FMRA
Fachgebiet Flugmechanik, Flugregelung und Aeroelastizität

Modified Optimal Control Model and Wake Vortex Encounter

Technische Universität Berlin

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WakeNet3 - Europe Specific Workshop: Models and Methods for WVE Simulations

Objective

Modelling of multi-axis manual control task

Tool

„Modified Optimal Control Model“ (MOCM)

Purpose

- Cost, time and risk reduction during development and flight test phase
- Understanding and explaining behaviour of Pilot-Vehicle Systems

Application

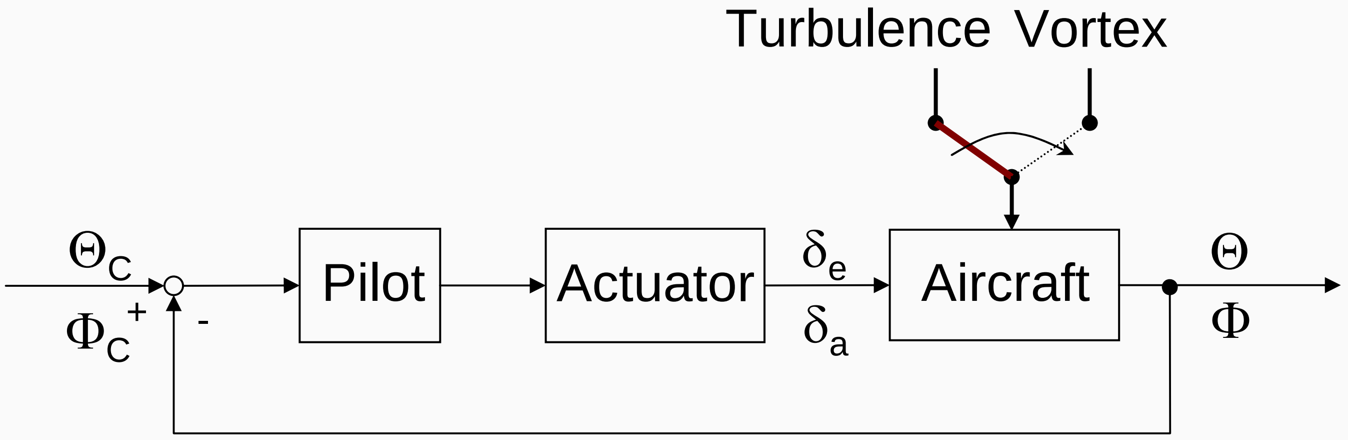
Investigation of wake vortex encounter (WVE)

