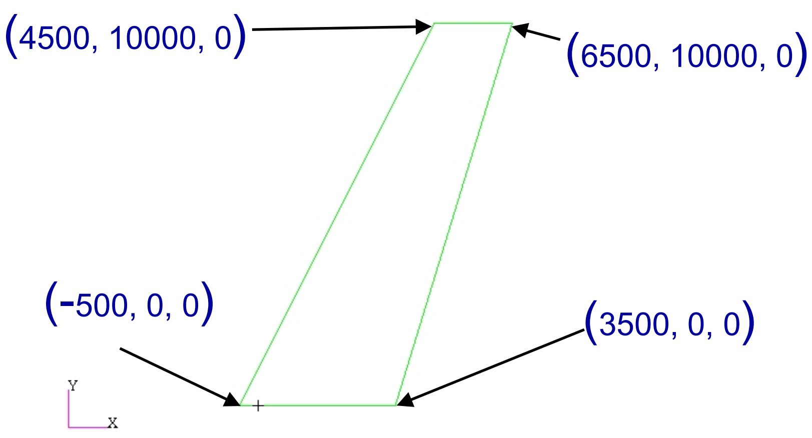
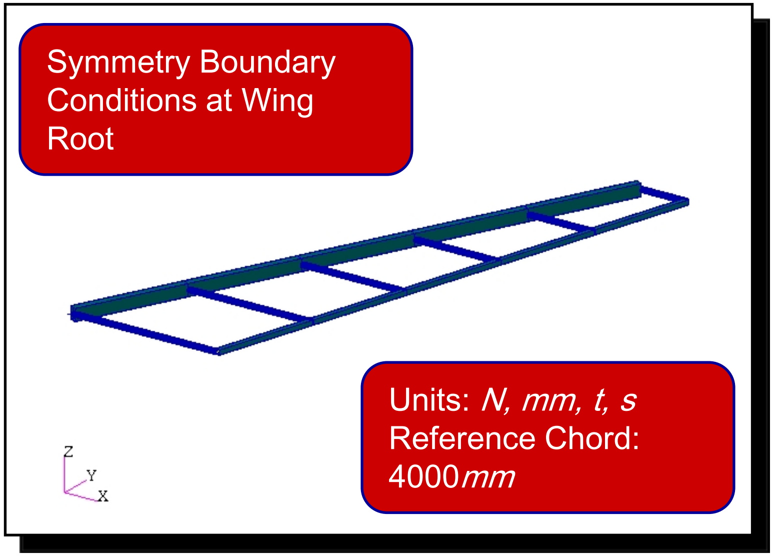
WORKSHOP 5

FLUTTER WORKSHOP OF A SWEPT WING

- **Workshop Objectives**
  - Find the matched point and the flutter boundary given the flight envelope
  - Verify and animate the splines using normal modes
  - Animate the flutter modes
- **Software Version**
  - FlightLoads 2014
- **Files Required**
  - modes.dat
  - structure.bdf: Bulk data deck with structural model
  - aero.bdf: Bulk data deck with aerodynamic model
  - modes.dat: MSC Nastran input deck to run a normal modes analysis
  - flutter_setup_import.bdf: Deck to import aero & structural mesh to proceed further with Flutter Setup

- **Problem Description (Swept Wing)**
  - Using the above files setup the flutter run, while following the guidelines for aeromesh, and find the matched flutter point.
  - The structural model of the wing is a beam model, consisting of the front and rear spar and some ribs.
  - The objective of this workshop is to find matched points and the flutter boundary.





- **Suggested Steps**
  1. Read in the structure model and aero model provided using flutter_setup_import.bdf
  2. Verify the box/wave length by fringe plot
  3. Run Modes.dat.
  4. Import the results for Modes run.
  5. Verify the Splines.
  6. Create unsteady aerodynamics
  7. Select the mach number, velocity and densities.
  8. Run the analysis
  9. Observe the flutter point and find matched point

Tasks

- **Compute the first 5 symmetric normal modes of the wing.**
- **Import the structure into Flightloads.**
- **Verify the box/wave length by Fringe plot.**
- **Verify the spline.**
- **Run several flutter analyses to find the flutter boundary.**
  - Hint: Begin with M = 0.5.

Atmosphere

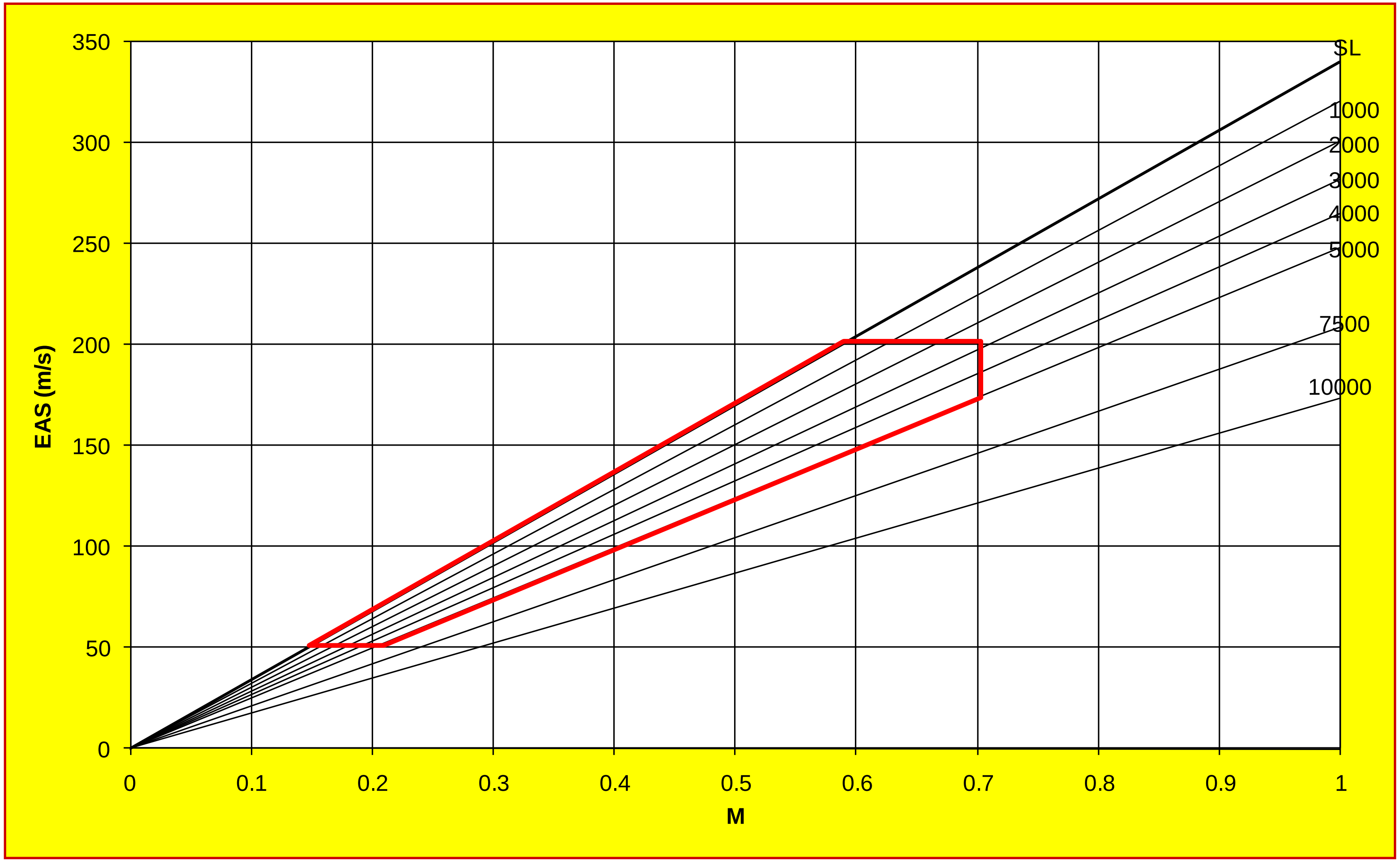
- **Atmosphere for the purpose of finding matched point is shown below**
- **Needed to fill in Density Ratios for PK method: SL to 5000m**
  - FLFACT, 100, 1., 0.908, 0.821, 0.735, 0.669, 0.601

Altitude	ρ	c	ρ/ρ_0	$\sqrt{(\rho/\rho_0)}$
0	1.225	340.290	1.000	1.107
1000	1.112	336.430	0.908	1.055
2000	1.006	332.525	0.821	1.003
3000	0.901	328.574	0.735	0.949
4000	0.819	324.575	0.669	0.905
5000	0.736	320.526	0.601	0.858
7500	0.557	310.172	0.455	0.746
10000	0.413	299.460	0.337	0.643
m	*kg/m^3*	*m/s*		

MSC Software

Flight Envelope

- **See if flutter point exists within the Flight envelope below**



Normal Modes Analysis

- **Header file of modes.dat**

```
SOL 103
CEND
$
SPC = 1
METHOD = 10
DISP(PLOT) = ALL
$
BEGIN BULK
$
PARAM, POST, 0
PARAM, GRDPNT, 0
$
EIGRL, 10,,, 5
$
INCLUDE 'structure.bdf'
$
SPC1, 1, 123456, 1, 7
$
ENDDATA
```

Resonance Frequencies

- **Normal modes analysis is needed for spline verification and to obtain highest frequency of interest to calculate minimum number of box/wavelength.**

