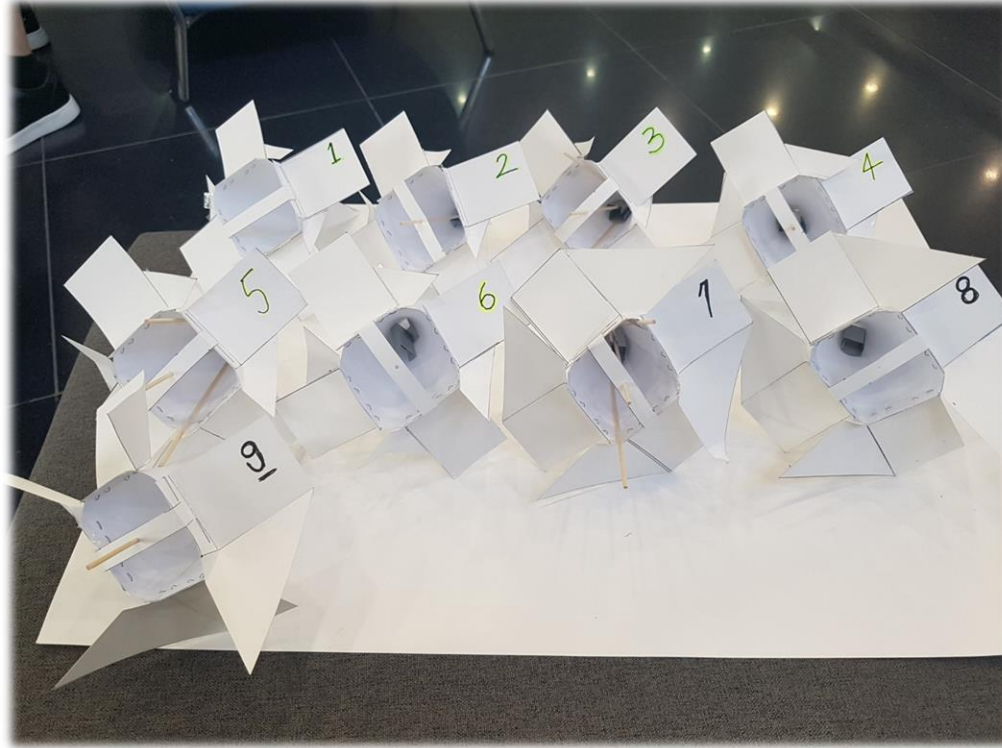


# Robust and Optimized Design for Bladed cone

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**Group 1**

Tae H. Lee, Hee J. Lee, Hyun J. Bang

# Contents

## I. Design & Control factors

- 1) Selection of control factors
- 2) P-diagram & Photo of design models

## II. Statistic analysis

- 1) Dynamic S/N ratio and  $\beta$  for each design
- 2) Parameter effect by ANOM
- 3) Parameter sensitivity by ANOVA
- 4) Ideal functions with initial and optimal designs
- 5) P.D.F with initial and optimal designs

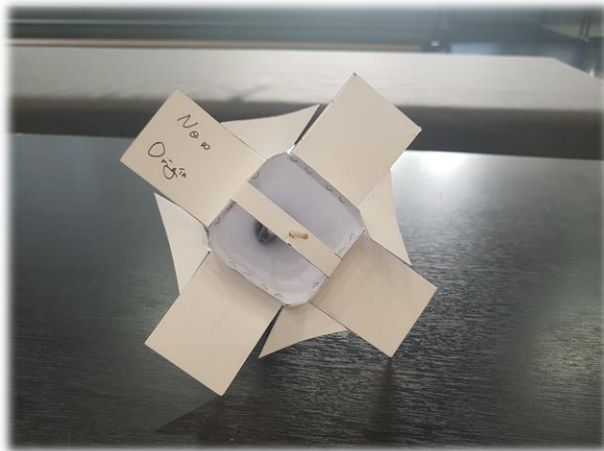
## III. Interpretation

- 1) Engineering interpretation of optimal design
- 2) Interaction plots
- 3) Distinct features (originally unique and creative design idea)



# Selection of Control factors

**Function:** Flight (비행)



## Design factors

날개 치수

날개 개수

콘의 형태

재질

무게중심

중심 손잡이

## Specification

4cm X 6 cm (직사각형)

4 (개)

14 cm X 14 cm (부채꼴)

A4용지와 도화지

Stapler 심 (Bulk 1개)

꼬치 나무

## Improvement

Target: 제공시간 길게 (Larger the better)

# Selection of Control factors

## Candidates for Control factors

### Noise factors

1. Human factor
2. Rain condition

### A $\tau$ (Space time) $\propto$ Resistnace

넓이

1. 날개 폭
2. 날개 수
3. 날개 길이
4. 이음새
5. 콘의 각도

### B $\tau$ (Space time) $\propto$ $\Delta$ Pressure

유체 흐름 (압력 조정)

1. 날개 각도
2. 콘 구멍 (유체의 흐름)
4. 날개의 송곳 구멍 (부력)
5. 날개 곡률 (기하적 유체 저항)
6. 이음새 각도 (베르누이)

### C $\tau$ (Space time) $\propto$ Flow direction

유동 방향

1. 콘의 높이
2. 옆면 자르기
3. 회전 방향
5. 콘의 각도
6. 이음새 각도

### D $\tau$ (Space time) $\propto$ Stiffness

강도 Stiffness (비바람)

