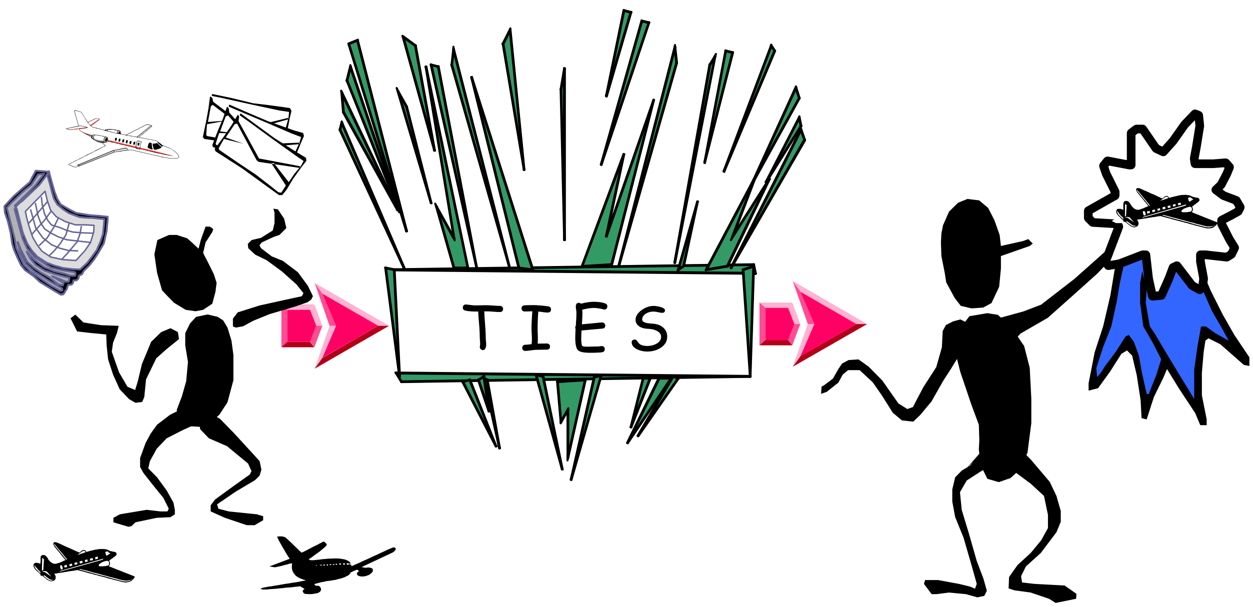
TIES for Dummies

3rd Edition

(Technology Identification, Evaluation, and Selection)

Basic how to's to implement the TIES method



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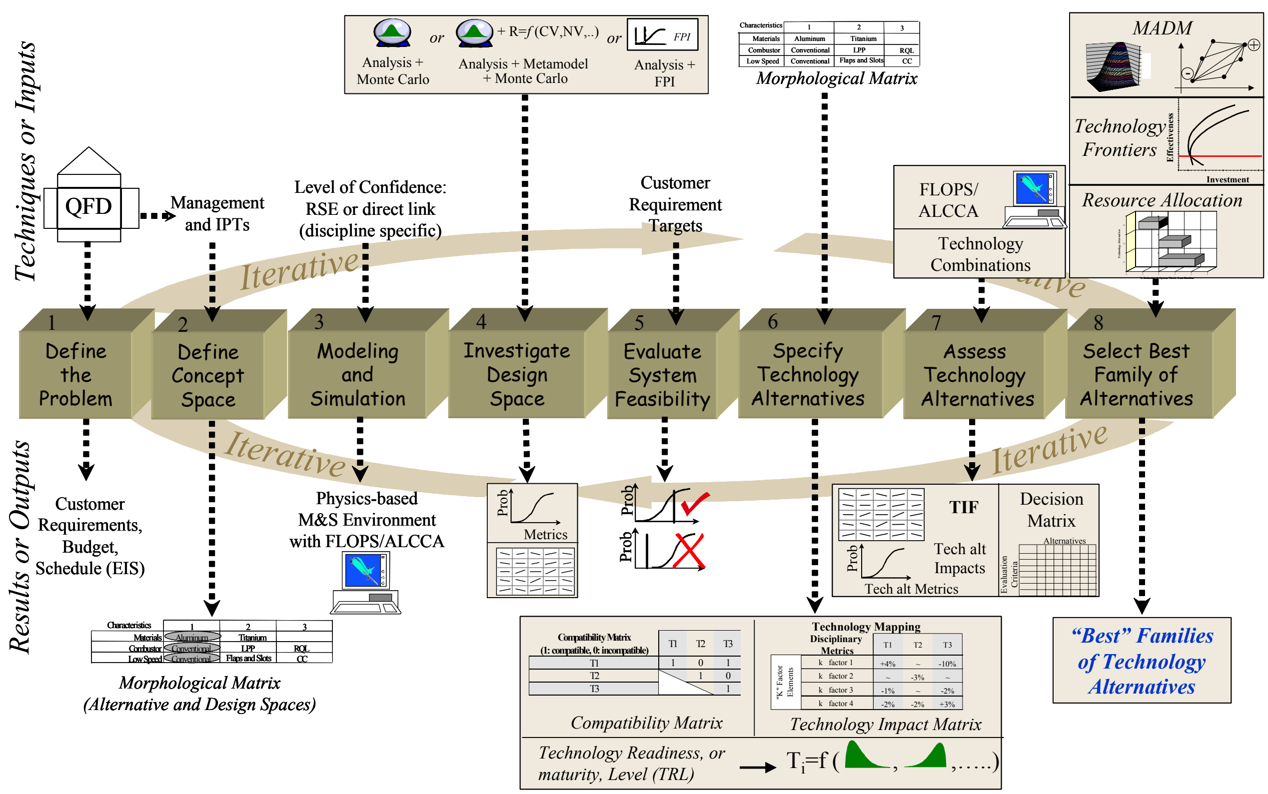
TIES for Dummies

The TIES method is a forecasting environment whereby the decision-maker has the ability to easily assess and trade-off the impact of various technologies without sophisticated and time-consuming mathematical formulations. TIES provides a methodical approach where technically feasible alternatives can be identified with accuracy and speed to reduce design cycle time, and subsequently, life cycle costs, and was achieved through the use of various probabilistic methods, such as Response Surface Methodology and Monte Carlo Simulations. Furthermore, structured and systematic techniques are utilized from other fields to identify possible concepts and evaluation criteria by which comparisons can be made. This objective is achieved by employing the use of Morphological Matrices and Multi-Attribute Decision Making techniques. Through the execution of each step, a family of design alternatives for a given set of customer requirements can be identified and assessed subjectively or objectively. This methodology allows for more information (knowledge) to be brought into the earlier phases of the design process and will have direct implications on the affordability of the system. The increased knowledge allows for optimum allocation of company resources and quantitative justification for program decisions. Finally, the TIES method provided novel results and quantitative justification to facilitate decision making in the early stages of design so as to produce affordable and quality products.

The steps of TIES:

1. Define the problem
2. Define Concept Space: design and technology concepts identification
3. Modeling and simulation
4. Investigate design space
5. Evaluate of system feasibility/viability: probability of success
6. Specify Technology Alternatives
7. Assess Technology Alternatives
8. Select Best Family of Alternatives



The following tutorial explains how to implement each of the steps from a computational or evaluation point of view. References associated with the TIES method are listed below and can be obtained from the web site: http://www.asdl.gatech.edu/publications/index.html.

1. Kirby, M.R., Mavris, D.N., "A Method for Technology Selection Based on Benefit, Available Schedule and Budget Resources", SAE 2000-01-5563.
2. Kirby, M.R., Mavris, D.N., "Forecasting Technology Uncertainty in Preliminary Aircraft Design", SAE Paper 1999-01-5631.
3. Mavris, D.N., Kirby, M.R., "Technology Identification, Evaluation, and Selection for Commercial Transport Aircraft", 58th Annual Conference Of Society of Allied Weight Engineers, San Jose, California 24-26 May, 1999.
4. Mavris, D.N., Kirby, M.R., Qiu, S., "Technology Impact Forecasting for a High Speed Civil Transport", World Aviation Congress and Exposition, Anaheim, CA, September 28-30, 1998. SAE-985547.
5. Mavris, D.N., Mantis, G., Kirby, M.R. "Demonstration of a Probabilistic Technique for the Determination of Economic Viability," World Aviation Congress and Exposition, Anaheim, CA, October 13-16, 1997. SAE-975585.

So, let's begin.

Step 1: Problem Definition

The first step in TIES is to define the problem in terms of the customer requirements for which the product will be designed, the available budget to expend on the development, and the time frame in which the product must enter the market. In order to formulate the problem, a customer or societal need must exist or a request for proposal must be stated to drive the design of a new product. This need is often termed the "voice of the customer" and is typically qualitative, or ambiguous, in nature. For example, a commercial airline performs a market study and identifies that a majority of potential passengers wish to have lower fares and more flight time options. These are subjective and qualitative "wants" that must be mapped into some economic, engineering, or mathematically quantifiable terminology. The result of this step is the identification of the system level metrics which capture the customer requirements and will be the measure of success of the system under consideration.

Table 1: Metrics and Constraints:

Parameter	Acronym	Target or Constraint	Units
Performance			
Approach Speed	Vapp	= 155	kts
FAR Stage II Flyover Noise	FON	= 106	EPNLdB
Landing Field Length	LdgFL	= 11,000	ft
FAR Stage II Sideline Noise	SLN	= 103	EPNLdB
Takeoff Field Length	TOFL	= 11,000	ft
Takeoff Gross Weight	TOGW	= 1,000,000	lbs
Economics			
Acquisition Price	Acq$	*Minimize*	FY96 $M
Research, Development, Testing, and Evaluation	RDT&E	*Minimize*	FY96 $M
Average Required Yield per Revenue Passenger Mile	$/RPM	= 0.10	FY96 $M
Total Airplane Related Operating Costs	TAROC	*Minimize*	FY96 ¢
Direct Operating Costs plus Interest	DOC+I	*Minimize*	FY96 ¢

Step 2: Define Concept Space: Design and Technology Concepts

Once the customer requirements are defined in terms of quantifiable engineering parameters, the thrust of the TIES method begins with the definition of the concept space and is driven by innovation and "out-of-the-box" thinking. Initially, the experience, knowledge, and intuition of the designer is utilized to identify a potential class of vehicles and provides the methodology with a starting point for selecting potential solutions to satisfy the customer requirements. The focus of this step is two-fold: identify the space of alternative concepts that is based on a defined class of vehicles, and establish the geometric and propulsive design space for which system feasibility is initially sought.

Define Technology and Concept Space

In the design of any complex system, there exists a plethora of combinations of particular subsystems or system characteristics that may satisfy the problem at hand. For example, how many engines are needed? What is the cruise speed? What type of high lift system is needed? Is a horizontal stabilizer preferred over a canard? A functional and structured means of decomposing the system and identifying component options is through the use of a morphological analysis. The Morphological Matrix is formed by identifying the major functions or characteristics of a system on the vertical scale and all the possible alternatives for satisfying the characteristics on the horizontal scale. In essence, this is where the technology alternatives, both mature and immature, to be considered in later steps are defined. Once the matrix is populated, an alternative design concept is defined as a mix of the characteristic alternatives. All possible design alternative combinations define the alternative concept space. In general, one alternative concept is established to begin the feasibility investigation and will be called the baseline concept and is typically drawn from mature technologies. Please refer to references 3 and 4 for more info.

Table 2: Morphological Matrix for HSCT

	Characteristics \ Alternatives	1	2	3	4
Config	Vehicle	Wing & Tail	Wing & Canard	Wing, Tail & Canard	Wing
	Fuselage	Cylindrical	Area Ruled	Oval	
	Pilot Visibility	Synthetic Vision	Conventional	Conventional & Nose Droop	
Mission	Range (nmi)	5000	6000	6500	
	Passengers	250	300	320	
	Mach Number	2	2.2	2.4	2.7
Propulsion	Type	MFTF	Turbine Bypass	Mid Tandem Fan	Flade
	Materials	Conventional	High T Comp		
	Combustor	Conventional	RQL	LPP	
	Nozzle	Conventional	Internal Flow Alteration	Mixed Ejector	Mixer Ejector & Acoustic Liner
Aero	Low Speed	Conventional Flaps	Conventional Flaps & Slots	C C	
	High Speed	Conventional	NLFC	Active Control	HLFC
Struct	Materials	Aluminum	Titanium	High Temp. Composite	
	Process	Integrally Stiffened	Spanwise Stiffened	Monocoque	Hybrid

Define the Design Space

Once the baseline concept is defined from the alternative concept space, the baseline may be further decomposed into product and process characteristics. This can be performed via the Morphological Matrix or through brainstorming sessions with IPTs. Primary product attributes include the physical design parameters that describe a characteristic of the system. In conceptual and preliminary aircraft design phase, all of the design parameters should not be fixed but should vary within some specified range until such time as a configuration is “frozen”. The process attributes include certification, manufacturing, economic, and operational parameters, which are inherently uncertain.

Within the context of TIES, the product attributes are the key design variables (with associated ranges) which define the design space of interest for a given alternative concept. These design variables are often referred to as “control” factors, or variables that are within the designer’s control. These key design variables, and associated ranges, define the design space in which system feasibility is sought. The design variable ranges are chosen such that the largest possible deviations in the given baseline configuration may be captured. This implies that the system must have a converged solution, that is, be capable of flying the specified mission. However, care should be taken so that a handful of variables do not artificially dominate the design space due to larger relative ranges. For example, if one variable is allowed to deviate ±5%, other variable deviations should be the same order of magnitude.

Table 3: Design Variables and Ranges With Baseline Configuration.

Variable	Minimum	Maximum	Baseline Value	Units	Description
SW	7500	9000	900	ft2	Wing Area
TWR	0.29	0.33	0.29	~	Thrust-to-weight ratio
TIT	3000	3400	3000	°R	Turbine Inlet Temperature
FPR	3.5	4.5	4.5	~	Fan Pressure Ratio
OPR	18	21	18	~	Overall Pressure Ratio
CLdes	0.08	0.12	0.1	~	Design Lift Coefficient
X2	1.54	1.69	1.609	~	LE kink x-location*
X3	2.1	2.36	2.36	~	LE tip x-location*
X4	2.4	2.58	2.58	~	TE tip x-location*
X5	2.19	2.37	2.19	~	TE kink x-location*
X6	2.18	2.5	2.18	~	TE root x-location*
Y2	0.44	0.58	0.51	~	LE kink y-location*
t/c root	3	5	4	%	Wing root thickness-to-chord ratio
t/c tip	2	4	3	%	Wing tip thickness-to-chord ratio
SHref	400	700	550	ft2	Horizontal Tail Area
SVref	350	550	450	ft2	Vertical Tail Area

*Variable normalized by wing semi-span

Step 3: Modeling and Simulation

A modeling and simulation (M&S) environment is needed to facilitate rapid assessments with minimal time and monetary expenditures of the alternative concepts identified in the Morphological Matrix. Most companies have an in-house developed M&S environment to perform the design trades. The TIES method is not code specific, but the M&S tool utilized must have some basic features as outlined in Table 4. One cannot underestimate the importance of having a cohesive M&S environment. Without this environment, application of the TIES method is arduous. A principle requirement for any decision making process is the ability to quantitatively assess the customer requirements that drive a design. This can only be achieved through an M&S environment. The requirements for the M&S environment in Table 4 are directed towards aircraft analysis codes. However, one may extrapolate the features needed for ANY system design code.

If the class of vehicle that you are considering falls in the validity range of the analysis tool, you are ready to go. Most of the existing public domain codes are based on historical data for evolutionary concepts. If the designs of interest fall within this range, the sizing and synthesis codes can accurately assess the objectives. Yet, for a revolutionary concept the validity of the results will be questionable. This inability can be overcome through direct linking of more physics-based analytical models, or using metamodels to represent the physics-based analysis tool. Look at reference 4 for more information.

Table 4: Required Features Needed for an M&S Environment

Feature	Importance	Purpose
Parametric inputs	*High*	To quantify outputs in terms of inputs and facilitate the use of Response Surface Methods
Physics based	*Medium High* (based on level of confidence desired)	To analyze and model evolutionary or revolutionary concepts
Synthesis capability	*Average* (could use table look-ups created off-line)	To quantify the various disciplines (aerodynamics, structure, and propulsion) for a given configuration
Unconstrained mission analysis	*Medium High*	To "size" the system in terms of a fuel and thrust balance to fulfill a given mission that results in a "sized" vehicle and corresponding weights in an unconstrained manner so as to employ the use of metamodels for a continuous design space
Robust input definition	*High*	To allow for a wide range of configurations or missions to be analyzed
Economic analysis	*High* (assumes economics are a key driver)	To immediately quantify the impact of design changes on the economic requirements of the system
Responses are quantifiable	*Medium High*	To functionally relate the responses of interest to the variations of inputs
Disciplinary technical metric impact factors	*Very High*	To simulate the discontinuity associated with the addition of new technologies
Automation capability	*Average*	To facilitate probabilistic design methods and to have a "wrapper" around the tool
Rapid Assessments	*Average*	To facilitate reduced cycle time
Access to source code	*Average*	To modify fidelity deficiencies of different disciplines as needed and understand internal control laws or to add technical metric "k" factors

Table 5: HSCT Baseline Metrics

Parameter	Acronym	Baseline Value
Performance		
Approach Speed	Vapp	154.1 kts
FAR Stage II Flyover Noise	FON	112.3 EPNLdB
Landing Field Length	LdgFL	9,063.2 ft
FAR Stage II Sideline Noise	SLN	111.6 EPNLdB
Takeoff Field Length	TOFL	12,407 ft
Takeoff Gross Weight	TOGW	937,108 lbs
Economics		
Acquisition Price	Acq$	218.58 FY96 $M
Research, Development, Testing, and Evaluation	RDT&E	16,124.9 FY96 $M
Average Required Yield per Revenue Passenger Mile	$/RPM	0.1236 FY96 $
Total Airplane Related Operating Costs	TAROC	5.948 FY96 ¢
Direct Operating Costs plus Interest	DOC+I	5.058 FY96 ¢

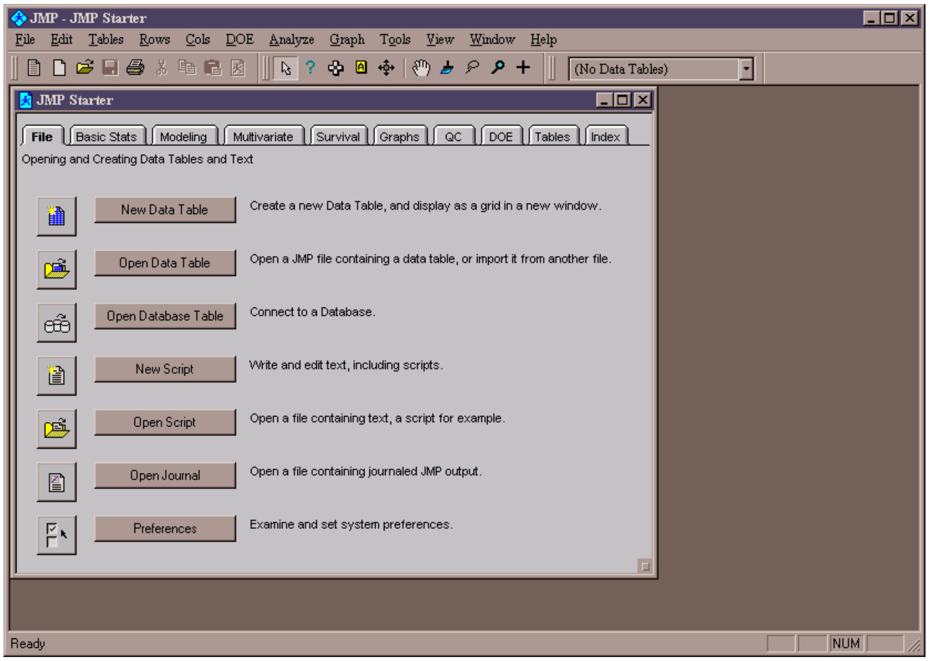
Step 4: Design Space Exploration

For the purpose of this tutorial, I will assume that you will use Response Surface Equations (i.e., a metamodel) representation of your metrics in conjunction with a Monte Carlo Simulation. In this step, you are trying to determine the metric values for any combination of design variables, i.e., where the metrics are as a function of design variables relative to the target values you identified in Step 1. The first step is to create a Design of Experiments (DoE) table. DoE is a technique to study the interactions between the design variables and their effects on the response metrics. Full factorial DoEs can only handle up to 16 variables, because the number of cases to run increases exponentially with more variables. For example, if you had 12 variables with two possible settings or levels, you would have 4096 or 2^{12} combinations to investigate. This is why it is important to use a fractional factorial DoE or to perform a screening test to eliminate some of the non-contributing variables. DoEs for more than 16 variables do not exist. Based on the Pareto Principle, it is rare that more than a handful of variables actually contribute to the response of interest. You can do a screening test at anytime, no matter how many variables you have. So, let's perform a screening test.

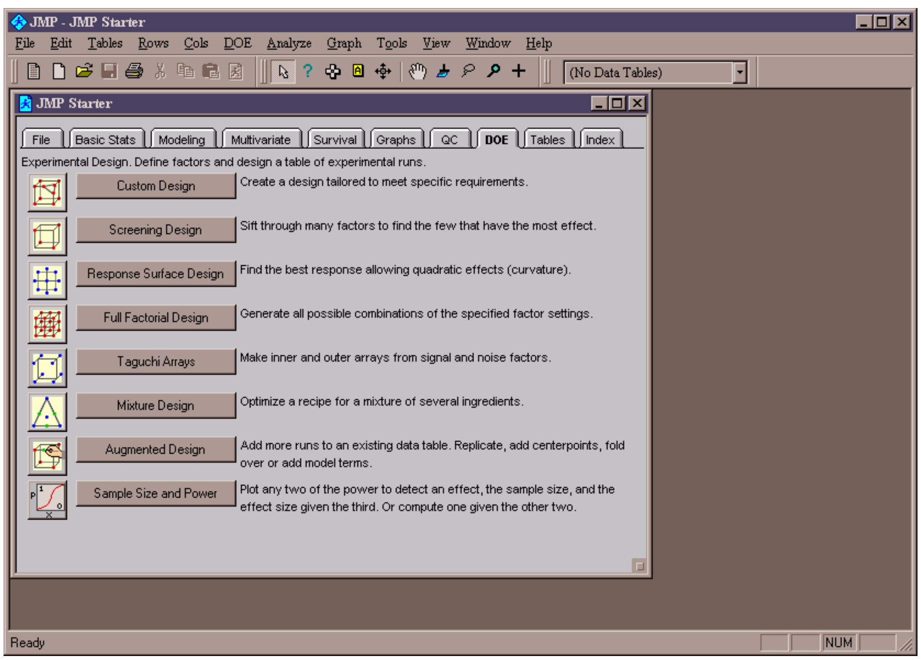
Screening Test

Start up JMP

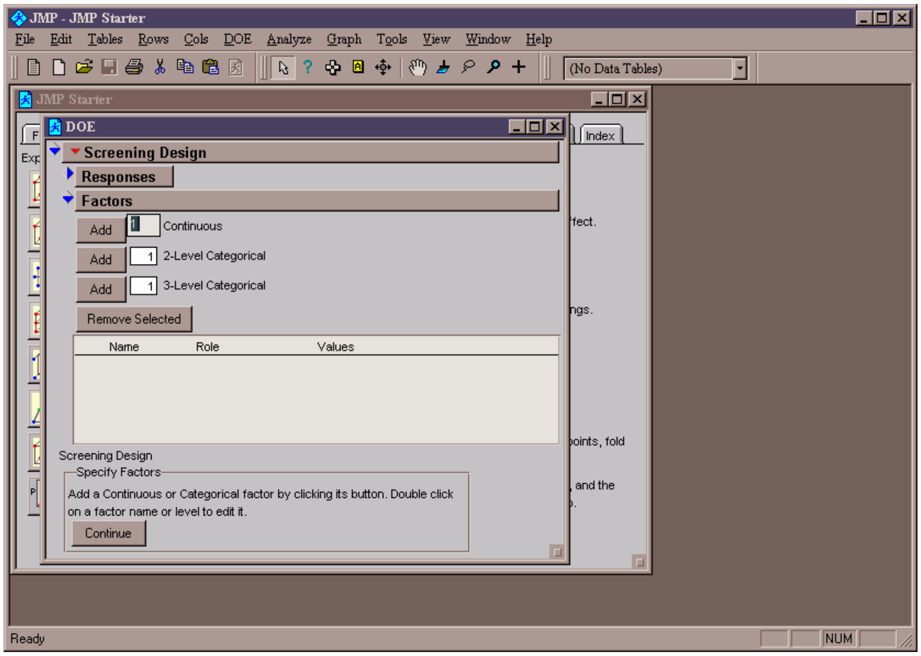
Go to the **JMP Starter** window. If the window doesn't come up when you start JMP, then go to **View** and select **JMP Starter** and the window below will come up.



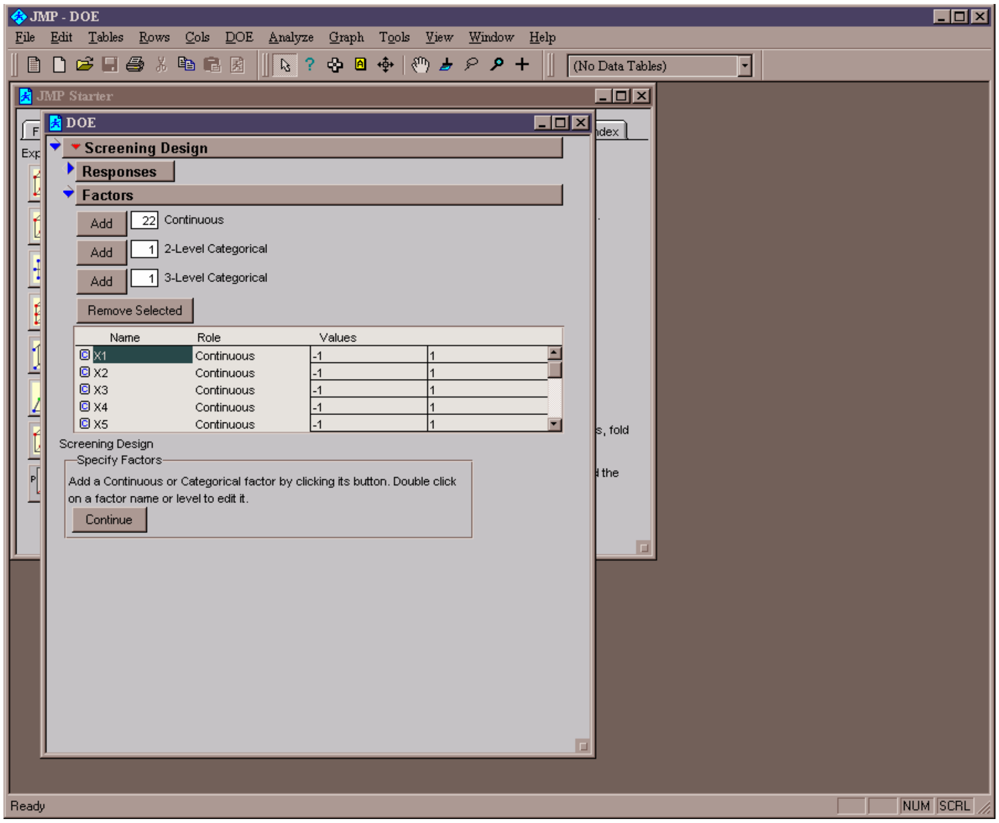
To create a Design of Experiments (DoE) table for a screening test go to **DOE** tab



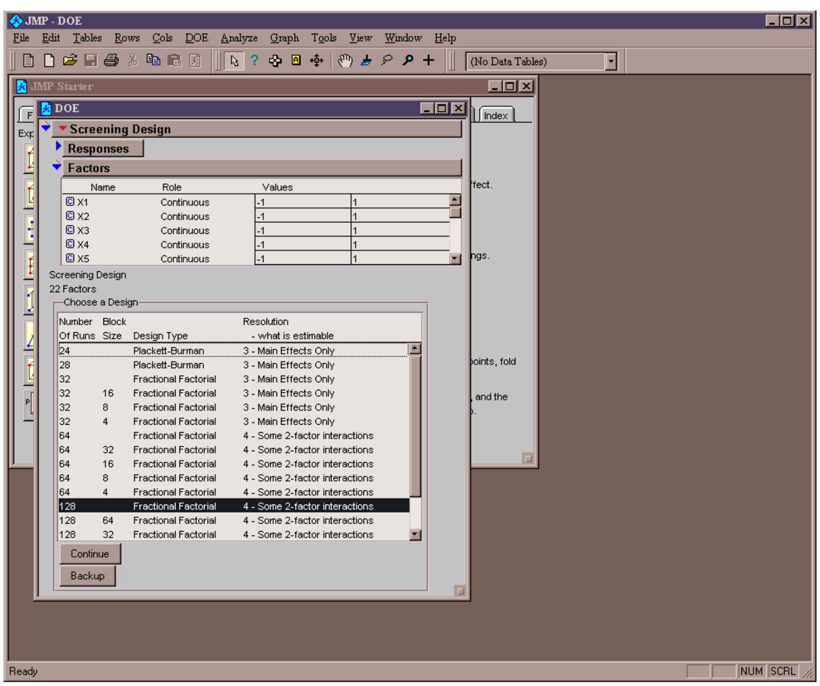
Then select the **Screening Design** button and add the number of continuous variables that you are considering. Let's add 22 variables.


JMP - JMP Starter
File Edit Tables Rows Cols DOE Analyze Graph Tools View Window Help
(No Data Tables)
JMP Starter
DOE
Screening Design
Responses
Factors
Add Continuous
Add 2-Level Categorical
Add 3-Level Categorical
Remove Selected
Name Role Values
Screening Design
Specify Factors
Add a Continuous or Categorical factor by clicking its button. Double click on a factor name or level to edit it.
Continue
Index
Ready
NUM

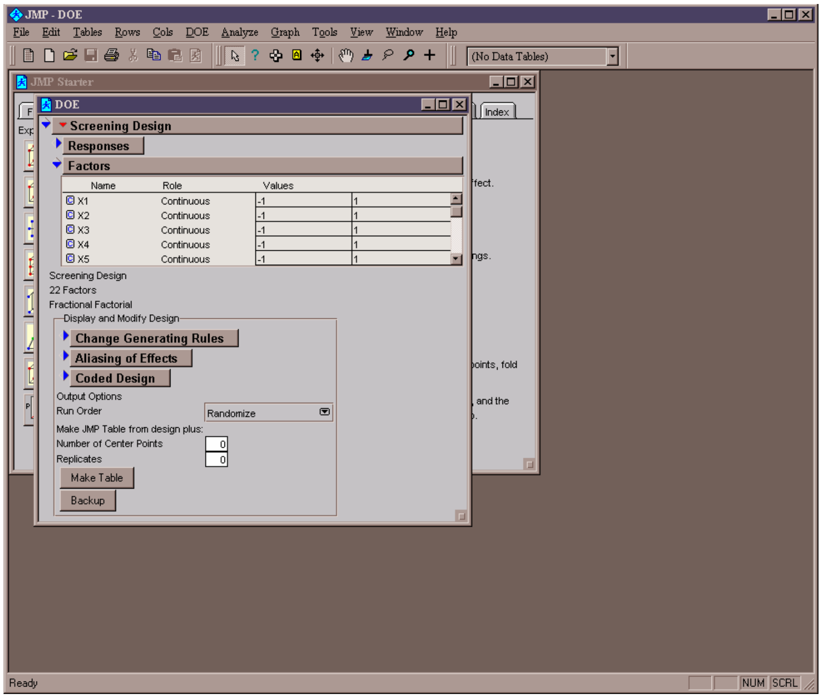
JMP will add X1 through X22 in the window that pops up. The variable ranges are set at a minimum of "-1" and a maximum of "1". If you would like to change the names of the variables from X1 to something more intuitive, just double click on X1 and enter the variable name. Also, if you would rather look at a dimensional DoE, double click on the "-1" or "1" and add in the real values. Once you are done, click the **Continue** button.



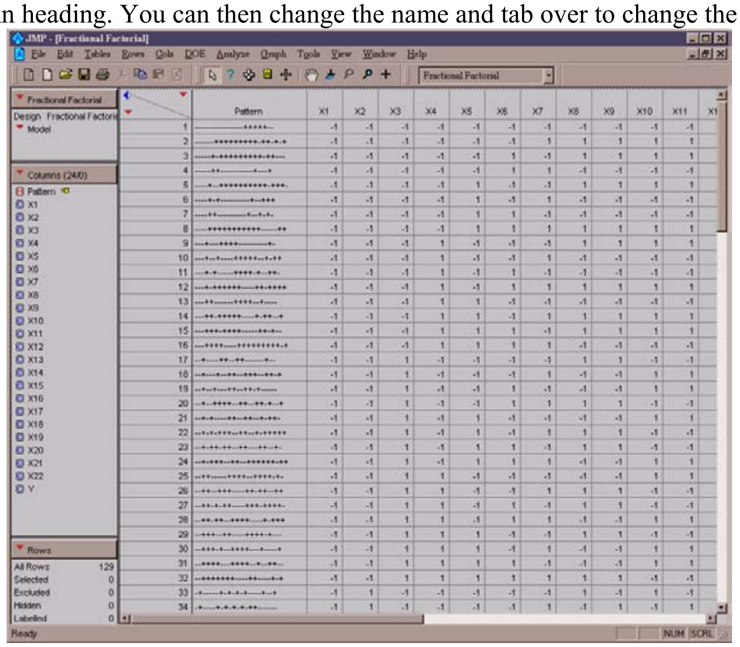
In general, the larger number of runs is better, so choose a Fractional Factorial with a Resolution IV with some 2-factor interactions with no value in the block size column and then select the **Continue** button, or if you have messed up for some reason you can hit the **Back** button and it will take you to the previous screen.



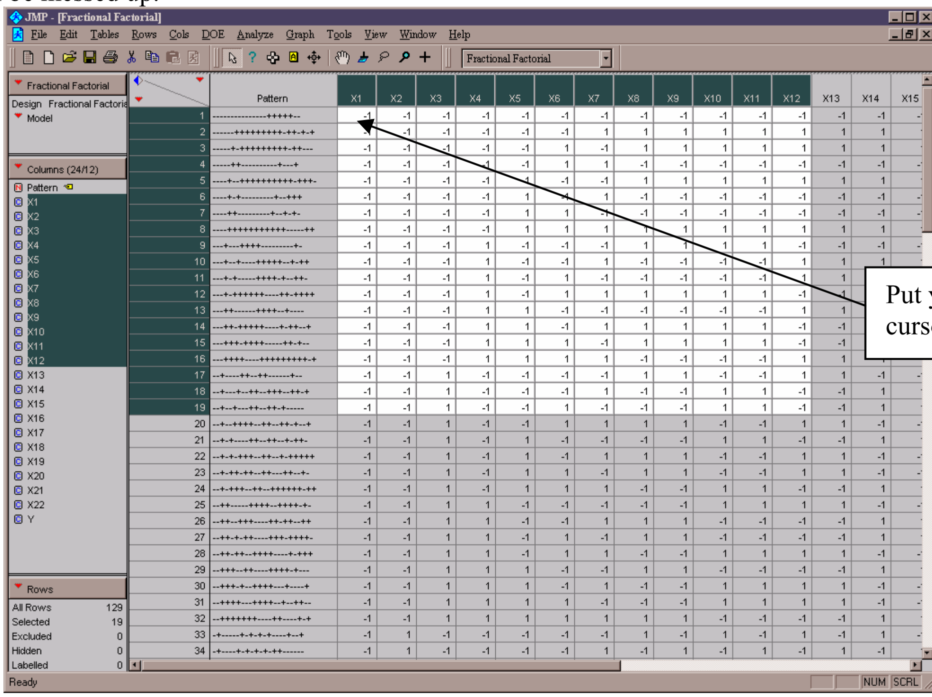
The next screen will come up. There is a lot of information here. In particular, under the **Change Generating Rules** you can modify the choice of different fractional factorial designs for a given number of factors. The **Aliasing of Effects** button shows you the aliasing structure of the design you have selected and the **Coded Design** button shows you the pattern of high and low values for the factors in each run. For our purposes, the DoE that JMP will create is fine. We do need to add a few things before continuing. In particular, add 1 center point so that any quadratic effects could be simulated. And under the drop menu for "Run Order", select the option "Keep the Same" rather than the default of "Randomize" so that you can always repeat the identical DoE in the future. Once you are done, select the **Make Table** button.



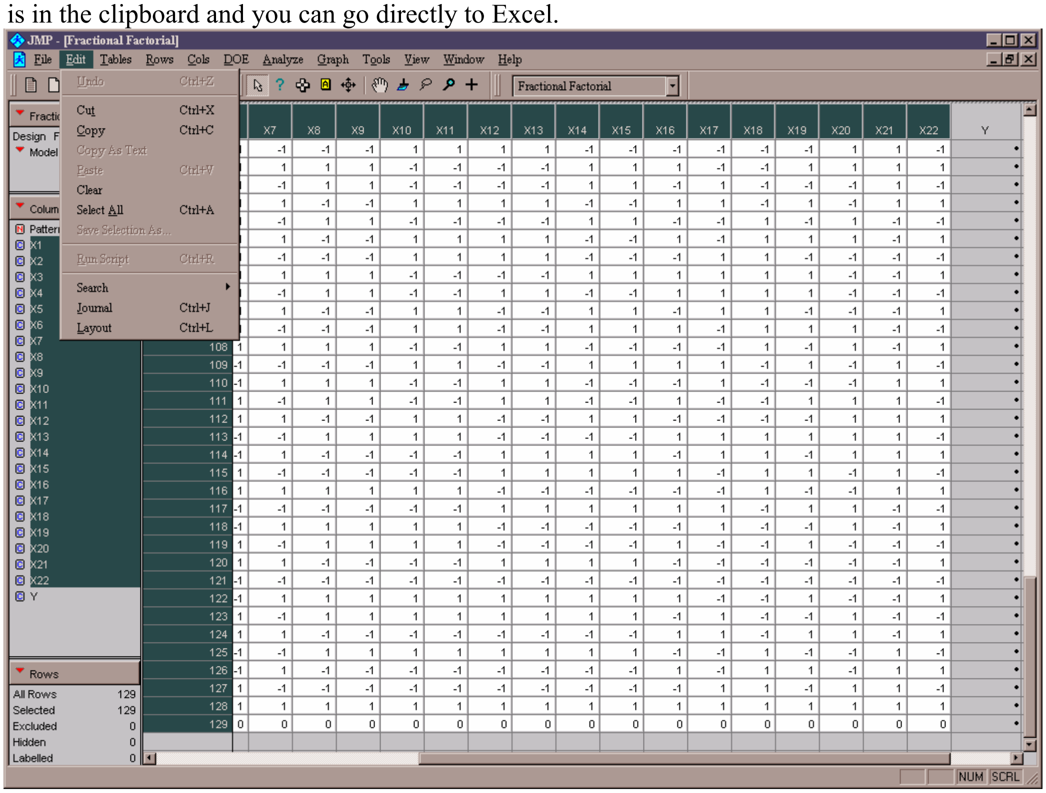
The following window will come up. This is your DoE for your screening test. If you did not enter in real values or names for your input variables then the table represents the non-dimensional settings of the 22 variables that you have (X1 through X22). It shows you that there are 129 rows which corresponds to the number of cases to be executed by your analysis code. In addition, the settings for the 22 variables that you have are shown, i.e. "-1" corresponds to the minimum setting of the variable, "+1" is the maximum value, and "0" is the midpoint. Note you can also change the labels on the columns to reflect the actual variable names that you have. You can do this by double clicking on the X1 column heading. You can then change the name and tab over to change the rest.



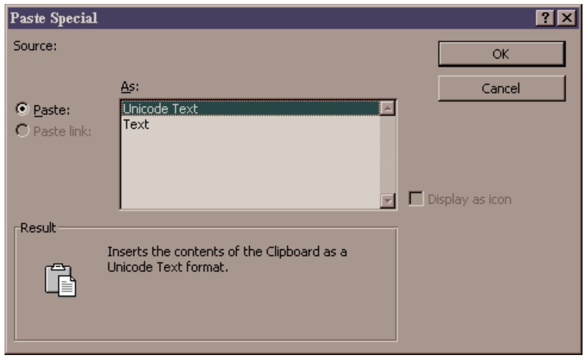
Now, what you need to actually run your analysis tool is the setting for the different variables for each case in the DoE, i.e., and actual values not non-dimensional ones. If you place the mouse cursor in the cell under “X1” and row 1, you can highlight the entire DoE table and then copy it into Excel. Below is shown a sample of a highlight. If I were to copy this and then paste it into Excel, I would get all the info for X1 through X12 and rows 1 through 19. You want the entire DoE table. NOTE: make sure that your copy and paste areas are the same dimensions. If they are not, your results will be messed up.



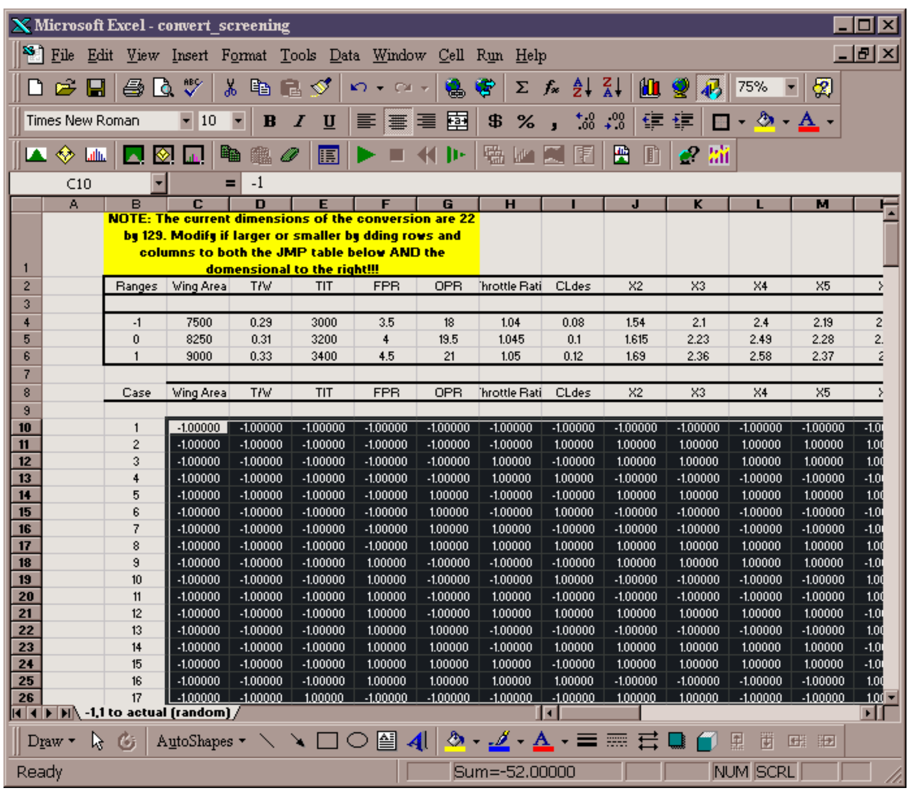
To copy the entire table, highlight all cells as shown below and then go to **Edit** and then click **Copy**. The entire DoE is in the clipboard and you can go directly to Excel.



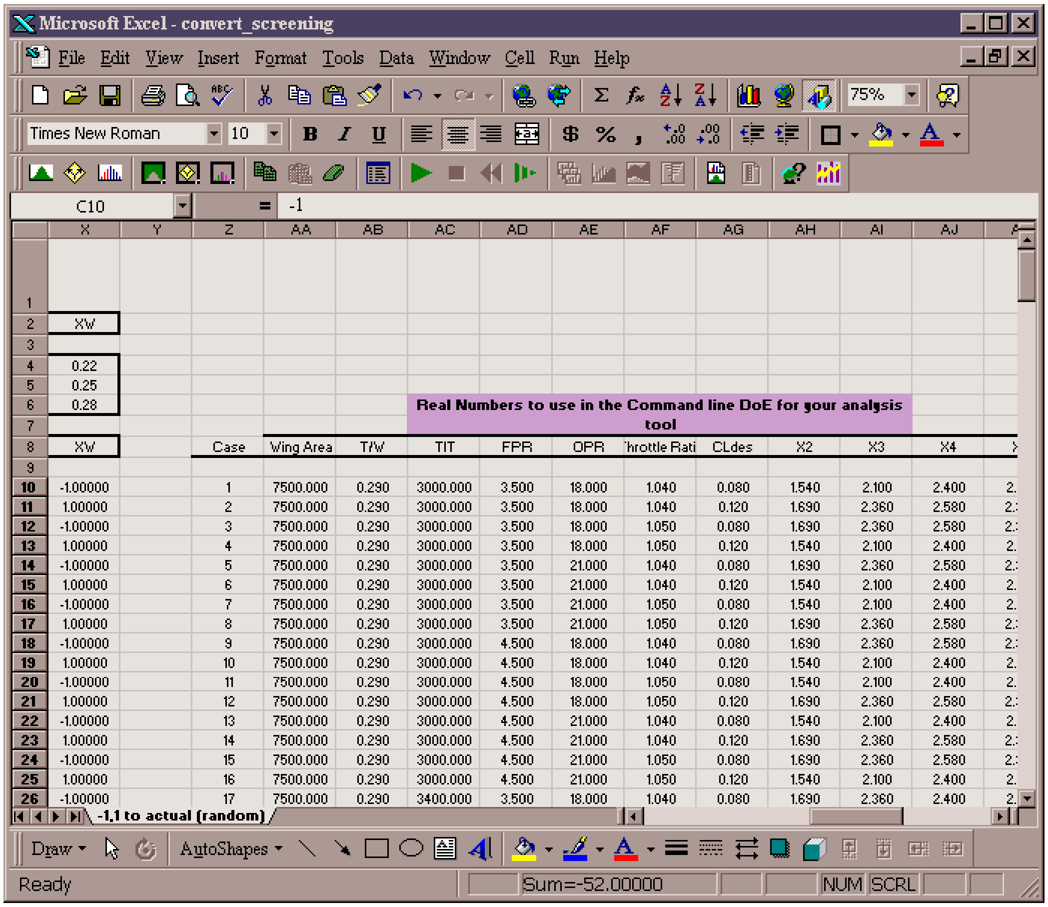
You will be given an Excel spreadsheet entitled “convert_screening” which will take the above non-dimensional table from JMP and convert the design variables to real values to use in the command line *rundoe*. Open the “convert_screening” file and make the active cell C10. Then go under **Edit** and select **Paste Special** and you will get the following window, select Unicode Text or Text, and press **OK**. NOTE: look at the dimensions of the table you have in the “convert_screening” Excel file and make sure you have the right number of columns for the variables and the number of rows for the number of cases. If you have more or less than either one of these, you need to increase or decrease the dimensions by copying or deleting the cells or adding more columns, etc before you paste the JMP DoE table.



And you will see that the table you selected in JMP will fill out the table in Excel. What you see here is the non-dimensional table with the variables listed above (e.g. Wing area, T/W, TIT, etc.) and the corresponding “real value” ranges if you scroll to the right. The minimum value for the wing area is 7500 that corresponds to the “-1” of the JMP table. The maximum value is 9000 that is the “+1” value of JMP. You need to input your design variable names and ranges as applicable to your problem. Also note that the mid-point (i.e., “0”) is automatically calculated from the “-1” and “1” values you entered.

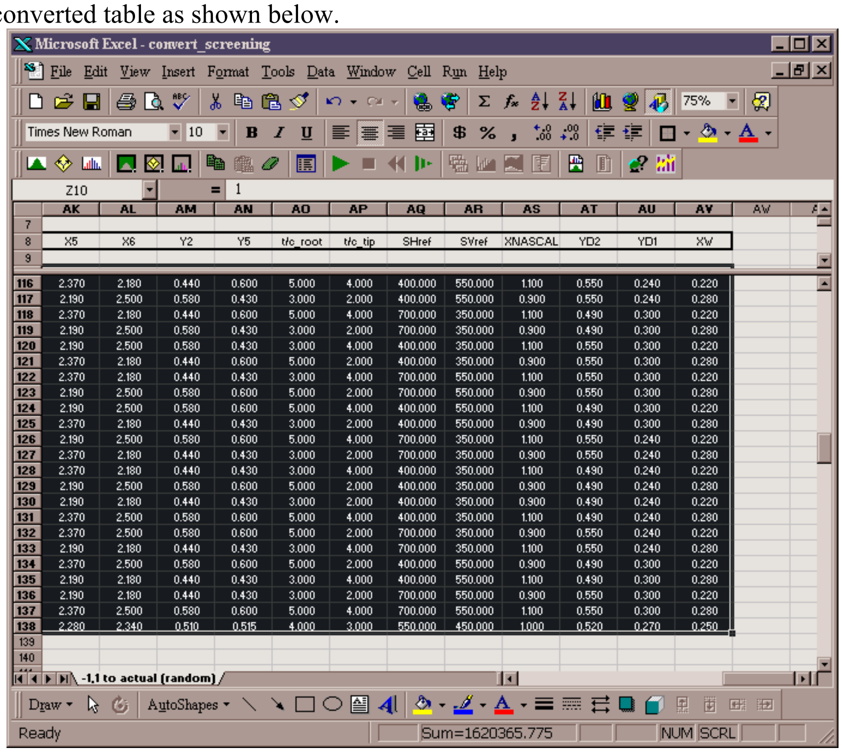


Now, if you scroll over to the right, you will see the real number DoE values that were converted from the non-dimensional JMP table as shown below.



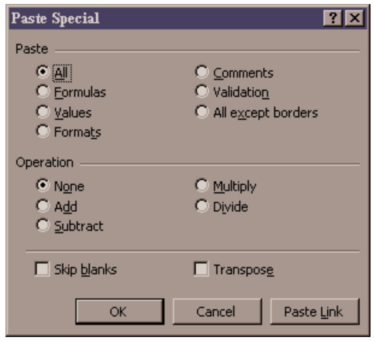
	XW	Case	Wing Area	T/W	TIT	FPR	OPR	Throttle Ratio	CLdes	X2	X3	X4
10	-1.00000	1	7500.000	0.290	3000.000	3.500	18.000	1.040	0.080	1.540	2.100	2.400
11	1.00000	2	7500.000	0.290	3000.000	3.500	18.000	1.040	0.120	1.690	2.360	2.580
12	-1.00000	3	7500.000	0.290	3000.000	3.500	18.000	1.050	0.080	1.690	2.360	2.580
13	1.00000	4	7500.000	0.290	3000.000	3.500	18.000	1.050	0.120	1.540	2.100	2.400
14	-1.00000	5	7500.000	0.290	3000.000	3.500	21.000	1.040	0.080	1.690	2.360	2.580
15	1.00000	6	7500.000	0.290	3000.000	3.500	21.000	1.040	0.120	1.540	2.100	2.400
16	-1.00000	7	7500.000	0.290	3000.000	3.500	21.000	1.050	0.080	1.540	2.100	2.400
17	1.00000	8	7500.000	0.290	3000.000	3.500	21.000	1.050	0.120	1.690	2.360	2.580
18	-1.00000	9	7500.000	0.290	3000.000	4.500	18.000	1.040	0.080	1.690	2.360	2.580
19	1.00000	10	7500.000	0.290	3000.000	4.500	18.000	1.040	0.120	1.540	2.100	2.400
20	-1.00000	11	7500.000	0.290	3000.000	4.500	18.000	1.050	0.080	1.540	2.100	2.400
21	1.00000	12	7500.000	0.290	3000.000	4.500	18.000	1.050	0.120	1.690	2.360	2.580
22	-1.00000	13	7500.000	0.290	3000.000	4.500	21.000	1.040	0.080	1.540	2.100	2.400
23	1.00000	14	7500.000	0.290	3000.000	4.500	21.000	1.040	0.120	1.690	2.360	2.580
24	-1.00000	15	7500.000	0.290	3000.000	4.500	21.000	1.050	0.080	1.690	2.360	2.580
25	1.00000	16	7500.000	0.290	3000.000	4.500	21.000	1.050	0.120	1.540	2.100	2.400
26	-1.00000	17	7500.000	0.290	3400.000	3.500	18.000	1.040	0.080	1.690	2.360	2.400

You need to copy this tables from cell Z10 (or wherever the cell is that corresponds to the case number) to the bottom right of the converted table as shown below.

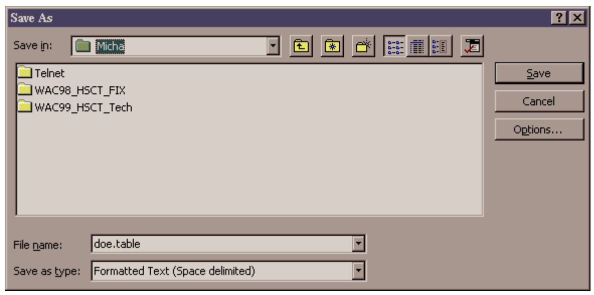


	X5	X6	Y2	Y5	t/c_root	t/c_tip	SHref	SVref	XNASCAL	YD2	YD1	XW
116	2.370	2.180	0.440	0.600	5.000	4.000	400.000	550.000	1.100	0.550	0.240	0.220
117	2.190	2.500	0.580	0.430	3.000	2.000	400.000	550.000	0.900	0.550	0.240	0.280
118	2.370	2.180	0.440	0.600	5.000	4.000	700.000	350.000	1.100	0.490	0.300	0.220
119	2.190	2.500	0.580	0.430	3.000	2.000	700.000	350.000	0.900	0.490	0.300	0.280
120	2.190	2.500	0.580	0.430	3.000	4.000	400.000	350.000	1.100	0.550	0.300	0.220
121	2.370	2.180	0.440	0.600	5.000	2.000	400.000	350.000	0.900	0.550	0.300	0.280
122	2.370	2.180	0.440	0.430	3.000	4.000	700.000	550.000	1.100	0.550	0.300	0.220
123	2.190	2.500	0.580	0.600	5.000	2.000	700.000	550.000	0.900	0.550	0.300	0.280
124	2.190	2.500	0.580	0.600	5.000	4.000	400.000	550.000	1.100	0.490	0.300	0.220
125	2.370	2.180	0.440	0.430	3.000	2.000	400.000	550.000	0.900	0.490	0.300	0.280
126	2.190	2.500	0.580	0.600	5.000	4.000	700.000	350.000	1.100	0.550	0.240	0.220
127	2.370	2.180	0.440	0.430	3.000	2.000	700.000	350.000	0.900	0.550	0.240	0.280
128	2.370	2.180	0.440	0.430	3.000	4.000	400.000	350.000	1.100	0.490	0.240	0.220
129	2.190	2.500	0.580	0.600	5.000	2.000	400.000	350.000	0.900	0.490	0.240	0.280
130	2.190	2.180	0.440	0.430	3.000	2.000	400.000	350.000	0.900	0.490	0.240	0.220
131	2.370	2.500	0.580	0.600	5.000	4.000	400.000	350.000	1.100	0.490	0.240	0.280
132	2.370	2.500	0.580	0.600	5.000	2.000	700.000	350.000	0.900	0.550	0.240	0.220
133	2.190	2.180	0.440	0.430	3.000	4.000	700.000	350.000	1.100	0.550	0.240	0.280
134	2.370	2.500	0.580	0.600	5.000	2.000	400.000	550.000	0.900	0.490	0.300	0.220
135	2.190	2.180	0.440	0.430	3.000	4.000	400.000	550.000	1.100	0.490	0.300	0.280
136	2.190	2.180	0.440	0.430	3.000	2.000	700.000	550.000	0.900	0.550	0.300	0.220
137	2.370	2.500	0.580	0.600	5.000	4.000	700.000	550.000	1.100	0.550	0.300	0.280
138	2.280	2.340	0.510	0.515	4.000	3.000	550.000	450.000	1.000	0.520	0.270	0.250

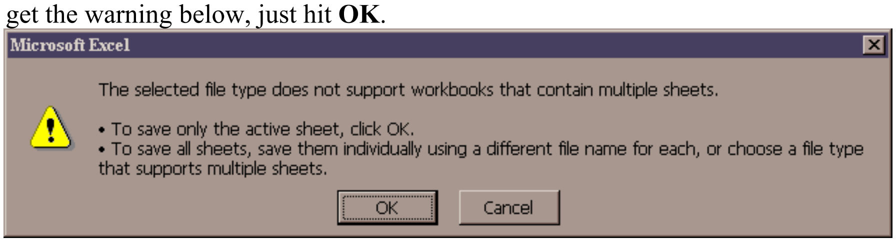
Now, open a new sheet and go to **Edit** and the **Paste Special**. And the following window will come up. You want to select **Values** and then **OK**.



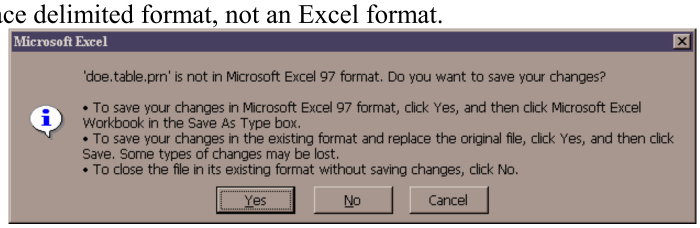
Your values will be pasted into a 22 by 129 range. Now go to **File** and then **Save As** and you will get a "Save As" window. Under **Save as type**, choose the "Formatted Text (Space delimited)" option and call your file "doe.table". Then hit the **Save** button.



You will get the warning below, just hit **OK**.



Then go to **File** and select **Close**. You will get another warning as shown below. Select the **No** option because you want the file in the space delimited format, not an Excel format.



Now you need to FTP this file to your account to run your analysis code. Make sure you FTP as ASCII NOT binary. I assume you know how to do this. Then you need to set up your "rundoe" script. An example script for an HSCT design space is shown below. You will create one similar to this on your UNIX account. Call the file *rundoe*. Additionally, when you ftp your doe.table file to your account, make sure that there are spaces between each number. In our case, we should have 23 columns of numbers and 129 rows. If your file did not transfer as such, go back to Excel and copy your table again to a new worksheet and increase the column width so that you see spaces between the numbers and then save the file again.

```
#!/usr/local/bin/tcl -f
for_file line doe.table {
        lassign $line a var1 var2 var3 var4 var5 var6 var7 var8 var9 var10 var11 var12 var13 var14 var15 var16
        puts stdout "########  CASE # $a  ########"
# Set up the input to tsw
                                  set file [open varfile w]
                                  puts $file "CONFIN SW $var1 "
                                  puts $file "CONFIN TWR $var2 "
                                  puts $file "CONFIN ETIT $var3 "
                                  puts $file "CONFIN EFPR $var4 "
                                  puts $file "CONFIN EOPR $var5 "
                                  puts $file "DESIGN CLDESGN $var6 "
                                  puts $file "DESIGN X2 $var7 "
```

```
                                  puts $file "DESIGN X3 $var8 "
                                  puts $file "DESIGN X4 $var9 "
                                  puts $file "DESIGN X5 $var10 "
                                  puts $file "DESIGN X6 $var11 "
                                  puts $file "DESIGN Y2  $var12 "
                                  puts $file "DESIGN TCRT  $var13 "
                                  puts $file "DESIGN TCTP  $var14 "
                                  puts $file "DESIGN SHREF $var15 "
                                  puts $file "DESIGN SVREF  $var16 "
                                  close $file
# Run tsw
        puts stdout "   Running tsw"
        catch "exec tsw -input opt_baseline -output case$a varfile"
        exec cp case$a fl98.in
        exec flops_subs_modified
        exec mv flopsin.new case$a
}
exit
```

Make sure your baseline file name that you are using corresponds to this name

Another sample file is shown below.

```
#!/usr/local/bin/tcl -f
for_file line doe.table {
        lassign $line i var1 var2 var3 var4 var5 var6
        puts stdout "########  CASE # $i  ########"
# Set up the input to tsw
                set file [open varfile w]
                puts $file "MAININ THRSO $var1 "
                puts $file "TOLIN THRTO\[1\] $var1 "
                puts $file "TOLIN THRTO\[2\] $var1 "
                puts $file "TOLIN THRTO\[3\] $var1 "
                puts $file "TOLIN THRTO\[4\] $var1 "
                puts $file "TOLIN THRTO\[5\] $var1 "
                puts $file "TOLIN THRTO\[6\] $var1 "
                puts $file "TOLIN THRTO\[7\] $var1 "
                puts $file "TOLIN THRTO\[8\] $var1 "
                puts $file "TOLIN THRTO\[9\] $var1 "
                puts $file "TOLIN THRTO\[10\] $var1 "
                puts $file "MAININ GW $var2 "
                set land_wt [expr ($var2-381987.4)]
                puts $file "MAININ WLDG $land_wt "
                puts $file "MAININ CLTOM $var3 "
                puts $file "TOLIN CLTOM $var3 "
                puts $file "MAININ CLLDM $var4 "
                puts $file "TOLIN CLLDM $var4 "
                puts $file "TOLIN ALPROT $var5 "
                puts $file "TOLIN ALMXLD $var6 "
                close $file
# Run tsw
        puts stdout "   Running tsw"
        catch "exec tsw -input base -output case$i varfile"
}
exit
```

This syntax is based on THRTO having a 10 element array and this is how you substitute a particular element of that array

Now you need to write another script to run your DoE. A simple script is shown below. You can call the file anything you like. Just make sure that you change the mode of the file to make it executable. For example, if you call the file *runcases*, then at the UNIX prompt, type `chmod 700 runcases`. Also, do this for the *rundoe* file you created.

```
echo "Running the b1 script for DoE cases"
i=1
imax=129
while [ $i -le $imax ]
do
        echo "Now running file:  $i"
        flops case$i  case$i.out
        echo "$i completed"
        echo "**********************************************************************"
        let i=i+1
done
```

To execute both the *rundoe* and the *runcases*, you simply need to type the file name and the script will run. You want to run the *rundoe* first and create all your case files and then run the *runcases* to execute FLOPS. Just a reminder, your baseline file is called *opt_baseline* in the first *rundoe* script and *base* in the second. Make sure you have the baseline file and the *doe.table* file in the directory that you are running the script.

