

# HOW TO INCREASE DESIGN OF EXPERIMENT SUCCESS

COLLINS AEROSPACE

Analytical Solutions Conference  
20 June 2019

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# AGENDA

## Section 1: Welcome

- Introduction and Background
- Objective

## Section 2: Stories

- Total Air Temperature Heater Power
- De-icing Heater Power Test
- Battery Fill
- Pre-qualification Failure

## Section 3: Tips

- Set Up
- Execution
- Analysis
- Confirmation / Validation



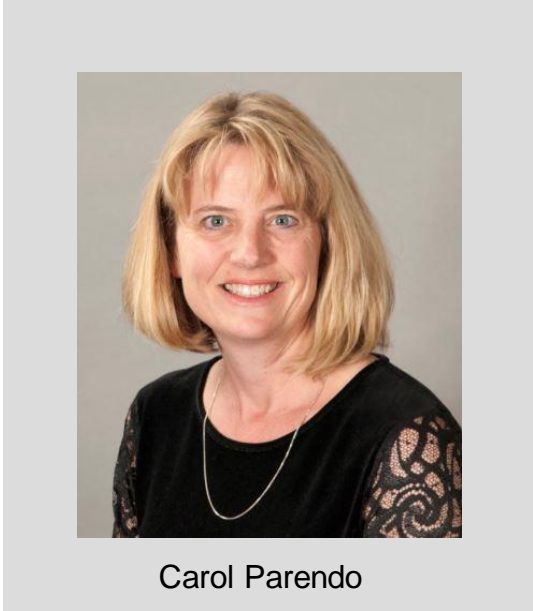
**SUBJECT MATTER EXPERT**

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# WELCOME

## SECTION 1

# INTRODUCTION



30 YEARS OF EXPERIENCE

SPECIAL EXPERTISE:

- MN Site Lead for Reliability and Statistics
- Industry Level Statistics Educator
- Diverse engineering background in the practical application of statistics

WHY I AM SPEAKING

To share my experiences in the practical application of Design of Experiments to help increase others success.

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# OBJECTIVE

In this session, we will look beyond the math and delve into several tips for successful Design of Experiments (DOE) execution. The speaker will share her real life stories in order to bring these tips to life. Through these stories, you will understand that these tips may make all the difference between completing a DOE and having DOE results that are impactful. Learn these tips and you will be more impactful with your DOEs.

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# DOE STORIES

## SECTION 2

# CREATIVE SOLUTIONS TO MEET BUDGET

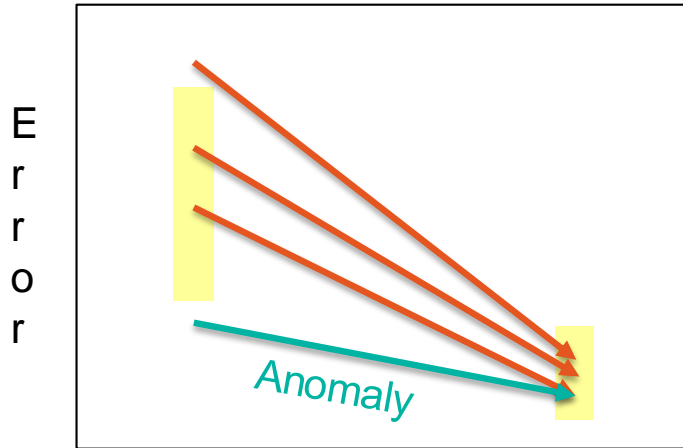


Total Air Temp, Heater Power

- ✓ GRR and test system improvement first
- ✓ Use of technically equivalent parts
- ✓ Consult subject matter experts
- ✓ Account for material lots as appropriate (change or constant)
- ✓ Held in-process variables constant
- ✓ Additional in-process responses
- ✓ Implement and monitor