1. 겹 (장수)
2. 재질 변화
3. 덧대기

# Selection of Control factors

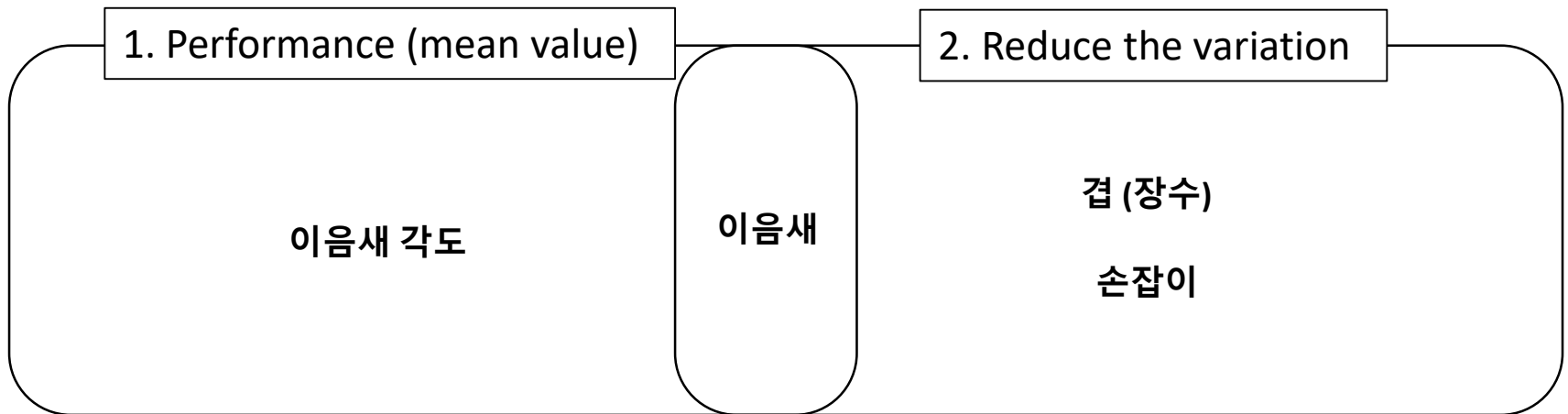
## Selected Control factors

### Function

1. Prolong the flight time

### Noise factors

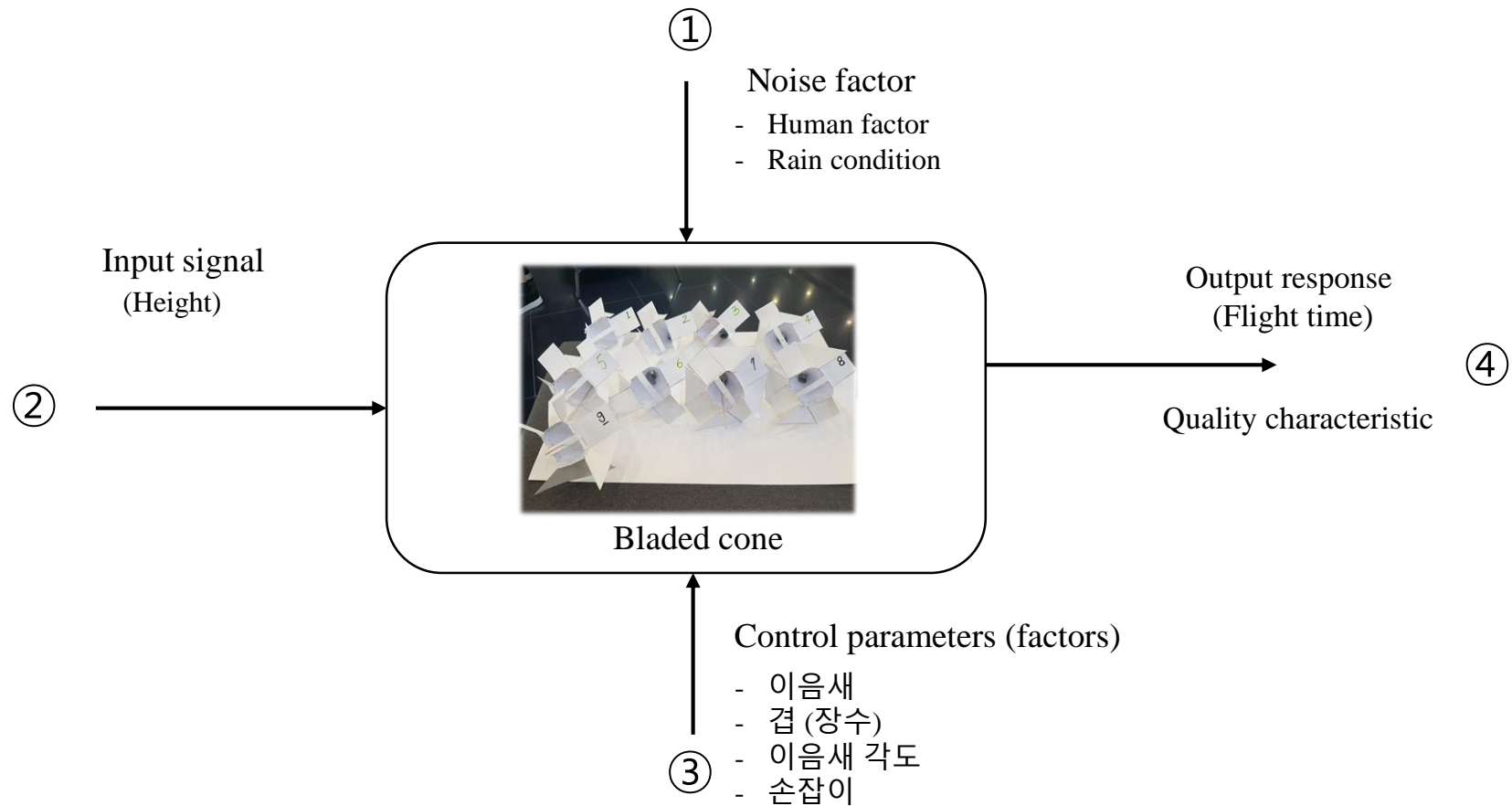
1. Human factor
2. Rain condition



➔ P-Diagram

# P-Diagram & Photo of Design Model

## Parameter Diagram (P-Diagram)



Orthogonal array (L9, 3<sup>4</sup>)

Run	이음새 (ratio)	이음새 각도 (°)	손잡이 (개)	Stiffness (결)
1	¼ Cover	30°	0	1
2	¼ Cover	45°	1	2
3	¼ Cover	60°	3	3
4	½ Cover	30°	1	3
5	½ Cover	45°	3	1
6	½ Cover	60°	0	2
7	1 cover	30°	3	2
8	1 cover	45°	0	3
9	1 cover	60°	1	1
Original	½ cover	45°	1	2

\*이음새 (ratio) 날개길이 대비

# Results – (1)

## Noise factor (Rain) – Reference state

2m	태혁	희재	현준	2.8m	태혁	희재	현준	4.9m	태혁	희재	현준
Input 1	Noise1			Input 2	Noise1			Input 3	Noise1		
1	1.32 s	1.25 s	0.92 s	1	1.29s	1.32 s	1.41 s	1	2.16s	2.05 s	2.16 s
2	1.1 s	0.98 s	0.79 s	2	1.22s	1.32 s	1.29 s	2	1.88s	1.71 s	1.8 s
3	0.98 s	0.93 s	0.96 s	3	1.35s	1.32 s	1.19 s	3	1.70s	1.97 s	1.65 s
4	1.12 s	0.92 s	0.92s	4	1.52s	1.18 s	1.06 s	4	1.93s	1.77 s	1.75 s
5	1.09 s	0.92 s	0.92s	5	1.33s	1.38 s	1.29 s	5	2.02s	2.01 s	1.96 s
6	1.23 s	1.00 s	0.93s	6	1.3s	1.12 s	1.39 s	6	2.03s	1.84 s	1.9 s
7	1.16s	1.00 s	1.05s	7	1.33s	1.25 s	1.4 s	7	2.02s	2.11 s	1.96 s
8	0.98s	1.13 s	0.99s	8	1.32s	1.29s	1.5 s	8	1.86s	1.91s	2.04 s
9	1.06s	1.12s	1.12s	9	1.45s	1.31s	1.45 s	9	2.25s	2.17s	2.15 s
<b>(Origin)</b>	1.03s	1.12s	1.06s	<b>(Origin)</b>	1.38s	1.39s	1.43 s	<b>(Origin)</b>	2.01s	2.04s	2.02 s



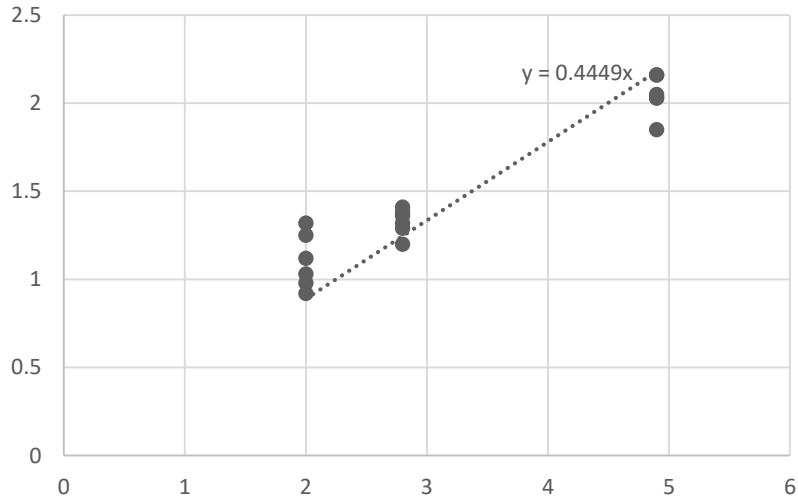
## Results – (2)

### Noise factor (Rain) – Rain condition

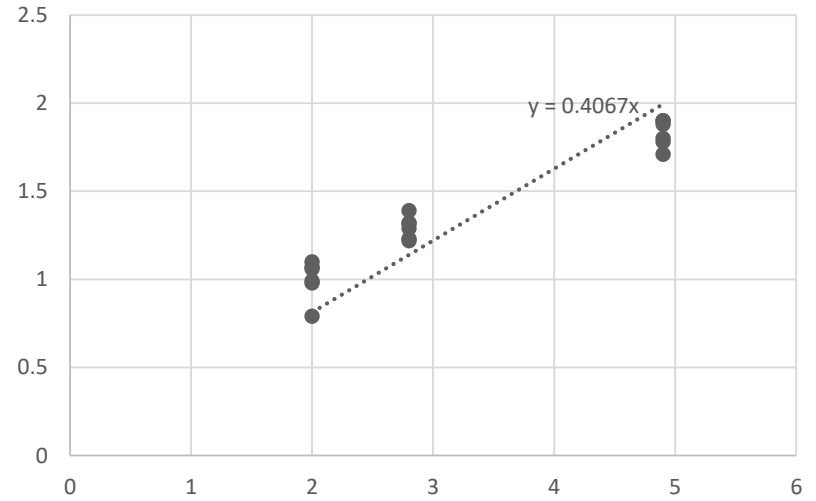
2m	태혁	희재	현준	2.8m	태혁	희재	현준	4.9m	태혁	희재	현준
Input 1	Noise1			Input 2	Noise1			Input 3	Noise1		
1	0.98s	1.12s	1.03 s	1	1.36s	1.20s	1.38s	1	1.85s	2.03s	2.03s
2	0.99s	1.06s	1.07 s	2	1.23s	1.32s	1.39s	2	1.9s	1.78s	1.9s
3	0.96s	1.38s	1.12 s	3	1.26s	1.21s	1.19s	3	1.65s	1.84s	1.65s
4	0.98s	0.86s	1.00 s	4	1.30s	1.12s	1.38s	4	1.85s	1.91s	2.1s
5	1.2s	0.92s	1.12 s	5	1.35s	1.26s	1.32s	5	2.0s	2.10s	1.9s
6	1.05s	1.06s	0.93 s	6	1.26s	1.38s	1.38s	6	2.13s	1.90s	1.97s
7	1.11s	0.99s	1.13 s	7	1.32s	1.25s	1/45s	7	1.95s	1.96s	1.98s
8	1.03s	0.86s	1.16 s	8	1.3s	1.19s	1.25s	8	1.98s	1.96s	1.9s
9	1.13s	1.06s	0.96 s	9	1.29s	1.25s	1.39s	9	2.05s	2.03s	2.02s
<b>(Origin)</b>	1.03s	0.92s	0.96 s	<b>(Origin)</b>	1.32s	1.18s	1.39s	<b>(Origin)</b>	1.98s	1.91s	1.97s

