

## Advances in LS-DYNA<sup>®</sup> Metal Forming (I)

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### Abstract

*Some of the new features developed since the last conference will be discussed.*

- 1) *Movable adaptive fission/fusion box*  
*The movable fission/fusion box is an essential enabler in completing a simulation in a efficient manner, especially in cases where deformation is relatively localized. Related keywords include: \*CONTROL\_ADAPTIVE, \*DEFINE\_BOX\_ADAPTIVE.*
- 2) *Checking fixture clamp definition and simplification of FORMING contact definition*  
*The keywords, \*DEFINE\_FORMING\_CLAMP, \*DEFINE\_FORMING\_CONTACT, are created to ease the user definition of checking fixture clamps and contacts definition.*
- 3) *New options in \*INTERFACE\_BLANKSIZE*  
*Additional features under this keyword allow users to include/exclude a particular trim lines and to define symmetric conditions for the part, using keywords: \*INTERFACE\_BLANKSIZE\_SCALE\_FACTOR, \*INTERFACE\_BLANKSIZE\_SYMMETRIC\_PLANE.*
- 4) *Some major improvements to \*CONTROL\_FORMING\_SCRAP\_FALL*  
*In conjunction with the Ford Motor Company, the original “Constraint Release” method is evolved into the “Scrap Trimming” method, making the scrap trimming and fall simulation much more closer to reality.*
- 5) *2D and 3D trimming of solids and laminates*  
*An important feature in metal forming simulation using solid elements and laminates, 2D and 3D trimming are now available.*
- 6) *Automatic offset of tool element/node IDs*  
*The creation of the keyword \*INCLUDE\_AUTO\_OFFSET enables user to offset individual tools with overlapping element/node IDs, allowing the user to bypass a metal forming GUI when updating just one or two tooling pieces.*
- 7) *Positioning of unfolded blank in one-step simulation*  
*Allows user to specify three points used to position the unfolded blank relative to the part’s initial position and orientation..*

### Movable Adaptive Fission/Fusion Box

Compared with the original adaptive box, this new feature, implemented in \*DEFINE\_BOX\_ADAPTIVE with new parameters LIDX/NDID, LIDY and LIDZ:

- 1) allows the value of parameter LEVEL to be greater than 1;
- 2) makes the defined box movable;
- 3) removes the restriction of only the original elements within the box are adapted;
- 4) enables mesh fusion.

A typical use of this feature is in roller hemming and incremental forming simulation, where mesh refines as elements enter one box and fused together as they enter another box.

In a partial roller hemming keyword example below, referring to Figure 1, a strip of sheet metal is being roller hemmed. The process consists of pre- and final hemming. Each pre- and final roller

is defined with a moving adaptive box ID 2 and 3, respectively. The first box, a fission box, was set at LEVEL = 3, while the second box, a fusion box, was set at LEVEL = 1. Elements outside of the volume envelope made by the moving boxes undergo no fission and fusion (MAXLVL = 1). This settings allows mesh fission when entering the moving box 2 (LEVEL = 3), fusion only when elements entering the moving box 3 (LEVEL = 1), no fusion/fusion (MAXLVL = 1) at all outside of the volume envelope created by the moving boxes. Futhermore, the boxes 2 and 3 are to be moved in global X direction for a distance of 398mm defined by load curve 11, and 450mm defined by load curve 12, respectively.

```
*CONTROL_TERMINATION
...
*CONTROL_ADAPTIVE
$ ADFREQ ADPTOL ADPOPT MAXLVL TBIRTH TDEATH LCADP IOFLAG
8.05E-4 0.200000 2 1 0.0001.0000E+20 0 1
$ ADPSIZE ADPASS IREFLG ADPENE ADPTH MEMORY ORIENT MAXEL
0.300000 1 0 5.0
$ IADPN90 NCFREQ IADPCL ADPCTL CBIRTH CDEATH
-1 0 1 1 10.0 0.000 10.30
*DEFINE_BOX_ADAPTIVE
$# BOXID XMN XMN YMN YMX ZMN ZMX
2 -10.00000 36.000000 -15.03000 3.991000 1.00E+00 48.758000
$# PID LEVEL LIDX/NDID LIDY LIDZ
6 3 11
*DEFINE_BOX_ADAPTIVE
$# BOXID XMN XMN YMN YMX ZMN ZMX
3 -100.0000 -60.0000 -15.03000 3.991000 1.00E+00 48.758000
$# PID LEVEL LIDX/NDID LIDY LID
6 1 12
*DEFINE_CURVE
11
0.000 0.0
0.00100000 1.0
0.19900000 397.0
0.20000000 398.0
1.000 398.0
*DEFINE_CURVE
12
0.0 0.0
0.05 0.0
0.051 1.0
0.251 401.0
0.252 450.0
: :
```

The box can also follow a node, which can be on a moving rigid body (a roller, for example). Load curves defining the boxes' movement can be skipped, instead, NDIDs for the boxes should be defined. In the example below, box 2 will be following node #33865 on the pre-roller, and box 3 to follow node #38265 on the final roller.

```
*DEFINE_BOX_ADAPTIVE
$# BOXID XMN XMN YMN YMX ZMN ZMX
2 -10.00000 36.000000 -15.03000 3.991000 1.00E+00 48.758000
$# PID LEVEL LIDX/NDID LIDY LID
6 3 -33865
*DEFINE_BOX_ADAPTIVE
$# BOXID XMN XMN YMN YMX ZMN ZMX
3 -100.0000 -60.0000 -15.03000 3.991000 1.00E+00 48.758000
$# PID LEVEL LIDX/NDID LIDY LID
6 3 -38265
```

