FMRA
Fachgebiet Flugmechanik, Flugregelung und Aeroelastizität

Probabilistic Pilot Model Approach for Wake Vortex Encounter Simulations

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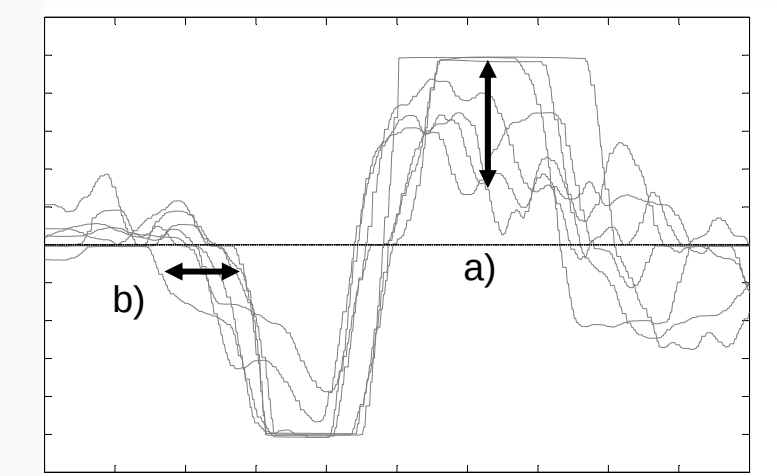
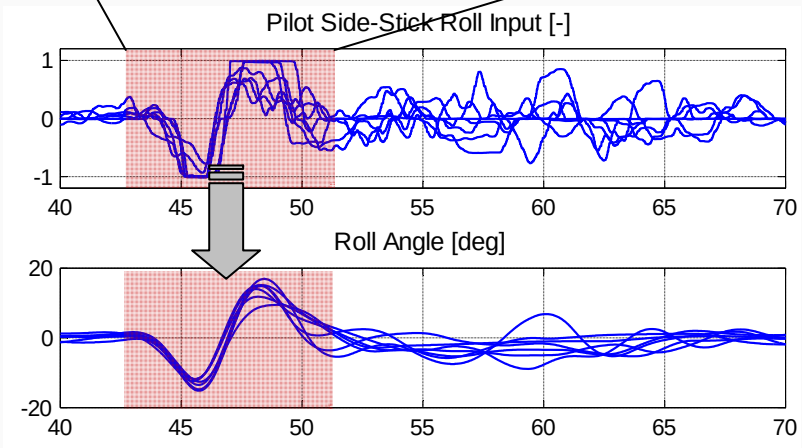
WakeNet3 - Europe Specific Workshop: Models and Methods for WVE Simulations

- Objective / Motivation
- Pilot Model Requirements
- Development Process
- Model Structure
- Types of Simulation Data
- Exemplary Results
- Conclusions

Objective / Motivation





Why is a probabilistic PM needed?

- Scatter in pilot inputs results in scattered A/C response
- Severity model approaches are based on parameters of A/C response (e.g. roll angle, roll rate)

Pilot model quality directly affects inputs to severity model

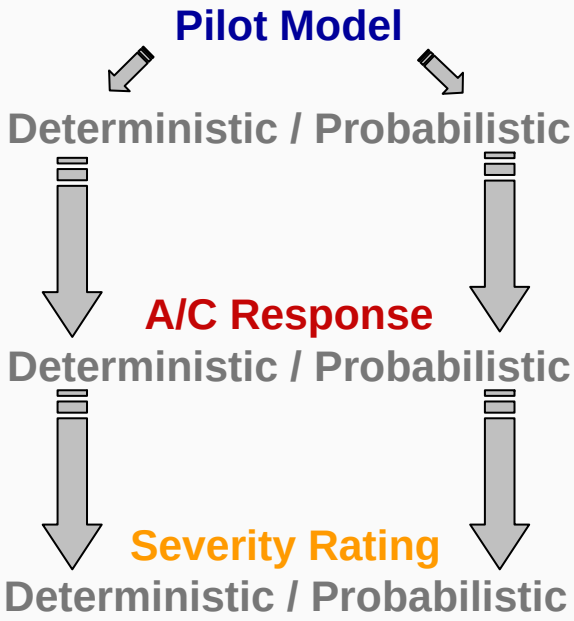
For identical vortex encounters a variation in pilot control inputs can be observed for one single pilot and in-between pilots.

- Variation observed for:
  - a) magnitude
  - b) phase of control inputs
- Modelling these variations via a probabilistic pilot model expands worst case simulation capabilities

