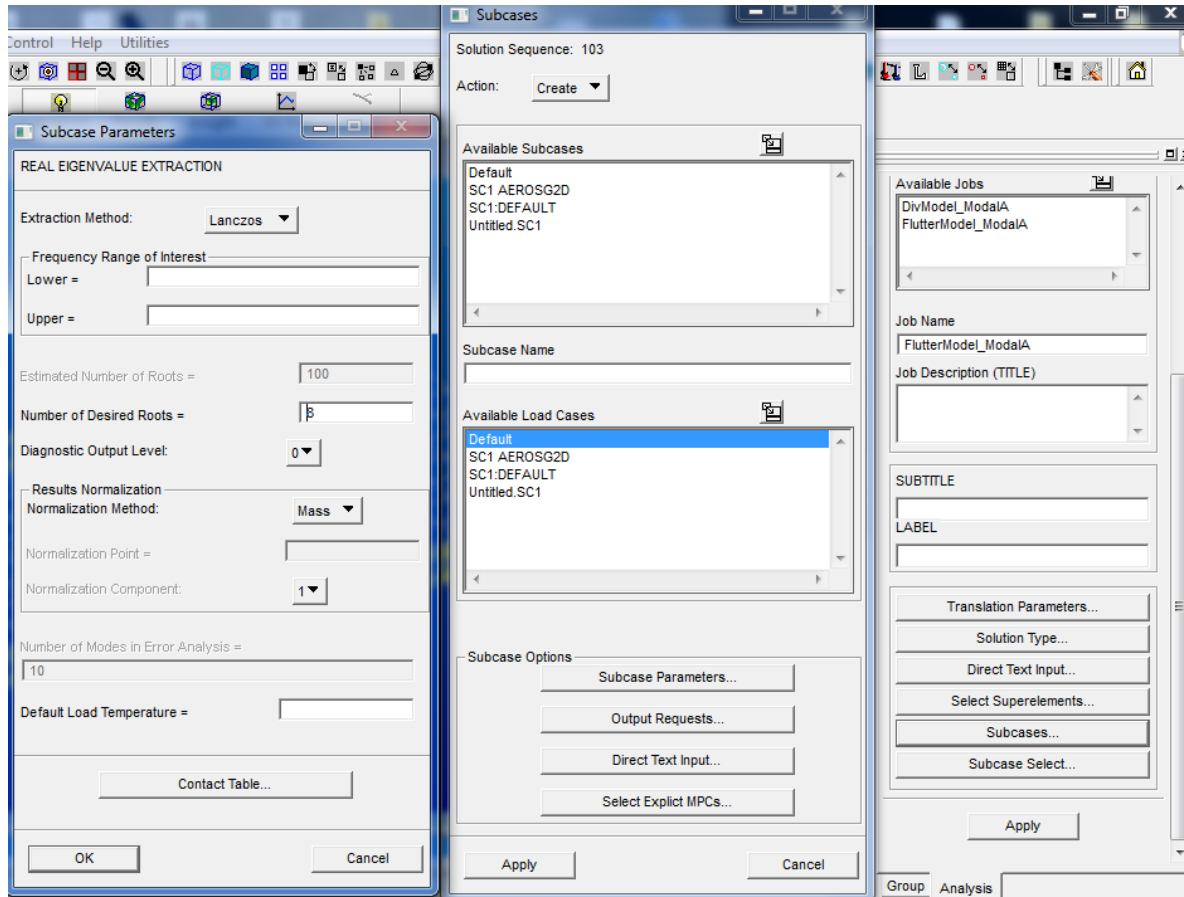
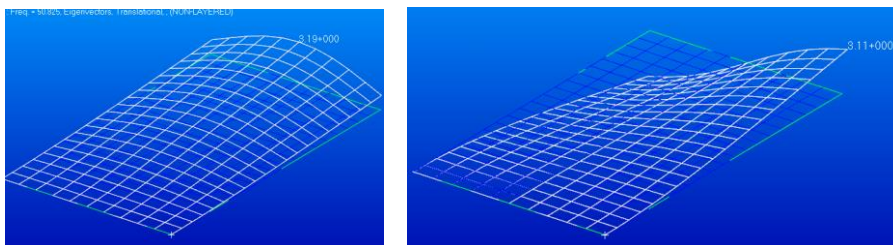


Case Study on Flutter Analysis

- 1- Rename the divergence model that is created as TAI_Flutter.db and open the model with Patran.
- 2- Redo modal analysis to see the bending and torsional frequencies. Ask for 8 modes.



- Look at the first bending and torsional mode shapes



- Take a note of the frequencies. Lowest frequency is 50.825 Hz!

```

Default, A1:Mode 1 : Freq. = 50.825;-N
Default, A1:Mode 2 : Freq. = 86.409;-N
Default, A1:Mode 3 : Freq. = 104.64;-N
Default, A1:Mode 4 : Freq. = 137.61;-N
Default, A1:Mode 5 : Freq. = 170.56;-N
Default, A1:Mode 6 : Freq. = 254.23;-N
Default, A1:Mode 7 : Freq. = 259.45;-N
Default, A1:Mode 8 : Freq. = 279.51;-N

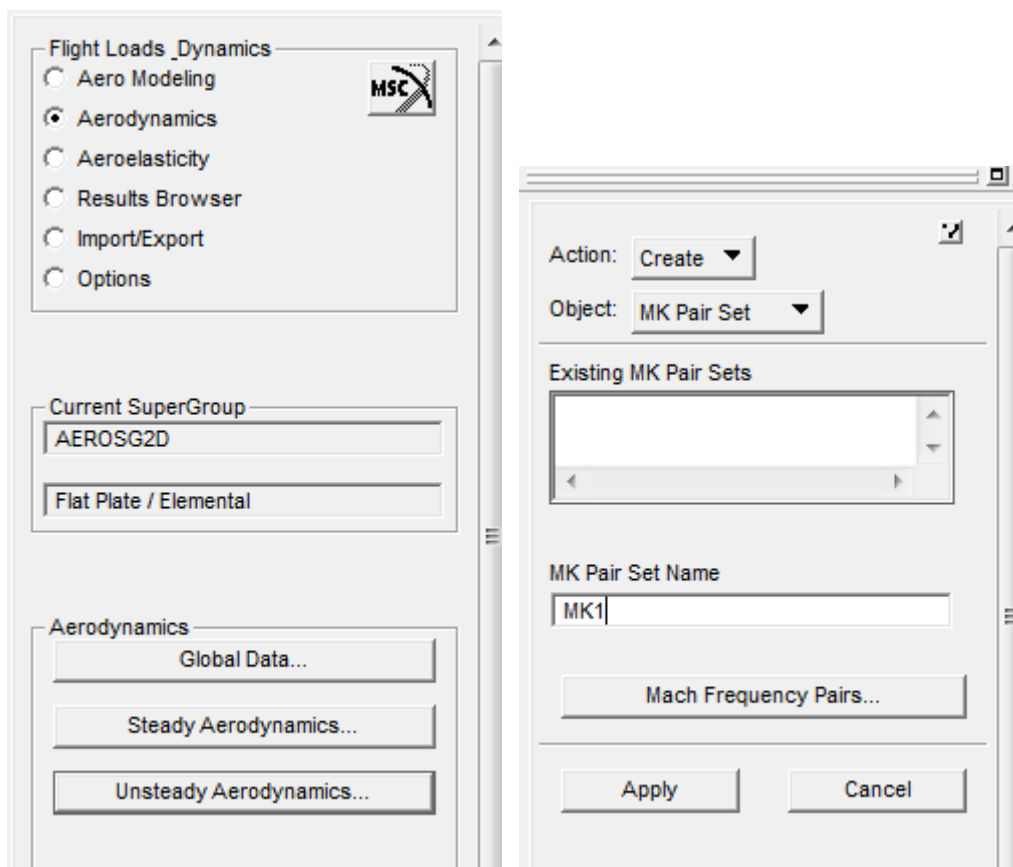
```

3- Open the model in Flightloads and post all the groups.

- Do the following selection

Aerodynamics / Unsteady aerodynamics / Create / MK pair set

Aerodynamic matrices are pre-computed for a set of user-defined (M, k) pairs. The actual matrices needed are obtained by interpolation.

