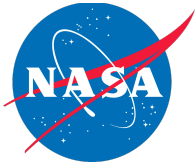


NASA's Statistical Engineering Journey

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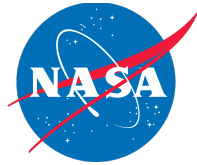
July 28th, 2021
Quality and Productivity Research Conference
Tallahassee, FL



Journey Overview

- **A retrospective look at NASA's journey of introducing and implementing statistical engineering in aeronautics, space exploration, and atmospheric science**
 - **Milestones in technical and organizational impact**
 - **Targeted educational resources**
 - **Methodological contributions**
 - **Growing acceptance by the aerospace community**
- **Our assessment of the current state of practice, celebrating strengths and identifying weaknesses**
- **Propose vital elements to reach our aspired destination of greater awareness, routine application, and broadened technical and organizational impact of statistical engineering within NASA**

Destination: NASA infusing statistical engineering routinely in aerospace research and mission execution



Statistical Engineering Motivation

- **A scalable, teachable, repeatable, approach to accelerate learning, ensure strategic resource investment, inform rigorous decision making, across NASA's missions.**

2008 White Paper

**Infusing Statistical Engineering into Programs and Projects
February 5, 2008**

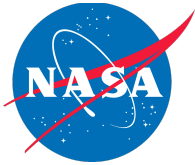
**Prepared by Peter Parker for Chief Engineer, Systems Engineering Directorate,
NASA Langley Research Center**

The purpose of this document is to provide a brief description of an SED-lead initiative to integrate statistical engineering into all levels of program and project management and to outline an implementation plan. Motivating this initiative is the requirement to systematically use the best tools and practices available to achieve the Agency's ambitious mission goals. Statistical engineering represents a mature discipline, used throughout industry for over 50 years, to improve competitiveness and profitability. In other government research agencies, statistical engineering is used to ensure the veracity of national defense systems and international commerce. Currently across the Agency, statistical engineering utilization is sporadic rather than systematic. From years of demonstration projects within the Agency, statistical engineering has proven itself to be a scalable, teachable, and repeatable methodology. Therefore, strategically institutionalizing its practice will improve the Agency's ability to achieve their mission objectives.

So, what's there not to like about it?

- **Historically, statistical engineering concepts and tools were unfamiliar to the aerospace engineering community.**

An Engineer's Statistical Awakening



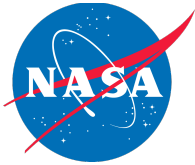
- Traditionally, academic training of engineers lacked relevant, applicable, practical courses in statistics (*that's me*)
 - Engineers are generally trained to “fear” uncertainty
- In 1999, I stumbled upon a 20-year old report from a visiting statistics professor that proposed “radical” ideas and offered significant schedule and cost benefits.

A few “radical” statistical concepts

- Experimental Design starts with questions, not data
- Factorial Experiments are efficient for learning, not chaotic
- Modeling is more than plotting to discern subtle differences

Discovered “new” statistical engineering techniques to efficiently learn and gain deeper insights

Early Significant Demonstration in 2006



Shuttle



Ares I



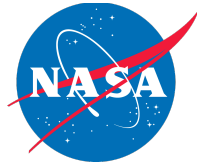
Flight Test



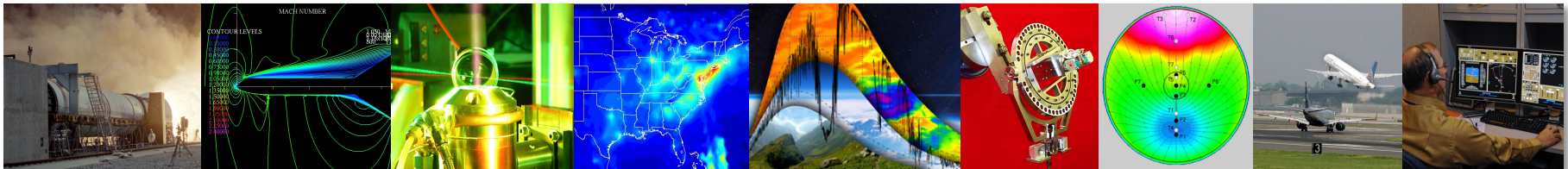
**Full-Scale
Static Firing**



Statistical Engineering Team Formed

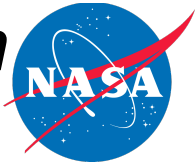


- **Motivated by successful demonstrations with Agency-level recognition and impact**
- **Langley leadership proposed a group to be formed to be an Agency resource and established the first Statistical Engineering Team in NASA in 2008**
- **Crucial elements of successful team formation and growth**
 - **Visionary, multi-level leadership**
 - **Strategic hiring authority**
 - **Consistent demonstration of benefits in applications**
 - **Building external connections DoD and Academia**



