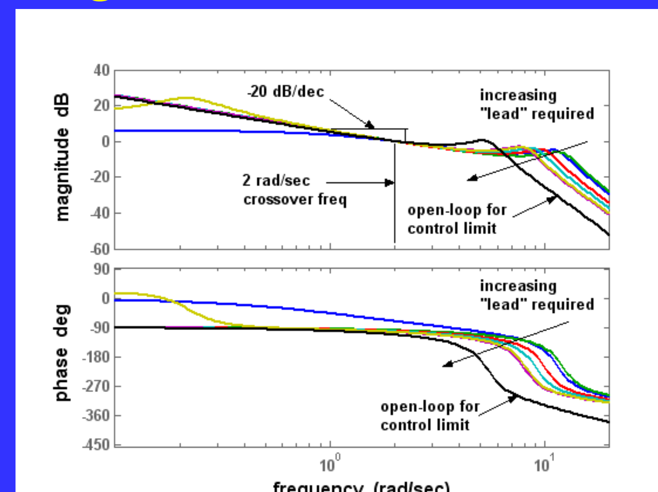
Simplified "Pursuit" Pilot Model



$$G_{nm} = \frac{10^2}{s^2 + 2(0.707)10s + 10^2}$$

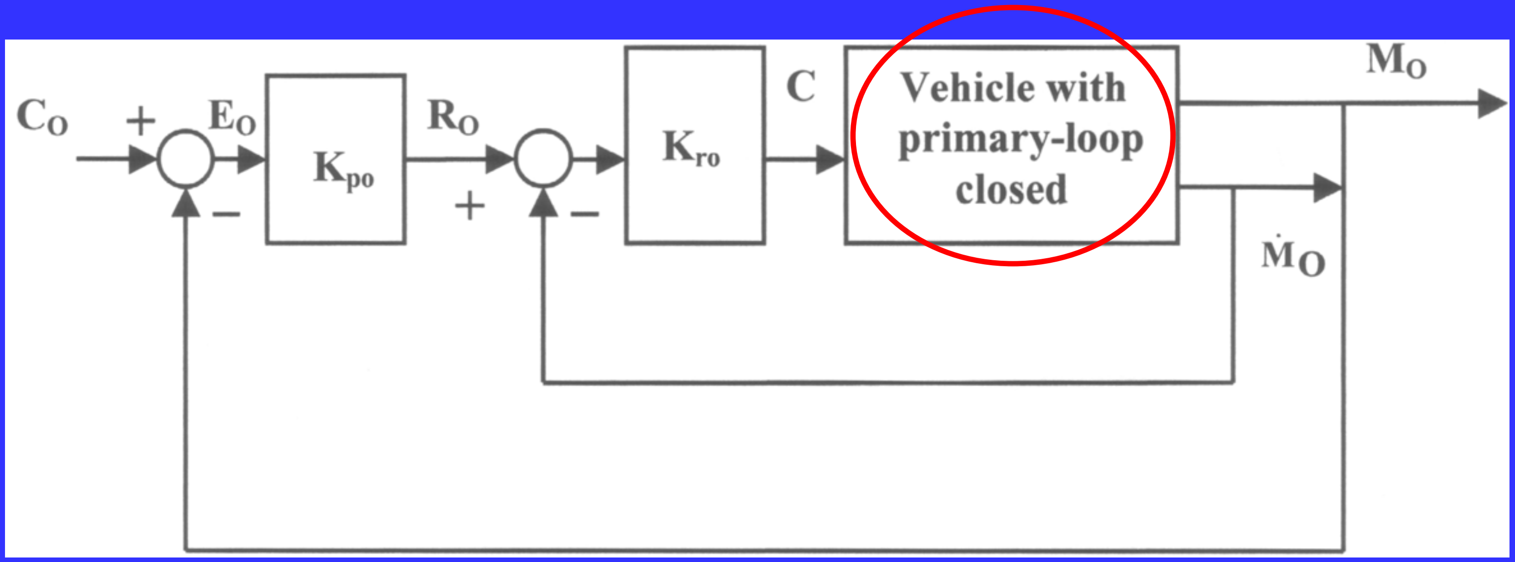
Pursuit Pilot Model – single axis

Controlled element	K_r	K_p
$\frac{1}{s(s+10)}$;	20.5	2.91
$\frac{1}{(s^2+2(0.707)5s+25)}$;	13.5	3.62
$\frac{1}{s(s+4)}$;	11.5	2.56
$\frac{1}{s(s+2)}$;	9.19	2.35
$\frac{1}{s^2}$;	7.58	1.91
$\frac{0.696(s+0.14)}{s^3+0.424s^2+0.0353s+0.397}$	11.3	1.96
$\frac{1}{s^2(s+11)}$	58	1.76



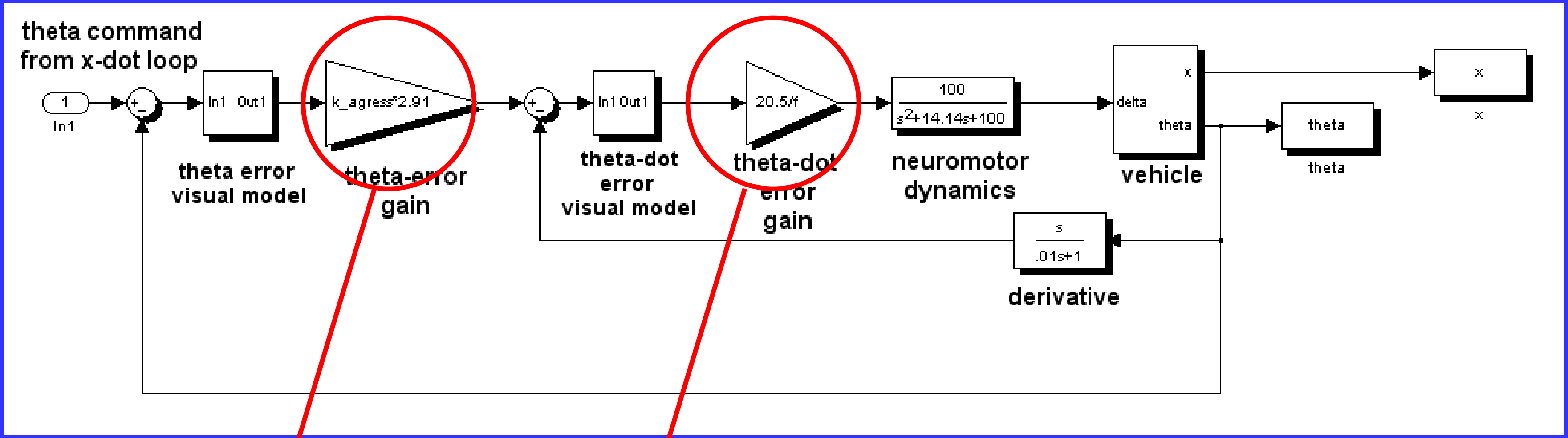
Hess, R. A., "Simplified Approach for Modelling Pilot Pursuit Control Behaviour In Multi-Loop Flight Control Tasks," *Proceedings of the Institute of Mechanical Engineers, Part G, Journal of Aerospace Engineering*, Vol. 220, No. G2, 2006, pp 85-102

