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Parameter identification studies using SIDPAC with Fenrir's 1st flight data set

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1.0 INTRODUCTION

This document summarizes the process of identifying unknown dynamic systems from measured flight test data. Several available system identification tools were evaluated based on accuracy and robustness. Among them,[1-3] SIDPAC developed by NASA (Ref. 1) was chosen. The objective of this study is to lay out the procedures to identify unknown systems from flight test data and to provide recommendations for following flight tests. Data from the Fenrir's 1st flight[4] was used.

2.0 ANALYSIS

The BFF model used at this analysis is at 40 kts. The full state space model is reduced using residualization to include rigid body and actuator states only. The control inputs in the model are the same controls that are used in the flight test with the stiff wing miniMUTT conducted on 9 February 2015 (refer to Ref. 4). The control inputs used in the flight test are listed below,

$\text{¢}e$ = main elevator, collective L3 and R3
$\text{¢}a$ = main aileron, differential L2 and R2
$\hat{\text{¢}}e$ = elevon elevator, collective R3 and R4
$\hat{\text{¢}}a$ = elevon aileron, differential R3 and R4

The transfer functions of the longitudinal short period mode and the dutch-roll mode are extracted from the reduced model as references to compare with identified models. The transfer functions for *p*, *q*, *r* to each control input are listed below.

$$\frac{p}{\text{¢}e} = \frac{5.855\text{e-}05[0.0001493, 0.05012](-18.72)}{(0)^2(18.18)}$$

$$\frac{q}{\text{¢}e} = \frac{76.52(14.4)}{[0.57,\ 23.65]}$$

$$\frac{r}{\text{¢}e} = \frac{-6.247\text{e-}10(18.03)}{1}$$

$$\frac{p}{\text{¢}a} = \frac{-46.92}{(21.34)}$$

$$\frac{q}{\text{¢}a} = \frac{3.193\text{e-}05(-10.64)}{(16.61)}$$

$$\frac{r}{\text{¢}a} = \frac{-4.818\text{e-}10(0.8463)(-1.998)(7.55)}{(0)[0.07898, 3.076]}$$

$$\frac{p}{\hat{\text{¢}}e} = \frac{7.422\text{e-}05[-0.0001929, 0.04234](-30.63)}{(0)^2(17.11)}$$

$$\frac{q}{\hat{\text{¢}}e} = \frac{111.8(15.49)}{[0.57,\ 23.65]}$$

$$\frac{r}{\hat{\text{¢}}e} = \frac{-1.476\text{e-}09(40.29)}{1}$$

$$\frac{p}{\hat{\text{¢}}a} = \frac{-46.92}{(21.34)}$$

$$\frac{q}{\hat{\text{¢}}a} = \frac{0.003214(3.854)}{[0.59,\ 22.28]}$$

$$\frac{r}{\hat{¢a}} = \frac{\text{-4.846e-10(0.9187)(-2.42)(5.638)}}{\text{(0)[0.07836,3.057]}}$$

Inspecting each transfer function indicates that the transfer functions $p/¢a$, $q/¢e$, $p/\hat{¢a}$, and $q/\hat{¢e}$ are important. For now, all the analysis presented in this document will be focused on the pitch axis only. The lateral-directional axis system identification will be explored later.

The simulated outputs with the measured inputs of the flight test are generated to provide input/output pairs to estimate unknown system parameters. This step is intended to provide the validity of the system identification tool and the procedure before using the actual flight test data. Initially, single-input-single-output system identification is performed. A multi-input-single-output system identification method will be explored later. Figure 1 shows the comparison of the time responses of the estimated system using the simulated pitch rate response of the model. The estimated model is the short period transfer function q to $¢e$ and presented in Table 1. The control inputs to the model were $¢e$ fixing other controls to zero. Both transfer functions, truth and estimated, show excellent agreement.

Table 1: Truth and estimated transfer functions with $¢e$ input only.

Truth	Estimated
$\frac{q}{¢e} = \frac{76.52(14.4)}{[0.57, 23.65]}$	$\frac{q}{¢e} = \frac{72.59(14.81)}{[0.57, 23.36]}$

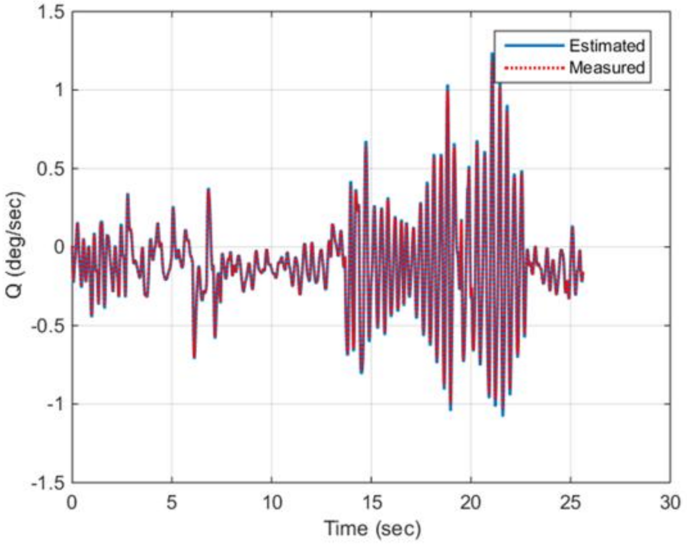

Figure 1: Estimated system response ($q/¢e$) with $¢e$ input only.