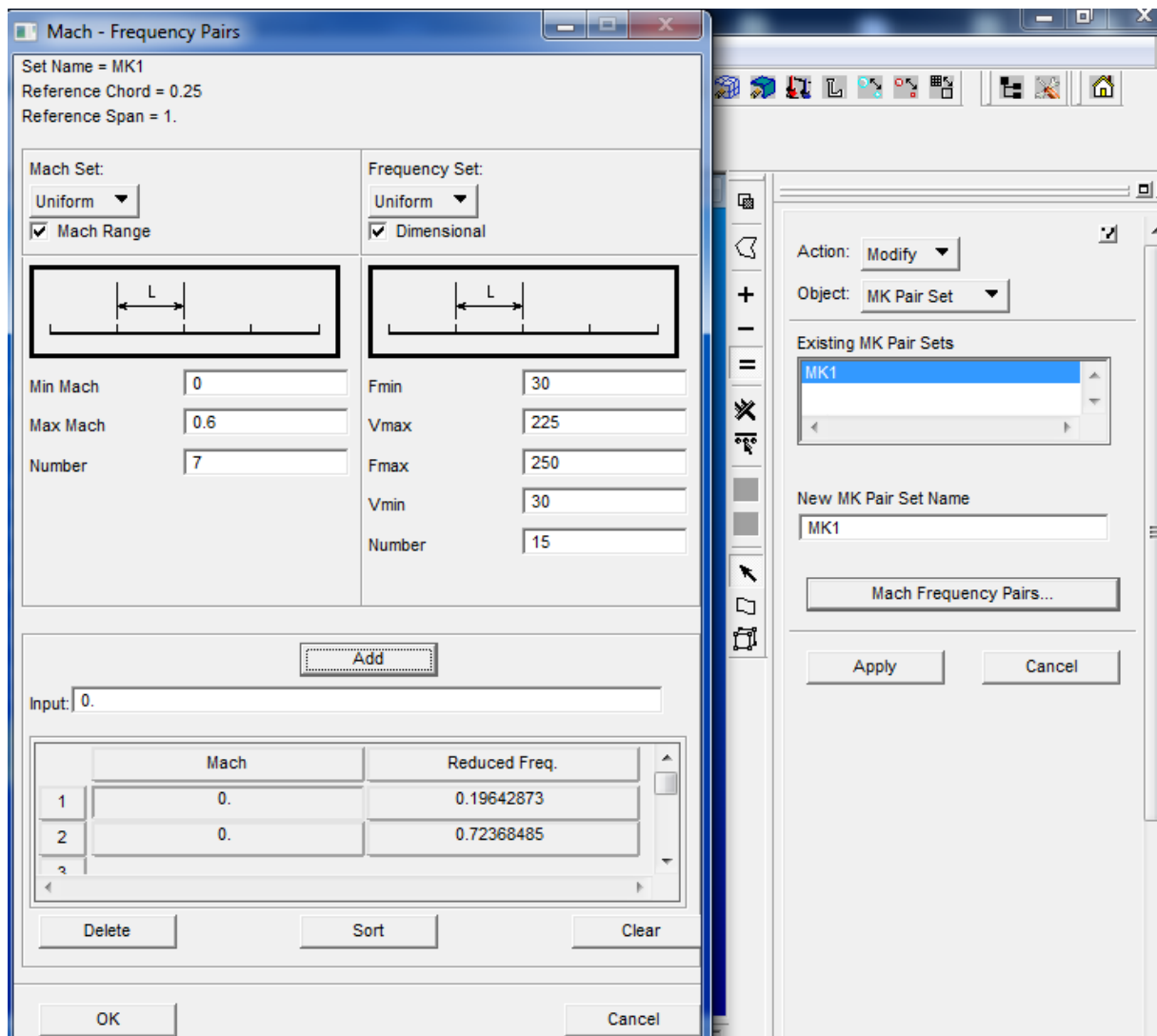


- Fmin, Vmax, Fmax, Vmin values should be defined to create a M-K set. Vmin is usually taken as the stall speed and Vmax is usually taken as the dive speed or a speed higher than the dive speed. Frequencies Fmin and Fmax can be defined according to modal analysis results. Fmin should be smaller than first bending mode frequency and Fmax should be greater than first torsion mode frequency, because flutter generally occurs between these modes. A higher frequency mode can be chosen for Fmax value

if first torsion and first bending modes are close to each other. Maximum and minimum reduced frequency (k) values are calculated using equations below and M-K values are created. M and k values are increasing k value uniformly from kmin to kmax.

$$k_{\min} = \frac{2 \times \pi \times f_{\min} \times c}{2 \times v_{\max}}$$

$$k_{\max} = \frac{2 \times \pi \times f_{\max} \times c}{2 \times v_{\min}}$$



- Ok the M-k menu and then press Apply to create the M-k set.

3- Check the aspect ratio of the lifting surface (max. Aspect ratio is selected as three in the example below)

Aero Modeling / Flat Plate Aero Modeling

Show/Lifting Surface/Aspect Ratio

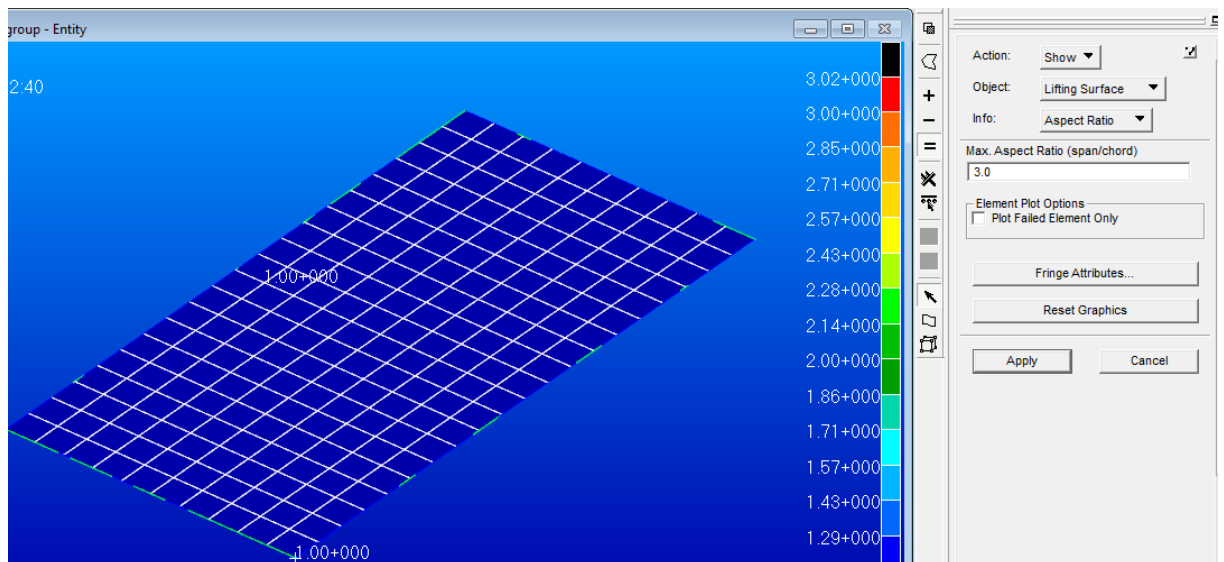
This form computes and shows the individual Box Aspect Ratio (mean span/mean chord) for all Lifting Surfaces in the current group. It can also be used to display only those elements that fail the plot criteria. This is useful to assess the model quality using the recommended modeling practices of MSC.Nastran. By default, the aerodynamic boxes are fringed according to their aspect ratio values. Users may, optionally, check failure criteria where any element values greater than a specified value (default=3.0) are color coded according to a user-selected color (default is red).

The INFO button displays the Flat Plate Model Show HTML help page (flds_model_show.html)

Maximum Aspect Ratio the user wishes to see. It is this number that is used to determine the failure criteria.

If this toggle is selected, then only those elements that fail the Maximum Aspect Ratio criteria are plotted.

Note: The same form as for the Finite Element: Verify/Quad/Aspect form in MSC.Patran. It controls the way colors are assigned to segments of the range of aspect ratios.



4- Check the boxes per wavelength

Aero Modeling / Flat Plate Aero Modeling

Show/Lifting Surface/Boxes/Wave

In unsteady aerodynamics, the number of aerodynamic model degrees of freedom in one wavelength (distance the flow travels during one unsteady cycle) is a critical parameter in determining chordwise mesh refinement.

The wavelength is a function of the freestream velocity, v , and the frequency of the unsteady, harmonic oscillation, f

$$\text{wavelength} = V/f, \text{ } f \text{ in Hertz}$$

So the number of boxes in a wavelength can be computed for each box as the wavelength divided by the mean chordlength.

$$\text{Boxes/wave} \propto$$

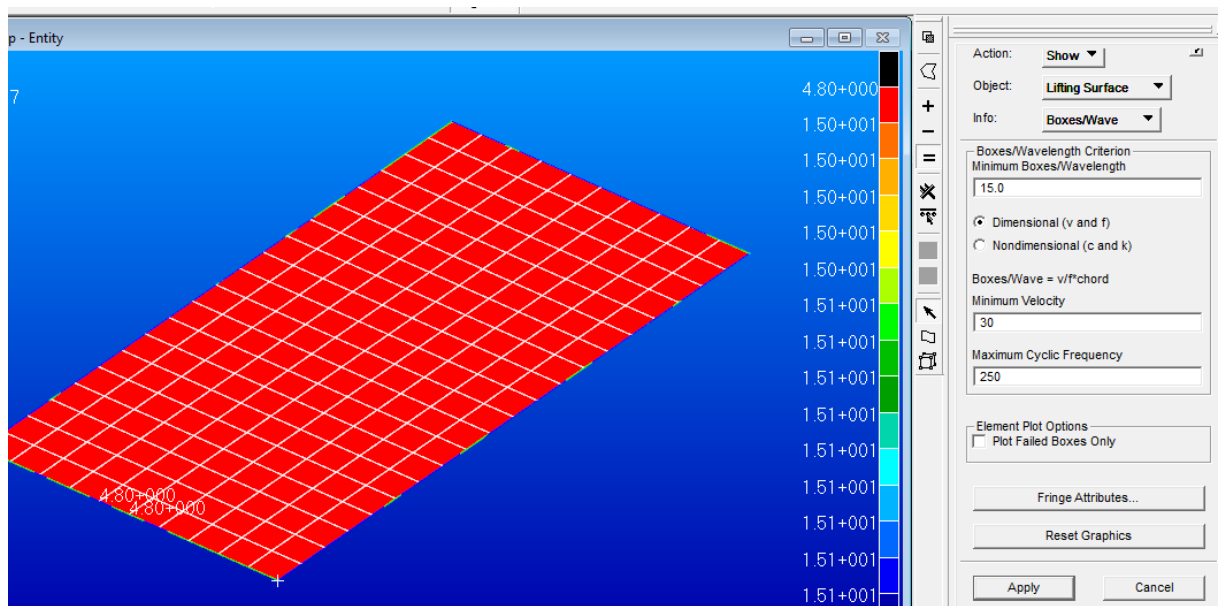
$$\frac{v}{(f)(\text{local} - \text{chord})}$$

