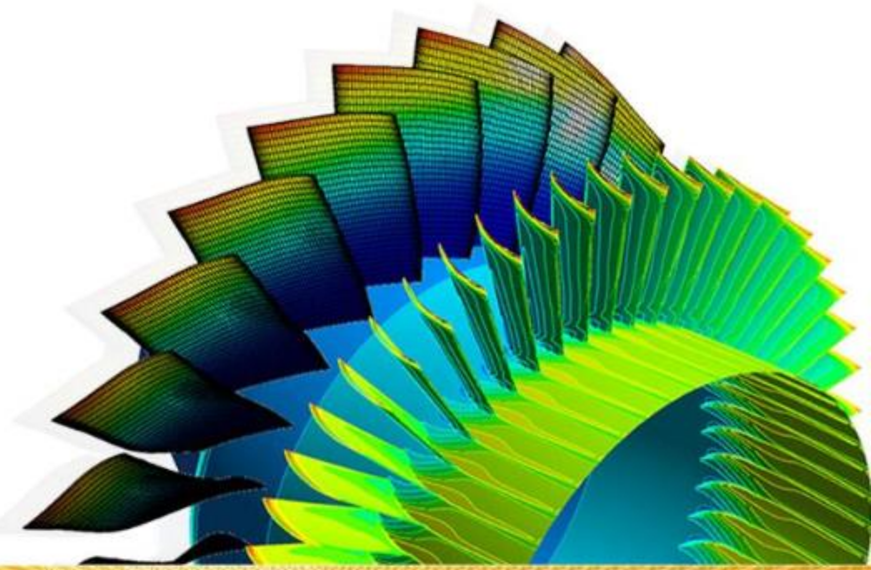
Transient Analysis Time Setting Tips and Tricks



Significance of time step settings in dynamic analyses

- Transient analysis is a technique used to determine the response of a structure under time-dependent loads.
- Time step settings influence simulation accuracy and solution time.
- Solution time for a transient dynamics simulation is not only a function of the model size, but also the time step size. It requires more computer resources due to the time integration.

Topics

- Concept of time step
- Time step settings for a preloaded transient analysis
- Time step size of the implicit solvers
- Time step size of the explicit solvers
- Time step size of thermal analyses and the undershot problem

Formulation: implicit solver vs. explicit solver

Equation of motion $$M\,{}^{t}\ddot{U} + C\,{}^{t}\dot{U} + K\,{}^{t}U = {}^{t}R \qquad (1)$$

Implicit Eq. 1 is solved at time t+Δt to get U(t+Δt)

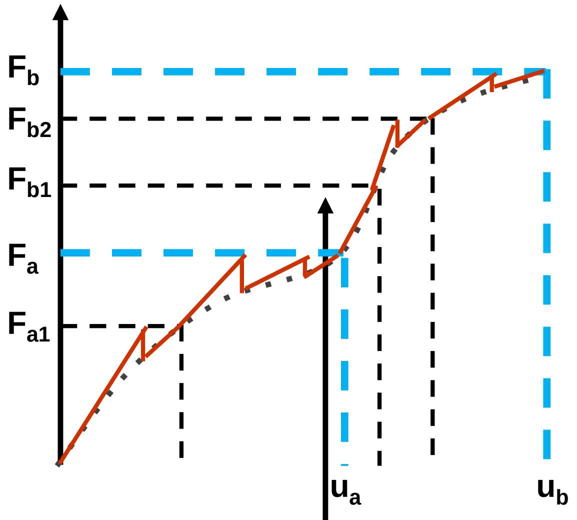
Explicit Eq. 1 is solved at time t to get U(t+Δt)

$$\left(\frac{2M + C\cdot\Delta t}{2\Delta t^2}\right)U^{t+\Delta t} = {}^{t}R - \left(\frac{K\Delta t^2 - 2\cdot M}{\Delta t^2}\right)U^{t} - \left(\frac{2M - C\cdot\Delta t}{\Delta t^2}\right)U^{t-\Delta t} \qquad (2)$$

