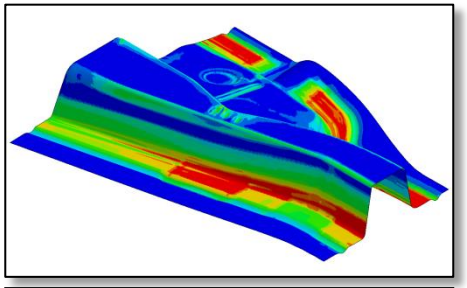

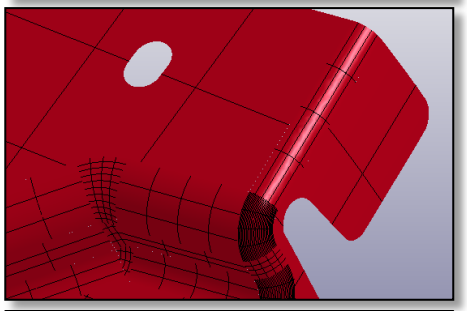

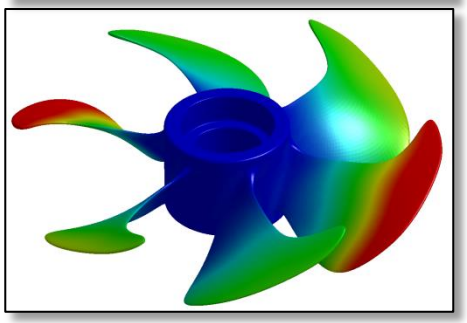

# Sheet metal forming simulation with IGA in LS-DYNA


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LSTC, Livermore, CA, USA

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**15th German LS-DYNA Forum, Bamberg, Germany**

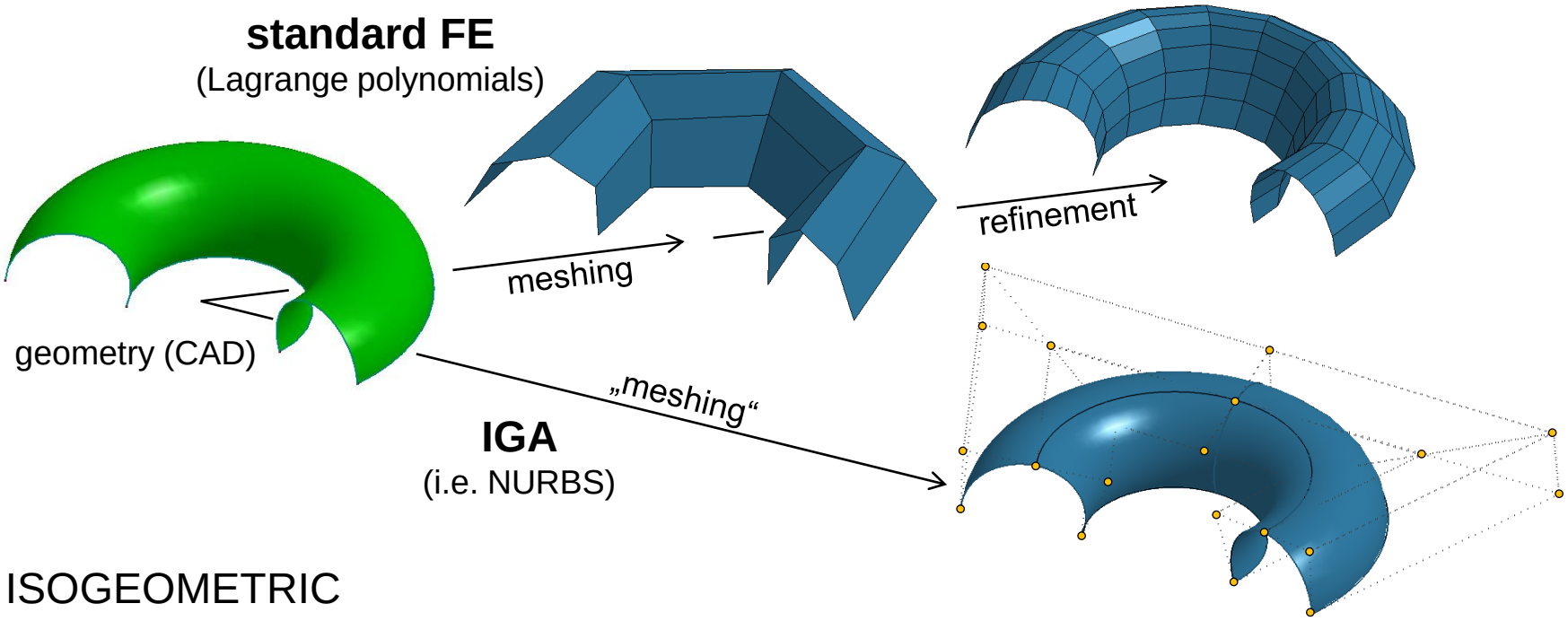
June 10-12, 2018

# Outline

- Introduction to IGA in LS-DYNA
  - Motivation & Definition
  - NURBS-based finite elements in LS-DYNA
  - Analysis capabilities
- A multistage sheet metal forming process
  - Stage 1 – Gravity
  - Stage 2 – Deep drawing
  - Stage 3 – Trimming
  - Stage 4 – Springback analysis
- Summary and Outlook

# Isogeometric Analysis (IGA) – motivation & definition

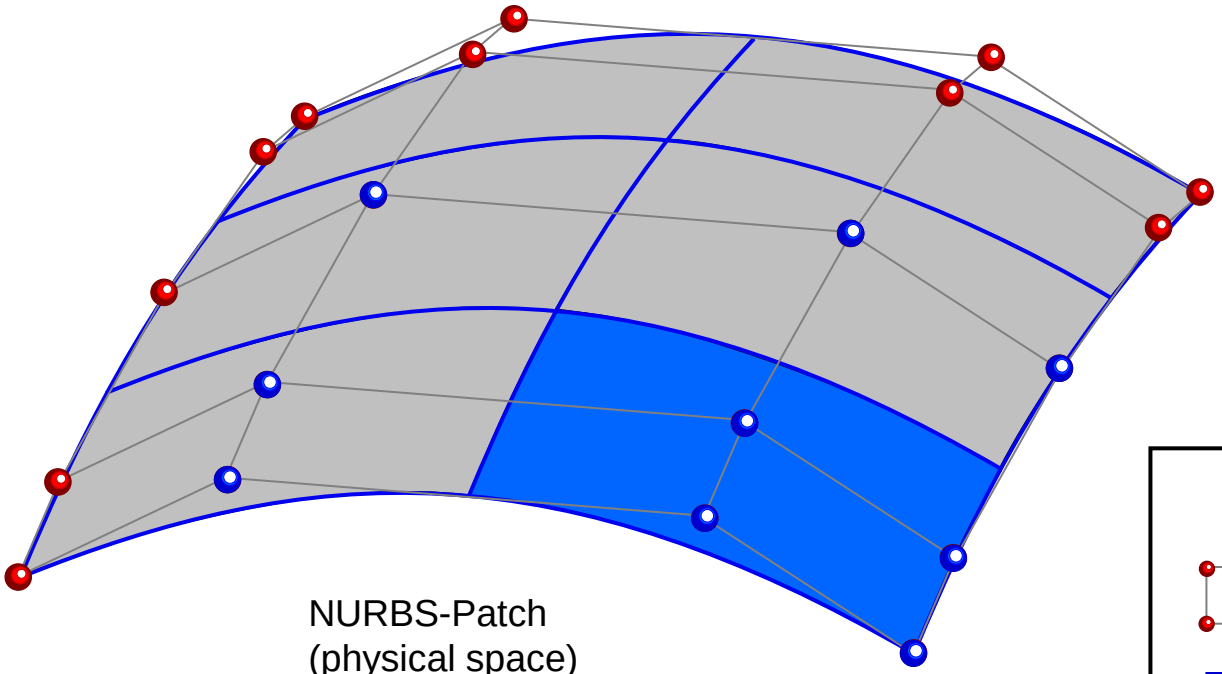
- Reduce effort of geometry conversion from CAD into a suitable mesh for FEA




