Design For Quality, Manufacturing And Assembly
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Lecture - 18
Paper Helicopter Case Study - II

So, here is there Case Study that there taking let me just go here.

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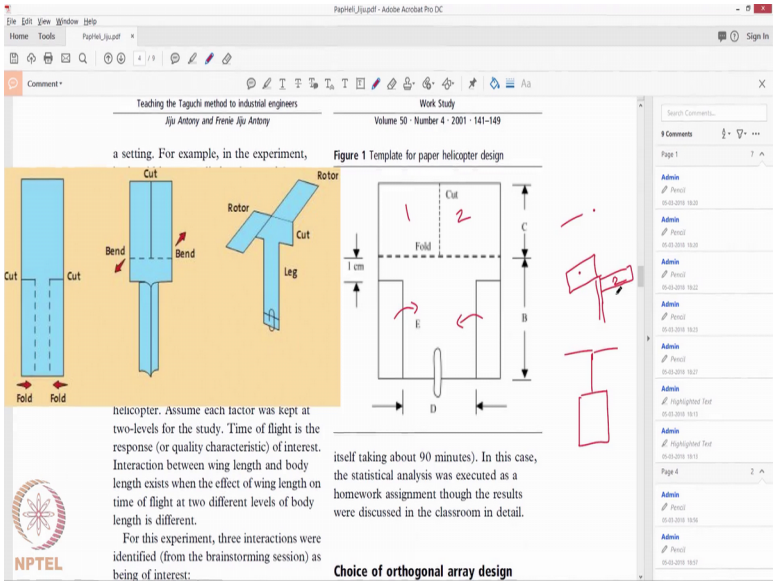

So, this is the Paper Helicopter ok. It is simple. What happens is you take a paper like this, you folded across here, you cut this (Refer Time: 00:36) in between and then you fold the heads like this. So, it will be something like. So, these two you know these two that I am talking about. So, let me name this 1 and 2, this is over to look like. And of course, I will have this intermediate stuff that will run through and this part, you will fold it this way.

So, that becomes a; so if you see from the top, it will look something like this. If you see from the front, this is would looks this is the 2 blades that we are talking about. This is the body; you will have a brief spot here and then, you will have a smaller portion. So, this is your body and this is your tail portion ok.

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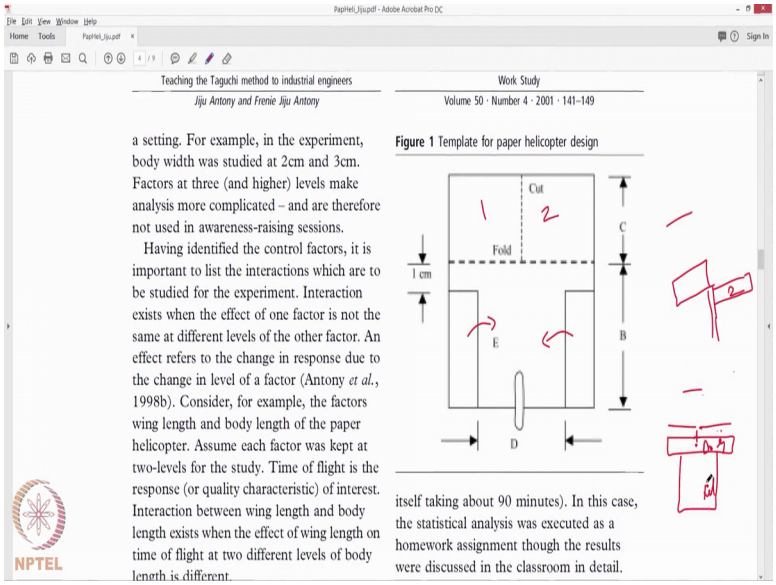

Like it is a simple stuff, then you just stare these two guys and you drop it from the third of the fourth floor. It will go rotating like this. And then, it will take about 20 to 25 seconds to reach the floor depending on the draft the wind and all that. So, this is an interesting thing, because the wind and the any point in time is not under your control.

So, that is a nice variable that you will not account for. But you need to get that design in terms of your C which is your the wing height and then, this body height, they call this one. This is fixed and then, your boy or tail width ok. You can, these are the variable say or A or B C D and the number of jump clips in the type of paper that they have use; the regular paper and then bond paper. These are the stuff that they would have used. So, this is the basic helicopter that is there ok.

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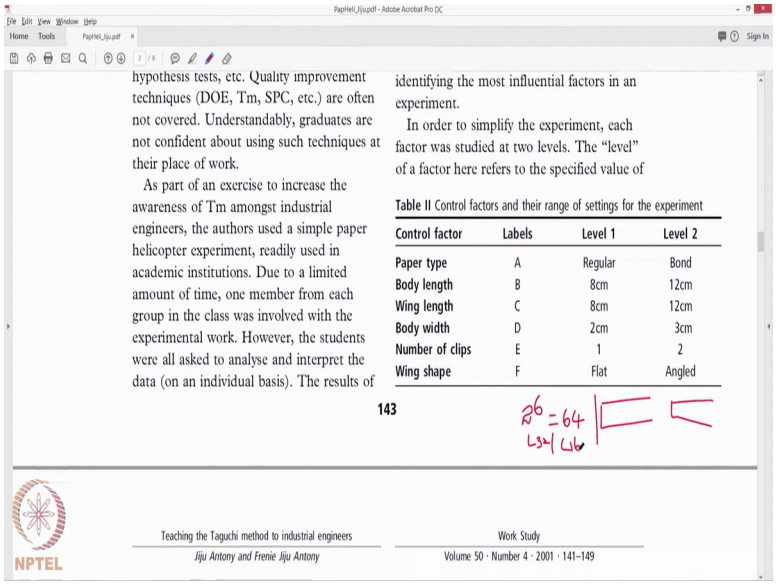

hypothesis tests, etc. Quality improvement techniques (DOE, Tm, SPC, etc.) are often not covered. Understandably, graduates are not confident about using such techniques at their place of work.

As part of an exercise to increase the awareness of Tm amongst industrial engineers, the authors used a simple paper helicopter experiment, readily used in academic institutions. Due to a limited amount of time, one member from each group in the class was involved with the experimental work. However, the students were all asked to analyse and interpret the data (on an individual basis). The results of identifying the most influential factors in an experiment.