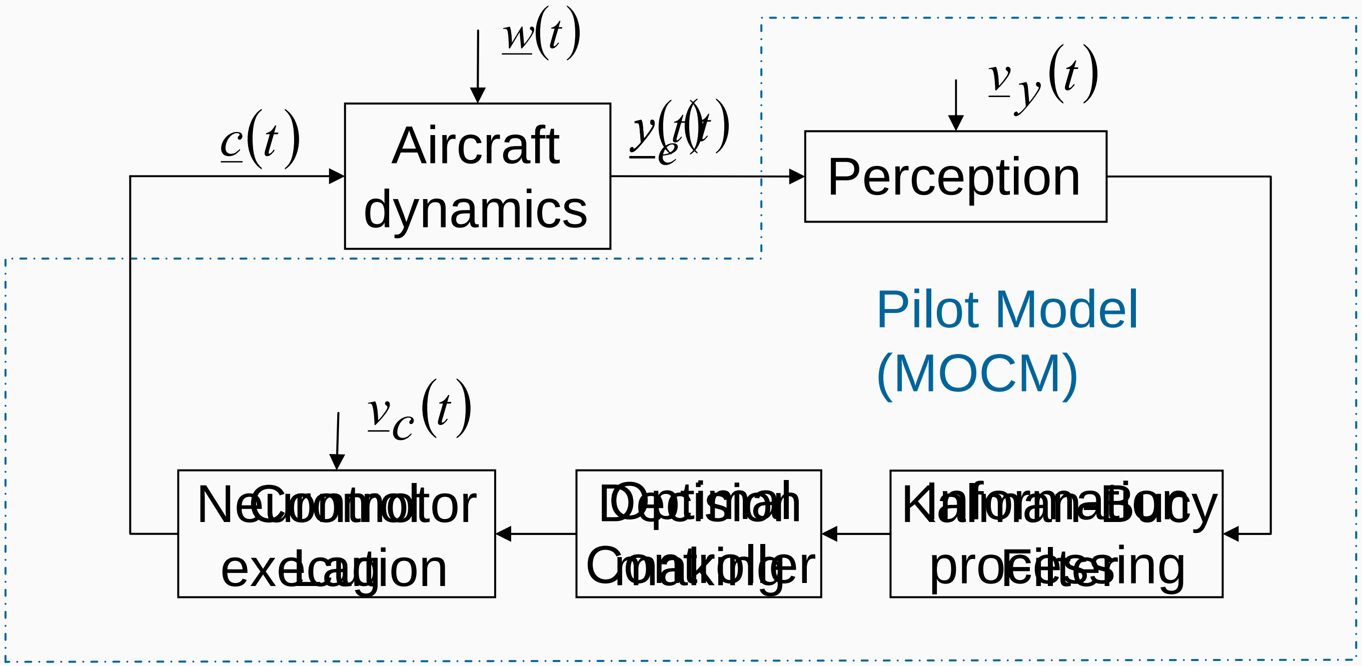
Control Task – Flight in Turbulence

- Linear rigid body dynamics
    - altitude 50 m
    - approach speed 80 m/s
- Decoupled longitudinal and lateral channel
- Control of aircraft with side stick

Input

- Dryden Turbulence Model
    - Longitudinal standard deviation: $\sigma_{\Theta} = 1°$
    - Lateral standard deviation: $\sigma_{\Phi} = 5°$

