FMRA
Fachgebiet Flugmechanik, Flugregelung und Aeroelastizität

Overview on pilot models for wake vortex encounter simulations

- Robert Luckner

Berlin Institute of Technology

WakeNet3-Europe

WakeNet3-Europe, Specific Workshop
“Models and Methods for Wake Vortex Encounter Simulations”
Berlin, 1-2 July 2010

WakeNet3-Europe
A network on Aircraft Wake Turbulence

Day 2
Models of Pilot Behaviour and Severity Assessment

Wake generating aircraft

Wake creation

Initial rolled-up vortex

Wake evolution

Evolved & aged vortex

Wake encounter

vortex impact on follower aircraft

Aircraft reaction

Reaction of follower aircraft

Encounter hazard

Hazard

The models are needed for safety and risk assessments of new separation standards

Source: Airbus

Pilot models for wake vortex encounter risk assessment

Pilot behavioural models

- for manual flight
- for automatic flight (autopilot / auto throttle)

Severity criteria that represent pilots perception of a WVE

Objectives and expected outcome of day 2:

1) Summary of existing, state-of-the-art pilot models for
   a) pilot control behaviour
   b) severity assessment (severity criteria)

2) Evaluation of these state-of-the-art models and identification of research needs

3) Contribution to the WakeNet3-Europe report on Research Needs

   regarding “Wake vortex models for encounter simulations in real-time piloted simulator tests and for fast-time flight simulations for risk assessment”.

National Research Council (NRC), US:

Wake Turbulence - An Obstacle to Increased Air Traffic Capacity, pp 48 (2008)

On "Safety Analysis and Hazard Boundaries":

- **Finding**

3.14 Although the current air transportation system was designed to avoid wake vortex encounters, they do occur and are safely tolerated using present spacing criteria

3.15 It is difficult to quantify acceptable reductions in wake turbulence spacing because there is no agreed metric for, nor definition of, hazard boundaries for wake encounters

- **Recommendation**

regarding pilot control behavior models: none

3.11 A **hazard boundary** needs to be defined and used as a metric in forming spacing criteria

National Research Council (NRC), US:

Wake Turbulence - An Obstacle to Increased Air Traffic Capacity (2008)

- **Milestones for Wake Vortex Modeling**

Time Horizon	Milestone
1) Short term	a) Identify metrics for hazard definition b) Review European studies and complete detailed plan for simulator studies c) Begin conducting simulator studies d) Identify conservative hazard boundaries
2) Medium term	a) Analyse results from simulator studies to quantify hazard b) Develop risk assessment methodology and apply it to simulator studies c) Refine hazard boundaries based on available data
3) Long term	a) Test and implement refined hazard boundary b) Demonstrate real-time safety analysis in actual flight

WakeNet2-Europe in Collaboration with WakeNet-USA:

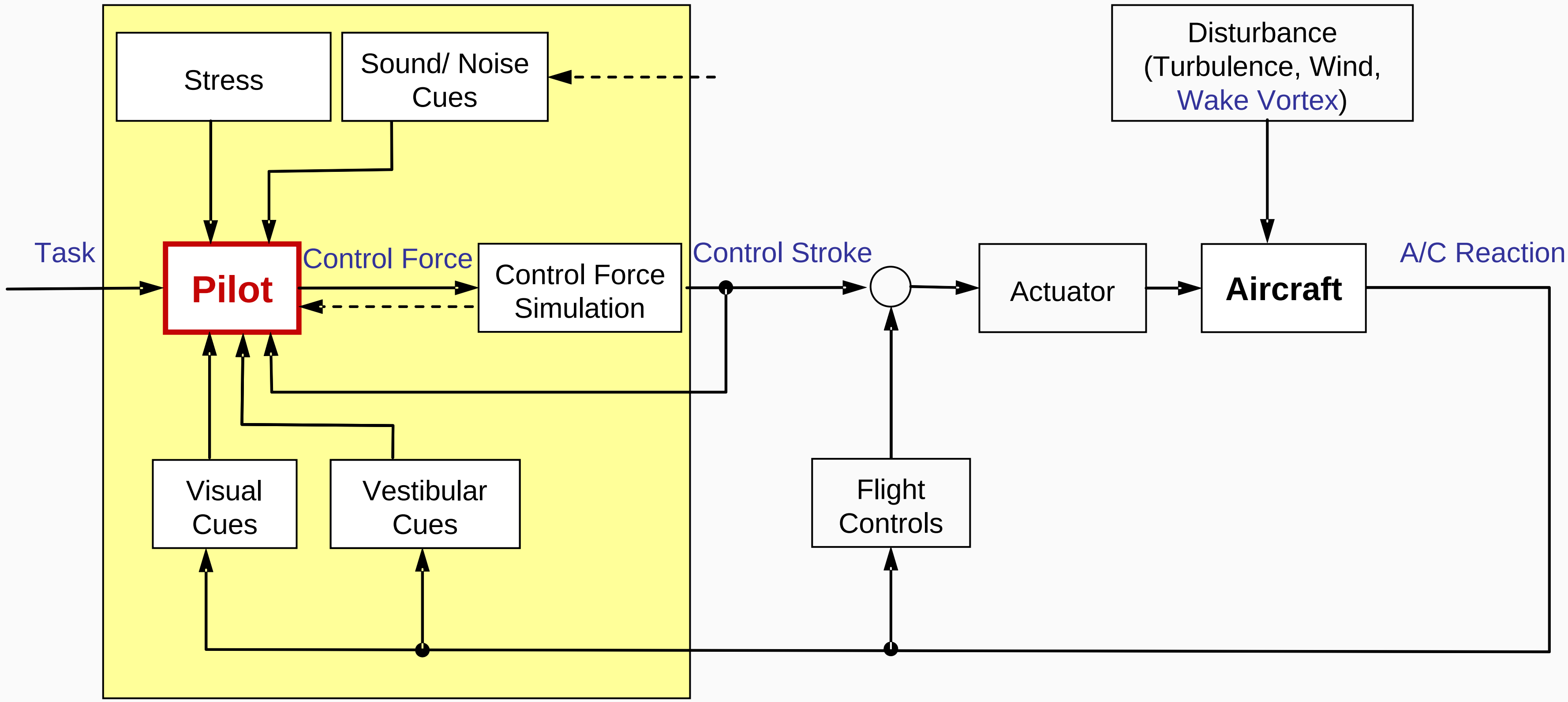
Wake Vortex Research Needs for Improved Wake Vortex Separation Ruling and Reduced Vortex Signatures (March 2006)