Simplified “Pursuit” Pilot Model



Pursuit Pilot Model – multi-axis

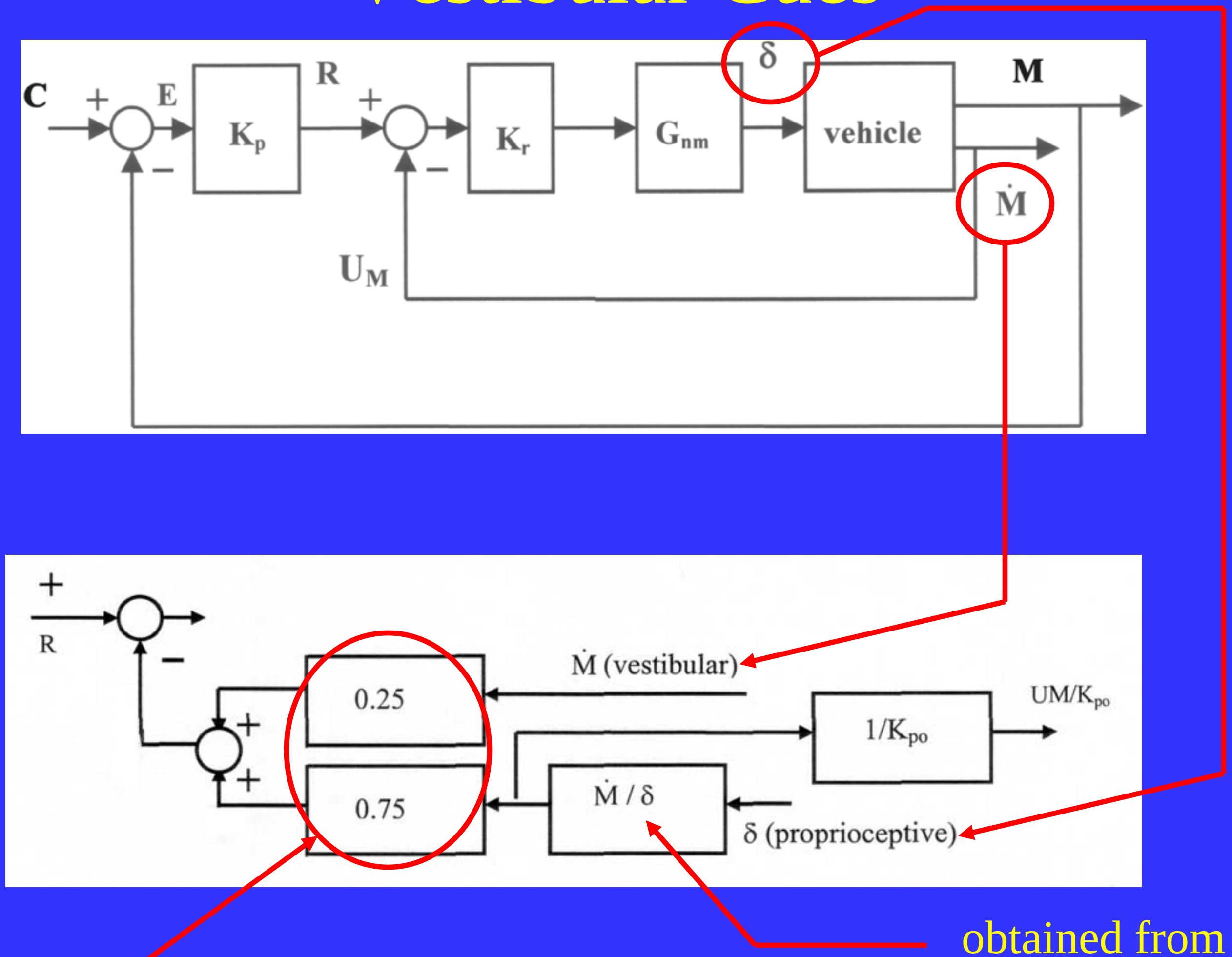
Pilot Model



K_r/f -- f is part of visual cue model

$K_p K_{agress}$ -- K_{agress} determines pilot "aggressiveness" in control

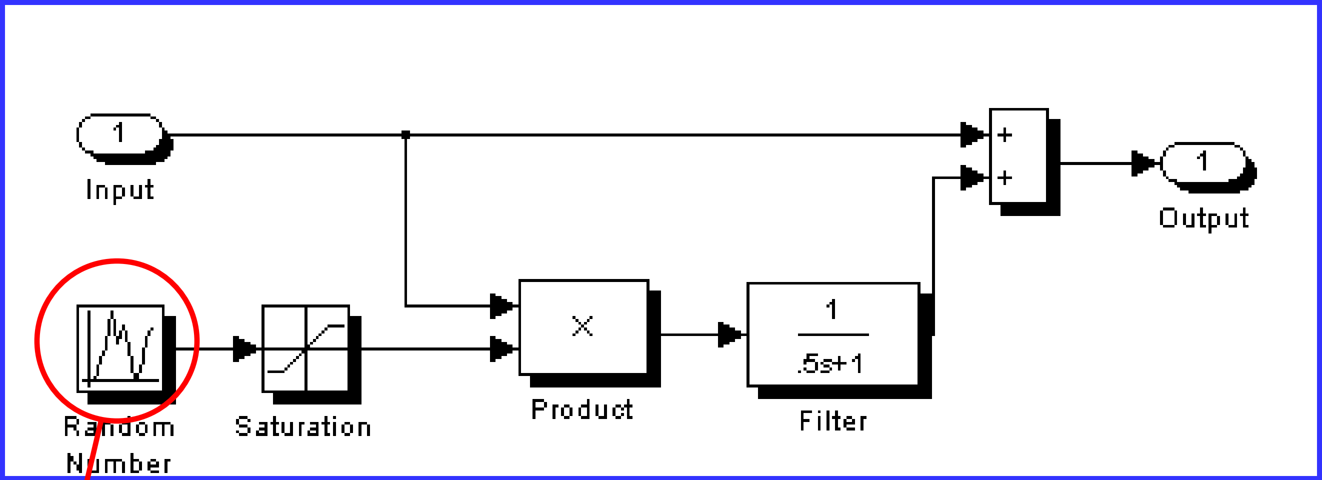
Modification for Proprioceptive and Vestibular Cues



assumed split

obtained from model of pilot/vehicle system

Visual Cue Quality



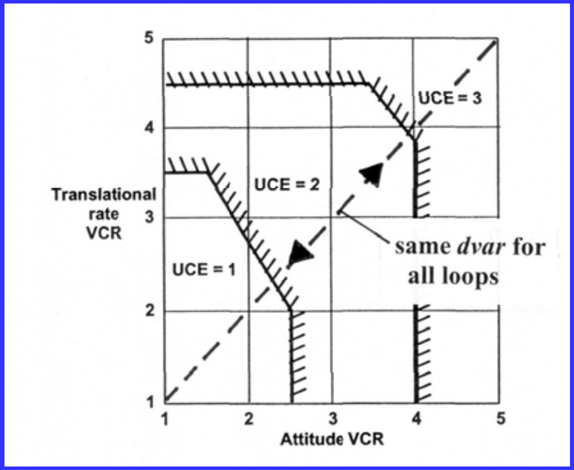
Visual Cue Model

variance = *dvar*

If $0 \leq dvar_{vis} < 0.1$, UCE = 1

$0.1 \leq dvar_{vis} < 0.2$, UCE = 2

$0.2 \leq dvar_{vis} < 0.3$, UCE = 3



Task Interference in Multi-Axis Tasks

n = number of axes being controlled

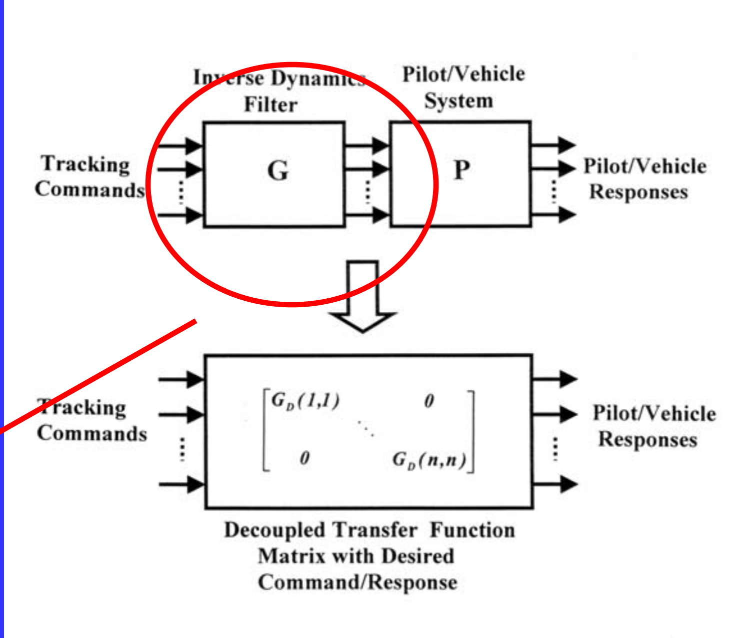
$$dvar_{task} = 0.01n \quad \text{for } n > 1$$
$$= 0 \quad \text{for } n = 1$$

