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Data-driven Pilot Behavior Modeling Applied to a VMCG Determination Flight Test Task

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Data-driven Pilot Behavior Modeling Applied to a VMCG Determination Flight Test Task

- Agenda
  - Introduction and motivation
  - Flight test task and model structure
  - Experimental procedure and real test data
  - Model identification and results
  - Conclusions and further work

Data-driven Pilot Behavior Modeling Applied to a VMCG Determination Flight Test Task

- Introduction and motivation
  - Increasing use of modeling and simulation to lower development time, costs and increase maturity;
  - Pilot-in-the-loop simulations although very effective, are costly and in some terms, subjective;
  - Mathematical models allow use of computational tools like Monte Carlo analysis or optimization algorithms;
  - Pilot models are usually PID like structures (with varying levels of complexity), but could it be that system identification techniques could provide better models?

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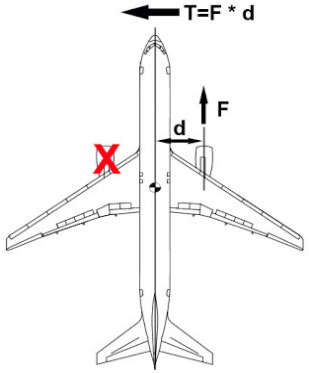
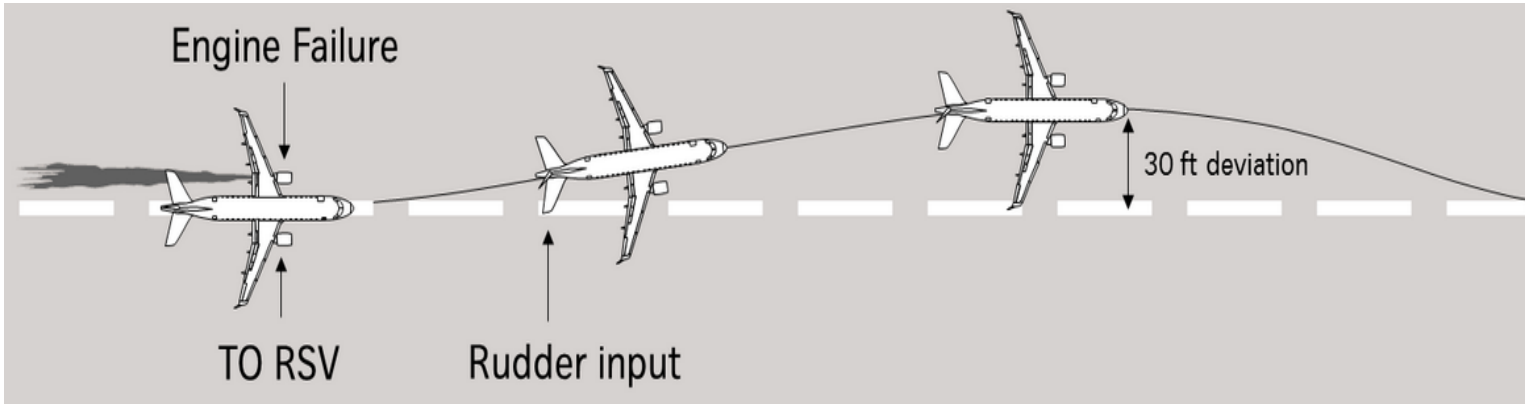
- Flight test task and model structure
  - V_{MCG} maneuver was chosen as a proof of concept