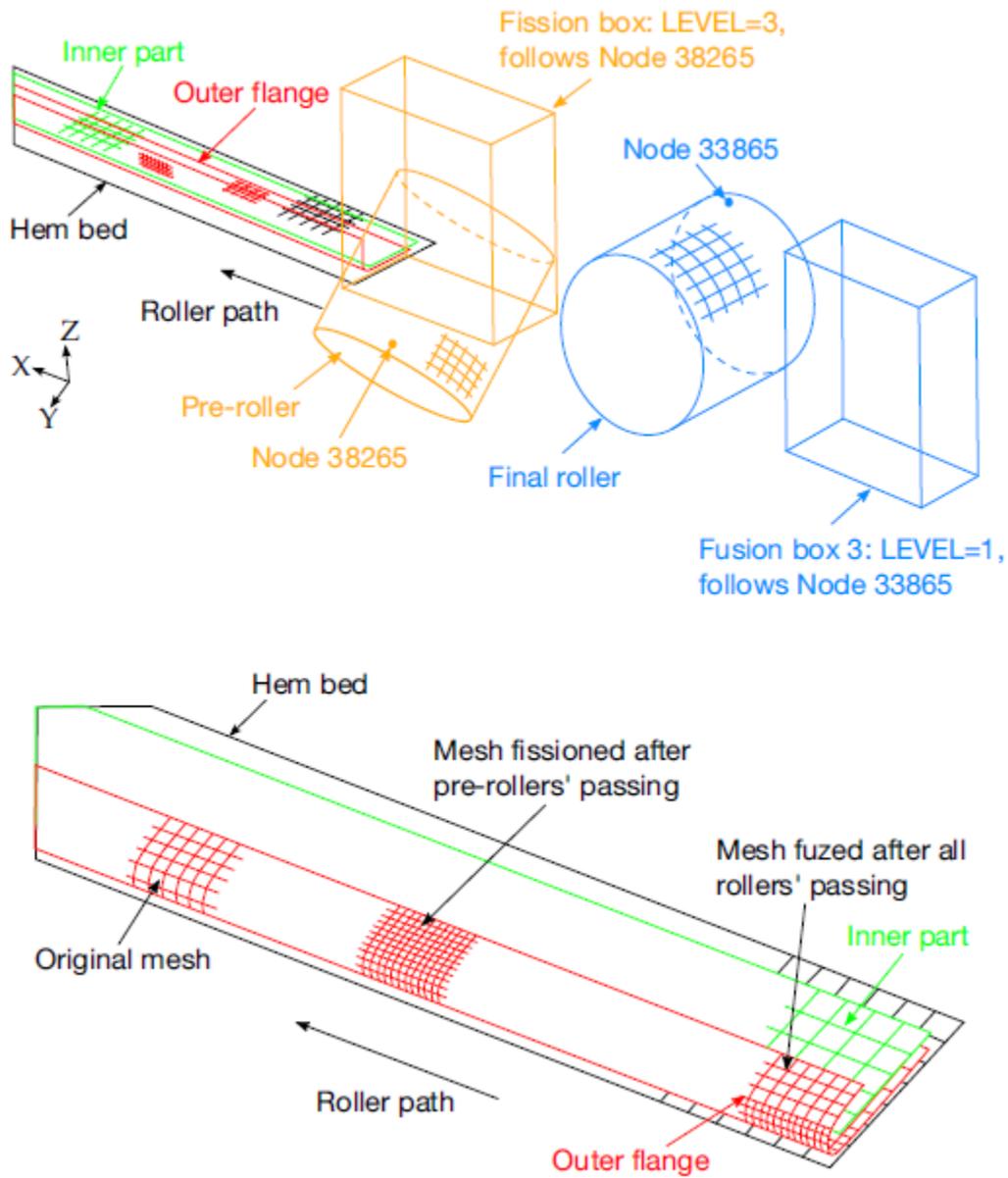


Figure 1. Define a moving fission and a fusion box.

### Checking Fixture Clamp/Contact Definition

Clamping of formed/trimmed panel on a checking fixture is sometimes used for springback prediction. The new feature, implemented in keywords `*DEFINE_FORMING_CLAMP` and `DEFINE_FORMING_CONTACT`:

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

A partial keyword example of using the feature is listed below. Referring to Figures 2 and 3,, the drawn and trimmed blank is positioned between the clamps CLP1 and CLP2. The implicit termination “time” is set at 1.0, with a stepping size of 0.25, for a total of four steps – two steps each for the two CLP1. With the original blank thickness of 1.0 mm, the CLP1s are set to close with the lower CLP2s at “time” of 1.0, leaving a total GAP of 1.02 mm. Note the VIDs are defined as “-46980”, indicating that the moving clamps (CLP1) will move in the normal direction defined by Node #46980. The contact definition between the panel and the clamps are defined using `*DEFINE_FORMING_CONTACT`.

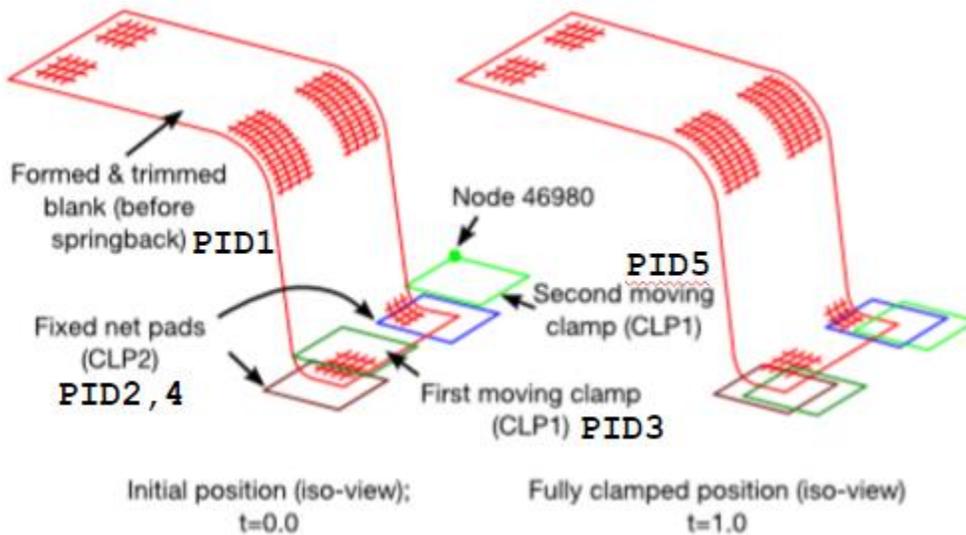


Figure 2. Variable definition for `*DEFINE_FORMING_CLAMP` and `*DEFINE_FORMING_CONTACT`

```
*KEYWORD
*INCLUDE
./trimmed.dynain
./nets.k
*CONTROL_TERMINATION
1.0
*CONTROL_IMPLICIT_forming
1
*control_implicit_general
1,0.25
*CONTROL_SHELL
```

```

:
*DATABASE_EXTEND_BINARY
:
*PART
Blank
$ PID SECID MID
1 1 1
Clamp1
2,2,2
Clamp2
3,2,3
Clamp3
4,2,2
Clamp4
5,2,3
*MAT_TRANSVERSELY_ANISOTROPIC_ELASTIC_PLASTIC
$ MID RO E PR SIGY ETAN R HLCID
1 2.700E-09 12.00E+04 0.28 0.0 0.0 0.672 2
*MAT_RIGID
$# mid ro e pr n couple m alias
2 7.8500E-9 2.1000E+5 0.300000
$# cmo con1 con2
1.000000 7 7
$# lco or a1 a2 a3 v1 v2 v3
0.000 0.000 0.000 0.000 0.000 0.000
*MAT_RIGID
$# mid ro e pr n couple m alias
3 7.8500E-9 2.1000E+5 0.300000
$# cmo con1 con2
1.000000 4 7
$# lco or a1 a2 a3 v1 v2 v3
*SECTION_SHELL
1,16,,7
1.0,1.0,1.0,1.0
*LOAD_BODY_Z
9997 1.0
*DEFINE_CURVE
9997
0.0000 9810.0000
1.0000 9810.0000
*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
*END

