LINK-SIC

System Identification of Flight Mechanical Characteristics

Roger Larsson (roglar@isy.liu.se), Martin Enqvist (maren@isy.liu.se)

LINKÖPINGS UNIVERSITET

Background

Identification of the physical characteristics of a modern fighter aircraft is challenging since it works under conditions where the physical properties change from linear to nonlinear and from unstable to stable, and since it always operates in closed loop. Furthermore, the measurement noise might be considered to be white, but the process noise comes from atmospheric turbulence that is not white. This adds an extra complexity to the problem.

Gripen

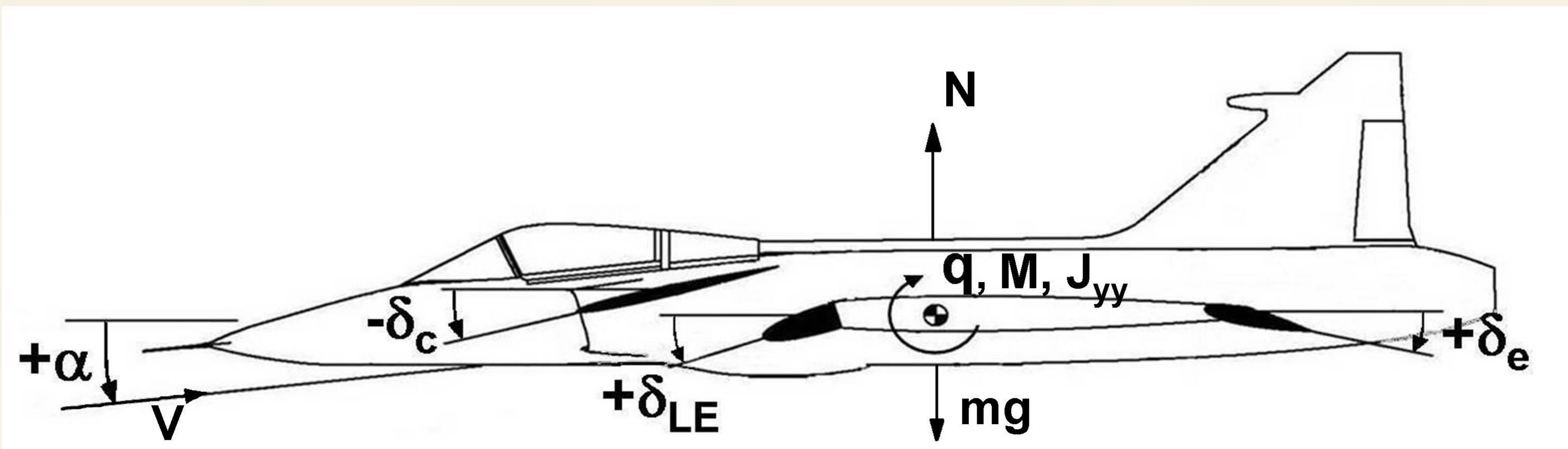
Problem formulation

A general mathematical model of an aircraft can be written

$$x(k+1) = f_d(x(k)), u(k), w(k))$$
$$y(k) = h(x(k), u(k), v(k))$$

where $u(k), w(k), x(k), v(k)$ and $y(k)$ are the input, process noise, state, measurement noise and output, respectively.

Application: A Gripen model



A simplified model of the pitch dynamics:

$$x(k+1) = f_d(x(k), u(k)) + w(k)$$
$$y(k) = x(k) + e(k)$$

where $x(k) = \begin{pmatrix}\alpha(k) & q(k)\end{pmatrix}^T$, $u(k) = \begin{pmatrix}\delta_e(k) & \delta_c(k)\end{pmatrix}^T$ and $f_d(x(k), u(k))$ is the linear or nonlinear dynamics. The measurement noise $v(k)$ is here denoted $e(k)$ to indicate that it is white.