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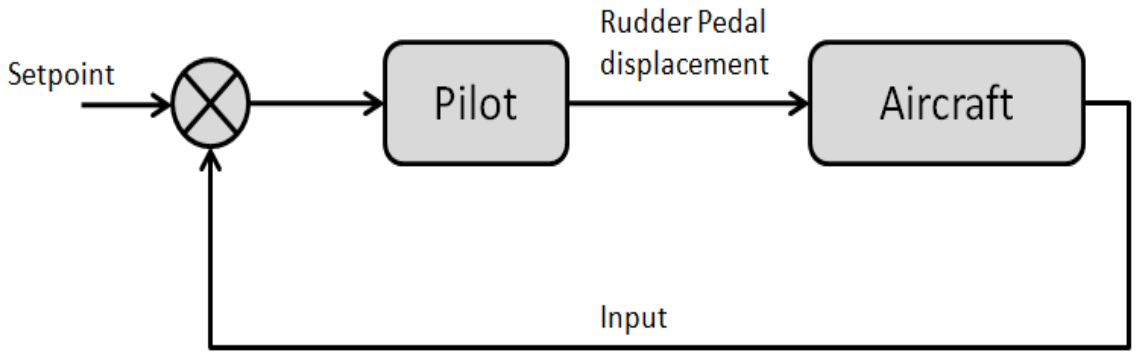
- Flight test task and model structure
  - Input-> Yaw rate integral
  - Output -> Rudder pedal displacement
    - Non-linearity at output-> Saturation



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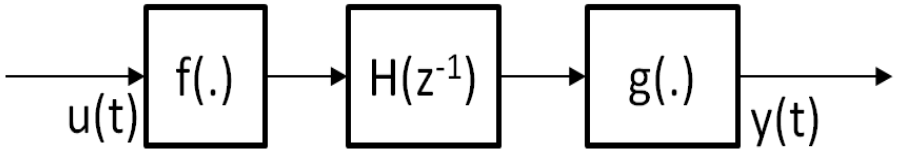
- Flight test task and model structure
  - Considering the factors (specially the non-linearity), two structures were evaluated
    - Hammerstein-Weiner model
      - Linear model with static non linearity's at the input and output



    - PID with anti-windup
      - Regular discrete PID with a switch at the input to zero the input when the saturation was reached

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- Experimental procedure and real test data
  - Initially an experiment was envisioned to obtain data;
  - Due to difficulties in the experimentation, real flight test data was used;
  - Two sets were used
    - Identification set
    - Validation set
    - Same aircraft, same test pilot, same day, same weather conditions…

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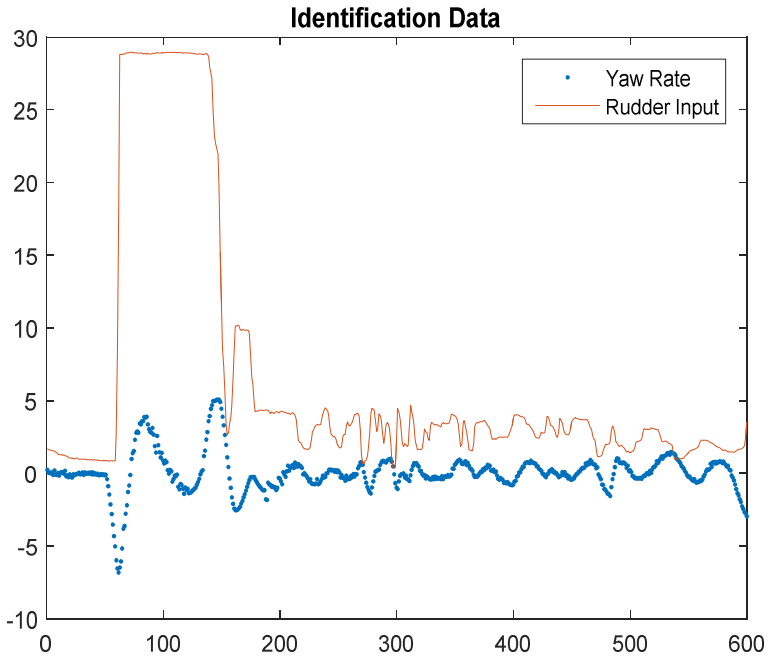
- Experimental procedure and real test data



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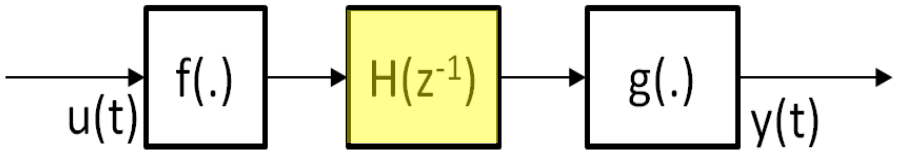
- Model identification and results
  - Hammerstein-Wiener model
    - Which order to use on the linear part of the model?