To ensure converge, you must look at the minimum number of boxes/wavelength given the intended frequency and velocity range of the analysis. This corresponds to the maximum k value or, dimensionally, to the combination of the minimum velocity and highest frequency of interest. In modeling terms, one typically would choose the lowest velocity of interest and the highest natural frequency in the retained set of normal modes. (Note that the extremely low velocities demand very high numbers of elements.)

Here local chord is the chord length of the aerodynamic box.

subdivided into "boxes" (see [Figure 3-1](#)), which are similarly configured trapezoids. The following are guidelines that are not enforced by the program; the user is expected to ensure adherence to these rules.

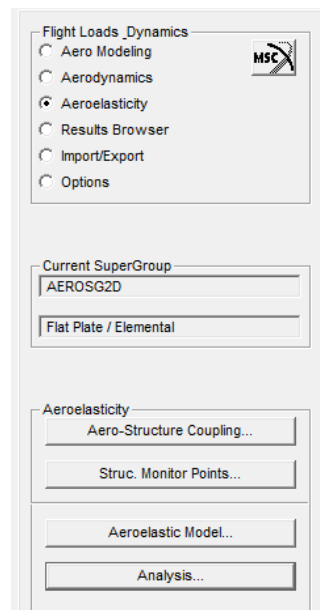
If a surface lies in (or nearly in) the wake of another surface, then its spanwise divisions should lie along the divisions of the upstream surface. The strips near the intersection of intersecting surfaces should have comparable widths. The aspect ratio of the boxes should approximate unity; less than three is acceptable in the subsonic case, and of order one is desirable in the supersonic case. The chord length of the boxes should be less than 0.08 times the velocity divided by the greatest frequency (in Hz) of interest, i.e., $\Delta x < 0.08 V/f$ (Note that this is a requirement for approximately 12 boxes per minimum wavelength; however, no less than four boxes per chord should be used.) Boxes should be concentrated near wing edges and hinge lines or any other place where downwash is discontinuous and pressures have large gradients. [Note that concentrating boxes near hinge lines is a requirement of Potential Theory (which neglects viscous effects); not increasing the concentration of boxes near hinge lines lowers the calculated control surface effectiveness and leads to closer agreement with experimental data (with the added benefit of reduced computational time).] The chord lengths of adjacent boxes in the streamwise direction should change gradually. A further discussion of the choice of models is found in Rodden, Harder, and Bellinger (1979).



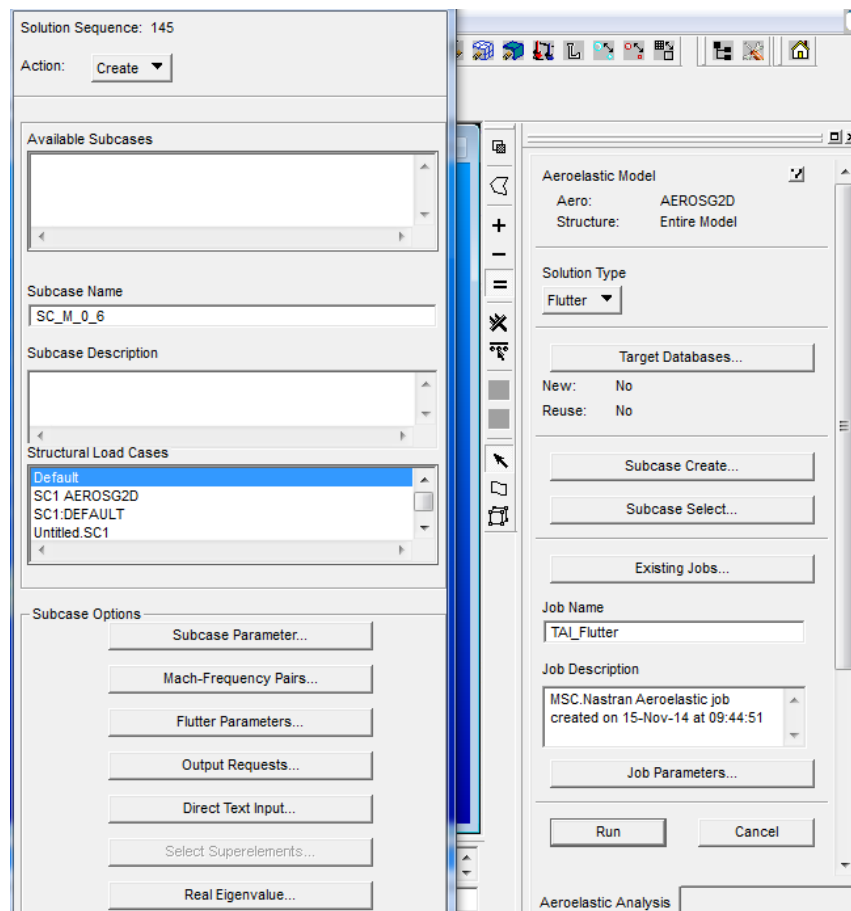
In the example given above:

$V_{\min} = 30 \text{ m/s}$, $F_{\max} = 250 \text{ Hz}$ (which is very high and not necessary for this problem)
 Boxes per wavelength = $30 / (250 \cdot 0.025) = 4.8$ (higher than 4!)

