Quality Assurance – IE 508

Mini Project – 3

Group – 1

Members:

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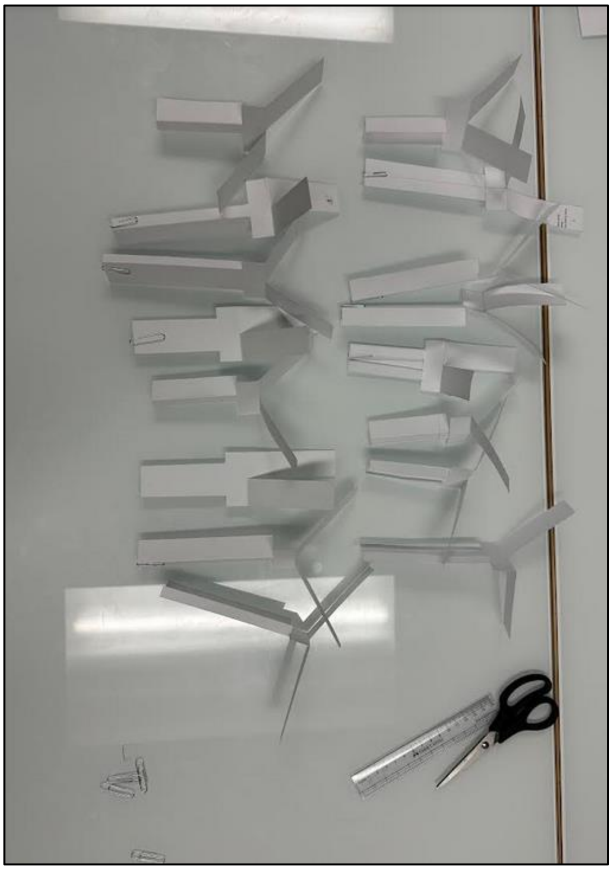
Objective: To improve the design of a paper helicopter, increase its flight time to greater than 3 seconds when dropped from a height of 2 meters.

1. Design the experiment shown above and photo document the helicopter designs (sample) and the flight measuring activities.

	Current	Low (-)	High (+)
Rotor length	7.5 cm	7.5 cm	8.5 cm
Leg length	9.75 cm	7.5 cm	12 cm
Leg width	2 cm	3 cm	1 cm
Paper type	Printer Paper	Printer Paper	Cardstock
Paper clip	Yes	No	Yes

- The above five factors were considered for the experiment.
- A 2^{5-1} fractional factorial design with Resolution V experimental design is done that includes 5 factors, each with 2 levels, and can estimate main effects and two-factor interactions with a high degree of precision.
- A total of 16 values, with variable combinations were taken.
- The experiment is designed to evaluate the performance of the paper helicopters by dropping each helicopter three times and recording the average flight time as the response variable. The helicopters will be constructed according to the treatment design order, which specifies the levels of each factor for each experimental run.

Photo document of the helicopter:



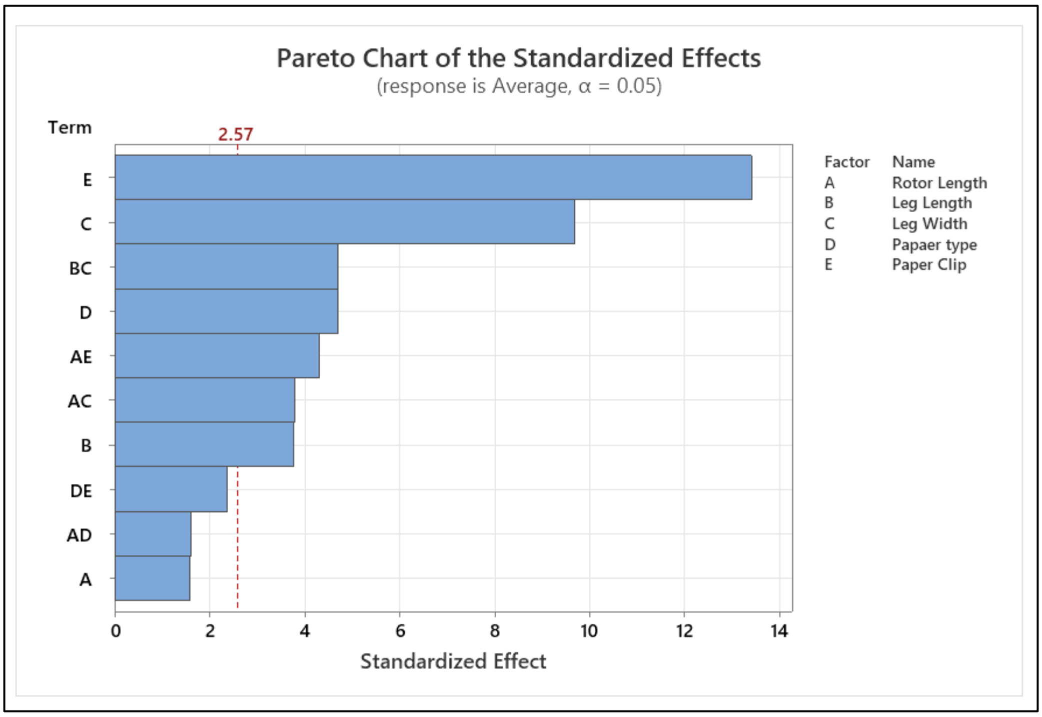
3. Following the treatment design matrix, construct a helicopter, label it with the corresponding treatment combination, and using your qualified measurement device, measure the drop time at a height of 200cm. Drop the helicopter 3 times and record the average time in Minitab corresponding with the appropriate treatment combination. Repeat this process until you have made and measured all helicopters.