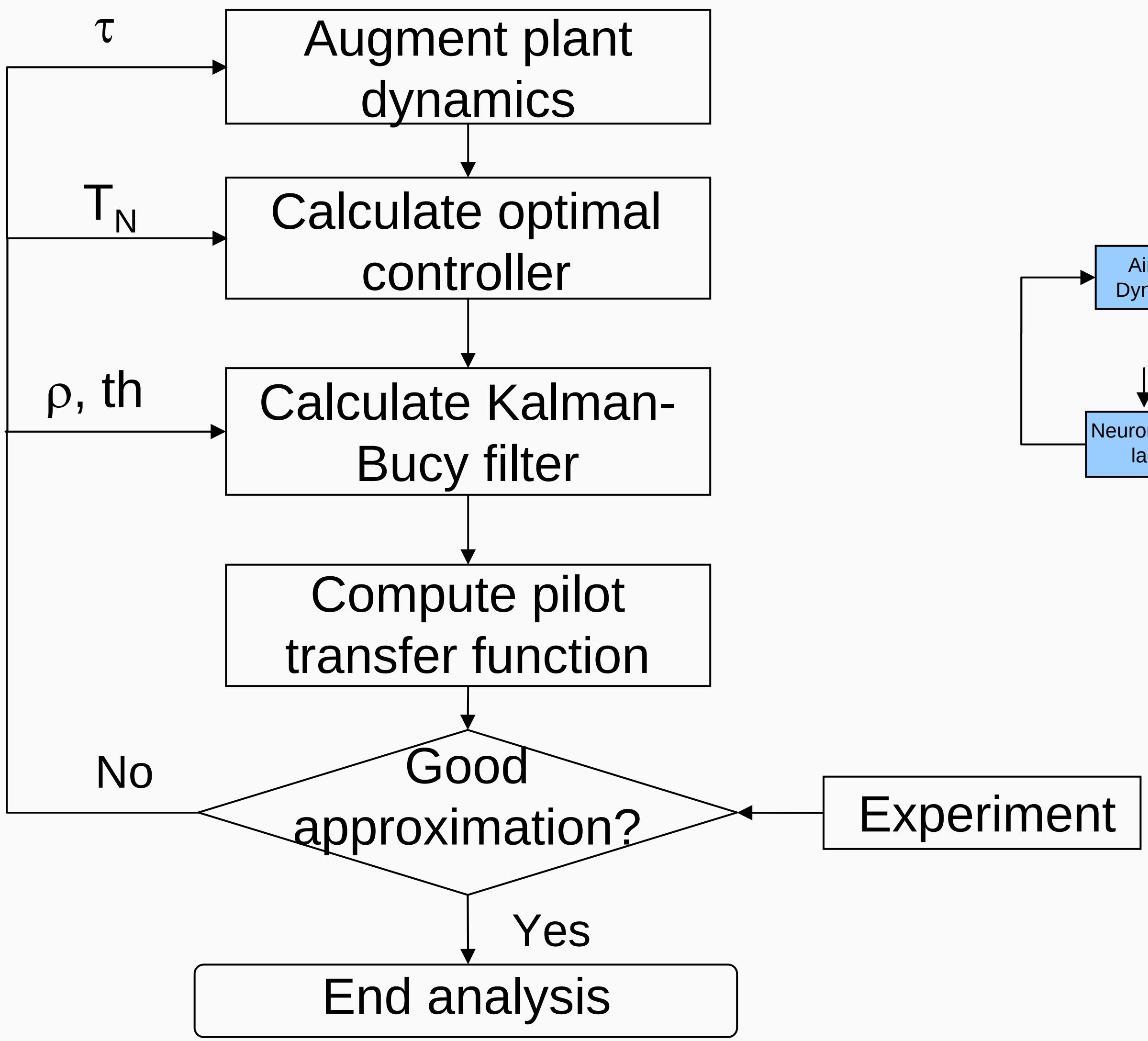


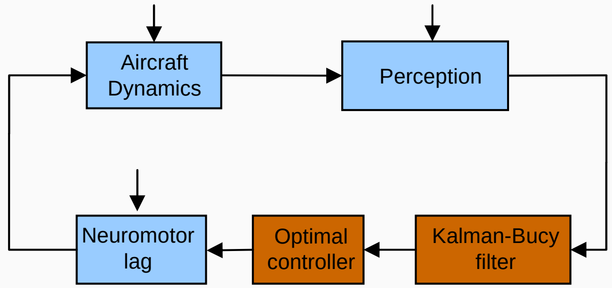


Cost function

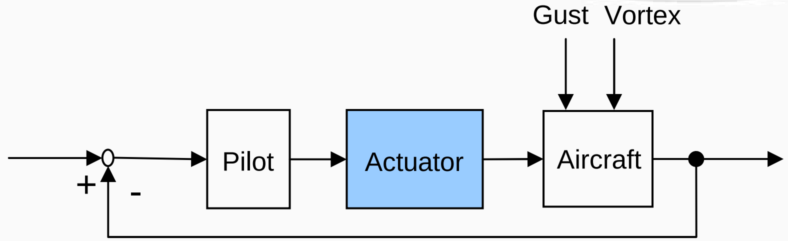
$$J = \int_{-\infty}^{\infty} \left(\underline{y}_e^T(t) \underline{\underline{Q}} \underline{y}_e(t) + \cancel{\underline{c}^T(t) \underline{\underline{R}}} \underline{c}(t) + \underline{\dot{c}}^T(t) \underline{\underline{G}} \underline{\dot{c}}(t) \right) dt$$

