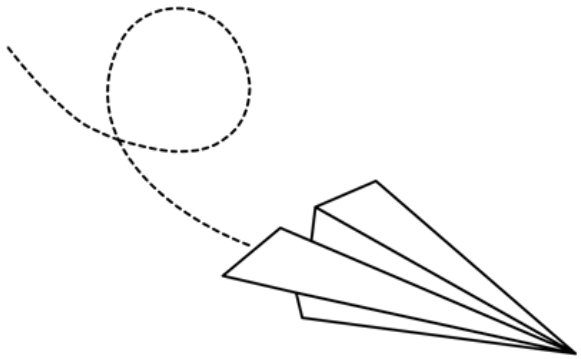
SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

Established in collaboration with MIT

40.004 Recitation Week 1

Paper Airplane Contest

Please form teams of 4~5 people.



Paper Airplane Contest

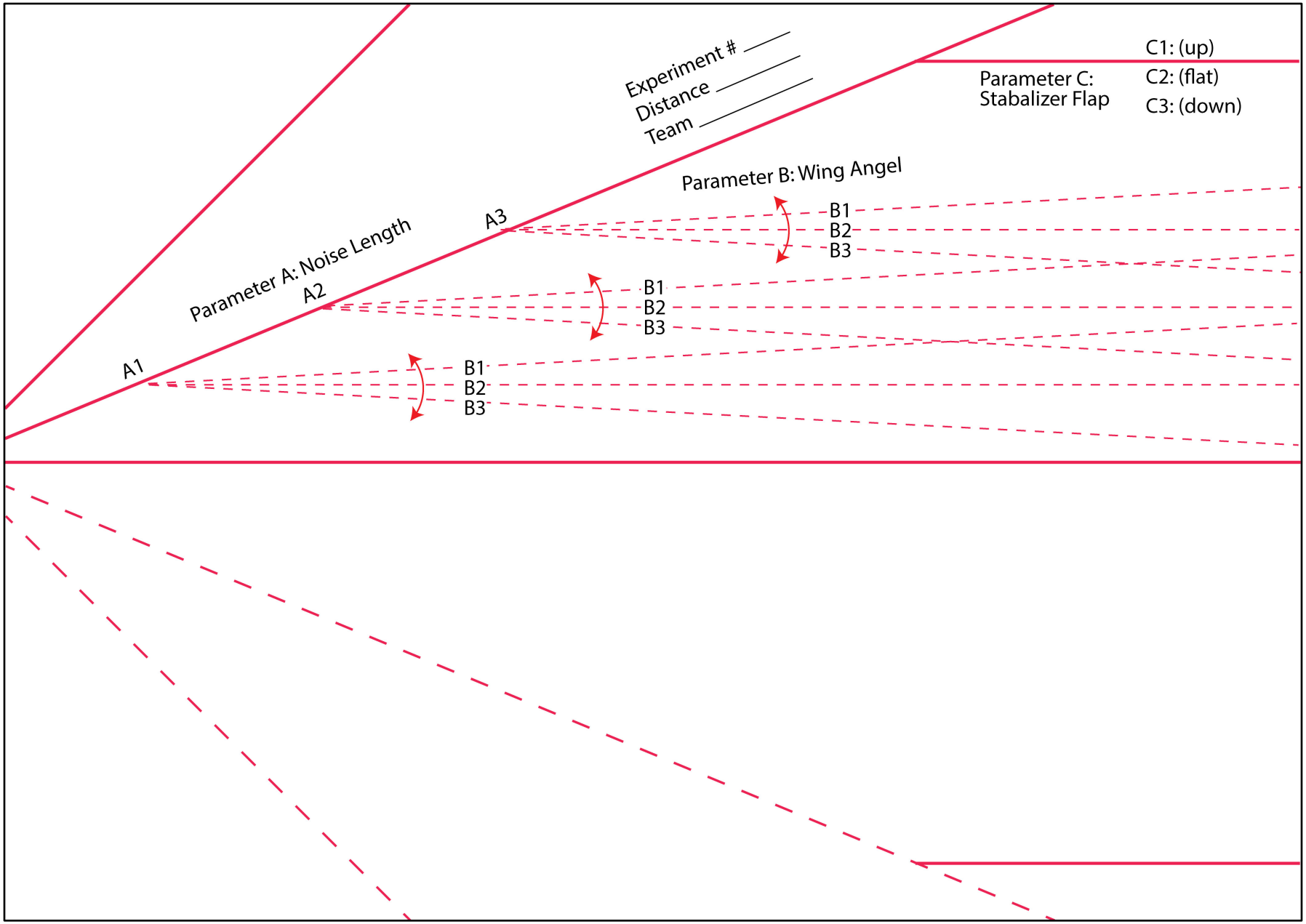
You will be provided with paper to fold airplanes following some guidelines.

Your task is to figure out the optimal configuration so that the airplane can fly the longest distance.

There are three factors that can be changed:

- Factor A: Nose length
- Factor B: Wing angle
- Factor C: Stabilizer flap

Each factor has three levels.


Experiment #
Distance
Team
Parameter C:
Stabalizer Flap
C1: (up)
C2: (flat)
C3: (down)
Parameter B: Wing Angel
Parameter A: Noise Length
A1
A2
A3
B1
B2
B3
B1
B2
B3
B1
B2
B3

Paper Airplane Contest

In total 3x3x3=27 potential configurations.

Each team has 6 pieces of paper. Build some airplanes and run tests to see which configuration works better.

You can only explore 6 different airplane configuration. Plan wisely! What configurations to explore?

Do NOT unfold any airplane and reuse the paper to explore different configurations!

Contest Rules

A new piece of paper will be provided to each team to fold a new airplane.

The configuration of this airplane can either be the same or different from any of the 6 airplanes you built earlier. (If different, what configuration to use?)

Fly your airplane. Winning team will get prizes ☺

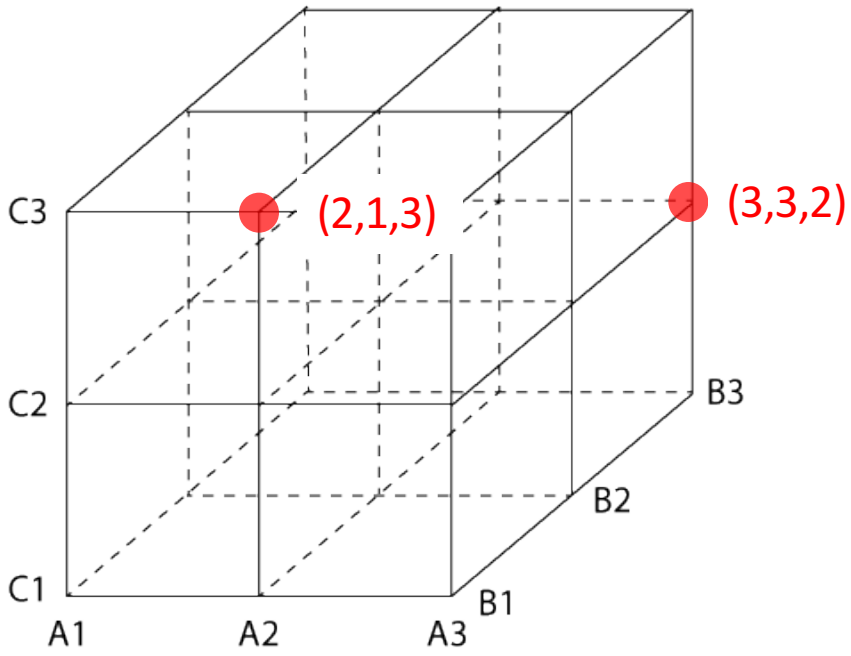
Questions

- What is your strategy to decide which airplane configurations to fold and test?
- How did you test your paper airplanes?
- What are the uncertainties (noise/nuisance factors) that influence the results?