- **Recommendation (Part 2, pp 49)**

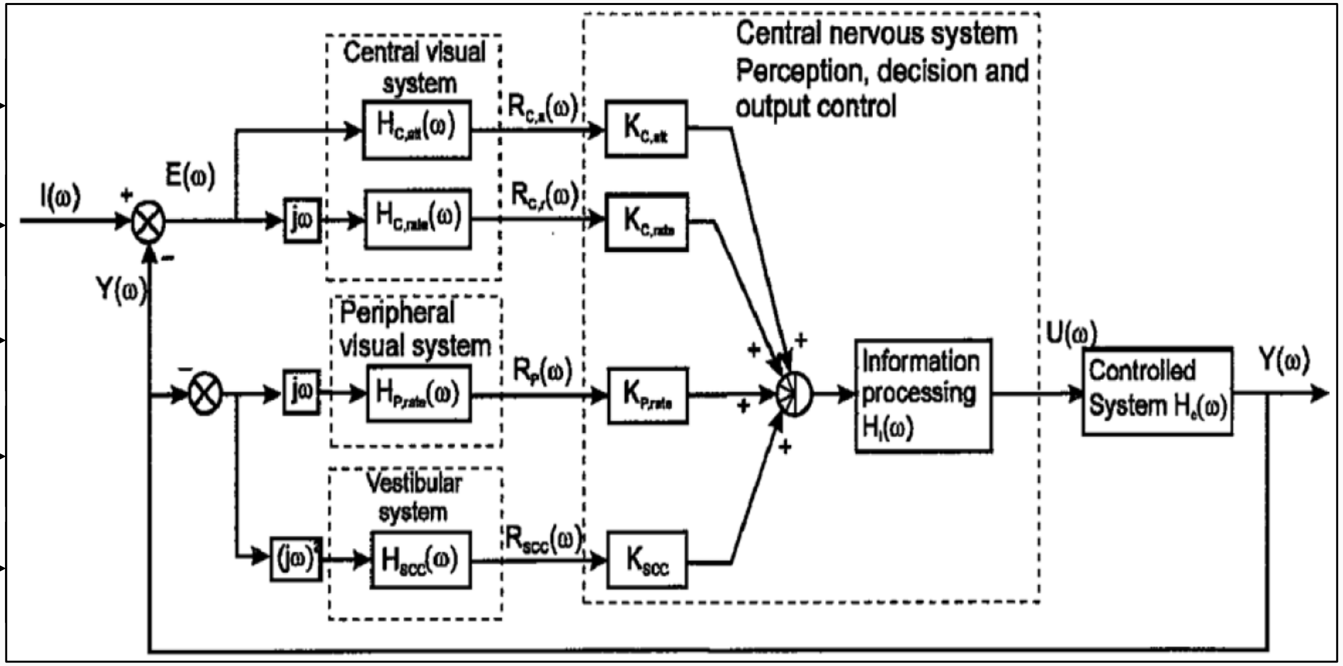
  Reliable definitions of (non-)**hazard criteria** (levels) are urgently required, …

