Problem description
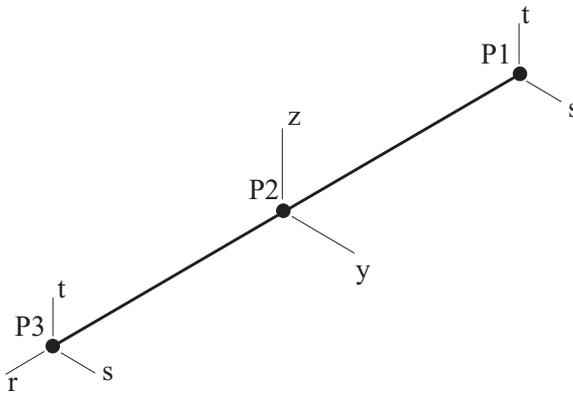
Consider an initially straight beam as shown:

All lengths in mm   E=207000 MPa   Cross-section
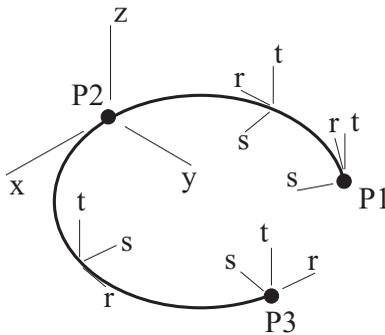(not drawn to scale)

We would like to bring the free ends of the beam together to form a ring, as shown:
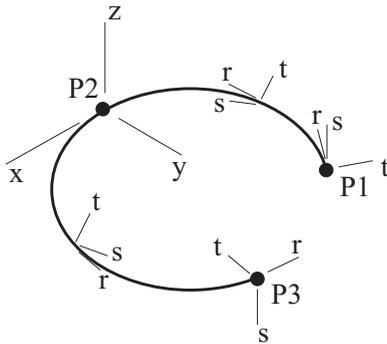
Initial configuration:

Ring: (ends separated for clarity)

Then we would like to twist the free ends of the beam to form a Möbius strip, as shown:

Möbius strip: (ends separated for clarity)

Both of these tasks can be done using an alignment element.

In this problem solution, we will demonstrate the following topics that have not been presented in previous problems:

- Using alignment elements
- Selecting the nonsymmetric sparse solver

Before you begin

Please refer to the Icon Locator Tables chapter of the Primer for the locations of all of the AUI icons. Please refer to the Hints chapter of the Primer for useful hints.

This problem can be solved with the 900 nodes version of the ADINA System.

Much of the input for this problem is stored in the following file: prob58_1.in. You need to copy this file from the folder samples\primer into a working directory or folder before beginning this analysis.

If you are unfamiliar with the alignment element, we recommend that you read Section 2.12 of the ADINA Theory and Modeling Guide. In particular, you should familiarize yourself with the concept of the alignment element triads.

Invoking the AUI and choosing the finite element program

Invoke the AUI and choose ADINA Structures from the Program Module drop-down list.

Forming the ring

Model definition

We have prepared a batch file (prob58_1.in) that defines the following items:

Problem heading

Control data, including solution tolerances.

Geometry points and lines

Cross-section

Boundary conditions. One point has both translations and rotations fixed, in order to remove rigid-body motions.

Element group 1, which is a large displacement Hermitian beam element group. The element group contains 20 equally spaced beam elements.