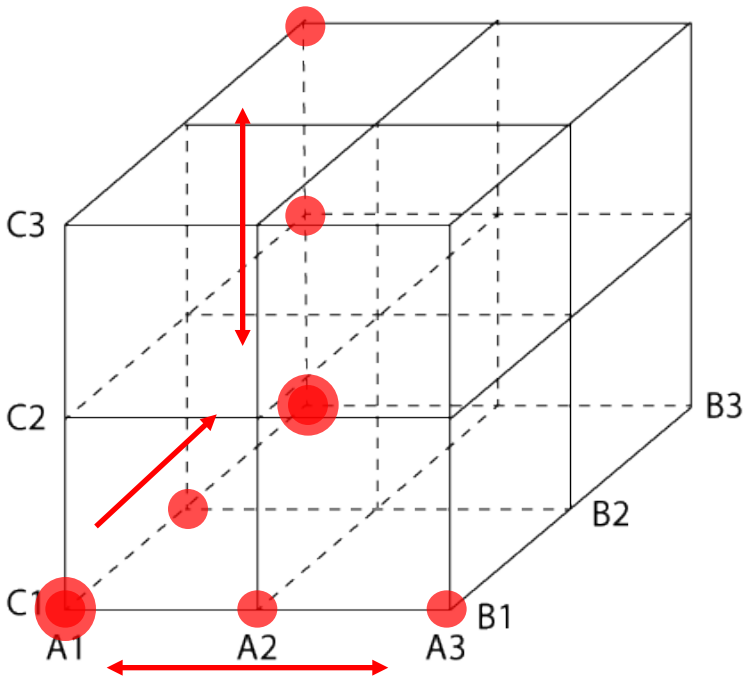
Design of Experiment (DoE)

3 x 3 x 3 matrix

Each point represents one configuration



One Factor At a Time



Step 1: Randomly select a starting point

Step 2: Fix B and C, vary A

Step 3: Fix A = A1 and C, vary B

Step 4: Fix A = A1 and B = B3, vary C

Optimal: A = A1, B = B3, C = C1

Advantage:

- Intuitive

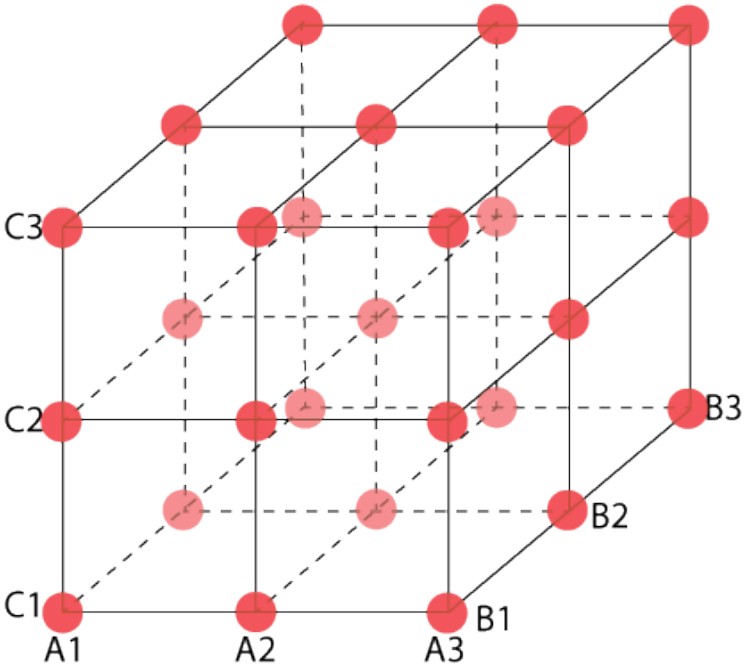
Disadvantage:

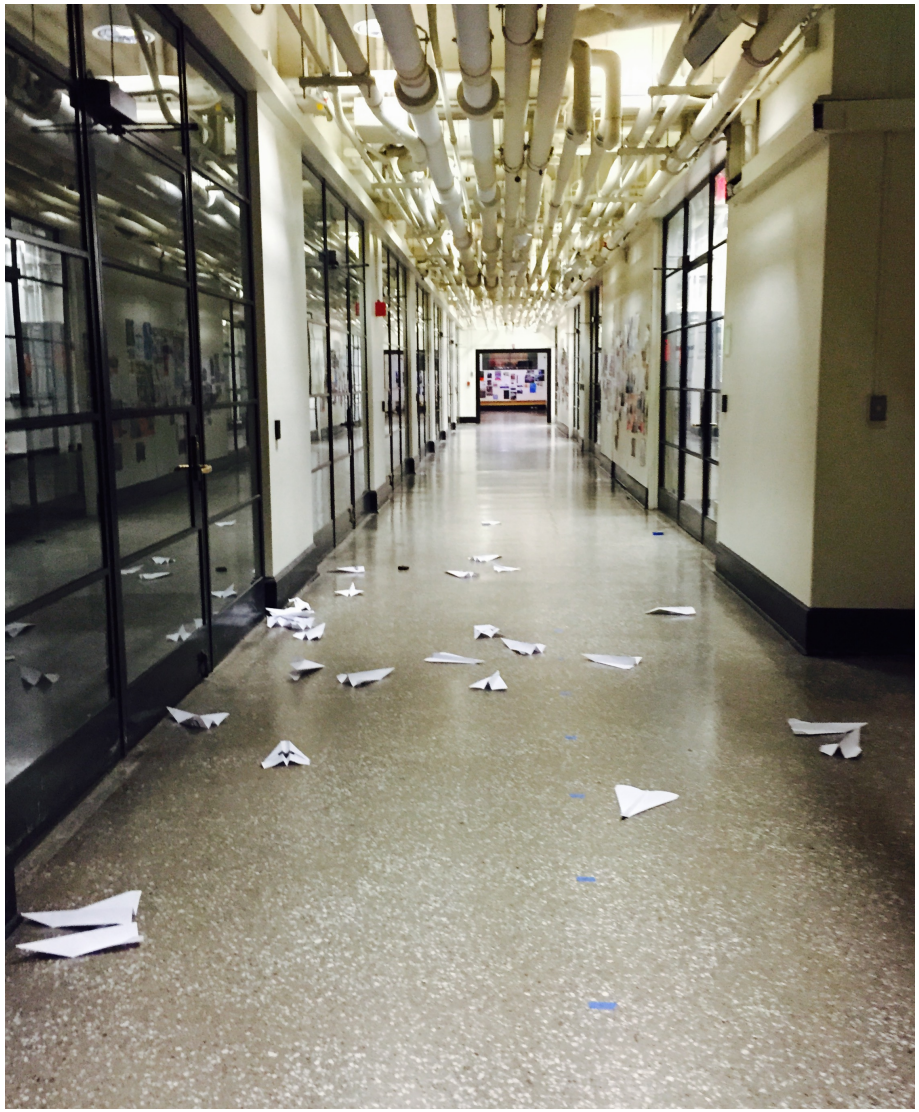
- No guarantee of optimal, if interaction effect exists

How to run the experiment more systematically?

