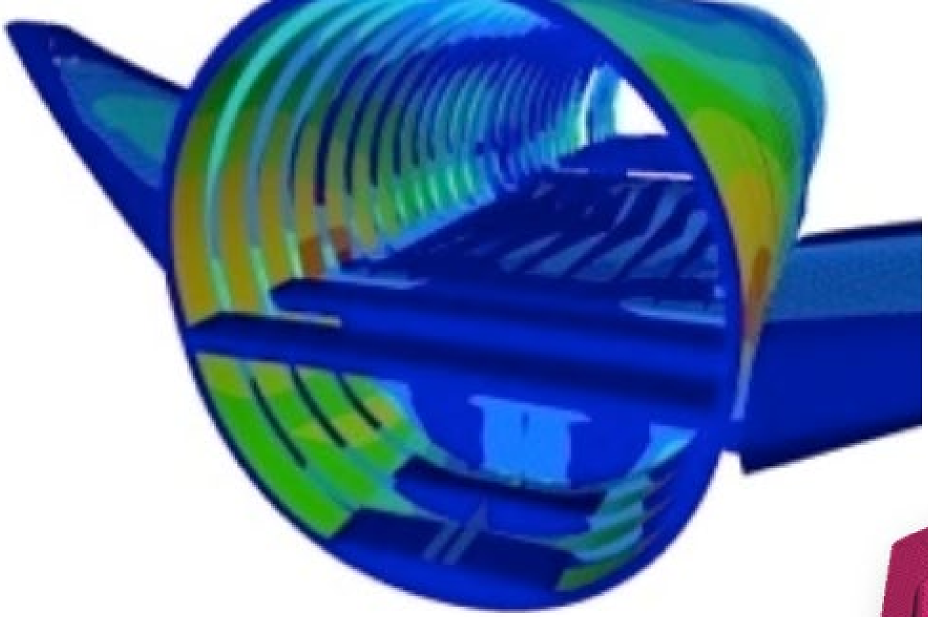
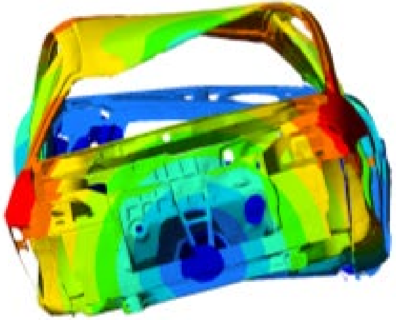
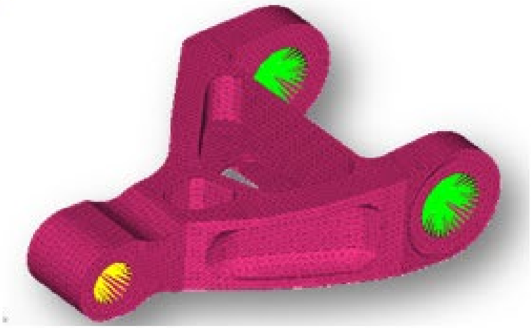






OPTISTRUCT FOR LINEAR ANALYSIS, V2019
CHAPTER 5: LINEAR BUCKLING ANALYSIS

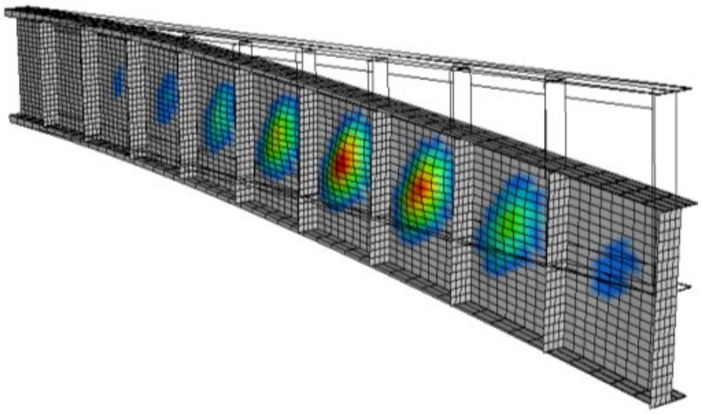
Altair

AGENDA

LINEAR BUCKLING ANALYSIS

Thin structures subject to compression loads that haven’t achieved the material strength limits can show a failure mode called buckling.