Choose File→Open Batch, navigate to the working directory or folder, select the file prob58_1.in and click Open. The graphics window should look something like this:
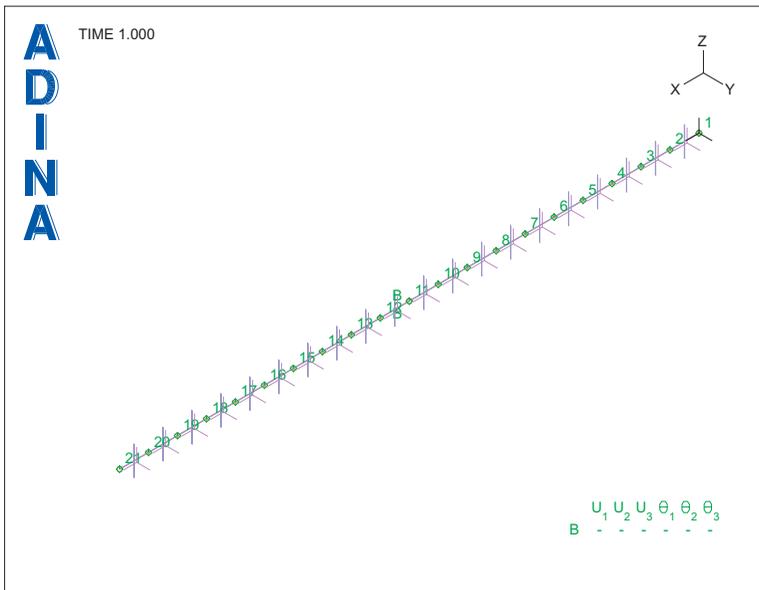
Alignment element definition

Now we will define the alignment element. The alignment element will connect the end-nodes of the beam model (nodes 1 and 21), as shown:
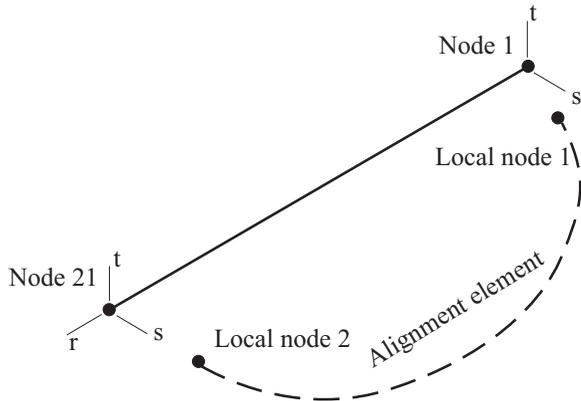
Click the Define Element Groups icon ⊕, add group 2 and set the Type to Alignment. Set the Save field to Verbose and click OK.

Choose Meshing→Elements→Element Nodes, and, in the first row of the table, set the Alignment Element # to 1, Node 1 to 1, Node 2 to 21 and click OK.

Plotting the alignment element triads:

Click the Modify Mesh Plot icon 🗒, click the Node Depiction... button, check the A triads field and click OK twice to close both dialog boxes. Then, in the Model Tree, expand the Zone field, right-click on 3. EG2 and choose Display. The graphics window should look something like the top figure on the next page.

The display shows the alignment element, along with the A triads of the nodes. We see that the A triads coincide with the beam element axes (that is, the A1 direction coincides with the r direction, the A2 direction coincides with the s direction, the A3 direction coincides with the t direction).