- ISOGEOMETRIC
  - Same description of the geometry in the design (CAD) and in the analysis (FEA)
- Common geometry descriptions in CAD
  - NURBS (Non-uniform rational B-splines) → most commonly used
  - T-splines, LR-splines, HRB-splines, subdivision surfaces
  - … and others

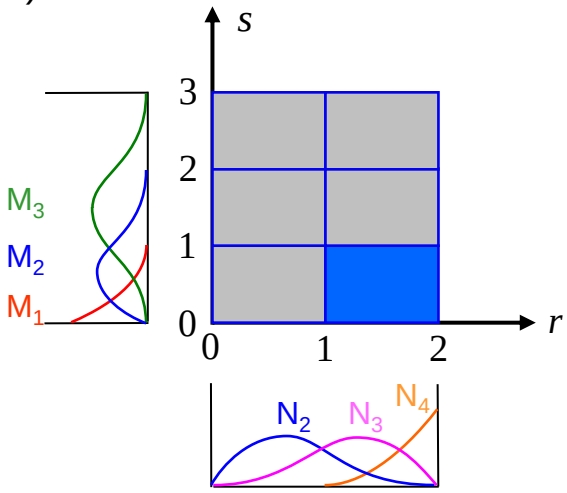
# NURBS-based finite elements in LS-DYNA

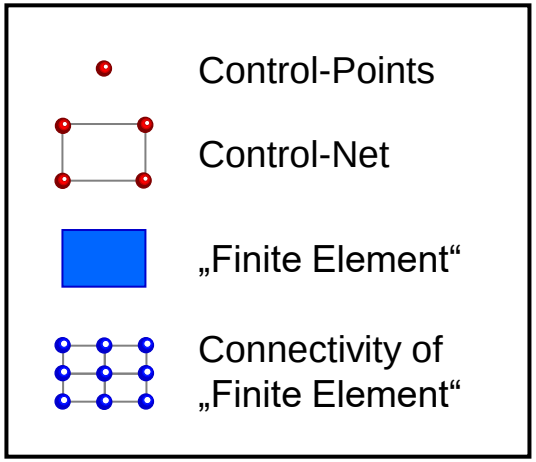
- A typical NURBS-Patch – Connectivity of elements
  - Possible „overlaps“ (→ higher continuity!)
  - Size of „overlap“ depends on polynomial order (and on knot-vector)



NURBS-Patch
(physical space)

NURBS-Patch
(parameter space)

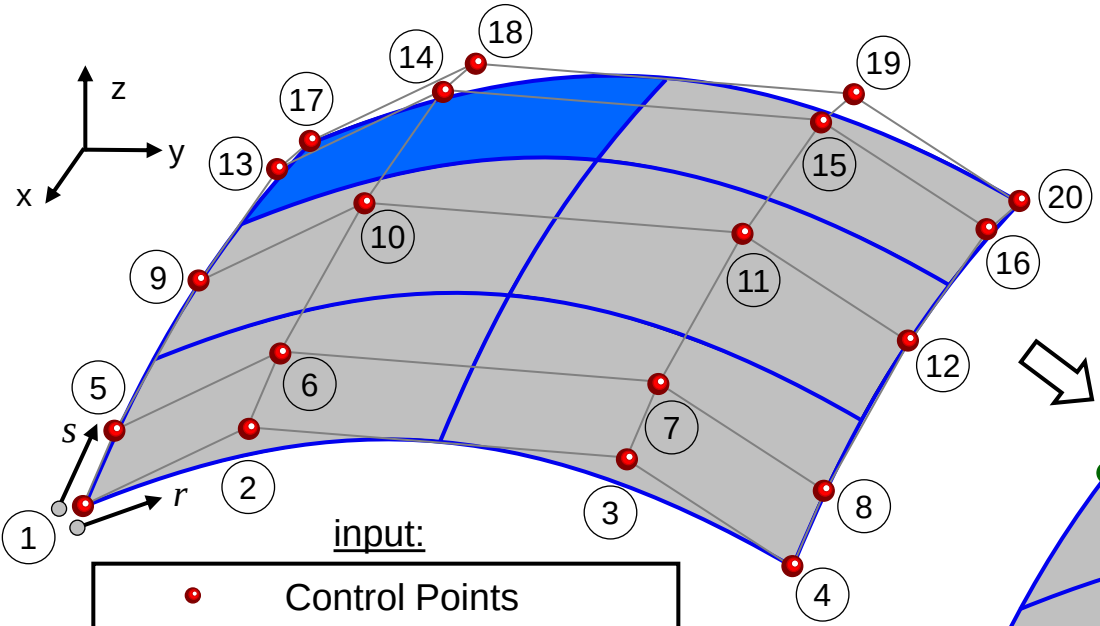


# NURBS-based finite elements in LS-DYNA

```
...
$---+--WFL----+-FORM----+--INT----+-NISR----+-NISS----+IMASS
          0          0          1          2          2          0
```

- NISR/NISS – Number of Interpolation Elements per NURBS-Element (r-/s-dir.)
  important for post-processing, boundary conditions and contact treatment




input:

Control Points

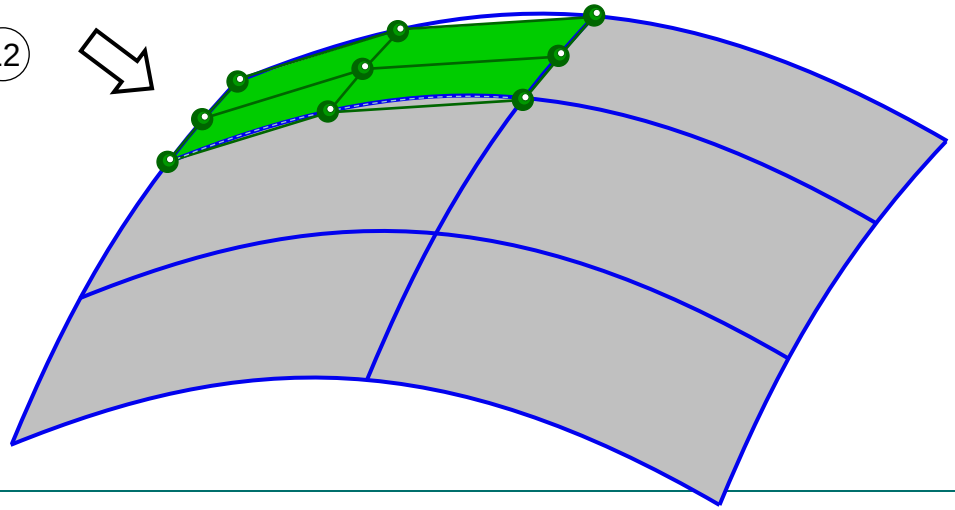
Control Net

automatically created:

NURBS-Element

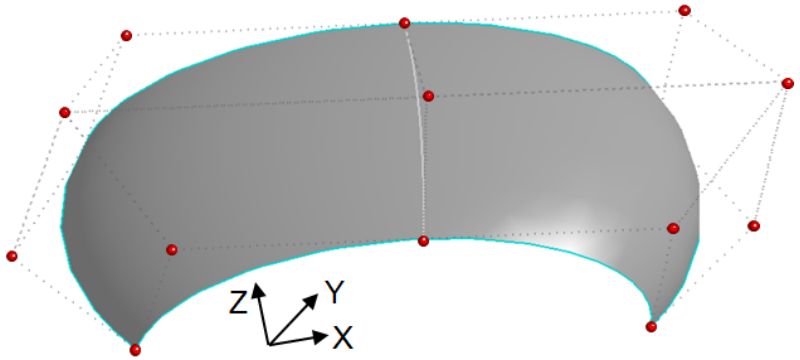
Interpolation Node

Interpolation Element

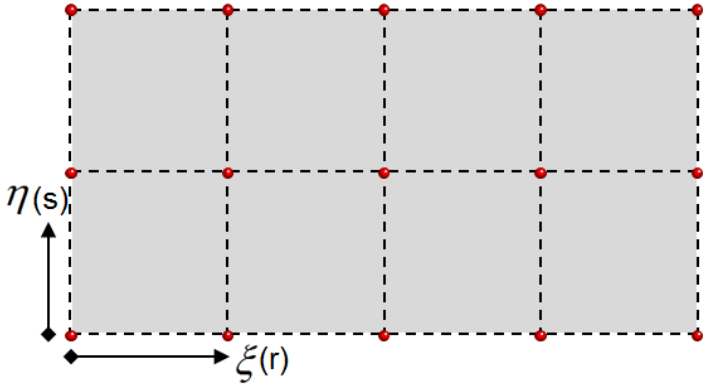


# Isogeometric Analysis (IGA) – NURBS

- NURBS: Non-Uniform Rational B-Splines

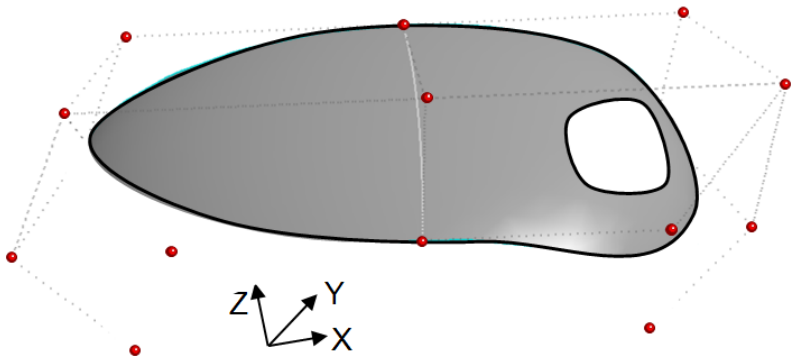



physical space

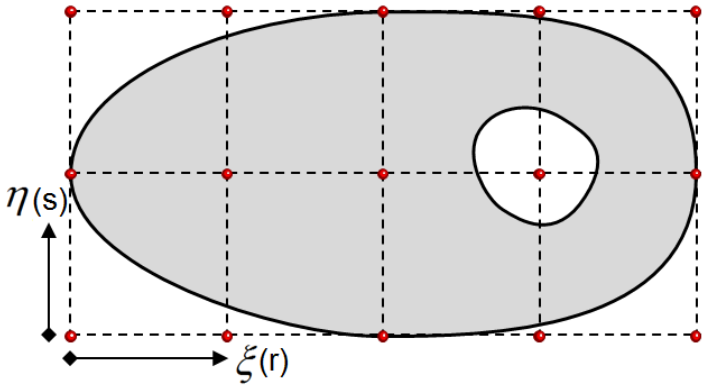



parametric space

- trimmed NURBS: standard in CAD



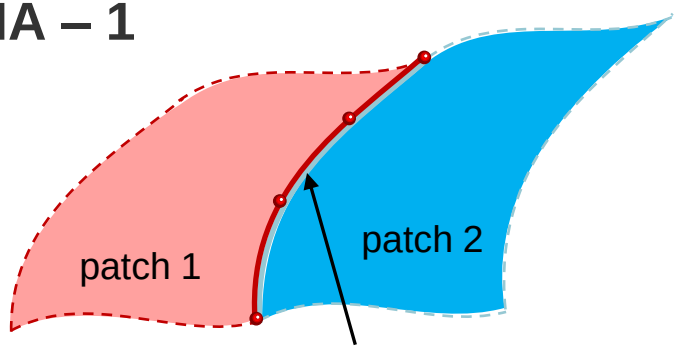

physical space




parametric space

# Analysis capabilities with NURBS in LS-DYNA – 1

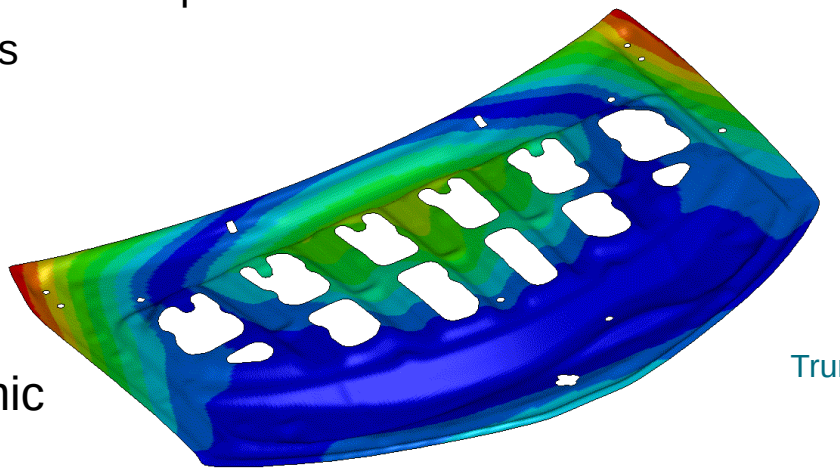
- Shell-element types (with/without rotation DOFs)
  - Shear deformable (Reissner-Mindlin)
  - Thin (Kirchhoff-Love)
  - Blended shells



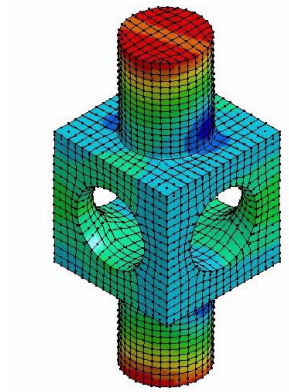

- Options
  - Trimmed and untrimmed NURBS patches
  - Different integration rules
  - Large material library

- Solid-elements

- Implicit static and dynamic
  - i.e. eigenvalue analysis



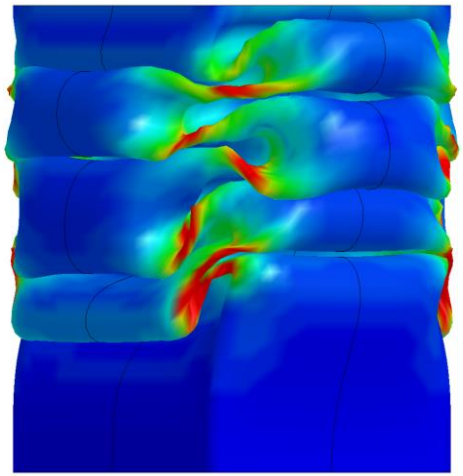
Toyota Camry – Inner hood
*www.ccsa.gmu.edu/models/2012-toyota-camry/*



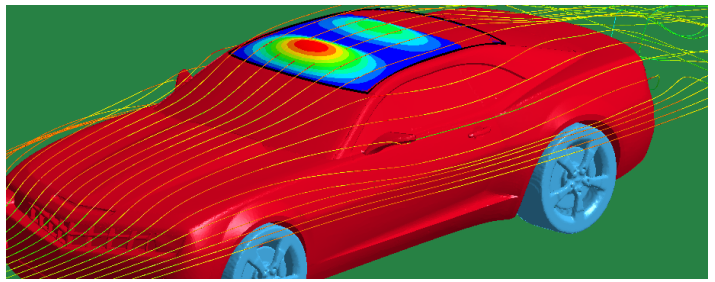
Truncated hierarchical T-spline
*Carnegie Mellon University*
*Honda Motor Co., Ltd.*