Now, you will need to extract the metric data for each case. To do so, you will use the *parse98* program. A sample file is shown below. I call this file *getinfo*. You also need to change the mode of the file as you did above. NOTE, make sure you are parsing the proper info before you run this script. You can check this by executing a given line at the UNIX command prompt. For example,

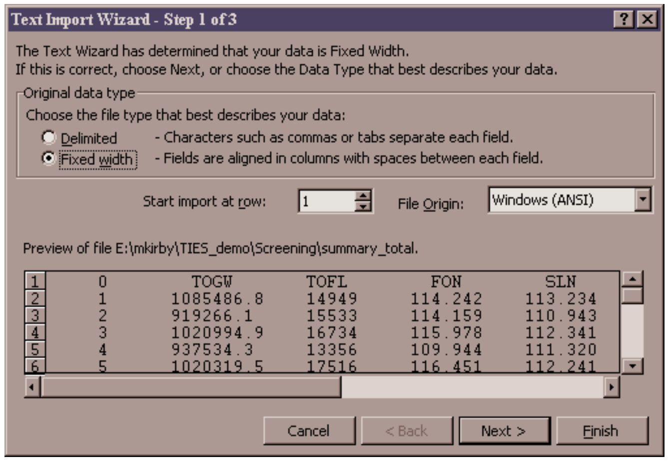
```
parse98 -search "TOGW" -read 3 -occurance 1 -offset 0 case1.out
```

```
#!/usr/local/bin/wishx -f

set Number_of_Cases 289
exec touch summary_total
exec rm summary_total

exec touch noise_summary
exec rm noise_summary

exec echo " TOGW TOFL LDGFL VAPP ACQ RDTE RPM TAROC DOC+I" >> summary_total
exec echo " THRUST TOGW K2T K2A K1A WLDG" >> noise_summary
for {set i 1} { $i <= $Number_of_Cases} { incr i 1} {
      puts stdout "getting info case$i"
      set togw    [ exec parse98 -search "TOGW"                   -read 3 -occurance 1 -offset 0 case$i.out]
      set tofl    [ exec parse98 -search "DFAROFF"                -read 3 -occurance 1 -offset 0 case$i.out]
      set ldgfl   [ exec parse98 -search "DFARLDG"                -read 3 -occurance 1 -offset 0 case$i.out]
      set vapp    [ exec parse98 -search "DVAPP"                  -read 3 -occurance 1 -offset 0 case$i.out]
      set acq     [ exec parse98 -search "Final"                  -read 7 -occurance 1 -offset 0 case$i.out]
      set rdte    [ exec parse98 -search "TOTAL RDT&E COST"       -read 4 -occurance 1 -offset 0 case$i.out]
      set rpm     [ exec parse98 -search "Average Yield/RPM"      -read 4 -occurance 1 -offset 0 case$i.out]
      set taroc   [ exec parse98 -search "Method SubTotal"        -read 5 -occurance 1 -offset 0 case$i.out]
      set doci    [ exec parse98 -search "Method SubTotal"        -read 4 -occurance 1 -offset 0 case$i.out]

      set thrust  [ exec parse98 -search "DTHRUST"               -read 3 -occurance 1  -offset 0 case$i.out ]
      set k2t     [ exec parse98 -search "K2T ="                 -read 3 -occurance 1  -offset 0 case$i.out ]
      set k2a     [ exec parse98 -search "K2A ="                 -read 3 -occurance 1  -offset 0 case$i.out ]
      set k1a     [ exec parse98 -search "K1A ="                 -read 3 -occurance 1  -offset 0 case$i.out ]
      set wldg    [ exec parse98 -search "MAXIMUM LANDING WEIGHT" -read 4 -occurance 1  -offset 0 case$i.out ]

        exec echo "$i $togw $tofl $ldgfl $vapp $acq $rdte $rpm $taroc $doci" >> summary_total
        exec echo "$i $thrust $togw $k2t $k2a $k1a $wldg" >> noise_summary
}

puts stdout "Parsing is now completed!!"

exit
```

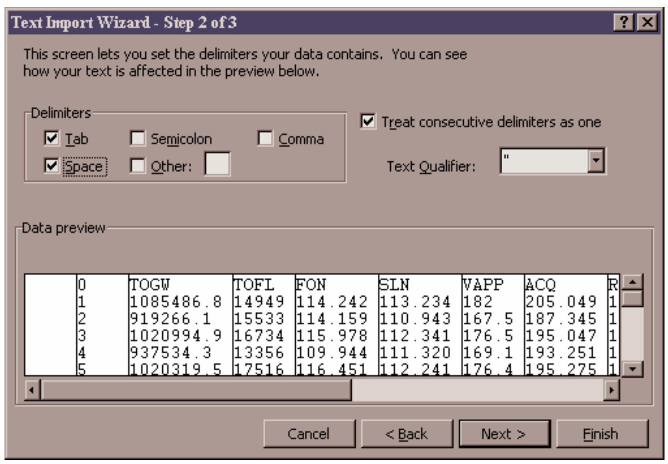
You should get the TOGW value from case1.out. This command is looking for the character string "TOGW" (`-search`), for the first time it occurs (`-occurance 1`), looking on the same line that parse98 finds "TOGW" (`-offset 0`), getting the 3rd character string on that line (`-read 3`), and will return that value to the screen. Do this for each metric to make sure you are getting the right values. All of your data will be extracted and put into a file called *summary_total*. A sample of one of these files is shown below for the first 12 cases. You need to ftp this back to your PC and then open in Excel.

 TOGW TOFL VAPP FON SLN ACQ RDTE RPM
1 1085486.8 14949 182 114.242 113.234 205.049 16850.698 0.13147
2 919266.1 15533 167.5 114.159 110.943 187.345 15240.811 0.11494
3 1020994.9 16734 176.5 115.978 112.341 195.047 15806.297 0.12553
4 937534.3 13356 169.1 109.944 111.32 193.251 16021.355 0.11602
5 1020319.5 17516 176.4 116.451 112.241 195.275 15820.057 0.12552
6 955509.4 13322 170.7 110.159 111.527 194.7 16143.683 0.1181
7 1028392.3 14247 177.1 112.5 112.526 199.759 16433.2 0.12553
8 860729.5 14323 162 112.585 110.359 181.794 14819.3 0.10916
9 951218 14090 170.3 112.972 111.292 193.578 16015.582 0.1176
10 1019691.4 15701 176.4 114.206112.224 194.959 15808.73 0.12532
11 976201.8 15621 172.6 114.724 111.729 192.515 15641.596 0.12062
12 1018651.7 14374 176.3 112.924112.345 198.327 16294.583 0.12447……..

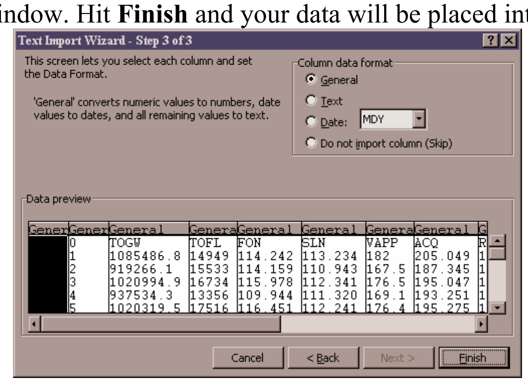
Now, open Excel and go to **File**, then **Open**, and then select "List all file types" and find the *summary_total* file that you ftp. You will get the following window. You want to open it as a **Delimited** character file. Select that option and hit **Next >**.



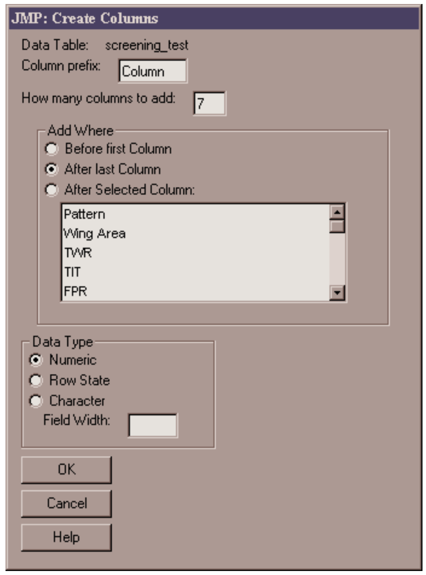
You will get the window below. You want to open it as delimited by **Tab** and **Space**. Then hit **Next**.



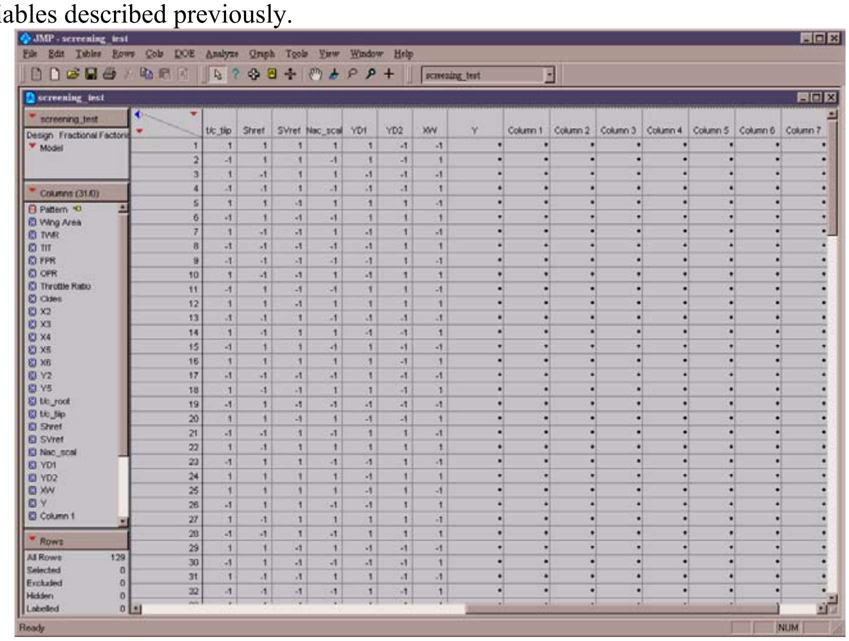
You will get the below window. Hit **Finish** and your data will be placed into separate cells.



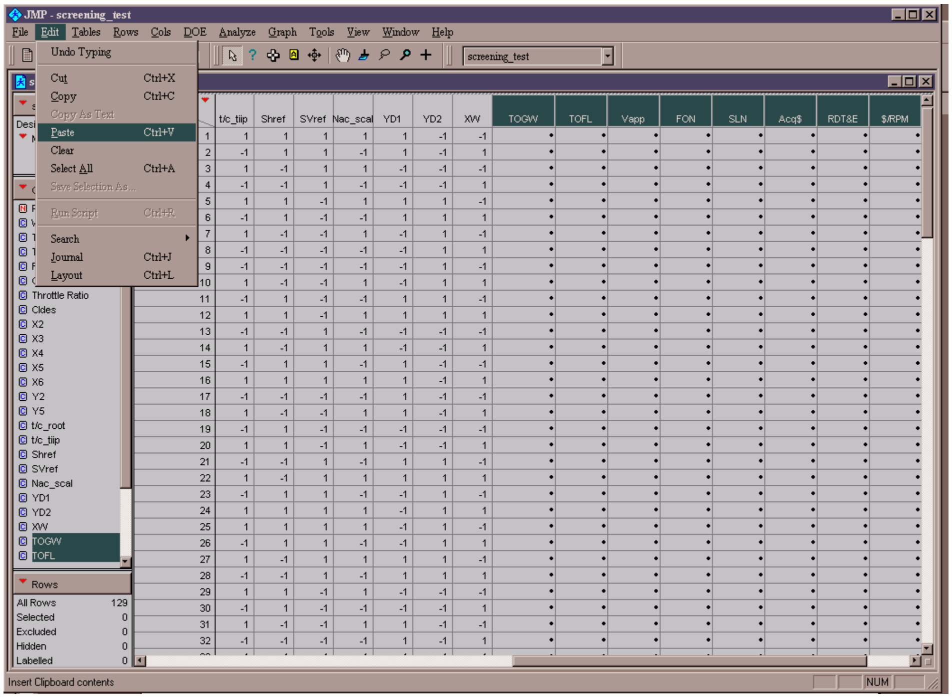
Now select all the data and copy it back to JMP so that you can look at the influence of each design variable on the metrics (or responses) of interest. Highlight all the data and copy. Open JMP and recreate your DoE. You will need to add more columns for your data. To do this, go to **Cols** and then select **Add Multiple Columns…** and you will get the following window. The DoE table has one response column entitled "Y". For the example I am showing here, there are 8 responses. Hence, we need to add 7 columns "After last Column" and then hit **OK**.



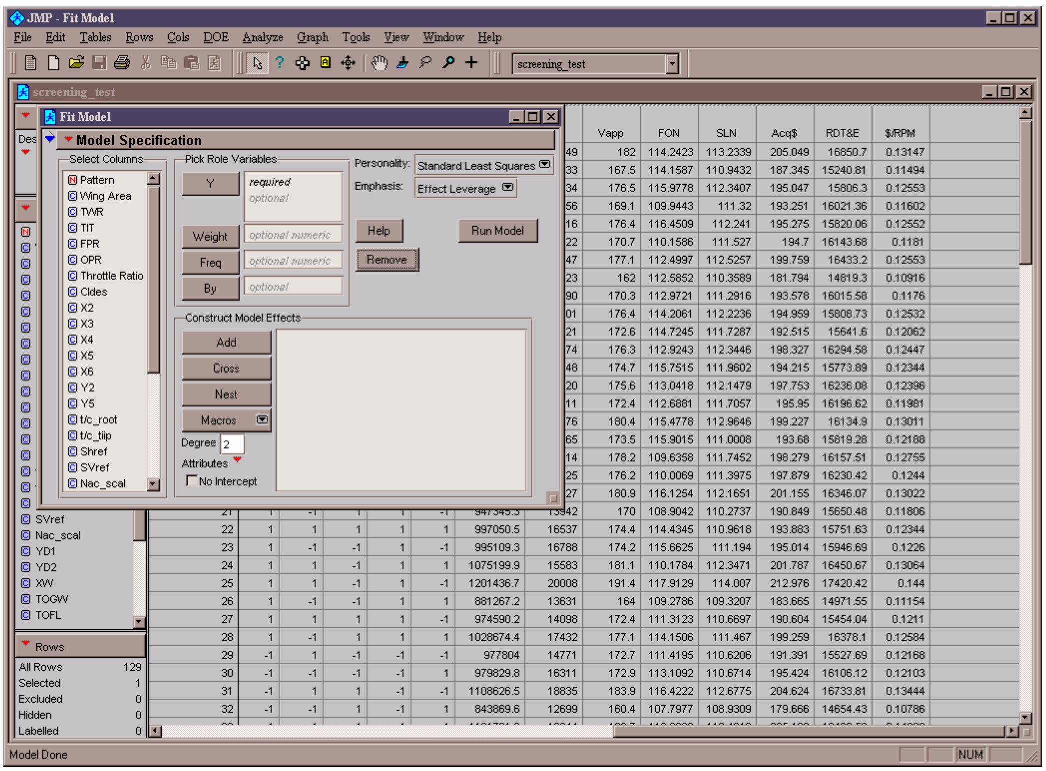
As you see below, 7 columns were added at the end. You can change the names of the columns just as you did with the design variables described previously.



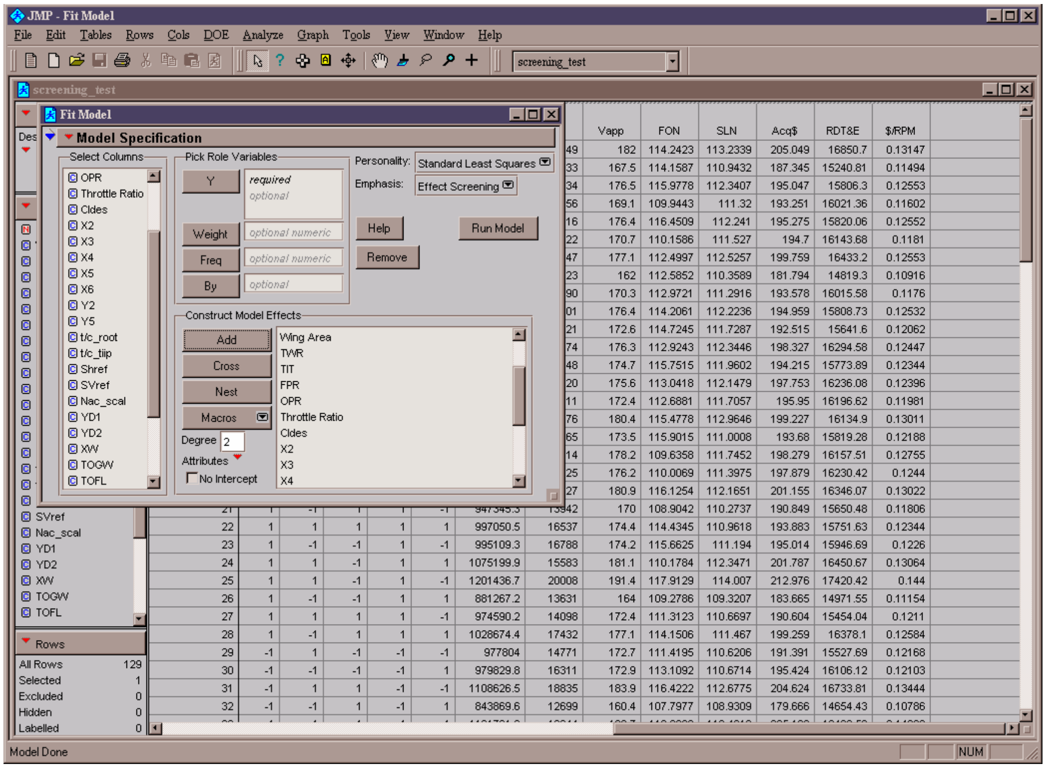
Now, highlight your response columns in JMP (as shown below) and go to **Edit** and then **Paste** and you will see that your response columns fill with the data that you copied from Excel.



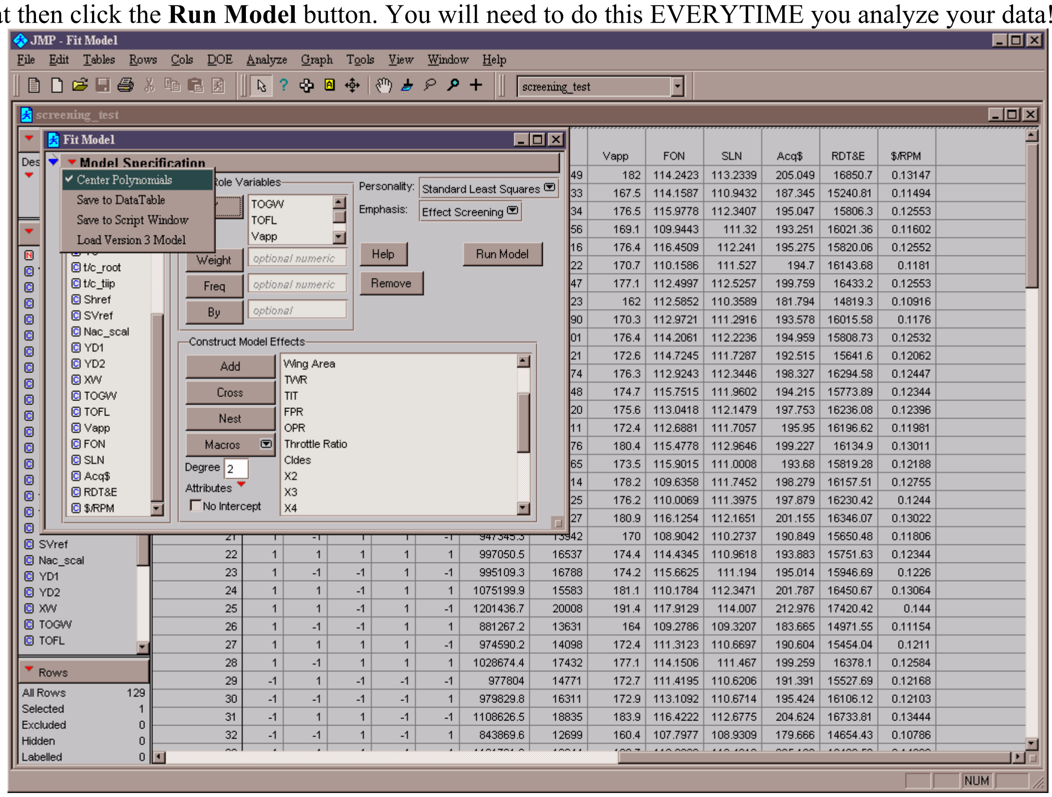
Now you need to analyze your data. Go to **Analyze** and select **Fit Model** and the following window will pop up. In the top left corner of the window are your variables. Click on your first variable (Wing_Area) and it will be highlighted. Then scroll down until you see your last design variable (XW). Hold down the shift key and then click on the last variable. You want to select the **Add** button.



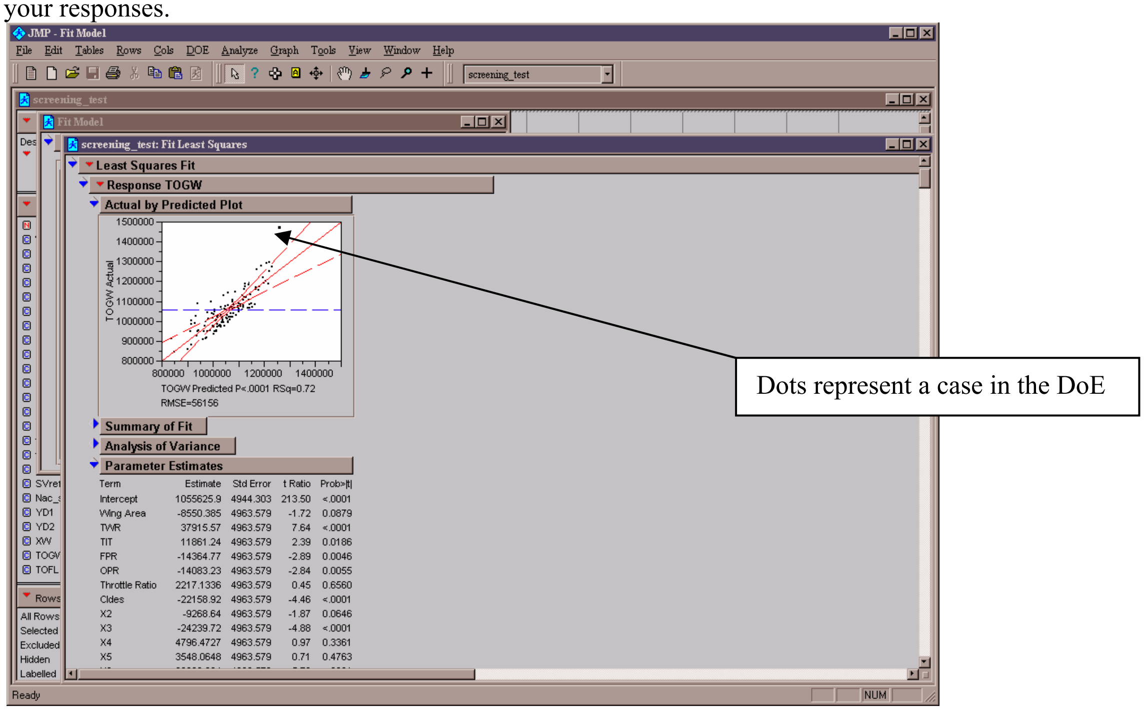
Your design variables will then be placed into the previously empty area under "Construct Model Effects". In the same manner that you selected your design variables, select your responses and click on the **Y** button.



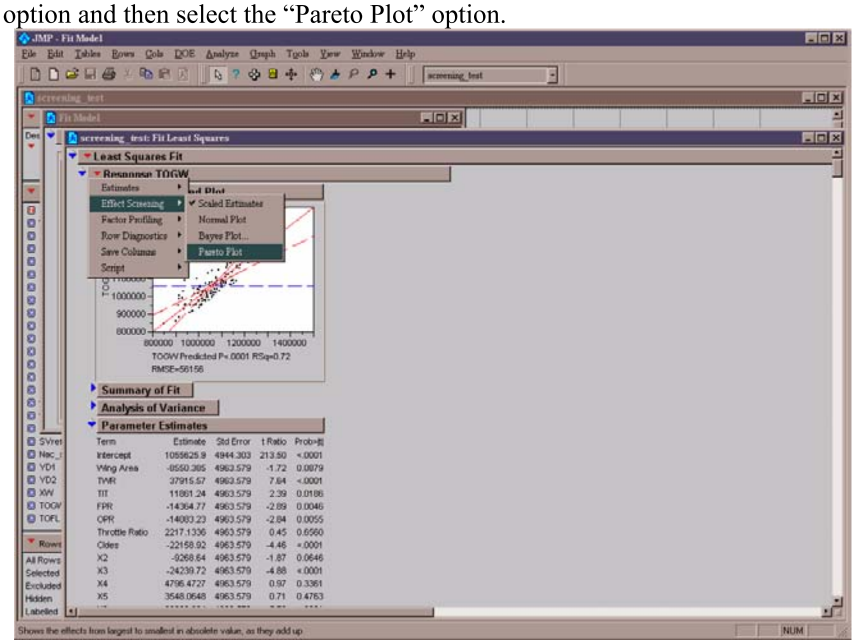
<u>IMPORTANT</u>: Now, go under the drop menu for **Model Specification** and <u>unclick</u> the "Center Polynomials" option. If this option is enabled a continuous term participating in a crossed term will be centered by its mean. Thus, your coefficients will not be simple numerical values. So unclick it to avoid difficulties. Once you have done that then click the **Run Model** button. You will need to do this EVERYTIME you analyze your data!!!



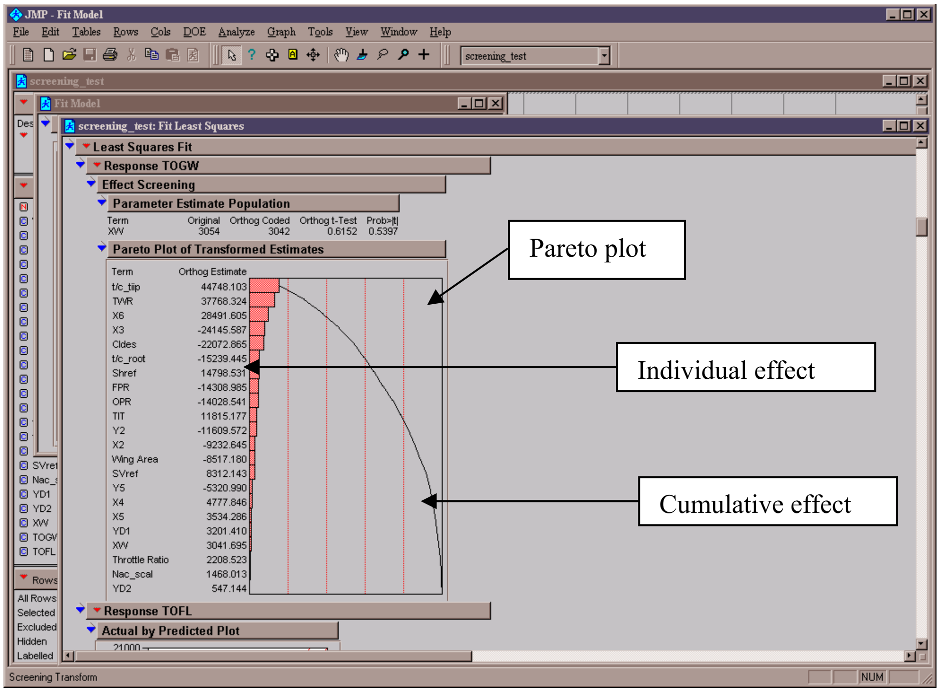
The following window will appear. Your responses will be listed in the order in which you entered them in the **Fit Model** window. In the example below, you will see the "Actual by Predicted Plot". Each of the little dots in this plot represent one of the 129 cases you ran. If you put your mouse over a dot, JMP will tell you which case it corresponds to. Also, as you can see below, the dotted red lines correspond to how well you model is being predicted. The straight red line is indicative of a perfect model fit. The further away the dotted lines are from this "perfect" line implies that your analysis code is NOT being predicted very well by the model you chose. This large deviation is expected in a screening test since you are only trying to identify the main contributors to the responses from the use of a linear DoE. You are not actually trying to fit an RSE to the analysis code. However, if your analysis code was very linear, then the screening test would probably capture the variability quite well. Remember, the screening test is a linear model of your responses.



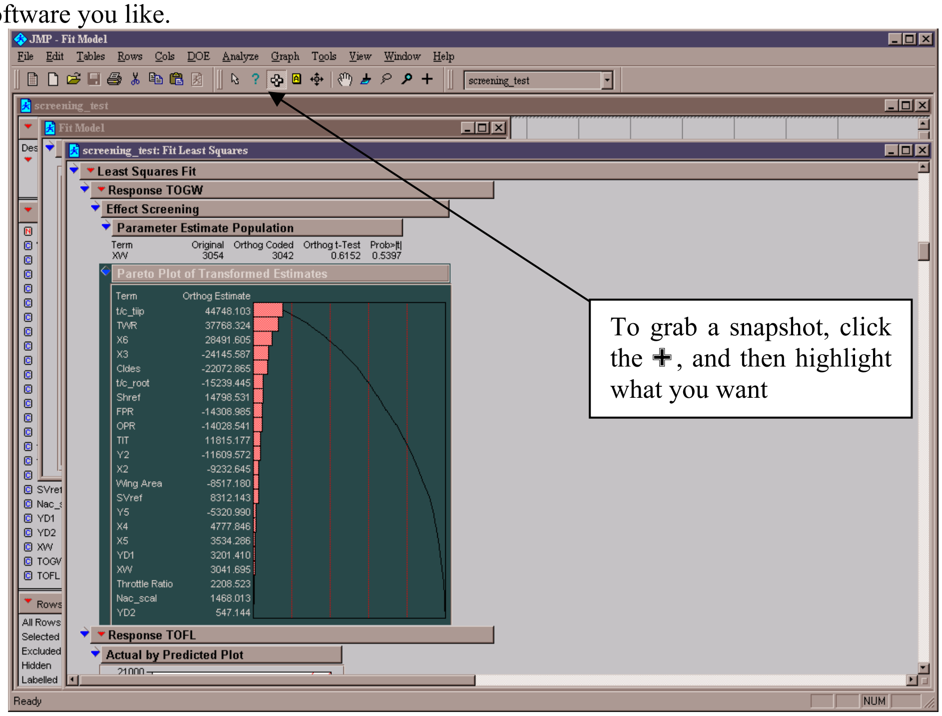
Now, we would like to know which of the 22 variables that we are considering actually contribute the most to our different responses. We can do this via a Pareto Analysis, which results in a Pareto plot. To view the Pareto plot for a response, click the little red ▼ by the "Response TOGW" drop menu and the following will appear. Click on the "Effect Screening" option and then select the "Pareto Plot" option.



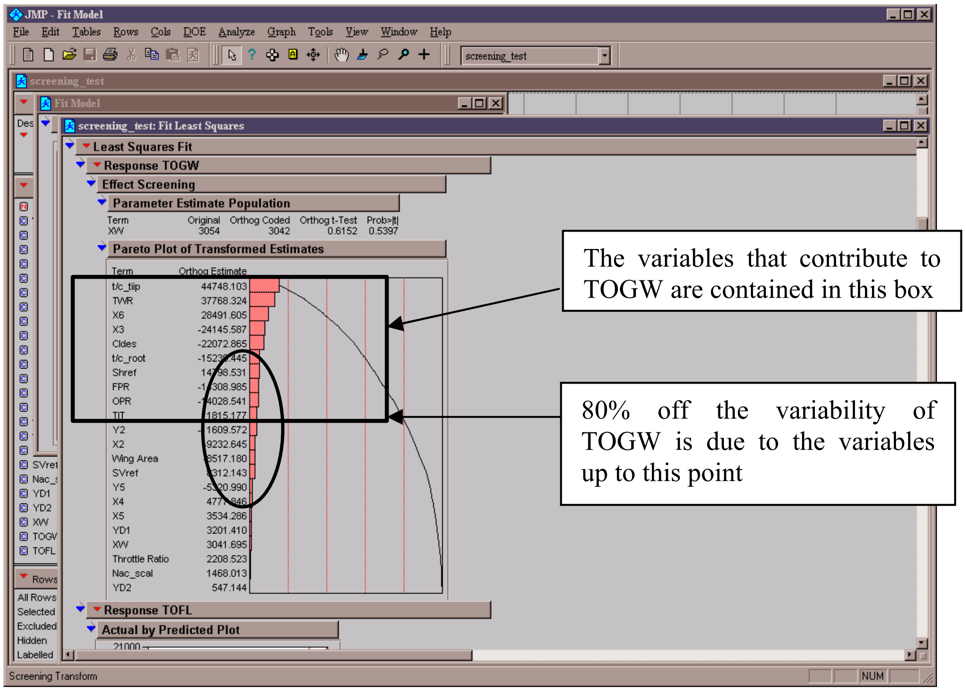
The Pareto plot shows the individual influence of each design variable on the response with the horizontal bars, and then the cumulative effect of the variables with the line. As you can see, the T/W and the t/c_tip are the two primary contributors to the TOGW, while X5 and Throttle Ratio hardly contribute at all. Here is where you can down select to the top 7, 8, or 11 main contributors and use those to create your RSEs. Do this for each of the responses and then you can identify which variables contribute to all the responses. For computational purposes, you would like to select a common set of variables such that you only have to run 1 DoE to capture all of the responses. However, this is not always possible.



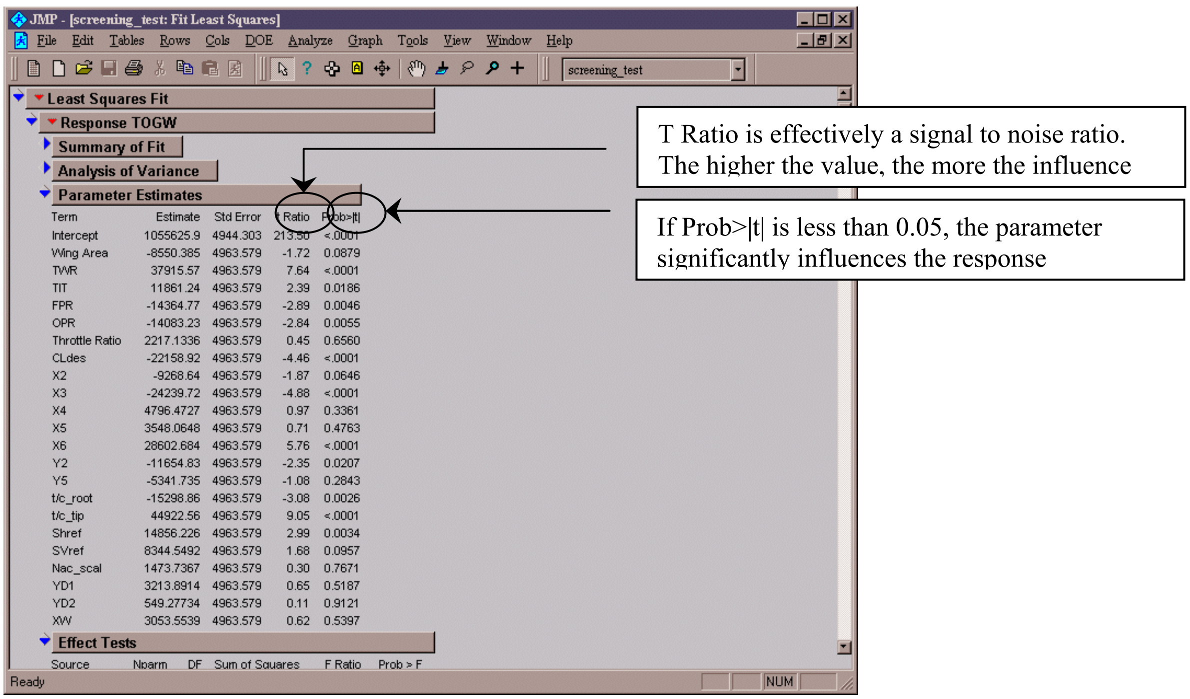
You may want to copy the Pareto Plots to PowerPoint for presentation purposes. To do so, select the ✚ icon in the menu bar and then click the bar that says "Pareto Plot of Transformed Estimates" or on the Pareto plot itself and you will see that the entire section is highlighted as below. Then go to **Edit** and select **Copy** and you can paste the image in any software you like.



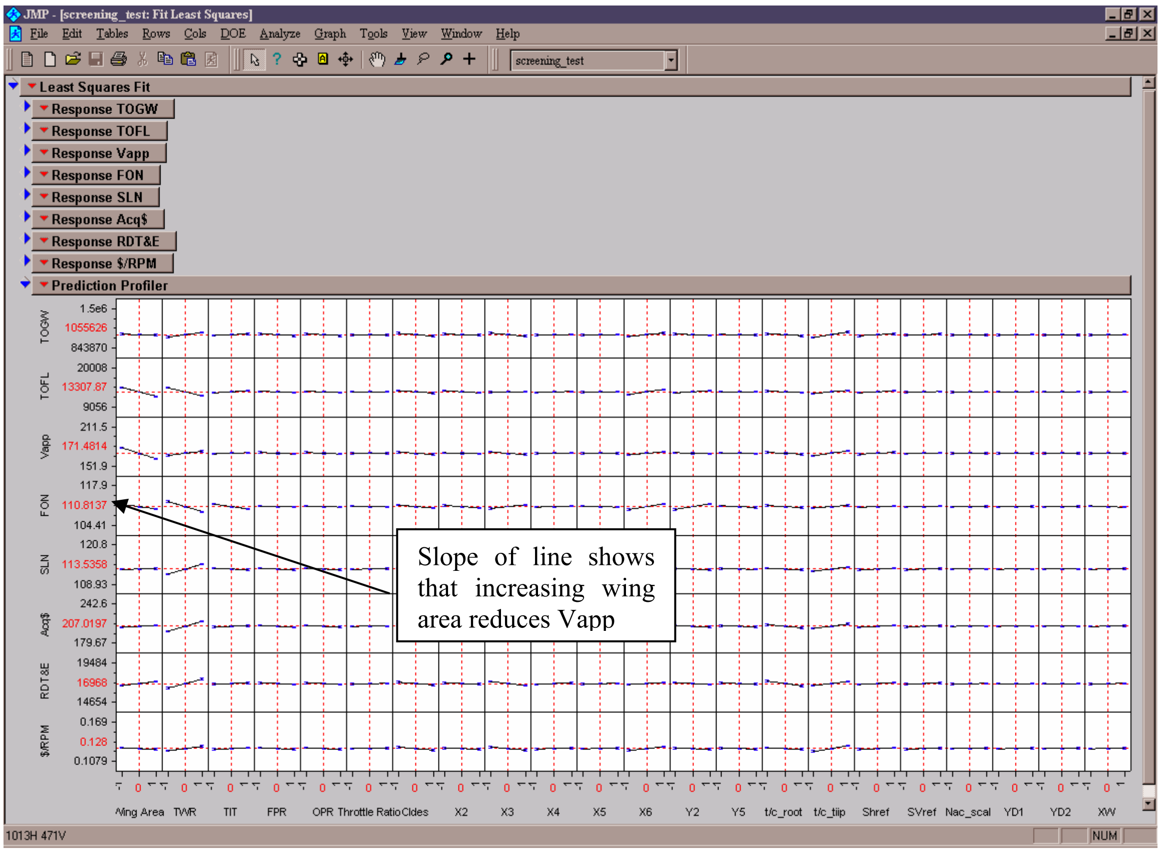
Let's talk a little bit more about how you select the important contributing variables. In particular, based on the Pareto Principle, 80% of the variability in a response is due to 20% of the variables. So, for TOGW, one might select the variables that are contained in the box below. However, look at the individual effects of the variables that are contained in the oval. Each of the variables contribute about the same amount. In fact, their effects could be indistinguishable. This is where you need to use your engineering knowledge and experience as to which variables to choose. Since you are doing a screening test, you are only looking at linear effects and some variables may show up as significant, when in fact they are not. This is also due to the confounding structure of a linear DoE. Please refer to the JMP Help for more info on this. So, lesson learned…DON'T ARBITRARILY PICK VARIABLES WITHOUT FIRST UNDERSTANDING WHAT IS HAPPENING.



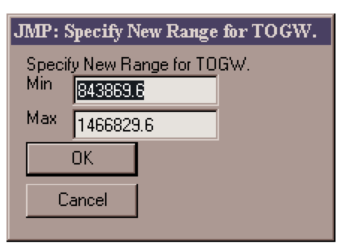
The Pareto Plot is a means to visually determine the most significant contributors to a response. However, you can also determine the important variables numerically. This information is actually provided as part of the fit model option. Consider the picture below. Without going into the mathematics behind the generation of the number below, let's put the definition into something more tangible. Under the Parameter Estimates bar, you see each of the variables you entered for the main effects of the fit model. Now, look at the two columns entitled "t Ratio" and "Prob>|t|". The "t Ratio" column represents the ratio of the estimate to its standard error, or effectively the signal to noise ratio of that given parameter's influence to the response. The larger the number, the more influence that parameter estimate has on the response. You can also determine this by inspection of the "Prob>|t|" value in the next column. As a general rule of thumb, if this value is less than 0.05, then the parameter estimate significantly influences the response. If you compare the variables that had a value of less than 0.05 in the picture below to the Pareto plot generated above, you will find that the variables contained in the box of the Pareto Plot are the same. So, you could identify your significant contributors either way. But, if you had an enormous set of variables, you would probably want to choose the Pareto Plot to down select.

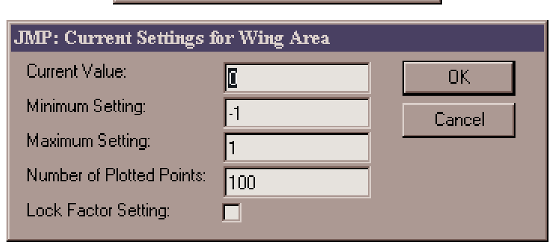


Another important feature of JMP is the Prediction Profile feature as shown below. This should appear automatically when you fit your model. If it is not at the bottom of the window, then go to the drop menu at the top entitled “Least Squares Fit” and enable the drop menu, then select the “Profilers” option and then select the “Profile” option and scroll back down to the bottom of the window. On the left are the responses you have. Each of the bars is showing you the influence of a given design variable on the response. You could pick your variables from here, but when you get down to ones that “look” to have the same influence, the Pareto Plots help you make better decisions. The dotted vertical red lines will move if you left mouse click and drag. The line that you grab and move will change the variable setting (value shown in red) and then update the response value for the new variable setting. Play with this to get a feel for the Profiler.



Also with the Profiler, you can change the range of the variables and the responses. In effect, you can zoom in on a range or zoom out. You do this by putting your mouse over the name of the variable or the response, hold down the “Ctrl” button and then left mouse click. And the window below will come up for a response and the window below that will come up for an input variable.





That's pretty much it for the Screening test. For the variables that do not really contribute to the responses, you can set them at a value that minimizes or maximizes your responses. Although the impact is minimal, might as well help yourself as much as possible. Now you are ready for RSEs!!! Note, to avoid having to run a DoE for EACH metric, try to come up with a set of common variables that capture ALL metrics.

Creating Response Surface Equations

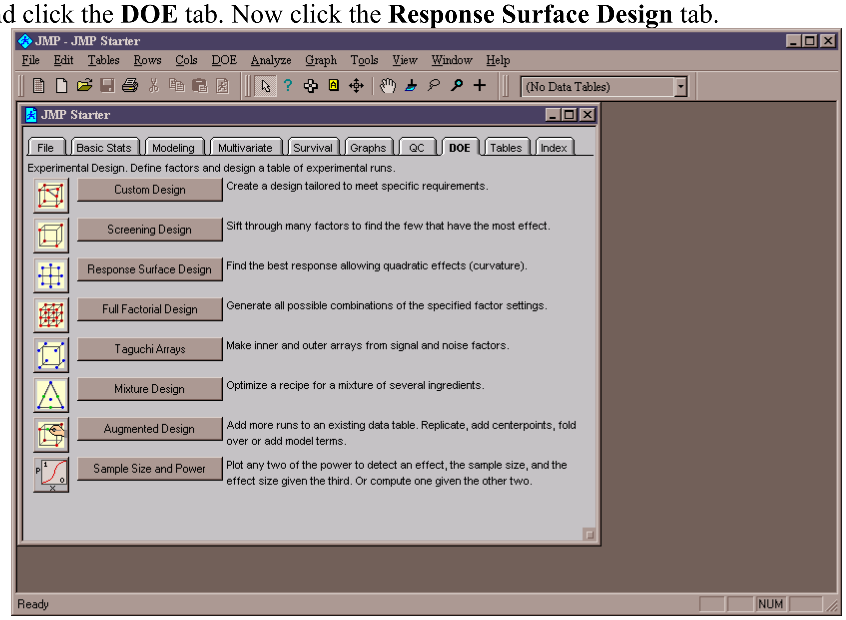
Once you have down-selected your variables to something more manageable, you are ready to create your RSE for your metrics or responses. These are calculated using the following equation:

$$R = b_o + \sum_{i=1}^{k} b_i k_i + \sum_{i=1}^{k} b_{ii} k_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} b_{ij} k_i k_j$$

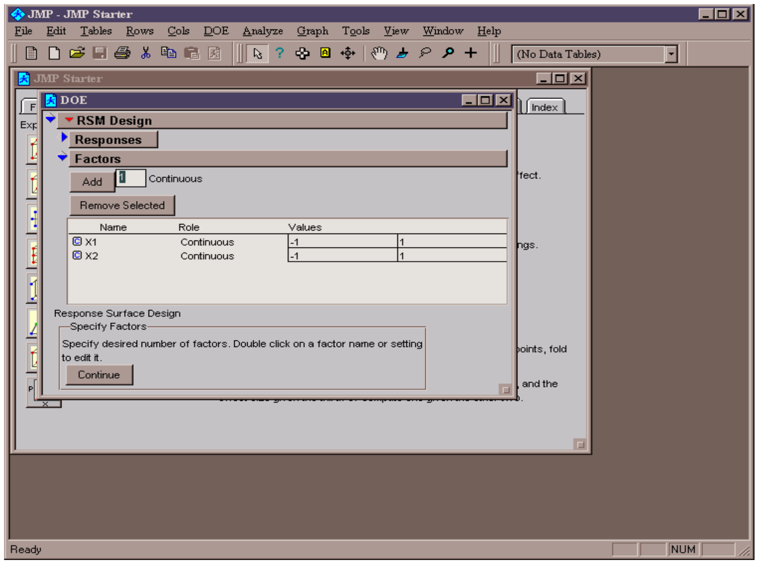
where b_i are regression coefficients for linear terms, b_{ii} are coefficients for pure quadratic terms, b_{ij} are coefficients for cross-product terms (second order interactions), and x_i, x_j are the design variables and $x_i x_j$ denotes interactions between two design variables.

You will go through most of the same steps as you did with the Screening test. The only differences will be with the type of DoE and the method for analyzing the data. So, let me describe those aspects and you can refer to the previous section for the other stuff.

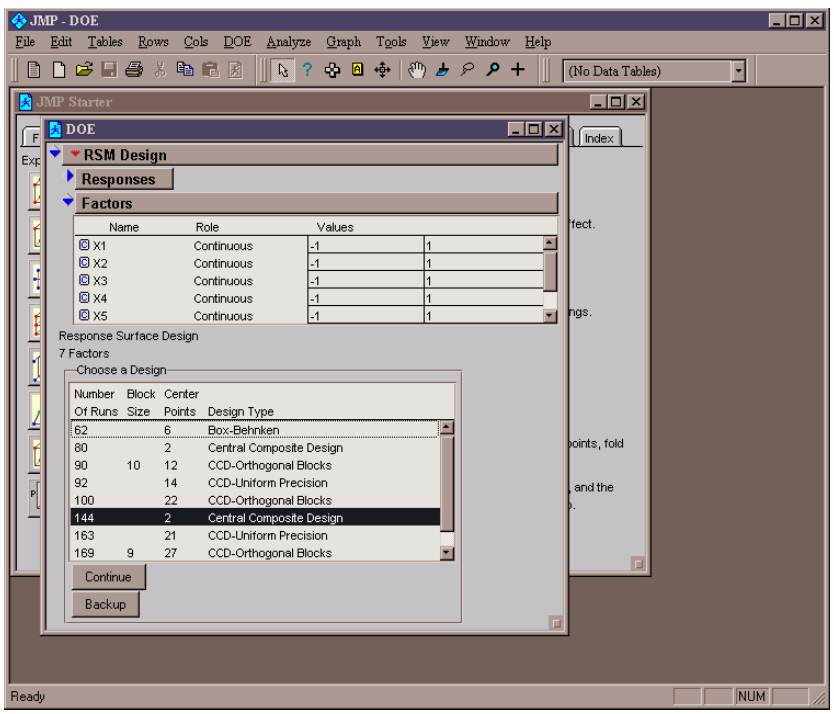
Let's say that we identified 7 variables that contribute to the responses of interest. Go back to JMP and go to the **JMP Starter** and click the **DOE** tab. Now click the **Response Surface Design** tab.



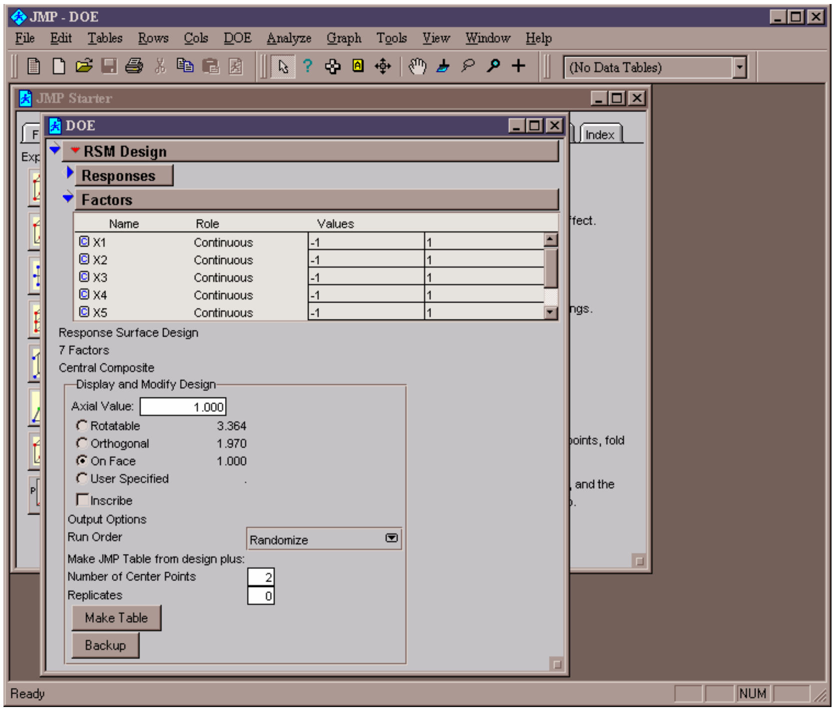
The following window will come up. As you did when you were creating the DoE for the screening test, add the number of variables and input the real names and values if you like. Say we have 7 variables, since the window already provides 2 variables, I just need to add 5. Then press **Continue**.



The following will come up. You will then get a bunch of DoE options as shown below. Typically, more runs are better since you have more data for the regression. So, let's pick the Central Composite Design (CCD) with 144 cases and 2 center points. Then hit **Continue**.



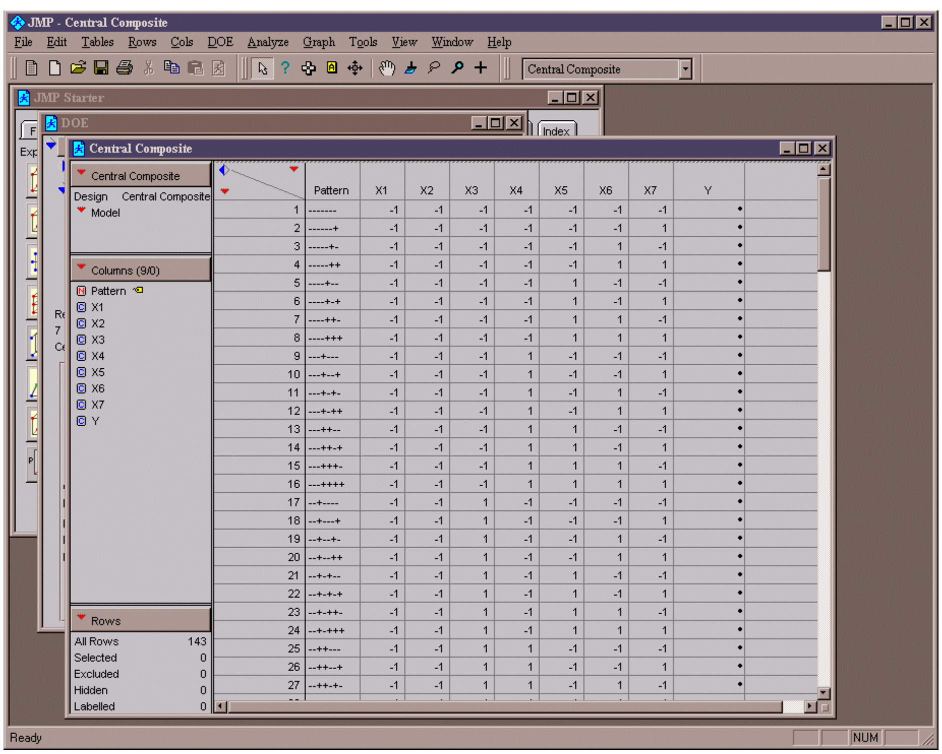
The window below will then open up. Note, the number of center points is there for when you are doing experiments that have noise, such as variations in a control environment. Since we are running computer simulations, the experiment is 100% repeatable and we will only need 1 center point. So, in the cell where the number of center points is defined as 2, change that to a 1. Also, if the "On Face" option is not selected for the design you chose, please select it. The reason for this is beyond the scope of this tutorial, but trust me, just select it. Again, change the **Run Order** to "Keep the Same" option as you did before. Then hit **Make Table**.



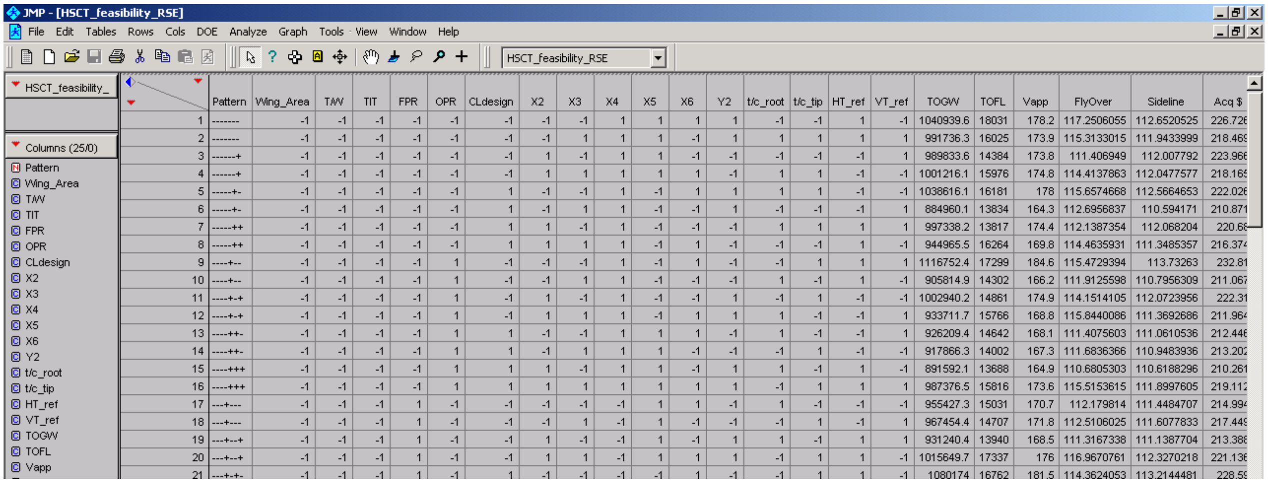
Your DoE table will open up. As shown below. Now, go through the same procedure that you did for the screening test.

1. copying your table to Excel,
2. convert to real numbers,
3. saving as *doe.table*,
4. ftp to your UNIX account,
5. modify your shell scripts for the new number of cases and variable names,
6. switch out variables, and
7. parse your data.

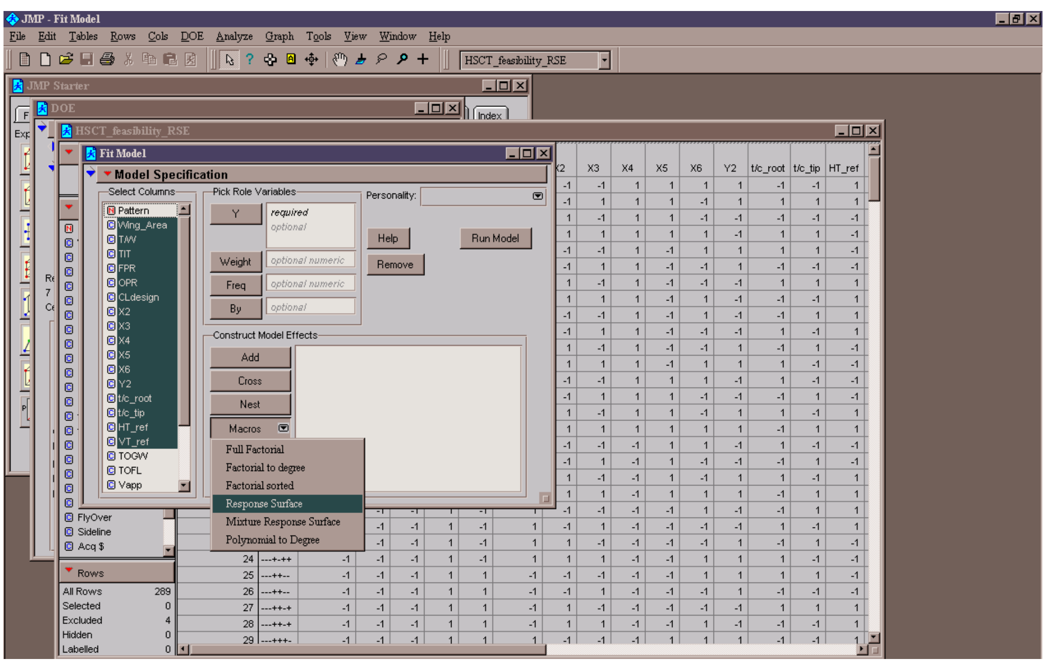
Bring the results back to Excel and import over to JMP. Now the difference is how you analyze the data.



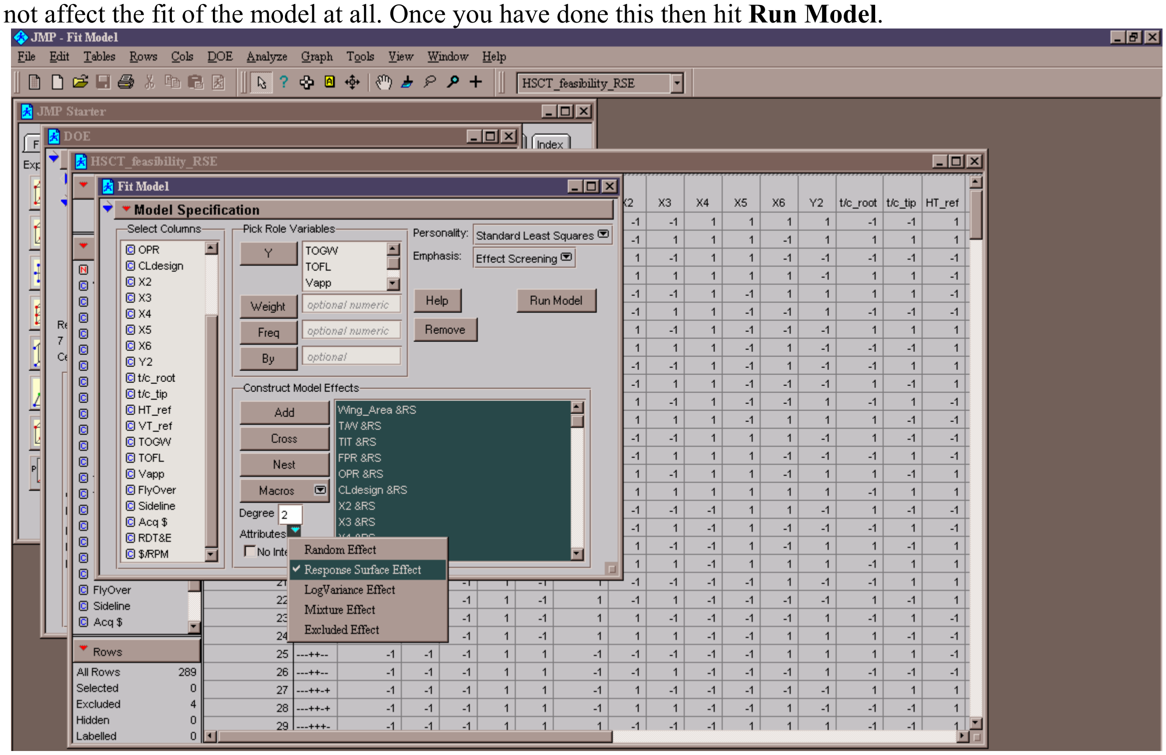
The example that I have shown you thus far was for an HSCT aircraft concept. When I performed the screening test, I discovered that 16 variables were required to define the RSE. Within JMP, only an 8 variable RSE can be created. However, there are custom designs created by Dr. Oliver Bandte that can handle up to 16 variables. These designs are face-centered CCDs with a Resolution IV fractional factorial design. These custom DoEs allow for estimates of all main effects as well as all interactions between main effects. This is called a Resolution IV DoE. Then, the fractional factorial designs were merged with a center point in the hyper-cube and a set of face-centered axial points to form the higher than 8 variable CCDs. Regardless, the process to fit the data is the same and I will show you the one for the 16 variable. So, we open up the 16 variable design (which required 289 runs) and insert more columns for our 8 responses and then paste the data from our analysis code.



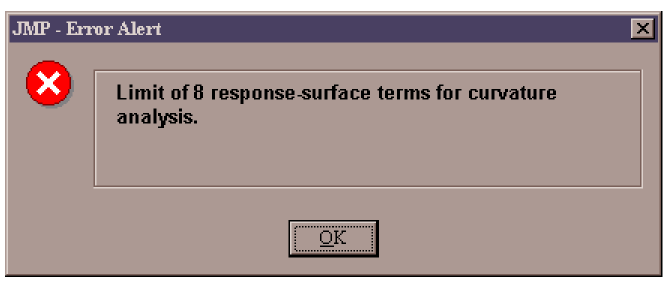
Now, let's create the RSEs! Consider the example JMP file below. There are 8 responses and 16 design variables. Again, go to **Analyze** and **Fit Model**. Highlight your variables and instead of clicking the **Add** button as you did for the screening test, you want to click **Macros ▶**. A drop menu will appear. Select the **Response Surface** option. The white area under the "Construct Model Effects" will fill out with the coefficients for a second order RSE that JMP will be solving for in the regression. Then, select your responses and put them in the **Y** area again. DON'T FORGET TO UNSELECT THE CENTER POLYNOMIALS OPTION UNDER MODEL SPECIFICATION!



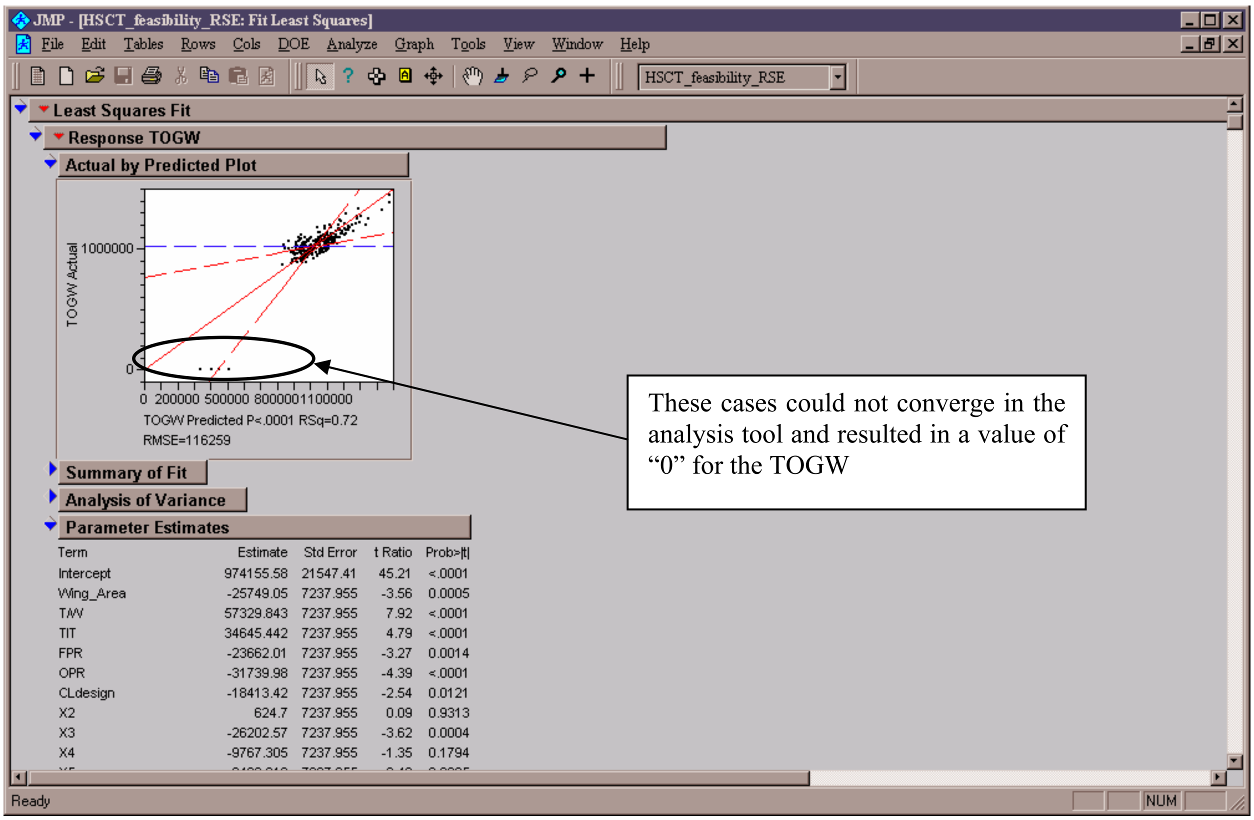
One thing before you proceed: in the “Construct Model Effects”, you have your “to be determined” coefficients. Highlight all of the main effect variables that have the symbol “&RS” by them. Then click the **Attributes** drop menu and unselect the “Response Surface Effect”. The reason for this is that JMP only likes to have 8 variables and just gives you a warning when you fit the model. Doing what you just did suppresses the annoying little error. This does not affect the fit of the model at all. Once you have done this then hit **Run Model**.



