Developments in LS-DYNA for Metal Forming Simulation

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Improvements to *ELEMENT_LANCING

Keywords: *ELEMENT_LANCING, *DEFINE_CURVE_TRIM_3D

- Specify instant or progressive lancing
- Define lancing curves

Drawbacks

- Only 1 part (PID) is allowed
- Only X, Y, Z data pairs are allowed to define lancing curves
- No adaptive refinement along lancing route
- Lanced scraps cannot be removed
- Lancing start point cannot be defined directly using distance from punch bottom.

Enhancements

- A part set is now allowed, which enables lancing across tailor-welded blanks.
- IGES format curves can now be used as input to define the lancing route.
- Meshes along the lanced boundary is now automatically adapted to provide a smooth edge.
- Trimming now can be defined after lancing to remove the scrap. This is done with the new keyword *DEFINE_LANCE_SEED_POINT_COORDINATES.
- Lancing activation distance can now be defined using a new variable CIVD.

negative IDPT: part set ID

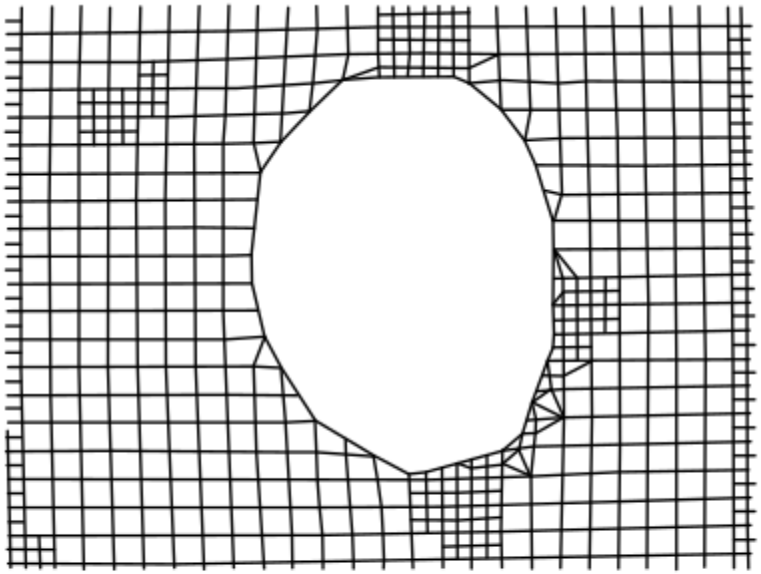
IREFINE activated, =1

AT, ENDT=distance from punch bottom if CIVD is used.

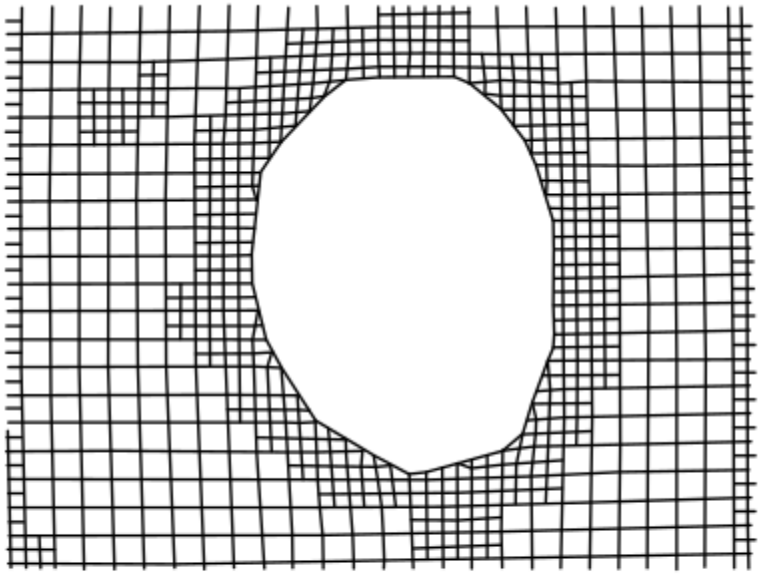
CIVD: load curve ID under *BOUNDARY_PRESCRIBED_MOTION_RIGID

Card 1	1	2	3	4	5	6	7	8
Variable	IDPT	IDCV	IREFINE	SMIN	AT	ENDT	NTIMES	CIVD
Type	I	I	I	F	F	F	I	I
Default	none	none	1	none	none	none	none	none

- Automatic mesh refinement along the lancing curves
- To improve the mesh quality

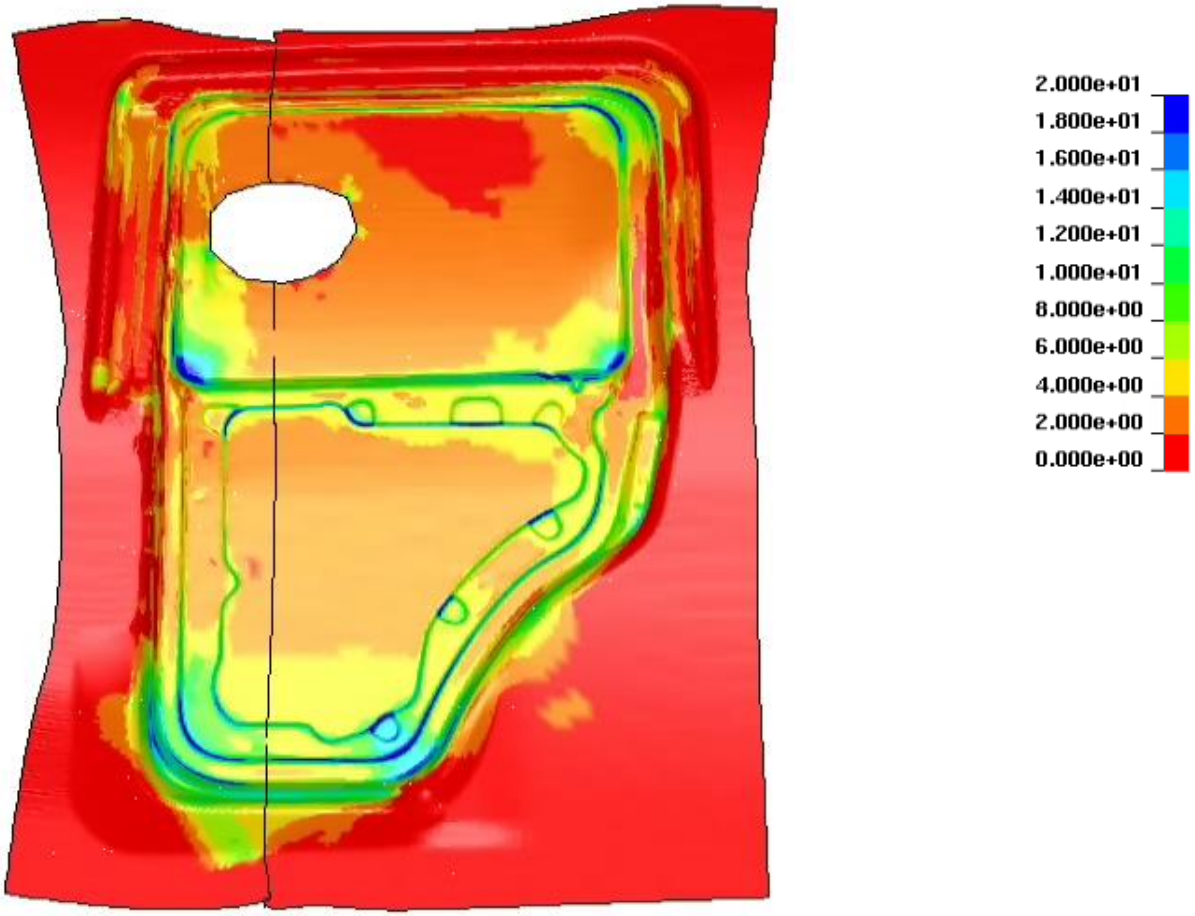


Lanced mesh prior to
Revision 107708

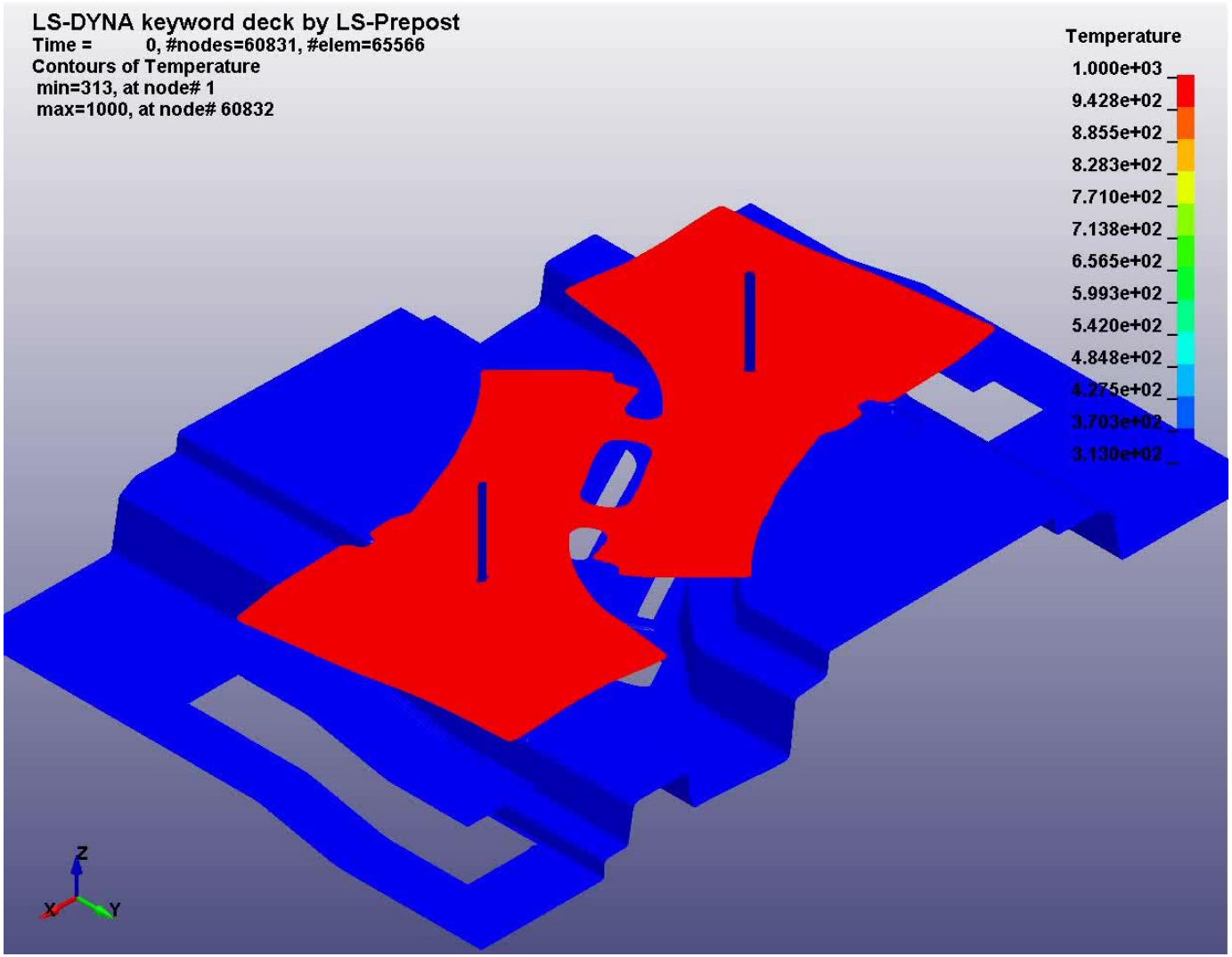


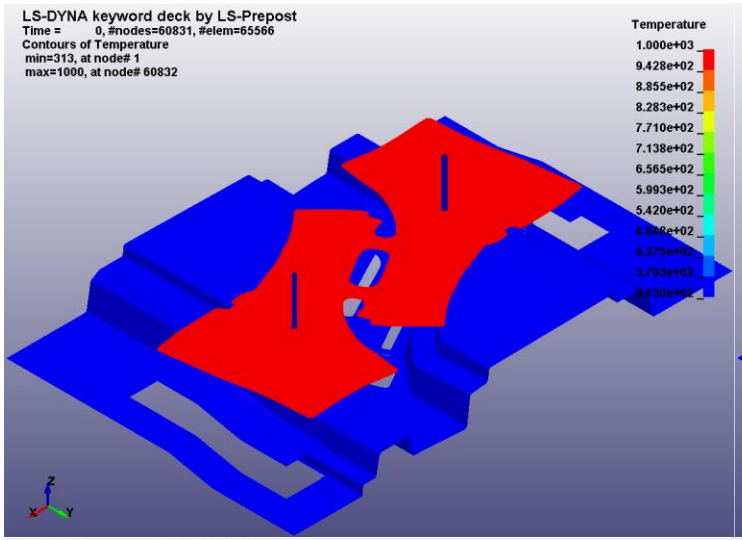
Improved lanced boundary mesh with
IREFINE=1 after Revision 107708

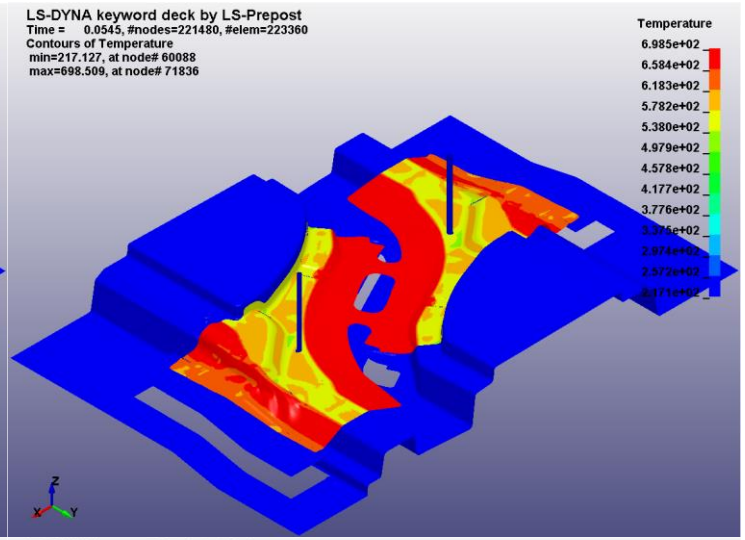
- Lancing across laser welded line using negative IDPT.
- Lancing scrap removal.
- Automatic mesh refinement along lancing route.