# Analysis capabilities with NURBS in LS-DYNA – 2

- Explicit dynamics
  - Stable timestep estimates
  - Conventional mass scaling
- Parallelization
  - SMP: shared memory parallel
  - MPP: massively parallel processing (domain decomposition)
    - Very good speed-up
- Boundary conditions
  - All penalty contact via interpolation elements
  - A NURBS-contact via IGACTC=1 in **`*CONTROL_CONTACT`**
  - Pointwise boundary conditions (Dirichlet & Neuman) via **`*CONSTRAINED_NODE_TO_NURBS_PATCH`**
  - **`*LOAD_NURBS_SHELL`** (line/pressure)
- Coupling to standard finite elements and other stuff … (i.e.) FSI

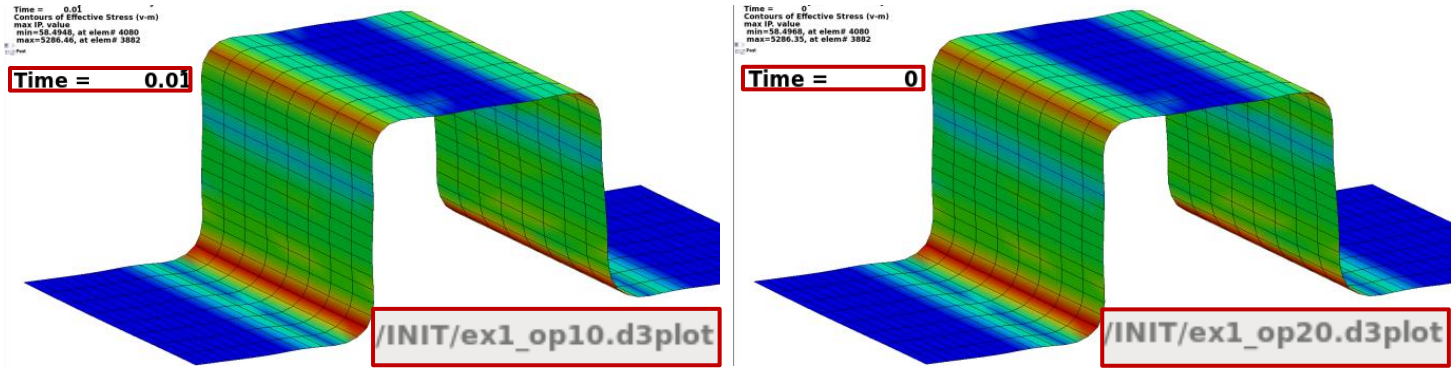


Chevrolet Camaro
with Facundo del Pin



# Analysis capabilities with NURBS in LS-DYNA – 3

- Features for forming simulations
  - Stress/strain/thickness mapping via ***INTERFACE_SPRINGBACK** (dynain-file) for multistage analysis




  - Initialization via ***INITIAL_STRESS_*SHELL/SOLID*_NURBS_PATCH**
  - Thinning of shells (ISTUPD=1 in ***CONTROL_SHELL**)
  - Trimming after forming (***CONTROL_FORMING_TRIMMING**)
  - One-step solver available for shells and solids (***CONTROL_FORMING_ONESTEP**)

- Frequency domain steady state dynamics for shells and solids

# Outline

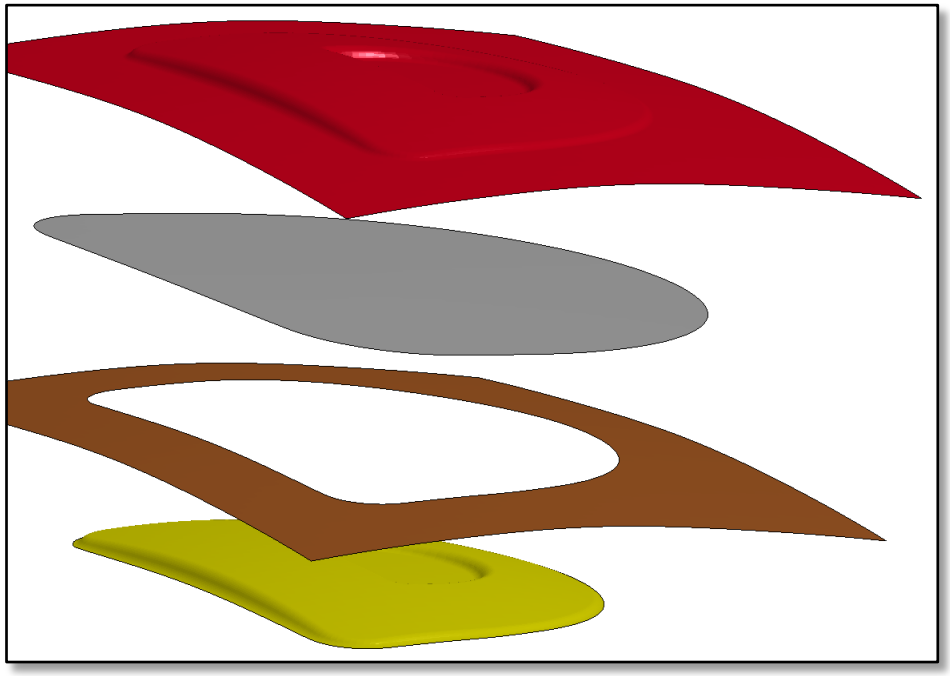
- Introduction to IGA in LS-DYNA
  - Motivation & Definition
  - NURBS-based finite elements in LS-DYNA
  - Analysis capabilities

- **A multistage sheet metal forming process**
  - **Stage 1 – Gravity**
  - **Stage 2 – Deep drawing**
  - **Stage 3 – Trimming**
  - **Stage 4 – Springback analysis**

- Summary and Outlook

# A multistage sheet metal forming process

- Stage 1 – Gravity
  - Placing the blank onto the forming tool
  - Implicit static analysis
  - **MAP** results to next step (current geometry, stresses, strains, history variables, …)
- Stage 2 – Deep drawing
  - Explicit analysis
  - **MAP** results to next step
- Stage 3 – Trimming
  - No ”real” analysis
  - Cutting the formed blank
  - **MAP** results to next step
- Stage 4 – Springback
  - Implicit static analysis
  - Find equilibrium for final geometry



# How to map the data

- ***INTERFACE_SPRINGBACK_LSDYNA**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Card 1 | **PSID** | **NSHV** | **FTYPE** | | **FTENSR** | **NTHHSV** | | **INTSTRN** |

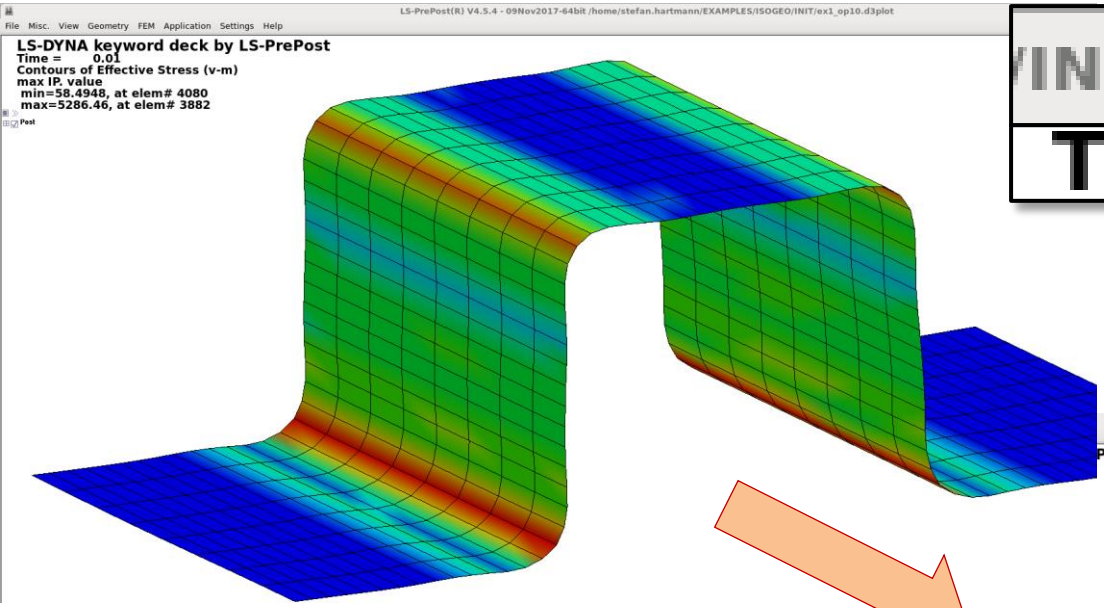
  - **PSID** Part set ID (***SET_PART**)
  - **NSHV** Number of history variables to be initialized
  - **INTSTRN** Flag to output strains (***INITIAL_STRAIN_SHELL**)
- The above keyword invokes LS-DYNA to write a “dynain”-file including:
  - ***INITIAL_STRESS_SHELL_NURBS_PATCH**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Card 1 | **EID** | **NPLANE** | **NTHICK** | **NHISV** | **LARGE** | | | |
| Card 2 | **R** | **S** | **T** | | | | | |
| Card 3 | **SIGXX** | **SIGYY** | **SIGZZ** | **SIXY** | **SIGYZ** | **SIGZX** | **EPS** | |
| Card 4 | **HISV1** | **HISV2** | **HISV3** | **HISV4** | **HISV5** | **HISV6** | **HISV7** | **HISV8** |
| Card .. | ... | ... | ... | ... | ... | ... | ... | ... |