- This failure can be analyzed using a technique well known as linear buckling analysis.
- Linear buckling is a mathematic tool used to predict the theoretical buckling strength of an ideal elastic structure. It is solved by first applying a reference level of loading, $\mathbf{P}_{ref}$, to the structure.
- A standard linear static analysis is then carried out to obtain stresses which are needed to form the geometric stiffness matrix $\mathbf{K}_G$.



LINEAR BUCKLING ANALYSIS

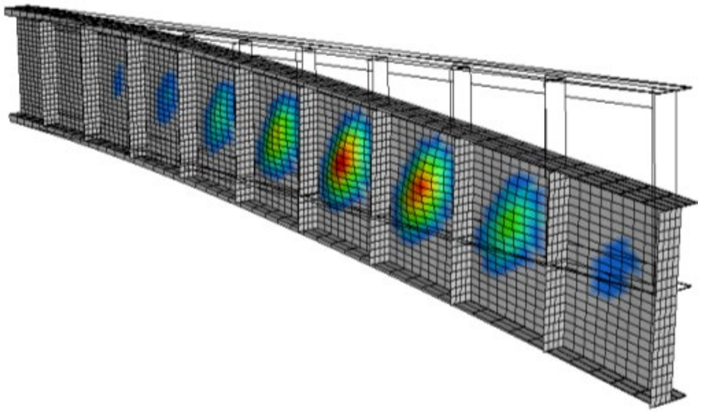
- This new matrix is evaluated using the initial stiffness matrix augmented by the initial stress matrix corresponding to the load specified in the static load step, multiplied with a factor that is determined such that the resulting matrix has zero as its lowest Eigen frequency.

- The buckling loads are then calculated by solving an eigenvalue problem:

$$\left[\mathbf{K} - \lambda \mathbf{K}_G\right]\mathbf{x} = 0$$

- The lowest eigenvalue λ_{Cr} is associated with buckling and the critical or buckling load is:

$$\mathbf{P}_{\mathrm{Cr}} = \lambda_{\mathrm{Cr}} \mathbf{P}_{\mathrm{Ref}}$$



LINEAR BUCKLING ANALYSIS

The problem of linear buckling is solved in two stages:

- A standard linear static analysis is carried out to obtain stresses, which form the geometric stiffness matrix .
- The buckling loads are then calculated by solving the eigenvalue problem.

A subcase requires a `STATSUB` card for a Buckling Analysis:

```
SUBCASE 1
  SPC      =        2
  LOAD     =        3
SUBCASE 2
  SPC      =        2
  METHOD   =        4
  STATSUB  =        1
BEGIN BULK
EIGRL          4                       2                            MASS
FORCE          3      82        01.0      0.0      0.0      -1000.0
SPC            2       1   123   0.0
```

HOW TO SETUP A LINEAR BUCKLING ANALYSIS

Linear buckling analyses can be defined in seven steps:

Step 1 – Generate a FEM model

Step 2 – Set up material and properties

Step 3 – Define the constraint load collector and the BCs

Step 4 – Define the loads

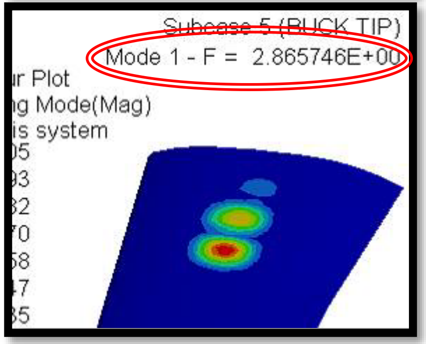
Step 5 – Define the `EIGRL` card

Step 6 – Define the linear buckling load case

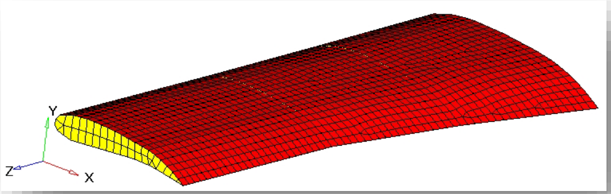
Step 7 – Run and post process the results

