Design of Experiments
The Science of *Test*

Wanted: A Star Trek Transporter

presented to:

StatEase DOE Summit

Oct 6, 2022

Greg Hutto, Chief Ops Analyst - 96 Ops Group, Eglin AFB, Florida gregory.hutto@us.af.mil

Short Bio

Mr. Gregory Hutto is Wing Operations Analyst for the 96th Test Wing, responsible for embedding designed experiments as the principal test method for several hundred tests each year. He teaches an extensive series of short courses in test methods to all testers in the Wing from the Wing Commander to our 520 scientists and engineers. As a LtCol in the USAF Reserves, he served as senior military advisor to AF Operational Test & Evaluation Center Test Support Director and as special advisor for test design to the AF Flight Test Center commander at Edwards AFB, California. Mr. Hutto is a distinguished graduate of the US Naval Academy in Operations Research and holds a Master's in the same field from Stanford University. Over the past 43 years, he has served in nearly every branch of test and evaluation from laboratory basic science to joint operational field testing. He would like to publicly repent of his 11 years of testing without the benefits of the principles of well-designed experiments.

He is proud of his two children who make their livings in the sky – one serves martinis; the other mayhem. Ariel is a Delta Flight Attendant and Daniel is a F-15E Strike Eagle WSO - bomb/nav. He is inordinately proud of his highly educated wife, Dr. Deb, with 6 degrees.

Abstract
Wanted: A Star Trek Transporter

Until a Craig's List ad succeeds, our Air Force aircraft must traverse the sky searching for targets. Sensor performance depends on sensor-target geometry so statistical models include range, azimuth, elevation, etc. Without our transporter, aircraft position is a **sequential** hard-to-change (HTC) factor. That is, short ranges follow long ranges inbound towards the target and vice versa as we recede from the target. Result: a physics-imposed design grid with several sequential ranges for each altitude.

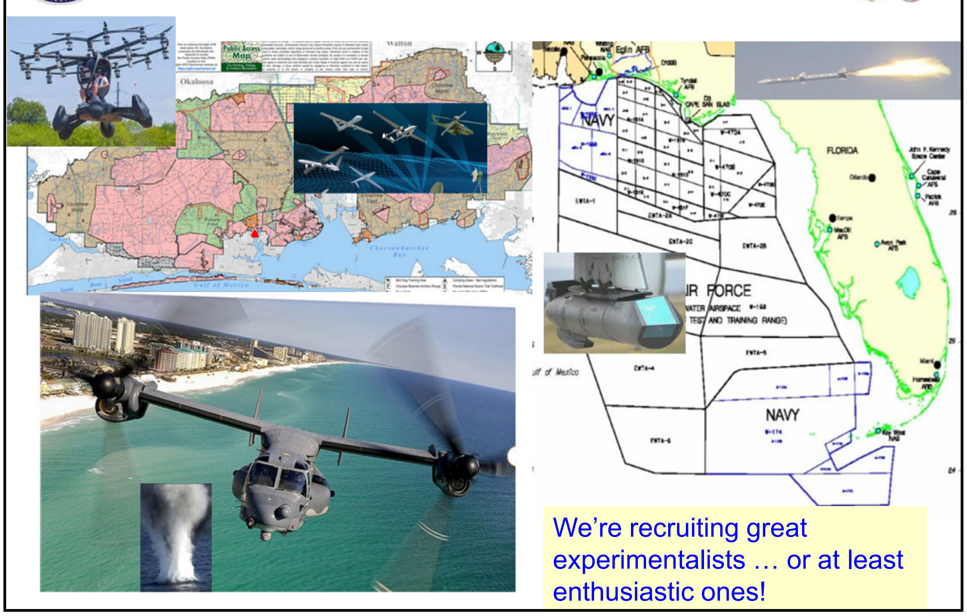
In addition to these geometric variables we have several other easy-to-change (ETC) "modal" variables:

- side of the aircraft (is performance symmetric?),
- electromagnetic spectrum used,
- target tracking algorithm selected,
- target type, etc.

The design challenge is that the HTC values are determined and sequenced. How shall we mate the large number of combinations of the modal variables to the fixed geometric values so that the resulting design has excellent modeling properties - orthogonality, power, low variance inflation, good prediction variance, etc.? A fractional split plot design invariably leaves "holes" where the aircraft occupies positions when no points are to be taken - an obvious inefficiency.

This paper describes the algorithm we derived that takes advantage of several of Design Expert's features including building and importing custom design and using DX's excellent evaluation features to ensure that the modeling properties are acceptable. Because the resulting design incorporates both the whole plot geometric design stitched to an (often) optimal blocked design for the modal variables, the resulting design can be viewed as a "Franken-design", a term of art we invented to describe designs built from individually crafted pieces and merged. The author introduced Franken-designs last year at the StatEase Summit!