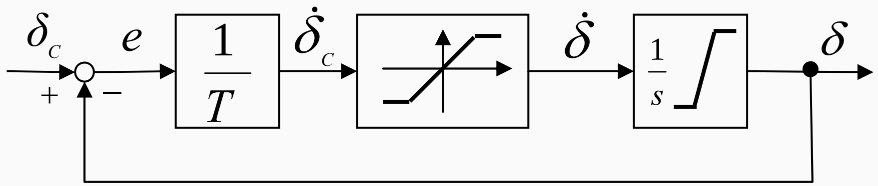
Pilot Modelling (2/2)





Actuator Dynamics





$$K = f(\dot{\delta}_{c\,\max}, \sigma_{\dot{\delta}c})$$

$$Y_A(s) = \frac{1}{(T/K)s + 1}$$

Rate Limit

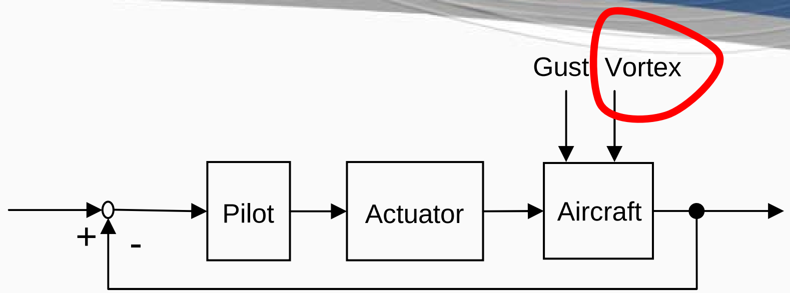
$$\dot{\delta}_{\max} = \pm 20°/s$$

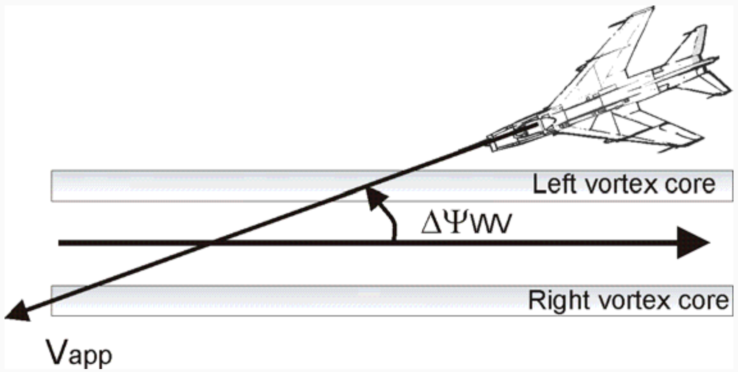
Position Limit

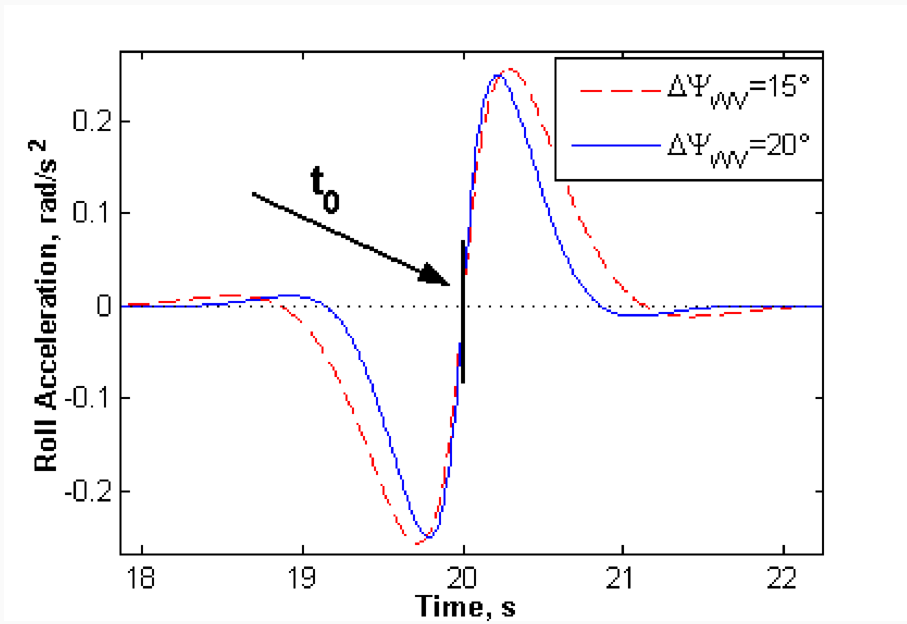
$$\delta_{e\,max} = -10°/+20°$$

