Practical Multiple-Input Design for Aircraft System Identification Flight Tests

Dr. Gene Morelli

NASA Langley Research Center

F-16

Impala

T-2

AIAA Aviation Forum

August 2, 2021

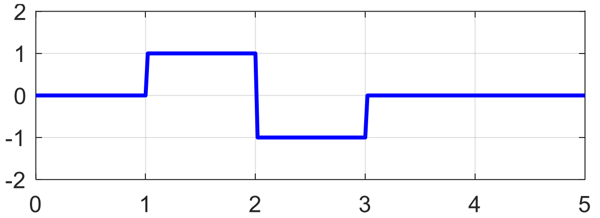
Introduction

***Aircraft System Identification* is the process of building mathematical models for aircraft based on measured data**

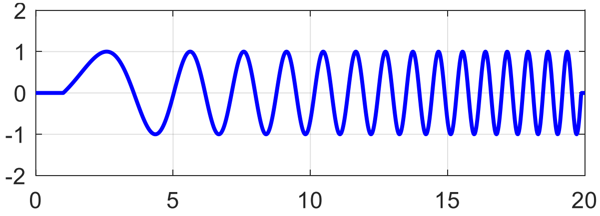
***Single-input design*:**

- One-at-a-time sequential

Doublet



Frequency Sweep

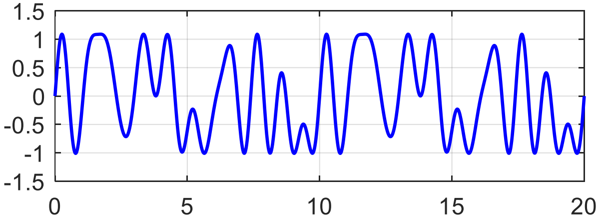


time, s

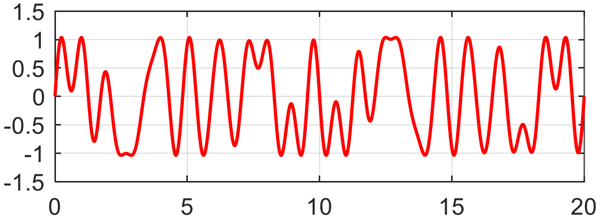
Multiple-input design:

- Many simultaneous in parallel

u_1



u_2



time, s

Multiple Input Design

Advantages of Multiple Inputs Applied Simultaneously:

- Better flight test efficiency
- Richer multi-axis aircraft response
- Higher rate of multi-axis excitation
- Control interaction effects

➢ Optimal multiple-input design approaches exist, but depend on prior models

➢ This work focuses on orthogonal optimized multisine input design:
  - Practical, multi-input design, does not require prior models
  - Very successful in past flight tests
  - Useful variations and practical flight test implementation considerations