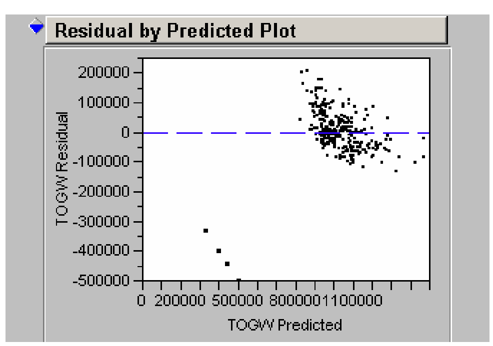
Oh, this is the little error window you would get if you didn’t de-select the Attributes.



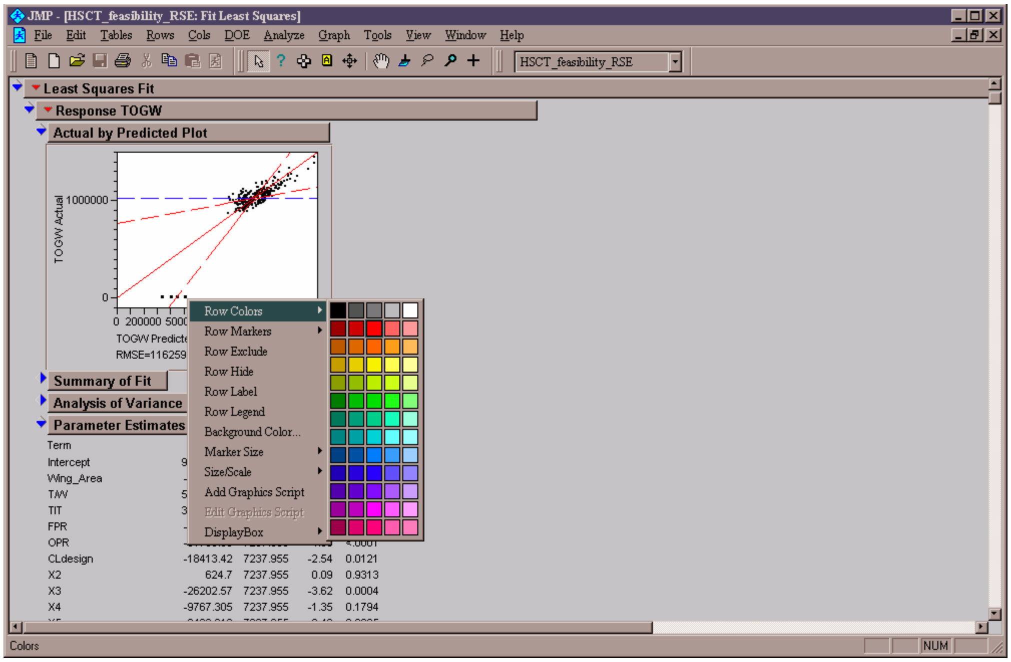
When JMP is finished fitting the model, similar windows will pop up as they did in the screening test. I want you to note some differences here. Look at the error bars (the dotted red lines) around the perfect model fit and compare those to the ones you saw in the screening test earlier. Note the HUGE spread. One would think that the original linear fit was better, but look at the 4 cases that are on the bottom. These cases actually did not converge in the analysis program. The particular combination of variable settings inhibited the program from converging. Thus, the values of “0” for each of the responses will mess up the model. There are a couple of solutions. First, go back to the DoE table and determine which variables might be affecting the failure. You do this by looking at the rows before and after the failed case and determine which combination of the variable settings is causing the program to fail. Then, you can modify the ranges and re-execute another DoE if there are too many failed cases. Another option is at your disposal, ONLY IF YOU HAVE A FEW FAILED CASES. Maybe a good rule of thumb is that you can exclude only 2-3% of the total cases you executed before you should modify the ranges or the DoE that you ran. For 289 cases considered herein, I am going to “Exclude” these 4 failed cases from the model and allow a regression on the remaining 285 cases.



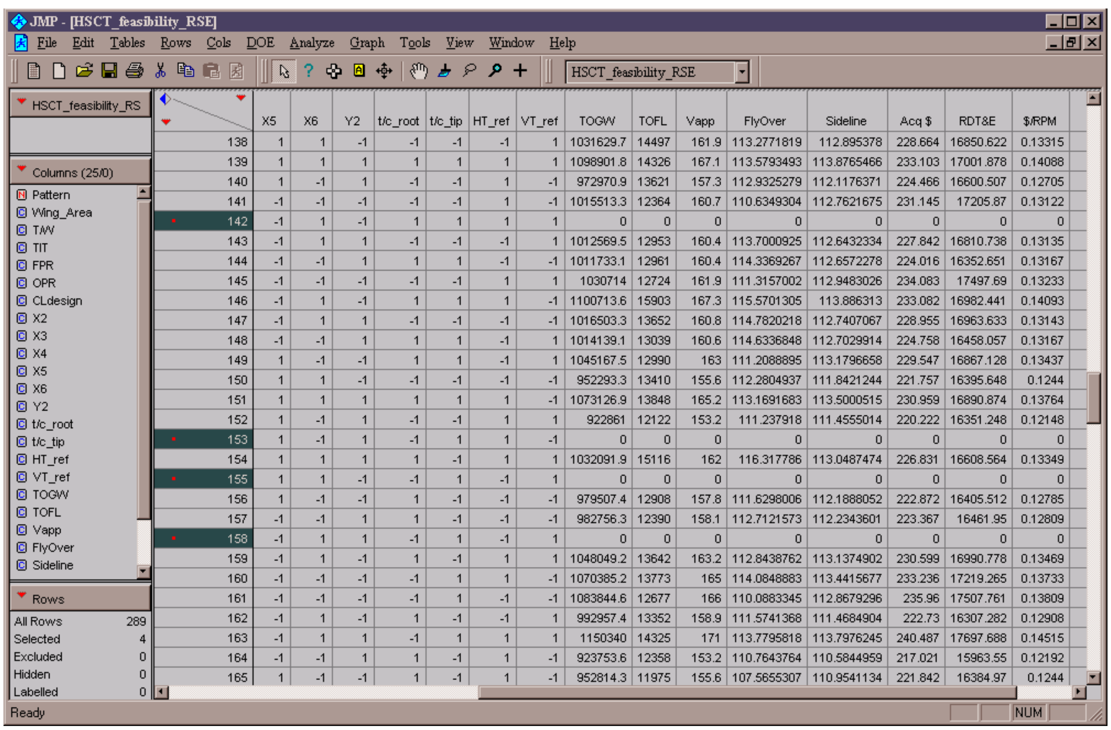
If you look at the Residual Plot below you can see that there is a clumping of responses. Also, the Y-axis scale is one-third the size of the X-axis. This implies very large residuals and a poor fit. The Y-axis should be lass then one tenth of the X-axis for residuals to be considered reasonable. It is important to examine the scale as well as the shape.



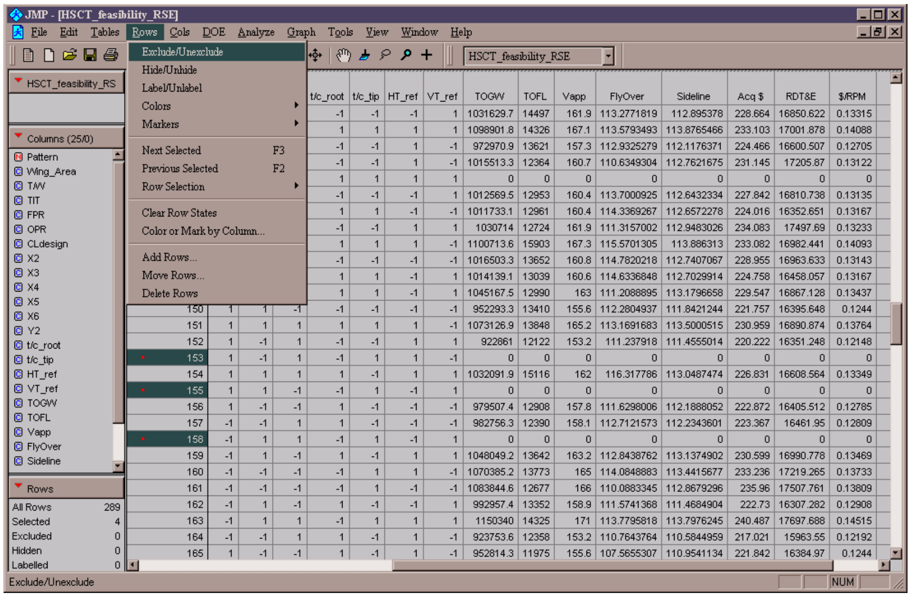
To do this, put your mouse over one of the four dots in the "Actual by Predicted Plot" above and left mouse click one of them. You will see that the little dot gets bigger. Then hold down the shift key and click another, and another and another. Now, right mouse click and the window below will pop up. Select the **Row Colors** option and then pick one of the colors, say red. You will see that the 4 dots that you selected are now red.



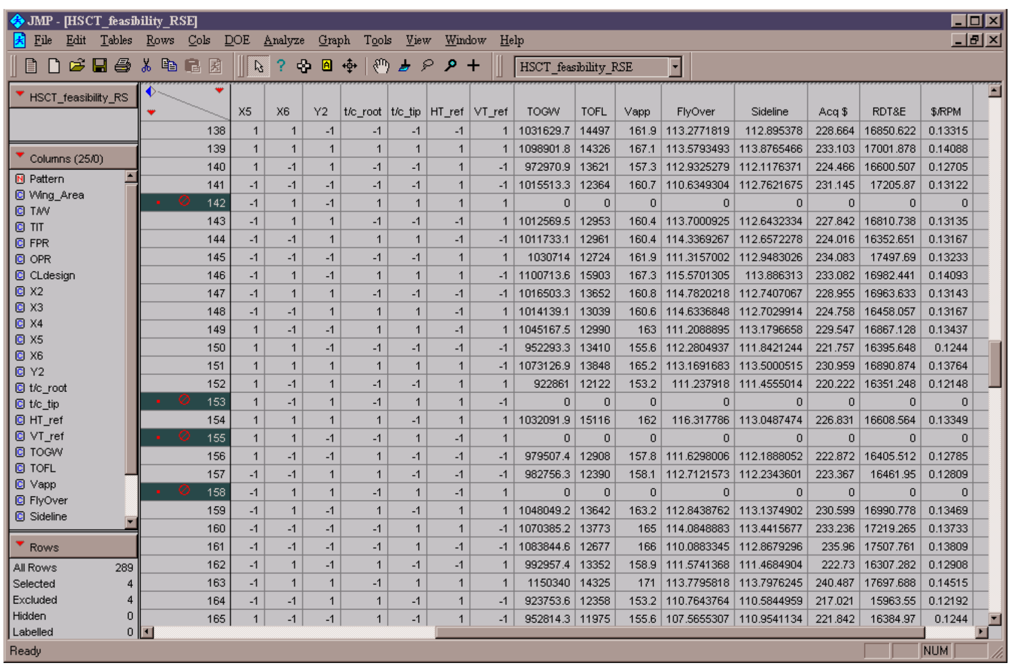
Go back to the DoE table window and scroll down until you find the highlighted rows that have little red dots beside them as shown below.



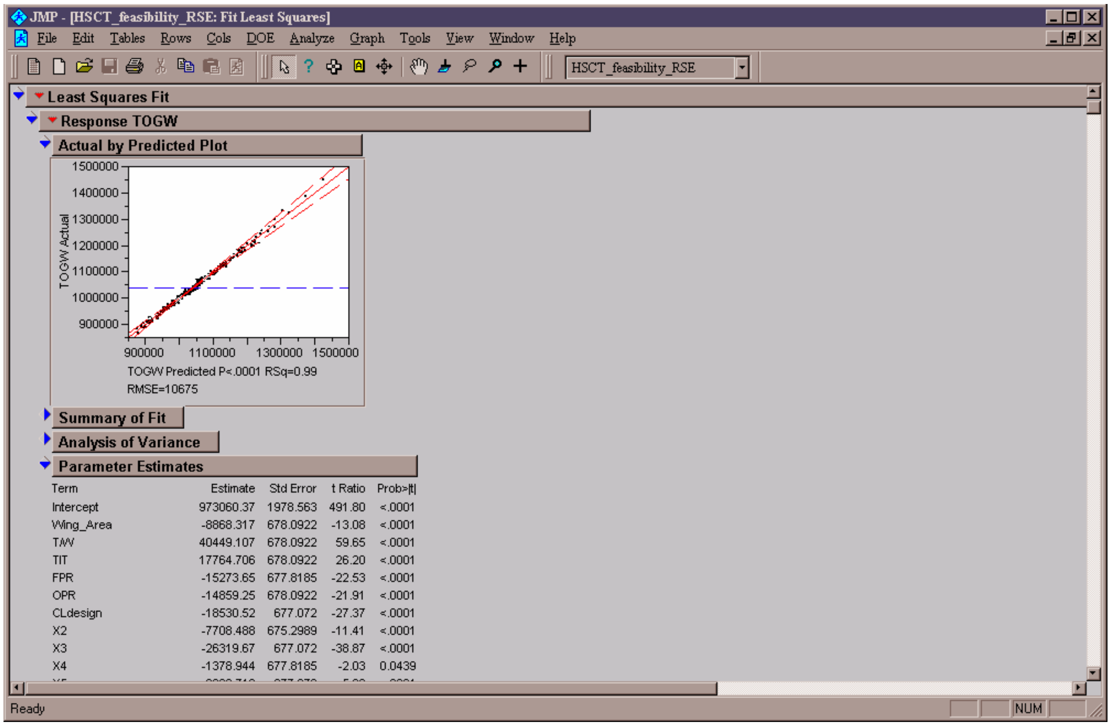
We want to exclude these 4 cases from the analysis, so, go under **Rows** and select the "Exclude/Unexclude" option.



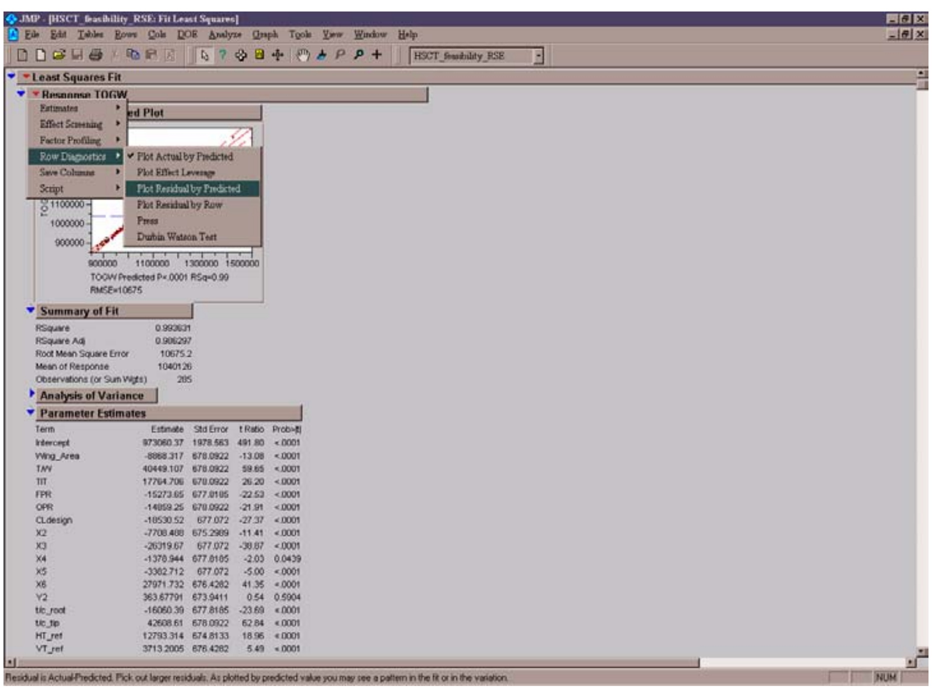
JMP will add ⊘ by each row. This means that these rows will be excluded from the model. You will lose some degrees of freedom, but if you only eliminate a few cases, you should be ok. Please look at any DoE or Response Surface book or the JMP Help menu for more information about degrees of freedom. Now go through the same process as above regarding fitting the model.



Now when we get our new window that has the "Actual by Predicted", look at the significant difference in the error bars. They are much tighter! For a good "Actual by Predicted", you want to have each of the dots (or cases) to be as close to the diagonal line as possible. The diagonal represents the perfect fit. AS the dots (or cases) move away from the diagonal, the error in the prediction increases. The red dashed lines around the diagonal represent the 95% confidence intervals of the prediction and the blue horizontal dashed line represents the mean of the response. If by chance the blue dashed line falls inside the red dashed lines, you have a VERY bad fit.

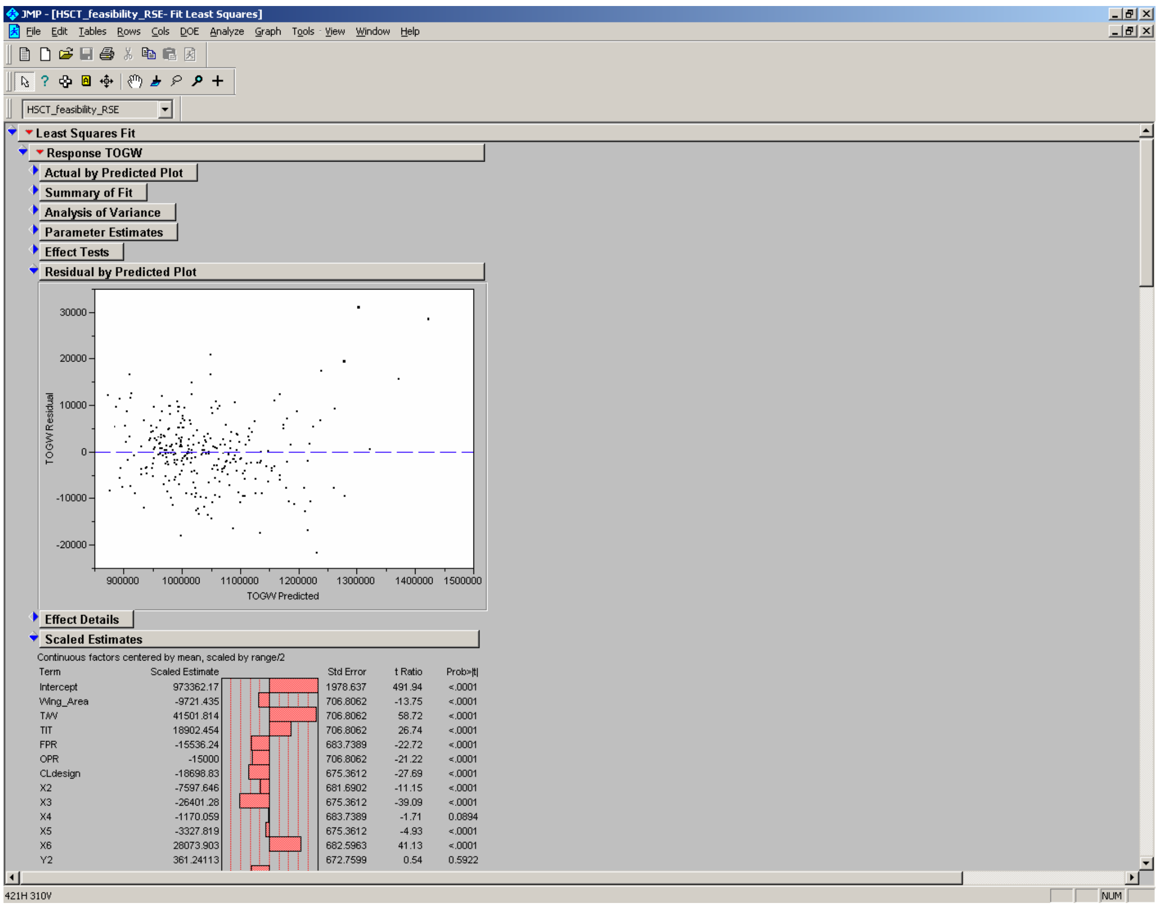


For another check of you model, go to the little red ▼ by the "Response TOGW" drop menu and click on **Row Diagnostics** and then select "Plot Residual by Predicted" option as shown below.

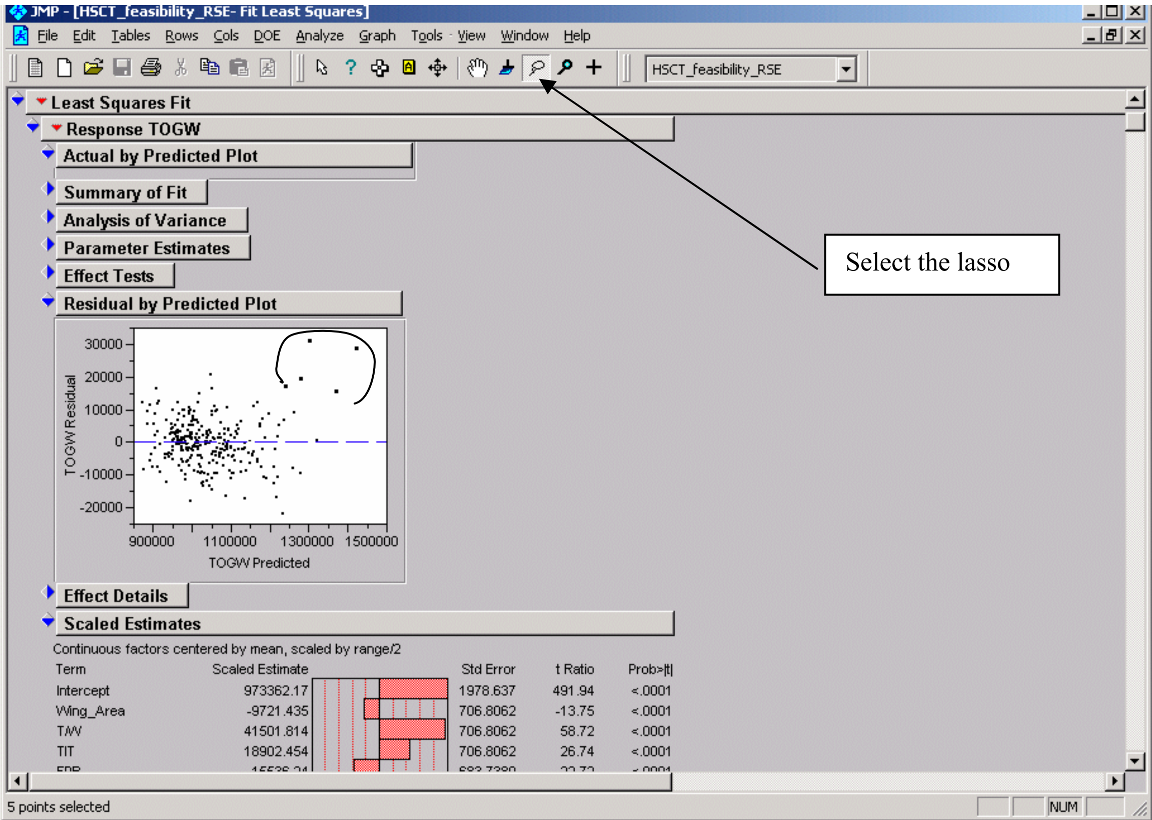


Then scroll down until you see the Residual plot. This plot is also called a “scatter plot”. The residual is the error in the fitted model and is the difference between the actual value of each observation and the value predicted by the fitted model. You typically want a nice *random shotgun scatter of your error with a very small magnitude* on the vertical scale with respect to the predicted values. The example below isn’t too bad. There are only a few points at the top that stand out as having high error. For only a few cases like this, you could simply exclude those from your model and refit. However, you should look at the particular cases and try to determine if there is a pattern of variable combinations that are inducing an error. If so, you might want to investigate your analysis code to determine if there is a modeling problem.

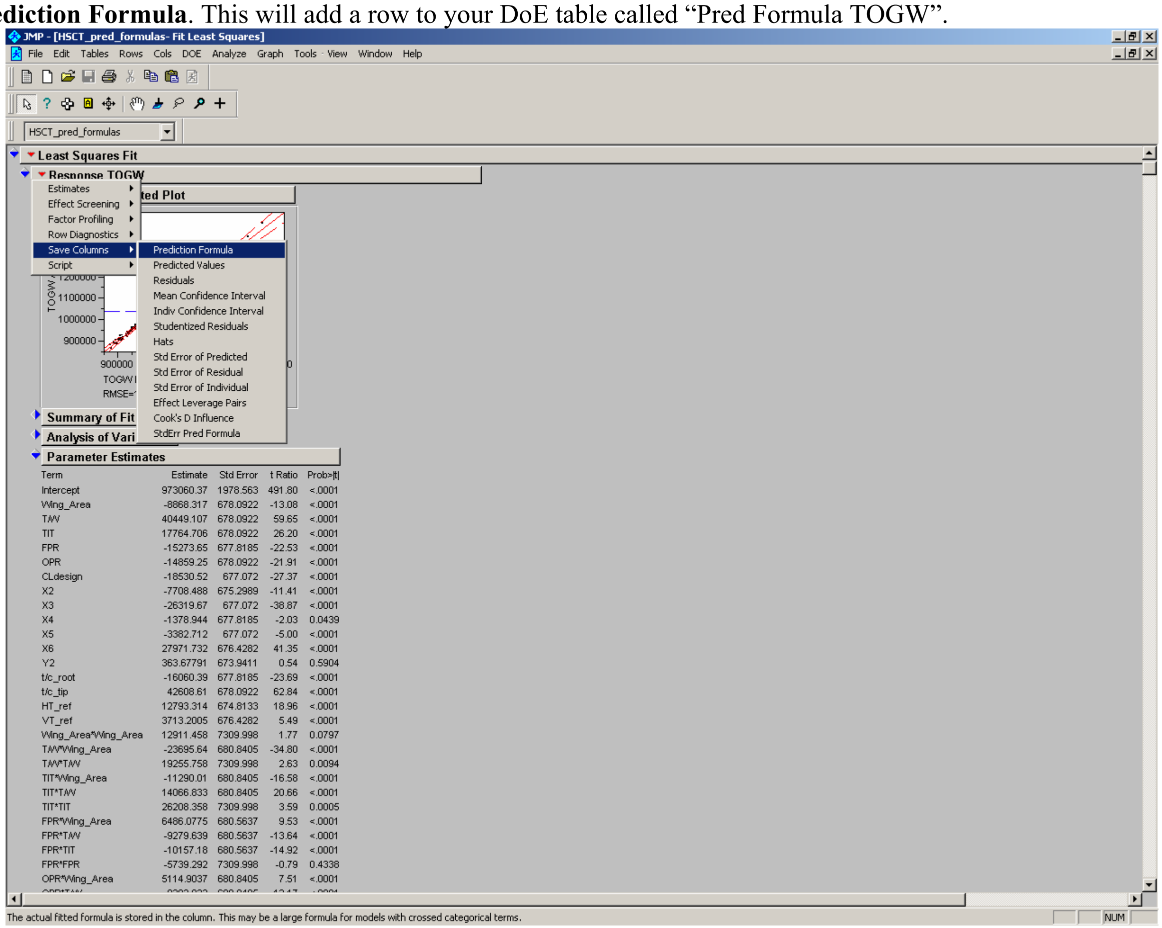
Also, if there is a pattern to the residual (i.e., looks like a smiley face or a sine wave), a couple of things may be going on: 1) you may need a transformation of your dependent variables to get a random gunshot, or 2) you may need higher order effects of your model.



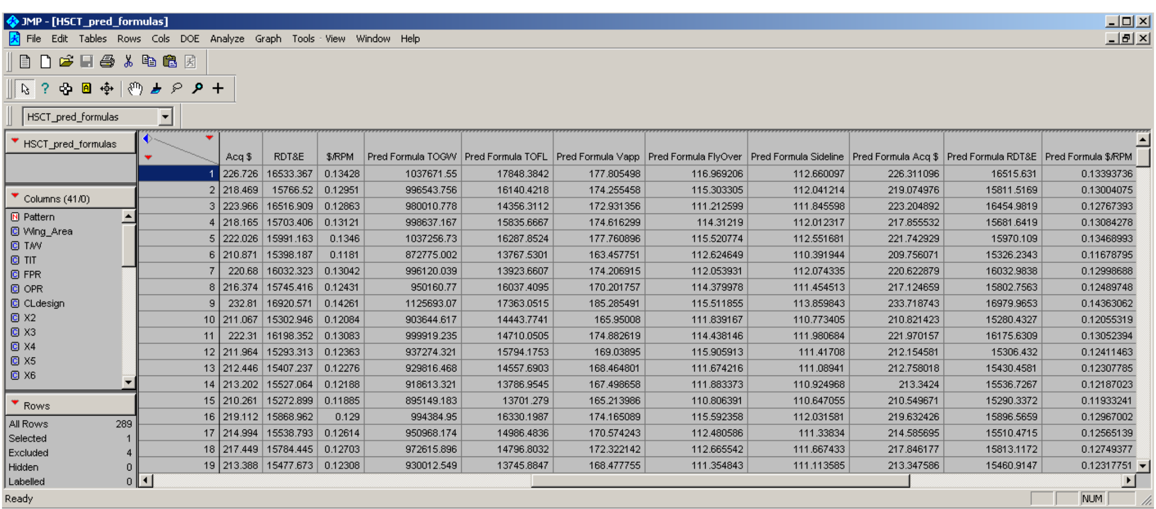
There are two ways to select the dots on the Residual plot. The first is to simply click on each dot individually. Another is to go up on the top menu and select the little lasso icon. Then draw a circle around the cases that are outliers by holding down the left mouse button and drawing the circle to "lasso the cases"! Then you can highlight them as you did before and identify the cases from the DoE table. For this example, excluding the 4 cases above helped the fit sufficiently that we can proceed.



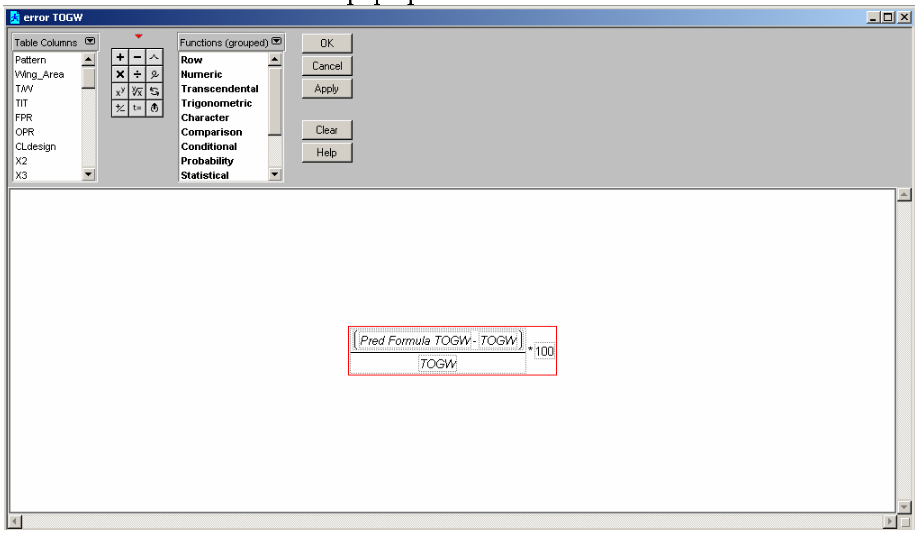
There is an assumption that a second order model will fit the data and that the higher order terms clump into an error term with normal distribution. The foundation for this is that you are fitting a model based on a Taylor Series expansion. For a second order model, you assume that all higher order effects are negligible and can be lumped into an error term. For this assumption to be valid, that error term usually needs to be a standard normal distribution with a mean of 0 and a standard deviation of 1. Checking this error distribution is a good way of determining if you have a good fit with the RSE. If the distribution is not normal, it implies that the model you fit is not good, you may have bad cases or you may need a transformation of inclusion of higher order effects. To find the percent error and the error dsitribution, you must save the predicted formulas. Under the little red ▼ by Response TOGW, select **Save Columns**, then **Prediction Formula**. This will add a row to your DoE table called “Pred Formula TOGW”.



Repeat this for every response so your data table looks like this:



Now you want to find the percent error between the actual and the predicted responses. Add columns with **Cols**, **Add Multiple Columns**, and add eight columns after the last column. Rename the first column ‘error TOGW’. Each column will find the percent error for one response, so name them appropriately. Right click on the first of the columns and select “formula”. This window will pop up:

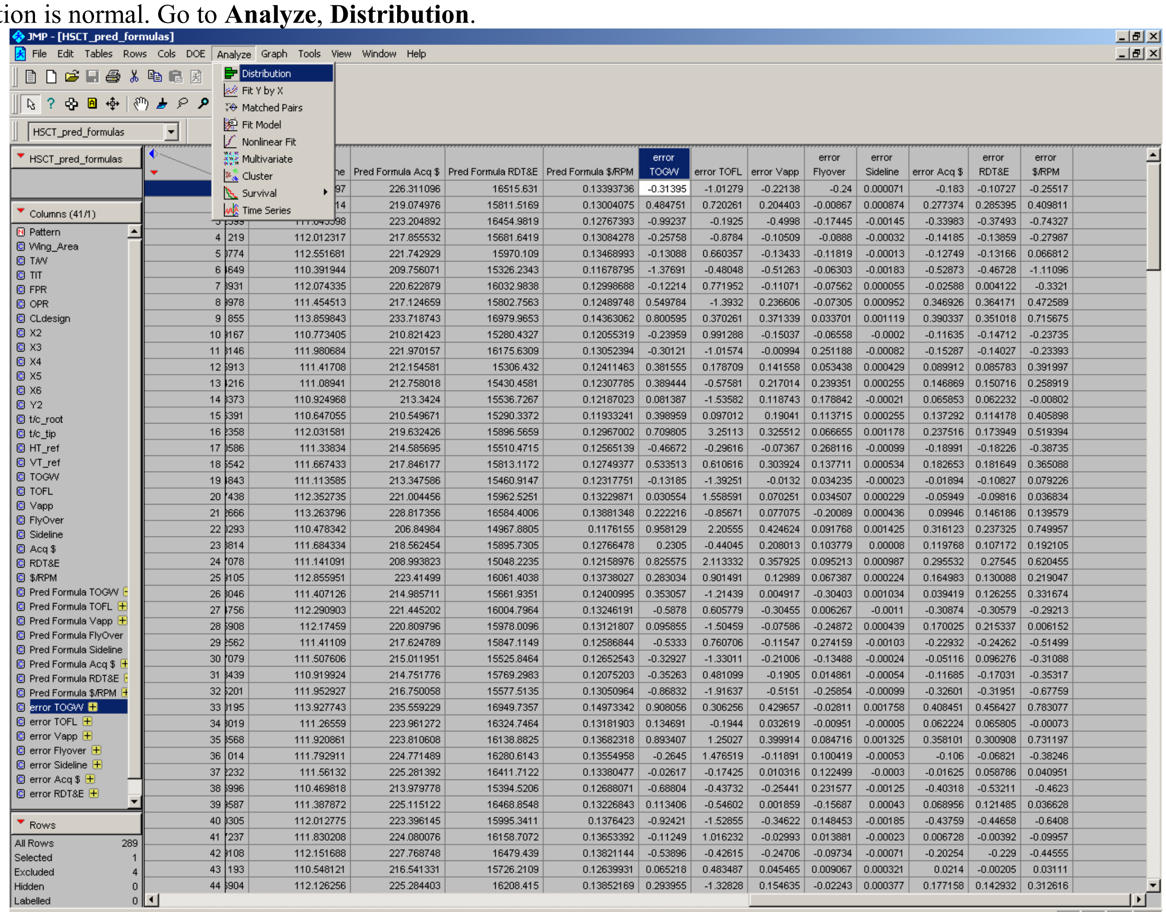


Enter the formula for percent error using the column names:

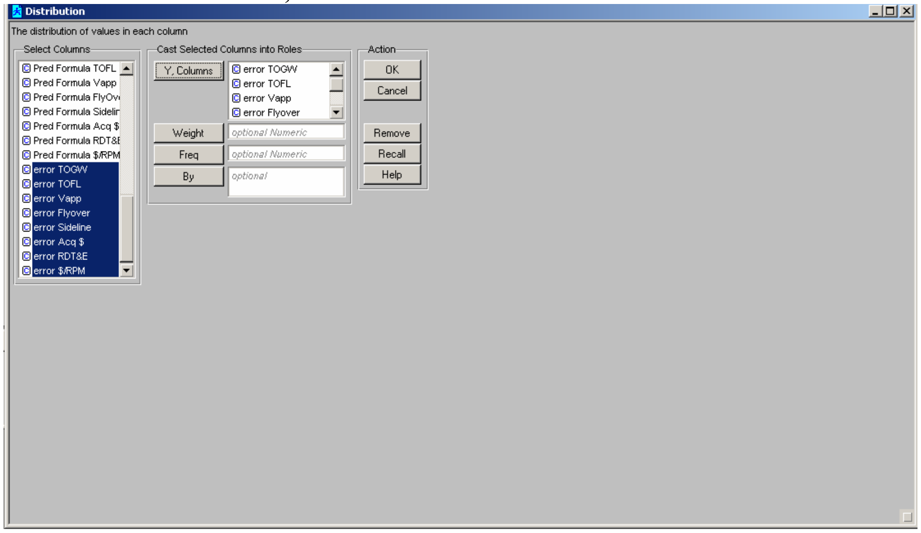
Percent error = (Predicted Value – Actual Value) / Actual Value *100

NOTE: JMP does not like number entered first into the formula. If you are multiplying by a constant, do so at the end of the formula.

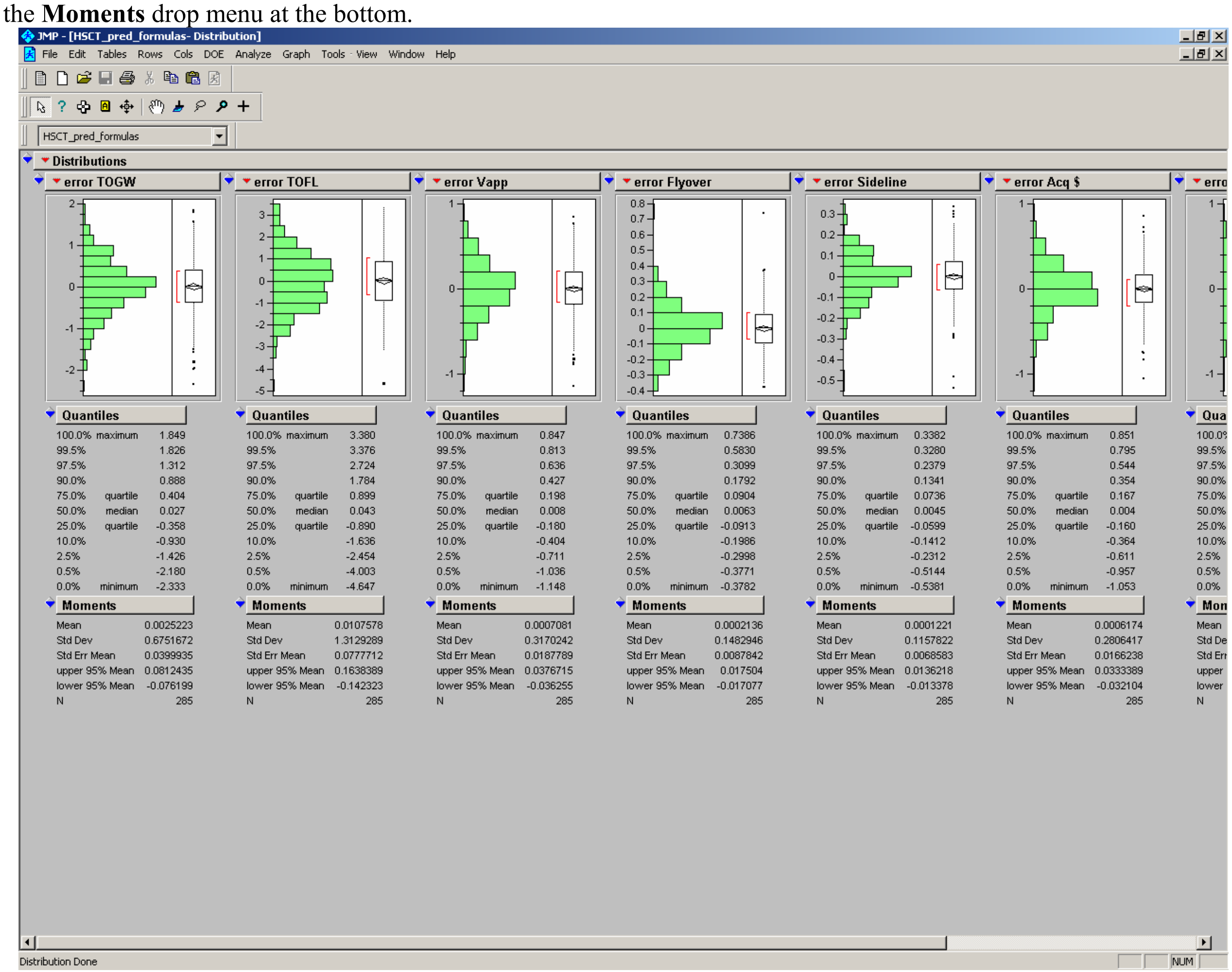
After the percent error for each response has been calculated using the entered formula, you want to see if the distribution is normal. Go to **Analyze**, **Distribution**.



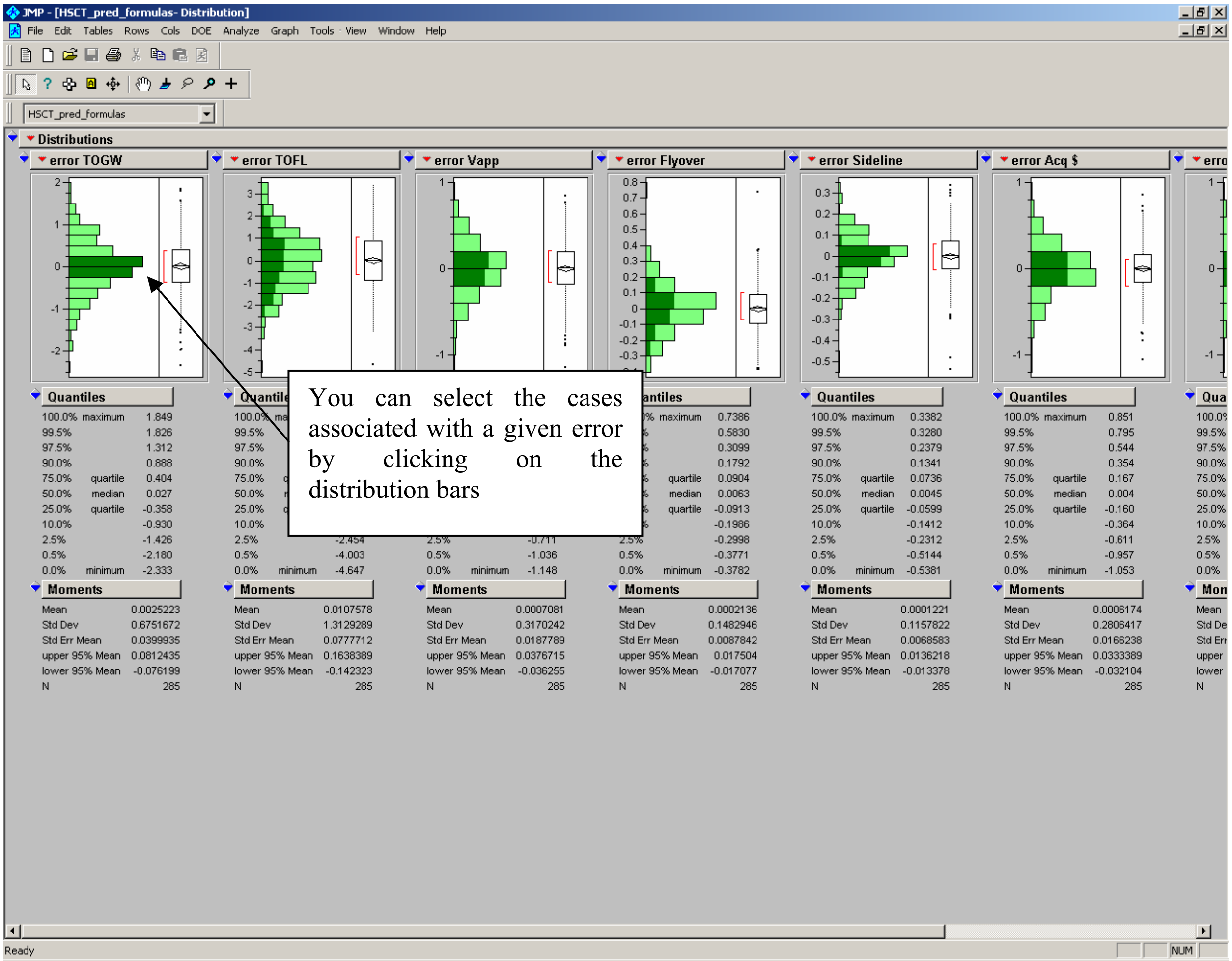
Place the error columns into the **Y, Columns** box.



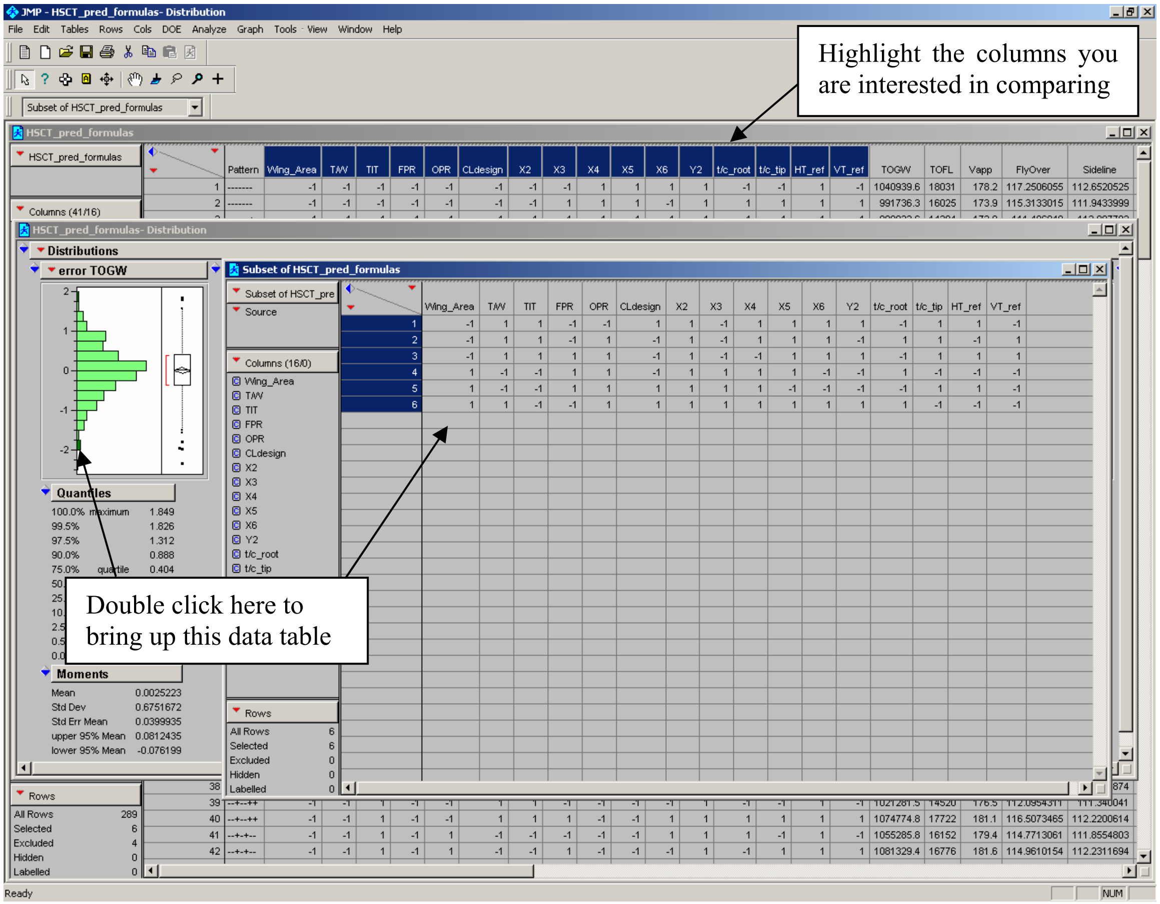
The distribution for the error will pop up. This gives you a distribution, a box plot, quantiles, and moments about each column. Here you can check for normal distribution with a mean of 0 and a standard deviation of 1 under the **Moments** drop menu at the bottom.



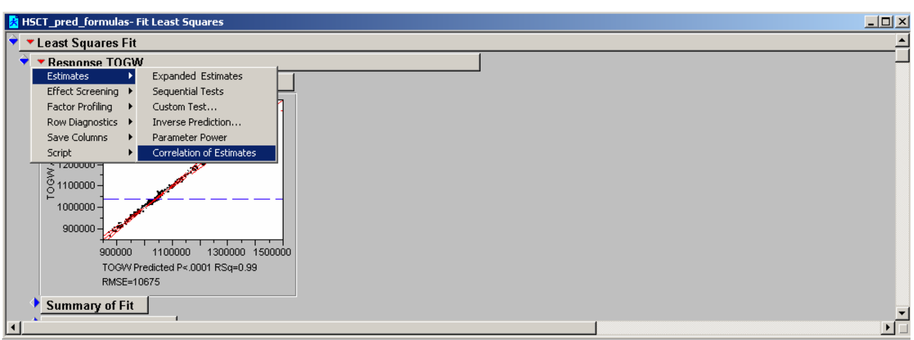
If the distributions are not normal you have three options: exclude cases, transform the responses with logarithmic or exponential functions, or include higher order effects. For this tutorial, we will focus on excluding cases. To select cases to exclude, you can click on the distributions or the box plots. Selecting a bar of the distribution selects all the cases within that bar. If you only want to select some of the cases within a bar, use control and the left mouse button to scroll the axis or zoom in with the magnifier in the tool bar. An interesting aspect of these distributions is that selecting a case in one selects it in all of them so you can see where the cases fall throughout all the distributions.



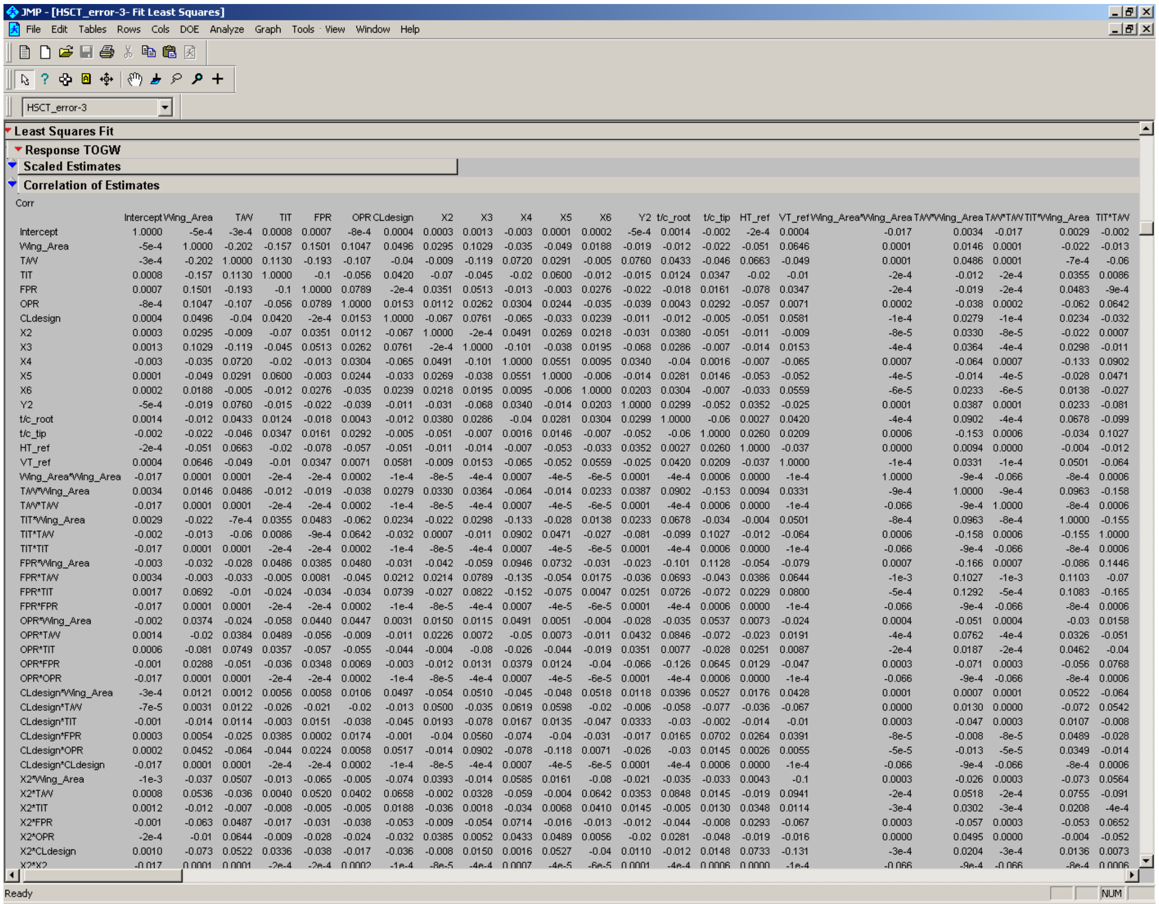
You want to exclude cases that have large percent errors to improve the fit of your RSEs. After selecting the cases you wish to exclude, it is a good idea to check if there is a pattern to those cases. In the DoE table, select the columns you want to compare by highlighting the name row. Go back to the distributions and double click on any of the selected points. This will bring up a table containing the information for those points. This is an easy way to find patterns and see if anything specific is causing the large error.



With the cases you want to exclude selected, go back to the data table and try excluding these. Rerun the analysis. You have to be careful how many cases are excluded. One way to judge if you have excluded too many cases is to look at the Correlation of Estimates.

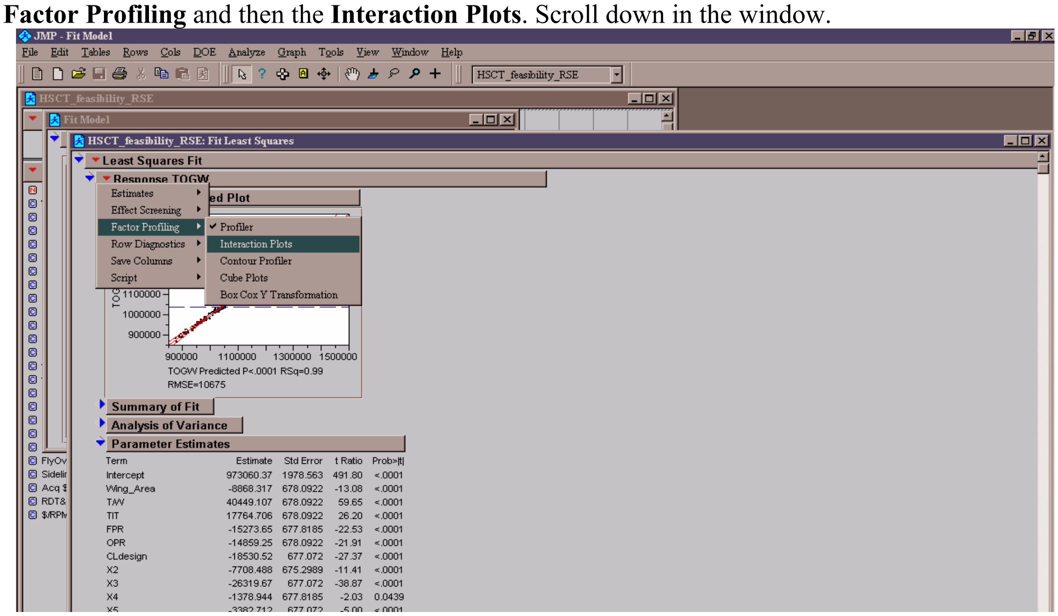


The Correlation of Estimates is a symmetric matrix that shows the mathematical correlation between the coefficient estimates. You should check that these numbers, except for the "1"s that make up the diagonal, are below ±0.15. If any number in this matrix exceeds ±0.25, you will not be able to differentiate between the influences of those coefficient estimates due to the prediction being correlated. What this implies is that if you are trying to estimate the coefficient for one term in your RSE and it has a high correlation with another coefficient, you will not be able to distinguish which of those coefficients is actually contributing to the response. This means you have excluded too many cases from your DoE and you cannot estimate your responses with your current data set and DoE. Check this matrix for each response when you exclude more than 5% of your original DoE cases. If your correlations start getting high, you need to modify your DoE by changing ranges, transforming your data, and/or check your analysis tool to see if you set up your model correctly.

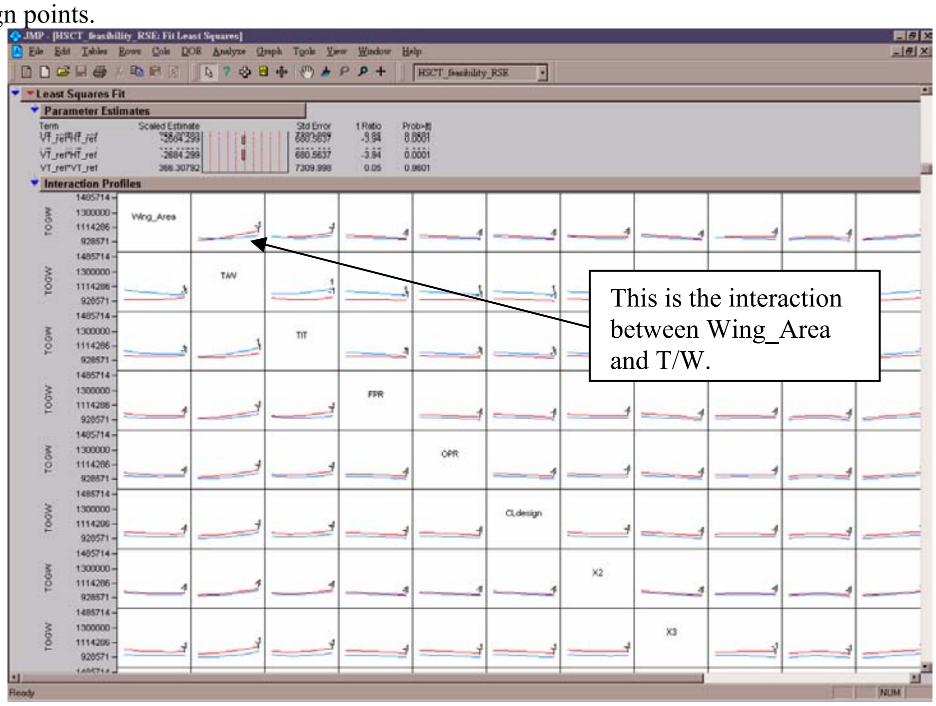


Looking at your actual versus predicted plot and the residuals plot, the fit of these two plots should reflect a better fit through the remaining cases.

The most accurate means of determining how well your RSEs model your analysis code is to run a set of random cases. This is especially important if your responses are highly quadratic and there are very strong interactions amongst variables. To establish the interactions between variables, go to the red arrow beside "Response TOGW" and select the **Factor Profiling** and then the **Interaction Plots**. Scroll down in the window.

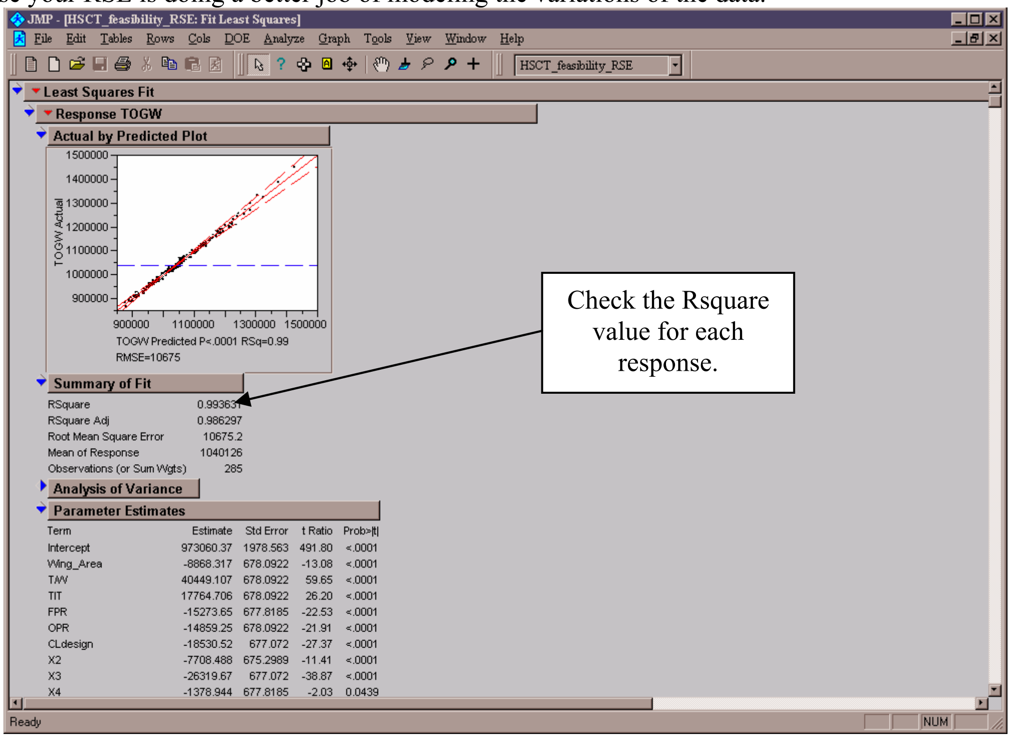


The plot below will come up. To identify if there are strong interactions between variables, look at one of the boxes. For example, consider the interaction between Wing_area and T/W. If these two variables had a small interaction between each other, the two lines that you see would be parallel. However, when interactions exist, the lines will have different slopes. Very strong interactions can be identified when one line crosses the other. What happens within the RSE for cases like this is that one effect can be masked by the other and when you evaluate your RSEs at values other than the cases used to create the RSEs, you may have significant prediction errors. However, if the interactions between variables are small and your responses are not extremely quadratic, your RSEs should behave well at off design points.

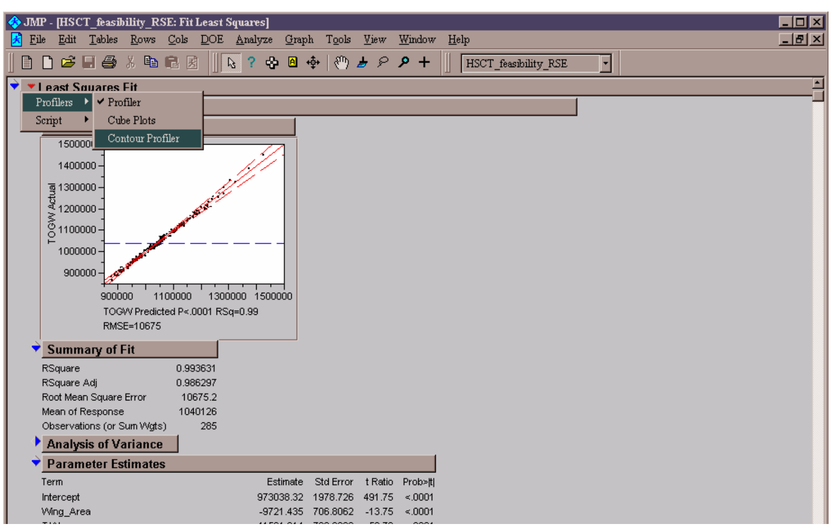


However, if you do have strong interactions and highly quadratic responses, you need to run a set of random cases. Especially if you don't know a priori the behavior of a response. The suggested amount of random cases is an equivalent amount to the number of cases you ran for the original DoE. You can do this by randomly picking values between "-1" and "1" and creating a new DoE table. You can do this in Excel in your convert spreadsheet using the formula =2*rand( )-1. This will give you a value between –1 and 1. You will want to paste special these numbers as values into the convert sheet because they have a tendency to change with any change in the spreadsheet. Re-execute your analysis tool for those random cases to get your "Actual Response Values". Bring the responses into the DoE with the newest prediction formulas calculated after excluding cases and save as a new file. Bring in the random values, which will automatically update the values in the predicted formulas and the error columns. Now you can look at the error distribution to see how the RSE performs at off design points, again look for a normal distribution. An acceptable level of error is ± 5%. If your error is higher than this, you should re-examine your ranges and the DoE that you used. For a given design problem, this effort should be done at least once to get a feel for how well a 2nd order RSE can capture a given response. This is a valuable one-time investment.