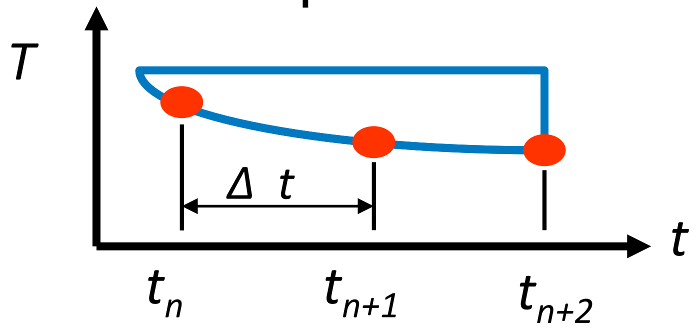
Leapfrog method

Load Step & Substep

- A load step is a configuration of load sets to differentiate changes in general loading.

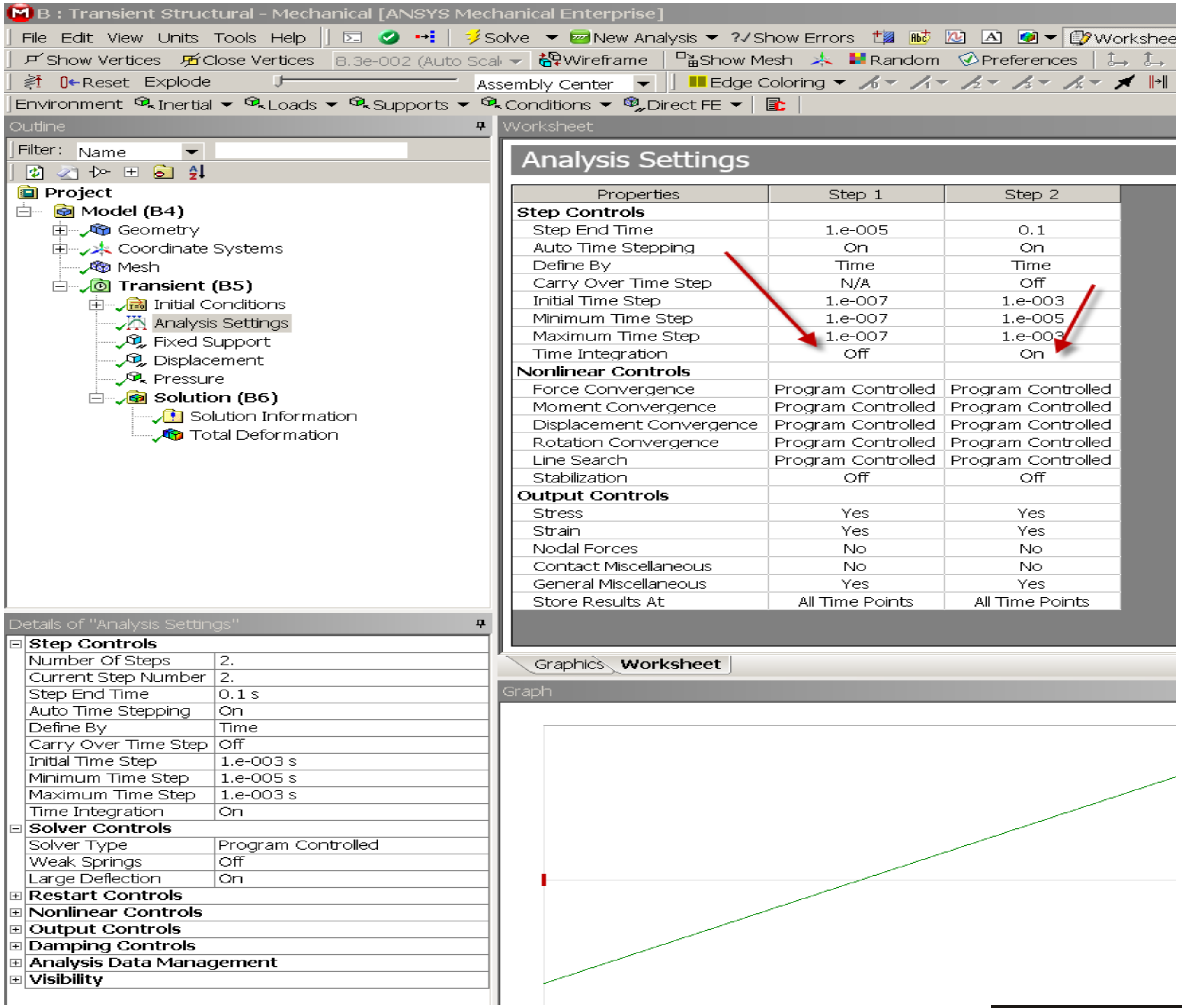


- Substeps are time increments between successive time points within a load step, mainly for accuracy and convergence purposes in transient and nonlinear analyses.