Name	Value
Solver Keyword	SUBCASE
Name	Buck
ID	1
Include File	[Master Model]
User Comments	Hide In Menu/Export
Subcase Definition	
Analysis type	Linear buckling
SPC	constraints (1)
MPC	<Unspecified>
STATSUB	LOAD (2)
METHOD (STRUCT)	EIGRL (3)
DEFORM	<Unspecified>
Subcase Options	
LABEL	☐
SUBTITLE	☐
ANALYSIS	☑
TYPE	BUCK
EIGVRETRIEVE	☐
EIGVSAVE	☐
EXCLUDE	☐
RADSND	☐
RESVEC	☐
OUTPUT	☐
SUBCASE_UNSUPPORTED	☐

Name	Value
Solver Keyword	EIGRL
Name	EIGRL
ID	3
Color	
Include File	[Master Model]
Card Image	EIGRL
User Comments	Hide In Menu/Export
V1	
V2	
ND	1
MSGLVL	
MAXSET	
SHFSCL	
NORM	MASS



EXERCISE 5A: WING LINEAR BUCKLING ANALYSIS



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Objectives (1/2)

This exercise runs a linear buckling analysis on a simple aircraft wing. This is a typical problem in aerospace structures that need to be very light and consequently become slender. Because the structure has a high slenderness ratio, the buckling failure verification becomes necessary.

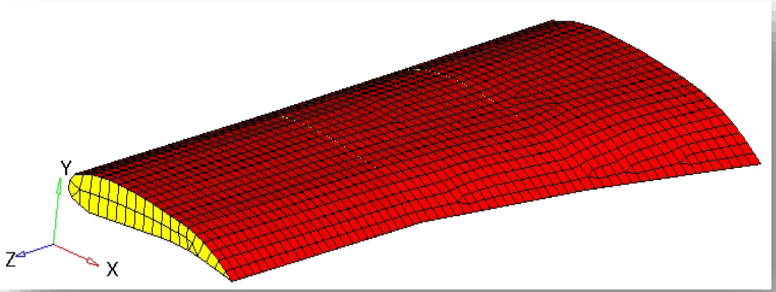
The objective of this project is to determine if the 3 static load cases applied to the wing will cause failure, the positive buckling factors should be higher than 1.5.

1. Open the model in HyperMesh Desktop
2. Review the model (control cards, components, properties, materials, load collectors & steps)
3. Run the static analysis in OptiStruct, review the results in HyperView and check if
   - Max. static displacement < 20 mm for all load cases.
   - Max. von Mises stress < 70 MPa
4. Create a load collector `buckling` (card image `EIGRL`) and set the number of desired roots (ND) to `10` and V1 to `0.001`

EXERCISE 5A: WING LINEAR BUCKLING ANALYSIS

Objectives (2/2)

5. Create the buckling load steps for each static load step
6. Run the analysis with OptiStruct
7. Review the `.out` file wrt warnings and errors and check if the lowest λ for each buckling subcase is > 1.5
8. Review contours of the buckling modes in HyperView



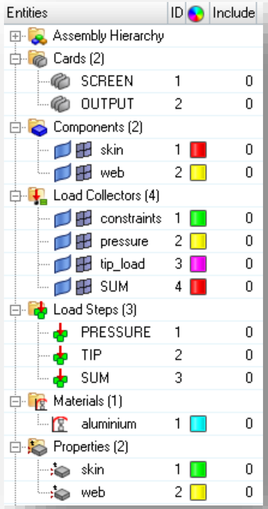
EXERCISE 5A: WING LINEAR BUCKLING ANALYSIS

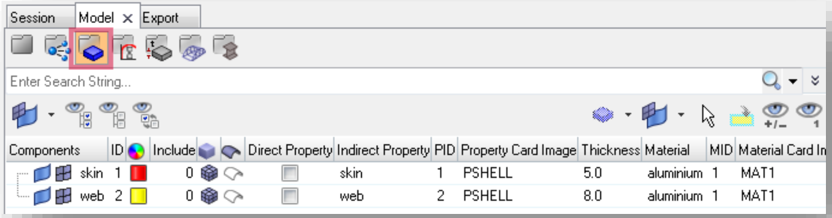
Hints (1/4)

