Flight Test System Identification

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LINK-SIC Workshop

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LINKÖPING UNIVERSITY

Sequential Identification

A state-space representation of a linear time-invariant system can be written as

$$\dot{x}(t) = A\,x(t) + B\,u(t) + w(t) \tag{1a}$$
$$y(t) = C\,x(t) + D\,u(t) + v(t) \tag{1b}$$

For a finite time interval the continuous-time Fourier transform is defined by

$$\tilde{f}_T(\omega_i) \equiv \int_0^T f(t) e^{-j\omega_i t} dt \tag{2}$$

$$\tilde{f}_T(\omega_i) \approx T_s \sum_{k=0}^{N-1} f_k\, e^{-j\omega_i\, k T_s} = T_s \tilde{F}_N(\omega_i) \tag{3}$$

$$j\omega_i \tilde{Y}_N^T + \frac{1}{T_s}(y_N^T e^{-j\omega_i N T_s} - y_0^T) = \left[\tilde{Y}_N^T \;\; \tilde{U}_N^T\right] \left[A \;\; B\right]^T + \tilde{V}_N^T \tag{6}$$

$$\tilde{z}(\omega) = \tilde{\Phi}(\omega)\,\theta + \tilde{V}^T(\omega) \tag{7}$$

Sequential Identification

Original method:

$$\hat{\theta} = (Re(\tilde{\Phi}^* \tilde{\Phi}))^{-1} Re(\tilde{\Phi}^* \tilde{z}). \qquad (10)$$

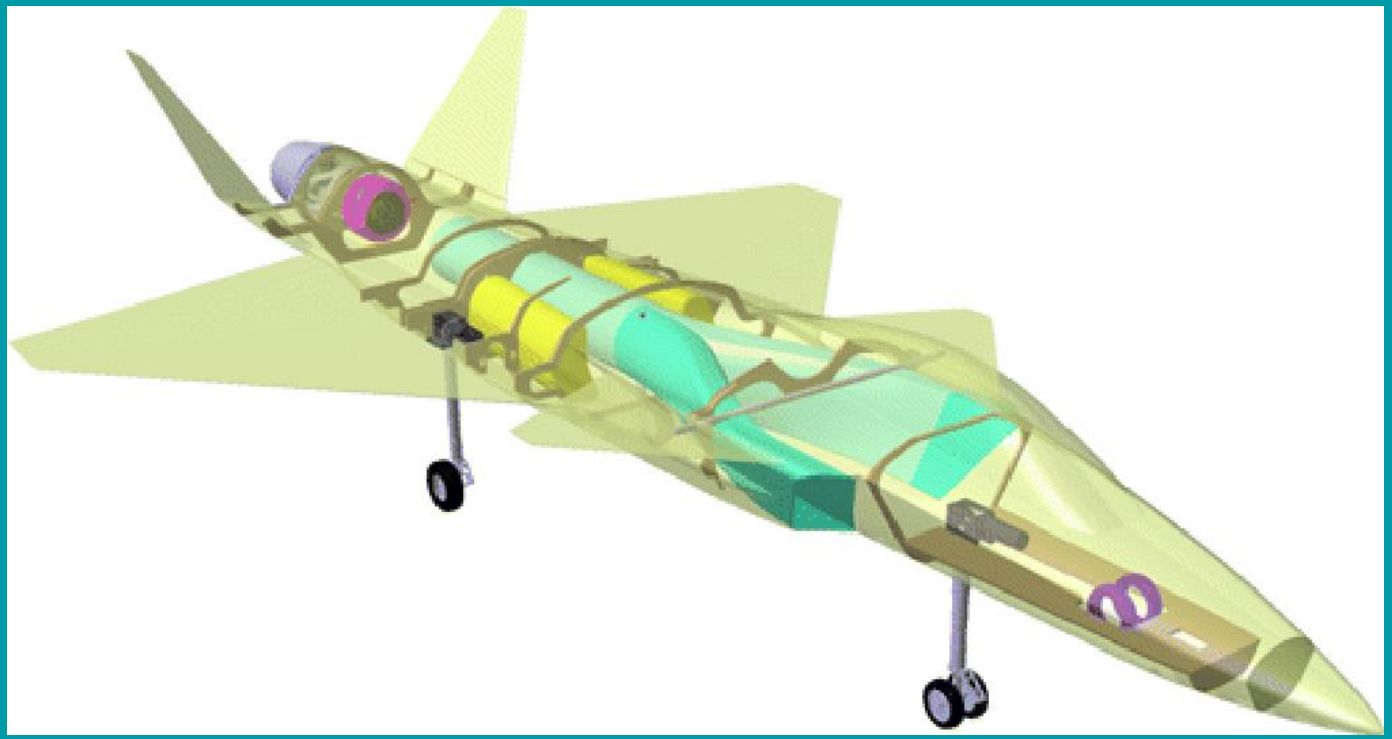
New method:

$$\hat{\theta} = (Re(\tilde{\zeta}^* \tilde{X}))^{-1} Re(\tilde{\zeta}^* \tilde{z}) \qquad (14)$$