- 16 different helicopters were constructed using varying factors.
- The helicopters were dropped individually, three times, in a random order, from 200cms height.
- The time readings were noted.
- At a given time, one member was designated to drop the helicopter, one was designated to use the stopwatch and one was designated to enter the data in MiniTab.
- The average time for each helicopter was then calculated.

The following are the observed results:

Std Order	Run Order	Centre Point	Blocks	Rotor Length	Leg Length	Leg Width	Paper type	Paper Clip	Trail 1	Trail 2	Trail 3	Average
6	1	1	1	8.5	7.5	3	Printer Paper	Yes	2.07	1.63	1.72	1.81
7	2	1	1	7.5	12	3	Printer Paper	Yes	1.72	1.46	1.65	1.61
3	3	1	1	7.5	12	1	Printer Paper	No	2.38	2.5	2.35	2.41
8	4	1	1	8.5	12	3	Printer Paper	No	2	1.68	1.99	1.89
1	5	1	1	7.5	7.5	1	Printer Paper	Yes	2.06	1.81	1.7	1.86
5	6	1	1	7.5	7.5	3	Printer Paper	No	2.25	2.51	2.33	2.36
9	7	1	1	7.5	7.5	1	Cardstock	No	2.19	2.36	2.02	2.19
4	8	1	1	8.5	12	1	Printer Paper	Yes	2	2.3	2.1	2.13
2	9	1	1	8.5	7.5	1	Printer Paper	No	2.38	2.62	2.22	2.41
11	10	1	1	7.5	12	1	Cardstock	Yes	1.78	1.65	1.85	1.76
16	11	1	1	8.5	12	3	Cardstock	Yes	1.74	1.56	1.67	1.66
10	12	1	1	8.5	7.5	1	Cardstock	Yes	1.98	1.87	2.14	2.00
13	13	1	1	7.5	7.5	3	Cardstock	Yes	1.8	1.72	1.72	1.75
15	14	1	1	7.5	12	3	Cardstock	No	2.02	1.87	1.74	1.88
14	15	1	1	8.5	7.5	3	Cardstock	No	2.23	1.8	2	2.01
12	16	1	1	8.5	12	1	Cardstock	No	2.3	2.17	2.27	2.25

4. After collecting the data, analyze the data using the most appropriate model possible with Minitab assuming (α = 0.05). Provide a descriptive analysis of all figures and output.



- We have analyzed the model with minitab using the function analyze factorial designs, under DOE, with 95% confidence interval.
- A pareto chart of standardized effects was generated and the model is refined by removing insignificant terms step by step.
- Finally, optimal results, mentioned below, were obtained.