R E A L   E I G E N V A L U E S

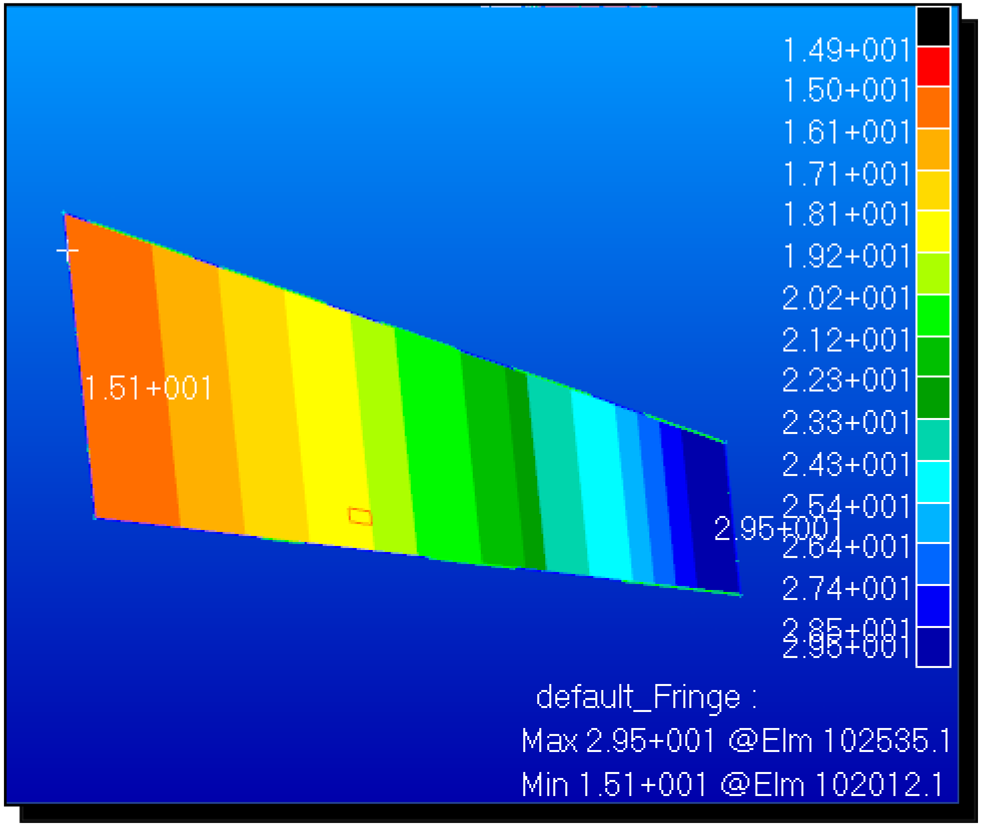
MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	8.965433E+01	9.468597E+00	1.506974E+00	1.000000E+00	8.965433E+01
2	2	1.302369E+03	3.608835E+01	5.743640E+00	1.000000E+00	1.302369E+03
3	3	2.051788E+03	4.529667E+01	7.209188E+00	1.000000E+00	2.051788E+03
4	4	3.463376E+03	5.885046E+01	9.366341E+00	1.000000E+00	3.463376E+03
5	5	8.250501E+03	9.083227E+01	1.445640E+01	1.000000E+00	8.250501E+03

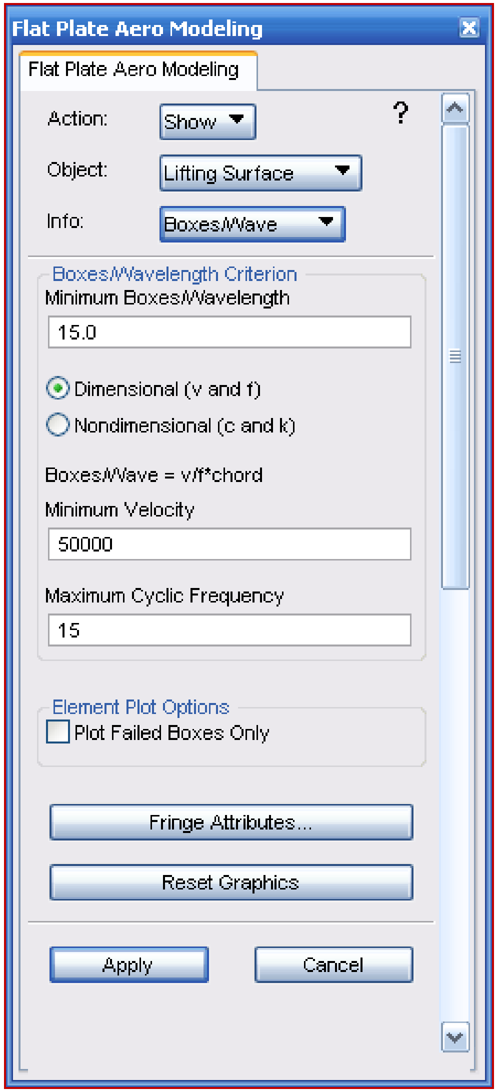
Aerodynamic Mesh – Number of Boxes

- **Requirement: 15 Boxes per Wavelength**
- **Minimum Velocity: $V_{min} = 50 m/s$**
- **Maximum Frequeny: $f_{max} = 15 Hz$**
- **Minimum Wavelength = $V_{min}/f_{max} = 3.33 m$**
- **Maximum Chord Length: 4 *m***
- **We need 15 ·(4/3.33) = 18 boxes in chordwise direction.**

Aerodynamic Mesh

- **Verify Aero mesh by using Aero Modeling … Flat Plate Aero Modeling as shown.**
- **Plot the boxes/wave after entering minimum velocity and maximum frequency**