Now click the Modify Mesh Plot icon 🗒, click the Node Depiction... button, uncheck the A triads field, check the B triads field and click OK twice to close both dialog boxes. The graphics window should look something like the bottom figure on the next page.
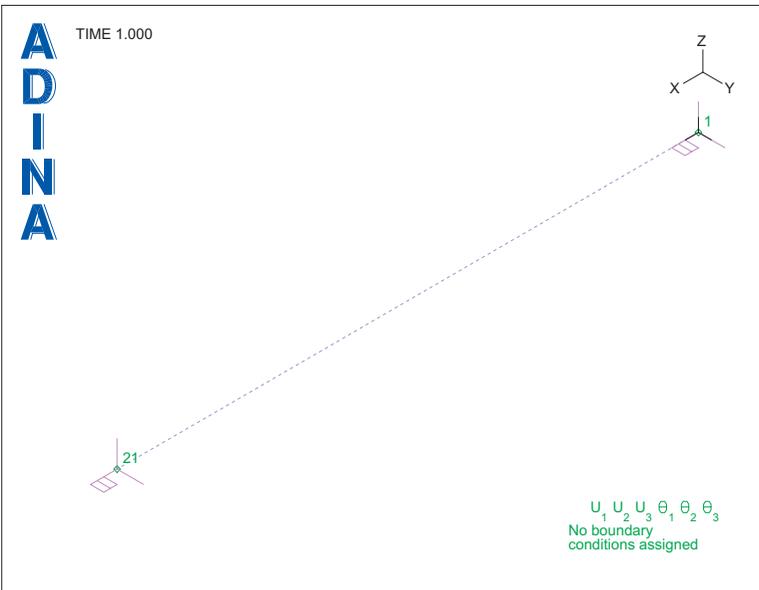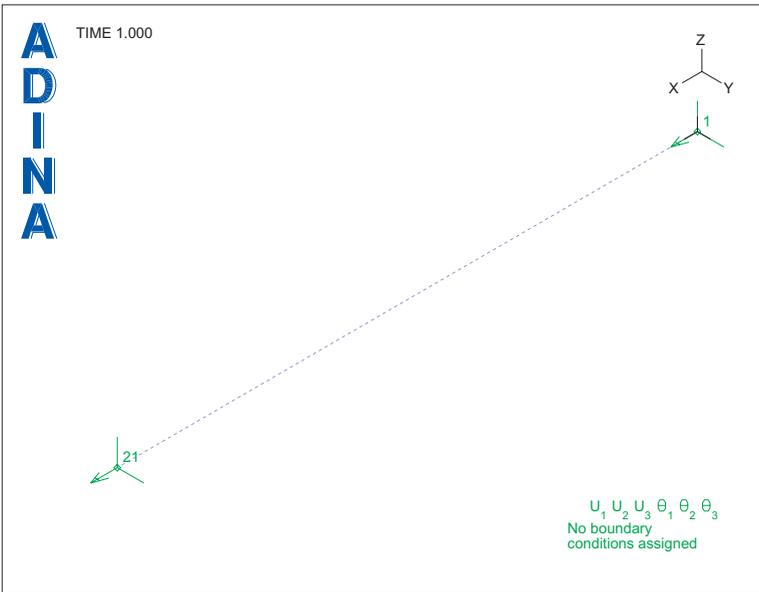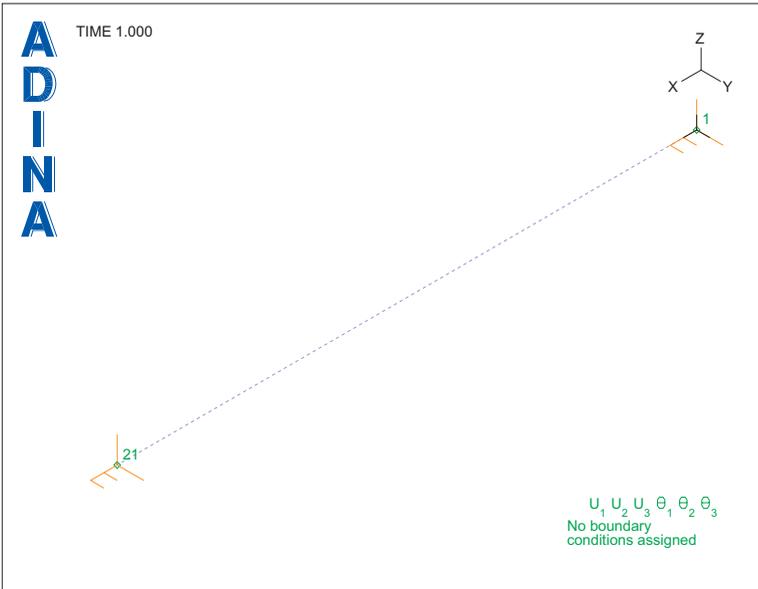
Now the B triads of the nodes are displayed. The B triads coincide with the A triads by default.

Now click the Modify Mesh Plot icon [icon], click the Node Depiction... button, uncheck the B triads field, check the C triads field and click OK twice to close both dialog boxes. The graphics window should look something like this:


Now the C triads of the nodes are displayed. The C triads coincide with the B triads by default.