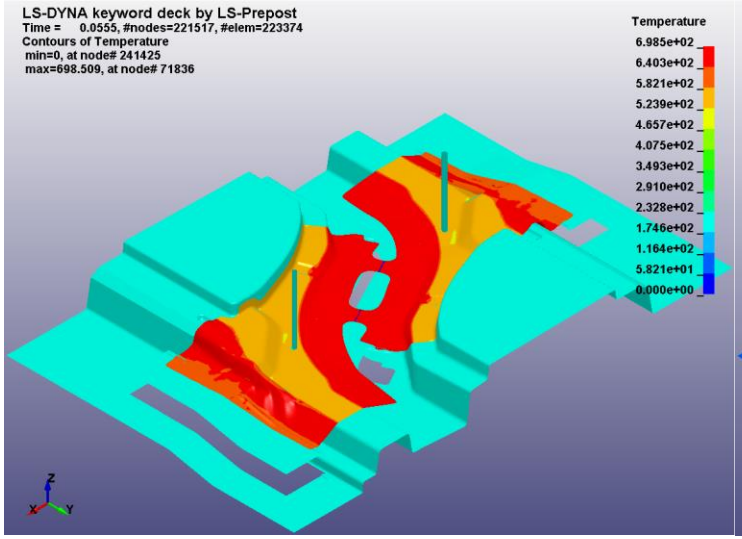


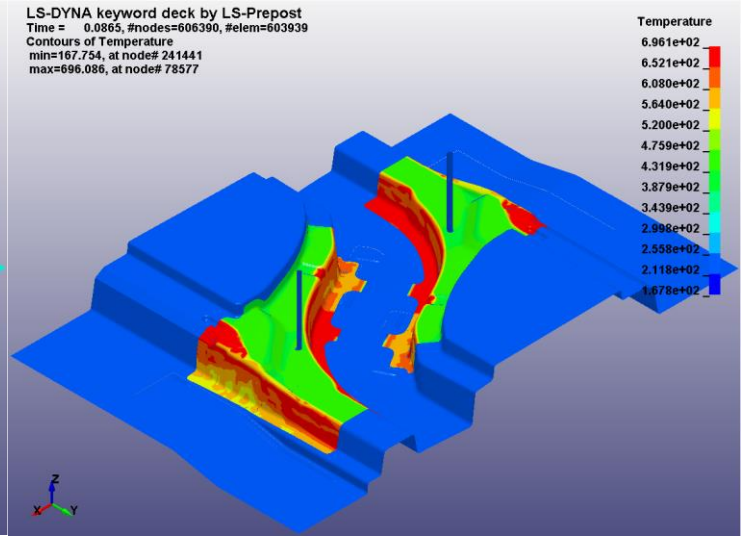
Lancing in Hot Forming







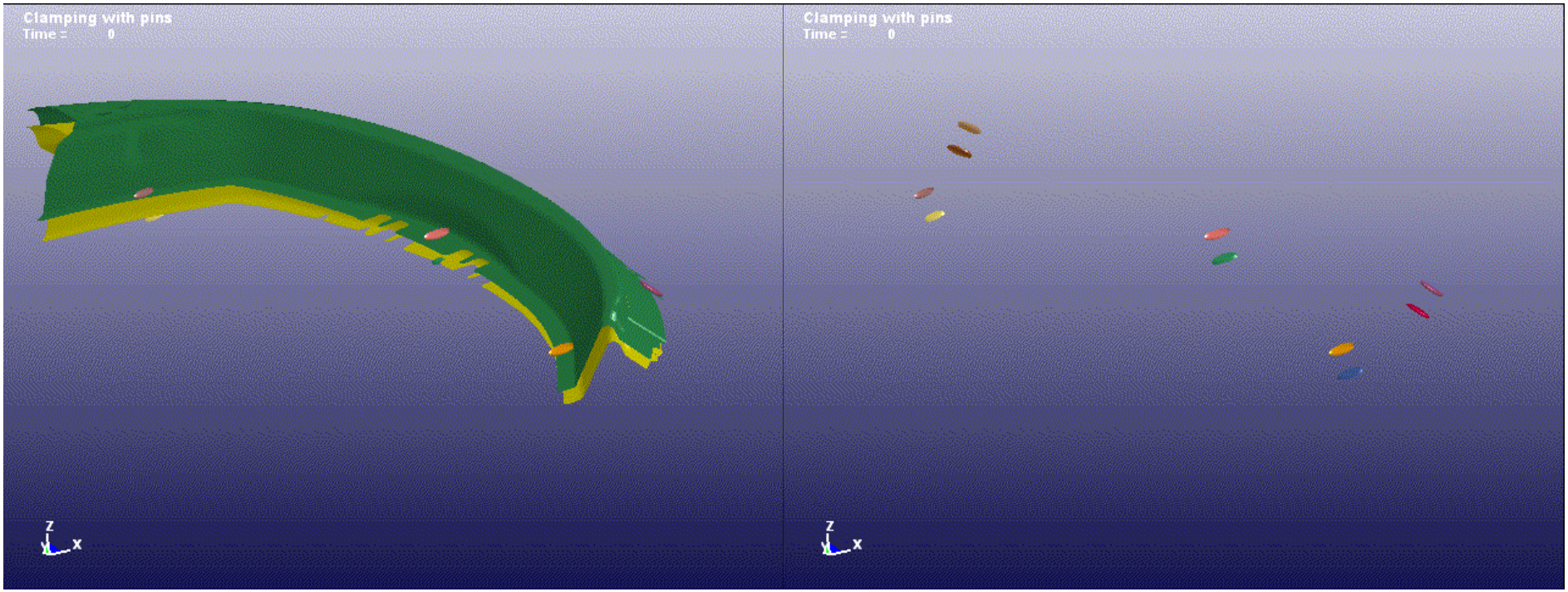




Checking Fixture Clamp Definition and Simplification of FORMING Contact Definition

Clamping Simulation

- Example of clamping simulation



Keywords:

***DEFINE_FORMING_CLAMP**

***DEFINE_FORMING_CONTACT**

Advantages:

- eliminate the need to use auto-position cards between the formed panel and clamps;
- do away with prescribed rigid body motion (*BOUNDARY… and *DEFINE_CURVE);
- simplify the contact definition between the panel and the clamps.

Moving clamp PID

Corresponding fixed clamp PID

Clamping direction:
G.T.0: vector
L.T.0: nodal normal

```
*DEFINE_FORMING_CLAMP
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$      CLP1       CLP2        VID        GAP         AT         DT
         3          2     -46980       1.02        0.0        0.5
         5          4     -46980       1.02        0.5        0.5
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
*DEFINE_FORMING_CONTACT
$       IPS        IPM         FS     ONEWAY
         1          2      0.125          1
         1          3      0.125          1
         1          4      0.125          1
         1          5      0.125          1
```

Final clamps gap

Activation time

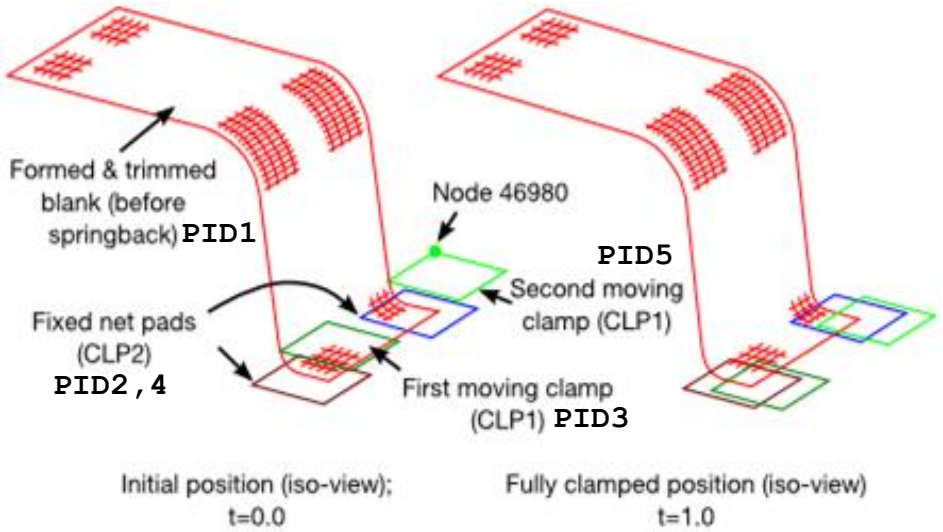
Duration

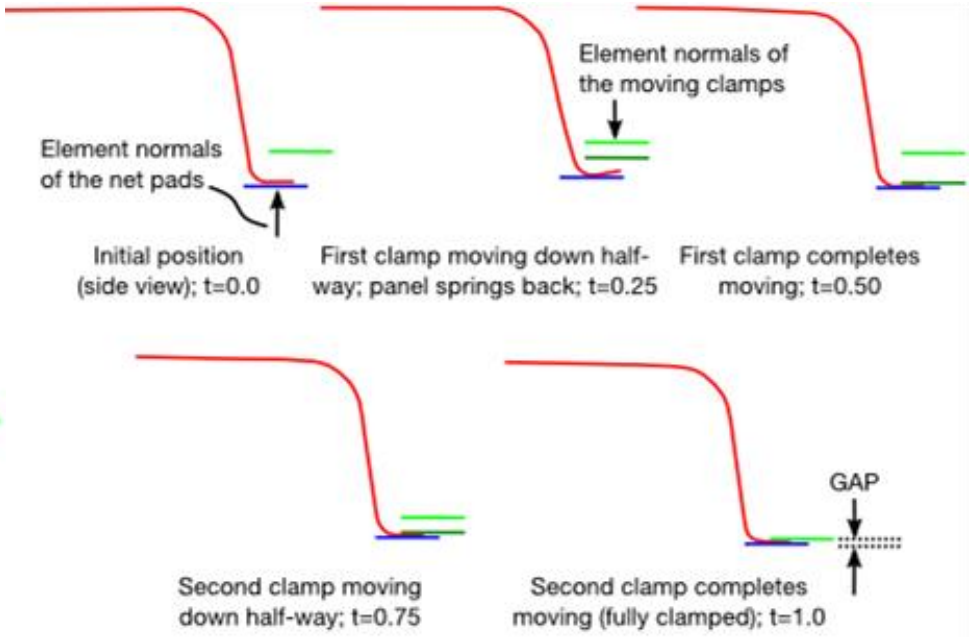
Slave PID

Master PID

Contact friction

Contact way





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New Options in *INTERFACE_BLANKSIZE

Keywords:

***INTERFACE_BLANKSIZE_SCALE_FACTOR**

***INTERFACE_BLANKSIZE_SYMMETRIC_PLANE**

Advantage:

- The option SCALE_FACTOR allows user to include or exclude a target curve in the calculation of the initial curve. It also allows user to scale up or down in size of a target curve involved in the calculation.
- The option SYMMETRIC_PLANE allows user to define a symmetric plane by specifying a point on the symmetric plane with X, Y, Z coordinates, and vector components for the normal of the plane.

```
*KEYWORD
*INTERFACE_BLANKSIZE_DEVELOPMENT
$   IOPTION                IADAPT
        -2                     1
$ target boundary curves
targetline.k
$ final mesh
final.k
$ initial mesh
initial.k
*INTERFACE_BLANKSIZE_SCALE_FACTOR
1,0.0
2,1.0
3,1.0
*INTERFACE_BLANKSIZE_SYMMETRIC_PLANE
$        X0          Y0          Z0          V1          V2          V3
        -76     2.63844        0.38         1.0         0.0         0.0
*end
```

Target curve #

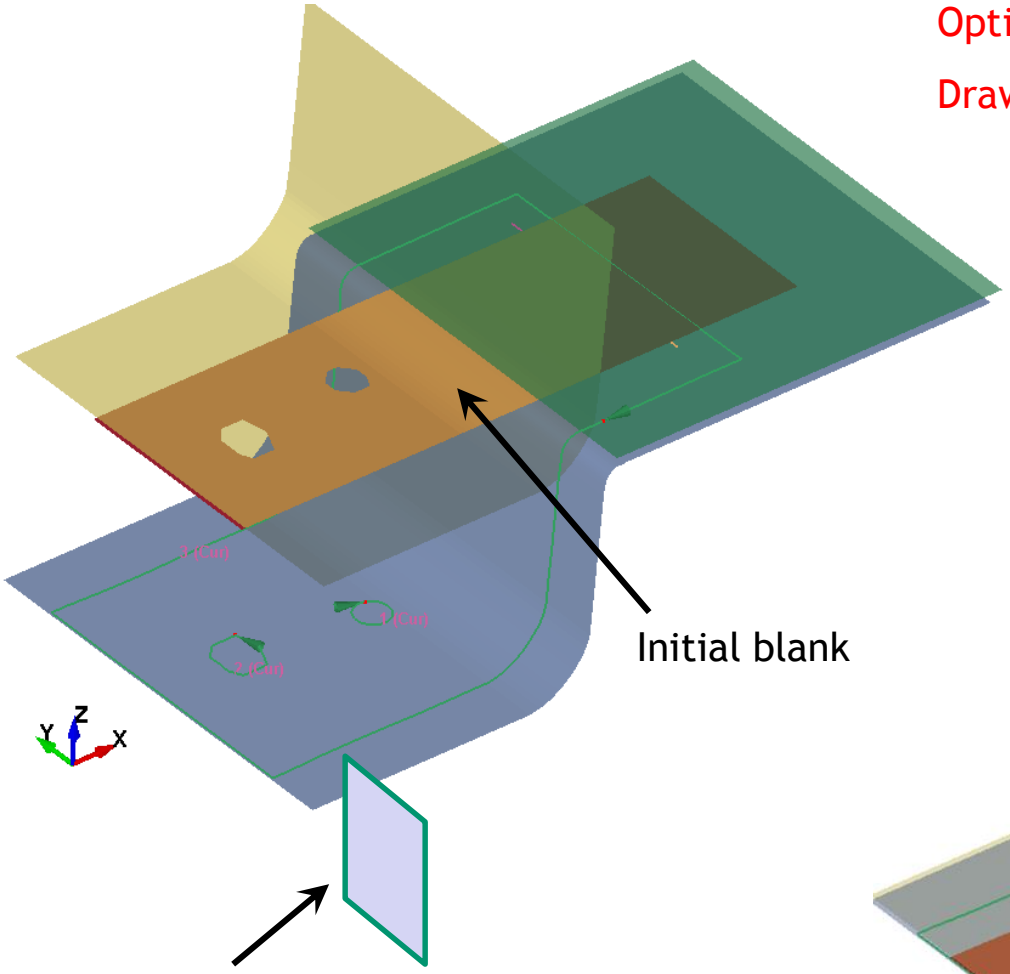
Scale factor:
0.0= not to optimize
1.0= to optimize