Full Factorial Design

27 configurations





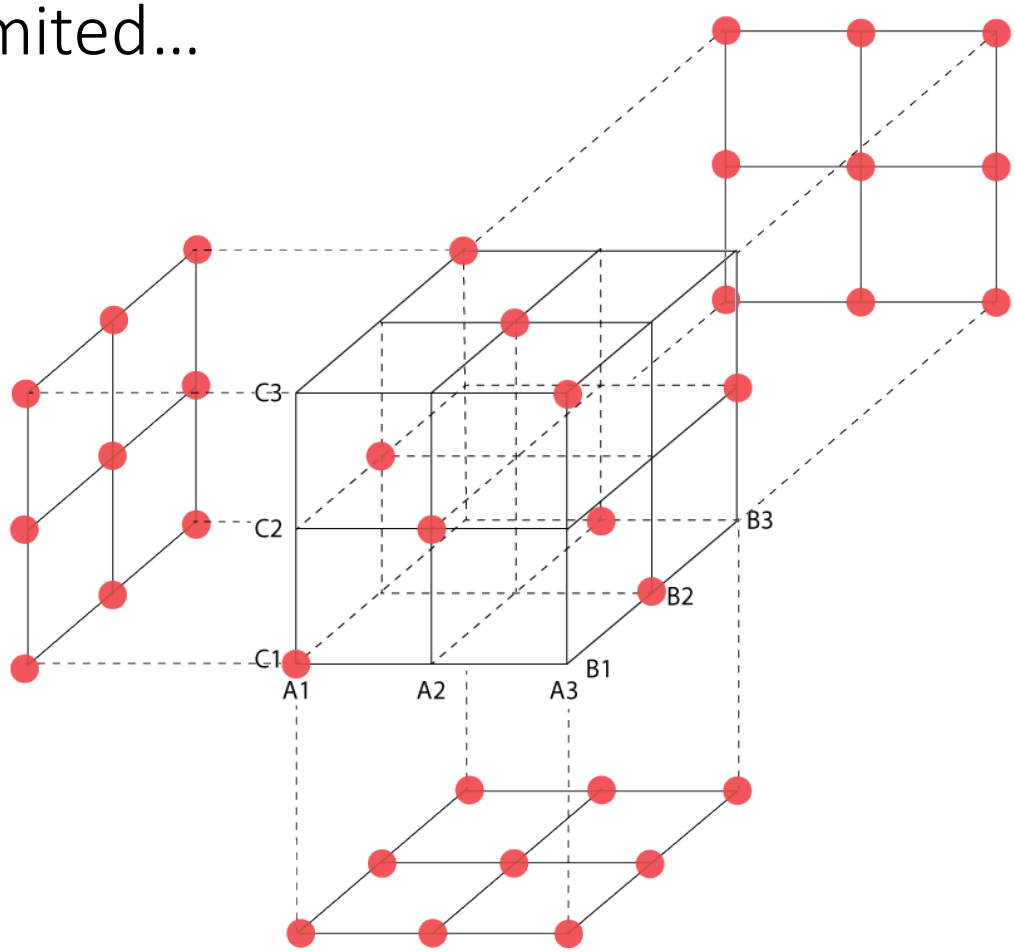
Advantage: More accurate
Disadvantage: High cost

Fractional Factorial Design

When resources are limited…

9 configurations

Configuration	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

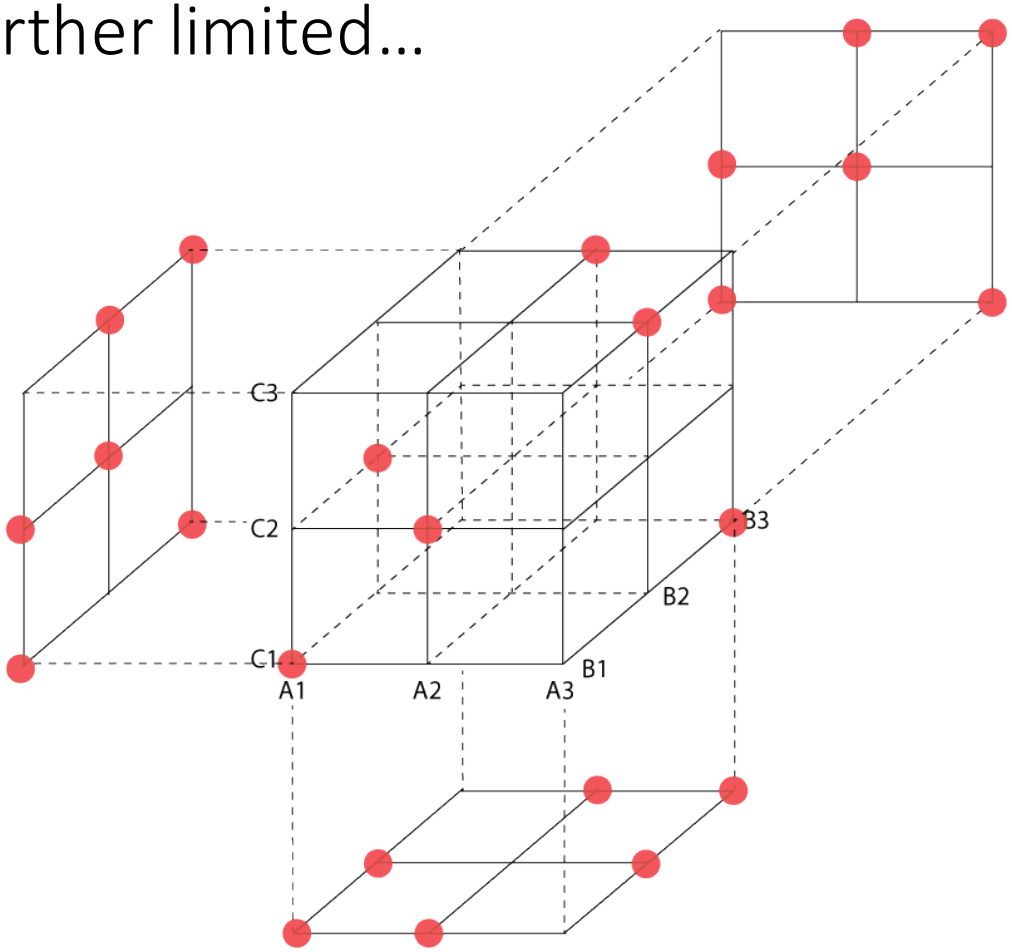


Fractional Factorial Design

When resources are further limited…

6 configurations

Configuration	A	B	C
1	1	1	1
2	1	2	2
3	2	3	3
4	2	1	2
5	3	2	3
6	3	3	1



Advantage

- Save cost

Disadvantage:

- Lower accuracy
- Main effects and interaction effects are confounded

Main Effect & Interaction Effect

Main effect: the effect of one factor on the result, ignoring the effects of all other factors.

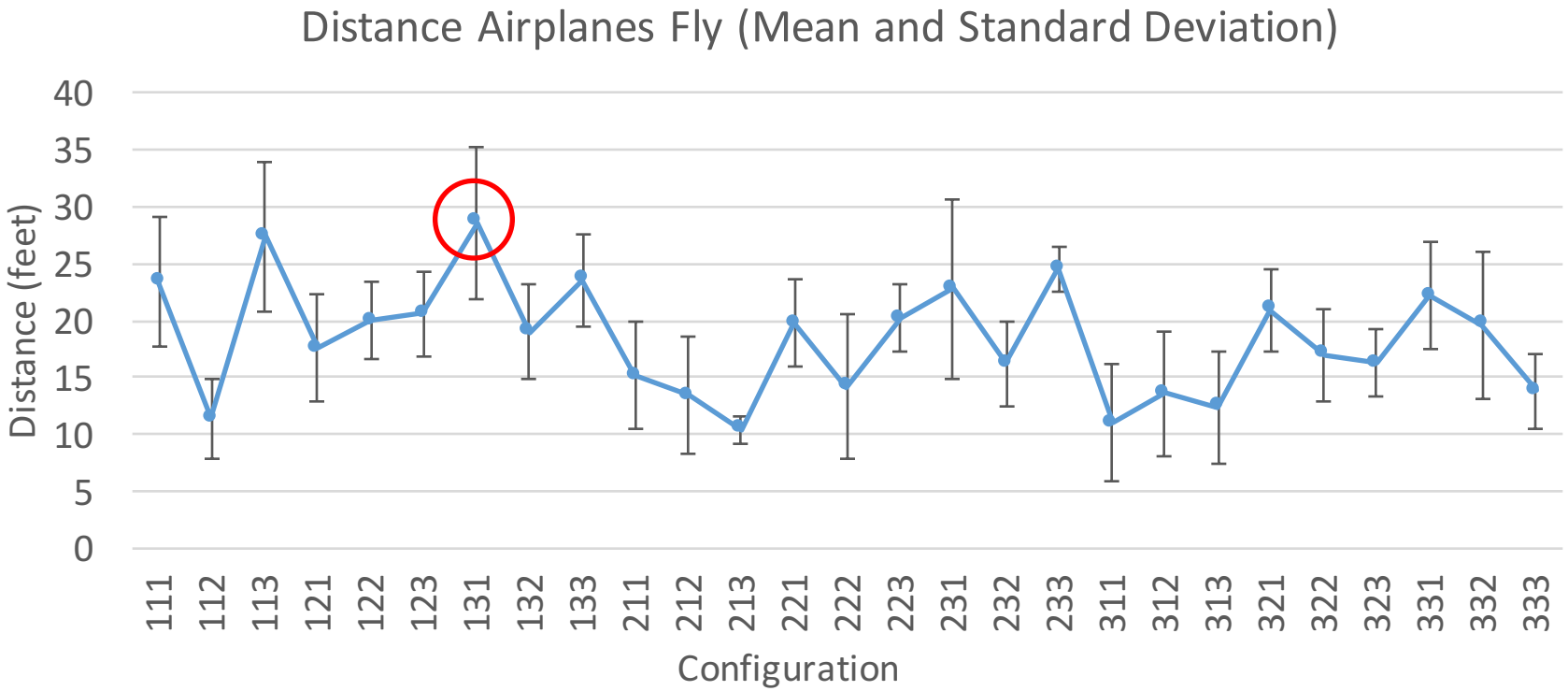
Interaction effect: the effect of one factor may depend on the level of the other factor

