24th Annual NDIA Test and Evaluation Conference
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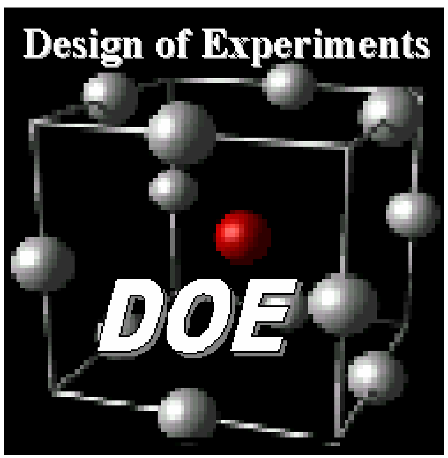
Applying Design of Experiments (DOE) methodology to Sortie Generation Rate (SGR) Evaluation



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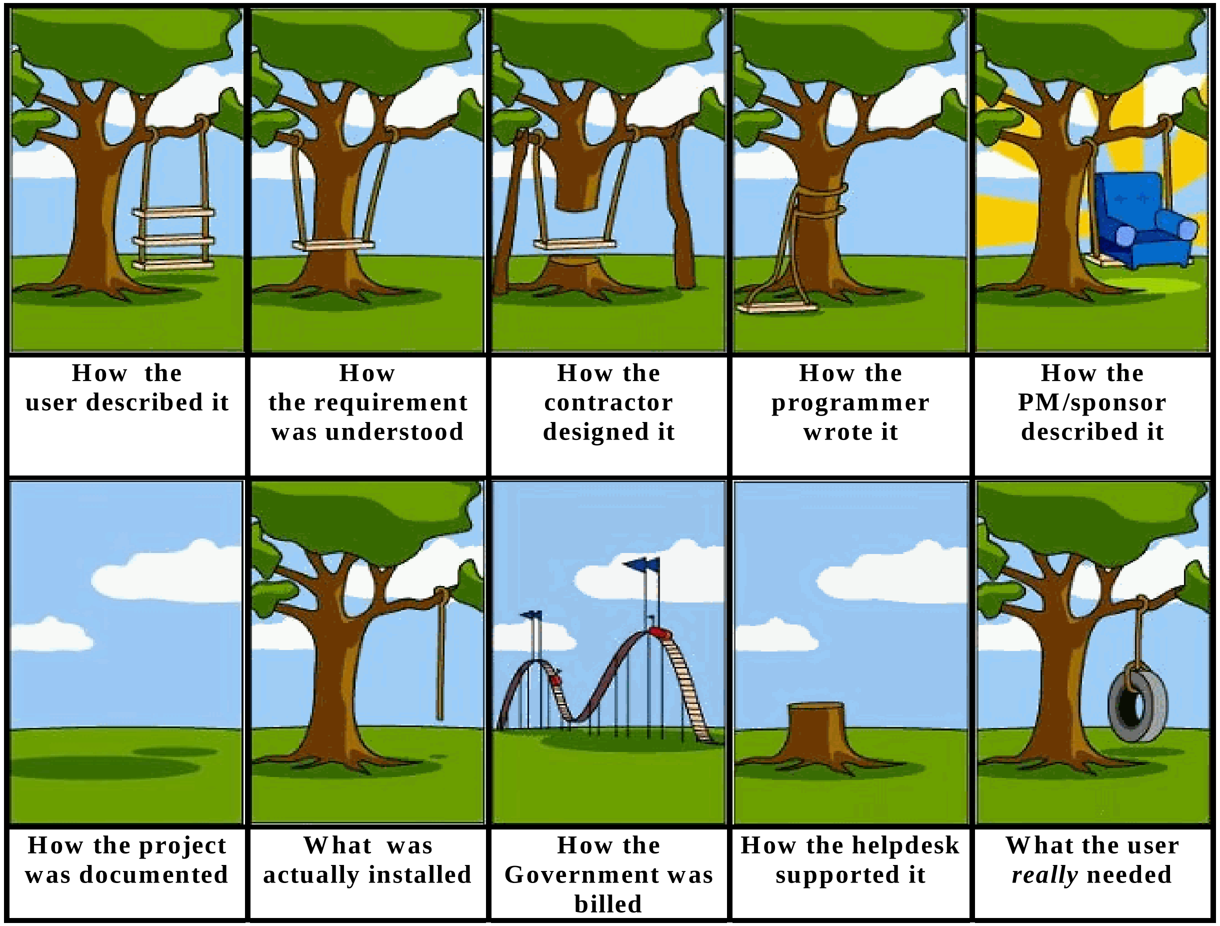
Agenda