```

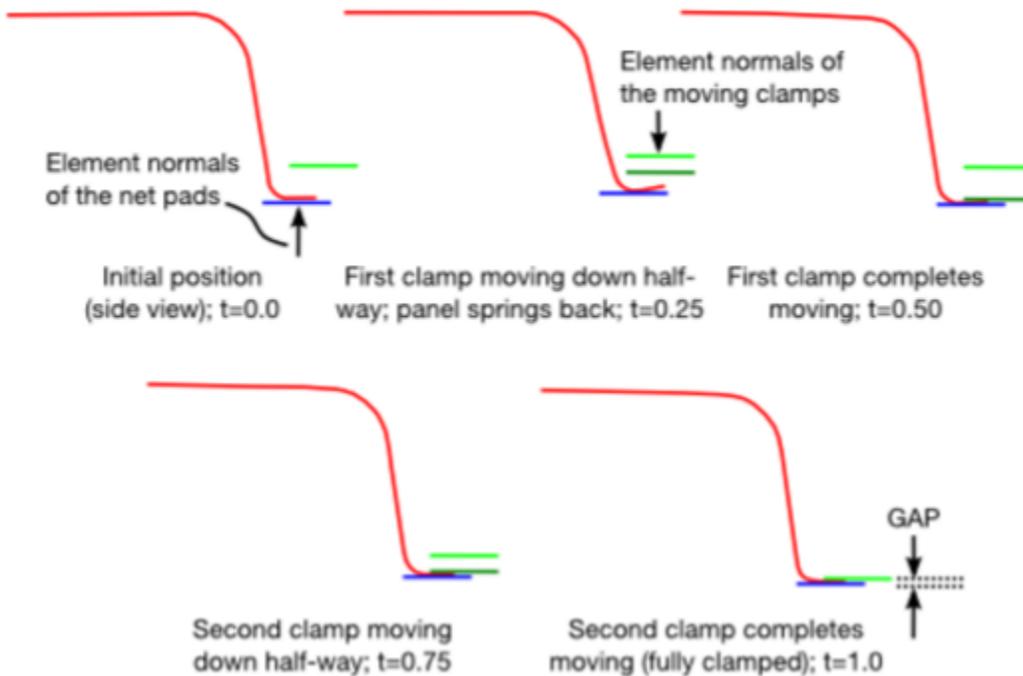


Figure 3. A clamping example for *\*DEFINE\_FORMING\_CLAMP*, and *\*DEFINE\_FORMING\_CONTACT*.

### New Options in Blank Size Development

New features associated with *\*INTERFACE\_BLANKSIZE* consist of an option for a scale factor (*SCALE\_FACTOR*) to allow users to include or exclude a particular target curve for optimization, and an option to define symmetric boundary condition with (*SYMMETRIC\_PLANE*).

In an example below, referring to Figures 4 and 5, and input file below, a symmetric plane is defined with a point coordinates (X0, Y0, Z0) through which the plane lies along with the vector components (1.0, 0.0, 0.0) of the plane normal. Target curves 2 (inner hole) and 3 (blank outer boundary) will be optimized in shape, size and location (SF=1.0), while curve 1 (another inner hole) will be left alone (SF=0.0). After 2 iterations of optimization, the initial blank is modified to achieve to final target curves in terms of the blank size and inner holes, Figures 5, 6 and 7.

```

*KEYWORD
$---+---1---+---2---+---3---+---4---+---5---+---6---+---7---+---8
*INTERFACE_BLANKSIZE_DEVELOPMENT
$ IOPTION IADAPT
      -2      1
$ target boundary curves:
targetline.k
$ final formed mesh:
final.k
$ initial mesh:
initial.k
*INTERFACE_BLANKSIZE_SCALE_FACTOR
$ IDCRV SF
    
```

```

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
    
```

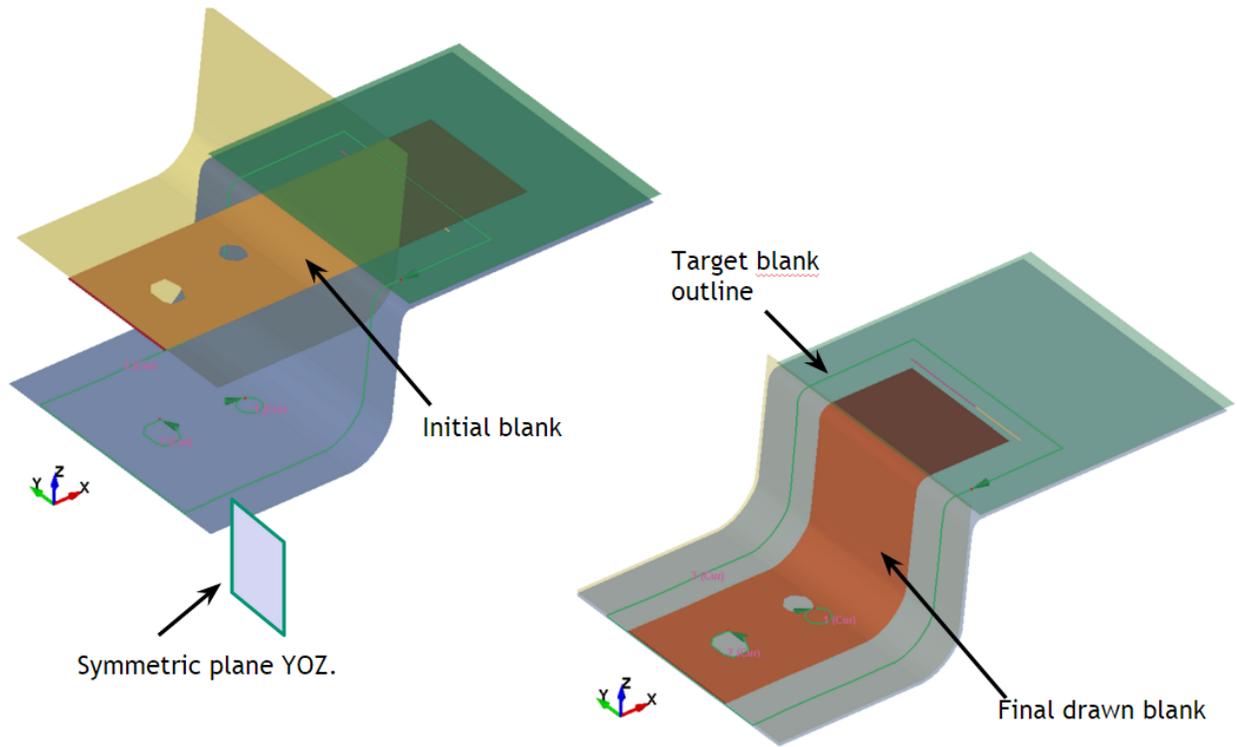


Figure 4. A channel in deep draw, one-half model with symmetric plane.

