DoE with Paper Helicopters

ISEN - 616

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Approach

Preliminary Analysis

- To identify important factors that affect flight time and optimal settings to maximize flight time.

Designing of the Experiment

- Factorial Design (2-Level Factorial Design & its Resolution)
- Specify the Number of Replicates Required for each Run.
- Identify the different levels of the Test Factors selected.
- Gather the Experiment Data & Run the Analysis.

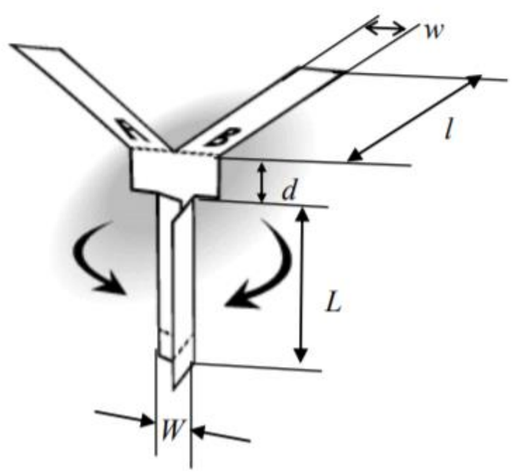
Factorial Design Charts

- Pareto Chart along with ANOVA Table
- Main Effect & Interaction Effect Plots
- Response Optimizer Plot

Preliminary Analysis

- Objective - To identify factors that affect flight time and thus improve it.
- Input factors considered which might affect the flight time are:

1) Wing length (l)
2) Wing width (w)
3) Body length (L)
4) Body width (W)
5) Middle body length (d)



Create Factorial Design: Factors

Factor	Name	Type	Low	High
A	Wing Length	Numeric	5.5	9.5
B	Wing Width	Numeric	4	6
C	Body Length	Numeric	5.5	9.5
D	Body Width	Numeric	4	6
E	Middle Body L	Numeric	2.5	4.5

Help OK Cancel

Designing of the Experiment

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Factorial Design (3 Available Options)

- We selected a 2^(5-2) fractional factorial Design - Resolution III
- K = 5 ; P = 2 ; Resolution = 3 ; Total Runs = 8
- Since we took a best 5 out of 7 replications.
- Total Number of Experiments = 5 * 8 = 40

Create Factorial Design: Designs

Designs	Runs	Resolution	2^(k-p)
1/4 fraction	8	III	2^(5-2)
1/2 fraction	16	V	2^(5-1)
Full factorial	32	Full	2^5

Number of center points per block: 0

Number of replicates for corner points: 1

Number of blocks: 1

Help OK Cancel

Fractional Factorial Design

Design Summary

Factors:	5	Base Design:	5, 8	Resolution:	III
Runs:	40	Replicates:	5	Fraction:	1/4
Blocks:	1	Center pts (total):	0		

* NOTE * Some main effects are confounded with two-way interactions.

Design Generators: D = AB, E = AC

Alias Structure

I + ABD + ACE + BCDE
A + BD + CE + ABCDE
B + AD + CDE + ABCE
C + AE + BDE + ABCD
D + AB + BCE + ACDE
E + AC + BCD + ABDE
BC + DE + ABE + ACD
BE + CD + ABC + ADE

Gathering of the Data

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- The below figure shows a design planning matrix for the first 10 runs with average flight times in Minitab.

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
	StdOrder	RunOrder	CenterPt	Blocks	Wing Length	Wing Width	Body Length	Body Width	Middle Body Length	Flight time
1	1	33	1	1	5.5	4	5.5	6	4.5	1.94
2	2	22	1	1	9.5	4	5.5	4	2.5	2.46
3	3	21	1	1	5.5	6	5.5	4	4.5	1.75
4	4	10	1	1	9.5	6	5.5	6	2.5	1.81
5	5	34	1	1	5.5	4	9.5	6	2.5	1.63
6	6	17	1	1	9.5	4	9.5	4	4.5	1.51
7	7	35	1	1	5.5	6	9.5	4	2.5	1.37
8	8	32	1	1	9.5	6	9.5	6	4.5	1.73
9	9	20	1	1	5.5	4	5.5	6	4.5	1.80
10	10	25	1	1	9.5	4	5.5	4	2.5	2.54

- The order in which certain experimental settings are applied in performing the experiment, and the order in which the responses are measured, should be randomized.
- A randomized run order is provided in the "RunOrder" column.