- Introduction
  - Acquisition humor
  - The Integrated T&E Challenge
- Intro to Design of Experiments
- SGR Assessment Methodology
  - Overview of SGR Assessment to date
  - SGR Assessment objectives, MOEs, factors
  - SGR Testbed Assessment Design Factors / Run Matrix
  - SGR Live Testing Validation
- Benefits of DOE over single scenario based analysis
- Conclusion / Q&A

NOTE: My remarks are intended to spur thought on improving how we as testers can do business better to support the warfighter. While I hope this aligns well with DoD and Services T&E initiatives, I am not representing any government agencies' official position.

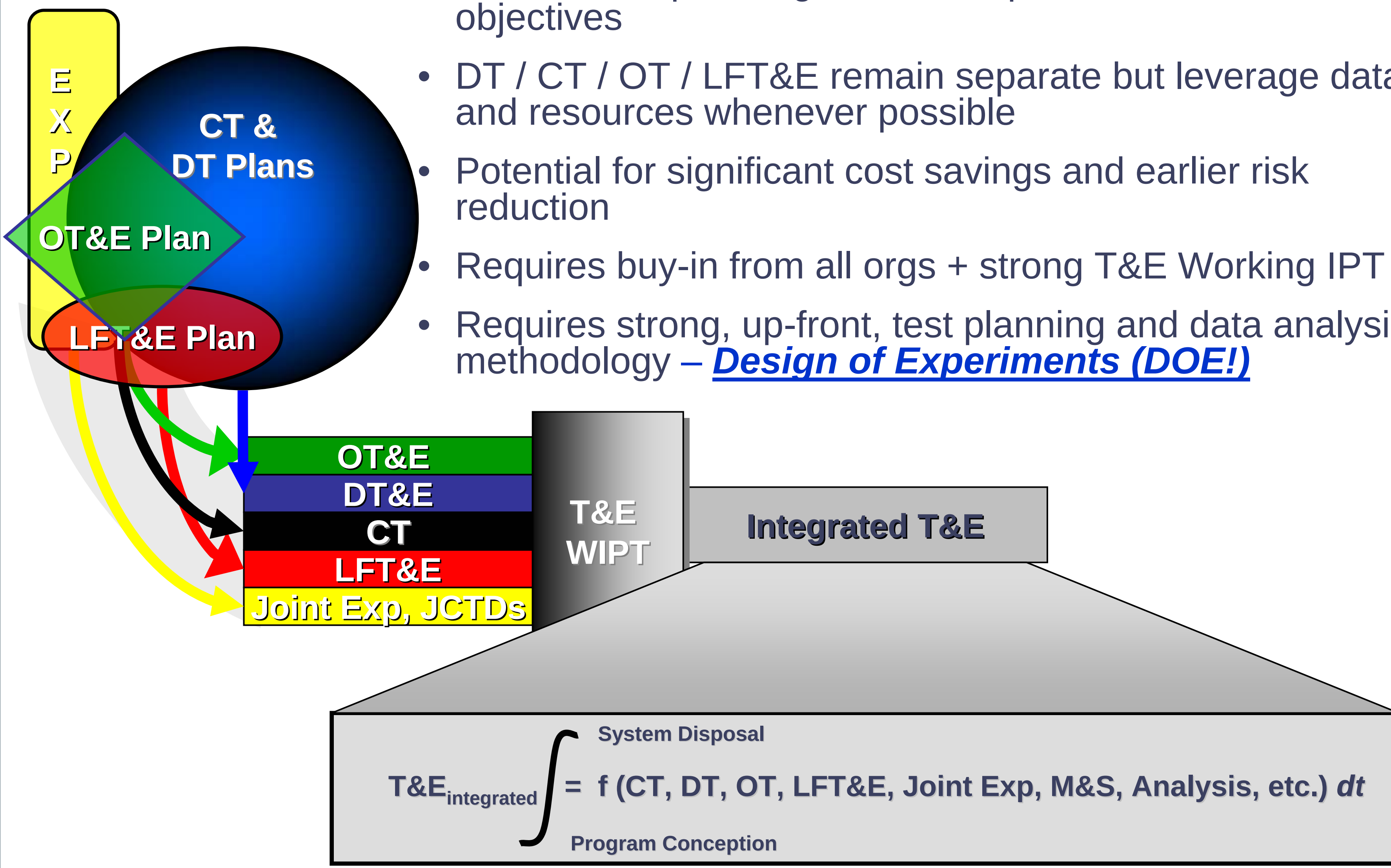
Acquisition 101?



