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Modeling Articulation

Use *Articulation* to model the articulation of selected elements in the model. This feature provides simulation of the transient radiative heat exchange induced by the motion of mechanized assemblies such as solar arrays, tracking antennas, or robotic systems. Time-varying radiative conductances and heat loads (including orbital heating) are computed based on the articulation sequence. Thermal Couplings are recalculated based on displacement at each time step. You can visualize and animate the motion when you post-process the solution results.

With models that include an *Orbit/Attitude Modeling* entity, you can view articulation using the Orbit Visualizer. The animated FE model in orbit accurately displays all the rotations and translations of its articulated parts, including compound articulations and articulations that track an orbit parameter.

For models that include an *Orbit/Attitude Modeling* entity, the start time, end time and calculation interval for the articulation simulation are taken from the orbit definition. Otherwise, you must specify these explicitly on the Articulation Parameters form.

In articulation, the motion of part of the model has an effect on view factor calculations. Translational and revolute joints are supported; compound joints may be defined. During the transient analysis, the view factors are recalculated at discrete time intervals specified by the user. If the articulation is used with *Orbit/Attitude Modeling*, the calculation points specified on the orbit definition form are used. To minimize calculation time, the program identifies which view factors must be recalculated due to movement.

Locate the icon.

Defining Articulation

Articulation models rigid-body motion of selected elements with respect to the rest of the model.

Set up this motion by characterizing the mechanics of the joint at the interface. Rotation of the moving elements is modeled by selecting the *Revolute* joint type; linear displacement is modeled by specifying a *Translational* joint.

For a *Revolute* joint, first define an axis vector about which the object will rotate. (The axis vector and the right hand rule determine the direction of rotation.) Then define rotation as a *Constant* rate (degrees/second) or as a table of angular displacement versus time (*Time varying*). If you enter a negative value for the rotation rate or angular displacement, the direction of rotation will be reversed.

For a *Translational* joint, the translation along a direction can be specified as a *Constant* speed (such as m / s) or as a table of linear displacement versus time (*Time varying*).

Orbit Dependent Articulation

Revolute articulation can be linked to defined orbits. (Translational articulation cannot.) This is accomplished simply by selecting a vector on the part and selecting the desired orbit dependent direction:

- Nadir
- Sun

- Star
- Velocity Vector
- Orbit Normal
- North
- South

If, because of a conflict with a vector defined on the Spacecraft Attitude form, it is not geometrically possible to perform the orbit dependent articulation specified, TMG will articulate the member so as to minimize the descrepancy.

Modeling Compound Articulation

You can model articulated assemblies with multiple (compound) joints. For each ancillary joint, simply select the affected elements, then select the *Articulation* entity which defines the *Parent* joint. Compound articulation can be revolute or translational or both.

For example, to model a robotic manipulator arm functionally resembling a human arm, including three rotational joints, a shoulder, an elbow and a wrist, you would create three Articulation entities as follows:

1. Select the upper arm segment, then define the rotation about the shoulder joint. Call this the "Shoulder" articulation.
2. Select the forearm segment, then define the rotation about the elbow joint. Select the "Shoulder" articulation entity as the Parent. Call this the "Elbow" articulation.
3. Select the hand segment, then define the rotation about the wrist joint. Select the "Elbow" articulation entity as the Parent. Call this the "Wrist" articulation.

Parent Articulation entities can also contain no elements, if they are not needed for the radiation model. For example to model a unit that rotates about a pin which is traveling along a track, you would probably not be interested in the pin itself. In this case, first create an Articulation entity containing no elements, that defines the translation direction and speed. Then create a second Articulation entity for the rotating unit, selecting the first entity as the parent joint.

Setting up a Radiation Model with Articulation

To model articulation of elements in a thermal radiation model, you must carry out the following.

1. Create a *Radiation Request* (Choose the *Enclosure* or *All Radiation* type).

Locate the icon.

2. Create the Articulation entities necessary to model the motion.
3. If you do not have an *Orbit/Attitude Modeling* entity defined in your model, you must specify the start time, end time, and calculation interval for the articulation sequence on the *Articulation Parameters* form.

Locate the icon.

Articulation and Thermal Couplings

Thermal Couplings which vary due to the motion of articulated elements are calculated at each time step.

Post-Processing a Model with Articulation

You can visualize the motion of articulated elements when you post-process the model. When you solve a model that includes articulation, *Deformation Results* containing nodal displacements are automatically recovered at the output time points. By selecting these *Deformation Results* and activating the *Deformed Model* option on the Display Template form, you can post-process the results of an articulated thermal model on the actual displaced geometry. You can also create an animation of the articulation motion (see *Post Processing a Transient Analysis*).

Previewing the Articulation

You can have a quick look at the articulation in motion without doing a complete analysis by following these steps:

1. Set the End Time on the *Articulation Parameters* form. If you are doing an *Orbit/Attitude Modeling* analysis, enter the orbit period.
2. Set the Calculation Interval at about 1% of the End Time, close the form with *OK*. (If TMG issues a message, ignore it).
3. Under Solver Control, select a Transient Solution and open the Transient Parameters form.
4. On the Transient Parameters form, set the End Time to be equal to the one you specified on the Articulation Parameters form. Close all forms with *OK*
5. On the TMG Study Setup form, select a new Run Directory and open the Initial Condition & Restart form.
6. On the Restart form, select the option *Specify Restart* as the analysis type. Do not toggle any of the Reuse or Calculate options.
7. Solve the model.
8. After the analysis, go to the Post Processing task and import the file called tmgdisp.unv from the Run Directory (do not use *Get Results)*. This file contains the node displacements. Post Process the displacements as explained previously.

The articulation displacements are the only results obtained through this analysis. Temperature results files are created but you do not use them since view factors and heat loads have not been calculated.

See Also

- Post Processing Transient Analysis

Understanding Articulation

To simulate articulation in a radiative thermal model, the black body view factors are recomputed at discrete time intervals and used to establish time-varying radiative conductances. The software incorporates an intelligent time-marching scheme to minimize the recomputation of view factors during the articulation sequence, using the view factors themselves to isolate regions of the model unaffected by the articulating components. The time interval at which view factors are computed is specified on the Articulation Parameters form; however, if an *Orbit/Attitude Modeling* entity is defined, the view factors are computed at the orbital calculation points only.

The calculation procedure for articulating models is based on an extension of Oppenheim's method for computation of the environmental heat loads, where the radiative exchange is formulated as a radiosity network and solved using an iterative sparse matrix solver. This approach achieves substantial gains in numerical efficiency by avoiding the repeated reconstruction of the gray body view matrices and by limiting the number of time-varying radiative conductances in the model.

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