Eglin AFB Florida – Weapons, Special Ops, Software, Data Links, Fighters & e-VTOL



U.S. AIR FORCE

AF Ops Research Recognized

informs

US Air Force awarded the 2017 Institute for Operations Research and the Management Sciences (INFORMS) Prize for Operations Research

The INFORMS Prize honors effective integration of advanced analytics and operations research/ management sciences (OR/MS) into organizational decision making. The award is given to organizations that have repeatedly applied the principles of OR/MS in pioneering, varied, novel, and lasting ways. Past recipients of the award include General Motors, Intel, UPS, HP, IBM, Ford, Procter & Gamble, and GE Research.

It All Started with Beer!

- Gosset – Dublin Guinness Brewery circa 1899-1908
- Brewing stouter porter, stout, or Guinness
- Guinness decided to make brewing scientific
- Hired Gosset, a chemist, -- self-taught in statistics and worked with Karl Pearson developing comparative test
- Paper on ***Probable Error of A Mean*** forms the basis for our statistical "Student t" tests
- Temperature, robust hops, and Archer breed of barley -- plus experimentation key in Guinness findings!
- Gosset's paper corrected by RA Fisher who later extended 2 sample t to M-way/k-Variable ANOVA

W. S. Gosset, 1899

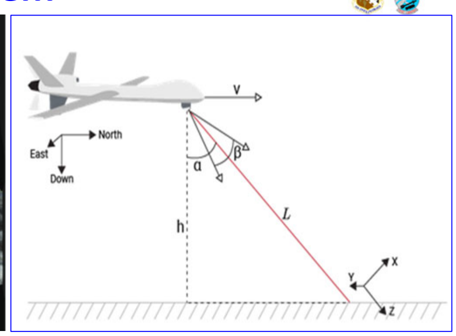
BIOMETRIKA.

THE PROBABLE ERROR OF A MEAN.

By STUDENT.

Sensor Cross-Blocks Problem

Critical features of target coordinates problem

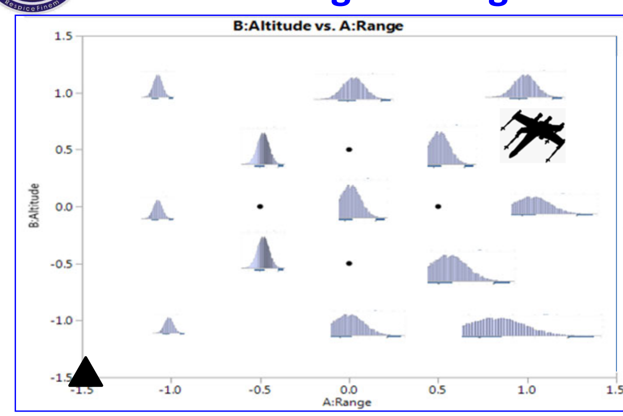


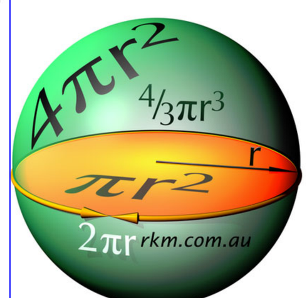
1. Estimating target coordinates is a frequent, DOD-wide problem
2. The target battlespace is large, with many variables
3. The response variable is skew with unstable variance
4. We have both hard-to-change factors and restrictions on randomizing execution order (no transporter) …

Source (line drawing): https://www.vectornav.com/ 1 Oct 22

Target Coordinates are a common test problem as we frequently roll out new "operating systems"

Complications – response distribution changes with geometry





- Coordinate error increases as slant range (radius) squared
- At low graze angle, long slant range, errors are more skew
- And, we are challenged to model percentiles (50th, 90th)
- But today let's focus on the design issues…

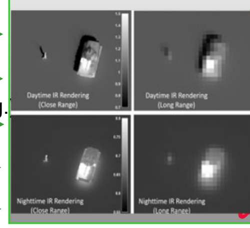
Input-Process-Output
Sensor Target Location Error

INPUTS
(Factors)

- **Altitude**
- **Ground Range**
- **Angle off the nose**
- Sensor (visual or infrared)
- Target type (flat, vehicle, bldg.
- Side of Aircraft
- Direction (In-Out)
- Aircraft, sensor #, pilot, weather, software, terrain

weather, sensor number, pilot

PROCESS:



OUTPUTS
(Responses)

- Target Coordinates

Noise

There are at least $3^4 * 2^3 = 648$ unique points … so fractional designs essential

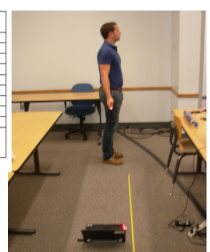
You CAN do this at home… laser safety procedures … of course…

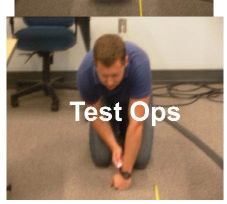
Step 1a: Experiment Planning and Power Analysis