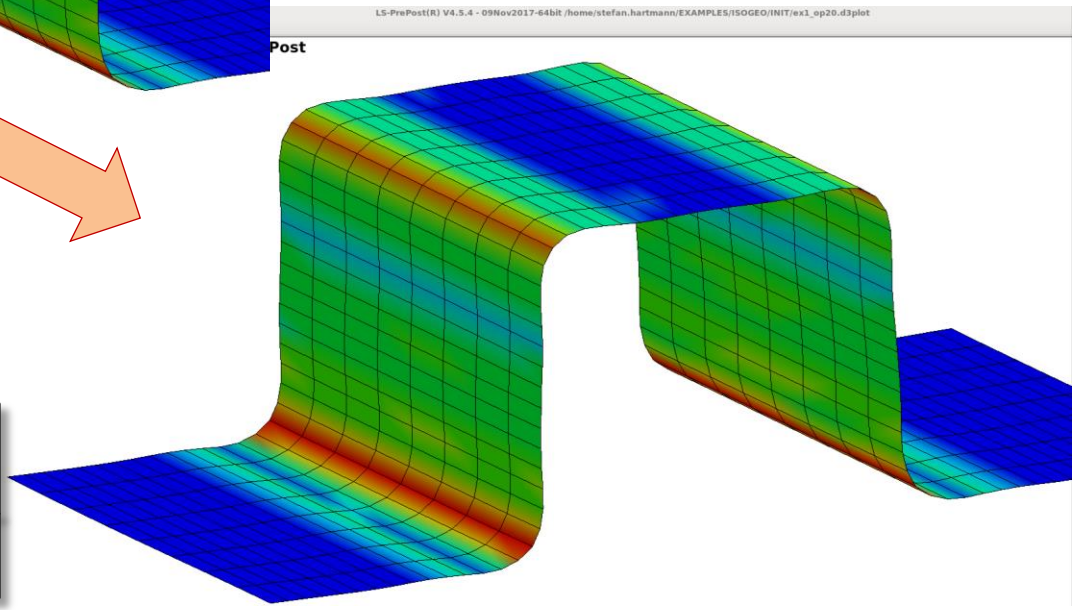
  - ***INITIAL_STRAIN_SHELL_NURBS_PATCH**