# Statistic Analysis – (Ideal function for each models)

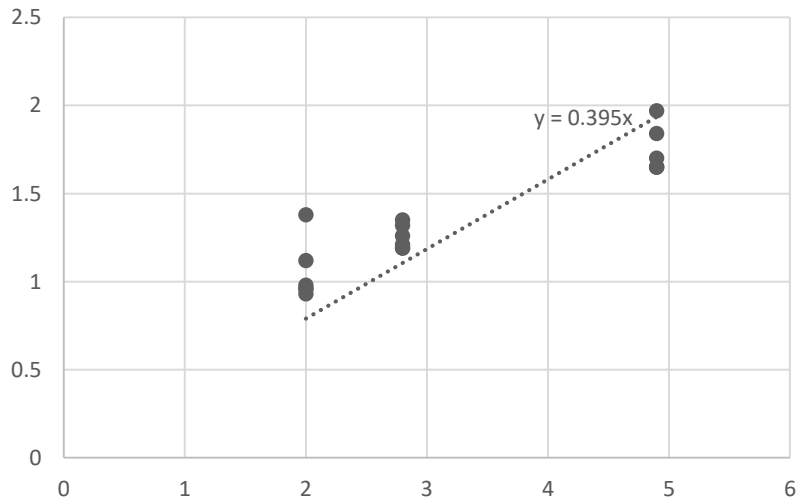
**Model 1**



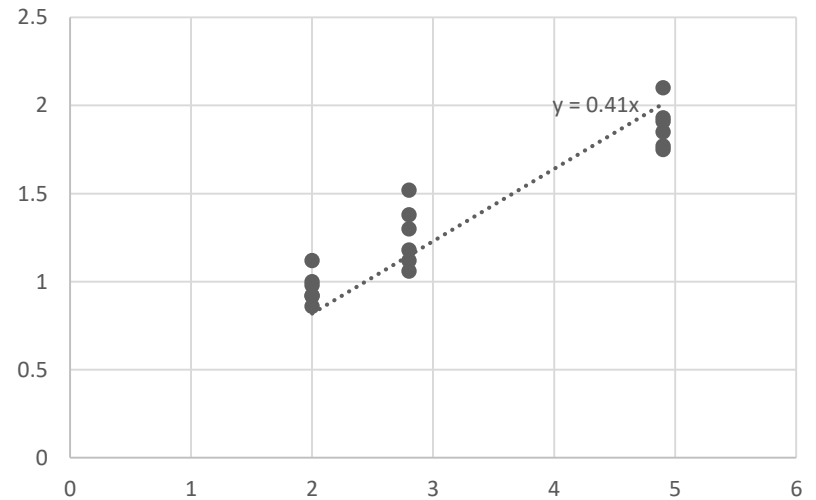
**Model 2**



**Model 3**

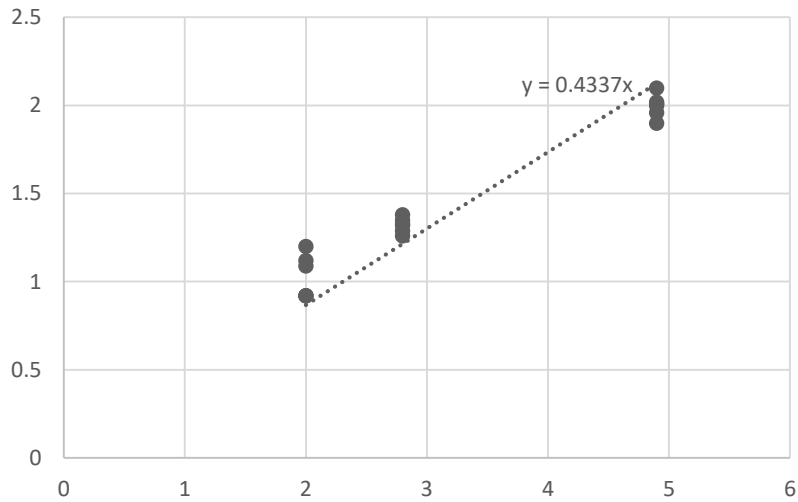


**Model 4**

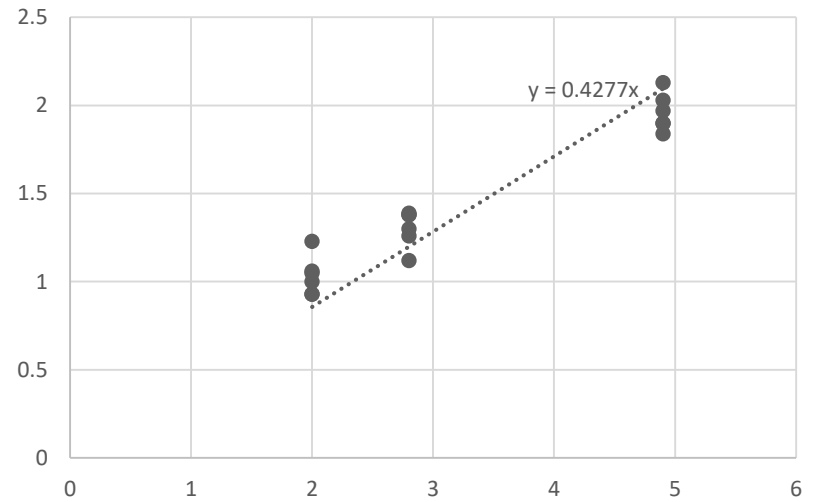


# Statistic Analysis – (Ideal function for each models)

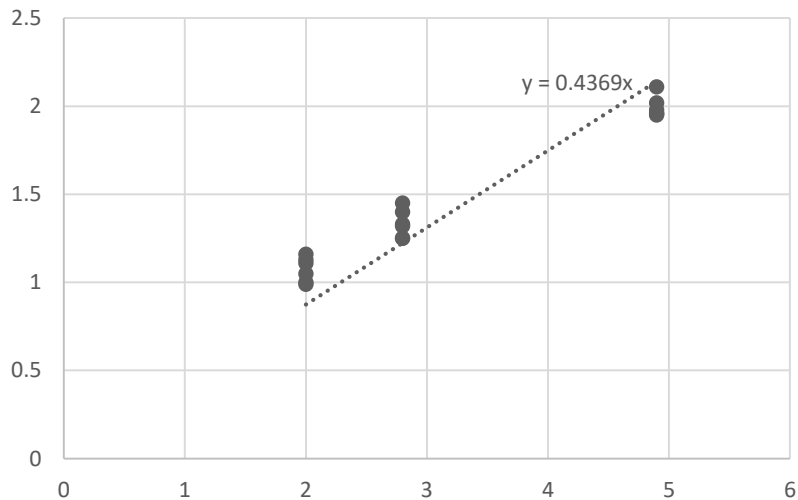
### Model 5



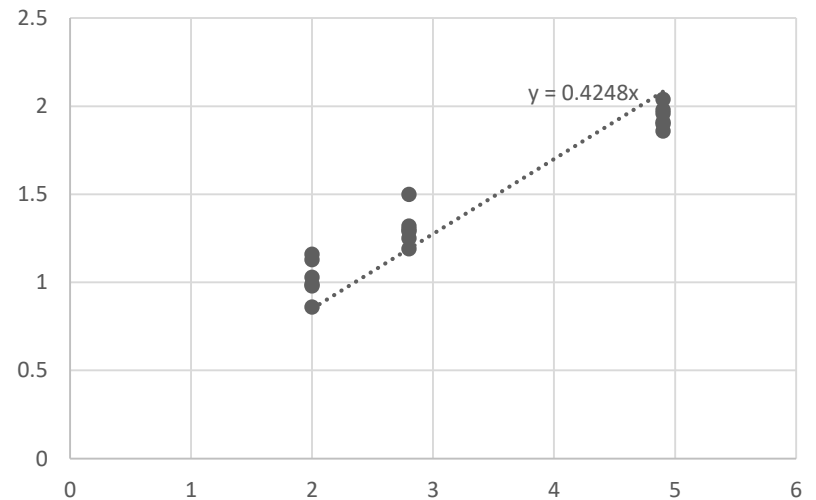
### Model 6



### Model 7

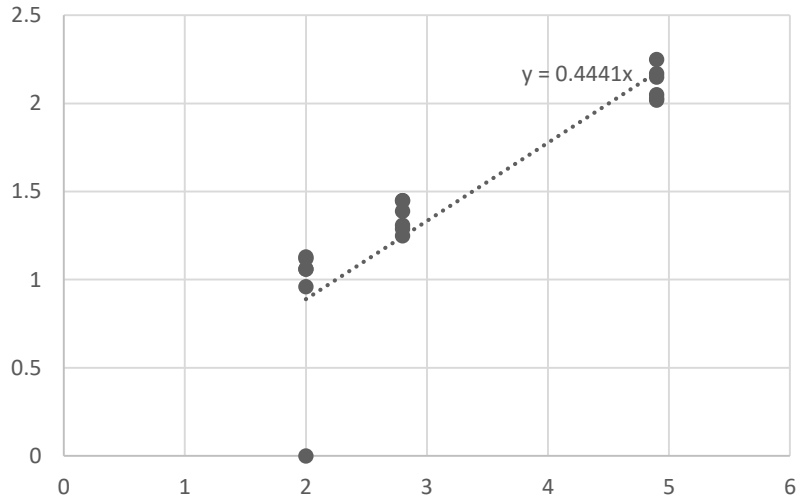


### Model 8

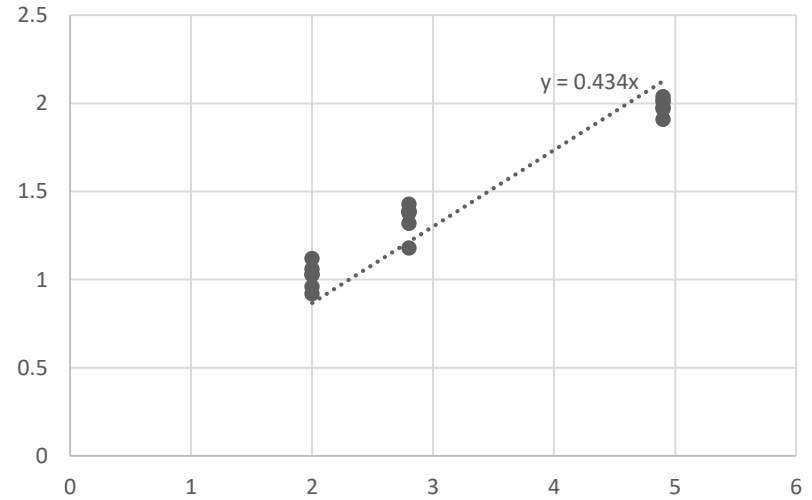


# Statistic Analysis – (Ideal function for each models)

**Model 9**



**Model Original**



<b>B1</b>	<b>B2</b>	<b>B3</b>	<b>B4</b>	<b>B5</b>	<b>B6</b>	<b>B7</b>	<b>B8</b>	<b>B9</b>	<b>B origin</b>
0.4449	0.4067	0.395	0.41	0.4337	0.4277	0.4369	0.4248	0.4441	0.434