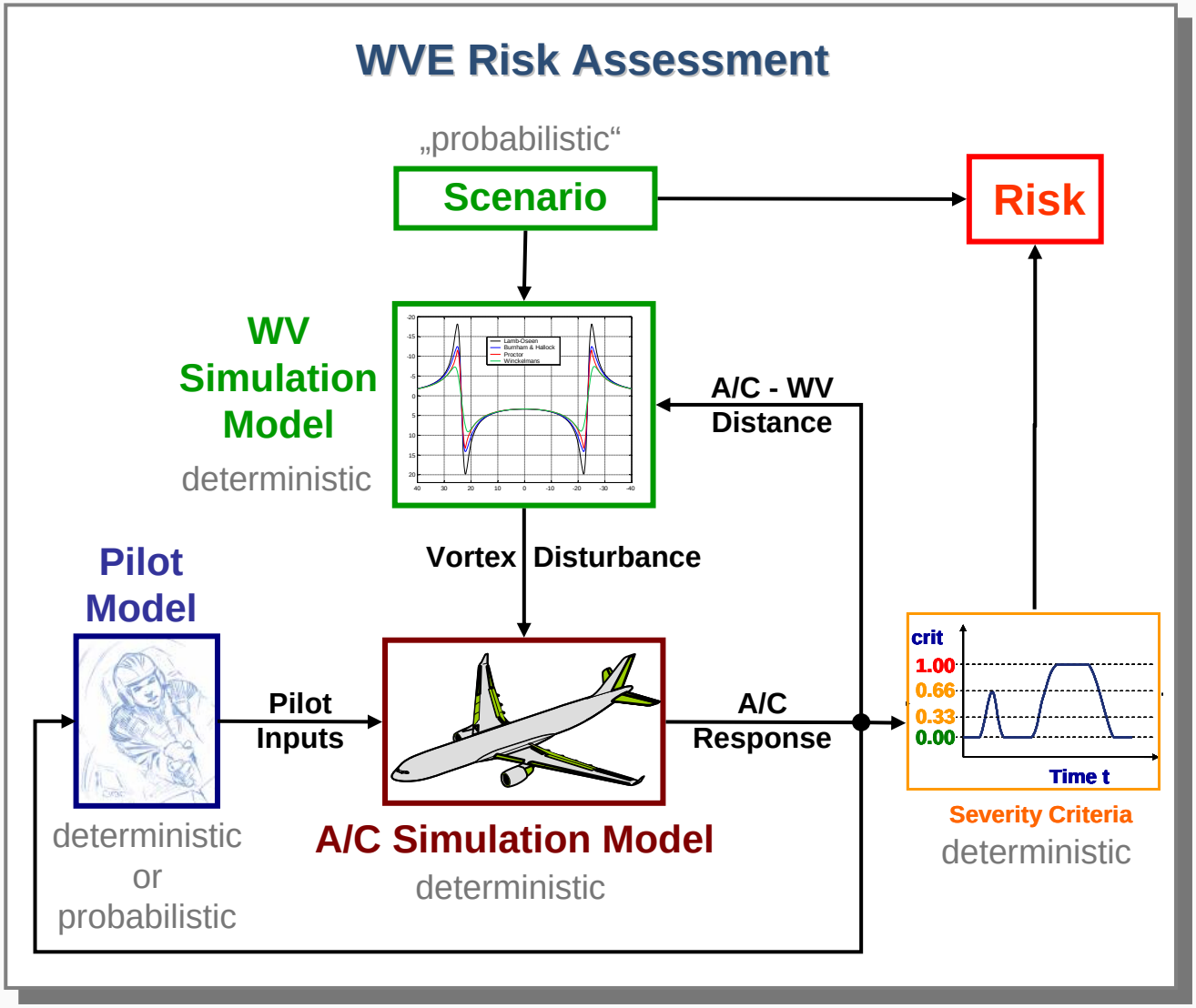
Worst case	=	Worst case encounter scenario	+	Worst case pilot reaction

Probabilistic pilot model contributes to severity assessment

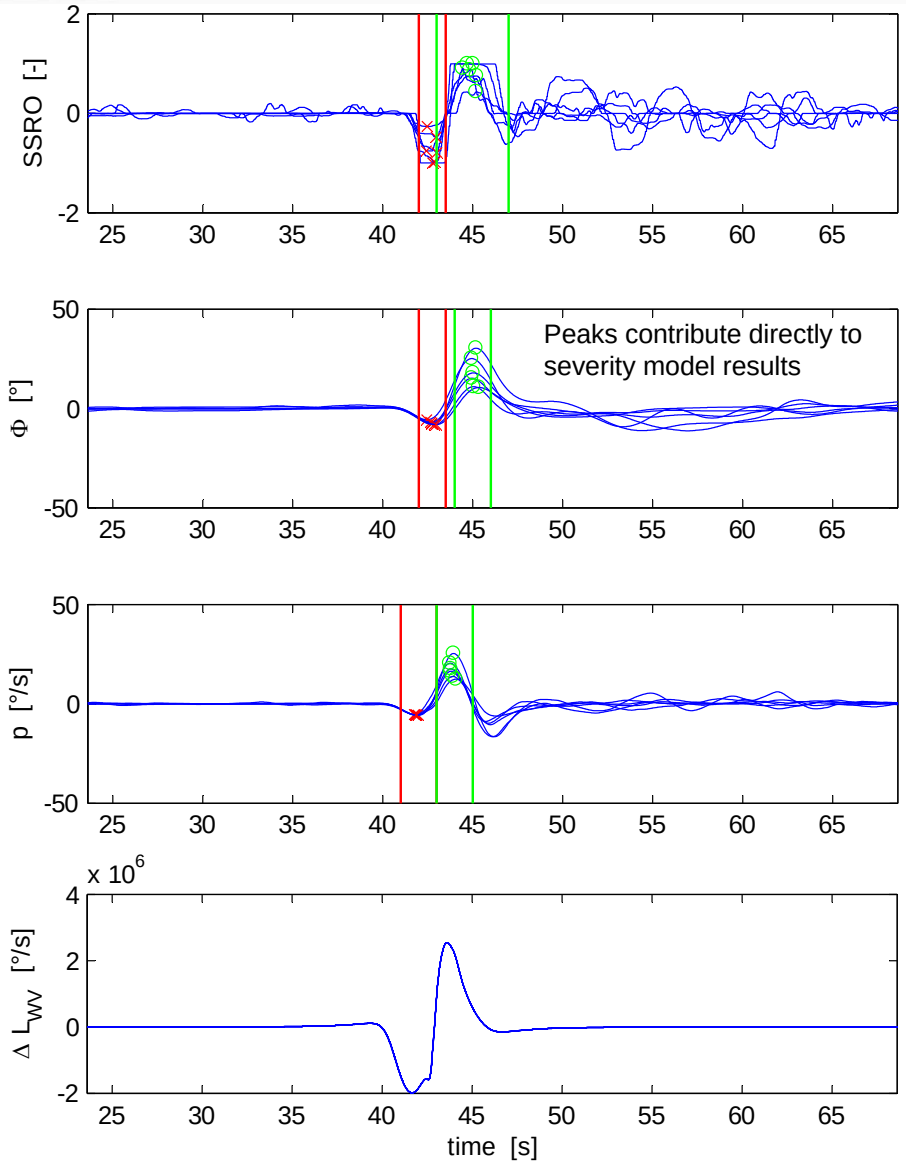
Objective / Motivation



Probabilistic PM contributes to risk assessment results



Pilot Model Requirements



Qualitative Requirements

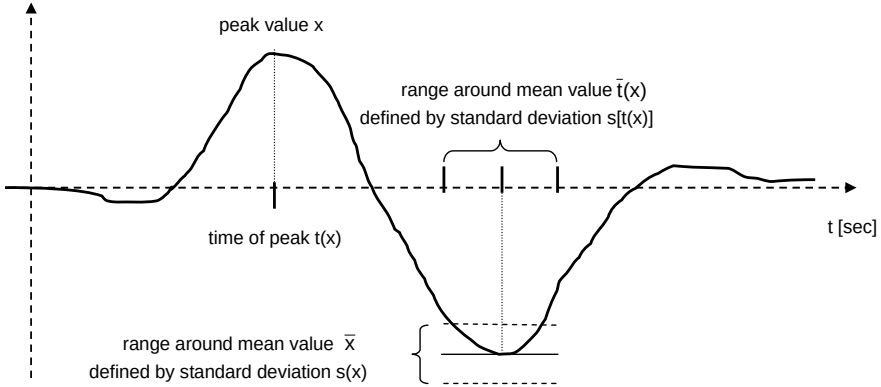
The *deterministic* pilot model shall result in pilot control inputs and aircraft reactions that are well-within (< 1σ) the natural, statistical scatter observed in piloted WVE simulations.