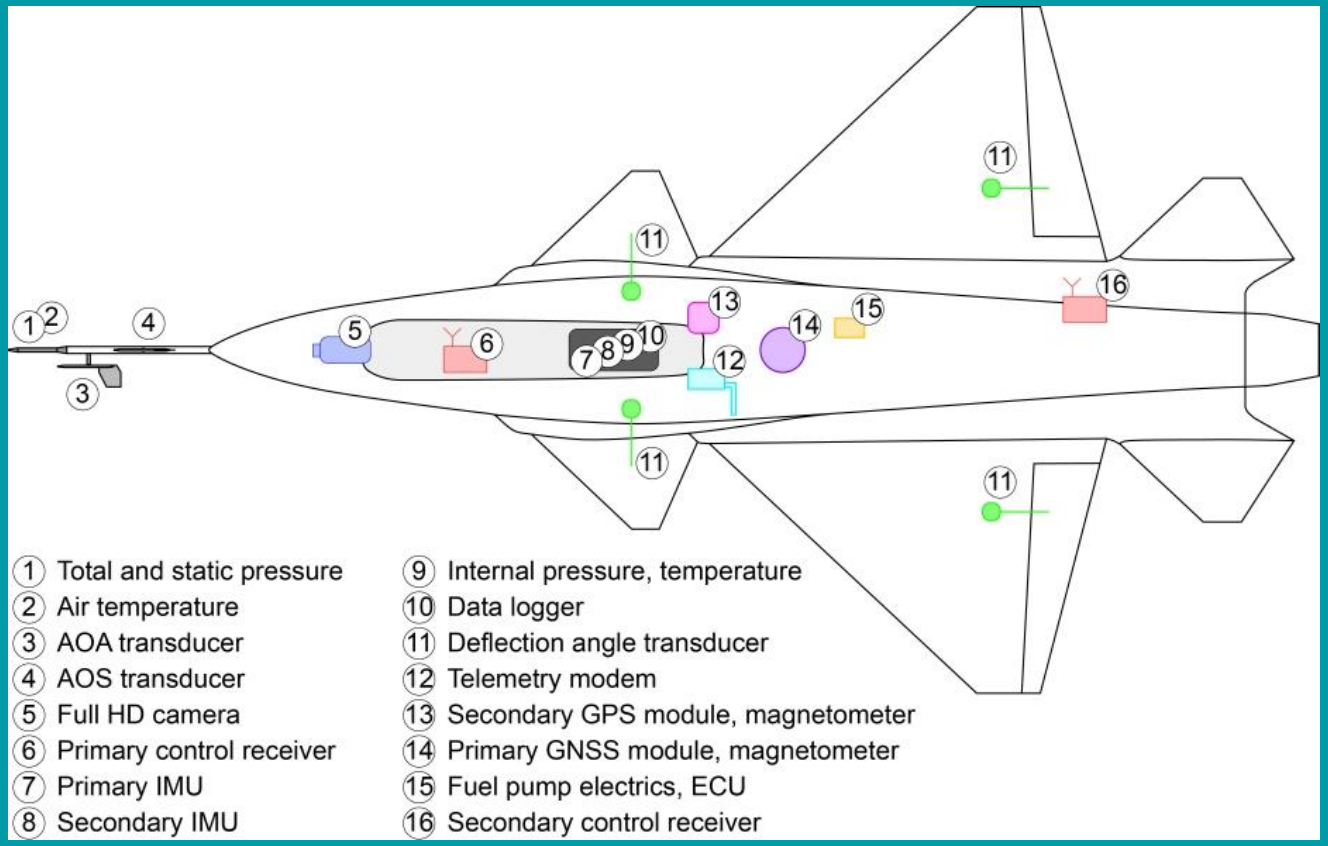
Generic Future Fighter (GFF)

- Ordered by the Swedish Defense Material Administration (FMV)
- Participants: Saab, FOI, Volvo Aero, LIU, KTH
- First flight 2009

Generic Future Fighter (GFF)

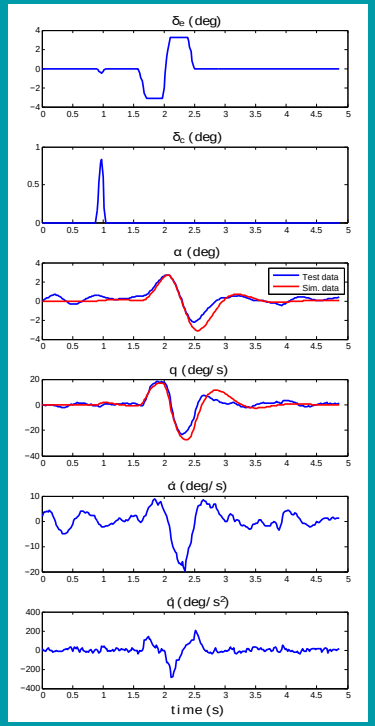


Generic Future Fighter (GFF)