# INVESTIGATING AN ANOMALY WAS KEY



Flow Rate

De-icing Heater Error Test

- ✓ Recognized a favorable anomaly in an alternative measurement relationship (i.e. slope)
- ✓ Investigated cause of anomaly and used that for the basis of the DOE
- ✓ Factors high and low levels far apart
- ✓ Variability held constant with interchangeable assemblies
- ✓ Measured responses 3 times and averaged to reduce measurement variability
- ✓ Measured other dependent responses
- ✓ Analyzed with log transformation

# TECHNICAL EXPERTISE GUIDES RCCA / DOE



Battery Fill

- ✓ Advantage of high volume and SPC charts (special cause and common cause)
- ✓ Initial improvements guided by SPC charts and subject matter expertise
- ✓ Added pressure measurements to gain additional information
- ✓ Chose first DOE run with the most challenging setting to refine level
- ✓ Accounted for process effect where current run is affected by previous run
- ✓ DOE determined machine setting relationships (nominal and adjust)
- ✓ Validation with SPC charts

# REDUCE SCOPE WITH PHYSICS-BASED EVIDENCE



Wire Open

Pre-qualification Failure

- ✓ No overarching fishbone. Evaluated all evidence (test, non-destructive, destructive) to gain insight into specifics of the failure mechanism, thus narrowing factors.
- ✓ New configuration options in DOE along with step stress testing
- ✓ Creatively shift measures from categorical / discrete to continuous
- ✓ Measure non-destructively (CT scan) before test, at points within the test, and at the end of test
- ✓ Evaluate destructively at the end of test for signs of degradation

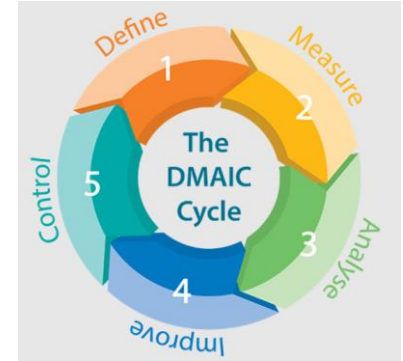
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# TIPS

## SECTION 3

# SET UP TIPS

1. First consider pre-work (GRR, low hanging fruit, pre-evaluate)
2. Determine the DOE objective which may be a sub-set of the problem
3. Always incorporate subject matter expertise
4. Budget and schedule considerations
5. Be prepared to augment (fold over, replicate, or follow-up experiment)
6. Find the sweet spot for number of factors and high and low levels
7. Consider additional responses and repeated measurements
8. Determine approach to natural variation (as-is and record, fix)
9. Random run order alterations
10. Easy documentation with a location for comments
11. Communication



Objective



# EXECUTION TIPS

Seven

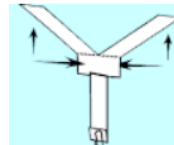
Eight factors in sixteen runs:  $2^{7-3}$

Random Order	Standard Order	A Paper Type	B Wing Length	C Body Length	D Body Width	E Paper Clip	F Fold Fuselage	G Taped Body	Average Time	Optional: 1.0/Avg Time
11	1	-	-	-	-	-	-	-	5.23, 4.48	Added comments for quality of flight
2	2	+	-	-	-	+	-	+	2.75, 3.35	
5	3	-	+	-	-	+	+	-	6.59, 5.45	
7	4	+	+	-	-	-	+	+	3.97, 3.93	
12	5	-	-	+	-	+	+	+	4.59, 3.30	
14	6	+	-	+	-	-	+	-	3.53, 3.10	Optimized launching hold.
3	7	-	+	+	-	-	-	+	5.75, 4.20	
15	8	+	+	+	-	+	-	-	4.34, 3.7	
17	9	-	-	-	+	-	+	+	4.95, 4.92	
16	10	+	-	-	+	+	+	-	2.97, 3.48	
13	11	-	+	-	+	+	-	+	5.64, 5.36	
6	12	+	+	-	+	-	-	-	3.81, 3.05	
1	13	-	-	+	+	+	-	-	4.07, 4.04	
8	14	+	-	+	+	-	-	+	4.03, 3.48	
9	15	-	+	+	+	-	+	-	5.63, 4.57	
12	16	+	+	+	+	+	+	+	3.56, 4.36	

