# Master Thesis Preparations: Modelling and Identification of the HalfWing

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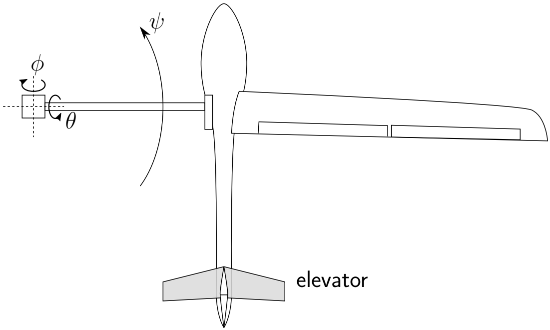
# Objective of the master thesis

"NMPC of a constrained model airplane"

- ✓ Develop system and tools
- ✓ Record data
- → Choose model and identify
- ✗ Develop controller(s)
- ✗ Evaluate

# The HalfWing

- Model airplane, fixed via two joints to the carousel
- 3 DOF: carousel rotation $\psi$, elevation $\phi$, pitch $\theta$
- Input: elevator angle
- Output: pitch / elevation angle



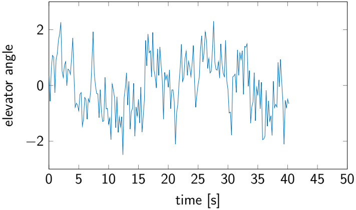
# Choosing a model[1]

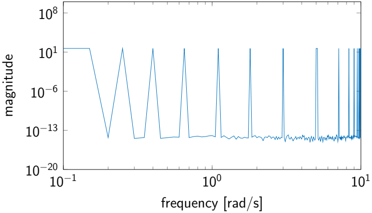
| Model type | pros | cons |
|---|---|---|
| **White-box** | | |
| explicitly modeled physical properties | extendable, values correspond to real-world properties | gets complex quickly, easy to neglect important factors |
| **Grey-box** | | |
| only prescribe general characteristics | remove complexity while keeping structure | changing requirements may need larger modifications |
| **Black-box** | | |
| no explicit knowledge about the system structure | choose best result regardless of the means | same as grey-box, also no direct correspondence to real-world values |

[1] L.Ljung, 'Approaches to Identification of Nonlinear Systems'

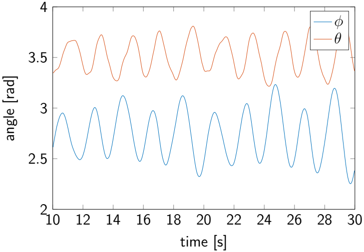
# Black Box Model I

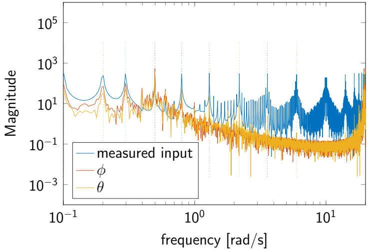
- Apply multisine exitation to system:



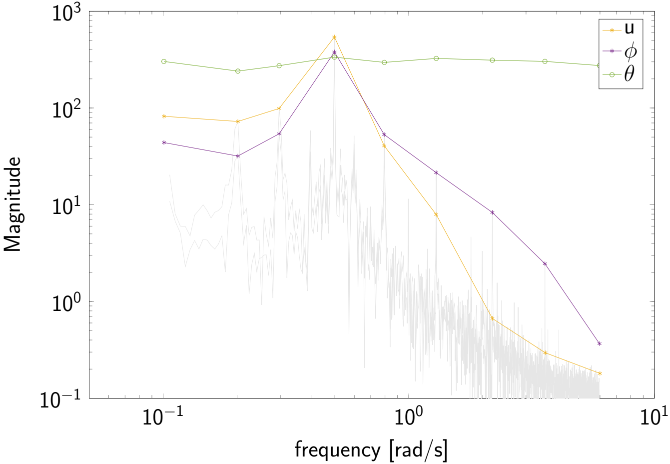

- Record response:



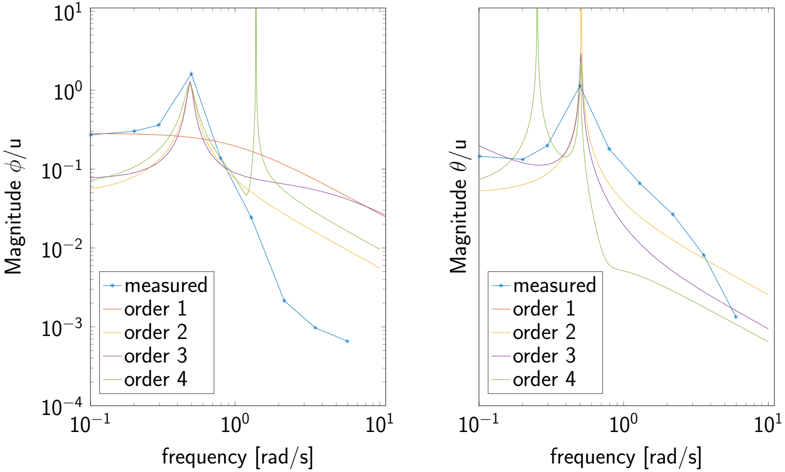
# Black Box Model II

- Filter out chosen frequencies:



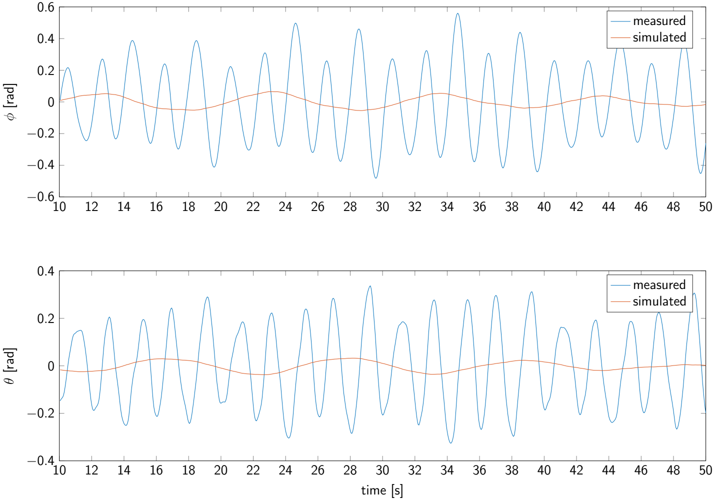
# Black Box Model III

- Estimate transfer function with varying order (n poles, n-1 zeros):



# Black Box Model IV

- However...