    - First guess, 3 at the numerator and 2 at the denominator, obtained from the discrete PID equation

$$u[k] = -\frac{a_1}{a_0}u[k-1] - \frac{a_2}{a_0}u[k-2] + \frac{b_0}{a_0}e[k] + \frac{b_1}{a_0}e[k-1] + \frac{b_2}{a_0}e[k-2]$$

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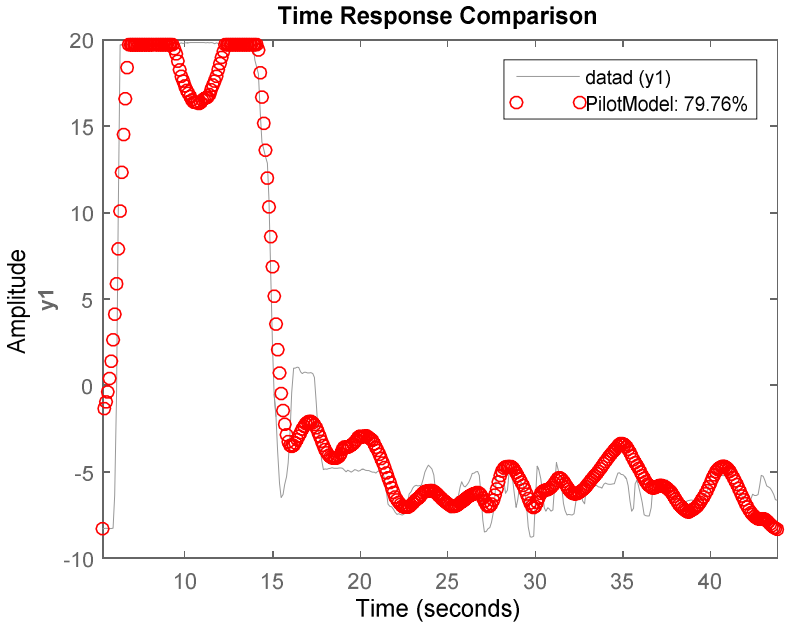
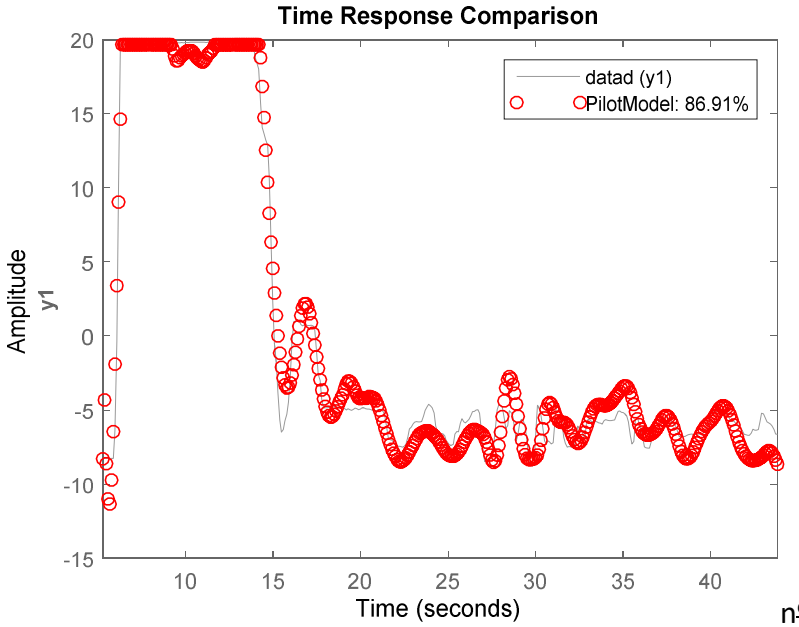
- Model identification and results
  - Hammerstein-Wiener model
    - But raising the orders up to a certain point (5/4) did improve the model fit