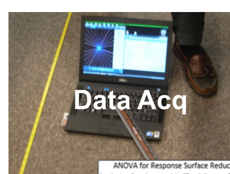
Planning

Sample Factors	Factor Label	Numeric or Categoric	Minimum	Maximum
Height Above Target	A		3"	36" (Waist)
Horizontal Range	B		1'	7.5'
Angle off Nose	C		0	90 deg
Sensor*	D		Eyes	Ears
Sensor Quality	E		One (Mono)	Both (Stereo)
Hand	F		Dominant	Off
Aim Prop	G		Unstable	Stable
Operator Orientation	H		1 spin	3 spins
Target offset	J		0	2 feet
Aim assist	K		No extension (pistol)	Dowel extension (rifle)

*Sensor = Eyes suggests looking to aim without laser on, then lasing without correction



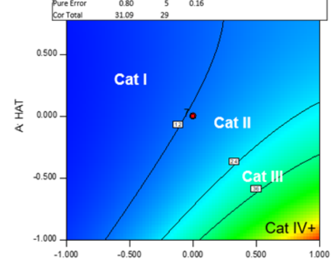




Analyze & Interprete

ANOVA for Response Surface Reduced Quadratic Model
Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Block	0.27	1	0.27			
Model Total	24.74	5	4.95	18.69	< 0.0001	significant
A-HAT	6.27	1	6.27	23.68	< 0.0001	
B-Range	19.02	1	19.02	71.85	< 0.0001	
AB	1.27	1	1.27	4.81	0.0387	
A^2	[illegible]	1	[illegible]	[illegible]	[illegible]	
B^2	0.88	1	0.88	3.34	0.0805	
Residual	6.09	23	0.26			
Lack of Fit	5.28	18	0.29	1.82	0.2625	not significant
Pure Error	0.80	5	0.16			
Cor Total	31.09	29				

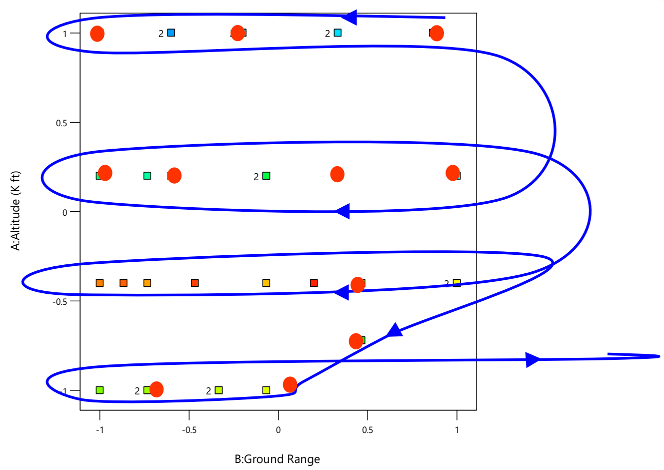


- We have a classroom physical laser-pointer TLE lab you can execute as a science experiment … complete with .mp3 files

First we'll deal with geometry, then modes

Source: https://www.quora.com

Transporter vs. 2022 Tech



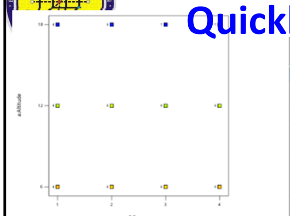
- Gold standard is a randomized and blocked experimental design **but**…
- Until Craig's List ad is answered we must occupy space sequentially

Geometric Design Looks Like This

- Constrained to a sequential vs. random order
- First problem is this imposes a split-plot structure on us
- Ameliorated by
  a. We understand the physical model
  b. We can afford several replicates at the Whole Plot level
- Second Problem is what to do with Easy-to-Change (ETC) variables?

	Point	Altitude mF	Ground Range kC	Angle to Target	
Nose-Tail	1	10	15	0	inbound
	2	10	12	0	
	3	10	8	0	
	4	10	4	0	
	5	10	4	180	outbound
	6	10	8	180	
	7	10	12	180	
	8	10	15	180	
	9	15	15	0	inbound
	10	15	12	0	
	11	15	8	0	
	12	15	4	0	
	13	15	4	180	outbound
	14	15	8	180	
	15	15	12	180	
	16	15	15	180	
	17	20	15	0	inbound
	18	20	12	0	
	19	20	8	0	
	20	20	4	0	
	21	20	4	180	outbound
	22	20	8	180	
	23	20	12	180	
	24	20	15	180	
Quarters	25	10	15	45	inbound
	26	10	12	45	
	27	10	8	45	
	28	10	4	45	
	29	10	4	135	outbound
	30	10	8	135	
	31	10	12	135	
	32	10	15	135	
	33	15	15	45	inbound
	34	15	12	45	
	35	15	8	45	
	36	15	4	45	
	37	15	4	135	