NASA Statistical Engineering Symposium

May 2011



- **Unique forum, with senior leaders, discipline experts and practitioners**
- **Keynotes by Director of Operational Test and Evaluation (DOT&E), and Roger Hoerl, GE Global Research**
- **150 attendees, spanning NASA Centers, 4 other government agencies, 5 universities, and industry**

Office of the Secretary of Defense

Los Alamos National Laboratory

NIST

United States Air Force

**National Oceanic and Atmospheric
Administration**

Naval Postgraduate School

Virginia Tech

Arizona State University

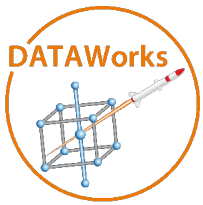
Old Dominion University

University of Virginia

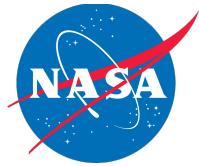
General Electric

Aerospace Corporation

Pratt & Whitney



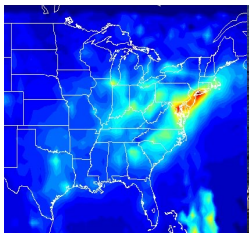
DOT&E / NASA Statistical Engineering Inter-Agency Agreement, est. 2014

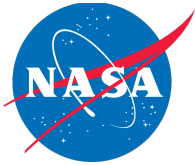


- DoD and NASA develop, acquire, evaluate, and operate some of the world's most advanced and sophisticated systems.
- Partnership to advance and broaden statistical engineering practice, and a catalyst to engage the broader statistical engineering community in industry, academia, and other government agencies.

Key Elements

- Leadership and tactical practitioner collaboration
- Annual meeting - DATAWorks
 - **Defense and Aerospace Test and Analysis Workshop, 5th year**





Embedded Academic Collaboration

Virginia Tech – Geoff Vining, since 2009

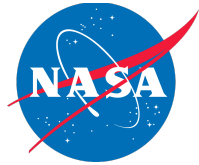
Expected Reliability of Carbon Overwrapped Pressure Vessels at Use Conditions over Expected Mission Life

- DOE for Reliability, with Anne Driscoll
- Inspired 3 PhDs and 2 Post Docs, 9 papers (JQT, QREI, QE)

Virginia Commonwealth – David Edwards, since 2012

Next Generation Air Transportation Systems

- Inspired 1 PhD, 1 MS, 5 papers (JQT, QREI, QE)
- Model specification and confidence intervals for complex voice clearance communication during approach to an airport
- Improving the realism of computer-simulated experiments with aircraft trajectory clustering in fast-time computer simulations
- Space-filling designs for multi-layer nested factors, where the level of one factor affects the range of possible levels for the nested factor.



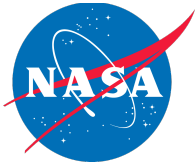
Statistical Interns at NASA Langley

- Marcos Carzolio (VT)
- Anne Driscoll (VT)
- Laura Freeman (VT)
- Rebecca Medlin (VT)
- Austin Rhodes (VT)
- John Szarka (VT)
- Casey Turner (VT)
- Matt Williams (VT)
- Sara Wilson (VT)
- Emily Winfree (VT)
- Michael Beyrodt (ODU)
- Josh Burch (ODU)
- Sean Commo (ODU)
- Tom Johnson (ODU)
- Ken Toro (ODU)
- Joseph Burris (VCU)
- Evan Freitag (VCU)
- Ryan Gryder (VCU)
- Robert Leonard (VCU)
- Stuart Cooke (VCU)
- Jasme Lee (NCSU)
- Doug Stefanski (NCSU)
- Munir Winkel (NCSU)
- Adam Bolton (NCSU)
- Ashraf Almimi (ASU)
- Chris Rigdon (ASU)
- Rachel Silvestrini (ASU)
- Dan Cromartie (Lehigh)
- Jason Corman (GT)
- Kathryn Dugan (W&M)
- Laurel MacMillian (AU)
- Christine Watters (LSU)
- Benjamin Remy (FIT)
- Yu Xuan Huang (CCNY)