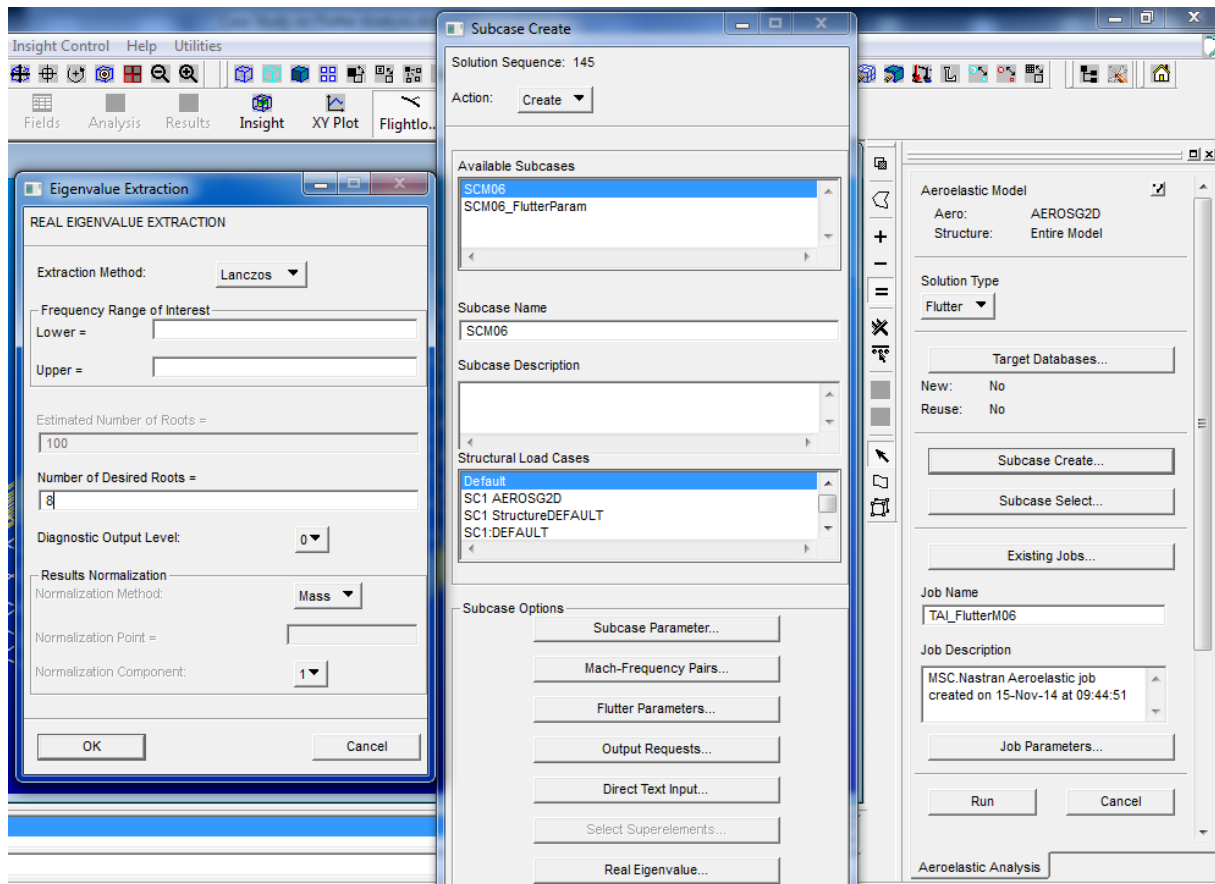
5- Select Aeroelasticity / Analysis



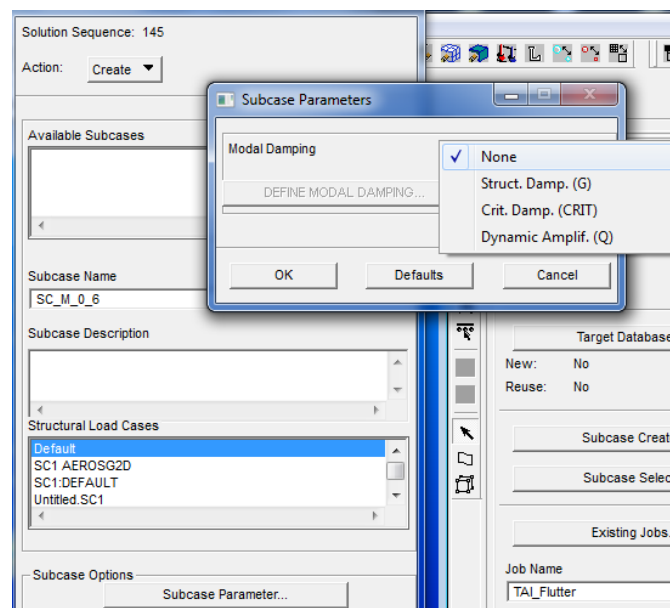
- Solution type / Flutter
- Subcase create /SC_M_0_6
- Select Default load case



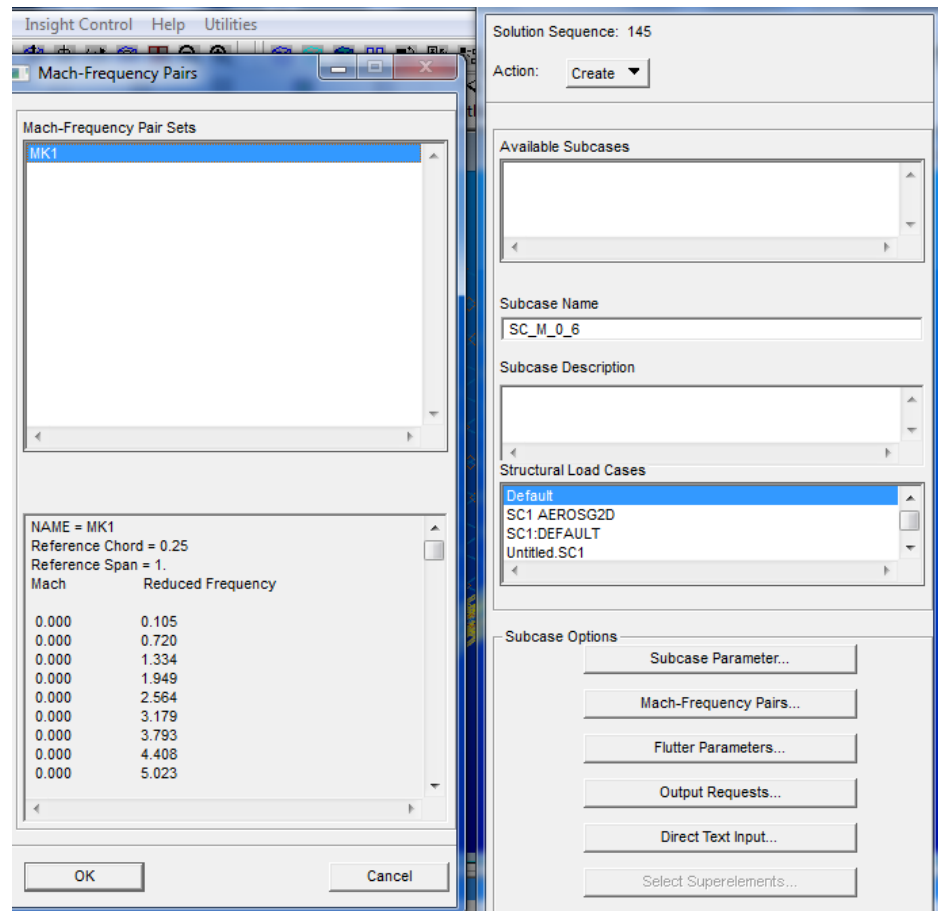
- Click Real Eigenvalue and ask for 8 roots (Flightloads adds 6 more modes)



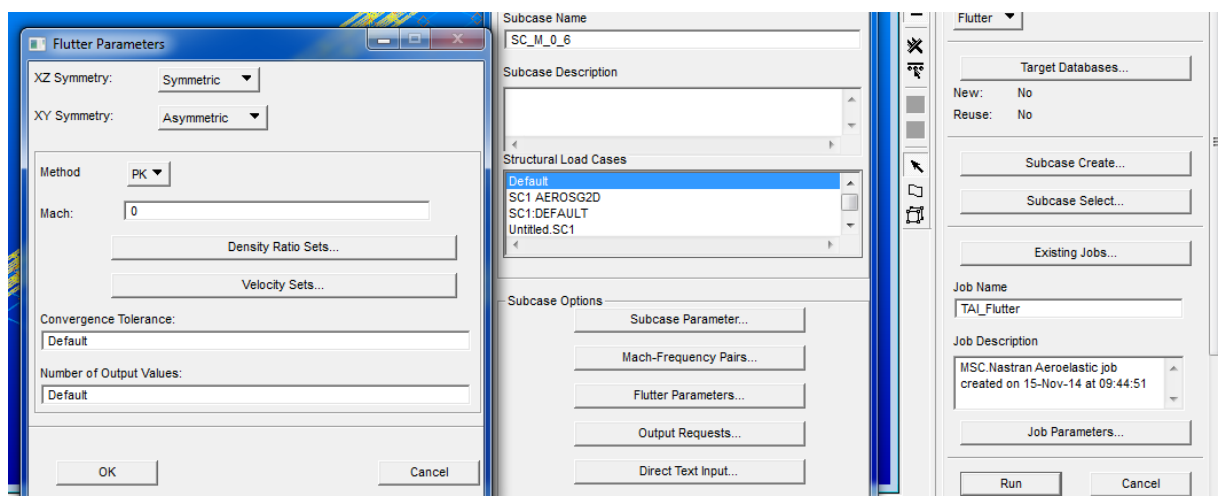
- Subcase Parameters /Modal Damping / None (if one wants to add structural damping one can adjust it in this menu)



- Click on Mach-Frequency pair that was created.

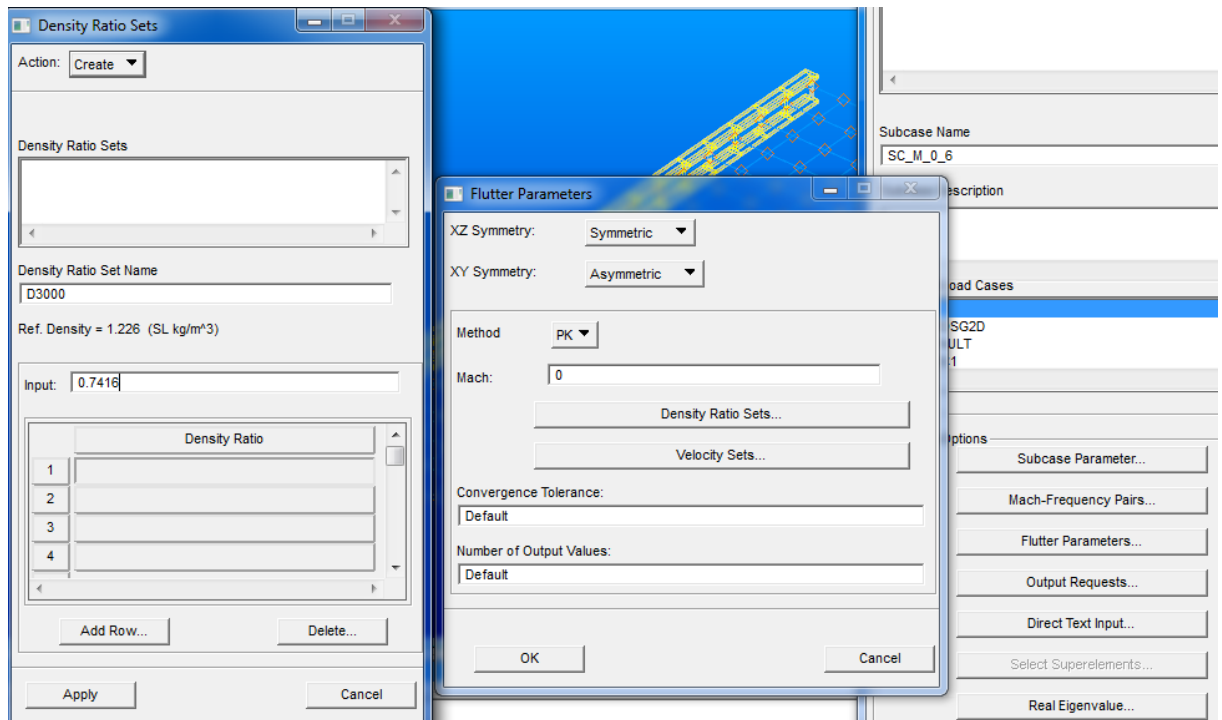


- Press on Flutter parameters (XZ symmetry: Symmetric, XY symmetry: Asymmetric)
- Select PK method
- Enter M=0 (first analysis will be made assuming incompressible flow)