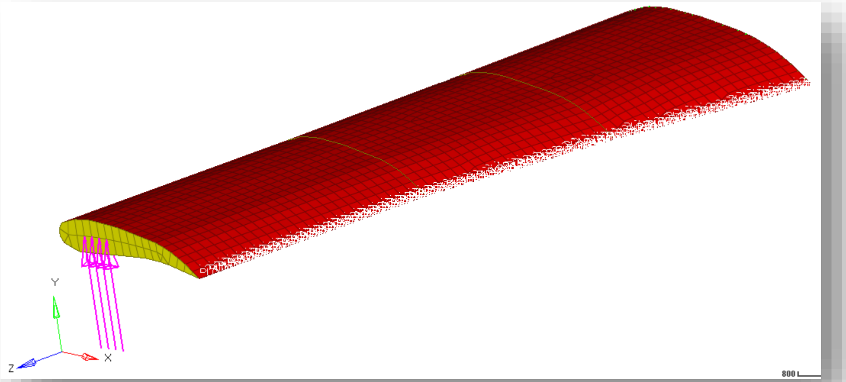
2. To review the model wrt components, properties and materials the component view in the model browser is well suited.

   Common control cards requests are set: `SCREEN` and `OUTPUT`

   There are three static load steps defined:
   (1) pressure on skin
   (2) load on tip
   (3) combination of both
   using `LOADADD` card



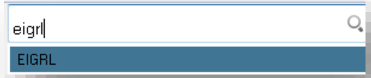


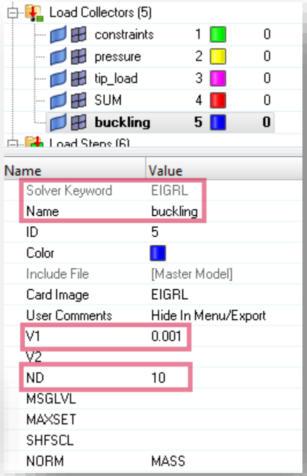


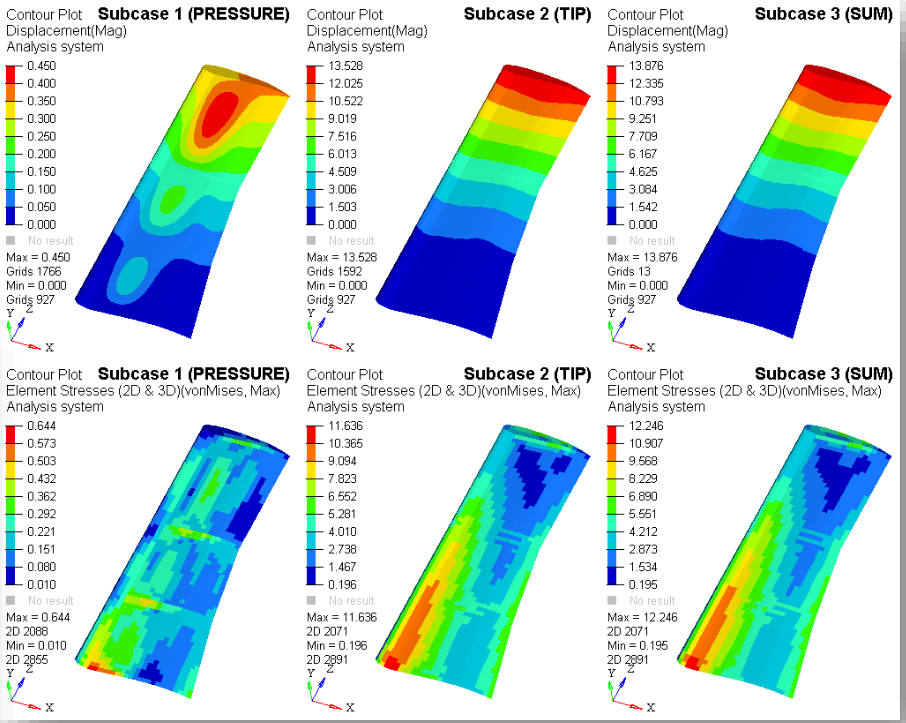
EXERCISE 5A: WING LINEAR BUCKLING ANALYSIS