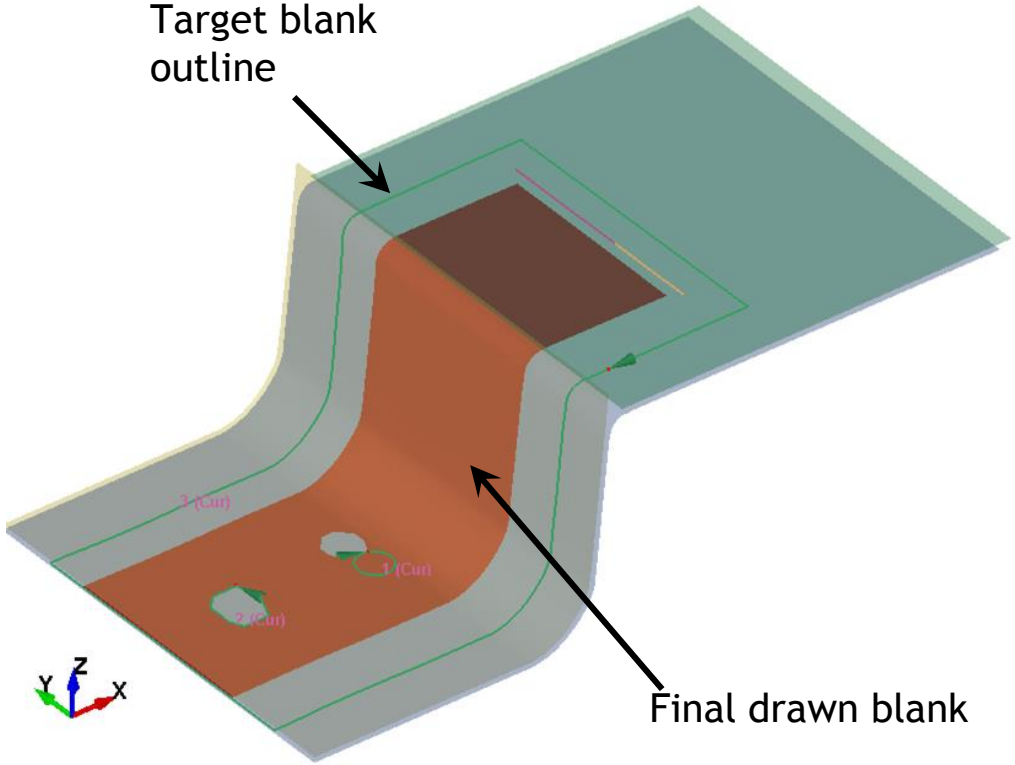
A point coordinates on the sym. plane

Vector components of the symmetric plane normal

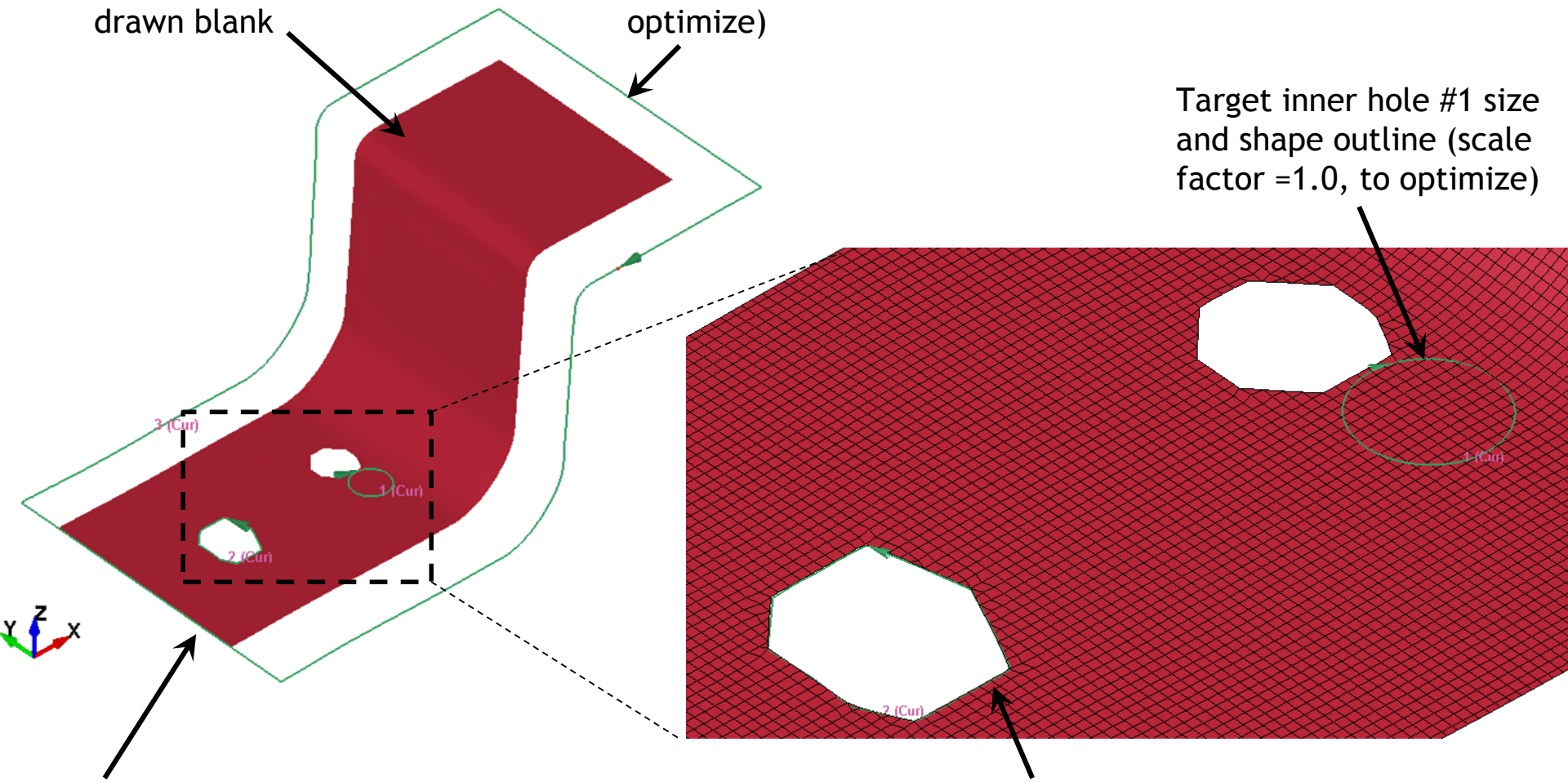
Optimization loop:

Draw baseline → Opt1 → Draw #1 → Opt2 → Draw #2

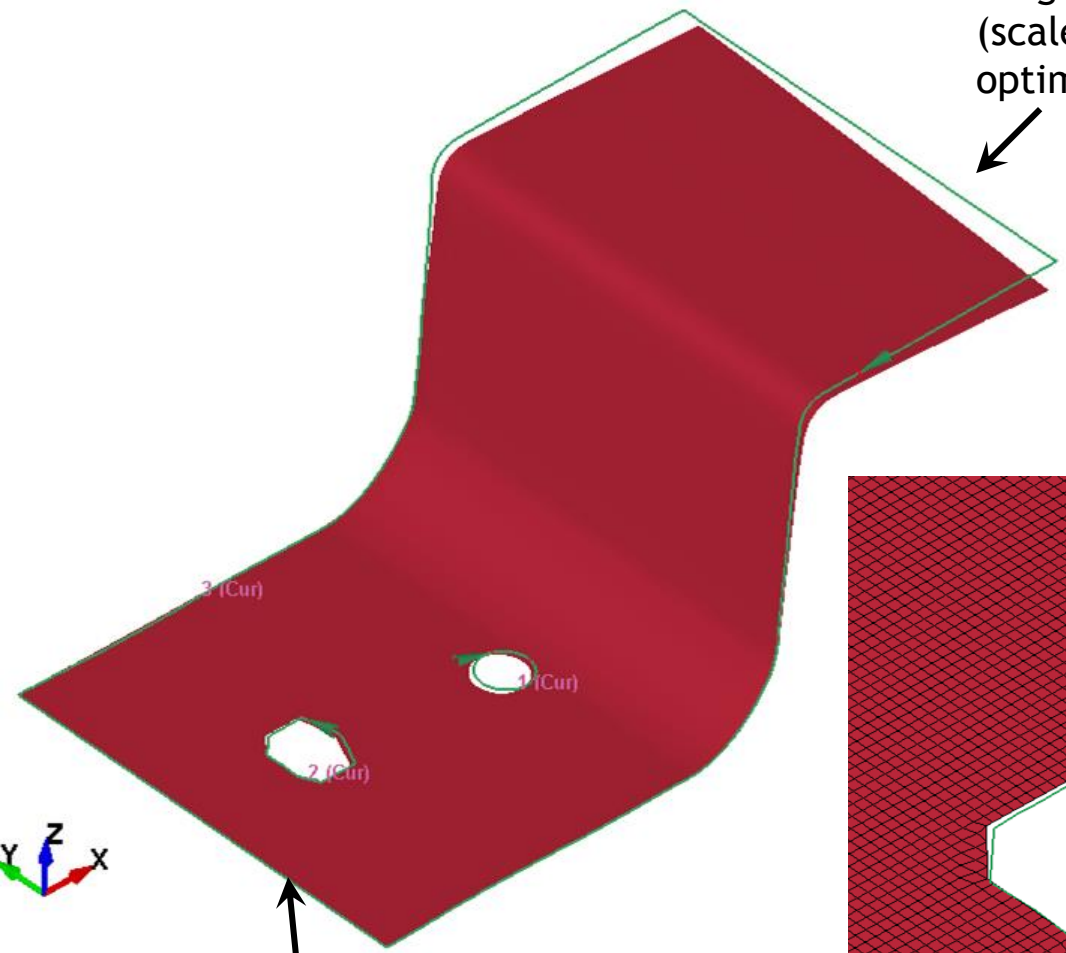




- A channel in deep draw, one-half model with symmetric boundary condition.



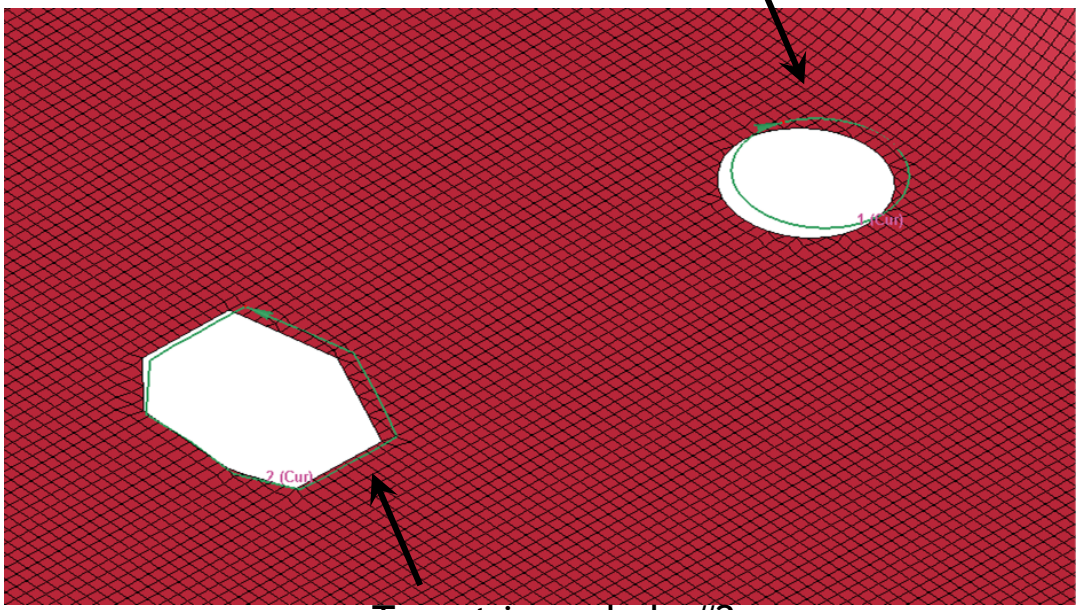
❑ Baseline results.



Target blank outline (scale factor=1.0, to optimize)

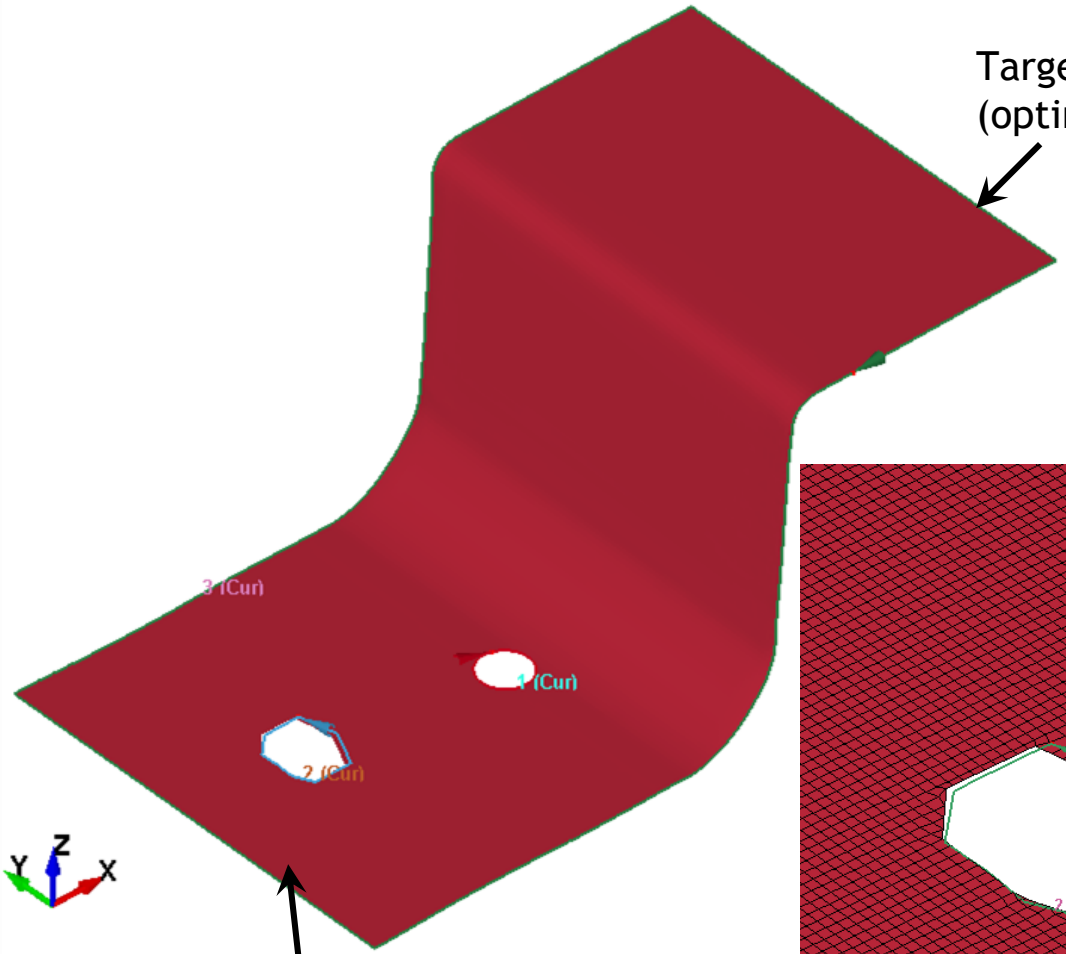
Iteration 1 final drawn blank

Target inner hole #1 size and shape outline (scale factor =1.0, to optimize)



Target inner hole #2 size and shape outline (scale factor =0.0, not to optimize)

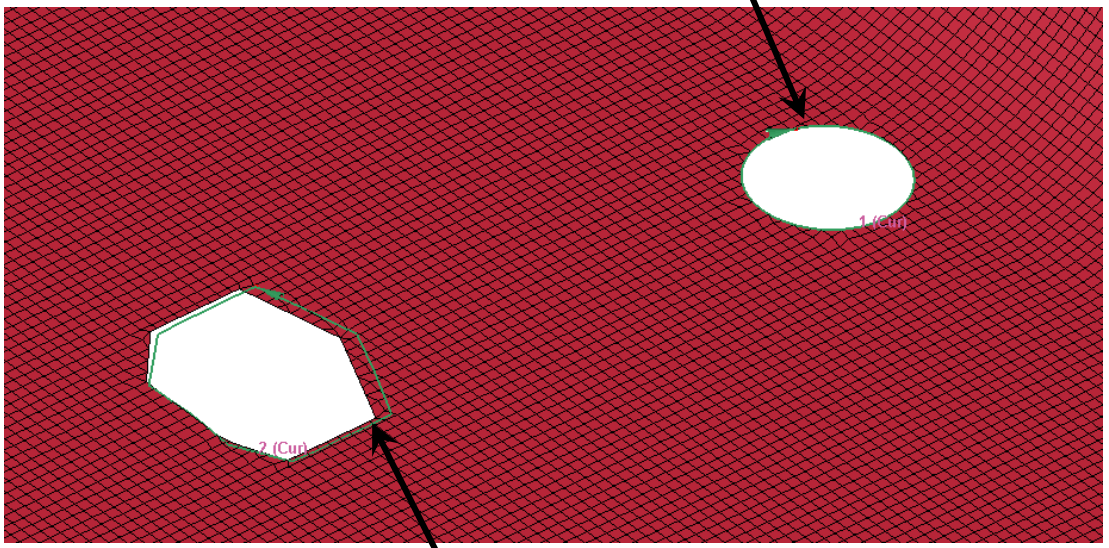
- Iteration 1 based on blank optimization: final drawn blank is much closer to the target.