$$f = 1 + 10(dvar_{vis} + dvar_{task})$$

f factor has following effects on pilot model

- an apparent time delay
- a reduction in crossover frequency

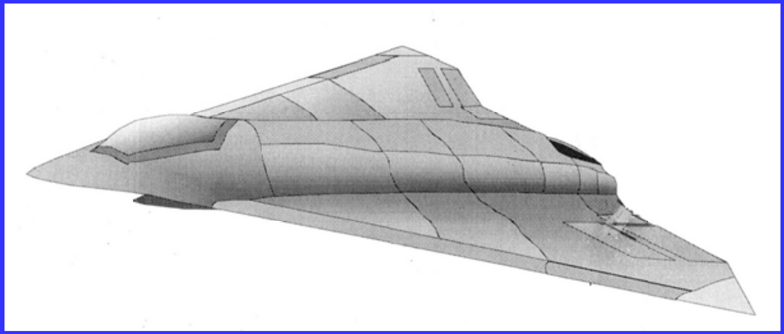
Higher Levels of Skill Development



linear dynamic inversion

Element "G" transforms tracking commands based upon task description into commands to the pilot/vehicle system "P" that produces pilot/vehicle responses representative of "skilled" pilot behavior

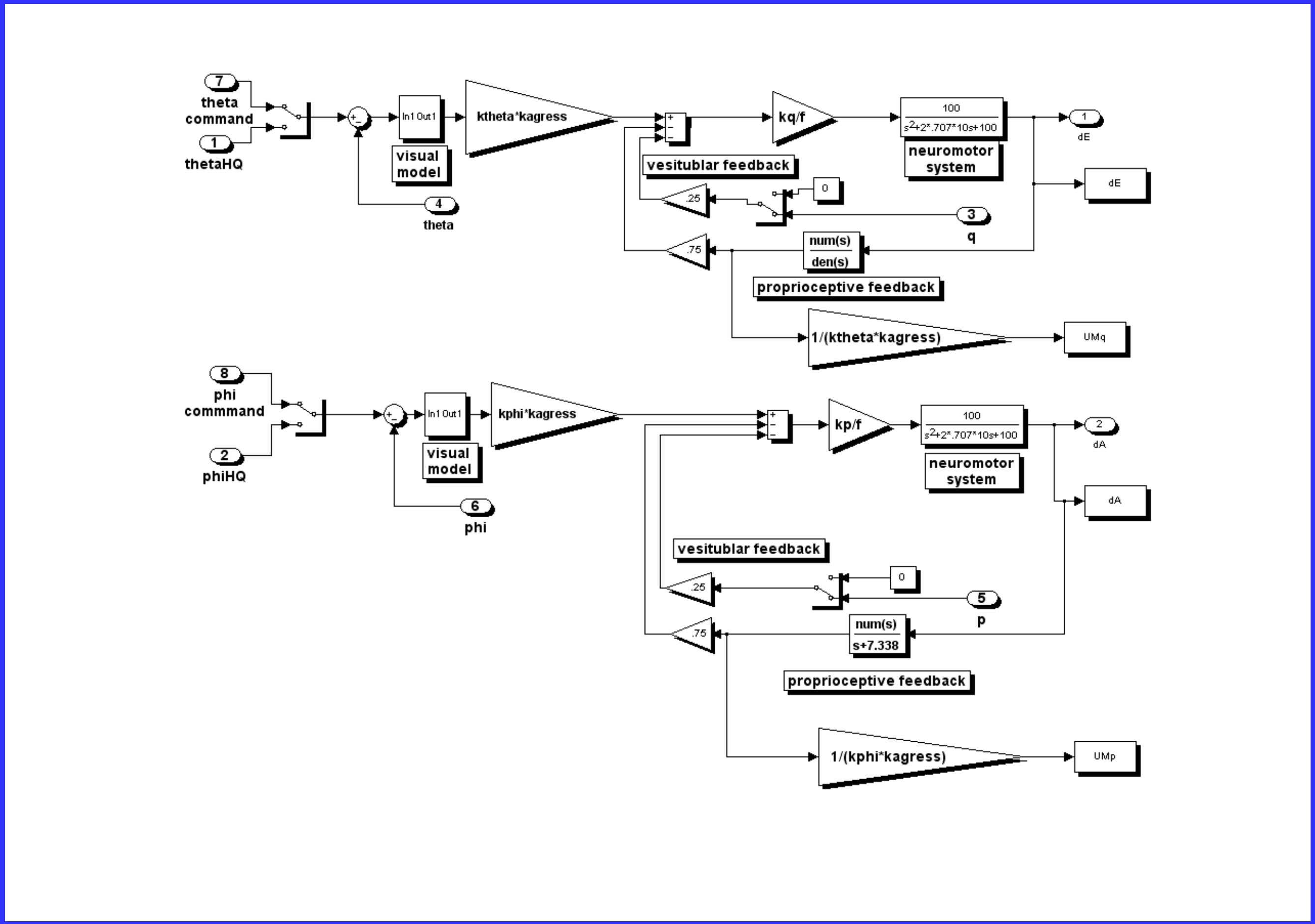
Example: Fighter Aircraft (ICE Vehicle)



- Flight Condition: Mach No. = 0.3, Alt = 15,000 ft
- Task: Pitch and roll command following (2 control axes)