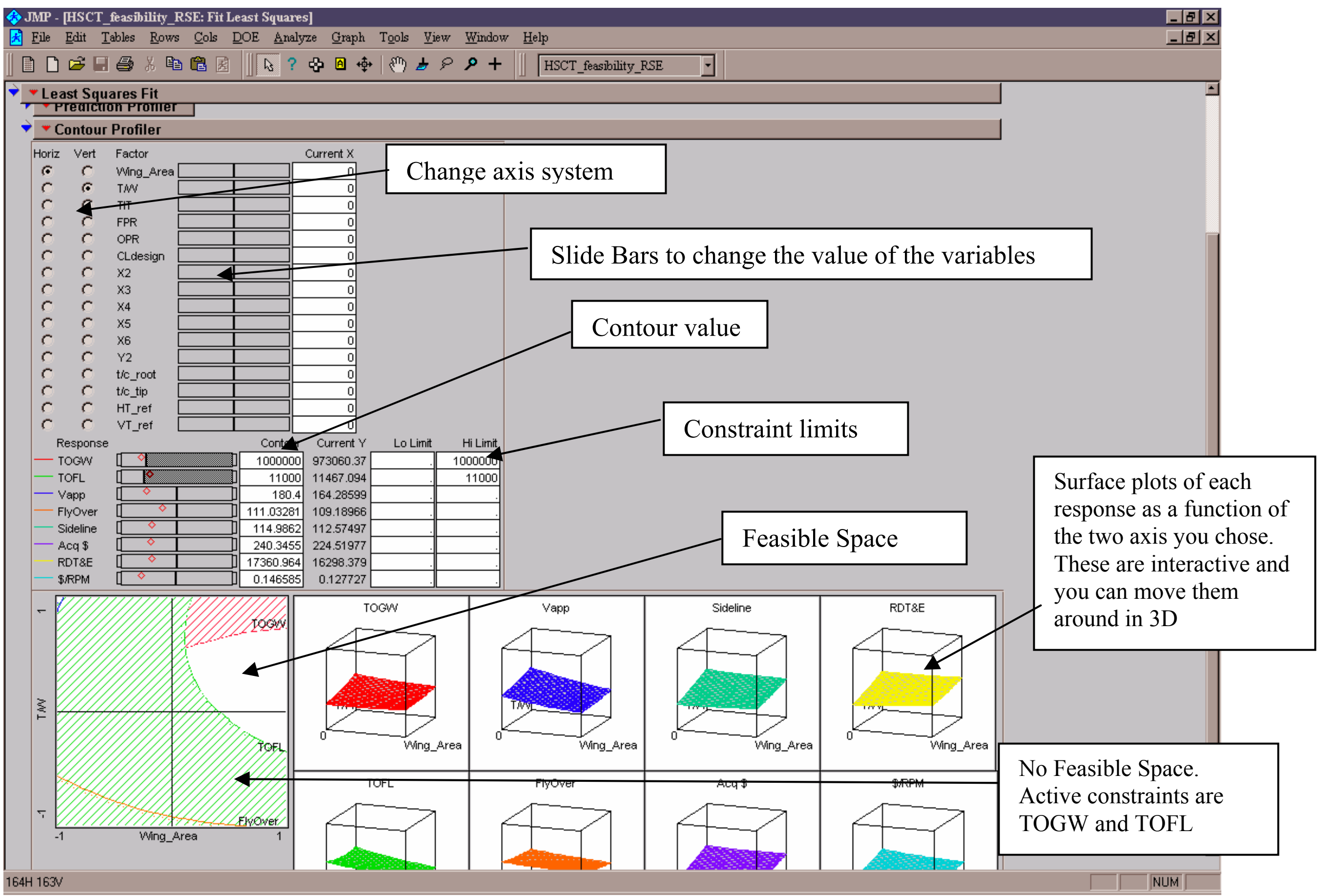
For one last test to see how well the RSE is predicting your analysis code, click the **Summary of Fit** button and observe the "Rsquare" value. Rsquare is a number that indicates the accuracy of your predicted graph. A value of one indicates that the relationship is perfect, while zero indicates no relationship whatsoever. As you can see it has a value of 0.993631. This means that the second order DoE model that you chose explains over 99% of the variation in the data. With this check for the goodness of the fit of your model, you typically want a value greater than 90%. However, the R^2 value IS NOT THE ONLY CHECK FOR THE GOODNESS OF FIT! The R^2 tells you how well you are predicting the responses at the values prescribed by your DoE table. It DOES NOT tell you how accurate your responses will be at variable settings other than "-1", "0", or "1". This value will be closer to one if you have excluded cases, because your RSE is doing a better job of modeling the variations of the data.

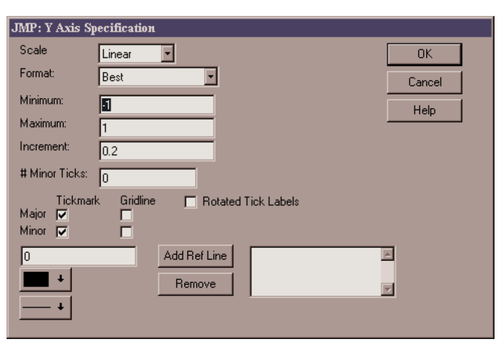


Another great feature of JMP is the ability to see contour plots. So, go under the **Least Squares Fit** drop menu again and select the **Profilers** option again, but now select the "Contour Profiler" option.

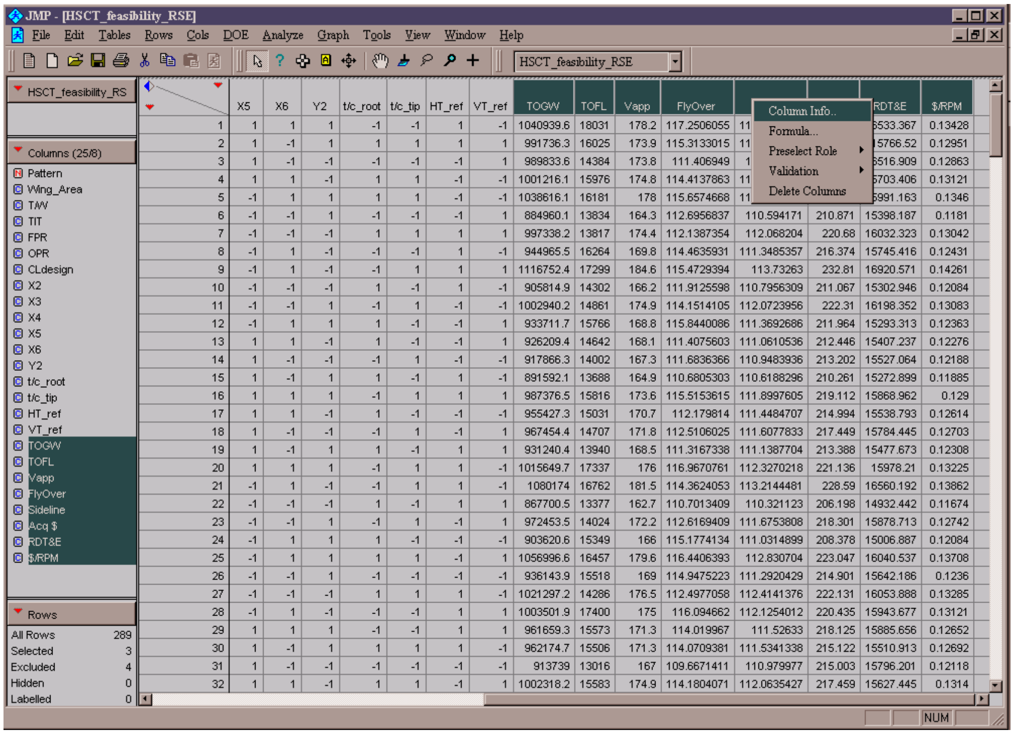


Scroll down in the window to see the "carpet" plot shown below. Here is where you can play with constraints that may be hurting you. You can change which variables are displayed in the contour by simply clicking in the boxes under "Horiz" and "Vert". You can assign specific values to your responses by clicking in the boxes under "Contour" and adding values. You can put limits on the responses as either Hi (high) or Lo (low) limits. You can set the design variables to different values by moving the slide bars, etc. For presentation purposes, copy this in the same manner as you did before. An example of the contour plot is shown below. There are upper limits on 2 responses, and the design variables are all set at "0". Note that the contour values were set to the limit values so that you can visualize which constraints are active. In this case, the TOGW and the TOFL are active constraints. Just play with this, it is VERY easy. Note, to expand the contour plot for easier viewing or presentation, put your cursor in the bottom right hand corner and then click and drag the corner of the box. You can also turn off the Surface Plots if you like under the drop menu for the Contour Profiler. You can zoom in and out on the contour plot by putting your mouse over one of the axes (either T/W or Wing_Area), hold the "Ctrl" key down and then right mouse click and select the "Size/Scale" option and then either X or Y axis. If you select the Y-axis, you get the window down below. You can modify any range you like.

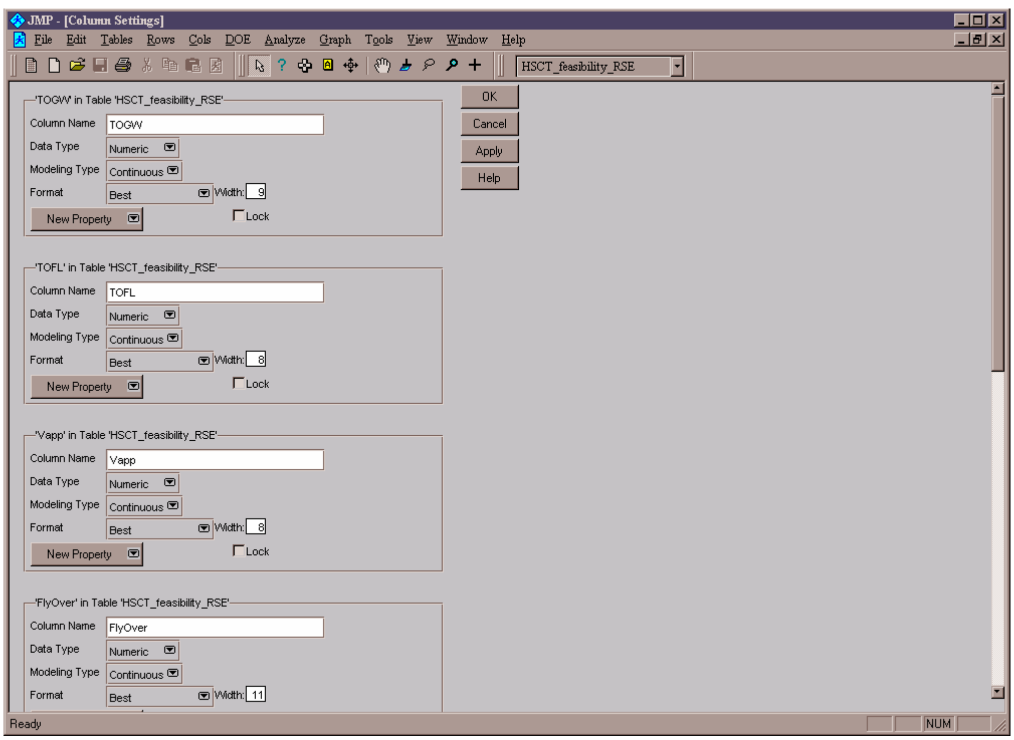




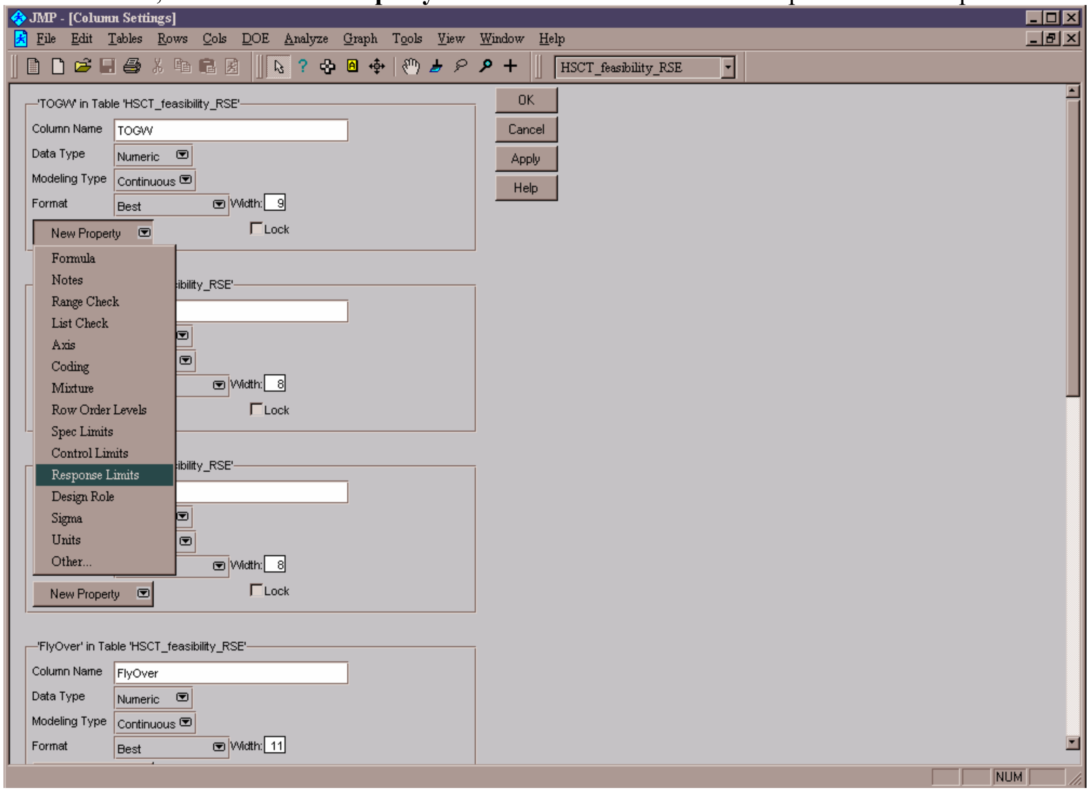
One item of interest to you might be the following: What are the settings of the variables that optimize my responses? JMP can optimize your variables for you through a feature called the “Desirability Function”. Consider our 8 responses, each of which we would like to minimize. We need to tell JMP this information. Go back to the DoE table and click on the first response column title cell, TOGW, and hold down the shift key and click the last response title cell ($/RPM). Note that all of the column headings are highlighted. Now, right mouse click and you will get the following menu and select the **Column Info** option.



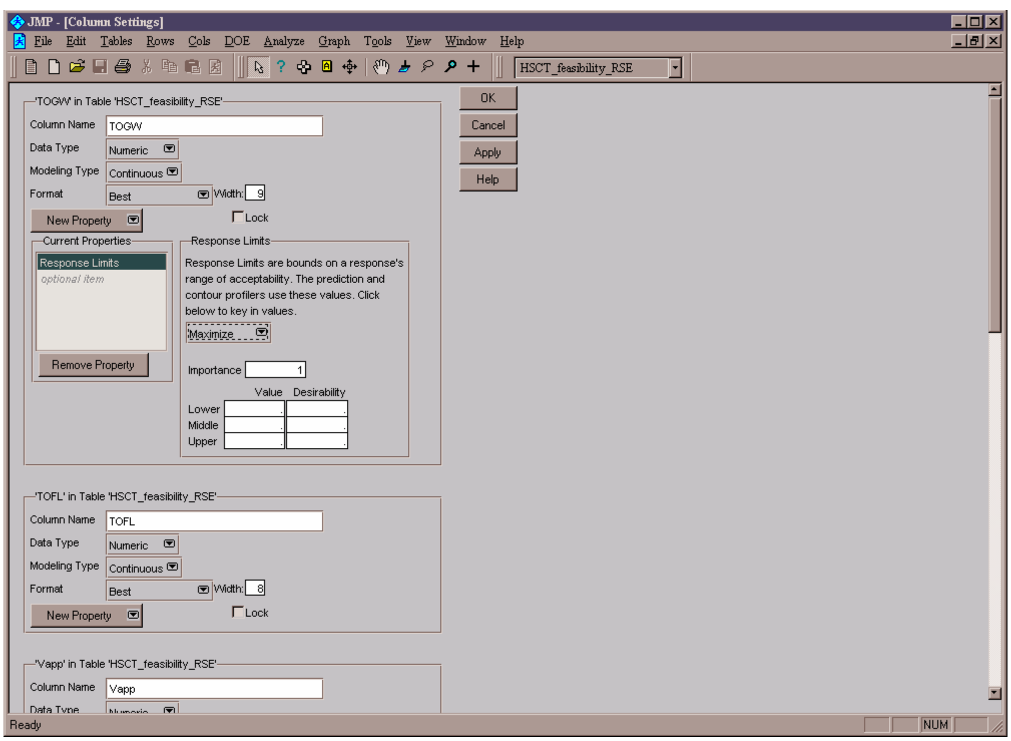
The window below will come up.



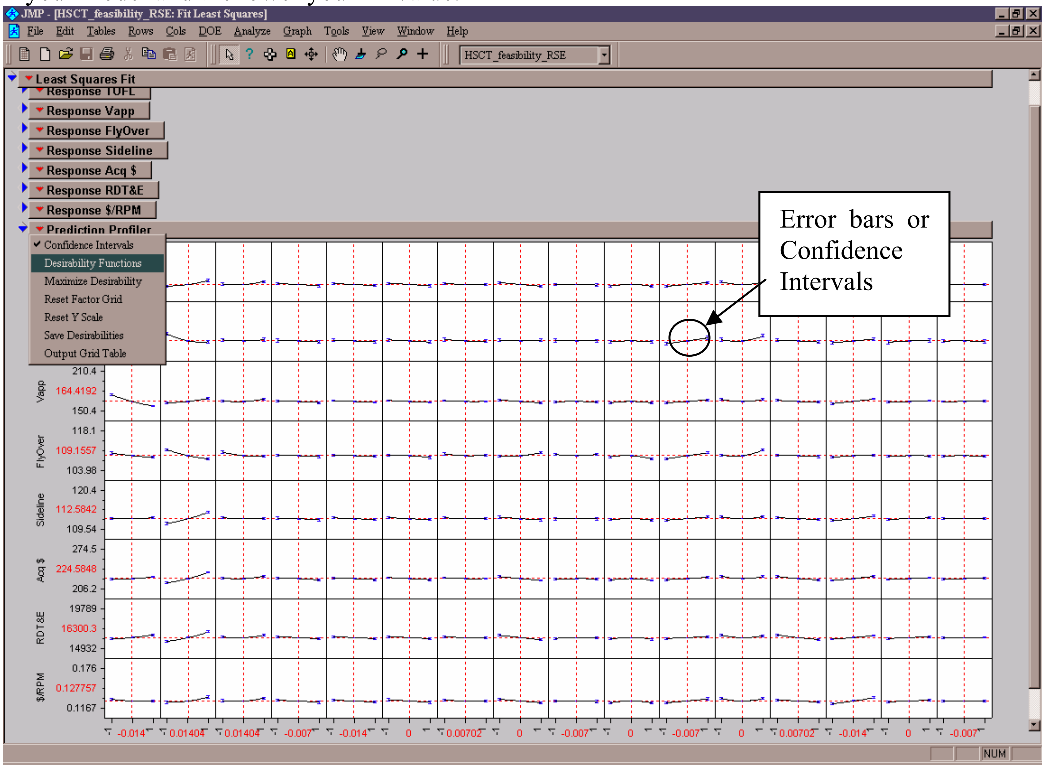
Under TOGW, select the **New Property** button. And then select the "Response Limits" option.



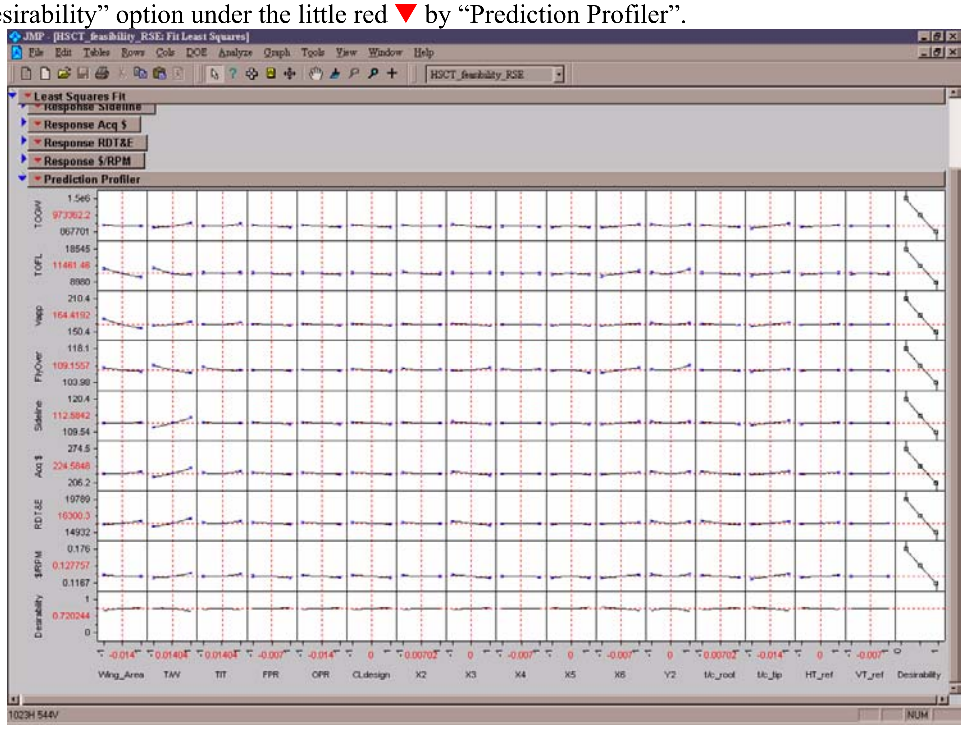
The following will come up. Click the **Maximize** button and change it to the "Minimize" option. This tells JMP that the response is to be minimized when we do the search for the most desirable settings. Repeat this for each response and then click the **Apply** button and then **OK** and go back and **Fit Model** again.



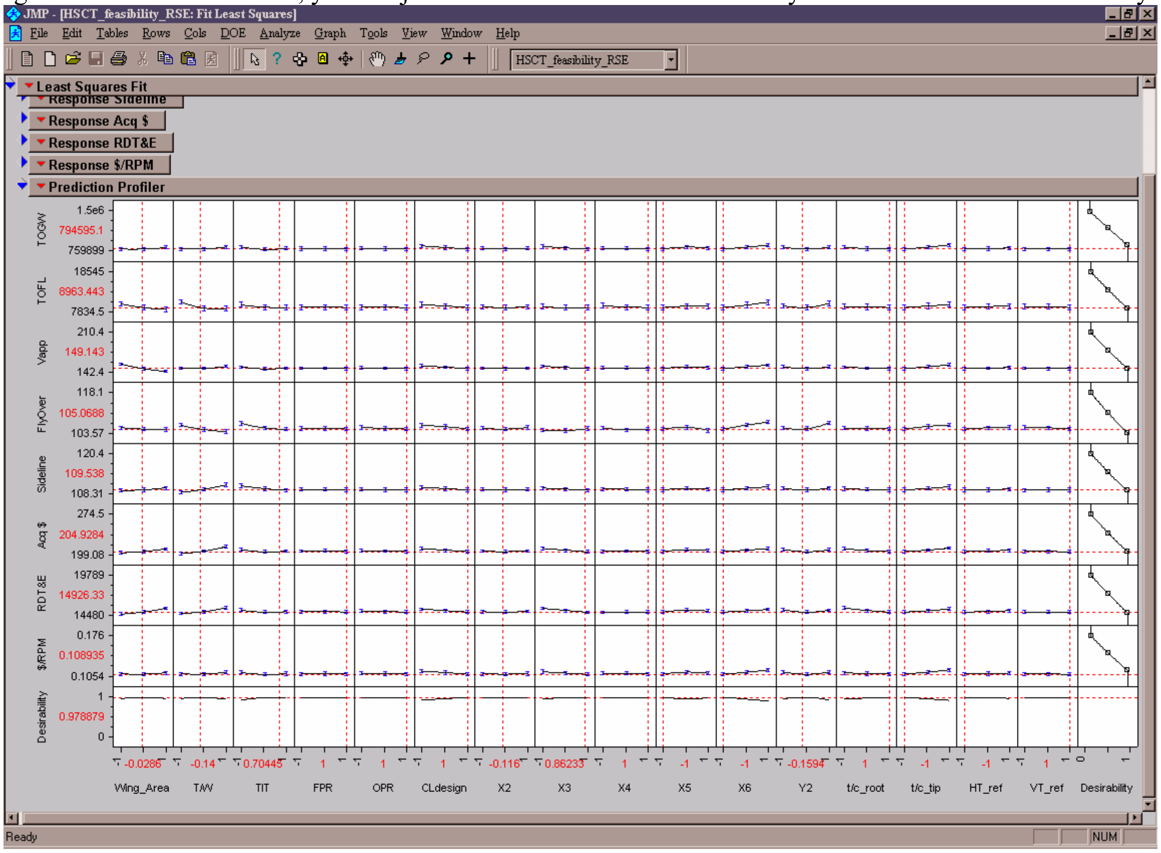
Go back to the “Least Squares Fit” window and go to the Prediction Profiler and click on the little red ▼ and select the “Desirability Functions” option. Notice that the “Confidence Intervals” are checked in the box below. The Confidence Intervals are the little error bars on the Prediction traces of the Profiler. The larger they are, the more error that exists in your model and the lower your R^2 value.



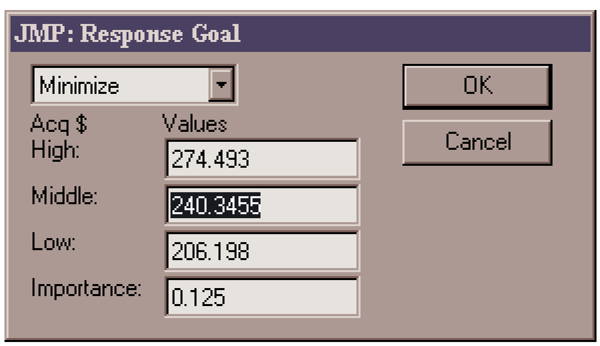
After you select the “Desirability Function” option, another column will appear in your Profiler and another row. On the right, this is the direction of the desired response; it is shown in minimization right now. If any of the responses were to be maximized, then the slope would be positive, rather than negative as shown. On the bottom, the influence of a variable on the desirability is shown. For example, increasing Wing_Area increases the desirability, reducing T/W increases desirability, and so on. JMP will automatically find the optimal settings by selection the “Maximize Desirability” option under the little red ▼ by “Prediction Profiler”.



JMP will then come back with the most desirable settings for the responses as shown below, if it in fact can converge on a solution. If it can't, you can just move the hairlines around until you can maximize the desirability.



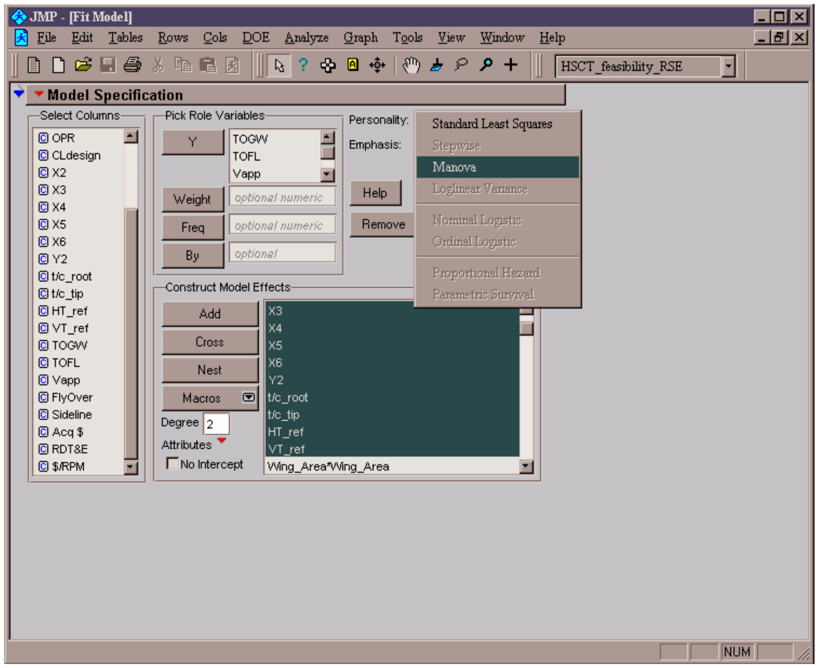
Also, there is another way to change the desirabilities. Put your cursor in one of the desirability boxes on the right and hold down the "Alt" key and click. The window below will open up and you can change the options.



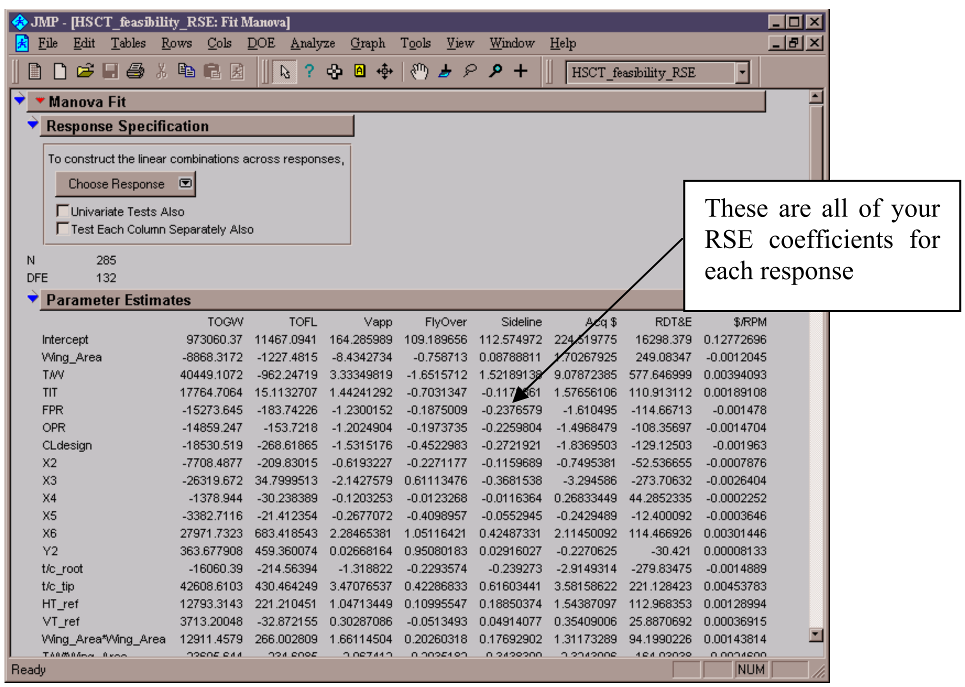
Let's summarize what we should have done up to this point.

- Look at the "Actual versus Predicted Plots" to check the goodness of fit
- Look at the "Residual Plots"
- Check the error distribution
- Exclude bad or high error cases
- Run random cases if you have strong interactions and large quadratic behaviors
- Check the R^2 value for EACH response
- If an acceptable value is obtained, we can proceed, if not, then we need to check what went wrong
- Modify ranges if needed and run another DoE
- Refit data
- Create Contour Plots and Prediction Profiler for presentation purposes

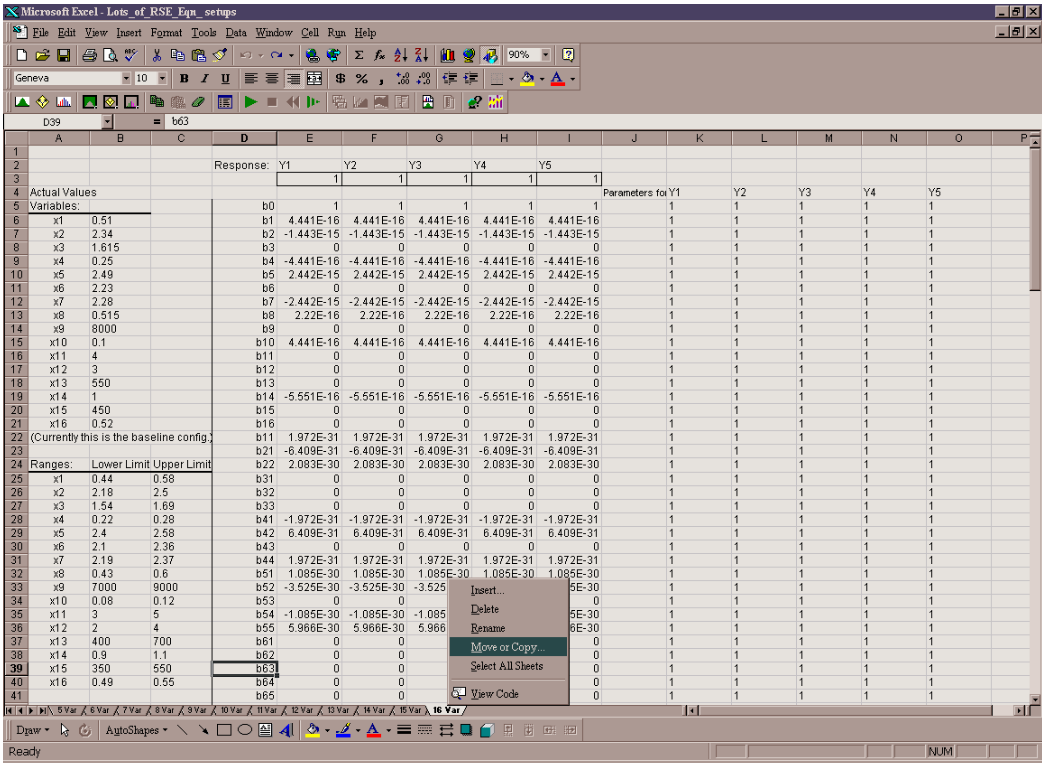
Let's press onwards with investigating the design space. We now want the coefficients for all of the responses. The easiest way to do this is to go back to the **Fit Model** window and select the **Manova** option under "Personality" menu then select **Run Model**.



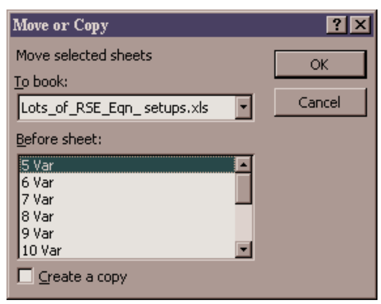
The window below will come up. Select the little cross icon from the menu bar and then click anywhere under the **Parameter Estimates** bar and all of the area will be highlighted. You will have an Excel file called *Lots_of_RSE_Eqn_setups*, which contains spreadsheets to calculate the RSEs for 5 to 29 variables.



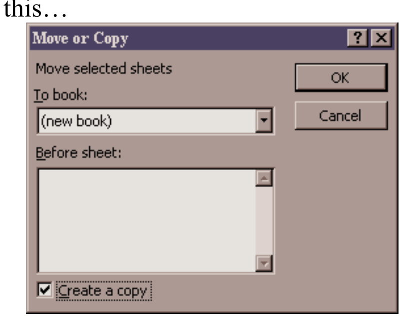
Open Excel and the *Lots_of_RSE_Eqn_setups* file. Go to the sheet that has the appropriate number of variables. Right mouse click on the sheet tab name as shown below and select “Move or Copy…”



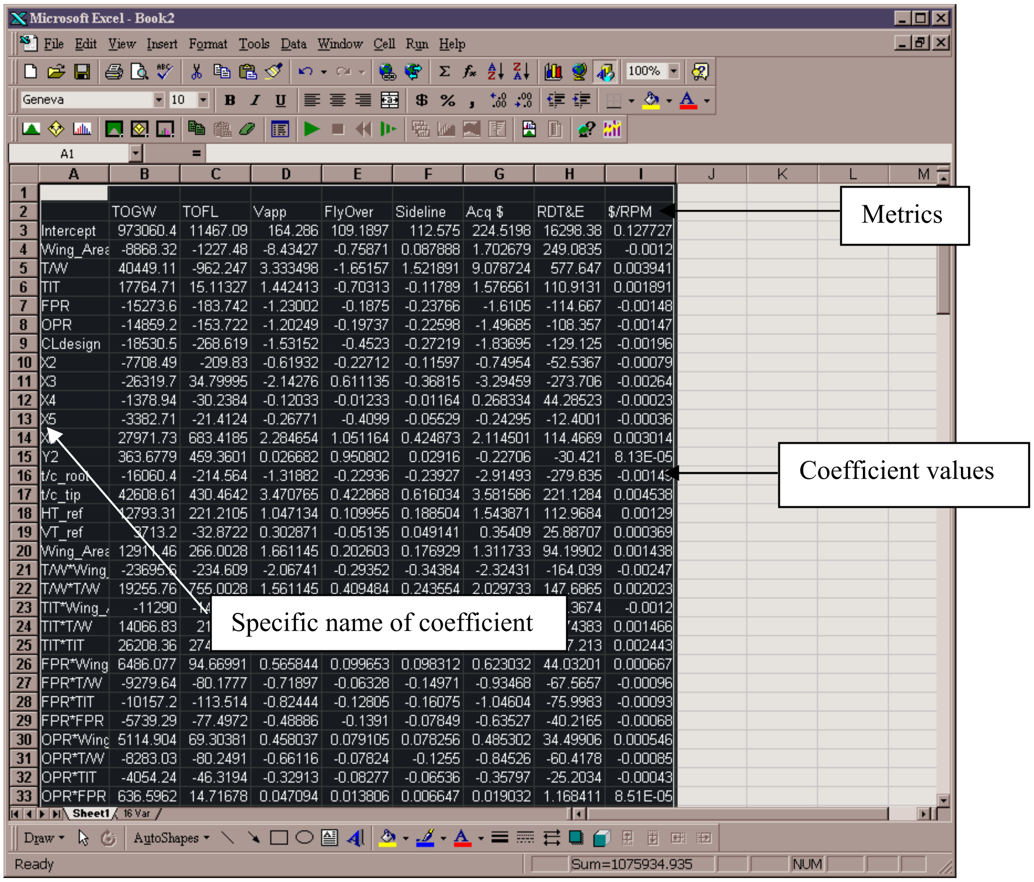
The following window will come up. Under “To Book” select “(new book)” and click the “Create a copy” at the bottom.



Your window should look like this…

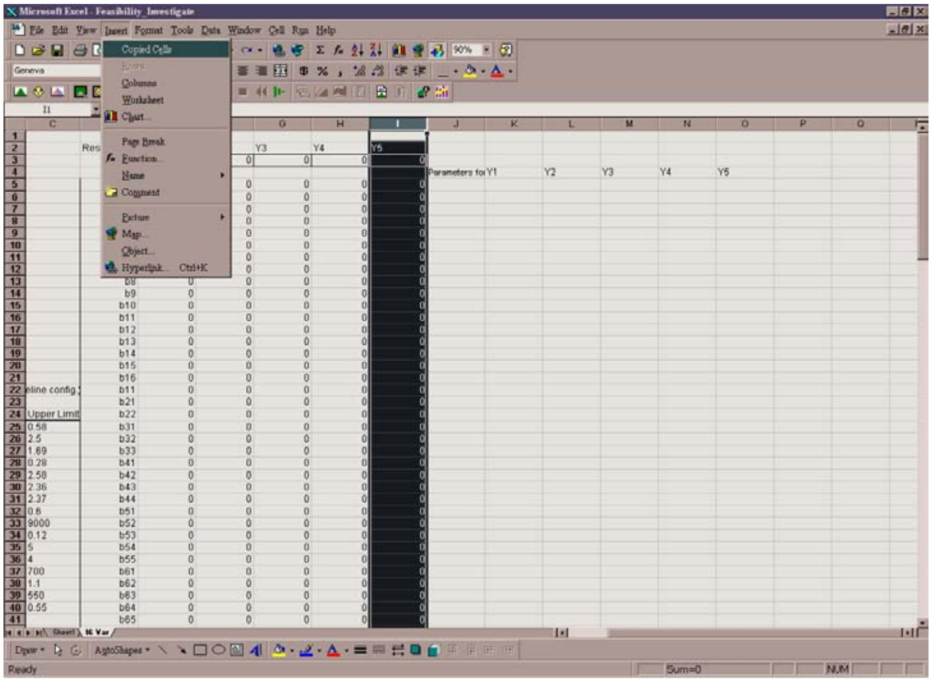


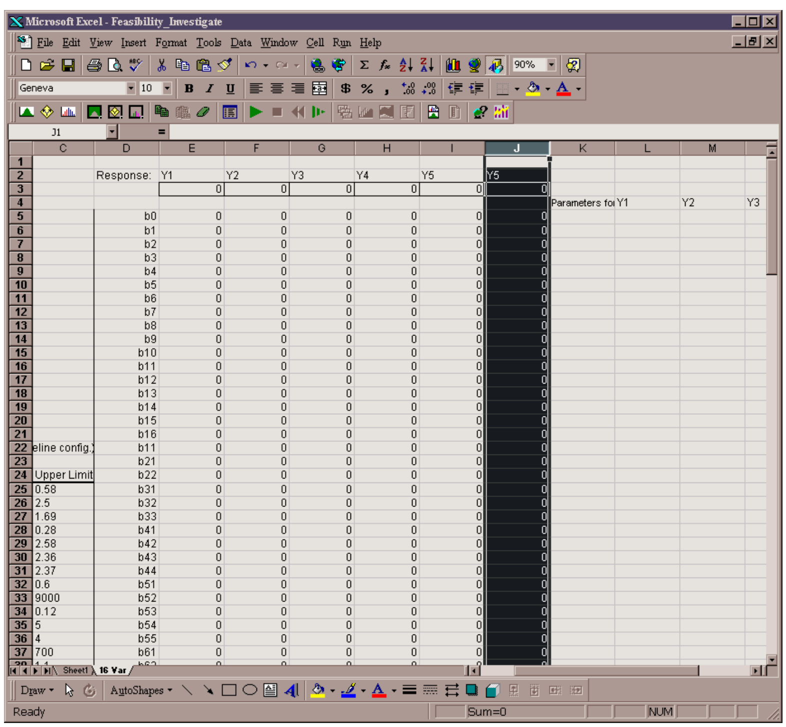
Go back to the *Lots_of_RSE_Eqn_setups* sheet and close it. Save your new file as “Feasibility_Investigate”. Click **Insert** and select “Worksheet”. Go back to JMP and copy the highlighted area by going to **Edit** and select **Copy.** Go back to Excel and go to **Edit** and then **Paste Special**, and then paste as **Unicode Text**. Your RSE coefficients will then be pasted into different cells on the new worksheet.



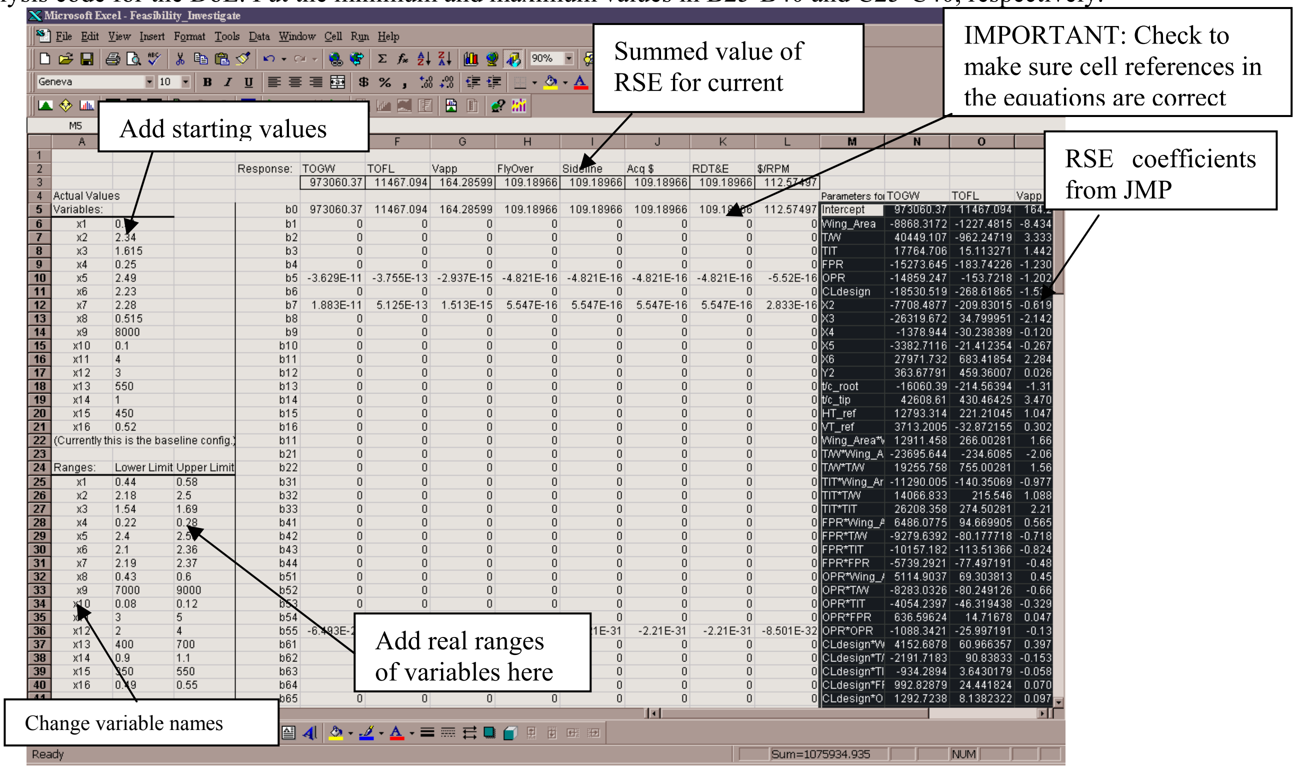
	A	B	C	D	E	F	G	H	I
1									
2		TOGW	TOFL	Vapp	FlyOver	Sideline	Acq $	RDT&E	$/RPM
3	Intercept	973060.4	11467.09	164.286	109.1897	112.575	224.5198	16298.38	0.127727
4	Wing_Area	-8868.32	-1227.48	-8.43427	-0.75871	0.087888	1.702679	249.0835	-0.0012
5	T/W	40449.11	-962.247	3.333498	-1.65157	1.521891	9.078724	577.647	0.003941
6	TIT	17764.71	15.11327	1.442413	-0.70313	-0.11789	1.576561	110.9131	0.001891
7	FPR	-15273.6	-183.742	-1.23002	-0.1875	-0.23766	-1.6105	-114.667	-0.00148
8	OPR	-14859.2	-153.722	-1.20249	-0.19737	-0.22598	-1.49685	-108.357	-0.00147
9	CLdesign	-18530.5	-268.619	-1.53152	-0.4523	-0.27219	-1.83695	-129.125	-0.00196
10	X2	-7708.49	-209.83	-0.61932	-0.22712	-0.11597	-0.74954	-52.5367	-0.00079
11	X3	-26319.7	34.79995	-2.14276	0.611135	-0.36815	-3.29459	-273.706	-0.00264
12	X4	-1378.94	-30.2384	-0.12033	-0.01233	-0.01164	0.268334	44.28523	-0.00023
13	X5	-3382.71	-21.4124	-0.26771	-0.4099	-0.05529	-0.24295	-12.4001	-0.00036
14	X[illegible]	27971.73	683.4185	2.284654	1.051164	0.424873	2.114501	114.4669	0.003014
15	Y2	363.6779	459.3601	0.026682	0.950802	0.02916	-0.22706	-30.421	8.13E-05
16	t/c_root	-16060.4	-214.564	-1.31882	-0.22936	-0.23927	-2.91493	-279.835	-0.0014[illegible]
17	t/c_tip	42608.61	430.4642	3.470765	0.422868	0.616034	3.581586	221.1284	0.004538
18	HT_ref	12793.31	221.2105	1.047134	0.109955	0.188504	1.543871	112.9684	0.00129
19	VT_ref	[illegible]713.2	-32.8722	0.302871	-0.05135	0.049141	0.35409	25.88707	0.000369
20	Wing_Area	1291[illegible].46	266.0028	1.661145	0.202603	0.176929	1.311733	94.19902	0.001438
21	T/W*Wing_	-23695.6	-234.609	-2.06741	-0.29352	-0.34384	-2.32431	-164.039	-0.00247
22	T/W*T/W	19255.76	755.0028	1.561145	0.409484	0.243554	2.029733	147.6865	0.002023
23	TIT*Wing_	-11290	-1[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].3674	-0.0012
24	TIT*T/W	14066.83	21[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]4383	0.001466
25	TIT*TIT	26208.36	274[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]7.213	0.002443
26	FPR*Wing	6486.077	94.66991	0.565844	0.099653	0.098312	0.623032	44.03201	0.000667
27	FPR*T/W	-9279.64	-80.1777	-0.71897	-0.06328	-0.14971	-0.93468	-67.5657	-0.00096
28	FPR*TIT	-10157.2	-113.514	-0.82444	-0.12805	-0.16075	-1.04604	-75.9983	-0.00093
29	FPR*FPR	-5739.29	-77.4972	-0.48886	-0.1391	-0.07849	-0.63527	-40.2165	-0.00068
30	OPR*Wing	5114.904	69.30381	0.458037	0.079105	0.078256	0.485302	34.49906	0.000546
31	OPR*T/W	-8283.03	-80.2491	-0.66116	-0.07824	-0.1255	-0.84526	-60.4178	-0.00085
32	OPR*TIT	-4054.24	-46.3194	-0.32913	-0.08277	-0.06536	-0.35797	-25.2034	-0.00043
33	OPR*FPR	636.5962	14.71678	0.047094	0.013806	0.006647	0.019032	1.168411	8.51E-05

For this example, switch to the "16_var" sheet. Note, this template was set up for only 5 responses (Y1 through Y5). We have 8 responses so we need to add some more columns. To do so, click in column "I" header and go to **Edit** and select **Copy**. Then go to **Insert** and select **Copied Cells**. Excel adds an exact copy as you can see below. You need to copy the last column of responses (in this case Y5) and then insert that column. Make sure you check that the formulas were copied. Change the generic response names from Y1 and so on to your actual response names (i.e., TOGW). You should also put them in the row that contains the cell called "Parameters for:" to the right of all of the zeros.

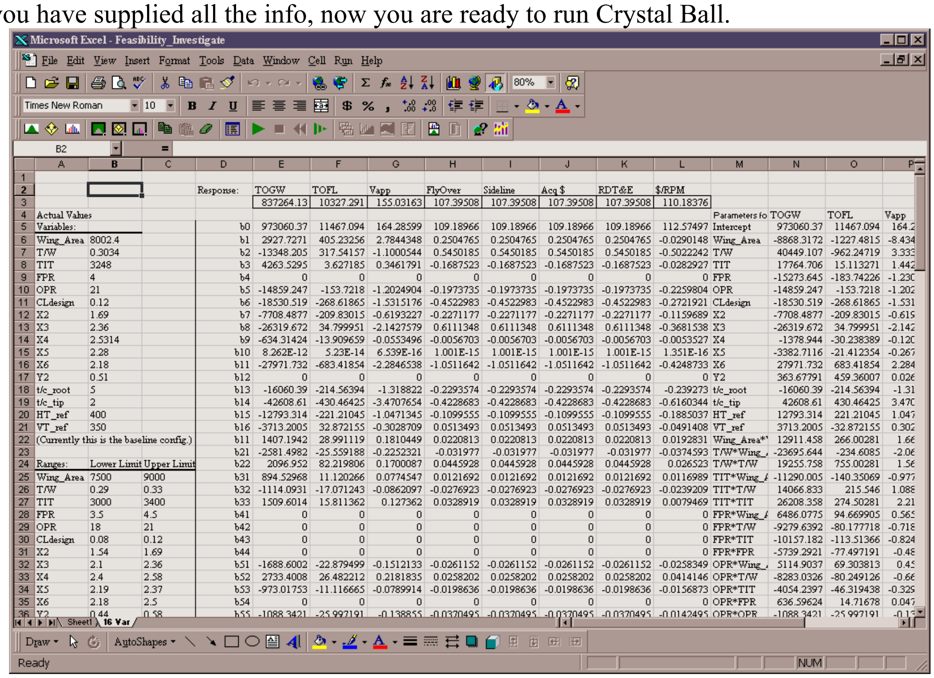




Go back to the sheet where you pasted your coefficients from JMP and highlight cell A3 through the bottom of the coefficients, in this case that would be cell I155. Copy and then switch back to the “16 Var” sheet. Make the active cell the one DIRECTLY under the cell with “Parameters for:” in it. In this case, it would be J5 and then paste your info as shown below. You will see that column E through L fills out with numbers besides “0”. Now, you need to change the input variables (X1 through X16) to your actual variable names. In this case, X1 corresponded to Wing_Area, X2 was T/W, and so on. Do this for cells A6 through A21 and then A25 through A40 and A46-A61. You should put in your baseline values (in dimensional form) in cells B6 through B21. Then add the ranges that you used in your analysis code for the DoE. Put the minimum and maximum values in B25-B40 and C25-C40, respectively.

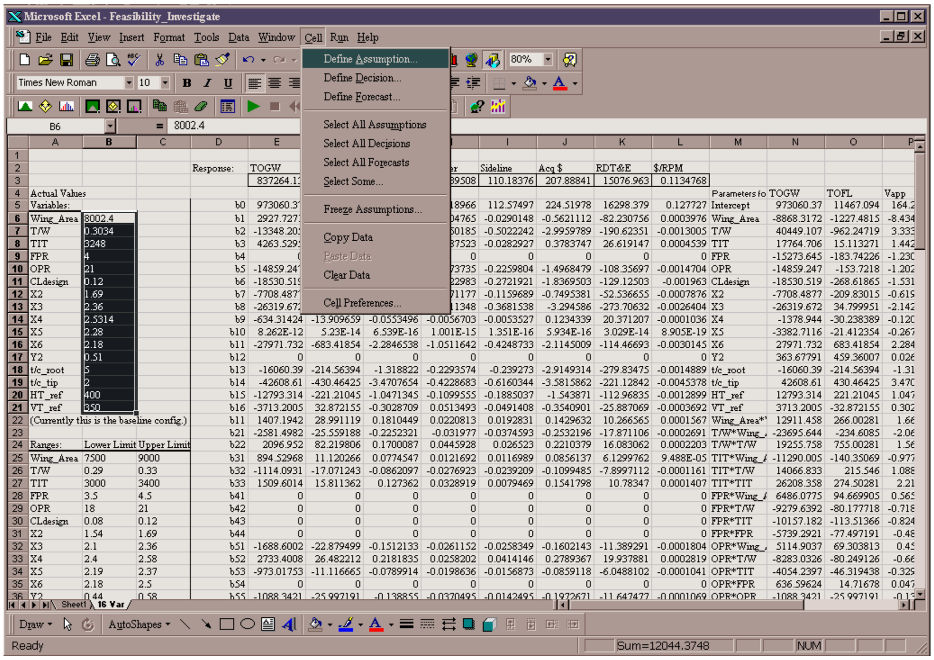


Once you have supplied all the info, now you are ready to run Crystal Ball.

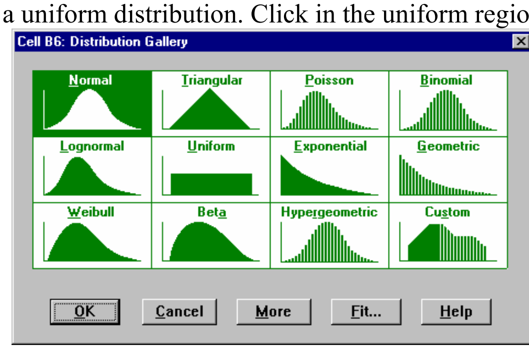


Running Crystal Ball: A Monte Carlo Simulation

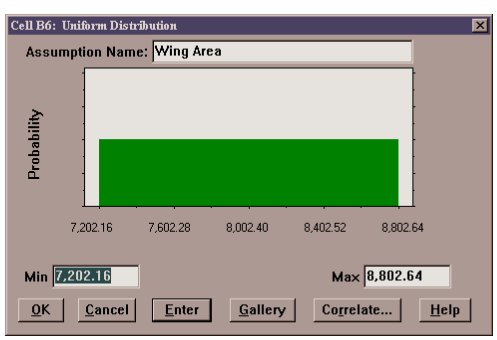
This is probably the easiest and quickest part of the whole method. You should still have your Excel spreadsheet from above open. Crystal Ball is already linked to Excel. If you do not have the drop menus in Excel entitled **Cell** and **Run**, contact Dr. Kirby. Else, let's continue. First you need to tell Crystal Ball which cells you want to vary. In this example, you will be doing your 7 design variables. So, highlight the 7 cells as shown below. Then, go to **Cell** and select **Define Assumption**.



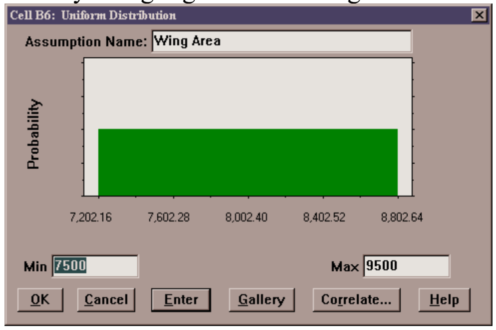
You will get the below window. For the feasibility investigation (i.e., design variable variation), you want all of your variables to be defined by a uniform distribution. Click in the uniform region and then hit **OK**.



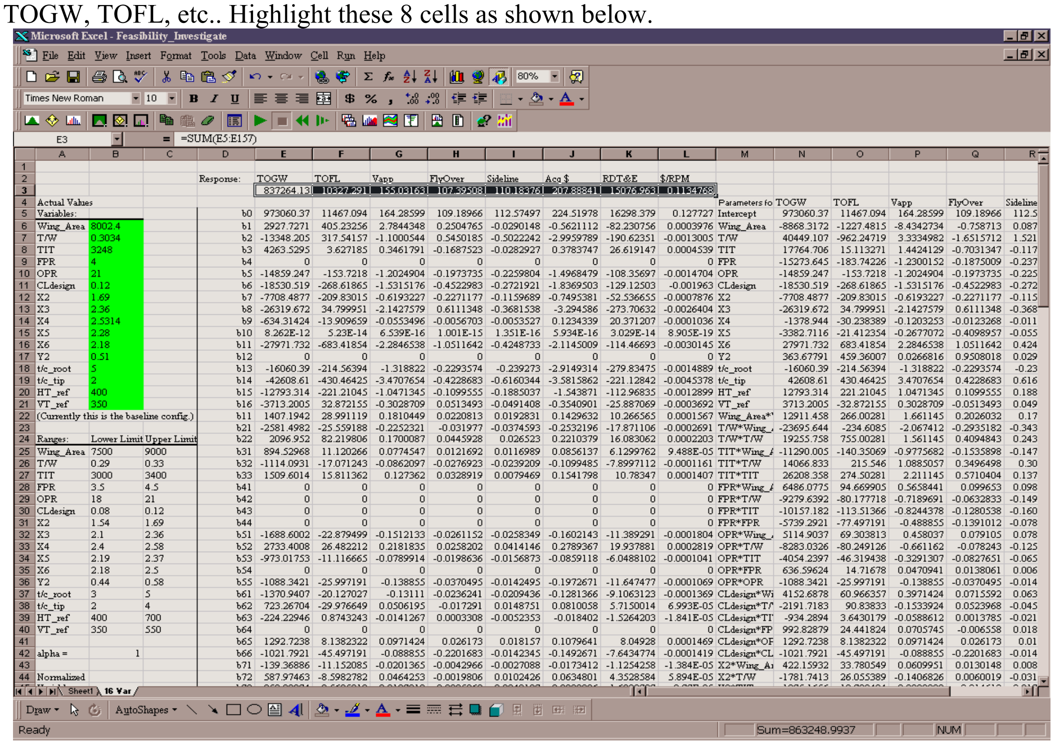
Your first variable will come up as shown in the next window. In this example, it is AR (wing aspect ratio). You need to modify the distribution range by clicking in the **Min** and **Max** cells and changing the values to the ranges you used in your DoE.



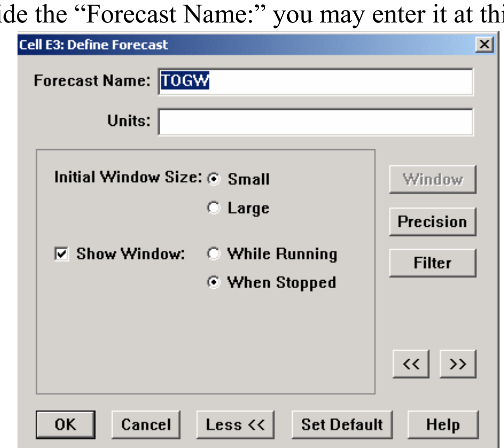
This is shown in the following window. Once you have done that, click **OK**. Repeat this for EVERY design variable. When you are done, the cells that you highlighted will change colors. This means they are ready to go.



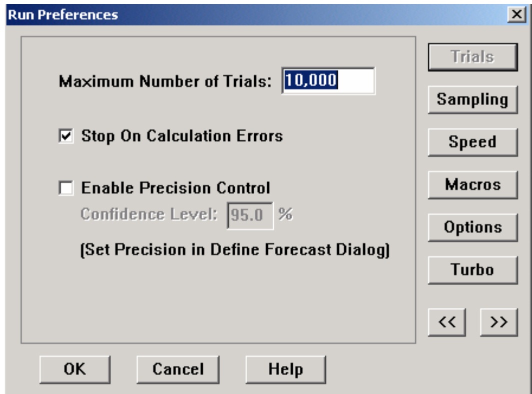
Now you need to define your forecasts (i.e., what you are interested in tracking). In this case, it is the 8 responses TOGW, TOFL, etc.. Highlight these 8 cells as shown below.



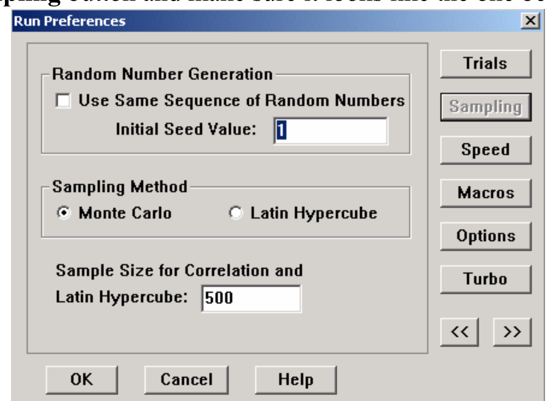
Click the **Cell** menu and select the **Define Forecast** option. You will get the following window. This is telling Crystal Ball that these cells are what you want to keep track of. Make sure that the **Forecast Window Size** is selected as **Small**, and the window is displayed **When Stopped**. Then click **OK**. Another window will pop up for the next metric. Do the same thing for all and when you are done, the forecast cells will change colors. Also, if the correct name of your response is not listed beside the "Forecast Name:" you may enter it at this time.



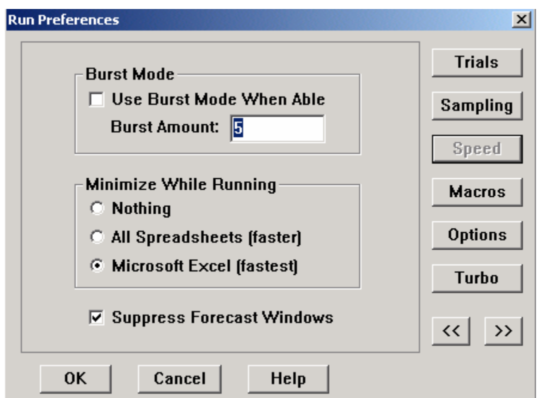
Go to the **Run** menu and select the **Run Preferences** option. Click on the **Trials** button and make sure it looks like the one below.



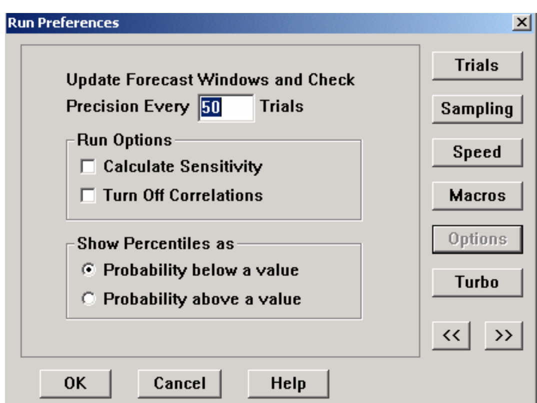
Then click on the **Sampling** button and make sure it looks like the one below.



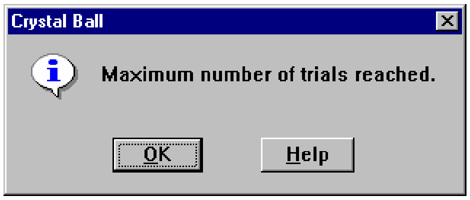
Then click on the **Speed** button and make it look like this one.