Table 2 and Figure 2**Figure 2: Estimated system response ($q/\hat{¢e}$) with $\hat{¢e}$ input only.** present the comparison of q to $\hat{¢e}$. Again other control inputs are set to zero. The time responses of both truth and estimated models show excellent agreement.

Table 2: Truth and estimated transfer functions with $\hat{¢e}$ input only.

Truth	Estimated
$\frac{q}{\hat{¢e}} = \frac{111.8(15.49)}{[0.57, 23.65]}$	$\frac{q}{\hat{¢e}} = \frac{96.13(16.95)}{[0.62, 22.93]}$

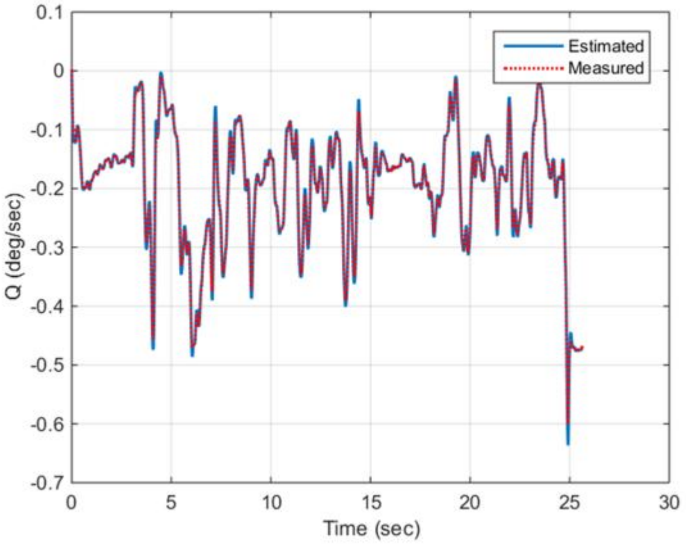

Figure 2: Estimated system response ($q/\hat{¢}e$) with $\hat{¢}e$ input only.

Table 3 and Figure 3 show the identified system model and the time responses for q to $¢e$. In this case, the control inputs were the measured $¢e$ and $¢a$ fixing other two controls $\hat{¢}e$ and $\hat{¢}a$ to zero. The purpose of this study is to investigate the cross coupling effect of the two inputs $\hat{¢}e$ and $\hat{¢}a$ since they both use the same control surfaces. As seen in Table 3 and Figure 3 the estimated model shows excellent agreement with the truth model.

Table 3: Truth and estimated transfer functions with $¢e$ and $¢a$ inputs.

Truth	Estimated
$\frac{q}{¢e} = \frac{76.52(14.4)}{[0.57,\ 23.65]}$	$\frac{q}{¢e} = \frac{72.59(14.81)}{[0.57,\ 23.36]}$

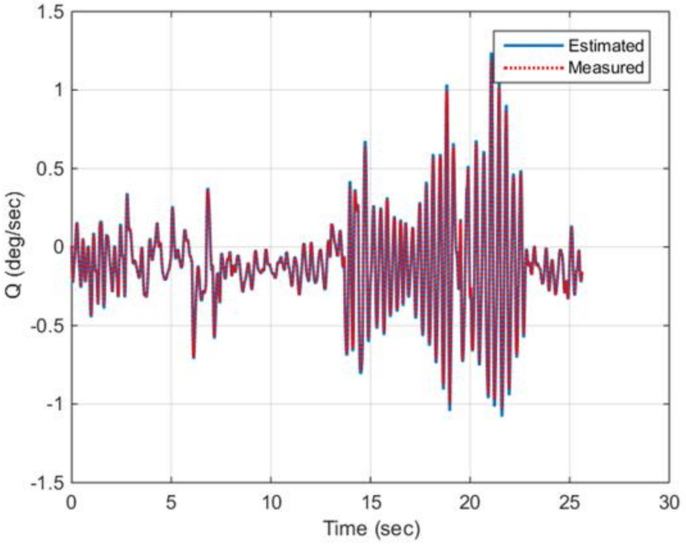

Figure 3: Estimated system response ($q/¢e$) with $¢e$ and $¢a$ inputs.

For the estimated model and its time responses presented in Table 4 and Figure 4, an extra control input $\hat{¢}a$ was fed to the model to investigate its influence. The estimated model and its time response agree with the truth model well.

Table 4: Truth and estimated transfer functions with $¢e$, $¢a$, and $\hat{¢}a$ inputs.

