Aircraft System Identification

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Outline

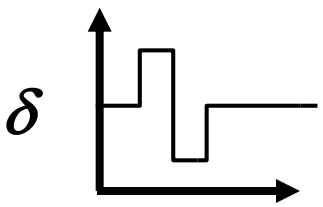
- Overview of Aircraft System Identification
- Procedure and Results
- Applications
- Demonstration Using SIDPAC Software
- Concluding Remarks
- References for Further Study

Aircraft System Identification

System Identification **is the process of building mathematical models for physical systems based on imperfect observations or measurements**

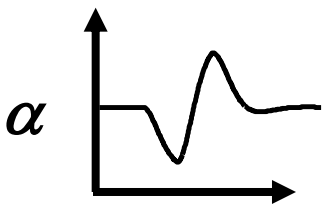
If the physical system is an aircraft, then this activity is called *aircraft system identification*

Problems In Dynamics



Input, *u*

System, *S*



Output, *z*

Simulation: **Given *S* and *u*, find *z***

Control: **Given *S* and *z*, find *u***

Identification: **Given *u* and *z*, find *S***

Aircraft System Identification

$$m\dot{V} + \omega \times mV = F_{Aero} + F_{Thrust} + F_{Gravity} \qquad \left[\frac{d}{dt}(mV) = \sum F\right]$$

$$I\dot{\omega} + \omega \times I\omega = M_{Aero} + M_{Thrust} \qquad \left[\frac{d}{dt}(I\omega) = \sum M\right]$$

***Typical aircraft system identification problem*:**

From measurements of the inputs and outputs, determine mathematical model forms for F_{Aero} and M_{Aero}, then estimate the unknown parameters in those models

System Identification is used to model what is not known, based on measured data

How Does It Work?

Pitching moment equation: $M = I_y \dot{q} + \left(I_x - I_z\right) pr + I_{xz}\left(p^2 - r^2\right)$

Equation-Error

$$M = I_y \dot{q} + \left(I_x - I_z\right) pr + I_{xz}\left(p^2 - r^2\right)$$

Output-Error

$$\dot{q} = \frac{1}{I_y}\left[M - \left(I_x - I_z\right) pr - I_{xz}\left(p^2 - r^2\right)\right]$$

Unknowns

Postulated model: $\hat{M} = M_o + M_\alpha \alpha + M_q q + M_\delta \delta$

Integrate → $\hat{q}$

$$J = \frac{1}{2}\left(M - \hat{M}\right)^T \left(M - \hat{M}\right)$$

$$J = \frac{1}{2}\left(q - \hat{q}\right)^T \left(q - \hat{q}\right)$$

Solve with one-shot linear algebra

Solve with iterative nonlinear optimization

What Are the Results?

Pitching moment model: $\hat{M} = M_o + M_\alpha \alpha + M_q q + M_\delta \delta$

$M_o =$ **pitching moment bias**

$M_\alpha =$ **static stability**

$M_q =$ **dynamic stability or damping**

$M_\delta =$ **pitch control authority**

Results include estimated numerical values for all unknown parameters, as well as statistical uncertainties (error bounds).

Modeling results characterize the stability and control of the aircraft

It's Not Easy

1) Aircraft are multiple-input, multiple-output, nonlinear dynamical systems with complicated, nonlinear, time-varying aerodynamics