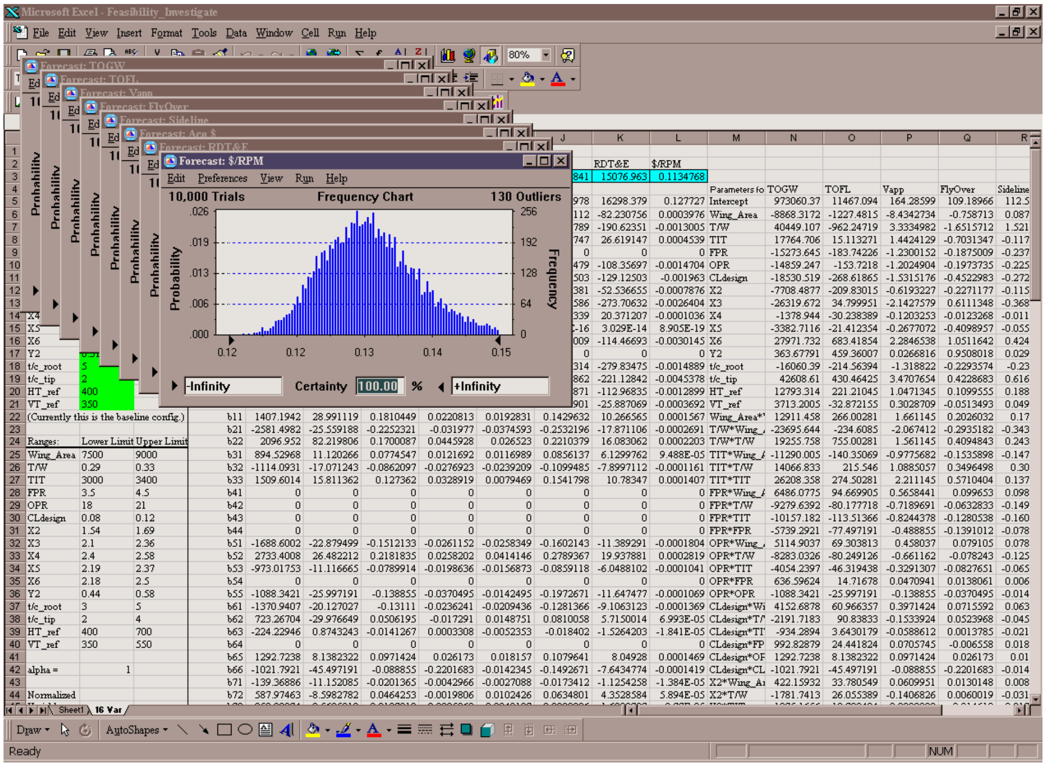
Then click on the **Options** button and make it look like this one.



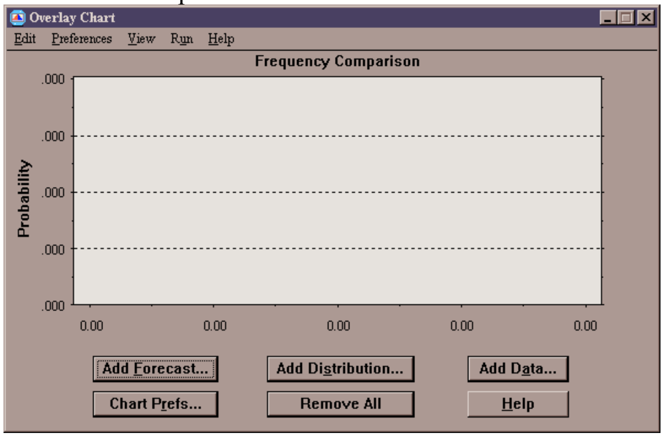
You are now ready to run Crystal Ball!!!!!!. Go to the **Run** menu and select **Run**. Excel will automatically minimize itself to run faster. When Excel/Crystal Ball is done running the 10,000 simulations, it will pop back up with the following. Click **OK**.



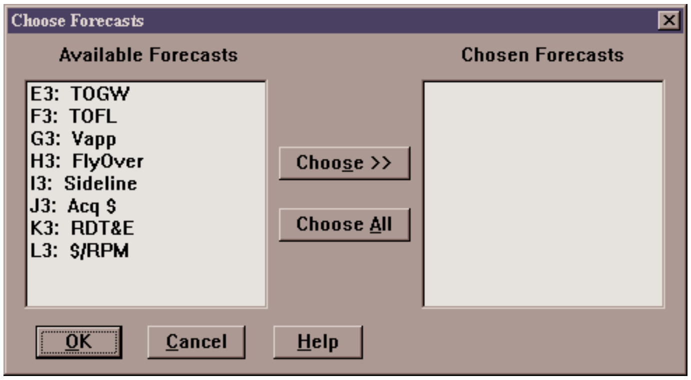
Once you click **OK**, the forecast windows will pop up as shown below. The windows are tiled and are the frequency distributions for your metrics as a function of the 7 design variables you had. You can sit and play with all of these windows. Look at the different options and the preferences. Crystal Ball is very straightforward.



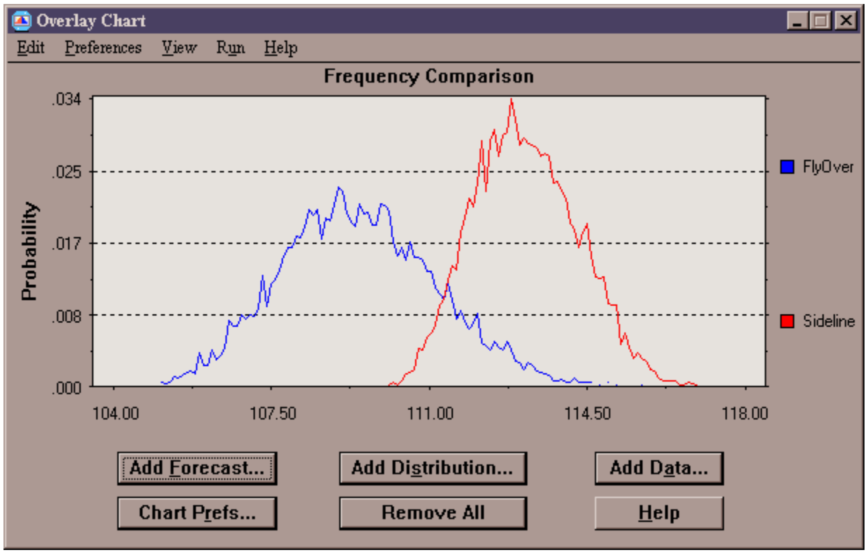
One of the more interesting features of Crystal Ball is the Overlay Option. Go to **Run** and select **Open Overlay Chart** and the window below will open. Click the button **Add Forecast…** .



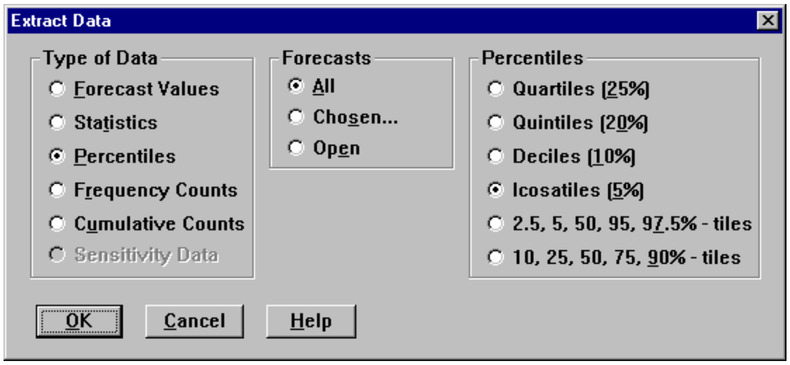
The window below will open. Now you can add different forecasts (responses) and look at them concurrently.



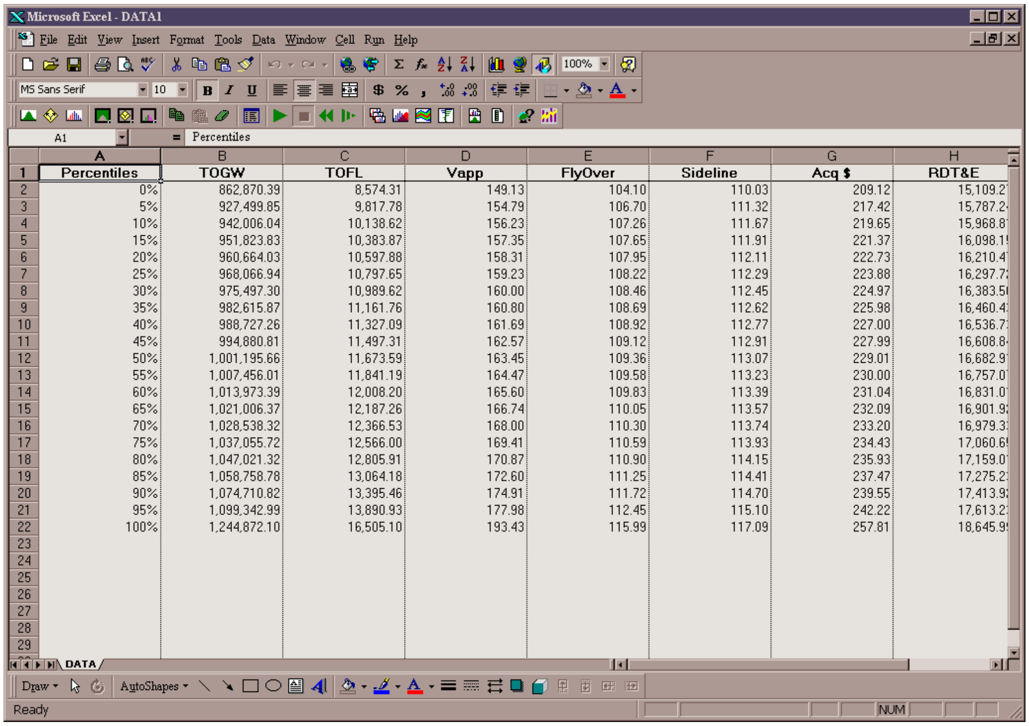
Let's look at the Flyover and the Sideline Noise. Click the Flyover and then click **Choose**, do the same for Sideline and select **OK**. The window below will come up and show you where the design space lies for the Sideline and Flyover noise level. Play with the "Preferences" and "Views" to get exactly the picture you want. You can also copy the Overlay chart by going to **Edit** and then **Copy**.



What you really want from the Monte Carlo Simulation are the values of the metrics for different probability levels. So, go under **Run** and select **Extract Data** and the window below will pop up. Make sure yours looks like the one below. Click **OK**. Or you can extract other info that interests you.



Excel/Crystal Ball will open another worksheet that looks like the one below. These are your response values for different probability percentages. In this form, you can make plots in Excel and overlay any other info you want.

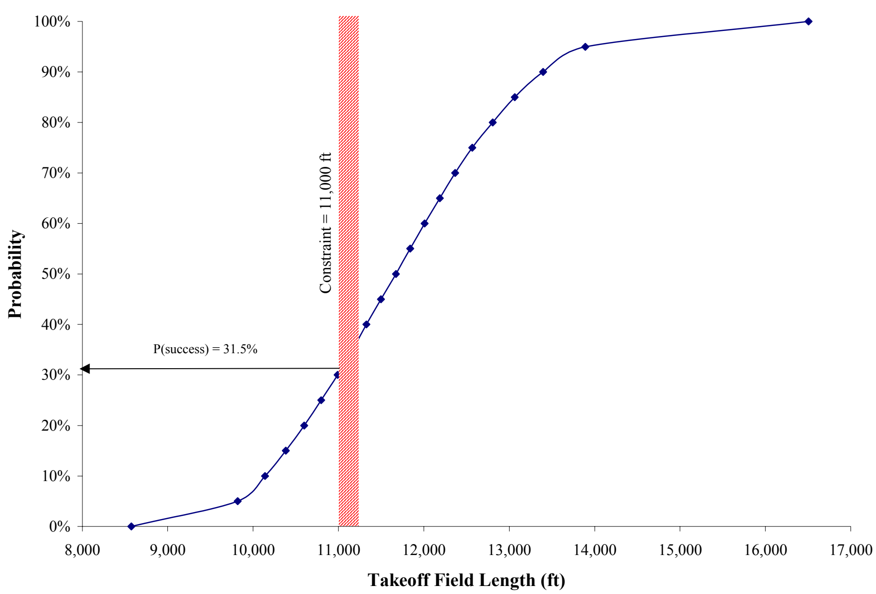


Microsoft Excel - DATA1

Percentiles	TOGW	TOFL	Vapp	FlyOver	Sideline	Acq $	RDT&E
0%	862,870.39	8,574.31	149.13	104.10	110.03	209.12	15,109.2
5%	927,499.85	9,817.78	154.79	106.70	111.32	217.42	15,787.2
10%	942,006.04	10,138.62	156.23	107.26	111.67	219.65	15,968.8
15%	951,823.83	10,383.87	157.35	107.65	111.91	221.37	16,098.1
20%	960,664.03	10,597.88	158.31	107.95	112.11	222.73	16,210.4
25%	968,066.94	10,797.65	159.23	108.22	112.29	223.88	16,297.7
30%	975,497.30	10,989.62	160.00	108.46	112.45	224.97	16,383.5
35%	982,615.87	11,161.76	160.80	108.69	112.62	225.98	16,460.4
40%	988,727.26	11,327.09	161.69	108.92	112.77	227.00	16,536.7
45%	994,880.81	11,497.31	162.57	109.12	112.91	227.99	16,608.8
50%	1,001,195.66	11,673.59	163.45	109.36	113.07	229.01	16,682.9
55%	1,007,456.01	11,841.19	164.47	109.58	113.23	230.00	16,757.0
60%	1,013,973.39	12,008.20	165.60	109.83	113.39	231.04	16,831.0
65%	1,021,006.37	12,187.26	166.74	110.05	113.57	232.09	16,901.9
70%	1,028,538.32	12,366.53	168.00	110.30	113.74	233.20	16,979.3
75%	1,037,055.72	12,566.00	169.41	110.59	113.93	234.43	17,060.6
80%	1,047,021.32	12,805.91	170.87	110.90	114.15	235.93	17,159.0
85%	1,058,758.78	13,064.18	172.60	111.25	114.41	237.47	17,275.2
90%	1,074,710.82	13,395.46	174.91	111.72	114.70	239.55	17,413.9
95%	1,099,342.99	13,890.93	177.98	112.45	115.10	242.22	17,613.2
100%	1,244,872.10	16,505.10	193.43	115.99	117.09	257.81	18,645.9

Step 5: Determine System Feasibility and Viability

Once you have the results of the Monte Carlo Simulation, you want to compare your results to your targets. An example plot is shown below. The TOFL is the metric. The constraint is 11,000 ft as shown. The probability, or amount of the design space investigated, that will satisfy the constraint value is 31.5%. You need to make a plot like this for *every* metric that you are considering. Recall the CDF that you have represents all the possible geometric combinations as bound by the design variable ranges that you defined. Finally, tabulate your results and find out which constraint is hurting your feasibility and viability.



Step 6: Specify Technology Alternatives

The objective of this step is three fold. One, identify potential technologies that may improve technical feasibility and economic viability of your vehicle. Second, establish physical compatibility rules for the different technologies identified. Third, determine the expected impact, both improvements and degradations, to the system of interest. The impact of a technology can be qualitatively assessed with technology metric "k" factors. These "k" factors modify disciplinary technical metrics, such as specific fuel consumption, cruise drag, and/or component weights that result from some analysis or sizing tool. The modification is essentially a change in the technical metric, either enhancement or degradation. In effect, the "k" factors simulate the discontinuity in benefits and/or penalties associated with the addition of a new technology. Once you have identified the impacts, you need to match the "k" factors to the appropriate FLOPS/ALCCA variables and namelists.

For step 6, the potential technologies are identified from the Morphological Matrix you created in Step 2. For the HSCT, eleven technologies and technology programs are considered. The technologies along with the primary purposes were identified through a literature search of potential sub-component. It is important to identify technology that will assist "show-stoppers". In the HSCT example, the "show-stoppers" are noise and economic factors. Two technologies that assisted the sound metrics are being considered. The other technologies selected are an attempt to improve the economic metrics through secondary effects. The "Show-stoppers" have a large influence on what technologies you select to consider adding to your design.

Technology Readiness Level

Many of the identified technologies are in the development stage. It is important to identify how advanced they are and one way to do this is to use the technology readiness level. The technology readiness level (TRL) represents the amount of progress that has been made on a technology. On a scale of one to nine, the higher TRL a technology has the more tests and integration it has gone through. A higher TRL is also associated with less uncertainty concerning the final impact, so when evaluating the impact of the technologies on the vehicle, less uncertainty will need to be incorporated. The TRL of a technology affects the certainty of the outcome, and when evaluating technologies with lower TRLs on the vehicle there is a lower probability of having a feasible and viable design.

Table 6: Technology Readiness Levels

Description	Level	Qualifier or Development Hurdle
Basic Research	1	Basic scientific/engineering principles observed and reported
Feasibility Research	2	Technology concept, application, and potential benefits formulated (candidate system selected)
Feasibility Research	3	Analytic and/or experimental proof-of-concept completed (proof of critical function or characteristic)
Technology Development	4	System concept observed in laboratory environment (breadboard test)
Technology Development	5	System concept tested and potential benefits substantiated in a controlled relevant environment
System Development	6	Prototype of system concept is demonstrated in a relevant environment
System Development	7	System prototype is tested and potential benefits substantiated more broadly in a relevant environment
Operational Verification	8	Actual system constructed and demonstrated, and benefits substantiated in a relevant environment
Operational Verification	9	Operational use of actual system tested, and benefits proven

Table 7: HSCT Technologies

(Identifier) Technology	TRL	Primary Purpose
(T1) Composite Wing	3	Wing weight reduction
(T2) Composite Fuselage	3	Fuselage weight reduction
(T3) Circulation Control	4	Increased low speed performance
(T4) Hybrid Laminar Flow Control	3	Cruise drag reduction
(T5) Environmental Engines	3	Reduce noise, fuel burn, and emissions
(T6) Advanced Flight Deck Systems	4	Synthetic vision removes fuselage nose droop weight penalty
(T7) Advanced Propulsion Materials	3	High temp. materials, reduced engine weight, lower fuel burn
(T8) Integrally Stiffened Aluminum Wing Structure	4	Wing weight and part complexity reduction
(T9) Smart Wing Structures	3	Reduced flutter and wing weight
(T10) Active Flow Control	3	Cruise drag reduction
(T11) Active Acoustic Control	3	Noise suppression

Compatibility Matrix

It is not possible, however, to add all of these technologies onto a single design because some are incompatible. Technologies are incompatible when they compete for the same space on the aircraft or when one technology causes extreme degradation in the function or integrity of another. For example, technologies 1 and 8, the composite wing and the integrally stiffened aluminum wing structure, are incompatible because they are competing wing material technologies. All of the incompatibilities in the technology compatibility matrix (TCM) below result from this competition for the same design space or from extreme degradation effects.

Now you need to provide a compatibility matrix for your technologies. This matrix formalizes which technologies are physically compatible and as a by-product, reduces the number of alternatives to evaluate. This is important if the number of technologies considered for application is large and the combinatorial problem is out of hand. A sample compatibility matrix is shown below for 11 technologies. A "1" represent compatible technologies while a "0" implies an incompatible combination. The TCM is a symmetric matrix so only half of it is filled in. A TCM is easily created by researching the possible technologies and seeing which ones compete for design space or severely degrade the intended function or integrity of the technologies.

										Aircraft Morphing		
	Compatibility Matrix (1: compatible, 0: incompatible)	Composite Wing	Composite Fuselage	Circulation Control	HLFC	Environmental Engines	Flight Deck Systems	Propulsion Materials	Integrally, Stiffened Aluminum Airframe Structures (wing)	Smart Wing Structures (Active Aeroelastic Control)	Active Flow Control	Acoustic Control
		T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
	Composite Wing	1	1	1	0	1	1	1	0	0	0	0
	Composite Fuselage		1	1	1	1	1	1	1	1	1	1
	Circulation Control			1	1	1	1	1	1	1	1	1
	HLFC				1	1	1	1	0	0	0	1
	Environmental Engines					1	1	1	1	1	1	0
	Flight Deck Systems						1	1	1	0	1	1
	Propulsion Materials			Symmetric Matrix				1	0	1	1	1
	Integrally, Stiffened Aluminum Airframe Structures (wing)								1	0	1	1
Aircraft Morphing	Smart Wing Structures (Active Aeroelastic Control)									1	1	1
Aircraft Morphing	Active Flow Control										1	1
Aircraft Morphing	Acoustic Control											1

Technology Impact Matrix

Once the compatibility matrix is determined, the influence of infusing these technologies must be determined. This is difficult to evaluate directly, but it can be quantitatively evaluated through "k" factors. These "k" factors describe the potential system and sub-system level impacts of each technology. The impact must include benefits and degradations to the entire system. These "k" factors allow for the impact of the technologies to be evaluated using an M&S environment.

The impact of each technology is determined through physics based modeling, literary research and questioning experts. This impact is based on the upper limit of the technology at full maturity and widespread application. The impact for each "k" factor defines a "k" vector for the technology. A technology may not have an influence in all of the "k" factors. The "k" vectors for each technology are combined into the Technology Impact Matrix (TIM).

An example TIM is shown below for the HSCT example. Also note to the right is the max and min values that a given "k" factor could ever achieve if all technologies were "on". The minimum and maximum values define the ranges you will use for the generation of your metric RSEs as a function of "k" factors, in lieu of design variables.

Technology Impact Matrix (TIM)

Technical K_Factor Elements									Aircraft Morphing				
	Composite Wing	Composite Fuselage	Circulation Control	HLFC	Environmental Engines	Flight Deck Systems	Propulsion Materials	Integrally, Stiffened Aluminum Airframe Structures (wing)	Smart Wing Structures (Active Aeroelastic Control)	Active Flow Control	Acoustic Control		
Technical K_Factor Vector	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	Min	Max
Wing Weight	-20%			+5%				-10%	-5%	+2%		-35%	+7%
Fuselage Weight		-25%				-15%						-40%	0%
Engine Weight				+1%	+40%		-10%				+5%	-10%	+46%
Electrical Weight			+5%	+1%		+2%	+5%		+5%	+2%	+2%	0%	+22%
Avionics Weight				+5%		+2%	+5%		+2%	+5%	+2%	0%	+21%
Surface Controls Weight			-5%						+5%	+5%		-5%	+10%
Hydraulics Weight			-5%						+5%			-5%	+5%
Noise Suppression					-10%		-1%				-10%	-21%	0%
Subsonic Drag	-2%	-2%		-10%						-5%		-19%	0%
Supersonic Drag	-2%	-2%		-15%						-5%		-24%	0%
Subsonic Fuel Flow			+1%	+1%	-2%		-4%				+1%	-6%	+3%
Supersonic Fuel Flow				+1%	-2%		-4%					-6%	+1%
Maximum Lift Coefficient			+15%									0%	+15%
O&S	+2%	+2%	+2%	+2%	+2%		+2%	-2%	+2%	+2%	+1%	-2%	+17%
RDT&E	+4%	+4%	+2%	+2%	+4%	+2%	+4%		+5%	+5%	+5%	0%	+39%
Production costs	+8%	+8%	+3%	+5%	+2%	+1%	+3%	-3%	-3%	-3%	-3%	-12%	+30%

Now you need to map these "k" factors to *actual* inputs to FLOPS/ALCCA (or your analysis code) and useable values. An example is shown below for the TIM provided above. Each of the "k" factors is mapped to a FLOPS/ALCCA input and namelist. The baseline values are established so as to determine how to deviate the input variable in accordance with a DoE. For example, the baseline engine weight is 9,238 lb. The minimum value is determined by the following: 9,238+9,238*(-0.1)=8314.2. The maximum is then 9,238+9,238*(0.46)=13487.48. Hence, the non-dimensional baseline value is –0.6428. You need to understand the dimensional minimum and maximum of your "k" factors if the non-dimensional impact is NOT symmetric about your baseline dimensional values. This is important for when you map the technologies to your RSEs.

						Dimensional impact		Non-dimensional impact	
		Variable	Namelist	Baseline value	Non-Dimensional Baseline Value	Min	Max	Min (%)	Max (%)
Technical Metric K_Factors	Wing Weight	FRWI	WTIN	1	0.666666667	0.65	1.07	-35	7
	Fuselage Weight	FRFU	WTIN	1	1	0.60	1.00	-40	0
	Engine Weight	WENG	WTIN	9238	-0.642857143	8314.20	13487.48	-10	46
	Electrical Weight	WELEC	WTIN	1	-1	1.00	1.22	0	22
	Avionics Weight	WAVONC	WTIN	1	-1	1.00	1.21	0	21
	Surface Controls Weight	FRSC	WTIN	1	-0.333333333	0.95	1.10	-5	10
	Hydraulics Weight	WHYD	WTIN	1	0	0.95	1.05	-5	5
	Noise Suppression	FSUPP	n/a	1	1	0.79	1.00	-21	0
	Subsonic Drag	FCDSUB	MISSIN	1	1	0.81	1.00	-19	0
	Supersonic Drag	FCDSUP	MISSIN	1	1	0.76	1.00	-24	0
	Subsonic Fuel Flow	FFFSUB	ENGDIN	1	0.333333333	0.94	1.03	-6	3
	Supersonic Fuel Flow	FFFSUP	ENGDIN	1	0.714285714	0.94	1.01	-6	1
	Maximum Lift Coefficient	CLMAX	AERIN	1	-1	1.00	1.15	0	15
	O&S	AKOANDS	IWGT	0	-0.789473684	-0.02	0.17	-2	17
	RDT&E	AKRDTE	IWGT	0	-1	0.00	0.39	0	39
	Production costs	AKPRICE	IWGT	0	-0.428571429	-0.12	0.30	-12	30

Step 7: Assess Technology Alternatives

The technologies identified in Step 6 are now applied to the vehicle concept and evaluated. The evaluation provides data and information to the decision-maker whereby selection of the proper mix of technologies is performed. Yet, the search for the mix that will satisfy the customer requirements is dominated by the "curse of dimensionality". Depending on the number of technologies (n) considered, the combinatorial problem can be enormous. If all combinations are physically compatible and assuming only an "on" or "off" condition, then 2^n combinations would exist. In addition, the technology "k" factor vector that influences a vehicle is probabilistic and a cumulative distribution function (CDF) must be generated for each combination, further complicating the evaluation. If the computational expense of the analysis is acceptable, a full-factorial investigation could ensue. For the purpose of this tutorial, the evaluation will be completed deterministically, then probabilistically.

For this tutorial, the computational expense is manageable due to the means by which the technology "k" vectors are modeled. Consider the TIM given before and a metamodel representation of a system response. If one were to bind each "k" factor element of the technical vector, a metamodel in the form of a second-order Response Surface Equation (RSE) could be generated for each of the system level response. Hence, the system response could be defined as a function of the "k" factors for a fixed geometry using the equation below, through a Design of Experiments.

$$R = b_o + \sum_{i=1}^{k} b_i k_i + \sum_{i=1}^{k} b_{ii} k_i^2 + \sum_{i=1}^{k-1} \sum_{j=i+1}^{k} b_{ij} k_i k_j \tag{1}$$

To understand the use of the RSE, consider a single technology (T1). If an RSE was generated for three "k" factors: k_1, k_2, and k_3, it would take on the form:

$$R_{|T1} = b_o + (\sum_{i=1}^{3} b_i k_i + \sum_{i=1}^{3} b_{ii} k_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} b_{ij} k_i k_j)_{T1}$$

$$R_{|T1} = b_o + (b_1k_1 + b_2k_2 + b_3k_3 + b_{11}k_1^2 + b_{22}k_2^2 + b_{33}k_3^2 + b_{12}k_1k_2 + b_{13}k_1k_3 + b_{23}k_2k_3)_{|T1}$$

The impact of T1 is to reduce k_1 by 10%, increase k_2 3%, and to have no impact on k_3. Using these values in the RSE yields:

$$R_{|T1} = b_o + b_1(-10\%) + b_3(3\%) + b_{11}(-10\%)^2 + b_{33}(3\%)^2 + b_{13}(-10\%)(3\%)$$

This procedure is repeated for all of the technologies and metrics that are considered. The coefficients (b_0, b_1, b_{11}, etc...) are determined by the least squares analysis of the DoE

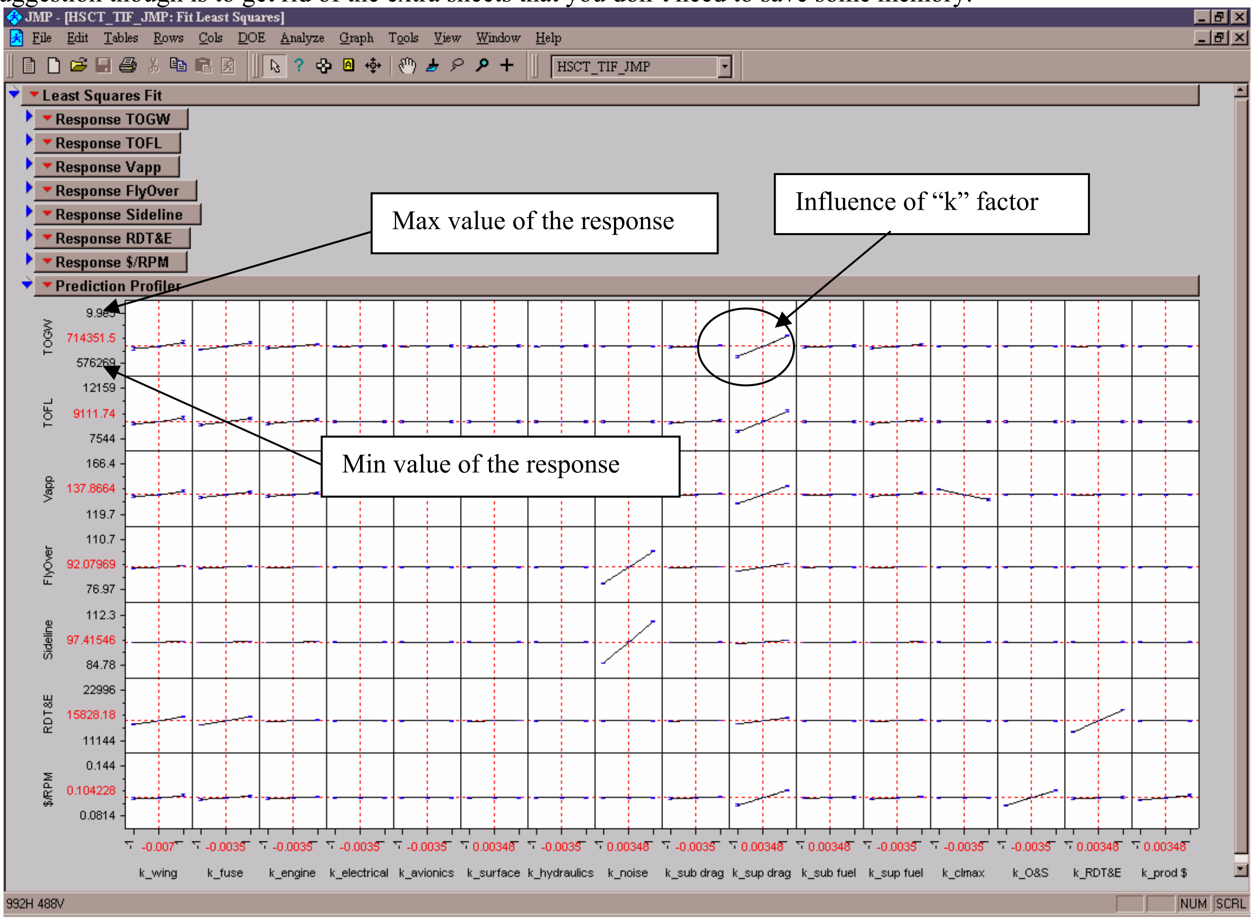
To find the RSE, go through the same process that you did in the design space exploration.

- generate a DoE or use one that was created if you have more than 8 variables,
- copy the table to Excel,
- save as "doe.table",
- take the "doe.table" to UNIX and run the appropriate shell scripts,
- extract data, and
- bring data back to JMP and create your RSEs just as you did with the design space

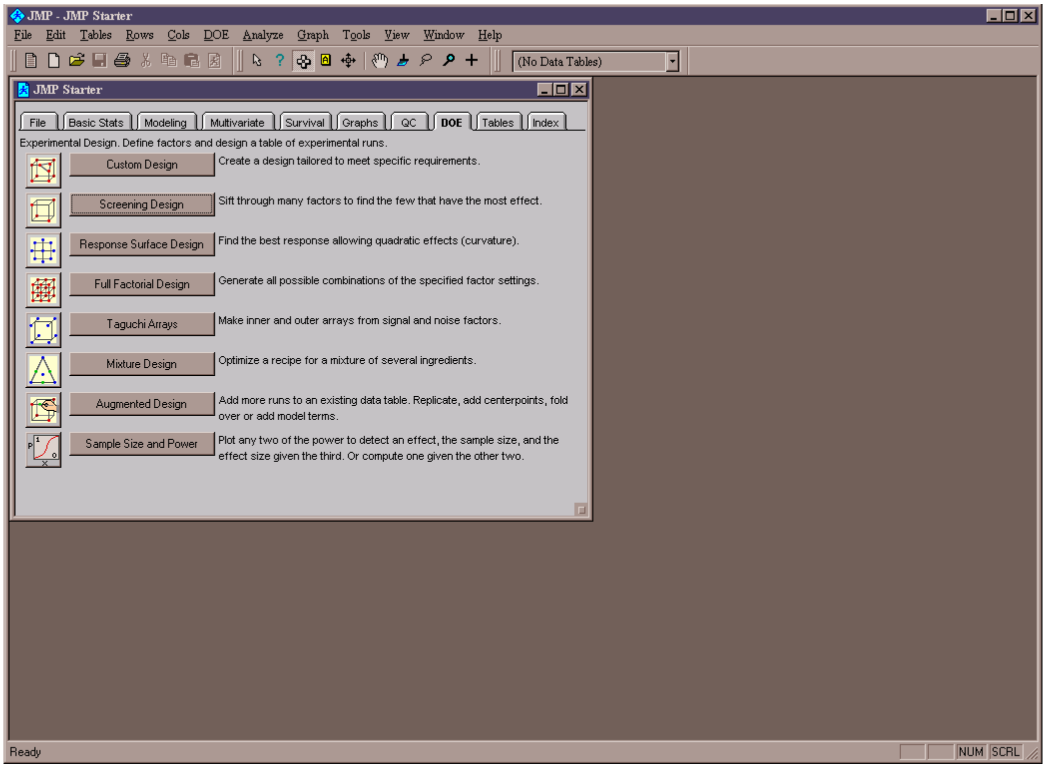
When you go to the model fit of your RSEs, you will get the Technology Impact Forecasting (TIF) environment, as shown below. This environment allows you to see which discipline will help you most with respect to improving certain metrics. For example, you can see that "k_noise" significantly reduces the SLN (sideline noise) and FON (flyover noise). In addition, "k_supersonic_drag" significantly reduces almost every metric. This is a good environment to see *if* you can even get anywhere near your response targets. For example, look at the minimum and maximum values of the response (on the left). These values represent some arbitrary combination of "k" factor settings. If the minimum or maximum *does not contain* the desired metric constraint value, then the technologies that you are considering will not help you. NO MATTER WHAT COMBINATION. You should identify technologies that are more aggressive.

Another aspect of this Profiler is that you could reverse engineer the problem and determine what values of the "k" factors create a feasible configuration. This is the heart of the TIF method. Thus, once the "k" factor values are established, the decision-maker must identify specific technologies providing the predicted values. The reverse approach was taken herein, such that specific technologies were identified for infusion, and the TIF environment was a fallout of this approach.

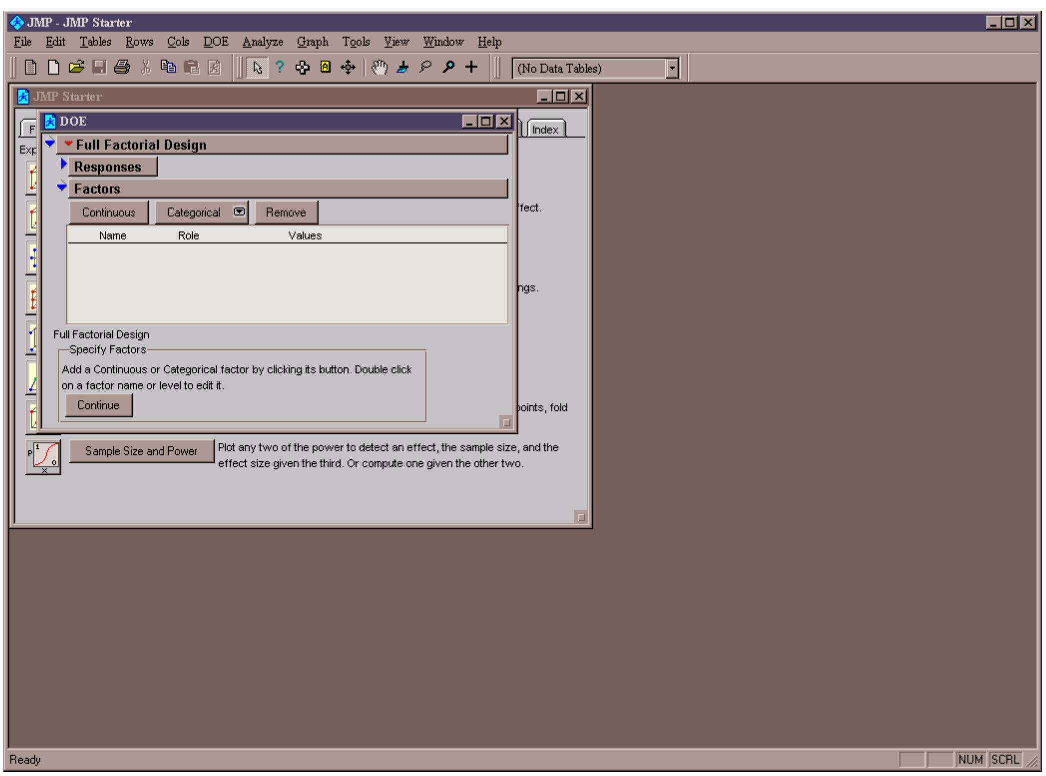
Go through the same process of getting your RSE coefficients by analyzing with a **Manova** as you did previously. Again, take the RSE's to the *Lots_of_RSE_Eqn_setups* Excel file. Save the file as what ever you like. One suggestion though is to get rid of the extra sheets that you don't need to save some memory.



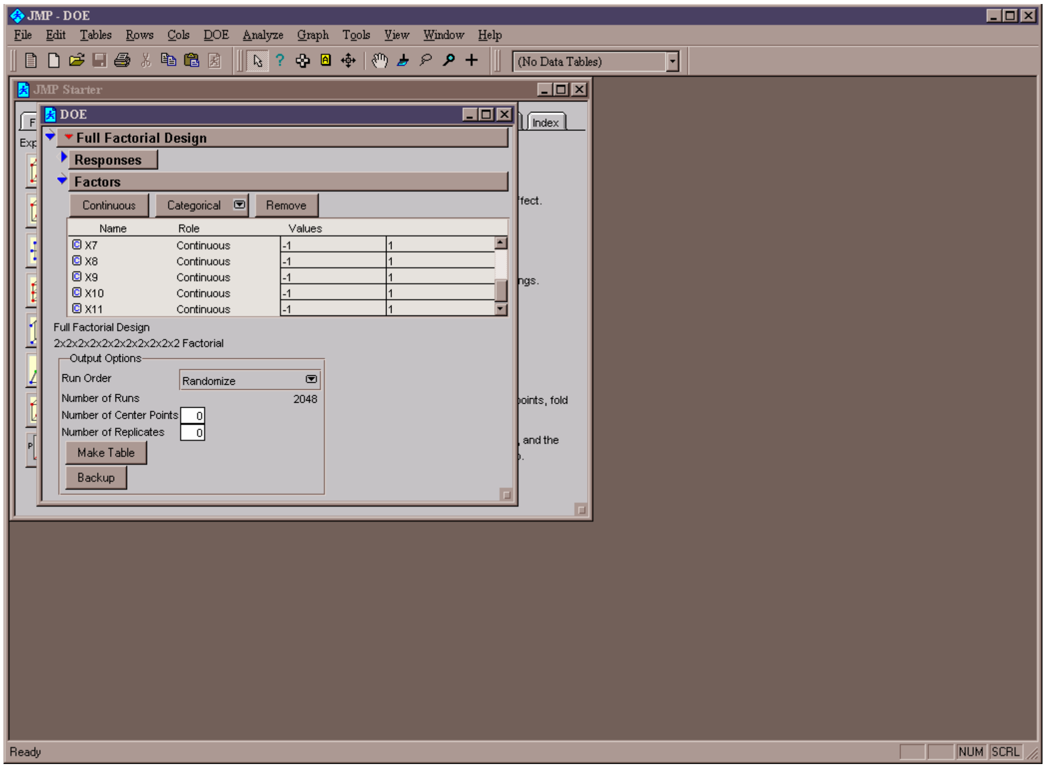
Now, you also need to create another JMP file that has a full-factorial DoE for your technologies. To do this, go back to the **JMP Starter** menu and select the **Full Factorial Design** button.



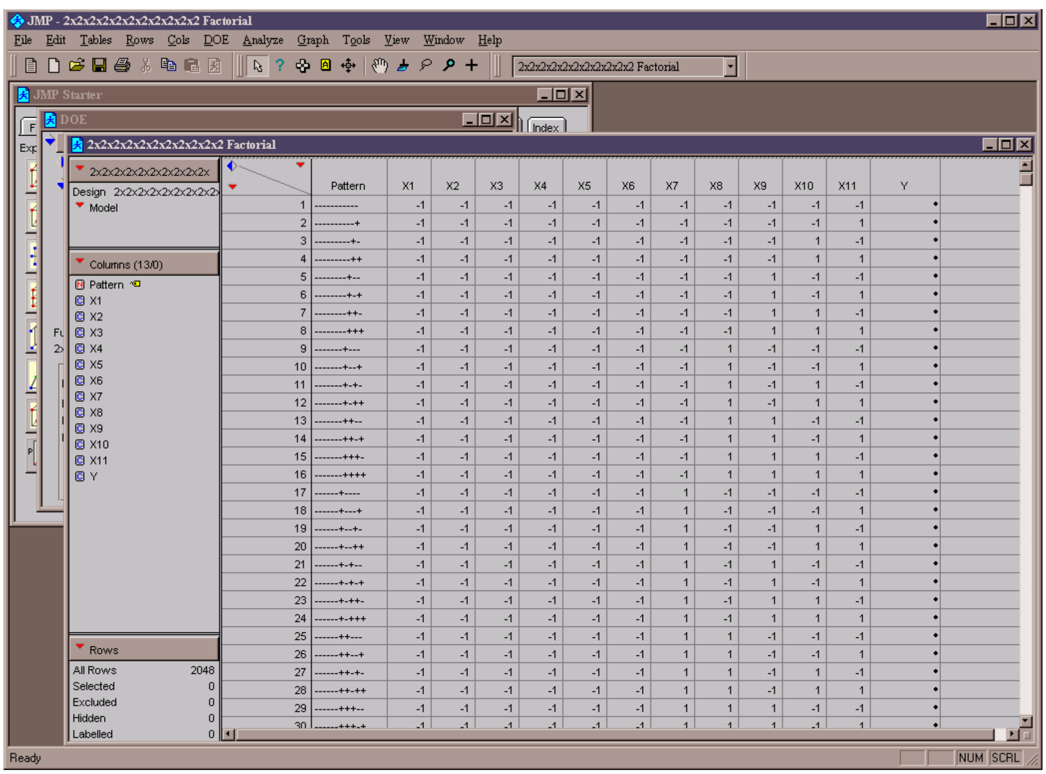
And the following screen will pop up. To add the number of technologies that you have, just hit the **Continuous** button for as many technologies as you have. In our case, we have 11. So we hit the **Continuous** button 11 times and then select **Continue**.



When you hit **Continue** the window will expand and look like the window below. Again change the "Run Order" to "Keep the Same", but DO NOT add a center point and then hit **Make Table**.



When you are done you will get the DoE below. As you can see, there are 2,048 rows which corresponds to 2^n, where n=11 (the number of technologies). The factor is 2 since you are only going to consider an "off" or "on" condition, i.e., "-1" or "+1". Now you can change the variables from X1 to T1 and X2 to T2 and so on. Add the appropriate number of response columns and save the file.



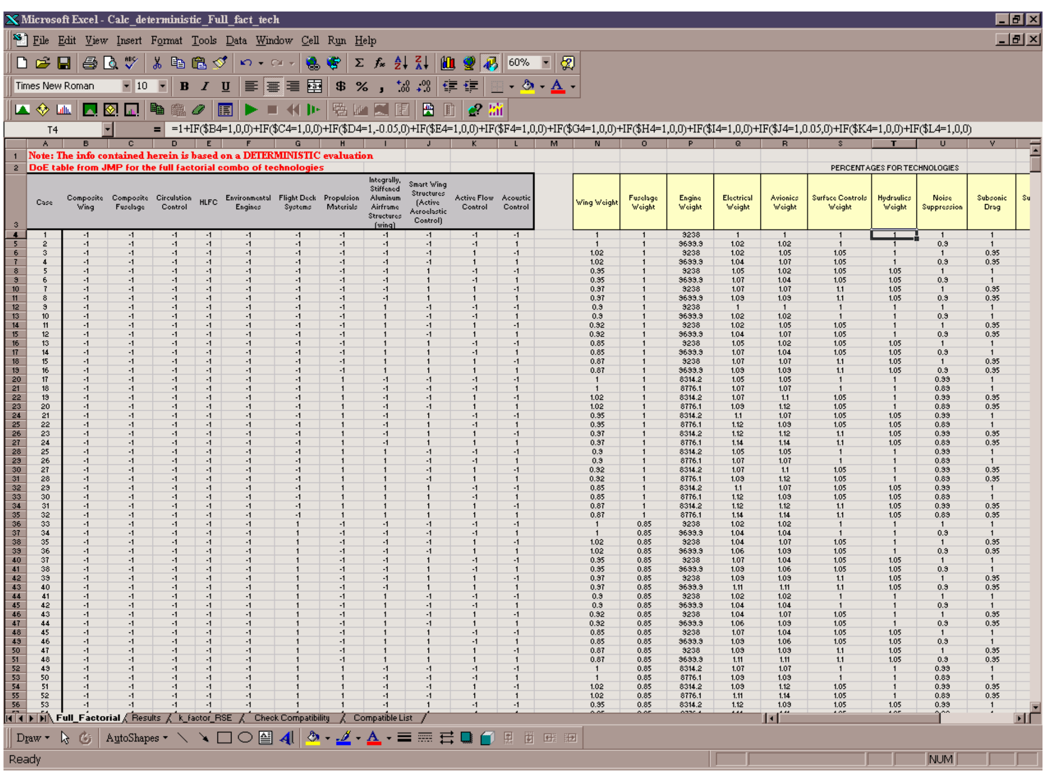
Deterministic Evaluation

You will be given a spreadsheet entitled "Calc_deterministic_Full_fact_tech". This spreadsheet will take the above full factorial design and map the technology "k" factors to the metric RSEs generating deterministic results. The spreadsheet contains 5 sheets: "Full_Factorial", "Results", "k_factor_RSE", "Check Compatibility", and "Compatible List" (this one is needed for TOPSIS in step 8) as shown below. The "Full_Factorial" sheet is where you copy your full factorial design created in JMP. As you can see, the technologies are listed on the left and on the right are the "k" factors. The purpose of this spreadsheet is to map a specific technology to the "k" factor values, then convert the dimensional values to the non-dimensional form, feed those numbers into the "k_factor_RSE" and calculate the RSEs and copy the results back to the results sheet. As you see below, this sheet maps the technology to the individual "k" factors. For example, some of the equations contained in the cells under the "k" factors are provided below, including the wing weight, engine weight, and hydraulics weight. The conventional value for these "k" factors, i.e. no technology added, is "1" and 9238 for the engine weight. Hence, if the composite wing is "on", e.g., $B4=1, then add –0.2 to the wing weight value of 1, else, don't add anything, "0". And if the composite fuselage is "on", e.g., $C4=1, then add "0" to the wing weight value of 1, else, don't add anything, "0", etc. Of note, consider the engine weight equation. The conventional technology weight is 9,238 lbs. Now, if a technology is "on", then the 9,238 lbs will change by a certain percentage as shown in the equation below. It is important to check that the equations match the "k" factors in the TIM. This spreadsheet is set up for 11 technologies and 16 "k" factors. If you have less than 11 technologies and 16 "k" factors, you need to modify the sheet. Also, if you have different technologies than the ones listed, you need to modify the spreadsheet. If you have no clue how to do this, just ask Dr. Kirby.

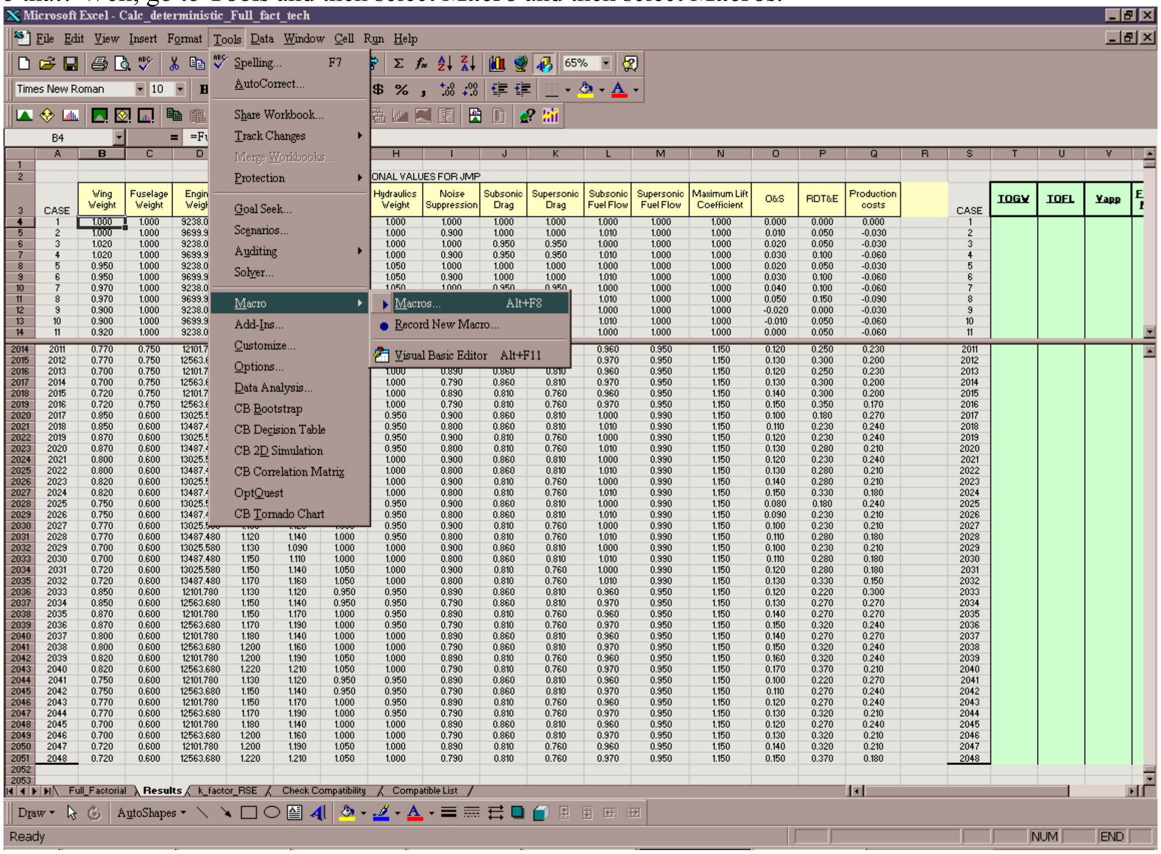
Wing weight:
=1+IF($B4=1,-0.2,0)+IF($C4=1,0,0)+IF($D4=1,0,0)+IF($E4=1,0.05,0)+IF($F4=1,0,0)
+IF($G4=1,0,0)+IF($H4=1,0,0)+IF($I4=1,-0.1,0)+IF($J4=1,-0.05,0)+IF($K4=1,0.02,0)+IF($L4=1,0,0)

Engine weight:
=(1+IF($B4=1,0,0)+IF($C4=1,0,0)+IF($D4=1,0,0)+IF($E4=1,0.01,0)+IF($F4=1,0.4,0)+IF($G4=1,0,0)
+IF($H4=1,-0.1,0)+IF($I4=1,0,0)+IF($J4=1,0,0)+IF($K4=1,0,0)+IF($L4=1,0.05,0))*9238

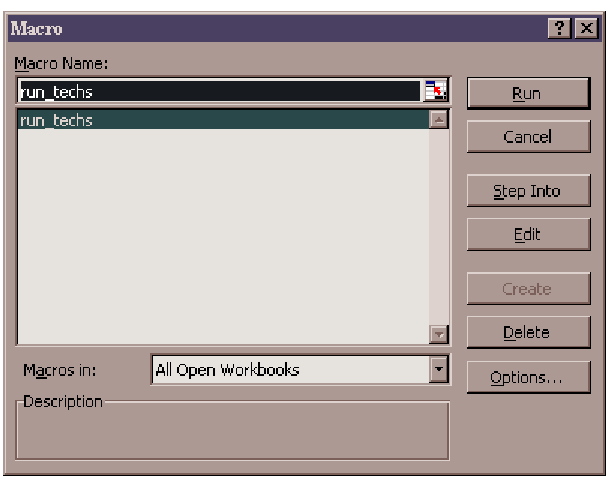
Hydraulics weight:
=1+IF($B4=1,0,0)+IF($C4=1,0,0)+IF($D4=1,-0.05,0)+IF($E4=1,0,0)+IF($F4=1,0,0)
+IF($G4=1,0,0)+IF($H4=1,0,0)+IF($I4=1,0,0)+IF($J4=1,0.05,0)+IF($K4=1,0,0)+IF($L4=1,0,0)



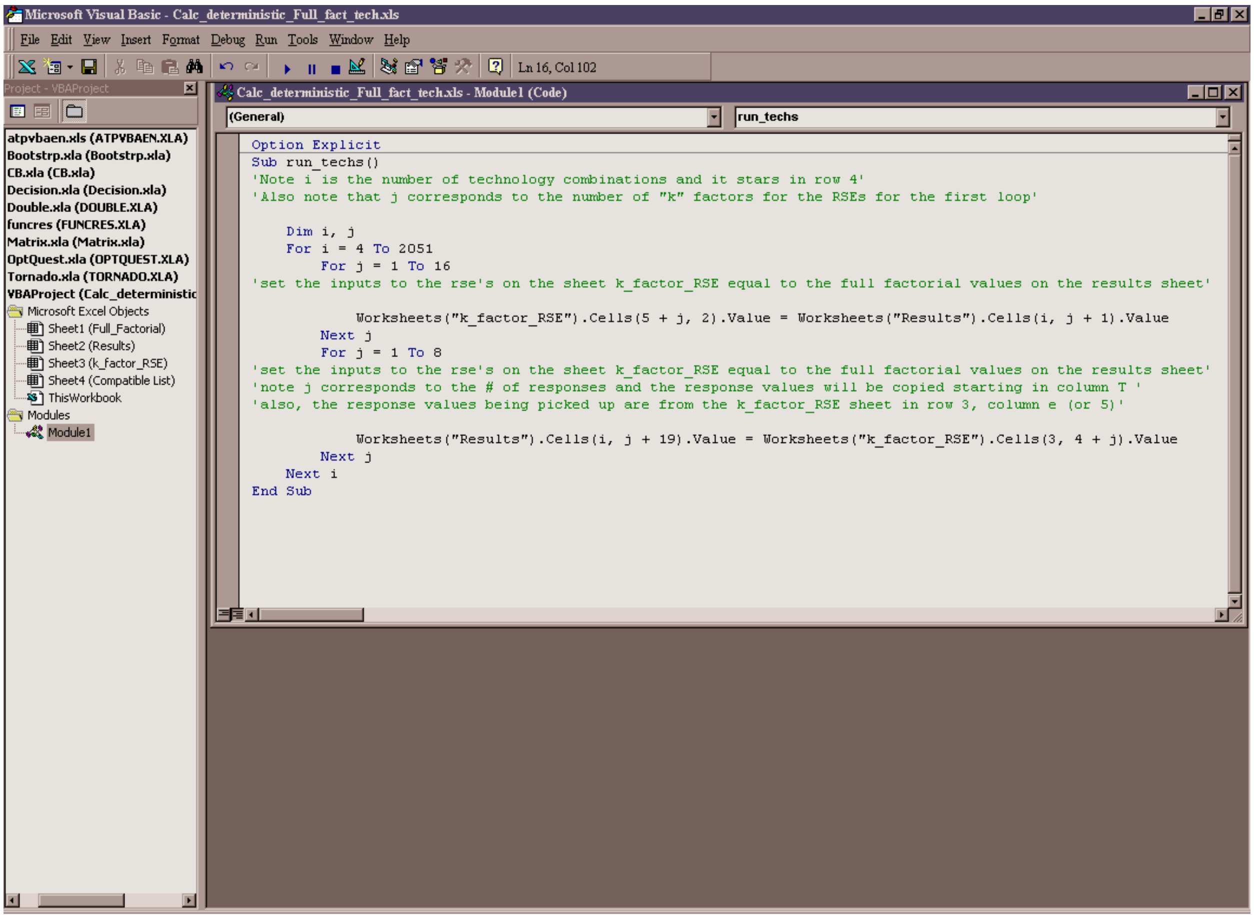
Now look at the sheet called "Results". In cell B4, the info from translating the impact of a mix of technologies should be copied into these cells. If you look to the right, starting in column "T", you will see where the responses are. At present, the response columns are empty since you haven't actually calculated the RSEs. How might you do that? Well, go to **Tools** and then select **Macro** and then select **Macros**.



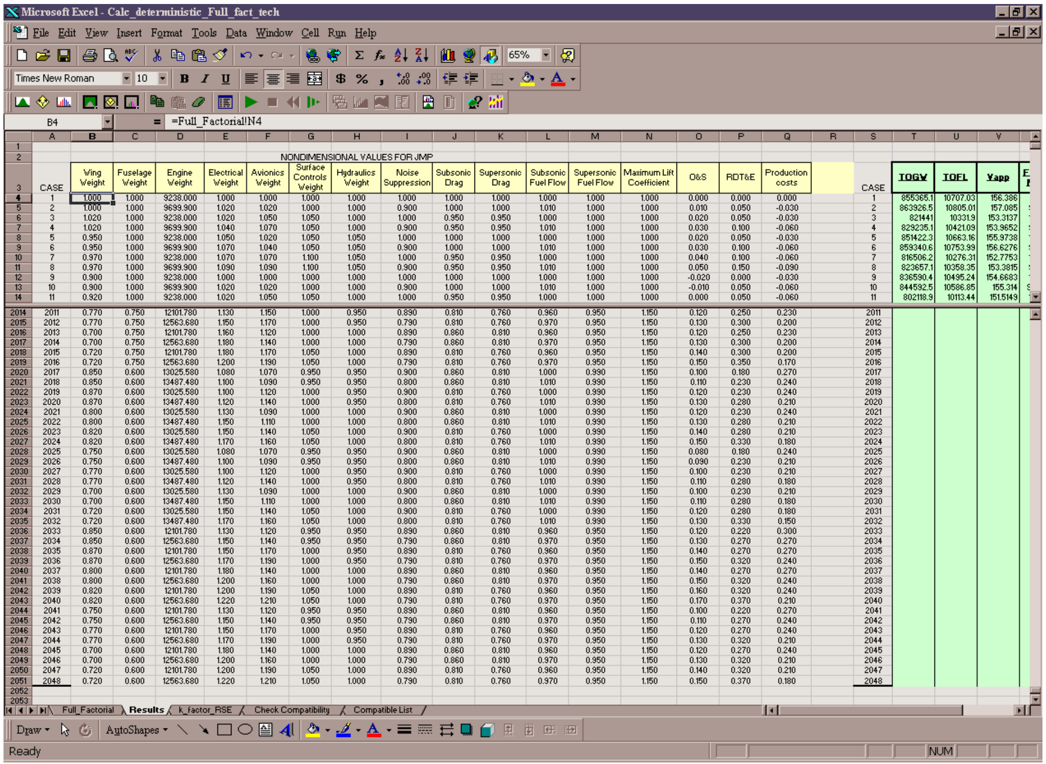
Then you will see the following window with the macro contained in this spreadsheet. It is entitled "run_techs". Let's take a look at what that macro does. Select "run_techs" if it is not highlighted and then select the **Edit** button.



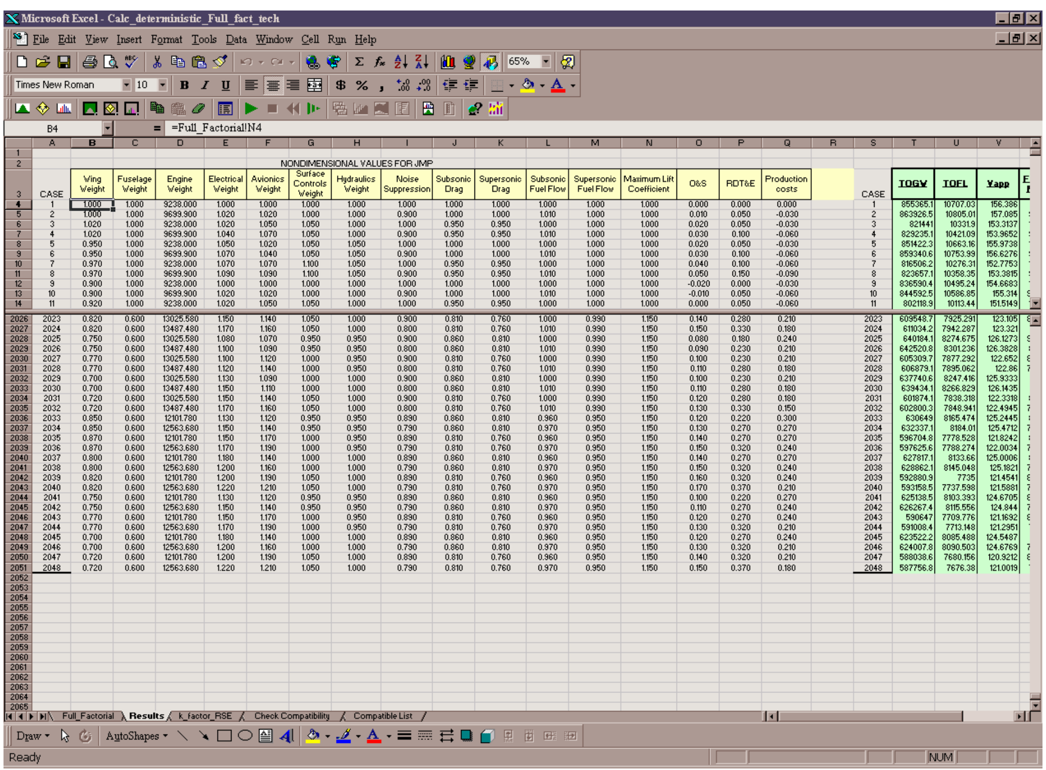
Then the following window will pop up, if you have the Visual Basic Editor. The macro is commented as to what it is doing. There are a few hitches here. The macro is set up for 11 technologies for a full factorial evaluation (2,048 cases) and for 16 "k" factors and 8 responses. This is important due to where the cells are being referenced. For example, the list of the full factorial cases starts in row 4 and column 2 (or B4) on the sheet "Results". Since there are 2,048 combination, the index "i" goes from 4 to 2,051. Next, the first occurrence of index "j" corresponds to the number of "k" factors and the second occurrence corresponds to the number of responses. Your response values must start in cell E3 on sheet "k_factor_RSE". If they do not, you must modify the references in the macro. Also if you have more or less technologies, then you must change the index for "i". Finally, if you have more or less "k" factors, then modify the value of the first occurrence of index "j" and if you have more or less responses, modify the second occurrence of index "j". If you modify anything, then save the work and return to Excel.



Let's actually evaluate all of our technology combinations. Go back to **Tools** and then select **Macro** and then select **Macros** and now select **Run**. You will see that the cells underneath the responses to the right start to fill out. The macro will continue to run until it has evaluated all the technology combinations that you provided.