The *probabilistic* pilot model shall result in pilot control inputs and aircraft reactions with means and variations about the means comparable to the natural, statistical scatter observed in piloted WVE simulation.

Quantitative Requirements

Means and standard deviations of first two significant roll axis peaks (magnitude and time of peak) for:

1) **Pilot control input**
2) **A/C response**



Piloted Model Development

FCOM

Flight Crew Operational Manual

Normal / special procedure

ONLINE

Pilot task

Wake vortex

Pilot-in-the-loop Simulator tests

Test evaluation (Time histories & Questionnaires)

e.g. S-WAKE CREDOS

Piloted WVE Simulation Data Base

A/C Reactions

Pilot Inputs

Test / Validation (Offline simulation, PM-in-the-Loop)

OFFLINE

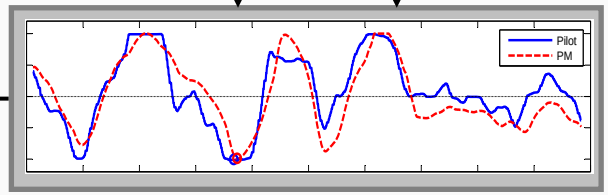
- Models of human pilot behaviour (e.g. Crossover Model)
- RMSE optimization criteria
- Quality assessment via AAM, R, DTW

Optimization

Pilot Model

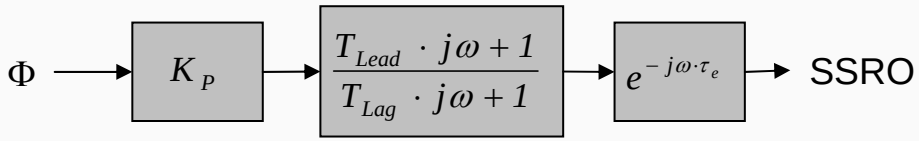
PM Inputs

Criterion



Crossover Pilot Model

- Developed by D. McRuer / E. Krendel in 1960ies
- Derived from Crossover Law which describes adaptation capabilities of human pilot
- Three elements:
  - Pilot Gain
  - Lead / Lag Filter
  - Time Delay

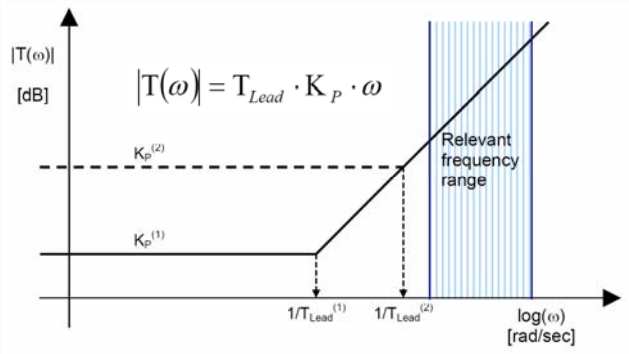


- Four parameters: K_P, T_{Lead}, T_{Lag}, τ_e
- WVE pilot modelling: generate side-stick roll input (SSRO) from roll angle Φ

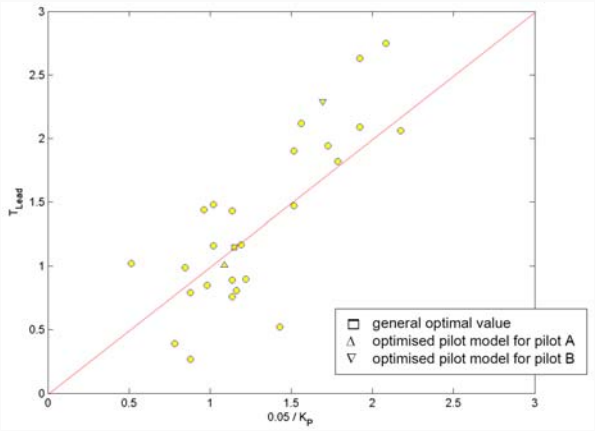
NOTICE!

- Parameters are correlated with respect to their effects on dynamic characteristics of describing function
- Parameter correlations may affect numerical optimizations

Effects of K_P and T_{Lead} on Amplitude [1]



Correlation of K_P and T_{Lead} as found in [1]