How do we avoid this?

Integrated T&E Challenge

- Coordinated planning and development of individual test objectives
- DT / CT / OT / LFT&E remain separate but leverage data and resources whenever possible
- Potential for significant cost savings and earlier risk reduction
- Requires buy-in from all orgs + strong T&E Working IPT
- Requires strong, up-front, test planning and data analysis methodology – ***Design of Experiments (DOE!)***



Intro to DOE

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Background of DOE

- DOE originated in the field of agricultural studies in the 1930s by R. Fisher, building on W.T. Gossett’s work at Guinness Brewery—Brilliant!
- Used throughout industry in industrial experiments, process improvement, statistical process control
- USAF has significant experience in use of DOE across numerous programs; Navy is beginning to implement
- DOE methodology is used to interrogate a process, improve knowledge of how the process works, and identify factors and interactions affecting variability of performance outcomes.

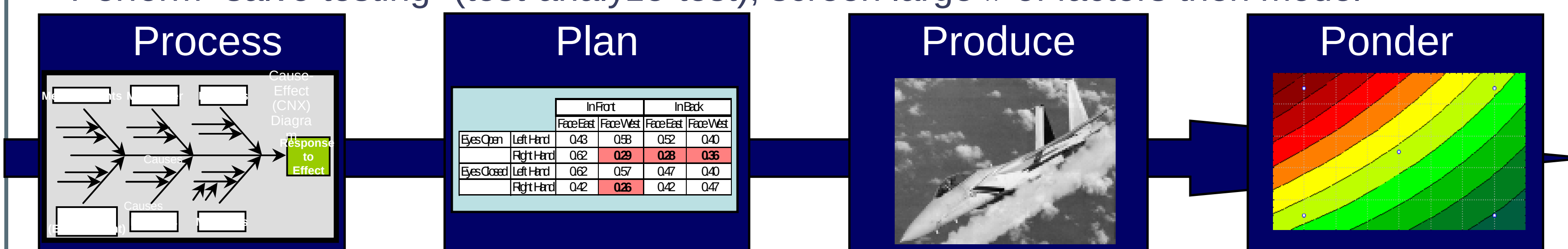
DOE Process Goal / Benefits

- Compared to other systematic methods DOE designs:

  - Yield better process understanding
  - Can be planned and analyzed faster
  - Cheaper – using between 20-80% of usual runs/tests/resources
  - Better exploration across range of performance—depth and breadth of testing
  - Challenge assumptions and demonstrate real performance
  - Better way to design and test complex systems