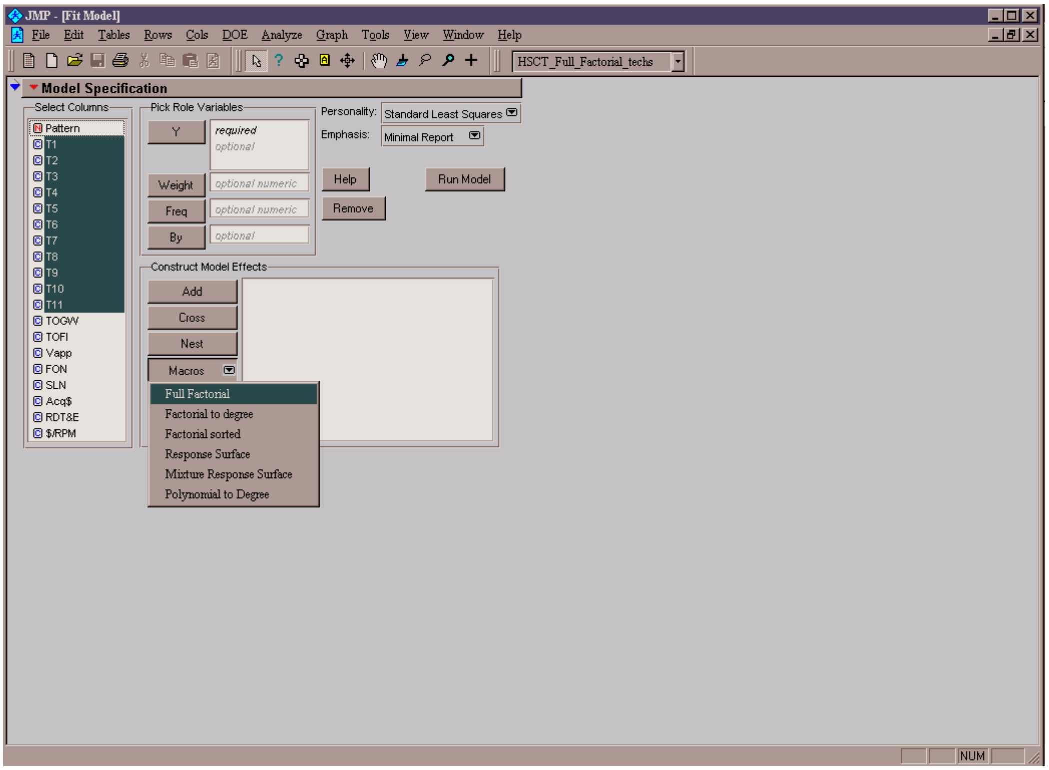
When the macro is finished, you now have the impact of ALL the technologies that you are considering on the responses that you were interested in as shown below.



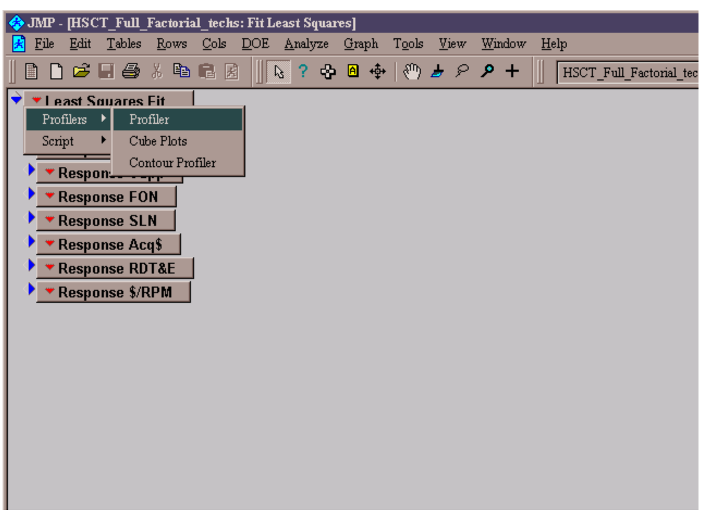
Now let's get a visual of how the sensitive the responses are to the technologies. To do so:

- Copy all of the values of the metrics as you have done so many times
- Open your full factorial JMP file
- Add the appropriate number of columns
- Paste your results

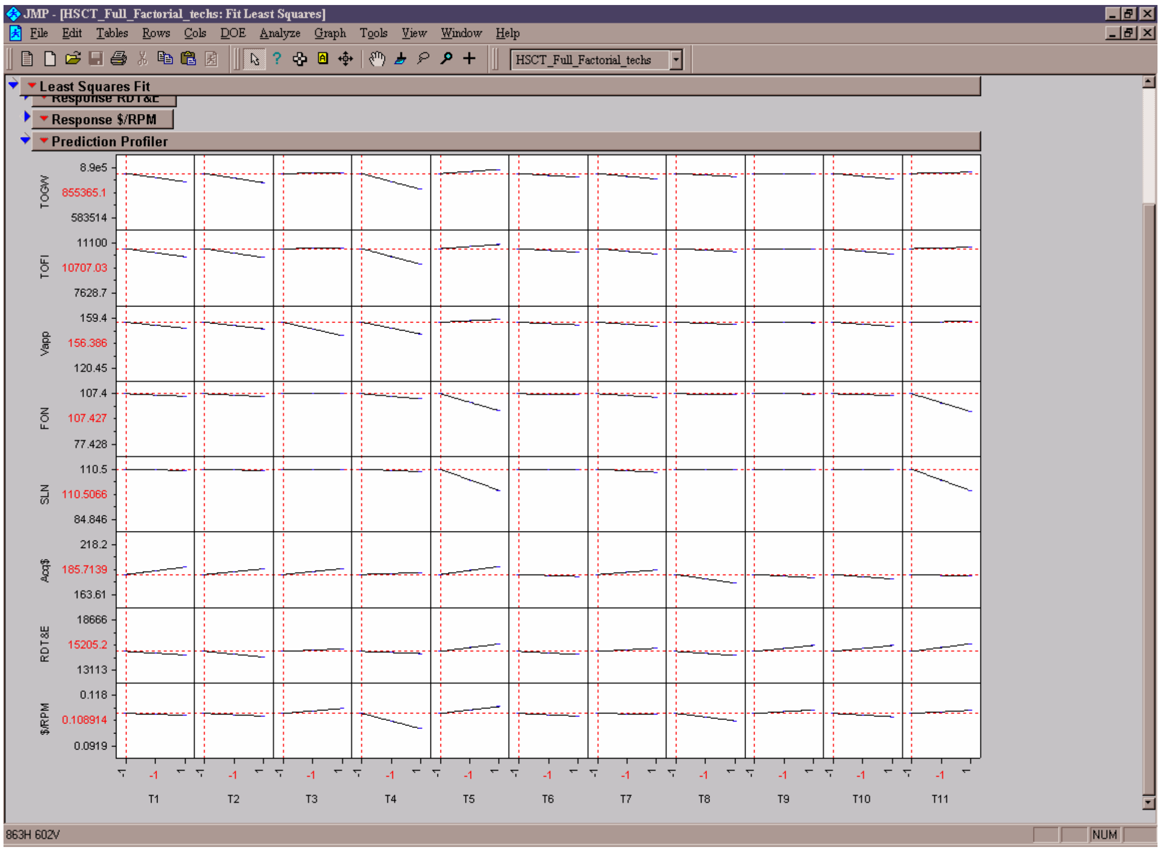
Then, go to **Analyze**, then **Fit Model**. When the **Fit Model** window comes up, select your technologies and then hit the **Macros** drop menu and select the **Full Factorial** option. The full factorial will fill out in the "Model Effects" window. Then select your responses and click the **Y** button. Don't forget turn off the "Center Polynomials" under the **Model Specification** drop menu. Once completed, hit **Run Model**.



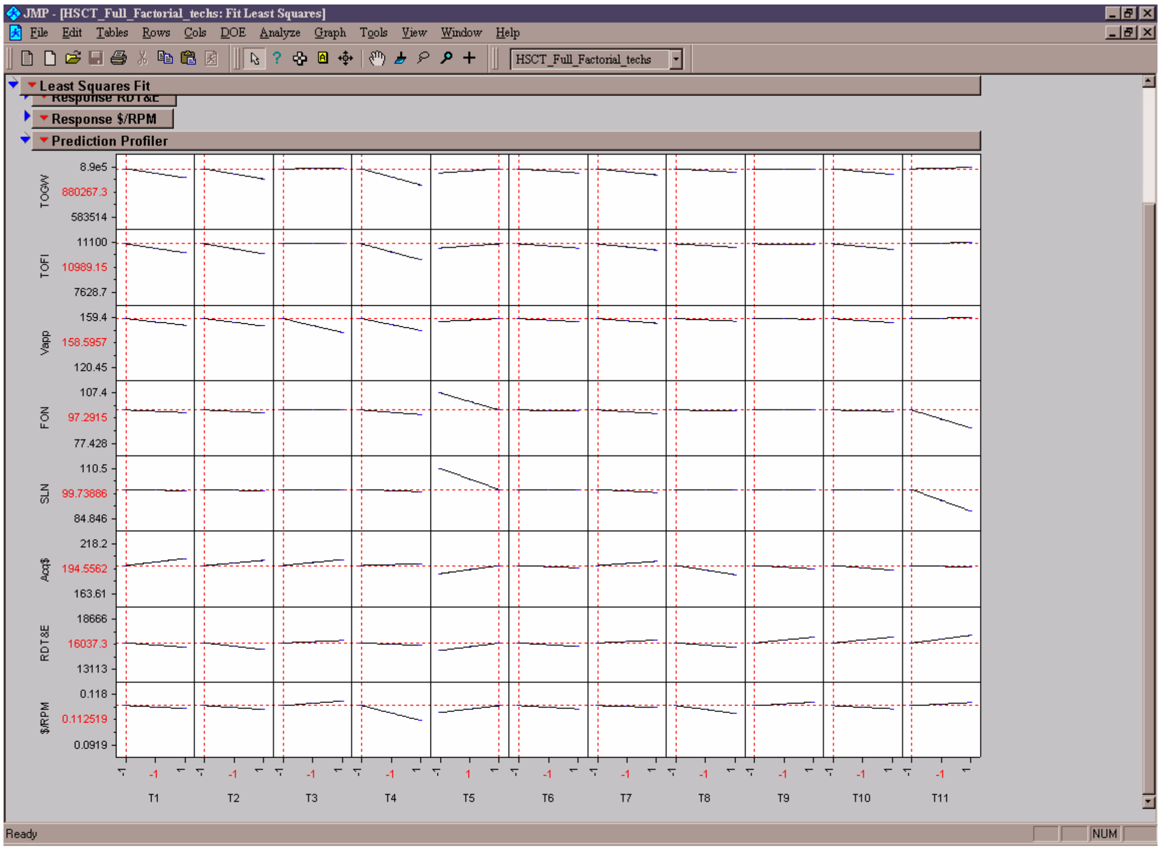
JMP will sit there for a bit while it is calculating all the statistics. Note, the more technologies you have, the longer it is going to take. Once JMP is finished, minimize all of the response analysis windows and open a Profiler.



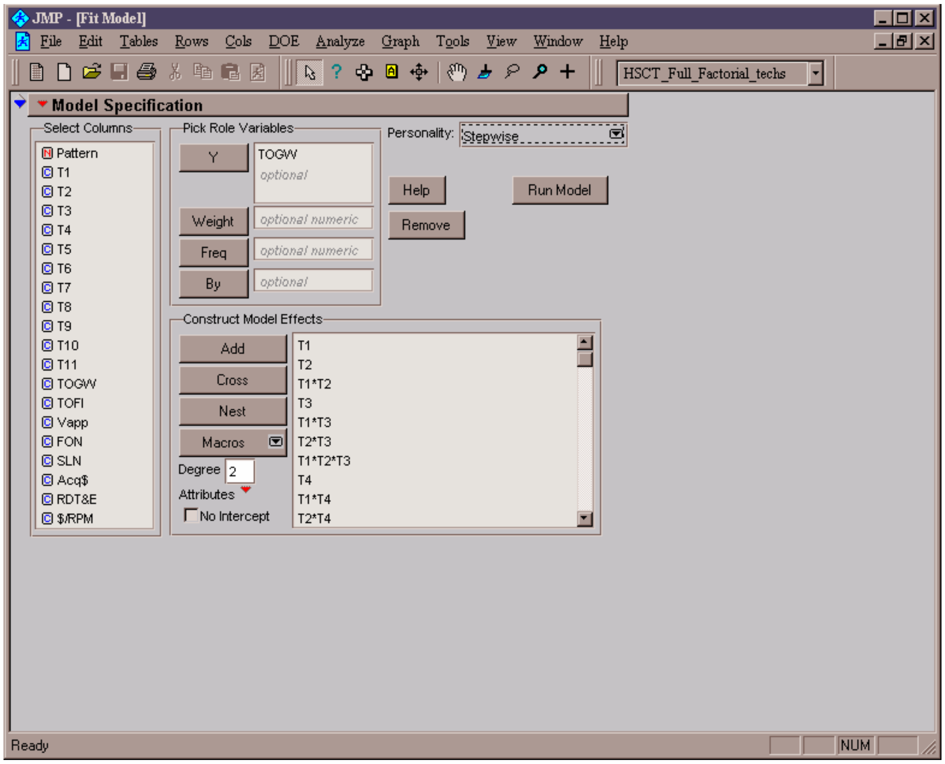
Again, if you have a lot of technologies, it is going to take JMP just a second to create the Profiler. Once the profiler is up, you now have a rapid environment whereby you can visualize the impact of ANY combination of technologies. As shown below. If you reset all of the technologies to a value of “-1”, this corresponds to all of the technologies being OFF. If you put any of the technologies to a value of “1”, then you will automatically update the values of the responses and see the impact that the chosen technology has on your system. Recall that all of the impacts to the system are inherent behind this profile. For each “-1” and “1” value in the full factorial DoE, you summed up all of the “k” factors and then calculated the RSEs. So, you are seeing the top level impact of all the “k” factors. You will never again have to run another code to determine the impact to your system from the set of technologies that you modeled. You can also determine if some combination of technologies will allow you to meet constraints by looking at the upper and lower bounds on your metrics.



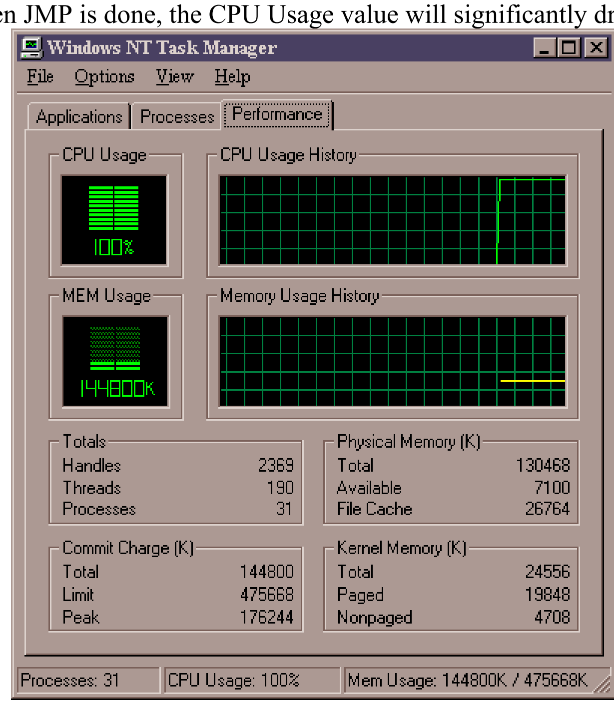
For example, Sideline Noise (or SLN) is a response with a constraint value of 103 EPNLdB. As you can see, once T5 is turned on, that constraint value can be met. Additionally, if you do not set a technology to a value of “1”, this is analogous to not getting the full impact from the technology that was described in the TIM. That is, if someone said that I am only getting 50% of what I was expecting from the technology, then you would set that technology value equal to “0” on the profile and read off the value of the responses. This is a poor man’s way of handling technological uncertainty or changing technological assumptions.



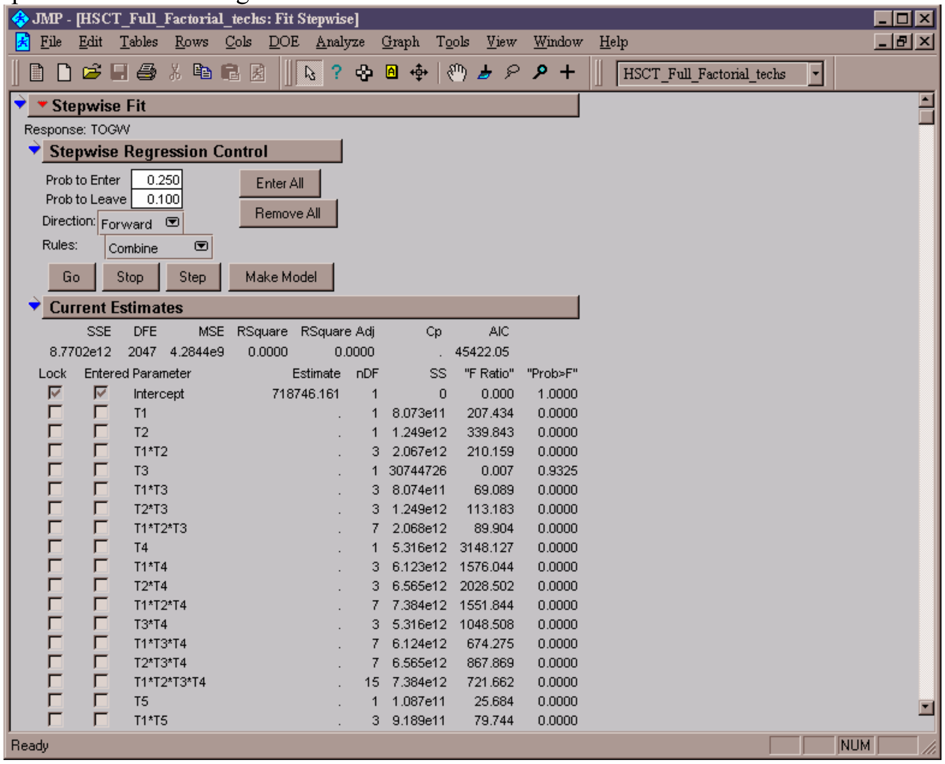
One way to get around the slowness of JMP creating the Prediction Profiler or the contour plot is to determine which interaction terms of the regressed coefficients do not need to be calculated. This is very important when you have a lot of technologies, or even with the RSEs if you have a lot of input variables. So, let's go through the steps of how you do that. Go back to your **Fit Model** window and only select one response, say TOGW. Now instead of selecting the "Standard Least Squares" option under the "Personality" drop menu, select the "Stepwise" option and then select **Run Model**.



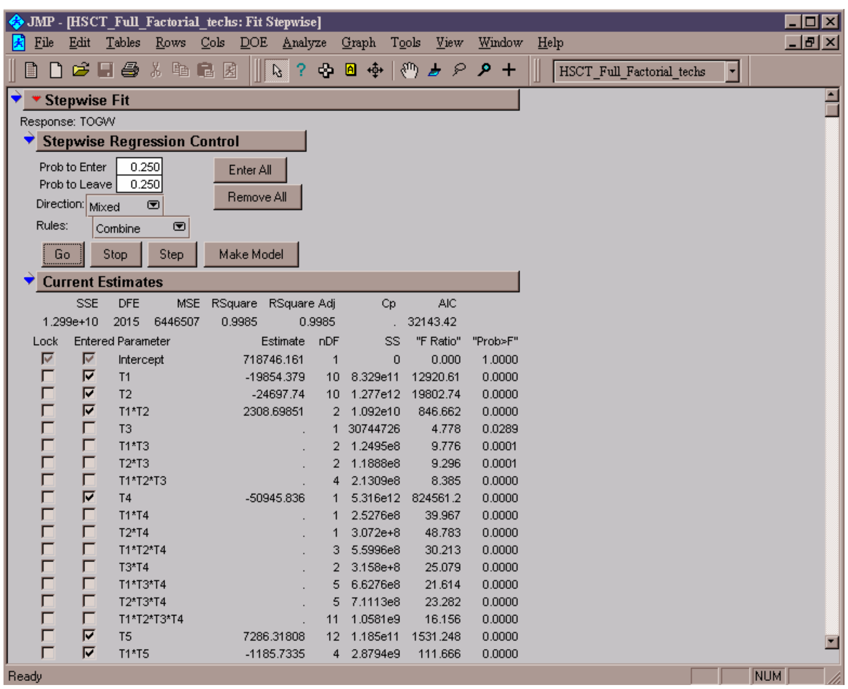
JMP will take a while doing its thing. If you would like to know that it is still running, go to the Windows Task Manager as shown below. JMP will consume a great deal of CPU when it is running as you can see by the "CPU Usage" running at 100%. When JMP is done, the CPU Usage value will significantly drop.



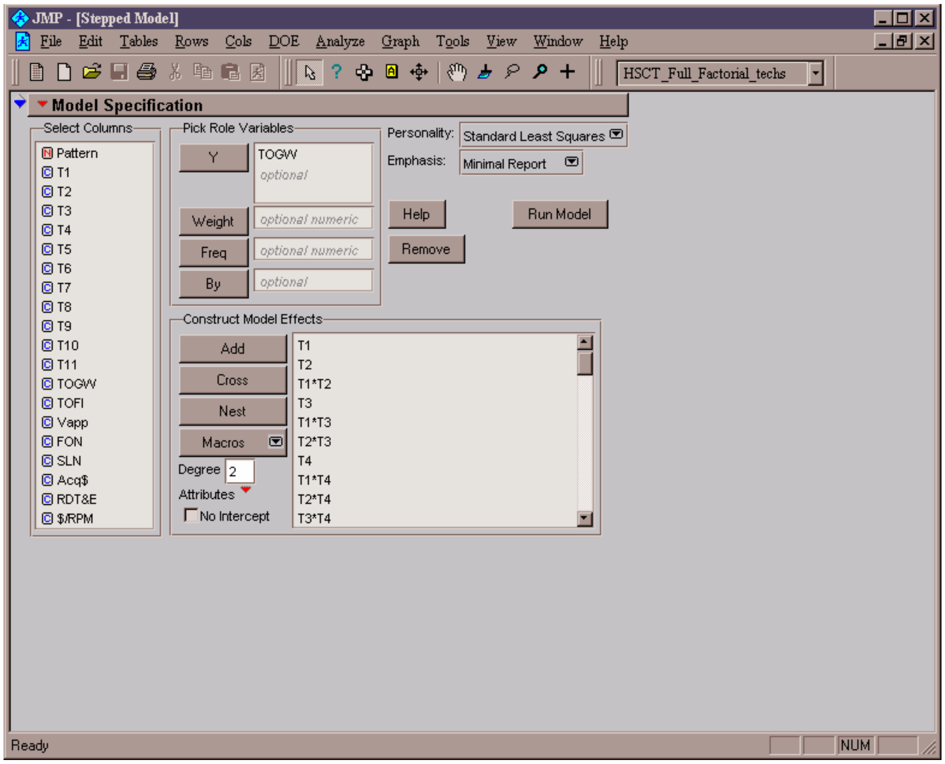
When JMP is done, the window below will come up. JMP has the ability to determine which coefficients of the regressed response are the most significant contributors.



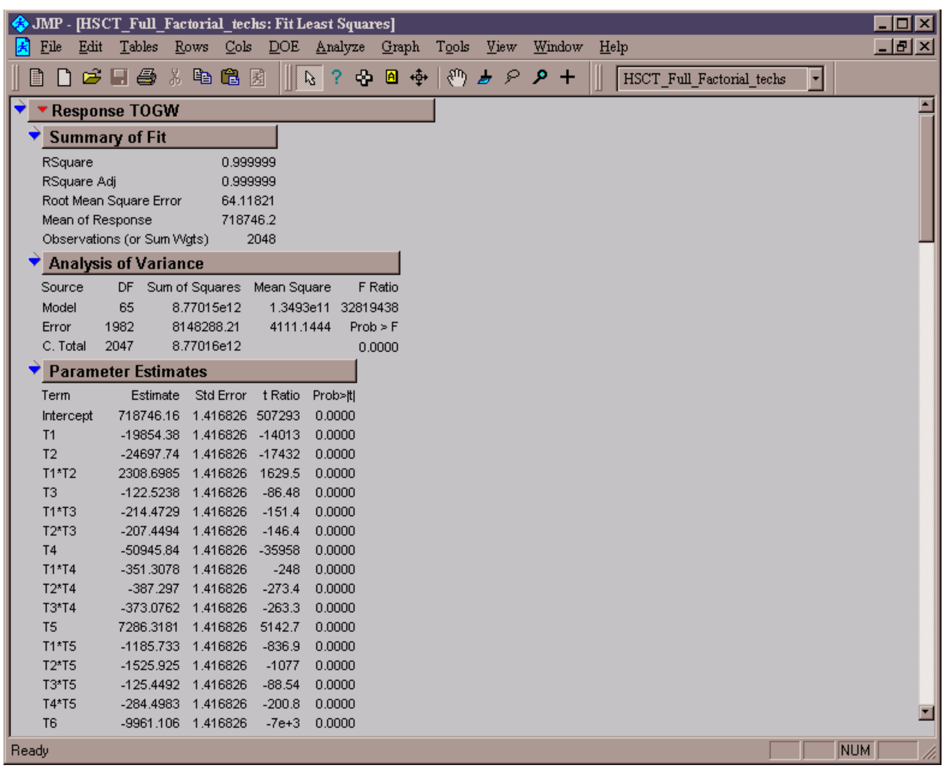
To determine the coefficients, under the "Direction" drop menu, select "Mixed" and take the default values that JMP gives you and then hit **Go**. You will see check marks appearing in the "Entered" cells. Again look at your Task Manager and you will know when JMP is finished by the CPU Usage significantly dropping. When JMP is done, click the **Make Model** button.



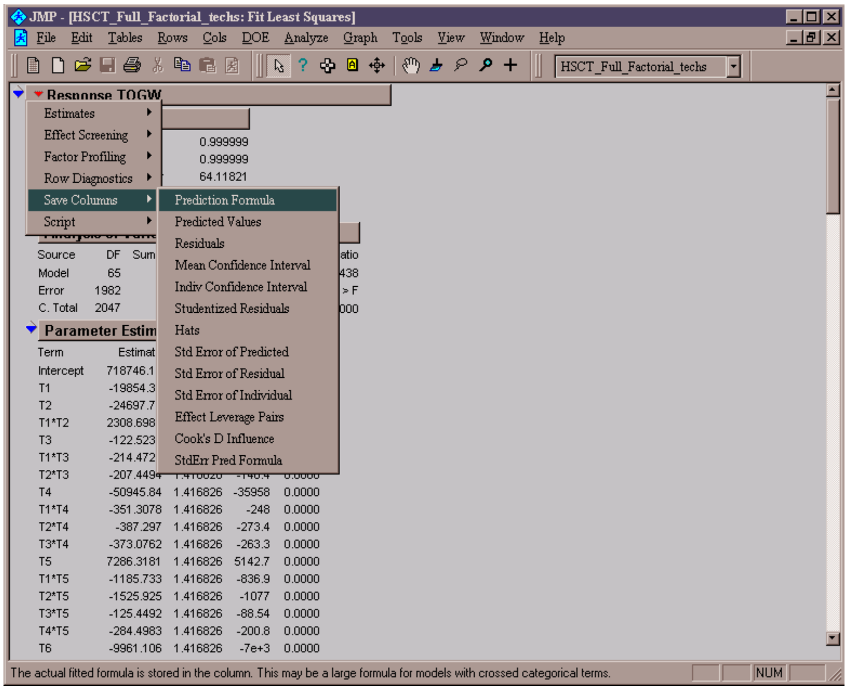
JMP will open a new **Fit Model** window with the chosen coefficient terms as shown below. Don't forget to turn off the "Center Polynomials" option under the **Model Specification** bar. If the "Emphasis" option is not on "Minimal Report" then select that option and click **Run Model**.



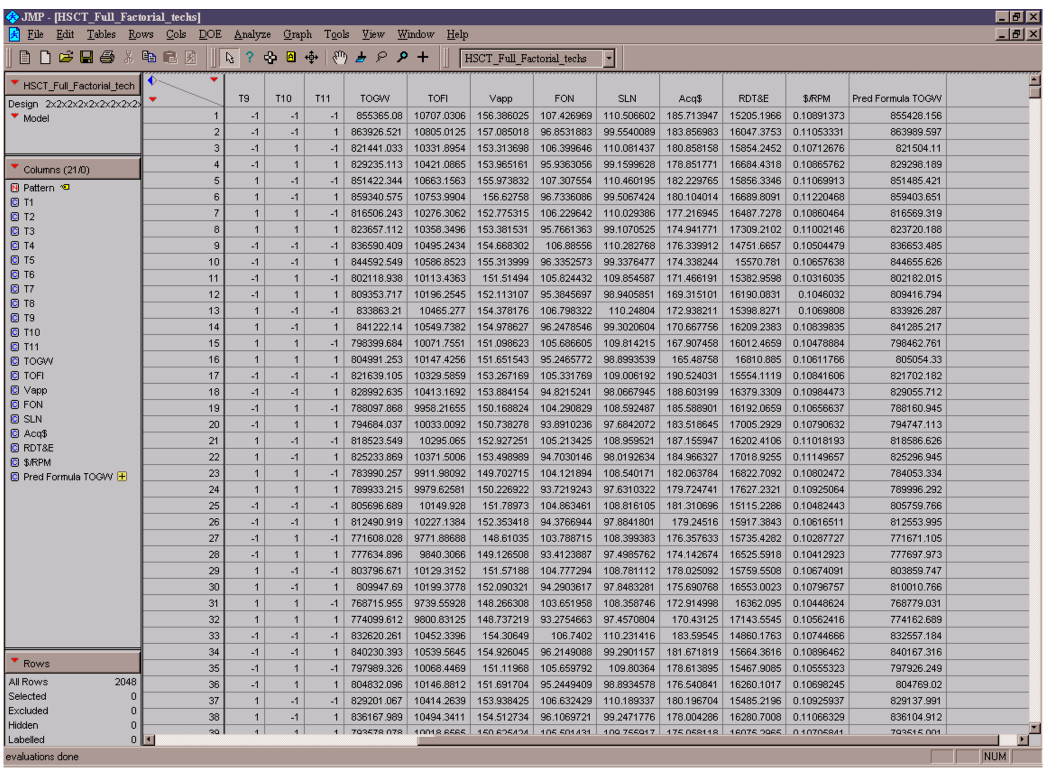
The window below will come up



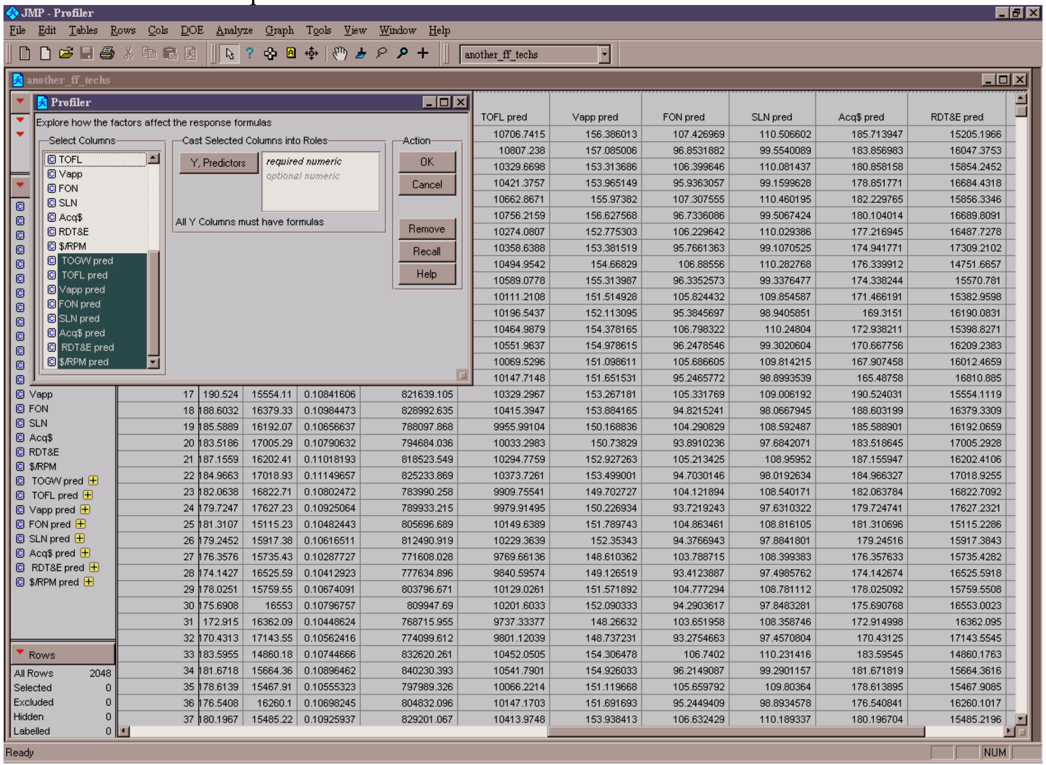
Now, go under the Response TOGW option and select “Save Columns” and then select “Predicted Formula”.



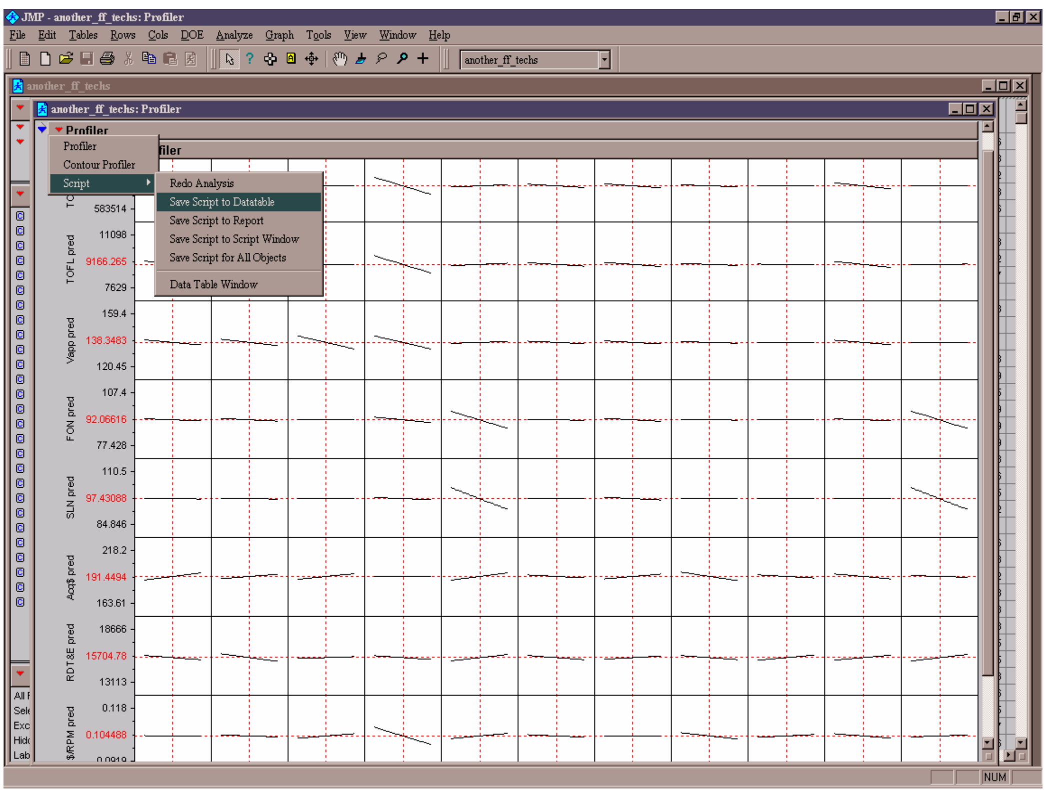
Look back in your DoE table and you will see a new column added called “Pred Formula TOGW”. This column has the RSE behind it.



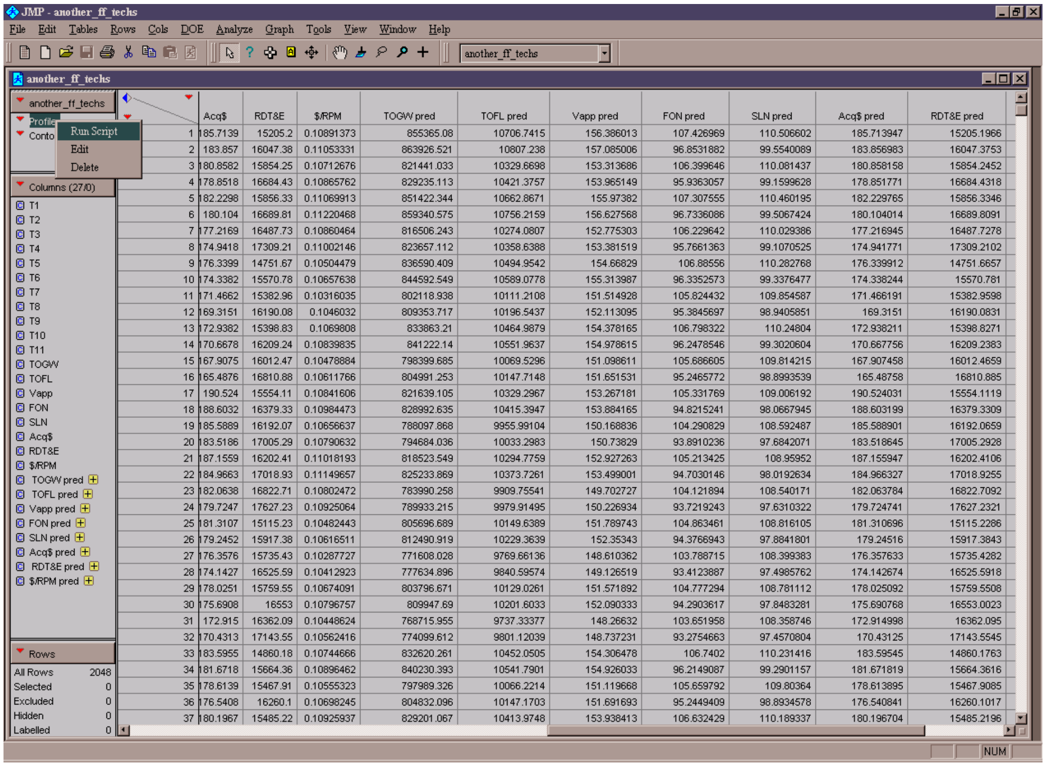
Repeat this process for every response that you have. Now, go to **Graph** and select the **Profiler**. Then select all of the columns that have the predicted formulas behind them and select **OK**.



Now, when the profiler comes up you can play technology games by turning on and off any technology you like. Also, under the **Profiler** drop menu, select the "Script" option and then select "Save Script to Datatable".



Go back to the JMP table and you will see "Profiler" has appeared in the top left corner. What this script does is automatically create the Profiler based on what you just did. To execute it, right mouse click on the "Profiler" and select **Run Script** and the profiler will automatically generate.



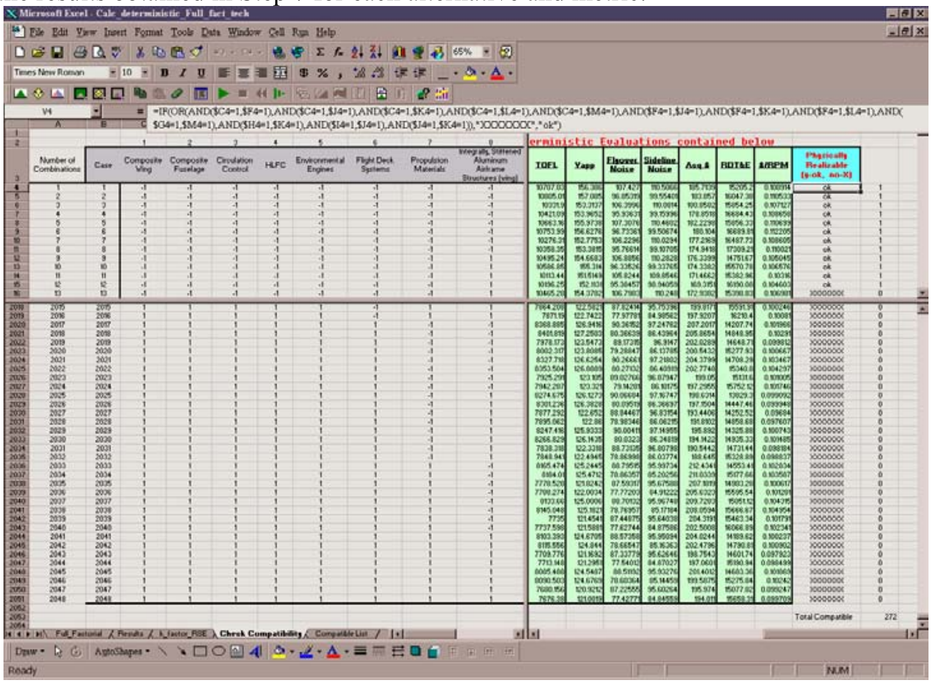
Populating the Decision Matrix

When you are finished with all the technology combinations, go back to Excekl and to the "Compatible list" sheet. This sheet is again formatted for 11 technologies and 8 metrics. This sheet will automatically update from the values that were calculated on the "Results" sheet. On the right of this sheet is the determination of whether or not the technology mix (case #) is physically compatible or not. If the mix IS compatible, an "ok" is shown in the column. If not, then "XXXXXX" appears. A physically compatible combination is determined from the compatibility matrix and is coded as shown below for this example. You need to make sure that your mix of technologies is coded properly here. In addition, the column beside the one that determines compatibility is simply a counter. When the technology mix is compatible, a "1" results for the row, if not, then a "0". At the bottom of the page is a summation to determine the number of physically compatible technology mixes. For this example, there are 272.

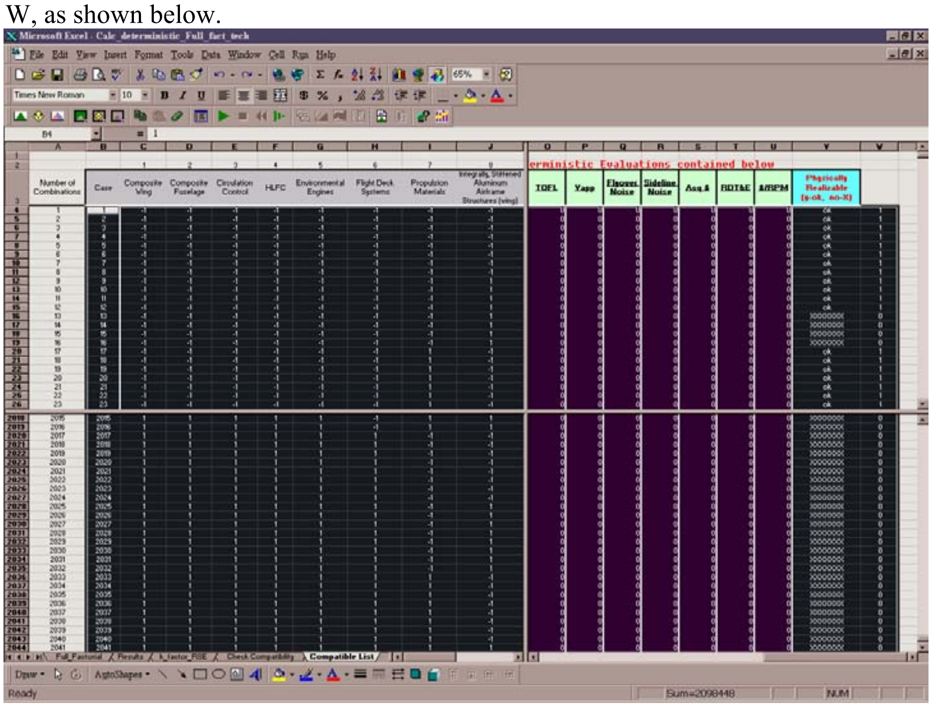
Example compatibility rule:

=IF(OR(AND($C4=1,$F4=1),AND($C4=1,$J4=1),AND($C4=1,$K4=1),AND($C4=1,$L4=1),AND($C4=1,$M4=1),AND($F4=1,$J4=1),AND($F4=1,$K4=1),AND($F4=1,$L4=1),AND($G4=1,$M4=1),AND($H4=1,$K4=1),AND($I4=1,$J4=1),AND($J4=1,$K4=1)),"XXXXXXX","ok")

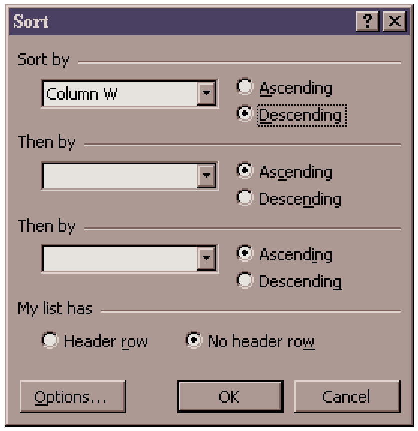
The concepts identified in Step 6 (i.e., only the compatible technology mixes) form the rows and the system metrics from the problem definition form the columns as shown below. The deterministic elements of the matrix are populated from the results obtained in Step 7 for each alternative and metric.



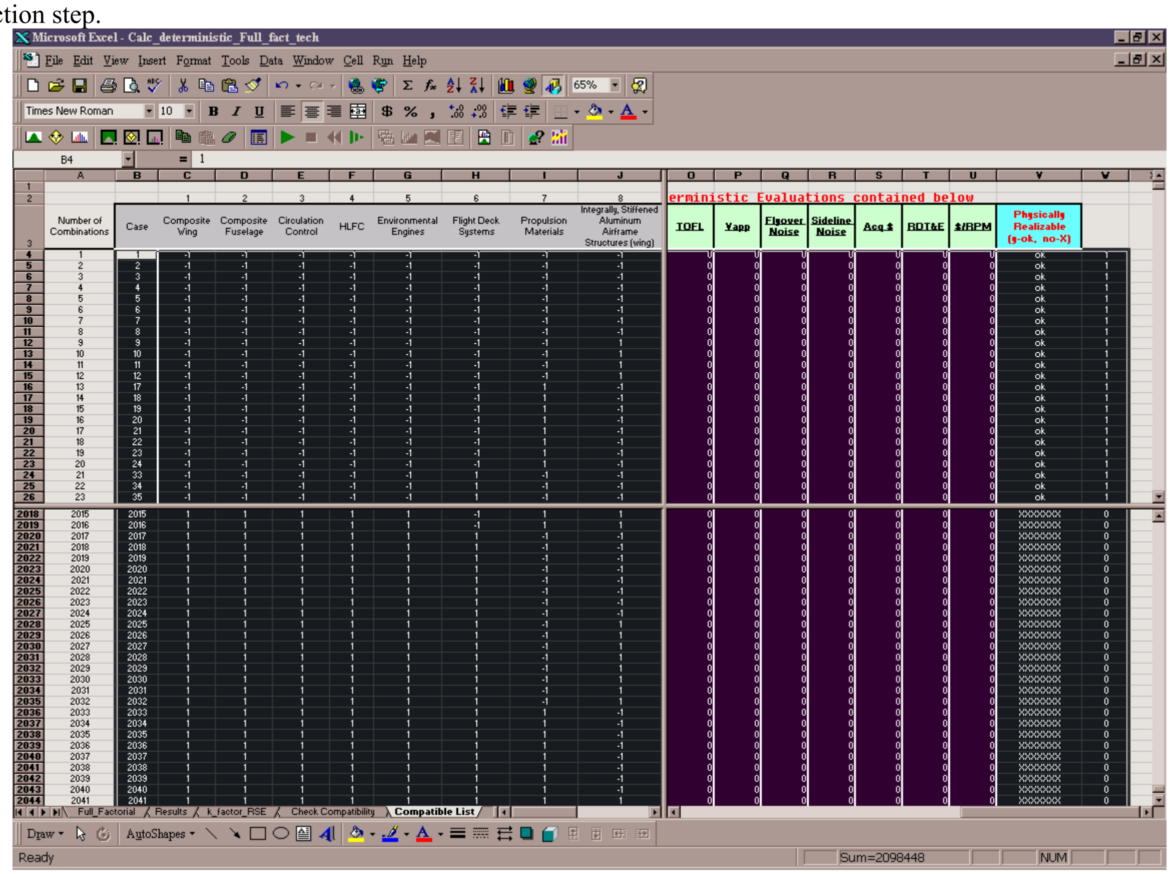
Note since you evaluated your technologies deterministically, you actually have your Decision Matrix defined. It is the matrix defined by the "compatible" list of technologies and the corresponding metric values in the "Compatible List" sheet in the "Calc_deterministic_Full_fact_tech" spreadsheet. Let's create our Compatible list of technologies based on the full factorial. Place your cursor in cell B4 and select everything including the compatibility rules in Column W, as shown below.



Now go to sheet “Compatible List” and **Paste Special”** and paste only values starting in cell B4. You should have a complete mirror of what the “Check Compatibility” sheet had except there are no formulas. Now, you want to sort this information based on whether or not the technologies are compatible. So, keep the area that you just pasted highlighted and go to **Data** and select **Sort**. When the window below comes up, you want to select the option for “My list has” no header row and then sort by Column W in Descending order. This will sort with all of the compatible technologies listed first and then the incompatible ones below that.

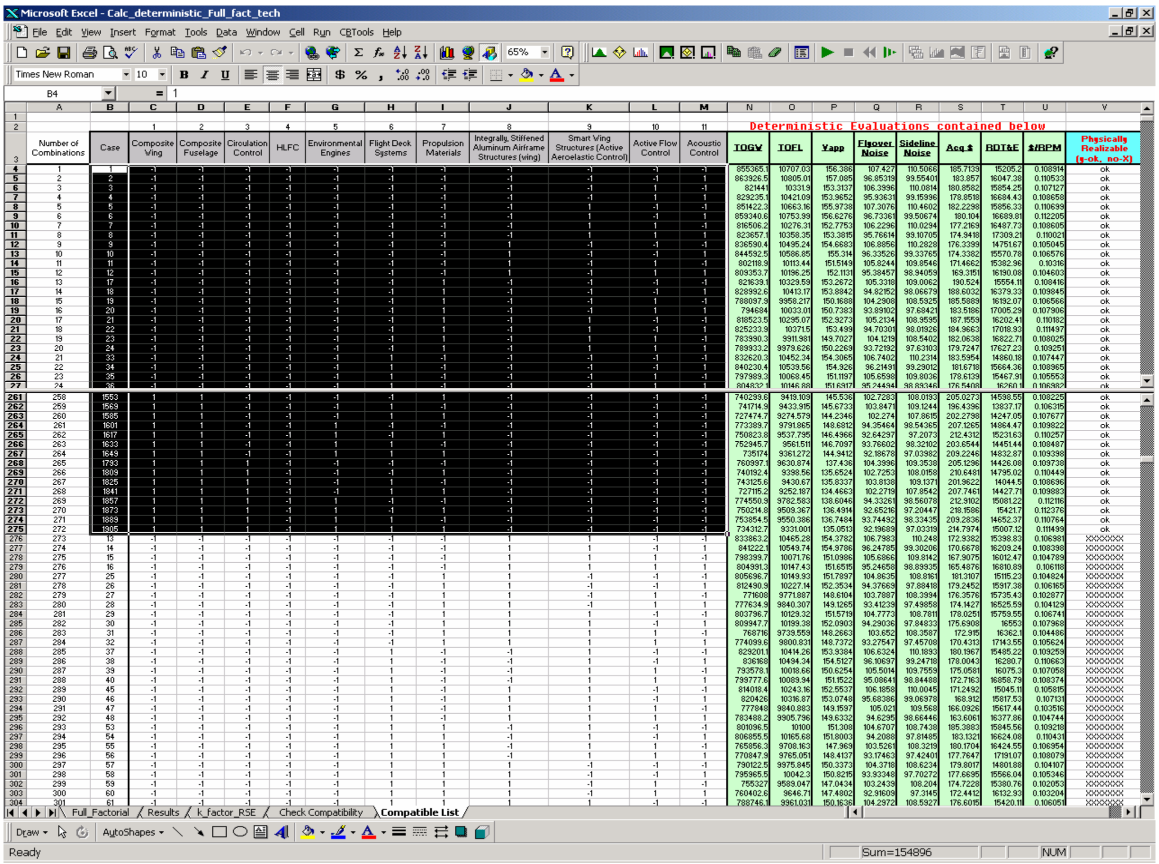


And you will see that the order of the technology combinations changes, as shown below. Now you can simply remove all of the incompatible cases. This should leave 272 compatible combinations that we will take to the selection step.

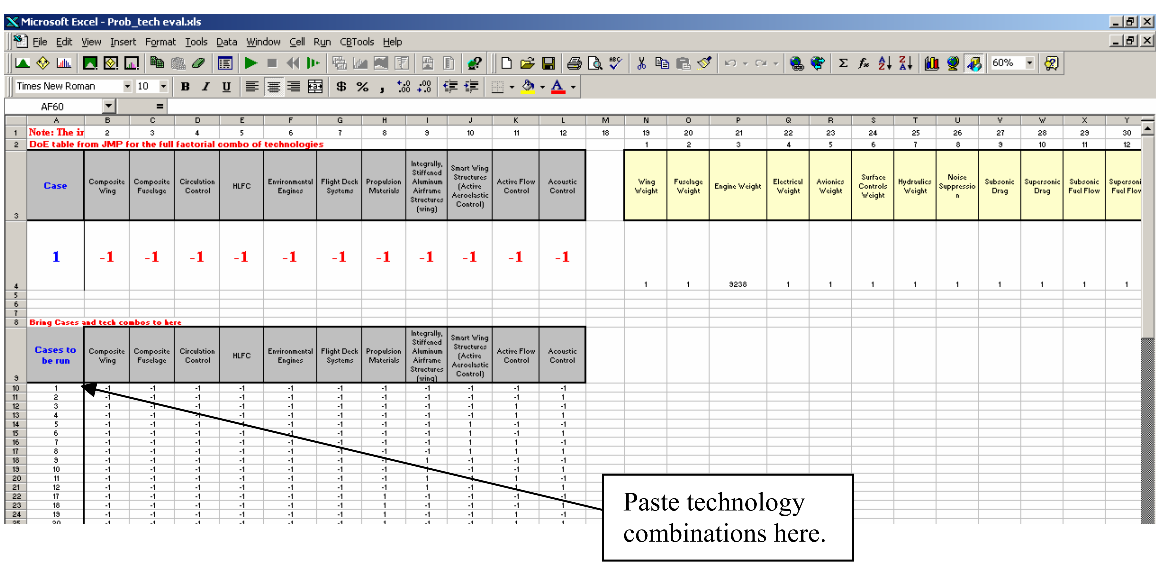


Probabilistic Technology Evaluation

All of the evaluation of the technologies so far has been deterministic. This assumes that the technologies will reach the maximum possible impact, the values found in the TIM. Since these technologies are not fully matured, there is a chance that the final outcome will be less then the value in the TIM. To account for this variation in final outcome, we can use probabilistic evaluation. The file "Prob_tech eval" will allow you to evaluate the impact of technologies probabilistically. This file contains the sheets "Definitions", "Prob Analysis", "Cases", and "RSE". There may also be response sheets (called R1, R2, etc.). If there are not, they will be created later. Go back to the "Compatible list" sheet in the "Calc_deterministic_Full_fact_tech" file. Copy the case numbers and technology indicators for the compatible cases.



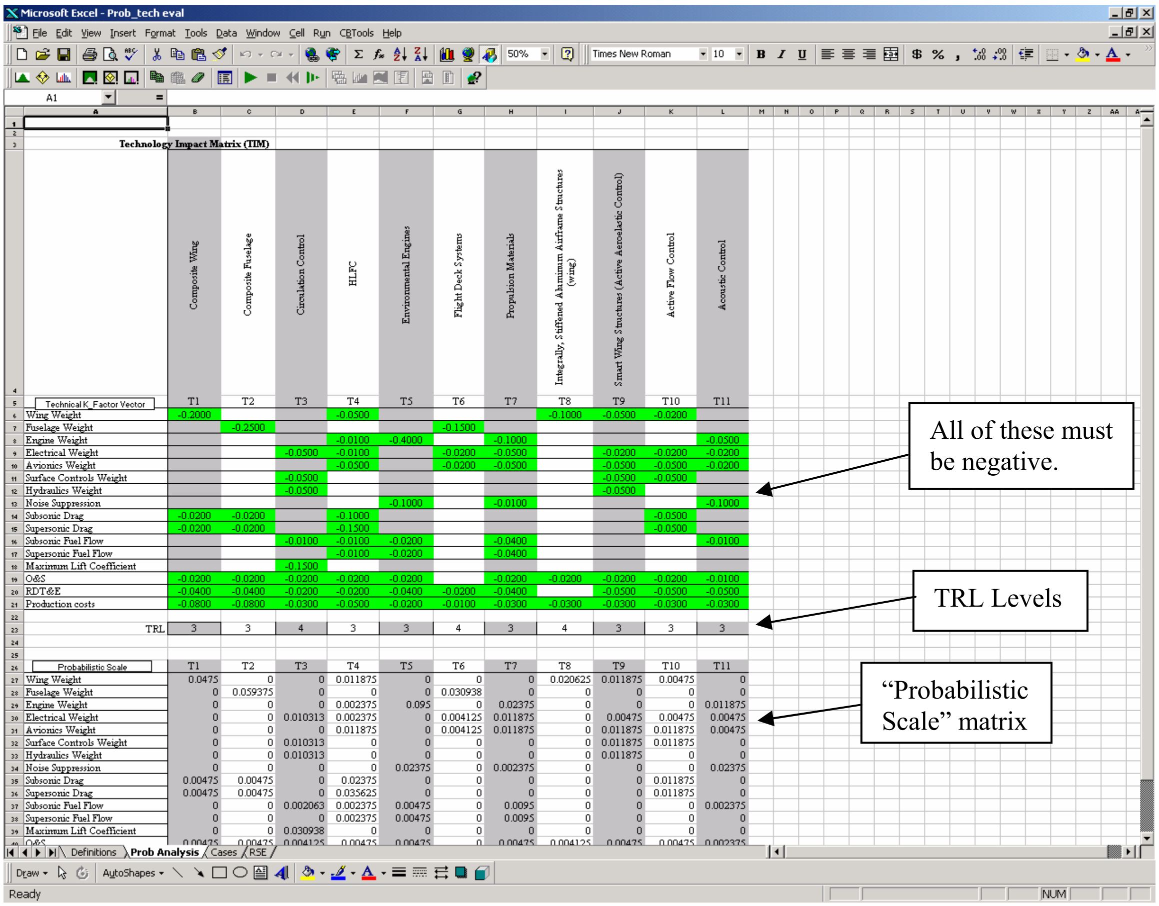
These are the cases you want to run probabilistically. Paste them into the "Cases" sheet by highlighting cell A10 and pasting the cases.



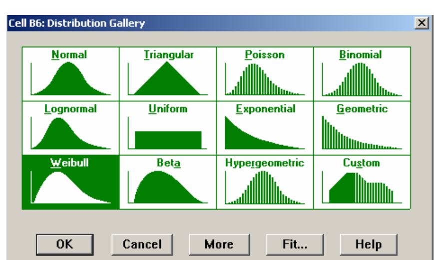
Bring your technology impact matrix into the “Prob Analysis” sheet. The ‘Probabilistic Scale’ matrix below the TIM will update automatically from the TIM and the TRLs. The scale is used in defining the distribution and follows the formula:

$$Scale = \left|(0.3*impact) - (TRL-1)\right| * \frac{\left|\left|0.3*impact\right| - \left|0.05*impact\right|\right|}{8}$$

If you have more technologies or “k” factors, you will need to expand both the TIM and the scale matrices. You must change all of the values in the technology impact matrix to negatives in order to run the simulation because you will use Weibull distributions to define each impact and this distribution must have a negative reference. The Weibul distribution is used because it best models the possible impacts of the technology by incorporating the TRL into the scale of the distribution.

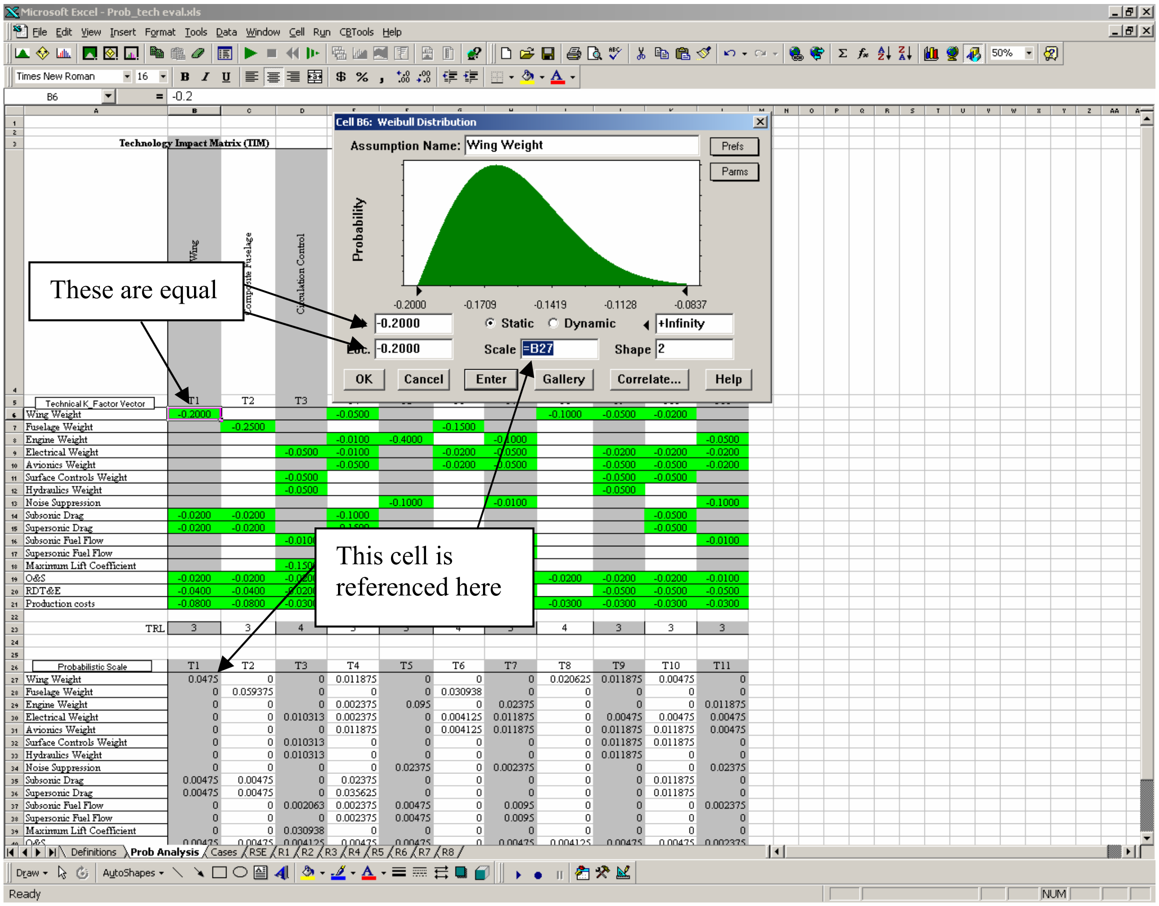


To define these distributions, highlight all of the cells in the TIM that contain influences (shown in green above). Click on the **Cell** menu, then **Define Assumptions**. This menu will pop up:

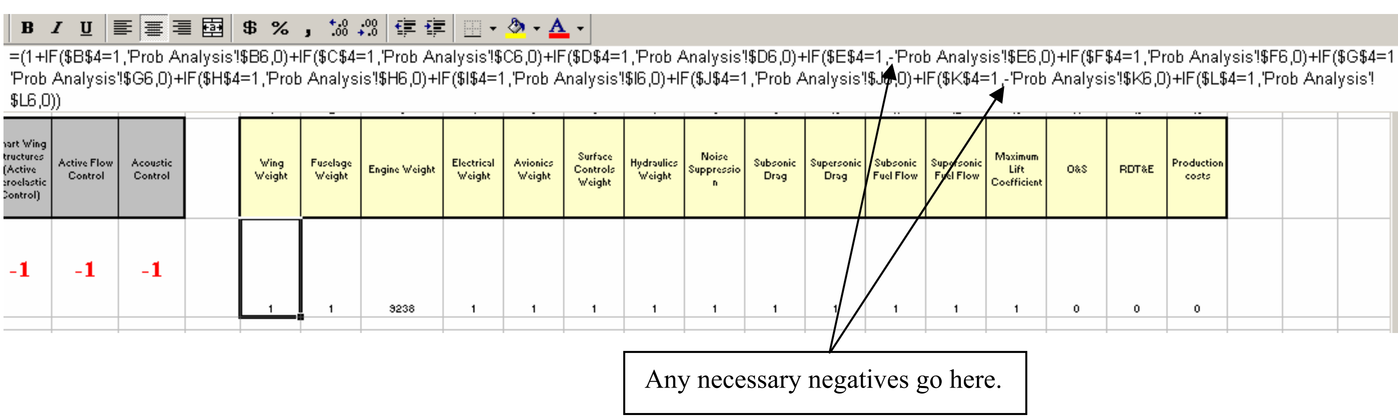


Select **Weibull** and then **OK**.

