Composite wing

1 Model definition

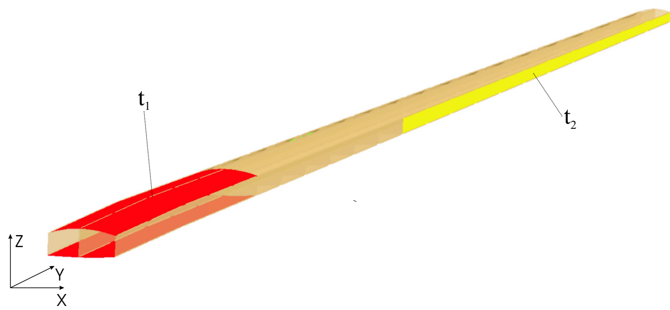

Figure 1: The composite wing

FE model summary:

- material: multilayer composite
- elements: 606 CQUAD4 - composite plates / 132 PROD - composite bars
- boundary conditions: clamped at the thick side
- load: static wind load and inertia load of $g_Z = -54.24 m/s^2$

Property	Nominal (=mean μ)	Low	High	Distribution	Variance (= σ)
Composite ρ [Kg/m^3]	1575	1450	1700	Normal	25
Composite layer t_1 [m]	0.015	0.010	0.025	Normal	0.33×10^{-3}
Composite layer t_2 [m]	0.015	0.010	0.025	Normal	0.33×10^{-3}

Table 1: Variabilities in the wing

In this table, 'Low' and 'High' refer to the range on the mean value in the design space. All parameters are assumed to have a normal distribution with a given standard deviation. This distribution is cut off at the $\pm 3\sigma$ interval. In the analysis, the main outputs of interest are the maximal vertical displacement at the wing tip (TZmax) and the total mass of the wing.

Following files are supplied:

- 'wing.dat' - nominal Nastran input model and analysis definition data
- 'wing.f06' - reference Nastran output file of nominal problem

Make a new local directory in your home folder on the I-disk, and copy all supplied files to this directory. Make sure that you use these files throughout the implementation. Also, create a scratch directory on the local disk 'C:\TEMP\rxxxxxxx.LUNA\scratch'.

2 Problem definition in Optimus

Open NOESIS Optimus. Start a new project, specifying as working directory the one you just created on the local data disk. To define the workflow, follow these steps:

1. Workflow ▷ Workflow execution ▷ Typical sequence
2. Edit InputArray1
   (a) Name: variabilities_wing
   (b) Number inputs: 3
   (c) Define variables (use table 1): fill in General tab ▷ name: rho/t1/t2
   (d) fill in: Nominal, Low and High values (use table 1)
   (e) fill in Distribution tab ▷ select On for all; Type: normal; Sigma(σ) from table 1; low='`-3*S`'; high='`3*S`'
3. Link the variables with the input file
   (a) Edit File1 ▷ Name: wing.dat
   (b) Substitution char: #
   (c) Load wing.dat
   (d) Set the format: Type: Scientific; Width: 16; Decimal places: 10
   (e) Use table 2 to identify the fields for each variability ▷ select the corresponding field in Optimus (16 characters) ▷ click on the corresponding input variable from the list Inputs
   (f) Use Verify to check the inserted inputs
4. Edit Action1
   (a) Name: Nastran
   (b) Commands:
```
C:\MSC.Software\MSC_Nastran\20170\bin\nastran.exe wing.dat ...
...  scr=yes sdir=C:\TEMP\rxxxxxxx.LUNA\scratch old=no news=no
```
5. Edit OutputArray1
   (a) Number of outputs: 2
   (b) Name: TZmax/mass
   (c) RightMouse on OutputArray ▷ Ungroup
6. Edit File2
   (a) Name: wing.f06
   (b) Load wing.f06

(c) Fill in the output extraction rules from table 3
(d) Use Verify to check the extracted outputs

7. Insert extra output variable
   (a) Name: absTZmax
   (b) Insert connection TZmax-absTZmax
   (c) Edit absTZmax ▷ Formula: `abs($TZmax$)`
8. Save the optimus file in a local directory
9. Test the sequence by performing a nominal run (Method ▷ Nominal ▷ Apply)
10. Check the result of the nominal run (Right Mouse on Nominal in the Workspace ▷ Load results / ▷ Postprocess ▷ Summary)

8[1]	16	16	16	16
MAT8*	2	2.31+11	7.7+9	.31
*	4.27+9	4.27+9	4.27+9	ρ=1575.
PCOMP*	10	-.06		1+6
*	HILL	0.	0.	SYM
*	2	t_1=.015	45.	YES
PCOMP*	52	-.105		1+6
*	HILL	0.	0.	SYM
*	2	t_2=.015	45.	YES

Table 2: The variable properties in the wing.dat file

Name	String	Occur	Substring	Occur	Offset	Extraction	
TZmax	POINT ID.	1	573	1	0	Word nr.	5
mass	MASS	1		1	1	Word nr.	2

Table 3: Output extraction rules

3 Response Surface Modelling (RSM)

The objective of this part is to construct various response surface models and to check their validity for further analysis. First, construct a model based on a 3-level full factorial Design Of Experiments (DOE) :

1. Method ▷ DOE ▷ Name: 3FF; Type: 3 level full factorial ▷ Apply (activate the Analysis Monitor to check the progress of your analysis
2. Right Mouse on 3FF in the Workspace ▷ Load results / ▷ Postprocess ▷ Summary
3. Right Mouse on 3FF in the Workspace ▷ New model ▷ Name: LinT; Model Terms: Definition: Taylor(polynomial); Order: Linear ▷ Outputs: select all ▷ Apply

4. Right Mouse on LinT in the Workspace ▷ Postprocess: Contribution to check the important terms in the RSM; Residual and Scatter to check the accuracy of the model; 2D, 3D, Contour to visualize the model.