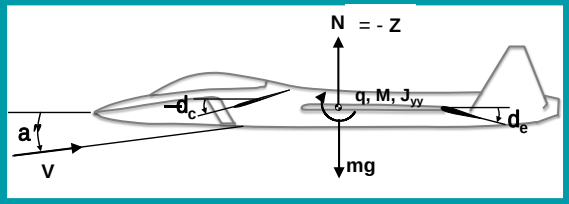


Input Signal Design

Estimation data



Aircraft



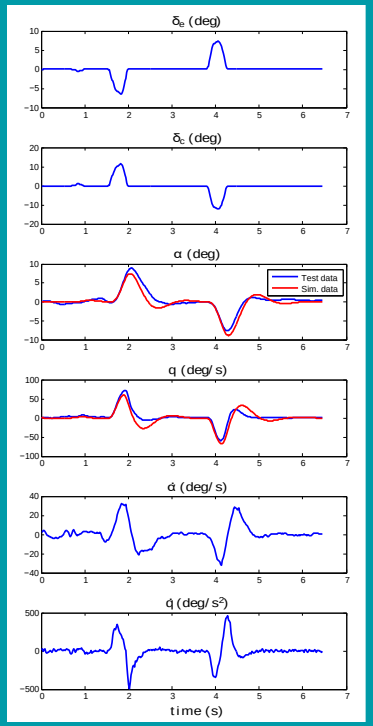
Linear regression

$$\begin{bmatrix} \dot{a}_1 & \dot{q}_1 \\ \vdots & \vdots \\ \dot{a}_N & \dot{q}_N \end{bmatrix} = \begin{bmatrix} a_1 & q_1 & d_{e\,1} & d_{c\,1} \\ \vdots & \vdots & \vdots & \vdots \\ a_N & q_N & d_{e\,N} & d_{c\,N} \end{bmatrix} \begin{bmatrix} Z_a & M_a \\ Z_q & M_q \\ Z_{d_e} & M_{d_e} \\ Z_{d_c} & M_{d_c} \end{bmatrix}$$

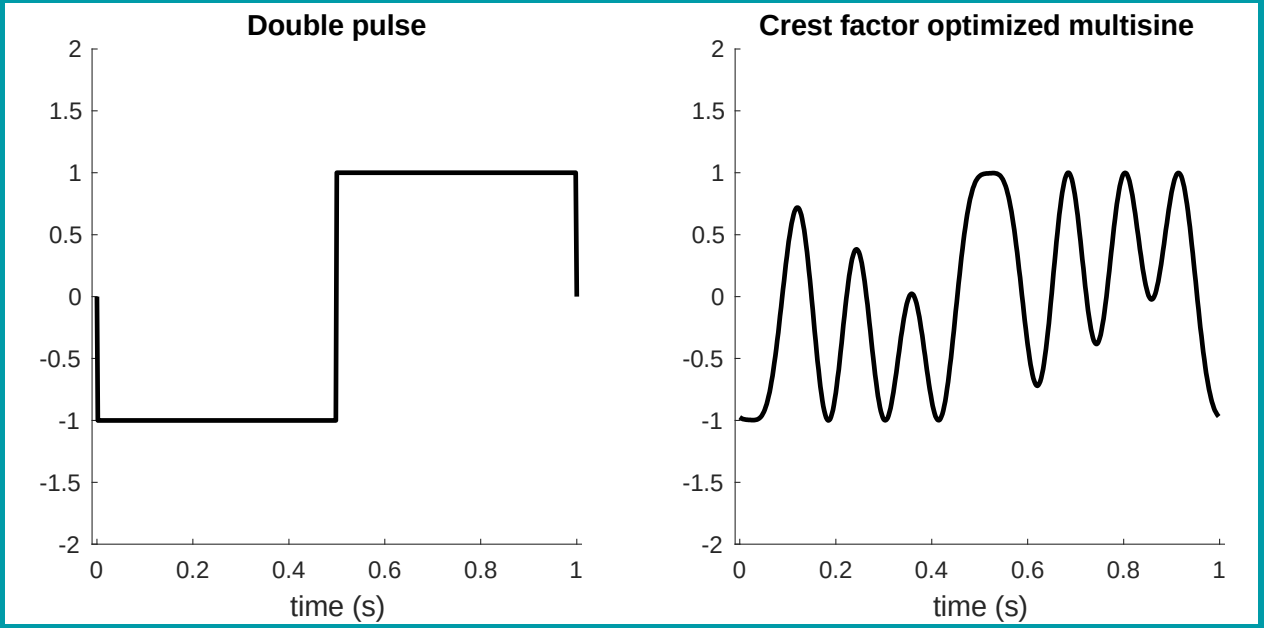
Dynamic Model

$$\begin{bmatrix} \dot{a} \\ \dot{q} \end{bmatrix} = \begin{bmatrix} -1.88 & 0.65 \\ -36.39 & -2.77 \end{bmatrix} \begin{bmatrix} a \\ q \end{bmatrix} + \begin{bmatrix} -0.33 & -0.37 \\ -39.04 & 17.49 \end{bmatrix} \begin{bmatrix} d_e \\ d_c \end{bmatrix}$$