Dynamic S/N ratio &  $\beta$  (slope) for each models

Model	이음새 (ratio)	이음새 각도	손잡이 개수	Stiffness (겹)	SSt	SSb	SSv	MSE	B (slope)	S/N ratio
1	0.25	30°	0	1	43.2136	42.57782427	0.635775732	0.037399	0.4449	7.236698
2	0.25	45°	1	2	36.2123	35.58496105	0.627338954	0.036902	0.4067	6.51495
3	0.25	60°	3	3	34.6001	33.56532264	1.034777359	0.060869	0.395	4.087962
4	0.5	30°	1	3	36.7233	36.15503007	0.568269926	0.033428	0.41	7.01462
5	0.5	45°	3	1	40.8937	40.46470026	0.428999744	0.025235	0.4337	8.723707
6	0.5	60°	0	2	39.886	39.34657373	0.539426272	0.031731	0.4277	7.607953
7	1	30°	3	2	41.5746	41.0628374	0.511762603	0.030104	0.4369	8.021445
8	1	45°	0	3	39.3299	38.80782531	0.522074686	0.03071	0.4248	7.690853
9	1	60°	1	1	44.832	44.4442149	0.3877851	0.022811	0.4441	9.368193
(Origin)	0.5	45°	1	2	40.9476	40.51155649	0.43604351	0.02565	0.434	8.658986

## Parameter effect - ANOM (S/N), ( $\bar{y}$ )

[S/N ratio]

이음새 (Ratio)	ANOM (S/N)
0.25	5.946536639
0.5	7.782093408
1	8.360163716

이음새 (Angle)	ANOM (S/N)
30°	7.42425404
45°	7.643170148
60°	7.021369575

손잡이 (개)	ANOM (S/N)
0	7.511834718
1	7.632587742
3	6.944371303

Stiffness (겹)	ANOM (S/N)
1	8.44286623
2	7.38144934
3	6.26447819

[ $\bar{y}$  (average flight time)]

이음새 (Ratio)	ANOM ( $\bar{y}$ )
0.25	1.405555556
0.5	1.417777778
1	1.468518519

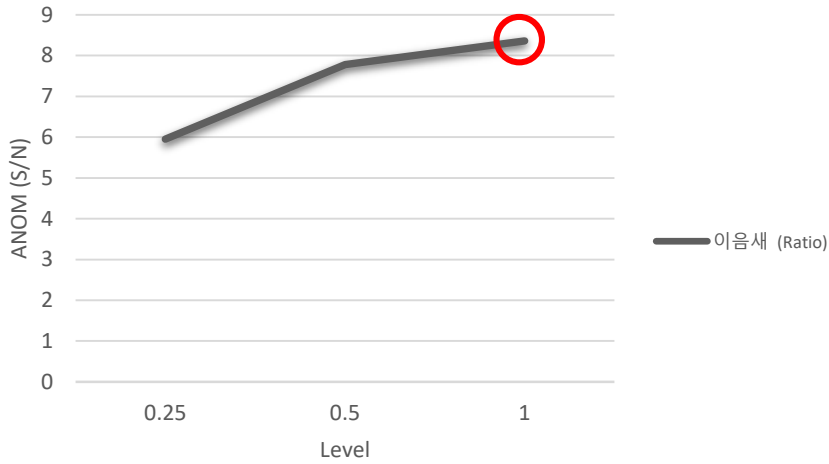
이음새 (Angle)	ANOM ( $\bar{y}$ )
30°	1.443518519
45°	1.416111111
60°	1.432222222

손잡이 (개)	ANOM ( $\bar{y}$ )
0	1.450185185
1	1.419074074
3	1.422592593

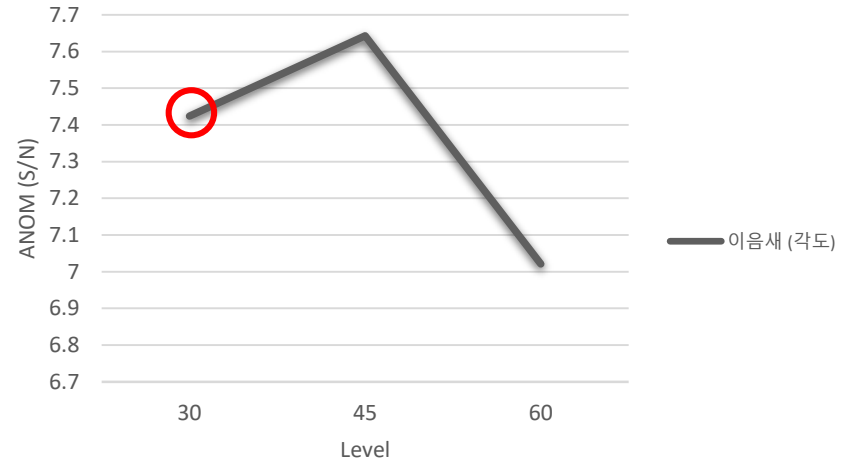
Stiffness (겹)	ANOM ( $\bar{y}$ )
1	1.484814815
2	1.425
3	1.382037037

# Parameter effect - ANOM (S/N), ( $\bar{y}$ )

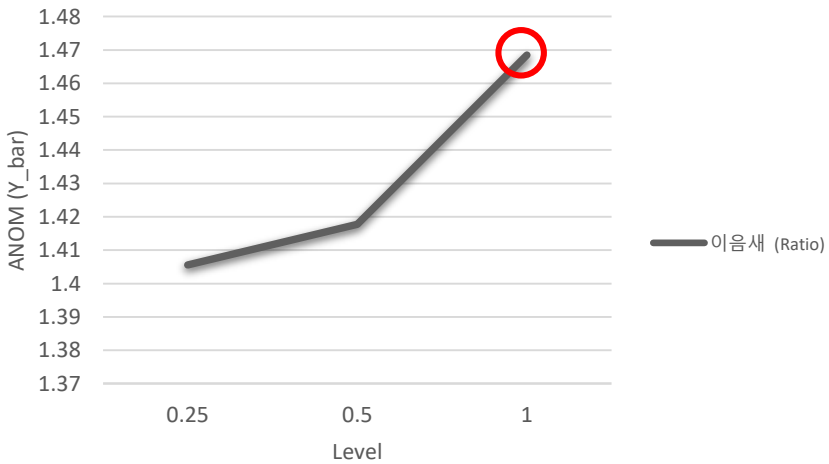
ANOM - (S/N, 이음새 Ratio)



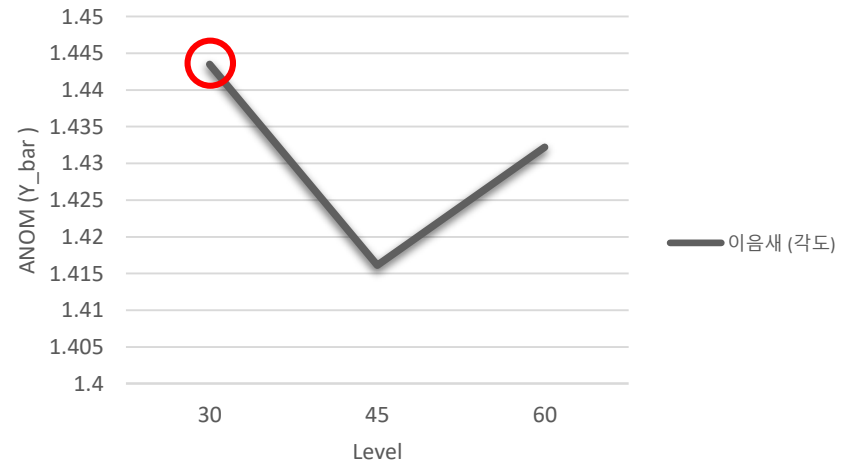
ANOM - (S/N, 이음새 각도)



ANOM - ( $\bar{Y}_{bar}$ , 이음새 Ratio)