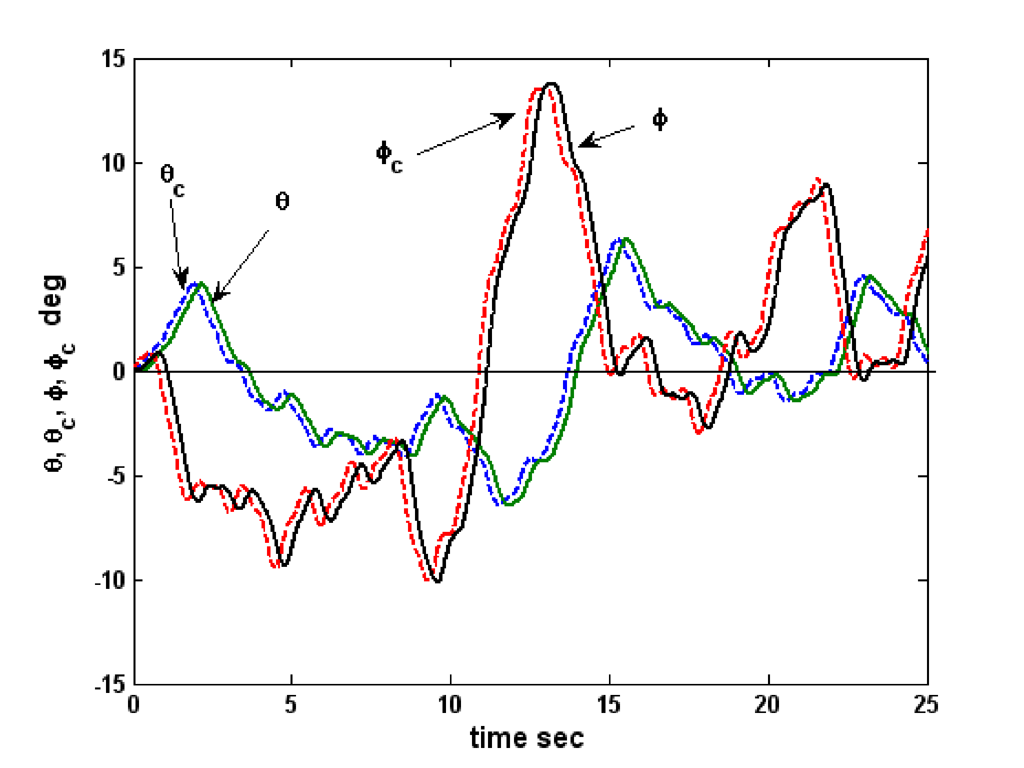
Hess, R. A., and Marchesi, F., “Pilot Modeling With Applications ro the Analytical Assessment of Flight Simulator Fidelity, *Journal of Guidance, Control and Dynamics*, Vol. 32, No. 3, June 2009, pp. 760-777.

Example 1: Fighter Aircraft (ICE Vehicle)



pilot model

Example: Fighter Aircraft (ICE Vehicle)



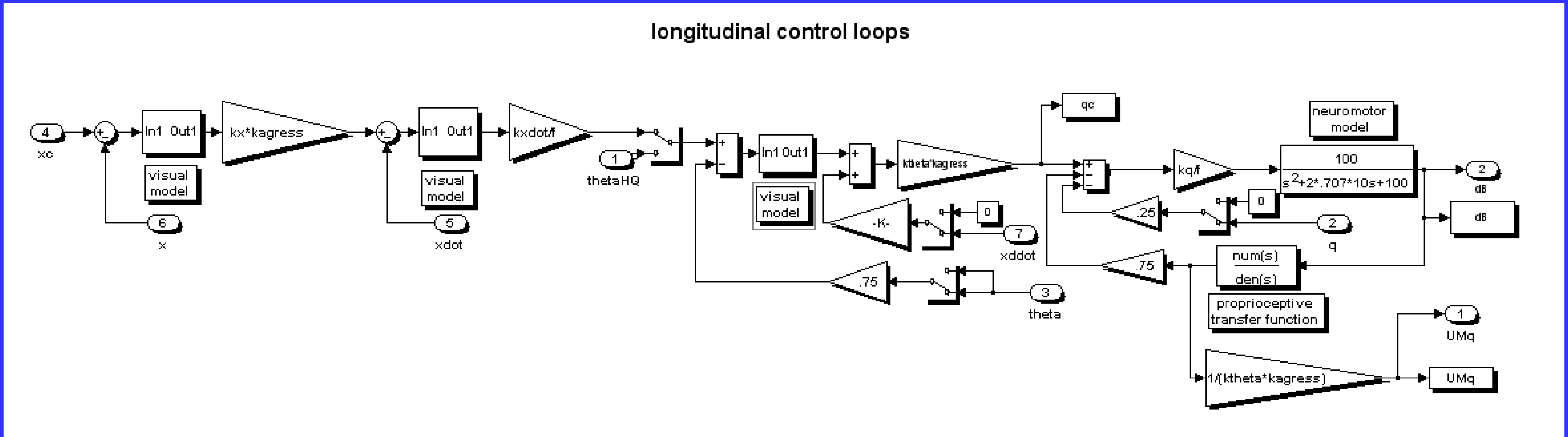
"nominal" pilot/vehicle tracking performance

Example: Rotorcraft (UH-60)

- Example included to demonstrate general applicability of pilot modeling procedure
- Vehicle model has with rotor degrees of freedom – complete model with SCAS is 42nd order
- Task: Reposition (4 control axes) with Lusardi/Tischler METS turbulence
- Flight Condition: near hover

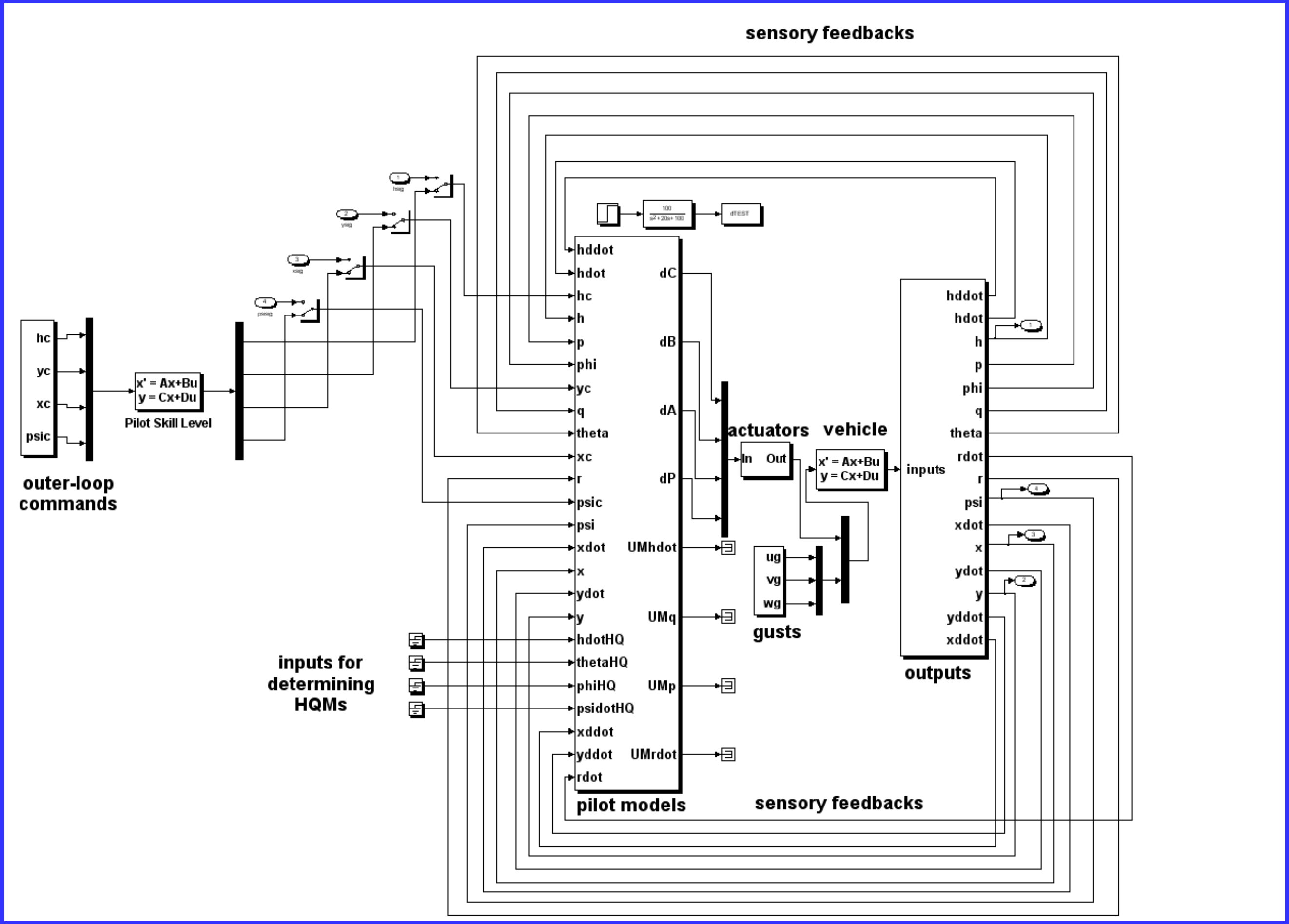
Hess, R. A., “Pilot-Centered Handling Qualities Assessment for Flight Control Design, Invited paper, AIAA Atmospheric Flight Mechanics Conference, Chicago, IL, Aug. 10-13, 2009