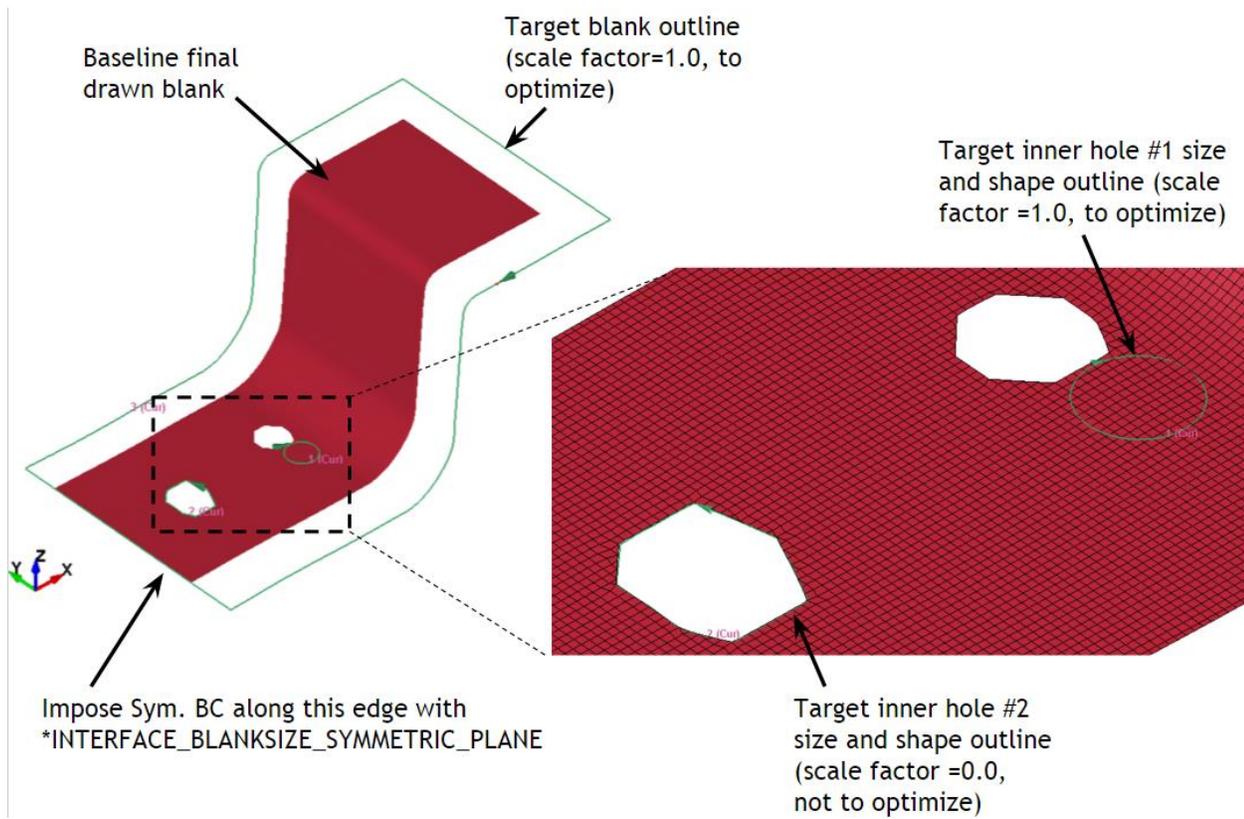


Figure 5. Baseline simulation.

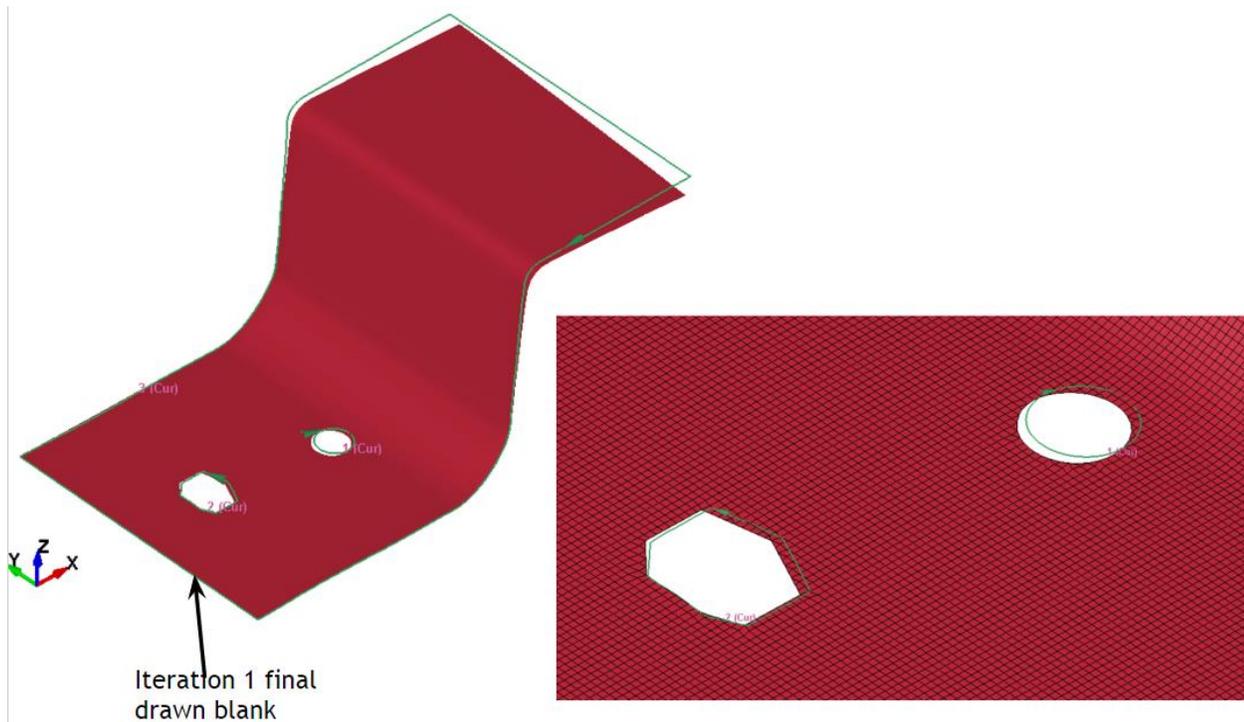


Figure 6. Iteration 1 result.

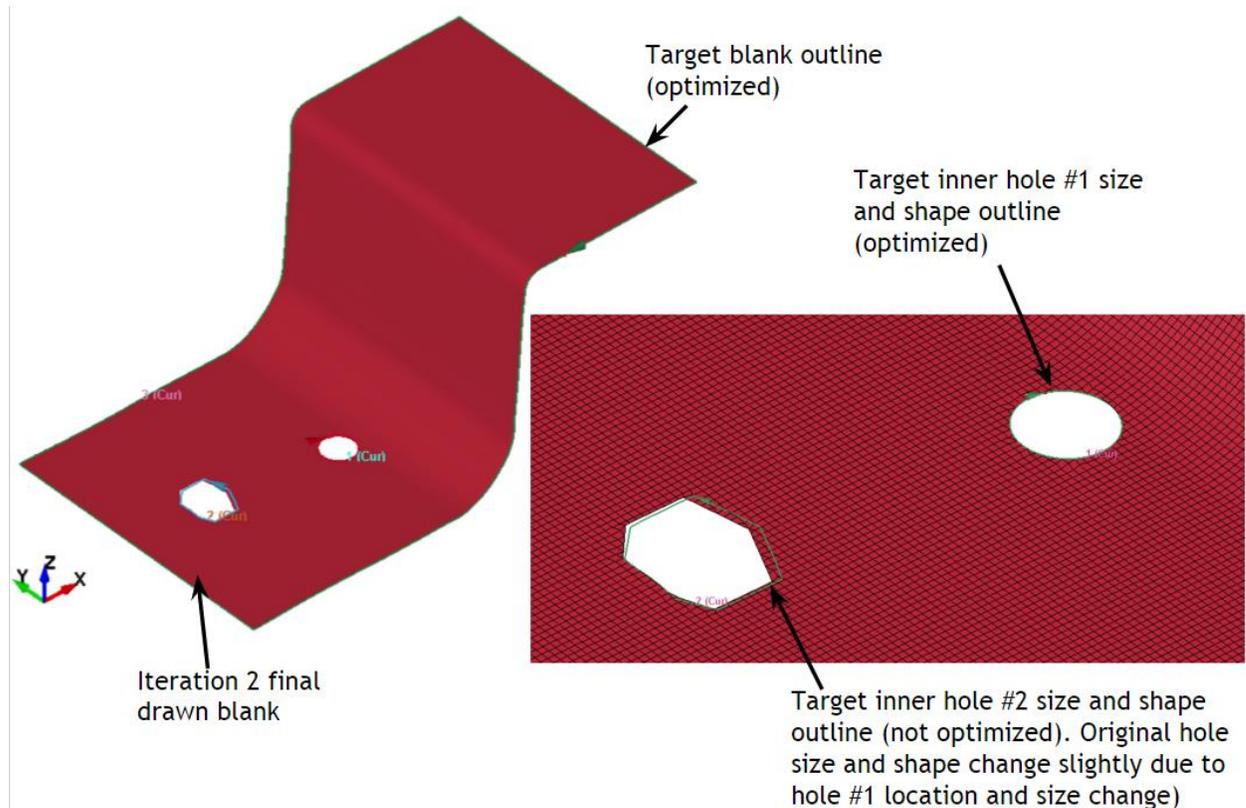


Figure 7. Iteration 2 result.