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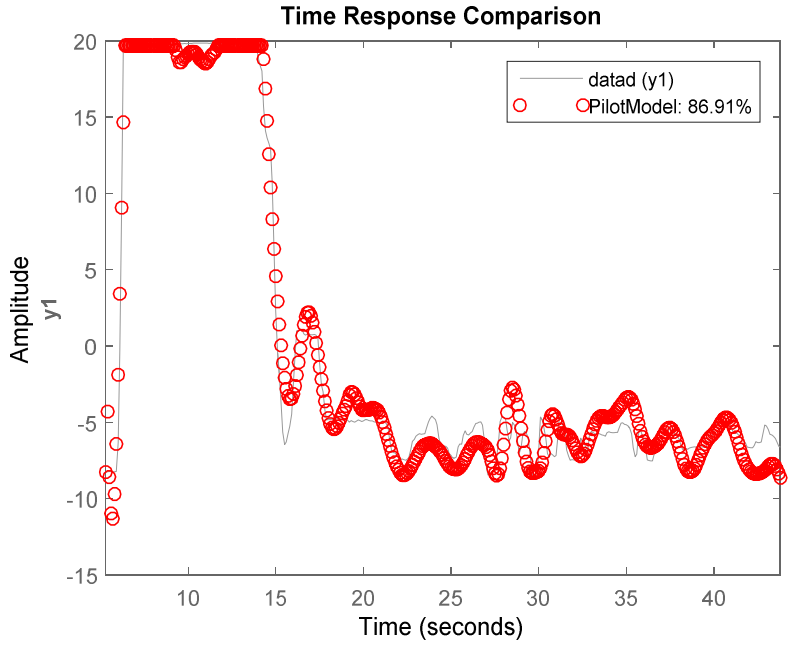
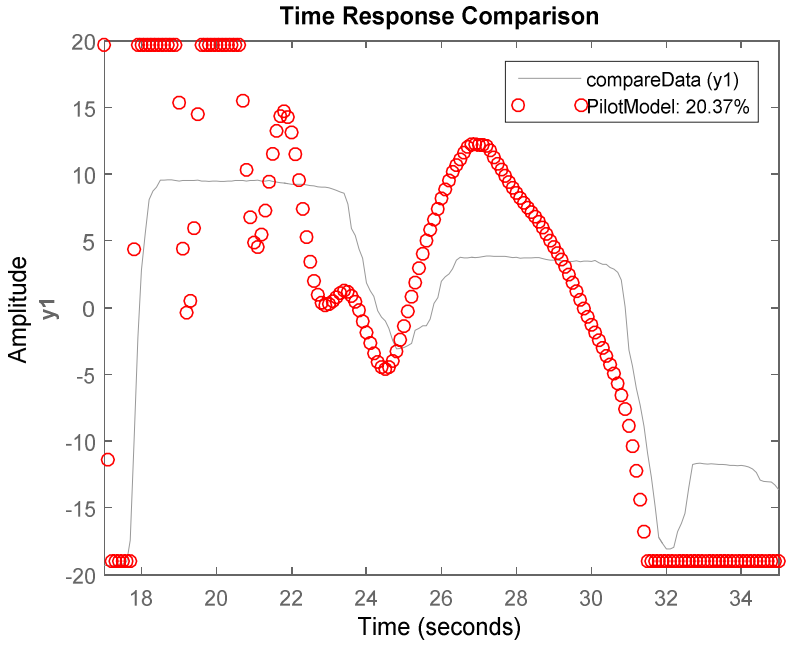
- Model identification and results
  - Hammerstein-Wiener model
    - Model response versus identification (left) and validation (right) data





