

# NONLINEAR MODELING WITH LEARNED PARAMETER REFINEMENTS FOR NMPC ON A REAL-WORLD AERODYNAMIC SYSTEM

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## Summary

- Comparison of classical and machine-learning modeling methods
- Design of a nonlinear model predictive controller
- Hard real-time implementation in C++
- Evaluation on a real-world AWE prototype

## Modeling

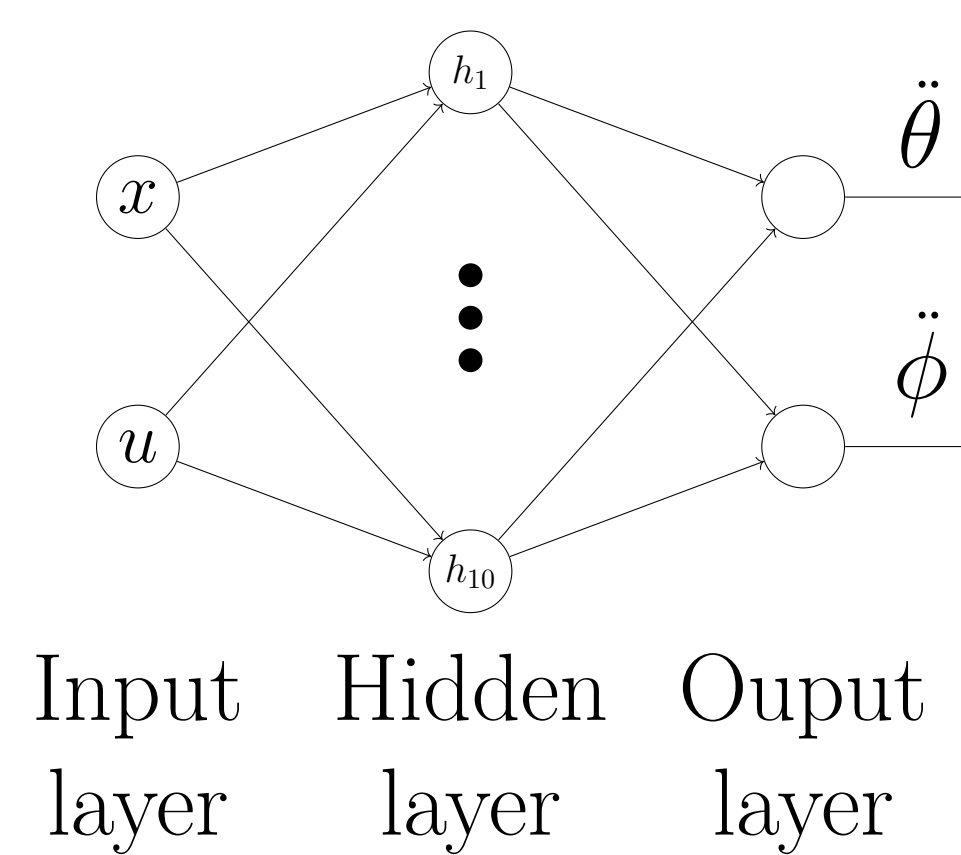
- Classic Approach: Quadratic Model & LLS Fitting

$$\dot{x}_i = x^T A_i^{\text{quad}} x + A_i^{\text{lin}} x + B_i u + C_i$$

**linear:**  $A_i^{\text{quad}} = 0, C_i = 0$  **lasso, elastic** and **huber** use respective  
**affine:**  $A_i^{\text{quad}} = 0$  regularizer with learned weighing parameters

- Novel approach:

- approximate system dynamics via neural network (NN)
- nonlinear state augmentation (quadratic and trigonometric)



## Real-world setup

- Reduced-DOF plane for rotational start experiments
- Custom hardware designed in-house for sensor/actuator IO
- Fully equipped for lift-mode energy production