Split Plot Optimal Designs Jump Quickly to Mind … but ohhhhh…



Design evaluates nicely

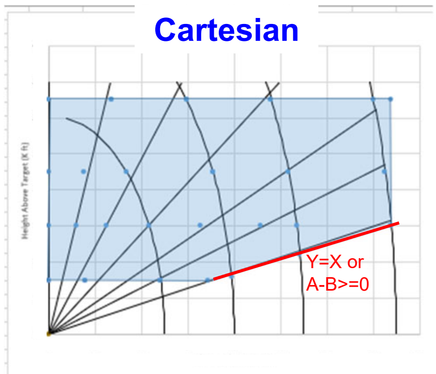
Term	Standard Error*	Error df†	VIF	Restricted‡ VIF	Power
Whole-Plot					
a	0.3150	14	1.01065	1.00161	83.9 %
c	0.2588	14	1.02106	1.01395	94.8 %
d	0.2588	14	1.02229	1.01416	94.8 %
Subplot					
B	0.1385	72	1.01149	1.0077	99.9 %
E[1]	0.1485	72			99.9 %
E[2]	0.1489	72			
F	0.1036	72	1.0045	1.00303	99.9 %
aB	0.1699	72	1.02738	1.02198	99.9 %
B^2	0.2340	72	1.00969	1.00469	98.8 %

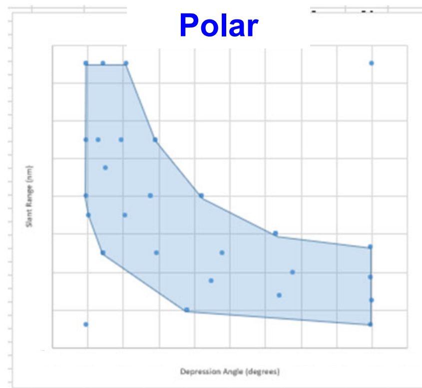
Group	Run	Factor 1 a:Altitude	Factor 2 B:Range	Factor 3 c:Direction	Factor 4 d:Freq	Factor 5 E:Target	Factor 6 F:Side	Response 1 R1
1	1	18	3	In	Lo	Vespa	Right	
1	2	18	4	In	Lo	Vespa	Right	
1	3	18	1	In	Lo	TinyHouse	Right	
1	4	18	2	In	Lo	TinyHouse	Left	
1	5	18	4	In	Lo	GoatPath	Left	
2	6	6	4	In	Lo	TinyHouse	Left	
2	7	6	2	In	Lo	GoatPath	Left	
2	8	6	1	In	Lo	GoatPath	Right	
2	9	6	3	In	Lo	Vespa	Left	
2	10	6	4	In	Lo	Vespa	Right	
2	11	6	2	In	Lo	TinyHouse	Right	
3	12	18	4	Out	Hi	GoatPath	Right	
3	13	18	1	Out	Hi	GoatPath	Left	
3	14	18	1	Out	Hi	TinyHouse	Right	
3	15	18	3	Out	Hi	Vespa	Left	
3	16	18	2	Out	Hi	TinyHouse	Right	
4	17	12	4	In	Hi	GoatPath	Left	
4	18	12	4	In	Hi	TinyHouse	Right	
4	19	12	3	In	Hi	Vespa	Right	
4	20	12	2	In	Hi	TinyHouse	Left	
4	21	12	1	In	Hi	GoatPath	Right	
5	22	12	4	Out	Hi	GoatPath	Left	
5	23	12	4	Out	Hi	Vespa	Right	
5	24	12	1	Out	Hi	Vespa	Left	
5	25	12	2	Out	Hi	TinyHouse	Right	
5	26	12	3	Out	Hi	GoatPath	Right	
5	27	12	1	Out	Hi	TinyHouse	Right	
6	28	18	3	Out	Hi	GoatPath	Right	

Any issues? Lots!

- Substantial by-hand re-ordering to make it somewhat executable…
- Fractional “holes” make us look dumb…
- Hovering fighters anyone? Climb-Dive-Climb again…
- “Ummmm … pilot take next two then skip 1 then skip 3 then go back one…”

BTW - Which Coordinate System Shall We Use to Build our Statistical Model?





- Represent with Cartesian (with Linear Constraint) or
- Polar Coordinates with physics constraints (no 60kft over target)?
- Objective decision is made easy with DX comparing Design Evaluations

Comparing Cartesian with Polar in Design Expert's Evaluation

Power-VIF

Cartesian

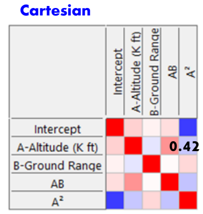
Term	Standard Error*	VIF	R_i^2	Power
A	0.2706	1.24813	0.1988	94.5 %
B	0.2912	1.03412	0.0330	91.1 %
AB	0.4576	1.25343	0.2022	55.9 %
A^2	0.4222	1.09754	0.0889	99.5 %

Polar

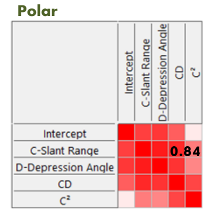
Term	Standard Error*	VIF	R_i^2	Power
C	0.7675	6.39183	0.8436	24.2 %
D	0.6149	5.11388	0.8045	34.8 %
CD	1.07	5.97806	0.8327	14.7 %
C^2	0.7602	2.29919	0.5651	71.8 %