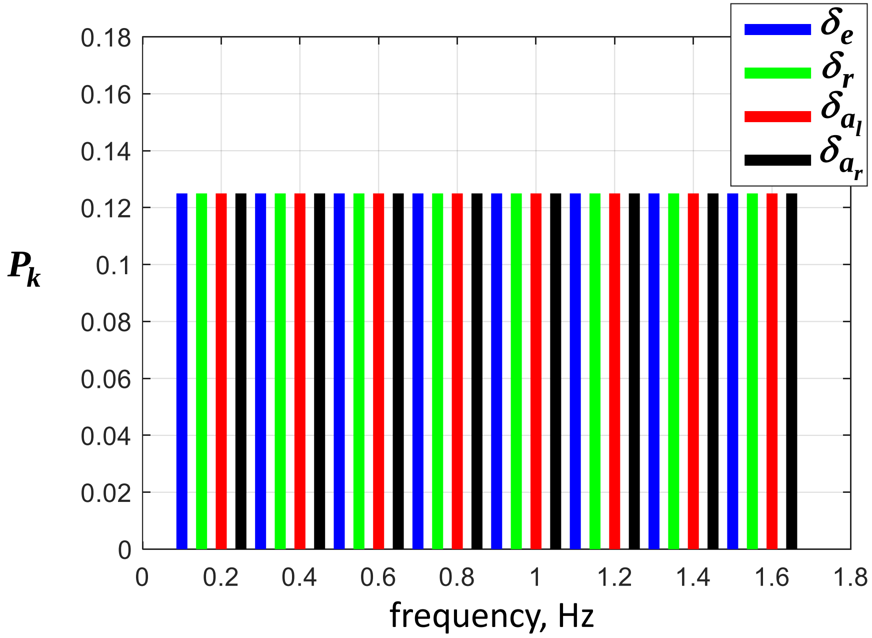
Orthogonal Optimized Multisine Inputs

$$u = \sum_{k \in \{1,2,\ldots,M\}} A\sqrt{P_k}\,\sin\left(\frac{2\pi k\,t}{T} + \phi_k\right)$$

T = maneuver length, s

A = input amplitude

- Time/Frequency orthogonal
- Simultaneous multi-input
- Phase angles optimized for minimum peak-to-peak amplitude
- Robust to various dynamics
- Decorrelated with good coverage
- Balanced, minimal excursions
- Easy to design
- Successful in past flight tests



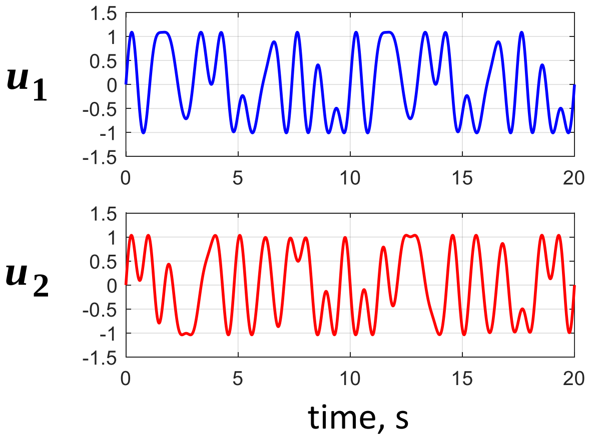
Useful Design Variations

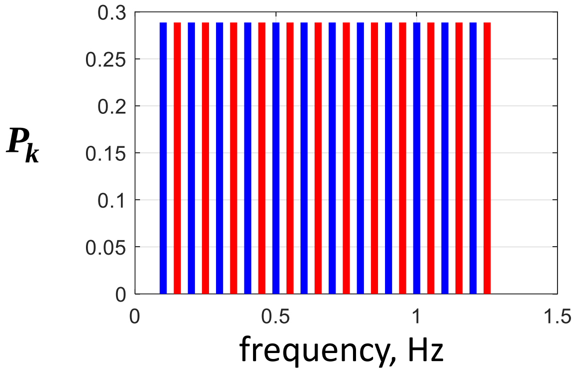
$$
\boldsymbol{u} = \sum_{k \in \{1,2,\ldots,M\}} A\sqrt{P_k}\, \sin\left(\frac{2\pi k t}{T} + \phi_k\right)
$$