34 interns over ~15 years

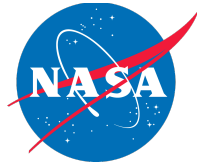
underlined were hired by NASA

Targeted Educational Resources



- **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.
- **American Institute of Aeronautics and Astronautics Short-Courses**
 - Design of Experiments and Response Surface Methods
- **NASA Engineering and Safety Center Academy**
 - Design of Experiments and Regression short-courses

Motivated Methodological Research



- **Restricted randomization in response surface methodology**
- **Advanced reliability engineering design and modeling**
- **Bayesian dose-response modeling for community noise**
- **Space-filling design for multi-layer nested factors**
- **Calibration experiments with multi-dimensional response surfaces**
- **Collaboration, the art and the science**

QUALITY ENGINEERING

<https://doi.org/10.1080/08982112.2018.1530357>



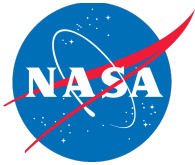
Taylor & Francis
Taylor & Francis Group



Effective interdisciplinary collaboration between statisticians and other subject matter experts

Christine M. Anderson-Cook^a, Lu Lu^b, and Peter A. Parker^c

with 6 Discussants: DeHart and White, Hoerl, Jensen, Litano, Slade, Typhina and Wilson

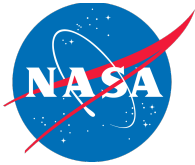


Current State of Practice

- **Statistical engineering has gained recognition and acceptance, and it has demonstrated significant impact, repeatedly**
 - **Acceptance across aerospace disciplines and research areas**
 - **Agency level recognition, contributing to top priority missions**
 - **Demands for statistical engineering expertise are difficult to fulfill**
 - **Difficult to attract and hire statistical engineers**
- **NASA has a distributed cadre of practitioners with their training ranging from short-courses to graduate degrees**
 - **Distributed across the Agency**
 - **NASA Engineering Safety Center Statistical Engineering Team**
 - **Lack a vibrant core team to sustain and grow the capability**

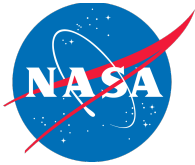
Acceptance, recognition, impact, and demand have broadened over the past 15 years, and the discipline is stable, but there's more to do...

Vital Elements to Reach our Destination

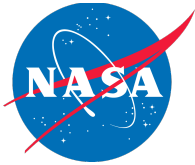


- **Leadership Team**
 - Capability must be understood and appreciated
 - Understand what it offers to seek opportunities to grow impact
 - Appreciated as a discipline, highlighted, and rewarded
- **Statistical Engineering Discipline Team**
 - Core group charged to sustain, nurture, and grow the capability strategically and ensure technical excellence and best practices
- **Training to institutionalize**
 - Tiered training approach ranging in depth and breadth
 - Internally developed training, simultaneously leveraging external resources in academia and partner agencies

External Collaboration is Critical



- **International Statistical Engineering Association (ISEA)**
isea-change.org
 - **Mission: To be the voice for statistical engineering, serving as a catalyst to drive sustainable results and impact by integrating multiple disciplines through the scientific method**
- **ASA Section in Defense and National Security (SDNS)**
 - **Maybe an opportunity to more formally include aerospace**
- **Other government entities**, leveraging and benchmarking their journey
 - **Director, Operational Test and Evaluation, Interagency Agreement**
 - **Institute for Defense Analyses, Test Science Team**
 - **Statistical Sciences Group at the US Army Combat Capabilities Development Armaments Center at Picatinny Arsenal, NJ**



Concluding Remarks

We hope you've gained an appreciation of NASA's Statistical Engineering journey over the past 20+ years

- **Discipline was unknown, rejected, accepted, and now sought after**
- **NASA Langley has been an Agency leader in introducing the discipline, building academic relationships and external collaboration**
- **Our vision is to grow from few highly-skilled practitioners to broader workforce practice, going from limited applications to ubiquitous implementation**
- **Vital elements include leadership team, discipline team, training development, and external collaboration**
- **State of the discipline within NASA is stable and growing slowly, but we have not reached our destination**

Destination: NASA infusing statistical engineering as a routine part of aerospace research and mission execution