We thus have, at each alignment element local node, the following triad definitions:
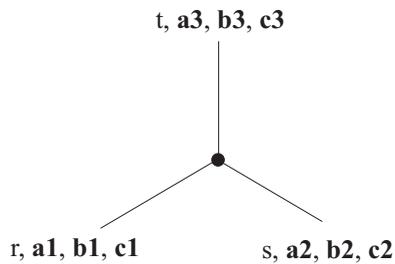
Align-translation and align-rotation definitions

Now we can specify the relative translations and rotations of the alignment element nodes. When the ring is formed, the alignment element nodes and triads will appear as in the following figure (triads separated for clarity):
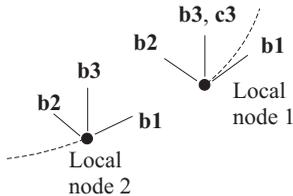
We see that the triad origins should coincide, and that the triad B axes directions should also coincide. Of course, the triad B axes directions initially coincide, but we note that if we rotate the triad B axes of local node 2 by 360 degrees about the c3 axis of local node 1, the triad B axes directions will again coincide, and that the process of rotating the triad B axes will bend the beam into a ring.

Thus, we specify the relative rotations of the alignment element nodes using an align-rotation definition. Choose Model→Alignment Properties→Rotation Alignment, add Rotation Alignment 1, set the Angular Unit to Degrees, enter the following information in the table and click OK:

Time	Option	Angle	Axis c3
1	Angle	90	1
2	Angle	180	1
3	Angle	270	1
4	Angle	360	1

Thus, for example, at time 1, we specify that the relative rotation of the triads is 90 degrees about the c3 axis of local node 1.

Now, after this rotation, the triad directions are forced to coincide, but the triad origins are still free to translate relative to each other. So we need to enforce the condition that the triad origins coincide. This is done using an align-translation definition.

Choose Model→Alignment Properties→Translation Alignment, add Translation Alignment 1, enter the following information in the table and click OK:

Time	Option
5	Factor
6	Aligned

Before time 5, the translation alignment is not active. At time 5, the translation alignment is activated with Option=Factor. Since the default Factor is 1.0, this means that the prescribed alignment for time 5 is equal to the current alignment, whatever that alignment might be. At time 6, the prescribed translation alignment causes the two triad origins to coincide.

Element group definition: Click the Define Element Groups icon , make sure that the Group Number is 2, set the Translation Alignment to 1, the Rotation Alignment to 1 and click OK.

Time stepping: Choose Control→Time Step, set the Number of Steps to 6 and click OK.

Generating the ADINA data file, running ADINA, loading the porthole file

Click the Save icon and save the database to file prob58. Click the Data File/Solution

icon , set the file name to prob58, make sure that the Run Solution button is checked and click Save.

You can ignore the "Model may be unstable" messages that appear in the Message Window.

When ADINA is finished, close all open dialog boxes. Choose Post-Processing from the

Program Module drop-down list (you can discard all changes), click the Open icon and open porthole file prob58.

Postprocessing

Click the Iso View 1 icon , then click the Modify Mesh Plot icon , click the Element Depiction... button, check the Display Beam Cross Section field and click OK twice to close both dialog boxes. The graphics window should look something like the top figure on the next page.

Now click the First Solution icon , use the Pick icon and the mouse to resize the