Coded Coefficients

Term	Effect	Coef	SE Coef	T-Value	P-Value	VIF
Constant		1.9975	0.0132	151.61	0.000	
Rotor Length	0.0417	0.0208	0.0132	1.58	0.175	1.00
Leg Length	-0.0992	-0.0496	0.0132	-3.76	0.013	1.00
Leg Width	-0.2550	-0.1275	0.0132	-9.68	0.000	1.00
Papaer type	-0.1242	-0.0621	0.0132	-4.71	0.005	1.00
Paper Clip	-0.3533	-0.1767	0.0132	-13.41	0.000	1.00
Rotor Length*Leg Width	-0.1000	-0.0500	0.0132	-3.80	0.013	1.00
Rotor Length*Papaer type	0.0425	0.0213	0.0132	1.61	0.168	1.00
Rotor Length*Paper Clip	0.1133	0.0567	0.0132	4.30	0.008	1.00
Leg Length*Leg Width	-0.1242	-0.0621	0.0132	-4.71	0.005	1.00
Papaer type*Paper Clip	0.0625	0.0312	0.0132	2.37	0.064	1.00

- The defining relation is I + ABCDE and the alias structures are obtained.
- To avoid redundancy, only two-way interactions were considered.

Alias Structure

Factor	Name
A	Rotor Length
B	Leg Length
C	Leg Width
D	Papaer type
E	Paper Clip

Aliases
I + ABCDE
A + BCDE
B + ACDE
C + ABDE
D + ABCE
E + ABCD
AC + BDE
AD + BCE
AE + BCD
BC + ADE
DE + ABC

- The R-sq is 98.69% and R-sq(adj) is 96.06. This signifies the capability of the model to explain the variability in the provided data.
- R-sq(pred) value of 86.55% signifies that the model is suitable for predicting future values.

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0526994	98.69%	96.06%	86.55%

ANOVA analysis summary:

- **Degree of Freedom (DOF):** Initially, Initially, there were no degrees of freedom for calculating the Mean Square Error (MSE). After removing the higher-order interaction, a DOF of 5 was obtained for the error.
- **Statistically Significant Interactions**: Five second-order interactions were found to be statistically significant.
- **Regression Equation**: The regression equation for the model was obtained from the output and is shown in uncoded units.

Analysis of Variance

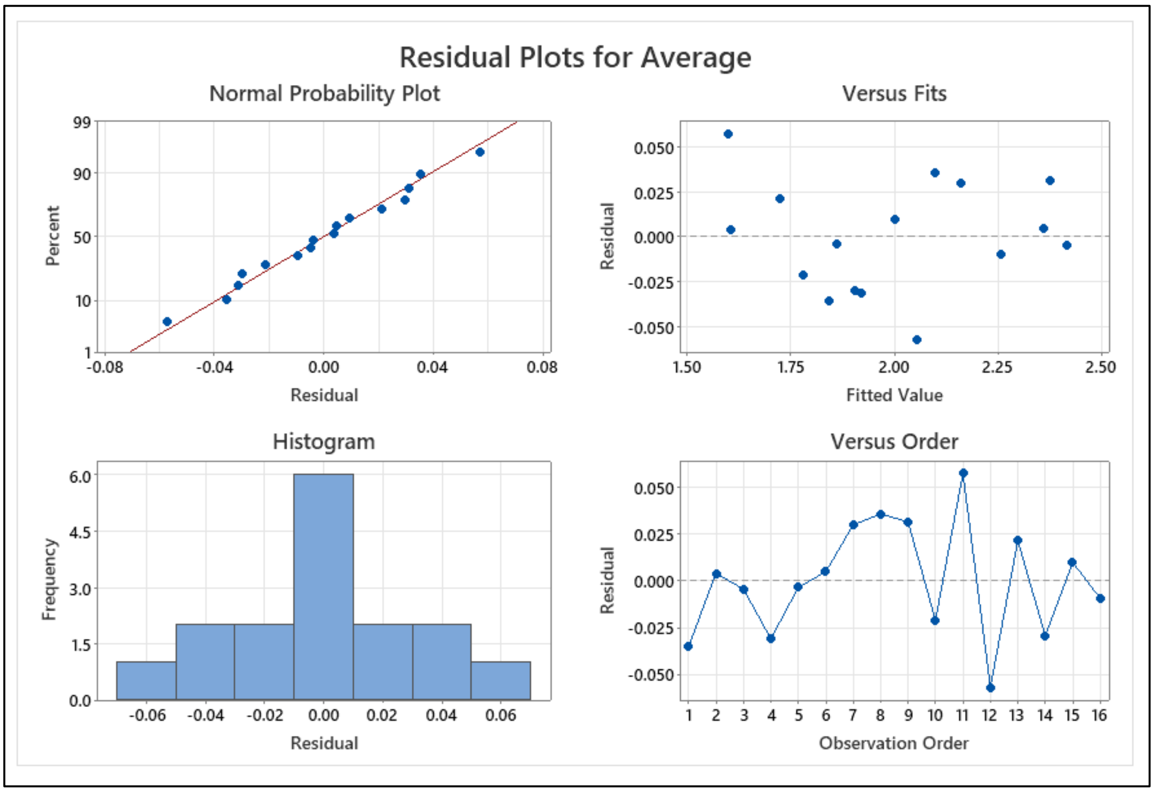
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	10	1.04333	0.104333	37.57	0.000
Linear	5	0.86743	0.173486	62.47	0.000
Rotor Length	1	0.00694	0.006944	2.50	0.175
Leg Length	1	0.03934	0.039336	14.16	0.013
Leg Width	1	0.26010	0.260100	93.65	0.000
Papaer type	1	0.06167	0.061669	22.21	0.005
Paper Clip	1	0.49938	0.499378	179.81	0.000
2-Way Interactions	5	0.17590	0.035179	12.67	0.007
Rotor Length*Leg Width	1	0.04000	0.040000	14.40	0.013
Rotor Length*Papaer type	1	0.00723	0.007225	2.60	0.168
Rotor Length*Paper Clip	1	0.05138	0.051378	18.50	0.008
Leg Length*Leg Width	1	0.06167	0.061669	22.21	0.005
Papaer type*Paper Clip	1	0.01562	0.015625	5.63	0.064
Error	5	0.01389	0.002777		
Total	15	1.05721			