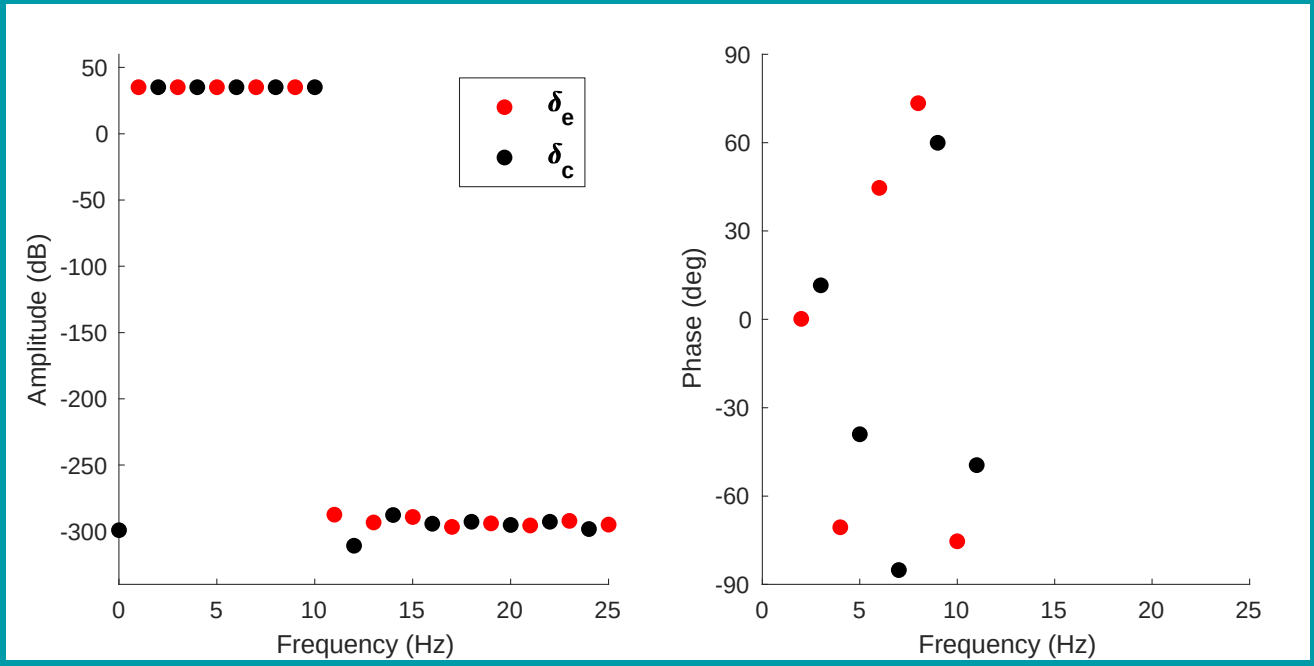
Validation data



Input Signal Design



Input Signal Design



Test Preparation

Flight FT. #2	Flight FT. #3
Take-off	Take-off
Multisine 1 separated, MSs1	Multisine 1 parallel, MSp1
Multisine 1 separated, MSs1	Multisine 1 parallel, MSp1
Multisine 2 separated, MSs2	Multisine 2 parallel, MSp2
Multisine 1 parallel, MSp1	Multisine 1 separated, MSs1
Multisine 1 parallel, MSp1	Multisine 1 separated, MSs1
Multisine 2 parallel, MSp2	Multisine 2 separated, MSs2
Double pulse parallel, DPp	Double pulse separated, DPs
Landing	Landing