mesh plot into the graphics window, click the Modify Mesh Plot icon , click the Node Depiction... button, check the B triads field and and click OK twice to close both dialog boxes. The graphics window should look something like the bottom figure on the next page.
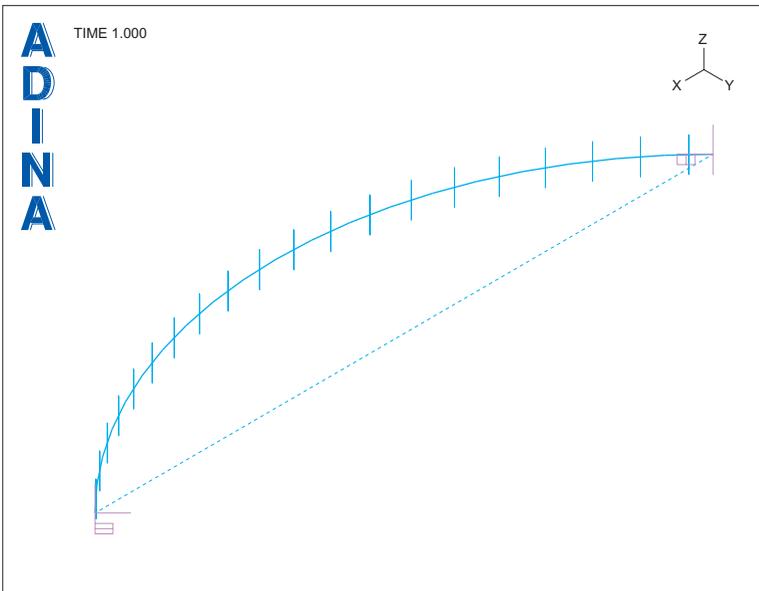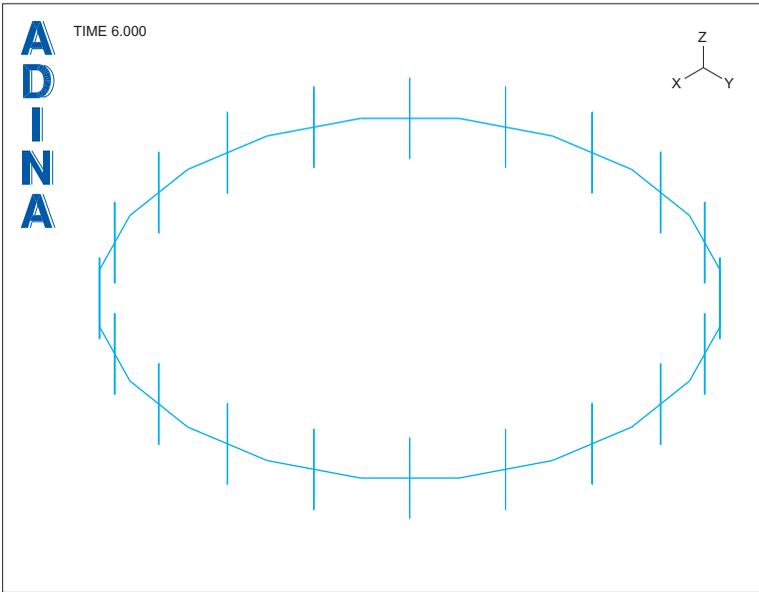
We see that at time step 1, the relative rotation of the B triads is 90 degrees.

When you examine the other solutions, you will notice that the solutions for times 4 to 6 are nearly identical.

Listing the alignments: Let's list the alignments, to verify that the prescribed alignments are in fact applied to the model. Choose List→Value List→Zone, set Variable 1 to (Alignment: ALIGN_ROT_ACTUAL_MAGNITUDE), Variable 2 to (Alignment: ALIGN_TRANS_ACTUAL-C1) and click Apply. We see that up to time 4, the actual rotation magnitude is the prescribed value, and that at time 4, the rotation magnitude is very small (corresponding to the directions of the triad axes coinciding). At time 5, the translational alignment is about -1.7E-8 (mm), and at time 6, the translational alignment is zero (corresponding to the triad origins coinciding). Click Close to close the dialog box.

Forming the Möbius strip

Now we will form the Möbius strip. Set the Program Module to ADINA Structures (you can discard all changes) and choose database file prob58.idb from the recent file list near the bottom of the File menu.

The additional step required in forming the Mobius strip is to twist the two ends of the strip 180 degrees. In terms of the alignment element triads, this appears as follows:
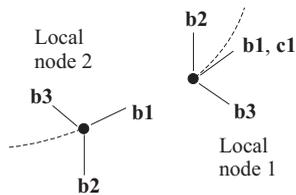
Evidently we need to specify a relative incremental rotation of 180 degrees about the c1 axis of local node 1.

Choose Model→Alignment Properties→Rotation Alignment, edit the table to read as follows and click OK:

Time	Option	Angle	Axis c1	Axis c3
1	Angle	90		1
2	Angle	180		1
3	Angle	270		1
4	Angle	360		1
6	Same as Previous			
24	Incremental Angle	180	1	

We see that the rotation about axis c1 occurs between times 7 and 24, so that the incremental rotation is 10 degrees per time step.