Example: the effect of two factors on your final exam score: how hard you study during the semester and your stress level the night before the exam.

	High stress before exam	Low stress before exam
Study hard during semester	90	100
Not study hard during semester	60	50

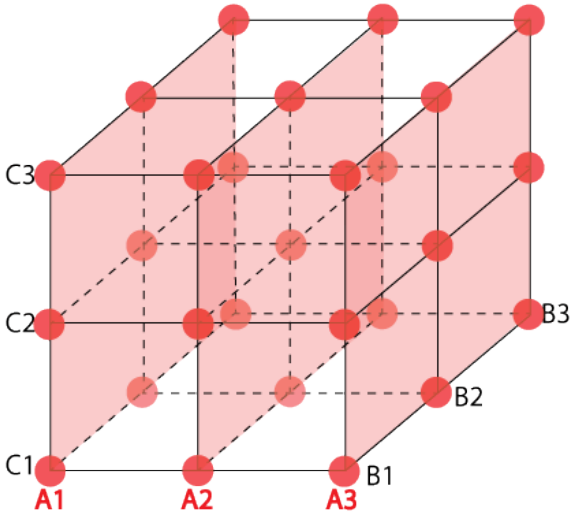
Full Factorial Design

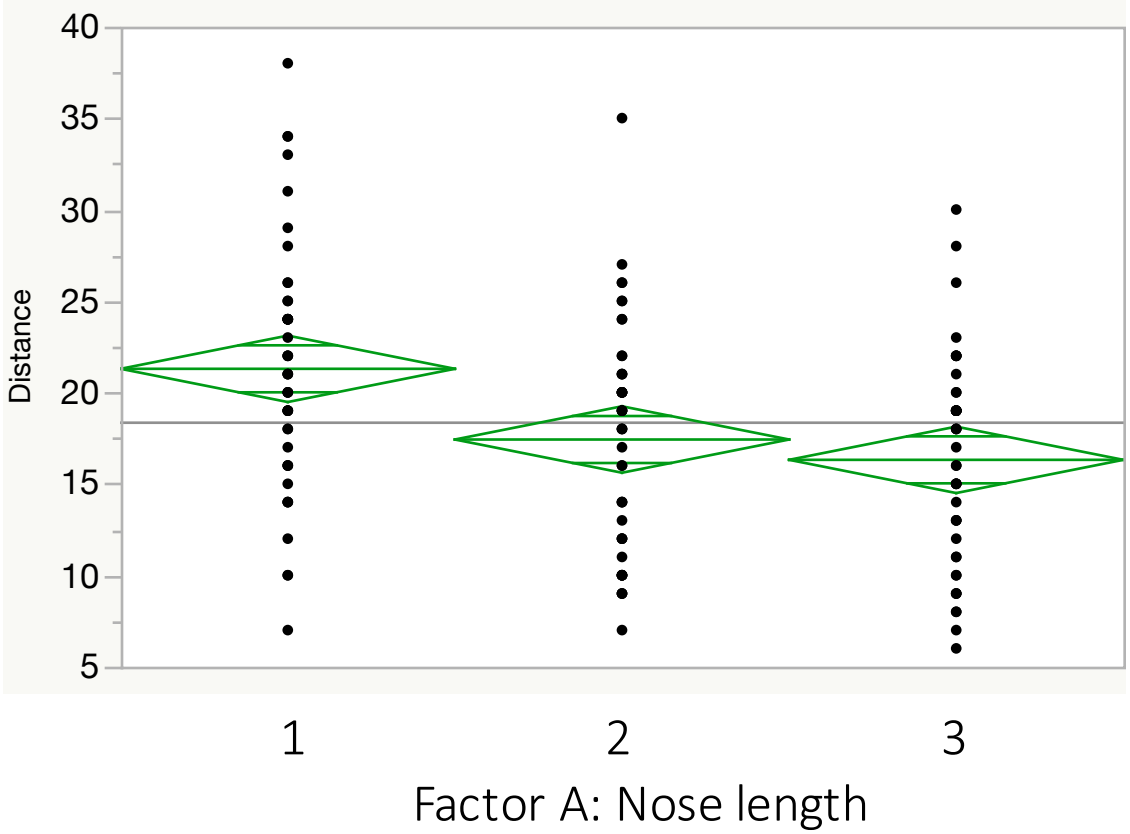
Five tests per airplane