Correlation

Cartesian



Polar



Matrix Measures

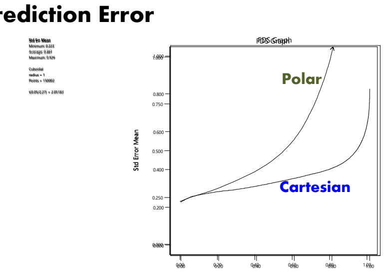
Cartesian

Description	Value
Condition Number of Coefficient Matrix	2.83
Maximum Variance Mean	0.6819
Average Variance Mean	0.1314
Minimum Variance Mean	0.0517
G Efficiency	22.91
Scaled D-optimality Criterion	2.82
Determinant of $(X'X)^{-1}$	5.36077E-6
Trace of $(X'X)^{-1}$	0.6266
I (Cuboidal)	0.1315

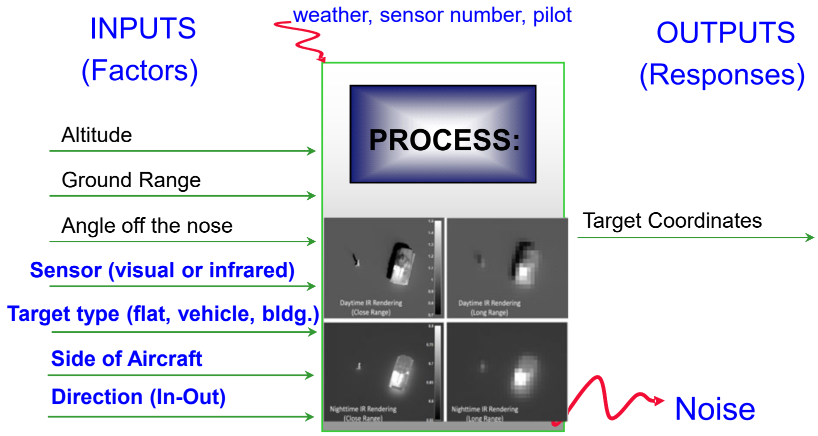
Polar

Description	Value
Condition Number of Coefficient Matrix	30.83
Maximum Variance Mean	9.79
Average Variance Mean	0.7405
Minimum Variance Mean	0.0521
G Efficiency	1.60
Scaled D-optimality Criterion	5.23
Determinant of $(X'X)^{-1}$	1.16772E-4
Trace of $(X'X)^{-1}$	2.85
I (Cuboidal)	0.7471

Prediction Error



Now Let's Deal with ETC Modal Variables



There are at least 34 * 23 = 648 unique points … so a fractional design is essential
How to build a combined design of our fixed geometric & modal variables?

History of Experimental Design Gives Inspiration

- Blocks are (nearly) orthogonal sub-designs of modal variables!
- Random Balance Designs were first attempts at fractional general factorials (Now NOLH)
- Generate blocked designs in the modal variables
  - Basic geometric design is 32 runs
  - So blocks of 4 to 8 runs are conveniently sized
  - And geometric design is replicated 2-4 times usually
- Sequentially roll the nearly orthogonal modal blocks across the geometric design
- Latin Squares give us the patterns to ~~roll~~
  - ABCD BCDA CDAB DABC ABCD…

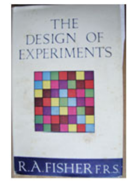
	Machine 1	Machine 2	Machine 3	Machine 4
Operator 1	A	B	C	D
Operator 2	C	A	D	B
Operator 3	B	D	A	C
Operator 4	D	C	B	A

4x4 Latin Square

Random Balance Experimentation
F. E. Satterthwaite
Pages 111-137 | Published online: 30 Apr 2012

Academic review of some inspiring work by our progenitors…

- **Blocks*** (1925) preserve effect estimates by sacrificing some effects to measure/isolate nuisance variance
- **Latin Squares*** (1930's & earlier) are double blocking designs for (typically) a single effect

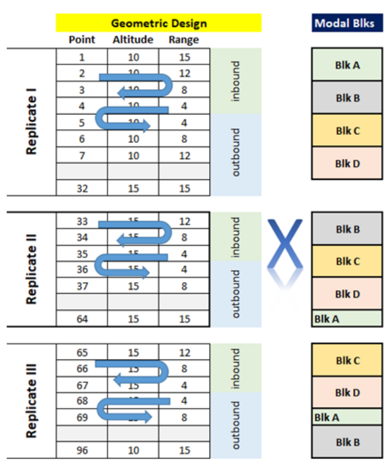


- **Random Balance**+ designs (1956) fractionate multilevel categoric designs

- Montgomery[x] (1988) introduces **Partially Aliased** designs by alternating the fractional block generators from one replicate to the next

**RA Fisher and the Design of Experiments, 1922-1926*, JF Box, *The American Statistician* Vol. 34, No. 1 (Feb., 1980), pp. 1-7
+*Random Balance Experimentation* Author(s): F. E. Satterthwaite, *Technometrics* , May, 1959, Vol. 1, No. 2, pp. 111-137
X Ch 7.8 *Design and Analysis of Experiments*, DC Montgomery, 10th edition, Wiley 2020