-- 20 -- 3 -- 3 -- 1.25 -- No -- No -- No  
 += 60 += 4.75 += 4.75 += 2.00 += Yes += Yes += Yes

\*S = side wings

AC = BE = BG  
 AE = BC = DF



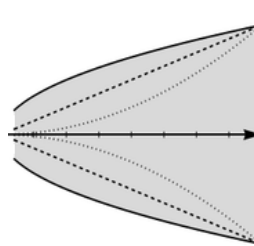
-3.4-  
 all good ones A = - E = -

Record, record, record... Similar to running qual.

1. Be available for the experiment.
2. Leave space for comments and encourage comments.
3. Observe the experiment for additional factors or special causes.
4. Order your runs so any risky run is first.
5. Check that the responses are realistic.
6. Check that you are seeing differences.
7. Repeat readings for accuracy if desired.
8. Consider pre, mid, and post measurements.

# ANALYSIS TIPS

1. If analysis has issues, check for typos, anomaly (in part, process, or test, run order vs. std order). Don't just delete the offending run!
2. Understand your aliasing.
3. Always perform residual analysis.
4. Consider transformations especially when large differences in responses.
5. Compare models.



“Megaphone”

## Clues for Non-normal Data in a DOE

- Residuals (Verses Fits plot, likely “megaphone” shape)
- Data range is large (max/min > 10 then likely, max/min < 3 then unlikely)
- Supported by data type (response is typically skewed, bounded, counts, etc.)
- Possible outlier issues without transformation

# CONFIRMATION / VALIDATION

Once experiment iterations are complete, perform confirmation / validation before any sweeping claims of having the answer.

## Confirmation Options:

- Per Collins RCCA recommendations, turn on and off the issue.
- Run a minimum of 3 runs at the improved factor levels in a production environment if possible.
- If low risk, implement and track performance with SPC. Fine tune after obtaining additional SPC data.

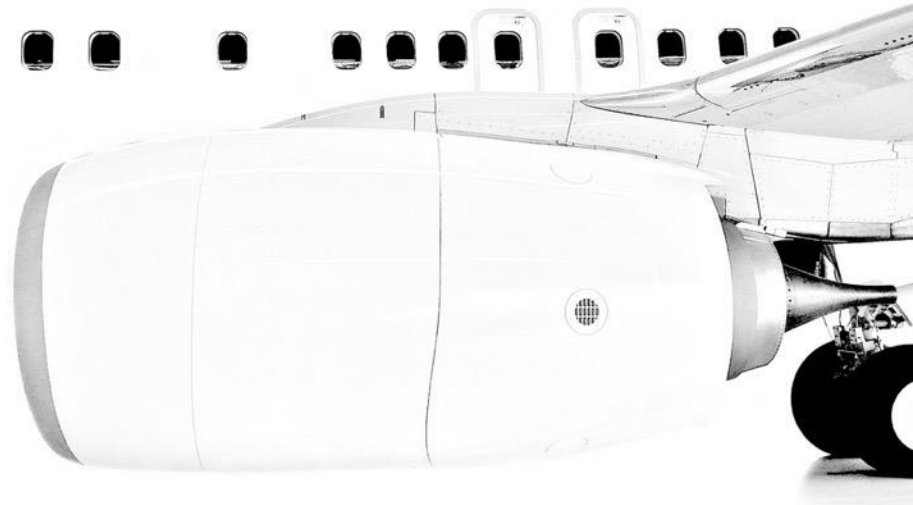
## Results Not As Expected?

- Check what else has changed. For example, a difference in the lab environment to a production environment, lot changes, etc.
- Revisit your analysis including any “grey areas” and verify your model and predicted values are correct.



# QUESTIONS?

NOW IS THE TIME TO ASK!





THANK YOU.

For additional follow-up,  
please contact me at:

[Carol.Parendo@Collins.com](mailto:Carol.Parendo@Collins.com)

651-681-5877