

## **HYPERSTUDY: MULTIDISCIPLINARY DESIGN OPTIMIZATION PROCESS**

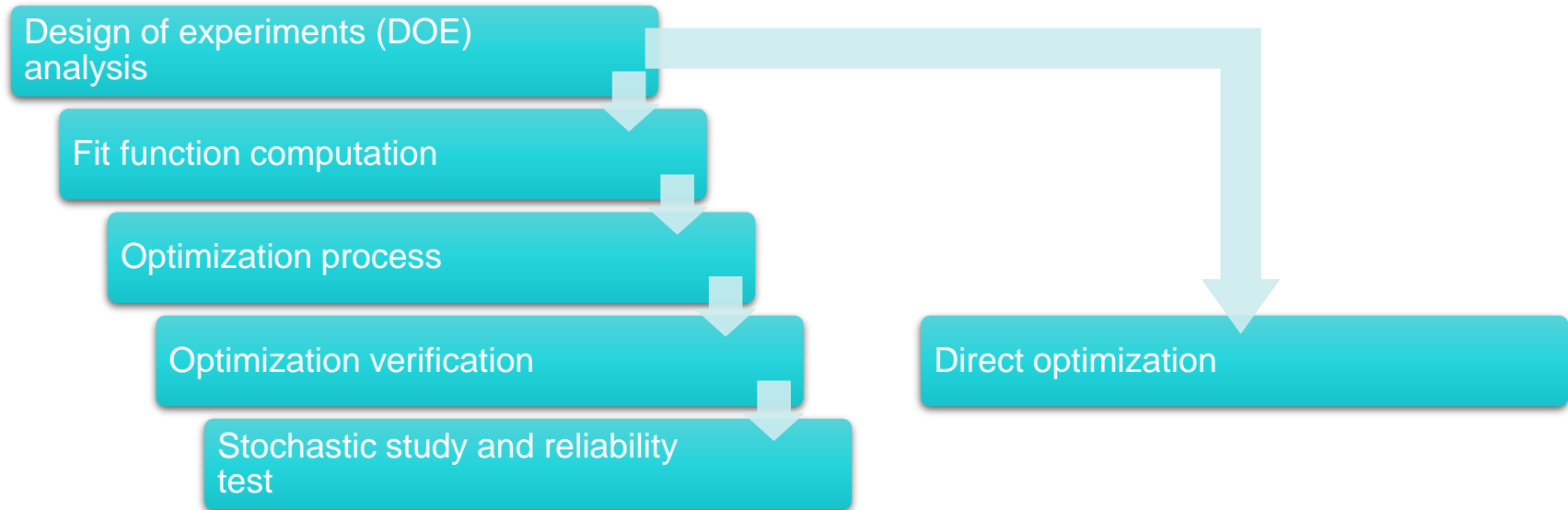
ALTair MULTIDISCIPLINARY DESIGN OPTIMIZATION PLATFORM  
FOR ELECTRIC MOTORS

October 2021, Altair Flux / FluxMotor Valorization and Support Team

# OUTLINE

Two optimization workflow are available in HyperStudy

- Optimization based on fit functions
- Direct optimization method



# OPTIMIZATION BASED ON FIT FUNCTIONS

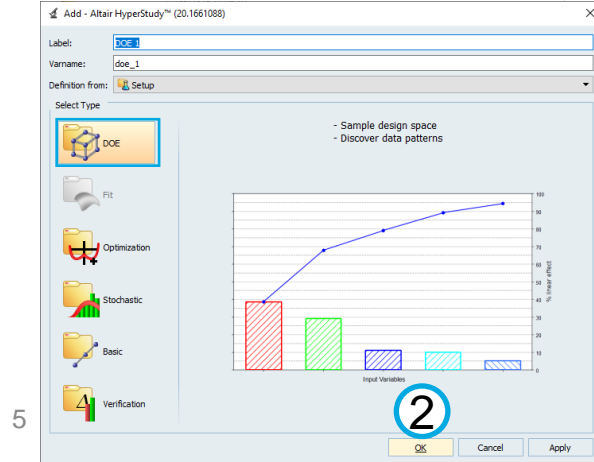
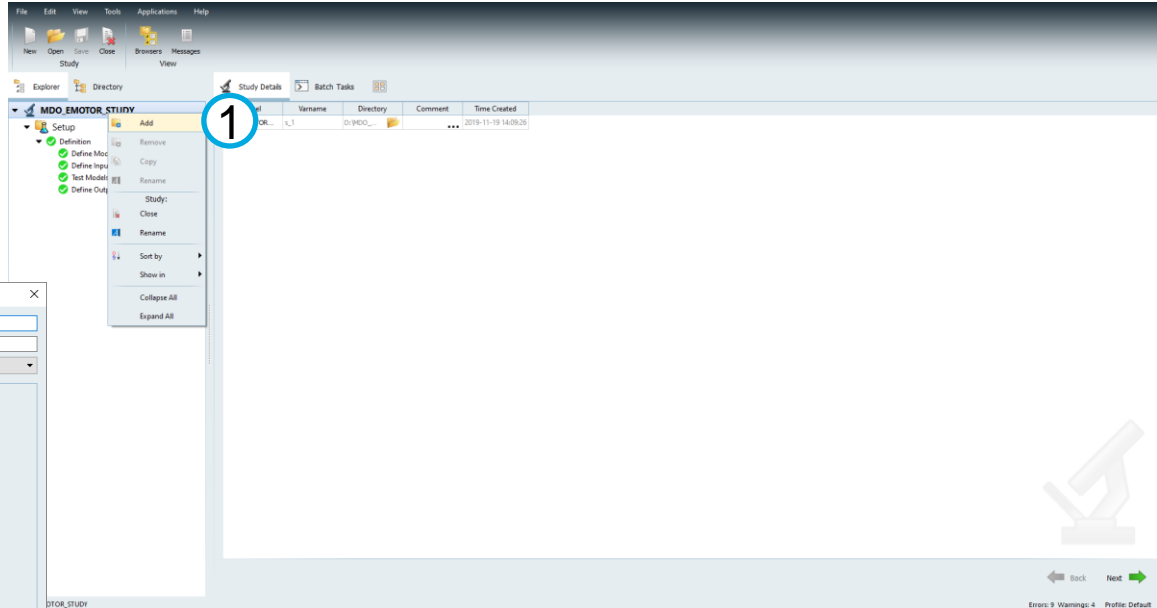
# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis initialization

- Add a new DOE analysis

Step	Action
1	Right click on the project "MDO_MOTOR_STUDY", click on [Add]
2	Select the type as "DOE", click on [OK]



# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis initialization

- Verify model definitions

Step	Action
1	Click on [DOE 1] – [Definition] – [Test Models]
2	Click on [Run Definition] to verify the models before the DOE analysis

The screenshot shows the Altair HyperMesh interface with the 'Test Models' tab selected. The 'Test Models' table lists the following models:

Active	Label	Write	Execute	Extract	AI	Type	Resource	Sequence
<input checked="" type="checkbox"/>	FluxMotor	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	AI	FluxMotor	D:\..._Connector_FluxMotor_F...	1
<input checked="" type="checkbox"/>	Flux Base Point	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	AI	Flux	D:\..._12_HagBasePointConnector_F...	2
<input checked="" type="checkbox"/>	Flux Operating Point	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	AI	Flux	D:\..._12_HagOperatingPointConnector_...	3
<input checked="" type="checkbox"/>	Flux Thermal	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	AI	Flux	D:\..._14_ThermalConnector_Flux_Ther...	4
<input checked="" type="checkbox"/>	HyperMesh	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	AI	Operator		5
<input checked="" type="checkbox"/>	OptStruct	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	AI	Operator		6

A red arrow points from the 'Run Definition' button at the bottom right to the 'Test Models' table. The 'Run Definition' button is highlighted with a red box and a circled '2'.

# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis initialization

- Verify output responses

Step	Action
1	Click on [DOE 1] – [Definition] – [Define Output Responses]
2	Verify all the output values

The screenshot shows the Altair HyperMesh software interface. On the left, the 'MDO\_EMOTOR\_STUDY' tree is visible, with 'DOE 1' expanded. Under 'DOE 1', the 'Define Output Responses' option is highlighted with a red circle and the number '1'. The main window displays the 'Define Output Responses' dialog box, which contains a table of variables and their corresponding expressions. The table has columns for 'Active', 'Label', 'Variable', 'Expression', 'Value', 'Goals', 'Evaluate from expression', 'Output Type', and 'Comment'. The 'Value' column is highlighted with a red circle and the number '2'. The table lists various variables such as 'MAGNET\_LOSSES\_OPERATING\_POINT\_BR...', 'T\_COIL', 'T\_MAG\_1A', 'T\_MAG\_1B', 'T\_MAG\_1B\_SYM', 'T\_MAG\_1C', 'T\_MAG\_1C\_SYM', 'T\_MAG\_2A', 'T\_MAG\_2A\_SYM', 'T\_MAG\_2B', 'T\_MAG\_2B\_SYM', 'T\_MAG\_2C', 'T\_MAG\_2C\_SYM', 'T\_ROTOR\_YOKE', 'T\_STATOR\_YOKE', 'TORQUE\_BASE\_SPEED\_RPM', 'MAX\_MAGNET\_TEMPERATURE', 'OUTPUT\_HYPERMESH\_MODEL', and 'MECHANICAL\_STRESS\_MAX'. Each variable has a corresponding expression and a numerical value listed in the 'Value' column.

# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis evaluation

- Specify the DOE analysis

Step	Action
1	Click on [DOE 1] – [Specification]
2	Define the “Number of Runs” for the DOE analysis
3	Click on [Apply]

**Attention:**  
Please define a number of run greater than or equal to this recommended value.



# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis evaluation

- Evaluate DOE tasks

Step	Action
1	Click on [DOE 1] – [Evaluate]
2	Click on [Multi-Execution] to increase the number of parallel computation
3	Click on [Evaluate Tasks]

Note:

The project is solved in a computation server.  
RAM of the server is **192 Gb**.

With the following information:

Number of Runs: **608**

Number of multi-execution: **10**

Computation time is **25 hours**

Multi-Execution - 4

Execution of concurrent tasks.  
Flux slows down using Multi-Execution.

4 Jobs

Attention: the multi-execution number depends on the computer system. Each execution need at least 15 G of RAM.

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# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## Evaluate tasks in DOE analysis

The screenshot displays the Altair DOE analysis software interface. The left sidebar shows the project hierarchy for 'MDO\_EMOTOR\_STUDY', with 'DOE 1' selected. The main window shows the 'Evaluation Tasks' table, which lists tasks 1 through 29. Tasks 1-4 are completed (Status: Success), and tasks 5-29 are in progress (Status: Started). The 'Run Tasks' button is visible at the bottom right. The status bar at the bottom indicates '1% (Remaining ~ 35:24:12)' and 'Errors: 0 Warnings: 24 Profile: Default'.

Active	Write	Execute	Extract	Comment
1	Success	Success	Success	
2	Success	Success	Success	
3	Success	Success	Success	
4	Success	Success	Success	
5	Success	Started		
6	Success	Started		
7	Success	Started		
8	Success	Started		
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Active	Task	Batch
1	Create Design	
2	Write Input Files	
3	Execute Analysis	
4	Extract Output Responses	
5	Purge	
6	Create Reports	

Run Tasks

Stop Evaluate Tasks Back Next

1% (Remaining ~ 35:24:12) Errors: 0 Warnings: 24 Profile: Default

# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis evaluation

- View DOE analysis results

Click on [Evaluation Data] to see all the evaluated combinations of input values and the results

Evaluation Tasks

Evaluation Data

Evaluation Plot

Evaluation Scatter

Show in Study Directory

Show in Explorer

Verify

Multi-Execution - 4

														Label																																																																																																	
fagne... (mm)														fagne... (mm)														fagne... (mm)														fagne... (mm)														fagne... (mm)														fagne... (mm)														fagne... (mm)														fagne... (mm)													
1	3.100000	3.600000	1.560000	1.530008	12.880824	10.403617	0.5020174	2.9747775	4.2107855	1.4550391	1.5043942	6.984883	6.1877805	1	Magnet-TM1A (mm)																																																																																																
2	4.300000	3.300000	1.380000	1.5900691	12.804489	8.7635654	0.7624570	2.6437115	4.2252024	1.4781167	1.4122094	8.5784343	5.2063534	2	Magnet-TM2A (mm)																																																																																																
3	3.820000	4.020000	1.632000	1.3861141	10.787933	7.6762252	0.5814746	4.0507510	3.3568544	1.4694417	1.3858816	9.3787846	4.4644556	3	Magnet-T2A (mm)																																																																																																
4	4.420000	3.120000	1.542000	1.5661659	12.680773	6.6325569	0.6898967	3.2449076	3.8404858	1.2374801	1.4393026	9.9882424	4.7952483	4	Magnet-T3A (mm)																																																																																																
5	5.140000	3.540000	1.614000	1.4222281	13.579813	10.619766	0.7361080	3.7742479	4.3423037	1.6437268	1.6207562	6.8837820	6.6522285	5	Magnet-WM1A (mm)																																																																																																
6	2.860000	3.960000	1.236000	1.5780311	11.872547	7.3599468	0.7365263	2.6782972	3.8666115	1.2257016	1.4912303	7.3846634	5.8168317	6	Magnet-WM2A (mm)																																																																																																
7	3.460000	3.060000	1.596000	1.4580830	13.765386	6.3162784	0.8449484	3.8724538	4.1702429	1.4437401	1.5446513	7.9941212	6.1476241	7	Magnet-WA (mm)																																																																																																
8	4.660000	4.260000	1.416000	1.5181867	10.697120	7.9616265	0.4886338	4.0802211	3.0080465	1.4109152	1.4879654	9.1117727	4.4571545	8	Magnet-TM1B (mm)																																																																																																
9	3.580000	4.380000	1.308000	1.4340933	12.775533	7.6144708	0.7058963	3.3803835	3.1387528	1.3149085	1.5007466	10.356518	7.1546045	9	Magnet-TM2B (mm)																																																																																																
10	2.524000	3.564000	1.502400	1.5252032	12.350488	6.0597994	0.9025014	3.4754412	4.4453840	1.6496423	1.6054662	6.5719196	6.1968835	10	Magnet-T2B (mm)																																																																																																
11	3.124000	4.164000	1.412400	1.4052280	10.116081	9.9774152	0.4875054	4.2950167	4.4338422	1.2269118	1.4498128	7.2664499	4.0055595	11	Magnet-T3B (mm)																																																																																																
12	3.724000	3.264000	1.322400	1.5852366	8.1488790	10.014690	0.9259150	3.6027041	3.6180203	1.4719679	1.3590251	8.1860592	6.4154547	12	Magnet-WM1B (mm)																																																																																																
13	2.644000	3.384000	1.214400	1.5012081	9.1643957	7.0956333	0.8682335	2.9684793	4.1451437	1.5365414	1.6020006	8.8318740	5.5032534	13	Magnet-WM2B (mm)																																																																																																
14	4.564000	3.504000	1.556400	1.4174821	9.7923141	9.0753467	0.6028244	3.1663429	3.6788258	1.2187162	1.4118143	6.1800120	5.7019221	14	Magnet-WB (mm)																																																																																																
15	5.164000	4.104000	1.466400	1.5977475	10.815070	10.193564	0.7215960	3.0944872	3.0662246	1.5296579	1.5307096	7.6407949	5.0987455	15	Magnet-TM1C (mm)																																																																																																
16	2.884000	3.024000	1.538400	1.4532505	9.1097767	7.5659624	0.9262181	4.2031267	3.4096180	1.6416063	1.3621123	8.9682516	6.5284176	16	Magnet-TM2C (mm)																																																																																																
17	3.004000	4.344000	1.250400	1.4292608	8.1179501	8.2319375	0.5829621	3.5064661	3.0581781	1.3187427	1.3927445	10.029022	6.4615910	17	Magnet-T2C (mm)																																																																																																
18	3.604000	3.444000	1.610400	1.6093127	10.008817	6.5560519	0.4871804	4.4860324	4.0418596	1.3427491	1.5207019	9.3368534	5.5785765	18	Magnet-T3C (mm)																																																																																																
19	4.504000	3.744000	1.340400	1.5494682	8.8314163	6.5226336	0.5203330	3.9376006	3.7337853	1.2530929	1.5793725	6.7643252	4.7606514	19	Magnet-WM1C (mm)																																																																																																
20	2.548000	4.128000	1.354800	1.4004063	9.8509754	6.1167181	0.6402518	2.6873171	4.2612085	1.5684468	1.5483311	9.6458281	4.8293265	20	Magnet-WM2C (mm)																																																																																																
21	3.148000	3.228000	1.264800	1.5804474	14.202325	7.3680422	0.6161894	3.0317109	3.6435951	1.2187930	1.4226405	7.5159720	5.4343956	21	Magnet-WC (mm)																																																																																																
22	2.668000	3.948000	1.516800	1.3764167	8.8611220	7.4149106	0.5011997	4.1952467	3.2297184	1.4396152	1.5044265	6.5082253	5.8363061	22	Magnet-R_hole (mm)																																																																																																
23	3.268000	3.048000	1.426800	1.5564145	9.3514425	6.9289084	0.5817405	2.6083967	3.8525128	1.5509857	1.3777634	6.0874657	4.0811138	23	CTRL_ANGLE																																																																																																
24	3.868000	3.648000	1.336800	1.4365528	12.110420	7.4574794	0.8390299	3.7770263	3.9276000	1.4992369	1.4955268	6.7493316	6.4525341	24	LRMS																																																																																																
25	2.788000	3.768000	1.228800	1.3524162	10.328791	8.1912667	0.7364671	3.6439587	3.7902873	1.4230829	1.5540012	6.1637481	7.0065066	25	SPEED																																																																																																
26	3.388000	4.368000	1.588800	1.5325113	9.2257536	9.1656826	0.9549764	3.0050026	4.1478463	1.5663170	1.4793932	6.1956472	4.2762017	26	IM_R_HOLE																																																																																																
27	3.988000	3.468000	1.498800	1.4125632	11.118593	8.1220143	0.4133985	4.1991591	4.4514777	1.3343555	1.5328142	6.8051050	4.6069941	27	IM_T2A																																																																																																
28	5.188000	3.168000	1.318800	1.4726669	8.0503265	9.7673623	0.7070839	4.4147264	3.2892813	1.3015305	1.4759554	6.5287098	6.8302845	28	Channel																																																																																																