Analyzing the Data

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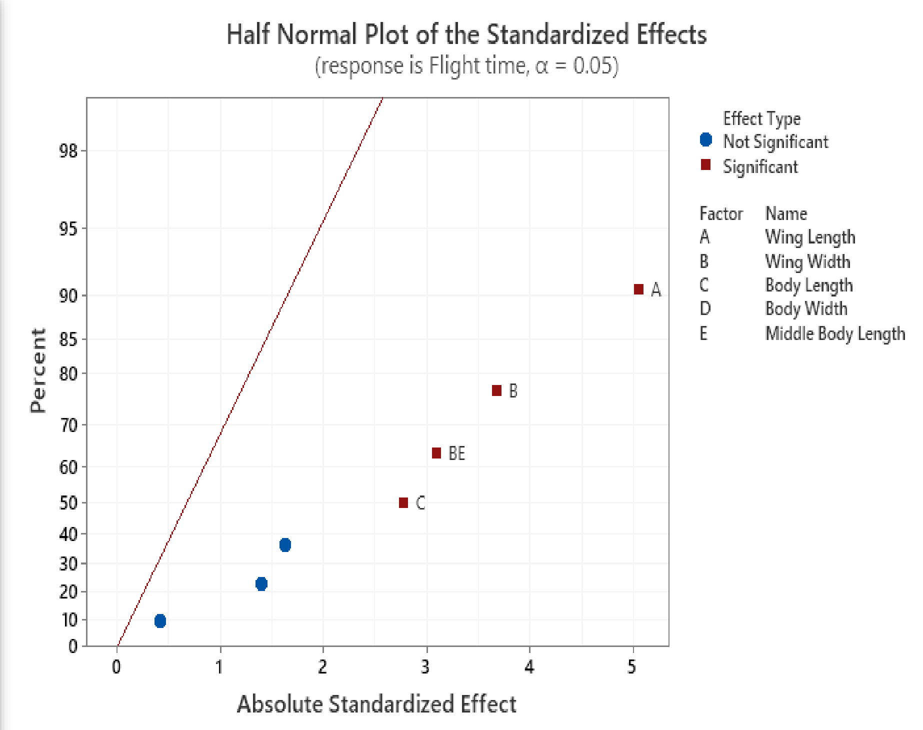
- Minitab provides a list of significant factors that influence the flight time in form of a Anova Table and Half-Normal Plot.
- The Half-Normal Plot of standardized effects shows that the main significant factors are Wing length (l), Wing width (w) and Body length (L). The interaction between Middle body length (d) and Wing width (w) also plays a significant role in influencing the response.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	2.79899	0.39986	8.70	0.000
Linear	5	2.35434	0.47087	10.24	0.000
Wing Length	1	1.16964	1.16964	25.44	0.000
Wing Width	1	0.62001	0.62001	13.49	0.001
Body Length	1	0.35344	0.35344	7.69	0.009
Body Width	1	0.12100	0.12100	2.63	0.115
Middle Body Length	1	0.09025	0.09025	1.96	0.171
2-Way Interactions	2	0.44465	0.22232	4.84	0.015
Wing Width*Body Length	1	0.00784	0.00784	0.17	0.682
Wing Width*Middle Body Length	1	0.43681	0.43681	9.50	0.004
Error	32	1.47120	0.04597		
Total	39	4.27019			

Regression Equation in Uncoded Units

Flight time = 4.177 + 0.0855 Wing Length - 0.438 Wing Width - 0.0120 Body Length - 0.0550 Body Width - 0.570 Middle Body Length - 0.0070 Wing Width*Body Length + 0.1045 Wing Width*Middle Body Length