Up to Licentiate

Linear Case: During flight

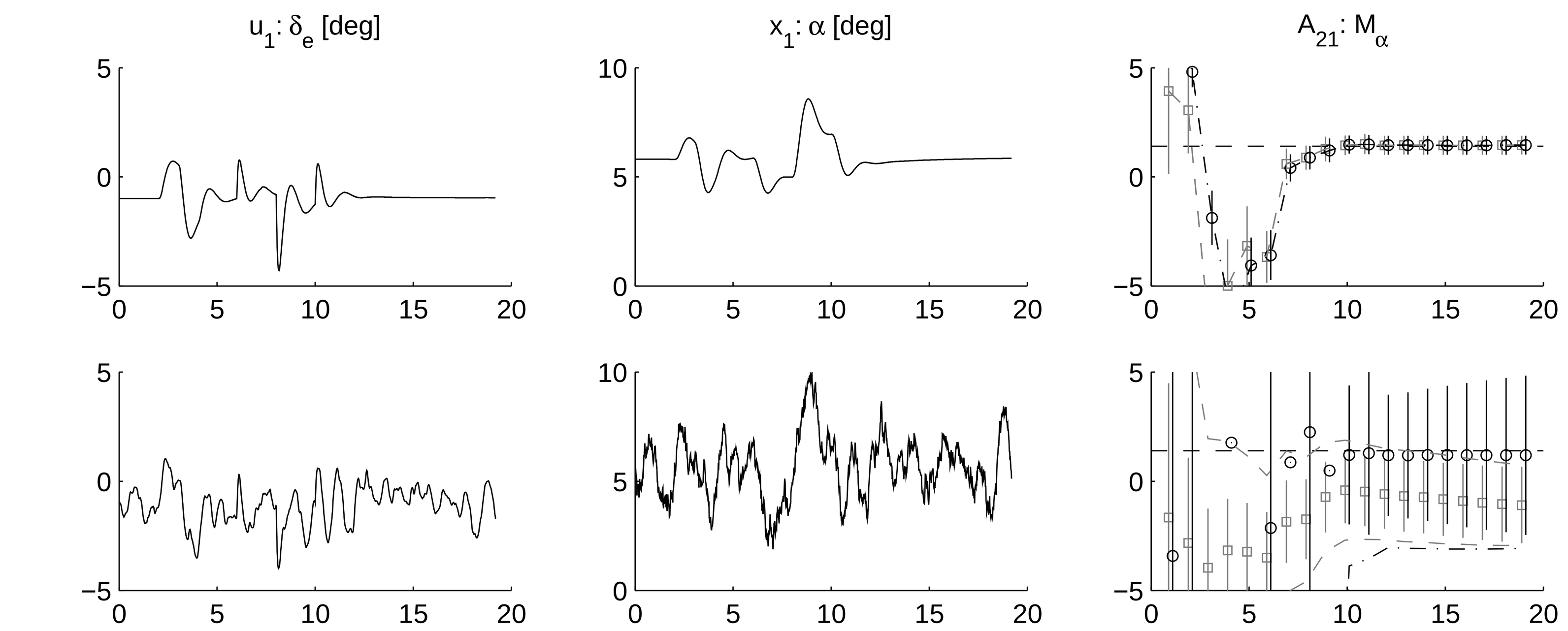
$$f_d(x(k), u(k)) = \begin{pmatrix} Z_\alpha \alpha(k) + Z_q q(k) + Z_{\delta_e}\delta_e(k) + Z_{\delta_c}\delta_c(k) \\ M_\alpha \alpha(k) + M_q q(k) + M_{\delta_e}\delta_e(k) + M_{\delta_c}\delta_c(k) \end{pmatrix}$$

System dynamics are linear in both states and inputs.

This concerns methods for real-time estimation during flight tests.

- ✘ Original method: Frequency domain least-squares (gray squares)
- ✘ New method: Boundary terms and IV added (**black circles**)

Investigation of measurement noise and process noise.



Non-linear Case: Post flight

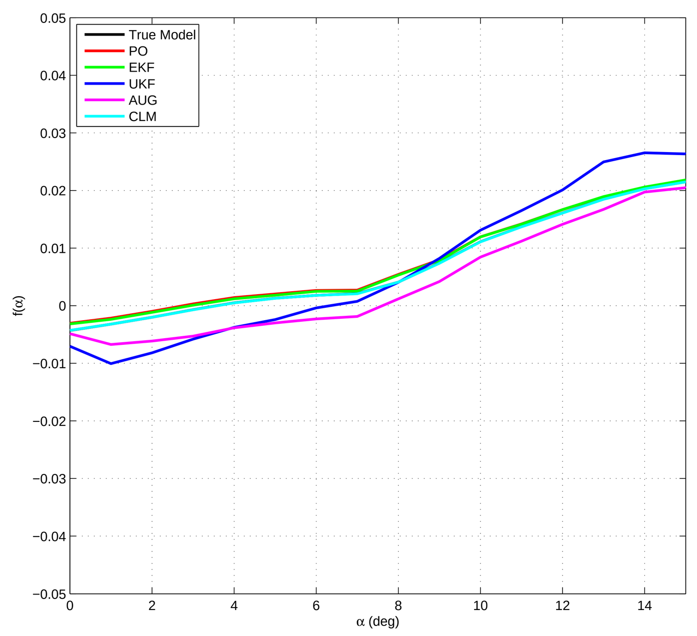
$$f_d(x(k), u(k)) = \begin{pmatrix} Z_\alpha \alpha(k) + Z_q q(k) + Z_{\delta_e}\delta_e(k) + Z_{\delta_c}\delta_c(k) \\ f(\alpha) + M_q q(k) + M_{\delta_e}\delta_e(k) + M_{\delta_c}\delta_c(k) \end{pmatrix}$$