Hints (2/4)

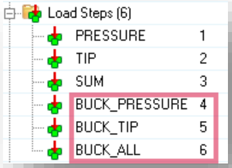
3. Max. displacement = 13.9 mm (load case SUM) < 20 mm
   Max. von Mises stress = 12.25 MPa (load case SUM) < 70 Mpa
4. Use HyperMesh’s Quick Access Tool (`Crtl+f`) to create an `EIGRL` card.
   Note that with `0.001` as V1 negative buckling factors (i.e. load with opposite direction) are not considered.





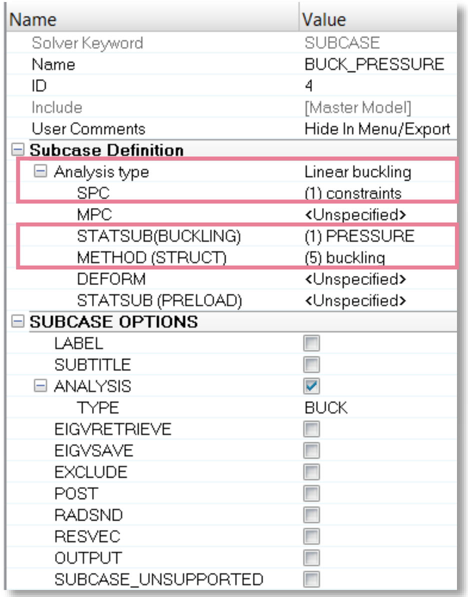


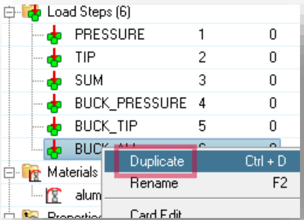
EXERCISE 5A: WING LINEAR BUCKLING ANALYSIS

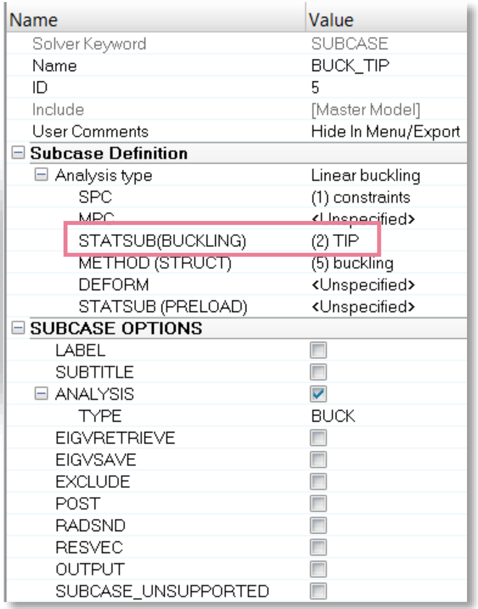


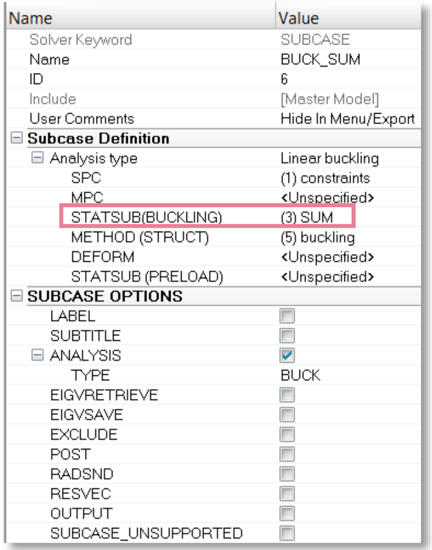
Hints (3/4)

5. As the three new linear buckling load steps only differ by `STATSUB` entry, it is easier to create the first and use duplicate functionality for the others.





