Aircraft System Identification Based on Flight Test Data

Roger Larsson, Martin Enqvist

Background

Modern fighter aircraft are challenging from a system identification perspective since they are examples of systems that change from linear to nonlinear, unstable to stable and always operate under closed-loop conditions. Two problems have been studied. The first is a post flight identification problem of unstable, nonlinear systems and the second is a sequential frequency domain method used for real-time identification of linear systems.

Gripen

Methods

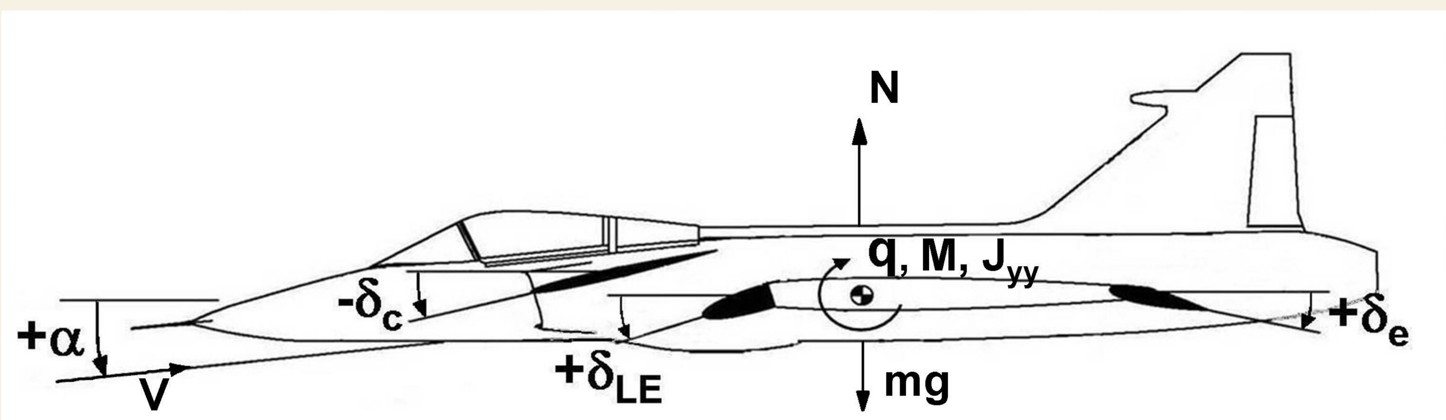
For the nonlinear case:

- PEM, Parameterized Observer (PO)
- PEM, Extended Kalman Filter (EKF)
- PEM, Unscented Kalman Filter (UKF)
- State Estimation, Augmented State Approach (AUG)
- State and Parameter Estimation Approach (CLM)

For the linear case:

- An existing method used today
- An improved method using a correct finite Fourier transform and IV

A Gripen model



A simplified model of the pitch dynamics:

$$x(k+1) = a(x(k)) + Bu(k) + w(k)$$
$$y(k) = x(k) + e(k)$$

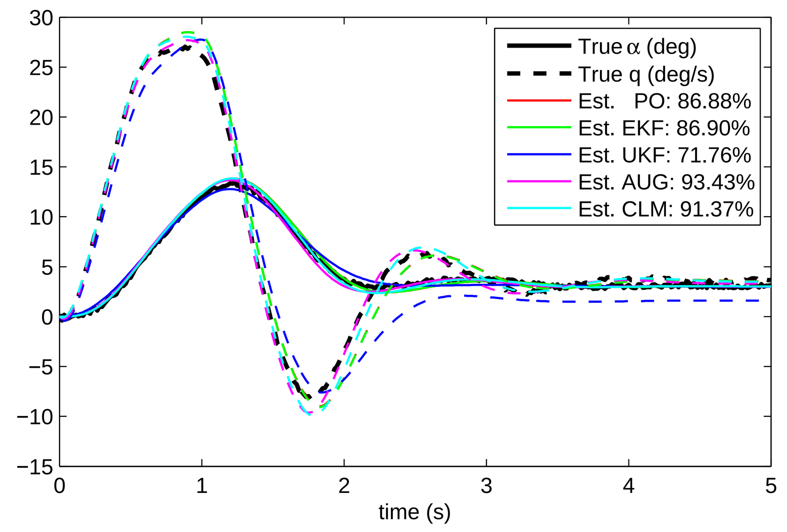
where $x(k) = \big(\alpha(k)\ q(k)\big)^T$, $u(k) = \big(\delta_e(k)\ \delta_c(k)\big)^T$