Truth	Estimated
$\frac{q}{¢e} = \frac{76.52(14.4)}{[0.57, 23.65]}$	$\frac{q}{¢e} = \frac{72.59(14.81)}{[0.57, 23.36]}$

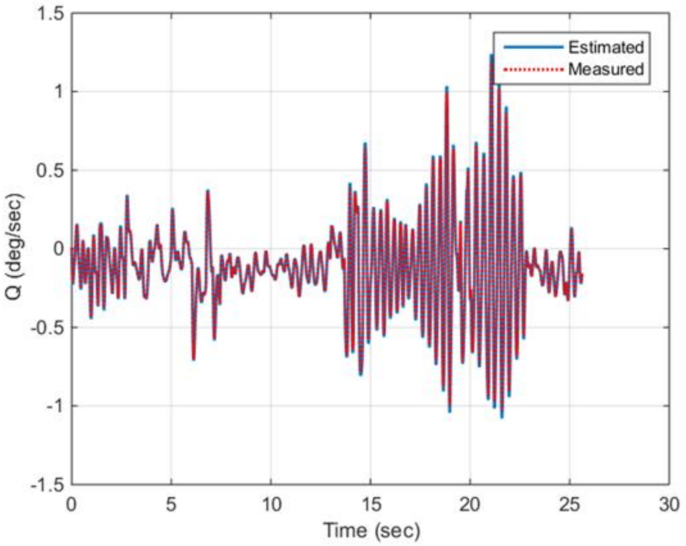

Figure 4: Estimated system response ($q/¢e$) with $¢e$, $¢a$, and $\hat{¢}a$ inputs.

Finally, all the measured inputs from the flight test, $¢e$, $\hat{¢}e$, $¢a$, and $\hat{¢}a$, were used to generate simulated data for identification. Even though all signals were used in the simulation, only signals $¢e$ and q were used for SISO ID. As presented in Table 5, the estimated model is significantly different from the truth model. This clearly indicates that injecting $\hat{¢}e$ and $\hat{¢}a$ at the same control surfaces will create some difficulty in estimating system parameters from the flight test data.

Table 5: Truth and estimated transfer functions with $¢e$, $¢a$, $\hat{¢}e$, and $\hat{¢}a$ inputs.

Truth	Estimated
$\frac{q}{¢e} = \frac{76.52(14.4)}{[0.57, 23.65]}$	$\frac{q}{¢e} = \frac{931.6(1.925)}{(1.171)(303.6)}$

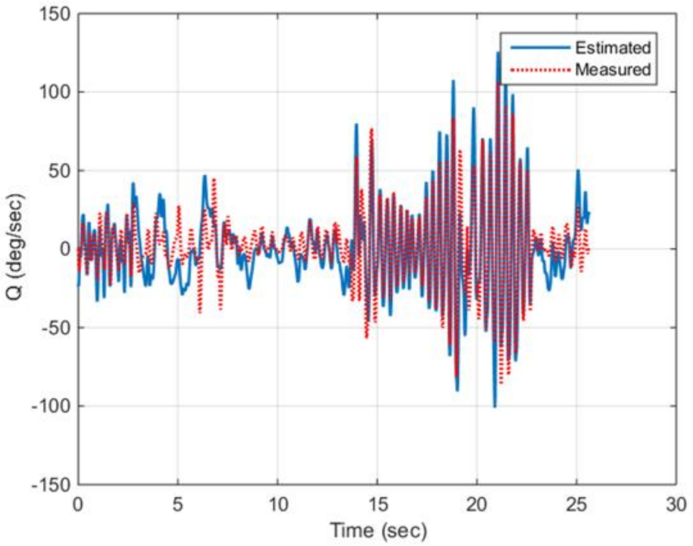

Figure 5: Estimated system response ($q/¢e$) with measured flight test data.

Finally, the same procedure used for the cases presented in Table 1 to Table 5 and Figure 1 to Figure 4 was applied to the measured flight test data. The $q/¢e$ transfer function was estimated as,

$$\frac{q}{¢e} = \frac{119.6(-1.567)}{[0.7853,\ 16.33]}.$$

The estimated model shows significant non-minimum phase and also a very high damping ratio, which is counter-intuitive considering the measured pitch responses. The comparison of the time responses in Figure 5 shows that the flight test data and the simulated time response of the estimated model in general agree, in particular the responses after 14 seconds.

REFERENCES

[1] Vladislav Klein, Eugene A. Morelli, "*Aircraft System Identification: Theory and Practice*," August, 2006.

[2] Ravindra V. Jategaonkar, "Flight Vehicle System Identification - A Time Domain Methodology," AIAA, August 2006.

[3] http://sigpromu.org/idtoolbox/index.html.

[4] Brian P. Danowsky, "Preliminary system identification studies with the stiff wing miniMUTT Fenrir," STI Working Paper 1439-6, February 20, 2015.