$$\delta_{a\ max} = \pm 20°$$

Wake Vortex Dynamics

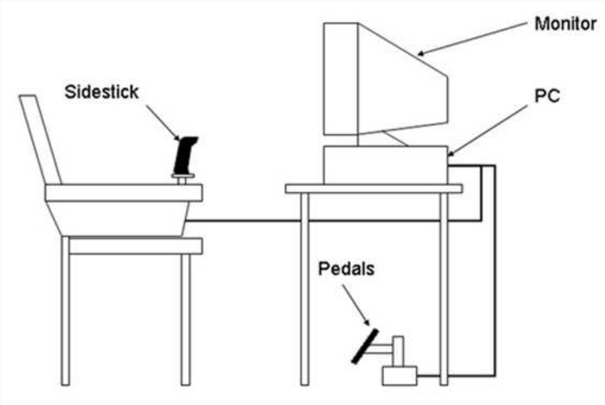


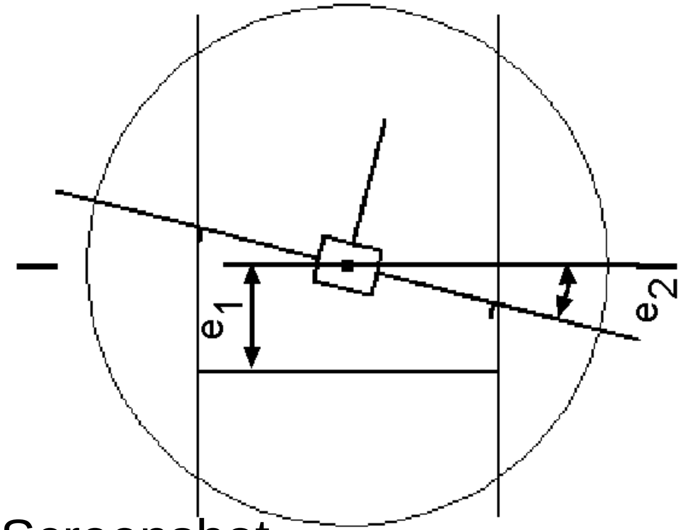


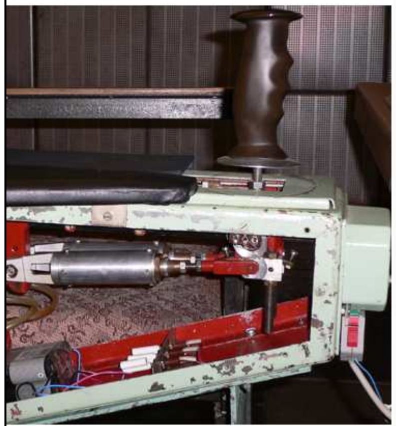


Approximation

$$\Delta L = A_{\max} e^{|t-t_0|\omega} \sin\left(\omega\left(t - t_0\right)\right)$$







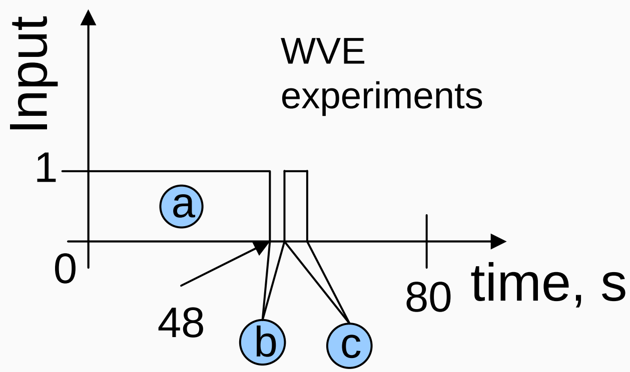
2 Pilots: Experienced engineer pilot and author