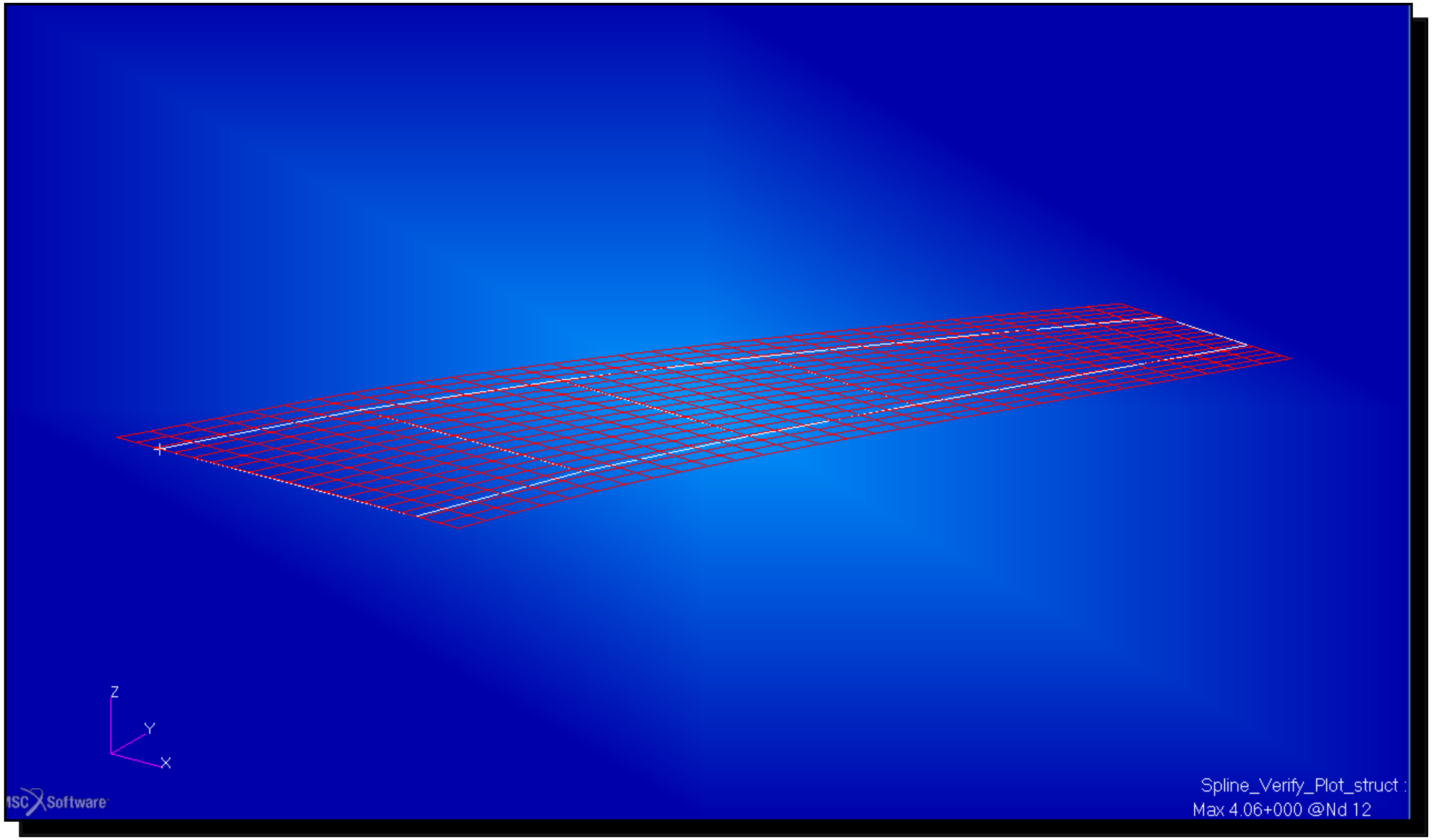




MSC Software

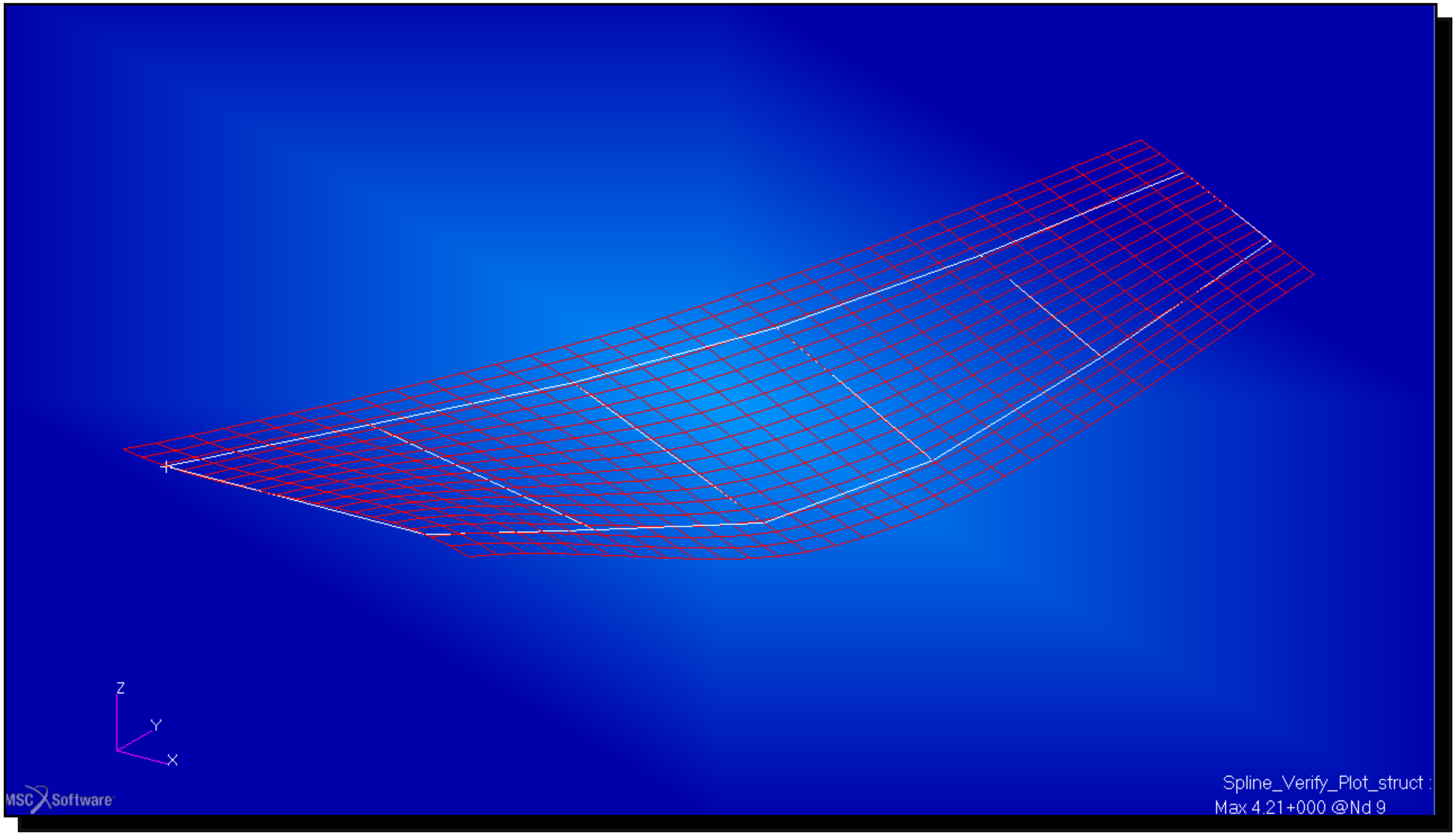
Verify Spline using Mode Shapes

- **Attach xdb file from modes.dat run**
- **spline verification of 1^{st} mode**



Verify Spline using Mode Shapes (Cont.)

- **Spline verification of 3rd mode**



Velocities and Reduced Frequencies

- **It is recommended to run a first flutter analysis at M = 0.5.**
- **Minimum and maximum velocity from the flight envelope, together with f_{min} and f_{max}, are used to get k_{min} and k_{max}.**
- **Values will be adjusted based on the results of the first analysis.**

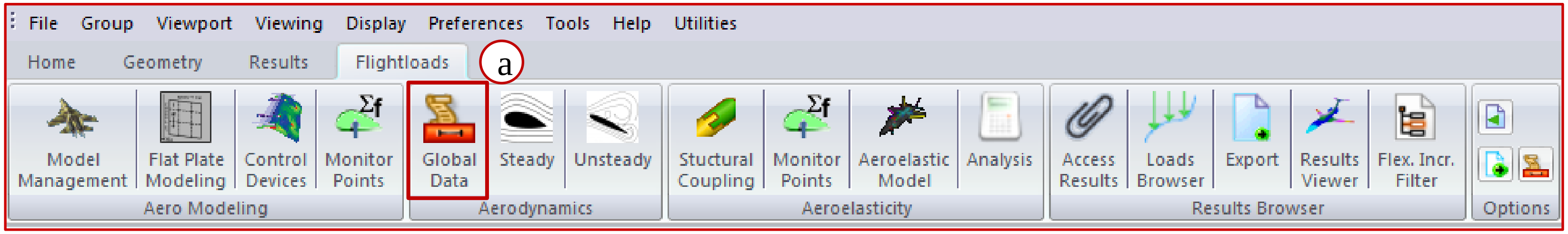
Altitude *m*	EAS *m/s*	TAS *m/s*
0	170	170
5000	125	146

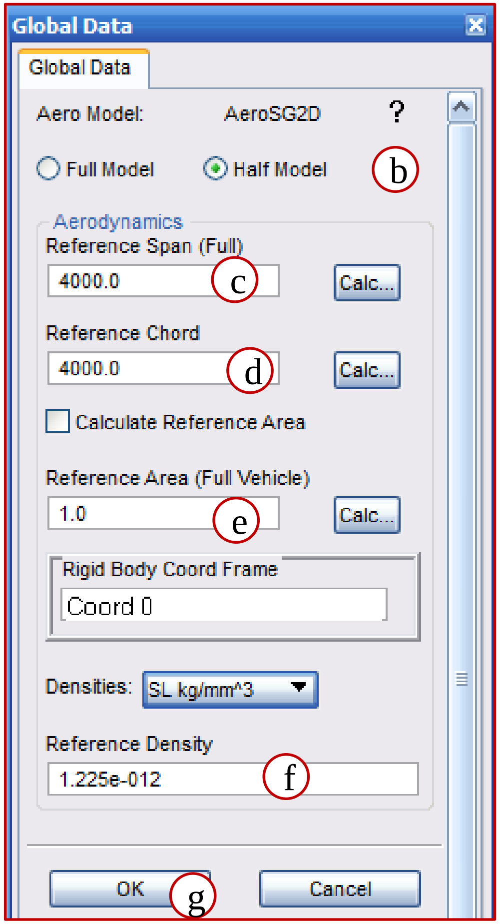
$$k_{min} = \frac{\omega_{min}\bar{c}}{2TAS_{max}} = 0.111 \qquad k_{max} = \frac{\omega_{max}\bar{c}}{2TAS_{min}} = 1.291$$

Set up the Analysis

- **Import flutter_setup_import.bdf structure and aero model in two steps**
  - First thru file menu in structure preference
    - This will import the structural portion of the model.
    - Then import the aero portion of the model via Flightloads import/export menu.
    - the INCLUDE statement will also import aero.bdf and structure.bdf)
- **Select the Splines (shown in earlier workshops)**

