Leading-Edge Experiment Design for Aerospace

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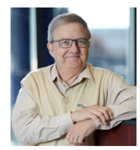
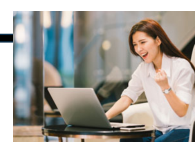


"One test is worth a thousand expert opinions." - Tex Johnston, Boeing

Maximizing this educational opportunity



Welcome everyone! To make the most from this webinar:

- Attendees on mute
- Chat addressed afterward
- Send further questions to mark@statease.com

PS: Presentation posted to www.statease.com/webinars/

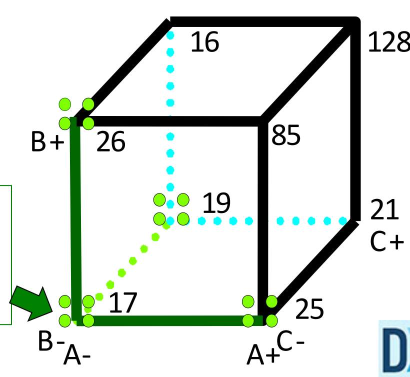
Please press the raise-hand button if you are with me.

- Multiple versus one factor at a time testing
- Aerospace case studies by design type:
  - ✓ Factorial (split plot): Paper helicopter
  - ✓ Response surface: Jet-fighter wing
  - ✓ Response surface (split plot): Flap design
  - ✓ Mixture & categorical: Composite material
- Conclusion

Multi-Factorial (VS OFAT)

Bearing life in hours from accelerated test

Start point for One Factor at a Time (OFAT). Goal: 40 hours.



Relative efficiency = 16/8

⇨ 2 to 1!

Bearings
Rebuld with d/s 40/15 & analyze.
Do 2nd model w log transform.

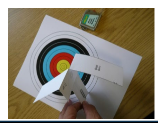
*The rest of the story**
DOE Saves the Company

Swedish SKF, inventors of the rolling bearing (1919), nearly went of business in the 1970's due to Japanese competition. Led by Christer Hellstrand, they abandoned one factor at a time (OFAT) for multifactor DOE. As a result, SKF improved bearing life ten-fold from 41 million to 400 million revolutions at reduced cost.**

"Christer showed them how they could test two additional factors 'for free' – without increasing the number of runs and without reducing the accuracy of their estimate of the cage effect."
-George Box, *Improving Almost Anything: Ideas and Essays*

*("Breaking the Boundaries," *Design Engineering*, Feb 2000, pp 37-38.)
**(US Patent 4227754 www.freepatentsonline.com/4227754.pdf)

Factorial (Split Plot):
Paper Helicopter



Inspired by news of a supreme paper—Conqueror CX22—made into an airplane that broke the Guinness World Record™ for greatest distance flown*, Stat-Ease engineers tested the following factors—the first four (all manufacturing related) being hard to change (HTC) and the other two easy to change (ETC):

a. Paper: 24# Navigator (standard) vs 26.6# CX22 (supreme)
b. Wing Length: Short vs Long
c. Body Length: Short vs Long
d. Body Width: Narrow vs Wide
E. Clip: Off vs On
F. Drop: Bottom vs Top


Copter

*("The Perfect Paper Airplane," *Mental Floss*, January 14, 2014. See the details, a video of the awesome flight and how to build a similar aircraft at www.mentalfloss.com/article/54488/perfect-paper-airplane.)

Response Surface
*Jet-Fighter Wing**

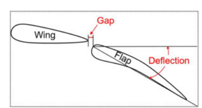
Via a faced-centered central composite design (FCD), NASA Langley engineers assessed a new active-aeroelastic wing technology. The response—wing weight—came from a physics-based finite-element-analysis simulator. They varied these three factors (all ratios):

A. Aspect: 3–5
B. Taper: 0.2–0.4
C. Thickness: 0.03–0.06

Wing
(w & w/o transform)

*(*RSM Simplified, Optimizing Processes Using Response Surface Methods for Design of Experiments, 2nd Ed*, Anderson & Whitcomb, 2016, Table 10.4)

Response Surface (split plot):
*Jet-Fighter Wing**



A wind tunnel experiment on an aircraft flap investigated the following hard to change (HTC)—requiring changeover of the test chamber—and easy to change (ETC) configurations affecting lift:

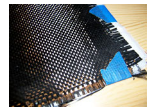
a. Gap
b. Deflection angle
C. Angle-of-attack
D. Reynold's number

They deployed a central composite design to accomplish their mission.

Airfoil tutorial data
Change color gradient to -400 to +200

*(Kowalski, Parker, & Vining, "Tutorial: Industrial Split-plot Experiments" *Quality Engineering*, V1, #19, 2007)

Mixture & categorical
*Composite Material**



Aerospace engineers aimed to maximize the impact and tensile strength of an epoxy-fiber composite by varying the materials as follows:

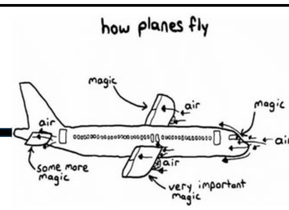
A. Elastomer, 5-20% (two types—Factor E)
B. Fiber, 54-62% (three types—Factor F)
*C. Hardener, 0-100%***
*D. Epoxy resin, 0-100%***

***Epoxy/hardener (C/D): 1.8-2.1 (<u>multicomponent ratio constraint</u>)*

Composite
Rebuild to show ratio constraint & KCV
Max impact (100-140) & tensile (1200-1400)

*(Mixture Design for Optimal Formulation workshop, Stat-Ease, 2020, Section 7.)

Conclusions
It's not magic!



Via a series of case studies, this webinar demonstrated multifactor testing tools for aerospace R&D.

It showed how Design-Expert empowers experimenters to quickly converge on the "sweet" spot—factor settings that meet all specifications.

Engineers and scientists working in the aircraft, space and defense industries will do well by applying design of experiments for screening and characterization, response surface methods for optimization (e.g., wing design), and mixture design for optimal formulation (e.g., composites).

Stat-Ease Webinars

[DOE Crash Course for Experimenters](#)

Step up your design of experiments (DOE) via this essential briefing that demonstrates how this multifactor method accelerates R&D.

[New-User Intro to Design-Expert® Software](#)

See how DX makes DOE easy, starting with factorial design, the core tool for DOE, followed by a peek at response surface methods (RSM) for process optimization and last, but not least, a look into mixture design for optimal formulation.

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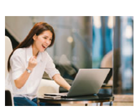

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