Preloaded Transient Analysis

- Step 1: Time Integration OFF, static analysis
- Step 2: Time Integration ON, transient analysis
- Results of Step 1 are carried into Step 2.



Choosing time step size *Δt*

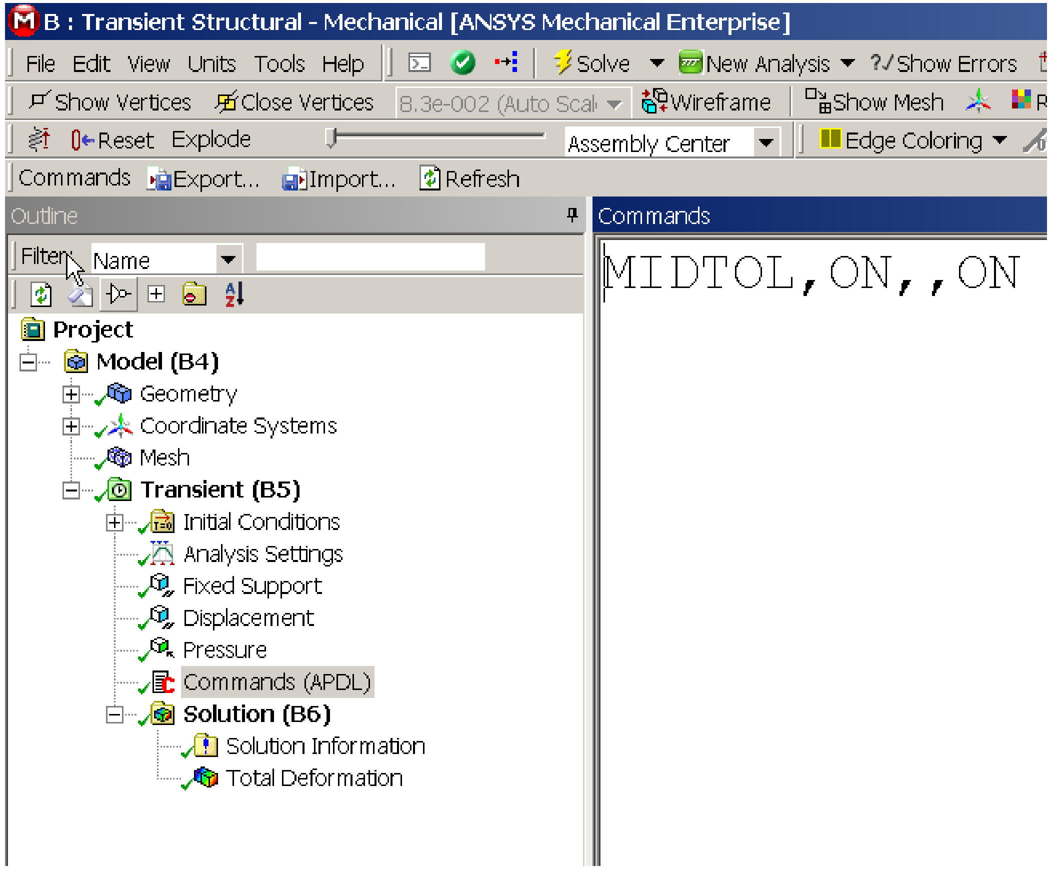
- Do an auxiliary Modal Analysis to determine the significant mode frequency f1 (Tmin=1/f1)