Regression Equation in Uncoded Units

Average = -0.004 + 0.2417 Rotor Length + 0.0331 Leg Length + 0.942 Leg Width
- 0.402 Papaer type - 1.083 Paper Clip - 0.1000 Rotor Length*Leg Width
+ 0.0425 Rotor Length*Papaer type + 0.1133 Rotor Length*Paper Clip
- 0.02759 Leg Length*Leg Width + 0.0313 Papaer type*Paper Clip

5. Check model adequacy by analyzing residual plots. Provide a descriptive analysis of all figures and output.

If the distribution of the data in a regression analysis is normal, the normal probability plot of the residuals will show a linear relationship between the residuals and their expected values, indicating that the error terms are normally distributed. The residuals histogram can also provide information on the distribution of residuals across all the data. However, there may be exceptions to this regular distribution, as seen in two severe cases. The residuals vs. fit plot shows the residuals on the y-axis and the fitted values on the x-axis, while the residuals vs. order plot displays the residuals in the order they were collected. A residual vs. order plot that reveals a positive serial correlation suggests that error terms are not independent, as residuals of the same sign and magnitude tend to follow each other sequentially over time. This violates the assumption of independent error terms in regression analysis.

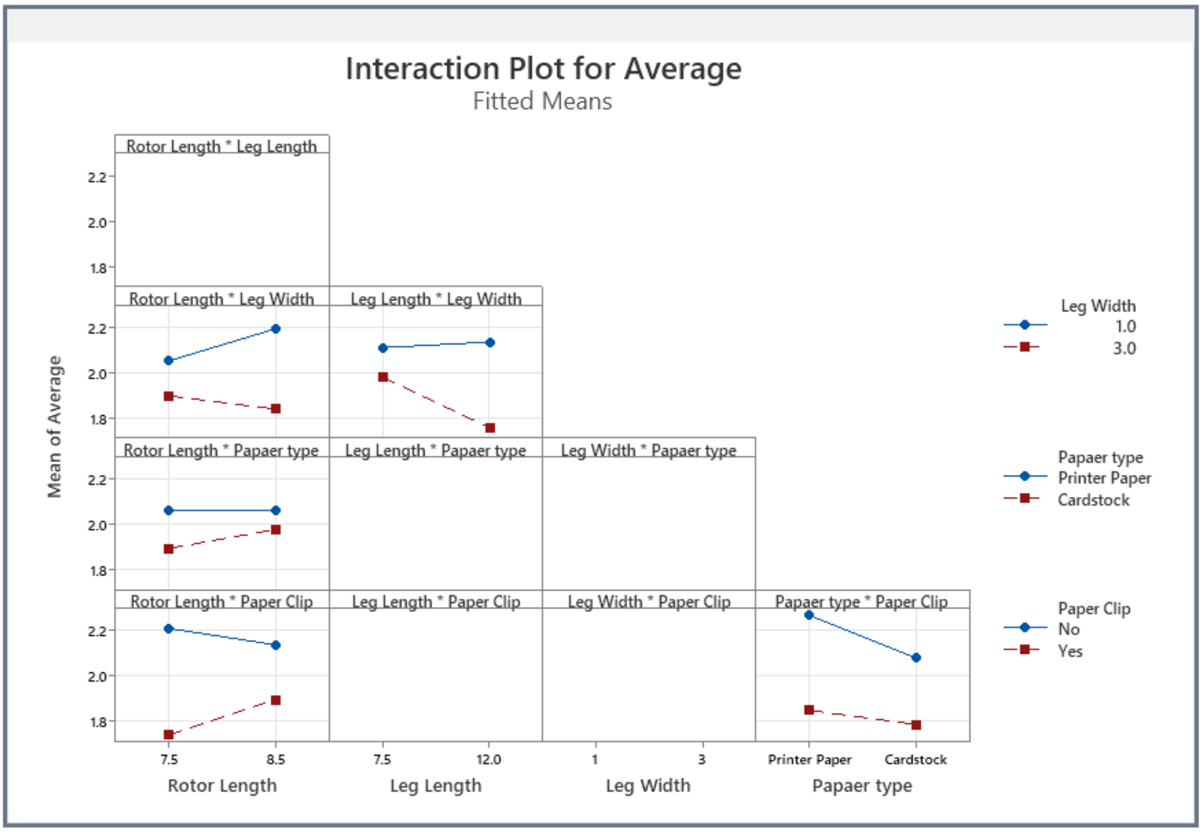


- The assumptions in regression analysis include normality, independence, and homogeneity of variance.
- Normality assumes that the distribution of the mean or means across samples is normal, which can be verified by a normal probability plot of residuals showing a linear relationship.
- Independence assumes that the data is not connected in any way, which is supported by a random order of residuals.
- Violations of this assumption make it impossible to analyze the experiment's design.
- Homogeneity of variance assumes that the degree of variance is consistent across samples, as evidenced by a residuals plot with a uniform spread.
- A funnel-shaped residual distribution implies a violation of the assumption of homogeneity of variance.