Set Global Data

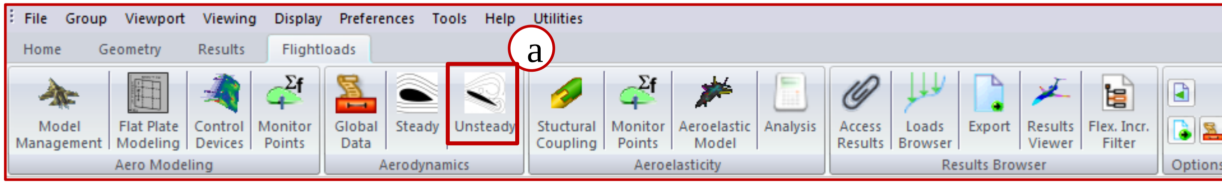


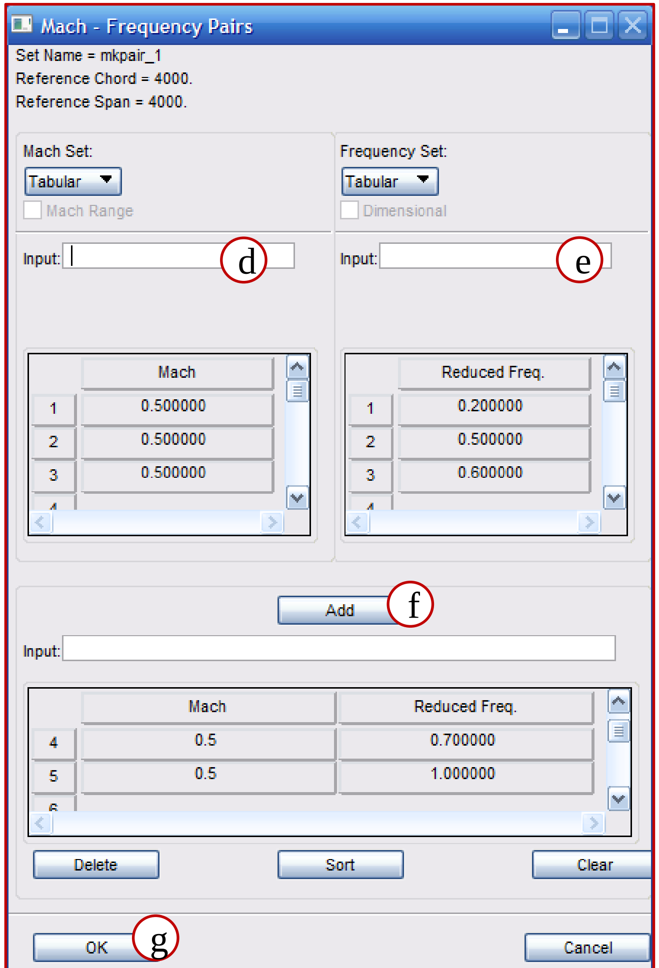


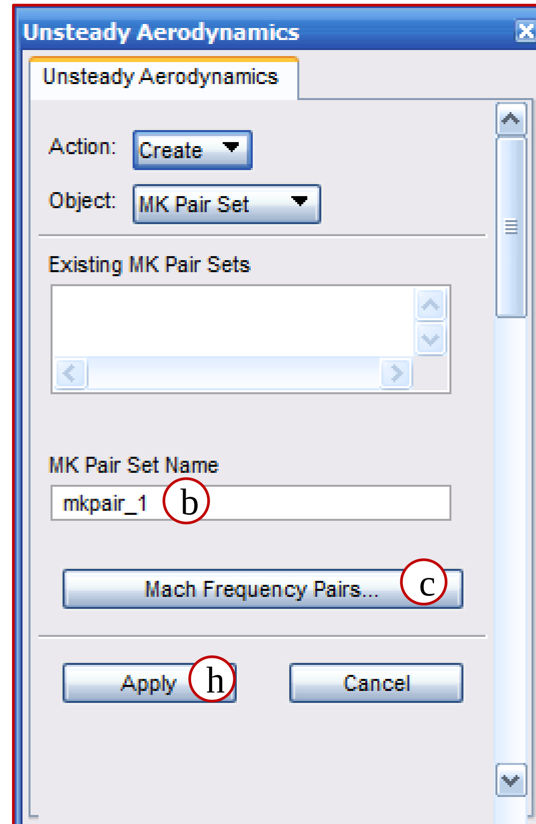
Setting Unsteady Aerodynamics

- **At Step d & e enter below table values.**

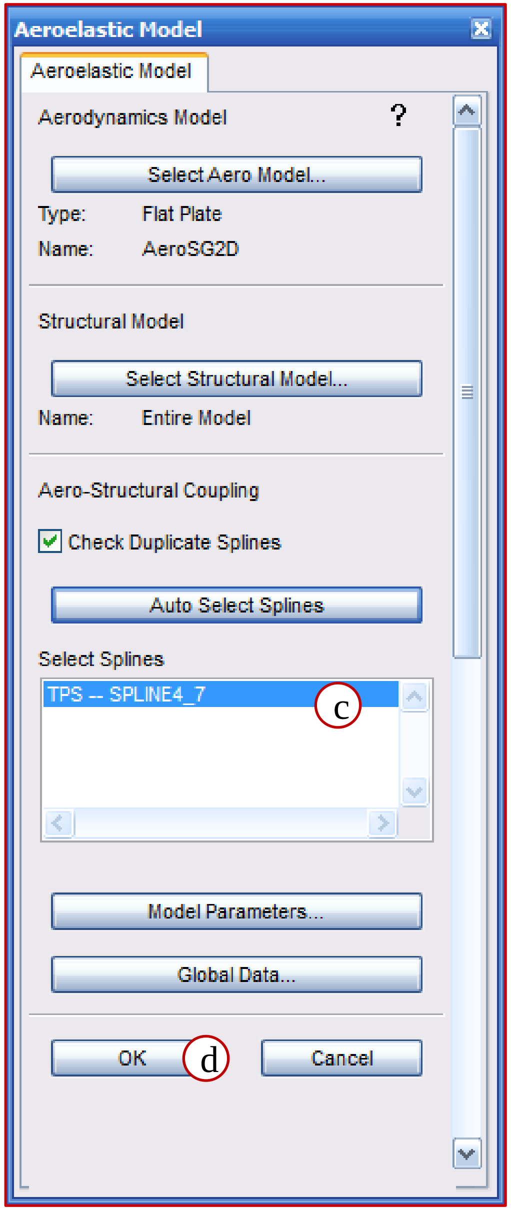
Mach No	Reduced Freq
.5	0.2
.5	0.5
.5	0.6
.5	0.7
.5	1.0