[1] Source: Airbus

Free / Forced WVE Simulation Data

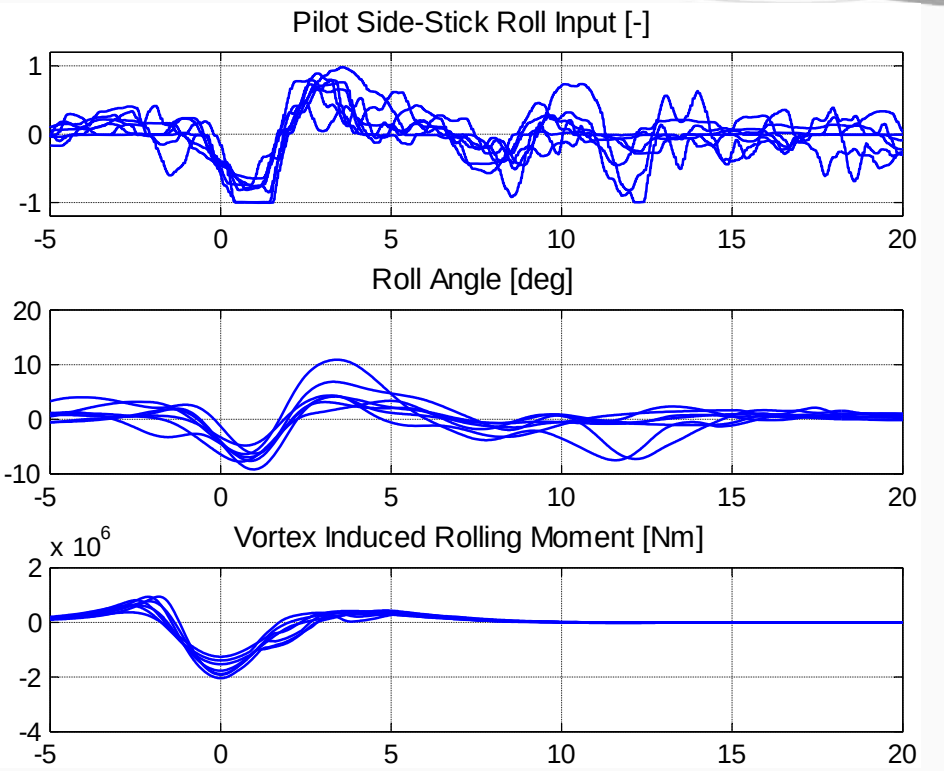
Simulation Characteristics

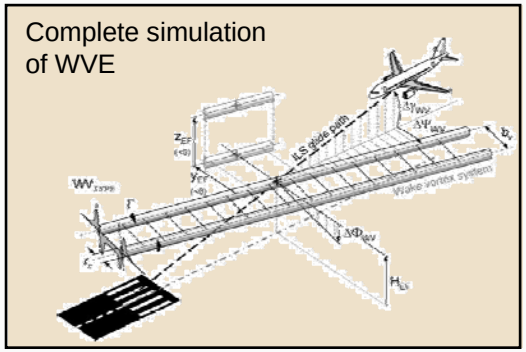
- Free evolution of vortex induced disturbances in time depending on A/C flight path
- Vortex disturbances comply exactly with simulated A/C motion
- Pilot inputs before encounter affect vortex disturbance via flight path

Characteristics w.r.t. PM Development

- Recorded data includes pilot reactions for a large number of different encounter scenarios **but**
  Each encounter is “unique”, no exact reproducibility
- Variation in pilot inputs may be a result of factors other than behaviour (e.g. WVE scenario)

Suited for ***deterministic*** pilot model tuning





Fixed WVE Simulation Data

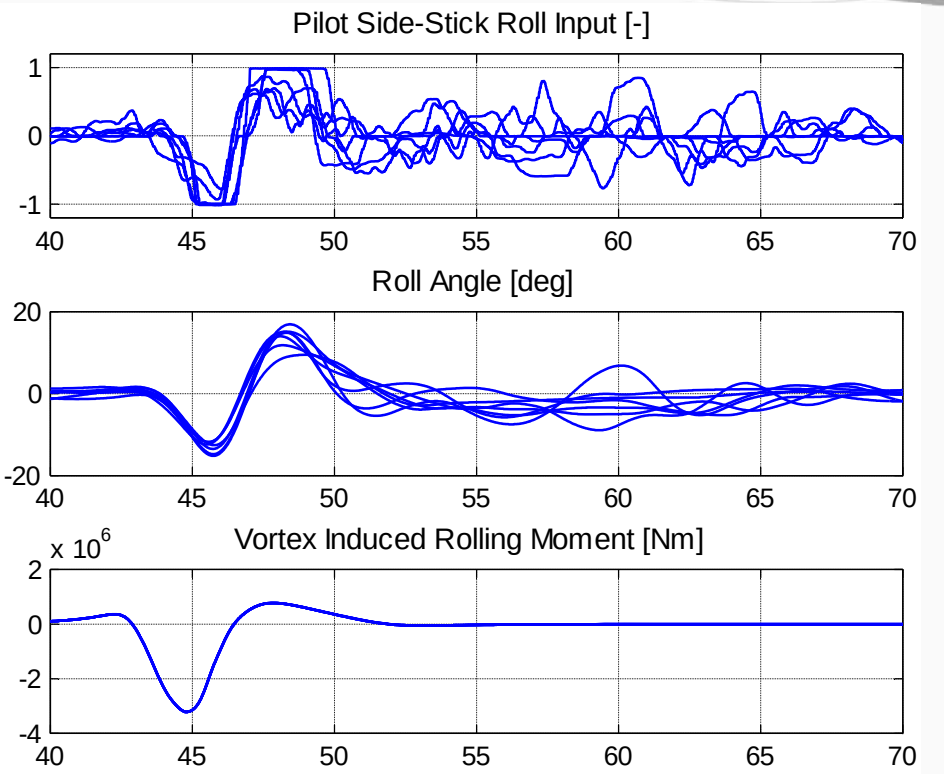
Simulation Characteristics

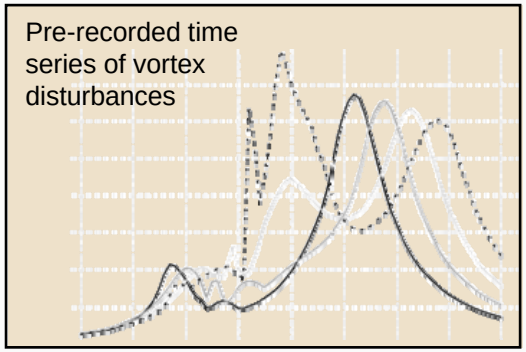
- Vortex induced disturbances are realistic but fixed in time
- Vortex disturbances do not comply exactly with simulated A/C motion
- Pilot inputs before encounter do not affect vortex disturbance via flight path

Characteristics w.r.t. PM Development

- Pilot reactions for small number of representative encounter scenarios,
  but
  Multiple recordings of pilot inputs for identically reproduced encounters
- Pilot inputs only affected by probabilistic behaviour

Suited for ***probabilistic*** pilot model tuning
Suited for pilot model testing / validation