Nonlinear Case

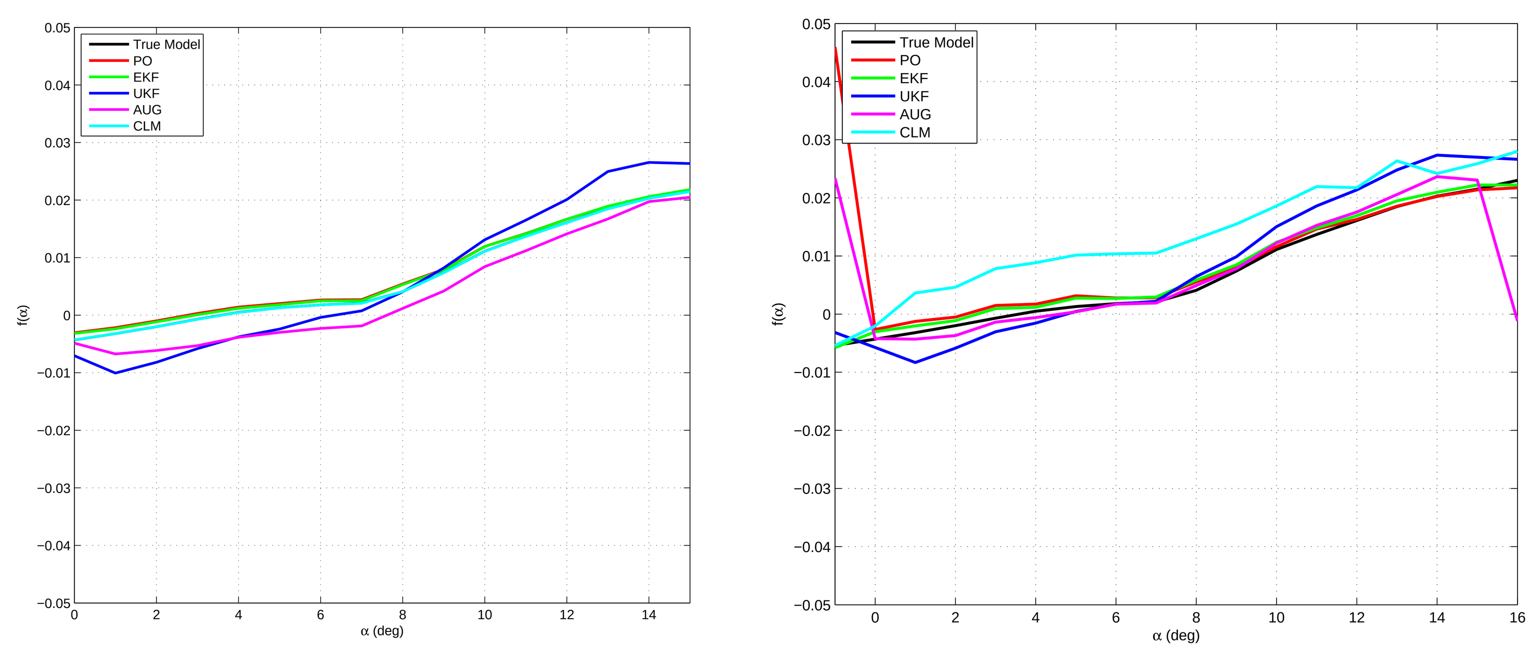
$$a(x(k)) = \begin{pmatrix} Z_\alpha \alpha(k) + Z_q q(k) \\ f(\alpha(k)) + M_q q(k) \end{pmatrix}, \quad B = \begin{pmatrix} Z_{\delta_e} & Z_{\delta_c} \\ M_{\delta_e} & M_{\delta_c} \end{pmatrix}$$

Here, $f(\alpha(k))$ is a piece-wise affine function.