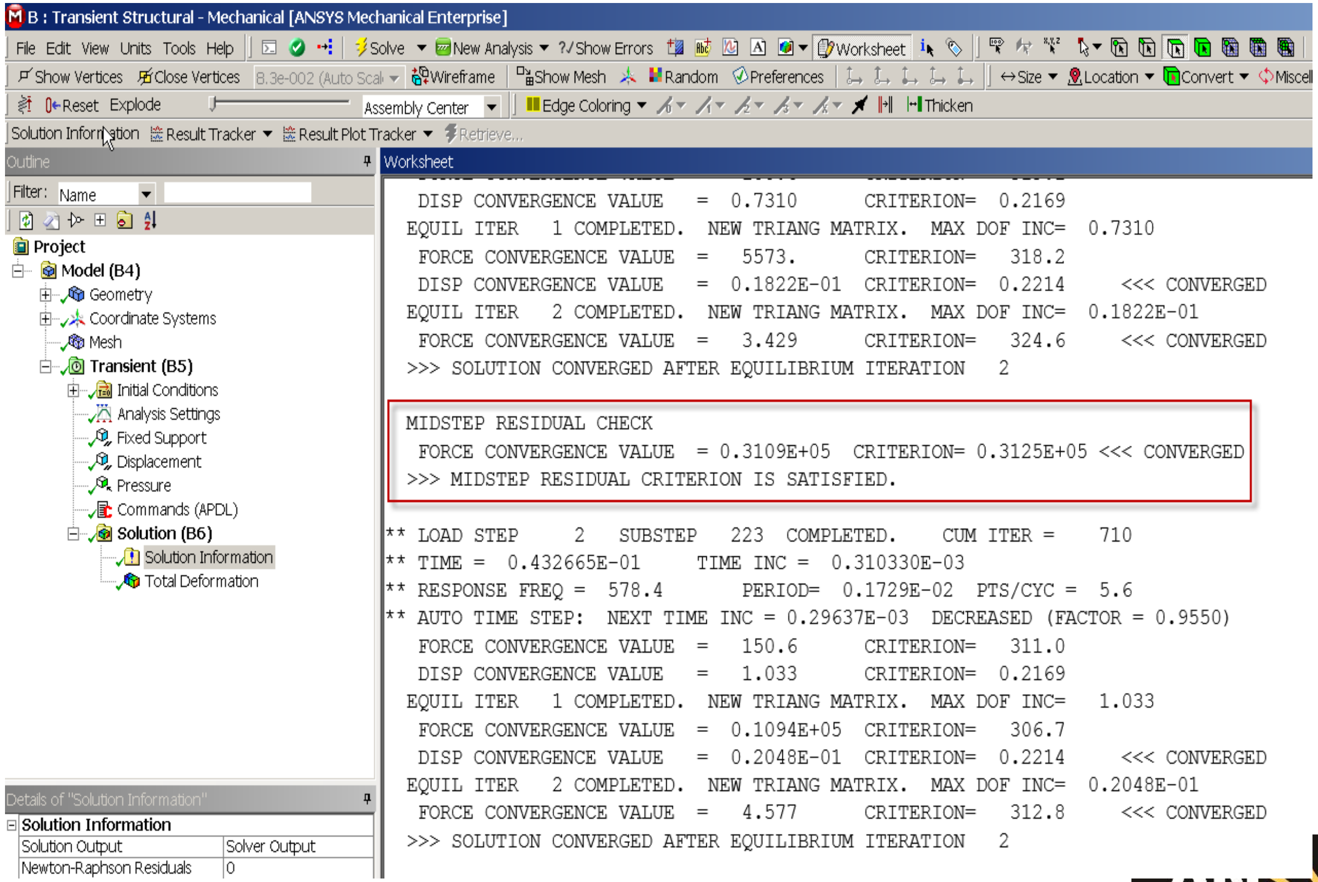
$$\Delta t \leq \frac{T_{\min}}{20}$$

- Correctly describe the time-varying loads
- Smaller Δt if acceleration results are needed.
- For an impact problem, stress waves must propagate through the model.
- Do not assume that ANSYS will make a good choice.