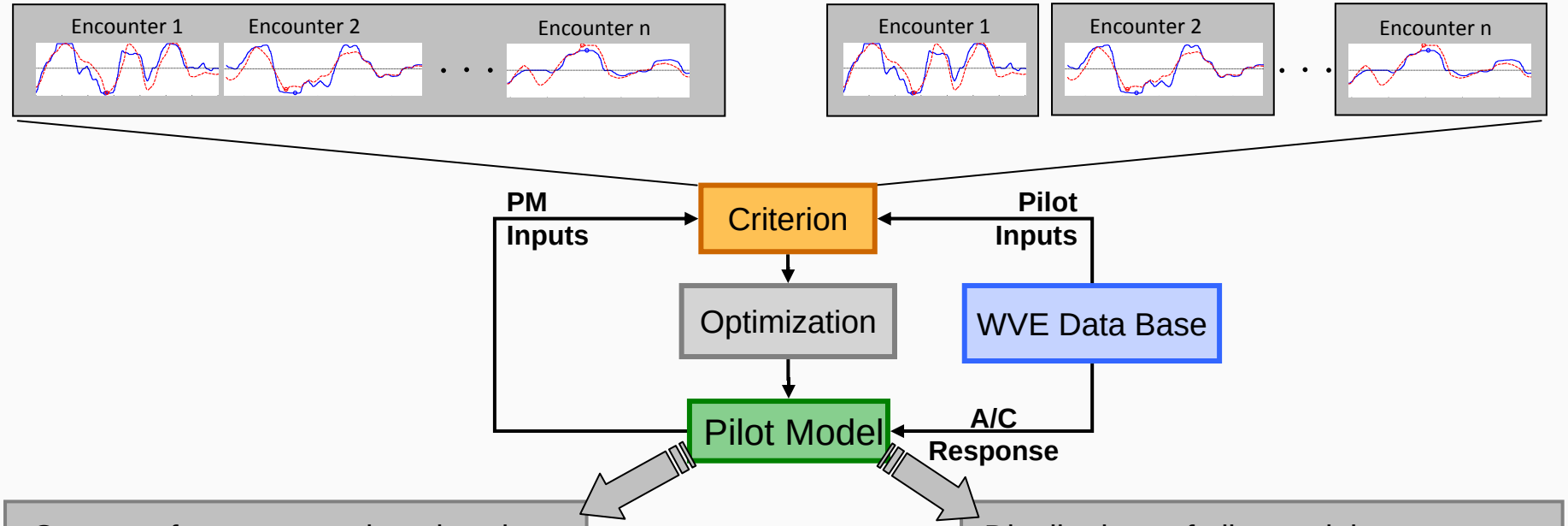
Parameter Optimizations

Deterministic PM

"Multi-Case": combine all encounters during optimization

Probabilistic PM

"Single-Case": optimization for each recorded encounter



One set of parameters that gives best overall result for ***all*** piloted encounters

Example:

$K_P = 2.63$ $T_{Lead} = 1.73$

$\tau_e = 0.66$ sec $T_{Lag} = 0.04$

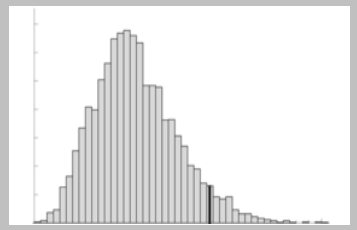
Distributions of pilot model parameters

$K_P =$

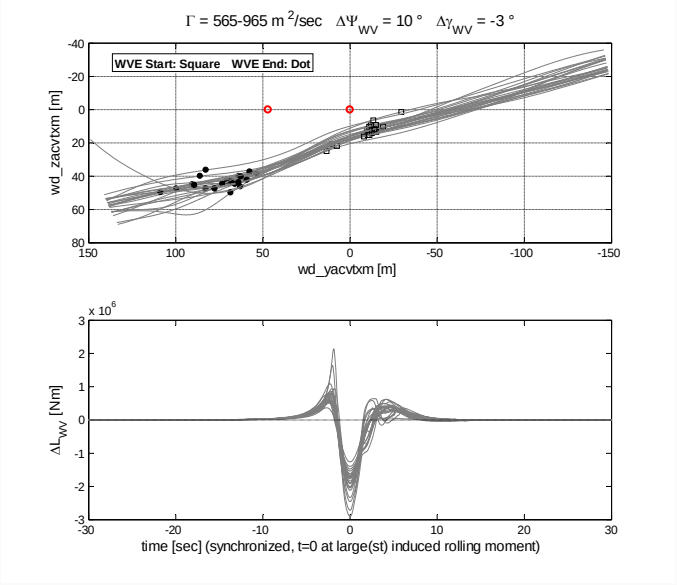
$T_{Lead} =$

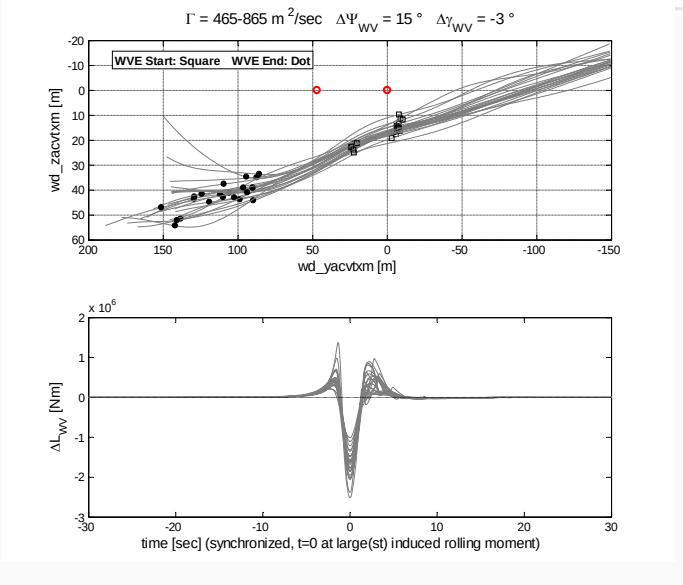
$T_{Lag} =$

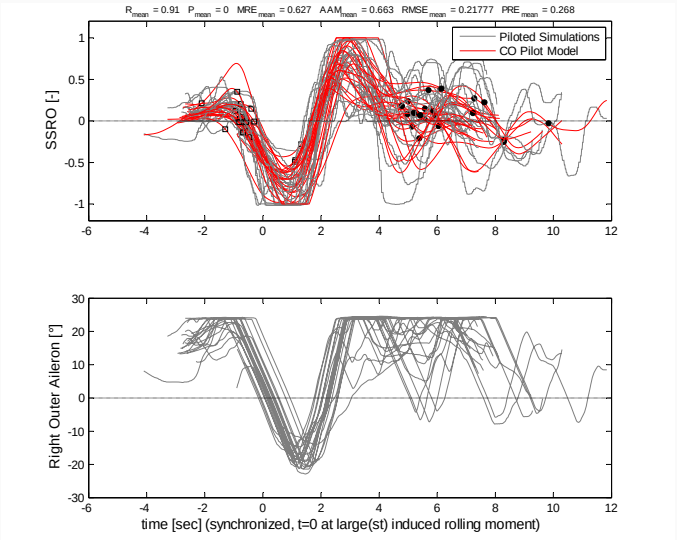
$\tau_e =$

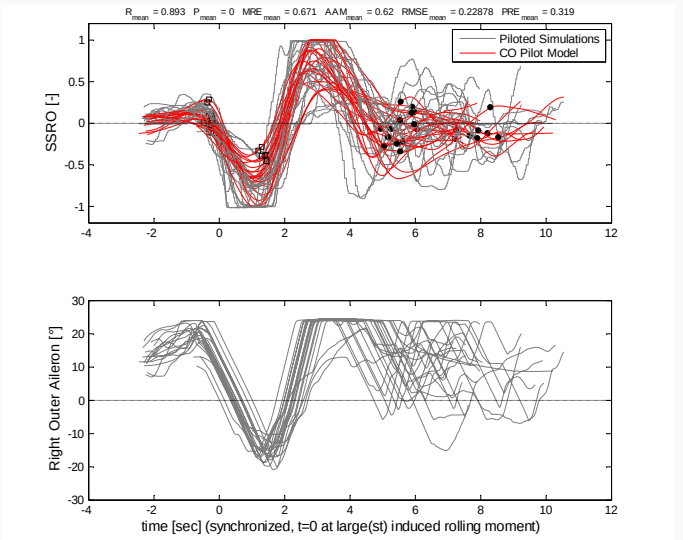


Deterministic PM Results - Offline

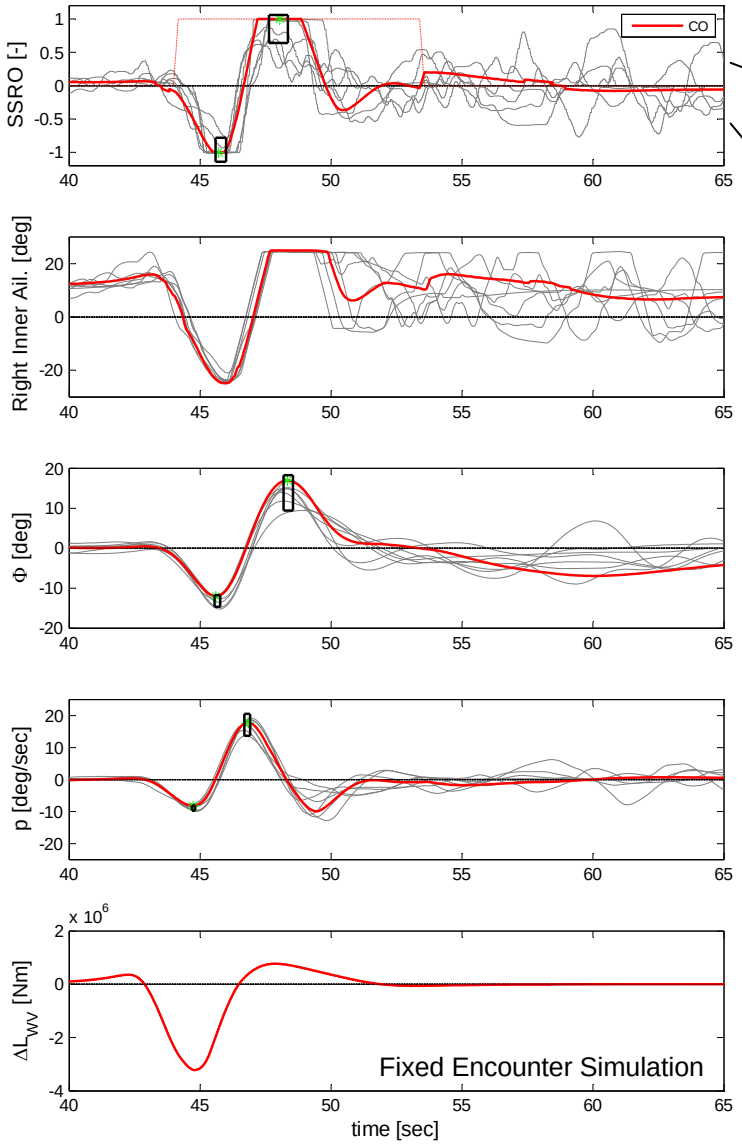


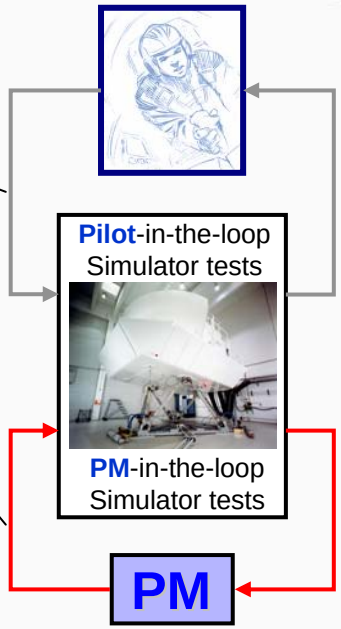






Deterministic PM Results - Online





PM-in-the-Loop Tests

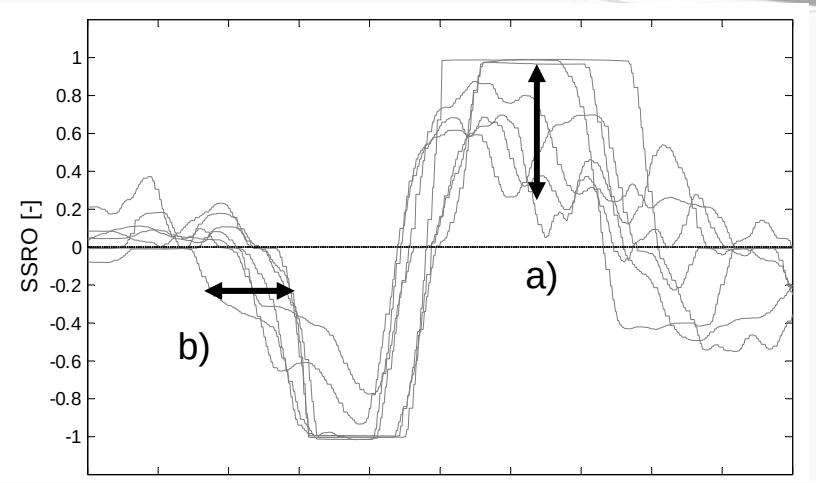
- Test pilot model within dynamic loop (e.g. check for instability problems, offline vs. online behaviour)
- Compare pilot model results to piloted simulations (only way to compare results for A/C response)
- Validation of pilot model (are requirements fulfilled?)