In order to simplify the experiment, each factor was studied at two levels. The "level" of a factor here refers to the specified value of

Table II Control factors and their range of settings for the experiment

Control factor	Labels	Level 1	Level 2
Paper type	A	Regular	Bond
Body length	B	8cm	12cm
Wing length	C	8cm	12cm
Body width	D	2cm	3cm
Number of clips	E	1	2
Wing shape	F	Flat	Angled

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Teaching the Taguchi method to industrial engineers
Jiju Antony and Frenie Jiju Antony

Work Study
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So, after brainstorming as per the paper after brainstorming, they have identified these kinds of control factors. They think that the paper type body length, wing length, body width, number of clubs, the wing shape plays an important role. There are 2 levels for each of these guys. For instance, the paper type could be a regular or a bond paper.

They say the body length is 8 centimeters minimal and 12 centimeter is second level like that they give a series of stuff. Number of jump clips could be 1 and 2. Then, they can have a flat wing shape meaning you can have a wing shape like this. You can have a flat wing shape like this or you can have a tapered wing shape like this. They would have discussed these studies.

So, these are the factors that they thought was contribute to the flight time. What they wanted to understand this is what combinations of these, should I have a paper of body length of 8 centimeters or 12 centimeters; should I have a number of clips to be 1 or 2? It could be a combination of these guys right.

So, I wanted to identify that one combination, where my flight time will be maximum and it should also be robust. Please understand, maximum is only a mean process; mean of the process. The flight time is a variable the mean of that variable is what I want to maximize, but at the same time I also wanted to be robust; you fly it hundred times only once you will get maximum what is the point ok? I want the process variability also to be less. So, I want to find a robust design that will also be maximum. So, the mean should be maximum that that is a point.

What they do is this?

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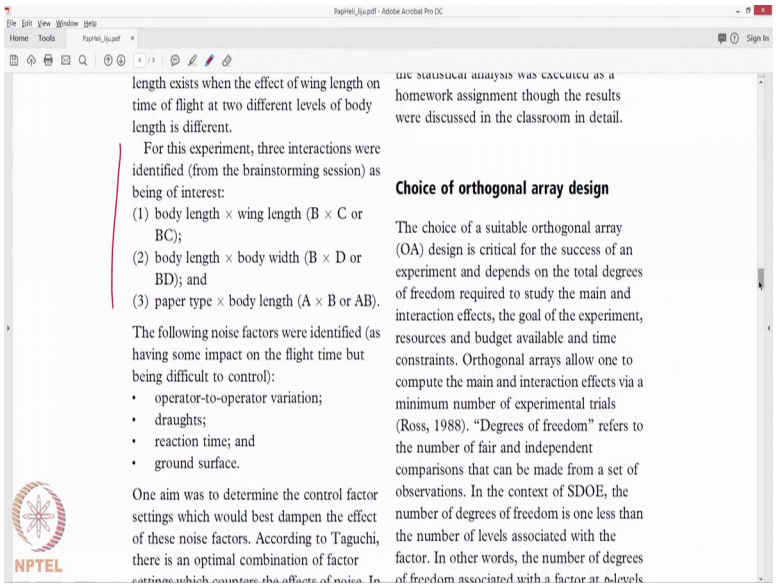
length exists when the effect of wing length on time of flight at two different levels of body length is different.

For this experiment, three interactions were identified (from the brainstorming session) as being of interest:

(1) body length × wing length (B × C or BC);
(2) body length × body width (B × D or BD); and
(3) paper type × body length (A × B or AB).

The following noise factors were identified (as having some impact on the flight time but being difficult to control):

- operator-to-operator variation;
- draughts;
- reaction time; and
- ground surface.

One aim was to determine the control factor settings which would best dampen the effect of these noise factors. According to Taguchi, there is an optimal combination of factor

homework assignment though the results were discussed in the classroom in detail.

Choice of orthogonal array design

The choice of a suitable orthogonal array (OA) design is critical for the success of an experiment and depends on the total degrees of freedom required to study the main and interaction effects, the goal of the experiment, resources and budget available and time constraints. Orthogonal arrays allow one to compute the main and interaction effects via a minimum number of experimental trials (Ross, 1988). "Degrees of freedom" refers to the number of fair and independent comparisons that can be made from a set of observations. In the context of SDOE, the number of degrees of freedom is one less than the number of levels associated with the factor. In other words, the number of degrees

So, after careful discussion and brainstorming and all that, they identified that only these 3 interactions are important. They say the body length and wing length B and C, body length and body width paper type and body length; they might have done some initial experiments trial and error to understand this. So, what they are saying is we are going to have, how many variables? 3 plus 3, 6; 2 levels each; so what is the full factorial experimental we will require you to do?

Student: (Refer Time: 05:13).

2 raised to 6 is how much?

Student: 64.

64 experiments, but let us put a cost on your helicopters; each helicopter is at least 100,000. Here, this putting a cost 6,400,000. You do not want to spend. How least can I spend; how much least can I spend? So, you can go for a fractional factorial experiment. So, you can either use and L 32 or an L 16. I guess in this particular study, they might use a L 6, L 16 sorry.

Then, they identified what all could be the noise factors? The sources of noise; so they say operator to operator variation; whose is going to drop it? If I drop, you might get a

different value; if x drops, you might get a different value; y drops, you might get a different value. So, there is a y operated to operator draught is what the wing speed that I spoke about.

The third one is the reaction time. You are waiting there with your cell phone to with a stopwatch, the moment it hits the ground you should do; you might be micro fraction faster compare to another person. But you are also doing seconds. So, even a fraction of a second means that it will be the next second. So, there is a variation; if two people are recording the same event some might say 19 and the other one might say 18 seconds.

Ground surface, the ground need not be parallel. If you do it in our department you will have blades of this grass there. At one particular point when the helicopter is coming to reach, you might not have a grass, it is a ground. So, that has to travel and extra few centimeters instead of stopping in the blade of the grass. So, that might take another 1 second or 1 and half seconds which will actually change your results.

But these are all you know you will say I am going to do this study for this course. So, let us concretize this entire space and I am not going to do that; that is a noise. So, you need to live with that noise and record all this value. So, this is the typical noise for this particular setup.