Time step size criterion in a transient structural analysis

- **The midstep residual norm provides a measure of the accuracy of the equilibrium for each time step. To activate the criterion, use command MIDTOL.**





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MSUP Transient Analysis *Δt*

- In Modal Super Position Transient analysis time step size has to be constant through out the analysis, it can't change in between like in FULL transient analysis. That is why auto time stepping is not activated when the transient analysis system is linked with modal analysis system for Modal Super Position Transient analysis. Δt is calculated by ANSYS based on material properties and element sizes in the model.

Search Keywords: Auto time stepping
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Reduced Transient Dynamic Analysis Δt

- The only valid general option is Integration Time Step (DELTIM). The integration time step is assumed to be constant throughout the transient.
- NSUBST command cannot be used.

Search Keywords: reduced transient

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For the explicit methods, *Δt*

- They are conditionally stable, which means that Δt is limited to a maximum value.
- Δt is calculated by ANSYS based on material properties and element sizes in the model.
- Users can leave time settings to the program for most applications.

Step Controls	
Resume From Cycle	0
Maximum Number of Cycles	1e+07
End Time	
Maximum Energy Error	0.1
Reference Energy Cycle	0
Initial Time Step	Program Controlled
Minimum Time Step	Program Controlled
Maximum Time Step	Program Controlled
Time Step Safety Factor	0.9
Automatic Mass Scaling	No

Mass Scalling for an explicit analysis

- **The idea is to manipulate the material density to increase Δt but still satisfy the stability condition.**
- **A larger Δt can reduce the solution time dramatically.**
- **A trade-off is that artificially increasing density can also adversely affect accuracy.**
- **This technique is appropriate for low acceleration scenarios because of the inertia effects.**
- **Addition of mass to just a few small elements in a noncritical region is a good strategy.**

Automatic Mass Scaling in explicit analysis

- **Masses in smaller elements are scaled up to increase the time step size**
- **Input required for this option**

  – **Maximum Element Scaling.**
    - **Limits the ratio of scaled mass / physical mass that can be applied to each element in the model.**

  – **Maximum Part Scaling**
    - **Limits the ratio of scaled mass / physical mass that can be applied to an individual body.**

  – **Update Frequency**
    - **The frequency (in cycles) that mass scaling is performed.**
      – **A value of zero means mass scaling is only done once, at the start of the simulation**

Step Controls	
Resume From Cycle	0
Maximum Number of Cycles	1e+07
End Time	
Maximum Energy Error	0.1
Reference Energy Cycle	0
Initial Time Step	Program Controlled
Minimum Time Step	Program Controlled
Maximum Time Step	Program Controlled
Time Step Safety Factor	0.9
Automatic Mass Scaling	Yes
Minimum CFL Time Step	1.e-020 s
Maximum Element Scaling	100.
Maximum Part Scaling	5.e-002
Update Frequency	0