  For offline severity assessment of manually controlled flights wake vortex encounter **pilot models** are necessary and have been developed for the approach situation in S-WAKE. But for other flight phases, like departure, models are lacking. …

Pilot – Vehicle System



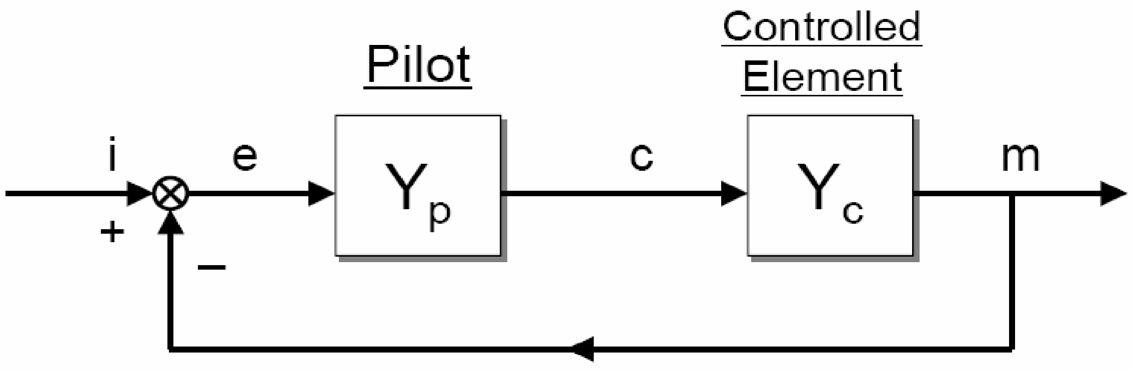
Stimuli



Sensor organs

Central Nervous System

Quelle: S. Advani

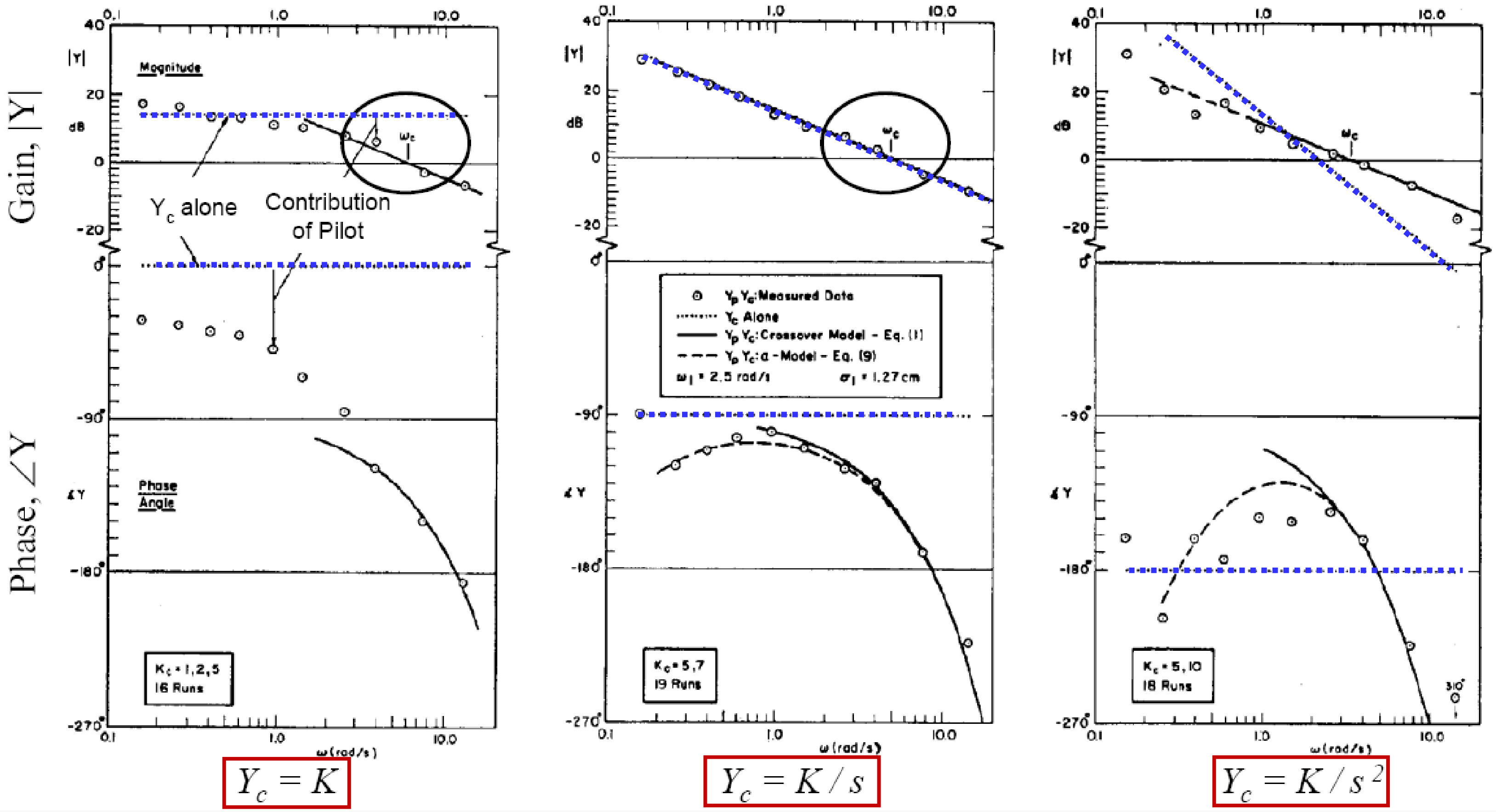


- Pilot adopts sufficient lead or lag so that the open-loop transfer function becomes :

$$Y_{OL}(j\omega) = Y_p Y_C \cong \frac{\omega_c e^{-j\omega\tau_e}}{j\omega}$$

near ω_c , i.e., the crossover frequency. (τ_e = effective time delay)