Example: Rotorcraft (UH-60)



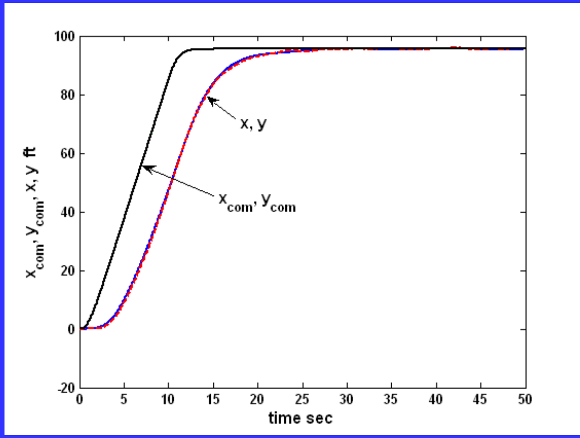
pilot model for pitch and longitudinal translation

Example: Rotorcraft (UH-60)

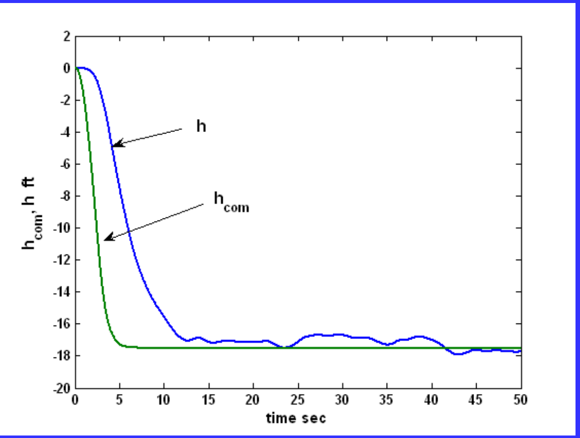


computer simulation model (4 axes)

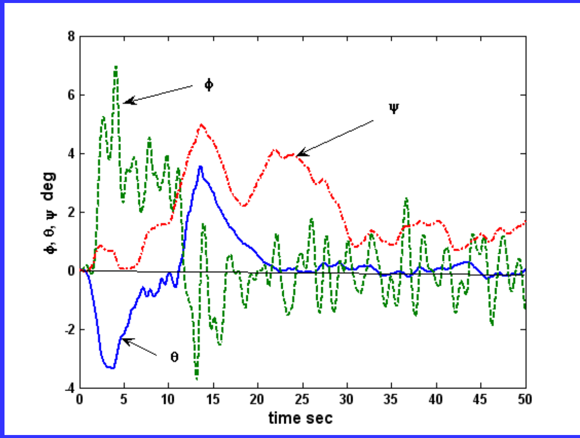
Example: Rotorcraft (UH-60)



x, y position



h position



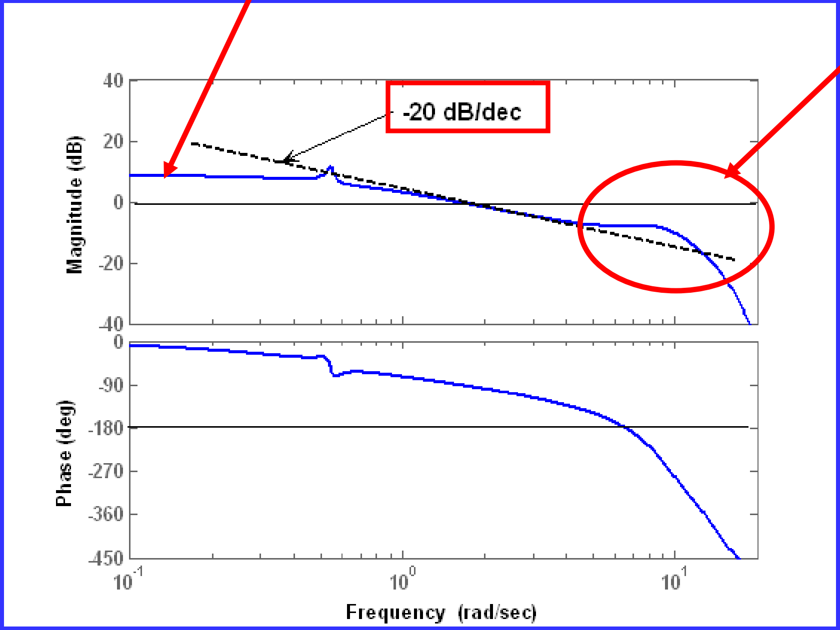
attitudes – showing effects of METS

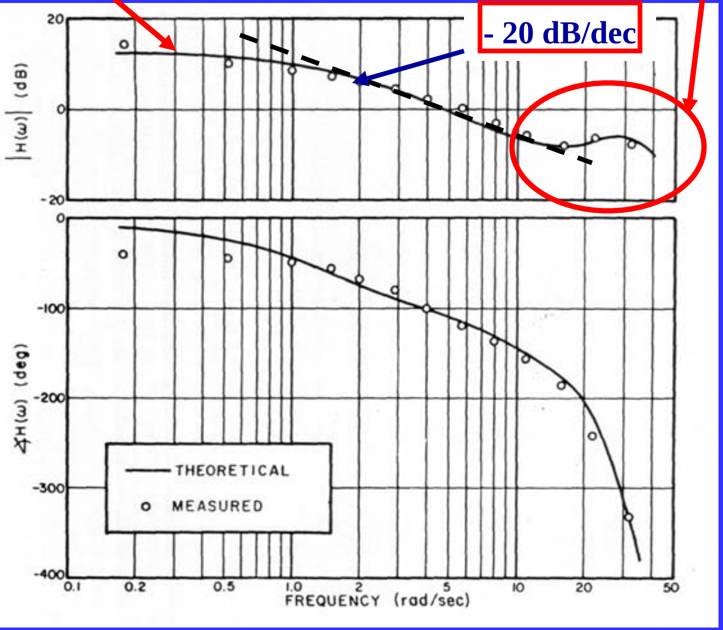
pilot/vehicle performance

Example: Rotorcraft (UH-60)