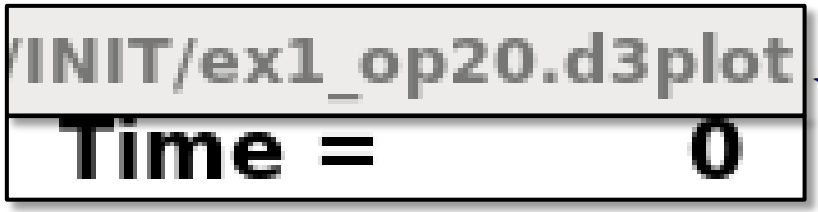
# How to map the data

- Effective Stress at the end of **op10** and start of **op20**



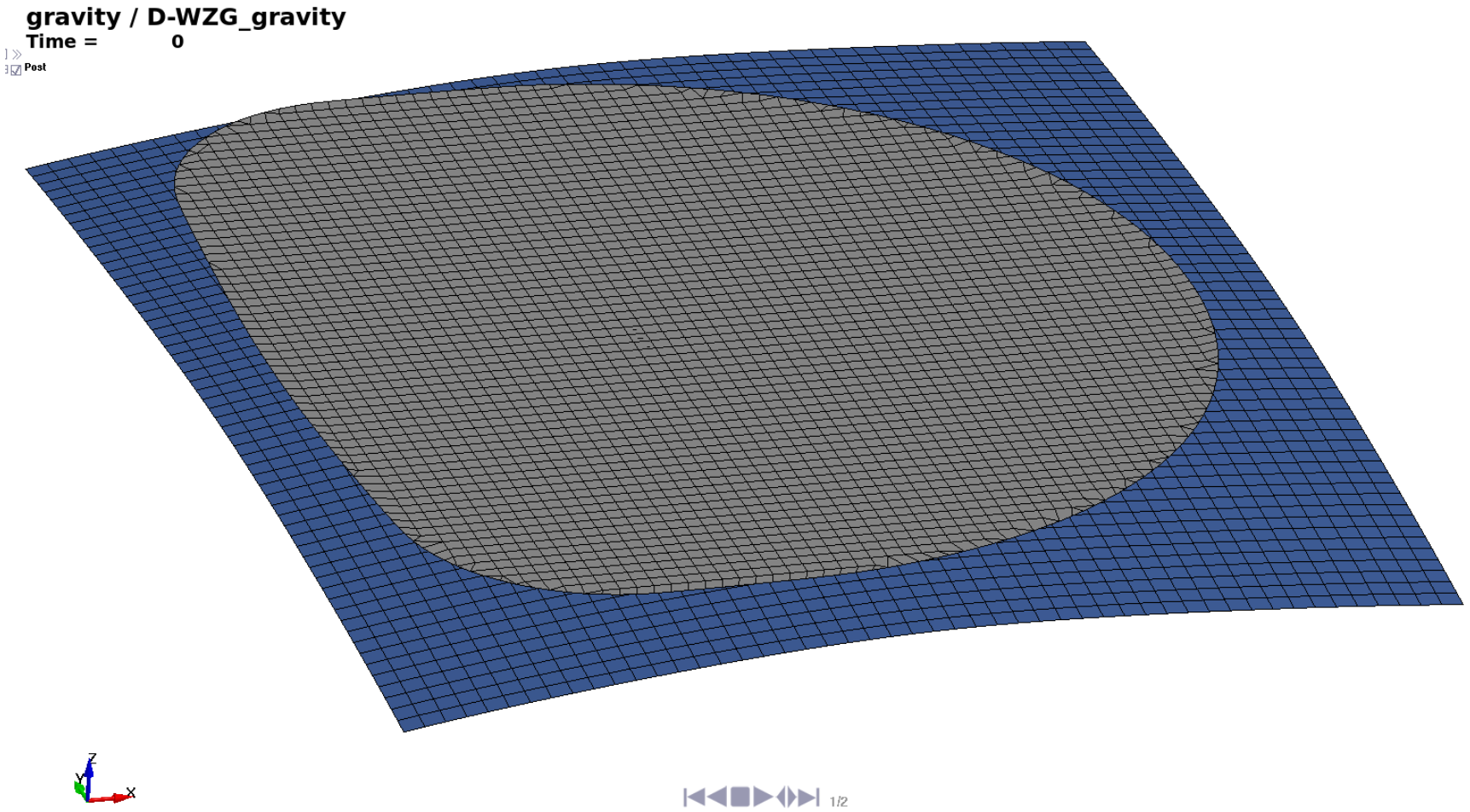




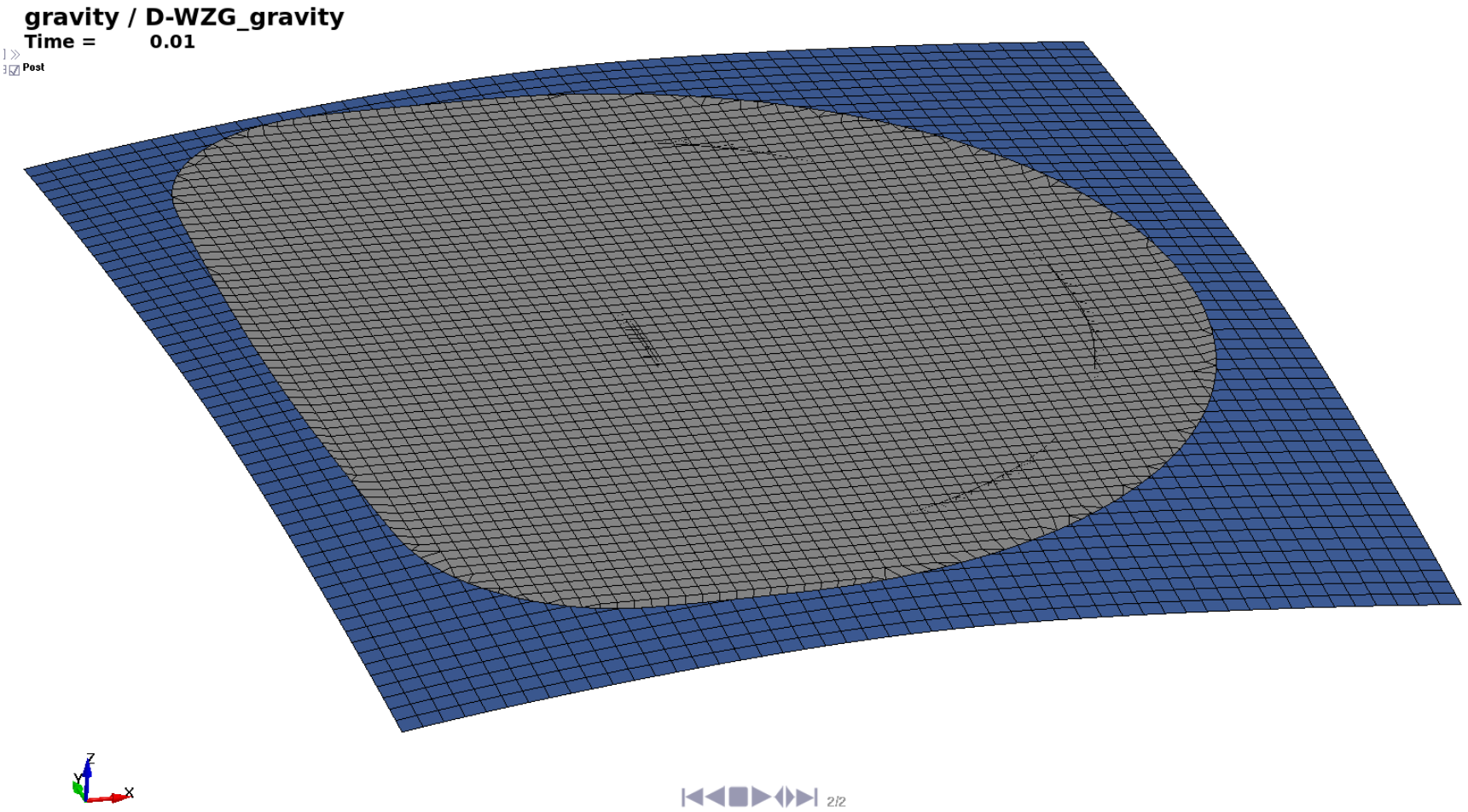
# Stage 1 – Gravity

- Standard Finite Elements