DOE Process Outline—
4 Basic Steps

- **Project description and decomposition**
  - Problem statement and objective of experiment (test)
  - Response variables, and potential causal variables – Ishikawa fish bone.
- **Plan test matrix**
  - Determine constraints, prioritize factors, and select statistical design (2^K vs. 3^K vs. mixed, Taguchi vs. classical arrays, full vs. fractional, non-linear effects?, replications?, blocking?)
  - Write the test plan with sample matrices, profiles, and sample output; run sample analysis.
- **Produce observations** –random run order & blocked against unknown effects
  - Block runs to guard against uncontrollable unknown effects as needed.
- **Ponder the results**
  - Analyze and project data; draw conclusions, redesign test as necessary and assess results.
  - Perform “salvo testing” (test-analyze-test); screen large # of factors then model



		In Front		In Back	
		Face East	Face West	Face East	Face West
Eyes Open	Left Hand	0.43	0.58	0.52	0.40
	Right Hand	0.62	**0.29**	**0.28**	**0.36**
Eyes Closed	Left Hand	0.62	0.57	0.47	0.40
	Right Hand	0.42	**0.26**	0.42	0.47

SGR Assessment Methodology

SGR Assessment Requirements

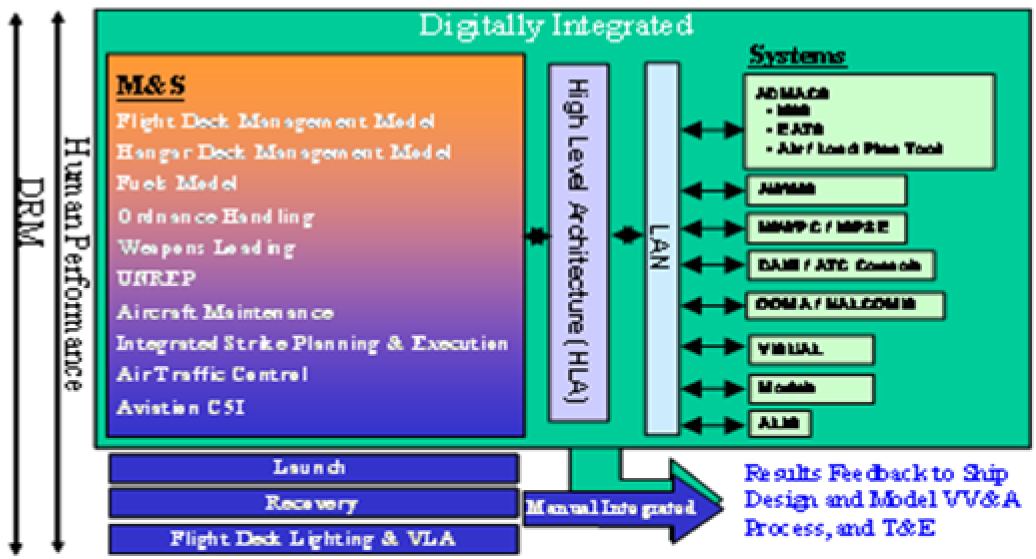
- **SGR Key Performance Parameter**

	THRESHOLD	OBJECTIVE
Sustained SGR	Average of 160 operational combat equivalent aircraft sorties in 12 hours of launching per day over 30 days (26 Flying and 4 Non-Flying Days as specified in the Design Reference Mission (DRM) – total cycle of 4160.	Average of 220 operational combat equivalent aircraft sorties with 12 hours of launching per day sustained over 30 days (26 Flying and 4 Non-Flying Days as specified in the DRM) – total cycle of 5720.
Surge SGR (requires crew augment)	Average of 270 operational combat equivalent aircraft sorties generated during each successive 24-hour period over 4 continuous days.	Surge: average of 310 operational combat equivalent aircraft sorties generated during each successive 24-hour period over 4 continuous days.

- **Other Measures of Performance:** cycle times, task timing, launch and recovery cycles, resource usage, crew fatigue levels, fuel states/rates, etc.

