Recent System Identification Research at NASA Langley Research Center

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Title: “Advances in Aircraft System Identification from Flight Test Data”

Editors: Jared A. Grauer and Eugene A. Morelli

10 papers from centers around the world in government, industry, and academia sectors

Publication expected mid 2023

https://arc.aiaa.org/journal/ja
Outline

Aircraft System Identification Overview

Experiment Design

Frequency Response Identification

Modeling in Turbulence

Aeroelastic Modeling

Conclusions
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Problems in Dynamic Systems

Simulation: Given $u(t)$ and $G$, predict $y(t)$

Control: Given $G$ and a desired $y(t)$, design $u(t)$

Identification: Given $u(t)$ and $y(t)$, estimate $G$
Aircraft Systems of Interest

Mission -> Pilot

Pilot Inputs -> Flight Control

Actuator Commands -> Vehicle

Vehicle Responses

Measurements -> Sensors

Pilot Inputs -> Flight Control

Measurements -> Sensors

Sensors

Flight Control

Pilot

Vehicle
Primary Uses of Aircraft System Identification

- Validate analytical models or wind tunnel data
- Verify control law implementation
- Updating simulations and control laws
- Checking robustness
Wide Range of Modeling Techniques at LaRC

Matching different responses
- Measured time histories
- Fourier transforms
- Frequency responses

Maximum likelihood estimation
- Theoretical underpinning
- Accurate uncertainty analysis
- Equation error and output error

Characteristics
- Efficient flight test
- Real-time identification
- Multiple input, multiple output
- Closed-loop testing
Textbook and SIDPAC Software

Aircraft System Identification
Theory and Practice

Second Edition

Eugene A. Morelli
Vladislav Klein

SIDPAC = System IDentification Programs for AirCraft

https://software.nasa.gov
Selected Aircraft Examples

- **T-2**
  - Credit: NASA LaRC

- **X-56A**
  - Credit: NASA AFRC

- **Modified F-15B**
  - Credit: NASA AFRC

- **Ares I-X**
  - Credit: NASA LaRC

- **X-43A Hyper-X**
  - Credit: NASA LaRC

- **Bat-4**
  - Credit: NASA LaRC

- **E1**
  - Credit: NASA LaRC

- **S-2**
  - Credit: NASA LaRC

Morelli and Grauer, “Advances in Aircraft System Identification at NASA Langley Research Center,” expected 2023
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Orthogonal Phase-Optimized Multisine Inputs

\[
 r_j(t) = \sum_{k \in K_j} a_k \sin \left( \frac{2\pi k}{T} t + \phi_k \right)
\]
Locations for Injecting Excitations

Pilot inputs

Flight Control → Mixer

Mixer → Actuators

Actuators → Bare Airframe

Sensors

Measurements

Responses

\[ r_{cl}, r_{mb}, r_{ba} \]
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Open-Loop Frequency Responses in Real Time

\[ u(j\omega_k) = \Delta t \sum_{i=1}^{N} u(t_i) e^{-j\omega_k t_i} \]

\[ y(j\omega_k) = \Delta t \sum_{i=1}^{N} y(t_i) e^{-j\omega_k t_i} \]

\[ \hat{G}(j\omega_k) = \frac{y(j\omega_k)}{u(j\omega_k)} \]

Credit: NASA Langley Research Center

Open-Loop Estimation from Closed-Loop Data

Grauer and Boucher, “Real-Time Estimation of Bare-Airframe Frequency Responses from Closed-Loop Data and Multisine Inputs,” 2020
Multiple-Loop Frequency Response Estimation

- Bare airframe
- Closed-loop system
- Open loop at mixer
- Open loop at sensor

Credit: NASA / Lockheed Martin

Credit: NASA / Jim Ross

Grauer, "Frequency Response Estimation for Multiple Aircraft Control Loops using Orthogonal Phase-Optimized Multisine Inputs," 2022
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Reconstructed Turbulence as a Measured Input

Basic concept: $\alpha_m = \alpha + \alpha_g - \frac{lq}{V}$

Credit: NASA Langley Research Center

Parameter Estimation Considering Process Noise

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X-56A Aeroelastic Model Identification

\[
\begin{bmatrix}
\dot{x}_r \\
\dot{x}_e
\end{bmatrix} = 
\begin{bmatrix}
A_{rr} & A_{re} \\
A_{er} & A_{ee}
\end{bmatrix}
\begin{bmatrix}
x_r \\
x_e
\end{bmatrix} 
+ 
\begin{bmatrix}
B_r \\
B_e
\end{bmatrix} u
\]

Credit: NASA / Jim Ross

Computed the full $14 \times 14$ frequency response matrix from a single CFD run.

Grauer, Waite, and Stanford, “Reduced-Order Aerodynamic Modeling Based on CFD Frequency Responses from Multisine Inputs,” 2021
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Conclusions

Many uses for aircraft system identification

Helpful to have a wide range of modeling tools

Expect continued importance of
  • Real-time identification
  • Rapid model updating
  • Aeroelastic systems
  • Distributed sensing
  • Non-conventional vehicle configurations
Selected References