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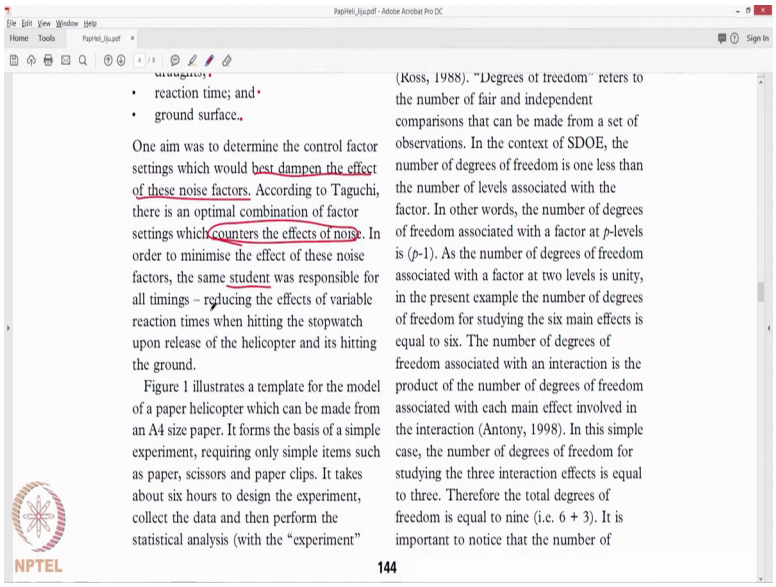

One name was to determine the control factor settings which would best dampen the effect of these noise factors; that is one of the goals.

According to Taguchi, there is an optimal combination of factor setting which counters the effects of noise. Please understand this is the whole concept of robustness. I am not getting rid of the noise. I have to live with the noise. But there is some combination, the way how I design my product that combination of those design variables will counter the effects of noise that is exactly this point.

In order to minimize the effect of these noise factor the stems whatever the same student of the user was responsible for all the timings. So, you do not want to have that variability, then you use the same person who will record all the timings; but there could also be a variability within the person. There is an intra variability and there is an inter variability ok. Actually, when we do the study, we put 2 people in the ground to record the time. So, that we can record the variability within an particular drop.

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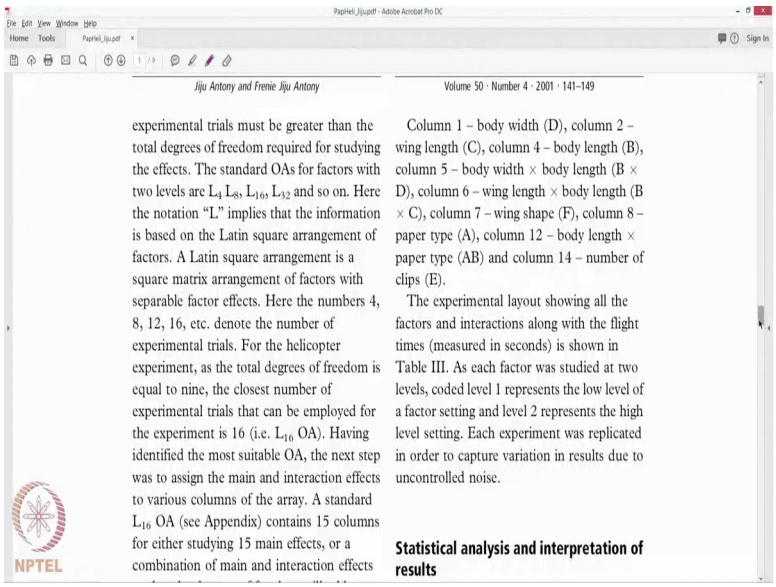

So, we have already talked about it should be L 64, but it should be either L 34 or L 60.

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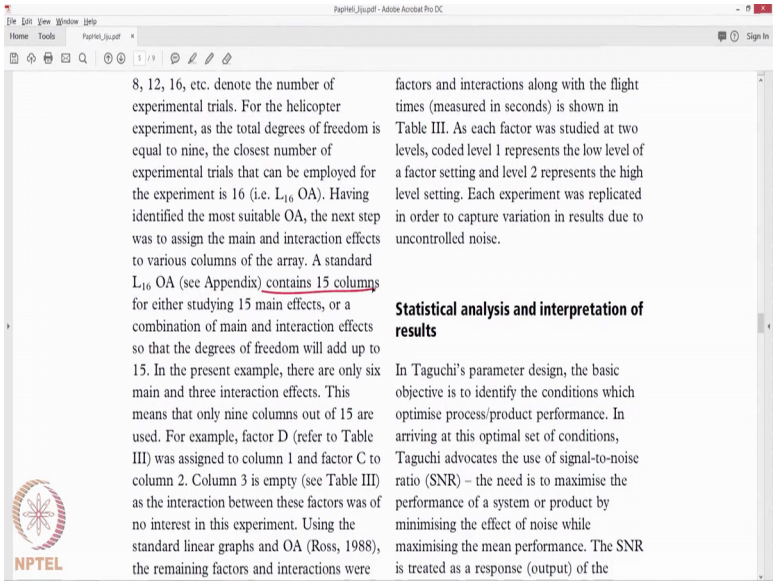

8, 12, 16, etc. denote the number of experimental trials. For the helicopter experiment, as the total degrees of freedom is equal to nine, the closest number of experimental trials that can be employed for the experiment is 16 (i.e. L_{16} OA). Having identified the most suitable OA, the next step was to assign the main and interaction effects to various columns of the array. A standard L_{16} OA (see Appendix) contains 15 columns for either studying 15 main effects, or a combination of main and interaction effects so that the degrees of freedom will add up to 15. In the present example, there are only six main and three interaction effects. This means that only nine columns out of 15 are used. For example, factor D (refer to Table III) was assigned to column 1 and factor C to column 2. Column 3 is empty (see Table III) as the interaction between these factors was of no interest in this experiment. Using the standard linear graphs and OA (Ross, 1988), the remaining factors and interactions were assigned to the columns of an L_{16} in the following manner.

factors and interactions along with the flight times (measured in seconds) is shown in Table III. As each factor was studied at two levels, coded level 1 represents the low level of a factor setting and level 2 represents the high level setting. Each experiment was replicated in order to capture variation in results due to uncontrolled noise.