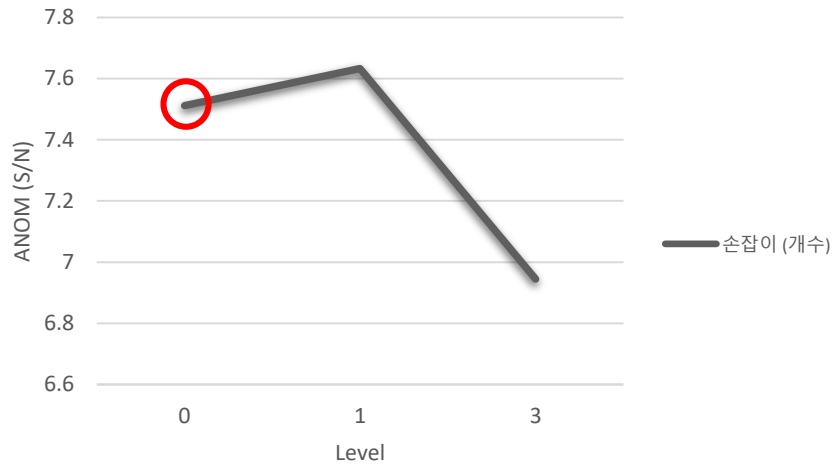


ANOM - ( $\bar{Y}_{bar}$ , 이음새 각도)

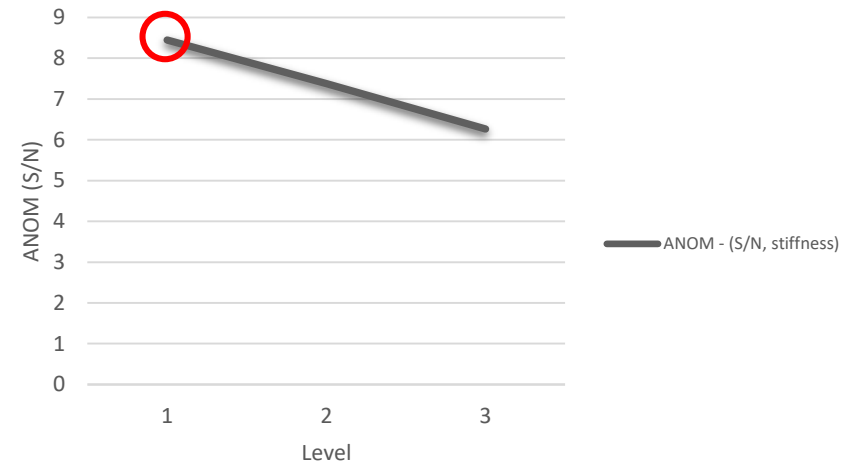


# Parameter effect - ANOM (S/N), ( $\bar{y}$ )

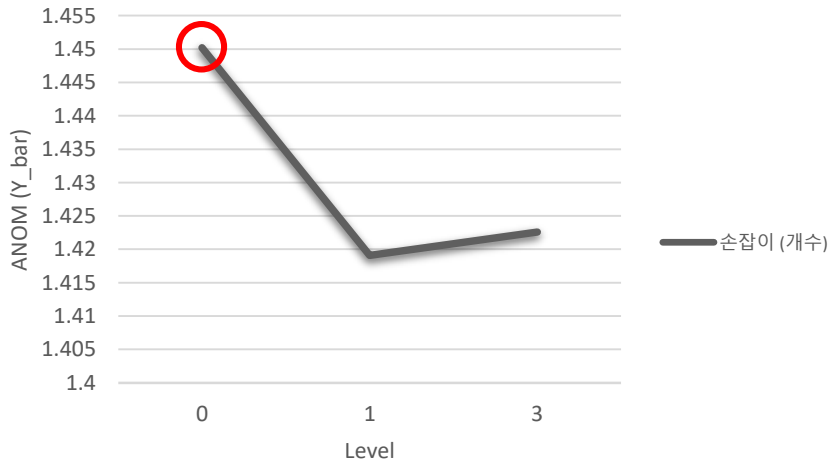
### ANOM - (S/N, 손잡이 개수)



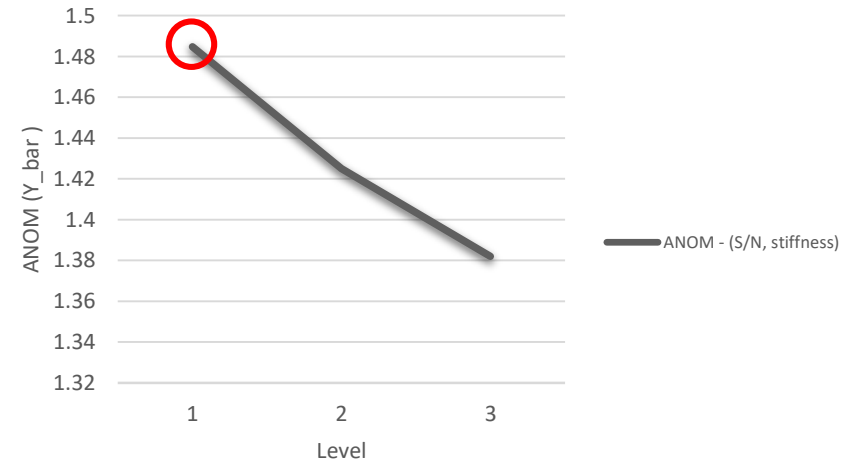
### ANOM - (S/N, Stiffness 겹)