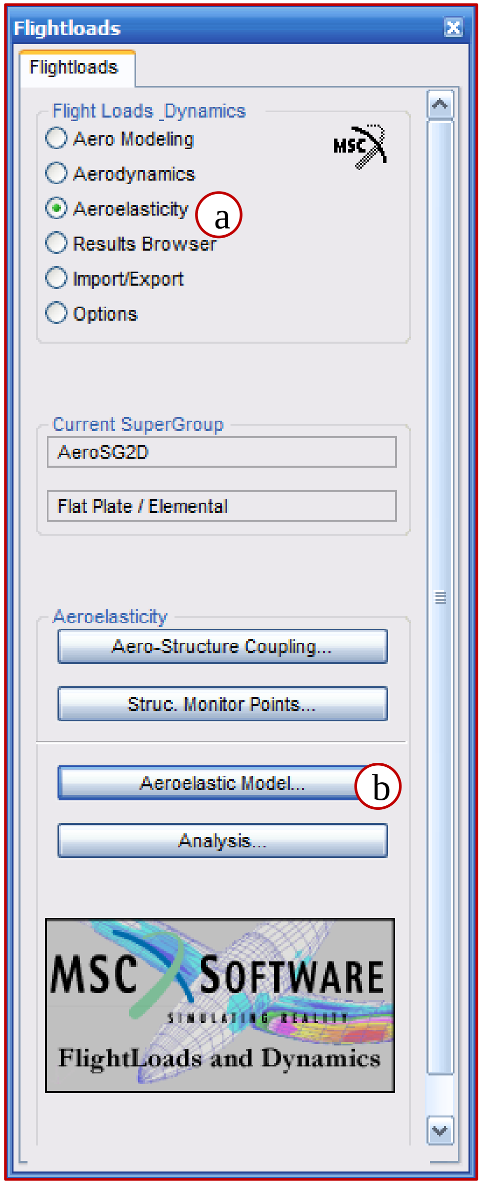




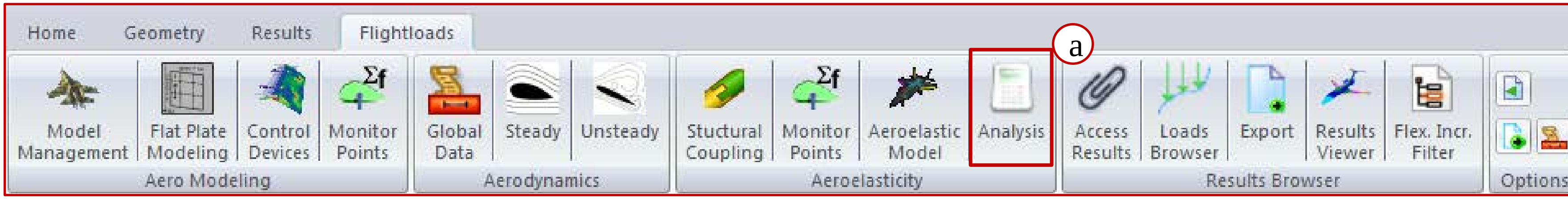


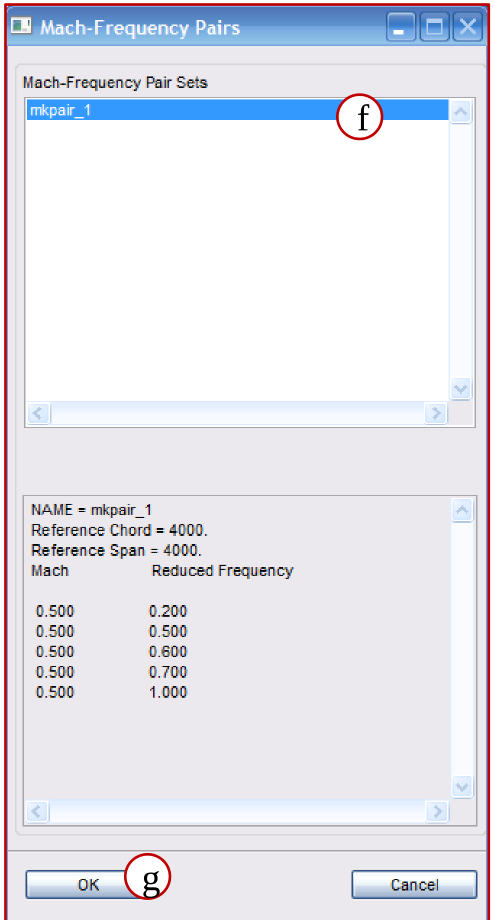
Spline Selection

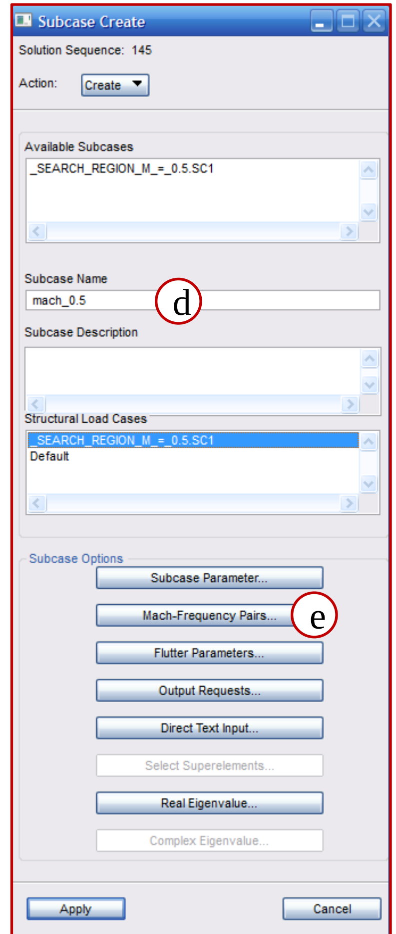


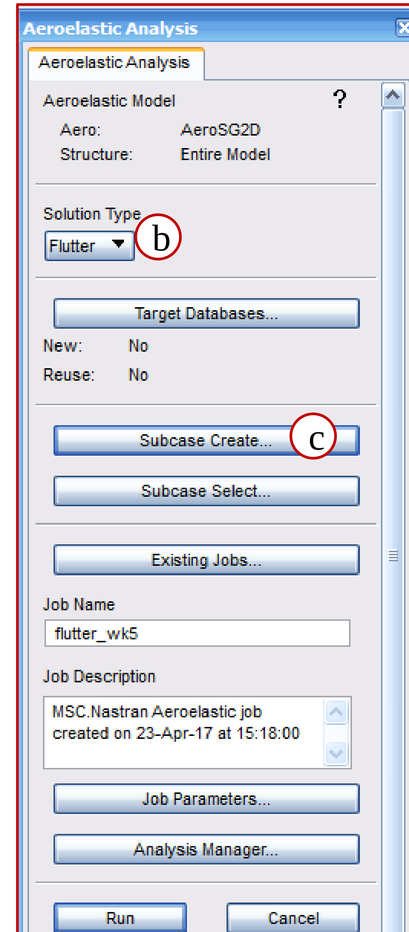


Setup Analysis



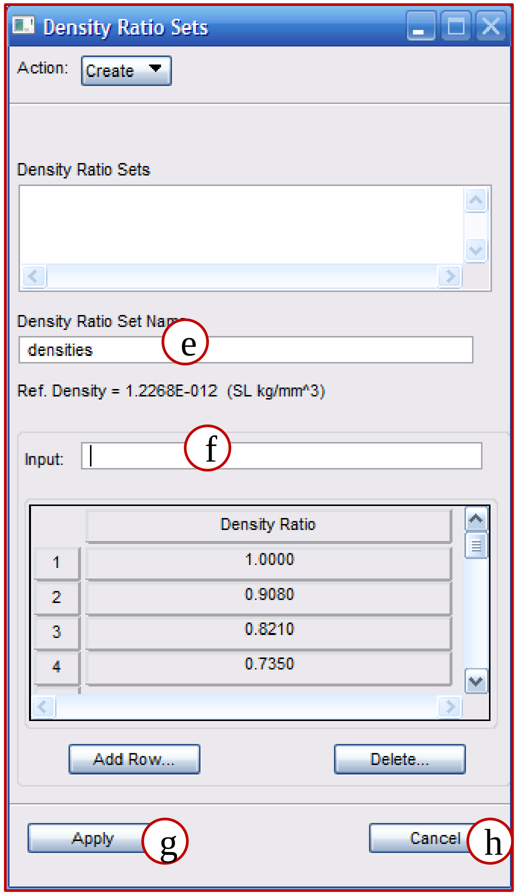


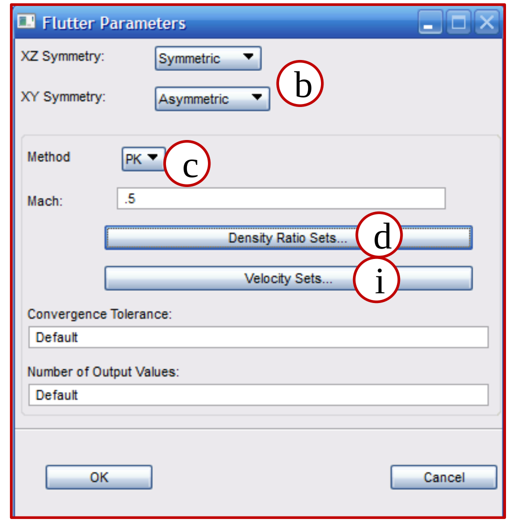


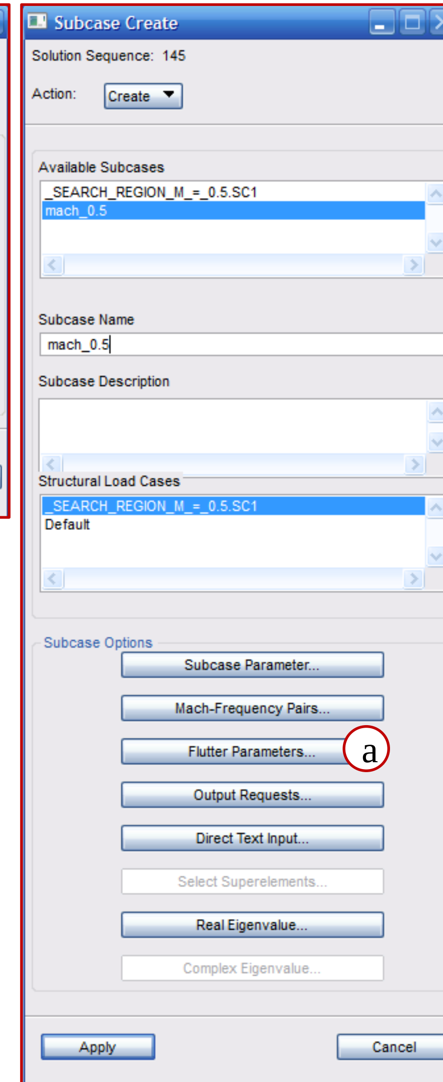


Setup Analysis → Define Flutter Parameters

Densities
1.
.908
.821
.735
.669
.601



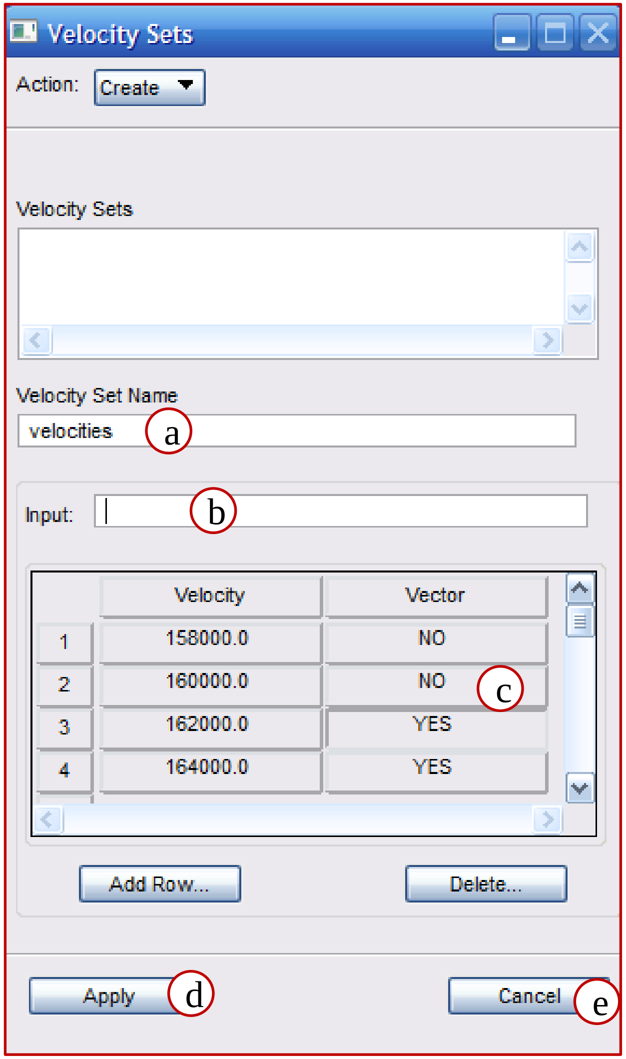




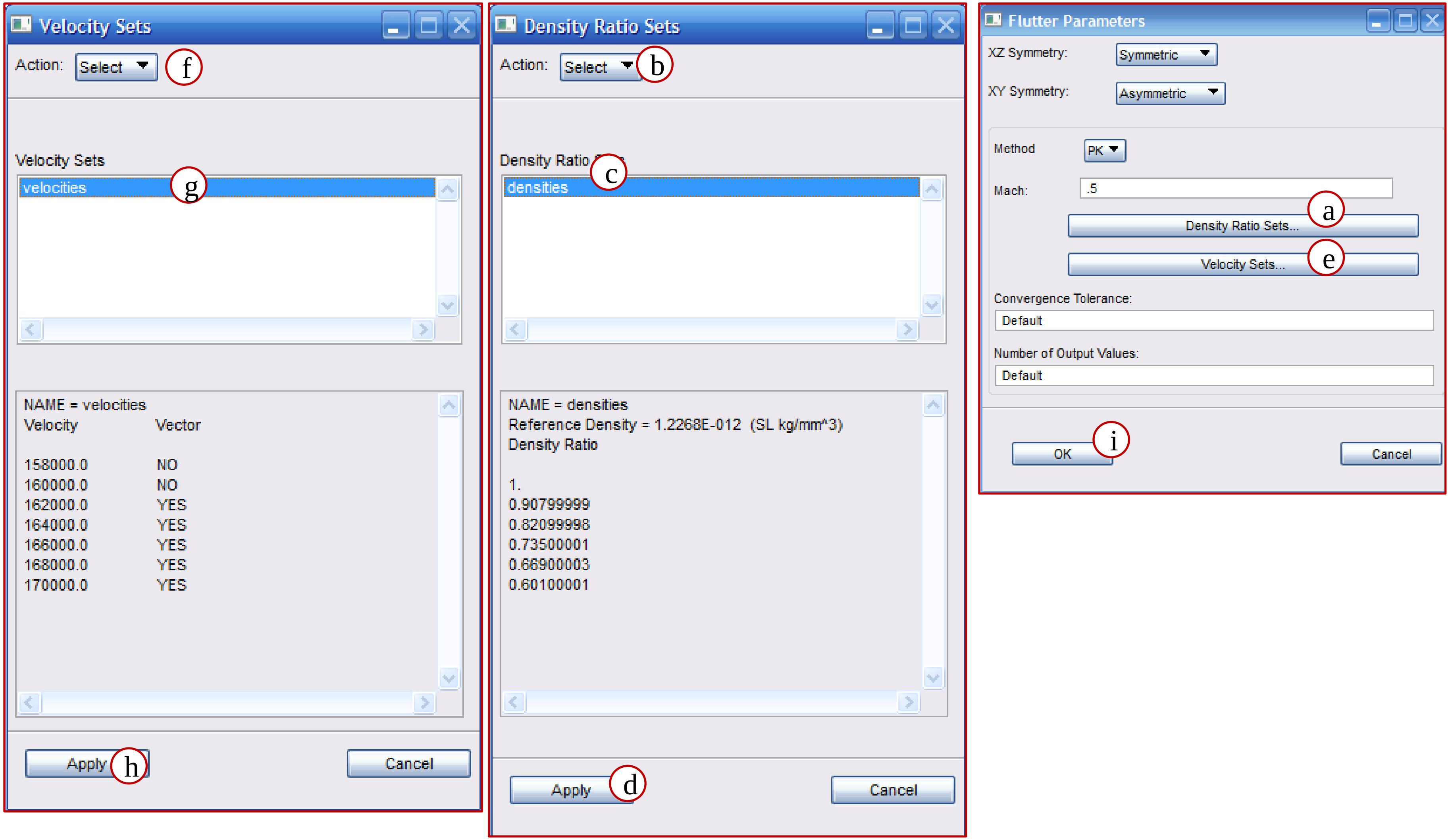
MSC Software

Setup Analysis → Define Flutter Parameters (Cont.)

- **Velocity Sets**
  - Enter the data shown. (158e3 to 170e3 in increments of 2.)
  - Be sure to select Yes for 162e3 through 170e3 mm/s



Selection of Velocity and Density Set



Select Output Requests

- **Insert below entries in Direct text input to obtain X-Y plot**

  OUTPUT (XYPLOT)

  XPAPER=29.

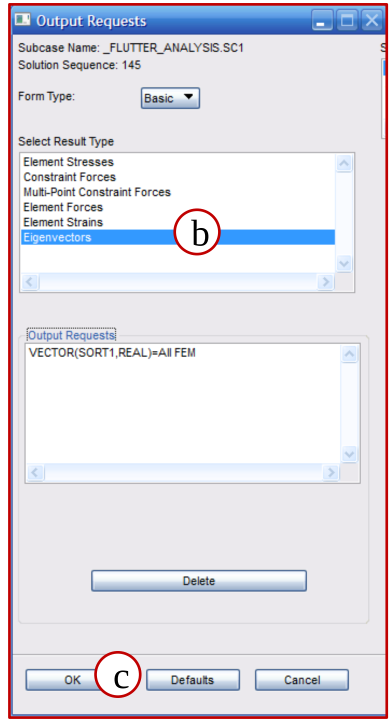
  YPAPER=21.