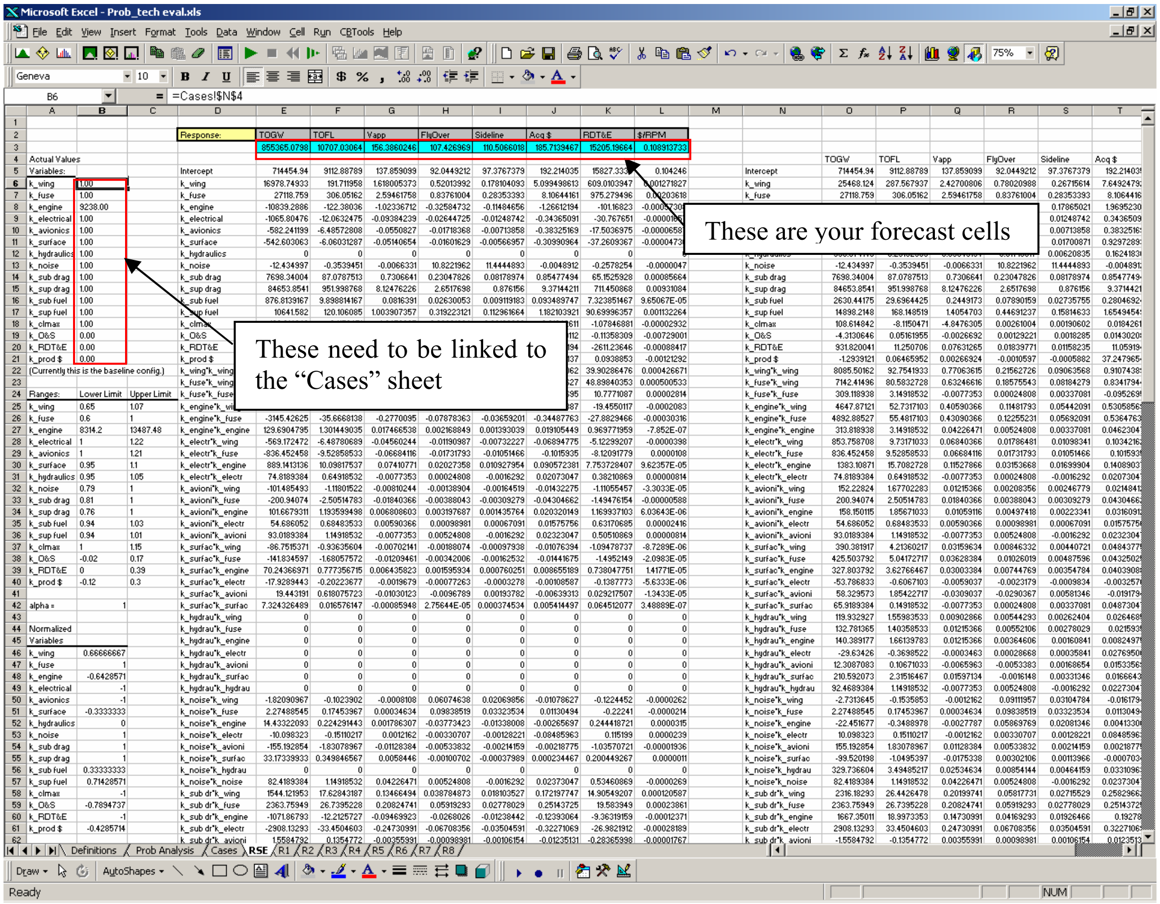
In the next menu, you should rename your assumption. Then check that the location and left bound are the impact from your TIM. The shape should be two and the right bound should be '+Infinity'. The scale will come from the probabilistic scale matrix. The cell can be referenced by entering '=B27' in the menu. The scale should remain static through the simulation. Repeat this as each pair of windows pops up. Be sure to reference the scale for that specific technology and "k" factor.



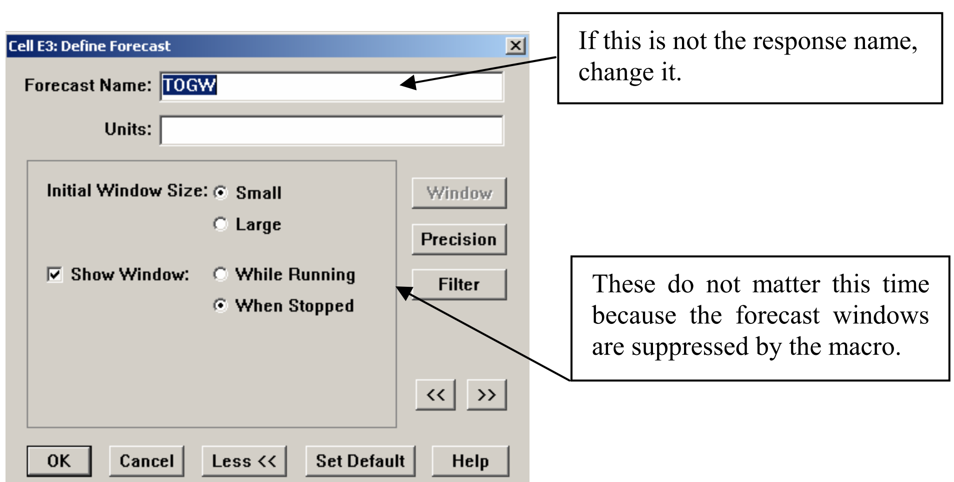
Now, go back to the "Cases" sheet. The cells that contain the normalized "k" factors must be updated. These are linked to the "Prob Analysis" sheets so they will change with the changing tech combinations and "k" factors distributions. This is where the negatives entered into the TIM must be corrected. If a value in the TIM was changed to be negative, add a negative before its reference in the equation in the appropriate "k" factor as shown below.



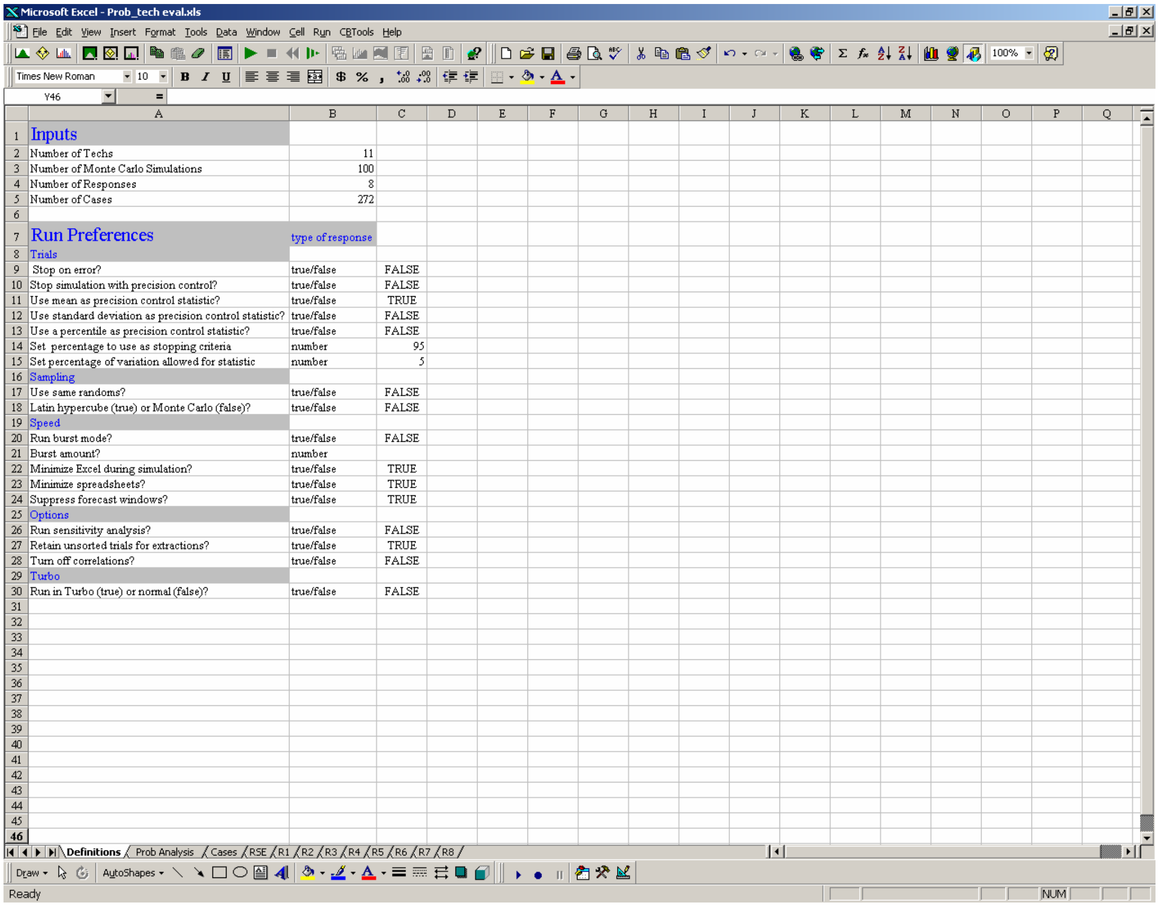
Add in your RSE on the “RSE” sheet. The ‘actual values’ for the “k” factors must be linked to the “k” factor cells you just checked on the “Cases” sheet. The responses should be highlighted and defined as the forecasts under the **Cell** menu and **Define Forecast**.



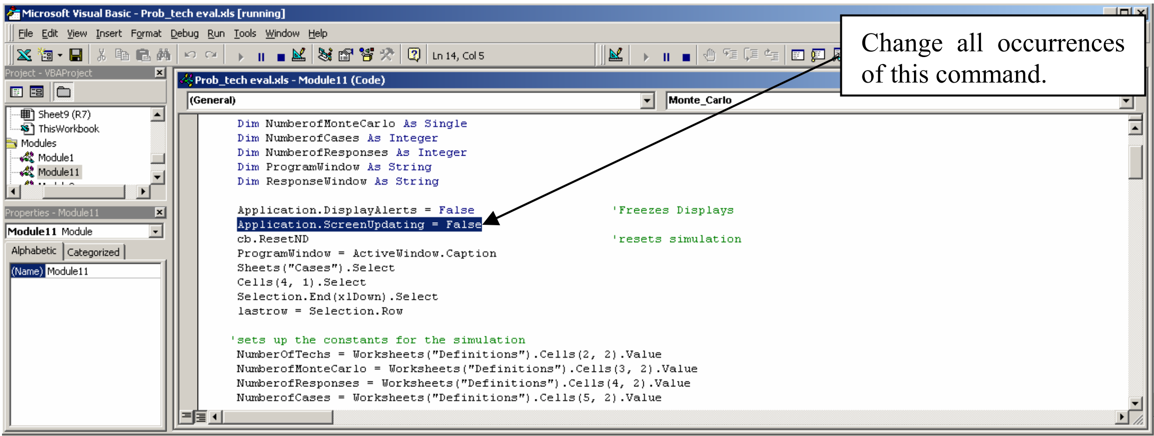
Rename the forecasts.



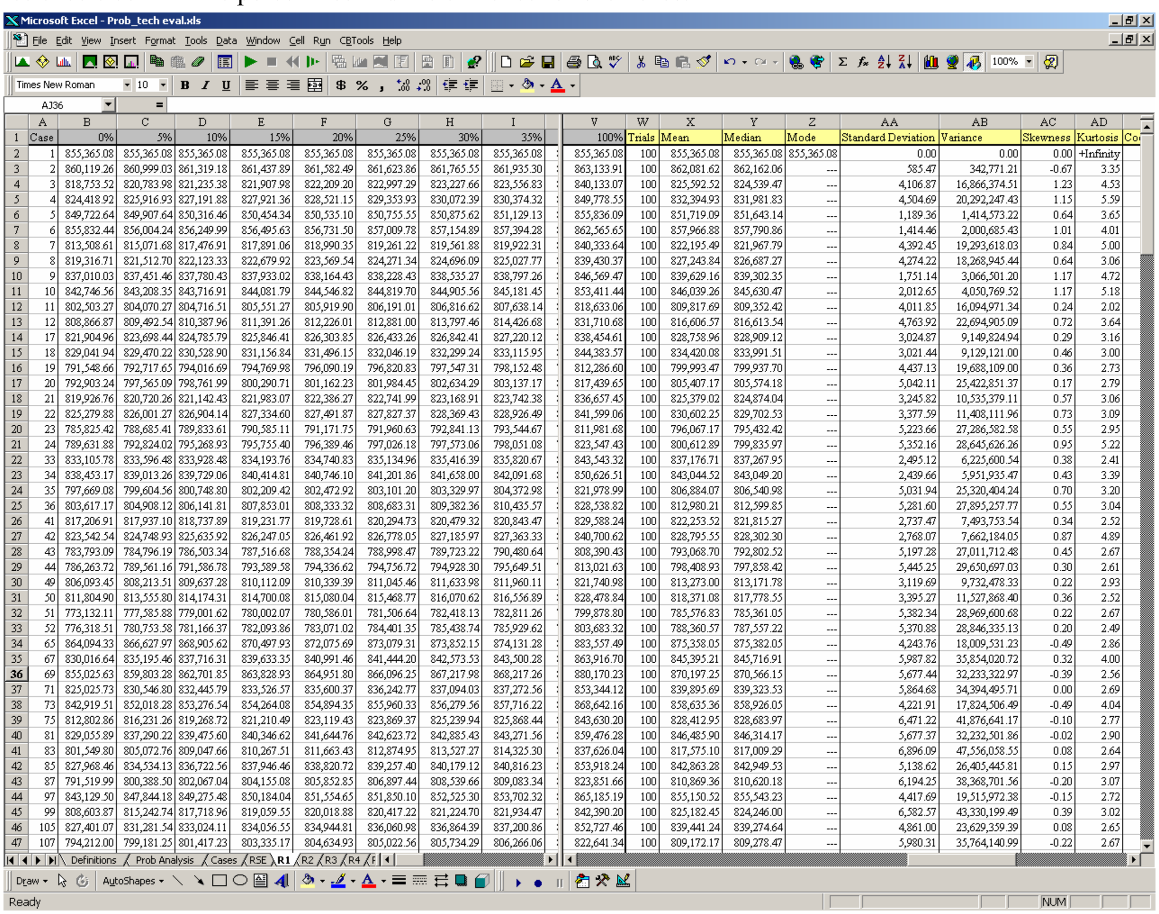
The "Definitions" sheet defines the necessary information in order to run the macro to assess the different technology combinations probabilistically. The 'Inputs' reflect the number of technologies, how many Monte Carlo repetitions you want, how many responses, and how many cases. The 'Run Preferences' set the run preferences for the macro. The setup in this shot is the fastest way to run. Your computer's Run Preferences will remain as set by the macro after it has completed. To change them, go to **Run**, **Run Preferences**. The Run Preferences will change to the preferences on the "Definitions" sheet every time you run the macro.



Unless you have changed sheet names, the macro should not require editing. Under **Tools**, choose **Macro**, then **Macros**. Select **Monte_Carlo** and **Run**. This macro will run Crystal Ball on each technology combinations. It extracts the percentiles and statistics and pastes them into the sheet for each response (R1 is the data for the first response and so on). If you want to see what it is doing, edit the macro and change all the Application.ScreenUpdating = False to true. This takes longer, but you can see each part of the macro.



A sheet for each response, numbered in the order of the RSE, has been created and filled by the macro. Your response sheets contain the percentiles and the statistics for each case.



These response sheets form a second decision matrix with probabilistic instead of deterministic results for each metric. Only compatible cases were brought in and evaluated so the cases do not need to be tested for compatibility as was done with the deterministic decision matrix. The probabilistic decision matrix will be used in step 8 to examine Technology Sensitivities and Technology Frontiers for different confidence levels.

Step 8: Select Best Family of Alternatives

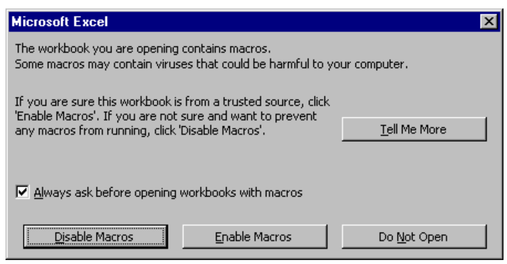
For any multi attribute, constraint, or criteria problem, the selection of the "best" family of alternatives is inherently subjective with no single answer fulfilling all requirements. Four techniques are used in the TIES method:

1) Multi-Attribute Decision-Making techniques (TOPSIS)
2) Technology Frontiers
3) Technology Sensitivities
4) Hierarchic Genetic Algorithms

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

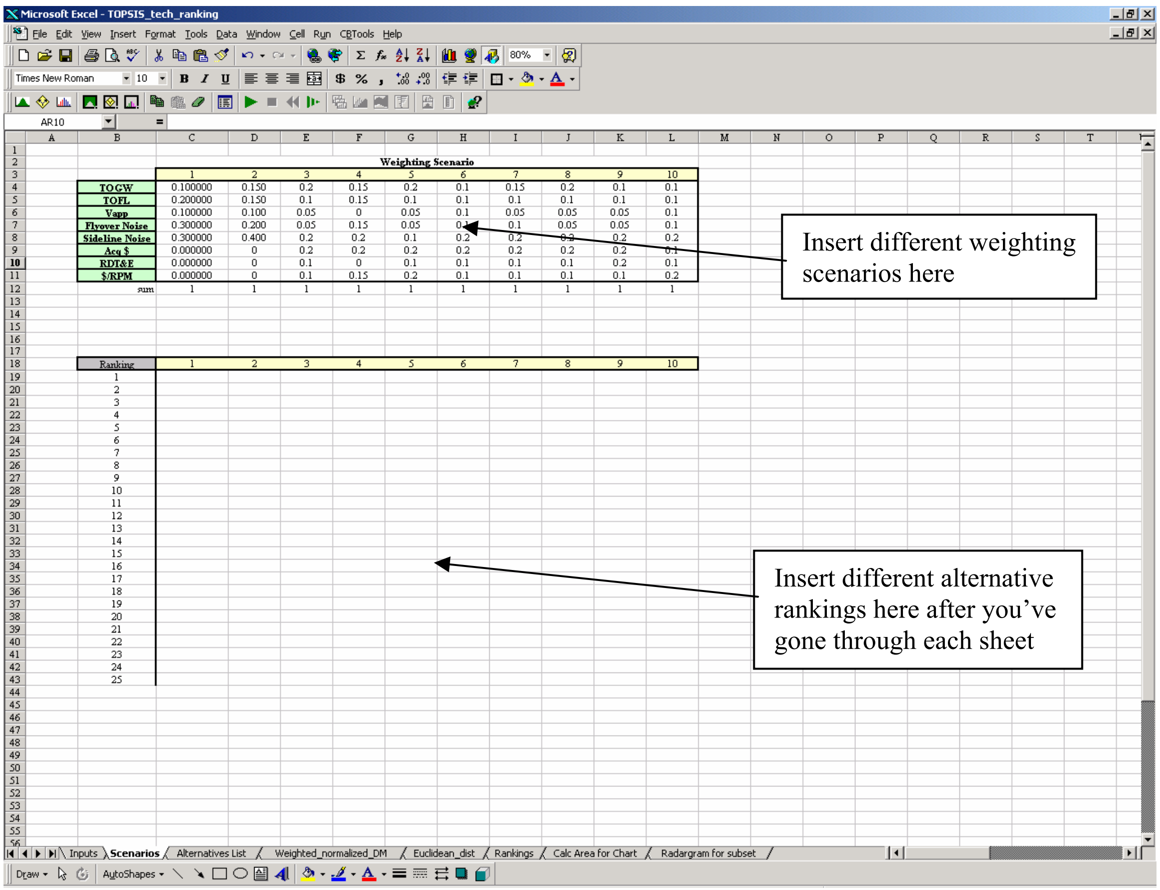
A Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is utilized to down select the proper mix of technologies satisfying the system level metrics. TOPSIS provides a preference order of the deterministic values obtained in the Decision Matrix, at a given confidence level, resulting in a ranking of the best alternative concepts. I will not go through the math behind the TOPSIS method. You can go read one of the references to get more info. I will simply explain how you do it with the spreadsheets that I have provided.

If you have the HSCT with 11 technologies and the compatibility matrix from Step 6 of this tutorial, you have only 272 compatible combinations (or alternatives). You have obtained your response values of the vehicle with those technologies "on". Open the Excel file "TOPSIS_tech_ranking". The window below will come up, just click the button **Enable Macros**.



Regardless of which TOPSIS spreadsheet you have, there are 8 sheets including "Inputs", "Scenarios", "Alternatives List", "Weighted_normalized_DM", "Euclidean_dist", "Rankings", "Calc Area for Chart", and "Radargram for subset".

The first sheet is the "Inputs" sheet, but we will come back to it. On the next sheet, "Scenarios", are 10 different subjective weighting scenarios. What I typically will do is place heavy weighting on the performance metrics on the left and shift to heavy economic weighting on the right. I tend to place more importance on the metrics that are the concept "show-stoppers", or constraints that are hurting me most. In the sheet below, one scenario that I would consider is one that places heavy weighting on the Flyover and Sideline Noise metrics, since both of those had very low, if even existent, feasibility values. Hence, insert 10 or more different weighting scenarios depending on the metrics, the significance of each metric, and try to capture varying importance of the different metrics. The idea here is to determine if a given set of technology mixes will dominate in importance regardless of the weighting scenario considered.



	1	2	3	4	5	6	7	8	9	10
TOGW	0.100000	0.150	0.2	0.15	0.2	0.1	0.15	0.2	0.1	0.1
TOFL	0.200000	0.150	0.1	0.15	0.1	0.1	0.1	0.1	0.1	0.1
Vapp	0.100000	0.100	0.05	0	0.05	0.1	0.05	0.05	0.05	0.1
Flyover Noise	0.300000	0.200	0.05	0.15	0.05	0.1	0.1	0.05	0.05	0.1
Sideline Noise	0.300000	0.400	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2
Acq $	0.000000	0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.1
RDT&E	0.000000	0	0.1	0	0.1	0.1	0.1	0.1	0.2	0.1
$/RPM	0.000000	0	0.1	0.15	0.2	0.1	0.1	0.1	0.1	0.2
sum	1	1	1	1	1	1	1	1	1	1

Ranking	1	2	3	4	5	6	7	8	9	10
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										
11										
12										
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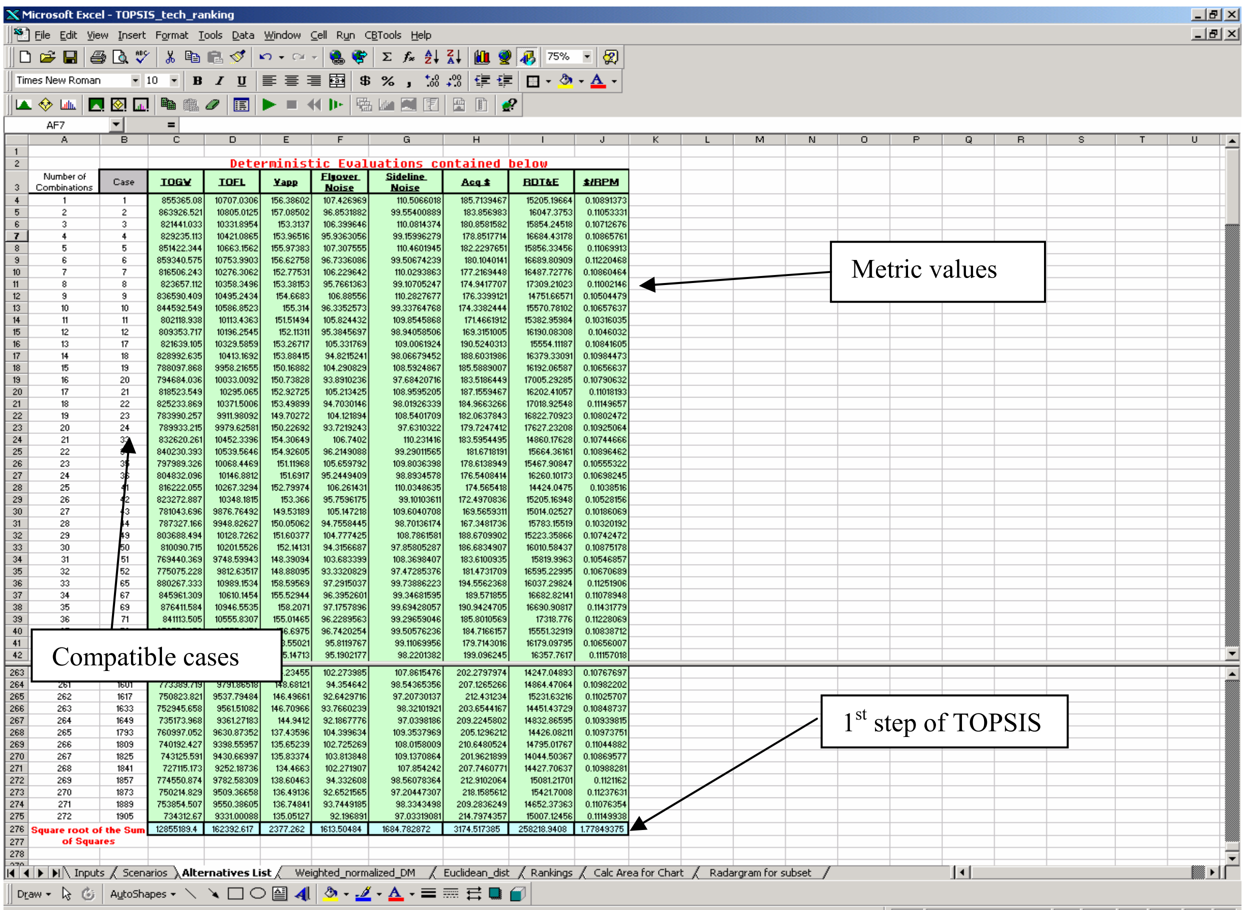
25										

The "Alternatives List" sheet has the case numbers of the compatible technology combinations and the corresponding metric values for 8 metrics. You need to copy the metric values and case numbers into this sheet for all the compatible cases. You can copy these from the "Compatible list" sheet in the "Calc_deterministic_Full_fact_tech" file. As shown below, the square root of the sum of squares is calculated for each metric as the bottom of the page. The equation for this is shown for the TOGW below.

Example Excel formula for square root of sum of squares (TOGW):
=SQRT(SUMSQ(C$4:C$275))

This format is used for all metrics. Note, if you have more or less responses than the 8 given in the HSCT file, you need to modify ALL sheets that are dependent upon the number of response (i.e., attribute) columns .



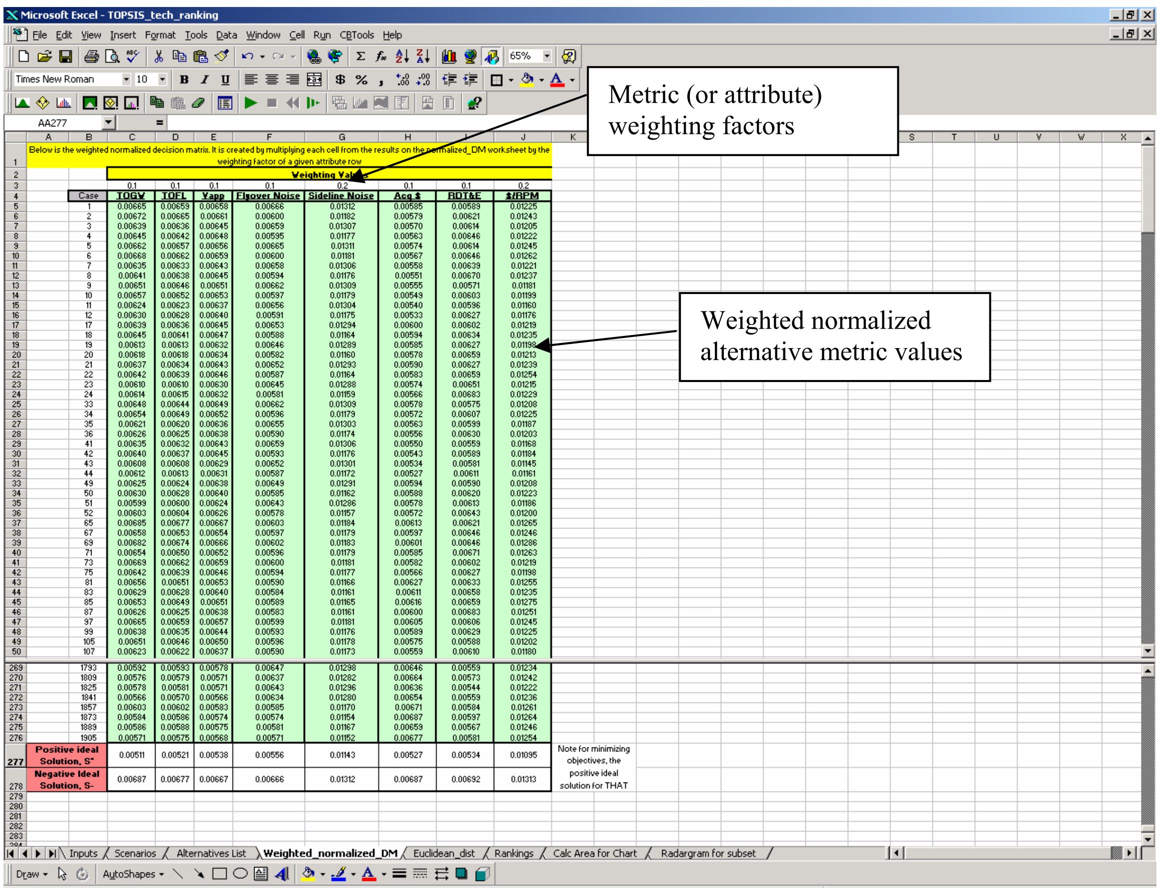
The next sheet is the "Weighted_normalized_DM". Two things are done on this sheet. First, the decision matrix is normalized and multiplied by the subjective weighting values defined by you. It is updated automatically from the alternatives sheet. It is found with this equation:

=('alternatives list'! original value/'alternatives list'! sum-of-squares)* weighting value

Next the positive ideal and negative ideal solutions are determined for each metric. These are at the bottom of the matrix and are determined based on the following equations. For both TOPSIS spreadsheets provided, all the metrics are desired to be minimized, i.e., in the context of TOPSIS, they are considered "costs". If you want to maximize a metric, it is considered a "benefit". So, the Excel formulas used to determine the positive and negative ideal solutions are:

If you want to minimize your metrics, say TOGW, the ideal solutions are defined as:
Positive Ideal Solution, S^+ =MIN(C5:C276)
Negative Ideal Solution, S^- =MAX(C5:C276)

If you want to maximize your metrics, say TOGW, the ideal solutions would be defined as:
Positive Ideal Solution, S^+ =MAX(C5:C276)
Negative Ideal Solution, S^- =MIN(C5:C276)



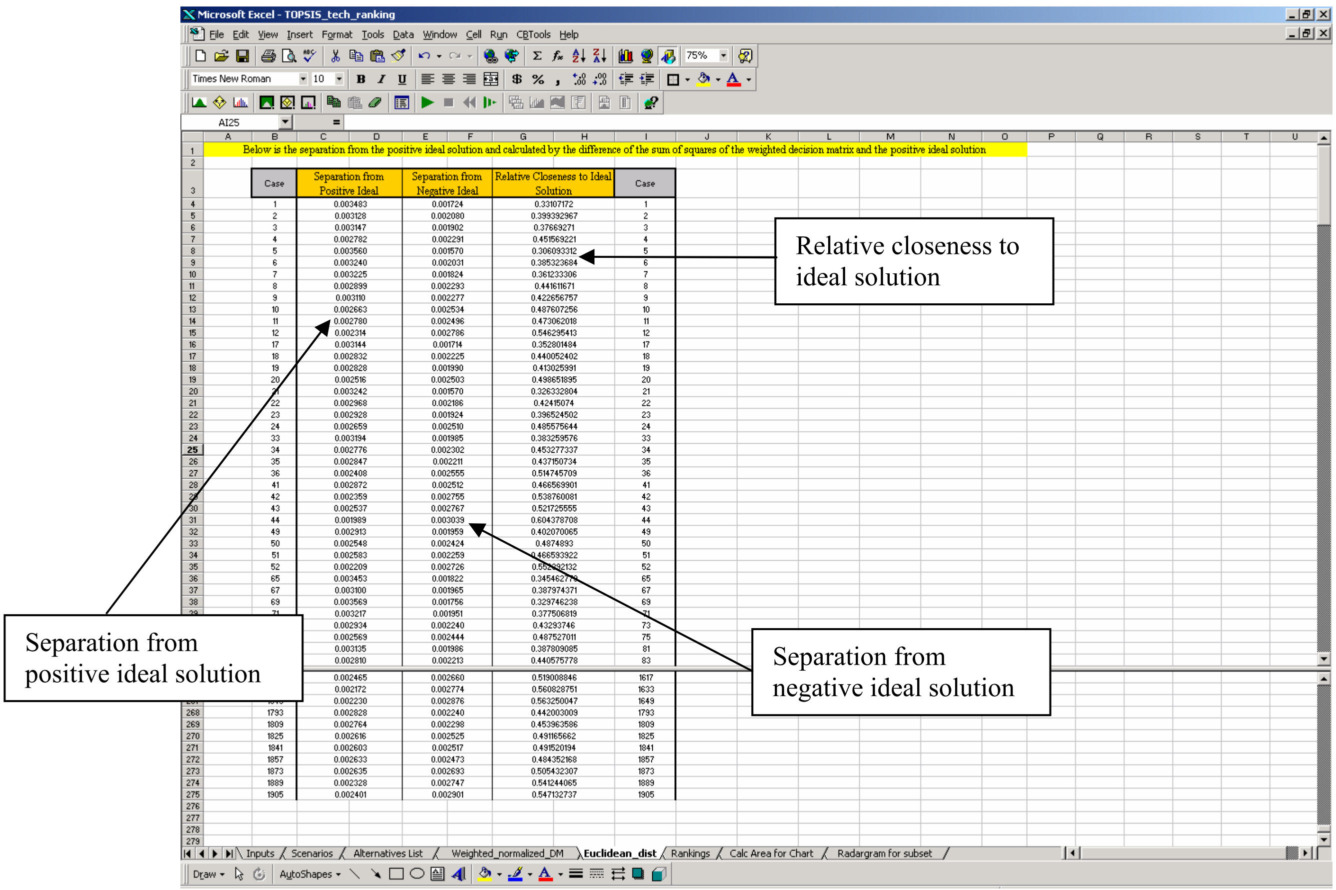
The next sheet is the "Euclidean_dist" sheet. This sheet determines the separation from the positive and negative ideal solutions and calculated by the difference of the sum of squares of the weighted decision matrix and the positive ideal solution and negative ideal solutions, respectively. Examples of these two calculations are provided. In addition, the relative closeness to the Ideal Solution is determined. You will use these values for the alternative rankings. An example of how this is calculated is also provided.

Example formula for the Separation from the Positive Ideal Solution:
=SQRT(SUMXMY2(Weighted_normalized_DM!C5:J5,Weighted_normalized_DM!C$277:J$277))

Example formula for the Separation from the Negative Ideal Solution:
=SQRT(SUMXMY2(Weighted_normalized_DM!C5:J5,Weighted_normalized_DM!C$278:J$278))

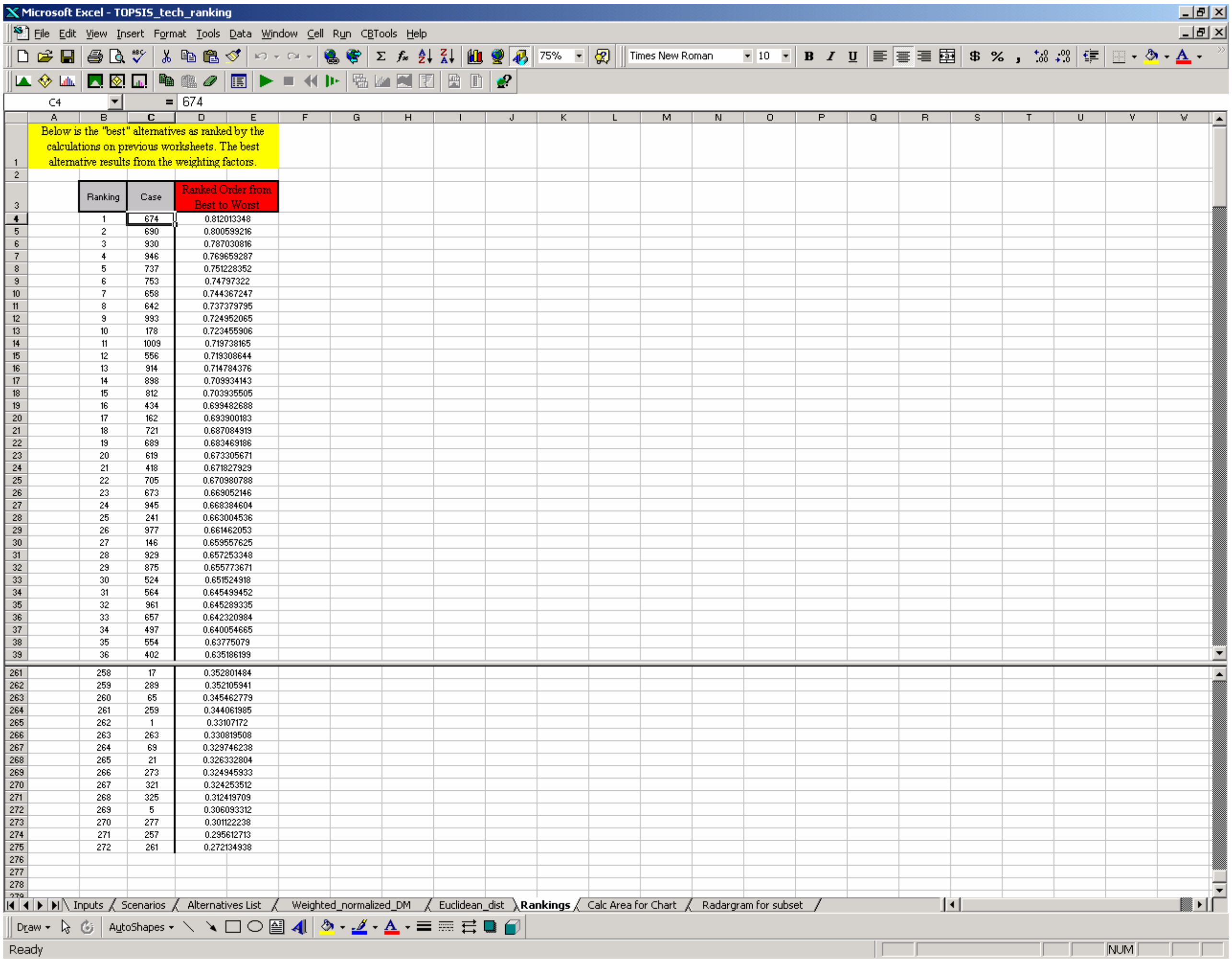
Example formula for calculating the Relative Closeness to the Ideal solution:
=E4/(E4+C4)

Remember, if you have a different number of cases or metrics, you need to modify the cell referencing.



Case	Separation from Positive Ideal	Separation from Negative Ideal	Relative Closeness to Ideal Solution	Case
1	0.003483	0.001724	0.33107172	1
2	0.003128	0.002080	0.399392967	2
3	0.003147	0.001902	0.37669271	3
4	0.002782	0.002291	0.451569221	4
5	0.003560	0.001570	0.306093312	5
6	0.003240	0.002031	0.385323684	6
7	0.003225	0.001824	0.361233306	7
8	0.002899	0.002293	0.441611671	8
9	0.003110	0.002277	0.422656757	9
10	0.002663	0.002534	0.487607256	10
11	0.002780	0.002496	0.473062018	11
12	0.002314	0.002786	0.546295413	12
17	0.003144	0.001714	0.352801484	17
18	0.002832	0.002225	0.440052402	18
19	0.002828	0.001990	0.413025991	19
20	0.002516	0.002503	0.498651895	20
21	0.003242	0.001570	0.326332804	21
22	0.002968	0.002186	0.42415074	22
23	0.002928	0.001924	0.396524502	23
24	0.002659	0.002510	0.485575644	24
33	0.003194	0.001985	0.383259576	33
34	0.002776	0.002302	0.453277337	34
35	0.002847	0.002211	0.437150734	35
36	0.002408	0.002555	0.514745709	36
41	0.002872	0.002512	0.466569901	41
42	0.002359	0.002755	0.538760081	42
43	0.002537	0.002767	0.521725555	43
44	0.001989	0.003039	0.604378708	44
49	0.002913	0.001959	0.402070065	49
50	0.002548	0.002424	0.4874893	50
51	0.002583	0.002259	0.466593922	51
52	0.002209	0.002726	0.552292132	52
65	0.003453	0.001822	0.345462779	65
67	0.003100	0.001965	0.387974371	67
69	0.003569	0.001756	0.329746238	69
71	0.003217	0.001951	0.377506819	71
	0.002934	0.002240	0.43293746	73
	0.002569	0.002444	0.487527011	75
	0.003135	0.001986	0.387809085	81
	0.002810	0.002213	0.440575778	83
	0.002465	0.002660	0.519008846	1617
	0.002172	0.002774	0.560828751	1633
	0.002230	0.002876	0.563250047	1649
1793	0.002828	0.002240	0.442003009	1793
1809	0.002764	0.002298	0.453963586	1809
1825	0.002616	0.002525	0.491165662	1825
1841	0.002603	0.002517	0.491520194	1841
1857	0.002633	0.002473	0.484352168	1857
1873	0.002635	0.002693	0.505432307	1873
1889	0.002328	0.002747	0.541244065	1889
1905	0.002401	0.002901	0.547132737	1905

The next sheet is "Rankings". This sheet has columns for the ranking, case number, and the 'relative closeness to ideal solution' value, which is labeled 'Ranked Order from Best to Worst'. The case number and ranked order columns should be blank until you run the macro.



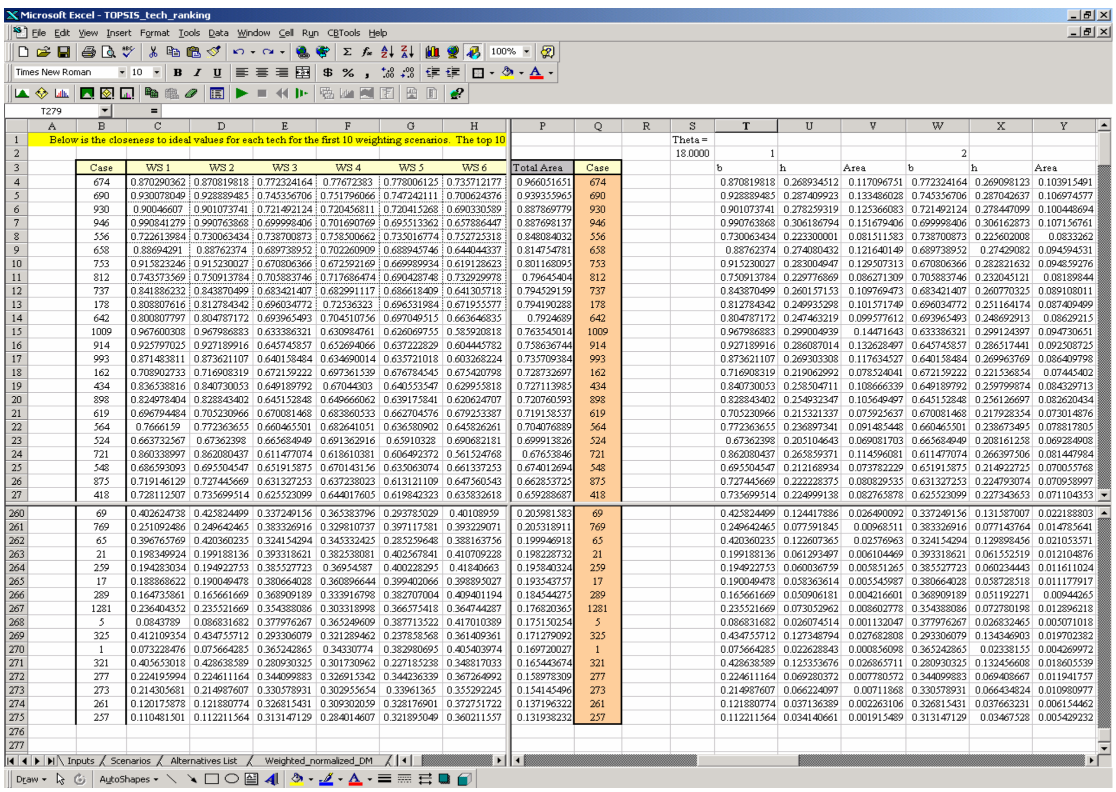
	Ranking	Case	Ranked Order from Best to Worst
4	1	674	0.812013348
5	2	690	0.800599216
6	3	930	0.787030816
7	4	946	0.769659287
8	5	737	0.751228352
9	6	753	0.74797322
10	7	658	0.744367247
11	8	642	0.737379795
12	9	993	0.724952065
13	10	178	0.723455906
14	11	1009	0.719738165
15	12	556	0.719308644
16	13	914	0.714784376
17	14	898	0.709934143
18	15	812	0.703935505
19	16	434	0.699482688
20	17	162	0.693900183
21	18	721	0.687084919
22	19	689	0.683469186
23	20	619	0.673305671
24	21	418	0.671827929
25	22	705	0.670980788
26	23	673	0.669052146
27	24	945	0.668384604
28	25	241	0.663004536
29	26	977	0.661462053
30	27	146	0.659557625
31	28	929	0.657253348
32	29	875	0.655773671
33	30	524	0.651524918
34	31	564	0.645499452
35	32	961	0.645289335
36	33	657	0.642320984
37	34	497	0.640054665
38	35	554	0.63775079
39	36	402	0.635186199
261	258	17	0.352801484
262	259	289	0.352105941
263	260	65	0.345462779
264	261	259	0.344061985
265	262	1	0.33107172
266	263	263	0.330819508
267	264	69	0.329746238
268	265	21	0.326332804
269	266	273	0.324945933
270	267	321	0.324253512
271	268	325	0.312419709
272	269	5	0.306093312
273	270	277	0.301122238
274	271	257	0.295612713
275	272	261	0.272134938

The last two sheets we'll talk about later. So, let's run the macro.

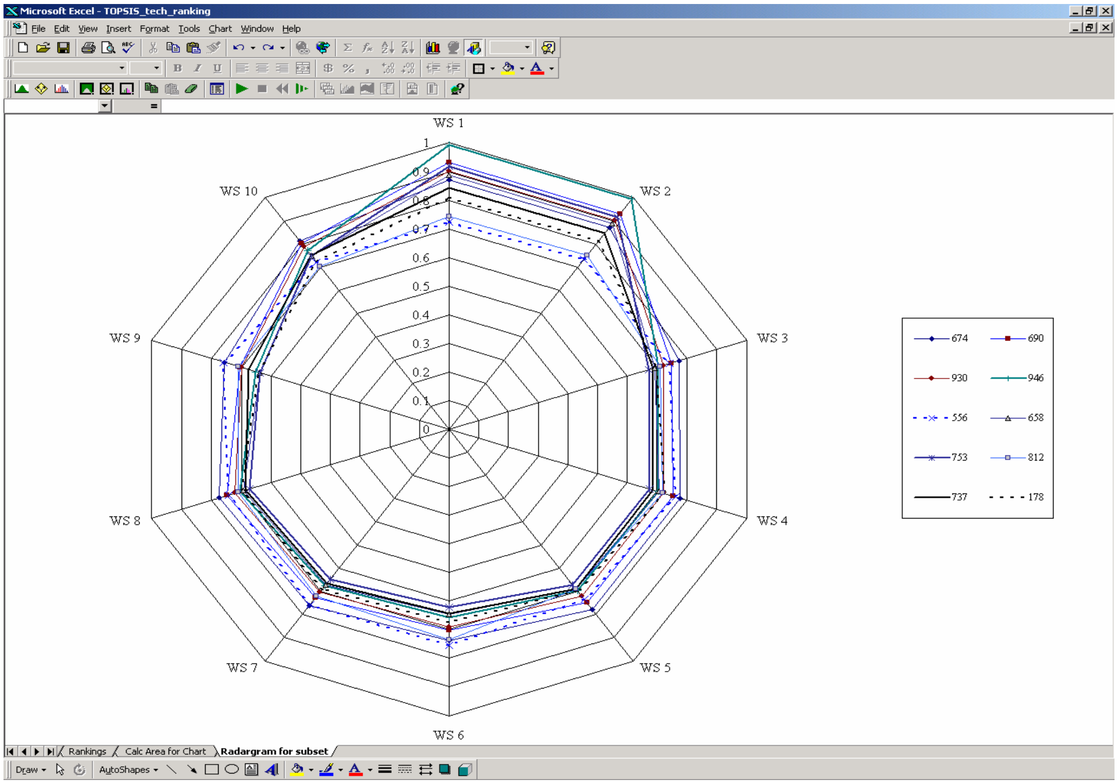
To evaluate the different weighing scenarios, you can run the “run_topsis” macro. In order to do this, you must fill in the “Inputs” sheet to reflect the number of technology combinations, responses, weighting scenarios, and top alternatives to extract. Then go to the **Tools** menu, select **Macro**, and then **Macros**. Select the “run_topsis” macro and hit **Run**.

The first thing the macro does is copy the weighting factors for the first scenario from the “Scenarios” sheet to the “Weighted_normalized_DM” sheet. The values for the weighted normalized responses automatically update. Then the values for the ‘Relative Closeness to Ideal Solution’, which also update automatically, are copied from the “Euclidean_distance” sheet and pasted to the “Rankings” sheet under the ‘Ranked Order from Best to Worst’ column and to the “Calc Area for Chart” sheet into the column for the first weighting scenario. The case numbers are then copied to the “Rankings” sheet in the ‘Case’ column. Next, the ‘Case’ and ‘Ranked Order from Best to Worst’ columns on the “Rankings” sheet are sorted in descending order by the ‘Ranked Order from Best to Worst’ column. Finally, the top 25 case numbers are pasted into the “Scenarios” sheet in the ‘Ranking’ column for the first scenario. This process is repeated for all the weighting scenarios.

The “Calc Area for Chart” sheet uses the relative closeness values to find a top ten overall. This page calculates area based on a ten spoke circle (based on ten weighing scenarios). It calculates the area, sums it, and uses this to rank its top ten combinations. These top ten are graphed, with their relative closeness values for each weighting scenario, on the last page, “Radargram for subset”. This graph should automatically update when the macro has been run. The “Calculated Area for Chart” sheet should look like this:



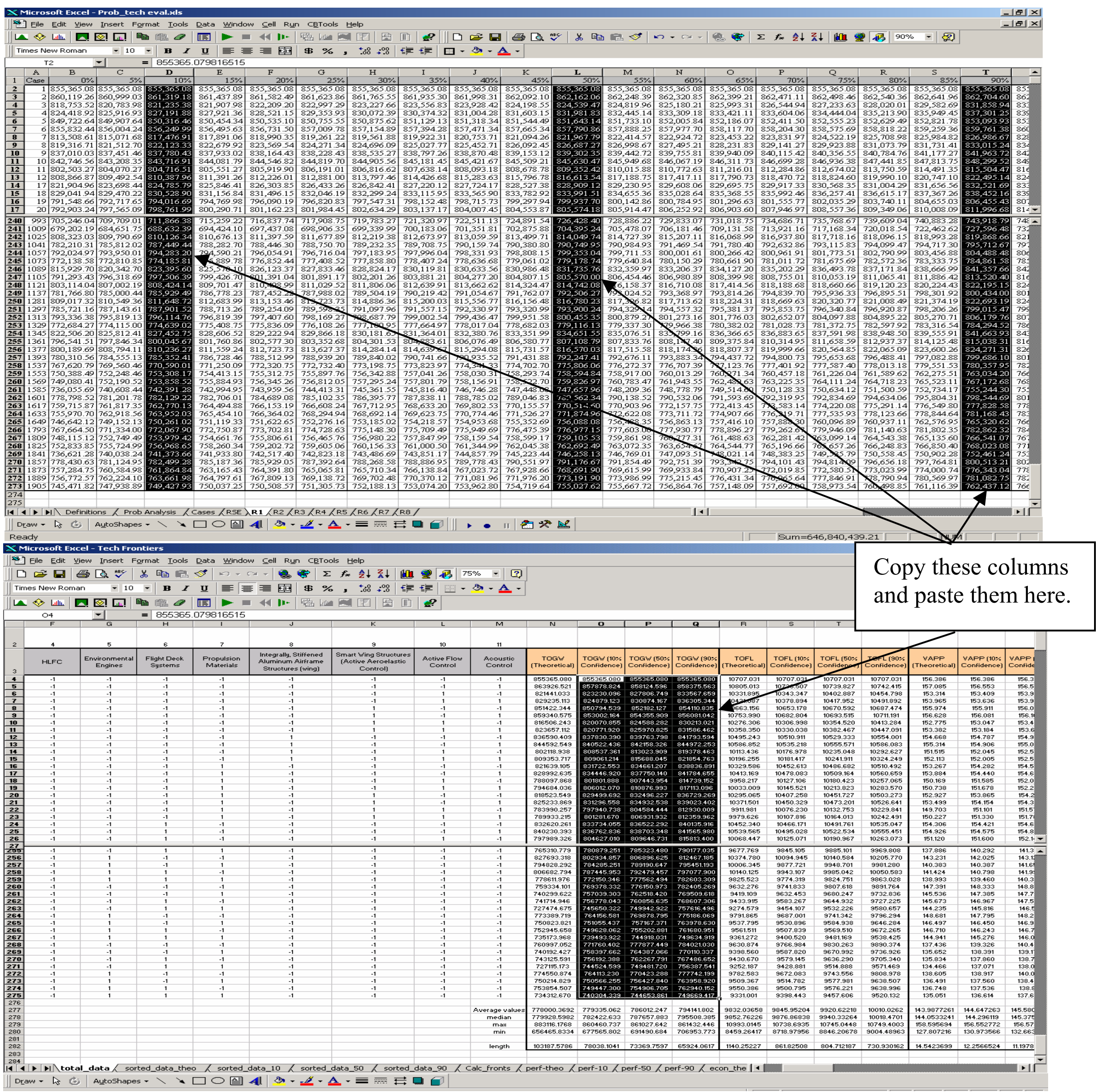
And the Radargram like this:



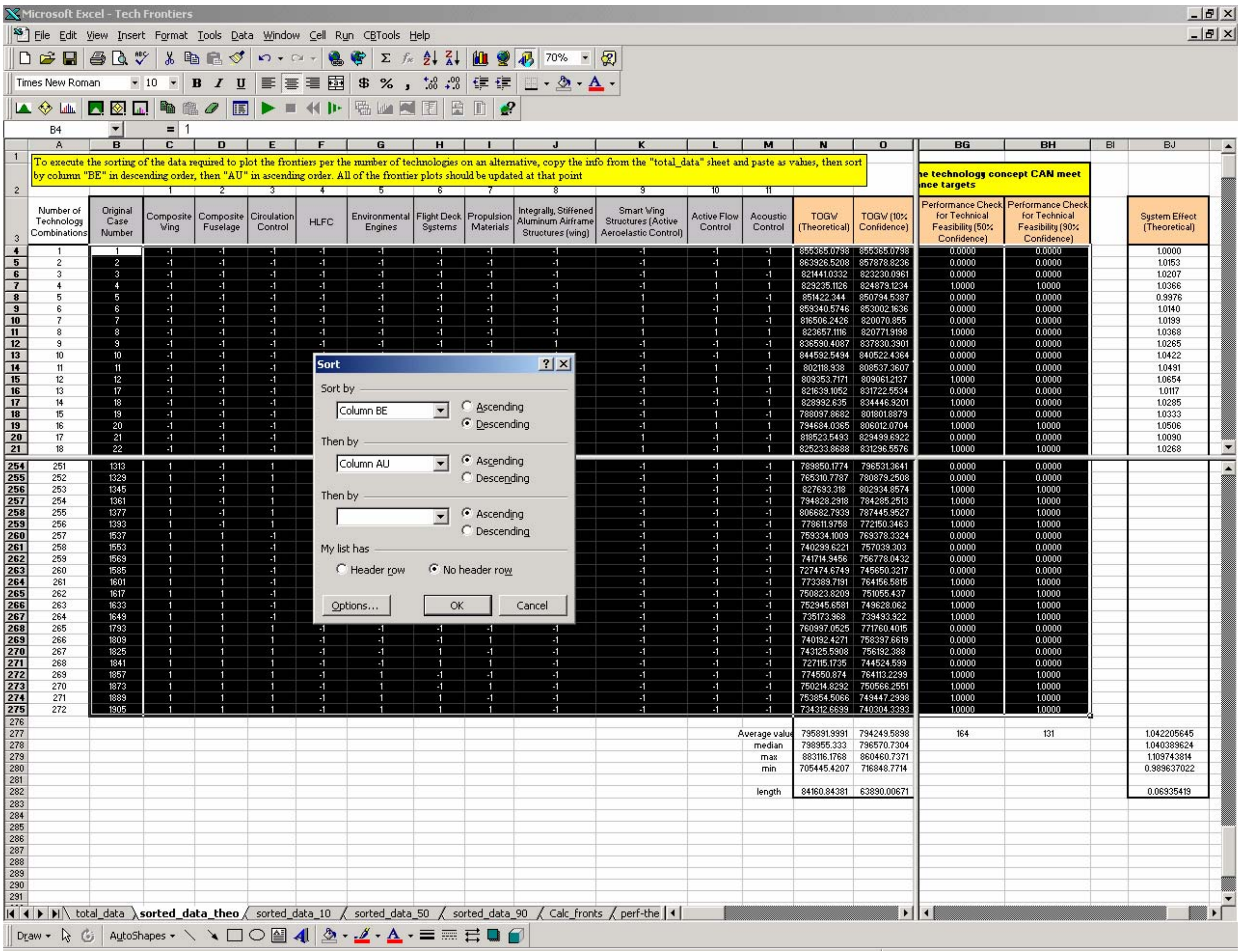
Technology Frontiers

The inefficiencies of the Multi-Attribute Decision-Making techniques, deterministics, and non-intuitive numerical results may be improved with the use of the Technology Frontiers. Technology Frontiers are defined as the limiting threshold of an “effectiveness” parameter. The technology frontiers are similar to TOPSIS with the use a user-defined function for which maximization is desired. The Technology Frontiers approach involves calculating the parameters for Performance Effectiveness (PE) and Economic Effectiveness (EE) using the baseline values and the value of the metrics for each alternative.

Open the file “Tech Frontiers”. This sheet will graph the technology frontiers for performance and economic effectiveness at each confidence level. This file has many sheets, including “total_data”, “sorted_data_theo”, “sorted_data_10”, “sorted_data_50”, “sorted_data_90”, and “Calc_fronts”, plus sheets for each of the graphs. First, you need to copy the compatible case numbers and 1s and –1s on the “total_data” sheet. Next, copy the value for each response from the “Compatible List” sheet of the “Calc_deterministic_Full_fact_tech” file and paste it into the ‘Theoretical’ column for each response. Now go back to the “Prob_tech eval” file and click on the first Response sheet. Since the “Tech Frontiers” file needs the response values for the confidence levels of 10%, 50%, and 90%, copy these columns from the response sheet into the appropriate columns on the “total_data” sheet. To clarify’ for the first response, which is TOGW on sheet “R1”, copy columns D, L, and T and paste them into columns O, P, and Q. Repeat this for all the responses. Be sure to modify the number of responses if you have more or less then eight. If your number of cases differs, change cell references as you move through the workbook.



Now scroll to the right. The columns after the response columns contain formulas to calculate feasibility and performance and economic effectiveness. Check the formulas in columns BE through BH (feasibility check) and change them if you have different constraints. When all the formulas are updated, place your cursor in cell A4 and highlight all cells from B4 to BH275. This should be 272 rows, or as many cases as you have, and all columns from the ‘Original Case Number’ column to the ‘Performance Check for Technical Feasibility (90% Confidence)’ column. Copy this and go to the next sheet, “sorted_data_theo”. Paste Special and choose Values into cell B4. On the “sorted_data_theo” sheet, sort by column "BE" in descending order, then "AU" in ascending order. Copy the original data from the “total_data” page into the “sorted_data_10”, “sorted_data_50”, and “sorted_data_90” sheets and follow the sorting instructions in yellow at the top of each page.

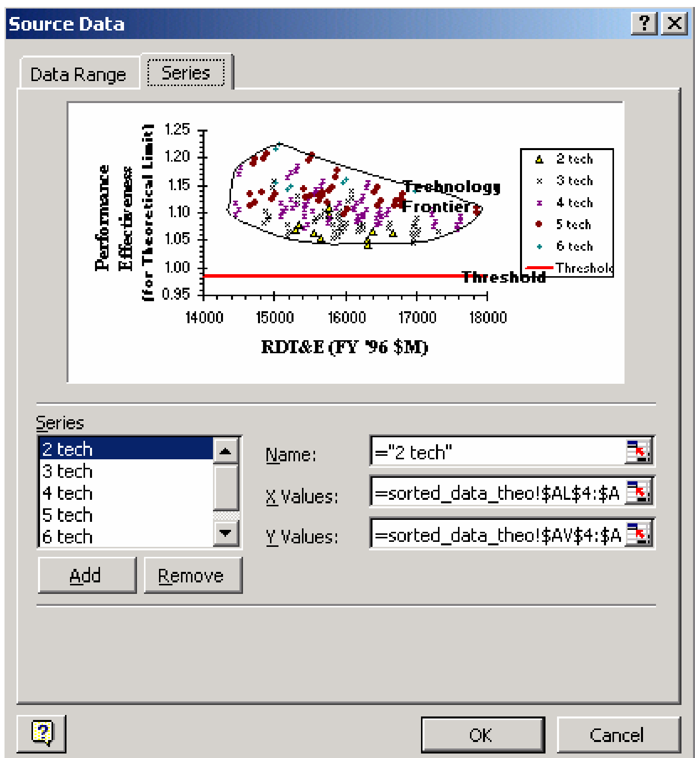


Now check the 16 graphs that follow. These are plots of RDT&E versus the various effectiveness parameters. These parameters are automatically calculated in the various sheets. If you have different variables or want a different weighing scenario, these formulas must be updated. The basic forms for these equations are:

$$PE_{Alt_i} = \alpha \frac{TOGW_{BL}}{TOGW_{Alt_i}} + \beta \frac{TOFL_{BL}}{TOFL_{Alt_i}} + \chi \frac{Vapp_{BL}}{Vapp_{Alt_i}} + \delta \frac{FON_{BL}}{FON_{Alt_i}} + \varepsilon \frac{SLN_{BL}}{SLN_{Alt_i}}$$

$$EE_{Alt_i} = \alpha \frac{Acq\$_{BL}}{Acq\$_{Alt_i}} + \beta \frac{\$/RPM_{BL}}{\$/RPM_{Alt_i}}$$

The graphs should automatically update based on the new data you copied in and sorted, but you need to change the cell range for each number of technologies. Click on the first graph page, "perf-theo", right-click and choose 'Source Data'. On the 'Series' tab, click on each of the data series and adjust the x and y values based on the number of technologies.