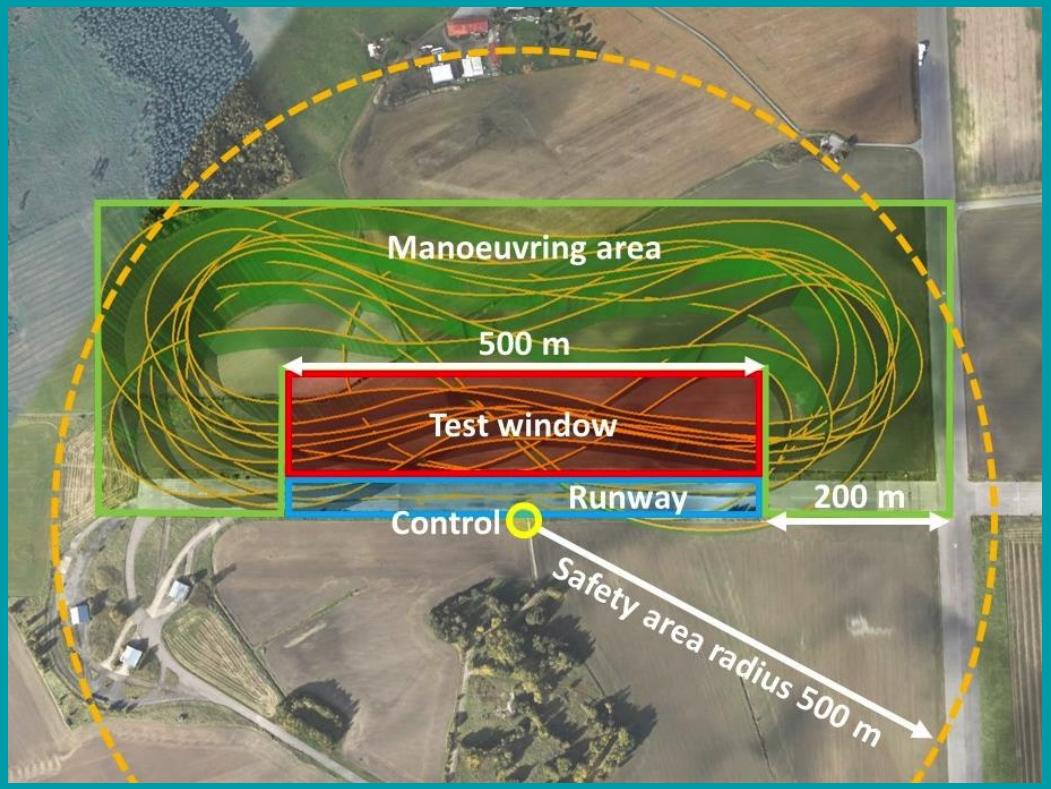
Test Preparation

TEST CARD ID: Pre-test check				Aircraft: GFF
Radio test freq:	Test id:	Test type:	Pilot:	Test Conductor:	Date:
	GFF1701	Check	David Lundström	Alejandro Sobrón	2017-06-XX
Test Object: GFF 	Test heading: Pre-test check				
	Sub heading: Airspeed calibration and altitude check				
Configuration:	Summary of test results:				
Restrictions and remarks: Max nz=4.8					