$T =$ **maneuver length, s**

$A =$ **input amplitude**

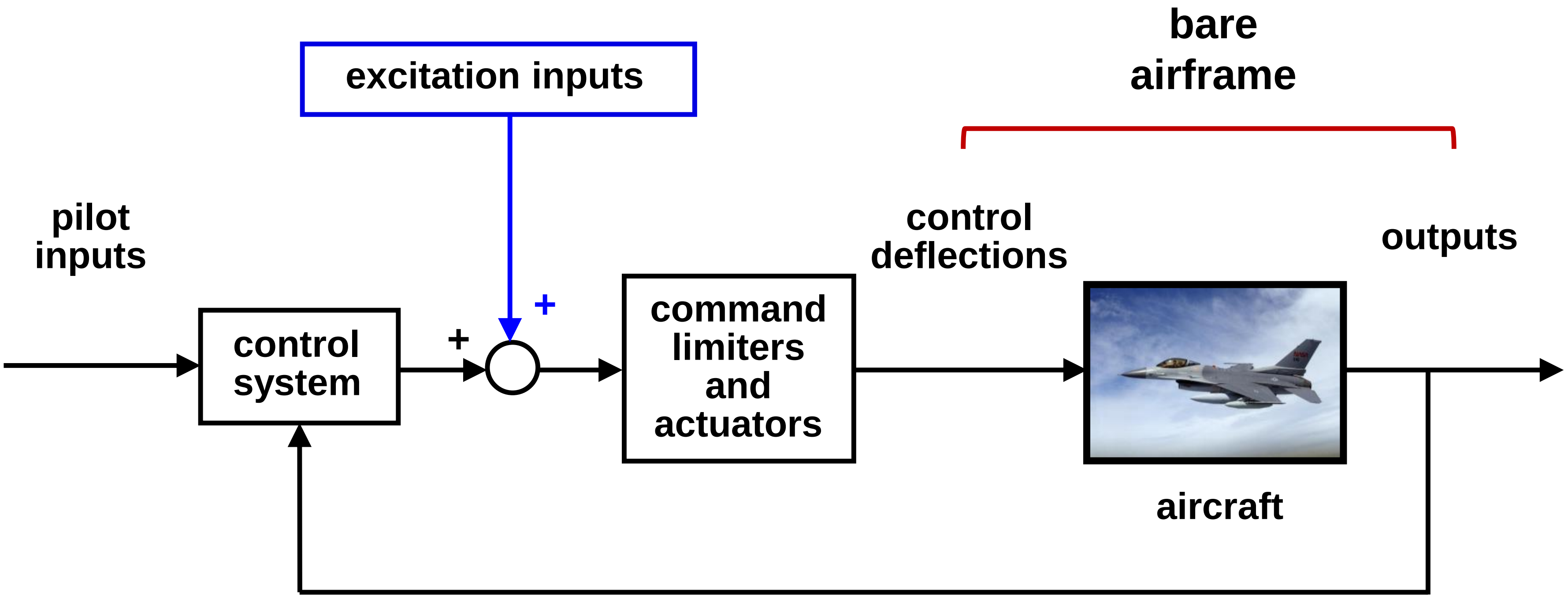
- Amplitudes and/or signs
- Assignments
- Linear combinations
- Time length T
- Harmonic square waves
- Power spectra
- Frequency content





Often the same multiple-input design can be used for different flight conditions or even different aircraft, with only simple amplitude changes

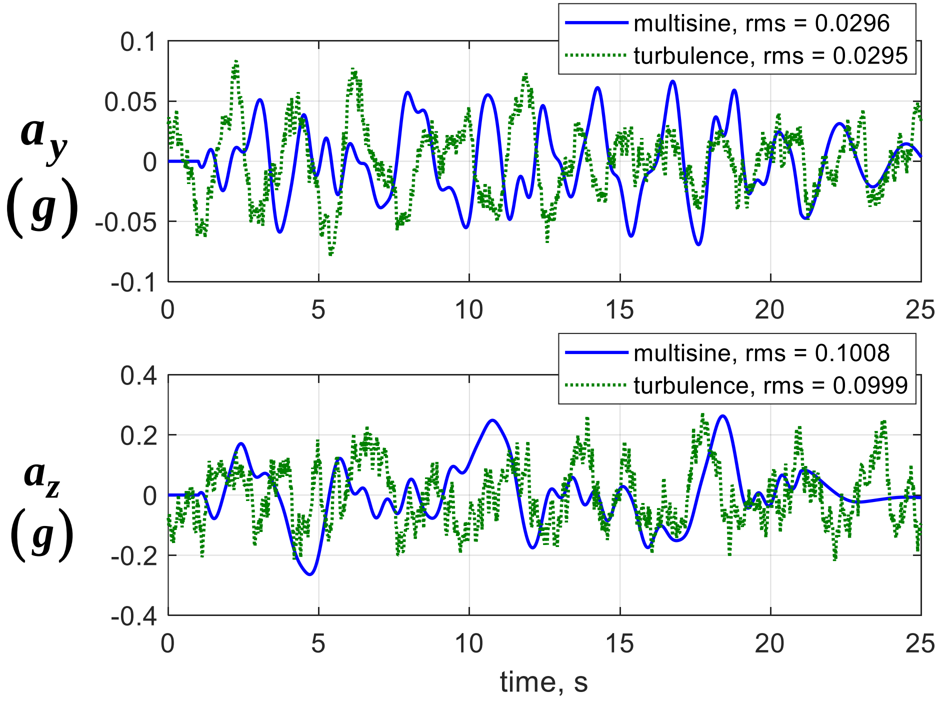
Flight Test Implementation



With this approach, informative flight data will be obtained *regardless of what the pilot or feedback control are doing*