Stop

Evaluate Tasks

Back

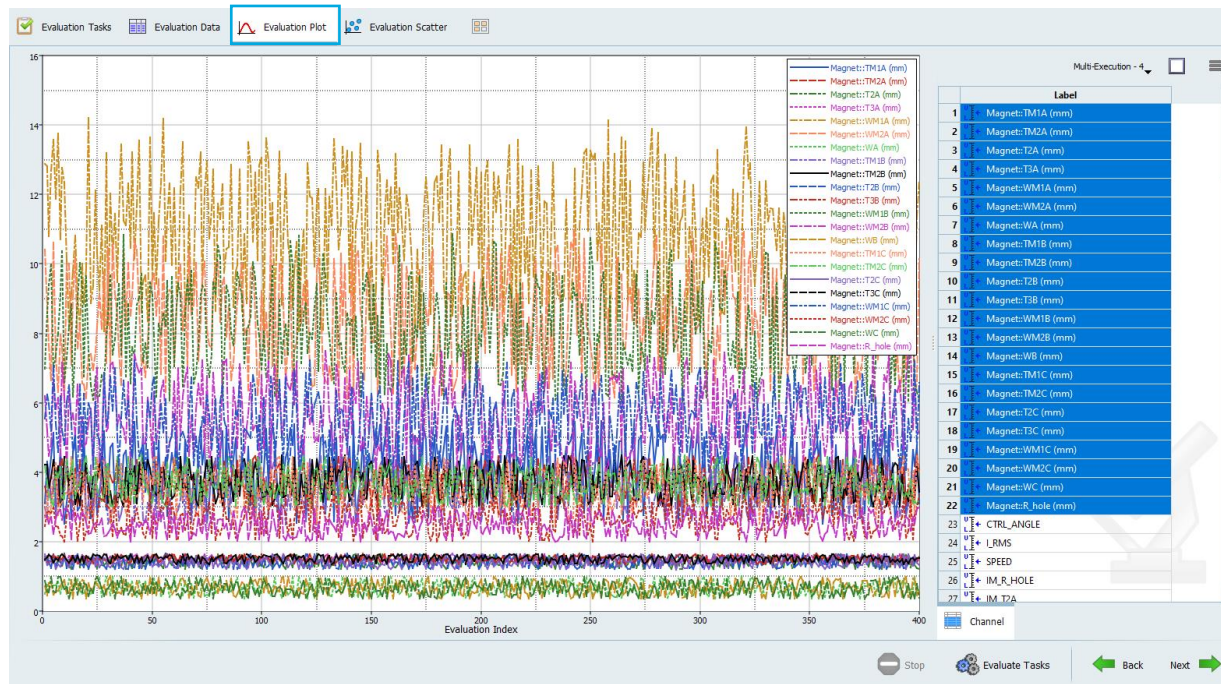
Next

# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis evaluation

- View DOE analysis results

Click on [Evaluation Plot] to plot the curves of parameters during the evaluation task

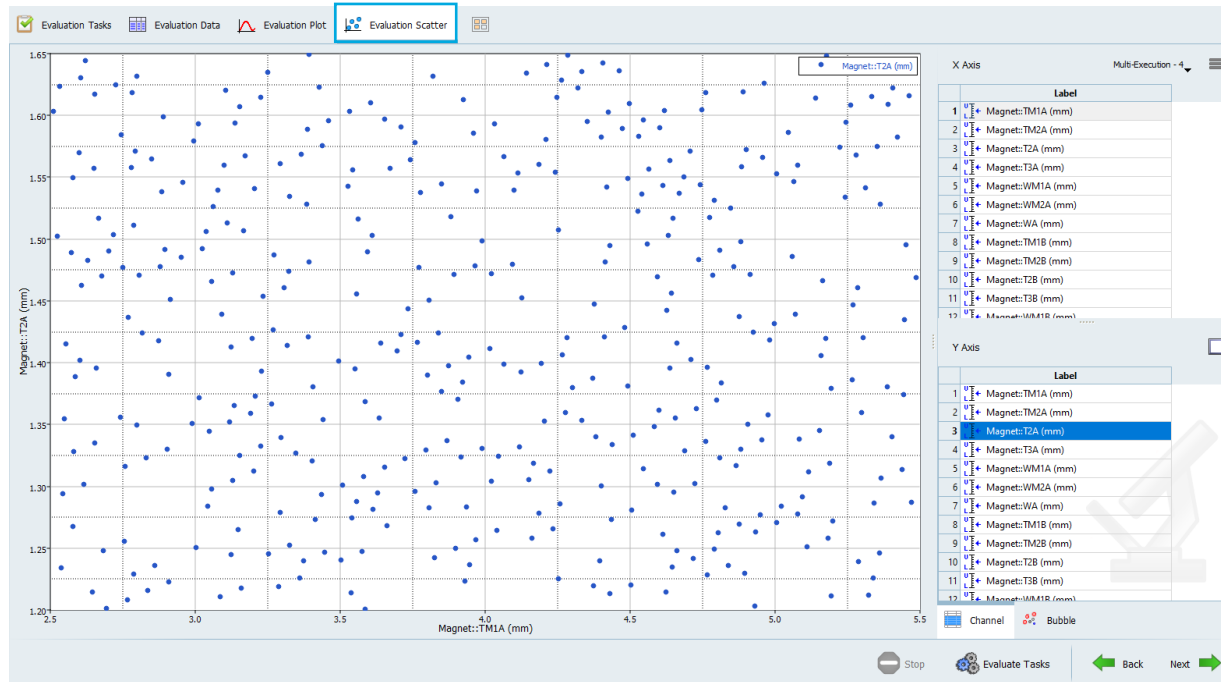


# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis evaluation

- View DOE analysis results

Click on [Evaluation Scatter] to plot the related curve between two evaluated parameters



# DESIGN OF EXPERIMENTS (DOE) ANALYSIS

## DOE analysis post-processing

Step	Action
1	Click on [Post-Processing] in the [DOE 1] model
2	Use the HyperStudy function to analyze the DOE results

The screenshot displays the Altair HyperStudy software interface. The project tree on the left shows the hierarchy: MDO\_EMOTOR\_STUDY > Setup > Definition > DOE 1 > Post-Processing. The main data table shows a list of experiments with columns for Label, Name, Category, Points, Unique, No Values, Bad Values, Excluded, and Range. The 'Post-Processing' tab is selected, and the 'Post-Processing' option in the project tree is highlighted with a red circle and the number 1. The 'Post-Processing' tab in the main data table is highlighted with a red circle and the number 2.

Label	Name	Category	Points	Unique	No Values	Bad Values	Excluded	Range
134	WAGNE_r_26	Response	400	399	0	1	0	0.064603
135	WAGNE_r_27	Response	400	399	0	1	0	0.2584004
136	WAGNE_r_28	Response	400	399	0	1	0	0.1022672
137	WAGNE_r_29	Response	400	399	0	1	0	0.0523275
138	WAGNE_r_30	Response	400	399	0	1	0	0.1045722
139	WAGNE_r_31	Response	400	399	0	1	0	0.0687084
140	WAGNE_r_32	Response	400	399	0	1	0	0.1231629
141	WAGNE_r_33	Response	400	399	0	1	0	0.2564706
142	WAGNE_r_34	Response	400	399	0	1	0	0.1397207
143	WAGNE_r_35	Response	400	399	0	1	0	0.2820214
144	WAGNE_r_36	Response	400	399	0	1	0	0.0480338
145	WAGNE_r_37	Response	400	399	0	1	0	0.0163522
146	T_COIL_r_38	Response	400	388	0	12	0	48.756347
147	T_MAO_r_39	Response	400	388	0	12	0	3.7122704
148	T_MAO_r_40	Response	400	388	0	12	0	3.7035573
149	T_MAO_r_41	Response	400	388	0	12	0	3.4384779
150	T_MAO_r_42	Response	400	388	0	12	0	3.4248960
151	T_MAO_r_43	Response	400	388	0	12	0	3.2745262
152	T_MAO_r_44	Response	400	388	0	12	0	3.279851
153	T_MAO_r_45	Response	400	388	0	12	0	2.8091899
154	T_MAO_r_46	Response	400	388	0	12	0	2.885228
155	T_MAO_r_47	Response	400	388	0	12	0	3.1118679
156	T_MAO_r_48	Response	400	388	0	12	0	3.1771322
157	T_MAO_r_49	Response	400	388	0	12	0	3.1887324
158	T_MAO_r_50	Response	400	388	0	12	0	3.1948952
159	T_ROTTO_r_51	Response	400	388	0	12	0	3.3318805
160	T_STATTO_r_52	Response	400	388	0	12	0	9.1271848
161	TORQU_r_53	Response	400	399	0	1	0	46.001326
162	MAX_IN_r_54	Response	400	388	0	12	0	3.1948952
163	OUTPUT_r_55	Response	400	1	0	0	0	0.0000000
164	MECHA_r_56	Response	400	398	0	1	0	253.91943

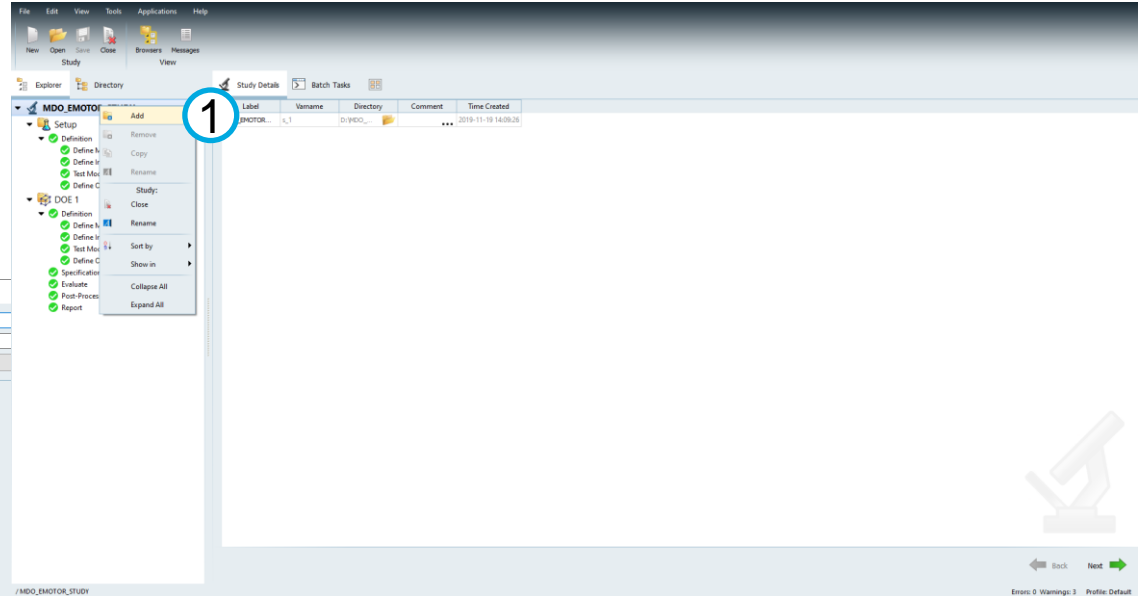
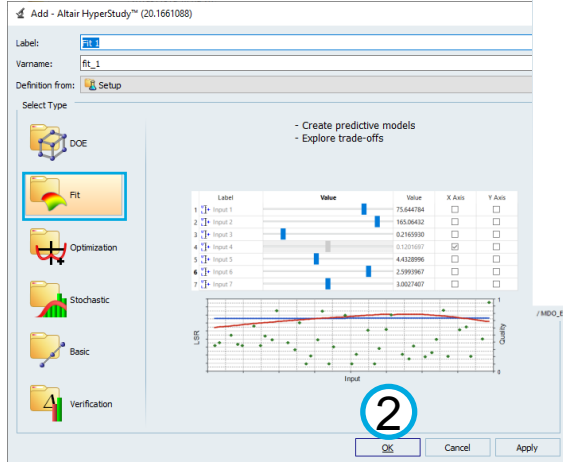
# FIT FUNCTION COMPUTATION

# FIT FUNCTION COMPUTATION

## Initialization for fit function computation

- Add a new fit function analysis

Step	Action
1	Right click on the project "MDO_MOTOR_STUDY", click on [Add]
2	Select the type as "Fit", click on [OK]



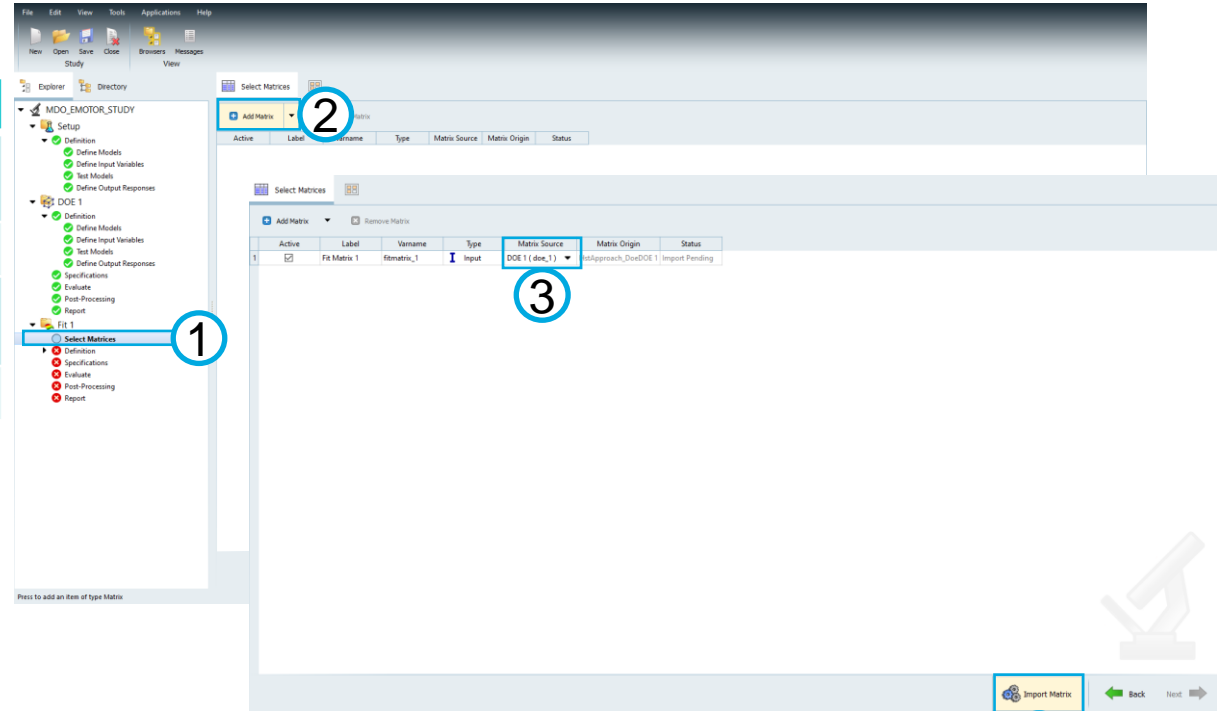


# FIT FUNCTION COMPUTATION

## Initialization for fit function computation

- Define input matrix

Step	Action
1	Click on [Fit 1] – [Select Matrices]
2	Click on [Add Matrix]
3	Select “DOE 1” as the Matrix Source
4	Click on [Import Matrix]

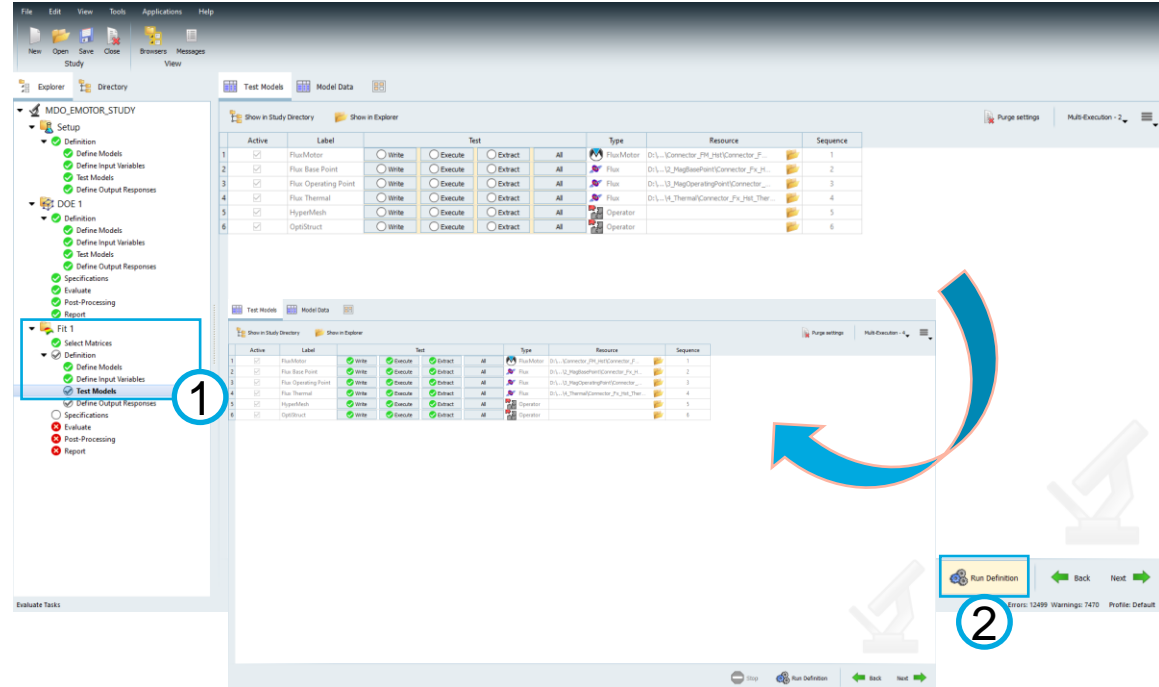


# FIT FUNCTION COMPUTATION

## Initialization for fit function computation

- Verify model definitions

Step	Action
1	Click on [Fit 1] – [Definition] – [Test Models]
2	Click on [Run Definition] to verify the models before computing fit functions

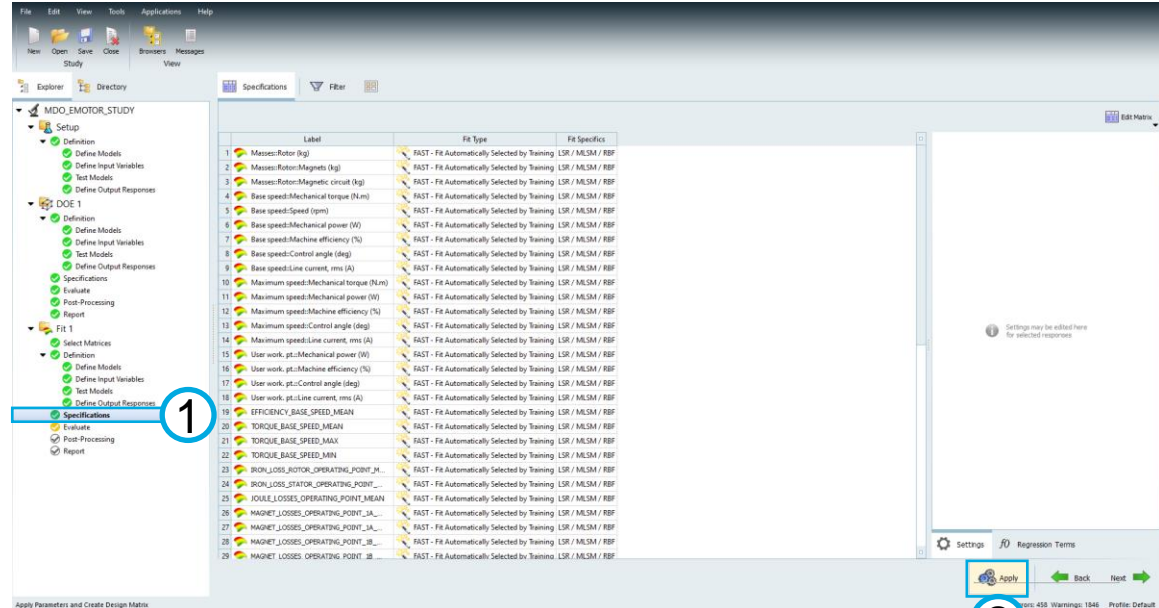


# FIT FUNCTION COMPUTATION

## Initialization for fit function computation

- Define fit function setting

Step	Action
1	Click on [Fit 1] - [Specifications]
2	Click on [Apply] to confirm the fit function setting