Target blank outline (optimized)

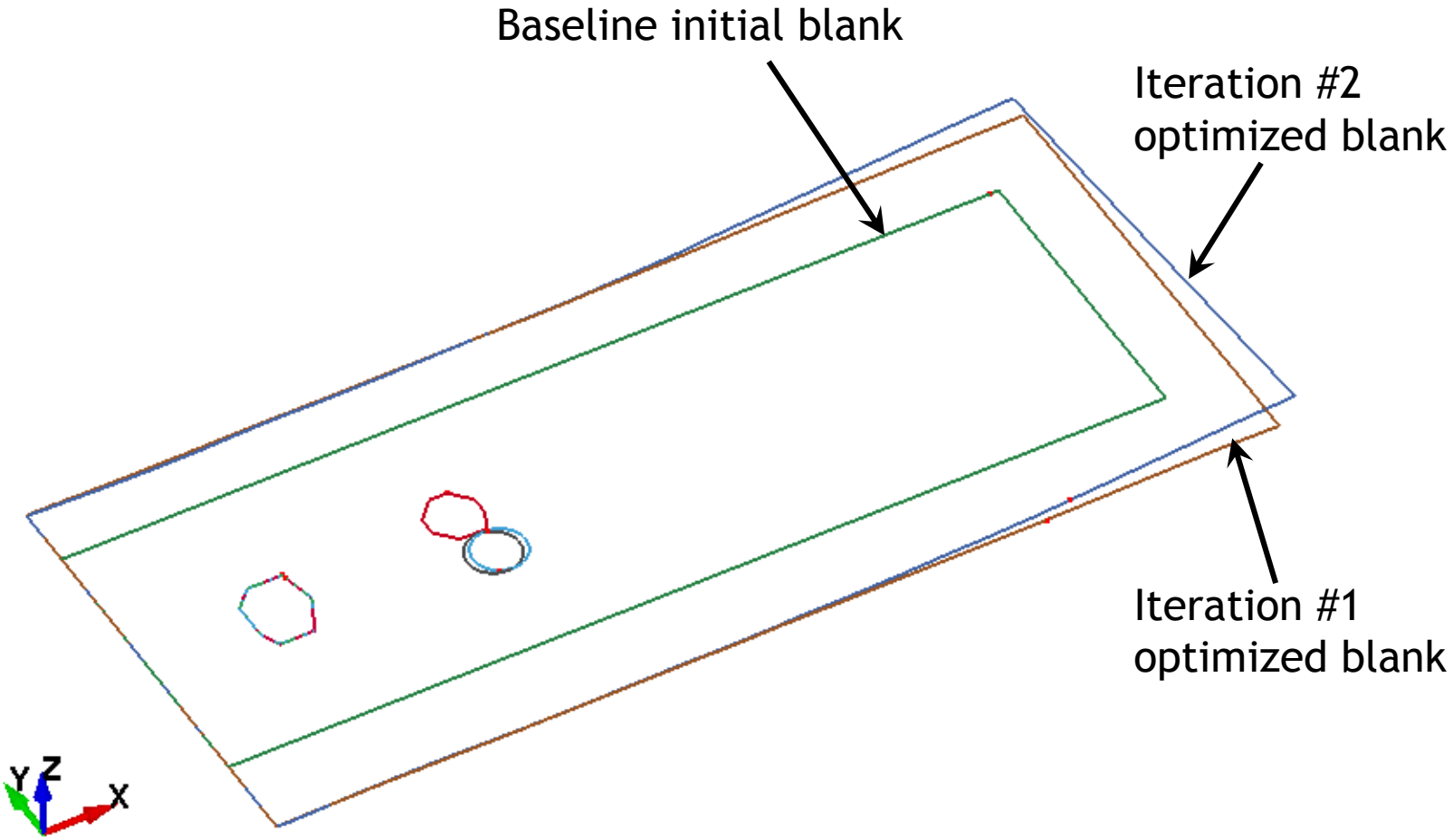
Iteration 2 final drawn blank

Target inner hole #1 size and shape outline (optimized)



Target inner hole #2 size and shape outline (not optimized). Original hole size and shape change slightly due to hole #1 location and size change)

- Iteration 2 based on blank optimization: final drawn blank and holes exactly overlap the target.



❑ Optimized initial blank evolution.

2D and 3D trimming of solids and laminates

(*CONTROL_FORMING_TRIMMING, *INCLUDE_TRIM, *DEFINE_CURVE_TRIM)

- **Solid, laminate, TSHELL trimming capability summary:**

	2D (along one direction)	3D (element normal)	2D & 3D Double Trim	Adaptive mesh
Shell	Yes	Yes	Yes	Yes
Solids	Yes	Yes	Yes*	N/A
Laminates	Yes	Yes	Yes*	One layer of solids only*; Multiple layers of solids okay for non-adaptive mesh*.
TSHELL	Yes*	N/A	N/A	N/A

Note: items designated * are new capabilities.

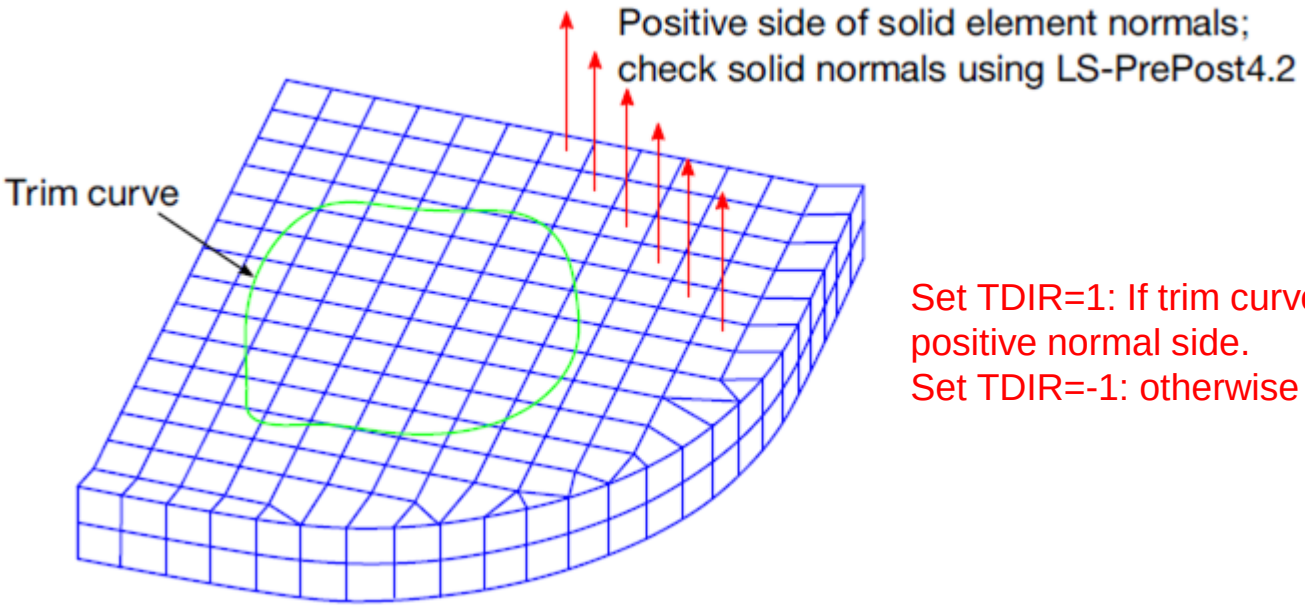
Trimming of Solids

- Inputs to trim of solids are like that for trimming of shells, use:

```
*ELEMENT_TRIM        (or, *CONTROL_FORMING_TRIMING)
*DEFINE_TRIM_CURVE_NEW, (or 3D)
*DEFINE_TRIM_SEED_POINT_COORDINATES
```

- Additional input to indicate solid normals:

```
*DEFINE_CURVE_TRIM_3D
$#  tcid     tctype      tflg      tdir      tctol      toln     nseed1     nseed2
       2          2         0         1        0.1       1.0
```



Set TDIR=1: If trim curve is close to the positive normal side.
Set TDIR=-1: otherwise

- Must use *INCLUDE_TRIM

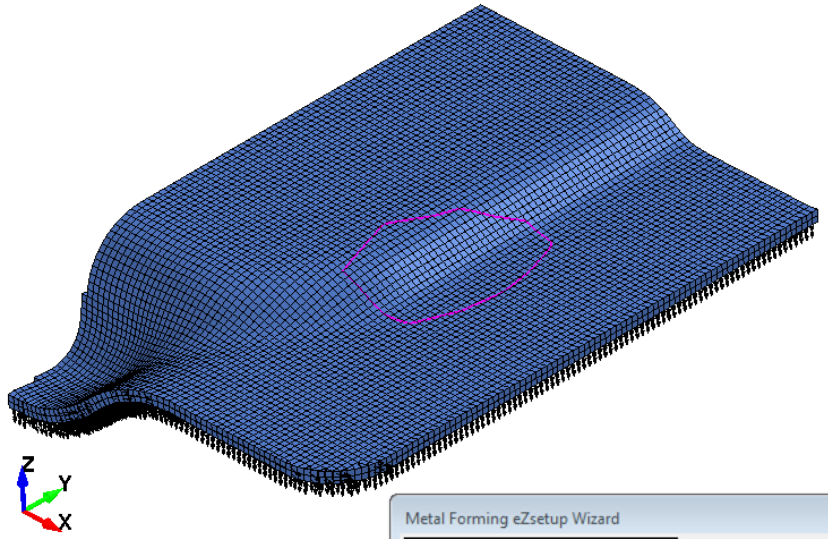
Usage - Laminates Trimming

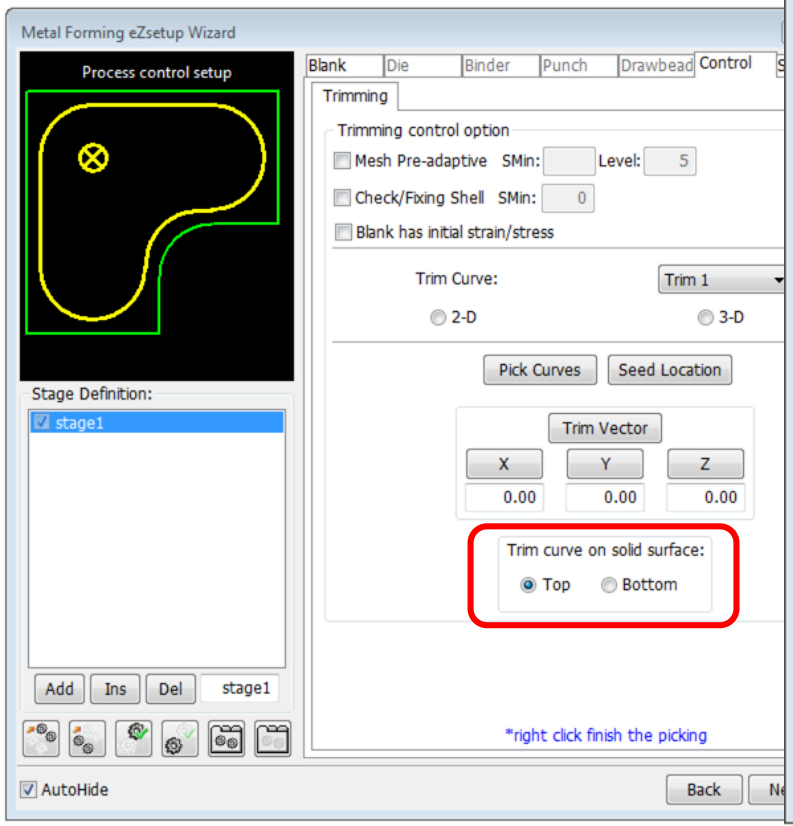
- Trimming of laminates (solid layers sandwiched by top and bottom layers of shells):

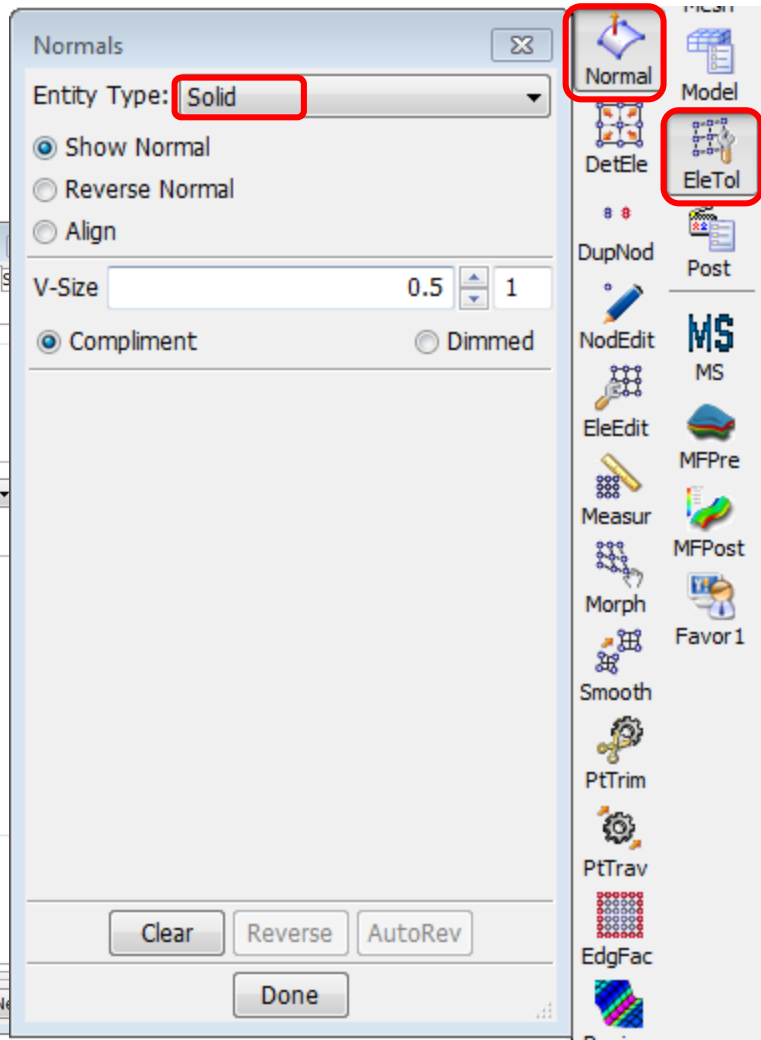
```
*ELEMENT_TRIM       (or, *CONTROL_FORMING_TRIMING)
$ PSID,,$ITYP
(set ITYP=1 to activate a laminate trim)
```