Main Effect – Factor A

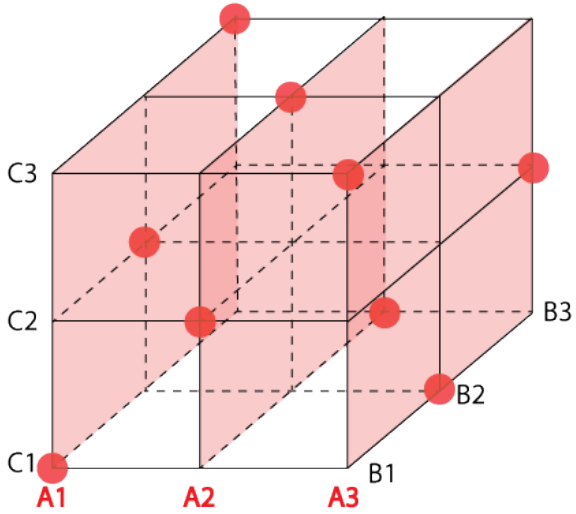
Full Factorial Design

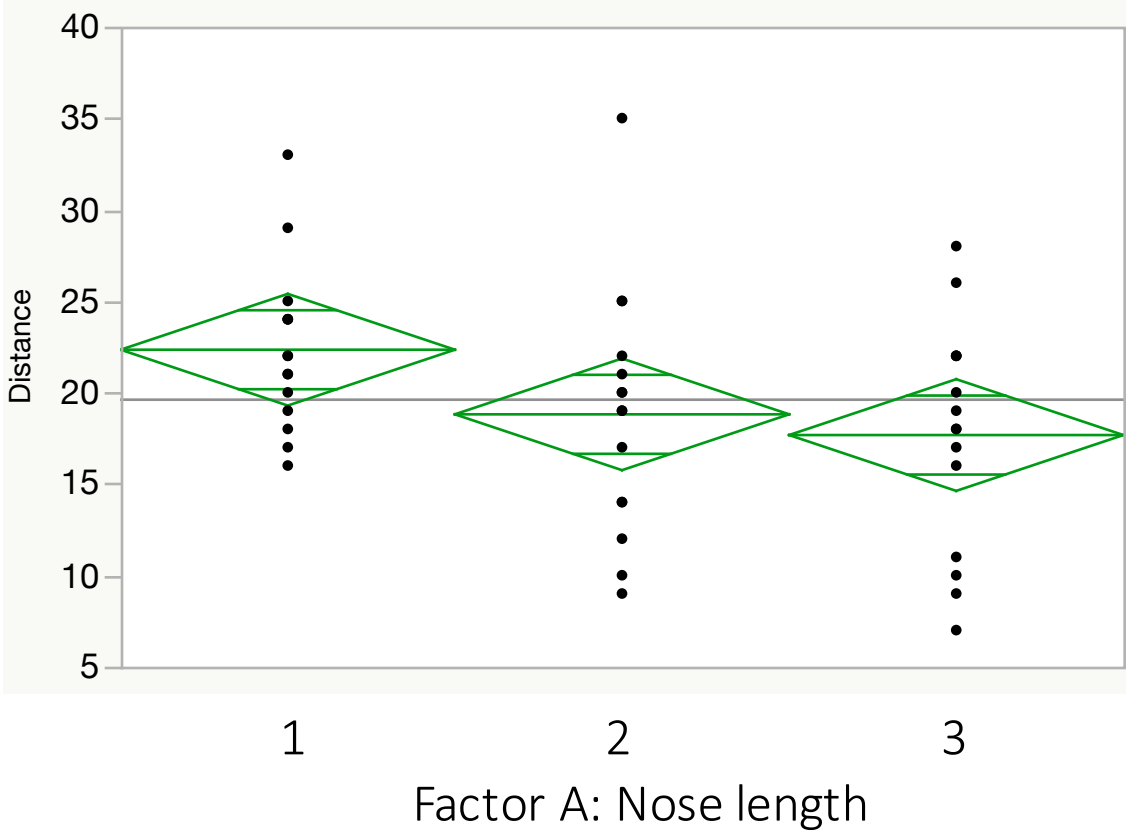




Main Effect – Factor A

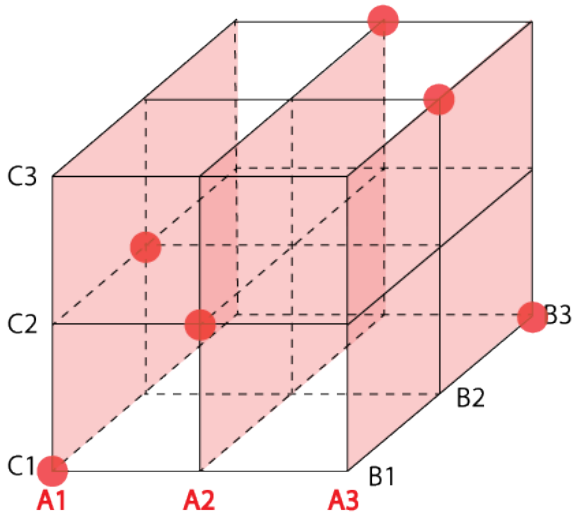
Fractional Factorial Design – 9 configurations

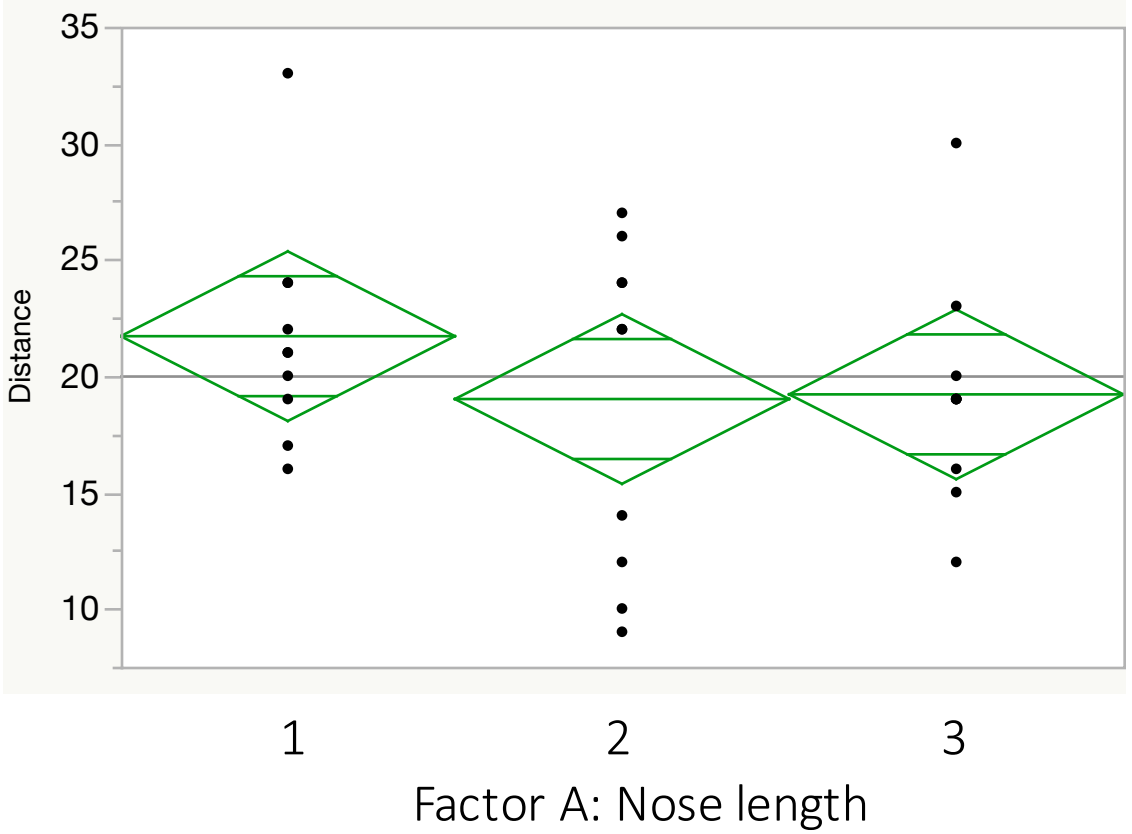




Main Effect – Factor A

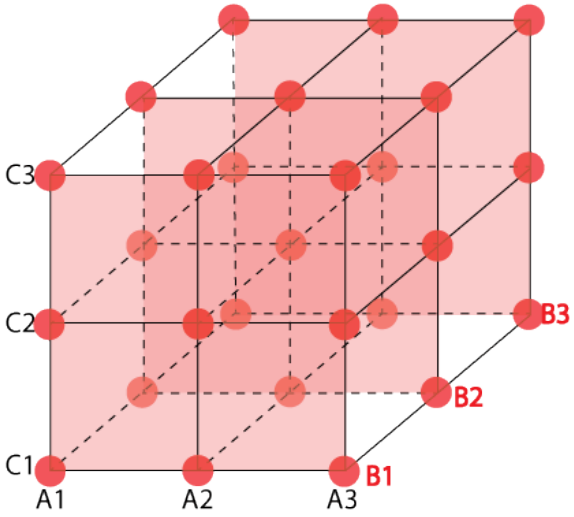
Fractional Factorial Design – 6 configurations