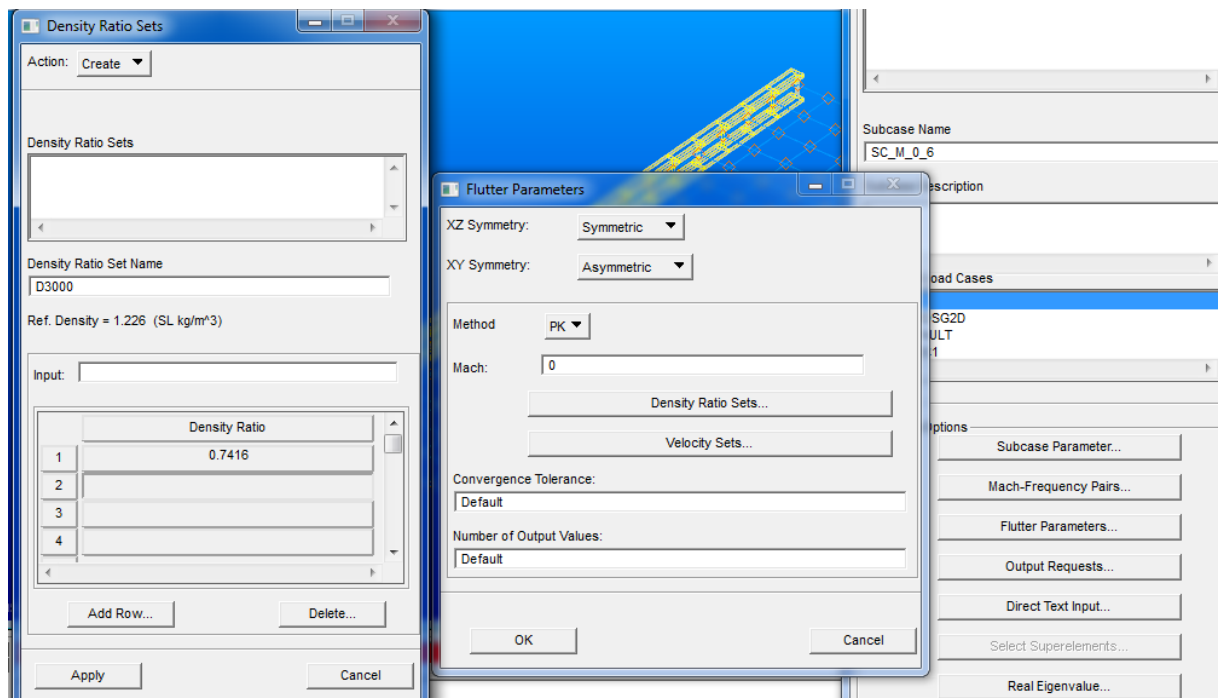


- We will perform flutter analysis at 3000 m altitude.

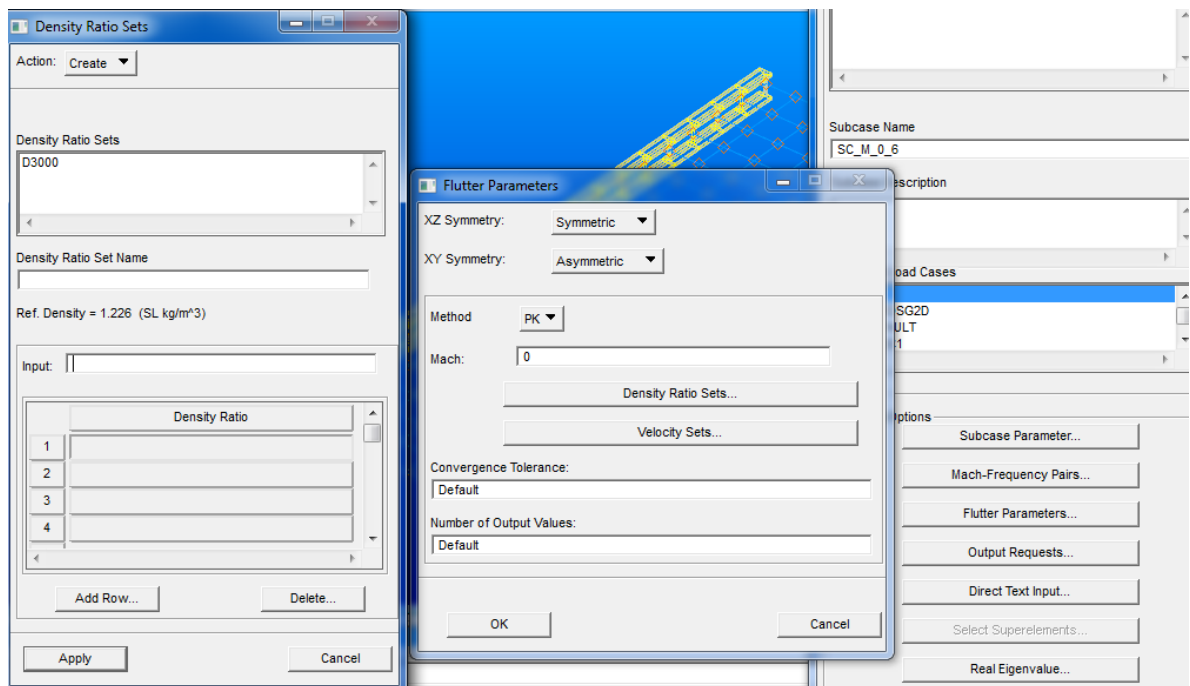
- Click on Density ratio set
- Give the set name : D3000m
- Write 0.7416 in the input field (ratio of air density at 3000 m / sea level air density)



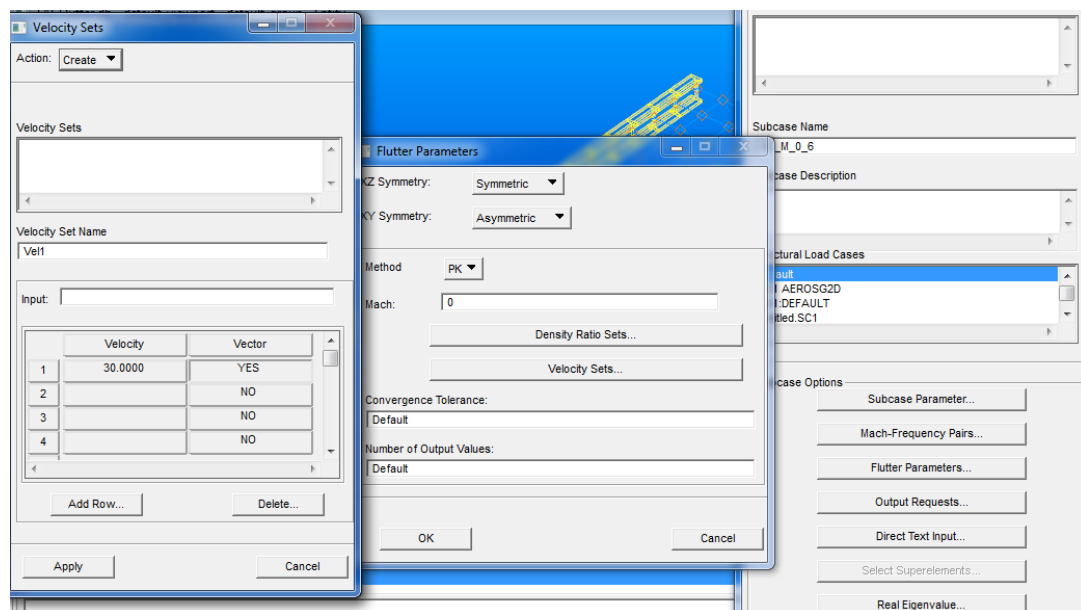
- Press enter so that density ratio shows up under the Density Ratio column