Backward Elimination

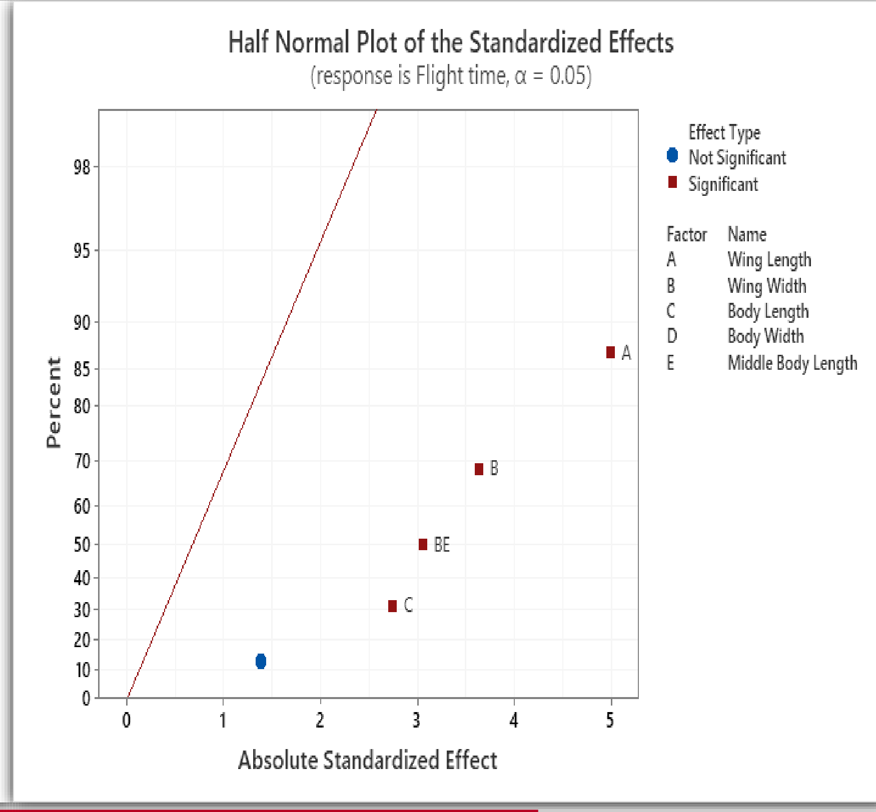
- The factors and interactions with p-value less than 0.05 are considered significant. Hence the Alpha to remove using the backward elimination Technique is = 0.05. Also, we get a linear regression model with all factors and their coefficients.
- The Anova & Half-Normal Plot of the Model with significant effects:

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	2.67015	0.53403	11.35	0.000
Linear	4	2.23334	0.55834	11.86	0.000
Wing Length	1	1.16964	1.16964	24.85	0.000
Wing Width	1	0.62001	0.62001	13.17	0.001
Body Length	1	0.35344	0.35344	7.51	0.010
Middle Body Length	1	0.09025	0.09025	1.92	0.175
2-Way Interactions	1	0.43681	0.43681	9.28	0.004
Wing Width*Middle Body Length	1	0.43681	0.43681	9.28	0.004
Error	34	1.60004	0.04706		
Lack-of-Fit	2	0.12884	0.06442	1.40	0.261
Pure Error	32	1.47120	0.04597		
Total	39	4.27019			