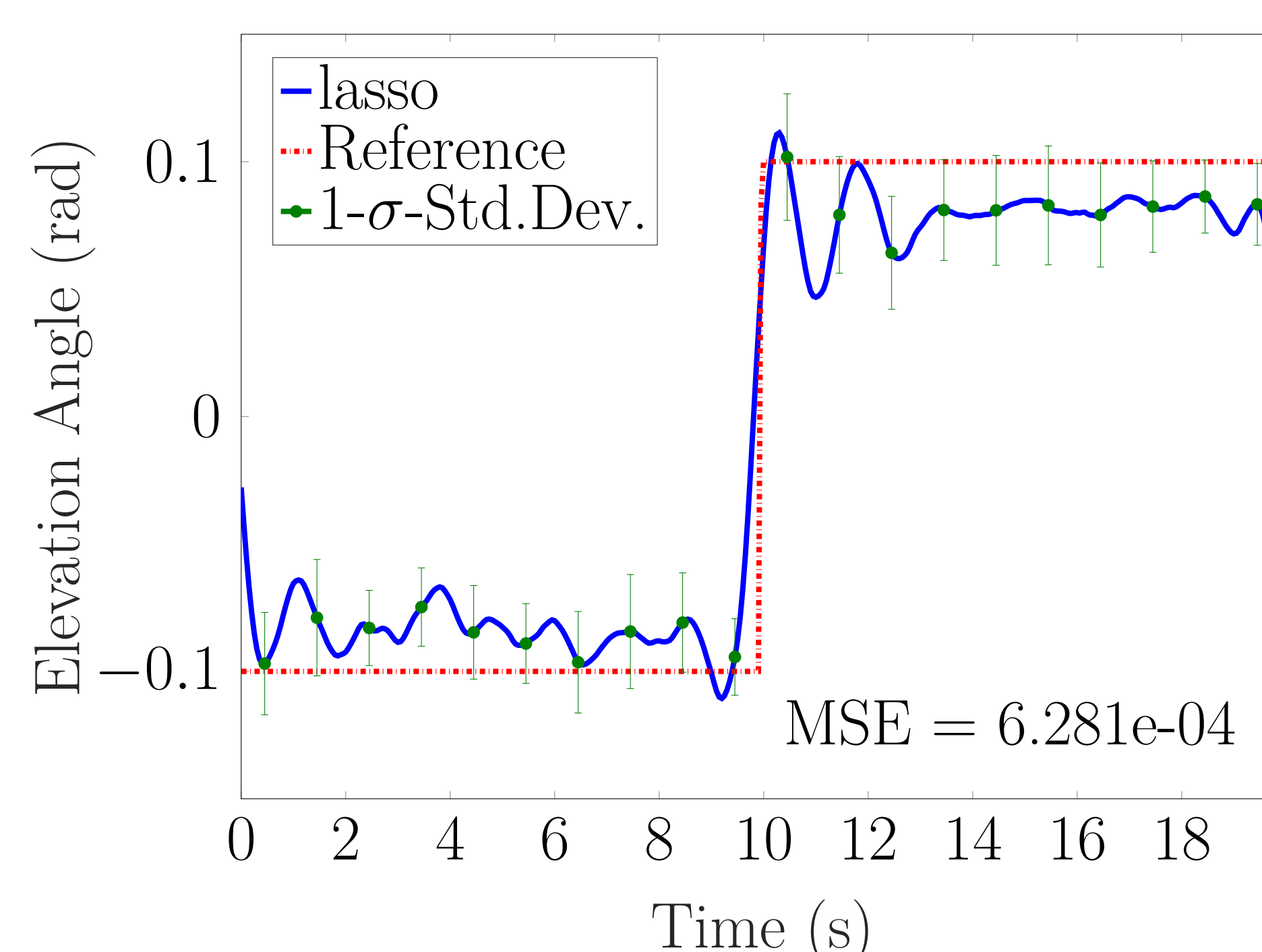
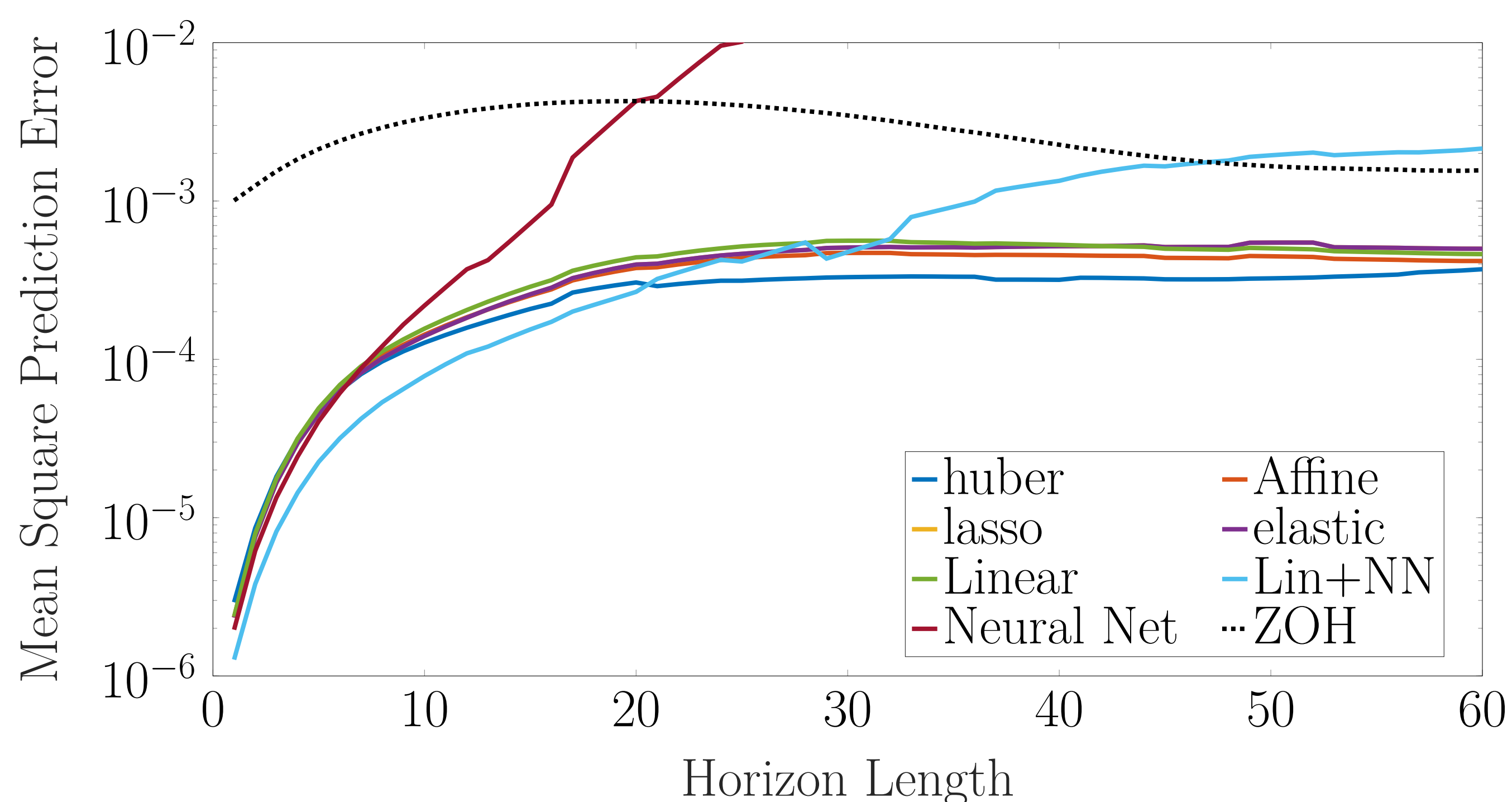
## Control

- Nonlinear Model Predictive Control (NMPC)
- Direct Multiple Shooting using explicit RK4
- Gauss-Newton Hessian approximation + condensing
- Constrained control surface position and speed
- C++ Code Generation from MATLAB via ACADO / QPOASES
- 4 states, 1 control, 100 steps, @20Hz, 5 sec Horizon

## Conclusion

- Robust results with linear regression fit
- Quadratic elements can reduce error, but are easy to overfit
- ML refinements achieve further improvement reduce overfitting
- Neural networks achieve good short time prediction and are suitable for integration in NMPC
- Evaluation on real-world setup shows adequate performance of machine learning approaches in a real-time control setup
- Future research aims to apply the presented approaches to tethered flight operation

## Experimental Results



Model	MSE
<b>lasso</b>	<b>6.281e-04</b>
linear	6.826e-04
elastic	6.949e-04
quad	9.100e-04
huber	9.161e-04
ridge	1.826e-03
$\Delta u$ -lin	3.164e-03
Lin+NN	1.269e-02