6. Create factorial plots for only significant (α = 0.05) factors and interactions.

- The analysis identified significant interactions between certain variables, and the passage presents the results of these interactions using factorial plots.
- The first interaction involves the effect of rotor length and leg width on flight time. The plot shows that when leg width is low, increasing rotor length leads to an increase in flight time, while at high leg width settings, increasing rotor length leads to a decrease in flight time.

- The second interaction involves the effect of leg length and leg width on flight time. The plot shows that at low leg width settings, leg length has no effect on flight time, but at high leg width settings, increasing leg length leads to a decrease in flight time.
- The third interaction involves the effect of rotor length and paper type on flight time. The plot shows that at low paper type settings (using printer paper), increasing rotor length has no significant effect on flight time, while at high paper type settings (using card stock), increasing rotor length also has no significant effect on flight time.
- The fourth interaction involves the effect of rotor length and paper clip on flight time. The plot shows that at low paper clip settings (using no clip), increasing rotor length leads to a decrease in flight time, while at high paper clip settings, increasing rotor length leads to an increase in flight time.
- Finally, the fifth interaction involves the effect of paper type and paper clip on flight time. The plot shows that at low paper clip settings, increasing paper type (from printer paper to card stock) leads to a decrease in flight time, while at high paper clip settings, increasing paper type has no significant effect on flight time.



7. Using the Response Optimizer, find the best helicopter settings for achieving the longest flight time. With helicopter parameters set at levels that give the longest flight times, what would you estimate the mean flight time to be?

The purpose here was to get the optimal conditions for achieving the target flight time of 3 secs.