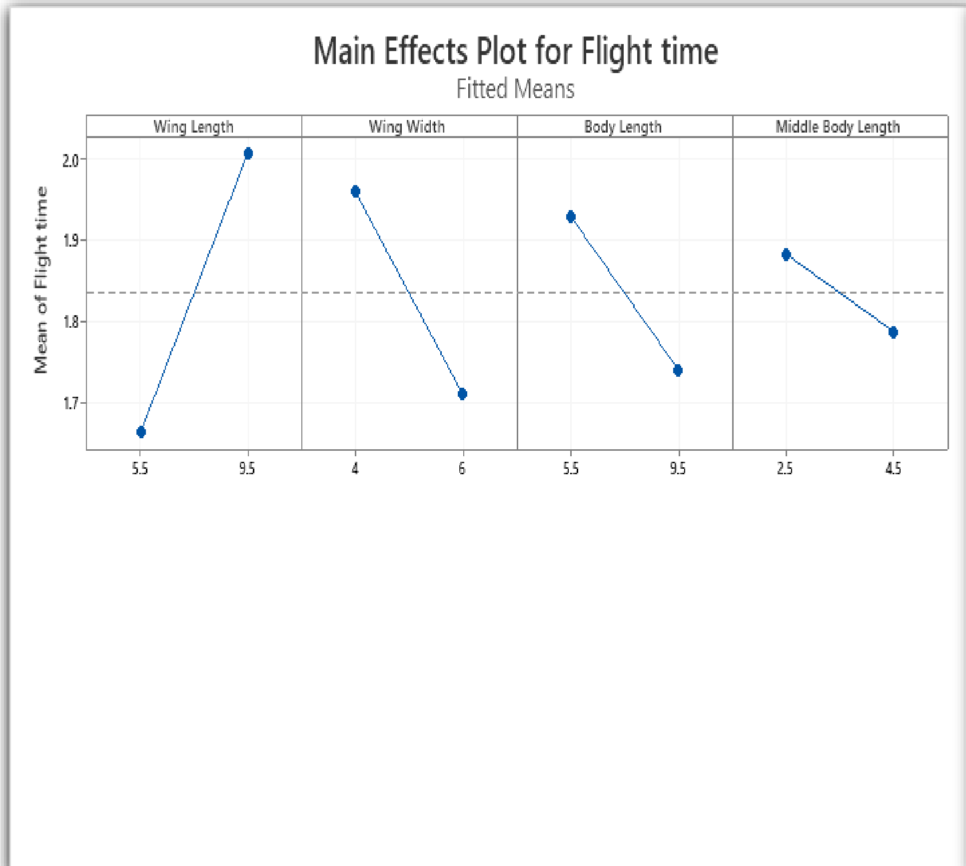
Regression Equation in Uncoded Units

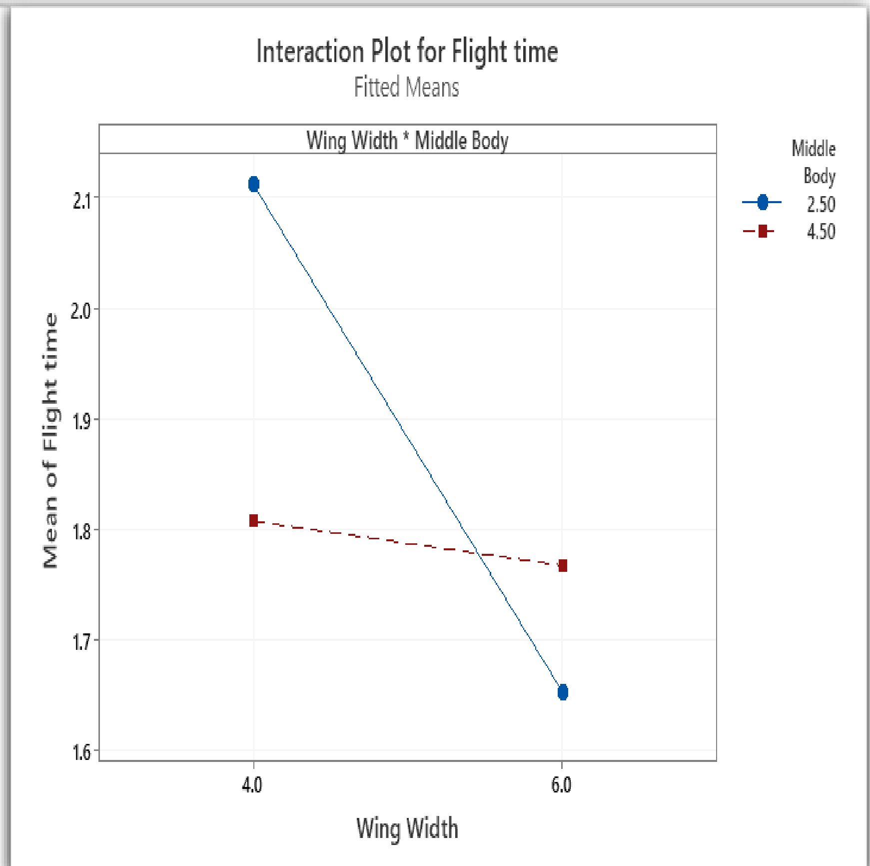
Flight time = 4.164 + 0.0855 Wing Length - 0.490 Wing Width - 0.0470 Body Length - 0.570 Middle Body Length + 0.1045 Wing Width*Middle Body Length