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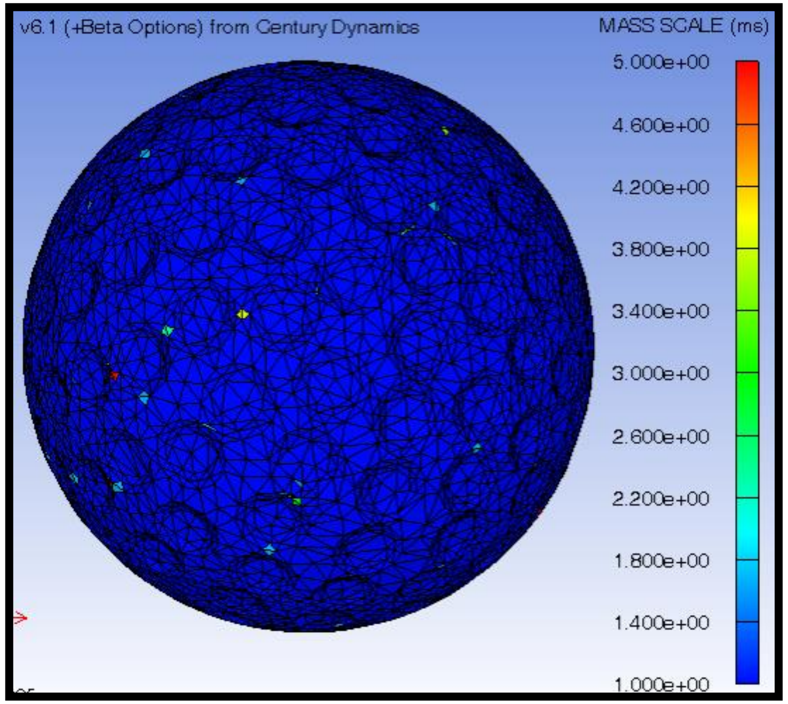
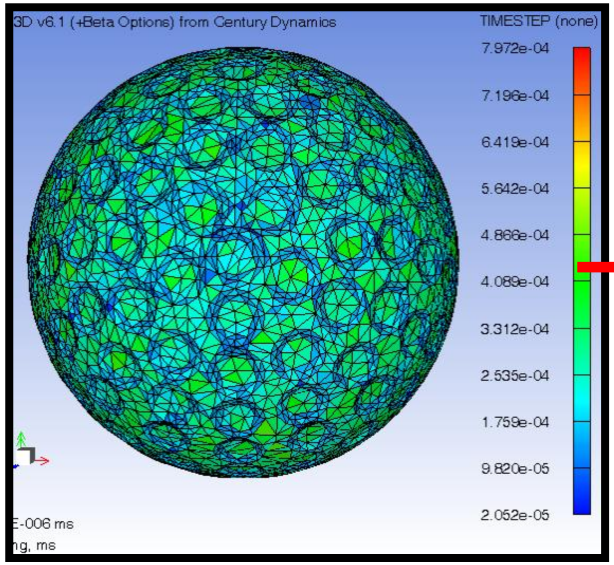
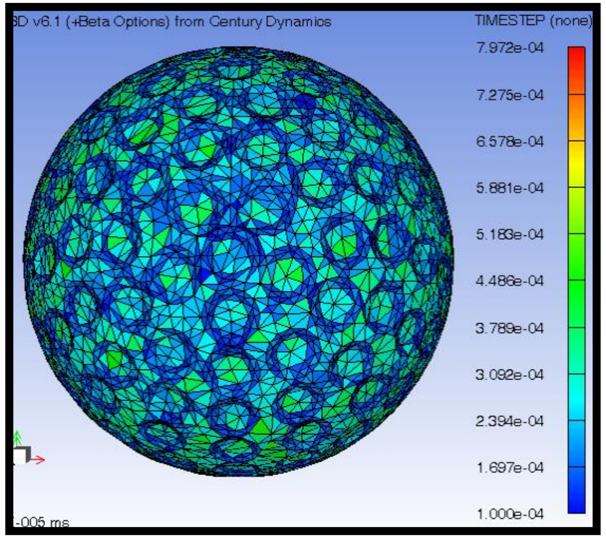
Mass Scaling example





Standard Timestep 2.0e-5



Mass scale timestep 1.0e-4

5x Increase in DT

0.02% Increase in mass

MASS_SCALE under Solution for a contour plot of the mass scaling

MASS SCALING SUMMARY BY PART

PART	MASS	ADDED MASS	TOTAL MASS	%ADDED
1-VOLUME	2.307E+04	4.945E+00	2.307E+04	2.144E-02
2-VOLUME	2.035E+05	0.000E+00	2.035E+05	0.000E+00

Mass scaling summary is in the Print file (.prt)

Choosing Δt in a transient thermal analysis

- **If Δt is too small, solution oscillations may occur which could result in temperatures which are not physically meaningful (e.g. thermal undershoot).**
- **If Δt is too large, temperature gradients will not be adequately captured.**

Choosing Δt in a transient thermal analysis

- Approximating a reasonable Δt use the Biot and Fourier numbers.
- The ***Biot Number*** is the dimensionless *ratio* of convective and conductive thermal resistances, where Δx is the mean element width, h is the average film coefficient, and K is an averaged conductivity.

$$Bi = \frac{h\Delta x}{K}$$

- The ***Fourier Number*** is a *dimensionless time* ($\Delta t/t$) which quantifies the relative rates of heat conduction vs. heat storage for an element of width Δx : Where ρ and c are *averaged* density and specific heat, respectively.

$$Fo = \frac{4K\,\Delta t}{\rho C(\Delta x)^2}$$

If $B_i < 1$, then we use the F_0 to calculate Δt. Otherwise, we use B_i F_0 to calculate Δt.