Simulation Results

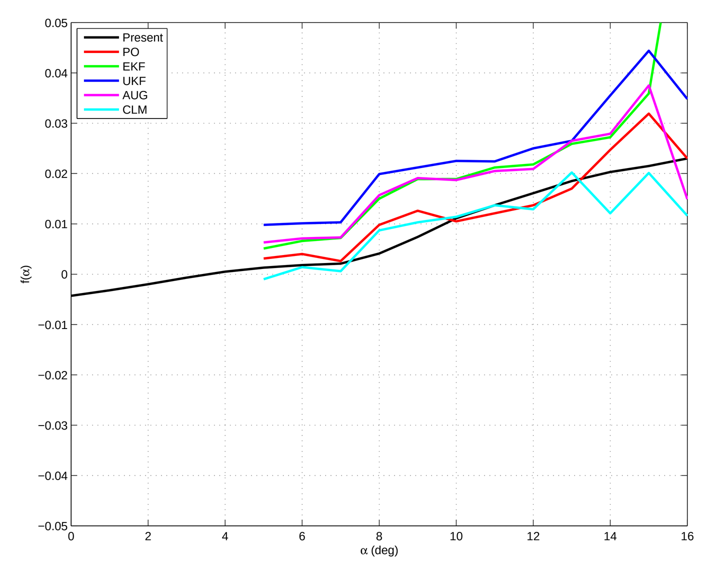


Average nonlinearity estimate for noisy data (left) and for a 10% error in the initial guess (right):



Results with Flight Test Data

Nonlinearity estimate:



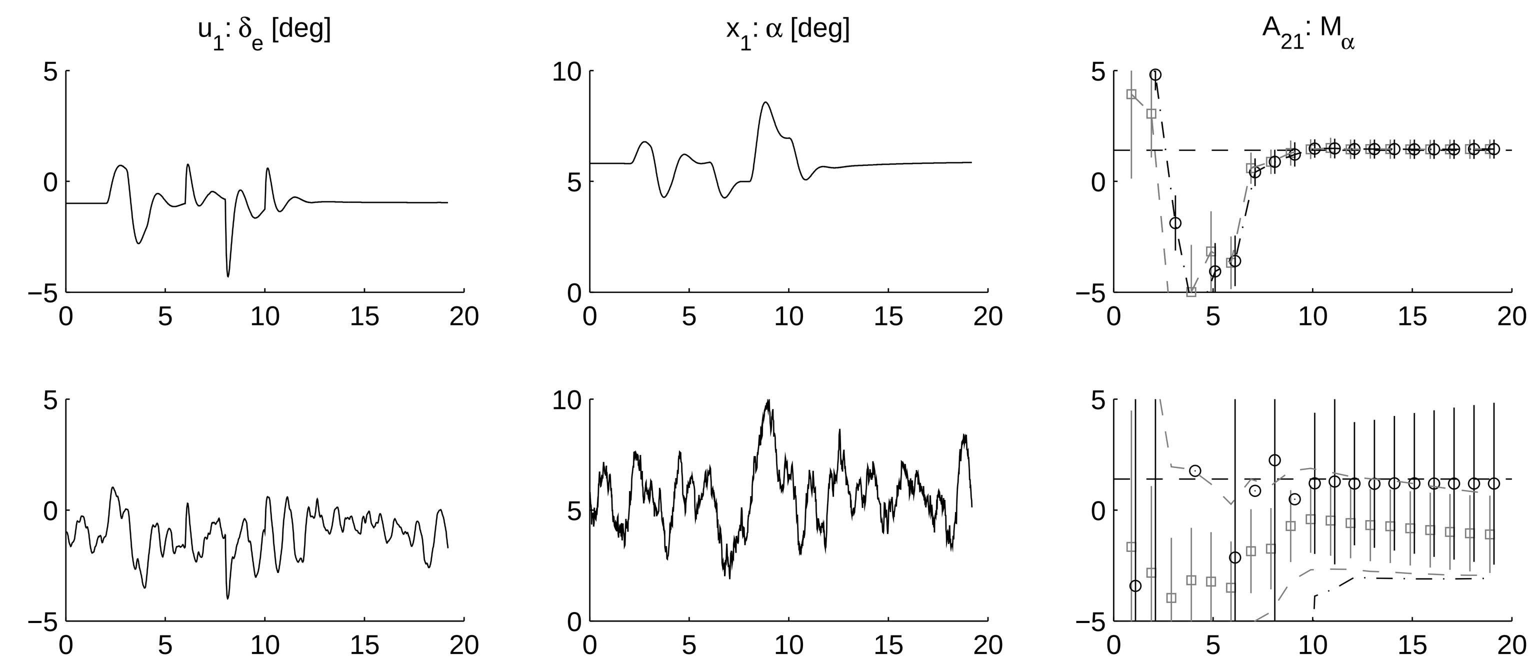
- Conclusion: PO and EKF perform best in simulations, PO and CLM perform best on real data.
- Future work: Better handling of process noise, choice of regularization parameter.