- Must use **`*INCLUDE_TRIM`**

LS-PrePost® 4.3 GUI



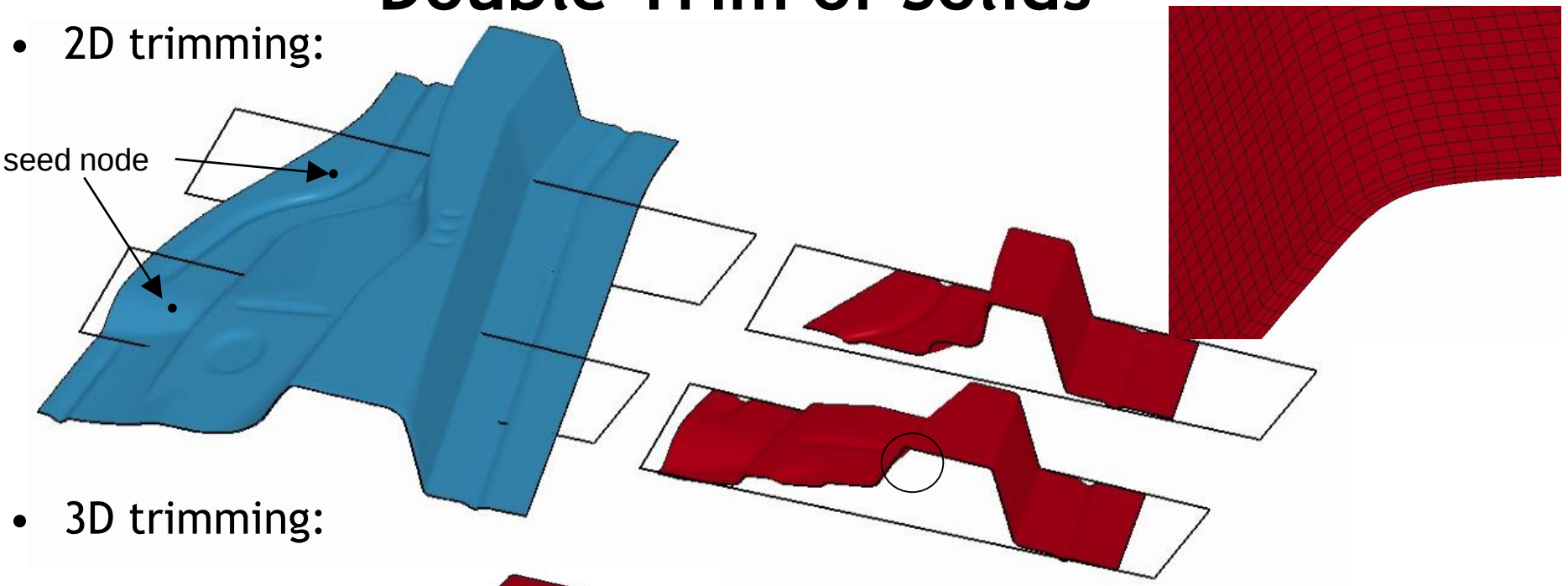




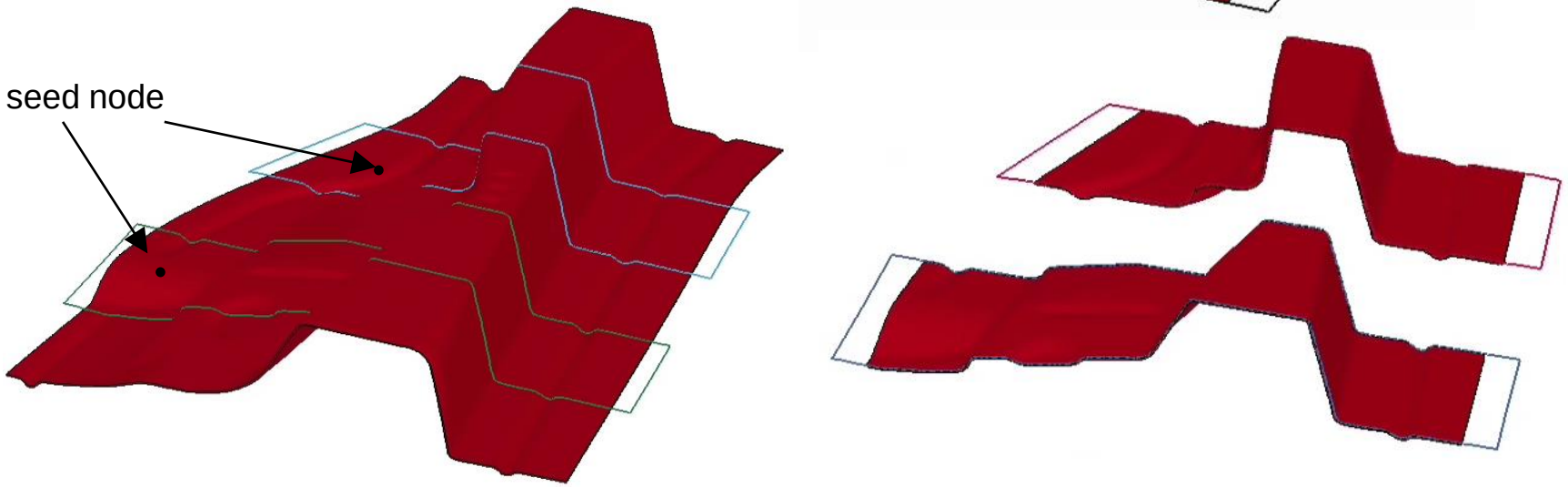
-Developed by Q.Yan.

Double Trim of Solids

- 2D trimming:



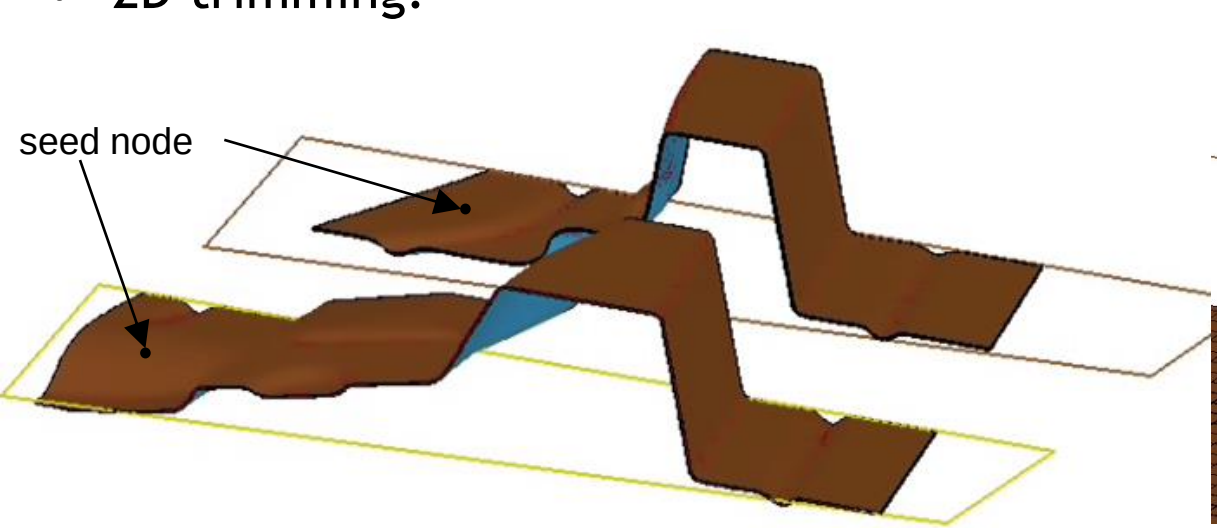
- 3D trimming:

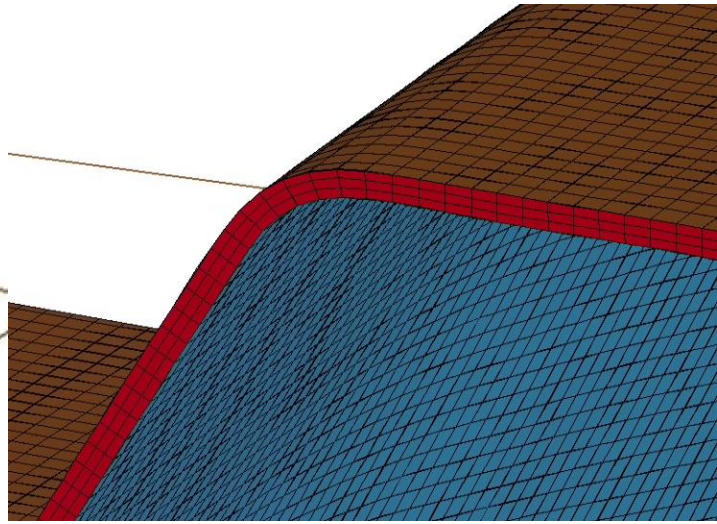



```
*DEFINE_TRIM_SEED_POINT_COORDINATES
$    NSEED        X1        Y1        Z1        X2        Y2        Z2
         2      20.7      -153.     -42.9      84.5      -410.   -42.990
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7
```

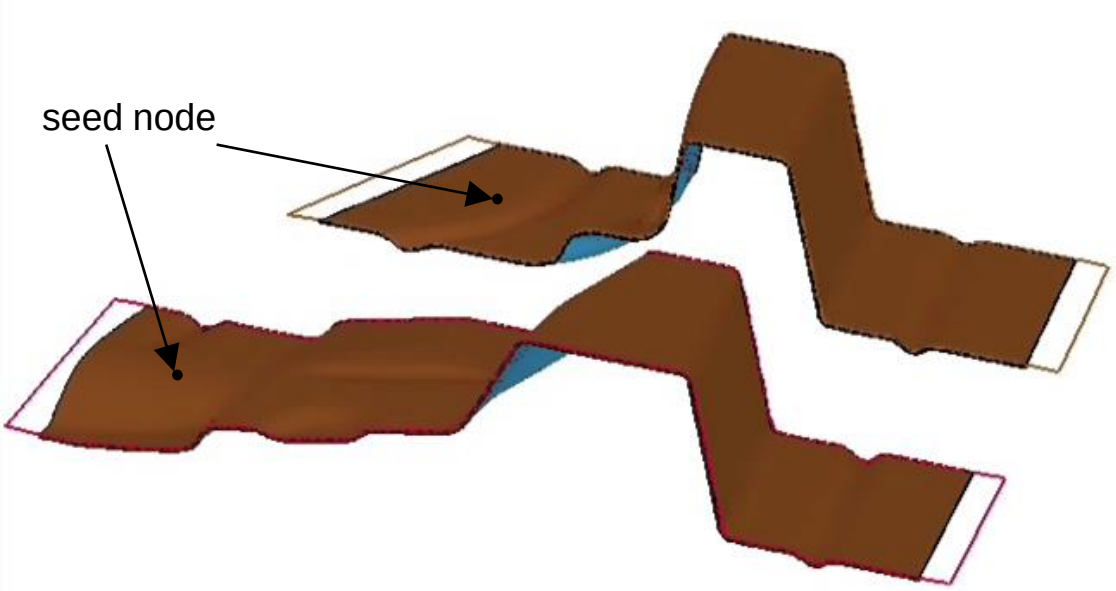
Double Trim of Laminates

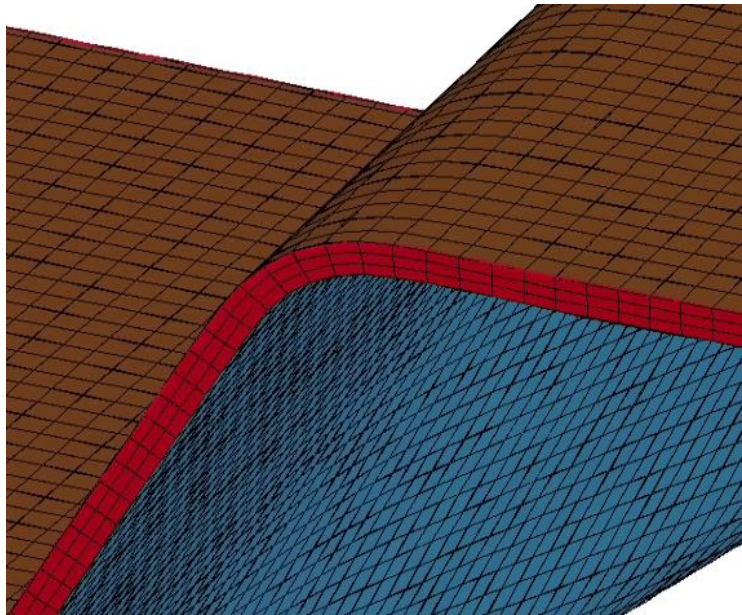
- 2D trimming:





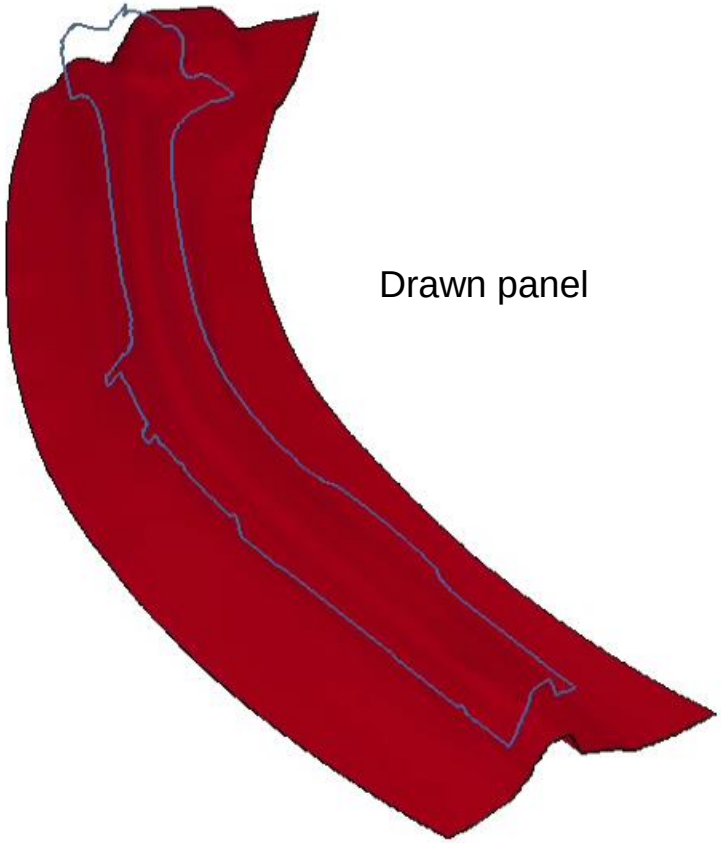
- 3D trimming:



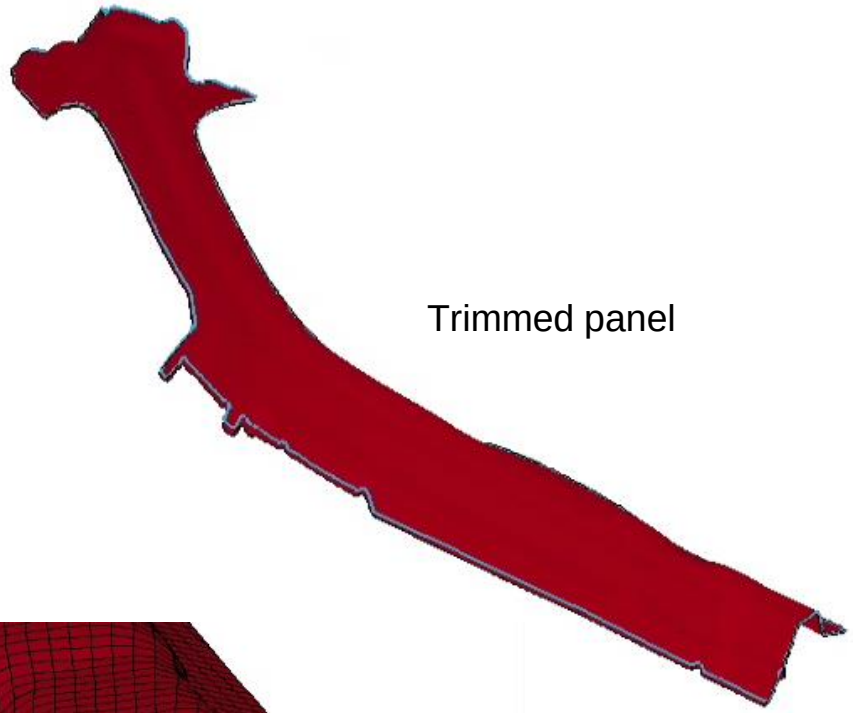


Trim of TSHELL

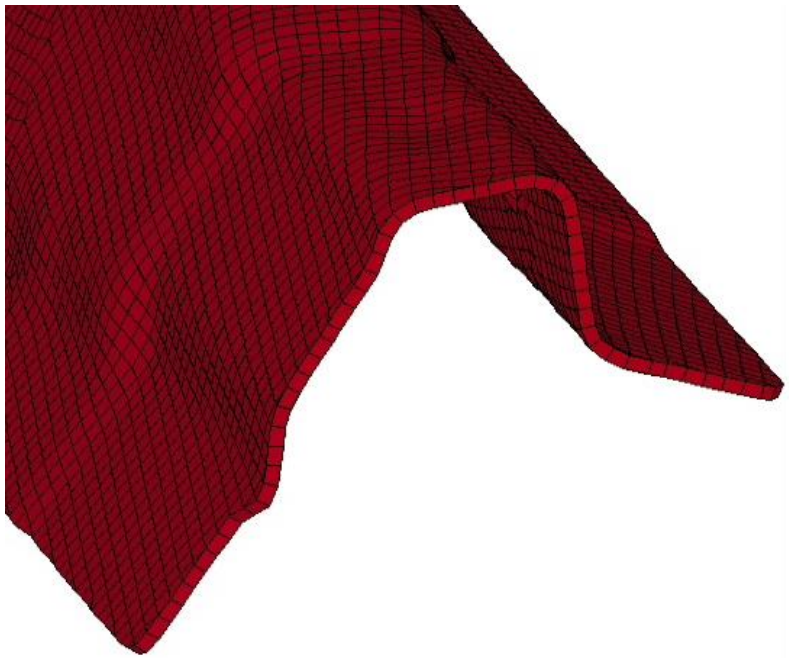
- 2D trimming only:



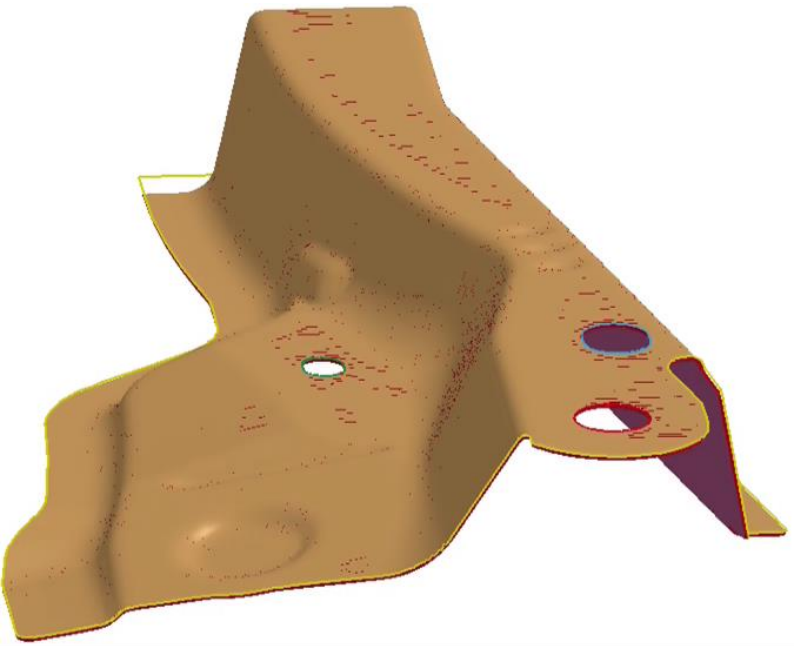
Drawn panel

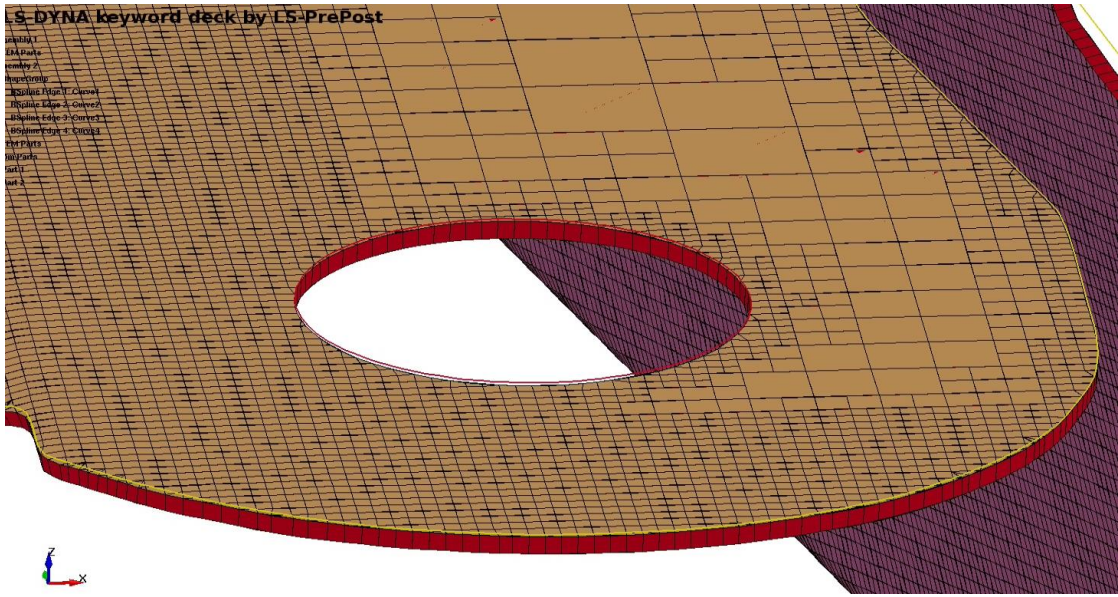


Trimmed panel

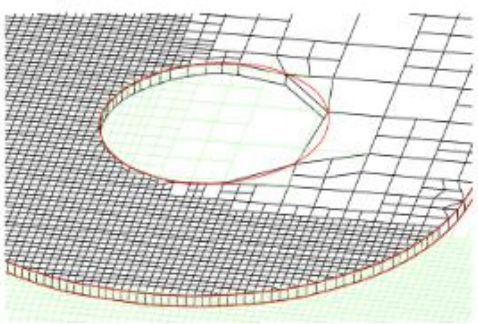


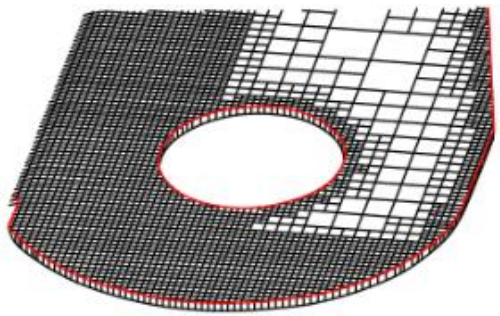
- Laminate trim - adaptive mesh trimming capable:





- Solid trim - automatic adaptive refinement along trim curve:



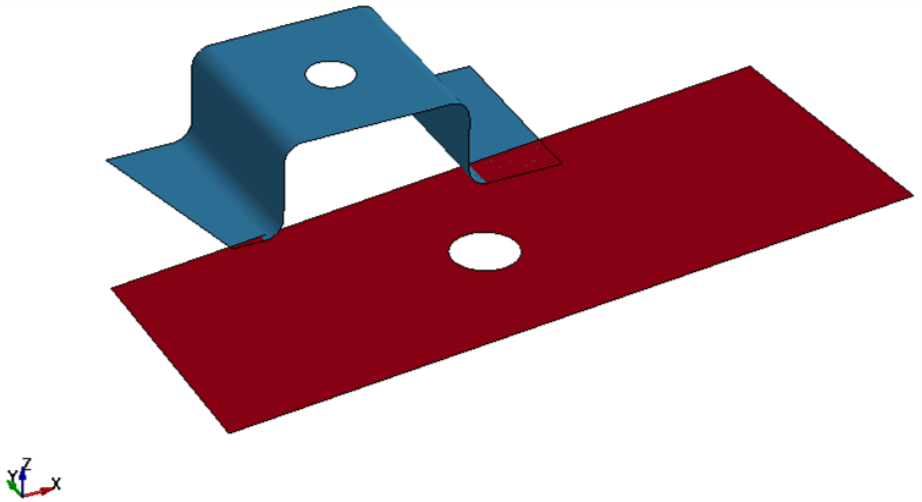


Enhancements in One-step Simulation

(*CONTROL_FORMING_ONESTEP)

1. Re-positioning of unfolded blank in one-step simulation:

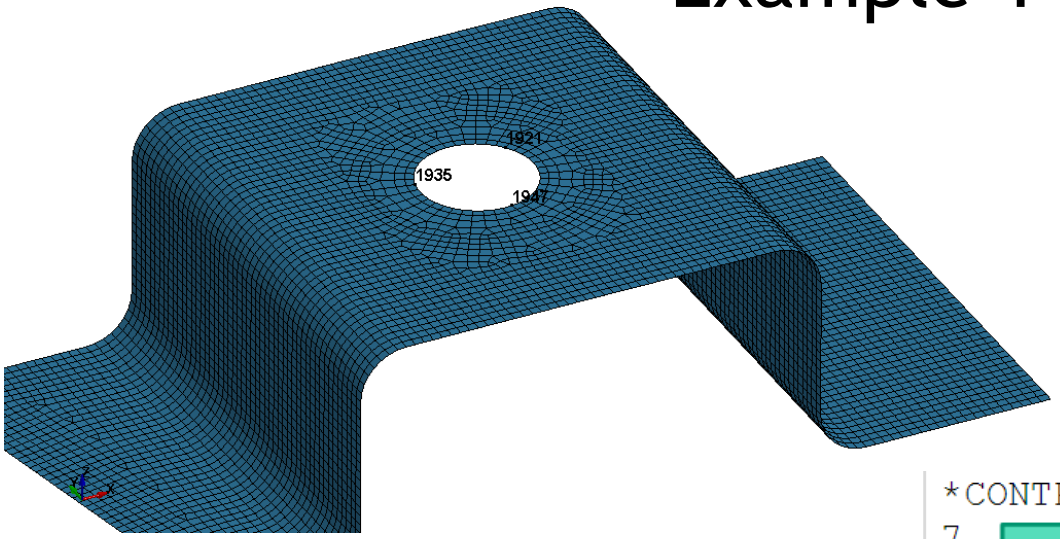
- ❑ The position of the blank can be undesirable after unfolding
- ❑ Not easy to be aligned in the forming tools



```
*CONTROL_FORMING_ONESTEP_AUTO_CONSTRAINT
1,NID1,NID2,NID3
```

- The option “AUTO_CONSTRAINT” is extended:
- NID1, NID2 and NID3 are the ID of the nodes on the folded part for repositioning after unfolding.

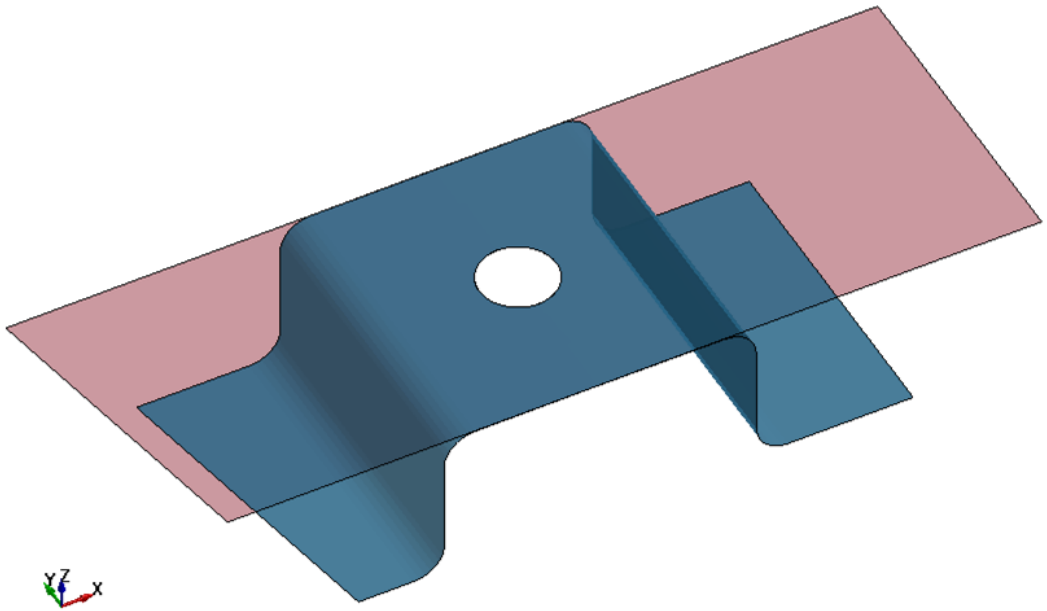
Example 1



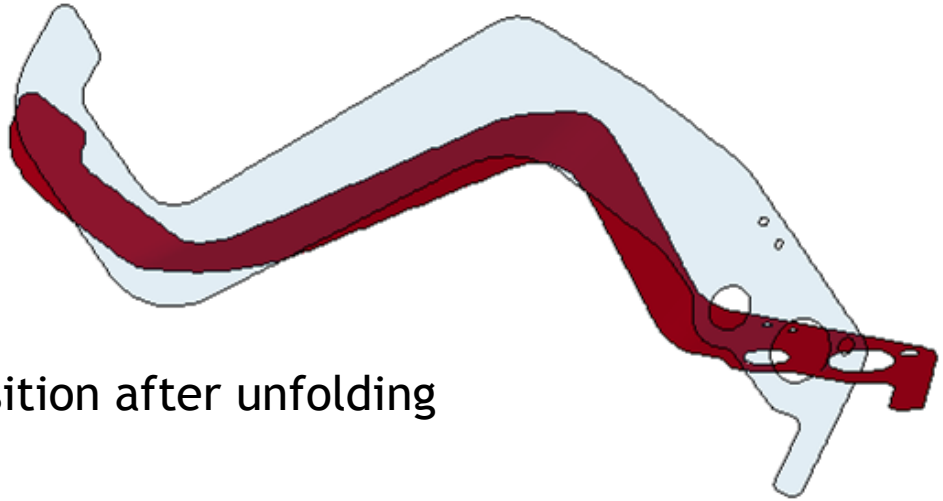
Select 3 nodes for reposition after unfolding

```
*CONTROL_FORMING_ONESTEP
7,
*CONTROL_FORMING_ONESTEP_AUTO_CONSTRAINT
1,1921,1935,1947
```