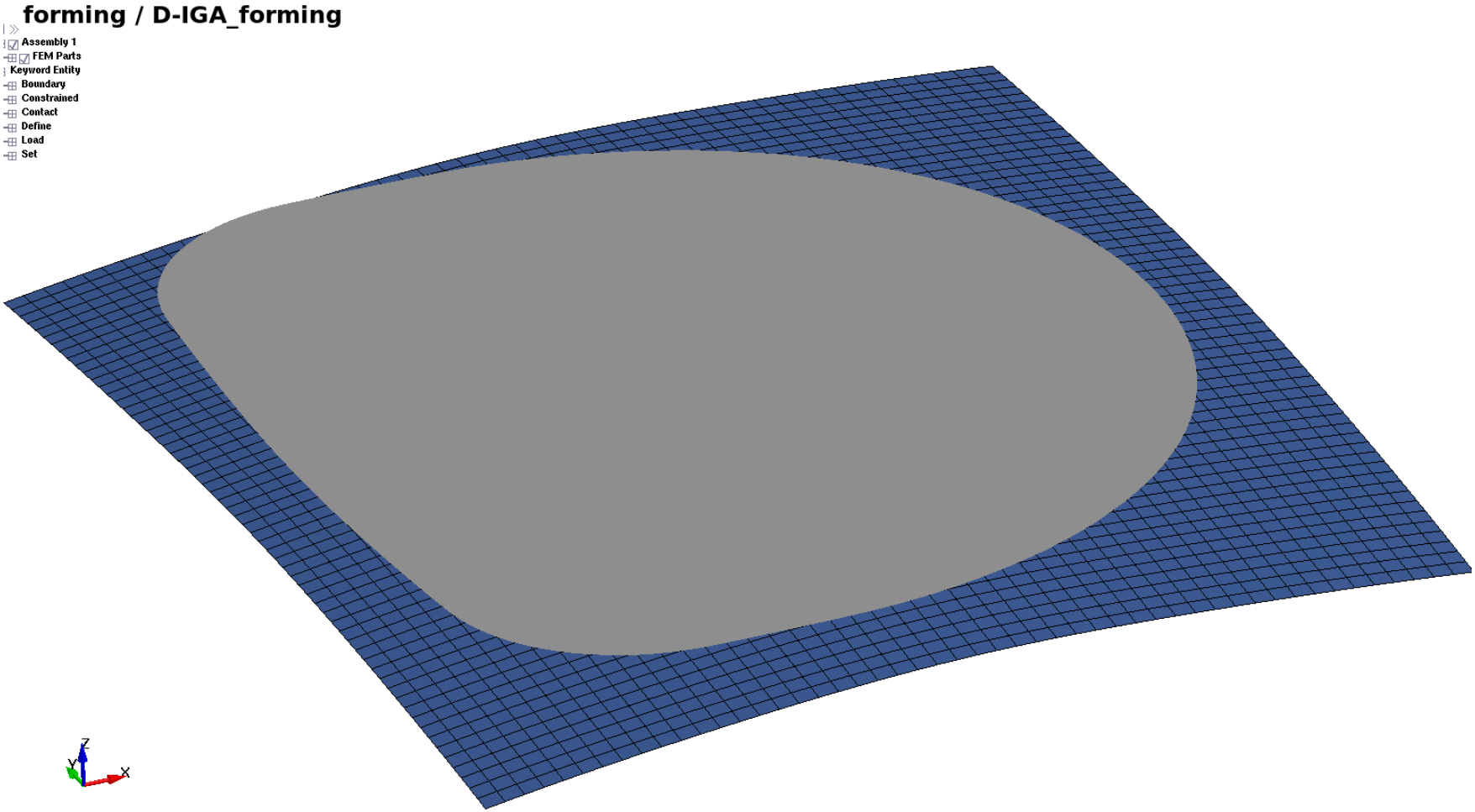
# Stage 1 – Gravity

- Standard Finite Elements



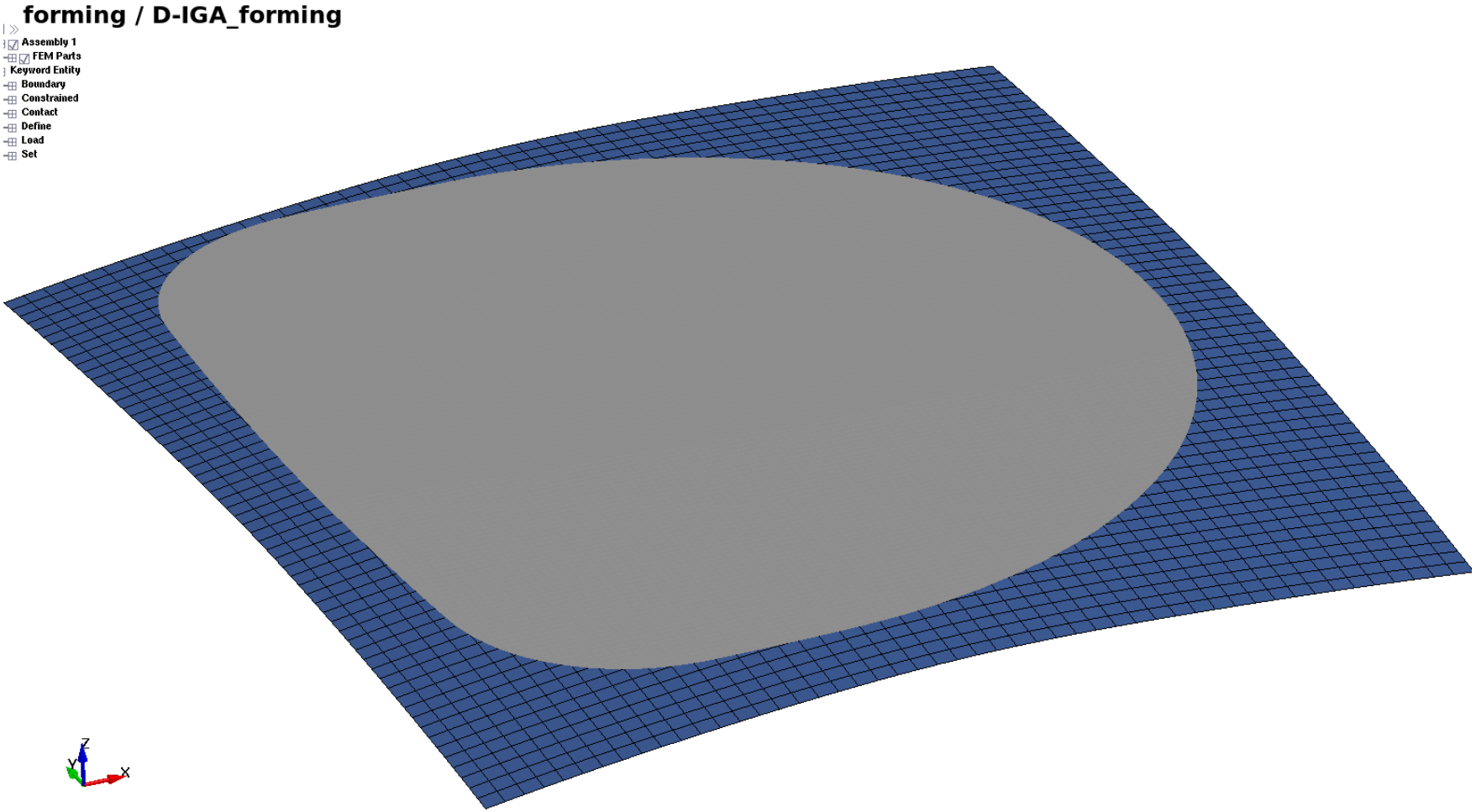
# Stage 1 – Gravity

- Isogeometric Elements



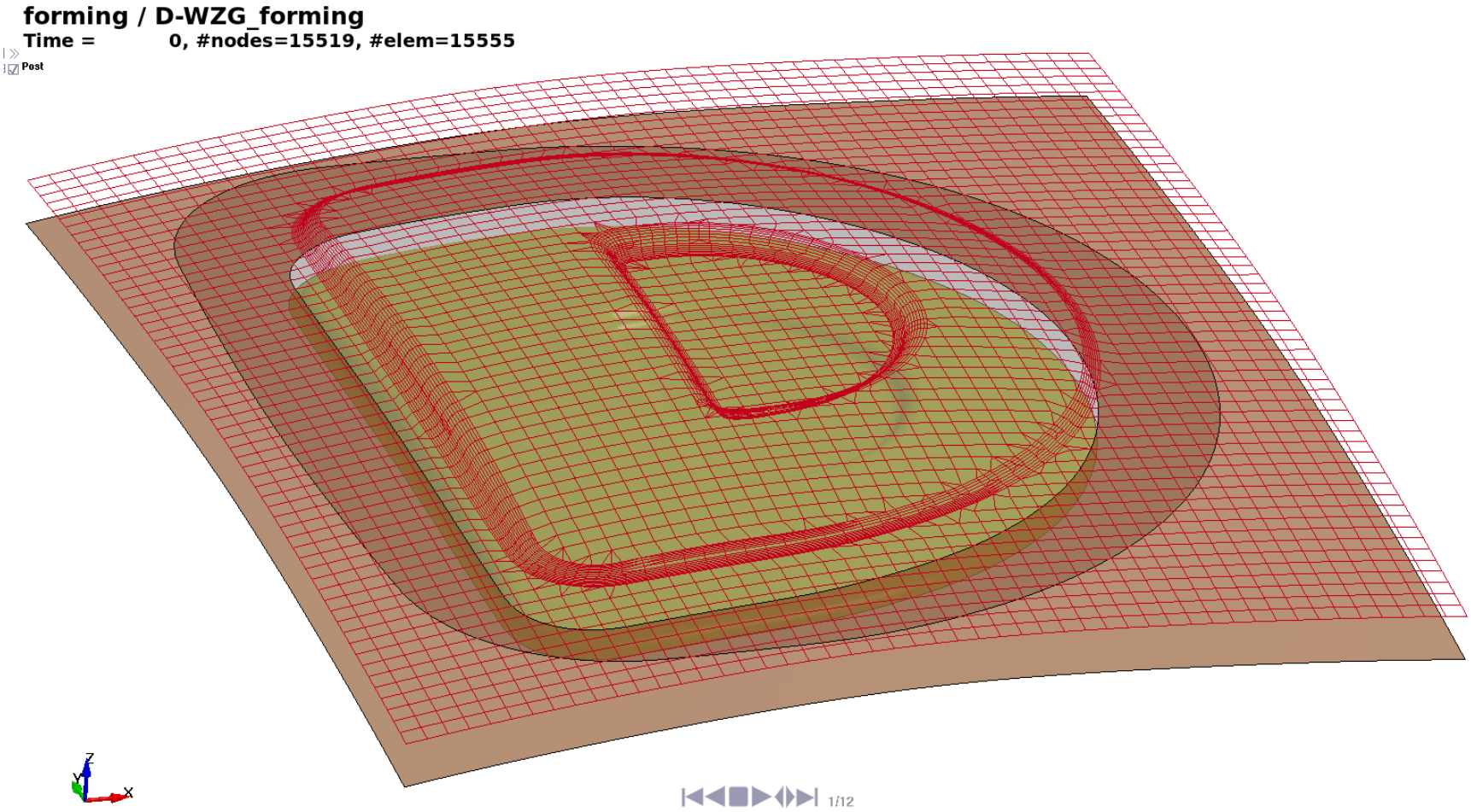