Statistical analysis and interpretation of results

In Taguchi's parameter design, the basic objective is to identify the conditions which optimise process/product performance. In arriving at this optimal set of conditions, Taguchi advocates the use of signal-to-noise ratio (SNR) – the need is to maximise the performance of a system or product by minimising the effect of noise while maximising the mean performance. The SNR is treated as a response (output) of the experiment, which is a measure of variation when uncontrolled noise factors are present in

Table III Experimental layout

Column no.	1	2	4	5	6	7	8	12	14	
Factors/interactions	D	C	B	BD	BC	F	A	AB	E	Flight time
Trial no.										
1	1	1	1	1	1	1	1	1	1	2.76, 2.83
2	1	1	1	1	1	1	2	2	2	2.20, 2,13
3	1	1	2	2	2	2	1	2	2	1.93, 2.30
4	1	1	2	2	2	2	2	1	1	2.19, 2.10
5	1	2	1	1	2	2	1	1	2	2.40, 2.50
6	1	2	1	1	2	2	2	2	1	2.82, 2.31
7	1	2	2	2	1	1	1	2	1	3.39, 3.01
8	1	2	2	2	1	1	2	1	2	2.62, 2.39
9	2	1	1	2	1	2	1	1	1	2.46, 2.12
10	2	1	1	2	1	2	2	2	2	2.08, 1.90

So, in this case, I guess that they there talking about L 16. So, they are taking the least possible because, since it is 6 factors are there, you cannot take an L 4 ok. So, they are taking L 16 in this particular case; standard L 16 we will contain about 15 columns. Now, the next one would be to allocate factors to the columns.

So, can you tell me if you are using 64, 16 means one-fourth. What all factor combinations we will sacrifice and what all the factors combinations we will retain, if there are 6 factors? Let me make sure, it is 6 factors.

(Refer Slide Time: 09:45)

E F means it 6 right; A B C D E F, there are 6 factors are there. So, can you tell me if it is L 16, you can accommodate only 15 columns; what are all the factor combinations they will take? Obviously, they will take the main factor A B C D E F, 6 factor, 6 columns are gone. What are the next 9 columns say they can take?

Student: They can take with 3; 3 is an interaction.

Exactly ok. Now, do not go and its talk about confounding because they have made life easier. They say 3 interactions we are identified from a brainstorm session has been of interest; otherwise you need to worry about AB AC AD AE AF BC BD all the combinations you need to worry about. But that is not the case here. They say out of all those combination, we believe only these 3 are important. So now, 6 plus 3 is 9. What do you do with the remaining 6? You make them domain ok.

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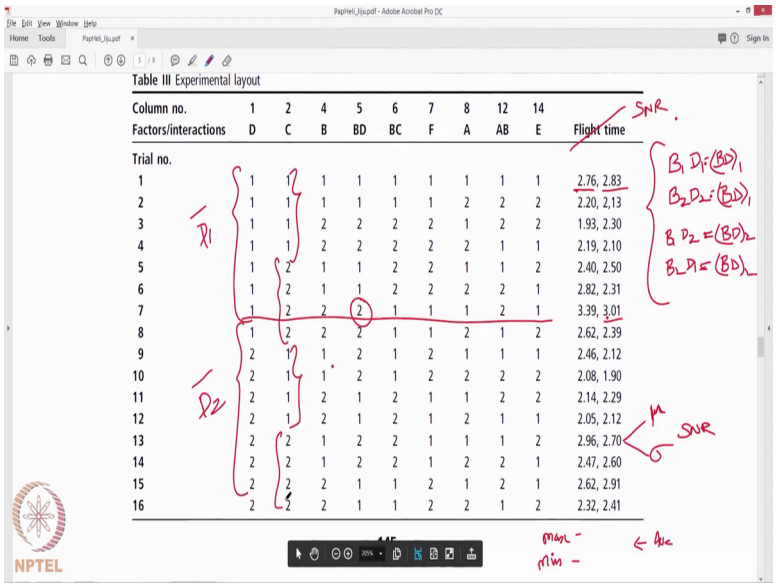

If you see this will not have 15 columns; actually 15 columns are there. I will I will show you what I mean this is what is the actual L 16 array; it has 15 columns; it will have 16 rows, each one of them is an experimental set. But now, what we discussed? 6 single factor plus 3 2 factor. So, there is only 9 for they are doing is there, they are only giving that sub set; they got rid of the columns where they are not assigning factors.

So, if you see here 1 2 3 4 5 6 7 8 9 is only 9 columns; but they are giving you the column numbers which they picked. How would they would have picked these ones from?

Student: Linear graphs.

They did using linear graph ok. So, they have done this. So, using a linear graph you can select this one that simple. Now what is happening? Let us take this particular case. Case number 7. What is this case number 7 mean? D is at level 1. What is D? D is body width. Body width is at level 1, 2 centimeters; then, let us say paper type is regular and one. Paper type is A; paper type A is here; A is bond paper. They are taking or regular paper whatever was level 1; they are taking that. Similar to that that are different levels in which they are doing.

But what is the meaning of, what is the meaning of BD? Meaning of B taking level 2, I understand. Meaning of D taking level 1, I understand. What is BD being 2; level 2? This we discuss the other day, there is no physical meaning for BD being 2 when your B is 1 and your D is 1; your BD is 1 and when your B is 2 and your D is 2; your BD is 1; when they interchange, you get the area. Let us check that D is 1, B is 2.

So, BD is 2. D is 1 B is 1. So, BD is 1. D is 2, D is 2, B is 2; BD is 1. Again you do not need to worry about it. It is not a automatically taken care. You just need to assign take the linear graphs, you assign the columns properly, you assign the factors to the columns properly; that is all. It is it automatically taken care; I did not go and do anything neither hood of Jiju done anything; it is automatically taken care, but you need to understand this part of it.

And if you ask me what do you mean by BD taking 1; this no physical meaning for that. Only the individual factors can take levels of 1 and 2, the combination we will dictate what will be BD 1 or BD 2; that is all. So, this is this time. What is happening? I am doing 2 drops every time. First, we drop it, we check out what the time was? It was 2.76 with the first set up. The same helicopter was taken to the third floor, then again dropped by the probably by the same person or by a different person and the same person tracks the time and records the time of 2.83 seconds ok. I think it seconds in this 2.83 is too less, but it is ok.