flat @ low frequency

neuromuscular modes





pilot/vehicle dynamics with high bandwidth ATTC/ATTH SCAS

pilot/vehicle dynamics from lab tracking task with $Y_c = 40/(s+40)$

Modeling Rotorcraft Interaction with Trailing Vortices – No Pilot Inputs

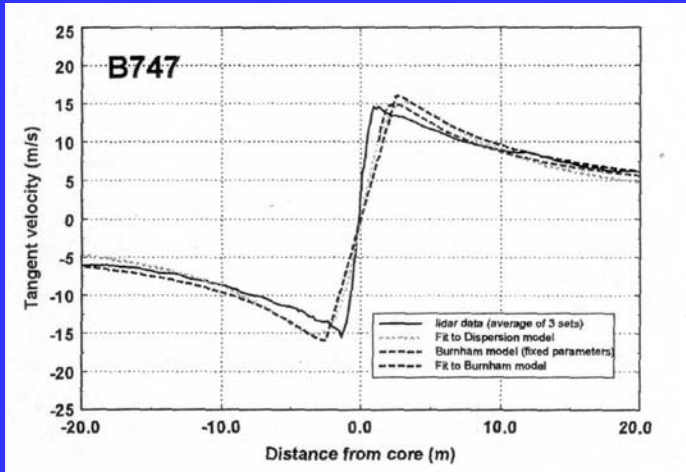


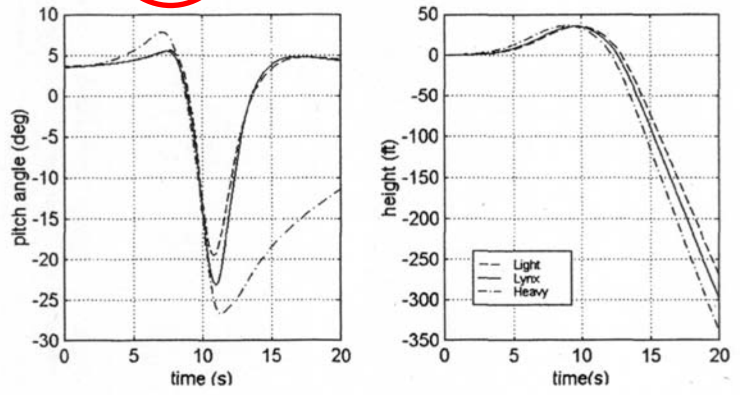
Fig. 2 Vortex velocity profile for Boeing 747.

vortex from B-747

$r_c = 2.4$ m, $V_c = 14.9$ m/s

Table 2 Sample of typical FATO traffic

Aircraft type	MTOW, lb	Blade loading, lb/ft^2
AS350 (B)	4298	83.0
SK76 (A)	10300	90.7
A109	5730	72.2
B206	4150	103.6
H500	3000	81.2
S-61	21500	91.3
Lynx	10689	99.2



rotorcraft pitch and altitude excursions

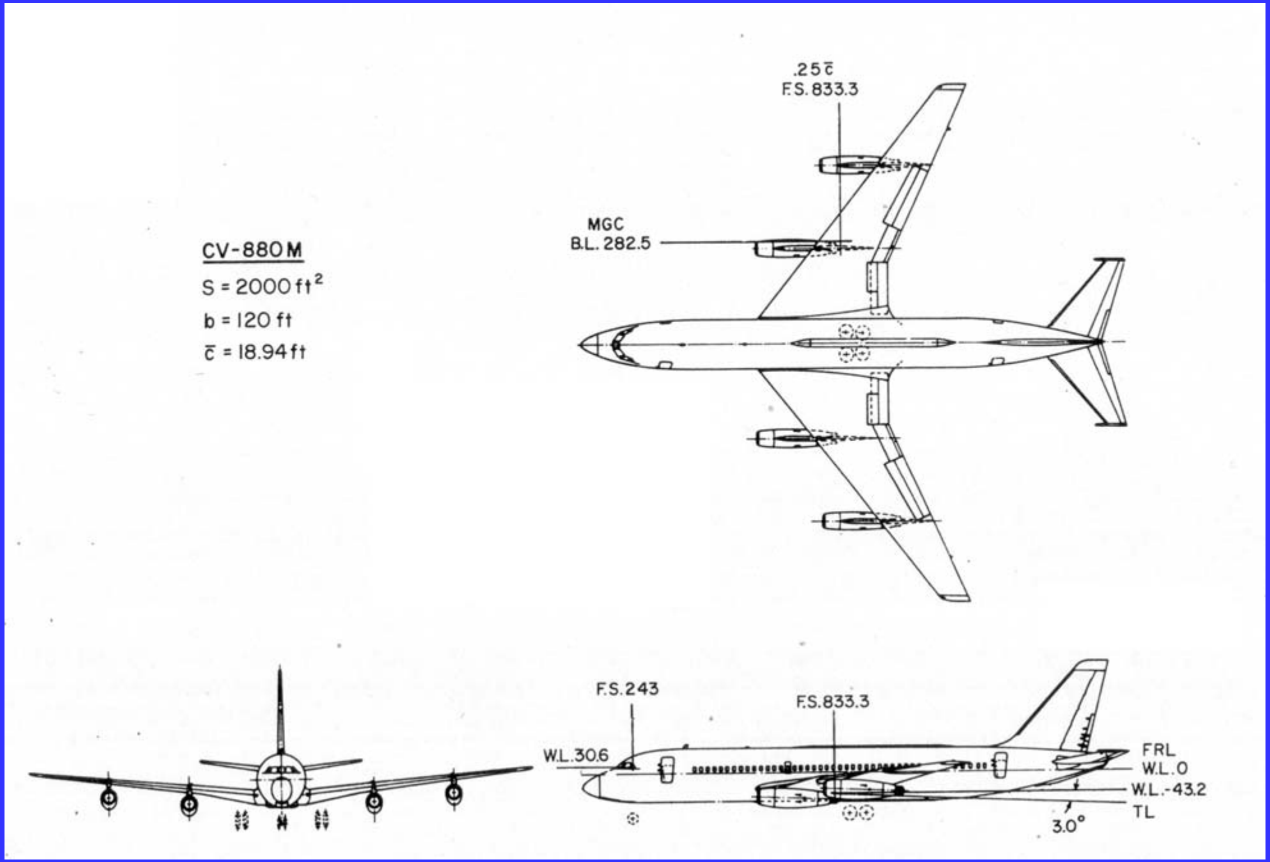
Turner, G P., Padfield, G. D., Harris, M., "Encounters with Aircraft Vortex Wakes: The Impact on Helicopter Handling Qualities," *Journal of Aircraft*, vol. 39, No. 5, 2002, pp. 839 – 849.

Example: Transport Aircraft (Convair 880)

Data from “Aircraft Handling Qualities Data,” NASA CR-2144, Dec. 1972

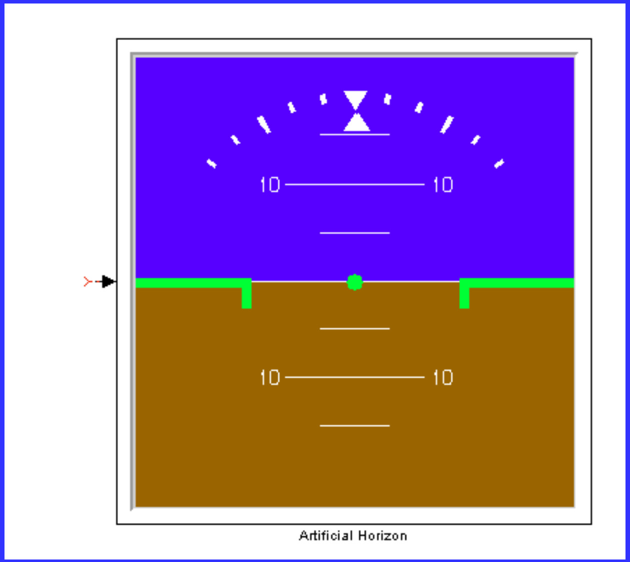
Flight Condition: Alt: Sea Level, M = 0.249

yaw-damper included in model



Example: Transport Aircraft (Convair 880)