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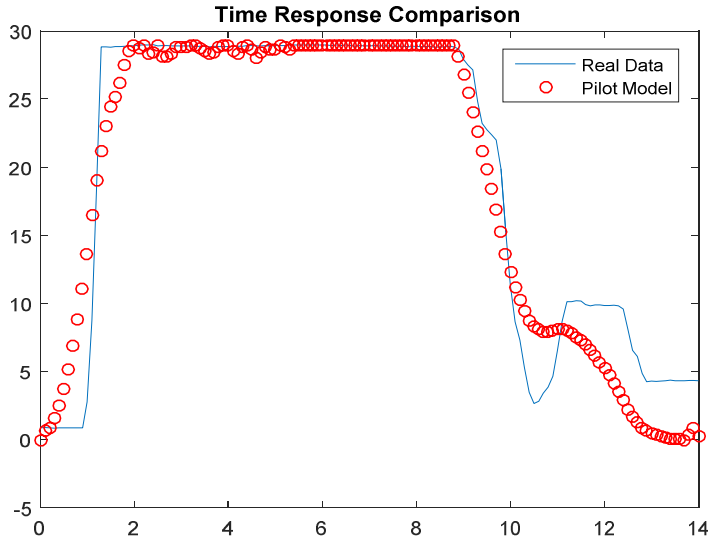
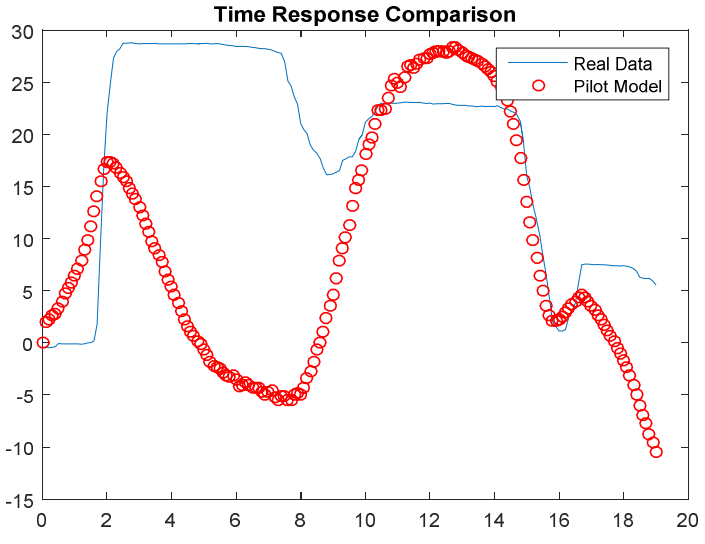
- Model identification and results
  - PID with anti-windup

$$u[k] = -\frac{a_1}{a_0}u[k-1] - \frac{a_2}{a_0}u[k-2] + \frac{b_0}{a_0}e[k] + \frac{b_1}{a_0}e[k-1] + \frac{b_2}{a_0}e[k-2]$$

    - This model yielded worse results when compared to the NLWH, specially against validation data





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- Model identification and results
  - Metrics for both models

NLHW (Higher order)		PID - Anti Windup	
Compared with Identification data	Compared with Validation data	Compared with Identification data	Compared with Validation data
Correlation=0.9915	Correlation=0.8417	Correlation=0.9646	Correlation=0.2764
R^2_0.9829	R^2=0.3658	R^2_0.9245	$R^2 \approx 0$
Fit=86.91%	Fit=20.37%	Fit=72.52%	Fit=-(63,54)%

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- Conclusions
  - The methodology seems feasible for application to this and other scenarios;
  - Representing human adaptability appears to be the main concern as it was observed with the validation data;
  - System identification appears to be a useful tool to obtain pilot models as it was capable of providing a more robust model than the regular PID structure.

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- Further work
  - Improving the experiment execution and investigating which variables do impact on the model qualities and characteristics;
  - Using different mathematical representations, such as Neural Networks and best linear approximations
  - Future applications for such models:
    - Detection and identification of events;
    - Compensating/controlling;
    - Using them in the loop with optimization algorithms to optimize flying qualities.

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