### ANOM - ( $\bar{Y}$ , 손잡이 개수)



### ANOM - ( $\bar{Y}$ , Stiffness 겹)

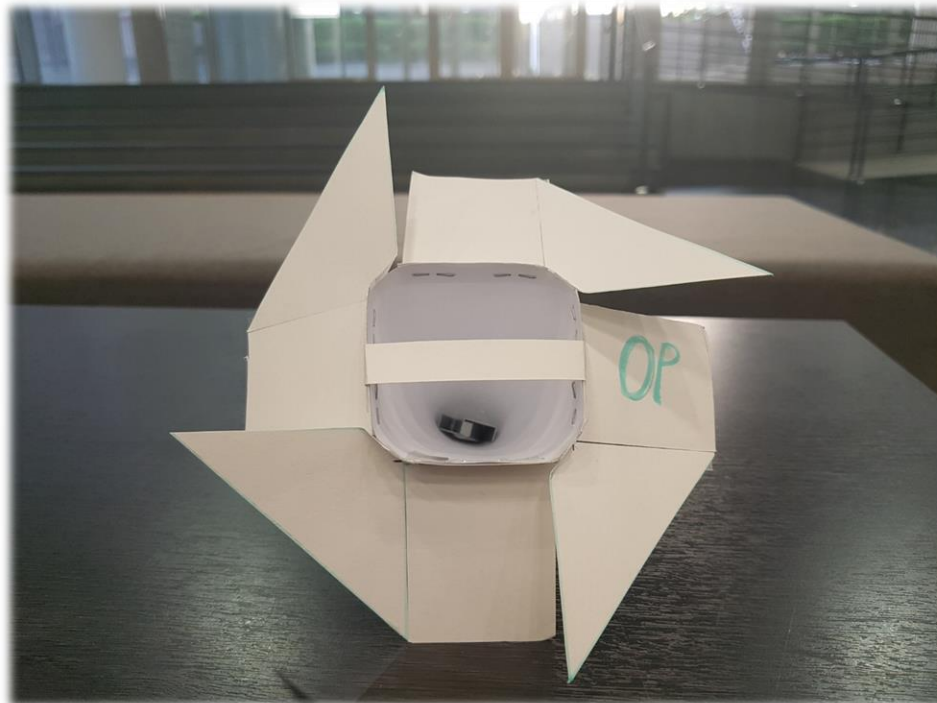




# Optimized Factors

Optimized Design			
이음새 ratio	이음새 angle	손잡이 개수	Stiffness 겹
1:1	30°	0	1

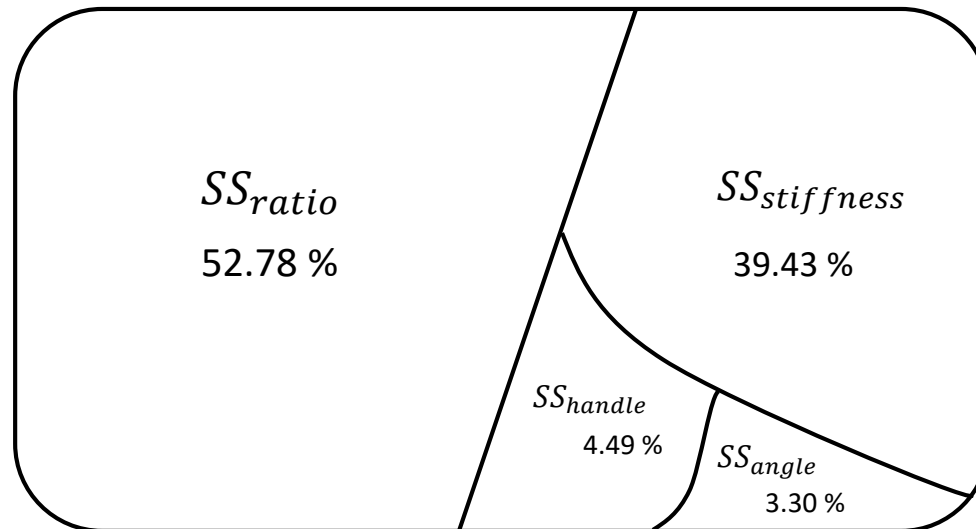
\* 이음새 ratio: 날개길이 대비



# Parameter sensitivity - ANOVA

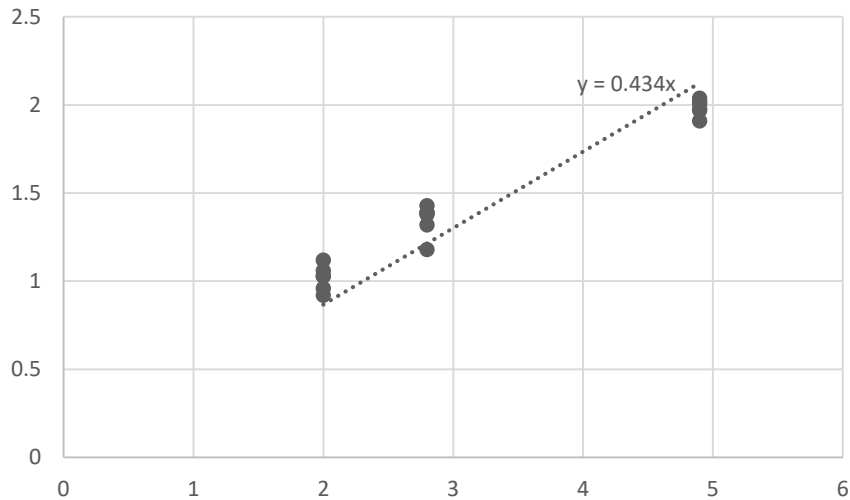
	TSS	SS(ratio)	SS (angle)	SS (손잡이)	SS (굽)
Value	18.056	9.529	0.597	0.811	7.120
Percentage (%)	100%	52.78 %	3.30 %	4.49%	39.43%

Model variance (TSS-error) – 100%

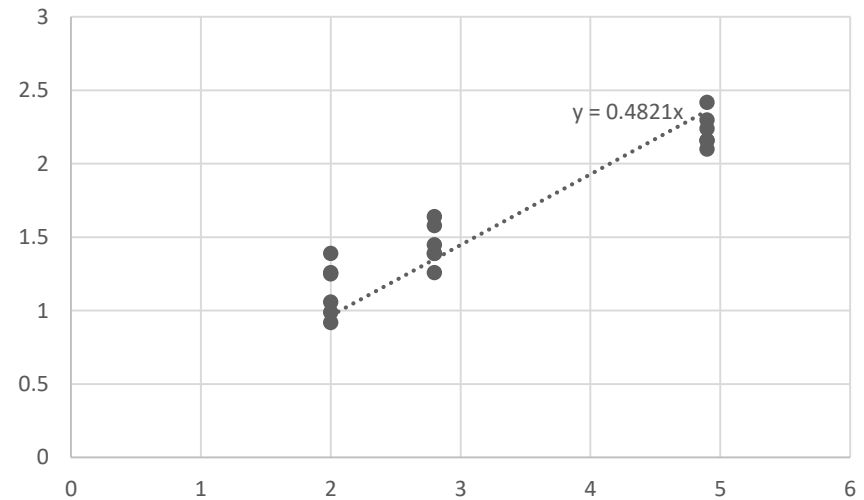


# Ideal Function (Optimized and Initial models)

### Model Original



### Model Optimized



$$B_{origin} = 0.434$$

&lt;

$$B_{optimized} = 0.4821$$

**Cost**

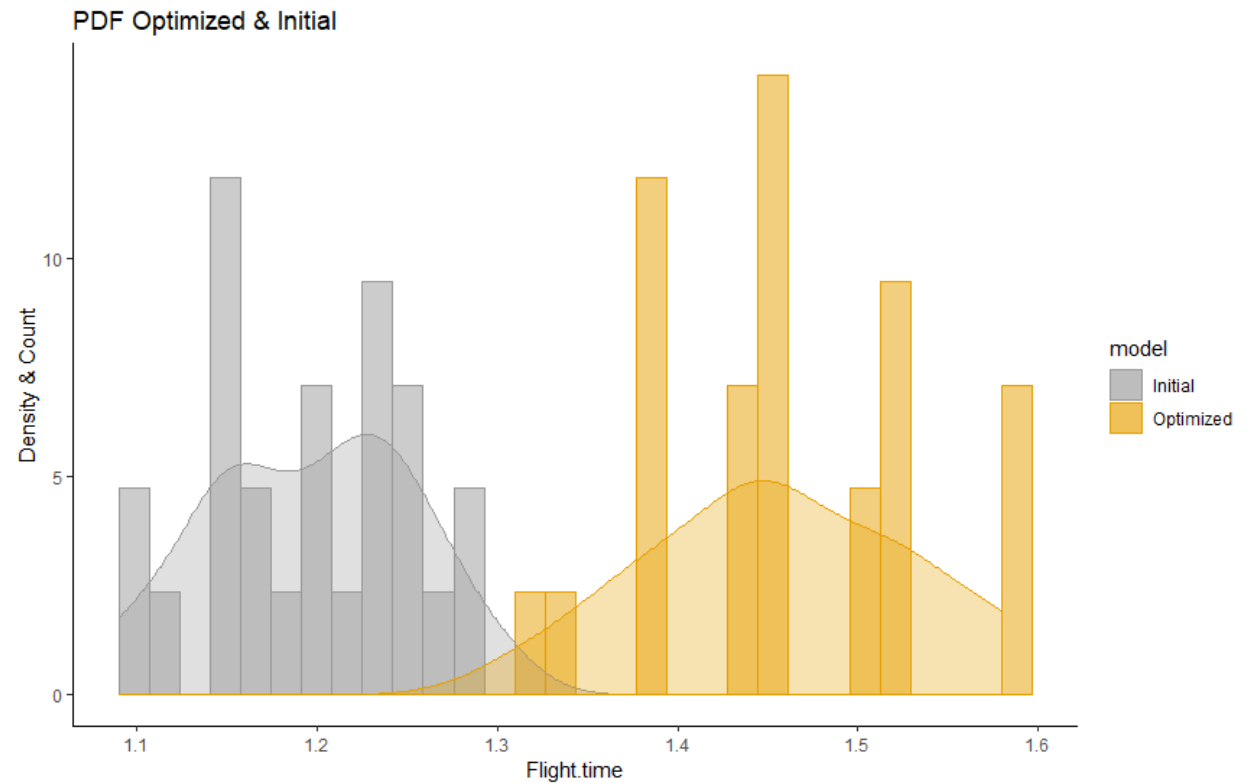
$$Std_{origin} = 0.419139$$

&lt;

$$Std_{optimized} = 0.490161$$

# Distribution (Optimized and Initial models - PDF)

Run#	Initial (s)	Optimized (s)
1	1.1	1.51
2	1.2	1.39
3	1.09	1.45
4	1.29	1.38
5	1.23	1.38
6	1.16	1.58
7	1.23	1.38
8	1.23	1.52
9	1.15	1.45
10	1.23	1.39
11	1.19	1.32
12	1.12	1.58
13	1.29	1.44
14	1.15	1.45
15	1.15	1.51
16	1.26	1.44
17	1.25	1.45
18	1.2	1.45
19	1.25	1.52
20	1.15	1.33
21	1.16	1.52
22	1.2	1.58
23	1.25	1.52
24	1.22	1.46
25	1.15	1.44



# Optimized Design (Interpretation)

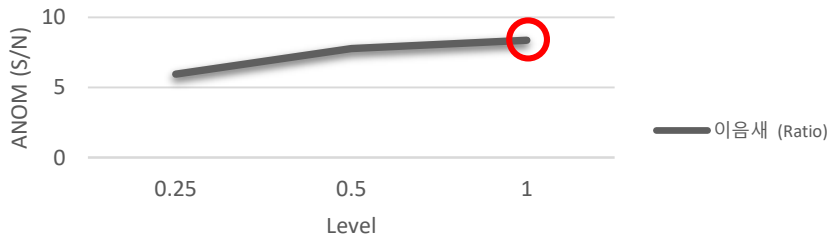
Optimized factors			
이음새 ratio	이음새 angle	손잡이 개수	Stiffness 겹
1:1	30°	0	1

## Step1) Selection of Control factors

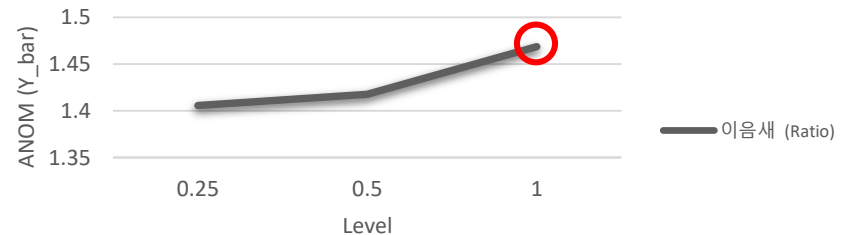
Expected effect (Performance)  
 Ratio of seam → Increase resistance area

## Step2) Statistic interpretation

ANOM - (S/N, 이음새 Ratio)



ANOM - (Y\_bar, 이음새 Ratio)