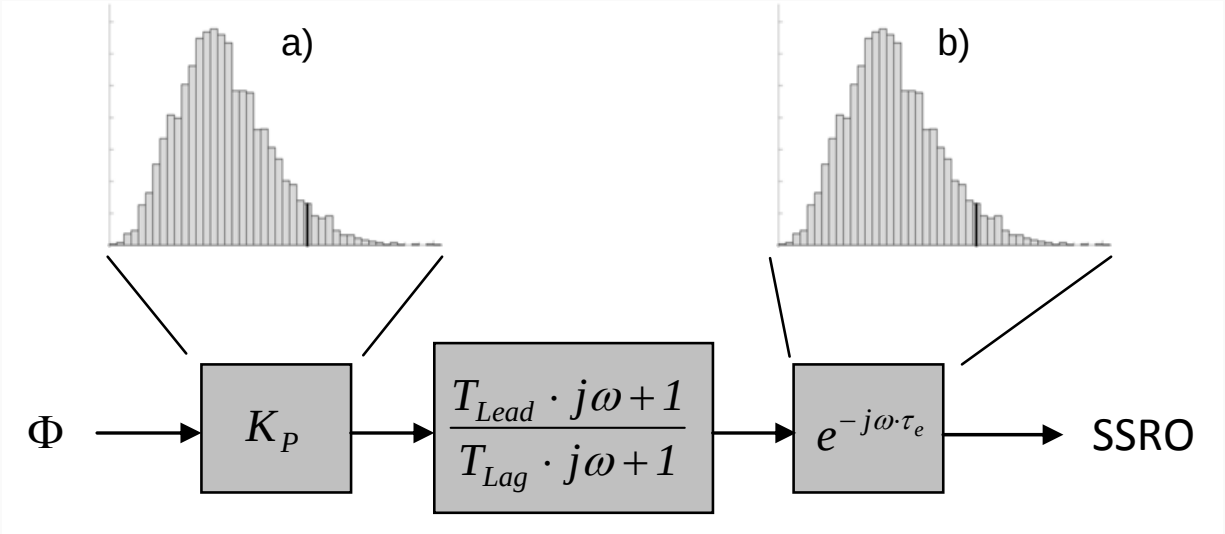
☐ Acceptable regions / limits as derived from statistical analysis of peaks

✱ Respective peaks of PM results

Considerations during Optimization

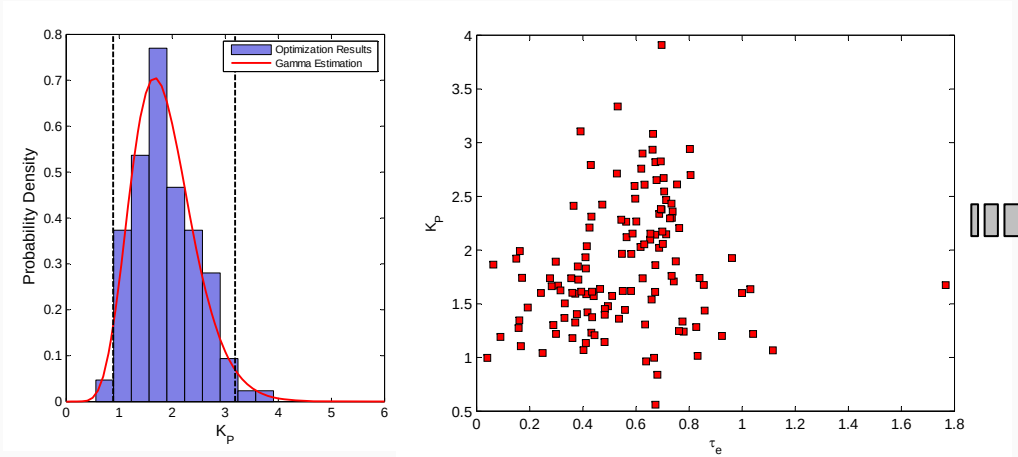
- Parameters correlations affect distribution results
- Avoid correlation affects by reducing number of tuners
- Gain sufficient to describe scatter in magnitude
- Time delay sufficient to describe scatter in phase
- Lead / Lag filter fixed (based on MC optimization)



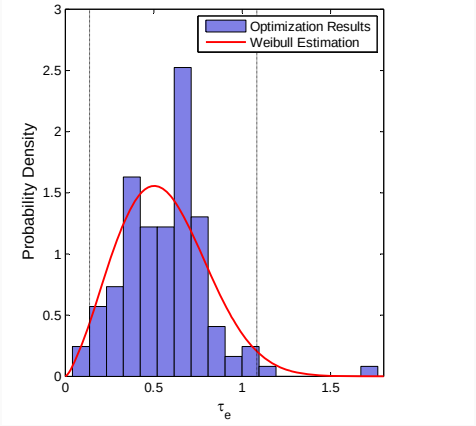


Optimization Results

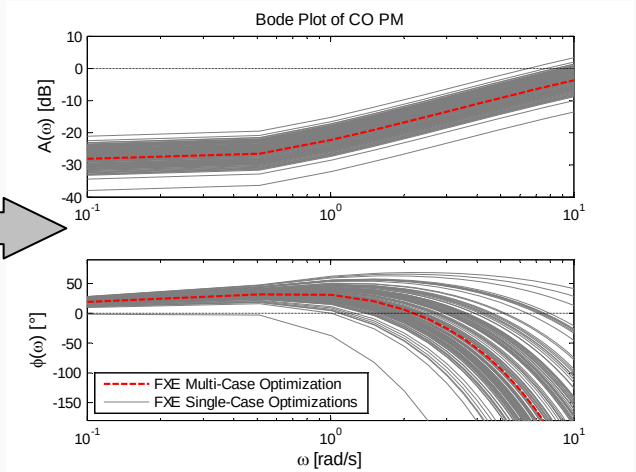
Exemplary K_P / τ_e optimization results (A330 Departure)