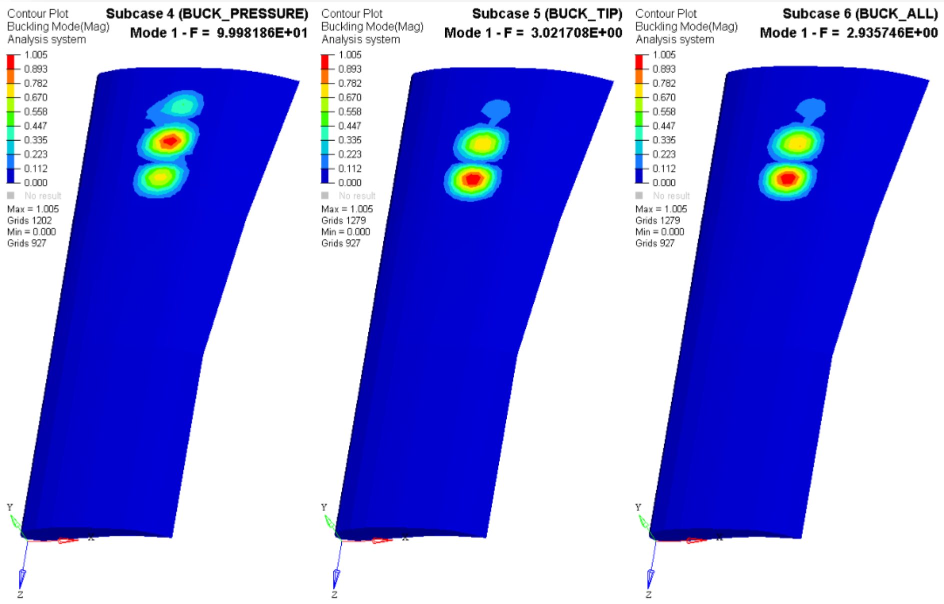




EXERCISE 5A: WING LINEAR BUCKLING ANALYSIS

Hints (4/4)

6. buckling factors $\lambda_4 = 10.0$, $\lambda_5 = 3.0$, $\lambda_6 = 2.9$, so $\lambda_i > 1.5$
7. buckling modes 1 for load steps 4-6



Subcase	Compliance	Epsilon
1	2.612521E+01	1.177384E-11
2	2.697079E+04	2.288366E-11
3	2.837233E+04	8.769668E-12

Note : Epsilon = Residual Strain Energy Ratio.

Subcase	Mode	Buckling Eigenvalue
4	1	9.998186E+01
4	2	1.005357E+02
4	3	1.165863E+02
4	4	1.180483E+02
4	5	1.414577E+02
4	6	1.512188E+02
4	7	1.538273E+02
4	8	1.563434E+02
4	9	1.623450E+02
4	10	1.677472E+02
5	1	3.021708E+00
5	2	3.130409E+00
5	3	3.607863E+00
5	4	3.687046E+00
5	5	3.845368E+00
5	6	3.899962E+00
5	7	4.522865E+00
5	8	4.742450E+00
5	9	4.932286E+00
5	10	5.006207E+00
6	1	2.935746E+00
6	2	3.038217E+00
6	3	3.525603E+00
6	4	3.575250E+00
6	5	3.733972E+00
6	6	3.804011E+00
6	7	4.382773E+00
6	8	4.643237E+00
6	9	4.785382E+00
6	10	4.889105E+00

QUESTIONS & ANSWERS

1. Which of the following describes linear buckling analysis?
   a) Determining the natural frequency values of a structure undergoing vibration.
   b) Determining the factor by which a load must be increased before the structure fails due to buckling
   c) Determining the mode shapes of a structure undergoing vibration.
   d) None of the above
   e) a) and c)
2. What does a buckling factor less than 1 for a load case signify?
   a) The structure would buckle under every load case in the analysis run
   b) The structure will not buckle under at least one load case in the analysis run
   c) The structure would buckle under the selected load case in the analysis run
   d) The selected load case is partially reinforcing the structure in the analysis run