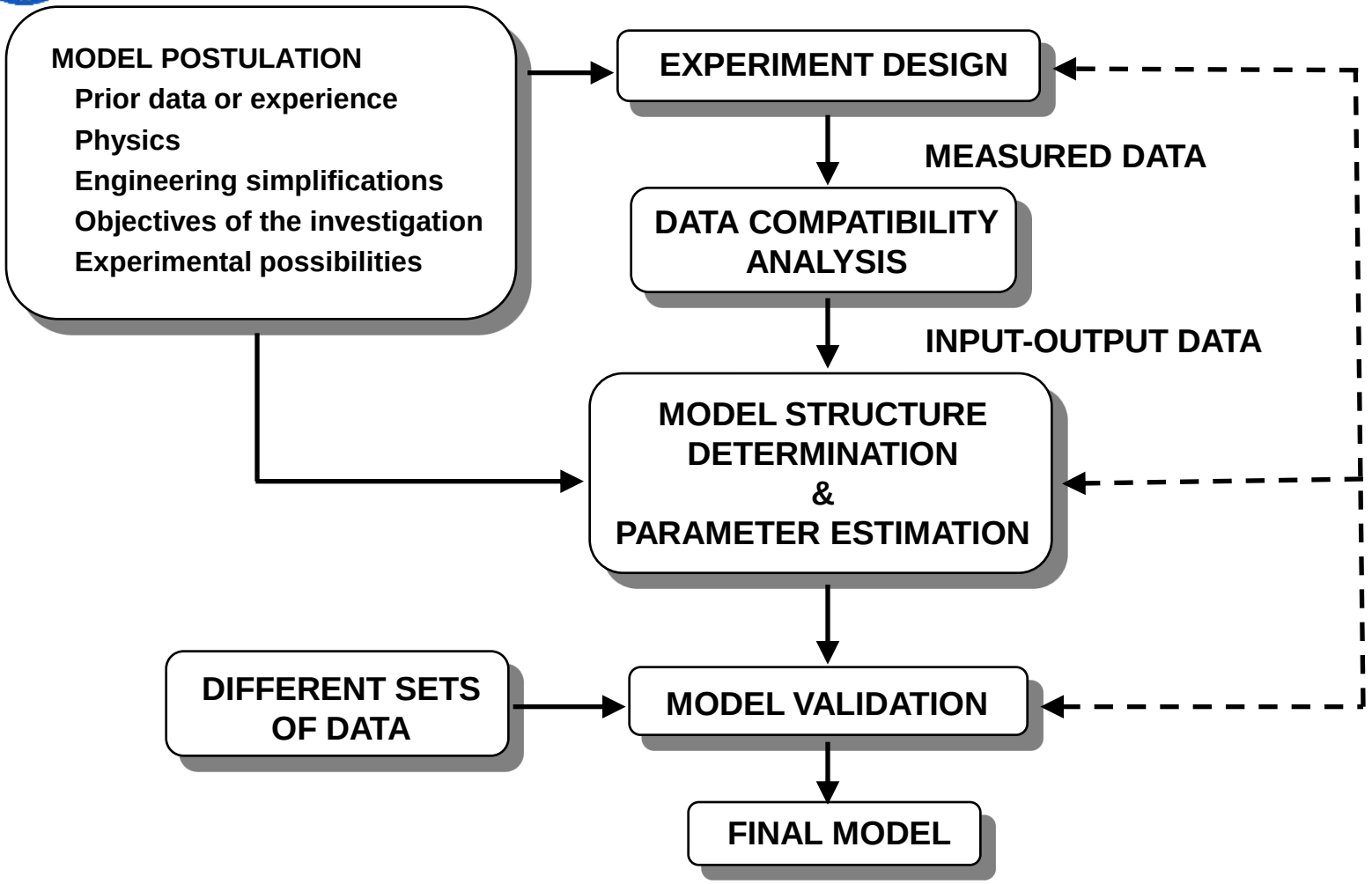
2) For an aircraft in flight, applied forces and moments must be inferred from measured responses

3) Large amounts of data must be processed

4) Aircraft measurements are noisy and sensors have practical limitations

5) Physical quantities cannot be varied independently for an aircraft in flight

Aircraft System Identification



Note that information embodied in a model is either assumed or derived from measurements

Physics and System Identification

Scientific theories are not discoveries of the laws of nature but rather inventions of the human mind.

-- Dr. Athanasios Papoulis

All models are wrong; some are useful.