Now, what they are doing is they are doing is they are doing it for 16 experiments. So, this is what we have discussed so far, correct in the other in the other example also we have done. But there are plenty more things that you can do out of it; what is it? That we have discussed so far. As if you want to know the maximum flight time; how will you find it? Because that is one of the outputs of your DOA right; it can give you statistics.

What you can do? You can go here, you can go here and then, you can tell I am going to find the I can going to find the max; I am going to find the min of each of these guys or I can I am going to find the average of this entire column. But that is not what you want. Of course, you want to find the maximum flight time, but also you want to reduce the variability for the noise.

Experiment number 7, gave me 3.39 in my second drop; it gave me 3.0901; why? There would have been a draught as a there would have been a draft; the first one landed on landed on the plain ground, the second one landed on a blade of grass. So, it was earlier than that there is some noise, but I want to find out the design that is insensitive to these noises, operator variability I need to find a design. So, it is not enough if you find a combination that gives you the max, but you also have to find an experiment that will reduce this guy. So, it is a 2 problem; you want to maximize your min and you want to minimize your variation. So, this is actually what we call the multi objective problem; it is 2 objectives.

But the beauty of SN ratio is it combines that for you; you want to maximize your mu. So, let us put your mu in the top in the numerator and you want to minimize your variance. So, what we will do is, we will put that guy in the denominator and now you want to maximize your ratio. Since, the variation is in the denominator. It is 1 over the quantity of interest maximizing that is equivalent to minimizing that minimize maximizing 1 over the quantity is equivalent to minimizing the quantity.

So, that is the beauty of SN ratio formulation. This is important that is was the first step says formulation of your problem. So, you can say like ok, I am going to do a trade of study I will do, I will fall, I will maximize my mean and then I will minimize my standard deviation or you can say I am going to do in SN ratio formulation where I will maximize my SN ration done. Otherwise you will have to solve a multi objective problem; that is not what you are doing here ok.

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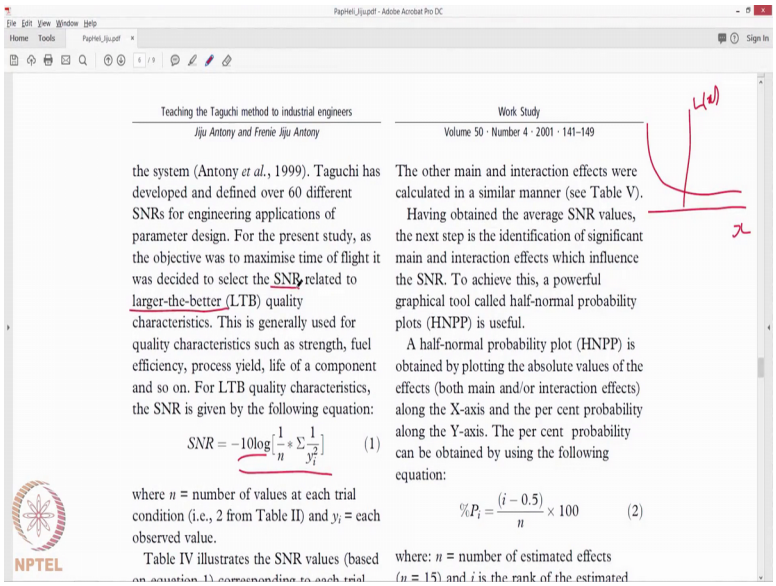

So, we will see how they are dealing with the problem; what type of a equality characteristic is this problem?

Student: (Refer Time: 17:57).

Larger the better; you want maximum flight time. So, what is the corresponding if you remember the want to know the loss function larger the better right. So, it should be like this larger is your x, the better it is the losses is minimum ok. So, I mean I can I have this axis wherever you want then that is fine ok. So, the lesser it is the error is large. So, the larger is your x, the error is getting better I mean the loss is getting better and better.

What equation describes is the best that we discuss here and it is 1 over y square; that is what is your SN ratio. So, what he says is I am going to take y I squared I runs from 1 to n. I am going to take a mean, if you want you can take a square root also, you can take a mean and then you can take a square root are just you can leave it like that. And this 10 log is just a normalizing factor I told you the other day, in this make it 10 sorry you can just make it log or you can make it 10 log 10; does not matter. It is only a normalizing factor. So, larger the better and we are looking at SN ratio.

Now, we will see this is stuff that we have already discussed. We will see how to use the data to drive us towards the information. Now, what you need to do for each of the row is you have 2 entries. So, what you will do is I need to get my mu and sigma for each of

this row, then I will be able to write my SN ratio. The moment I replace this information with my SN ratio, I will deal only with that SN ratio. This is something that we understood right. The moment you have more than one data; what it will discuss? You will use a average, but that is not enough here; you do not just want to maximize, you want to also minimize your variance. So, you are taking an SN ratio. So, you are going to replace this data with the SN ratio of the same data.

So, imagine that this axis is taken off and it is replaced with SN ratio. The moment that becomes a SN ratio, you can use the same stuff. What are the questions that you need to answer it? You want to find out which factor is important; what is the order of importance of the factors that is number 1, within a factor which level is important because that is what will give you the combination the optimal combination. For D, it could be 1 for F, it could be 2. So, then your experimental combination will be B 1 F 2 and the other one is accordingly, whatever levels they are. So, you want to identify those stuff.

So, I am going to replace this flight time with the SN ratio of the flight time. So, this 2 column will become 1 column now. But, it still preserves the property, meaning it preserves the information in the ratio sense.

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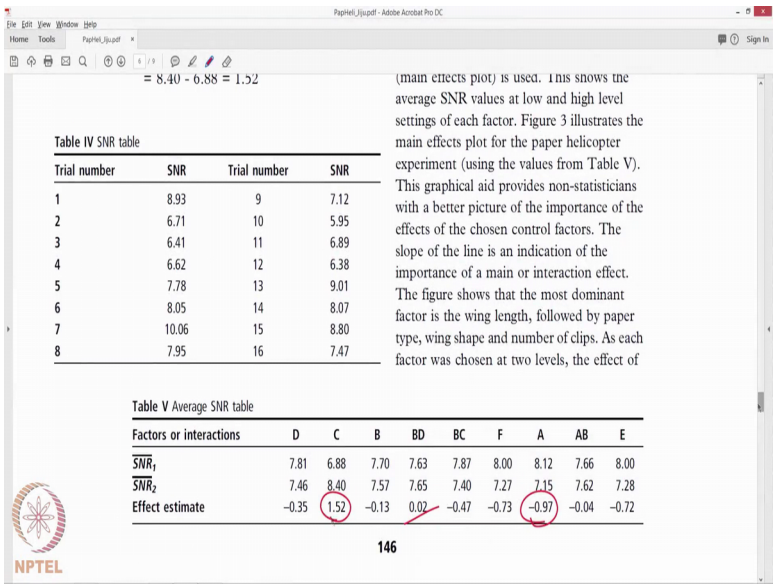
= 8.40 - 6.88 = 1.52