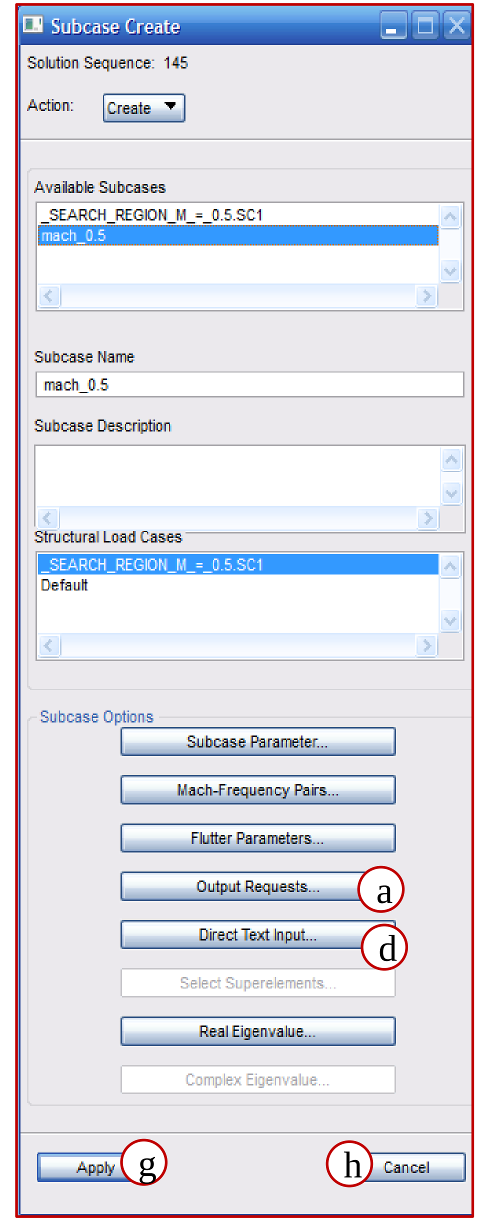
  XGRID=YES

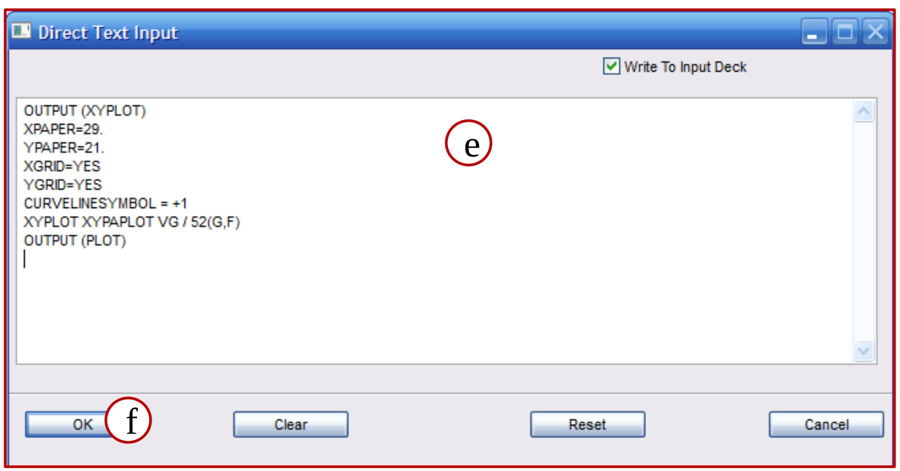
  YGRID=YES

  CURVELINESYMBOL = +1

  XYPLOT XYPAPLOT VG / 52(G,F)
  OUTPUT (PLOT)



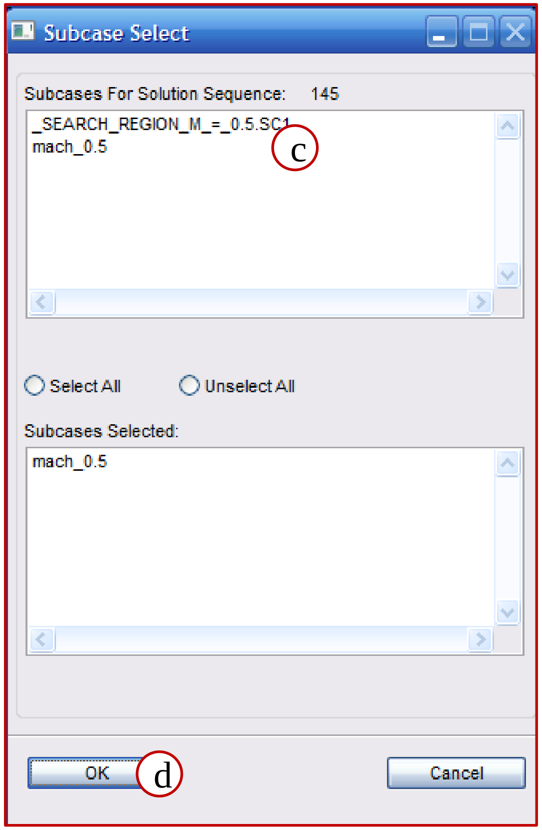


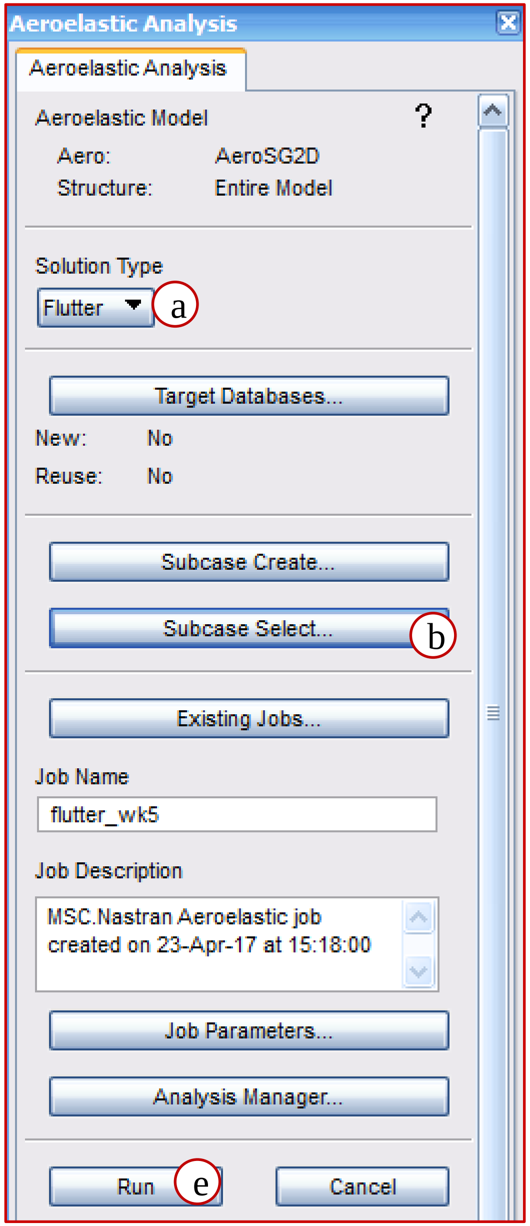


MSC Software

Generate Nastran Input File

- **In Job Parameters set the Analysis Type to Analysis Deck to Study the Input file**





MSC Software

First Results

- **Point=52 data has been sent to plt file. Pdf can be generated from it as shown in earlier workshop.**
- **The Flutter Summary in the .f06 shows that flutter occurs for points 4, 20, 36, 52, 68 and 84. Sample output shown in the next page.**
- **The flutter velocities are between 158 *m/s* and 170 *m/s*.**

Flutter Summary Results

```
0                                                    FLUTTER  SUMMARY
                             CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
      POINT =    4      MACH NUMBER =  0.5000     DENSITY RATIO =  1.0000E+00     METHOD = PK


      KFREQ           1./KFREQ        VELOCITY           DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
       0.5987       1.6703341E+00    1.5800000E+05    -3.2891823E-03    7.5273805E+00    -7.7782463E-02     4.7295927E+01
       0.5902       1.6944747E+00    1.6000000E+05     1.0735900E-02    7.5140666E+00     2.5343313E-01     4.7212273E+01
       0.5821       1.7178777E+00    1.6200000E+05     2.5805338E-02    7.5043472E+00     6.0837639E-01     4.7151204E+01
       0.5746       1.7404287E+00    1.6400000E+05     4.1761565E-02    7.4985581E+00     9.8379452E-01     4.7114830E+01
       0.5675       1.7620408E+00    1.6600000E+05     5.8407477E-02    7.4969093E+00     1.3756266E+00     4.7104470E+01
       0.5610       1.7826644E+00    1.6800000E+05     7.5525690E-02    7.4994569E+00     1.7794033E+00     4.7120478E+01
       0.5549       1.8022887E+00    1.7000000E+05     9.2900715E-02    7.5061059E+00     2.1907036E+00     4.7162254E+01
1    MSC.NASTRAN AEROELASTIC JOB CREATED ON 23-APR-17 AT 15:18:00           APRIL  23, 2017  MSC Nastran  7/ 3/15    PAGE   268
     _SEARCH_REGION_M_=_0.5.SC1
```

```
0                                                    FLUTTER  SUMMARY
                             CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
      POINT =   20      MACH NUMBER =  0.5000     DENSITY RATIO =  9.0800E-01     METHOD = PK


      KFREQ           1./KFREQ        VELOCITY           DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
       0.6033       1.6576322E+00    1.5800000E+05    -1.5735803E-02    7.5850606E+00    -3.7497114E-01     4.7658341E+01
       0.5940       1.6836008E+00    1.6000000E+05    -5.5804898E-03    7.5625975E+00    -1.3258463E-01     4.7517202E+01
       0.5850       1.7093672E+00    1.6200000E+05     5.6383898E-03    7.5417094E+00     1.3359025E-01     4.7385958E+01
       0.5764       1.7348226E+00    1.6400000E+05     1.7935517E-02    7.5227897E+00     4.2387978E-01     4.7267082E+01
       0.5682       1.7598406E+00    1.6600000E+05     3.1292873E-02    7.5062821E+00     7.3793853E-01     4.7163361E+01
       0.5604       1.7842857E+00    1.6800000E+05     4.5650694E-02    7.4926428E+00     1.0745640E+00     4.7077663E+01
       0.5531       1.8080254E+00    1.7000000E+05     6.0902843E-02    7.4822900E+00     1.4316010E+00     4.7012615E+01
1    MSC.NASTRAN AEROELASTIC JOB CREATED ON 23-APR-17 AT 15:18:00           APRIL  23, 2017  MSC Nastran  7/ 3/15    PAGE   284
     _SEARCH_REGION_M_=_0.5.SC1
```