- Crossover Models for $Y_c = K$, K/s, and K/s^2
  - *The open-loop transfer function ($Y_{OL} = Y_C Y_P$) has slope of approx. –20 dB/decade (solid line) in the crossover-frequency (ω_c) region.*



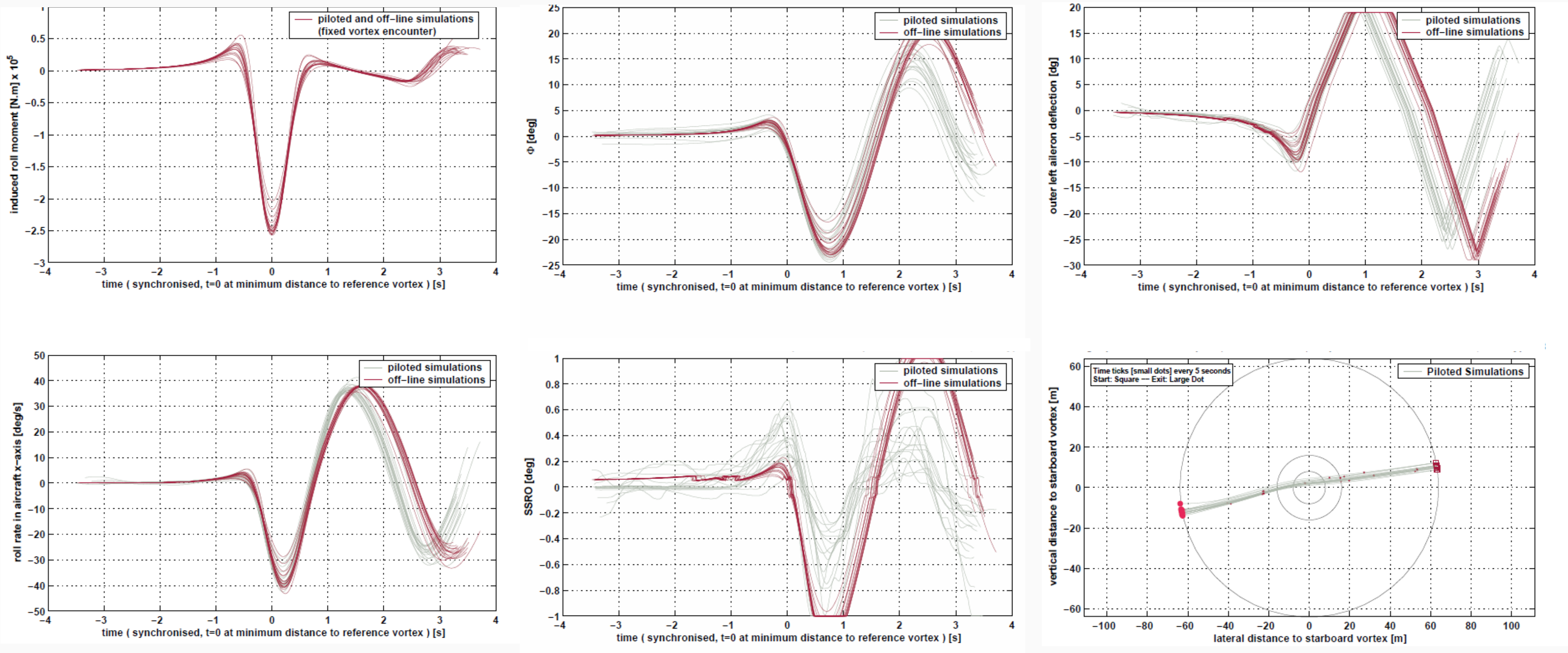
Describing Function of Pilot Behaviour

Controlled Element: $Y_c(s)$	Related Aircraft Control Situations	Pilot's Describing Function
K_c		$K_p e^{-j\omega\tau_e} / (T_I j\omega + 1)$
K_c / s		$K_p e^{-j\omega\tau_e}$
K_c / s^2		$K_p (T_L j\omega + 1) e^{-j\omega\tau_e}$
$K_c / s(Ts+1)$	Roll angle control by ailerons.	If $T > \tau_e$, $K_p (T_L j\omega + 1) e^{-j\omega\tau_e}$ If $T < \tau_e$, $K_p e^{-j\omega\tau_e}$