Graphically – Alternate Modal Blocks Across Geometric Reps



	Modal Variables		
	Freq	Target	Side
Blk A	-1	1	1
	-1	1	-1
Blk B	1	-1	-1
	1	-1	1
Blk C	-1	-1	1
	1	1	1
Blk D	-1	-1	-1
	1	1	-1

- Result is a largely orthogonal crossed design

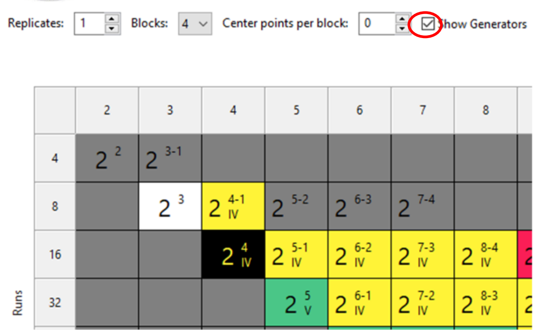
If Modal Variables Have Two Levels Then Blocks and Fractions are Simple

Table 3.15 Suggested Blocking Arrangements for the 2^k Factorial Design

Number of Factors, k	Number of Blocks, 2^p	Block Size, 2^{k-p}	Effects Chosen to Generate the Blocks	Interactions Confounded with Blocks
3	2	4	ABC	ABC
	4	2	AB, AC	AB, AC, BC
4	2	8	ABCD	ABCD
	4	4	ABC, ACD	ABC, ACD, BD
	8	2	AB, BC, CD	AB, BC, CD, AC, BD, AD, ABCD
5	2	16	ABCDE	ABCDE
	4	8	ABC, CDE	ABC, CDE, ABDE
	8	4	ABE, BCE, CDE	ABE, BCE, CDE, AC, ABCD, BD, ADE
	16	2	AB, AC, CD, DE	All 2-factor and 4-factor interactions (15 effects)
6	2	32	ABCDEF	ABCDEF
	4	16	ABCF, CDEF	ABCF, CDEF, ABDE
	8	8	ABEF, ABCD, ACE	ABEF, ABCD, ACE, BCF, BDE, CDEF, ADF
	16	4	ABF, ACF, BDF, DEF	ABE, ACF, BDF, DEF, BC, ABCD, ABDE, AD, ACDE, CE, BDF, BCDEF, ABCEF, AEF, BE
	32	2	AB, BC, CD, DE, EF	All 2-factor, 4-factor, and 6-factor interactions (31 effects)
7	2	64	ABCDEFG	ABCDEFG
	4	32	ABCFG, CDEFG	ABCFG, CDEFG, ABDE
	8	16	ABC, DEF, AFG	ABC, DEF, AFG, ABCDEF, DCFG, ADEG, BCDEFG
	16	8	ABD, EFG, CDE, ADG	ABCD, EFG, CDE, ADG, ABCDEFG, ABE, BCG, CDFG, ADEF, ACEG, ABFG, BCEF, BDEG, ACF, BDF
	32	4	ABG, BCG, CDG, DEG, EFG	ABG, BCG, CDG, DEG, EFG, AC, BD, DE, DF, AE, BE, ABCD, ABDE, ABEF, BCDE, BCEF, CDEF, ABCDEFG, ADG, ACDEG, ACEFG, ABDFG, ABCEG, BEG, BDEFG, CFG, ADEF, ACDF, ABCF, AFG
	64	2	AB, BC, CD, DE, EF, FG	All 2-factor, 4-factor, and 6-factor interactions (63 effects)

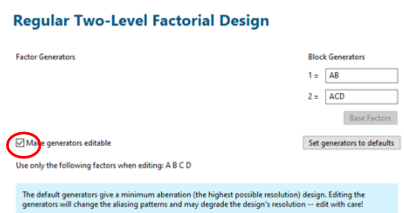
- Remember this table? Fractional 2^k patterns date to 1940's
- Cochran & Cox Experimental Design 2nd Edition (1957)
- Design Expert Readily Generates 2^k Blocks with Generator Control

DX can generate alternate blocks of equal resolution



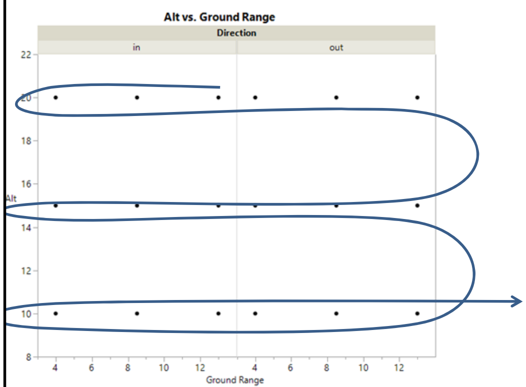
Equal min aberration choices include:
AB ACD (BCD)+