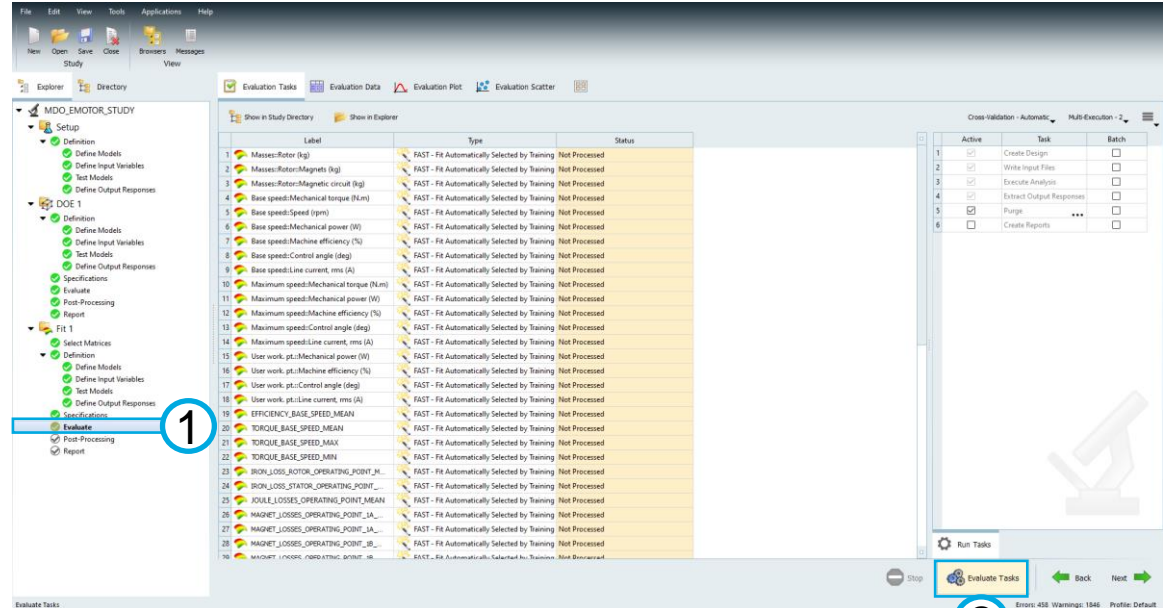


# FIT FUNCTION COMPUTATION

## Fit function computation process

- Evaluate tasks

Step	Action
1	Click on [Evaluate]
2	Click on [Evaluate Tasks] to compute fit functions



# FIT FUNCTION COMPUTATION

## Fit function computation process

- Post-processing

Step	Action
1	Click on [Fit 1] – [Post-Processing]
2	Use the HyperStudy function to analyze the fit function computation results

The screenshot displays the Altair HyperStudy software interface. The left-hand 'Explorer' pane shows a project tree for 'MDO\_EMOTOR\_STUDY'. Under the 'Fit 1' folder, the 'Post-Processing' option is highlighted with a blue circle and the number '1'. The main central window shows the 'Integrity' tab, which contains a table of results. A blue circle with the number '2' is placed over the 'Range' column of this table. The table lists various variables (e.g., Hagnet...\_var\_1 to Hagnet...\_var\_22) and responses (e.g., Hagnet...\_r\_1 to Hagnet...\_r\_9) with columns for Points, Unique, No Values, Bad Values, Excluded, and Range. The right-hand pane shows a 'Category' list with options: Health, Summary, Distribution, and Quality.

Label	Varname	Category	Points	Unique	No Values	Bad Values	Excluded	Range
1	Hagnet..._var_1	Variable	282	282	0	0	0	2.388980
2	Hagnet..._var_2	Variable	282	282	0	0	0	3.214490
3	Hagnet..._var_3	Variable	282	282	0	0	0	0.285600
4	Hagnet..._var_4	Variable	282	282	0	0	0	0.288754
5	Hagnet..._var_5	Variable	282	282	0	0	0	6.770841
6	Hagnet..._var_6	Variable	282	282	0	0	0	4.8719901
7	Hagnet..._var_7	Variable	282	282	0	0	0	0.6264261
8	Hagnet..._var_8	Variable	282	282	0	0	0	1.4973815
9	Hagnet..._var_9	Variable	282	282	0	0	0	1.4924435
10	Hagnet..._var_10	Variable	282	282	0	0	0	0.4966594
11	Hagnet..._var_11	Variable	282	282	0	0	0	0.3545768
12	Hagnet..._var_12	Variable	282	282	0	0	0	5.4001246
13	Hagnet..._var_13	Variable	282	282	0	0	0	3.7898477
14	Hagnet..._var_14	Variable	282	282	0	0	0	0.6482185
15	Hagnet..._var_15	Variable	282	282	0	0	0	1.8449136
16	Hagnet..._var_16	Variable	282	282	0	0	0	1.8874071
17	Hagnet..._var_17	Variable	282	282	0	0	0	0.4264701
18	Hagnet..._var_18	Variable	282	282	0	0	0	0.2981357
19	Hagnet..._var_19	Variable	282	282	0	0	0	2.4824811
20	Hagnet..._var_20	Variable	282	282	0	0	0	1.2933659
21	Hagnet..._var_21	Variable	282	282	0	0	0	0.6477540
22	Hagnet..._var_22	Variable	282	282	0	0	0	0.8912182
23	Hagnet..._r_1	Response	282	282	0	0	0	0.7468740
24	Hagnet..._r_2	Response	282	282	0	0	0	1.0745222
25	Hagnet..._r_3	Response	282	282	0	0	0	0.8292623
26	Hagnet..._r_4	Response	282	282	0	0	0	39.357704
27	Hagnet..._r_5	Response	282	282	0	0	0	815.93610
28	Hagnet..._r_6	Response	282	282	0	0	0	33919.806
29	Hagnet..._r_7	Response	282	282	0	0	0	1.4841133
30	Hagnet..._r_8	Response	282	282	0	0	0	18.454329
31	Hagnet..._r_9	Response	282	278	0	0	0	0.7043082

# FIT FUNCTION COMPUTATION

## Fit function computation process

- Post-processing

Step	Action
1	Use the [Diagnostic] function to analyze the fit function computation quality

The screenshot shows the Altair HyperStudy software interface. The 'Diagnostics' tab is selected in the top toolbar, highlighted by a red circle with the number '1'. The main window displays a table of fit functions and their R-Square values. The table has four columns: Label, Fit Type, Fit Specifics, and R-Square. The R-Square values range from 0.999991 to 0.942040. The table is titled 'MDO\_EMOTOR\_STUDY'.

Label	Fit Type	Fit Specifics	R-Square
Masses:Rotor (kg)	RBF	linear - Gaussian - 10.000000	0.999991
Masses:Rotor:Magnets (kg)	LSR	Custom	0.9998794
Masses:Rotor:Magnetic circuit (kg)	RBF	linear - Gaussian - 10.000000	0.9998642
Base speed:Mechanical torque (N.m)	LSR	Custom	0.9803255
Base speed:Speed (rpm)	LSR	Custom	0.9638009
Base speed:Mechanical power (W)	LSR	Custom	0.9543216
Base speed:Machine efficiency (%)	LSR	Custom	0.9230270
Base speed:Control angle (deg)	LSR	Custom	0.8236393
Base speed:Line current, rms (A)	LSR	Custom	0.8187910
Maximum speed:Mechanical torque (N.m)	LSR	Custom	0.9991551
Maximum speed:Mechanical power (W)	LSR	Custom	0.9991551
Maximum speed:Machine efficiency (%)	LSR	Custom	0.8738630
Maximum speed:Control angle (deg)	RBF	constant - Multiquadric - 5.21...	0.8499902
Maximum speed:Line current, rms (A)	LSR	Custom	0.8744747
User work_pt:Mechanical power (W)	LSR	Custom	0.9507720
User work_pt:Machine efficiency (%)	LSR	Custom	0.9617151
User work_pt:Control angle (deg)	LSR	Custom	0.9607791
User work_pt:Line current, rms (A)	LSR	Custom	0.9779928
EFFICIENCY_BASE_SPEED_MEAN	LSR	Custom	0.9420400
TORQUE_BASE_SPEED_MEAN	LSR	Custom	0.9593310

**Note: if the value is closer to 1, the more accurate is the Fit function obtained.**

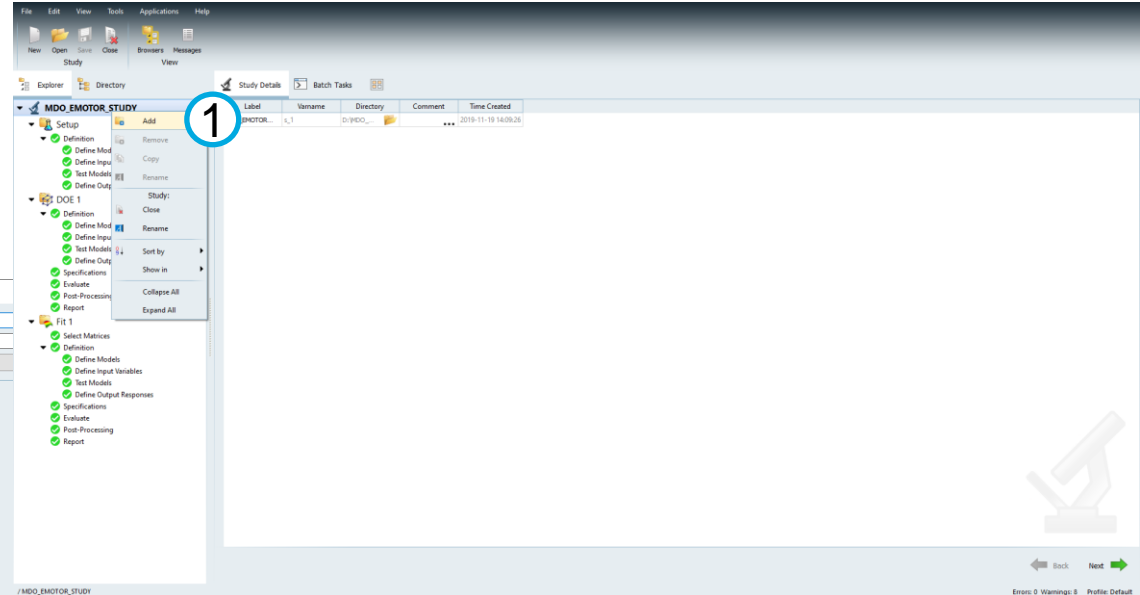
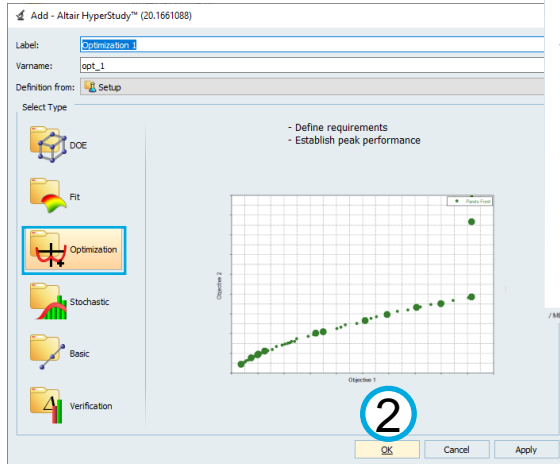
# OPTIMIZATION PROCESS

# OPTIMIZATION PROCESS

## Optimization initialization

- Add a new optimization application

Step	Action
1	Right click on the project "MDO_MOTOR_STUDY", click on [Add]
2	Select the type as "Optimization", click on [OK]





# OPTIMIZATION PROCESS

## Optimization initialization

- Link to fit function results

Step	Action
1	Click on [Optimization 1] – [Definition] – [Define output Responses]
2	Click on [Evaluate From] to select all the output responses
3	Click on [Evaluate from Fit Model] – [Fit 1] to link the optimization with the fit functions

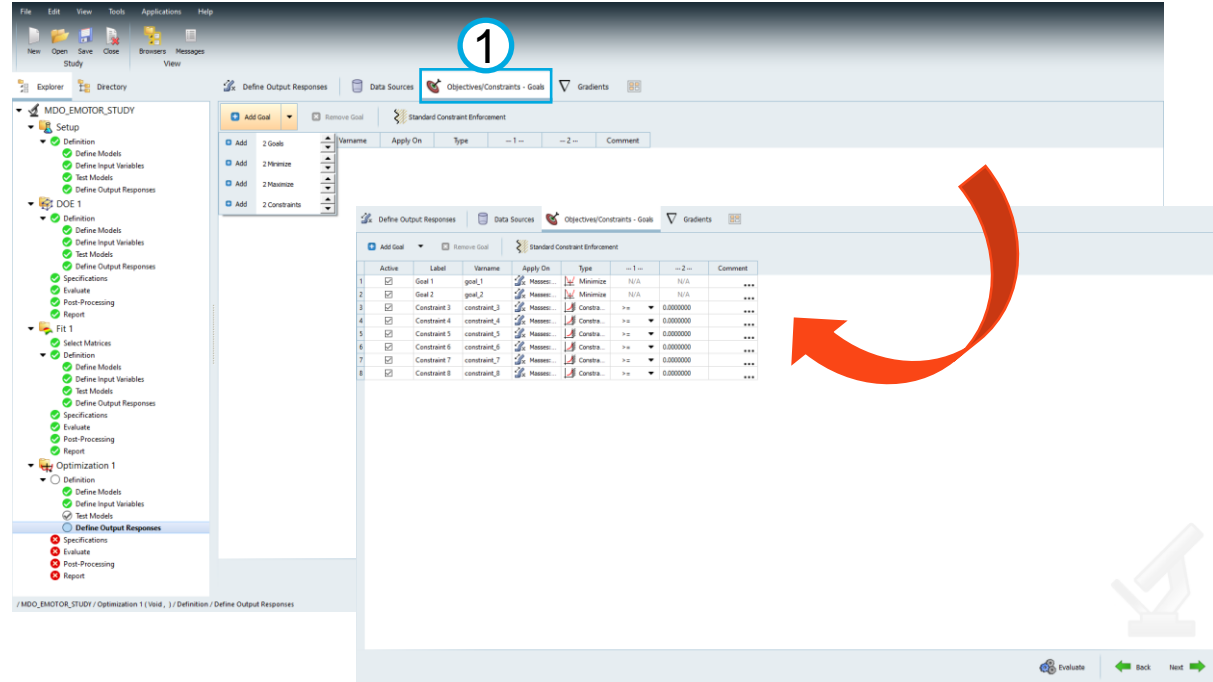
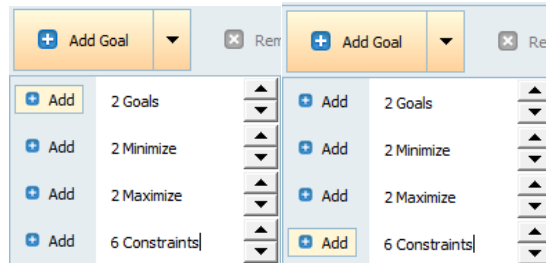
The screenshot shows the Altair HyperMesh software interface for optimization initialization. The left sidebar contains a tree view of the model structure, with 'MDO\_EMOTOR\_STUDY' expanded. Under 'Setup', 'DOE 1' is selected, and 'Define Output Responses' is highlighted. The central table lists various output responses, including 'Masses:Rotor (kg)', 'Masses:Rotor:Magnets (kg)', 'Base speed:Mechanical torque (N.m)', 'Base speed:Speed (rpm)', 'Base speed:Mechanical power (W)', 'Base speed:Machine efficiency (%)', 'Base speed:Control angle (deg)', 'Base speed:Line current, rms (A)', 'Maximum speed:Mechanical torque (N.m)', 'Maximum speed:Mechanical power (W)', 'Maximum speed:Machine efficiency (%)', 'Maximum speed:Control angle (deg)', 'Maximum speed:Line current, rms (A)', 'User work, pt.:Mechanical power (W)', 'User work, pt.:Machine efficiency (%)', 'User work, pt.:Control angle (deg)', 'User work, pt.:Line current, rms (A)', 'EFFICIENCY\_BASE\_SPEED\_MEAN', 'TORQUE\_BASE\_SPEED\_MEAN', 'TORQUE\_BASE\_SPEED\_MAX', 'TORQUE\_BASE\_SPEED\_MIN', 'IRON\_LOSS\_ROTOR\_OPERATING\_POINT\_MEAN', 'IRON\_LOSS\_STATOR\_OPERATING\_POINT\_MEAN', 'COIL\_LOSS\_OPERATING\_POINT\_MEAN', 'MAGNET\_LOSS\_OPERATING\_POINT\_1A\_MEAN', 'MAGNET\_LOSS\_OPERATING\_POINT\_1A\_SYM\_MEAN', 'MAGNET\_LOSS\_OPERATING\_POINT\_1B\_MEAN', and 'MAGNET\_LOSS\_OPERATING\_POINT\_1B\_SYM\_MEAN'. The right sidebar shows the 'Evaluate from Fit Model' button, which is highlighted by a red arrow. The table has columns for 'Active', 'Label', 'Vname', 'Expression', 'Value', 'Goals', 'Evaluate From', 'Output Type', and 'Comment'. The 'Evaluate From' column is highlighted in blue, and the 'Evaluate from Fit Model' button is highlighted in yellow.

# OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization goals and constraints

Step	Action
1	Click on [Objectives/Constraints - goals]
2	Click on the icon to add - 3 Goals - 6 constraints



# OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization goals and constraints

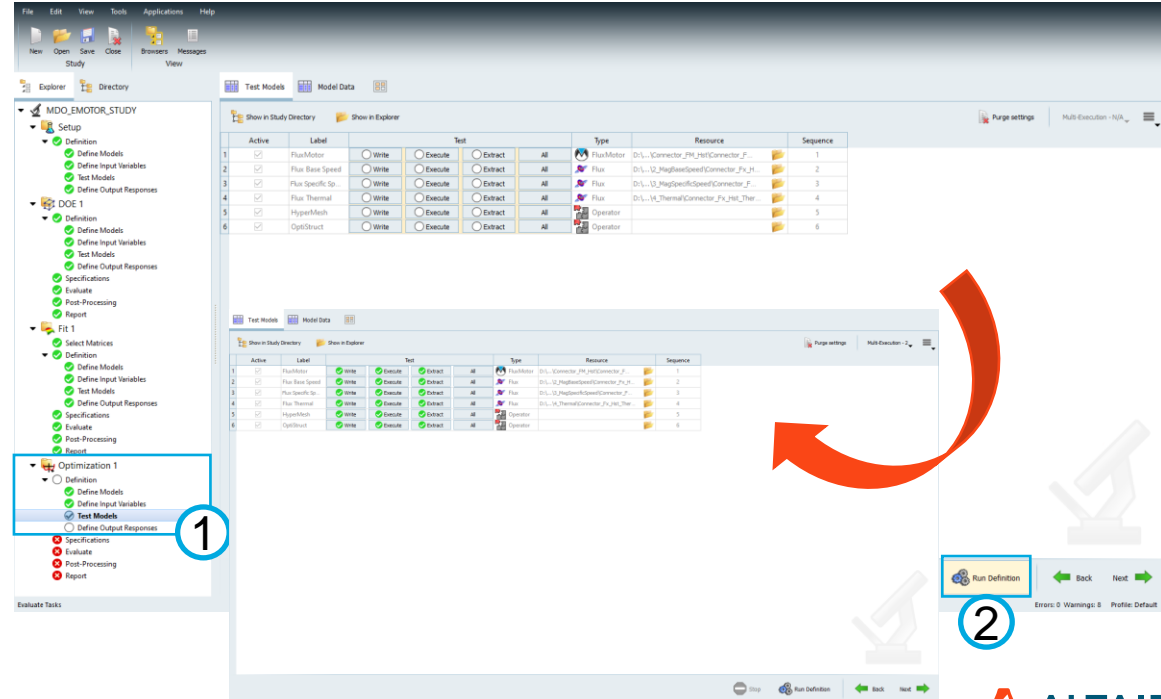
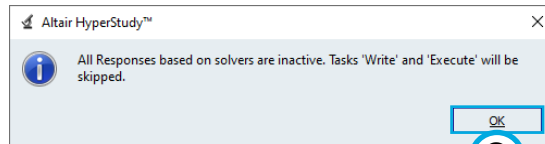
Step	Action	Label	Varname	Apply on	Type	1	2
1	Modify the goals and constraints as shown in the following table	MaxPowerBaseSpeed	goal_1	Base speed::Mechanical power (W) ( r_6 )	Maximize		
		MinRotorMass	goal_2	Masses::Rotor (kg) ( r_1 )	Minimize		
		TorqueBassSpeed	constraint_3	Base speed::Mechanical torque (N.m) ( r_4 )	Constraint	>=	180
		PowerBassSpeed	constraint_4	Base speed::Mechanical power (W) ( r_6 )	Constraint	>=	140000
		TemperatureWinding	constraint_5	T_COIL ( r_38 )	Constraint	<=	180
		TorqueBassSpeedRipple	constraint_6	TORQUE_BASE_SPEED_RIPPLE ( r_53 )	Constraint	<=	29
		TempMagnetMax	constraint_7	MAX_MAGNET_TEMPERATURE ( r_54 )	Constraint	<=	100
		MechanicalStress	constraint_8	MECHANICAL_STRESS_MAX ( r_56 )	Constraint	<=	400

# OPTIMIZATION PROCESS

## Optimization initialization

- Verify model definition

Step	Action
1	Click on [Optimization 1] – [Definition] – [Test Models]
2	Click on [Run Definition] to verify the models before running optimization process
3	Click on [OK]

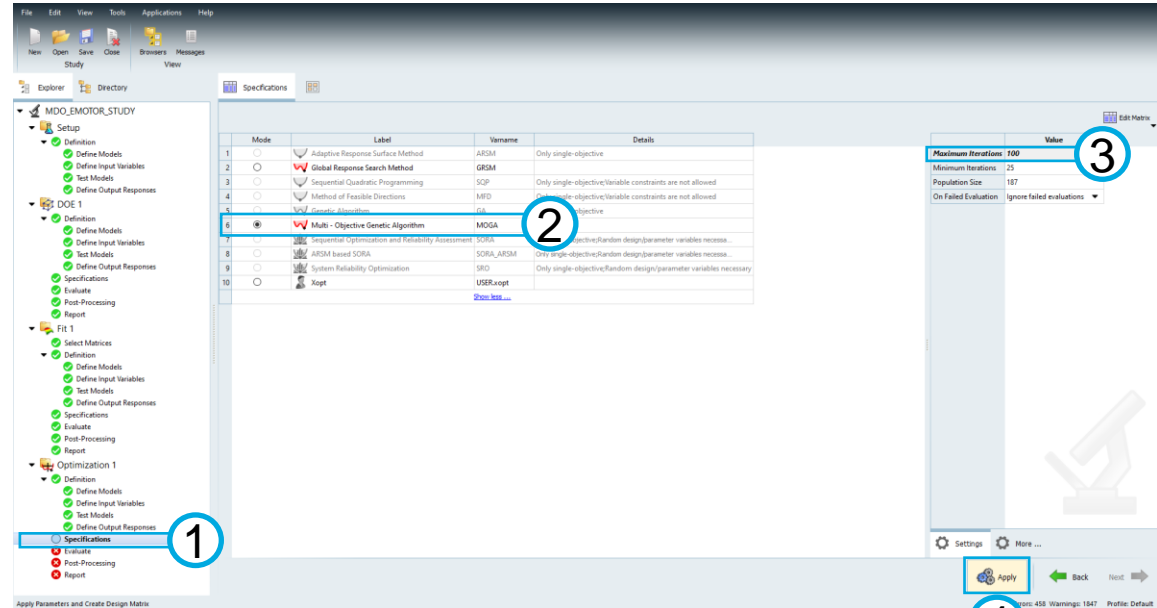


# OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization setting

Step	Action
1	Click on [Specifications]
2	Select “MOGA” algorithm
3	Define the “Maximum Iteration” number
4	Click on [Apply]



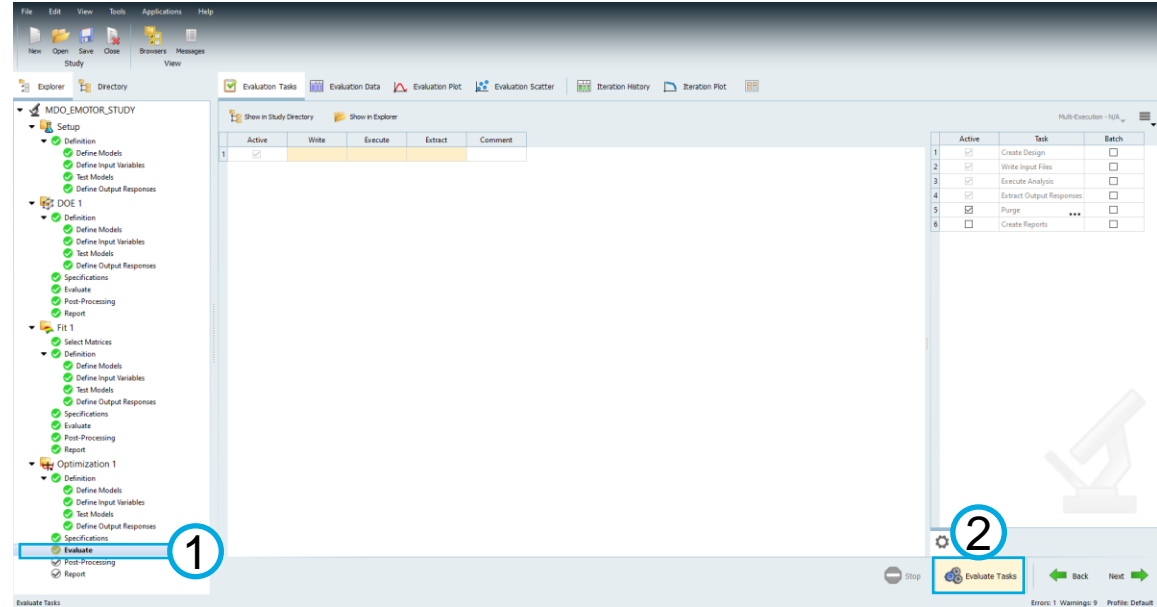
**Note: The Multi Objective Generic Algorithm is a suitable method for the optimization problem based on fit functions.**

# OPTIMIZATION PROCESS

## Optimization evaluation

- Evaluate tasks for the optimization problem

Step	Action
1	Click on [Evaluate]
2	Click on [Evaluate Tasks]



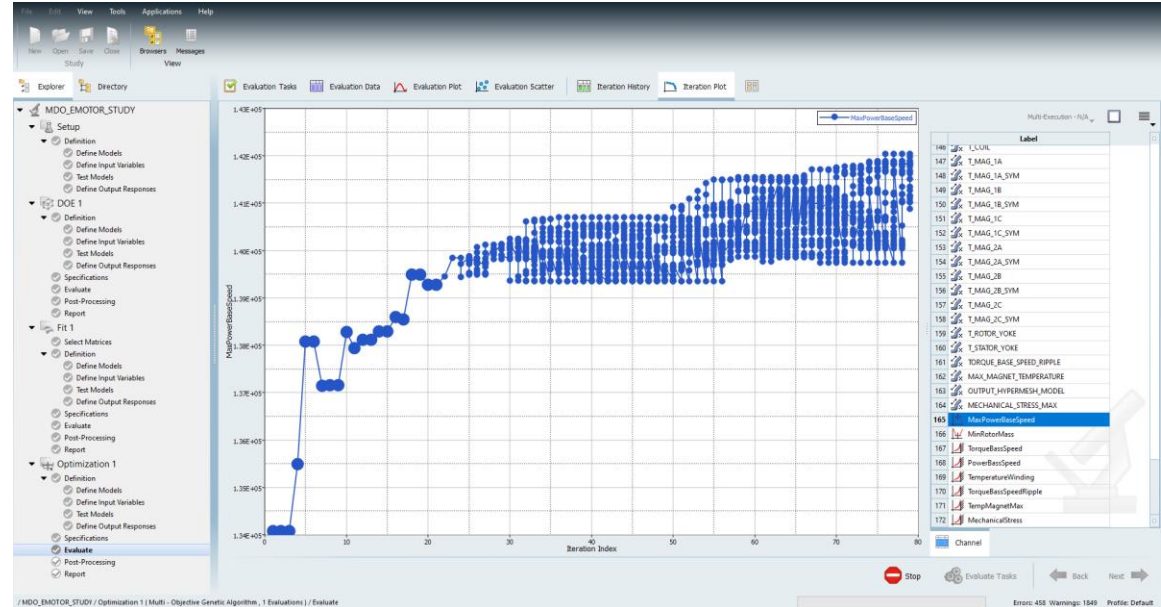
**Note: The optimization problem based on fit functions will cost just 15 minutes.**

# OPTIMIZATION PROCESS

## Optimization evaluation

- Verify iteration convergence during the optimization process

Step	Action
1	Click on [Iteration Plot]

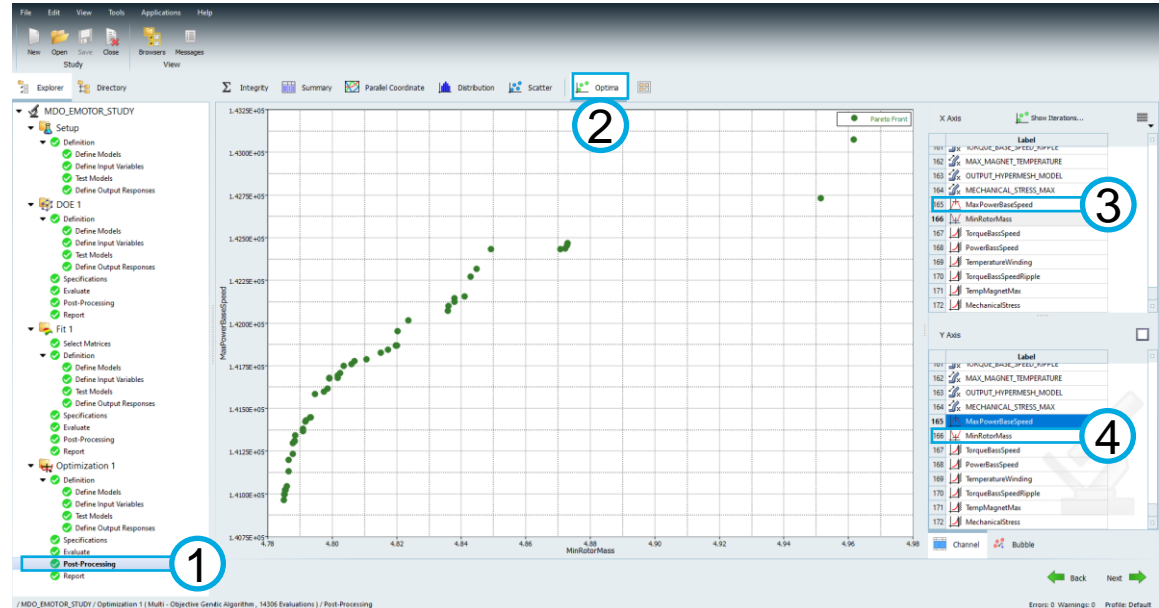


# OPTIMIZATION PROCESS

## Optimization post-processing

- Plot optimal curve

Step	Action
1	Click on [Post-Processing]
2	Click on [Optimal] to see all the optimization results for the electric motor
3	Select the Goal "MinRotorMass"
4	Select the Goal "MaxPowerBaseSpeed"





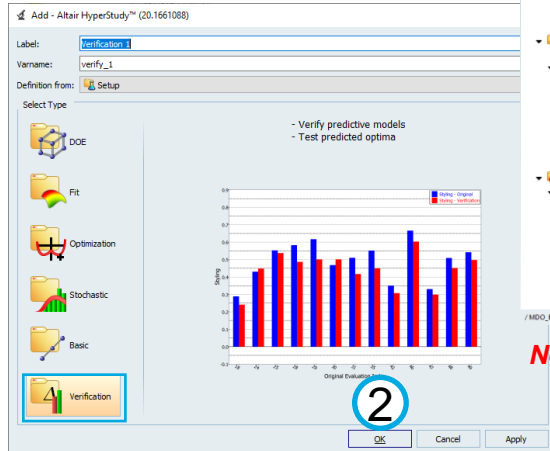
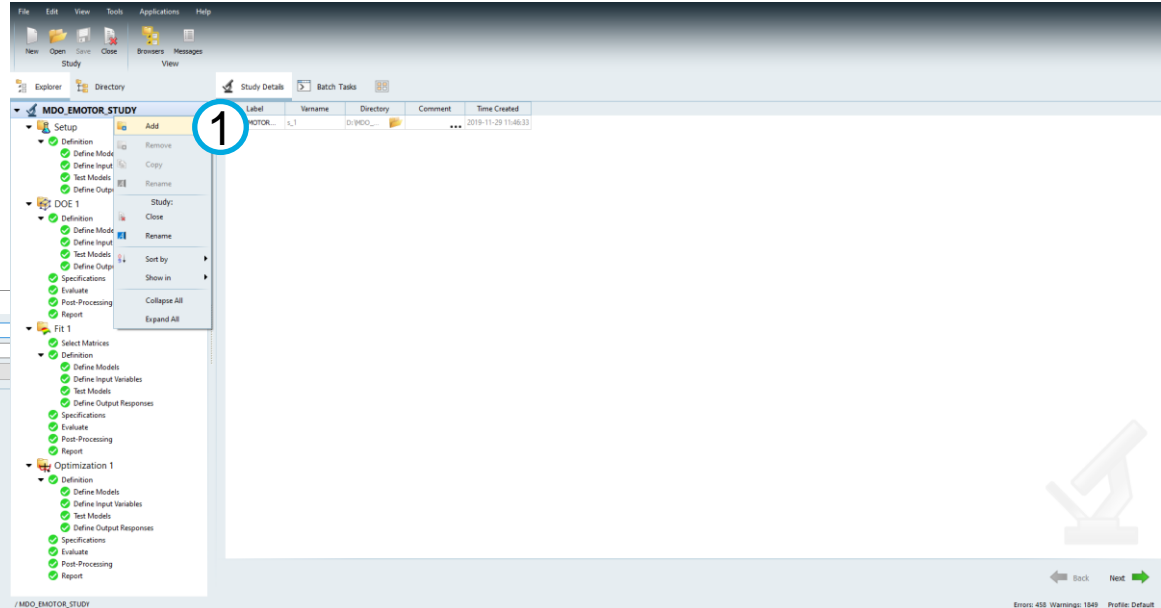
# OPTIMIZATION VERIFICATION

# OPTIMIZATION VERIFICATION

## Verification initialization

- Add a new verification

Step	Action
1	Right click on the project “MDO_MOTOR_STUDY”, click on [Add]
2	Select the type as “Verification”, click on [OK]



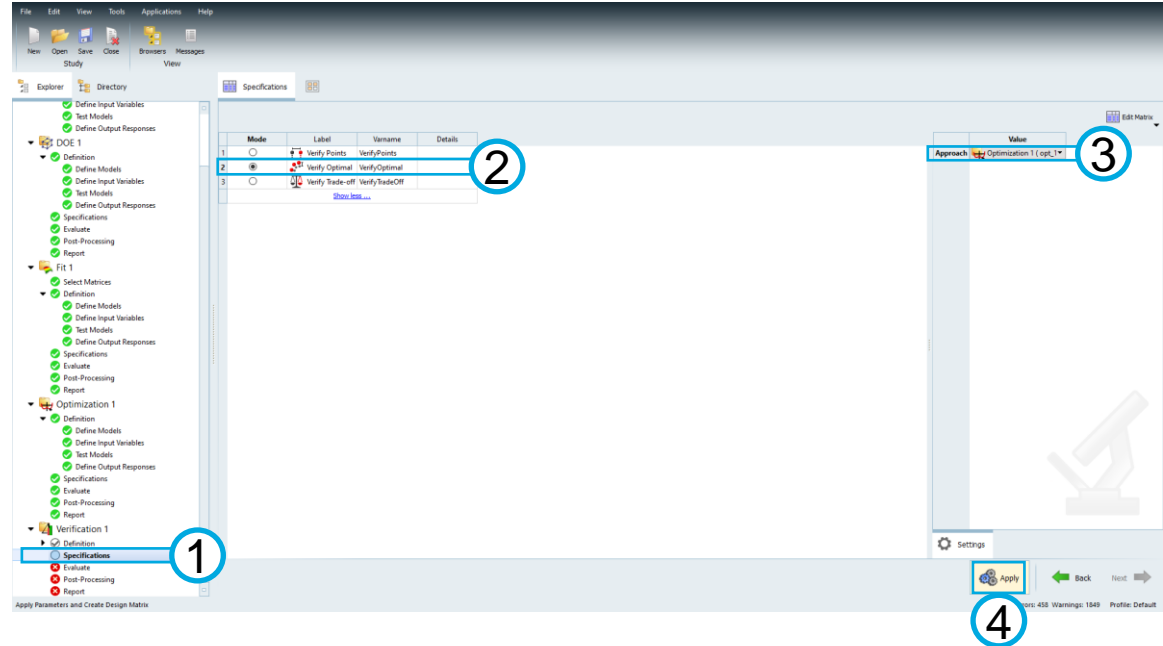
**Note: The results of optimization problem based on fit functions will need to be check with real model.**