Parameters

Response	Goal	Lower	Target	Upper	Weight	Importance
Average	Maximum	1.61	3		1	1

Solution

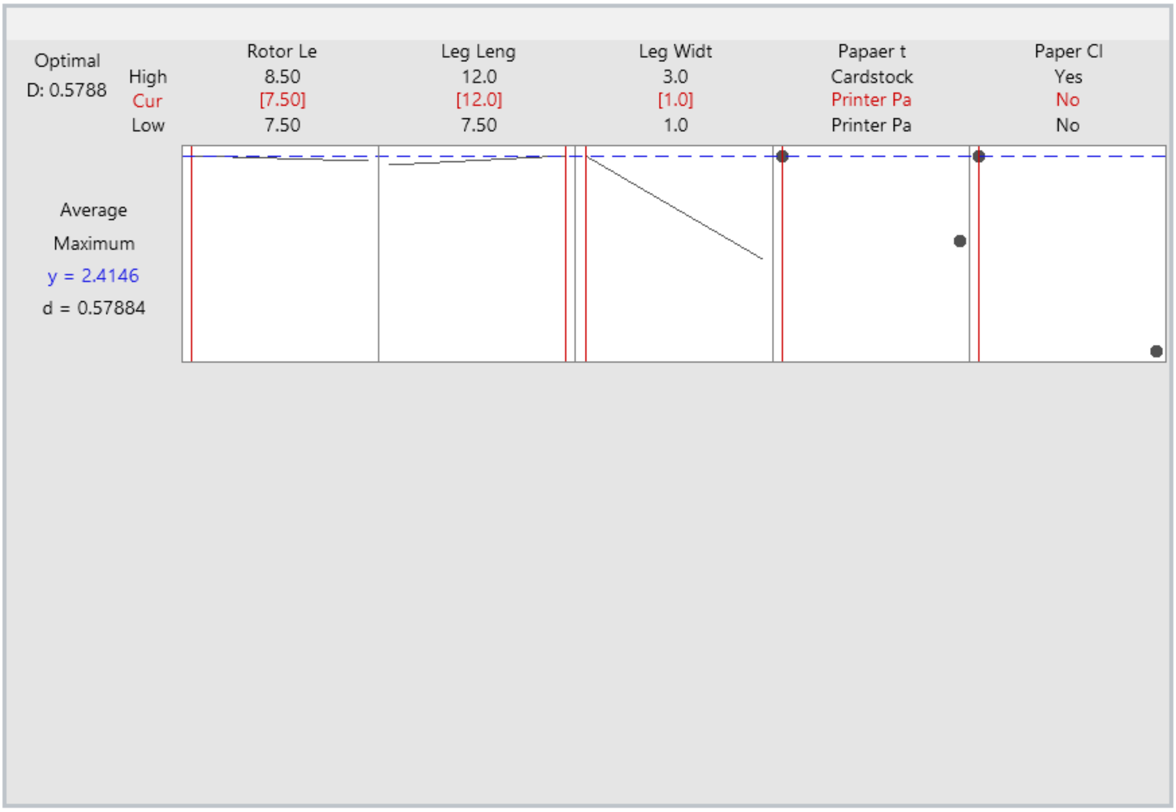
Solution	Rotor Length	Leg Length	Leg Width	Papaer type	Paper Clip	Average Fit
1	7.5	12	1	Printer Paper	No	2.41458

Solution	Composite Desirability
1	0.578837

Multiple Response Prediction

Variable	Setting
Rotor Length	7.5
Leg Length	12
Leg Width	1
Papaer type	Printer Paper
Paper Clip	No

Response	Fit	SE Fit	95% CI	95% PI
Average	2.4146	0.0437	(2.3023, 2.5269)	(2.2386, 2.5906)



- OPTIMAL CONDITIONS:
    - Rotor Length – 7.5
    - Leg Length – 12
    - Leg Width – 1
    - Paper – Printer Paper
    - Paper Clip – No
- Flight time predicted value – 2.4146 secs.

8. Create a helicopter using the optimal settings and create another helicopter using the original settings. Determine how many sample-flight-times are needed to compare the two helicopters to each other so as to find a difference of 1 second statistically significant at 95% confidence.

    - 10 readings were noted down for optimal and original helicopter.
    - The Standard Deviation observed was 0.0563 and 0.0649 for optimal and original parameters, respectively.
    - Higher Standard Deviation of 0.0649 was considered for the 2-sample t-test.