SGR Assessment Testbed

- M&S testbed captures times and actions associated with preparing, launching, and recovering sorties per the DRM



- M&S matured and validated over time prior to runs for score
- Live test used for validation once ship is delivered and aviation certified

SGR Model

SGR is a function of

- Launch Cycle/Interval Timing
- Recovery Times/Intervals
- Mission Planning Timing
- Aircraft Recovery Time Which Encompasses:
  - Fueling Time
  - Ordnance Handling Times
  - Aircraft Movement/Spotting Times On The Flight Deck
  - Aircraft Movement/Spotting Times In The Hangar Bay
  - Aircraft Availability

SGR Assessment Analysis Objectives

- Determine average SGR over DRM to meet KPP requirement
- Determine active factors influencing the variability & overall outcome
  - Measure % sorties completion rather than binomial pass/fail
  - Each day in the DRM treated as a single design point due to interdependencies of events within that day
- Provide the fleet with an analytical model showing probability of meeting a given airplan based on its size, mission composition, environment, and any other active factors

$$\%Airplan\_Sorties\_Completed = \frac{Daily\_sorties\_completed\_succesfull\,y}{Airplan\_sorties} x100\%$$

  - Allows equal comparison of the 4 T/O surge/sustained requirements across all factors
  - Continuous dependent variable provides more statistical power than pass/fail
  - Supports more robust assessment of capes and lims

SGR Factor Selection

Experimental control factors:

- Environmental
  - Sea/Winds: state 1 vs. 3
  - Visibility/Sky Cover: Clear Skies (Case I) or Cloudy/Night (Case III)
  - Time of day: midday or midnight (for 12 hour ops, N/A for 24 hour ops)
- Systems:
  - Availability: 100% & actual (for CVN-21 systems and aircraft)—allows for analysis of impact of equipment failures
- Mission
  - Sortie Size: Threshold & Objective levels from the DRM
  - Sustained and Surge Mission (12 vs. 24 hr ops (with augmented crew))
  - Operation day: early and late in ship on-station operational period; expect to interact with availability for system failures and also translates to possible crew fatigue
  - Airplan mission mix: early/late DRM days representing different ordnance mix;
  - Mission mix and operation day

SGR Factor Selection (cont’)

Controllable Factors held constant:

- Underway Replenishment
  - Not a factor of SGR but presumed to occur on assigned days or fuel and ordnance will not be available for the planned flight days)
- Aircrew augmentation
  - Confounded with mission type – assumed normal crew for sustained operations and augmented crew for surge missions

Measurable Noise Factors

- Other environmental factors not controlled (if in test / model)
  - Temperature extremes
- Specific metrics in the subordinate models driven by the main inputs, such as:
  - Crew fatigue (driven by the mission day)
  - Resource availability
  - Number of aircraft available
  - Weapon skids available
  - Timing for critical tasks, etc.

SGR Factor Selection (cont')

- Design factors:
  - Factors with highest expected influence listed first
    - Important when setting up fractional factorial matrices—usually easier to resolve factors and interactions
  - Setup for M&S only; cannot test all of these in live testing
  - Requires M&S improvements
  - Need buy-in for "excursions" above threshold
    - High levels force the "system" towards a higher failure rate to see more variation in response

Setting Factor		**(Low) -1**	**(Center Point) 0**	**(High) +1**
A	Surge/ Sustained Operations	Sustained (12 Hr ops)	N/A	Surge (24 Hr ops w/augment)
B	Sortie Size (T/O)	Thres-hold	Halfway btwn	Objective
C	operational day	Early (1/4 or 5/30)	Mid (2/4 or 15/30)	Late (4/4 or 26/30)
D	Availability	100%	Halfway btwn	actual/ spec
E	Visibility/ Cloud Cover:	Clear/ Case I	Partly Cloudy/ Case II?	Cloudy/ Case III
F	Seakeeping motion effects	5 kts/SS1	12 kts/SS2	20 kts/SS 3
G	Time of day	Day	Dusk?	Night
H	Mission Day	Early	Mid	late

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SGR Testbed Run Assessment Design