# OPTIMIZATION VERIFICATION

## Verification specification

- Define verification mode and original value

Step	Action
1	Click on [Verification 1] – [Specification]
2	Select the verification mode as “Verify Optimal”
3	Verify if the value is from the “Optimization 1”
4	Click on [Apply]

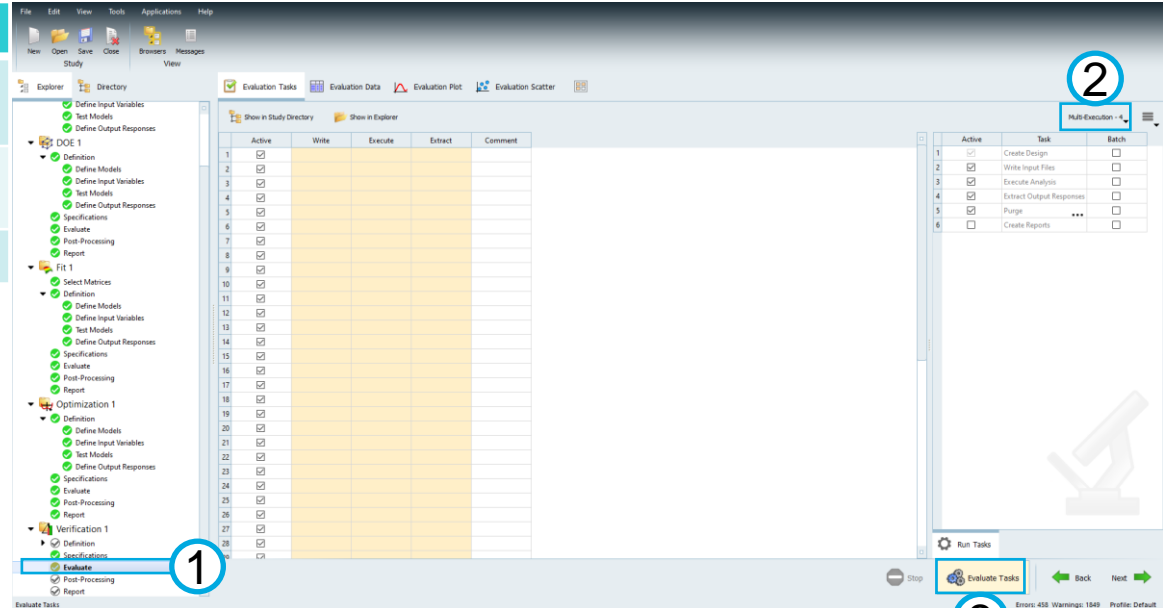


# OPTIMIZATION VERIFICATION

## Verification evaluation

- Evaluate the verification tasks

Step	Action
1	Click on [Verification 1] – [Evaluate]
2	Click on [Multi-Execution] to define the multi-execution number
3	Click on [Evaluate Tasks]

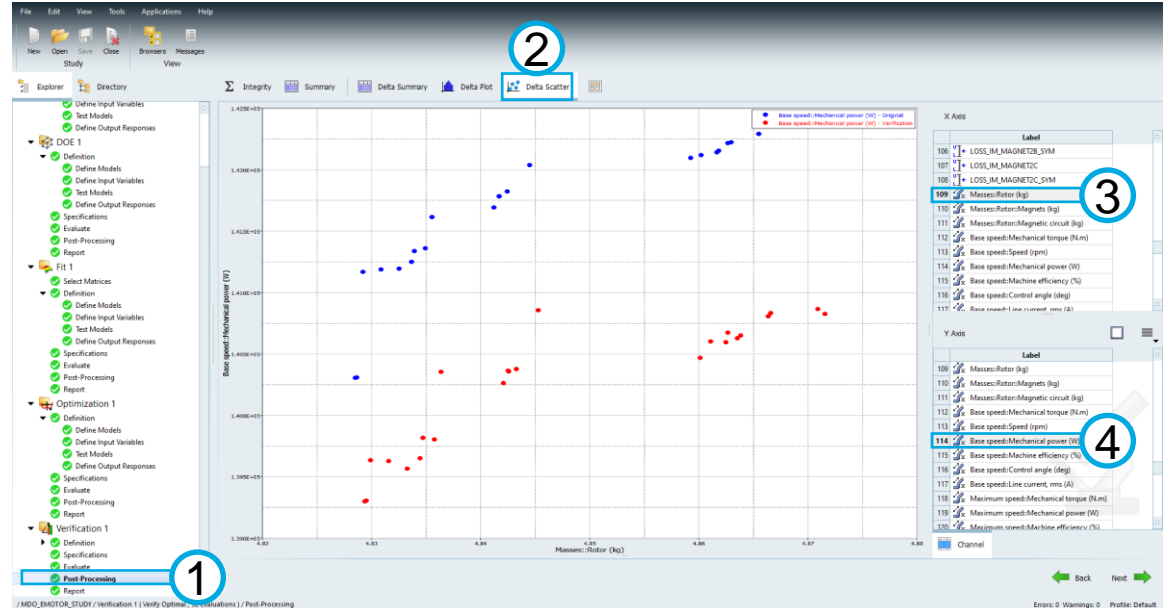


# OPTIMIZATION VERIFICATION

## Verification post-processing

- Plot the optimization curve with verification values

Step	Action
1	Click on [Verification 1] – [Post-Processing]
2	Click on [Delta Scatter]
3	Select the variable 109 “Masses: Rotor”
4	Select the variable 114 “Base speed: Mechanical power”



**Note:** The difference between original results from the optimization base on fit function and the verification results is about 0.7%.

# OPTIMIZATION VERIFICATION

## Verified optimization results

- Global optimal results



Objective power

# OPTIMIZATION VERIFICATION

## Verified optimization results

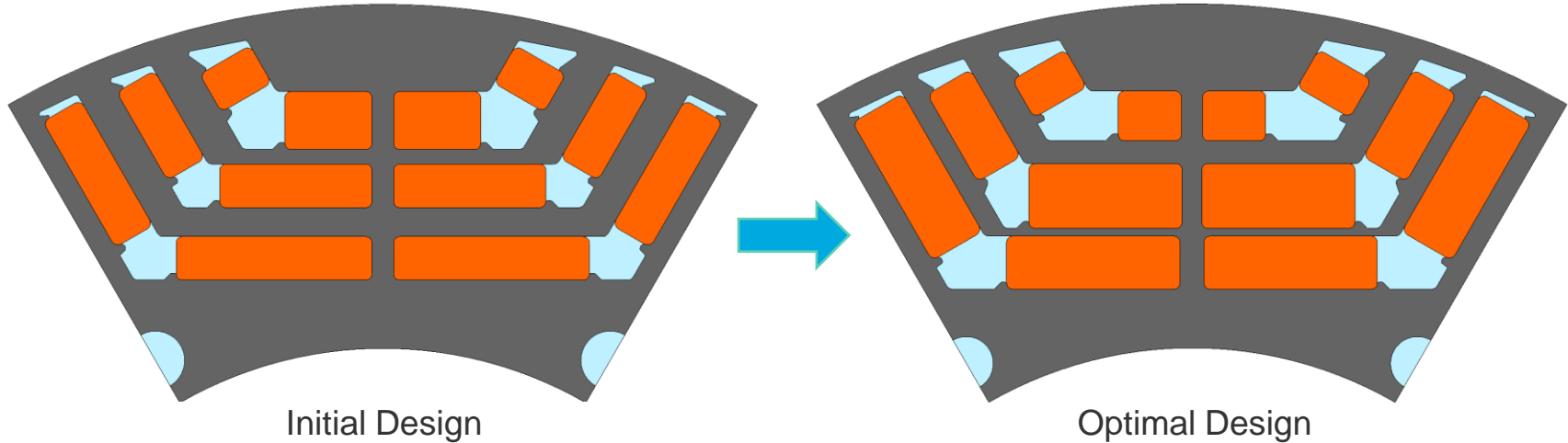
- Global optimal results comparison

	Original value	Verified value	Difference (between verified value and original value)
Mechanical power at base point / W	137818	140854.7	2.20%
Rotor mass / kg	4.96	4.85	-2.31%
Mechanical torque at base point / N*m	184.21	181.43	-1.51%
Mechanical torque ripple at base point / N*m	43.11	34.78	-19.33%
Winding temperature / °C	151.01	159.37	5.54%
Magnet temperature / °C	46.75	46.11	-1.36%
Mechanical stress / MPa	450.79	390.80	-13.31%

# OPTIMIZATION VERIFICATION

Verified optimization results

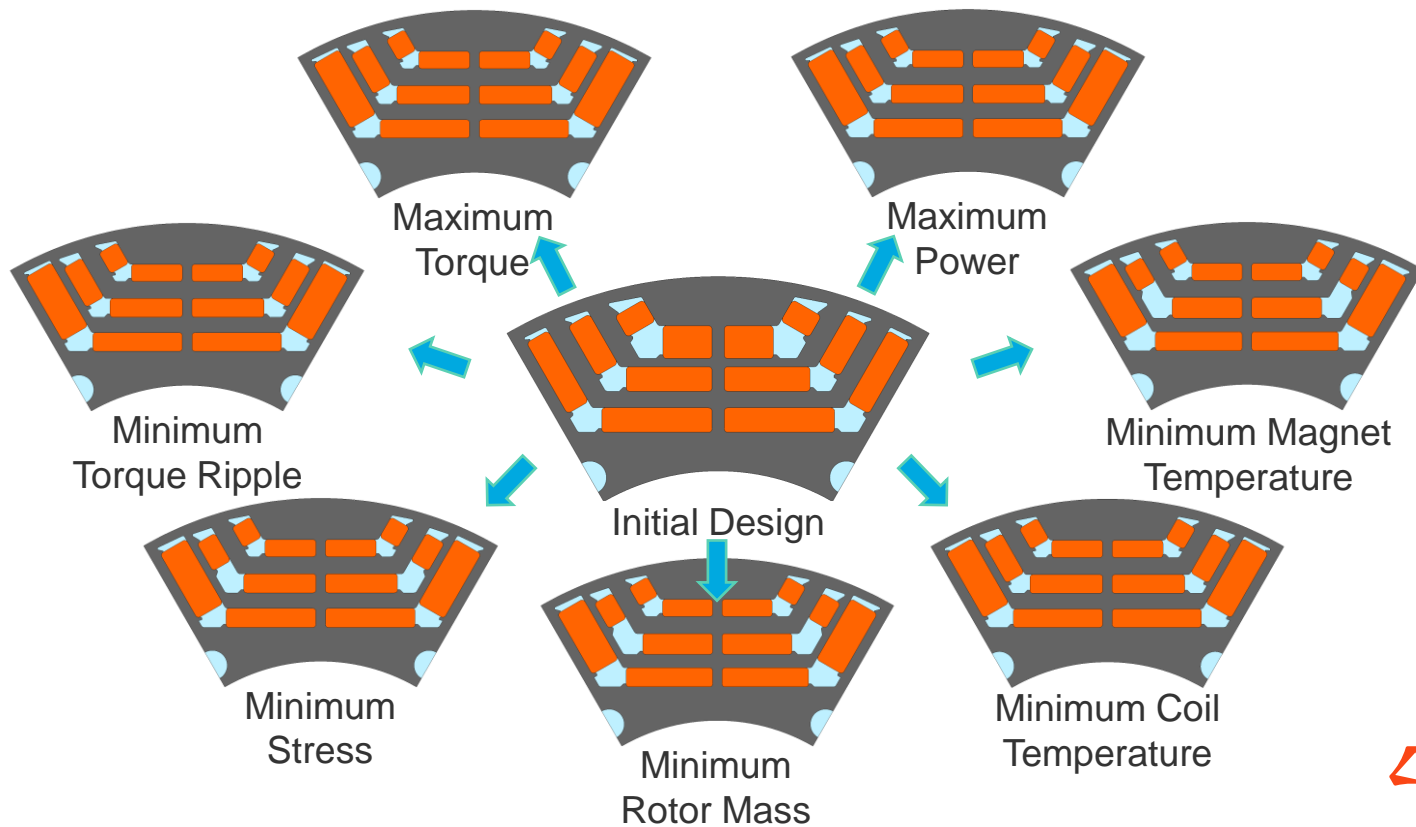
- Global optimal results





# OPTIMIZATION VERIFICATION

Verified optimization: local optimization results for each goal and constraints



# OPTIMIZATION VERIFICATION

Verified optimization: local optimization results for each goal and constraints

- Local optimal results

	Original value	Local optimal point 1	Local optimal point 2	Local optimal point 3	Local optimal point 4
Mechanical power at base point / W	137817.95	139299.49	139818.81	140356.21	140378.62
Rotor mass / kg	4.96	4.83	4.83	4.84	4.84
Mechanical torque at base point / N*m	184.21	182.36	181.77	181.56	181.57
Mechanical torque ripple at base point / N*m	43.11	34.59	34.99	34.19	34.26
Winding temperature / °C	151.01	158.04	159.07	159.23	159.22
Magnet temperature / °C	46.75	46.20	46.13	46.10	46.09
Mechanical stress / MPa	450.79	394.00	373.40	389.73	378.40

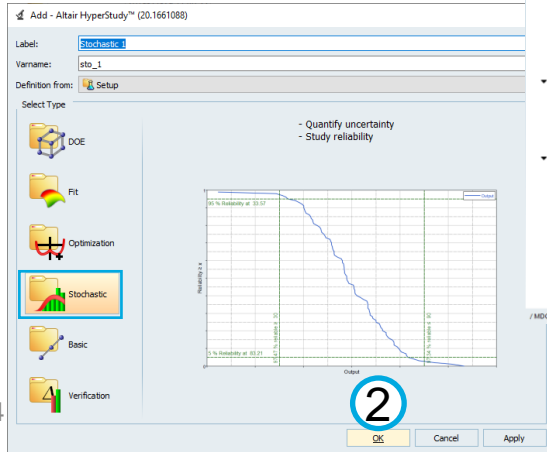
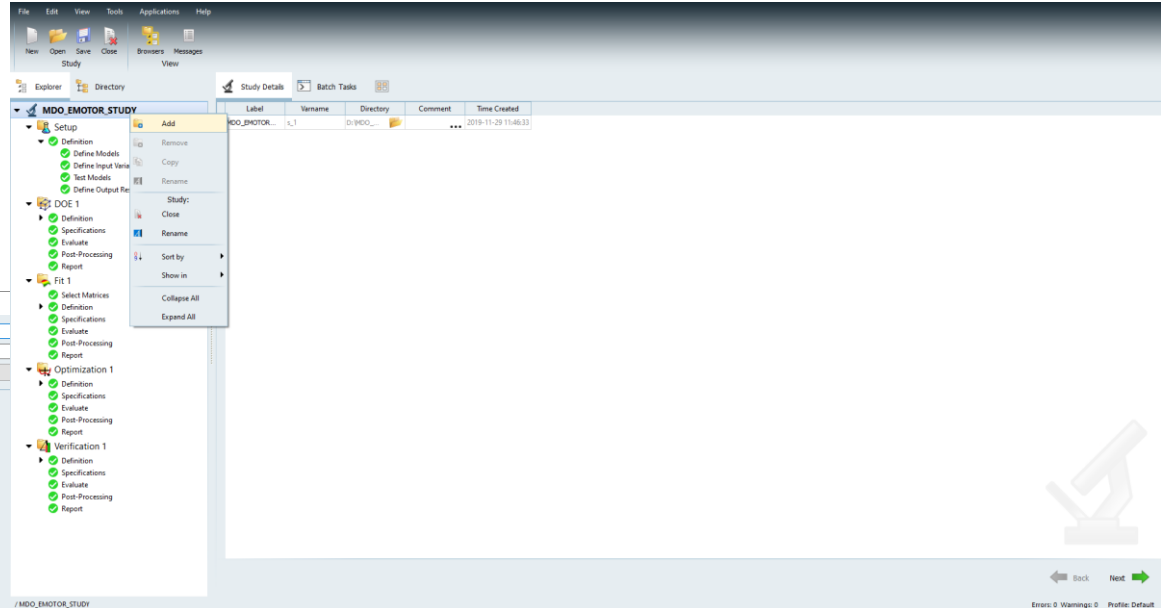
# STOCHASTIC STUDY AND RELIABILITY TEST

# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study initialization

- Add a new stochastic test

Step	Action
1	Right click on the project "MDO_MOTOR_STUDY", click on [Add]
2	Select the type as "Stochastic", click on [OK]

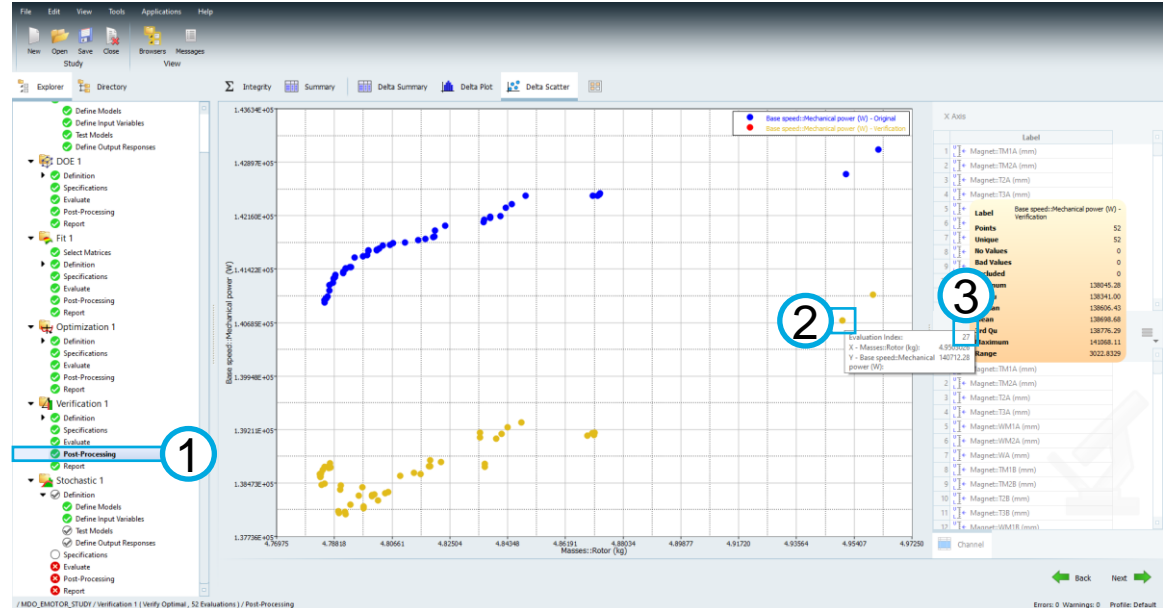


# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study initialization

- Select the “optimal” point

Step	Action
1	Click on [Verification 1] – [Post-processing]
2	Select an optimal point in the optimization curve
3	In this case, the index of the optimal point is 27



# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study initialization

- Copy the geometric values of the “optimal” point

Step	Action
1	Click on [Summary]
2	Select all the 22 geometric parameters
3	Select all the values in the row 27
4	Right click and click on [Copy]

The screenshot shows the HyperMesh interface with the 'Summary' tab selected. The table displays the following data for the 22 geometric parameters across 40 points:

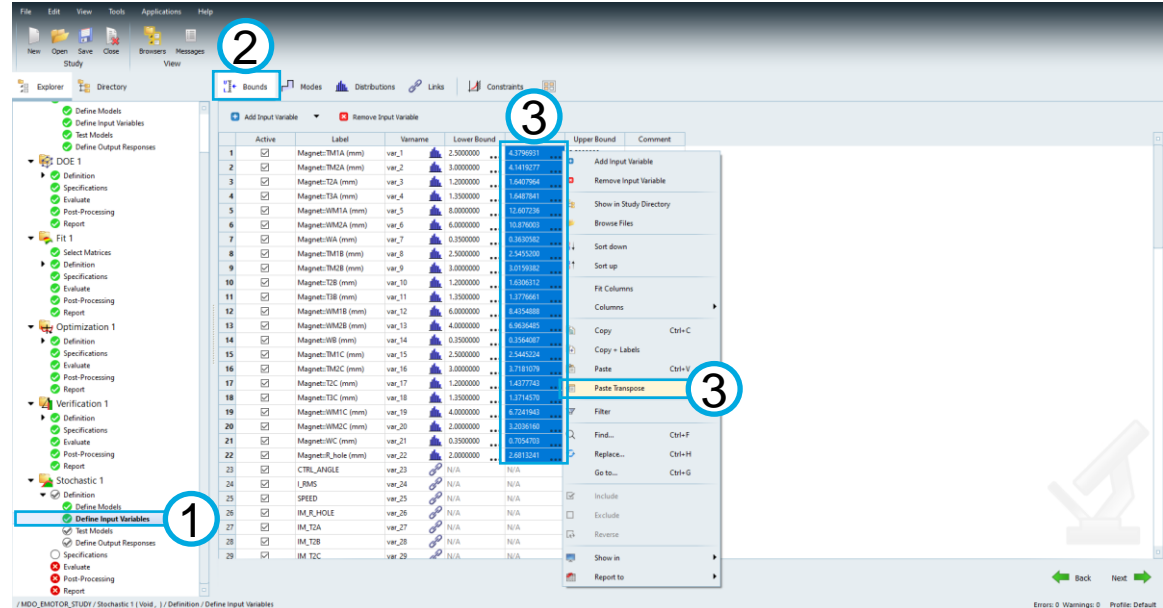
Point	Magnet:TM1A (mm)	Magnet:TM2A (mm)	Magnet:T2A (mm)	Magnet:TM1B (mm)	Magnet:TM2B (mm)	Magnet:T2B (mm)	Magnet:IM1A (mm)	Magnet:IM2A (mm)	Magnet:IM1B (mm)	Magnet:IM2B (mm)	Magnet:T2C (mm)	Magnet:T2D (mm)	Magnet:IM1C (mm)	Magnet:IM2C (mm)	Magnet:IM1D (mm)	Magnet:IM2D (mm)	CTRL_ANGLE	LIMS	SPEED	IM_R_HOLE	IM_T2A
13	52327	8.167581	6.834796	0.3613813	2.5510787	3.658488	1.4822378	1.3821332													
14	30000	8.220881	6.783281	0.3606283	2.5394151	3.6907107	1.4820183	1.3751374													
15	38757	8.2125137	6.8257116	0.3612022	2.5392988	3.6905027	1.4847782	1.3751654													
16	47657	8.2107311	6.7831683	0.3611484	2.5436186	3.6905051	1.4820880	1.3742090													
17	62088	8.1673804	6.8353722	0.3607348	2.5510719	3.6524554	1.4808841	1.3821095													
18	71977	8.2210313	6.8249575	0.3614032	2.5334646	3.6965081	1.4888845	1.3747276													
19	88462	8.1734655	6.8307885	0.3613744	2.5456677	3.6742026	1.4812888	1.3800802													
20	62839	8.1674410	6.8347728	0.3613813	2.5510787	3.6969230	1.4822300	1.3844890													
21	16387	8.2745362	6.7945672	0.3611405	2.5434600	3.6908818	1.4820888	1.3742689													
22	26021	8.1701224	6.8388071	0.3613728	2.5511576	3.6754673	1.4813285	1.3811488													
23	47763	8.2107314	6.7831984	0.3611488	2.5436184	3.6954880	1.4820793	1.3738048													
24	38758	8.2126695	6.8257190	0.3612022	2.5399865	3.6905027	1.4847778	1.3751654													
25	44772	8.2253437	6.7832384	0.3610436	2.5342137	3.6943563	1.4840873	1.3737557													
26	30000	8.2495202	6.8014676	0.3606283	2.5392024	3.6907687	1.4820381	1.3732628													
27	7661	8.4154888	6.9616485	0.3564887	2.5443224	3.7181079	1.4777763	1.3714670													
28	90412	8.2193367	6.8271872	0.3704025	2.5391249	3.6943418	1.4840854	1.3737600													
29	41296	8.2122124	6.8291338	0.3610701	2.5284775	3.6959163	1.4818385	1.3783304													
30	37162	8.1673852	6.8401872	0.3607388	2.5436186	3.6519789	1.4809949	1.3920161													
31	47132	8.1604982	6.8912289	0.3597830	2.5410214	3.6501578	1.4795942	1.3888120													
32	46135	8.1735625	6.8307885	0.3613744	2.5456680	3.6749818	1.4813288	1.3798816													
33	27887	8.2195135	6.8271434	0.3610828	2.5391258	3.6957938	1.4840881	1.3773384													
34	10580	8.432641	6.9616504	0.3589817	2.5431934	3.7815784	1.4791720	1.3689917													
35	38602	8.2387884	6.8014676	0.3606284	2.5393045	3.6907720	1.4820381	1.3733627													
36	44777	8.2253557	6.7832384	0.3610436	2.5342138	3.6943563	1.4840873	1.3737554													
37	50237	8.4906073	7.3594915	0.3610599	2.5373802	3.6618214	1.4844006	1.3773317													
38	41334	8.2172215	6.8291226	0.3610700	2.5286384	3.6957684	1.4818385	1.3783304													
39	31955	8.1397184	6.8294413	0.3637283	2.5451572	3.6767964	1.4840822	1.3787369													
40	31052	8.0810710	6.8221439	0.3770502	2.5458183	3.6630763	1.4881133	1.3864786													

# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study initialization

- Update the parameter values in the stochastic study


Step	Action
1	Click on [Stochastic 1] – [Definition] – [Define Input Values]
2	Click on [Bounds]
3	Select all the nominal values of the first 22 geometric parameters
4	Right click and click on [Paste Transpose]

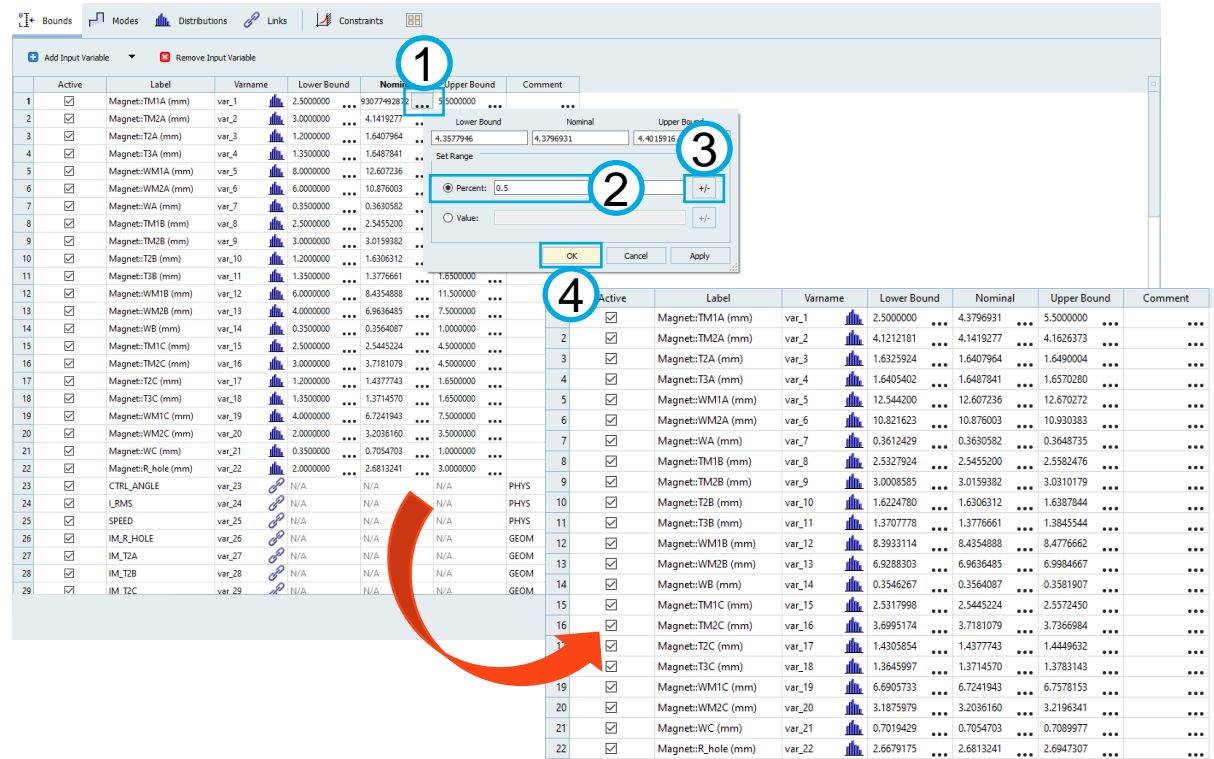


# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study initialization

- Define parameter variation

Step	Action
1	Click on [...]
2	Define the variation percentage as 0.5%
3	Click on the icon 
4	Click on [OK]
5	Change the variation range for all the 22 geometric parameters



The screenshot displays the 'Stochastic Study' initialization window in Altair HyperMesh. The main table lists 29 input variables, including 22 geometric parameters (Magnet:TM1A to Magnet:R\_hole) and 7 non-geometric parameters (CTRL\_ANGLE, LRMS, SPEED, IM\_R\_HOLE, IM\_T2A, IM\_T2B, IM\_T2C). The dialog box for defining variation is open, showing the 'Percent' radio button selected with a value of 0.5. The '+/-' icon is used to toggle between percentage and value-based variation. The 'OK' button is highlighted with a red arrow pointing to the 'OK' button in the main table.

Active	Label	Varname	Lower Bound	Nominal	Upper Bound	Comment
1	Magnet:TM1A (mm)	var_1	2.500000	930774928	5.000000	
2	Magnet:TM2A (mm)	var_2	3.000000	4.141927	4.162637	
3	Magnet:T3A (mm)	var_3	1.200000	1.640796	1.649004	
4	Magnet:T2A (mm)	var_4	1.350000	1.548784	1.657028	
5	Magnet:WM1A (mm)	var_5	8.000000	12.607236	12.670272	
6	Magnet:WM2A (mm)	var_6	6.000000	10.876003	10.930383	
7	Magnet:WA (mm)	var_7	0.350000	0.363058	0.368735	
8	Magnet:TM1B (mm)	var_8	2.500000	2.545520	2.558246	
9	Magnet:TM2B (mm)	var_9	3.000000	3.015938	3.031017	
10	Magnet:T2B (mm)	var_10	1.200000	1.630631	1.638784	
11	Magnet:T3B (mm)	var_11	1.350000	1.377661	1.384554	
12	Magnet:WM1B (mm)	var_12	6.000000	8.435488	8.477662	
13	Magnet:WM2B (mm)	var_13	4.000000	6.963648	6.998467	
14	Magnet:WB (mm)	var_14	0.350000	0.356487	0.358197	
15	Magnet:TM1C (mm)	var_15	2.500000	2.544524	2.557245	
16	Magnet:TM2C (mm)	var_16	3.000000	3.718107	3.736694	
17	Magnet:T2C (mm)	var_17	1.200000	1.437743	1.449632	
18	Magnet:T3C (mm)	var_18	1.350000	1.371457	1.378313	
19	Magnet:WM1C (mm)	var_19	4.000000	6.724194	6.757813	
20	Magnet:WM2C (mm)	var_20	2.000000	3.203616	3.219634	
21	Magnet:WC (mm)	var_21	0.350000	0.705470	0.708997	
22	Magnet:R_hole (mm)	var_22	2.000000	2.681324	2.694737	
23	CTRL_ANGLE	var_23	N/A	N/A	N/A	
24	LRMS	var_24	N/A	N/A	N/A	
25	SPEED	var_25	N/A	N/A	N/A	
26	IM_R_HOLE	var_26	N/A	N/A	N/A	
27	IM_T2A	var_27	N/A	N/A	N/A	
28	IM_T2B	var_28	N/A	N/A	N/A	
29	IM_T2C	var_29	N/A	N/A	N/A	

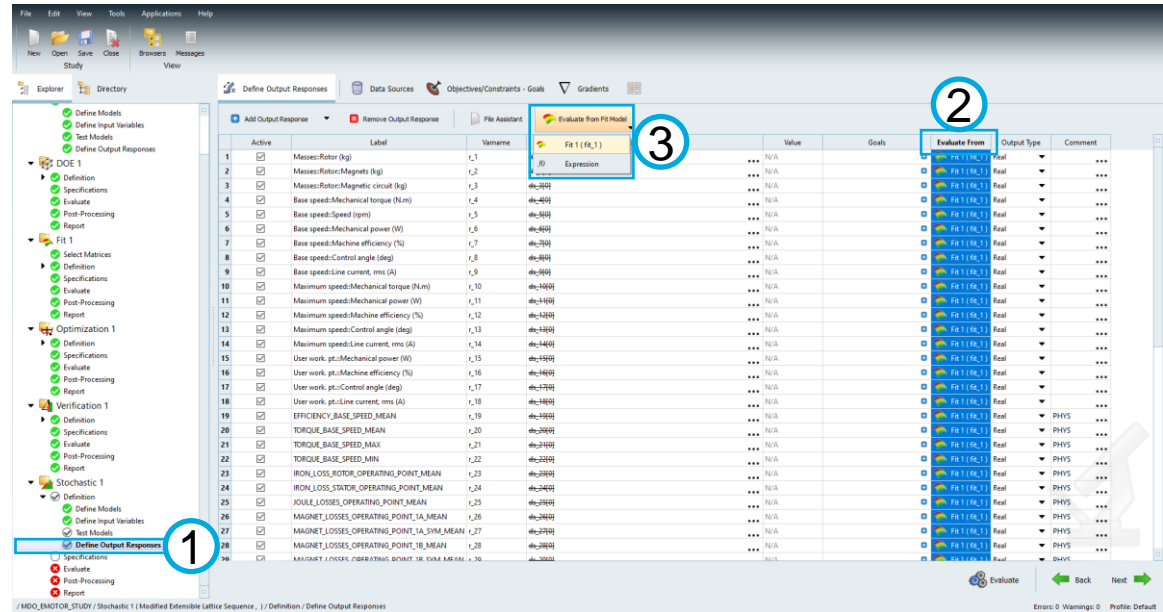


# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study initialization

- Update output responses

Step	Action
1	Click on [Stochastic 1] – [Definition] – [Define Output Responses]
2	Click on [Evaluate From] to select all the output responses
3	Click on [Evaluate from Fit Model] – [Fit 1] to link the optimization with the fit functions

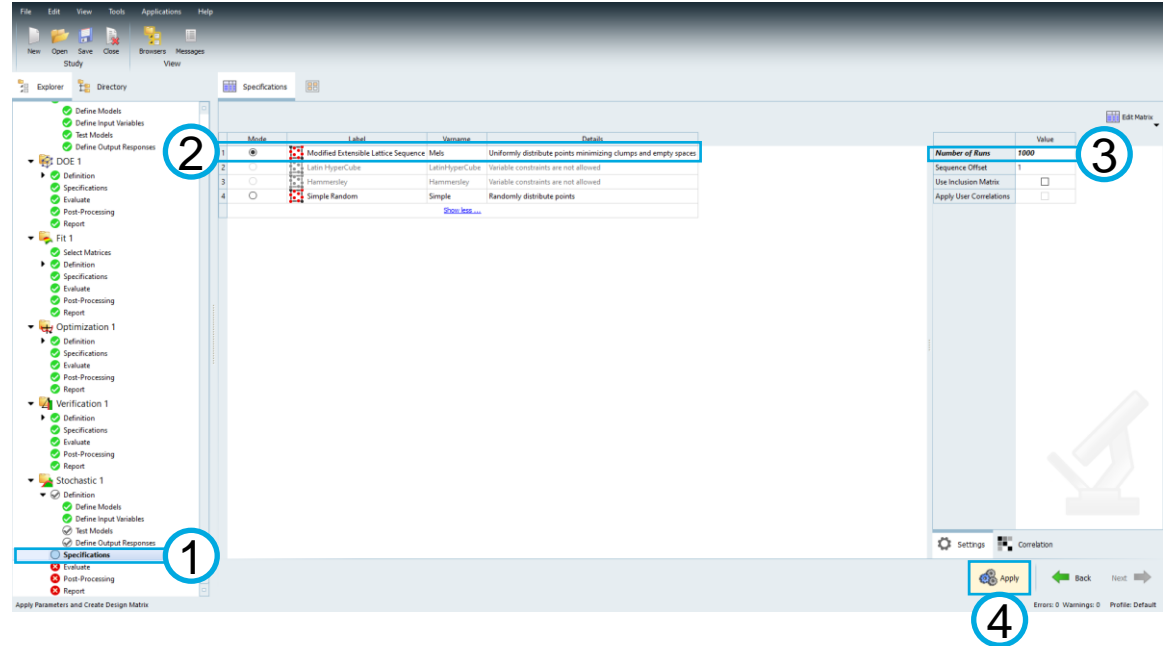


# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study evaluation

- Specify the stochastic study

Step	Action
1	Click on [Stochastic 1] – [Specification]
2	Select the method MELS
3	Define the number of runs as 1000 (by default is 100)
4	Click on [Apply]