Experiments

1. Parameterization of pilot model by turbulence tracking task
   - Several series of 3 flights a 144 s
2. WVE-campaign with linear A/C dynamics
3. WVE-campaign with nonlinear A/C dynamics

Variation

- Encounter angle $\Delta\Psi_{WV}$
- Encounter side
- Amplitude

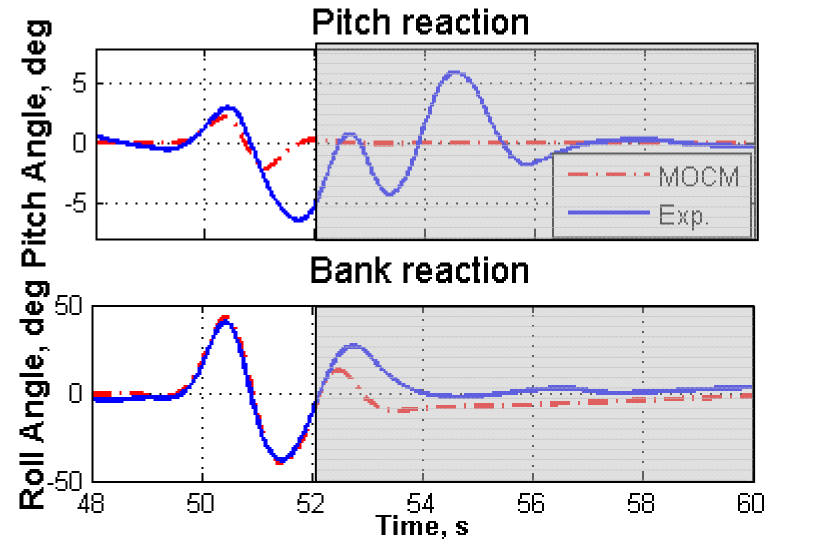


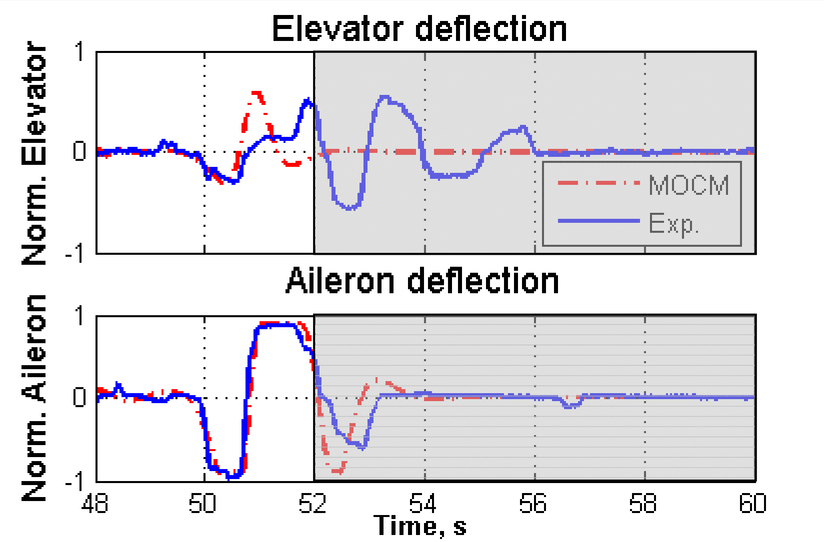
Aim

Extrapolation of Pilot-Vehicle system reaction to vortex encounter for at least one half oscillation of vortex input signal

Linear A/C Dynamics

- Around 38 test cases (TC)
- Good initial coincidence in roll motion for 31 TC
- Coincidence in pitch channel less
- Compliance time between 1.5 and 3 seconds
- First amplitude most serious one
- Stick limitation reached