(main effects plot) is used. This shows the average SNR values at low and high level settings of each factor. Figure 3 illustrates the main effects plot for the paper helicopter experiment (using the values from Table V). This graphical aid provides non-statisticians with a better picture of the importance of the effects of the chosen control factors. The slope of the line is an indication of the importance of a main or interaction effect. The figure shows that the most dominant factor is the wing length, followed by paper type, wing shape and number of clips. As each factor was chosen at two levels, the effect of

Table IV SNR table

Trial number	SNR	Trial number	SNR
1	8.93	9	7.12
2	6.71	10	5.95
3	6.41	11	6.89
4	6.62	12	6.38
5	7.78	13	9.01
6	8.05	14	8.07
7	10.06	15	8.80
8	7.95	16	7.47

Table V Average SNR table

Factors or interactions	D	C	B	BD	BC	F	A	AB	E
$\overline{SNR}_1$	7.81	6.88	7.70	7.63	7.87	8.00	8.12	7.66	8.00
$\overline{SNR}_2$	7.46	8.40	7.57	7.65	7.40	7.27	7.15	7.62	7.28
Effect estimate	−0.35	1.52	−0.13	0.02	−0.47	−0.73	−0.97	−0.04	−0.72

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So, then this is what happens; I have computed the SNR for the 16 trials it is given here for each trial what is the SN ratio. Now, you need to be able to tell; what is the effect of

A with respect to the SN ratio not with respect to your flight time; it is still the SN ratio of your flight and you want to maximize it right. So, what I am going to do is let us say that lets imagine that you are replacing you are replacing this with your SN ratio, it is a response orthogonal array or analysis does not care whether you replace it with the SN ratio or flight time; it is just analysis that you need to worry about ok.

Now, if I want to understand the effect of D on this SN ratio how will I do that?

Student: (Refer Time: 22:10).

For this particular guy, I will take the average of this guy that let me call it D 1 average and then I will take an average of this; that I will call D 2 average. The difference between the 2 will give me the effect of D. So, will be the case for C, I will take all the cases in which it is 1; I will find C 1 bar, then I will take this 8. I will take C 2 bar take the difference of those 2 that will tell you the effect of C this is exactly what they have done ok.

You know what I am talking about right. There is a SN ratio for these 8 entries that we saw. I m going to take an average of those 8 not the average of this, this is just 1. What I meant is those are the experiments, for those experiments what is your SN ratio? You take those 8 take an average, you take these 8 you take an average. Similarly, you take this 4, add up to this 4, you take an average for the second one. Similarly, the second 4 and the last 4, add them find an average that we will give the difference between the C 2 average and the C 1 average will give you the effect of C. That is exactly is what happening here. SNR 1 bar for D is 7.81. This is what I wrote as D 1 bar D 2 bar and then, the effective will give you this that is all.

Now, tell me which of this factor is more sensitive?

Student: (Refer Time: 23:52).

Sorry C. C is 1.52. Which one is the next sensitive?

Student: (Refer Time: 24:03).

Sorry I.

Student: D.

(Refer Time: 24:10) D why?

Student: BD.

BD 0.02.

Student: (Refer Time: 24:18).

I got it (Refer Time: 24:21) It is actually 0.97. I just said it sensitive. Did I say its negative or positive? It is sensitive. Whether it is positive or negative? It is sensitive that is important. You are interested in maximizing, but you should also know which factor will actually pull you down the worst. So, sensitivity why is it does not matter what your sign is there sensitive negative or positive. So, this is rank to 1, this is rank 2 with respect to this particulars ok. This is this is called SN ratio based analysis, you can call it. But there are also other ways in which you can get this study done.

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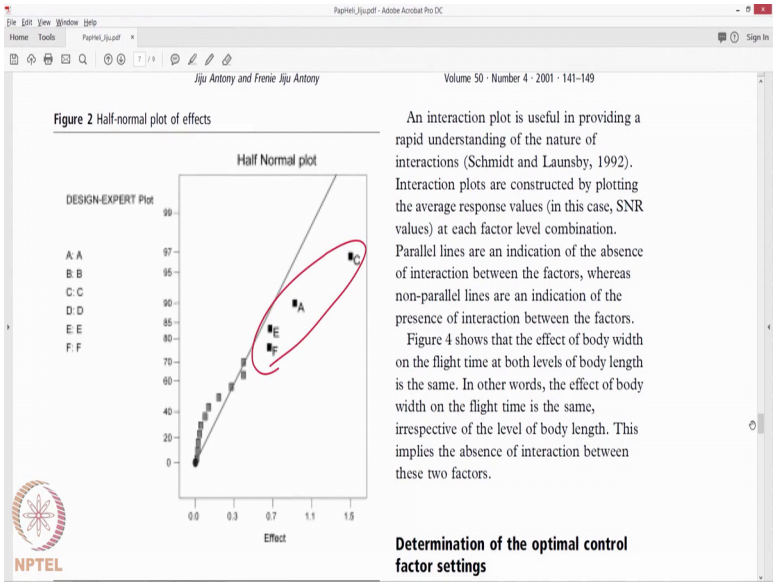

So, we will see there is something called an Half-normal probability plot with I am going to skip; this is an alternate. What it will do is this is some kind of a QQ plot; it is called Quantile-Quantile plot. And then you do the affect verses your factors in this case and in the ones that will depart has the most affected compared to the other guys. There is a 45 degree line drawn here and the ones that will fall out of that has the most effect; slightly out of scope for us. So, let us not discuss ok.

But you can read the paper and you will understand it is it is not a big deal they will find an empirical CDF accumulative distribution function from which they were able to plot this one.