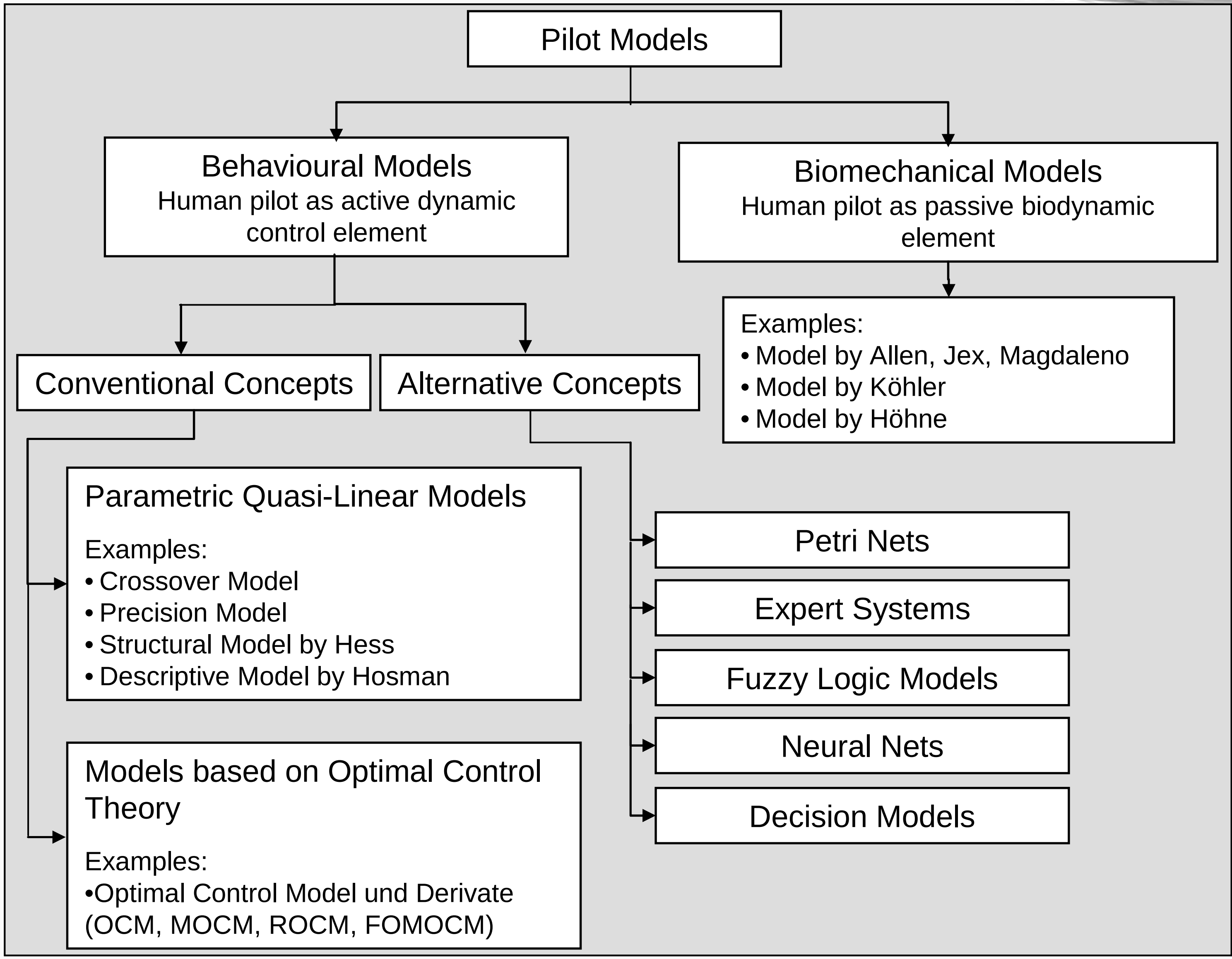
Crossover Pilot Model

$$K_p \frac{1+\tau_{lead} s}{1+\tau_{lag} s} e^{-T_p s}$$

Pilot-Aircraft response in a wake vortex encounter:



Pilot Models



Severity Criteria

- **Metrics**

  bank angle, roll rate, roll acceleration, roll control ratio (RCR)