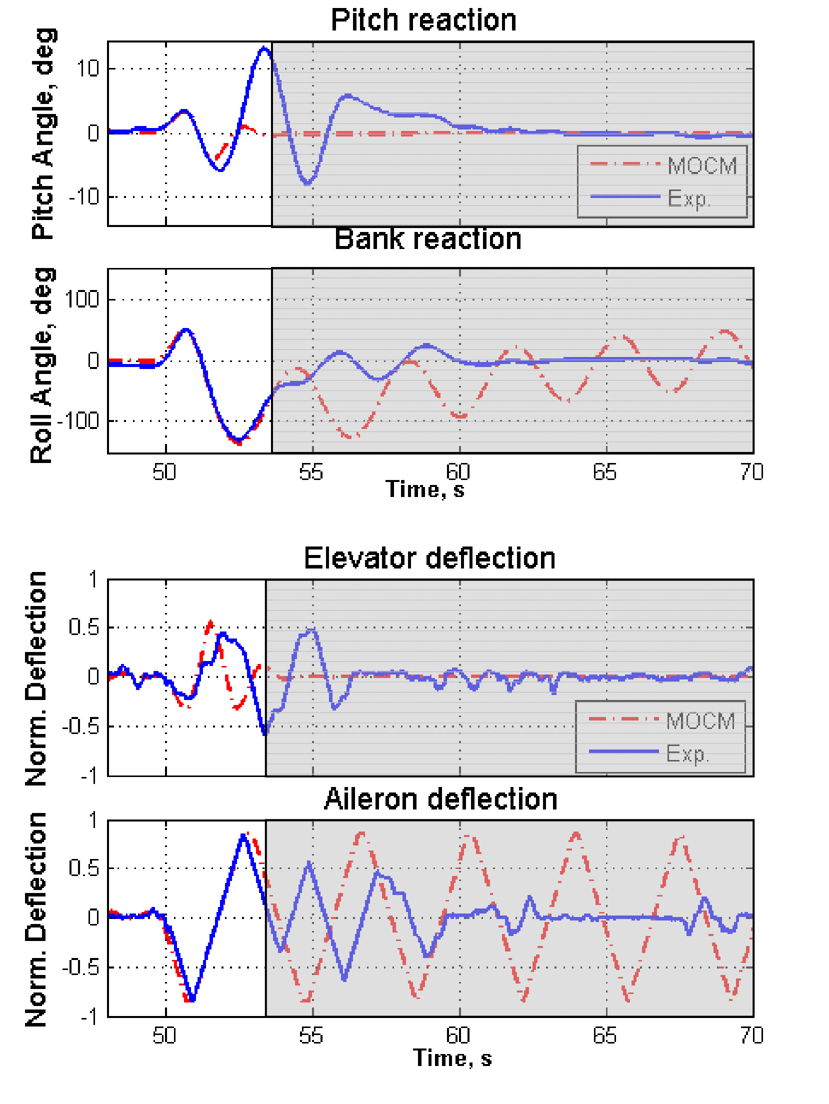




Results (2/2)

Nonlinear A/C Dynamics

- Around 40 test cases
- Good coincidence in 35 test cases
- Compliance time lower than in linear case
- Second amplitude normally higher
- MOCM has oscillation tendency for lower encounter angles
- Actuator rate saturation reached



Open Issues

Control Task

- Modelling of transport aircraft dynamics
- Simulating landing approach (flight path angle $\gamma \neq 0°$)

Conduction of Experiment

- Repeat experiments with airline pilots
- Investigate nonlinear dynamics more in detail

Summary

- Method developed for wake vortex encounter investigation
- Feasibility demonstrated
- Pilot reaction most serious in the beginning
- MOCM has PIO-Tendency in nonlinear case for low encounter angles

Thank you for your attention!
Questions?

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