BC ABD (ACD)
CD ABD (ABC) …



- Exploits Montgomery's partial aliasing approach in text ch 7.8
- Take care with generalized interaction of block generators
- Avoid, for example, AB & ABC

Build two designs - replicated geometric factorial & 2^k modal factorial



Block	Run	D-Side	E-Angle	F-Spectrum	G-Tgt
1	3	-1	1	1	1
1	13	1	-1	1	-1
1	6	1	1	-1	1
1	12	-1	-1	-1	-1
2	4	1	-1	1	1
2	16	-1	1	1	-1
2	7	-1	-1	-1	1
2	9	1	1	-1	-1
3	5	-1	1	-1	-1
3	10	1	-1	-1	1
3	2	1	1	1	-1
3	15	-1	-1	1	1
4	1	1	-1	-1	-1
4	11	-1	1	-1	1
4	8	-1	-1	1	-1
4	14	1	1	1	1

Build 2^4 in 4 Blocks Res III With Modes and Targets

- Build sequential geometric design & replicates (96)
- Build complete modal variables in convenient block sizes
- Rotate or cross the blocks across the geo design

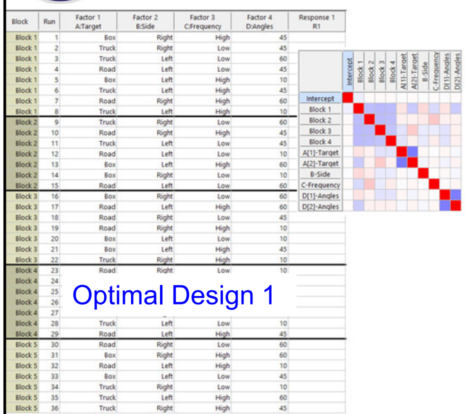
Cross-Block Design

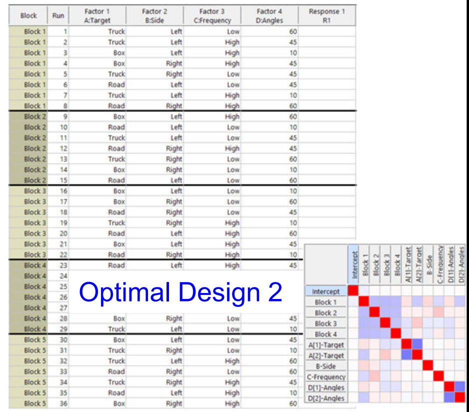
- Left side 3 replicates of a full geometric design (N=32 each)
- Right columns are 2^4 modal variables in four convenient blocks
- Use Latin Square pattern to cross blocks with geometric replicates
- 1234 2341 3412 4123…
- Change block generators for next replicate

Replicate I

	Geometric Design (Polar)				Modal Design in Blocks				
Point	A-Depression	B-Slant Range	C-Direction	Direction	D-Side	E-Angle	F-Spectrum	G-Tgt	Block
1	20.9	15	1	in	-1	1	1	1	1
2	29.1	11	1	in	-1	1	-1	2	1
3	42.0	8	1	in	1	-1	-1	1	1
4	63.1	6	1	in	1	-1	1	2	1
5	89.7	5.3	-1	out	1	-1	1	1	2
6	63.1	6	-1	out	1	-1	-1	2	2
7	42.0	8	-1	out	-1	1	-1	1	2
8	29.1	11	-1	out	-1	1	1	2	2
9	14.3	15	1	in	1	1	1	2	3
10	19.7	11	1	in	1	1	-1	1	3
11	27.6	8	1	in	-1	-1	-1	2	3
12	67.8	4	1	in	-1	-1	1	1	3
13	89.6	3.7	-1	out	-1	-1	-1	1	4
14	47.8	5	-1	out	-1	-1	1	2	4
15	27.6	8	-1	out	1	1	-1	2	4
16	9.5	15	1	in	1	1	1	1	4
17	9.5	11	1	in	1	-1	1	1	2
18	9.5	8	1	in	1	-1	-1	2	2
19	14.3	5	1	in	-1	1	-1	1	2
20	38.1	2	1	in	-1	1	1	2	2
21	89.6	1.2	-1	out	1	1	1	2	3
22	38.1	2	-1	out	1	1	-1	1	3
23	14.3	5	-1	out	-1	-1	-1	2	3
24	10.2	7	-1	out	-1	-1	1	1	3
25	9.5	15	1	in	-1	-1	-1	1	4
26	13.0	11	1	in	-1	-1	1	2	4
27	20.7	7.0	1	in	1	1	-1	2	4
28	44.9	3.5	1	in	1	1	1	1	4
29	90.0	2.5	-1	out	-1	1	1	1	1
30	63.9	2.75	-1	out	-1	1	-1	2	1
31	29.6	5.0	-1	out	1	-1	-1	1	1
32	15.1	9.5	-1	out	1	-1	1	2	1
33	20.9	15	1	in	1	1	1	2	3
34	29.1	11	1	in	1	1	-1	1	3
35	42.0	8	1	in	-1	-1	-1	2	3
36	63.1	6	1	in	-1	-1	1	1	3
37	89.7	5.3	-1	out	-1	-1	-1	1	4
38	63.1	6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