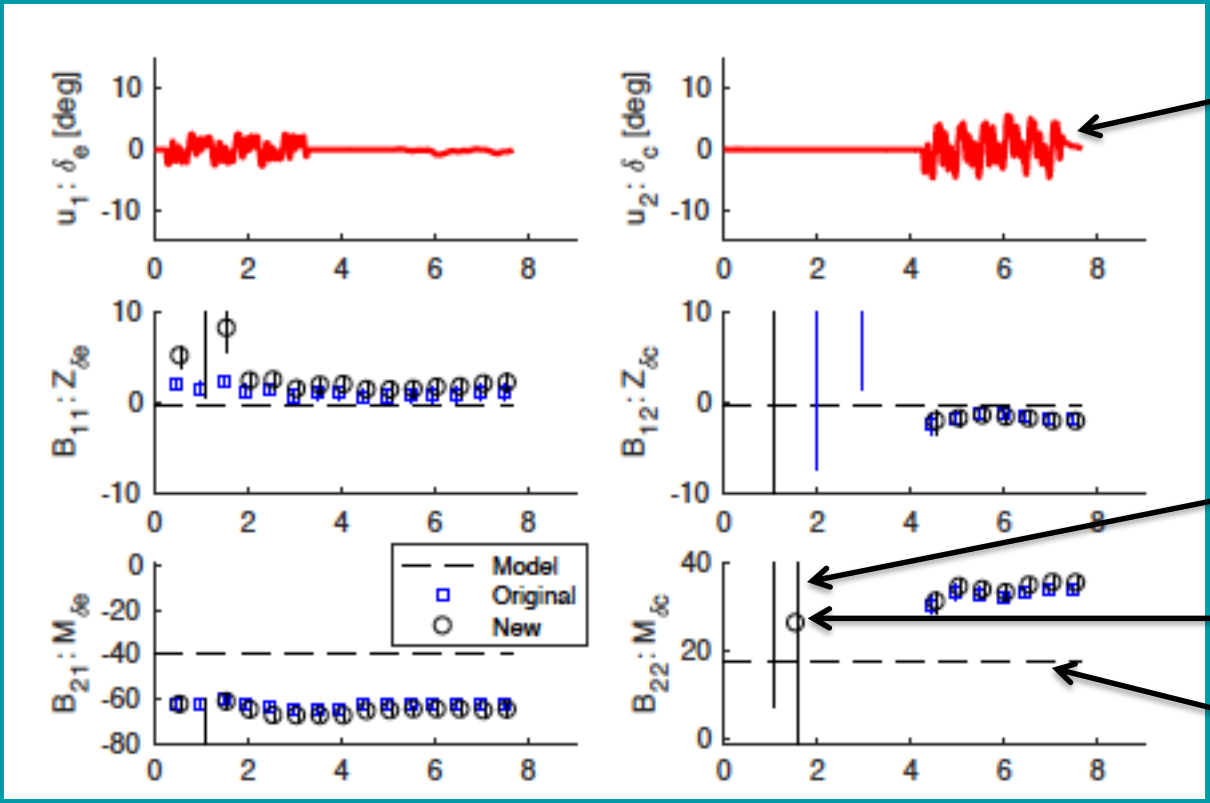
Test Preparation

Pos	Alt.	Speed	Header	ExpTime	%Fuel	Test type
0	0		Ground check and Take off			Check and Take off
Perform initial magnetometer calibration. Static pressure calibration. Taxi and Take-off						
Pos	**Alt.**	**Speed**	**Header**	**ExpTime**	**%Fuel**	**Test type**
1			Airspeed variable			Calibration
Calibrate airspeed reading in transmitter telemetry: probably various passes or "traffic circuits" will be needed **(Lua Pos. 0)**						
Pos	**Alt.**	**Speed**	**Header**	**ExpTime**	**%Fuel**	**Test type**
2			Airspeed variable			Calibration
Check and calibrate ground station readings: airspeed, barometers, magnetometers, general EKF health. **(Lua Pos. 0)**						
Pos	**Alt.**	**Speed**	**Header**	**ExpTime**	**%Fuel**	**Test type**
3		40 m/s	Airspeed ~40 m/s			Check
Amplitude check **(Lua Pos. 1)**: small input in elevons (+-4 deg?)						

