A Survey of Statistical Methods in Aeronautical Ground Testing

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Outline

• Background

• Survey of statistical methods in ground testing
  – Wind tunnel testing
  – Wind tunnel characterization
  – Measurement system calibration

• Future Opportunities and Challenges
  – Requirements and training
  – Overcoming cultural inertia
Aerospace Ground Testing

- Refers primarily to wind tunnel testing over a broad range of flight conditions
  - Fight Vehicles: Micro-UAV’s to hypersonic missiles
  - Propulsion: electric propulsion, turbofans to rocket motors

- Importance of Wind Tunnel Experiments
  - Characterize and optimize aerodynamic performance of flight vehicles
  - Validate computational simulations

- A controlled, low-noise environment in comparison to flight test
  - Requires facility calibration and data quality assurance programs
  - Demands highly precise instrumentation design and calibration
Some History

• Productive aerospace ground test facilities were developed at about the same time as Sir Ronald Fisher’s pioneering work in DOE (VDT shown)

• Pratt and Whitney, engine nozzle testing in the 1960’s (Motycka and Snowronek, 1966)

• Introduction of Statistical Engineering to ground test at NASA Langley started in the late 1990’s (Deloach and Hempsch)
Introduction

• Most of the statistical concepts in this talk are not new
  – However, their application to aero ground testing is relatively new

• Historically, academic training of engineers lacked relevant, applicable, courses in statistics and experiment design
  – Most engineers were unaware of industrial, applied statistics

• Engineers are (were) generally trained to ”fear” uncertainty
  – Uncertainty is a problem, a nuisance to be avoided

• Over last 15 years, there are better educational resources, accessible software, and an increasing appreciation for the role of statistical methods in aeronautical research

Statistical methods enable efficient, insightful, data-driven decisions in the presence of uncertainty
Initiatives and Inertia

- AIAA Ground Testing Technical Committee Statistically Defensible Test Methods Focus Group
  - A forum to raise awareness of methods and applications
  - Promote broader application
  - Demonstrate benefits and impact of statistical methods

- Even though training is more accessible and methods are becoming well-known, and well-accepted, application of statistical methods is still not commonplace – it’s not the way we routinely do business
  - Somewhat driven by the notion that our test facilities are so precise, we don’t require specialized statistical methods

- In the research community, there continues to be a pull to defend requested data volume (i.e. test time) to meet research objectives
  - Statistical methods empower data sufficiency arguments
  - Scientific approach to define test size, rather than heuristic
Predominant Statistical Methods

- Design of Experiments (Physical and Computational)
- Response Surface Methodology (Physical and Computational)
- Statistical Process Monitoring, Statistical Quality Control
- Modeling, Regression, Nonparametric
- Uncertainty analysis and propagation
- Simulation, such as Monte Carlo methods

Methods for rigorously understanding factor-response relationships
A Few “Radical” Statistical Concepts

• Experiment Design
  – Starts with precise questions, risks, and consequences
  – Defining an analysis plan before the data are collected
  – Evaluating experiment sufficiency before data are collected

• Factorial Experiments
  – Changing more than one factor at a time, simultaneously
  – Maximizing information acquisition efficiency
  – Providing insights on interactions

• Modeling with Quantified Inference
  – Estimating and isolating random variability
  – More than plotting, subjectively discerning subtle differences

Techniques to efficiently and sequentially learn
Wind Tunnel Testing


Measurement System Characterization


Education and Training Milestones

• Old Dominion University - Center for Experimental Aeronautics
  – Established in 2000, with statistical methods a core component
  – Graduate level, 2-course sequence
    • Design of Experiments and Response Surface Methodology
      – DOE is now a M.S. core course in Mechanical and Aerospace Eng.

• AIAA Short-Courses - Concepts in the Modern Design of Experiments
  – Dick DeLoach, NASA LaRC, founder (now retired)
  – Taught at many conferences, since about 2003
  – Raised awareness within the AIAA community
  – Drew Landman to teach again in 2020
Future Challenges and Opportunities

- Awareness remains a challenge, methods and benefits
  - DWWDLT – Do what we did last time…best efforts
  - Need to encourage leadership to expect more rigorous testing
  - Educating our “new” experimental aerodynamicists
  - Use case study demonstrations of benefits

- Leveraging partnerships
  - At the national level: Academia, Industry, and Government
    - Statistical Engineering Interagency Agreement between NASA and the Director, Operational Test and Evaluation, with Office of the Secretary of Defense (2014)
  - At the local level
    - Include statistical engineering experts in test campaigns
    - Establish go-to experts in statistical engineering for day to day test and analysis needs
      - Successful DOD operational test approach
Challenges in Wind Tunnel Testing

• Restricted randomization
  – Many wind tunnel tests involve Hard-to-Change factors
    • Flow conditions
    • Model configuration changes

• Subspace inference strategies
  – Experiment designs may not be practical over entire domain
  – Subspace division is a logical choice
    • Perceived problems at subspace boundaries

Mars Parachute Testing, NASA LaRC TDT

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