## Step3) Physical analysis

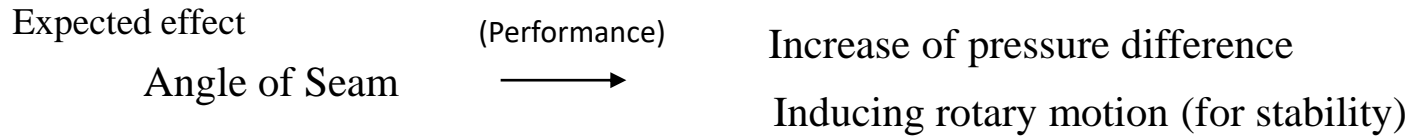
Air resistance (Drag force)

$$F_D = \frac{1}{2} \rho_{fluid} v^2 C_D A$$

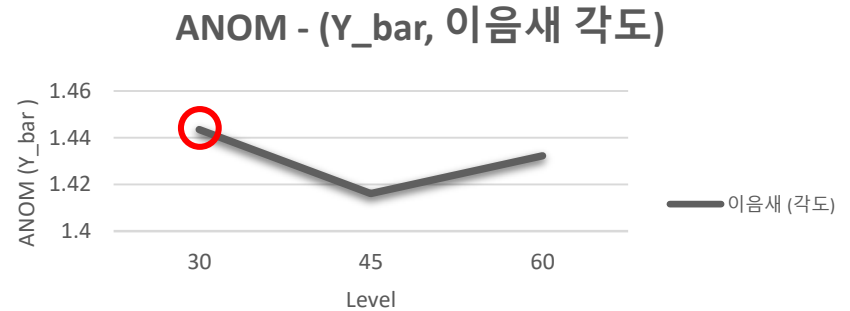
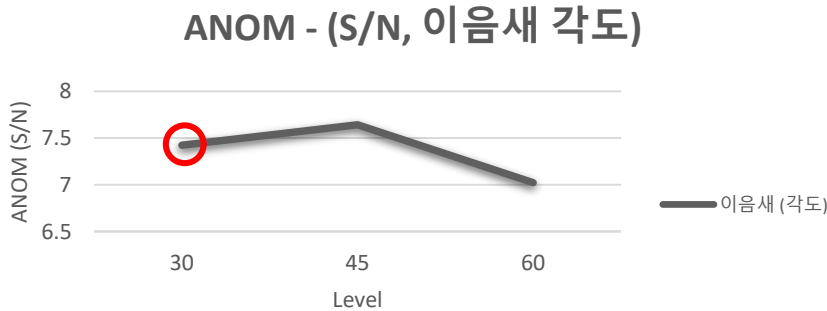
# Optimized Design (Interpretation)

Optimized factors			
이음새 ratio	이음새 angle	손잡이 개수	Stiffness 겹
1:1	30°	0	1

## Step1) Selection of Control factors



## Step2) Statistic interpretation



## Step3) Physical analysis

Bernoulli equation

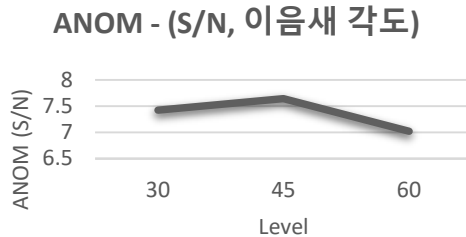
$$p + \frac{1}{2}\rho v^2 + \gamma h = Const$$

# Optimized Design (Interpretation)

## Step3) Physical analysis

Bernoulli equation

$$p + \frac{1}{2}\rho v^2 + \gamma h = Const$$

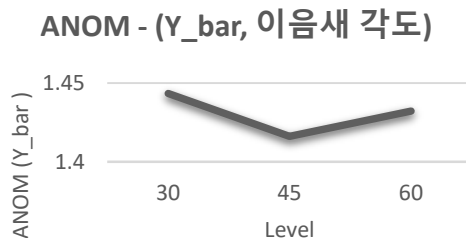


$\Delta P_{(45^\circ)} > \Delta P_{(30^\circ)}$   
 Pressure side – Suction side =  $\Delta P$



$Torque_{(45^\circ)} > Torque_{(30^\circ)}$   
 (안정성) 빠른 팻이 > 느린 팻이

At 60°, increase of angle → Unstable flow (박리 등)



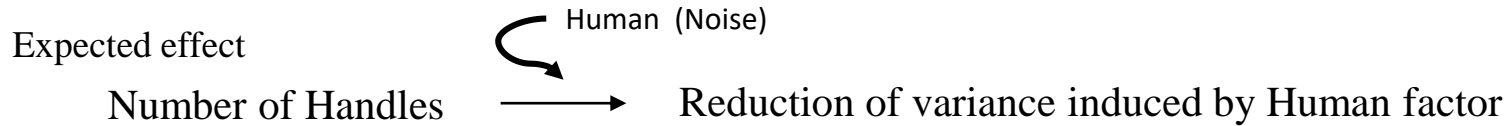
Angle of attack (어떤 각도에서)

→ 박리가 일어나며 Lift force 감소

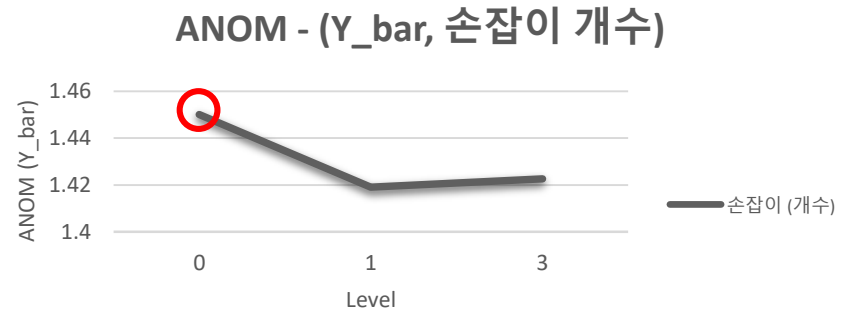
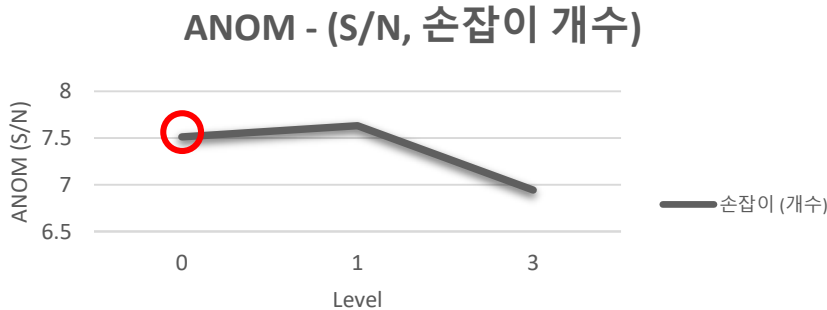
# Optimized Design (Interpretation)

Optimized factors			
이음새 ratio	이음새 angle	손잡이 개수	Stiffness 겹
1:1	30°	0	1

## Step1) Selection of Control factors



## Step2) Statistic interpretation



## Step3) Physical analysis

- 손잡이 0: 사람이 5손가락으로 잡는다
- 손잡이 1: 사람이 1손가락으로 잡는다
- 손잡이 2: 사람이 양손으로 잡는다



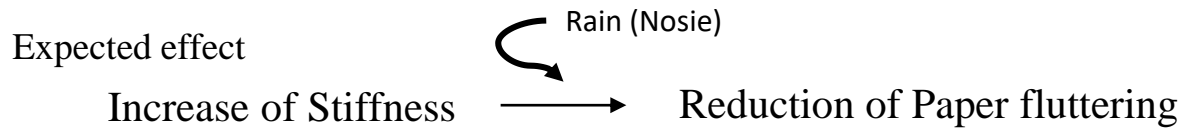
**손잡이 무게 고려**



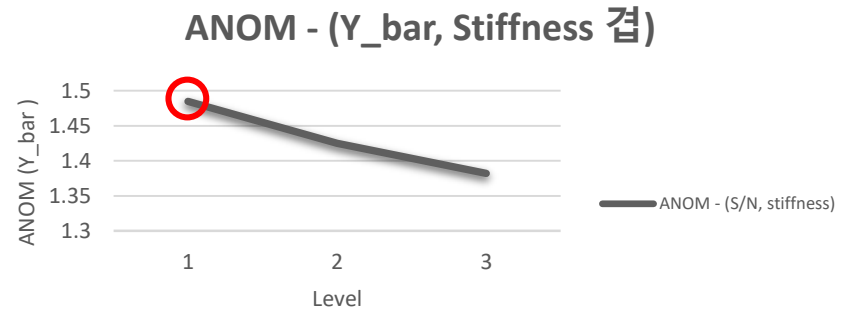
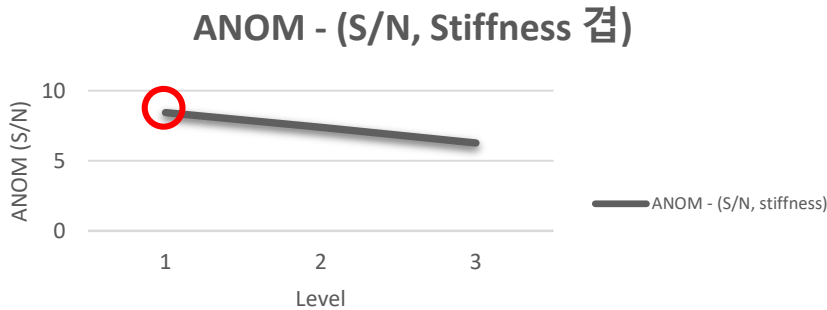
# Optimized Design (Interpretation)