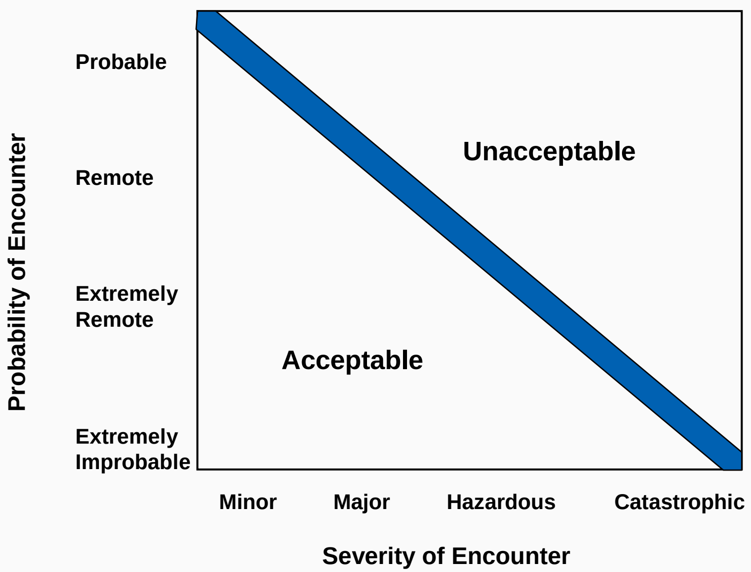
  as a function of height above ground

- **Boundaries**

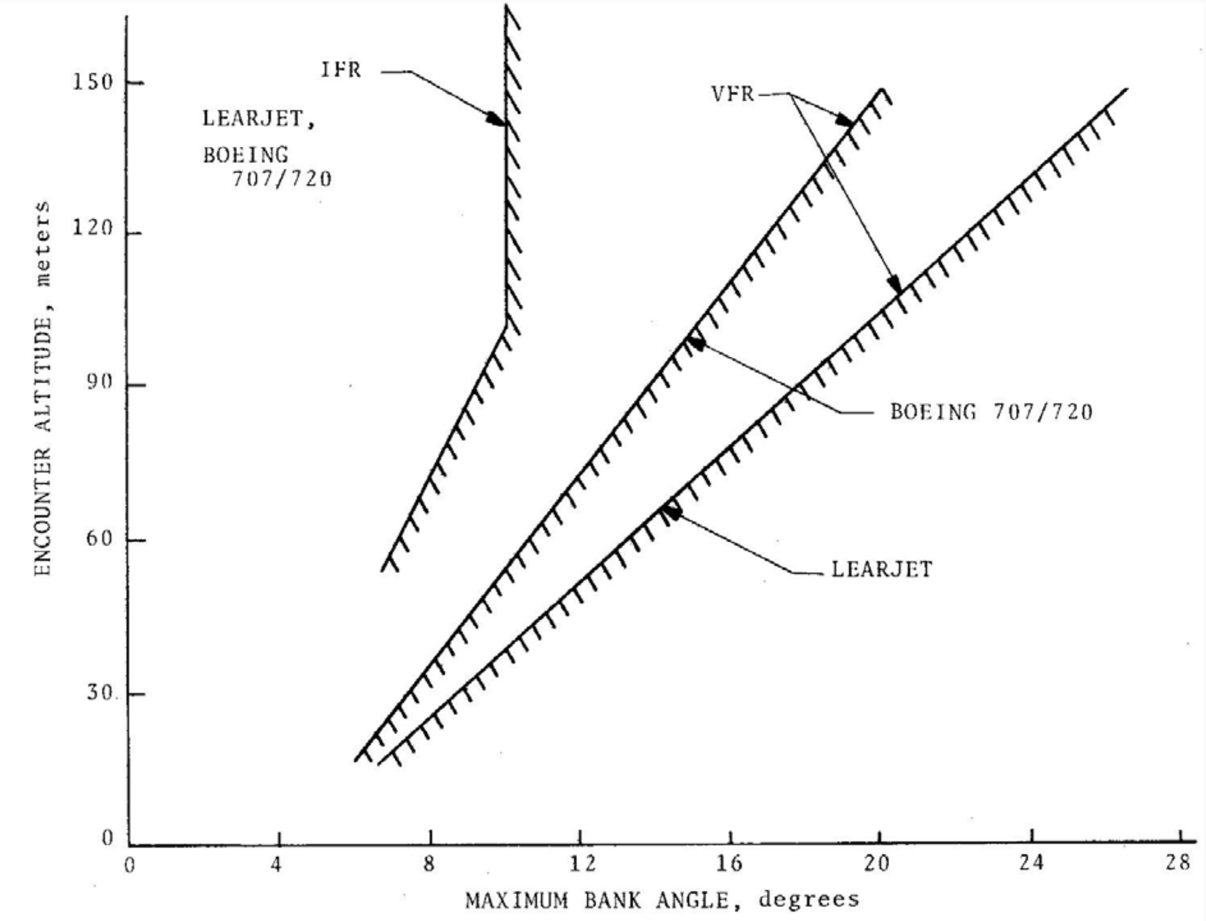
  What is acceptable?