Flutter Summary Results (Cont.)

```
0                                                       FLUTTER  SUMMARY
                              CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
       POINT =   36     MACH NUMBER =  0.5000     DENSITY RATIO =  8.2100E-01     METHOD = PK


       KFREQ          1./KFREQ        VELOCITY           DAMPING         FREQUENCY          COMPLEX   EIGENVALUE
        0.6093       1.6411460E+00    1.5800000E+05    -2.0962011E-02    7.6612564E+00    -5.0452515E-01     4.8137093E+01
        0.5997       1.6674862E+00    1.6000000E+05    -1.3988743E-02    7.6356828E+00    -3.3556483E-01     4.7976410E+01
        0.5903       1.6939574E+00    1.6200000E+05    -6.2657775E-03    7.6103155E+00    -1.4980541E-01     4.7817023E+01
        0.5812       1.7205253E+00    1.6400000E+05     2.2669116E-03    7.5853027E+00     5.4020348E-02     4.7659863E+01
        0.5724       1.7471427E+00    1.6600000E+05     1.1665802E-02    7.5608366E+00     2.7709859E-01     4.7506137E+01
        0.5638       1.7737413E+00    1.6800000E+05     2.1984915E-02    7.5371842E+00     5.2057557E-01     4.7357525E+01
        0.5555       1.8002302E+00    1.7000000E+05     3.3268862E-02    7.5146892E+00     7.8541437E-01     4.7216185E+01
1    MSC.NASTRAN AEROELASTIC JOB CREATED ON 23-APR-17 AT 15:18:00          APRIL  23, 2017  MSC Nastran  7/ 3/15   PAGE   300
     _SEARCH_REGION_M_=_0.5.SC1
```

```
0                                                       FLUTTER  SUMMARY
                              CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
       POINT =   52     MACH NUMBER =  0.5000     DENSITY RATIO =  7.3500E-01     METHOD = PK


       KFREQ          1./KFREQ        VELOCITY           DAMPING         FREQUENCY          COMPLEX   EIGENVALUE
        0.6162       1.6229435E+00    1.5800000E+05    -2.0957627E-02    7.7471832E+00    -5.1007709E-01     4.8676988E+01
        0.6065       1.6488471E+00    1.6000000E+05    -1.6185377E-02    7.7219989E+00    -3.9264713E-01     4.8518750E+01
        0.5970       1.6749990E+00    1.6200000E+05    -1.0970217E-02    7.6964524E+00    -2.6525017E-01     4.8358236E+01
        0.5878       1.7013963E+00    1.6400000E+05    -5.2657724E-03    7.6705850E+00    -1.2689381E-01     4.8195707E+01
        0.5787       1.7280464E+00    1.6600000E+05     9.6638755E-04    7.6443897E+00     2.3208337E-02     4.8031117E+01
        0.5698       1.7549510E+00    1.6800000E+05     7.7702443E-03    7.6178850E+00     1.8595975E-01     4.7864583E+01
        0.5611       1.7821028E+00    1.7000000E+05     1.5197353E-02    7.5911280E+00     3.6243001E-01     4.7696464E+01
1    MSC.NASTRAN AEROELASTIC JOB CREATED ON 23-APR-17 AT 15:18:00          APRIL  23, 2017  MSC Nastran  7/ 3/15   PAGE   316
     _SEARCH_REGION_M_=_0.5.SC1
```

Flutter Summary Results (Cont.)

```
0                                                                     FLUTTER   SUMMARY
                                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
         POINT =    68     MACH NUMBER =  0.5000     DENSITY RATIO =  6.6900E-01     METHOD = PK


         KFREQ           1./KFREQ        VELOCITY          DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
          0.6217       1.6086065E+00    1.5800000E+05    -1.8620466E-02    7.8162314E+00     -4.5723328E-01     4.9110830E+01
          0.6120       1.6339350E+00    1.6000000E+05    -1.4969082E-02    7.7924735E+00     -3.6645477E-01     4.8961555E+01
          0.6026       1.6595200E+00    1.6200000E+05    -1.1039229E-02    7.7682403E+00     -2.6940848E-01     4.8809293E+01
          0.5933       1.6853646E+00    1.6400000E+05    -6.8000421E-03    7.7435504E+00     -1.6542517E-01     4.8654162E+01
          0.5843       1.7114832E+00    1.6600000E+05    -2.2278344E-03    7.7183700E+00     -5.4020471E-02     4.8495949E+01
          0.5754       1.7378966E+00    1.6800000E+05     2.6982445E-03    7.6926411E+00      6.5208866E-02     4.8334290E+01
          0.5667       1.7646238E+00    1.7000000E+05     8.0046355E-03    7.6663198E+00      1.9278728E-01     4.8168908E+01
1     MSC.NASTRAN AEROELASTIC JOB CREATED ON 23-APR-17 AT 15:18:00                APRIL  23, 2017  MSC Nastran  7/ 3/15    PAGE   332
      _SEARCH_REGION_M_=_0.5.SC1
```

```
0                                                                     FLUTTER   SUMMARY
                                    CONFIGURATION = AEROSG2D     XY-SYMMETRY = ASYMMETRIC     XZ-SYMMETRY = SYMMETRIC
         POINT =    84     MACH NUMBER =  0.5000     DENSITY RATIO =  6.0100E-01     METHOD = PK


         KFREQ           1./KFREQ        VELOCITY          DAMPING          FREQUENCY           COMPLEX   EIGENVALUE
          0.6274       1.5938626E+00    1.5800000E+05    -1.5050944E-02    7.8885349E+00     -3.7300097E-01     4.9565126E+01
          0.6178       1.6185327E+00    1.6000000E+05    -1.2170379E-02    7.8666287E+00     -3.0077561E-01     4.9427486E+01
          0.6085       1.6434353E+00    1.6200000E+05    -9.1223937E-03    7.8442700E+00     -2.2480772E-01     4.9287002E+01
          0.5993       1.6685762E+00    1.6400000E+05    -5.8897903E-03    7.8214618E+00     -1.4472302E-01     4.9143694E+01
          0.5903       1.6939644E+00    1.6600000E+05    -2.4562441E-03    7.7981923E+00     -6.0174895E-02     4.8997487E+01
          0.5815       1.7196209E+00    1.6800000E+05     1.1859860E-03    7.7743966E+00      2.8966507E-02     4.8847975E+01
          0.5729       1.7455696E+00    1.7000000E+05     5.0448893E-03    7.7500035E+00      1.2282971E-01     4.8694708E+01
1     MSC.NASTRAN AEROELASTIC JOB CREATED ON 23-APR-17 AT 15:18:00                APRIL  23, 2017  MSC Nastran  7/ 3/15    PAGE   348
      _SEARCH_REGION_M_=_0.5.SC1
```

Flutter Mode Shape

0 FLUTTER SUMMARY

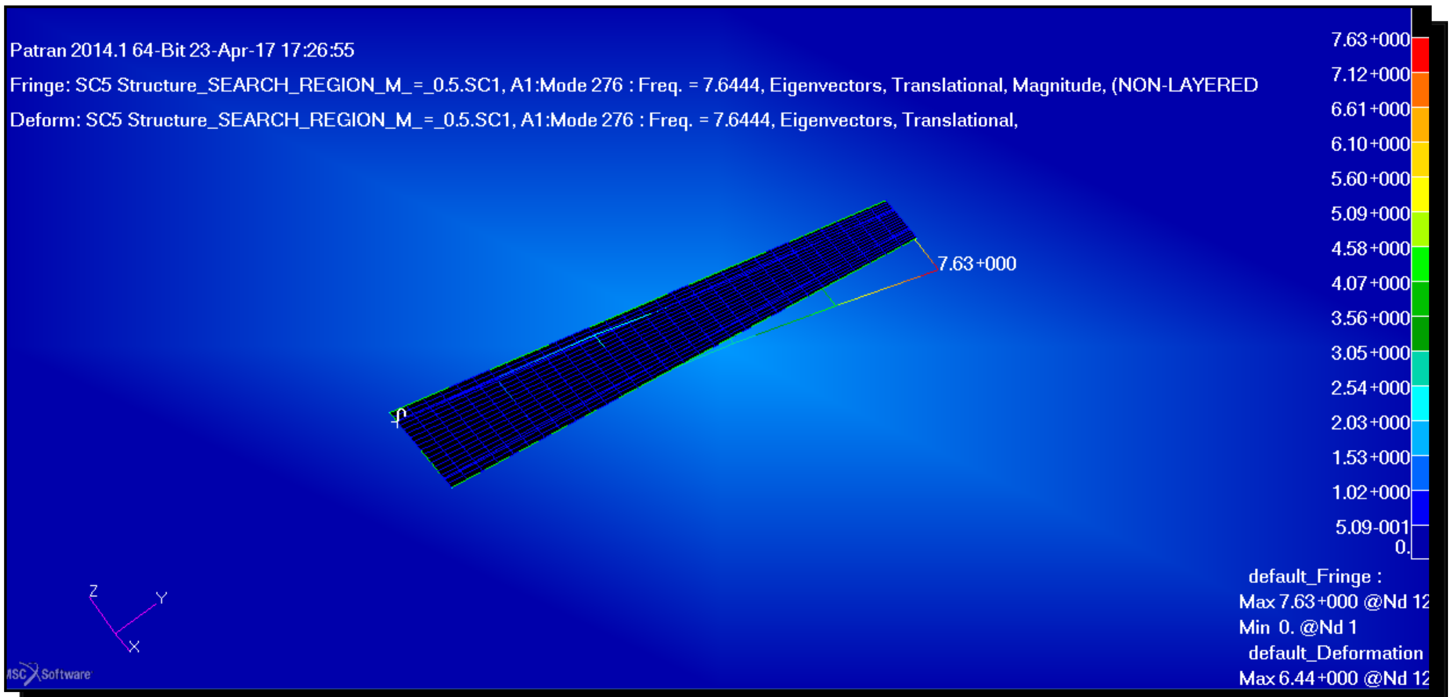
CONFIGURATION = AEROSG2D XY-SYMMETRY = ASYMMETRIC XZ-SYMMETRY = SYMMETRIC

POINT = 52 MACH NUMBER = 0.5000 DENSITY RATIO = 7.3500E-01 METHOD = PK

KFREQ	1./KFREQ	VELOCITY	DAMPING	FREQUENCY	COMPLEX	EIGENVALUE
0.6162	1.6229435E+00	1.5800000E+05	-2.0957627E-02	7.7471832E+00	-5.1007709E-01	4.8676988E+01
0.6065	1.6488471E+00	1.6000000E+05	-1.6185377E-02	7.7219989E+00	-3.9264713E-01	4.8518750E+01
0.5970	1.6749990E+00	1.6200000E+05	-1.0970217E-02	7.6964524E+00	-2.6525017E-01	4.8358236E+01
0.5878	1.7013963E+00	1.6400000E+05	-5.2657724E-03	7.6705850E+00	-1.2689381E-01	4.8195707E+01
0.5787	1.7280464E+00	1.6600000E+05	9.6638755E-04	7.6443897E+00	2.3208337E-02	4.8031117E+01
0.5698	1.7549510E+00	1.6800000E+05	7.7702443E-03	7.6178850E+00	1.8595975E-01	4.7864583E+01
0.5611	1.7821028E+00	1.7000000E+05	1.5197353E-02	7.5911280E+00	3.6243001E-01	4.7696464E+01