Factorial Plots

- We plot the main effect plots and interaction effect plots for flight time with the significant factors below
- Since this is a larger-the-better type of problem, we select those level values which result in a higher mean flight time.





Response Optimization

- The optimal values for all main effects and its corresponding flight time (after substituting all values in the linear regression model) is found to be as follows

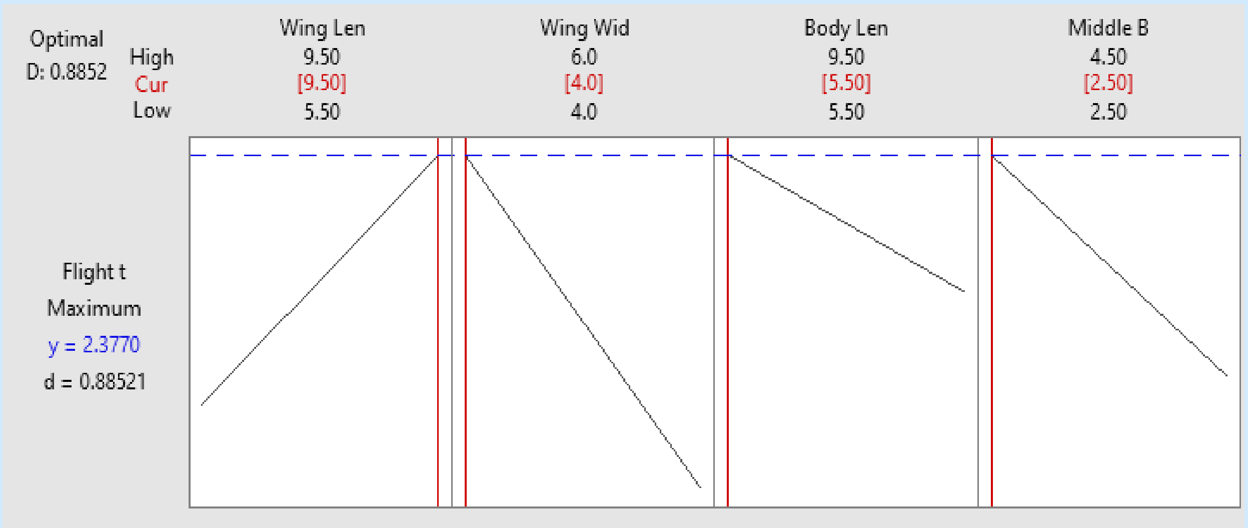
Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
Flight time	Maximum	1.12	2.54		1	1

Solution

Solution	Wing Length	Wing Width	Body Length	Middle Body Length	Flight time Fit	Composite Desirability
1	9.5	4	5.5	2.5	2.377	0.885211

Response	Fit	SE Fit	95% CI	95% PI
Flight time	2.3770	0.0840	(2.2063, 2.5477)	(1.9042, 2.8498)



Conclusion

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- For the data we collected, our analysis with Minitab indicates the optimal helicopter settings are-
  - Wing length = 9.5 cm
  - Wing width = 4 cm
  - Body Length = 5.5 cm
  - Middle body length = 2.5 cm
  - Response = Flight time = 2.377 secs

- **Future Recommendations**
  - To design an better helicopter, we could repeat the entire DoE using other factors such as types of paper, paper clips and cello tapes.
  - The design can also be improved by adding non-linear elements in the model and creating center-points, star-points and performing Canonical analysis to calculate higher order effects and their interactions.

- Thank You -