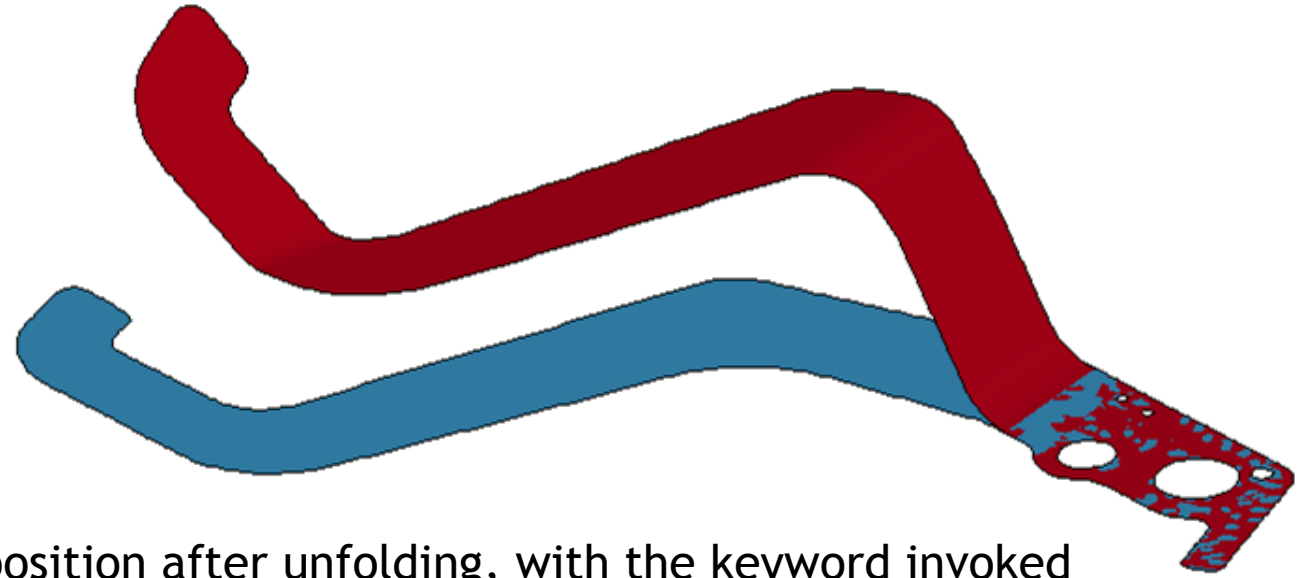
The reference nodes are defined



Example 2



Undesirable position after unfolding



Reposition after unfolding, with the keyword invoked and 3 nodes defined

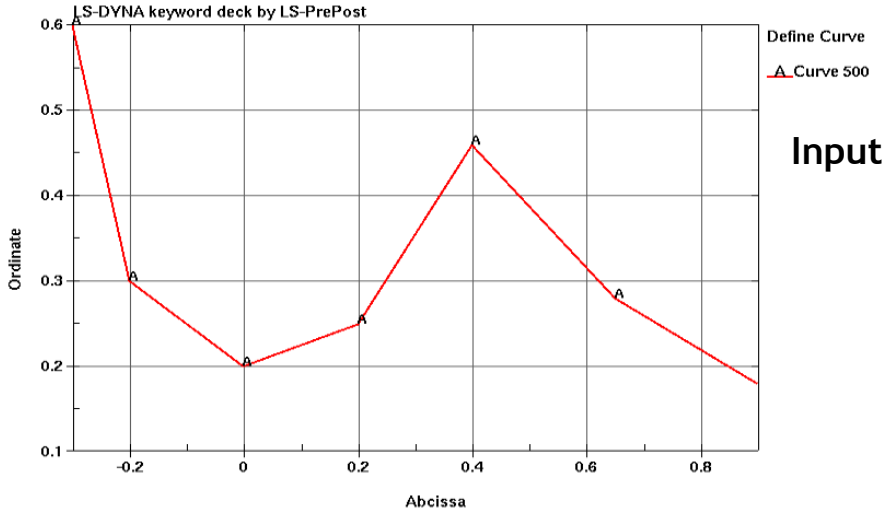
2. Damage inclusion in one-step simulation:

- Damage accumulation *D* is calculated based on (refer to *MAT_ADD_EROSION):

$$D = \left(\frac{\varepsilon_p}{\varepsilon_f}\right)^{\text{DMGEXP}}$$

- A load curve can be defined for plastic failure strain vs. stress triaxiality relationship and DMGEXP can be input. The calculated damage accumulation is written into a file called “onestepresult” as history variable #6, and can be plotted in LS-PrePost.

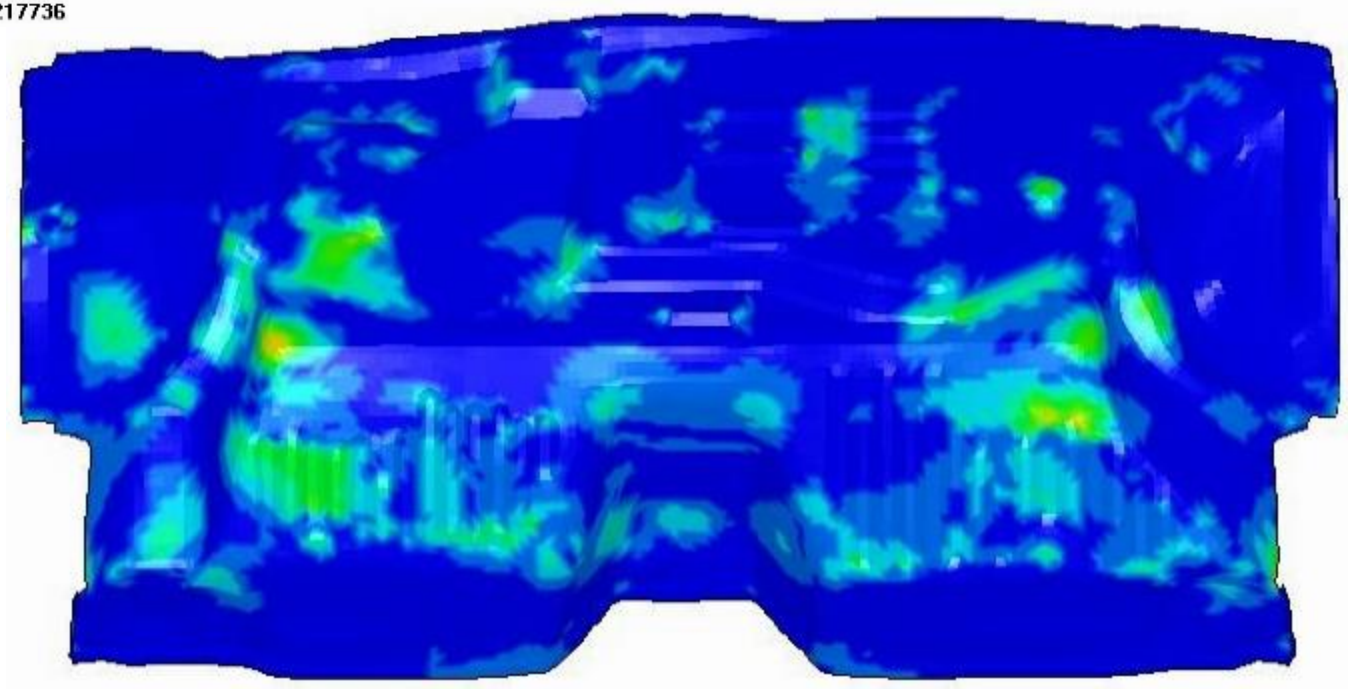
```
*CONTROL_FORMING_ONESTEP
$---+----1----+----2----+----3----+----4----+----5----+----6----+----7----+----8
$#  option              autobd   thinmin    epsmax                 LCID    DMGEXP
         7                                                          500     1.254

*DEFINE_CURVE
500
-0.3,0.6
-0.2,0.3
0.0,0.2
0.2,0.25
0.4,0.46
0.65,0.28
0.9,0.18
```



Input load curve ID 500

LS-DYNA keyword deck by LS-PrePost
Contours of History6
reference shell surface
min=0, at elem# 3008924
max=1.06, at elem# 3217736

History variable #6 fringe plot from file "onestepresult"



Damage

1.060e+00
9.540e-01
8.480e-01
7.420e-01
6.360e-01
5.300e-01
4.240e-01
3.180e-01
2.120e-01
1.060e-01
0.000e+00

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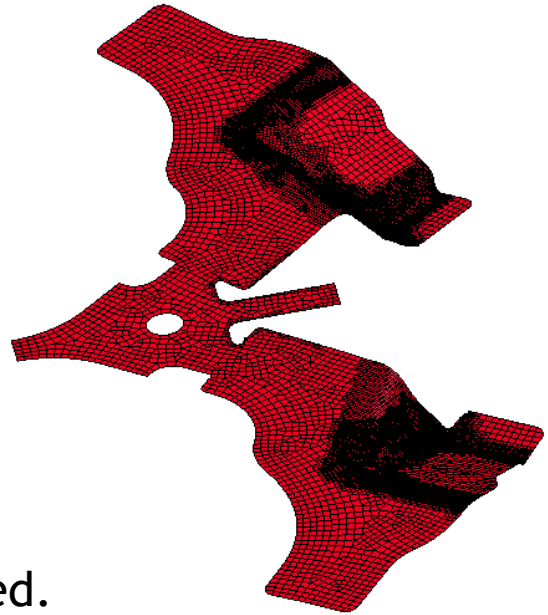
Automatic Offset of Tool Element & Node IDs

(*INCLUDE_AUTO_OFFSET)

- Adaptive trimming results in additional nodes and elements whose ID may overlap those of the tools of the following operations, resulting in error termination.

```
*INCLUDE
drawn.dynain
*DEFINE_CURVE_TRIM_3D
…
*CONTROL_ADAPTIVE_CURVE
```

Trimming



- Automatically offset mesh ID of any tools included.

```
*INCLUDE
trimmed.dynain
*INCLUDE_AUTO_OFFSET
upperdie.k
*INCLUDE_AUTO_OFFSET
lowerpunch.k
*INCLUDE_AUTO_OFFSET
binder.k
*INCLUDE_AUTO_OFFSET
pins.k
```

Forming

- Default in LSPP eZ-Setup for metal forming.

New features in state output with *CONTROL_FORMING_OUTPUT

- A new variable CIDT is added to allow definition of state outputs according to simulation time specified. The new state outputs will be in addition to the state outputs according to punch distance from home (bottom), specified by the existing variable LCID.

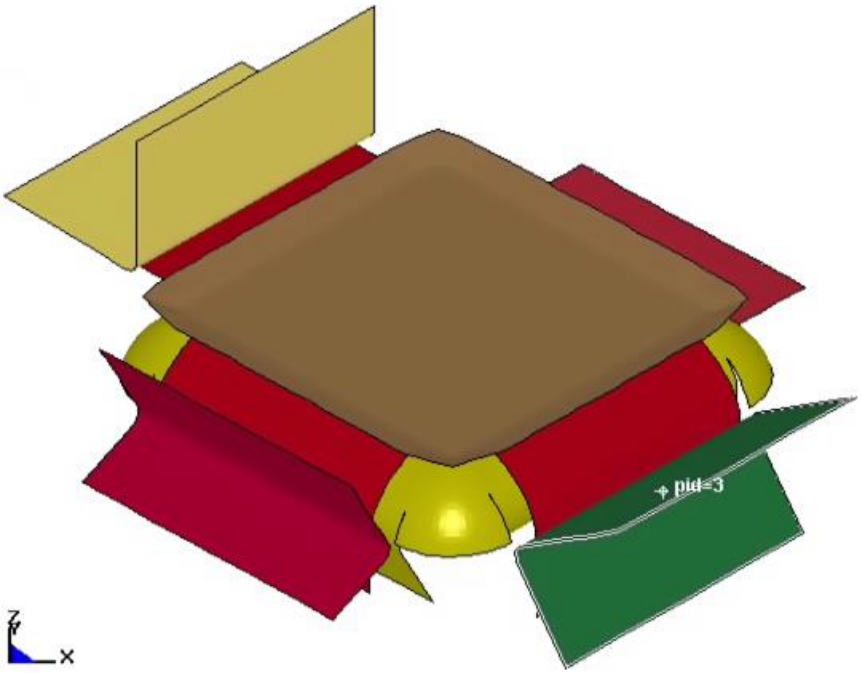
```
*CONTROL_FORMING_OUTPUT
$ -------1---------2---------3---------4---------5---------6---------7---------8
$      CID      NOUT      TBEG      TEND    Y1/LCID   Y2/CIDT        Y3        Y4
      1116         0  &clstime  &endtime      -980      -999
      1117         0  &clstime  &endtime      -980      -999
      1118         0  &clstime  &endtime      -980      -999
      1119         0  &clstime  &endtime      -980      -999
*DEFINE_CURVE
999
1.0e-03
2.0e-03
3.0e-03
4.0e-03
*DEFINE_CURVE
980
13.5,0.0
13.0,0.0
5.0,0.0
3.0,0.0
2.5,0.0
2.0,0.0
1.0,0.0
```

curve ID defining output distance from punch bottom

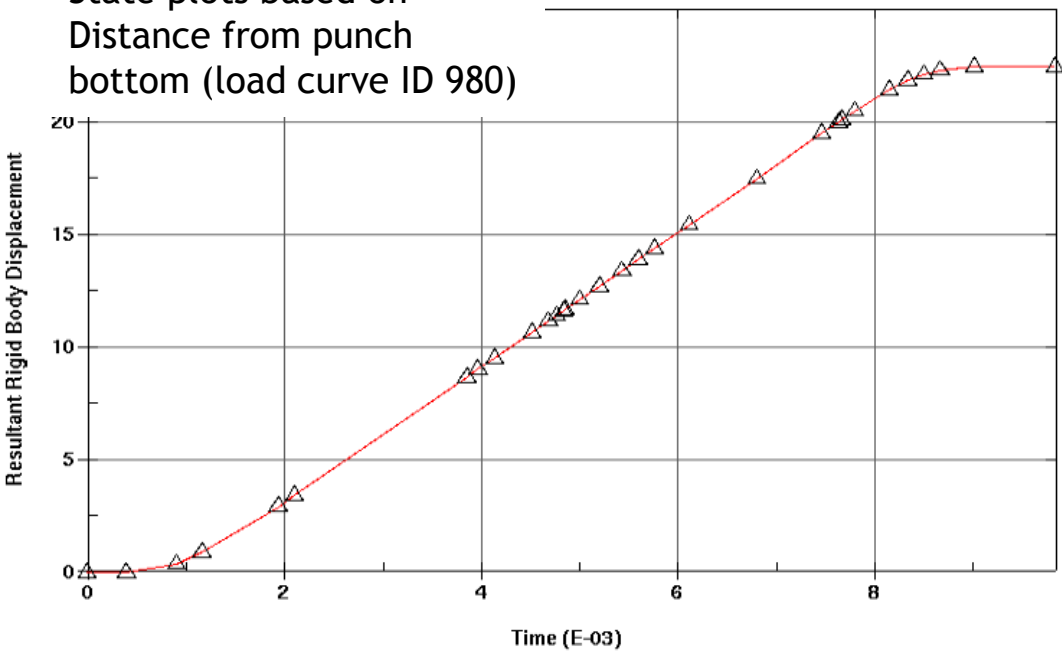
curve ID defining output time

output time

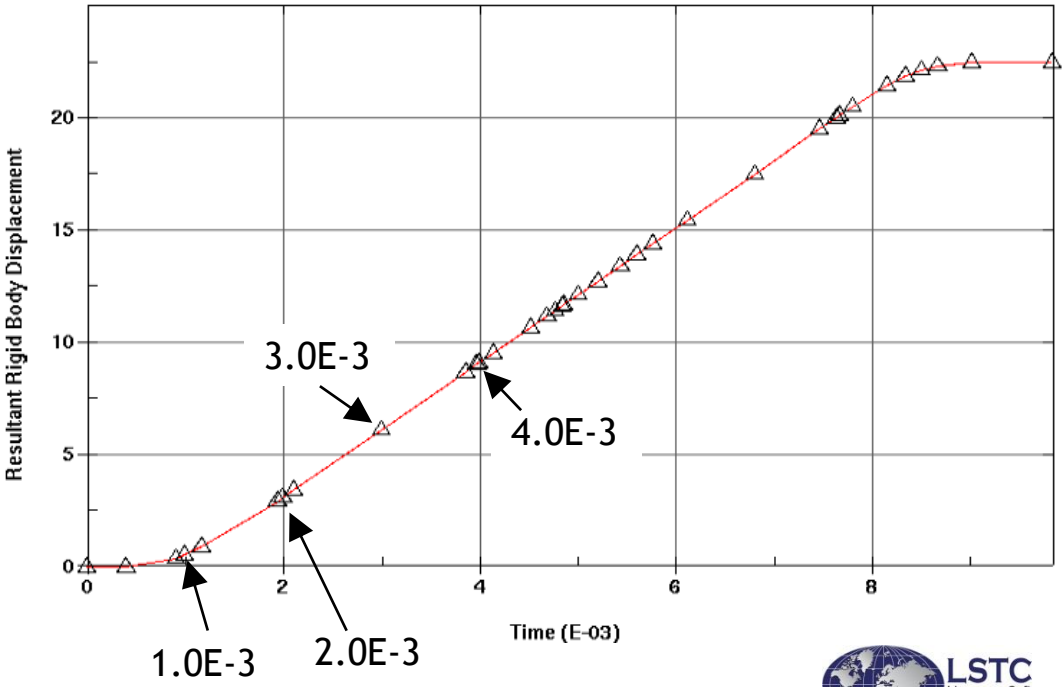
output distance from punch bottom



State plots based on Distance from punch bottom (load curve ID 980)