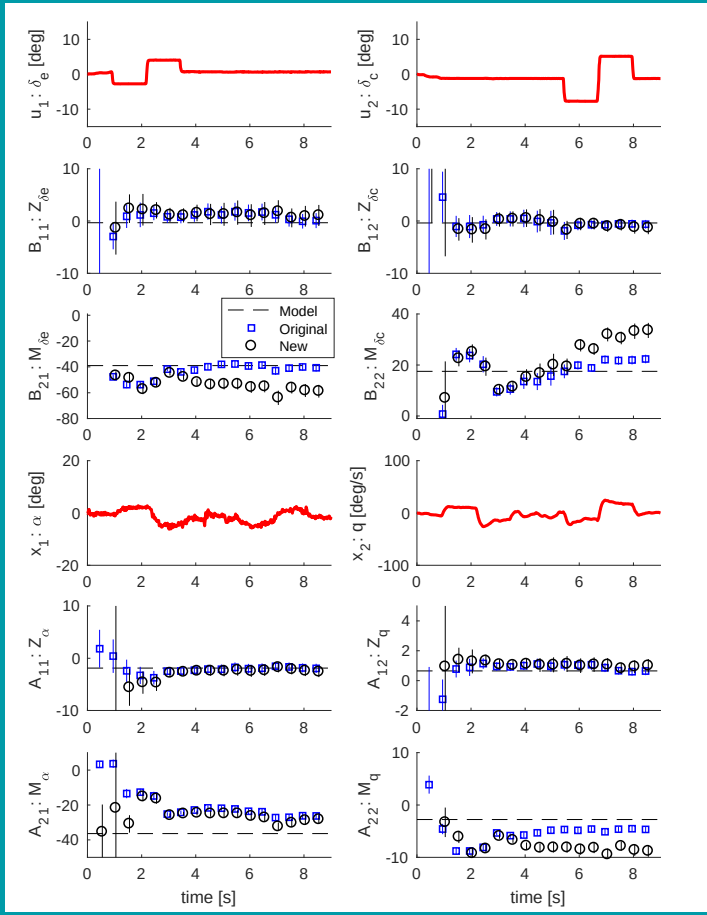
Bråvalla Test Area

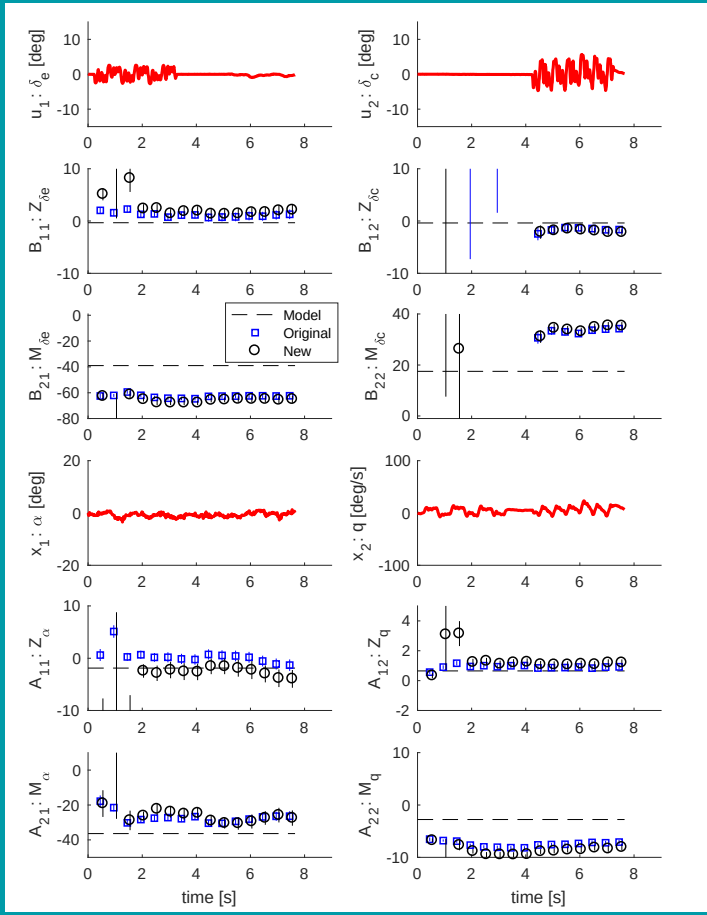


Results

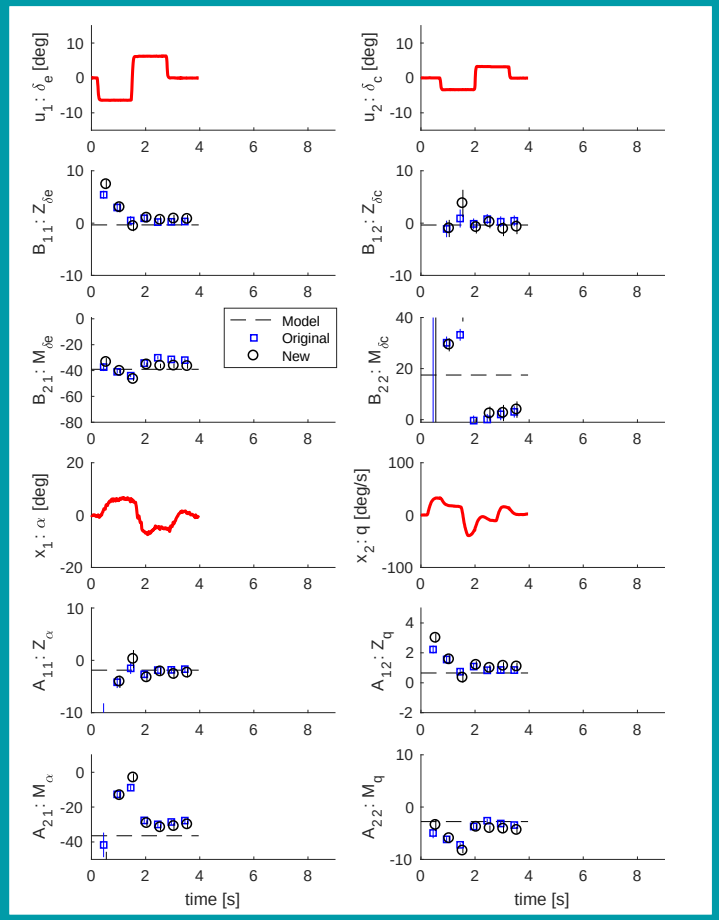

$u_1: \delta_e$ [deg]
$u_2: \delta_c$ [deg]
$B_{11}: Z_{\delta e}$
$B_{12}: Z_{\delta c}$
$B_{21}: M_{\delta e}$
$B_{22}: M_{\delta c}$
Model
Original
New
Data
Uncertainty
Estimate
Prior Model