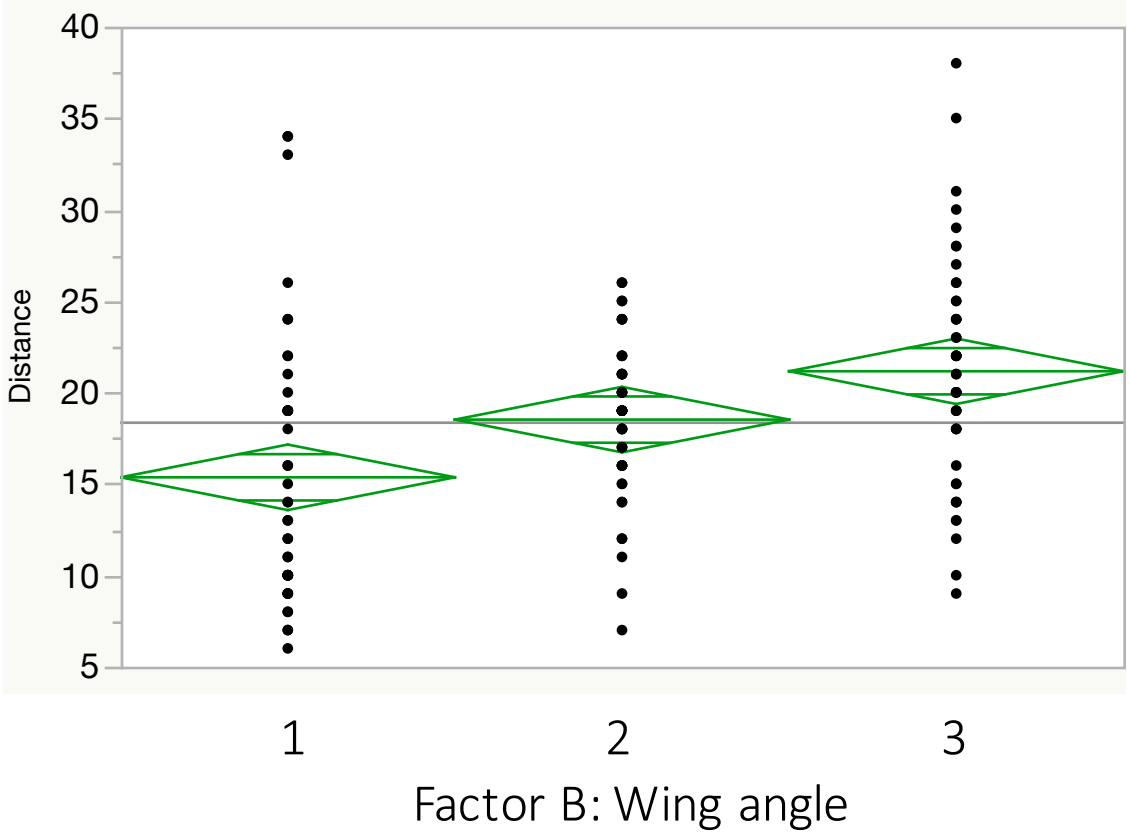




Main Effect – Factor B

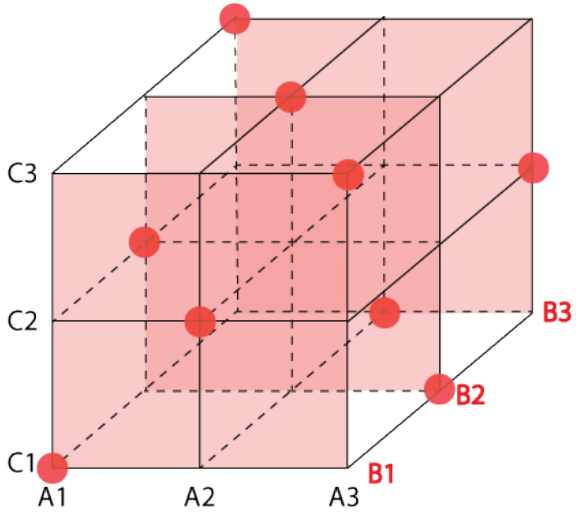
Full Factorial Design

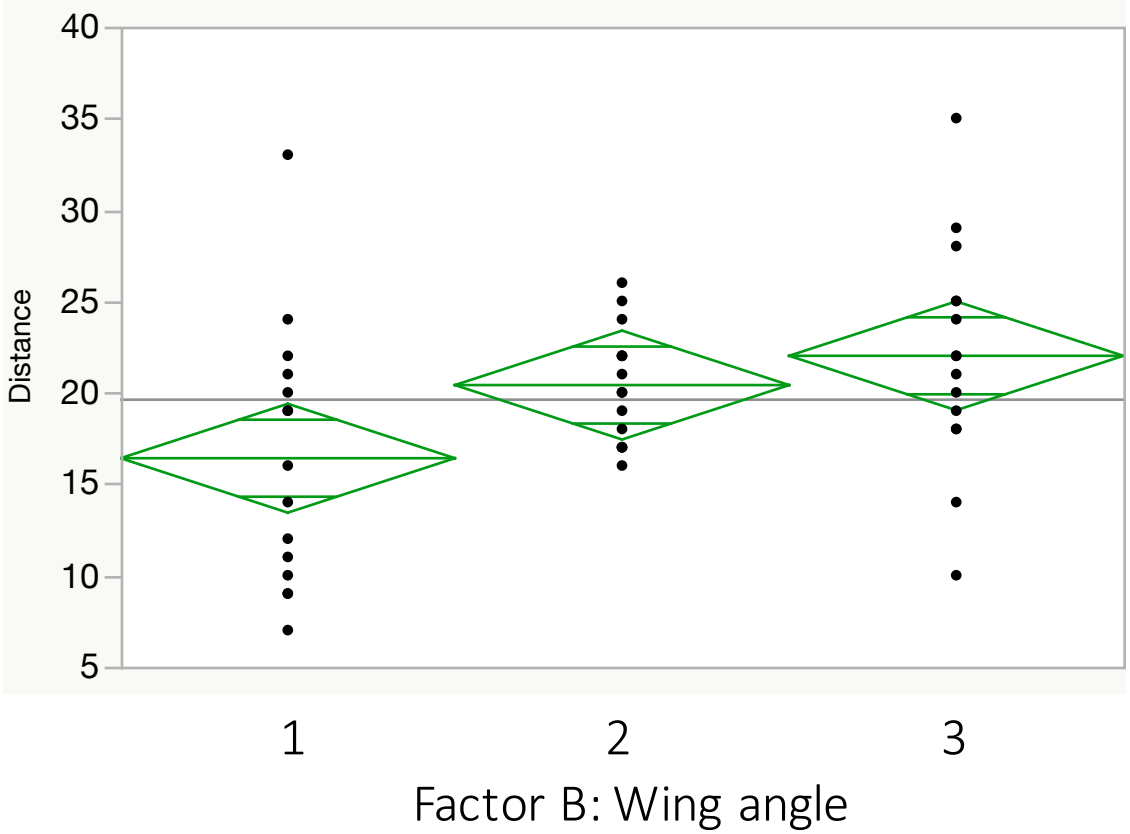




Main Effect – Factor B

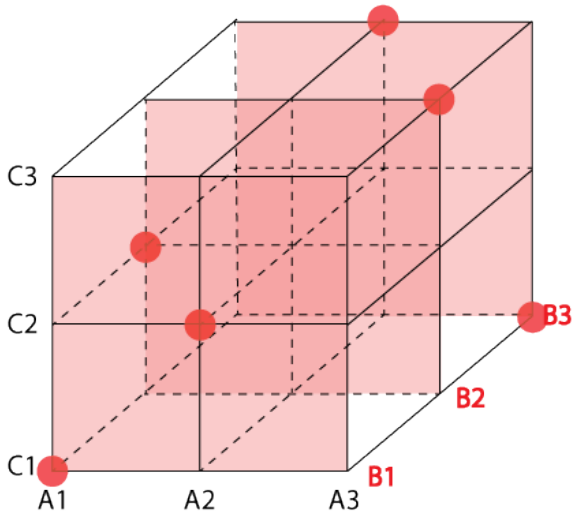
Fractional Factorial Design – 9 configurations