- Full factorial requires 2^8 or 256 runs
  - *Unnecessary since many effects are inactive*
- Resulting test matrix is a resolution IV 2^{8-4} fractional factorial of 16 runs + 8 additional runs for central composite design
  - *Some interactions are confounded but can be resolved*
- Model DRM days per the assigned settings and evaluate SGR Compl %
- “salvo test”:
  - Runs 1-8, then analyze for effects
  - Runs 9-16, then reanalyze for effects
  - Perform center points to check for linearity
  - If necessary, run CCD (face points) for non-linear effects

Run		Blk	A	B	C	D	E = ABD	F= ACD	G= BCD	H= ABC
1	Factorial	1	-1	-1	-1	-1	-1	-1	-1	-1
2	Factorial	1	-1	-1	-1	+1	+1	+1	+1	-1
3	Factorial	1	-1	-1	+1	-1	-1	+1	+1	+1
4	Factorial	1	-1	-1	+1	+1	+1	-1	-1	+1
5	Factorial	1	-1	+1	-1	-1	+1	-1	+1	+1
6	Factorial	1	-1	+1	-1	+1	-1	+1	-1	+1
7	Factorial	1	-1	+1	+1	-1	+1	+1	-1	-1
8	Factorial	1	-1	+1	+1	+1	-1	-1	+1	-1
9	Factorial	2	+1	-1	-1	-1	+1	+1	-1	+1
10	Factorial	2	+1	-1	-1	+1	-1	-1	+1	+1
11	Factorial	2	+1	-1	+1	-1	+1	-1	+1	-1
12	Factorial	2	+1	-1	+1	+1	-1	+1	-1	-1
13	Factorial	2	+1	+1	-1	-1	-1	+1	+1	-1
14	Factorial	2	+1	+1	-1	+1	+1	-1	-1	-1
15	Factorial	2	+1	+1	+1	-1	-1	-1	-1	+1
16	Factorial	2	+1	+1	+1	+1	+1	+1	+1	+1
17	Center rep 1	3	-1	0	0	0	0	0	0	0
18	Center rep 2	3	-1	0	0	0	0	0	0	0
19	cd face point –b	4	-1	-1	0	0	0	0	0	0
20	cd face point +b	4	-1	+1	0	0	0	0	0	0
21	bd face point –c	4	-1	0	-1	0	0	0	0	0
22	bd face point +c	4	-1	0	+1	0	0	0	0	0
23	bc face point –d	4	-1	0	0	-1	0	0	0	0
24	bc face point +d	4	-1	0	0	+1	0	0	0	0

SGR Live Testing Validation Test Design

- Live test conditions and cost (potentially $100M?) limit amount of live test and the conditions
- Focus on validating specific test points of interest and confirm within the M&S runs for score

Factor		-1	0	+1	Rationale
A	Surge/ Sust. Ops	**Sustained**	N/A	**Surge**	Both operations can be run
B	Sortie Size (T/O)	**Threshold**	**(T+ O)/ 2**	**Objective**	A mix of sortie sizes can be run
C	Operational day	**Early**	Mid	Late	No means of imposing a late day due to cost
D	CVN-21/A/C Ao	100%	Halfway	**Actual**	Actual equipment Ao
E	Cloud Cover	**Actual conditions?**			
F	Sea-State	**Actual conditions?**			
G	Time of day	**Actual conditions?**			
H	DRM Mission mix	**Early**	**Mid**	**Late**	Factor is probably inactive so randomly assign

SGR Live Testing Validation Test Design (cont')