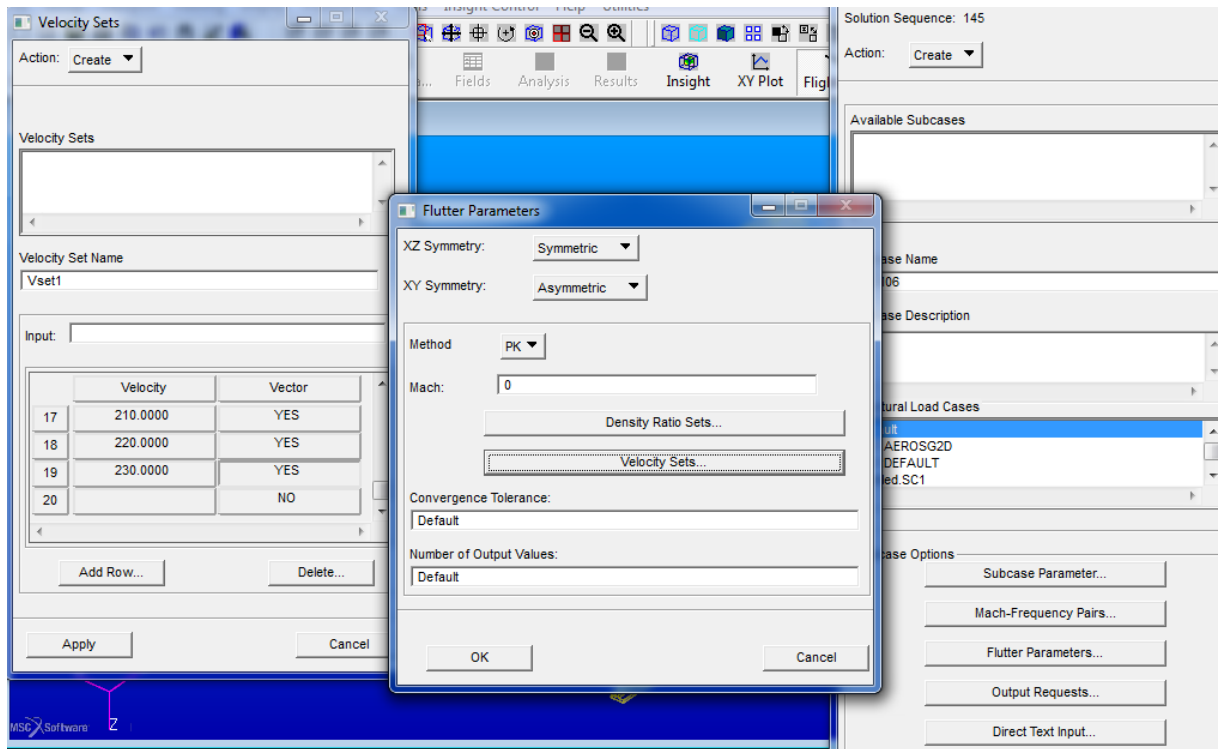
- Press Apply and create the density ratio set.



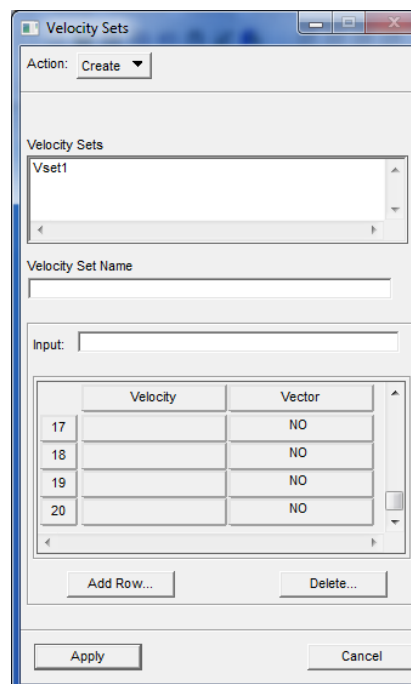
- Click on velocity set name (these are the velocities at which aerodynamic damping is calculated)
- Give a set name: Vel1
- Enter velocity values in the Input field
- Press enter
- In the vector field change NO to YES (YES will allow us to animate mode shapes at different velocities)



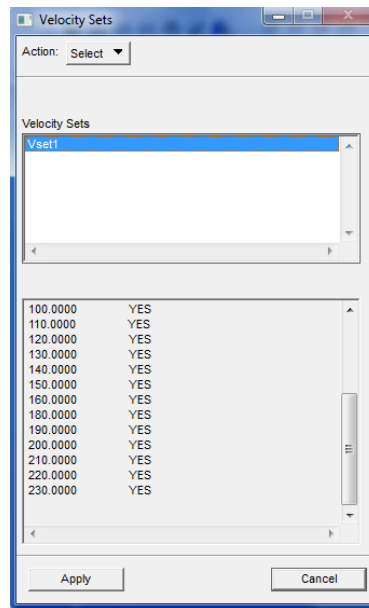
- Enter velocities up to 230 m/s (V_{max} was 225 m/s)
- Add one last row but do not enter any velocity in that last row.



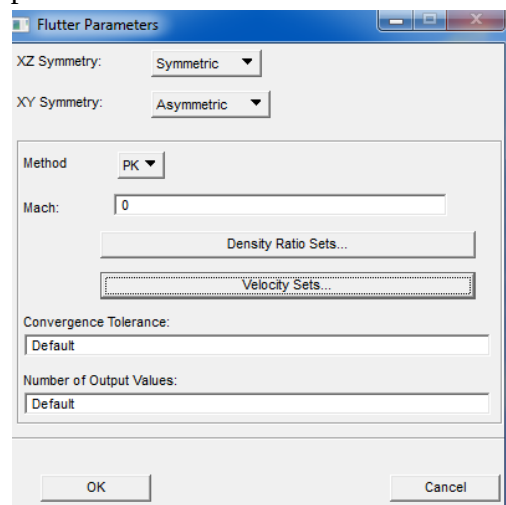
- Press Apply and then Cancel



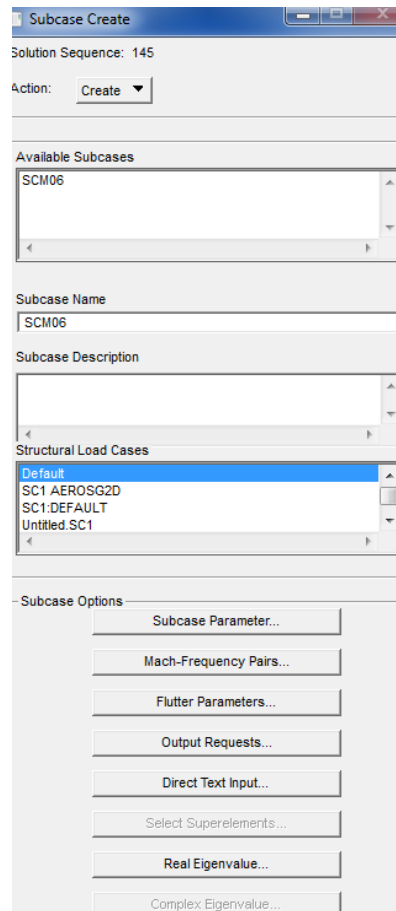
- Highlight the Velocity set just created as shown below.
- Press Apply



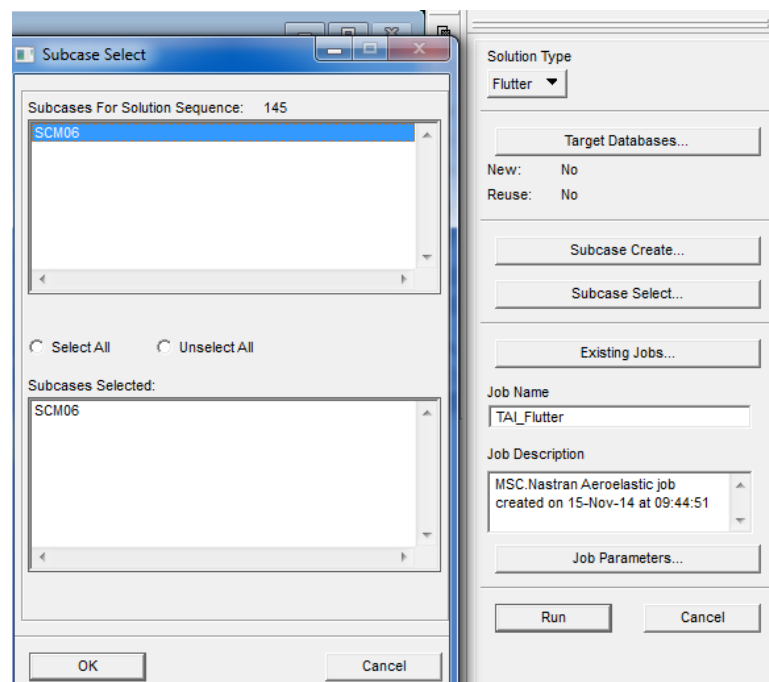
- Press OK in the Flutter parameters menu



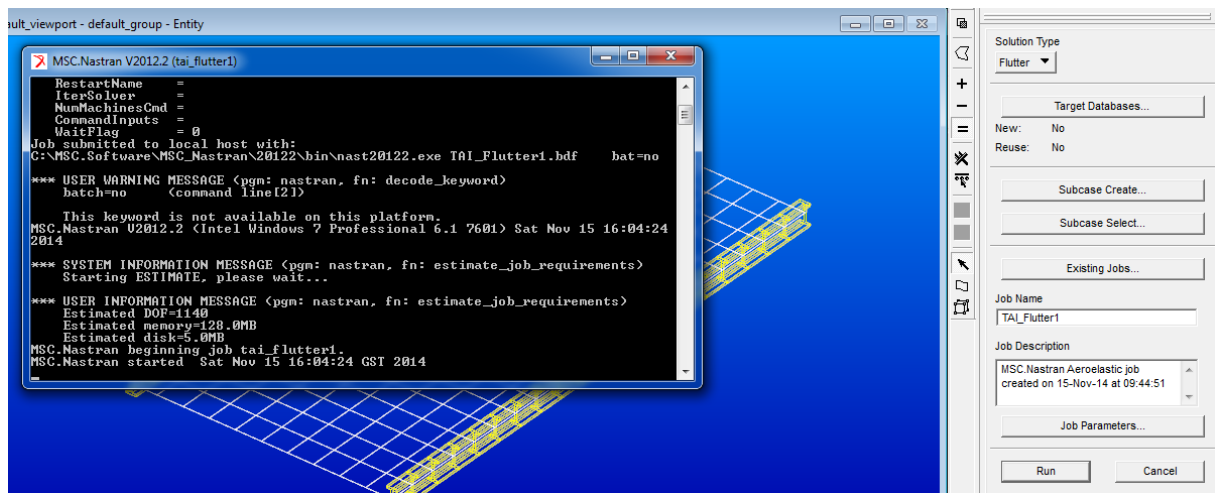
- Press Apply in the Subcase Create menu and create the subcase : SCM06 (Subcase name given above is modified to SCM06. Original name was SC_M_0_6 !