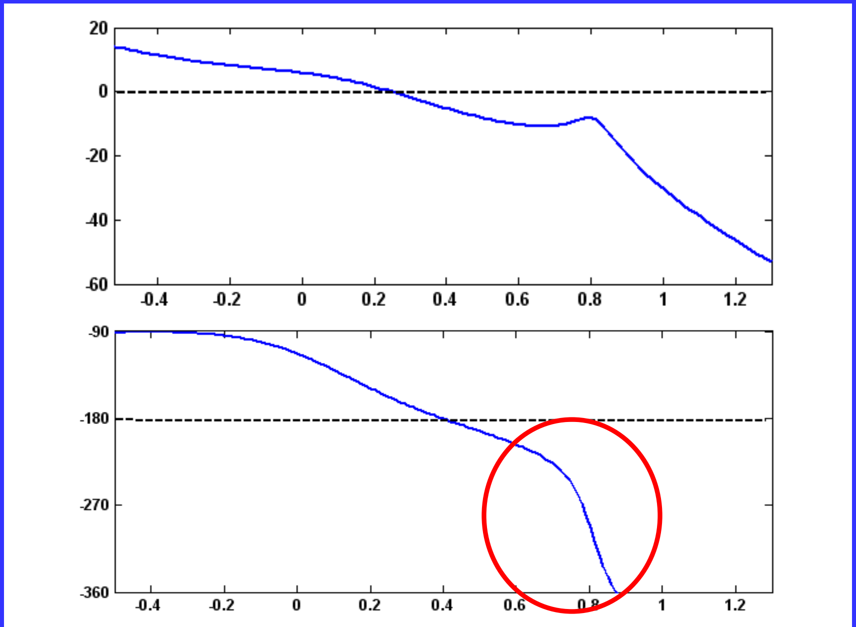
Laptop Simulation



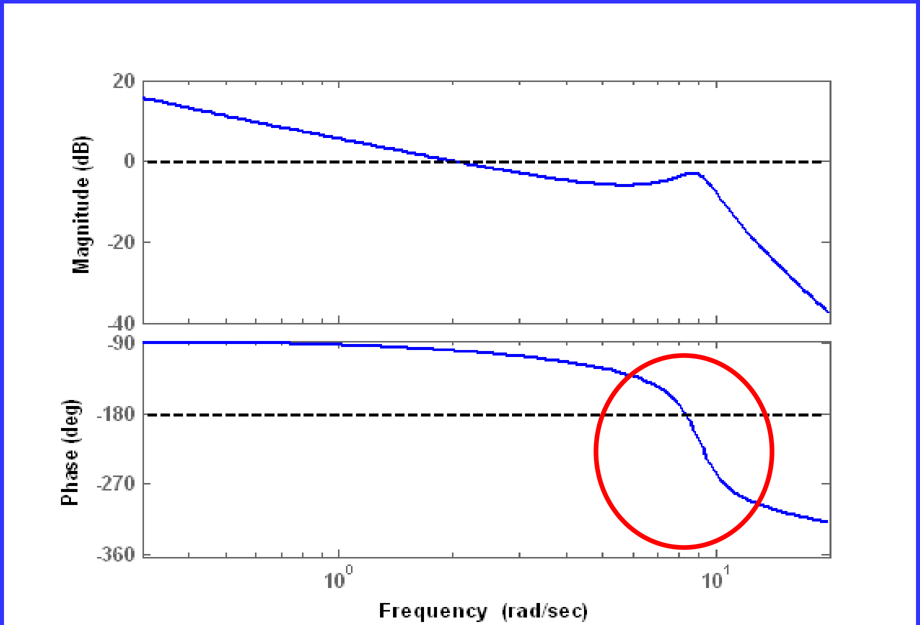
Artificial Horizon

Example: Transport Aircraft (Convair 880)
laptop simulation vs pilot model

- Task: Maintain trim attitudes in presence of random turbulence
- Control inputs: elevator and aileron



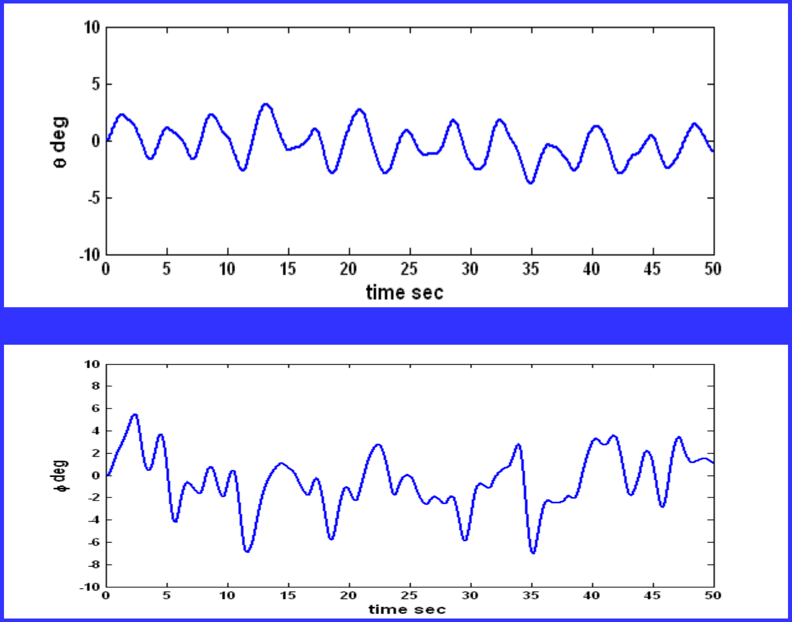
pitch tracking pilot/vehicle loop transmission identified from laptop simulation



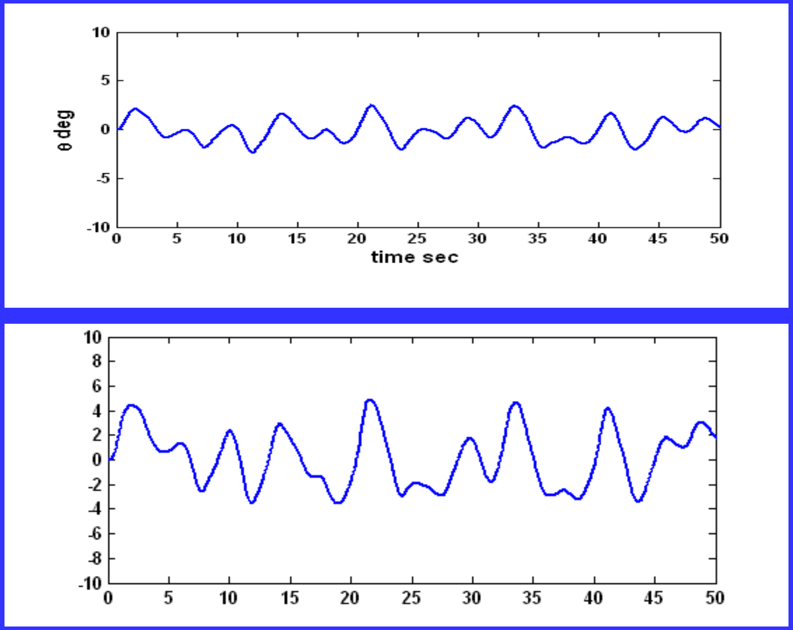
pitch tracking pilot/vehicle loop transmission obtained from multi-axis pilot model