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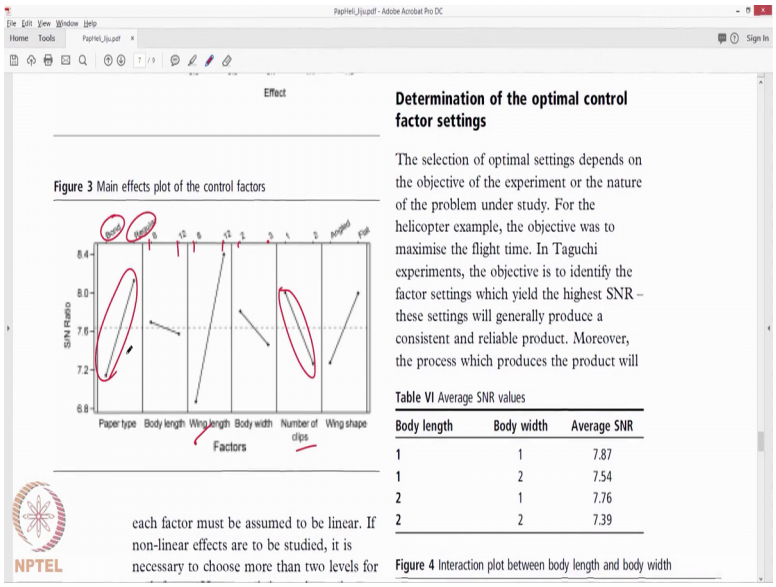

The other thing that you can do with your SN ratio is to create something call the main effects plot. For instance this is paper type; this is bond, this is regular; that is a level 1 and level 2 correct that is what they say. So, I think this is wrong, it should have been regular; and one that because that is what is level 1 and this is level 1 ok. You do level 1 and level 2 for each of these cases that that simple wherever you have this its level 1, level 1, level 2 level 2, level 1, level 2.

Now, what I am going to do? This y axis is an SN ratio. It does not it does not care what it is meet are? Is it 1 or 2 or whatever it is right? It is just SN ratio. So, I am plotting the SN ratios. Now from this I can directly tell you which is the most sensitive kind; how?

Student: Length.

Length?

Student: (Refer Time: 27:02).

It is not the length right. What is it actually?

Student: (Refer Time: 27:10).

Sorry, Flight? Flight is over; we are converted the flight time in the SN ratio. We are playing with the SN ratio here.

Student: (Refer Time: 27:22).

You should look for the slope of the line. Looking for a steep slope from your limited visual presentation that I give you here which do you think has the good slope; that is a word.

Student: Third (Refer Time: 27:46).

Third one wing length why because its long is it.

Student: (Refer Time: 27:51).

You know what slope is right; more y axis travelled for the same x axis. Please also remember that we do not care about the direction, it could be going lesser going more; you are still trying to find out which one is sensitive.

Student: Number of (Refer Time: 28:17) very sensitive.

Number of?

Student: (Refer Time: 28:20).

Clips; number of clips this guy ok. So, there is some visual stuff that you waste thing that wing length is one and the number of clips is right. So, it is we will see what they finally, find out. C was what? See, you guys were right C was 1. We got C. C 2 be the top most influencer even in this analysis from just plotting the SN ratio also you got it. The second best you claim is the number of clips, but here A; A is nothing but your paper type that had the best effect next that is this guy here ok.

If you see I hope you are able to see is the value of the slope the magnitude of the slope might be more or less same for these guys ok. So, we will check.

Student: So, within this identify the (Refer Time: 29:31) the larger the length the larger the (Refer Time: 29:33) larger the (Refer Time: 29:34).

That is the effect that is also true; if you take it if we normalize all of them that is what is happening is in a SN ratio. You can take the lengthwise also because what is happening is see the normalization is with thanks; the normalization is with respect to your x axis. So, for the same x you are moving from level 1 to level 2; I do not care whether you are moving from 8 to 12 or you are moving from meaning 8 centimeters to 12 centimeters or you are moving from 1 clip to 2 clips. It is the same with respect to me because it is normalize from level 1 to level 2. You are jumping from 1 level 2; another you have crossed 1 level that is what it is. For 1 level what is the maximum distance I have covered in y?

So, that is maximum with respect to wing length that is what is your slope. The second best would be this guy the best is this and probably the fourth best is this. So, if you paper type number of clips should be more or less the same; let us see, number of clips was E is it, E I think number of clips was RF. I am sorry I should have organize this much better number of clips was E in wing shape was F. So, number of clips is E as we pointed out and wing shape also has a good this thing see wing shape is of more or less the same in this one so.

So, these are supporting and if you see AC EF here also, it is showing. So, these are multiple ways of reaching the same, but it is not true that always you will get the same; sometime this might not capture F. Then you will have to pay additional attention to understand why that is happening; is it implementation issue or naturally there is a F is not is not that kind of an influencer ok.

Because these ideas come from slightly different all are statistics is slightly different basics. So, you just need to pay attention to that; that is all ok. So now, this gives you which is the highest influencer? This one tells you right. But now that is that is just not what you want? You want something more also you want to maximize your SN ratio. If you go here, I can just find the SN ratio which we have already found here.

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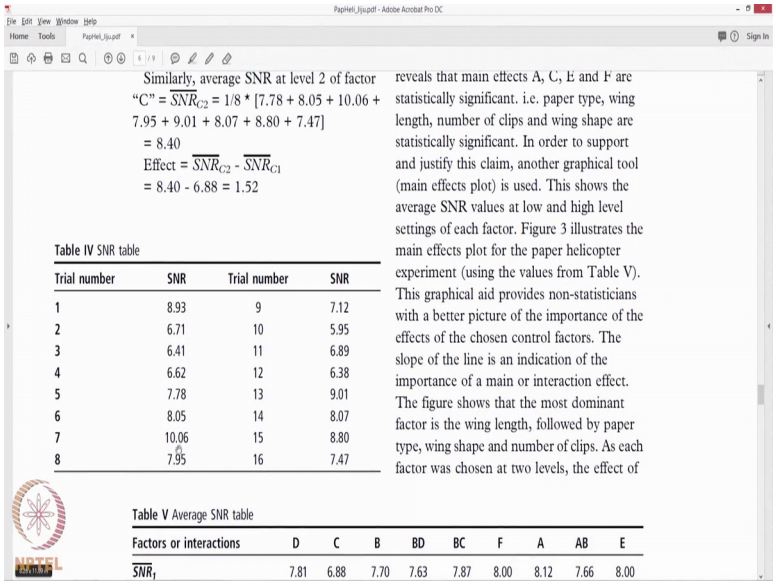