- Select the subcase in the Subcase Select menu



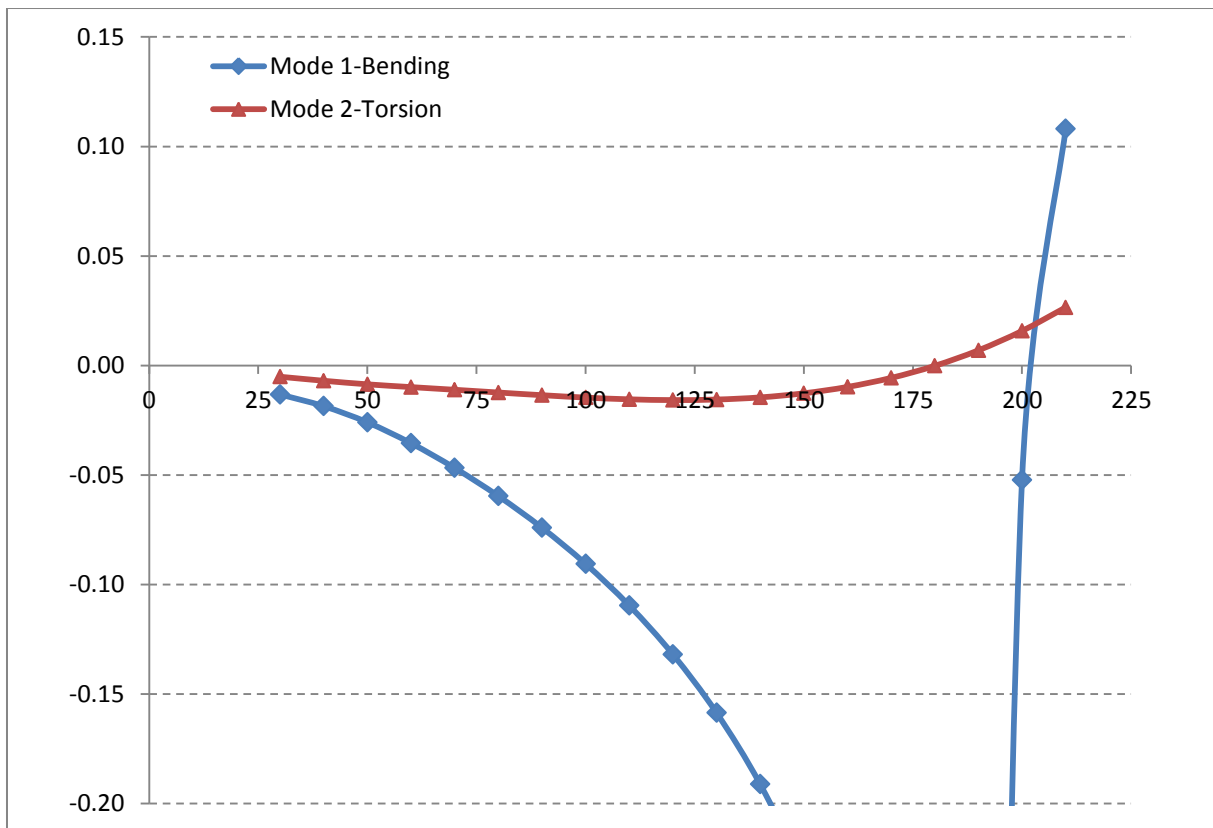
6. Press RUN



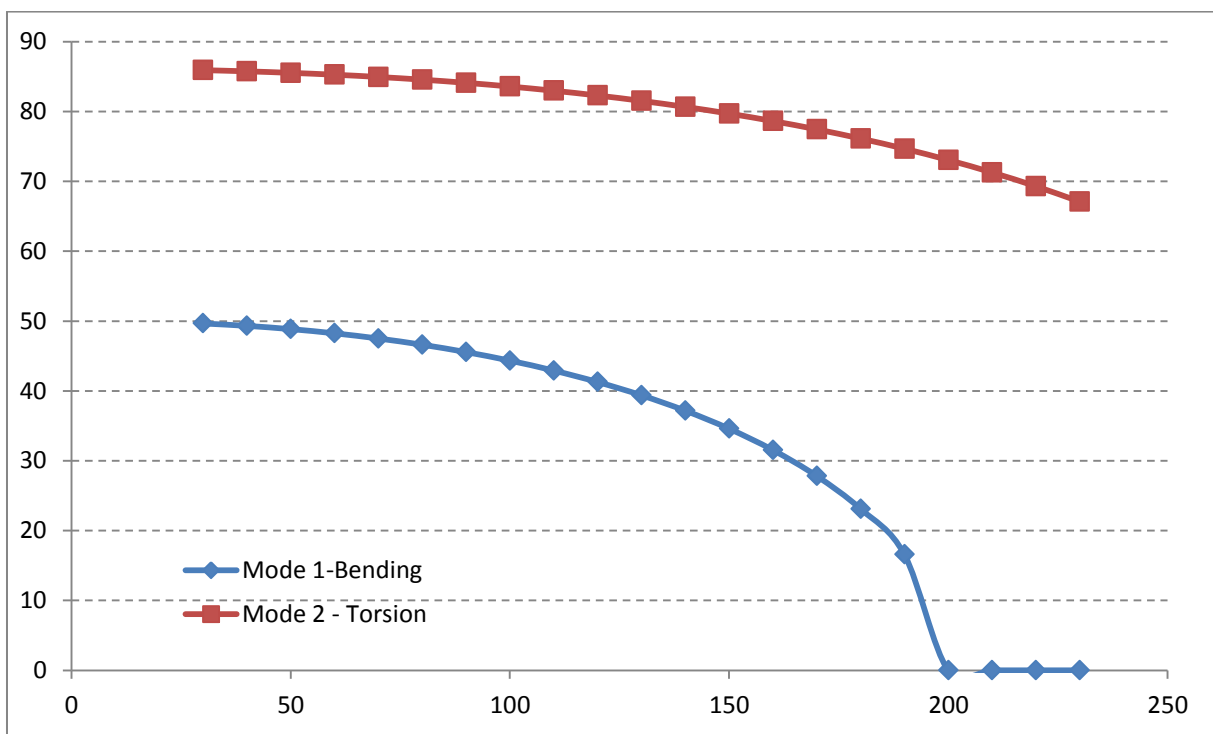
7. Open the .f06 file and go to point 1. Point 1 is the first mode which is the bending mode. Point 2 is the second mode which is torsion.