-- Dr. George Box

Applications

Flight Research, Envelope Expansion

Validate and Improve Predictions

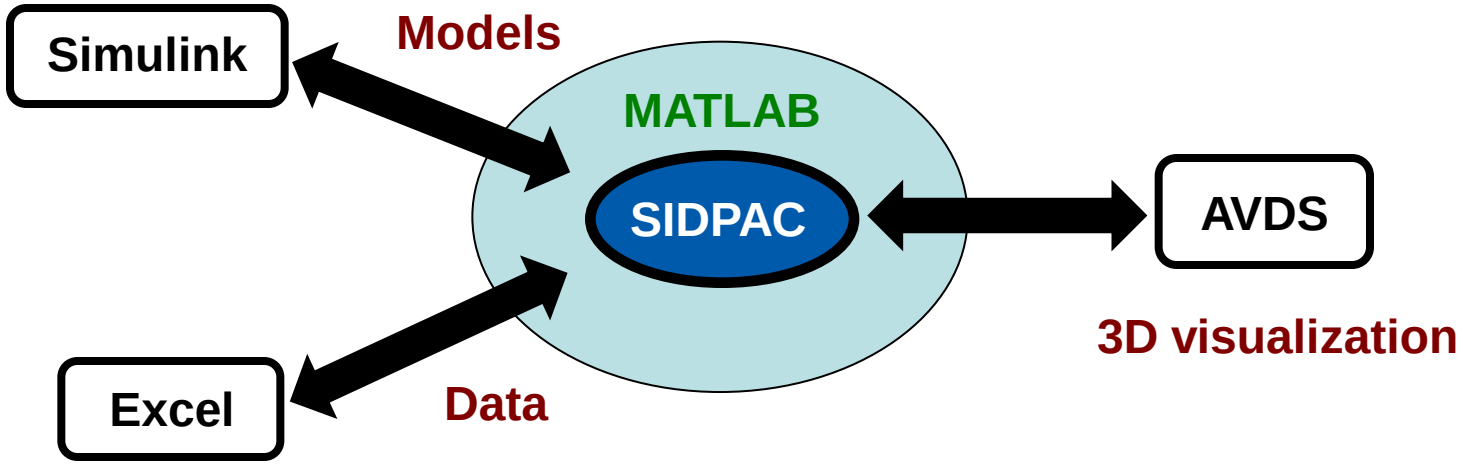
Flight Simulation

Accident Investigation

Evaluate New or Modified Aircraft

Flight Control, Flying Qualities

System IDentification Programs for AirCraft (SIDPAC)



- SIDPAC is a collection of over 350 programs that implement a wide variety of state-of-the-art methods for aircraft system identification
- SIDPAC programs are implemented as MATLAB® M-files, and have been thoroughly tested and successfully applied to real data
- SIDPAC is used at more than 80 organization worldwide to solve aircraft system identification problems
- SIDPAC documentation is the AIAA textbook *Aircraft System Identification – Theory and Practice*, by V. Klein and E.A. Morelli

What Does SIDPAC Do?