Choosing *Δt* in a transient thermal analysis

- When Δt is 100 times the ITS suggestion based on the Fourier Modulus, ANSYS issues a warning.

```
********** Initial Time Increment Check And Fourier Modulus **********
 Specified Initial Time Increment: 20
 Estimated Increment Needed, le*le/alpha, Body 1: 0.0140781
************************************************************
********************* SOLVE FOR LS 1 ******************
```

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Choosing *Δt* in a transient thermal analysis

The Response Eigenvalue represents the dominant system eigenvalue for the most recent time step solution (reported in Solution information). It can be viewed as a Fourier Number for the discretized system.

The Oscillation Limit is a dimensionless quantity that is simply the product of the Response Eigenvalue and the current time step size (reported in Solution information).

$$f = \Delta t_n \lambda_r \qquad\qquad \lambda_r = \frac{\{\Delta T\}^T [K] \{\Delta T\}}{\{\Delta T\}^T [C] \{\Delta T\}}$$

It is typically desirable to maintain the oscillation limit below 0.5 to ensure that the transient response of the system is being adequately characterized.

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Choosing Δt in a transient thermal analysis

By default, the Automatic Time Stepping (ATS) feature bases time step prediction on the Oscillation Limit. ATS seeks to maintain the Oscillation Limit below 0.5 within a tolerance, and will adjust the ITS to satisfy this criterion.