FLUTTER SUMMARY						
CONFIGURATION = AEROSG2D XY-SYMMETRY = ASYMMETRIC XZ-SYMMETRY = SYMMETRIC						
POINT = 1	MACH NUMBER = 0.0000	DENSITY RATIO = 7.4160E-01	METHOD = PK			
KFREQ	1./KFREQ	VELOCITY	DAMPING	FREQUENCY	COMPLEX	EIGENVALUE
1.3002	7.6908737E-01	3.0000000E+01	-1.3224266E-02	4.9665600E+01	-2.0633700E+00	3.1205817E+02
0.9684	1.0326694E+00	4.0000000E+01	-1.8597437E-02	4.9318375E+01	-2.8814542E+00	3.0987650E+02
0.7674	1.3031394E+00	5.0000000E+01	-2.5952777E-02	4.8852776E+01	-3.9831161E+00	3.0695105E+02
0.5330	1.8760239E+00	7.0000000E+01	-4.6793304E-02	4.7508331E+01	-6.9839864E+00	2.9850366E+02
0.4577	2.1850286E+00	8.0000000E+01	-5.9611827E-02	4.6616856E+01	-8.7302217E+00	2.9290234E+02
0.3976	2.5149131E+00	9.0000000E+01	-7.4072301E-02	4.5564812E+01	-1.0603160E+01	2.8629218E+02
0.3482	2.8715539E+00	1.0000000E+02	-9.0566099E-02	4.4339741E+01	-1.2615623E+01	2.7859482E+02
0.3064	3.2631934E+00	1.1000000E+02	-1.0959450E-01	4.2920029E+01	-1.4777421E+01	2.6967450E+02
0.2702	3.7013552E+00	1.2000000E+02	-1.3190363E-01	4.1279133E+01	-1.7105556E+01	2.5936444E+02
0.2379	4.2030516E+00	1.3000000E+02	-1.5857065E-01	3.9381184E+01	-1.9618303E+01	2.4743927E+02
0.2086	4.7948136E+00	1.4000000E+02	-1.9119658E-01	3.7176323E+01	-2.2330395E+01	2.3358572E+02
0.1812	5.5202827E+00	1.5000000E+02	-2.3248114E-01	3.4597126E+01	-2.5268393E+01	2.1738016E+02
0.1548	6.4597626E+00	1.6000000E+02	-2.8709793E-01	3.1536505E+01	-2.8444185E+01	1.9814970E+02
0.1009	9.9155073E+00	1.8000000E+02	-4.8971501E-01	2.3113602E+01	-3.5559933E+01	1.4522705E+02
0.0685	1.4592861E+01	1.9000000E+02	-7.5886887E-01	1.6577660E+01	-3.9522087E+01	1.0416051E+02
0.0000	9.9999996E+24	2.0000000E+02	-5.2341085E-02	0.0000000E+00	-2.9023756E+01	0.0000000E+00
0.0000	9.9999996E+24	2.1000000E+02	1.0808084E-01	0.0000000E+00	6.2928726E+01	0.0000000E+00
0.0000	9.9999996E+24	2.2000000E+02	1.7442721E-01	0.0000000E+00	1.0639417E+02	0.0000000E+00
0.0000	9.9999996E+24	2.3000000E+02	2.2013618E-01	0.0000000E+00	1.4037837E+02	0.0000000E+00

8. Plot damping versus velocity and frequency versus velocity curves.



Damping versus velocity plot for modes 1 and 2



Frequency versus velocity plot for modes 1 and 2 (zero frequency speed is divergence speed)

From the above plot it is seen that flutter speed is about 180 m/s which corresponds to $180/328.4=0.55$ Mach. Since we have created M-k pairs at 0,0.1,0.2,0.3,0.4,0.5,0.6 Mach numbers we can select M=0.6 in the flutter parameter section of the Subcase.

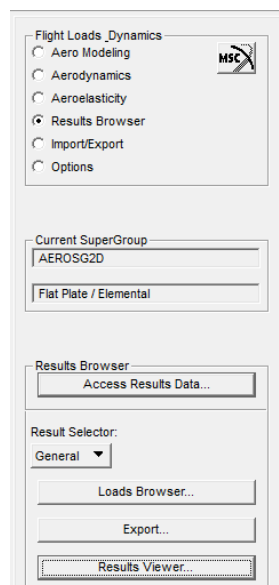
Results of the new run is given below for the flutter mode which is **mode 2 (torsional mode)**.

KFREQ	1./KFREQ	VELOCITY	DAMPING	FREQUENCY	
2.2511	4.4422731E-01	3.0000000E+01	-1.6923344E-02	8.5985672E+01	-
1.6813	5.9477758E-01	4.0000000E+01	-2.0908043E-02	8.5627937E+01	-
1.3396	7.4648428E-01	5.0000000E+01	-2.1900428E-02	8.5282410E+01	-
1.1118	8.9947480E-01	6.0000000E+01	-2.3540067E-02	8.4932190E+01	-
0.9486	1.0542343E+00	7.0000000E+01	-2.5771121E-02	8.4541710E+01	-
0.8255	1.2113566E+00	8.0000000E+01	-2.8262790E-02	8.4086845E+01	-
0.7291	1.3714852E+00	9.0000000E+01	-3.0756304E-02	8.3552887E+01	-
0.6513	1.5353127E+00	1.0000000E+02	-3.3031750E-02	8.2930313E+01	-
0.5870	1.7035435E+00	1.1000000E+02	-3.4835339E-02	8.2214714E+01	-
0.5328	1.8769648E+00	1.2000000E+02	-3.5924565E-02	8.1402023E+01	-
0.4863	2.0564804E+00	1.3000000E+02	-3.6071047E-02	8.0487579E+01	-
0.4458	2.2431467E+00	1.4000000E+02	-3.5040908E-02	7.9465843E+01	-
0.4101	2.4381986E+00	1.5000000E+02	-3.2586008E-02	7.8330750E+01	-
0.3783	2.6431203E+00	1.6000000E+02	-2.8443804E-02	7.7074928E+01	-
0.3497	2.8597136E+00	1.7000000E+02	-2.2342211E-02	7.5689644E+01	-
0.3236	3.0902452E+00	1.8000000E+02	-1.4007200E-02	7.4163406E+01	-
0.2996	3.3376420E+00	1.9000000E+02	-3.1827020E-03	7.2480965E+01	-
0.2773	3.6057520E+00	2.0000000E+02	1.0364941E-02	7.0622688E+01	-
0.2564	3.8997953E+00	2.1000000E+02	2.6832968E-02	6.8562653E+01	-
0.2366	4.2268763E+00	2.2000000E+02	4.6395041E-02	6.6269432E+01	-
0.2175	4.5969763E+00	2.3000000E+02	6.9303758E-02	6.3703854E+01	-

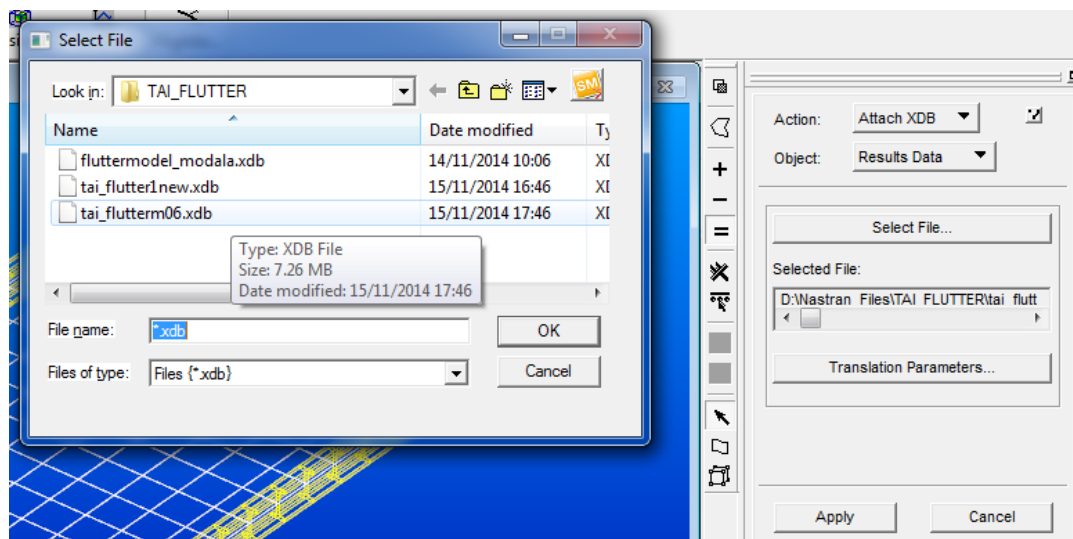
This table shows that damping crosses 0 between 190 m/s and 200 m/s (very close to 190 m/s). If we say that flutter speed is 190 m/s then $M=190/328.4=0.58$ which is very close to $M=0.6$. To be more exact we can create M-k pairs to also include $M=0.58$. But in this example $M=0.58$ is very close to $M=0.6$ so we can say that flutter speed is slightly higher than 190 m/s.

9. Flutter mode shapes

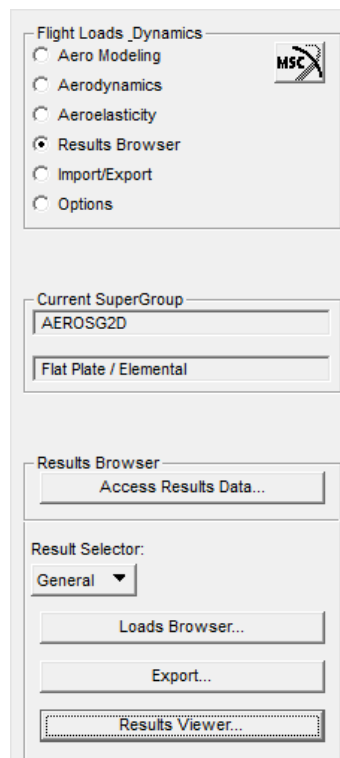
- Access results : Results Browser / Access Results Data



- Attach the .xdb file



- Click “Results Viewer”



- Click “Results Viewer”

Flutter frequency is read from the .f06 file. For mode 2 (torsional mode) flutter frequency is about 72.48 Hz.

KFREQ	1./KFREQ	VELOCITY	DAMPING	FREQUENCY	
0.3236	3.0902452E+00	1.8000000E+02	-1.4007200E-02	7.4163406E+01	-
0.2996	3.3376420E+00	1.9000000E+02	-3.1827020E-03	7.2480965E+01	-
0.2773	3.6057520E+00	2.0000000E+02	1.0364941E-02	7.0622688E+01	