Aircraft Response

Response to orthogonal optimized multisine input excitation is like flight in light-to-moderate turbulence



F-16

Frequency Response

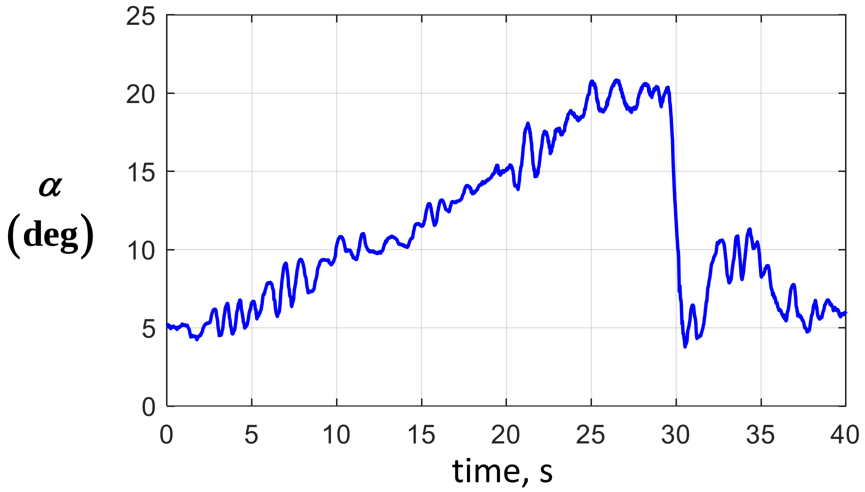
Because of the known frequency content of the orthogonal optimized multisine inputs, frequency responses can be computed simply and in real time

$$\hat{H}(\omega_k) = \frac{\tilde{y}(\omega_k)}{\tilde{u}(\omega_k)} = \frac{\textbf{Fourier transform of the output}}{\textbf{Fourier transform of the input}}$$

- Many frequency responses can be computed from a single maneuver
- Analogous to running parallel sine dwell tests at the input frequencies ω_k
- Interpolate to get the frequency response at other frequencies
- Modifications are necessary to use the technique with active feedback control

Varying Flight Conditions

T-2 flight test data: Maneuver length = 40 s



T-2

Automated multi-axis excitations during slow flight condition changes:

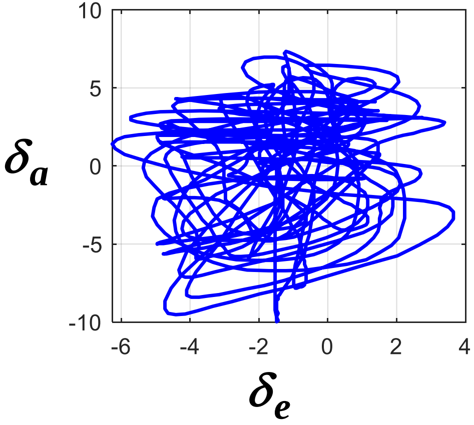
- Low pilot workload
- Global multi-axis modeling data collected efficiently
- Applied as Mach number varied during hypersonic flight tests on X-43A and X-51A