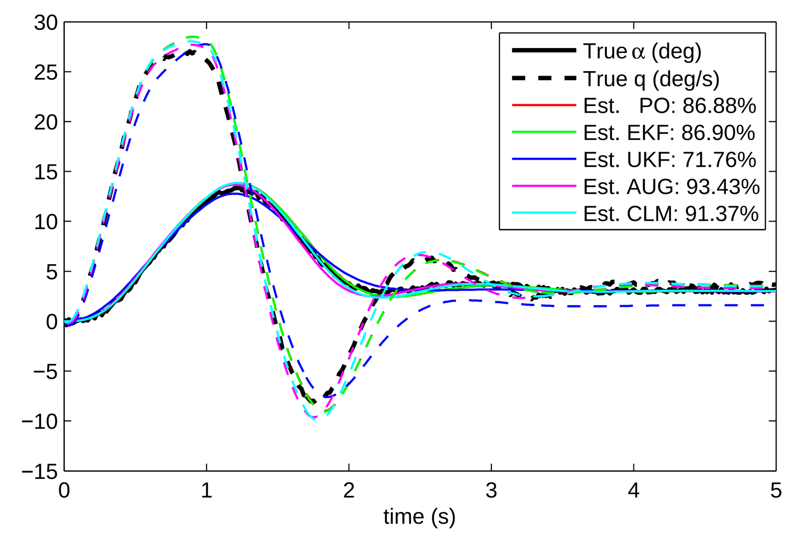
System dynamics are linear in both states and inputs except for the pitch stability $f(\alpha)$.

This concerns methods for post-flight evaluation.

- ✘ Comparison of five different methods.

Investigation of measurement noise and estimation initialization.





Post Licentiate

Linear Case: During flight

- ✘ Another method: Frequency domain subspace identification method instead of least-squares

Investigation of measurement noise and process noise.

$$\tilde{X}_k = A\tilde{X}_k + B\tilde{U}_k$$
$$\tilde{Y}_k = C\tilde{X}_k + D\tilde{U}_k$$

This can be reformulated as

$$\begin{bmatrix} \tilde{Y}_k(\omega_1) & \dots & \tilde{Y}_k(\omega_M) \\ \dot{\tilde{Y}}_k(\omega_1) & \dots & \dot{\tilde{Y}}_k(\omega_M) \\ \ddot{\tilde{Y}}_k(\omega_1) & \dots & \ddot{\tilde{Y}}_k(\omega_M) \end{bmatrix} = \begin{bmatrix} CA^0 \\ CA^1 \\ CA^2 \end{bmatrix} \begin{bmatrix} \tilde{X}_k(\omega_1) & \dots & \tilde{X}_k(\omega_M) \end{bmatrix} + \begin{bmatrix} D & 0 & 0 \\ CA^0B & D & 0 \\ CA^1B & CA^0B & D \end{bmatrix} \begin{bmatrix} \tilde{U}_k(\omega_1) & \dots & \tilde{U}_k(\omega_M) \\ \dot{\tilde{U}}_k(\omega_1) & \dots & \dot{\tilde{U}}_k(\omega_M) \\ \ddot{\tilde{U}}_k(\omega_1) & \dots & \ddot{\tilde{U}}_k(\omega_M) \end{bmatrix}$$

which can be shortened to

$$\tilde{Y}_{k;1,s,N} = \mathcal{O}_s \tilde{X}_{k;1,N} + \mathcal{T}_s \tilde{U}_{k;1,s,N}$$

By using numerical linear algebra tools (projection, QR factorization, SVD), one can estimate A, B, C and D.

A Master thesis project is planned for 2015 with the aim of implementing this real-time method at Saab with a user-friendly GUI and to adapt the method so that it can handle both data that come in small batches and loss of data for shorter periods of time.

Non-linear Case: Post flight

- ✘ Comparison of two of the five different methods.

Investigation of measurement noise and process noise.

A new controller is developed for this investigation. This controller is designed in **an internship project during the fall 2014**.

Core problems

- ✘ Real-time identification of linear unstable systems in closed loop
- ✘ Identification of nonlinear unstable systems in closed loop and with non-white process noise