  different levels?

  levels depending on probability

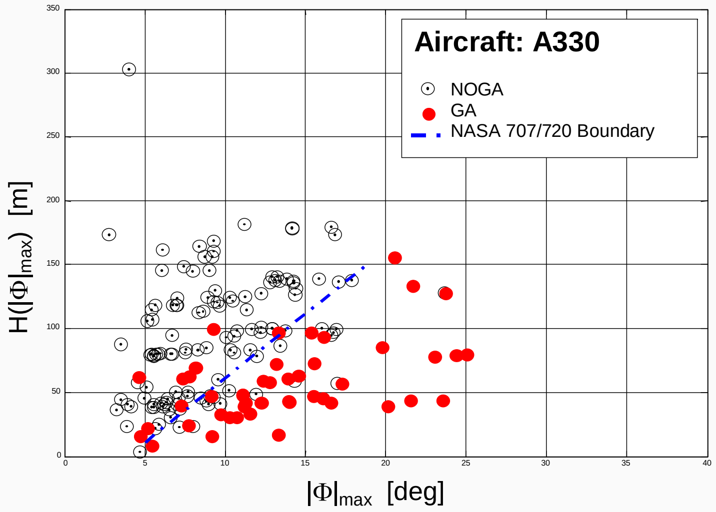


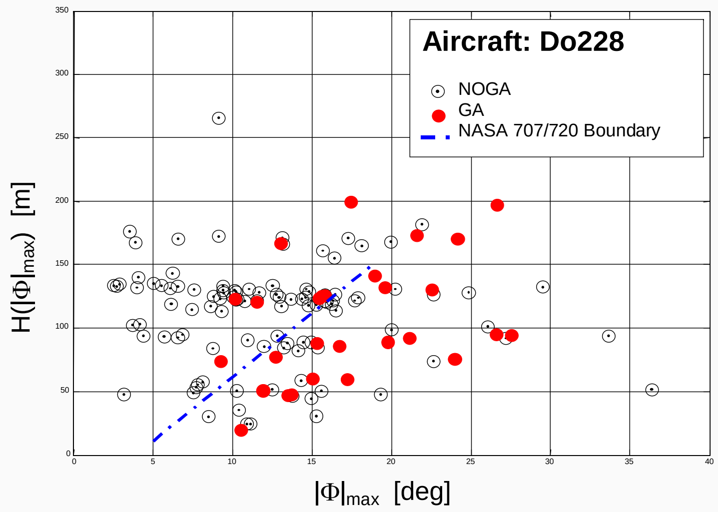
Results of NASA simulation experiments

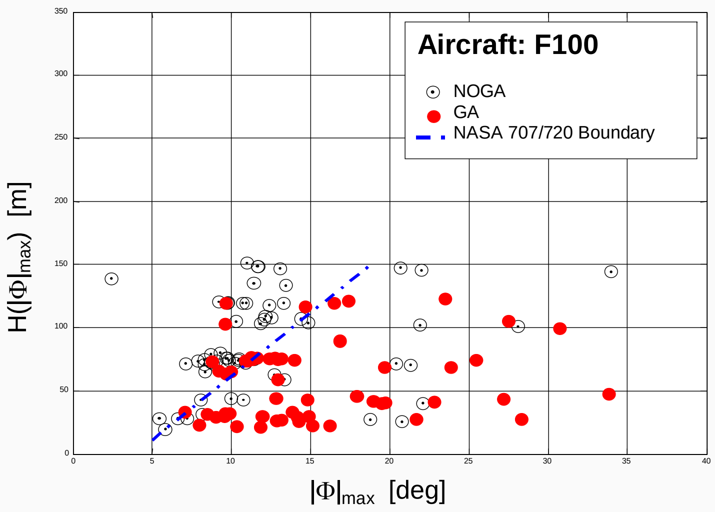


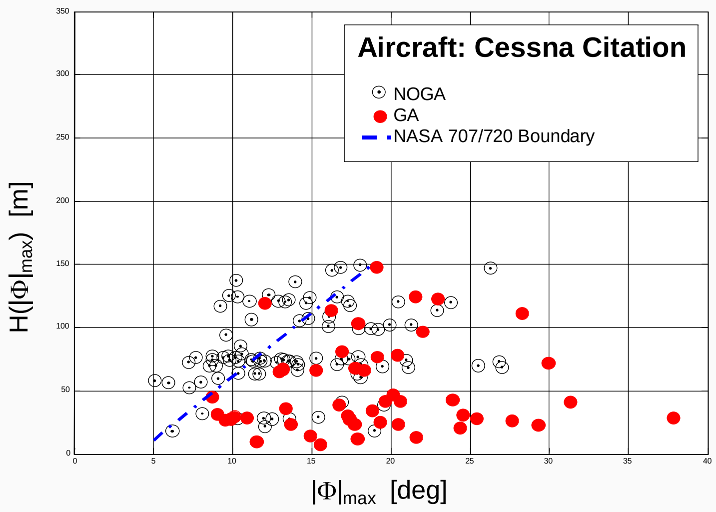
Sammonds R.I., Stinnett Jr G.W., Larsen WE: 'Wake vortex encounter hazard criteria for two aircraft classes'; NASA TM X-73,113, June 1976
Sammonds R.I., Stinnett Jr. G.W.: 'Hazard Criteria for Wake Vortex Encounters', NASA TM X-62.473, Moffet Field, CA, 1976

Go-Around Prediction during Landing









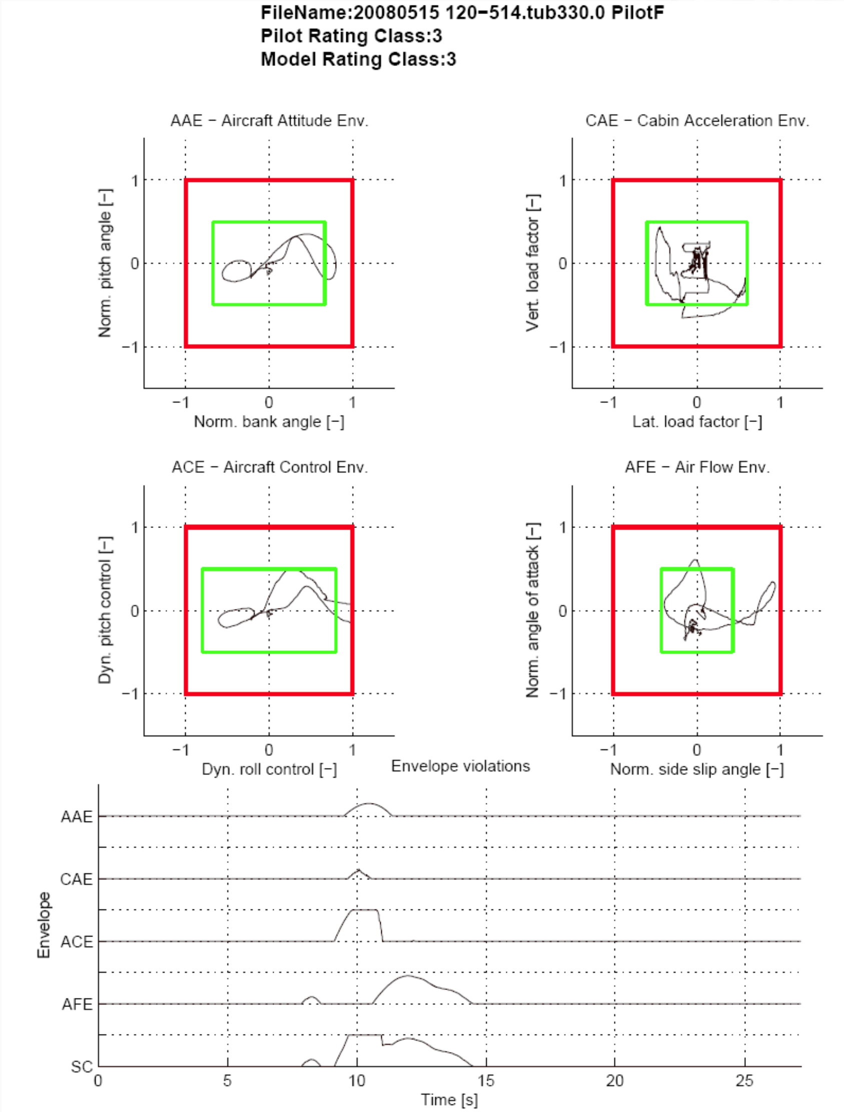
S-WAKE
Assessment of Wake Vortex Safety

- 1623 WVEs
- 48 Session
- 40 Pilots
- 5 Aircraft
- 4 Simulators

⇨ S-WAKE and NASA results in good agreement

Severity Criteria

- **Aircraft Attitude Envelope (AAE)**
  - Delta pitch angle
  - Bank angle
- **Cabin Acceleration Envelope (CAE)**
  - Vertical load factor
  - Lateral load factor
- **Aircraft Control Envelope (ACE)**
  - Sidestick pitch cmd
  - Sidestick roll cmd
- **Air Flow Envelope (AFE)**
  - Delta angle of attack
  - Sideslip angle



Questions

1. Is the performance of current **Pilot Models** (control behaviour and severity assessment) satisfying for WVE risk assessment?

2. Is there further research required? In which area?

2. How can validation and credibility of models be achieved