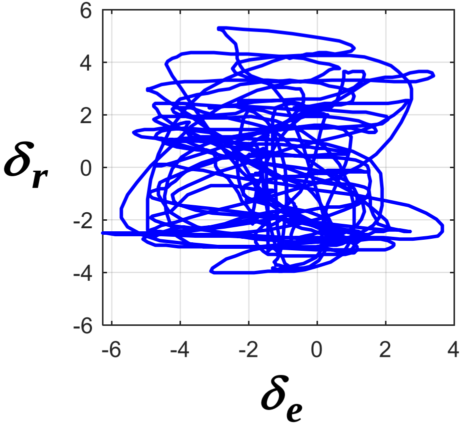
Pilot Implementation

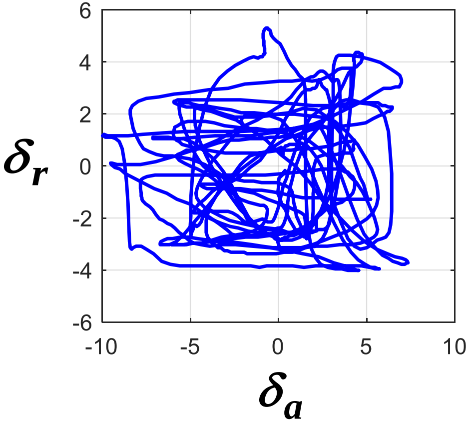
A pilot can approximate orthogonal optimized multisine inputs when the aircraft has no feedback control

Impala

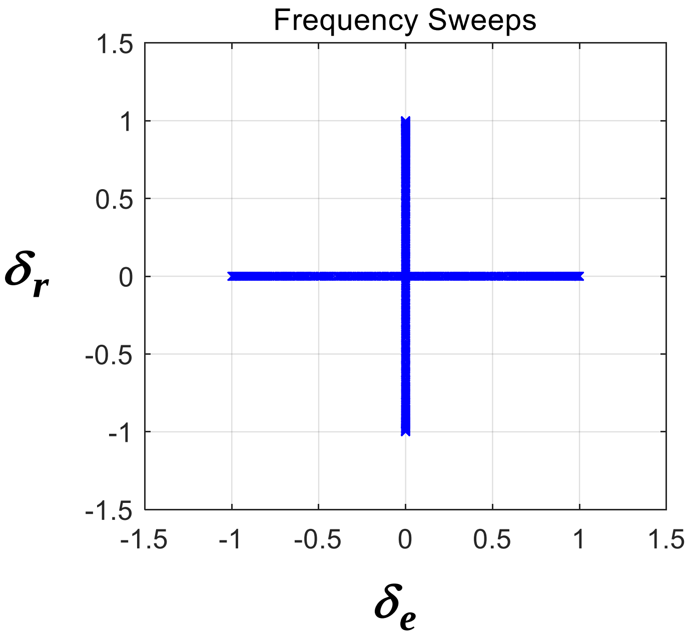
Maneuver length = 27 s

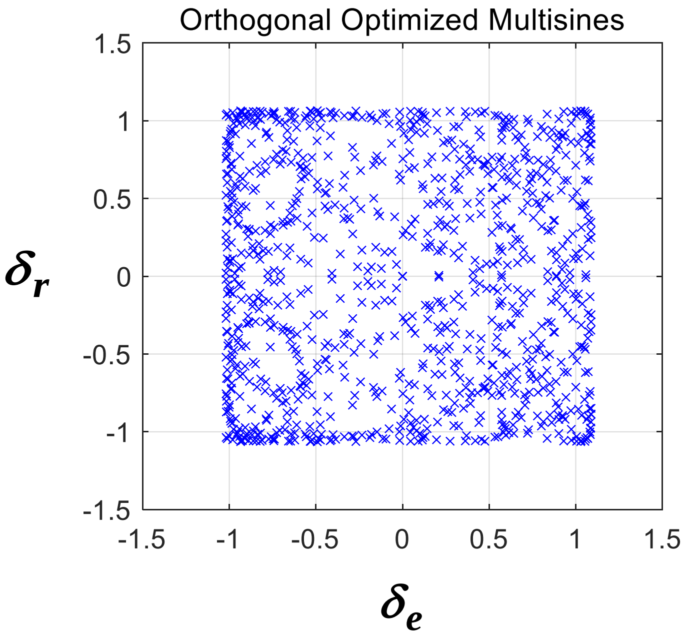






Control Interaction Effects





Summary:

- Automated orthogonal optimized multisine inputs can be applied to multiple inputs simultaneously to collect informative multi-axis flight test data very efficiently without affecting the nominal flight trajectory, for a wide variety of flight test situations and aircraft system identification problems
- Adding automated excitation inputs just before the command limiters provides practical and effective flight test capability regardless of pilot inputs or feedback control
- Test pilots can effectively approximate orthogonal optimized multisine inputs for aircraft without feedback control
- Input design software (and much more) is available in SIDPAC: https://software.nasa.gov/software/LAR-16100-1