Similarly, average SNR at level 2 of factor "C" = $\overline{SNR}_{C2}$ = 1/8 * [7.78 + 8.05 + 10.06 + 7.95 + 9.01 + 8.07 + 8.80 + 7.47]
= 8.40
Effect = $\overline{SNR}_{C2}$ - $\overline{SNR}_{C1}$
= 8.40 - 6.88 = 1.52

reveals that main effects A, C, E and F are statistically significant. i.e. paper type, wing length, number of clips and wing shape are statistically significant. In order to support and justify this claim, another graphical tool (main effects plot) is used. This shows the average SNR values at low and high level settings of each factor. Figure 3 illustrates the main effects plot for the paper helicopter experiment (using the values from Table V). This graphical aid provides non-statisticians with a better picture of the importance of the effects of the chosen control factors. The slope of the line is an indication of the importance of a main or interaction effect. The figure shows that the most dominant factor is the wing length, followed by paper type, wing shape and number of clips. As each factor was chosen at two levels, the effect of

Table IV SNR table

Trial number	SNR	Trial number	SNR
1	8.93	9	7.12
2	6.71	10	5.95
3	6.41	11	6.89
4	6.62	12	6.38
5	7.78	13	9.01
6	8.05	14	8.07
7	10.06	15	8.80
8	7.95	16	7.47

Table V Average SNR table

Factors or interactions	D	C	B	BD	BC	F	A	AB	E
$\overline{SNR}_1$	7.81	6.88	7.70	7.63	7.87	8.00	8.12	7.66	8.00

And I can find the maximum one which 10.06, experiment number 7. I can go and say that the experimental setup 7 is what the best is. Is that right or should we do something else?

Student: So, it should be (Refer Time: 32:05).

If there is any other combination because you remember it is only one-fourth of your original 64, you did only L 16 instead of 64. So, how do I do that is you just come here and you tell me for each factor for each factor which was the best operating condition, because a maximum of my factors will give me the maximum of my output because my interaction is only a reflection of my factors. It is automatically taken care in the orthogonal array ok. So, what you can do is this you can say paper type level 2; body length level one please remember here sign is important. Here, sign is important wing length level 2.

So, we will see whether that is correct.

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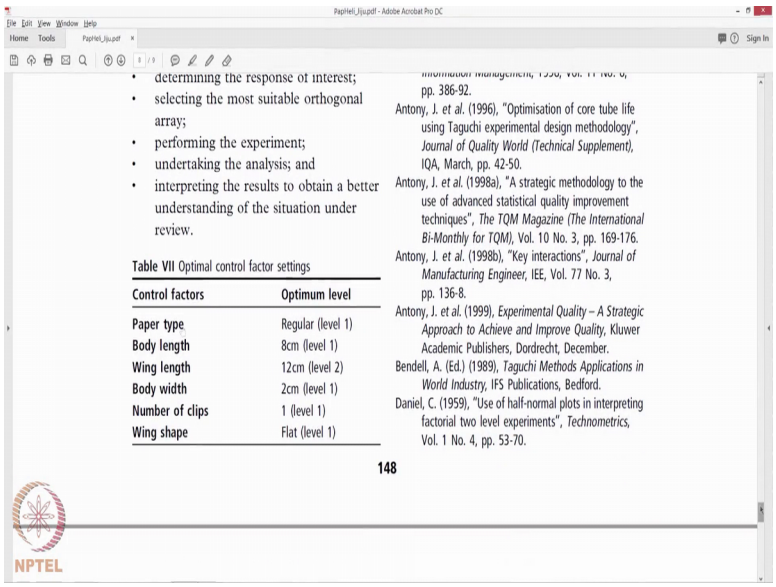

Paper type they have plotted level 1 on the right. So, you know why did that? So, regular is level 1 in this case ok; whereas, in body length it is 1; body length it is 1, wing length it is level 2. As you saw it had a positive slope and then body with. So, you can go around doing this and then you can say A 1 B 1 C 2 and so on. You can go and you say that is going to be my optimal combination which is what these people would have done and they have compare that value I guess; they did this and then they figured out that that gave you a better optima than the existing ones. So, you will have to valid it.

So, in the process of discussing this paper, we have revisited the entire process the workflow of your design of experiment. We just took a simple Paper Helicopter experiment. We decided what your problem statement is I want to maximize my SN ratio because I want to maximize my flight time. See your problem is to maximize your flight time, but that is not your problem statement. Your problem statement is I want to maximize my SN ratio because I also want to take care of my noise. It is not enough if I just maximize my its mean shift alone is not enough, I also want to minimize my variance. So, I am going to maximize my SN ratio that is something with we have discussed. Then, in order to do that you need to identify your factors.

In this particular example the claim is that it comes through brainstorm and they have identified 6 factors and you will have to choose the levels at which you want to do this test; then, which will again govern the orthogonal array. So, if you are having 6 factors and 2 levels it is about 64 experiments, but you take one-fourth of it, you run a L 16, you need to assign factors to it wherein they decided 6 single factors and only 3 interactions

are required. I do not want higher order interactions even in the two factor interactions I do not need more than 3. So, this comes from expert knowledge or brainstorming. So, they pull in that and the remaining rows or columns are kept as dummy; dummy means you do not bring them interaction; that is all ok.

So, you do that and then we looked at couple of ways in which you can do that; you can do an SNR based analysis or you can plot SNR, what they call is the main effect plots; you can do that and then you can get this result. There is one thing that we do not discuss in this course is called the ANOVA, analysis of variance which is more quantitative and which is the way usually people are satisfied by doing. This is kind of a first cut analysis that you can do. ANOVA gives you more information into the quantitative nature of the problem. Today, you can go to excellent do an ANOVA analysis; you can go to mini tab, you can go to mat lab and get an ANOVA analysis system that is not a big deal.

The only problem is not only problem they only challenges for you to be able to infer what it means. So, there is call something called an F metric. It will not say this is a best combination F metric is more of a probability. It says there is something called a hypothesis. It says with this much confidence, this hypothesis holds good. So, you should know how to be able to inherent to use that the information; that is all. So, ANOVA is the usual quantitative way of looking at it whatever we have looked at, right now is more qualitative in nature.