If Modal Variables Are Multi-level Categoric or Odd Then Optimally Block





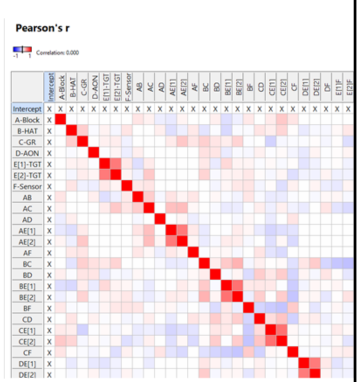
- 2^2 X 3^2 Design of Modal Variables N=36
- 5 Blocks of 7-8 Runs each
- In Geometric reps 2&3, use different sets 5 optimal blocks

96 Run Cross-Block Design Typical 2FI Evaluation

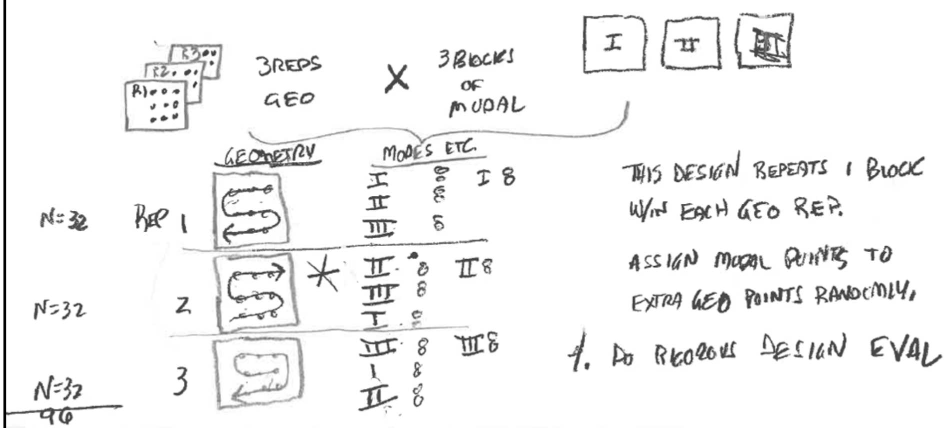
- Mild VIF inflation
- Mild 2FI and RSM covariances
- Flown these since circa 2018 – two dozen times
- Models confirm when flown on 4 ranges
- Models cross-validate nicely

Model Terms

Term	Standard Error*	VIF	R_i^2	Power
A	0.1332	1.13532	0.1192	99.9 %
B	0.1632	1.25105	0.2007	99.9 %
C	0.1794	1.30106	0.2314	99.9 %
D	0.1058	1.07118	0.0664	99.9 %
E[1]	0.1583			99.9 %
E[2]	0.1510			
F	0.1092	1.14409	0.1259	99.9 %
AB	0.1882	1.11911	0.1064	99.9 %
AC	0.2201	1.30829	0.2356	99.9 %
AD	0.1276	1.04193	0.0402	99.9 %
AE[1]	0.1953			99.9 %
AE[2]	0.1854			
AF	0.1301	1.08288	0.0765	99.9 %
BC	0.2804	1.428	0.2997	99.3 %
BD	0.1577	1.17885	0.1517	99.9 %
BE[1]	0.2429			99.9 %
BE[2]	0.2417			
BF	0.1630	1.24762	0.1985	99.9 %
CD	0.1716	1.19233	0.1613	99.9 %
CE[1]	0.2586			99.9 %
CE[2]	0.2648			
CF	0.1778	1.27779	0.2174	99.9 %
DE[1]	0.1562			99.9 %
DE[2]	0.1460			
DF	0.1070	1.09574	0.0874	99.9 %
E[1]F	0.1577			99.9 %
E[2]F	0.1555			



Original Written Directions Circa January 2018



DX Enables Complex Custom Designs & Evaluations

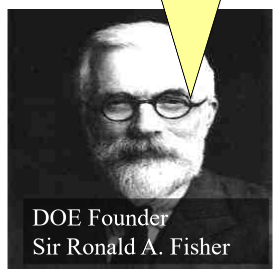
The physical world of flight test offers endless challenges to our creativity… DX a great partner tool

Wanted: A Star Trek Transporter!

US Space Force is working the tech

- In target location, we traverse the geometric space mated with blocked designs
- History of design development offered inspiration: Random Balance, Latin Squares, Partial Aliasing
- Algorithm easy to build & repeatable
- DX tools are critical – custom blocking, import & evaluate tailored designs
- Designs confirmed in experiments

"To call in the statistician after the experiment is . . . asking him to perform a postmortem examination: he may be able to say what the experiment died of."
Address to Indian Statistical Congress, 1938.



https://www.bbc.com/news/world-us-canada-51245262

Wanted: A Transporter

Source: https://www.vanityfair.com/hollywood/2017/12/star-trek-trouble-with-tribbles-50th-anniversary