## Major Improvements in Scrap Trim/Fall Simulation

Working together with the Ford Motor Company, the improvements, with the additions of many parameters (IDRGD, IFSEED, NDBEAD, SEEDX, SEEDY, SEEDZ, EFFSET, GAP, IPSET, EXTEND and NEWID) in \*CONTROL\_FORMING\_SCRAP\_FALL, address the following issues:

- 1) No scrap trimming: scrap piece cannot be trimmed directly from the parent piece.
- 2) Badly (or coarsely) meshed draw beads in tooling initially interfere with badly meshed draw beads on the scrap (they do not fit together), causing initial interference during contact initialization.
- 3) For badly (or coarsely) meshed tooling mesh and scrap edges, users have to manually modify the scrap trim edges so it does not interfere with tools initially.
- 4) User must clear all other initial interferences (e.g. between scrap and scrap cutter) manually.

As shown in Figure 8, one single sheet metal can be trimmed into a parent piece and a scrap piece, by defining the seed node coordinates for the scrap and assigning new PIDs for the scrap and the parent. The scrap will be trimmed along the NSET defined. To minimize the initial contact interferences due to the bad trim lines, EXTEND and EFFSET are created to ensure a

proper trimming, and falling of the scrap.

By defining NDBEAD, badly defined and meshed male beads that do not fit the corresponding female beads on the die can be released from the trimming process, ensuring proper fall of the scrap, shown in Figure 9.

In Figure 10, a part set ID and a GAP can be defined to automatically remove the initial interference between the scrap cutter and scrap piece, or interference between any part and scrap.

One original sheet metal can be trimmed into multiple scrap pieces and one parent piece, by defining multiple NEWIDs, as shown in Figures 11 and 12.

The new features dramatically reduced engineering time in getting the model ready for a successful scrap simulation, Figure 13.

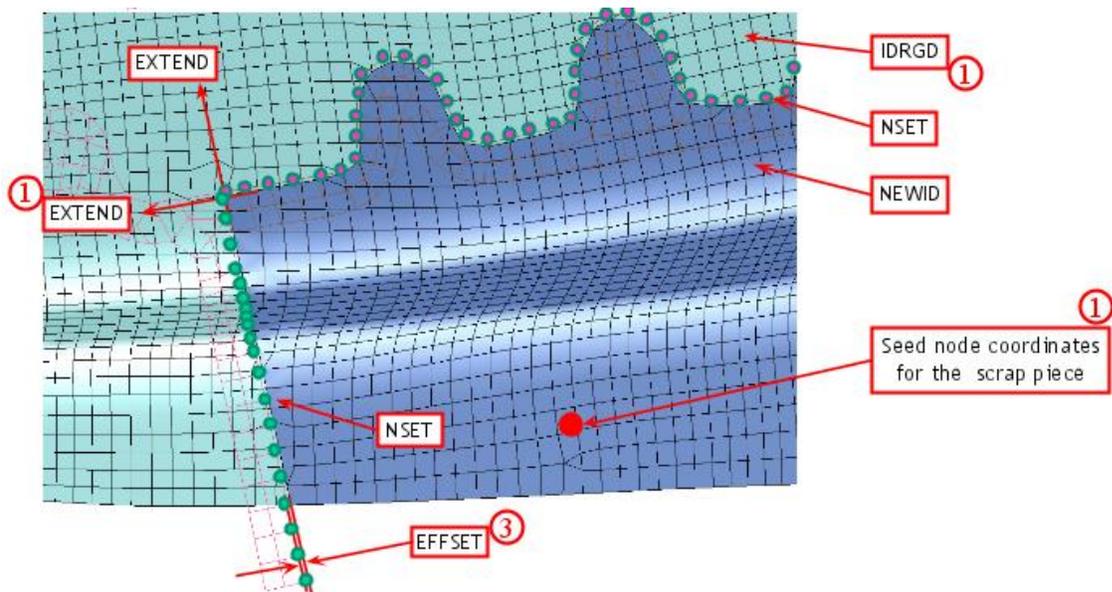


Figure 8. Trimming of scrap piece.

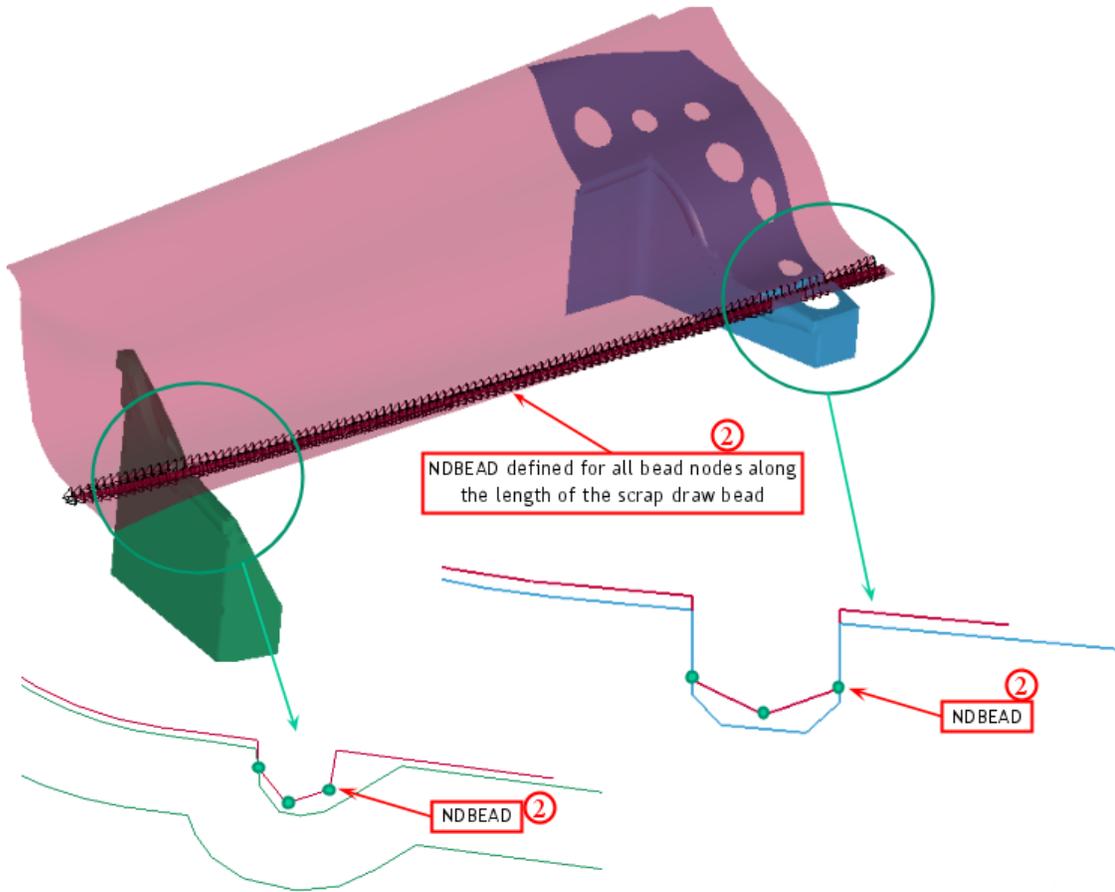


Figure 9. Fixing initial interference between male and female beads.