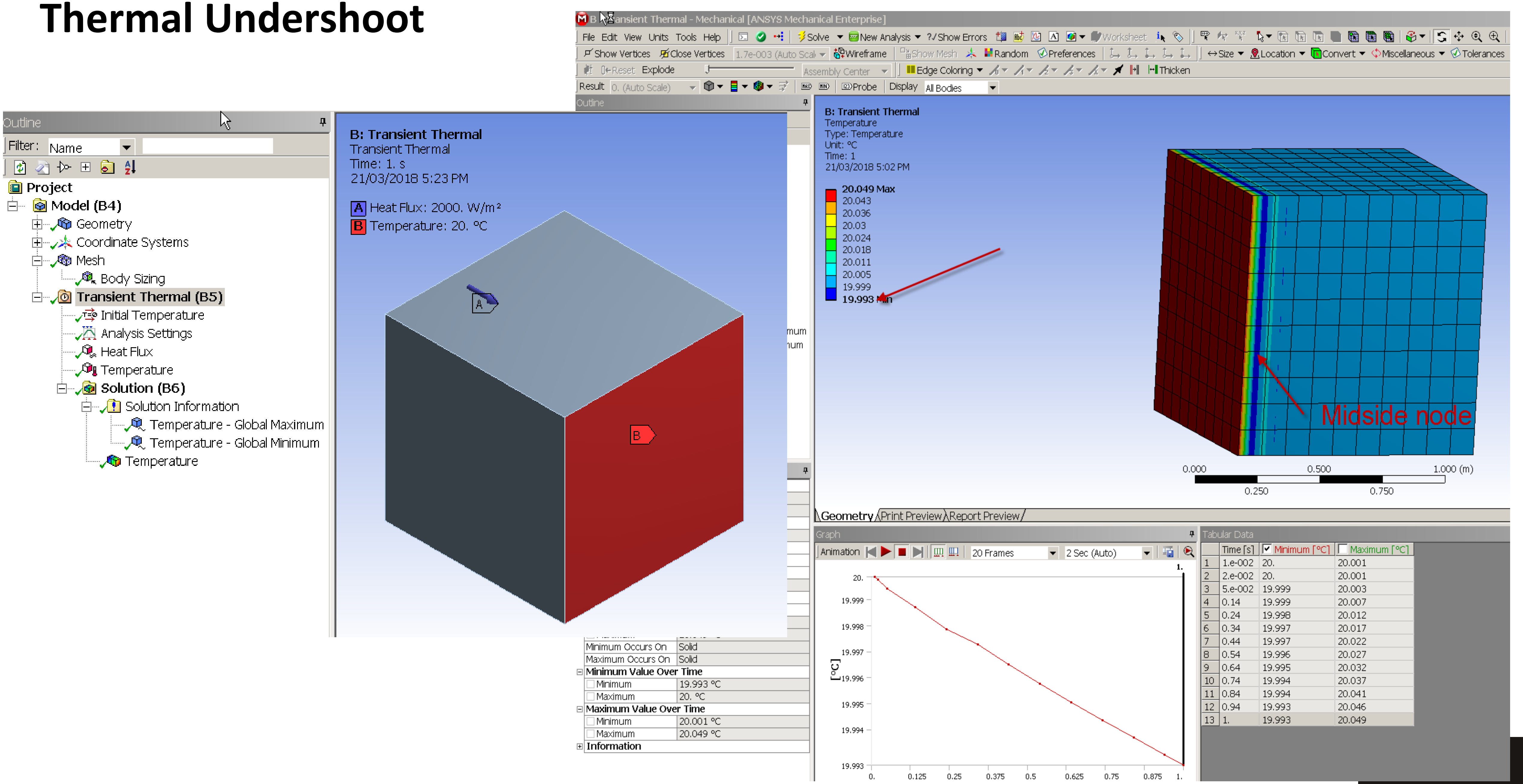
```
    HT FLOW CONVERGENCE VALUE=  4.764      CRITERION= 0.1641E-02
                               W TRIANG MATRIX.  MAX DOF INC=   1.675
                               .2895E-02  CRITERION= 0.2023E-02
                               W TRIANG MATRIX.  MAX DOF INC= -0.2429E-04
                               .3077E-08  CRITERION= 0.2023E-02 <<< CONVERGED
                               EQUILIBRIUM ITERATION   2
                                2  COMPLETED.    CUM ITER =      4
                               E INC =  0.351667
*** RESPONSE EIGENVALUE =  12.09       OSCILLATION LIMIT =  4.251
*** AUTO TIME STEP:  NEXT TIME INC = 0.11722      DECREASED (FACTOR = 0.3333)

    HT FLOW CONVERGENCE VALUE=  4.636      CRITERION= 0.2115E-02
   EQUIL ITER   1 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.5583
    HT FLOW CONVERGENCE VALUE= 0.1148E-02  CRITERION= 0.2192E-02 <<< CONVERGED
   >>> SOLUTION CONVERGED AFTER EQUILIBRIUM ITERATION   1
*** LOAD STEP     1   SUBSTEP     3  COMPLETED.    CUM ITER =      5
*** TIME =   1.52389         TIME INC =  0.117222
*** RESPONSE EIGENVALUE =  10.56       OSCILLATION LIMIT =  1.238
*** AUTO STEP TIME:  NEXT TIME INC = 0.11722      UNCHANGED

    HT FLOW CONVERGENCE VALUE=  4.938      CRITERION= 0.2288E-02
   EQUIL ITER   1 COMPLETED.  NEW TRIANG MATRIX.  MAX DOF INC=  0.5583
    HT FLOW CONVERGENCE VALUE= 0.1240E-02  CRITERION= 0.2361E-02 <<< CONVERGED
   >>> SOLUTION CONVERGED AFTER EQUILIBRIUM ITERATION   1
*** LOAD STEP     1   SUBSTEP     4  COMPLETED.    CUM ITER =      6
*** TIME =   1.64111         TIME INC =  0.117222
*** RESPONSE EIGENVALUE =  9.352       OSCILLATION LIMIT =  1.096
*** AUTO TIME STEP:  NEXT TIME INC = 0.10550      DECREASED (FACTOR = 0.9000)
```

Notice how ATS gradually reduces the ITS based on the Oscillation Limit.

Thermal Undershoot

- Smaller Δt may generate bad results in a transient thermal analysis.
- When $\Delta t < \frac{L^2}{4\alpha}$,unwanted oscillations may occur for the elements with midsize nodes so that temperatures could be outside of the physical ranges. L is element length and $\alpha = \frac{k}{\rho c}$ is the thermal diffusivity.
- Reducing mesh size will lead to smaller Minimum recommended time step.
- Therefore, users should consider rate of convergence, minimum time step as well as the oscillation limit output.

Thermal Undershoot



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