The time 6 row is necessary for the following reason. Suppose that the time 6 row is not entered. Then, for solution times between 4 and 24, the program interpolates data from the time 4 and 24 rows of this table, hence an incremental rotation is already prescribed at solution time 6. With the time 6 row entered, for solution times between 4 and 6, the program interpolates data from the time 4 and 6 rows, and for solution times between 6 and 24, the program interpolates data from the time 6 and 24 rows.

Time stepping: Choose Control→Time Step, set the Number of Steps to 24 in the first row and click OK.

Generating the ADINA data file, running ADINA

Click the Save icon , click the Data File/Solution icon , set the file name to prob58, make sure that the Run Solution button is checked and click Save.

The model does not converge for step 8 (the second step in which the incremental rotation is applied). Close all open dialog boxes.

Specifying the equation solver

We note that the incremental rotation causes torsion in the beam elements, thus the beam elements are under combined bending and torsion. For large displacement beam elements under combined bending and torsion, the nonsymmetric equation solver is frequently effective.

Choose Control→Solution Process, set the Equation Solver to Nonsym. Sparse and click OK.

Generating the ADINA data file, running ADINA, loading the porthole file

Click the Save icon , click the Data File/Solution icon , set the file name to prob58, make sure that the Run Solution button is checked and click Save.

This time the model runs for all 24 steps. When ADINA is finished, close all open dialog boxes. Choose Post-Processing from the Program Module drop-down list (you can discard all changes), click the Open icon and open porthole file prob58.

Postprocessing

Click the Modify Mesh Plot icon [icon], click the Element Depiction... button, check the Display Beam Cross Section field, click the Advanced tab, set the # Segments for Neutral Axis to 4 and click OK twice to close both dialog boxes. The graphics window should look something like this:
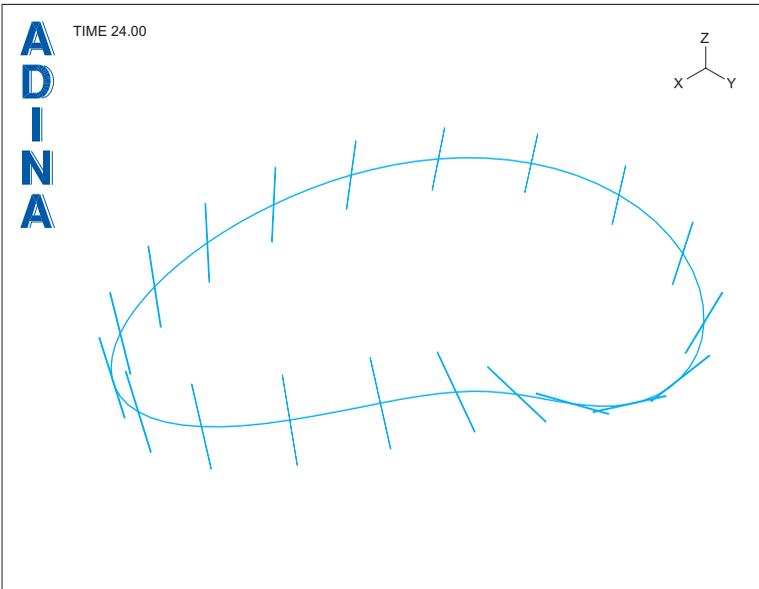
Evidently the incremental rotation has caused the ends of the beam to twist into the Möbius strip shape.

Listing the alignment element forces and moments: Choose List→Value List→Zone, set Variable 1 to (Alignment: ALIGN_TRANS_FORCE-C1), Variable 2 to (Alignment: ALIGN_TRANS_FORCE-C2), Variable 3 to (Alignment: ALIGN_TRANS_FORCE-C3) and click Apply. We see the force needed to maintain the translational alignment increases starting at time 7, and that at time 24, the force has components (6.88102E-02, 1.96067E-01, -4.34913E-07) (N); these components are measured in the C triad directions of local node 1. (Your force components might have slightly different numerical values.)

Now set Variable 1 to (Alignment: ALIGN_ROT_MOMENT_MAGNITUDE) and click Apply. At time 24, the moment has magnitude 1.44764E+01 (N-mm). Click Close to close the dialog box.

Exiting the AUI: Choose File→Exit to exit the AUI. You can discard all changes.