Example: Transport Aircraft (Convair 880)

laptop simulation vs pilot model



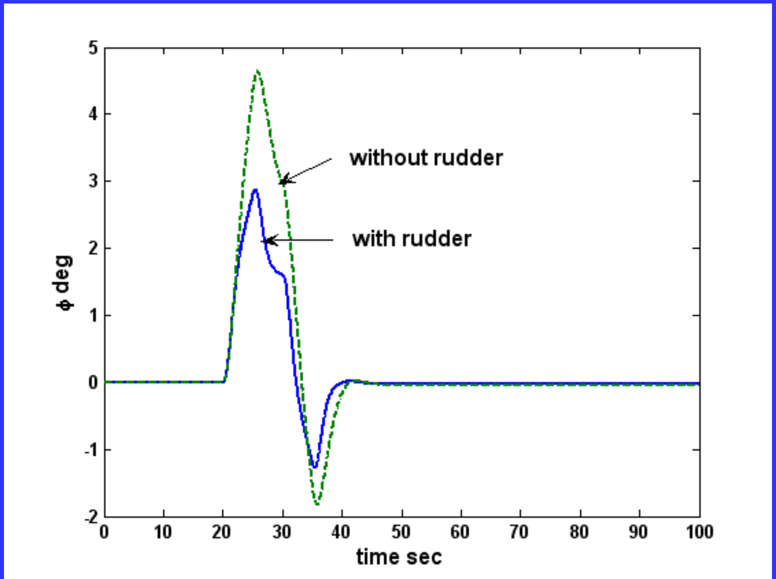
laptop simulation



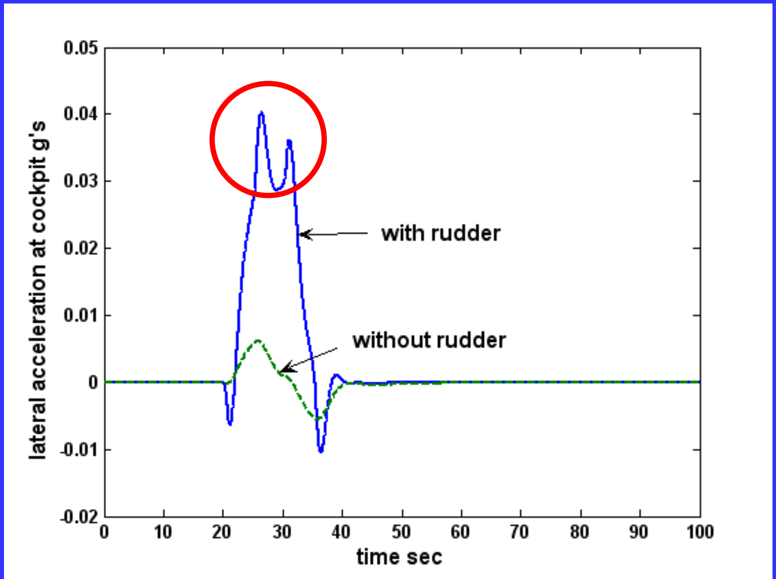
pilot model

Example: Transport Aircraft (Convair 880)

pilot model - simulated encounter with a "roll-rate" gust ($p_{g\text{-}max}$ = 0.25 rad/sec lasting 5 sec at peak value)



roll response with and without rudder input



lateral g's at cockpit with and without rudder input

Pilot Technique
(Regarding Use of Rudder for Up-and-Away Flight)

From presentation by Roger Hoh of Hoh Aeronautics, Inc.

- FAA Sponsored Simulation Study
- Study summarized at SAE/IEEE Aerospace Control and Guidance Systems Committee Meeting, March, 2010, Charlottesville VA.
- Summarizing piloted simulation study in NASA Vertical Motion Simulator to develop transport aircraft rudder control system requirements…22 pilots participated

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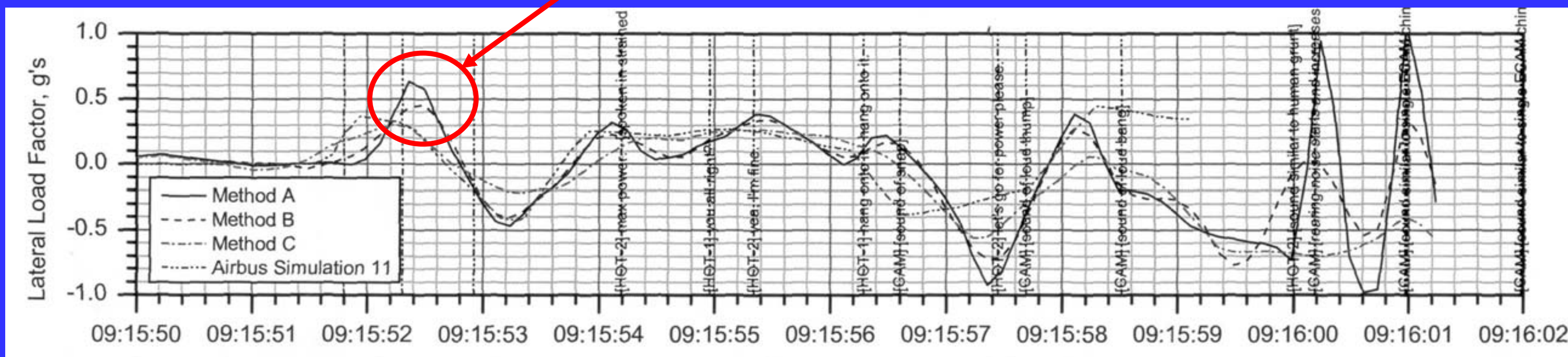
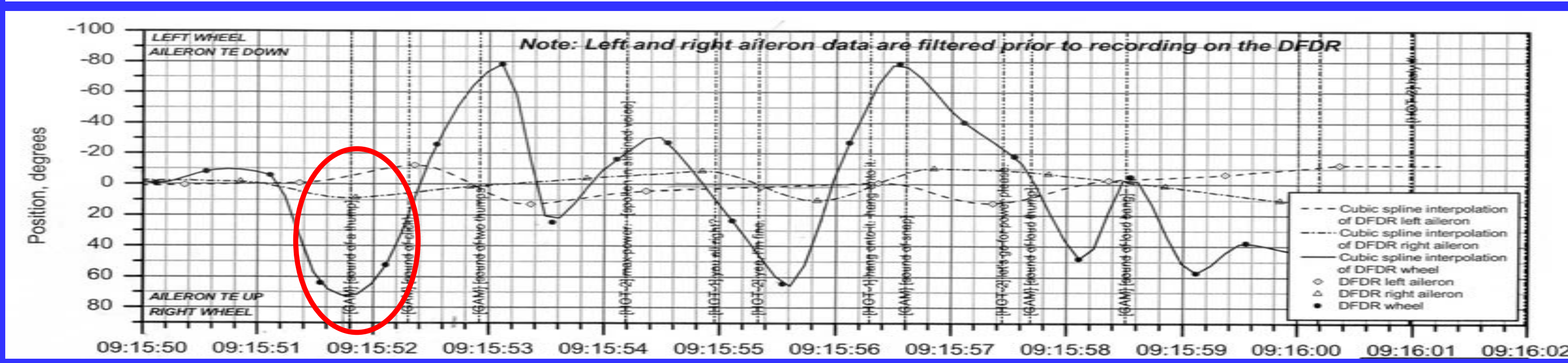
- Pilots are instructed to stay off rudder during up-and-away flight
- Assertion: If roll disturbance exceeds roll authority pilot WILL use rudder to augment aileron
- Developed task so roll disturbance exceeded aileron authority – similar to an extended wake vortex
- **<u>EVERY</u> pilot used rudder**

Example: Transport Aircraft (Airbus A-300)

American Airlines Flight 587

PIO triggering event?





lateral acceleration at cockpit in g's at second wake vortex encounter initiated by large rudder input

Conclusions

- Multi-axis pilot model developed that incorporates primary sensory information available to the human pilot:
  - Visual
  - Proprioceptive
  - Vestibular
- Model design begins with the simplified "pursuit" model of pilot
- Model can be created in a loop-by-loop process with the primary tool being the Bode plot
- Multi-loop (as opposed to multi-axis) pilot structure based upon serial loop closures with crossover frequency separation
- Area of concern to this speaker: the ability of a vortex encounter to create a "triggering event" for a pilot-induced-oscillation (PIO).