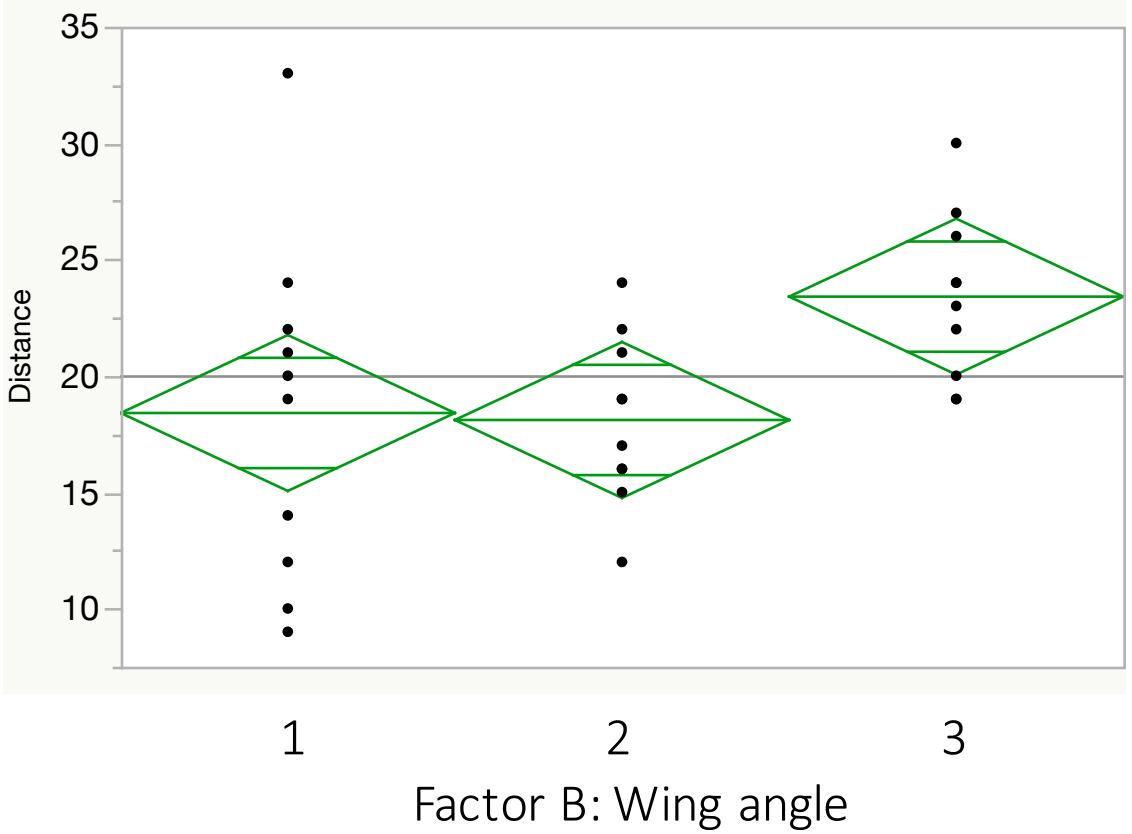




Main Effect – Factor B

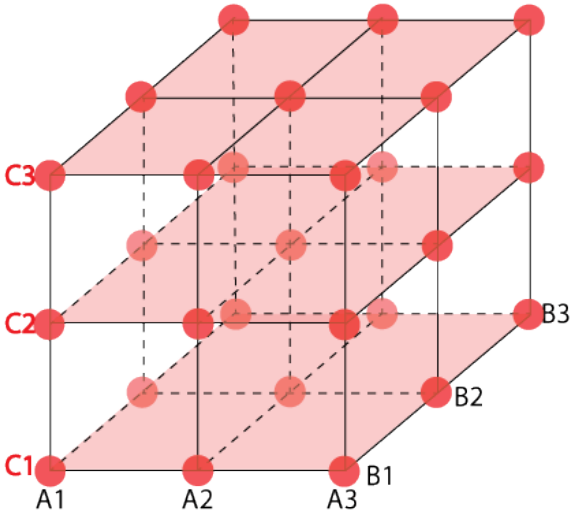
Fractional Factorial Design – 6 configurations