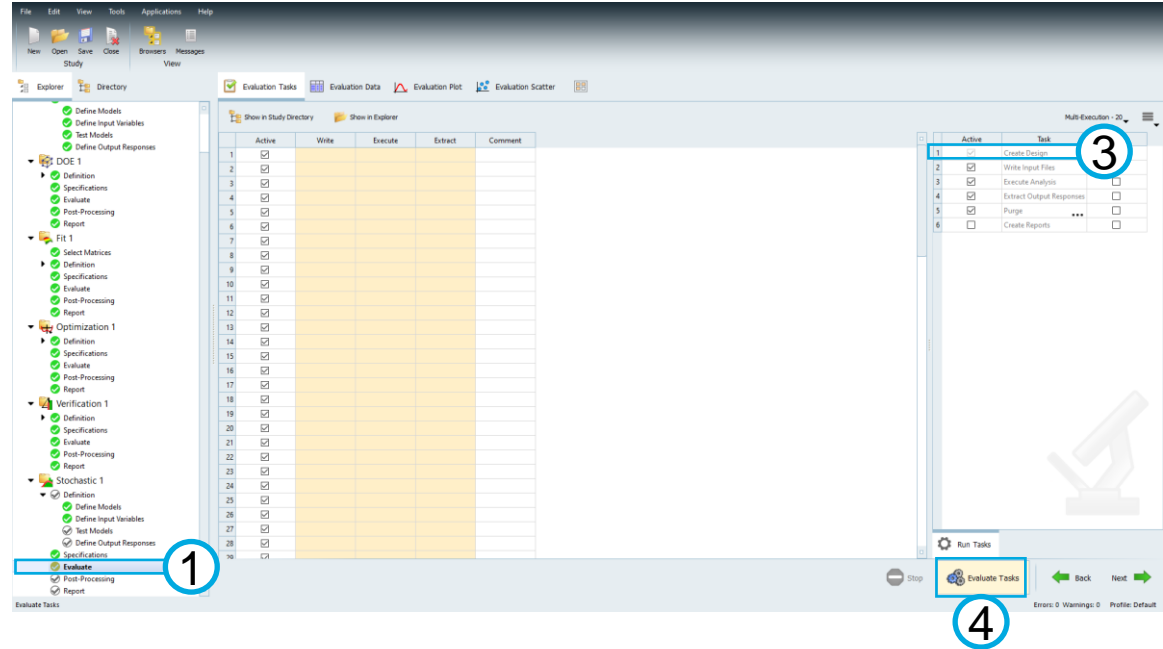


# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study evaluation

- Evaluate tasks in stochastic study

Step	Action
1	Click on [Stochastic 1] – [Specification]
2	Define the multi-execution number
3	Click on [Evaluate Tasks]

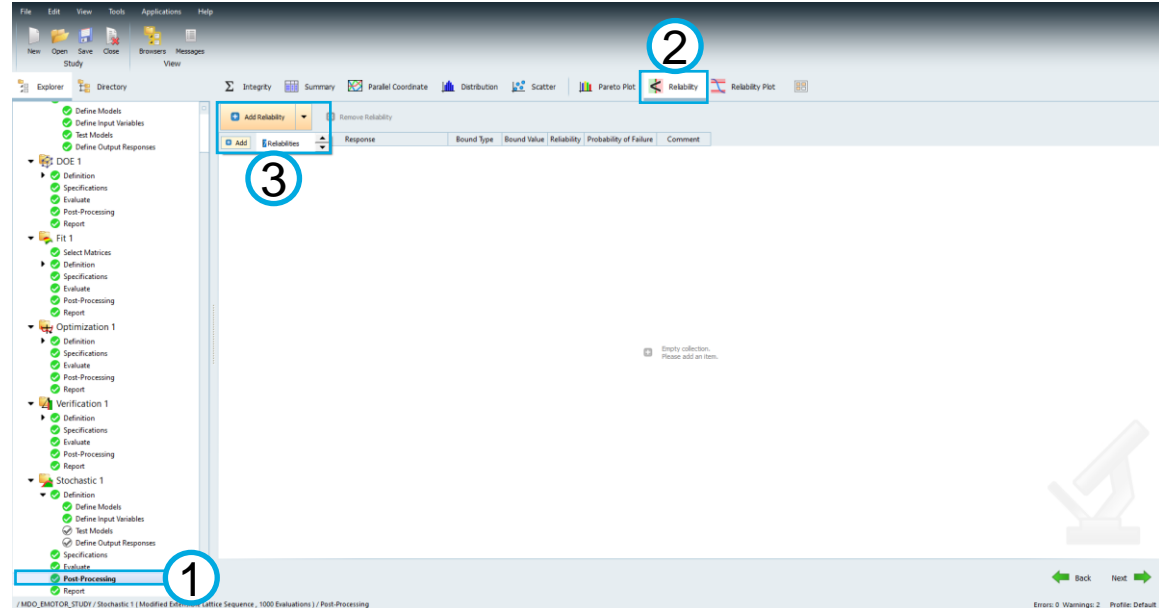


# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study post-processing

- Evaluate tasks in stochastic study

Step	Action
1	Click on [Stochastic 1] – [Post-Processing]
2	Click on [Reliability]
3	Click on [Add Reliability] to add 6 reliability test



# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study post-processing

- Verify the reliabilities of all the objectives

Step	Action
1	Define the responses as the optimization objectives
2	Modify the “Bound Type” and the “Bound Value”
3	Verify the reliabilities of all the objectives

Active	Response	Bound Type	Bound Value	Reliability	Probability of Failure	Comment
<input checked="" type="checkbox"/>	Masses:Rotor (kg) (r_1)	<=	4.9579463	0.9980000	0.0020000	...
<input checked="" type="checkbox"/>	Base speed:Mechanical torque (N.m) (r_4)	>=	180.00000	1.0000000	0.0000000	...
<input checked="" type="checkbox"/>	Base speed:Mechanical power (W) (r_6)	>=	140.00000	1.0000000	0.0000000	...
<input checked="" type="checkbox"/>	T_COIL (r_38)	<=	180.00000	1.0000000	0.0000000	...
<input checked="" type="checkbox"/>	MAX_MAGNET_TEMPERATURE (r_54)	<=	100.00000	1.0000000	0.0000000	...
<input checked="" type="checkbox"/>	TORQUE_BASE_SPEED_RIPPLE (r_53)	<=	29.000000	1.0000000	0.0000000	...
<input checked="" type="checkbox"/>	MECHANICAL_STRESS_MAX (r_56)	<=	400.00000	0.9830000	0.1170000	...

# STOCHASTIC STUDY AND RELIABILITY TEST

## Stochastic study post-processing

- Verify the reliabilities of all the objectives

Response	Bound Type	Bound Value	Reliability	Probability of Failure	Comments
Masses::Rotor (kg) ( r_1 )	<=	4.957946	0.998	0.002	99.8% of the optimization results are robust due to a 0.5% parameter variation
Base speed::Mechanical torque (N.m) ( r_4 )	>=	180	1	0	100% of the optimization results are robust due to a 0.5% parameter variation
Base speed::Mechanical power (W) ( r_6 )	>=	140	1	0	100% of the optimization results are robust due to a 0.5% parameter variation
T_COIL ( r_38 )	<=	180	1	0	100% of the optimization results are robust due to a 0.5% parameter variation
MAX_MAGNET_TEMPERATURE ( r_54 )	<=	100	1	0	100% of the optimization results are robust due to a 0.5% parameter variation
TORQUE_BASE_SPEED_RIPPLE ( r_53 )	<=	29	1	0	100% of the optimization results are robust due to a 0.5% parameter variation
MECHANICAL_STRESS_MAX ( r_56 )	<=	400	0.883	0.117	88.3% of the optimization results are robust due to a 0.5% parameter variation

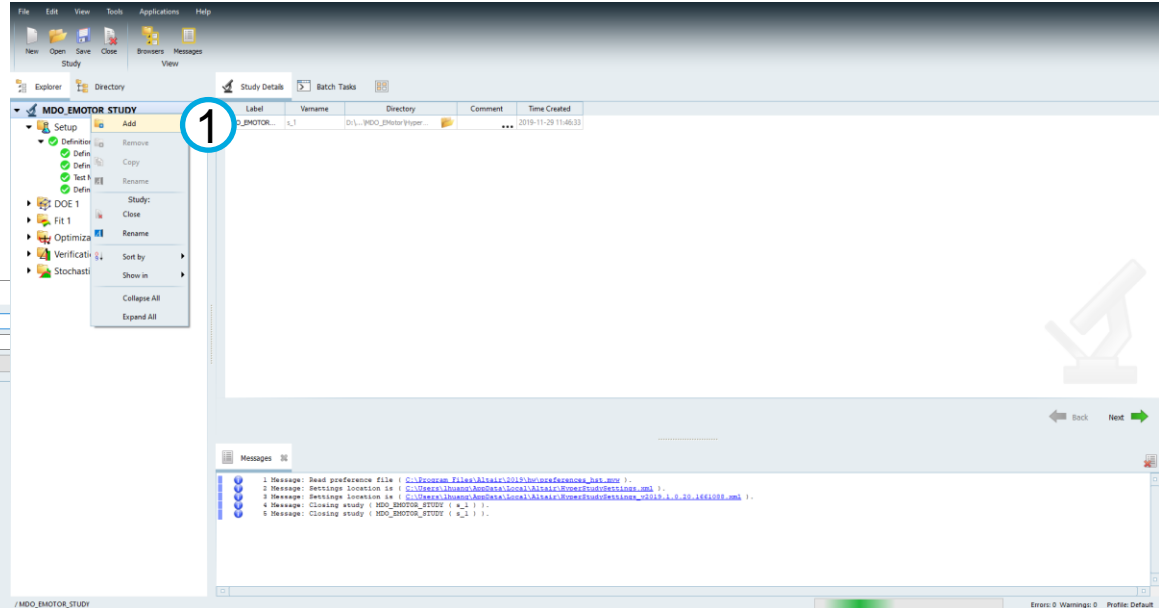
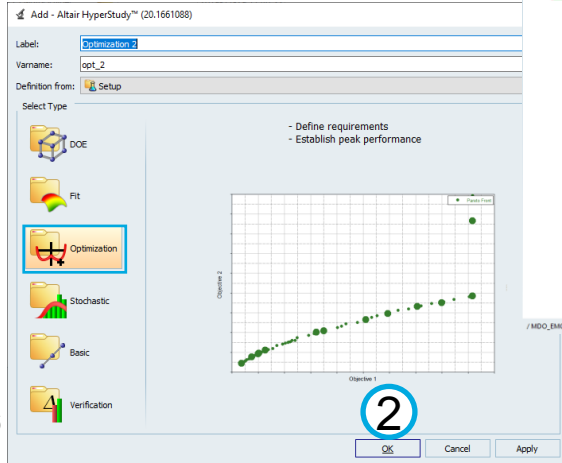
# DIRECT OPTIMIZATION

# DIRECT OPTIMIZATION PROCESS

## Optimization initialization

- Add a new optimization application

Step	Action
1	Right click on the project "MDO_MOTOR_STUDY", click on [Add]
2	Select the type as "DOE", click on [OK]



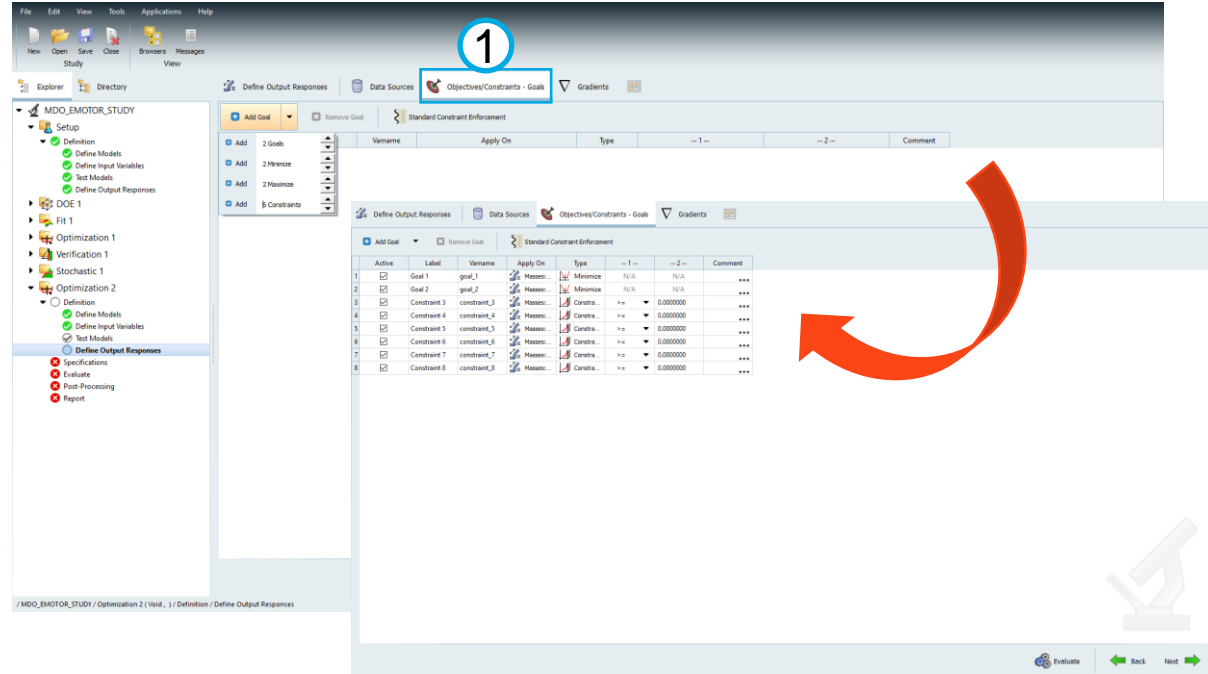
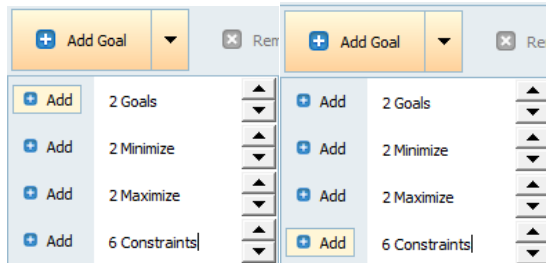


# DIRECT OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization goals and constraints

Step	Action
1	Click on [Objectives/Constraints - goals]
2	Click on the icon to add - 3 Goals - 6 constraints



# DIRECT OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization goals and constraints

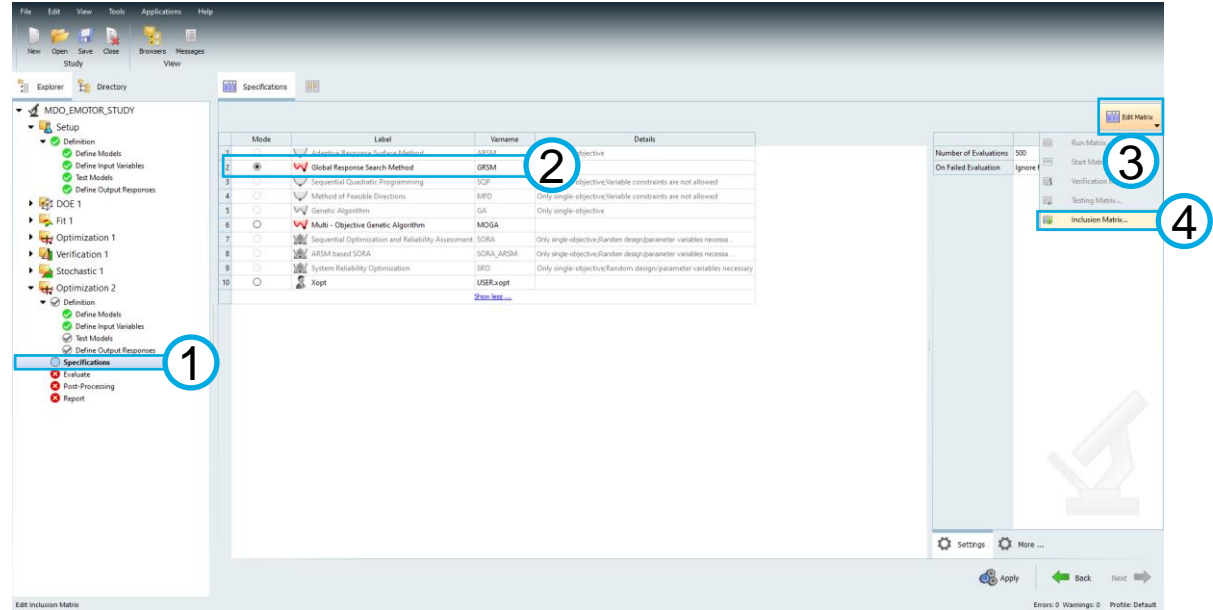
Step	Action	Label	Varname	Apply on	Type	1	2
1	Modify the goals and constraints as shown in the following table	MaxPowerBaseSpeed	goal_1	Base speed::Mechanical power (W) ( r_6 )	Maximize		
		MinRotorMass	goal_2	Masses::Rotor (kg) ( r_1 )	Minimize		
		TorqueBassSpeed	constraint_3	Base speed::Mechanical torque (N.m) ( r_4 )	Constraint	>=	180
		PowerBassSpeed	constraint_4	Base speed::Mechanical power (W) ( r_6 )	Constraint	>=	140000
		TemperatureWinding	constraint_5	T_COIL ( r_38 )	Constraint	<=	180
		TorqueBassSpeedRipple	constraint_6	TORQUE_BASE_SPEED_RIPPLE ( r_53 )	Constraint	<=	29
		TempMagnetMax	constraint_7	MAX_MAGNET_TEMPERATURE ( r_54 )	Constraint	<=	100
		MechanicalStress	constraint_8	MECHANICAL_STRESS_MAX ( r_56 )	Constraint	<=	400

# DIRECT OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization setting – import matrix from DOE

Step	Action
1	Click on [Optimization 2] – [Specifications]
2	Select “GRSM” algorithm
3	Click on [Edit Matrix]
4	Click on [Inclusion Matrix]