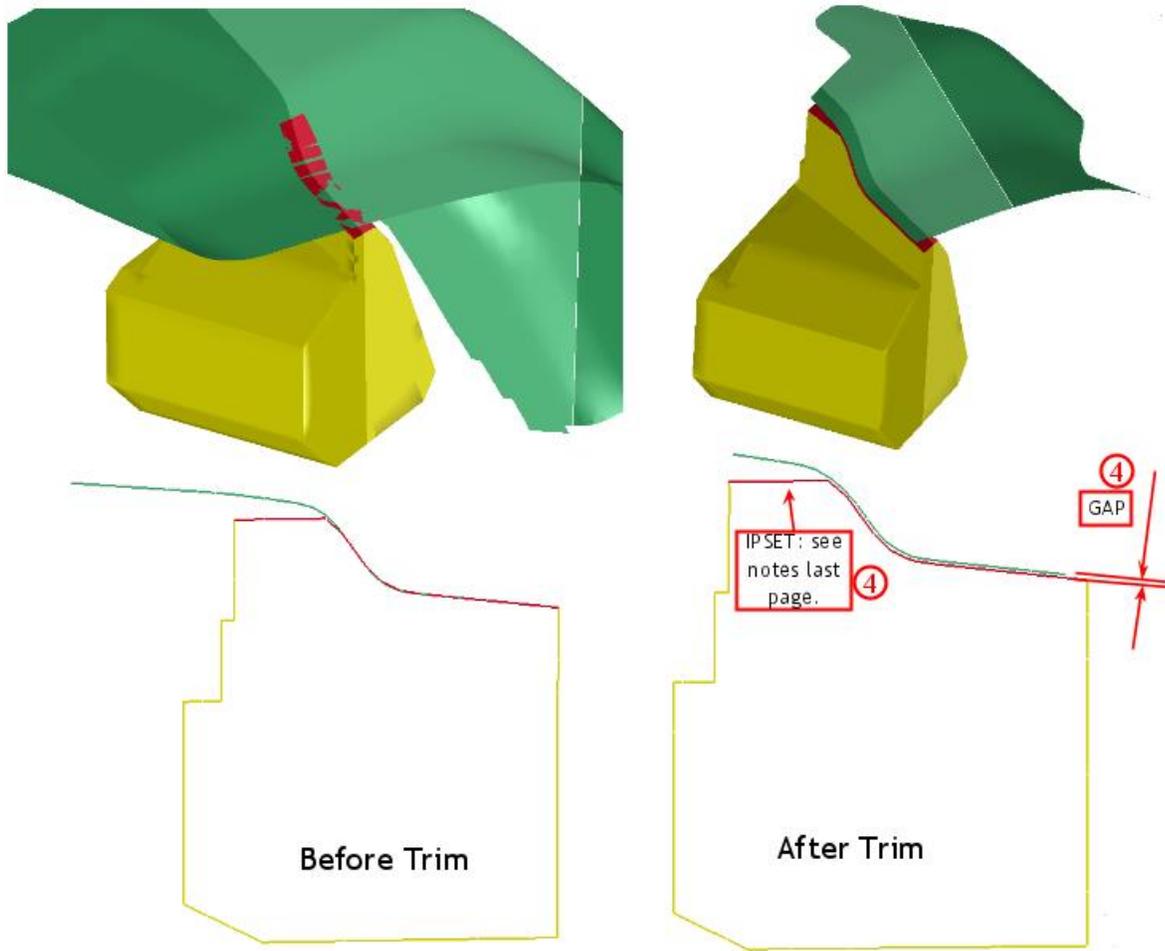


Figure 10. Fixing initial interference between scrap and scrap cutter.

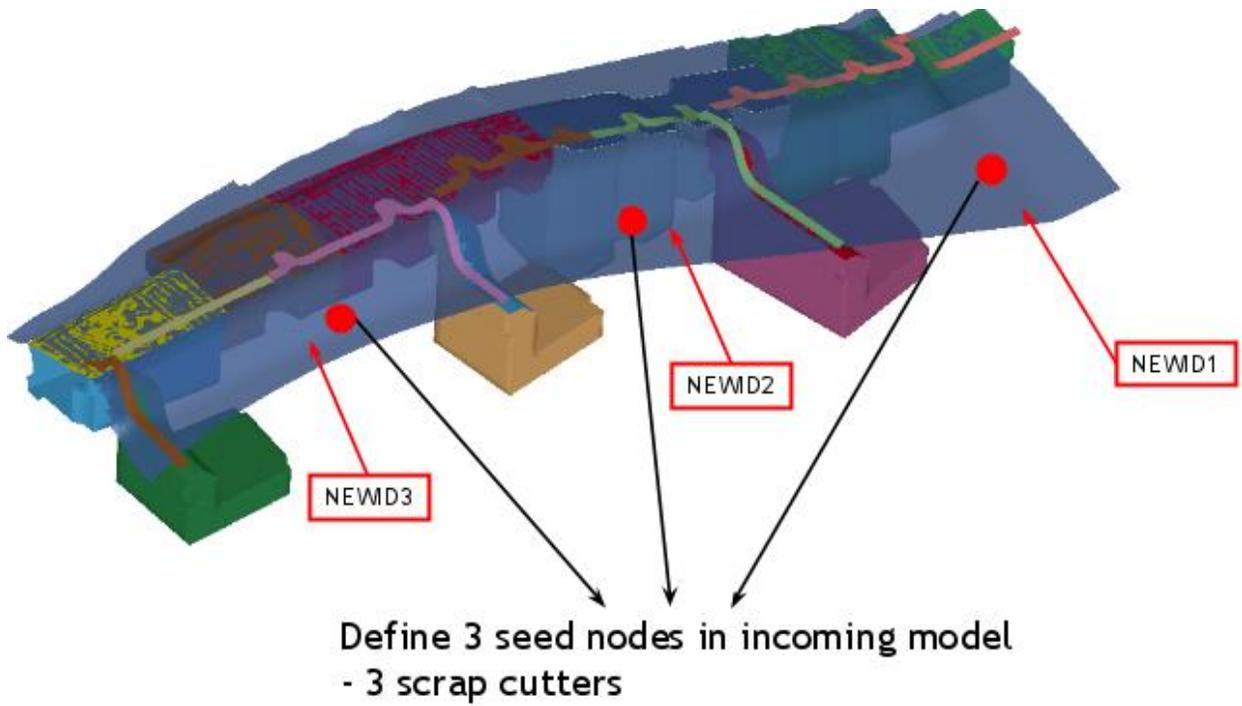


Figure 11. Trimming of multiple scraps - definition.