1 MSC.NASTRAN AEROELASTIC JOB CREATED ON 23-APR-17 AT 15:18:00 APRIL 23, 2017 MSC Nastran 7/ 3/15 PAGE 320

_SEARCH_REGION_M_=_0.5.SC1



Additional Runs to Get Flutter Boundary

- Matched point at M=0.5 and Density=0.735 identified by fitting the data point on the Flight envelope graph.
- To get flutter boundary more runs will be preformed at Mach numbers 0.46, 0.48, 0.52,0.54
- 4 more subcases need to be created within Patran at these Mach Numbers=0.46,0.48,0.52,0.54

Setup for Mach Number - 0.46, 0.48, 0.52, 0.54

- **Unsteady Aerodynamics**

Mach-0.46

Mach No	Reduced Freq
.46	0.2
.46	0.5
.46	0.6
.46	0.7
.46	1.0

Mach-0.48

Mach No	Reduced Freq
.48	0.2
.48	0.5
.48	0.6
.48	0.7
.48	1.0

Mach-0.52

Mach No	Reduced Freq
.52	0.2
.52	0.5
.52	0.6
.52	0.7
.52	1.0

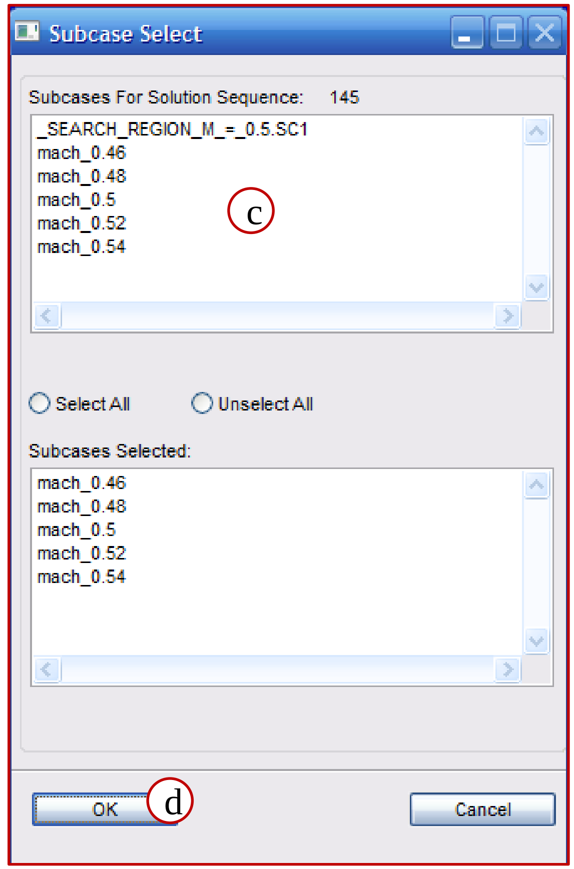
Mach-0.54

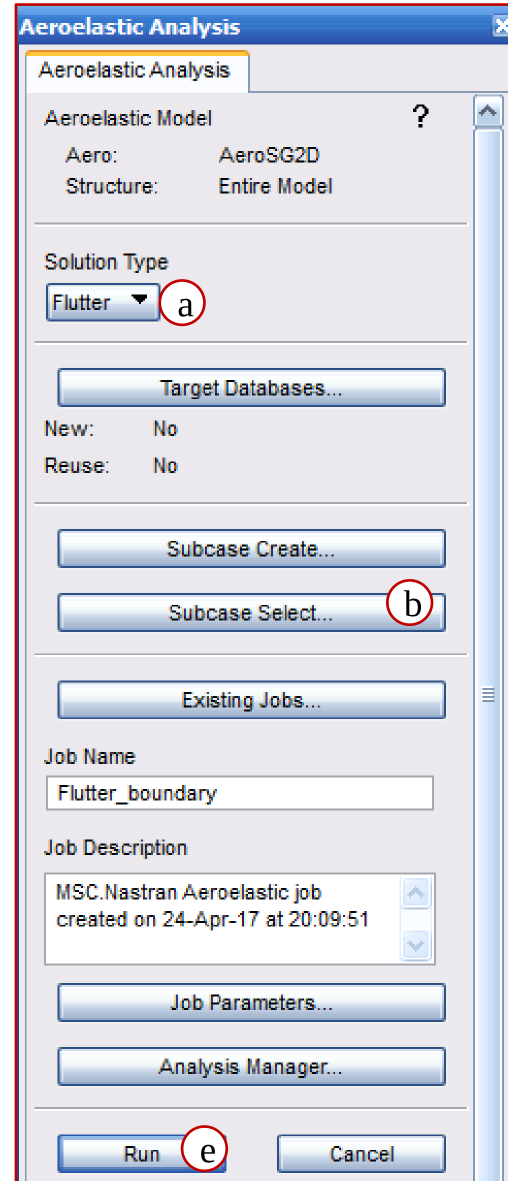
Mach No	Reduced Freq
.54	0.2
.54	0.5
.54	0.6
.54	0.7
.54	1.0

- **The specific MKPAIR needs to selected while setting up the Flutter subcase for the specific Mach number**

Generate Nastran Input File for All Mach Numbers

- **In Job Parameters set the Analysis Type to Analysis Deck to Study the Input file**



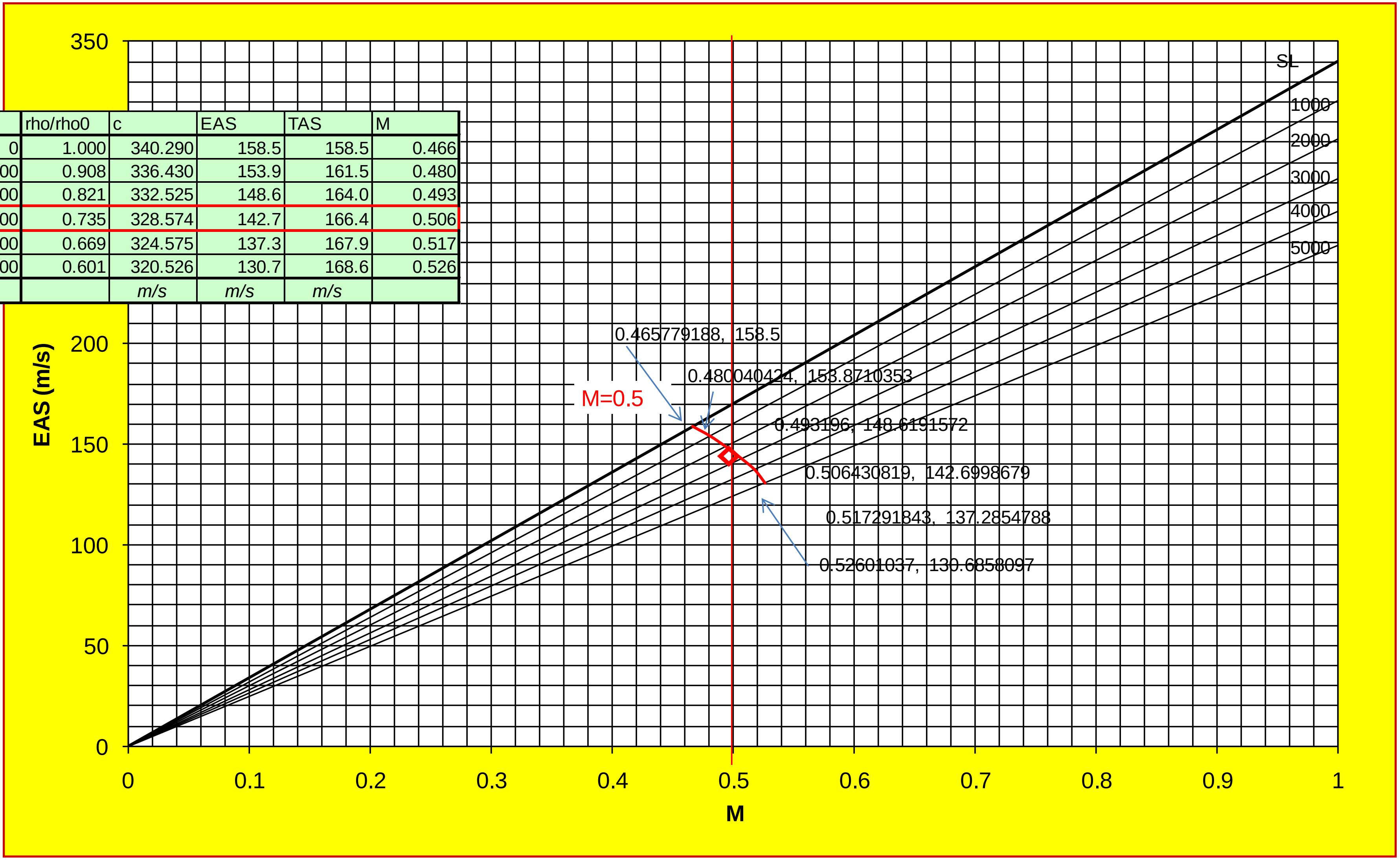


Flutter Boundary

- **The Flutter Summary for each Mach number is observed in f06 file.**
- **The EAS derived from the TAS at the specific air density is plotted on the graph to get the Flutter Boundary.**
- **The flutter analysis is repeated for intermediate Mach numbers to get specific values as shown in graph in next slide.**

Matched Point at M ~ 0.5

Altitude	rho/rho0	c	EAS	TAS	M
0	1.000	340.290	158.5	158.5	0.466
1000	0.908	336.430	153.9	161.5	0.480
2000	0.821	332.525	148.6	164.0	0.493
3000	0.735	328.574	142.7	166.4	0.506
4000	0.669	324.575	137.3	167.9	0.517
5000	0.601	320.526	130.7	168.6	0.526
m		*m/s*	*m/s*	*m/s*	



MSC Software

Flutter Boundary