# Grey Box Model - Structure

Linear state space model with assumptions about the dynamics:

$$\begin{bmatrix} \dot{\theta} \\ \ddot{\theta} \\ \dot{\phi} \\ \ddot{\phi} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ a_{21} & a_{22} & a_{23} & a_{24} \\ 0 & 0 & 0 & 1 \\ a_{41} & a_{42} & a_{43} & a_{44} \end{bmatrix} \begin{bmatrix} \theta \\ \dot{\theta} \\ \phi \\ \dot{\phi} \end{bmatrix} + \begin{bmatrix} 0 \\ b_2 \\ 0 \\ b_4 \end{bmatrix} u$$

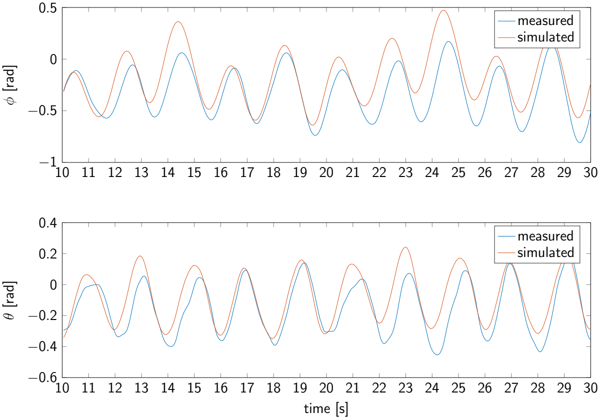
rearrange for parameters, set up least squares scheme:

$$\underbrace{\begin{bmatrix} \ddot{\theta}_i \\ \ddot{\phi}_i \end{bmatrix}}_{y_i} = \underbrace{\begin{bmatrix} \theta_i & \dot{\theta}_i & \phi_i & \dot{\phi}_i & 0 & 0 & 0 & 0 & u_i & 0 \\ 0 & 0 & 0 & 0 & \theta_i & \dot{\theta}_i & \phi_i & \dot{\phi}_i & 0 & u_i \end{bmatrix}}_{\Psi_i} \underbrace{\begin{bmatrix} a_{21} & \dots & b_4 \end{bmatrix}^\top}_{p}$$

$$p^* = \Psi^+ y = (\Psi^\top \Psi)^{-1} \Psi^\top y$$

# Grey Box Model - Identification

First results:




To do: Record more data, see if model still works

# White Box Model - Structure

- Determine all relevant forces:

$$F_g, F_{Lift,Wing}, F_{Lift,Elev}, F_{Drag,Wing}, F_{Drag,Elev}$$

- Calculate resulting torque using $M = r \times F$:

$$M = M_g + \ldots + M_{Drag,Elev} + M_{Constr} + M_{Friction}$$

- Obtain angular accelerations via the inertia tensor:

$$M = I \cdot \alpha$$

- Set up state space model:

$$x = \begin{bmatrix} \theta \\ \dot{\theta} \\ \phi \\ \dot{\phi} \end{bmatrix}, \quad \frac{d}{dt} \begin{bmatrix} \theta \\ \dot{\theta} \\ \phi \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} x_2 \\ \alpha_1 \\ x_4 \\ \alpha_2 \end{bmatrix}$$

# White Box Model - Identification

Combination of measuring and estimating:

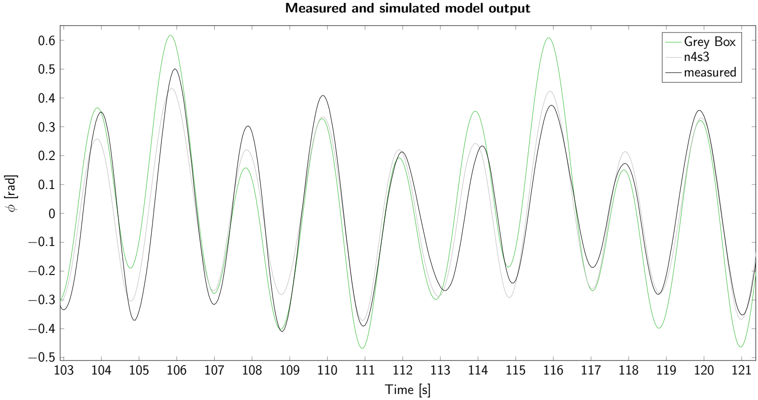
- Measure as much as possible: geometric features, weight, COM, ...
- Estimate intricate parameters: lift / drag coefficients, inertia tensor, ...

A lot of parameters to estimate from two angle measurements:

- 4x aerodynamic coefficients, 3x moment of inertia, friction, actuator delay, ...
- Good chance of being nonlinear in the parameters
- Solution: Identify parts separately (e.g. by fixing one axis)
- WIP

# Black Box Model (Again)

Using Matlab's prepacked modelling tools:




Drawback: non-trivial estimator needed

# What's next?

- Implement LQR and compare to PID
- ACADO + NMPC