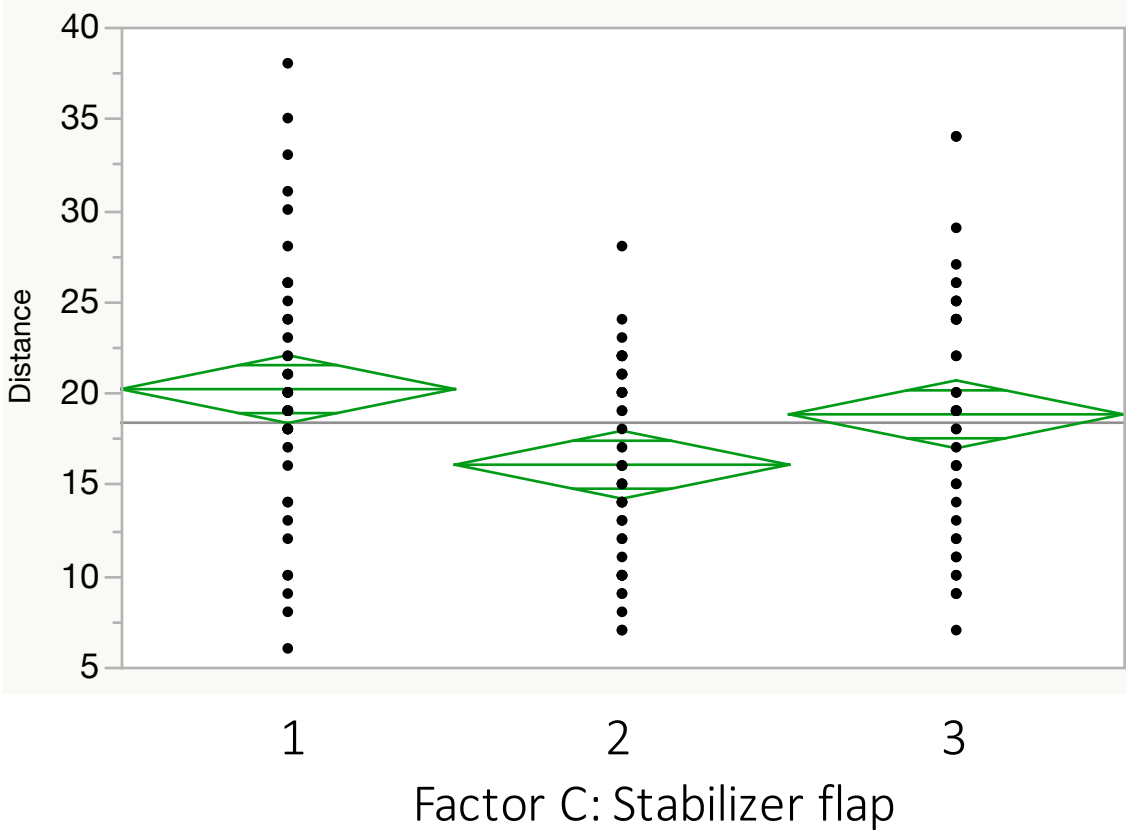




Main Effect – Factor C

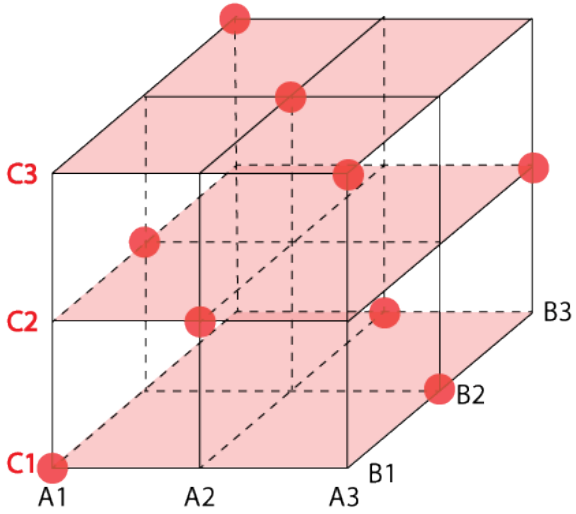
Full Factorial Factorial Design

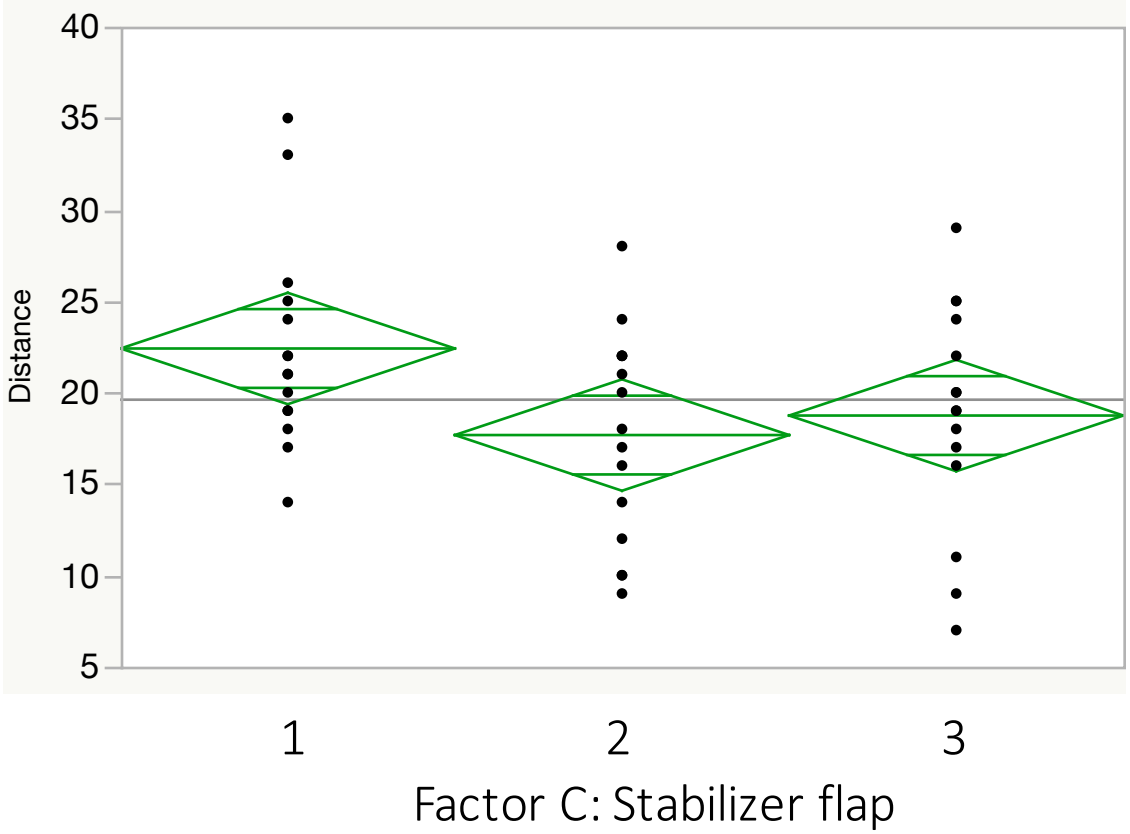




Main Effect – Factor C

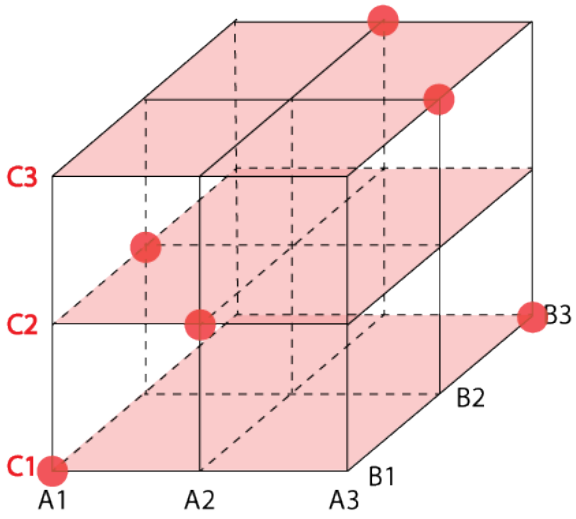
Fractional Factorial Design – 9 configurations

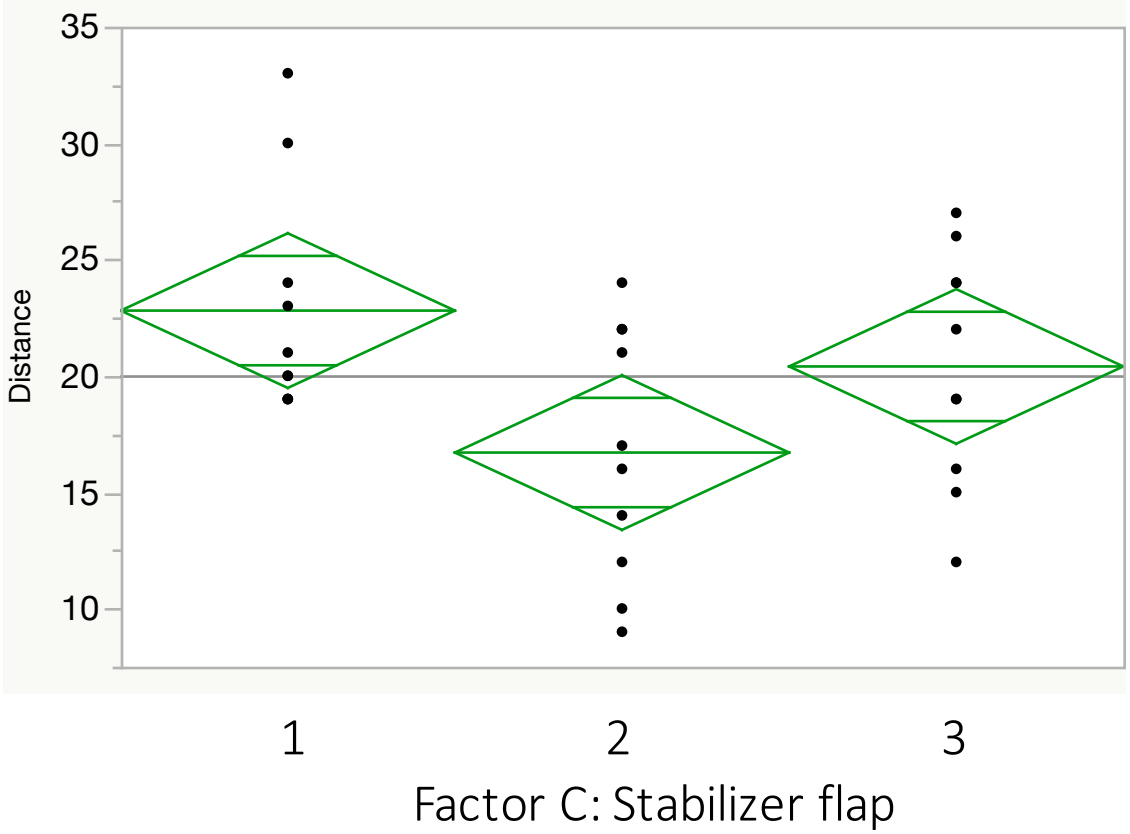




Main Effect – Factor C

Fractional Factorial Design – 6 configurations





Conclusion

Main Effect – Optimal Levels

- Factor A – Level 1
- Factor B – Level 3
- Factor C – Level 1

With only 9 or even 6 configurations of fractional factorial design, we reach the same conclusion as 27 configurations of full factorial design!

Reason: balanced levels for each factor.

Exercise

What's wrong with the following experimental design?

Configuration	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	1	1	1
5	1	2	2
6	1	3	3
7	1	1	1
8	1	2	2
9	1	3	3

Answer: All treatment has factor A = A1

Exercise

There are only 3 pieces of thick paper and 6 pieces thin paper available. We want to run a fractional factorial experiment. What's wrong with the following experimental design?

Configuration	A	B	C	
1	1	1	1	Thick Paper
2	1	2	2	
3	1	3	3	
4	2	1	2	Thin Paper
5	2	2	3	
6	2	3	1	
7	3	1	3	
8	3	2	1	
9	3	3	2	

Answer: Thick paper confounds with factor A1

Solution:

- Blocking: 1,5,9 using thick paper
- Randomization

Exercise

You have folded 9 airplanes according to the fractional factorial design of experiment. Now you want to test the designs. Which of the following testing plans is better?

Plan A: test plane No.1 five times, record the result, then test plane No.2 five times, then test plane No.3 …

Plan B: test all planes once, record the result, then test all planes twice ... in total test five times.

Answer: plan B

Reason: reduce uncertainties such as wind, you becoming tired after throwing too many paper planes…

Summary

Design of experiment strategies:

- One factor at a time
- Full factorial design
- Fractional factorial design

Analyze testing results

- Main effect
- Interaction effect

Address noise (nuisance) factors

- Repeating – use average result
- Blocking – for controllable factors
- Randomization – for uncontrollable factors