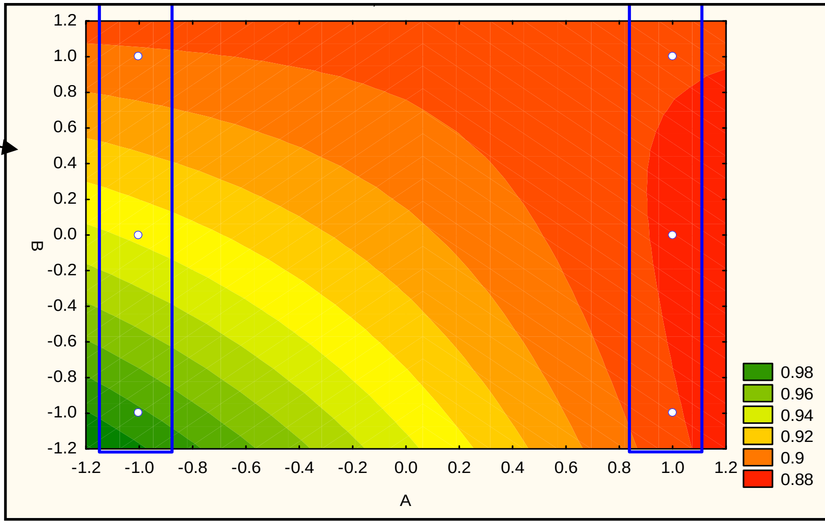
- Final Test Matrix with settings:

Test Case	**A: Ops Type**	**B: Sortie Level**	*Actual (# Sorties)*	**H: DRM Mission Day**	**Notes**
1	Sustained	Threshold	*160*	5	**Priority**
2	Sustained	Objective	*220*	26	**Priority**
3	Surge	Threshold	*270*	26	**Priority**
4	Surge	Objective	*310*	5	**Priority**
5	Sustained	Halfway btwn	*190*	15	Additional run for midpoint
6	Surge	Halfway btwn	*290*	15	Additional run for midpoint
7	Sustained	Threshold	*160*	26	Additional run for alternate mission mix
8	Sustained	Objective	*220*	5	Additional run for alternate mission mix

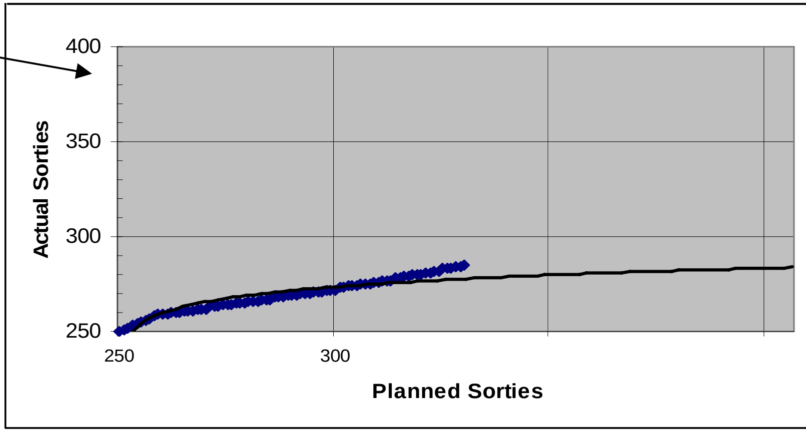
- Recommend run during Joint Task Force Exercise to ensure combat ready crew & systems
- Some analysis of variance can be run directly but main objective is to compare day for day with M&S results (including V&V of lower level measures within the specific process models)
- Runs 1-4 are priority; select additional runs based on M&S results

SGR Testbed Assessment
Sample Data Analysis

- Response surface plot across factors of interest showing response & interactions



- Table of plan vs. predicted actual SGR Completion Rate for factor settings of interest -- shows SGR completion % falling off as too many are sequenced



- ***demonstrates how analysis can describe ship caps & lims, not just a pass/fail grade for a KPP tested only to threshold***

Benefits of DOE

CONCLUSION

- **DOE methodology:**
  - –*may significantly* ***reduce the required runs*** *for Testbed Assessment and live test validation while...*
  - –*providing a* ***more robust process*** *for statistical analysis of variance to determine where the ship design can and cannot support a given air-plan under the other conditions*
  - –*supports robust & efficient* ***integration of M&S development, testing, VV&A, & evaluation***

- **DOE is:**
  - –***a smarter way of doing testing***
  - –***can provides superior knowledge to the systems engineers***
  - –***something all testers & systems engineers should become familiar with!***
- **QUESTIONS?**