Linear Case

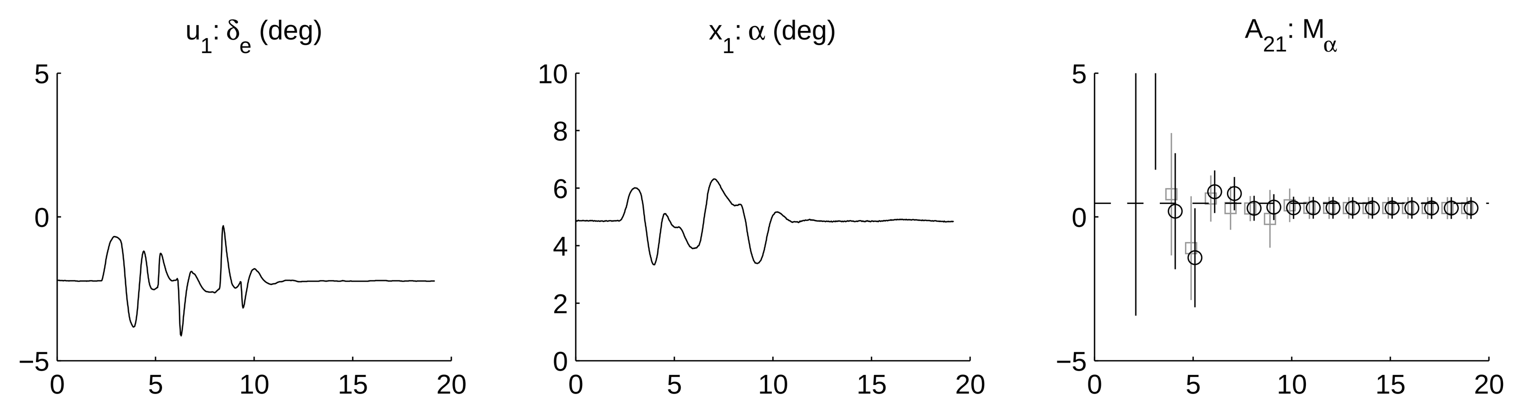
$$a(x(k)) = \begin{pmatrix} Z_\alpha \alpha(k) + Z_q q(k) \\ M_\alpha \alpha(k) + M_q q(k) \end{pmatrix}, \quad B = \begin{pmatrix} Z_{\delta_e} & Z_{\delta_c} \\ M_{\delta_e} & M_{\delta_c} \end{pmatrix}$$

System structue same as before, but $f(\alpha(k)) = M_\alpha \alpha(k)$ is linear.

Simulation Results



Results with Flight Test Data



- Conclusion: Correct finite Fourier transform and use of IV method helps in the open loop case. More work needed for the closed-loop case.
- Ongoing work: Master thesis work implementing the method at Saab's flight test department.
- Future work: Improved use of data and better uncertainty prediction.

Acknowledgments

This work has been performed in cooperation with Saab AB within the VINNOVA Industry Excellence Center LINK-SIC.