Optimized factors			
이음새 ratio	이음새 angle	손잡이 개수	Stiffness 겹
1:1	30°	0	1

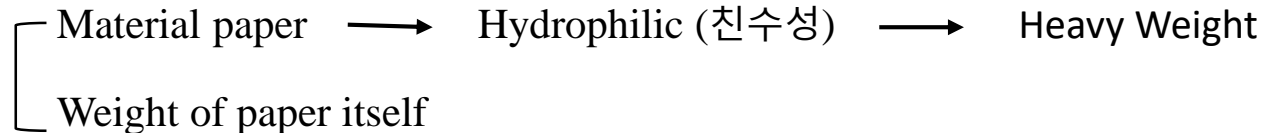
## Step1) Selection of Control factors



## Step2) Statistic interpretation



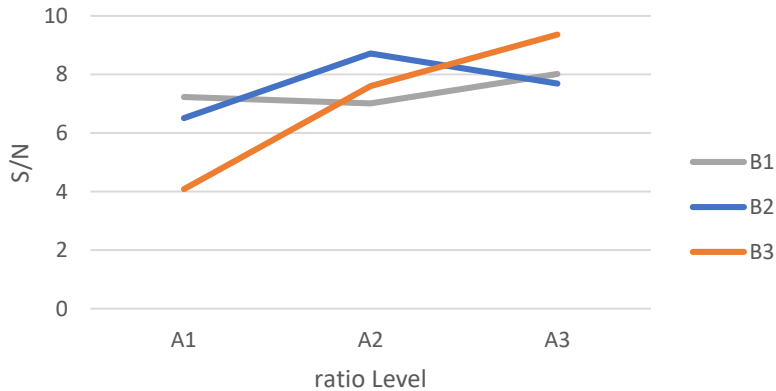
## Step3) Physical analysis



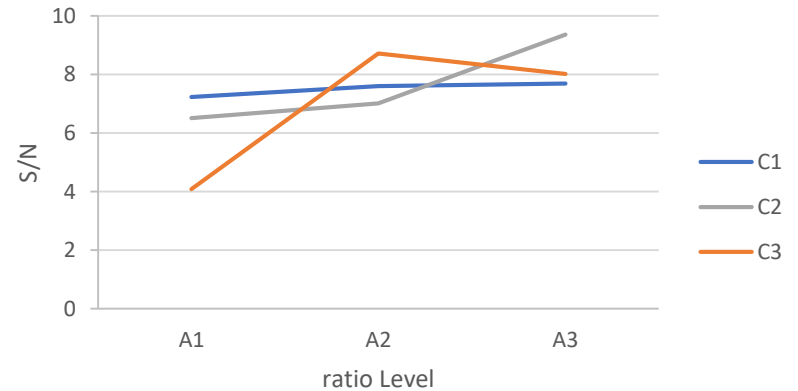
# Interaction Plots

A-B, A-C, A-D (Combination)

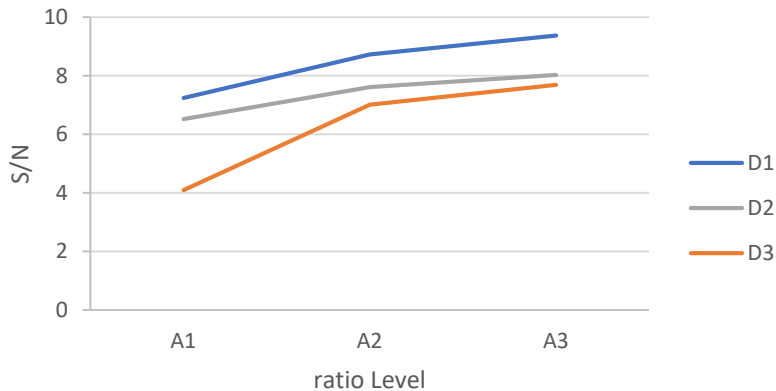
이음새 - ratio & angle



이음새 - ratio & 손잡이 수



이음새 - ratio & Stiffness (겹)



독립적

**A-D (ratio & Stiffness)**

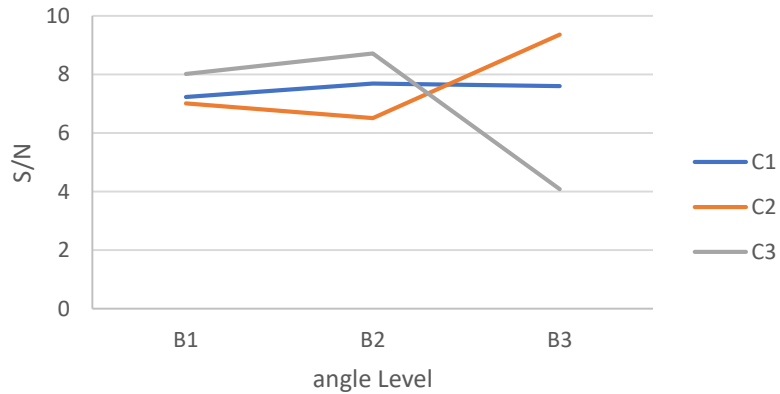
종속적

**A-B, A-C**

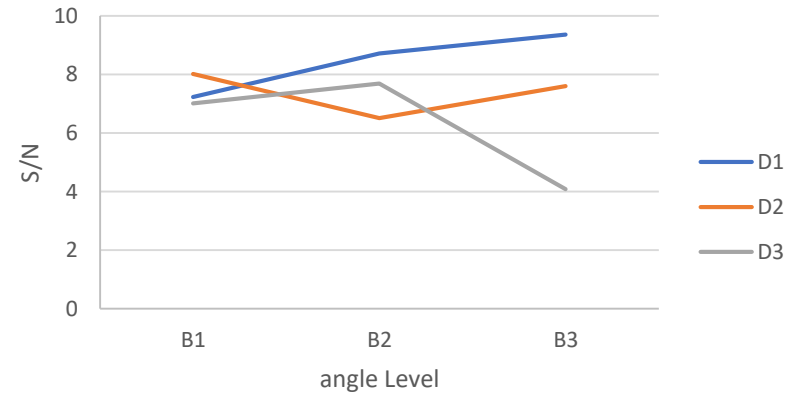
# Interaction Plots

B-C, B-D, C-D (Combination)

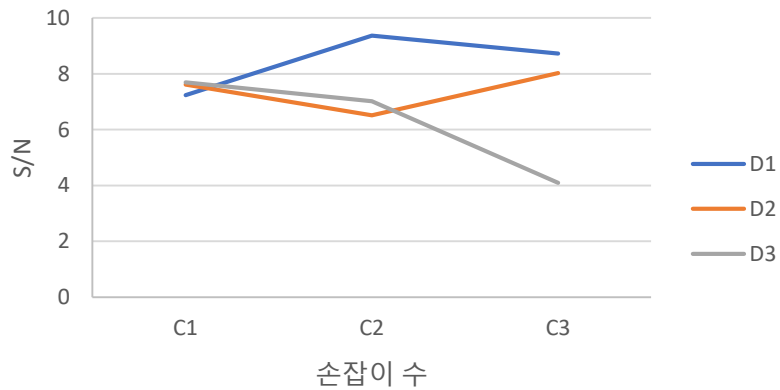
이음새 angle & 손잡이 수



이음새 angle & 손잡이 수



손잡이 수 & Stiffness (굽)



종속적

**B-C, B-D, C-D**

# Distinct Features

본 모델의 딜레마

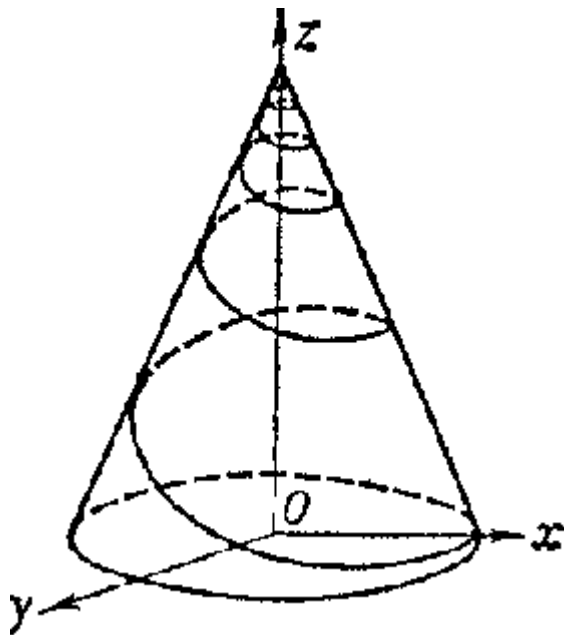
무게 감소

체공시간 늘리면 안정성 (전복 등)이 떨어짐

안정성 장치

손잡이 등의 추가 무게에 의한 체공 시간 감소

➡ 무게는 줄이면서 안정성을 높이고 체공시간을 증가시킬 수 있는 모델



## 날개 없는 원뿔 나선 모델

1. 날개를 없애고 옆면을 따라 나선형태의 이음새를 부착  
→ 넓은 면적의 이음새가 공기의 저항을 많이 받아 **체공시간 연장**
2. 이음새가 원뿔 모양을 360도로 여러 번 감아서 안정적  
→ 손잡이가 필요하지 않아 **무게 감소**

Thank you