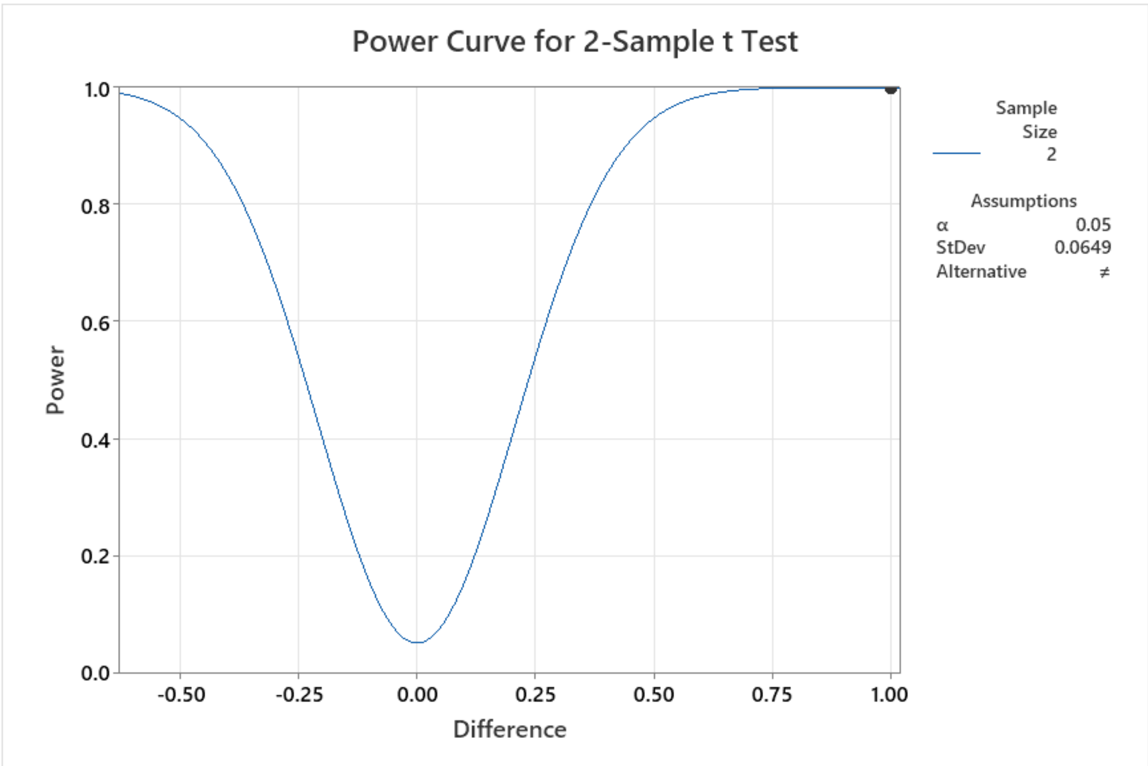
2-Sample t Test
Testing mean 1 = mean 2 (versus ≠)
Calculating power for mean 1 = mean 2 + difference
α = 0.05 Assumed standard deviation = 0.0649

Results

Difference	Sample Size	Target Power	Actual Power
1	2	0.85	0.99999

The sample size is for each group.

- Estimated Sample Size is 2.
- Power obtained is 99.99%.



9. Collect the flight-time data for the two helicopters and compare. Provide a descriptive analysis of all figures and output.

Optimal Parameters	Original
2.57	1.39
2.50	1.47
2.45	1.54
2.60	1.52
2.42	1.41
2.47	1.52
2.49	1.55
2.40	1.48
2.43	1.49
2.52	1.42

The sample size for the flight time was 2 with a power of 99.99%. Our set of 10 flight times seem adequate for our experiment.

Method

μ_1: population mean of Optimal Parameters
μ_2: population mean of Original
Difference: $\mu_1 - \mu_2$

Equal variances are not assumed for this analysis.

Descriptive Statistics

Sample	N	Mean	StDev	SE Mean
Optimal Parameters	10	2.4850	0.0649	0.021
Original	10	1.4790	0.0563	0.018

The observed data shows a significant difference between the mean of optimal and original parameters.

Estimation for Difference

Difference	95% CI for Difference
1.0060	(0.9487, 1.0633)

Test

Null hypothesis	H_0: $\mu_1 - \mu_2 = 0$
Alternative hypothesis	H_1: $\mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
37.05	17	0.000

The difference of 1.006 lies in the 95% CI band for difference of 0.9487, 1.0633, which shows that the target of having a difference of 1 second in the flight time, between the optimal design and the original design, has been achieved successfully.

Hypothesis test on the two sample data also confirms that p-value is less than the significance level of 0.05 we can reject the null hypothesis stating that there is no difference between the mean.

Hence, the observed difference in the flight time of optimal and original helicopter is 1.006secs.