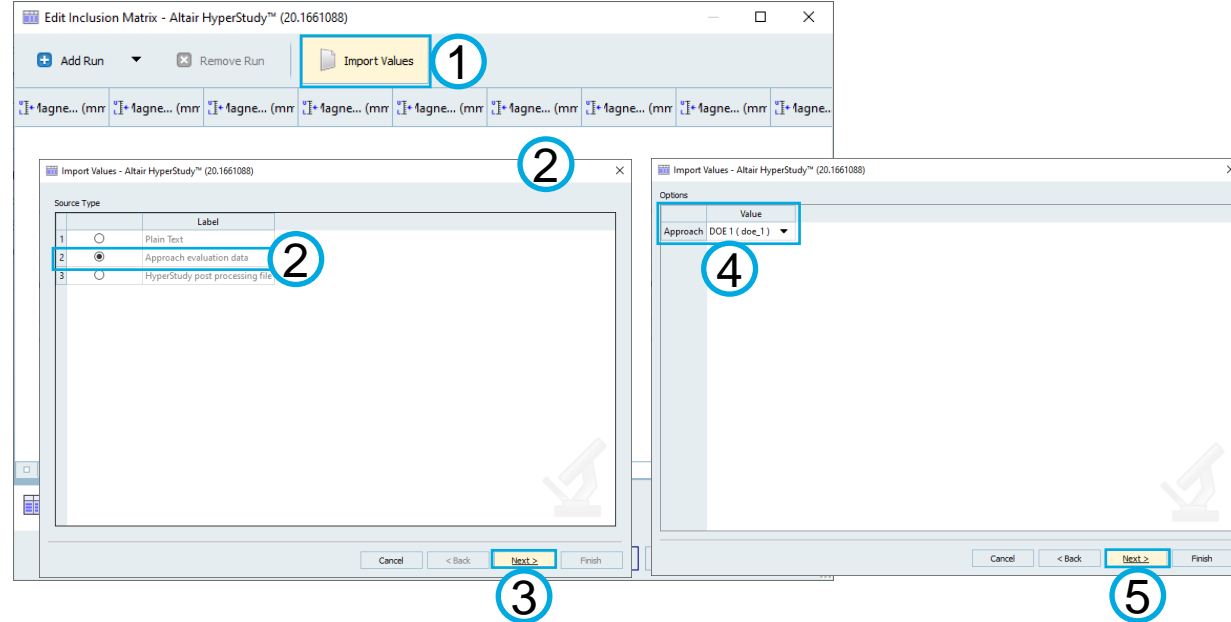
**Note: The Multi Objective Generic Algorithm is a suitable method for the optimization problem based on fit functions.**

# DIRECT OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization setting – import matrix from DOE

Step	Action
1	Click on [Import Values]
2	Select “Approach evaluation data”
3	Click on [Next]
4	Select on the [DOE 1] as the approach
5	Click on [Next]

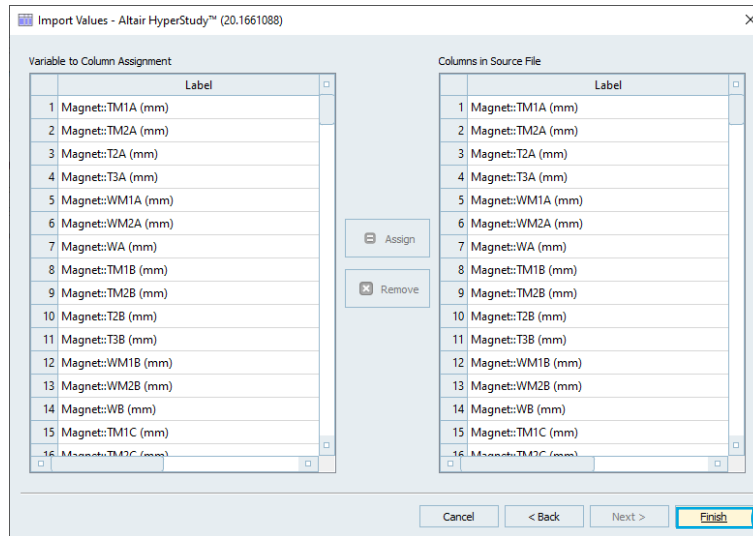


# DIRECT OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization setting – import matrix from DOE

Step	Action
1	Click on [Finish]
2	Click on [OK]



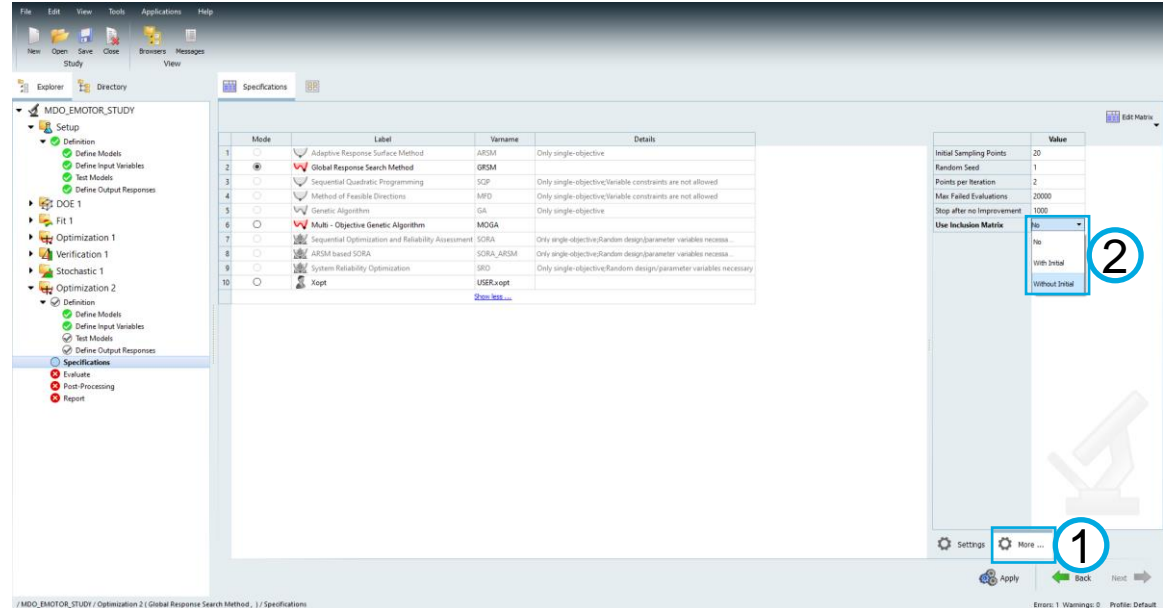
	1	2	3	4	5	6	7	8	9
1	3.1000000	3.6000000	1.5600000	1.5300086	12.880824	10.403617	0.5020174	2.9747775	4
2	4.3000000	3.3000000	1.3800000	1.5900691	12.804489	8.7635654	0.7624570	2.6437115	4
3	3.8200000	4.0200000	1.6320000	1.3861141	10.787933	7.6762252	0.5814746	4.0507510	3
4	4.4200000	3.1200000	1.5420000	1.5661659	12.680773	6.6325569	0.6898967	3.2449076	3
5	5.1400000	3.5400000	1.6140000	1.4222281	13.579813	10.619766	0.7361080	3.7742479	4
6	2.8600000	3.9600000	1.2360000	1.5780311	11.872547	7.3599468	0.7365263	2.6782972	3
7	3.4600000	3.0600000	1.5960000	1.4580830	13.765386	6.3162784	0.8449484	3.8724538	4
8	4.6600000	4.2600000	1.4160000	1.5181867	10.697120	7.9616265	0.4886338	4.0880211	3
9	3.5800000	4.3800000	1.3080000	1.4340933	12.775533	7.6144708	0.7058963	3.3803835	3
10	2.5240000	3.5640000	1.5024000	1.5252032	12.350488	6.0597994	0.9025014	3.4754412	4
11	3.1240000	4.1640000	1.4124000	1.4052280	10.116081	9.9774152	0.4875054	4.2950167	4
12	3.7240000	3.2640000	1.3224000	1.5852366	8.1488790	10.014690	0.9259150	3.6027041	3
13	2.6440000	3.3840000	1.2144000	1.5012081	9.1643957	7.0956333	0.8682335	2.9684793	4

# DIRECT OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization setting – import matrix from DOE

Step	Action
1	Click on [More]
2	Select “Without Initial”



# DIRECT OPTIMIZATION PROCESS

## Optimization initialization

- Define optimization setting – import matrix from DOE

Step	Action
1	Click on [More]
2	Define the “Point per iteration”
3	Select “Without Initial”

The screenshot shows the Altair HyperMesh software interface. The 'Specifications' tab is active, displaying a table of optimization methods. The 'Global Response Search Method' (GRSM) is selected. On the right, the 'Edit Matrix' dialog is open, showing 'Points per Iteration' set to 4 (circled with a blue 2) and 'Use Inclusion Matrix' set to 'Without Initial' (circled with a blue 3). At the bottom, the 'More...' button is circled with a blue 1, and the 'Apply' button is circled with a blue 4. A microscope icon is visible in the background of the settings panel.

Mode	Label	Yname	Details
1	Adaptive Response Surface Method	ARSM	Only single-objective
2	Global Response Search Method	GRSM	
3	Sequential Quadratic Programming	SQP	Only single-objective/Variable constraints are not allowed
4	Method of Feasible Directions	MFD	Only single-objective/Variable constraints are not allowed
5	Genetic Algorithm	GA	Only single-objective
6	Multi - Objective Genetic Algorithm	MOGA	
7	Sequential Optimization and Reliability Assessment	SORA	Only single-objective/Random design/parameter variables necessary
8	ARSM based SORA	SORA_ARSM	Only single-objective/Random design/parameter variables necessary
9	System Reliability Optimization	SRO	Only single-objective/Random design/parameter variables necessary
10	Xopt	USFR-opt	

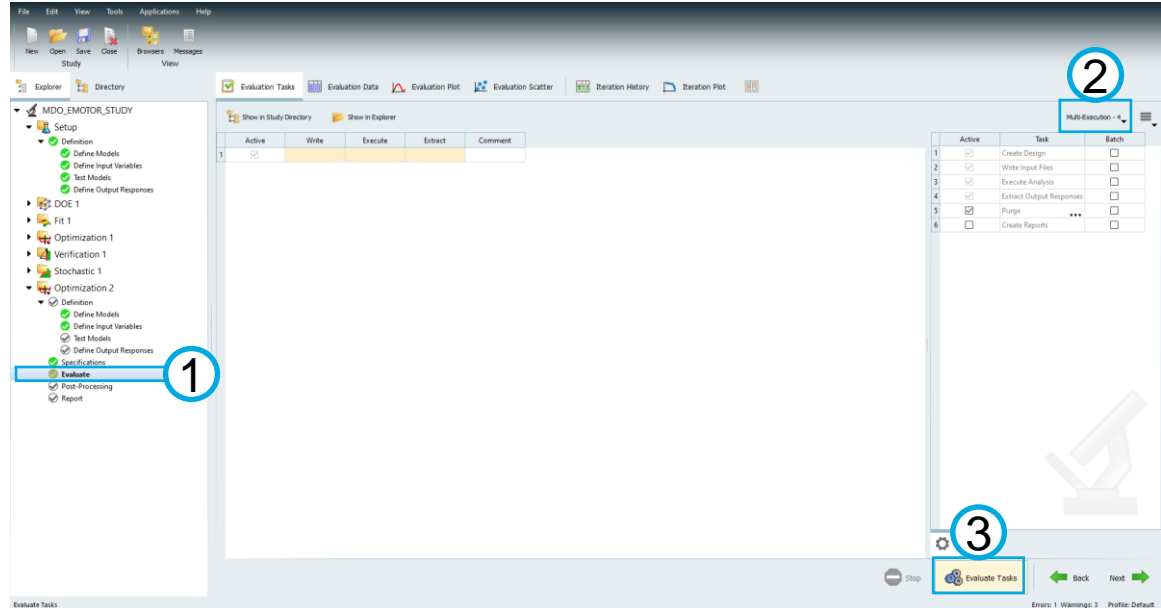
**Note: the Point per iteration is similar with the multi-execution.**

# DIRECT OPTIMIZATION PROCESS

## Optimization evaluation

- Evaluate tasks for the optimization problem

Step	Action
1	Click on [Optimization 2] – [Evaluate]
2	Define the “multi-execution” number as the same as the “Point per iteration”
3	Click on [Evaluate Tasks]



**Note: The optimization problem based on fit functions will cost as the same time as DOE analysis**

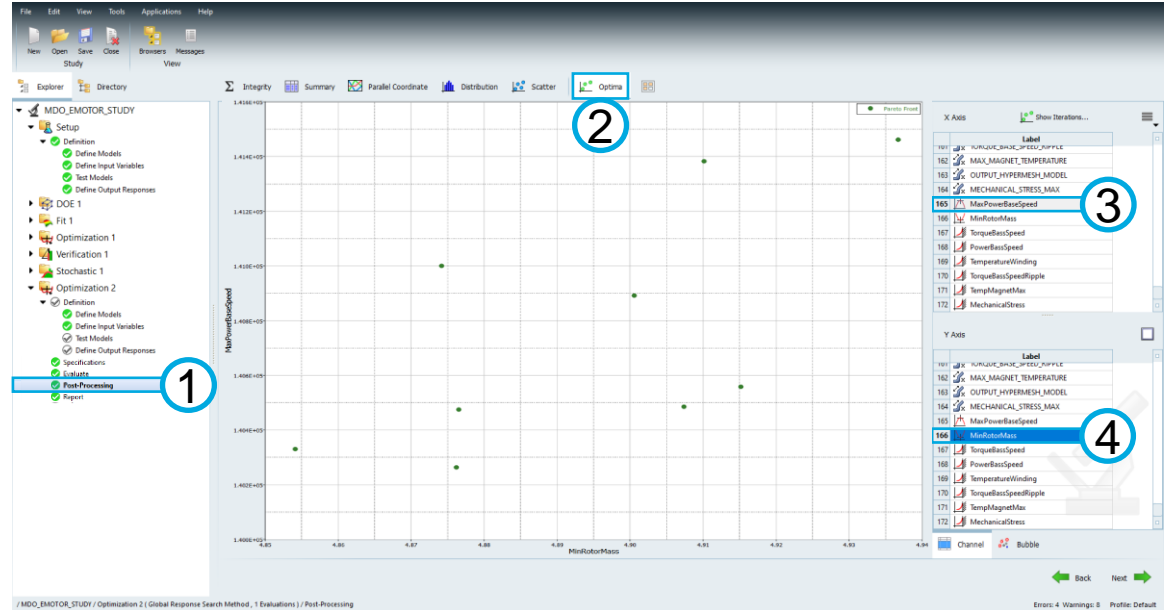


# DIRECT OPTIMIZATION PROCESS

## Optimization post-processing

- Plot optimal curve

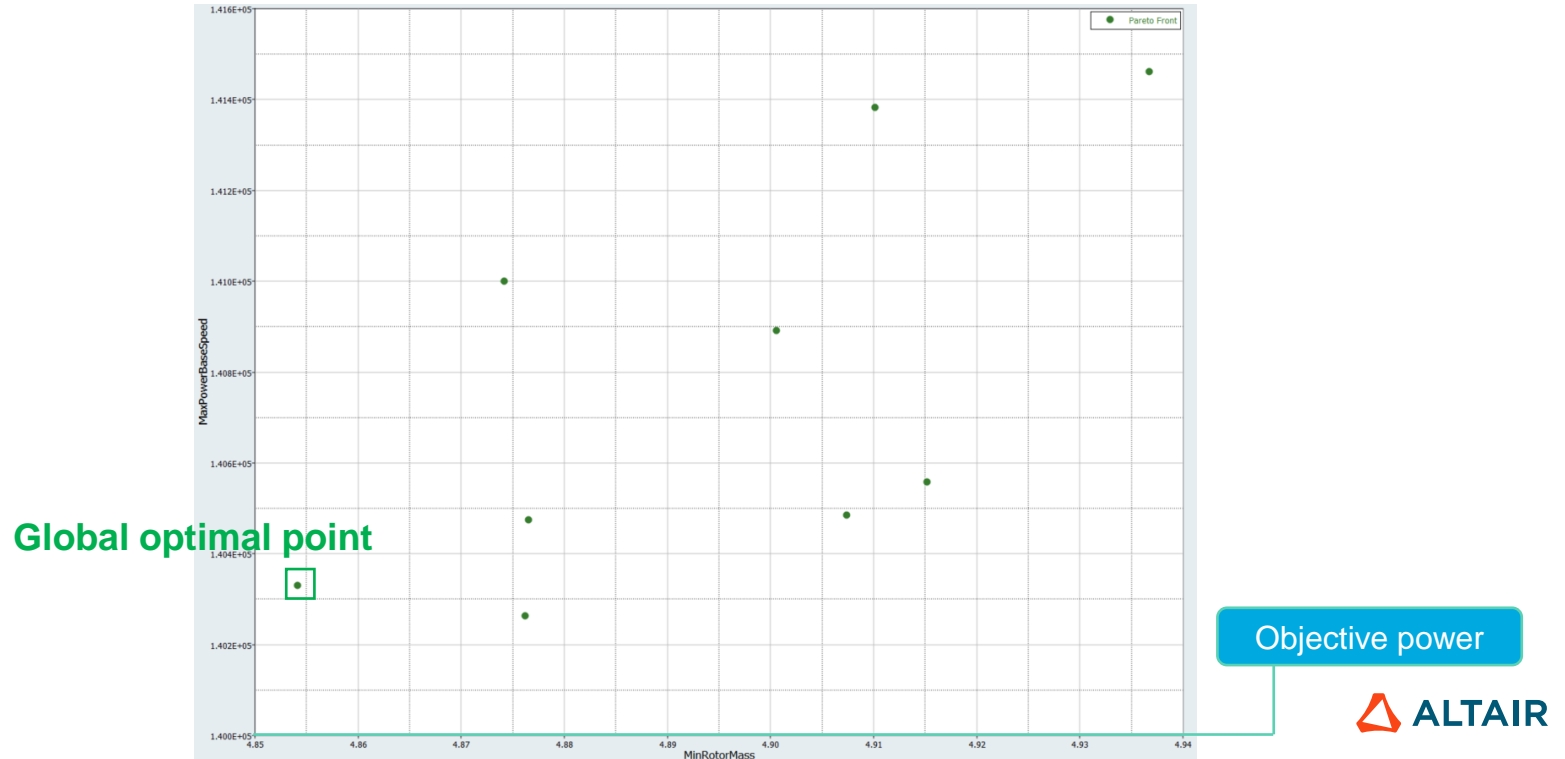
Step	Action
1	Click on [Post-Processing]
2	Click on [Optimal] to see all the optimization results for the electric motor
3	Select the Goal "MinRotorMass"
4	Select the Goal "MaxPowerBaseSpeed"



# DIRECT OPTIMIZATION PROCESS

## Optimization result comparison

- Global optimal results



# DIRECT OPTIMIZATION PROCESS

## Optimization result comparison

- Global optimal results (between direction optimization method and fit function based optimization)

	Original value	Fit function based optimization	Direction optimization method
Mechanical power at base point / W	137818	<b>140854.7</b>	140329.76
Rotor mass / kg	4.96	<b>4.85</b>	<b>4.85</b>
Mechanical torque at base point / N*m	184.21	181.43	<b>180.49</b>
Mechanical torque ripple at base point / N*m	43.11	34.78	<b>28.46</b>
Winding temperature / °C	151.01	159.37	<b>157.59</b>
Magnet temperature / °C	46.75	46.11	<b>45.88</b>
Mechanical stress / MPa	450.79	<b>390.80</b>	396.23

# CONCLUSION

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Both direction optimization method and fit function based optimization have been used and tested in the MDO platform



Both the optimum found by the two method fulfilling all criteria



The fit function based optimization can save more time in the optimization part



# THANK YOU

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