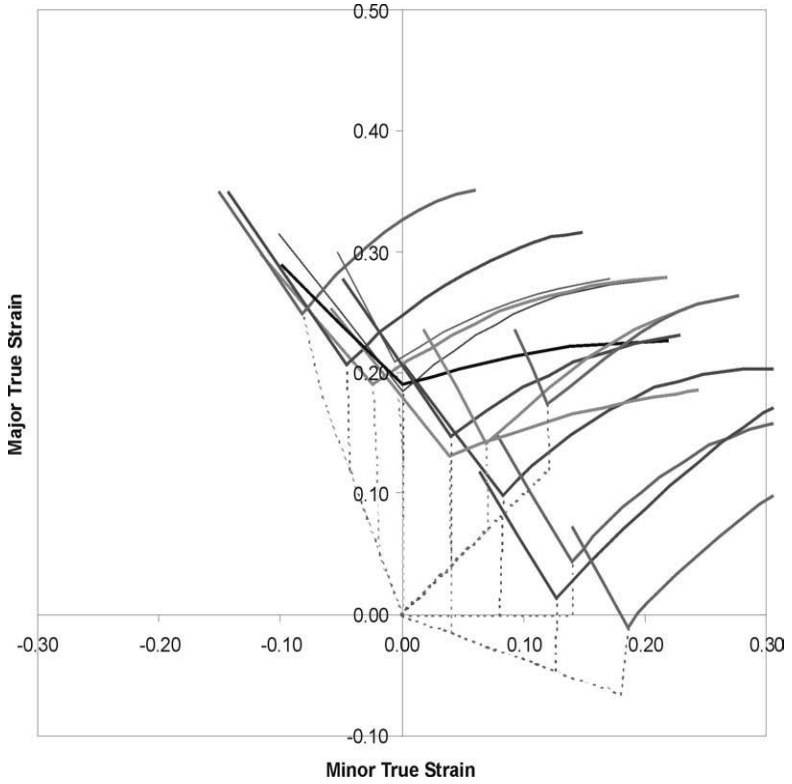
Extra state plots based on simulation time (load curve ID 999)

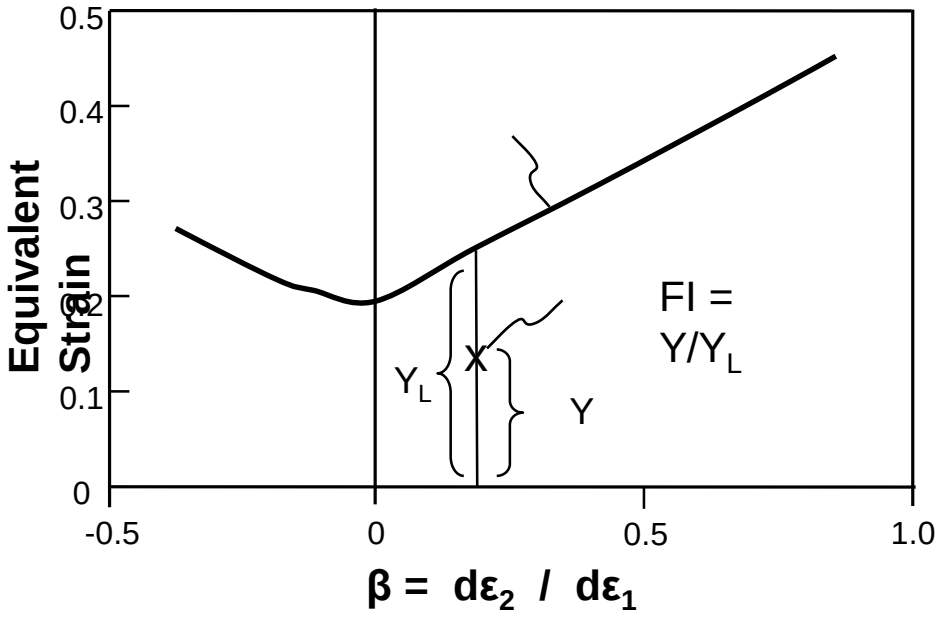


Strain Ratio Smoothing for Failure Prediction under Nonlinear Strain Paths

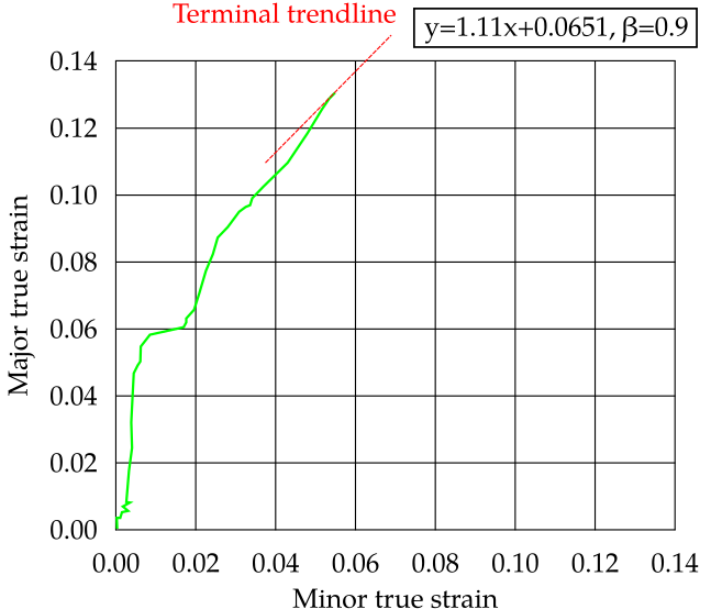
Effect of Non-linear strain path

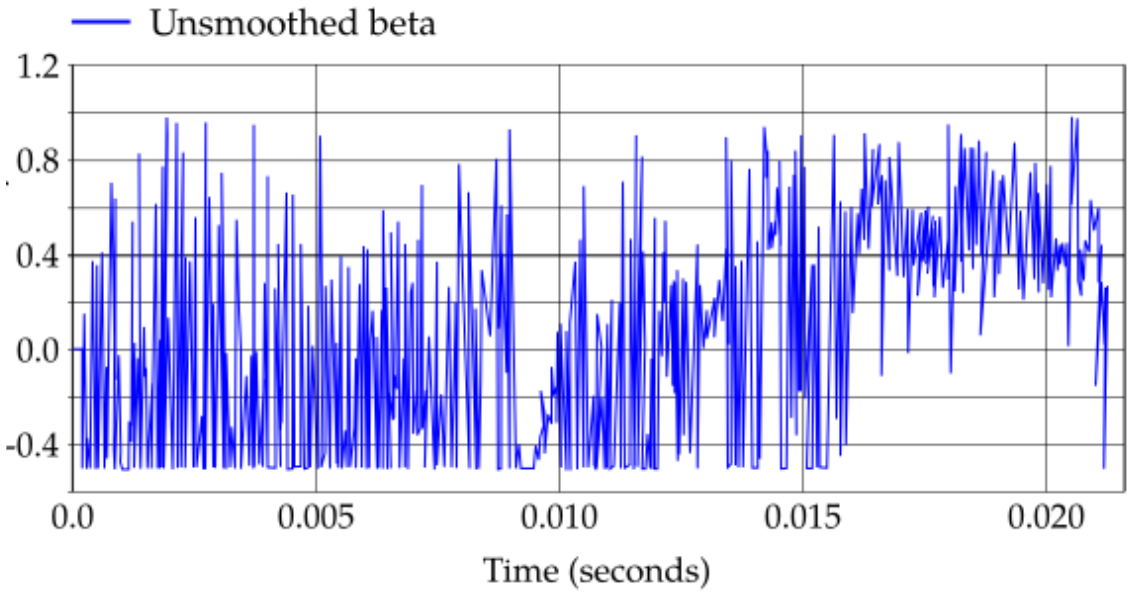
- Effect of non-linear strain path and FI





Real Strain Ratio is Noisy





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Issue:

- Choppy strain ratio affects Formability Index (F.I.) calculation

New keyword:

- **`*CONTROL_FORMING_TOLERANC`** (developed jointly with the Ford Motor Company)
- Applicable to *MAT_037 and *MAT_036 nonlinear strain path option (NLP).
- Smoothed history variables:
  - #1 - F.I.
  - #2 - β (strain ratio)
  - #3 - effective plastic strain
- Additional outputs to ".o" file (batch queue scratch file)

Advantage:

Much less noisy strain ratio output, better terminal strain ratio correlation.

DT/CYCLE.LT.0: The absolute value is the time interval between outputs.
DT/CYCLE.GT.0: Cycle numbers between outputs.

Card 1	1	2	3
Variable	DT/CYCLE	WEIGHT	OUTPUT
Type	F	F	I
Default	none	none	0

Coefficient α in equation:

$$\Delta\epsilon1_{(n-1)} * (1-\alpha) + d\epsilon1_{(n)} * \alpha$$
$$\Delta\epsilon2_{(n-1)} * (1-\alpha) + d\epsilon2_{(n)} * \alpha$$

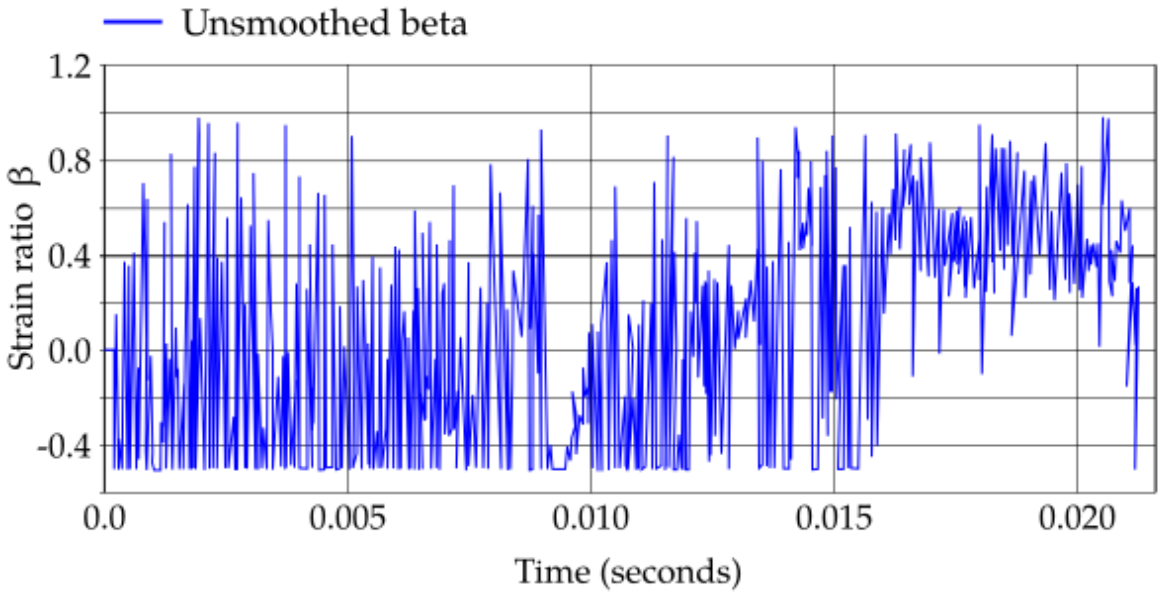
$$\beta = \frac{\Delta\epsilon2_{(n-1)} * (1-\alpha) + d\epsilon2_{(n)} * \alpha}{\Delta\epsilon1_{(n-1)} * (1-\alpha) + d\epsilon1_{(n)} * \alpha}$$

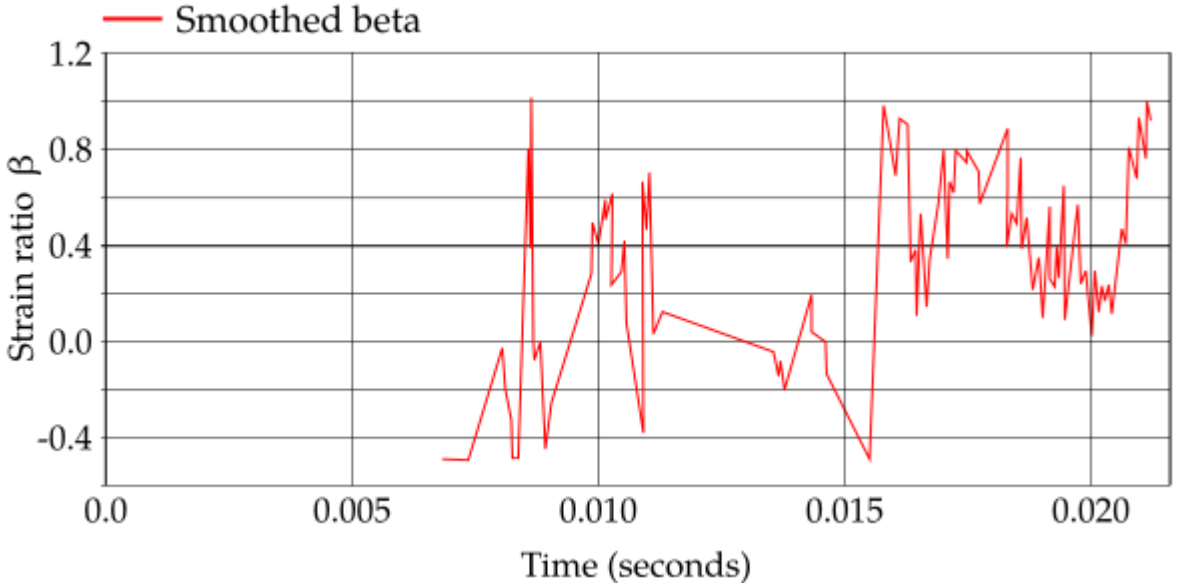
$$-\frac{\bar{r}}{1+\bar{r}} < \beta < 1$$

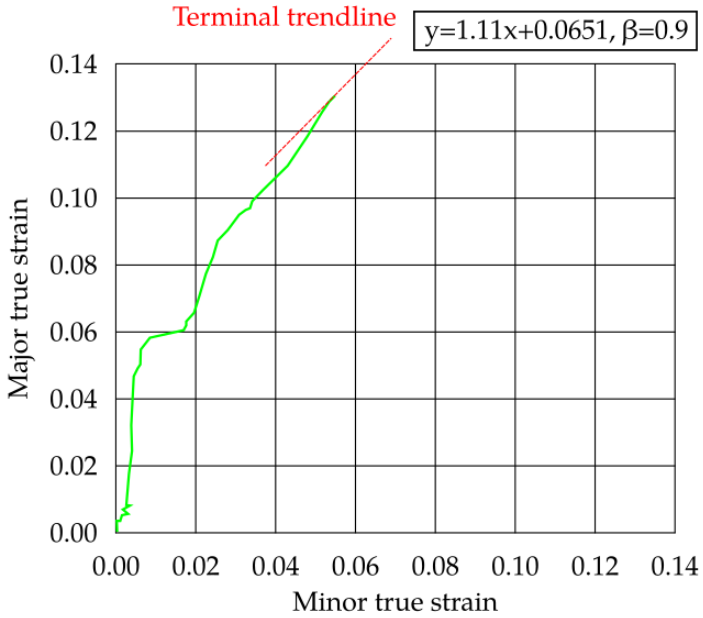
Output flag. When OUTPUT is set to 1, information such as integration point, element ID, time, strain ratio β, major and minor strains will be output to the ".o" file.

Output items	IP #	Element ID	Time	β	$\epsilon1$	$\epsilon2$
Columns	1st to 8th	9th to18th	19th to 29th	30th to 40th	41th to 51th	52th to 62th

Table 0-1. ".o" file output information and positions. Note only the mid-IP information are output.







Summary

- Many new features are developed and in production use.
- LSTC continue to work with our users to meet their future requirements.