Now go to the "Calc_fronts" sheet, which calculated the thresholds. To calculate the Performance threshold, use the formula:

$$PE_{threshold} = \alpha \frac{TOGW_{BL}}{1{,}000{,}000 lbs} + \beta \frac{TOFL_{BL}}{11{,}000 ft} + \chi \frac{Vapp_{BL}}{155 kts} + \delta \frac{FON_{BL}}{106 EPNLdB} + \varepsilon \frac{SLN_{BL}}{103 EPNLdB}$$

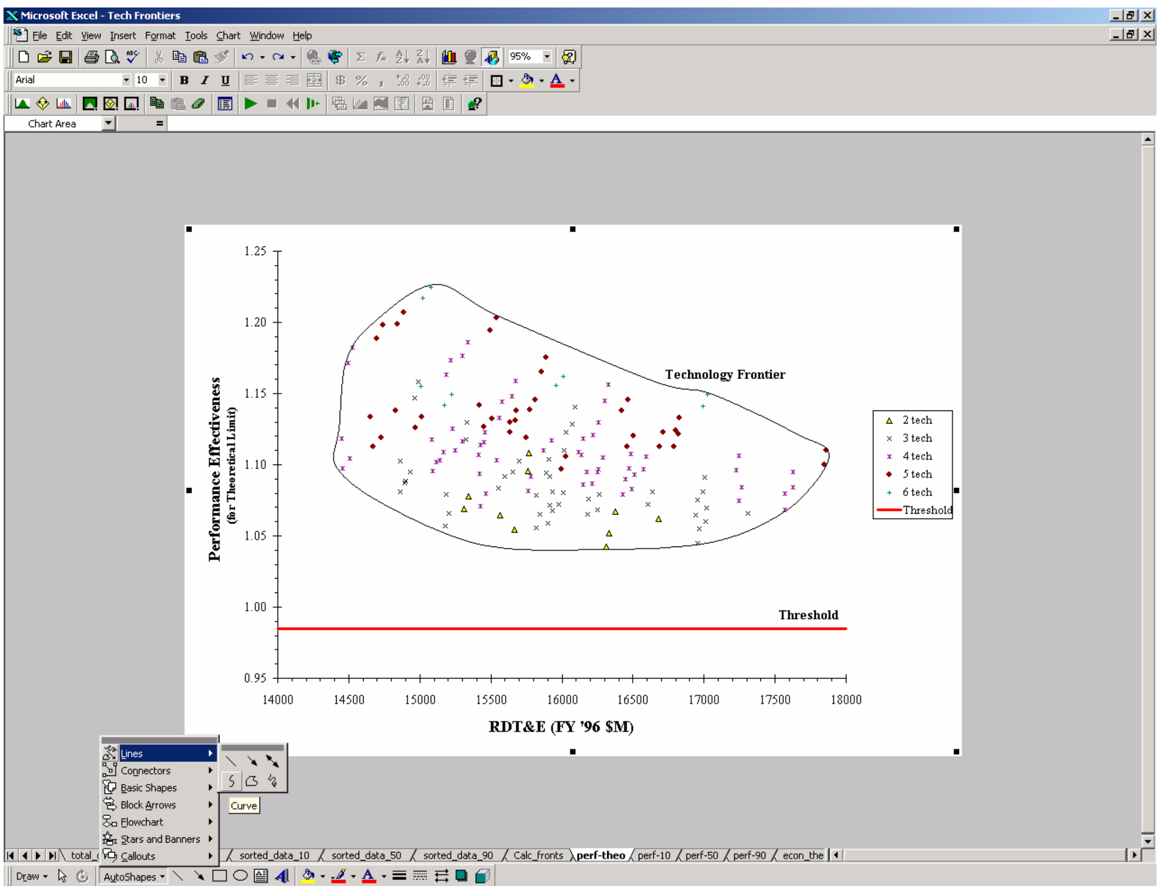
This formula should include all of your performance metrics. If you are using different constraints or metrics, you will need to adjust the formula. The weighing values are arbitrary. For this example, the different metrics have been weighted evenly. The coefficients must sum to one.

For the economic threshold, the formula is:

$$EE_{threshold} = \alpha \frac{Acq\$_{BL}}{\$185M} + \beta \frac{\$/RPM_{BL}}{\$0.10}$$

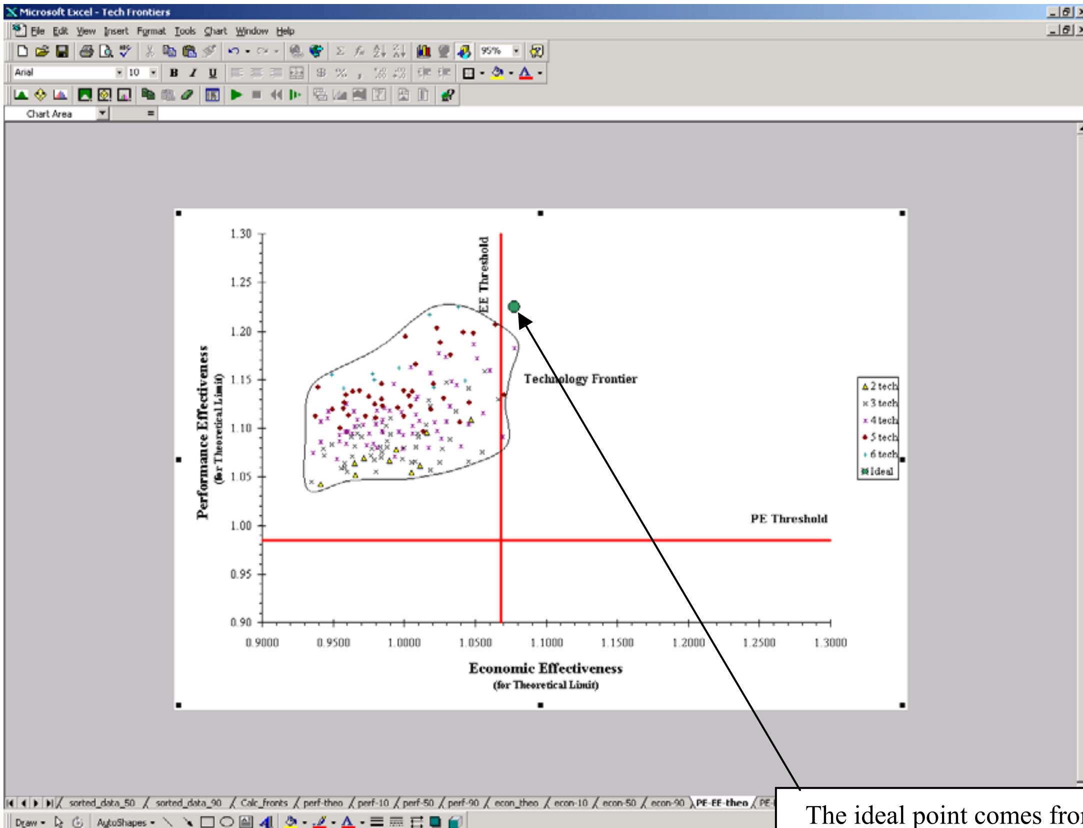
This reflects your economic metrics. If your metrics or constraints vary, the formula must be updated. For this threshold, $/RPM has been weighted with 0.75 in order to place more importance on that metric. The PE Threshold is the average of the performance and economic thresholds.

The Technology Frontier must be added using drawing tools. You can adjust an existing frontier by right clicking on the shape and selecting **Edit Points**. This will allow you to move and reshape the frontier. To add a new frontier, select **AutoShapes** from the drawing toolbar. Select **Lines** and then the curve as shown below.

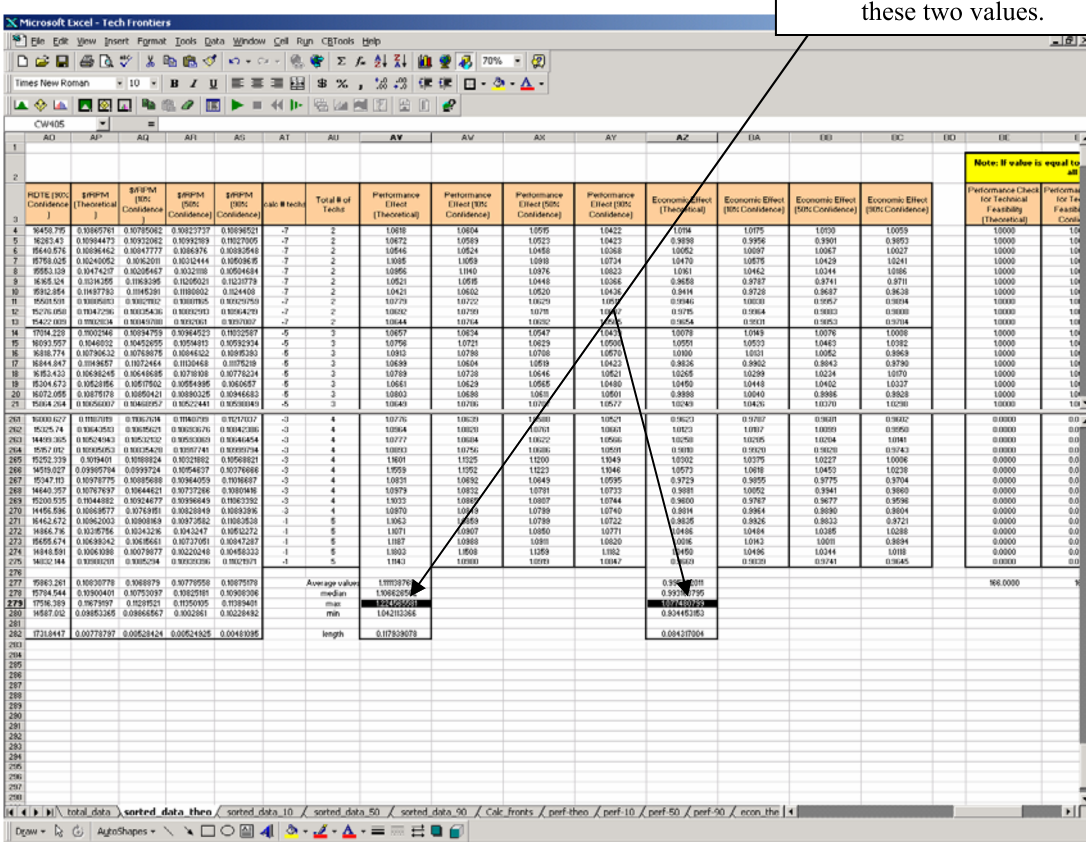


You can now drag and click points around the data points to make the technology frontier. Repeat checking that the number of technologies and the technology frontiers are correct on the rest of the graphs.

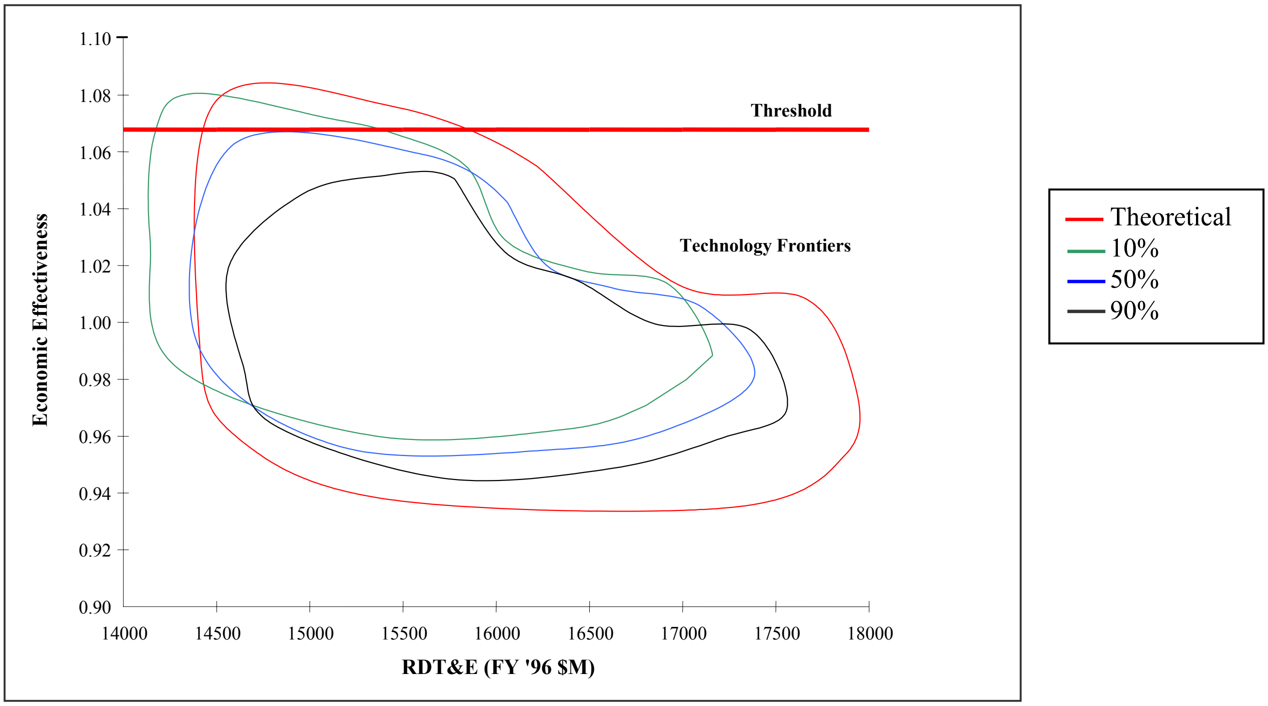
For the graphs of Economic versus Performance Effectiveness, check the data for the ideal point. This point should come from the maximum values of the two data groups at the given confidence level.



The ideal point comes from these two values.

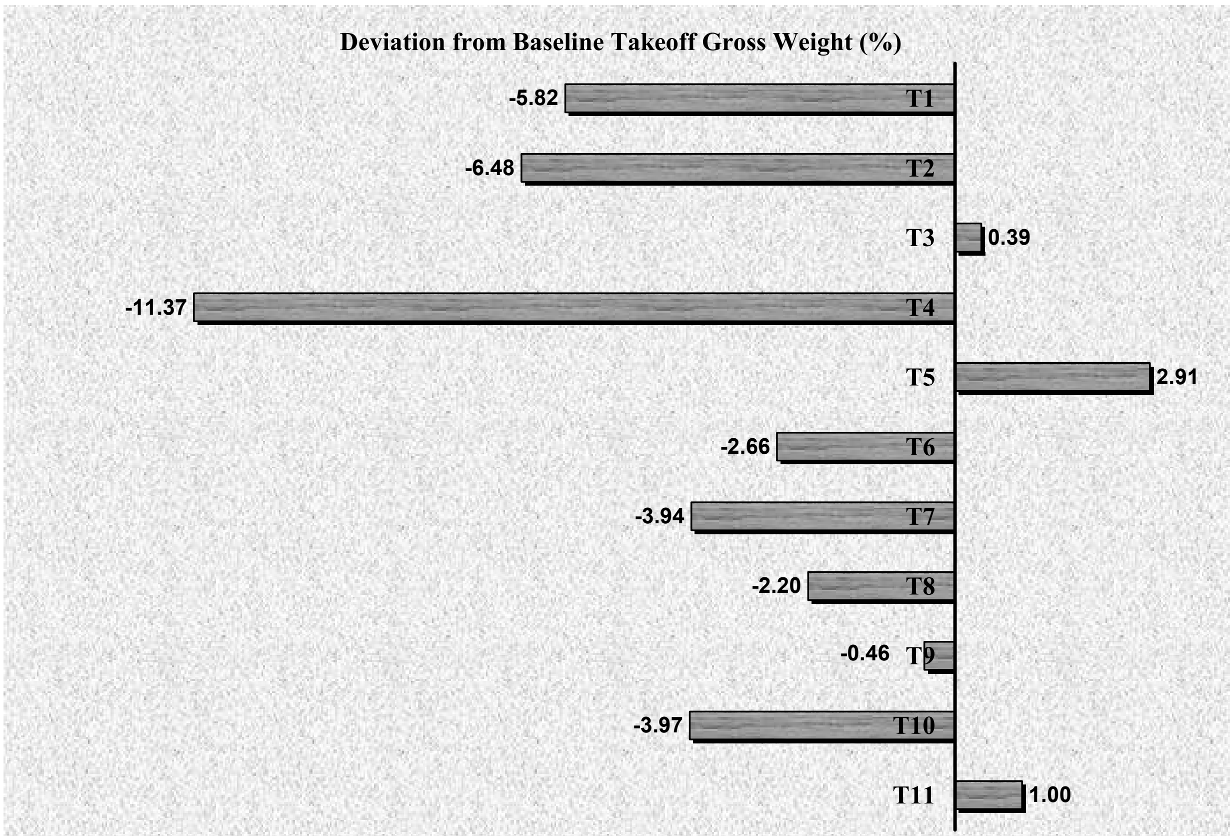


One interesting comparison is the Technology Frontiers between the confidence levels. This shows how the different confidence levels affect reaching the threshold without changing the general shape of the frontier.



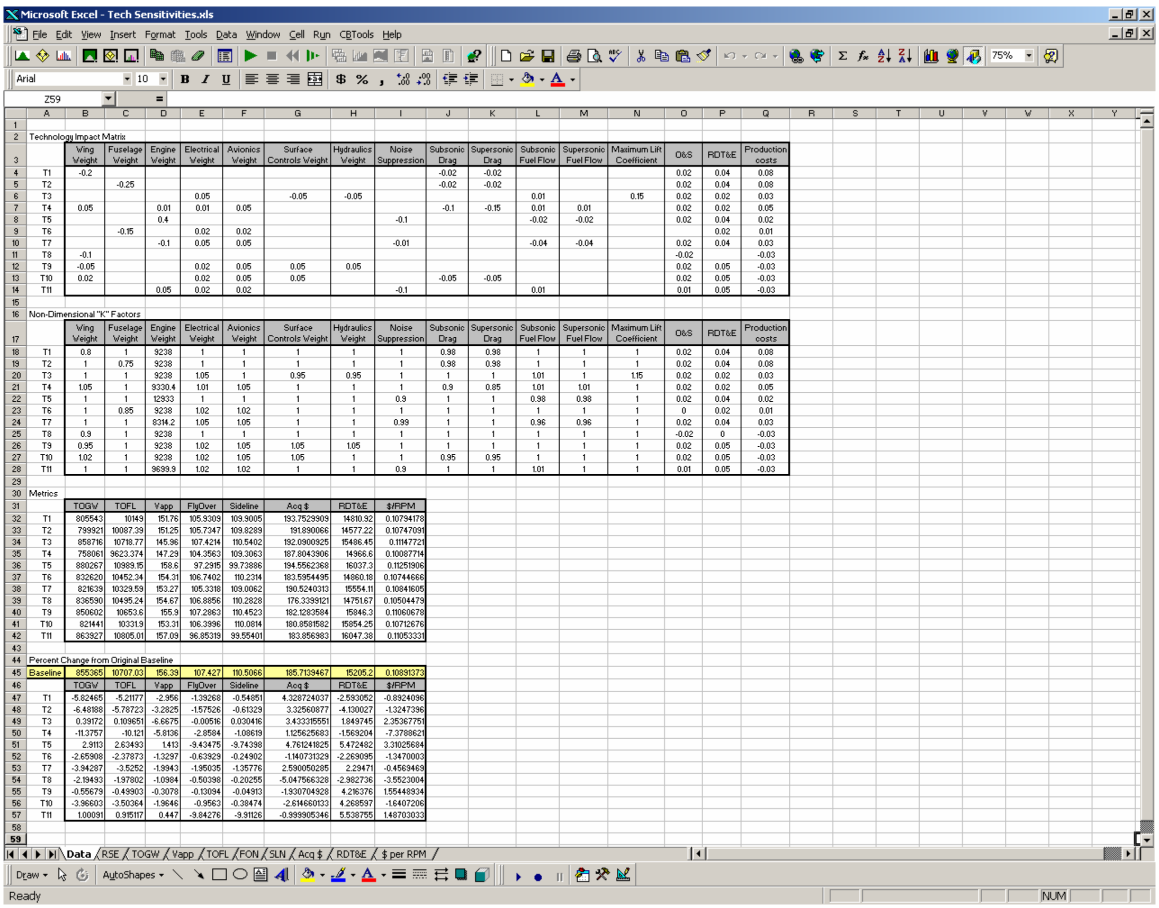
Technology Sensitivities

A technology sensitivity investigation is performed by a comparison of the infusion of the individual technologies to the conventional configuration, and evaluation of the deviations in metric values. The idea here is to determine which of the different technologies, as applied in isolation of the others, most influences the vehicle metrics. You have all the data and can simply manipulate it and format some pretty pictures. The example below is the impact of the 11 individual technologies on the TOGW of an HSCT. As you can see, T4, which was the HLFC technology, had the most significant impact on reducing the TOGW from the baseline value. Whereas T5, which was the Environmental Engines technology, had the most significant NEGATIVE impact on the TOGW.

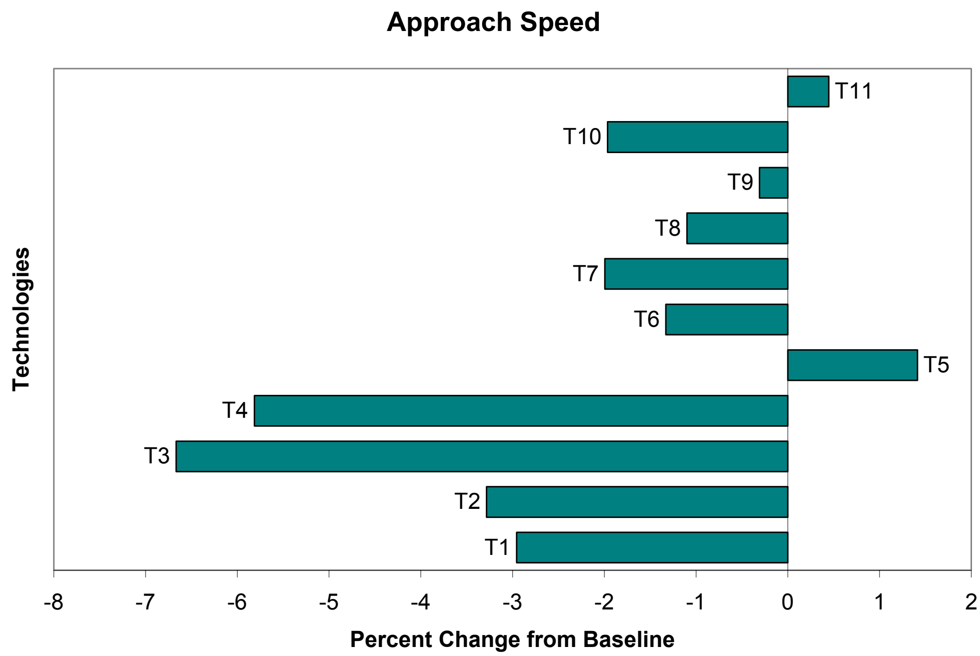


Now open the file "Tech Sensitivities". This file will calculate and graph the technology sensitivities. The first page is the "Data" page, where you need to copy in the technology impact matrix into the graph starting in cell B4. Then update the formulas for the "k" factors in the second graph starting in cell B18. Change the baseline in cells B45 to I45 if it differs from the one given. Be sure to edit the number of columns and rows if you have more or less technologies, metrics, or "k" factors. Next, you need to update the "RSE" page for your RSE. Then go back to the "Data" page and select the **Tools** menu, then **Macro** and then **Macros**. Choose the "run_techs" macro and edit it to reflect the number of technologies and responses. Make sure the cell references are right. Now run the macro. The cells from B32 to I42 should fill in with the metric values, and the 'Percent Change from Original Baseline' table should automatically update. Once the macro has finished, you can edit the graphs for the metrics.

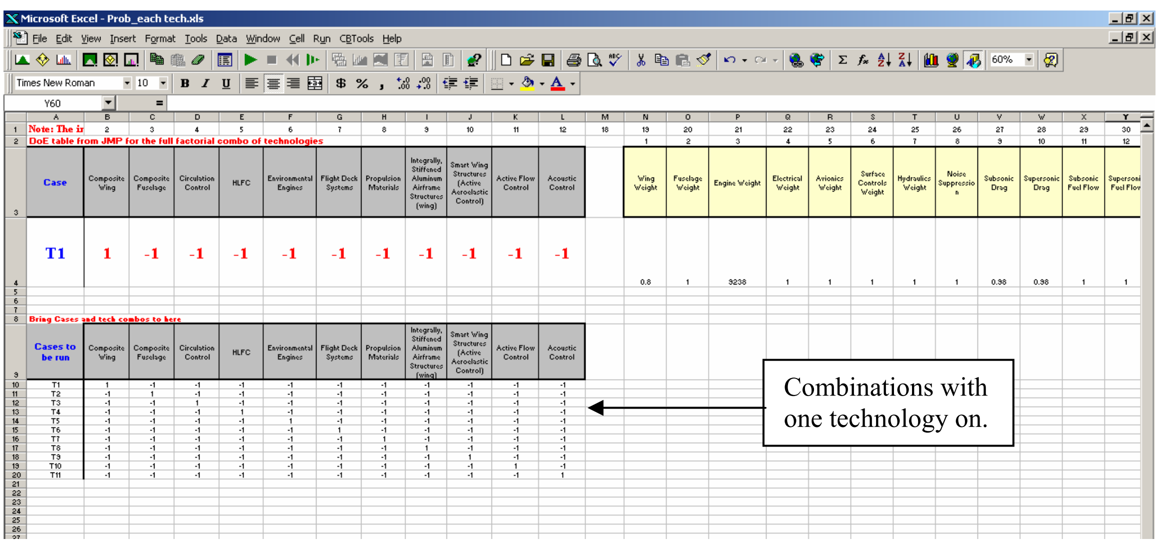
This information can also be found from the "Calc_deterministic_Full_fact_tech" spreadsheet. Find the case that has only the tech you are interested in on. Copy the metrics from these cases into the 'Metrics' matrix. This will update the 'Percent Change from Baseline' and the graphs.



Here's a sample technology sensitivity graph of approach speed. You can see that T5, environmental engines, increased the baseline the most, while T3, which is circulation control, reduced it the most.

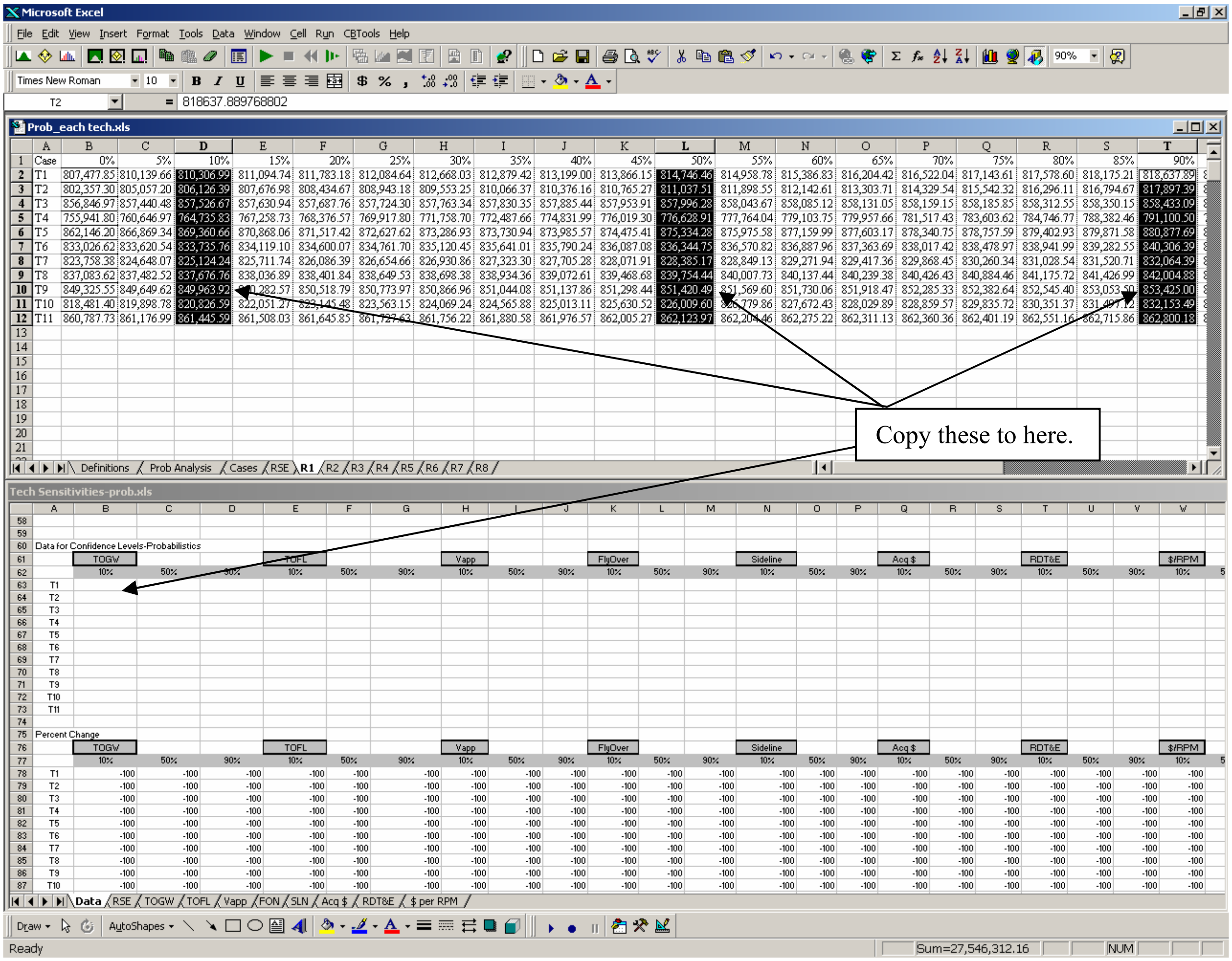


Using the "Prob_tech eval" sheet, it is possible to graph the different confidence levels for each technology sensitivity. Open the file and save it as "Prob_each tech". Now change the tech combinations on the "Cases" sheet so that each row has one tech on and the rest off. This chart should have as many rows as you have technologies.

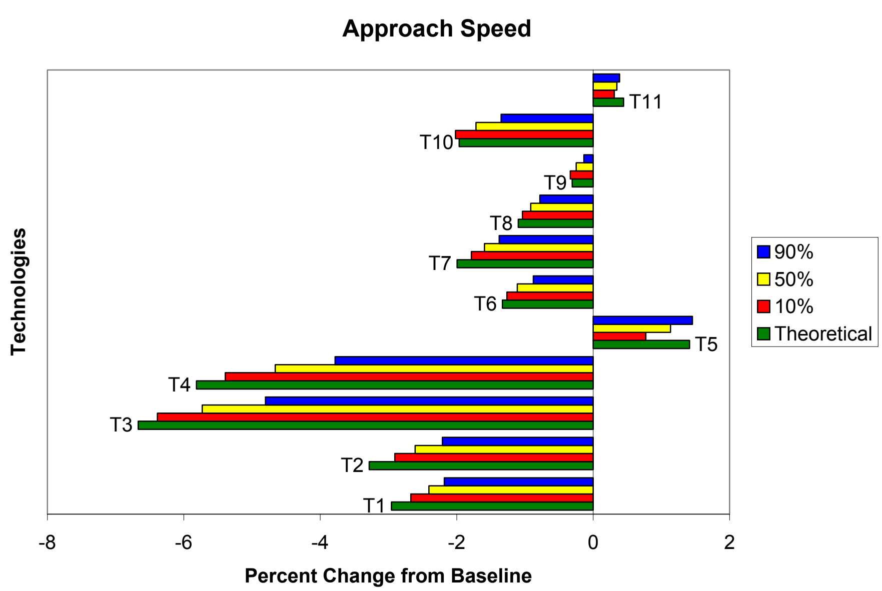


Now, change the number of cases on the "Definitions" sheet and rerun the **Monte_Carlo** macro.

Open the "Tech Sensitivities-prob" file. Copy the data from each response page into the probabilistic evaluation section.



The percent change and the graphs will automatically update for the new data. Here is what the graph for Approach Speed looks like now with the confidence levels:



Genetic Algorithms

Genetic Algorithms (GA) offer a unique way of selecting the best technology combination by simulating the natural processes of breeding and competition. Random combinations of technologies are created with an array of 1's and 0's representing the techs in the on and off configurations respectively. Each combination representing all the technologies in either the on or off position is called a chromosome. A certain number of chromosomes are randomly created within a population and then the RSE's are used to obtain the response for each combination. The responses are normalized by some kind of "fitness function" which allows one number to represent the goodness of the combination. A combination with a low fitness value is closer to the ideal since the minimization of the metrics is desirable. The population is then put through a reproduction scheme whereby the more "fit" a combination, the better the chance that it will be selected for reproduction and its offspring will become more dominant in the next generation. In addition to competition and reproduction, the concept of mutation is introduced into a population in order to capture effects that might not have been available in the first random selection. Thus after several generations the most fit combinations will have achieved prominence and the "best" combination can be found.

When a large number of technologies exist the only way to use JMP and the TOPSIS method is to break the techs down into groups of 13 or less and analyze them separately. This, however, does not capture all the interactions between technologies. The best use of genetic algorithms comes when the number of available technologies is greater than 13, which is the largest full factorial combination that JMP can create. GA is run through a Matlab code that is very modular and must be set up for each concept that is investigated. This is done by creating certain text files that contain the information needed by the program.

An example GA run for a 225 passenger subsonic passenger jet is shown here. The background information for this jet is found in the "225 Pax Info" Excel file. This concept has 36 possible technologies for infusion, which would require three separate groups under TOPSIS. Here we will analyze them all together using GA's. The first and most complicated task is to determine patterns within the technology compatibilities. Because each combination is compared to the others within each population and the next generation based on this result, it is imperative that only compatible combinations be used in competition.

Table 8: Technology Compatibility Matrix

	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	T13	T14	T15	T16	T17	T18	T19	T20	T21	T22	T23	T24	T25	T26	T27	T28	T29	T30	T31	T32	T33	T34	T35	T36
T1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T2			1	1	1	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T3				1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	0	1
T4					1	1	1	1	1	1	1	1	1	0	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T5						1	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	0
T6							1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T7								1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T8									1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	0	1
T9										1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	0
T10											1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T11												1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T12													1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T13														1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	0	1
T14															1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T15																1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	0
T16																	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
T17																		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T18																			1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T19																				1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1
T20																					1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T21																						1	1	1	1	1	1	1	1	1	0	1	1	0	1	1
T22																							1	1	1	1	1	1	1	1	1	1	1	1	1	1
T23																								1	1	1	1	1	1	1	1	0	1	1	0	1
T24																									1	1	1	1	1	1	1	1	0	1	1	0
T25																										1	1	1	1	1	1	1	1	1	1	1
T26																											1	1	1	1	1	1	1	1	1	1
T27																												1	1	1	1	1	1	1	1	1
T28																													1	1	1	1	1	1	1	1
T29																														1	1	1	1	1	1	1
T30																															1	1	1	1	1	1
T31																																1	1	0	1	1
T32																																	1	1	0	1
T33																																		1	1	0
T34																																			1	1
T35																																				1
T36																																				

By further analyzing this compatibility matrix, it would become evident that all the incompatible combinations fall within groups of technologies that are compatible with any technology outside the group but incompatible with anything in the group. These groups are shown in Table 9. The 12 remaining technologies are compatible with all other technologies under consideration.

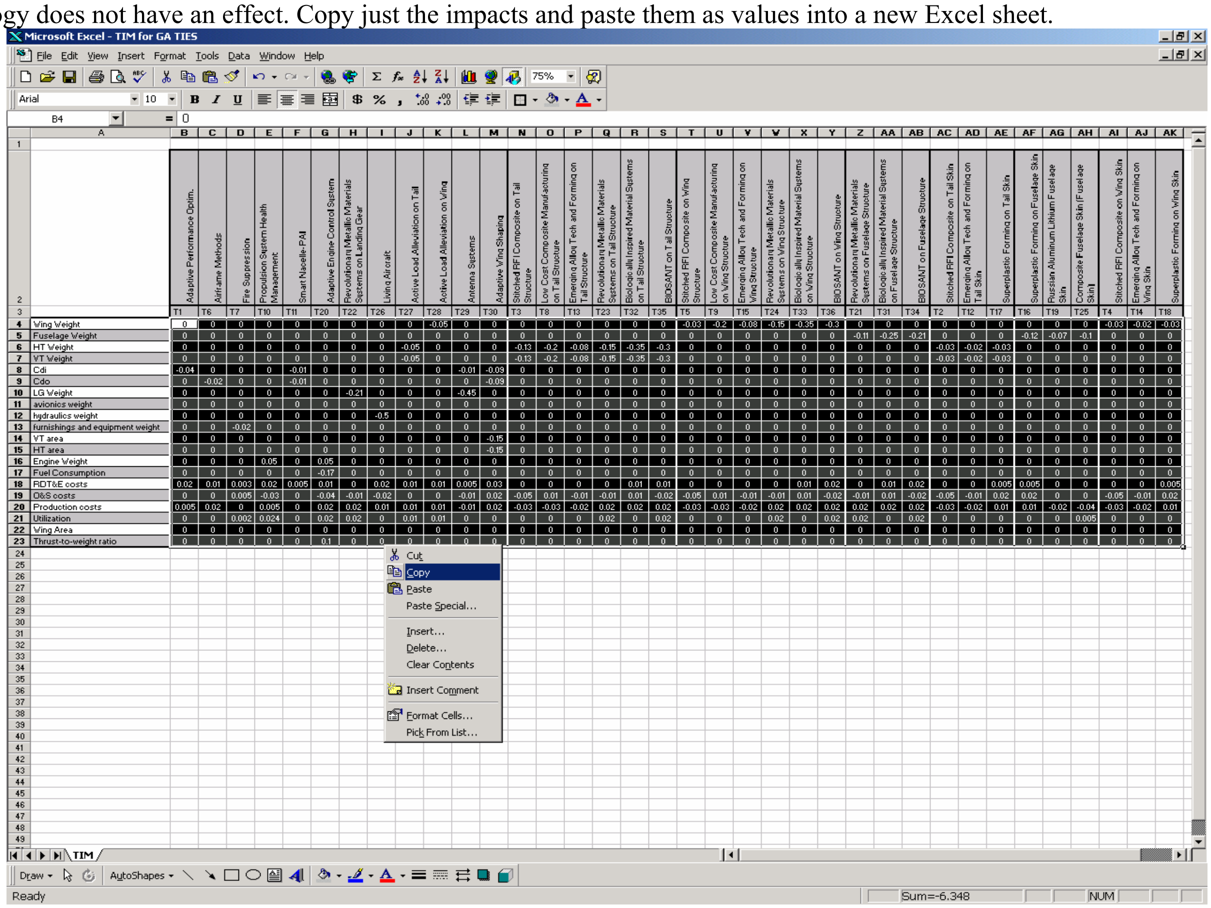
Table 9: Technology Groups

Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
T3	T5	T21	T2	T16	T4
T8	T9	T31	T12	T19	T14
T13	T15	T34	T17	T25	T18
T23	T24				
T32	T33				
T35	T36				

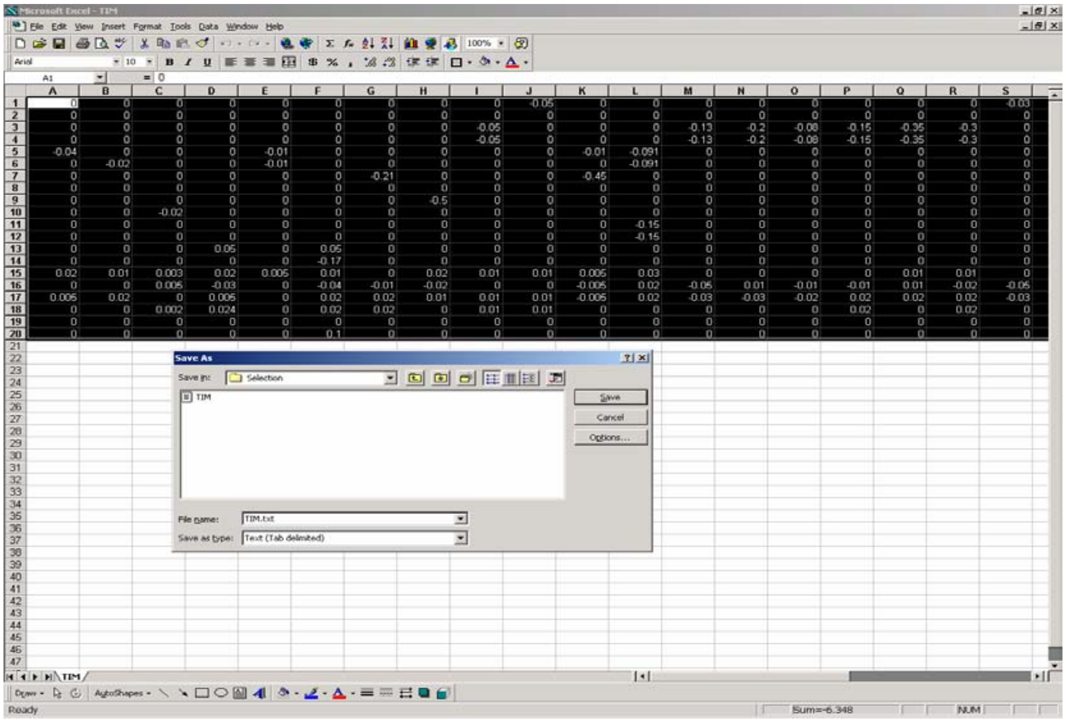
The original organization of the TIM had nothing to do with which techs were in which compatibility group but the Matlab requires that the chromosomes created for it be organized by these groups. Therefore, it is necessary to rearrange the values in the TIM. The order needed is given below.

Technologies Compatible with Everything												Group 1						Group 2						Group 3			Group 4			Group 5			Group 6		
1	6	7	10	11	20	22	26	27	28	29	30	3	8	13	23	32	35	5	9	15	24	33	36	21	31	34	2	12	17	16	19	25	4	14	18

Open the Technology Impact Matrix and rearrange the technologies in order. Be sure to put in zeros where the technology does not have an effect. Copy just the impacts and paste them as values into a new Excel sheet.



Save this file as the TAB delimited text, named "TIM.txt" as shown below.



Now create the other input files. Copy the RSE's from JMP into EXCEL, then remove the titles in the first column by removing column A. Save the file as TAB delimited text under the file name "RSE.txt". The RSE's need the inputs to be in the same form as FLOPS so the "k" factors must be converted in order to be useful. The converting factors and multipliers can be found in Table 10. Most of the values needed are factors distributed around 1, where an increase in the value leads to a number greater than 1 and a decrease leads to a value less than 1. Some of the economic factors, however, are based around 0. Other variables are needed as dimensional values and not factors (it will depend on which variables you are using, check the FLOPS manual for more information). The Matlab program will convert the "k" factors given the factors and multipliers in Table 10. You should copy and save the numbers in this table as TAB delimited with the filename "ranges.txt".

Table 10: K Factors and Baseline

	Minimum k	Maximum k	Factor	Baseline Multiplier
Wing Weight	0.65	1.15	1	1
Fuselage Weight	0.75	1	1	1
HT Weight	0.6	1	1	1
VT Weight	0.6	1	1	1
Cdi	0.8	1	1	1
Cdo	0.8	1	1	1
LG Weight	0.75	1	1	1
Avionics Weight	0.5	1.05	1	1
Hydraulics Weight	0.5	1.05	1	1
Furn. and Equip. Weight	0.9	1.05	1	1
VT Area	1	1.8	1	250
HT Area	1	1.888888889	1	450
Engine Weight	0.55	1.05	1	12126
Fuel Consumption	0.8	1.01	1	1
RDT&E Costs	-0.2	0.2	0	1
O&S Costs	-0.2	0.2	0	1
Production Costs	-0.2	0.2	0	1
Utilization	0.8	1.2	1	4915
Wing Area	0.82111437	1.026392962	1	3410
Thrust-to-weight ratio	1	1.166666667	1	0.3

In order for the chromosomes to be compared, there must be a number that represents the fitness of each. This number can be chosen from a variety of possibilities based on what metrics are of greatest interest in that case. For this example a comparison between several metrics and their constraint values will be used as the measurement. The equation for the fitness factor is:

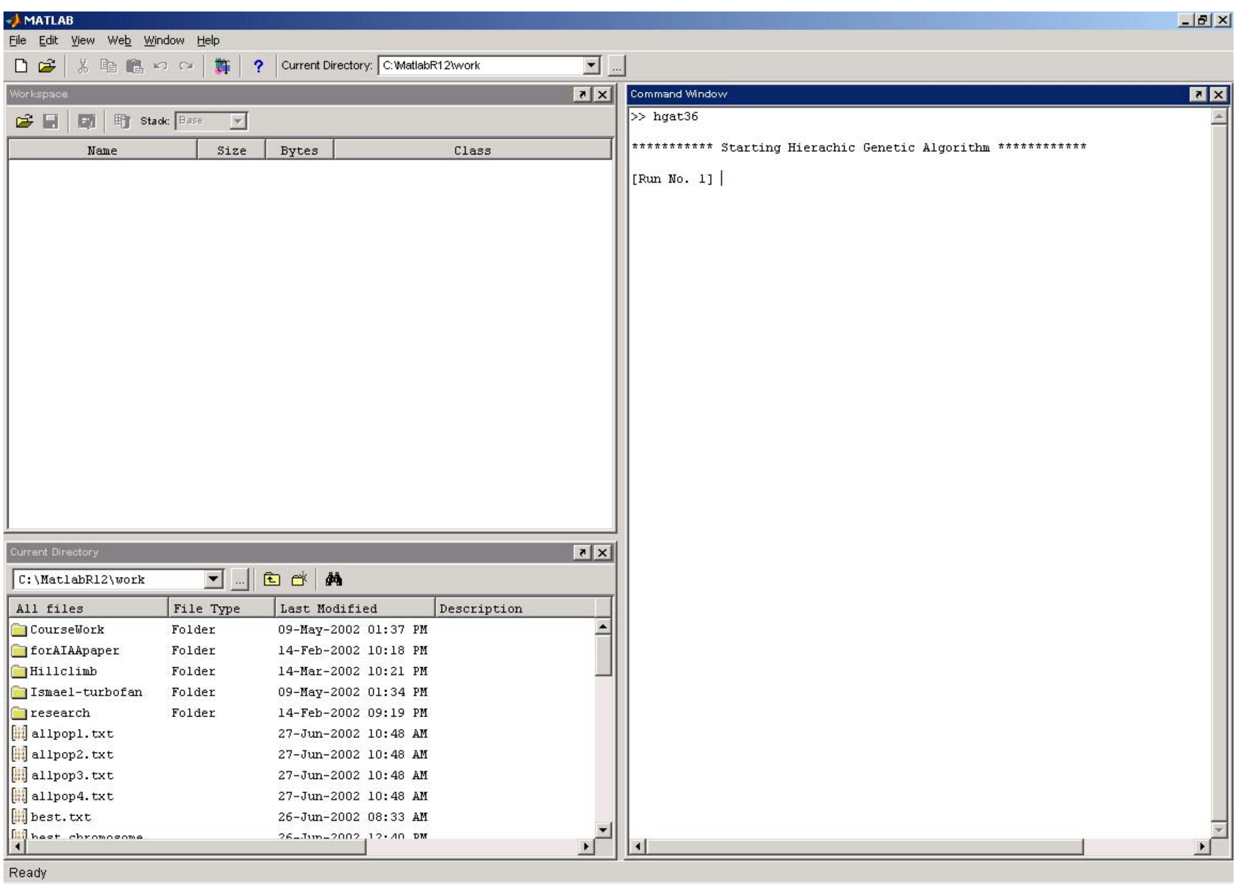
$$F = \alpha \frac{\text{response}_1}{\text{constraint}_1} + \beta \frac{\text{response}_2}{\text{constraint}_2} + \ldots$$

where alpha is the first weighting value, beta is the second weighting value, and so on. The constraints are stored in the order of this equation in a text file called "base.txt" with the weighting values for the metric located in the row beneath them. In this example, there are five metrics with constraints that are significant, which are CO_2, $/RPM, TAROC, DOC+I, and NOx. These constraints and weighting values can be entered into two lines of EXCEL and saved as TAB delimited text. The Genetic Algorithm programs are set up so that minimization is desirable. If you wish to maximize your responses, it is necessary to modify the "run225.m" file. To do this, add the following line of code after the last existing line:

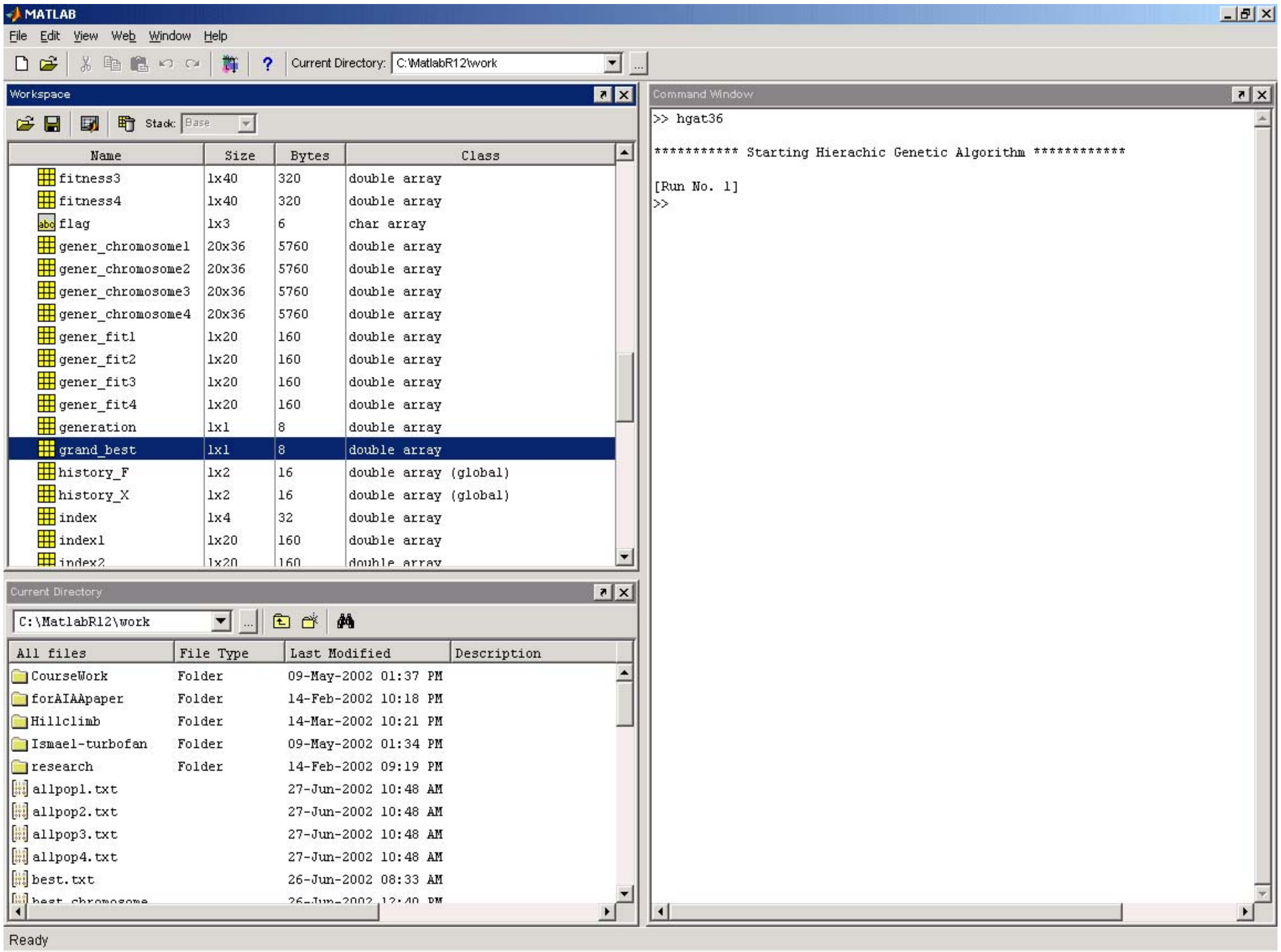
F_value = 1 / F_value

This is required because the "tournament.m" file is set up so that a smaller fitness value is preferable.

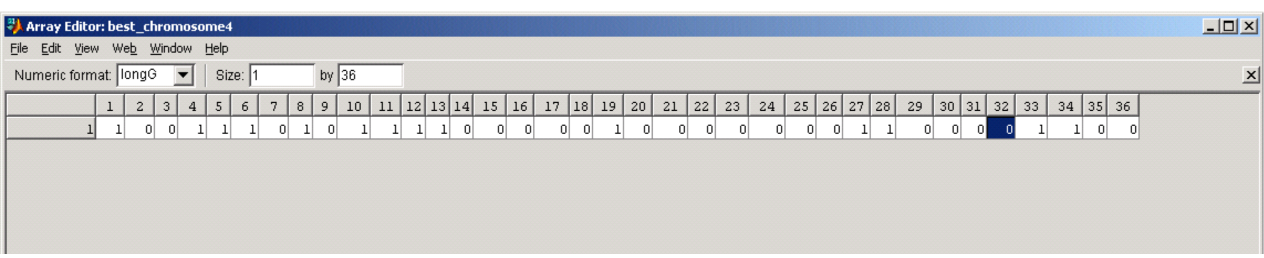
The Genetic Algorithm code is not a single program; instead it consists of 21 separate program files. These should all be in one folder called "Matlab Files". This folder should also contain the various input files you created above. It is essential to set up Matlab to recognize wherever you have the program and input files. To do this open the **File** menu, go to **Set Path** then **Add Folder** and add the "Matlab Files" folder where the files are located. Once all the input files are correctly set up all that's left is to run the code. Make sure that there are no files in your work directory that duplicate the names used for this program. If there are, these files will be used instead of the correct ones. If you plan on running a different number of runs, be sure to change the "hgat36.m" file by changing the 'RUNS' line in the 'Input' section. To run the Genetic Algorithms codes, type 'hgat36' in the Matlab command window. The entire Genetic Algorithm process will run from this code.



Once the program is finished running for the number of runs selected, it is just a simple matter to analyze the output and determine the best chromosome. Open the ‘grand_best’ variable in the Matlab Workspace window.



The number that this gives you represents the best fitness that any technology combination was able to obtain. Since there were four populations run simultaneously, it is necessary to determine from which of these populations this fitness value comes from. This can be done by opening the ‘best_fit’ variables and determining which matches the best overall value. Then open the ‘best_chromosome’ that corresponds to the best fit; this is your best technology combination. Note that the order of the “on” and “off” tech switches corresponds to that of the Technology Impact Matrix.



Modifying the Code

For a different vehicle and technologies this code must be significantly changed in order to be used. The most dificult aspect will be setting the code to only pick compatible cases. If your vehicle has technologies that can be organized into groups such as in the previous example where A ≠ B, A ≠ C, and B ≠ C then the changes to the code are minimal. However, for technology sets where A ≠ B, A ≠ C, but B = C then a whole new approach must be sought.

For the former case where the groups are different but still all the techs can be categorized into one then the procedure is rather straightforward. First let's look at the initial random population selection. Open the file "hgat36.m" and scroll down to lines 69-82.

Runs code to randomly pick a maximum of 1 tech from each compatibility group

```
% Zeroth generation: initial population

pop1h = rand(num_ch, 12) < 0.5;
pop1t = tail(num_ch);
pop1  = [pop1h, pop1t];
pop2h = rand(num_ch, 12) < 0.5;
pop2t = tail(num_ch);
pop2  = [pop2h, pop2t];
pop3h = rand(num_ch, 12) < 0.5;
pop3t = tail(num_ch);
pop3  = [pop3h, pop3t];
pop4h = rand(num_ch, 12) < 0.5;
pop4t = tail(num_ch);
pop4  = [pop4h, pop4t];
```

Randomizes first 12 completely compatible technologies

Change to number of completely compatible techs in study

In this area of the code change the 12 to the number of completely compatible technologies in your study. It will also have to be changed in lines 87, 181, and 234. In order to modify the code for the selection of techs in each group open the file "tail.m"

```
function pop = tail(num_ch)

for j = 1:num_ch
  II = eye(6);
  for i = 1 : 2,
    g(i) = floor(rand*7);
    if g(i) == 0, G(i,:) = zeros(1,6);
    else G(i,:) = II(g(i),:);
    end
  end
  II = eye(3);
  for i = 1 : 4,
    gg(i) = floor(rand*4);
    if gg(i) == 0, GG(i,:) = zeros(1,3);
    else GG(i,:) = II(gg(i),:);
    end
  end
  pop(j,:) = [G(1,:),G(2,:),GG(1,:),GG(2,:),GG(3,:),GG(4,:)];
end
```

# of groups with 6 techs in them

Groups 1 & 2 with 6 Techs

(# of techs in the group) +1

Groups 3-6 with 3 Techs

Selected Configuration from Group1, Grouip2, Group 3, …

The first thing that is evident is that there are only 2 calculations going on. This is due to our previous example having only 2 different sized groups- groups 1&2 with 6 techs each and groups 3-6 with 3 techs each. If your case has more variance in the size of the groups you will need to create new nested 'for' loops. The overall method of this code is blatantly simple: an identity matrix is formed with each row representing a case with only 1 of the technologies turned on. There is an equal probability for any of these rows to be selected along with the same probability that none will be selected which represents the case of no technologies from that group being activated. In order to modify the code the 'for' loops must be changed to represent the number of techs in each group. At the end of the file the selected configurations are combined to form the last section of the chromosome. This must be changed as well to correctly piece together the selections in your new technology set.

This takes care of the initial population creation but the later mutation of the chromosome must also be altered. Mutation is taken into account in order to possibly allow in technologies not selected in the initial population. The mutation code can, however, allow in technologies that are incompatible with those already selected. For this possibility another code is run in order to screen for this effect. Open the file "genemanipulation.m" and look at lines 5-16.

```
%look at 13, 14, 15, 16, 17, 18
if sum(pop(i,13:18)) > 1,
   loc = find(pop(i,13:18));
   if rand < 0.49,
      pop(i,loc(1)+12) = 1 - pop(i,loc(1)+12);
   elseif rand < 0.98
      pop(i,loc(2)+12) = 1 - pop(i,loc(2)+12);
   else
      pop(i,loc(1)+12) = 0;
      pop(i,loc(2)+12) = 0;
   end
```

13-18 represent section of the chromosome being affected

This section of the code looks through the part of the chromosome containing group 1 and determines if more than 1 of the technologies in the group is on and, if so, there is a 49% chance of the first tech being selected, a 49% of the second tech being selected and a 2% chance of both being turned off. This is run through several times for each group to ensure that if more than only 1 tech and most remains on. In your code you must edit these sections of the code in order to look at each section of the chromosome representing incompatible technologies and make a proper selection. Now that the chromosomes are correctly set up the rest of the code will run without needing any changes.

There are a few things that can be changed should you choose to do so such as the equation for fitness used by the algorithm to compare the chromosome in competition. This can be done in the file "run225.m" on line 44. This equation is simple to edit but you must remember that it and the file "base.txt" are linked so changes to one necessitate changes to the other. Changing the RSE's and TIM's can be done just as described in the previous 225 passenger example.

If you have any questions or comments, you can reach Dr. Kirby at michelle.kirby@aerospace.gatech.edu.

Appendix A: Parse Shell Script Description

```
############################################################################################### #
#                                                                                               #
#                                     PARSE                                                     #
#                                                                                               #
#                            Written by Samir El Aichaoui                                       #
#                           Supervised by Dr. Mark A. Hale                                      #
#                            Aerospace System Design Lab                                        #
#                           Georgia Institute of Technology                                     #
#                                   Summer 1998                                                 #
#                                                                                               #
############################################################################################### #

############################################################################################### #
# DESCRIPTION                                                                                   #
#                                                                                               #
# PARSE allows a user to extract data from a formatted data file.  We have found it to be       #
# particularly useful for use with automating analysis, "wrapping", programs for use in         #
# software architectures.                                                                       #
#                                                                                               #
# PARSE is command line driven and uses tk/tcl as its core.                                     #
#                                                                                               #
############################################################################################### #

############################################################################################### #
# ARGUMENTS                                                                                     #
#                                                                                               #
# This program supports the following command-line options :                                    #
#      -search      allow you to define the search criteria that will define a certain position #
#                     (or more specifically line) in the file. this option requires a string    #
#                     as an argument. This search string need to be present in the file         #
#                     This option is required.                                                  #
#      -read       specifies which word from the line you want to extract. When this option     #
#                     is not specified the default 1 is used.                                   #
#      -forward     start the search for the search criteria from the beginning of the file.    #
#       -back        start the search for the search criteria from the end of the file, this is #
#                     useful when the results sought are at the end of the output file. The     #
#                     default value is -forward.                                                #
#       -occurance   defines the number of times the search criteria occur in the file before   #
#                     reaching the line considered. the default value is equal to 1.            #
#       -offset      defines the number of lines offset with respect to the line defined by the #
#                     search string. the default value is equal to zero.                        #
#      -split string1 after string2 is used in the case of values following string2             #
#                     ( example = ) and separated by string1 ( example , ).                     #
#      -matrix int1 int2 allows to extract a matrix instead of a single string. int1 defines    #
#                     the number of rows and int2 specifies the number of columns.              #
#                                                                                               #
############################################################################################### #
```

```
################################################################################################ #
#       USAGE                                                                                    #
#        usage:  parse98 -search string [-read int] [-forward|-back] [-split char after char ]    #
#               [-matrix int int ] [-occurance int] [-offset int] [-help] file                   #
################################################################################################ #

#################################################################################################
#      EXAMPLES                                                                                  #
#                                                                                                #
# 1)           parse98 -search "something" input.dat                                             #
#                             will search for the first occurrence, first word in the line,      #
#                             from the beginning                                                 #
#                             of the file input.dat for the word "something"                     #
#                             the value returned will be the first value on the line             #
#                                                                                                #
# 2)           parse98 -search "something" -back input.dat                                       #
#                             will search for the first occurrence, first word in the line,      #
#                             from the end of the file input.dat for the word "something"        #
#                             the value returned will be the first value on the line             #
#                                                                                                #
# 3)           parse98 -search "something" -read 3 -matrix 3 3 -back -offset -2 -occurance 3 \   #
#                             input.dat will look for the matrix found two lines before the      #
#                             line containing "something" in its third occurrence in the file.   #
#                             The matrix will have three rows and three columns and will be      #
#                             starting in each line at the third word. The file used is          #
#                             input.dat.                                                         #
#                                                                                                #
# 4)           parse98 -search "something" -read 3 -split "after =" input.dat                    #
#                             if the line found is "something=3.4,5.6,7.6"                       #
#                             then the result returned is 5.6                                    #
#                                                                                                #
################################################################################################ #
```

Appendix B: TSW Program Guide

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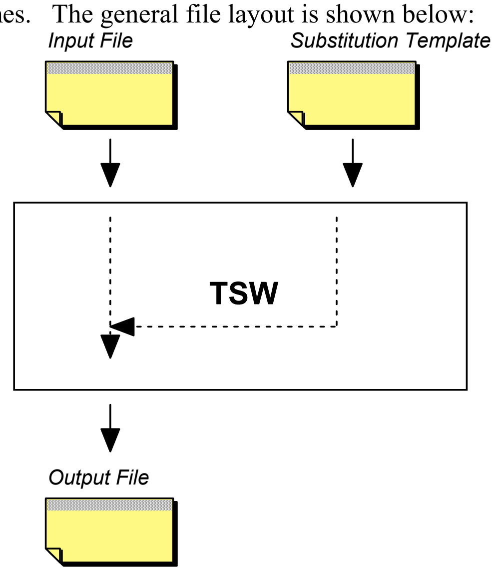
March 12, 2001

Background

TSW is a UNIX utility program that substitutes variable values into a namelist formatted input file.

Files

There are three main files of interest when using TSW for file substitution. The files can have any name but all three files must have unique file names. The general file layout is shown below:



Input File

The input file must be namelist formatted input file in which variable values are to be substituted. A sample input file follows:

```
$OPTION
   IOPT=1, IFITE=1,
   IANAL=3,
$END
$CONFIN
   DESRNG=800.0, TWR=0.63,
   GW=30000.0,0.0,25000.0,35000.0,
$END
```

The following rules apply:

- Namelists must be all $ or all & separated
- Variables may be scalar or array
- Tabs may not be used in the file (e.g. at the beginning of the line)
- Variables must be comma separated and the last variable in a namelist must have a comma after it

Substitution Template

The *Substitution Template* defines what variables are to be substituted into the namelist and what the new values are. The general file format is:

```
namelist variable value
```

```
        namelist variable value
        …
```

The following rules apply:

- All variable and namelist names must appear exactly as they are in the input file
- If a scalar variable does not appear in the given namelist, it is appended automatically to the end. Array variables cannot be appended.
- Array variable values are indicated by []. For example, the third element of the variable GW is indicated by GW[3].
- A "*" can be used to apply the substitution to all namelists.

A sample substitution template follows:

```
        OPTION IFITE 2
        OPTION IENG 1
        CONFIN DESRNG 750.0
        CONFIN GW[3] 28000.0
```

Output File

The output from the file parsing is put into the output file.

The following rules apply:

- The output filename cannot be the same name as the input filename
- The file is organized for single variables to appear on their own line
- Formatted text is ignored

A sample output file follows for the examples given above:

```
        $OPTION
           IOPT=1,
           IFITE=2,
           IANAL=3,
           IENG=1,
        $END
        $CONFIN
           DESRNG=750.0,
           TWR=0.63,
           GW=30000.0,0.0,28000.0,35000.0,
        $END
```

Execution

TSW is executed from the UNIX command prompt. The syntax is:

```
tsw –input InputFilename –output OutputFilename SubstitutionFile
```

The following rules apply:

- The input file must exist
- The substitution template file must exist
- The input and output file must not have the same name