Make a quadratic Taylor model on absTZmax. Follow the previous steps with a different Order: Quadratic. Compare the two models (residuals indicate the accuracy of the model).

Finally, make a third order RSM based on a Latin Hypercube sampling strategy (available under method 'Monte Carlo') with 50 samples.

Report the different response surfaces that were constructed, and discuss their accuracy based on the residuals.

From now on, the defined models will be available in future analyses whenever outputs are selected (you can select the model in the column 'Evaluation'). This will reduce the accuracy of the analyses, but will speed up the procedure significantly.

4 Monte Carlo Simulation (MCS)

Define a Monte Carlo simulation with 100 samples within the space of the probability distributions of the variabilities defined by the nominal values for μ and σ:

1. Method ▷ Monte Carlo: Select Outputs: mass, absTZmax ▷ Apply
2. Postprocess ▷ Correlation: are the observed correlations physical?
3. Define a new MCS for absTZmax on the third order response surface from the previous section by selecting the appropriate response surface in the output tab of the Monte-Carlo definition (under 'Evaluation', replace 'Analysis' with the previously defined response surface); compare the results for the correlation terms with the previous analysis.

Report the correlation matrix, and briefly discuss the observations, including their physical background.

5 Design Optimization

The objective of this part is to optimize a cost function C taking into account following constraints on the design variables: t_1,t_2 both inside $[0.01, 0.025]$ and ρ inside $[1450, 1700]$. The cost function represents a trade-off between mass and production cost:

$$C = M + \frac{1}{5t_1^2} + \frac{1}{4t_2^2}$$

An extra constraint of $3.2m$ is defined on the largest displacement $|TZmax|$. The wing is expected to fail if the tip displacement exceeds this value.

1. To generate a new workflow based on an existing model: Right Mouse on Graph ▷ Clone; after cloning, check the settings for the lower and upper bounds on the input variables to make sure that they are set to the above constraints
2. Edit absTZmax ▷ General tab: High: $3.2m$
3. Add C as additional output variable to the workflow using the above formula

4. Generate appropriate response surface models of C and $|TZmax|$

5. Optimize the design for minimal cost taking into account the constraints (Method ▷ Optimization). Use SQP as optimization algorithm. Perform the optimization two times: once based on actual analyses, once based on the response surface.

Review the results (e.g. 'Optimum' and 'Opt Progress'). Report the results of both optimizations, and briefly discuss the observed differences.

6 Reliability assessment

Taking into account that the system is considered in failure when absTZmax $> 3.2m$, calculate the reliability index based on a FORM analysis. Use the optimum point found in the previous step and the variance values as defined in table 1 for the reliability assessment.

1. Clone the previous Graph

2. Prepare FORM analysis: Edit absTZmax ▷ General tab: High: $3.2m$; Sigma tab: activate SIGMA{absTZmax} (this activates the calculation of the standard deviation of the output); Reliability High tab: activate FORMH{absTZmax} (this activates the calculation of the reliability index (β) of the output).

3. Method ▷ Nominal; Name: FORM; Select the optimum from the previous optimization as nominal values.

4. Load the results of FORM; Postprocess ▷ Summary; Read the standard deviation and the β (FORMH) of the output at the optimum.

Report the resulting reliability index at the design optimum. What is the corresponding reliability? Give a brief interpretation.

7 Reliability Based Design Optimization (RBDO)

Finally, perform the RBDO by minimizing the cost function with the extra constraint on the reliability of the system, expressed in terms of the reliability index $\beta \geq 3$ (design for 6σ).

1. Clone the previous Graph

2. Edit absTZmax ▷ Reliability High: activate Target Low=3

3. Method ▷ Optimization ▷ Name: RBDO; Objective: Minimize Cost; Outputs: select Cost, absTZmax (analysis), FORMH{absTZmax} ▷ Apply

4. Repeat the analysis using the response surfaces built in part 5.

5. Load results for RBDO ▷ Postprocess: Optimum

Report the final RBDO design optimum, including the corresponding reliability. Again, compare the results based on the full analysis and the one from the approximate response surface.

Check the reliability of the new optimum using Monte Carlo simulation on the response surface:

1. Method ▷ Monte Carlo: Number Experiments: 10000; Select the RBDO optimum for Nominal ...▷ Apply
2. Load the results ▷ Postprocess: Histogram and Scatter

Report and discuss the histogram, and draw conclusions regarding the quality of the final RBDO design.