Results modelled by continuous Gamma probability distribution



Results modelled by continuous Weibull probability distribution

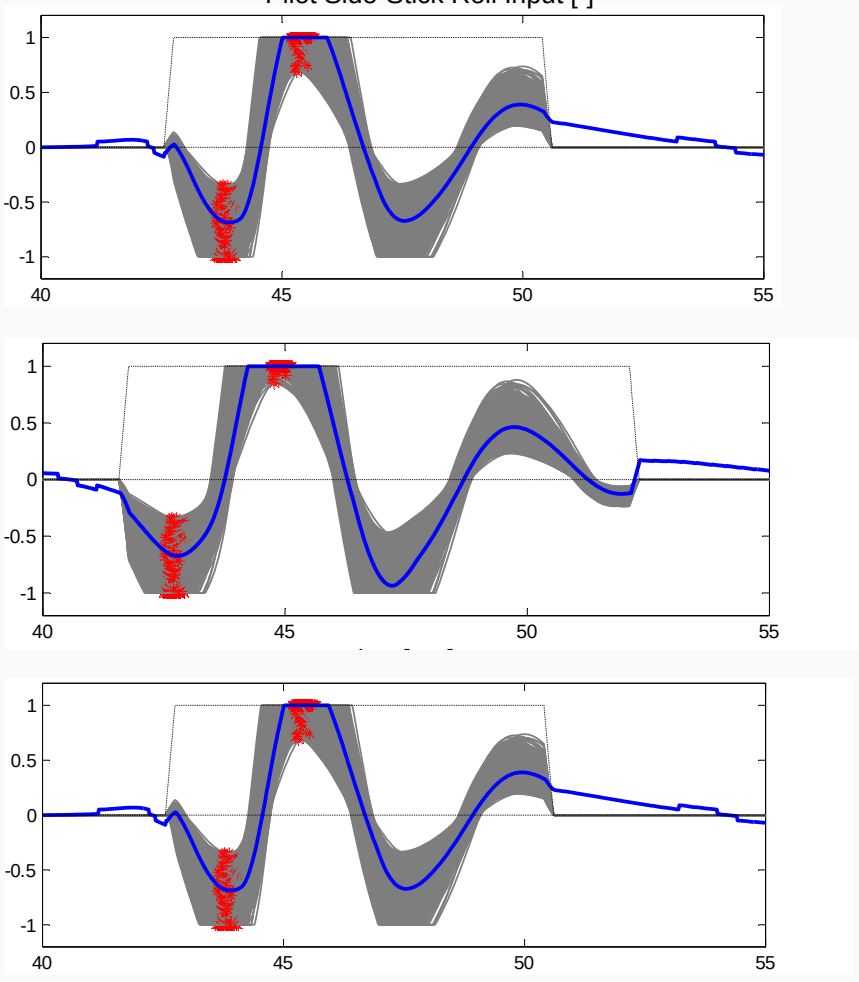


- Probabilistic parameters result in scatter of dynamic characteristics of pilot model describing function
- Describing function behaviour is scattered around mean behaviour resulting from Multi-Case optimizations
- No significant correlation between parameters K_P and τ_e
- Description of optimization results with continuous probability distributions (e.g. Gamma, Weibull)
- Possible limitation of parameter values at 2.5 and 97.5 percentiles of cumulative distribution function

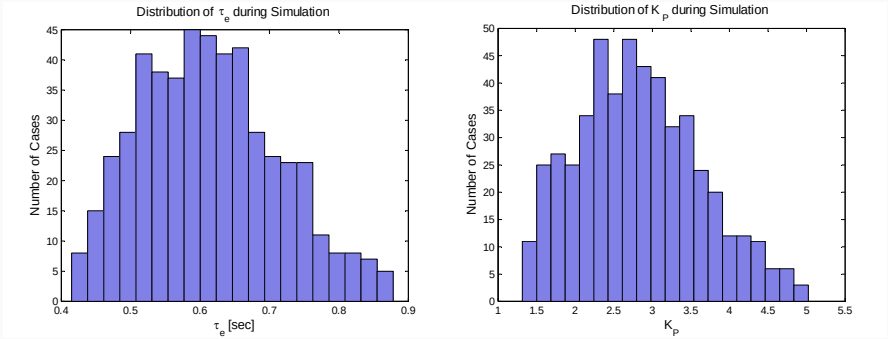
Offline Test

- Exemplary A330 encounters during ILS approach
- Bank angle inputs taken from PM-in-the-Loop simulations of these fixed encounter cases
- Examples show 500 simulation runs with parameters generated via identified probability distributions
- Side-Stick roll inputs of probabilistic PM are scattered around inputs of deterministic (mean) model
- Comparison of statistical scatter of peaks with standard deviations of piloted tests has been difficult because of side-stick saturation
- Evaluation of resulting scatter in A/C response should provides a more realistic quality assessment (PM-in-the-loop desktop simulation needed)

Pilot Side-Stick Roll Input [-]



Pilot Model Parameters during Simulation runs



Conclusions

- Probabilistic pilot models may contribute to worst case analysis
- Methodology to set up simple probabilistic roll axis WVE pilot models has been introduced
- Fast-time capable (model parameters are determined before simulation, similar to other probabilistic parts of Monte-Carlo simulation)
- Testing / validation of approach within dynamic simulation still needed
- Application to pitch axis is difficult because scatter in pilot behaviour much higher
- Is this approach feasible / should it be revised (e.g. other probability distributions)?
- Is this approach useful for future Monte-Carlo simulations?

Open Questions / Discussion

- Are pilot model optimization / validation criteria accepted by authorities?
- What is the necessary level of required pilot model quality to be accepted by authorities?
- Are additional single-event simulator tests (one unexpected encounter vs. sessions of 30-40 encounters) necessary to see more realistic pilot behaviour?

Thank you for your attention!

Questions?