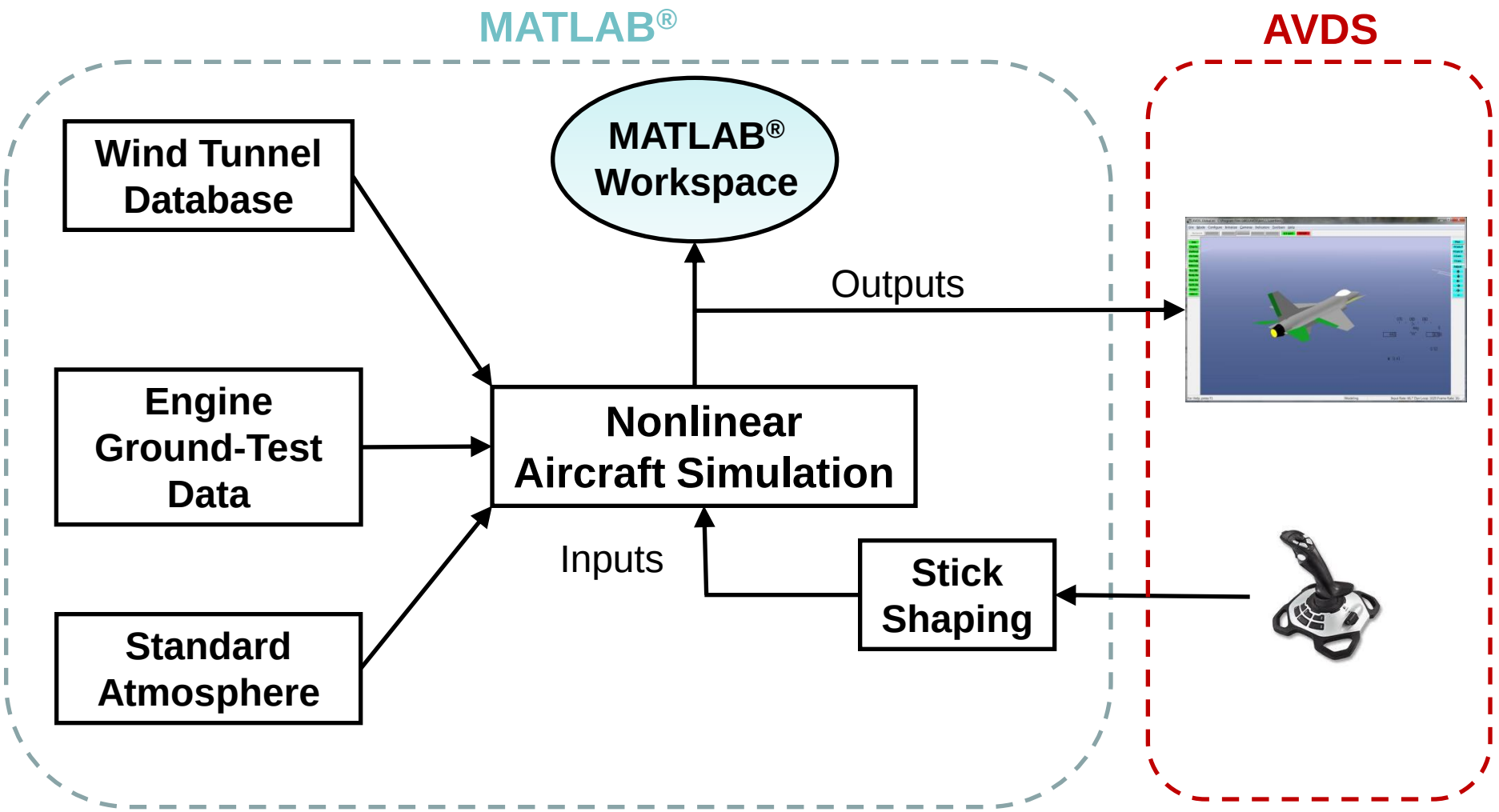
SIDPAC tools help an analyst to:

- **Design experiments**
- **Define instrumentation requirements**
- **Filter, smooth, transform, and visualize the data**
- **Identify math models that mimic the real system**
- **Check model accuracy and predictive capability**
- **Organize, report, and use the results**

SIDPAC Demonstration

F-16 Fighting Falcon

F-16 Nonlinear Simulation



Applications

Twin Otter

X-43A (Hyper-X)

Sub-scale Transport Aircraft

X-29A

Tu-144LL Supersonic Transport

ARES I-X Launch Vehicle

1903 Wright Flyer Replica

Global Hawk

There are many others …

Concluding Remarks

- System Identification can be applied to any system; Gauss, Newton, and Einstein were all outstanding practitioners of System Identification.
- For modern Aircraft System Identification, experiment design, instrumentation system design, understanding data analysis and modeling methods, and the ability to use System Identification software are important for success.
- System Identification is a critical technology for aerospace vehicles throughout their lifetime, from preliminary design, through testing and operations.
- System Identification is a tool for understanding and interacting with the physical world.

References For Further Study

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