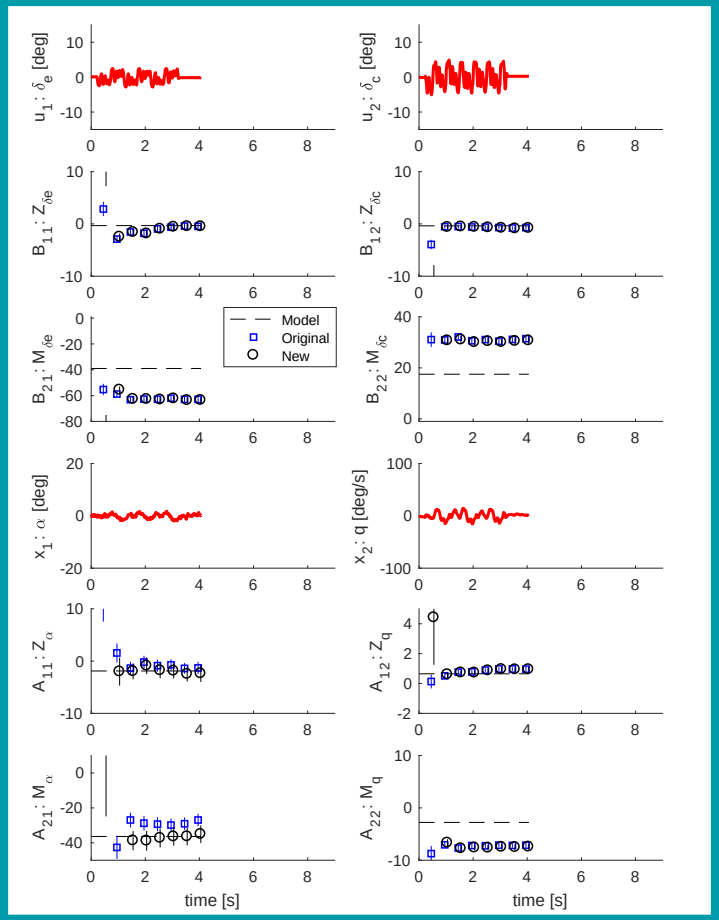
Results Separated Excitation



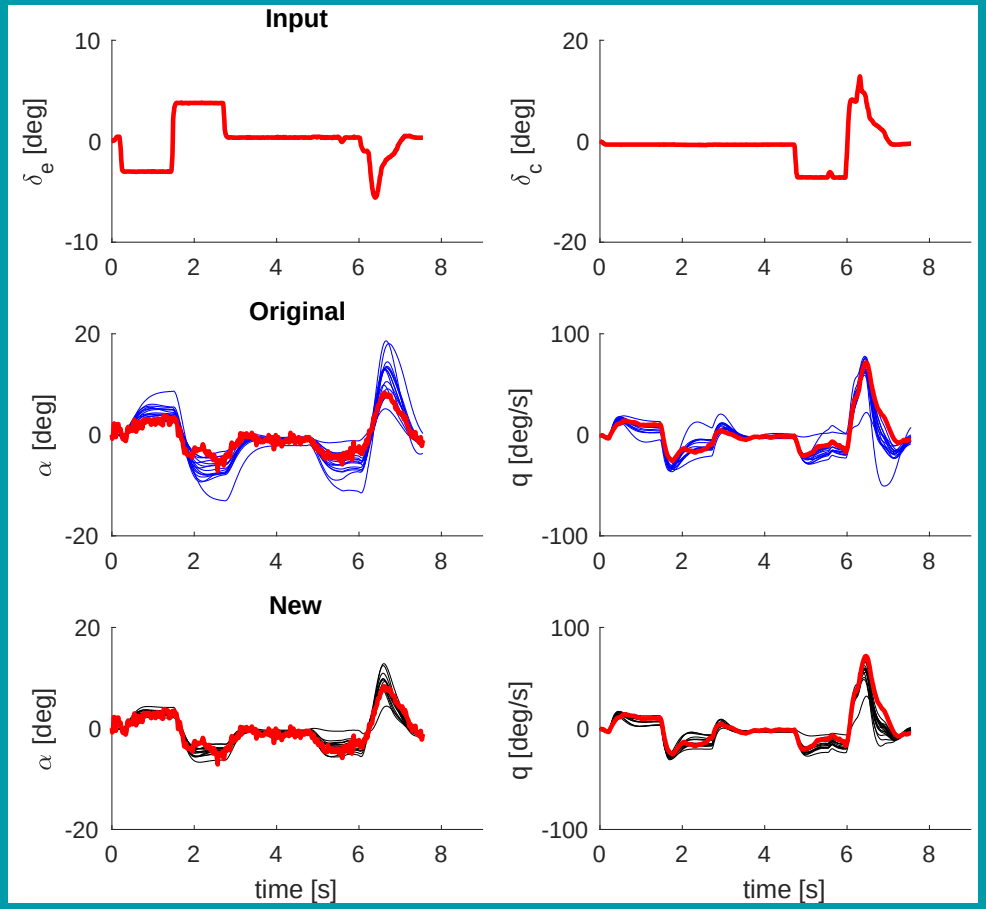


Results Parallel Excitation

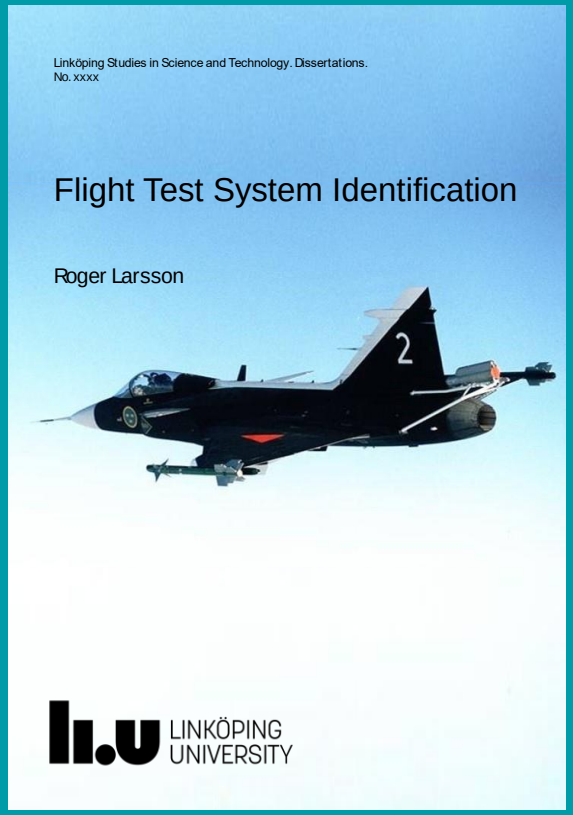




Identification Results



And so …



- Sequential Identification
- Generic Future Fighter
- Identification of Unstable, Nonlinear Systems working under Feedback Control

Questions?

Flight Test System Identification

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