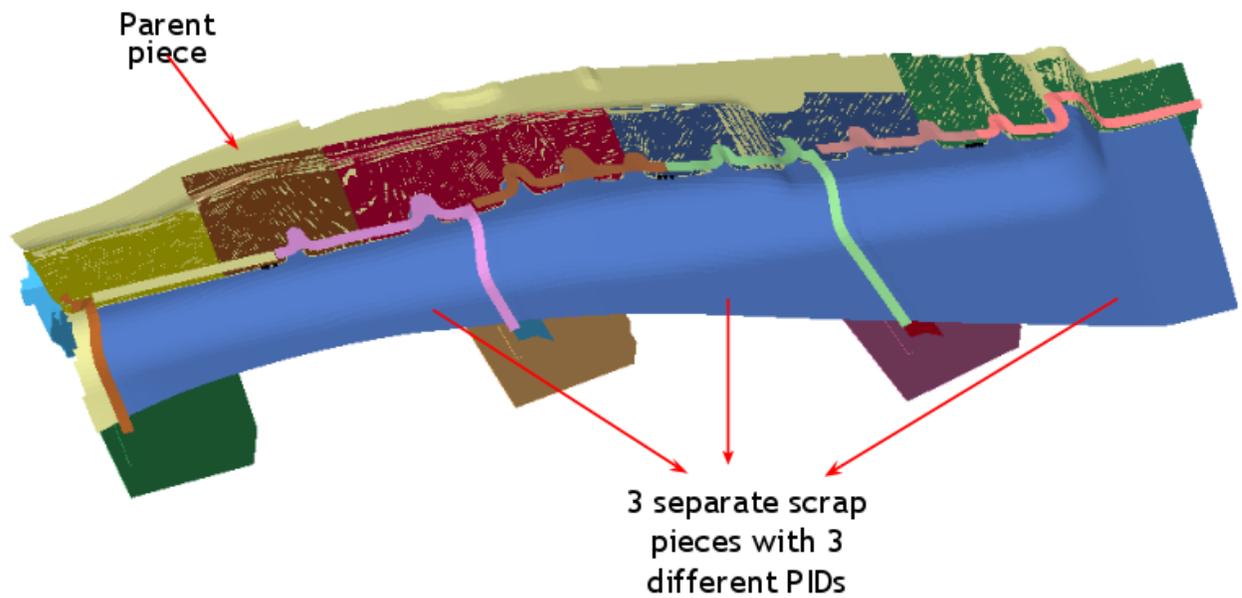


Figure 12. Trimming of multiple scraps - initialized result.

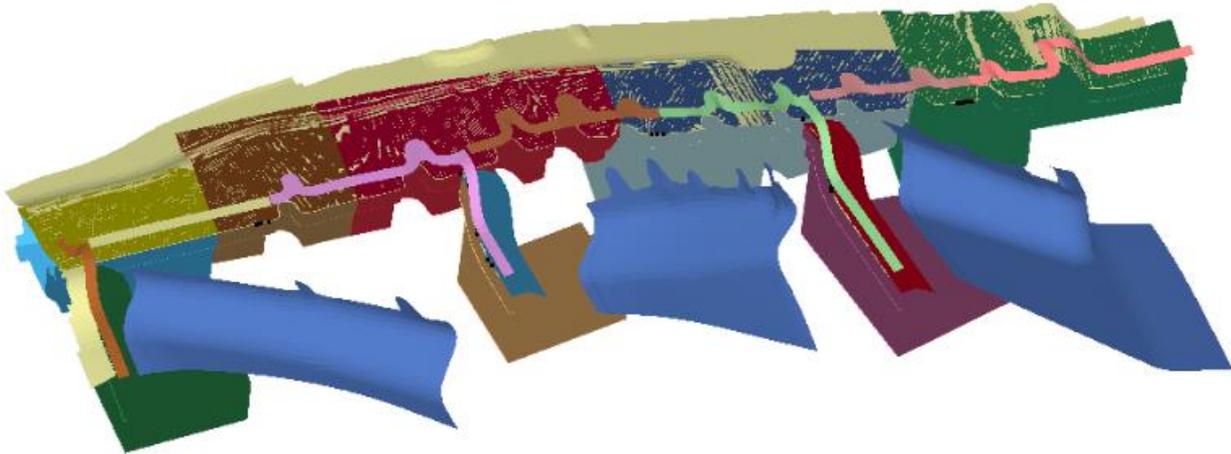


Figure 13. A successful scrap trim and fall simulation (all figures related to scrap trim/falls are courtesy of the Ford Motor Company).

## 2-D and 3-D Trimming of Solids and Laminates

New capabilities in trimming enables trimming of solid elements and laminates. The trimming keywords used for solids and laminates are the same as those for shells, except users need to indicate the position of the trim curves. The parameter TDIR in \*DEFINE\_CURVE\_TRIM\_3D needs to be set to “1” if the curves are located on the top surface of the solids; set to “-1” if they are on the bottom surface. Normal directions of solids can be viewed using LS-PrePost<sup>®</sup> 4.2. An example of the 2-D trimming of solids is shown in Figure 14.

For trimming of laminates, one more parameter needs to be set (ITYP=1 in \*CONTROL\_FORMING\_TRIMMING) to invoke the feature. Laminates are defined as a multiple layers of solid cores sandwiched by a layer of top and bottom shells (Figure 15). Shell and solids share common nodes. An example of trimming on laminates is shown in Figure 16.



Figure 14. 2-D trimming of solid elements.

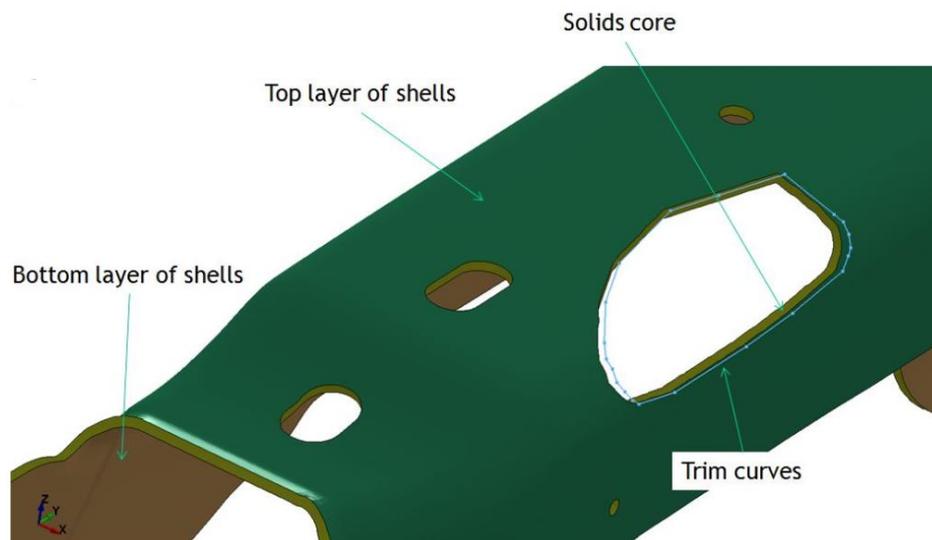


Figure 15. Laminates with a trim curve.

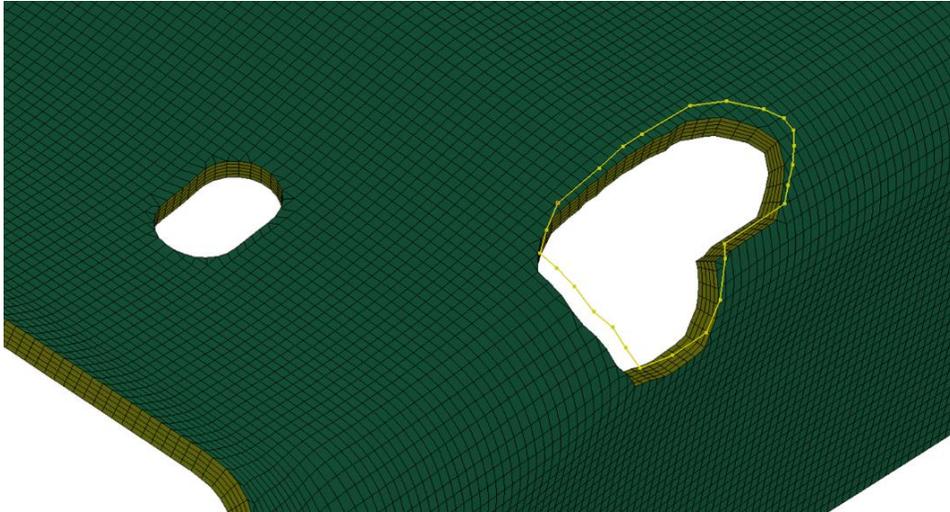


Figure 16. 3-D trimming of Laminates.

### Auto Offset of Tool Element/Node IDs

In a multi-stage automatic line die simulation the adaptivity feature may generate node and element IDs that collide with those of the tools used in the later stages of the process. Before the calculation begins, the set of IDs used by the tools is known. By setting MAXIDN to a value greater than the largest tool node ID and MAXIDE to a value greater than the largest tool element ID, it is guaranteed that mesh refinement during the early stages will not lead to conflicts with tool IDs in the later stages.

The following example shows this feature applied in a 2D trimming simulation. Nodes and elements ID numbers generated from an adaptive trim simulation will be larger than the specified ID numbers of 5921980 and 8790292, respectively, for a sheet blank with part ID of 4.

```
*KEYWORD
*INCLUDE_TRIM
sim_trimming.dynain
:
*CONTROL_ADAPTIVE_CURVE
$ IDSET ITYPE N SMIN
&blksid 2 2 0.6
*CONTROL_CHECK_SHELL
$ PSID IFAUTO CONVEX ADPT ARATIO ANGLE SMIN
&blksid1 1 1 1 0.250000150.000000 0.000000
*INCLUDE
EZtrim.k
$---+---1---+---2---+---3---+---4---+---5---+---6---+---7---+---8
*DEFINE_CURVE_TRIM_NEW
$# tcid tctype tflg tdir tctol toln nseed1 nseed2
90914 2 0 1 1.250000 1.000000 0 0
sim_trimming_trimline_01.igs
*DEFINE_VECTOR
$# vid xt yt zt xh yh zh cid
1 0.000 0.000 0.000 0.000 0.000 1.000000 0
*CONTROL_FORMING_MAXID
$ pid maxidn maxide
4 5921980 8790292
```

\*END

## Position of Blank in One-Step Simulation

Often times the input to one-step simulation is the final product part in the car axes. However, after the simulation, the unfolded part is in a different orientation and position, requiring users to manually reposition the part to its desired orientation and position. The new feature (NODE1, NODE2, NODE3) in \*CONTROL\_FORMING\_ONESTEP allows users to specify three nodes on the unfolded blank; the unfolded blank will be repositioned onto the final part (the input) superimposing the exact same three nodes in both parts. In an example shown in Figure 17, the three nodes (Nodes 197, 210 and 171) are defined near the edges of two holes. The transformed and unfolded flat blank (written in a keyword file “repositioned.k”) is seen superimposed onto the final part according to the three nodes specified. If these nodes are not defined, the simulation will result in the unfolded flat blank in a state shown in Figure 18, undesirable to most users.

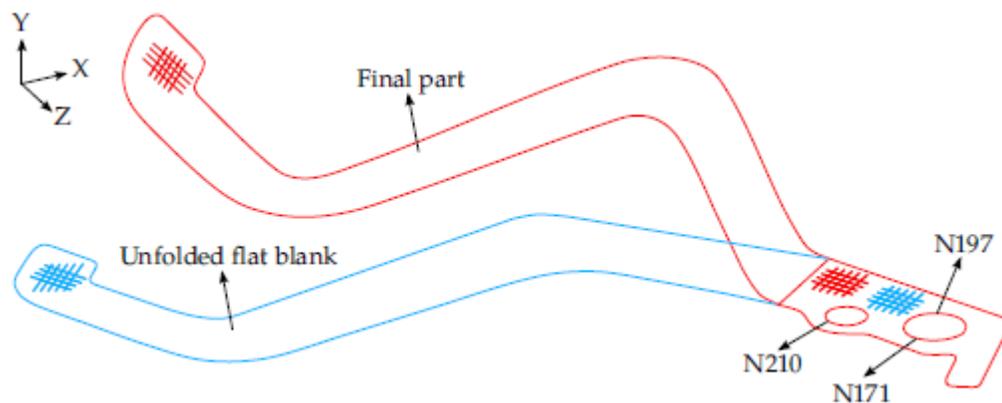


Figure 17. Unfold results using auto-reposition feature.

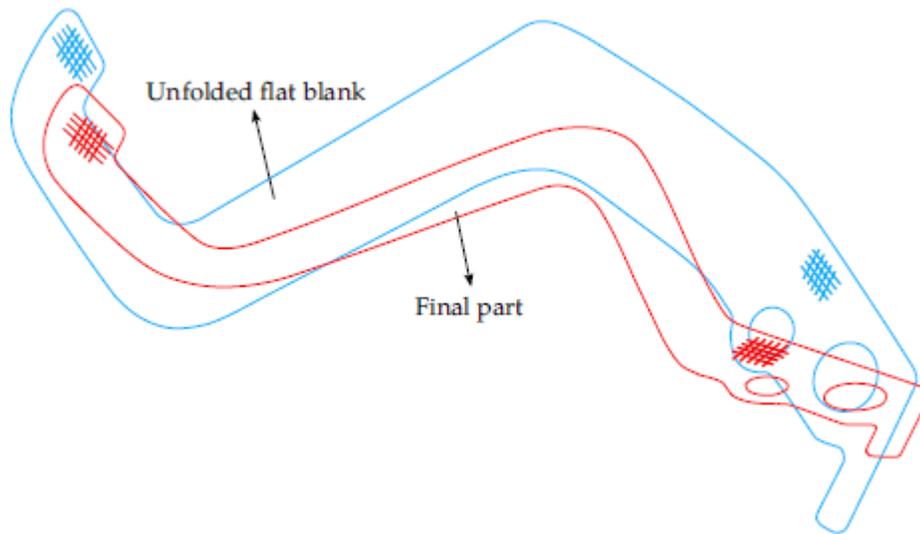


Figure 18. Unfold results without using auto-reposition feature, courtesy of Kaizenet Technologies Pvt Ltd, India.

### Summary

Several new features related to metal forming application were developed, tested and applied in production environment over the past two years. LSTC will continue to work with our user community to meet the future challenges facing the metal forming industry.

### References

1. *LS-DYNA User's Manual I, II.*