# Stage 1 – Gravity

- Isogeometric Elements



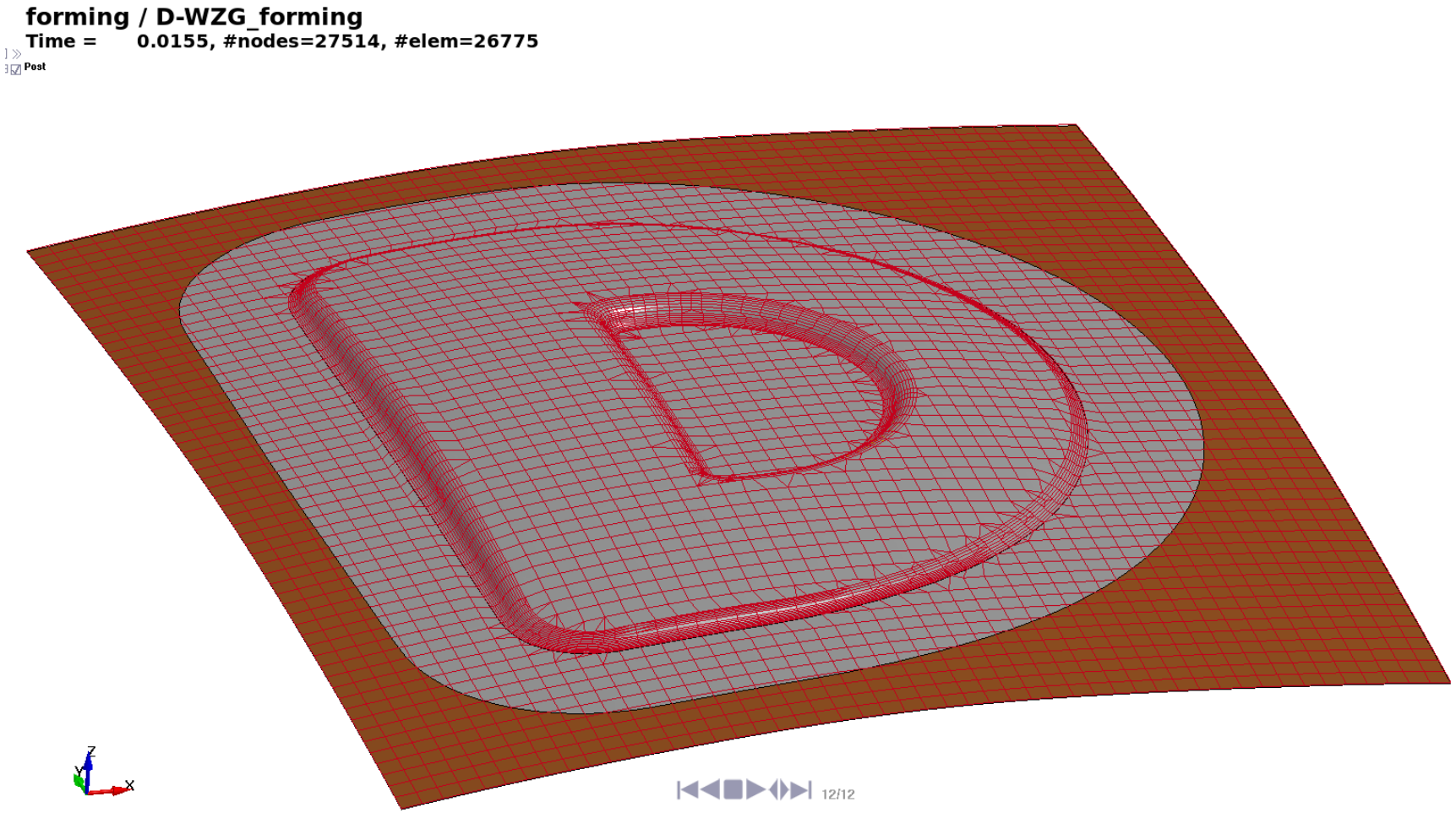
# Stage 2 – Deep drawing

- Standard Finite Elements



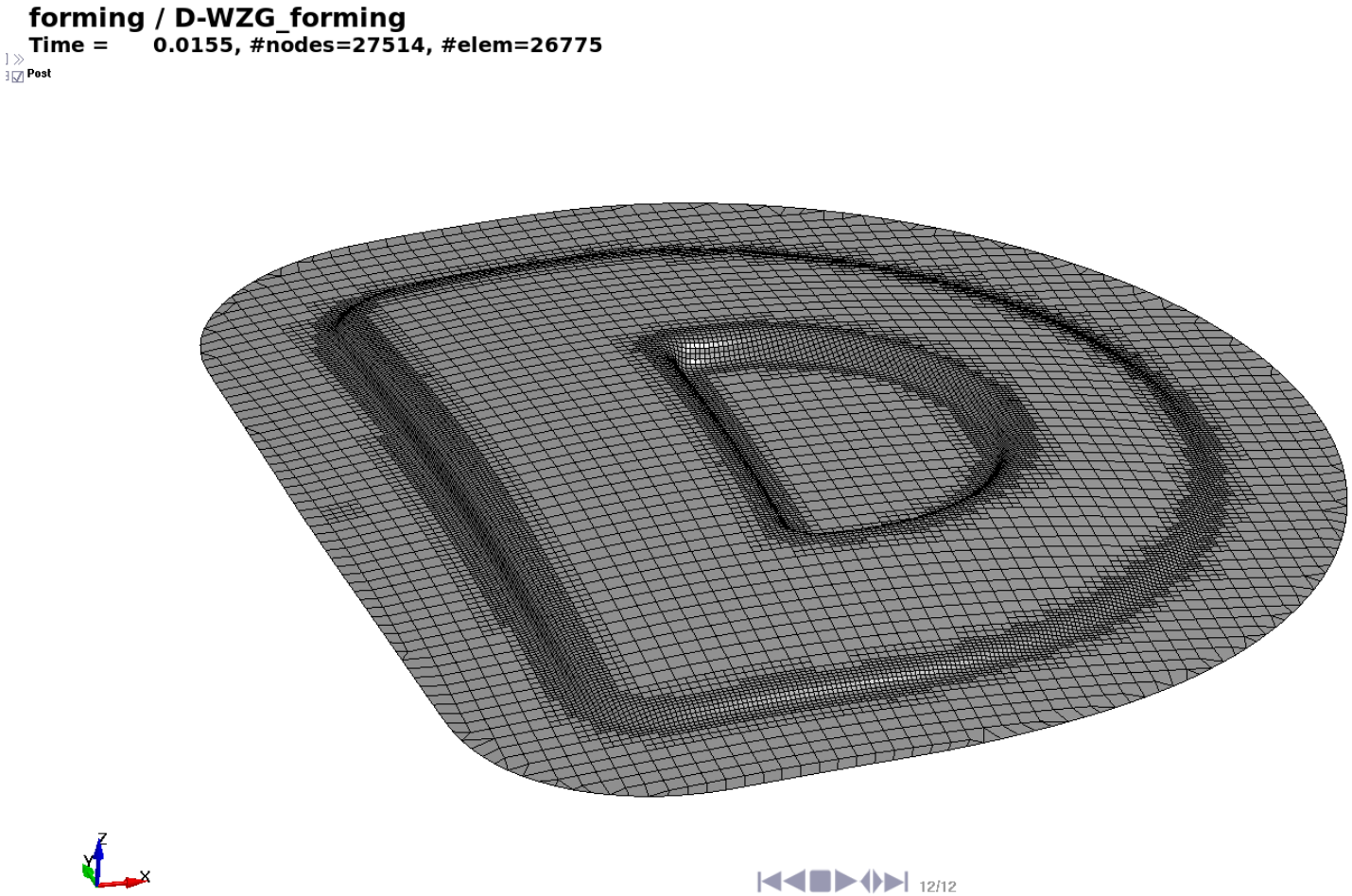
# Stage 2 – Deep drawing

- Standard Finite Elements



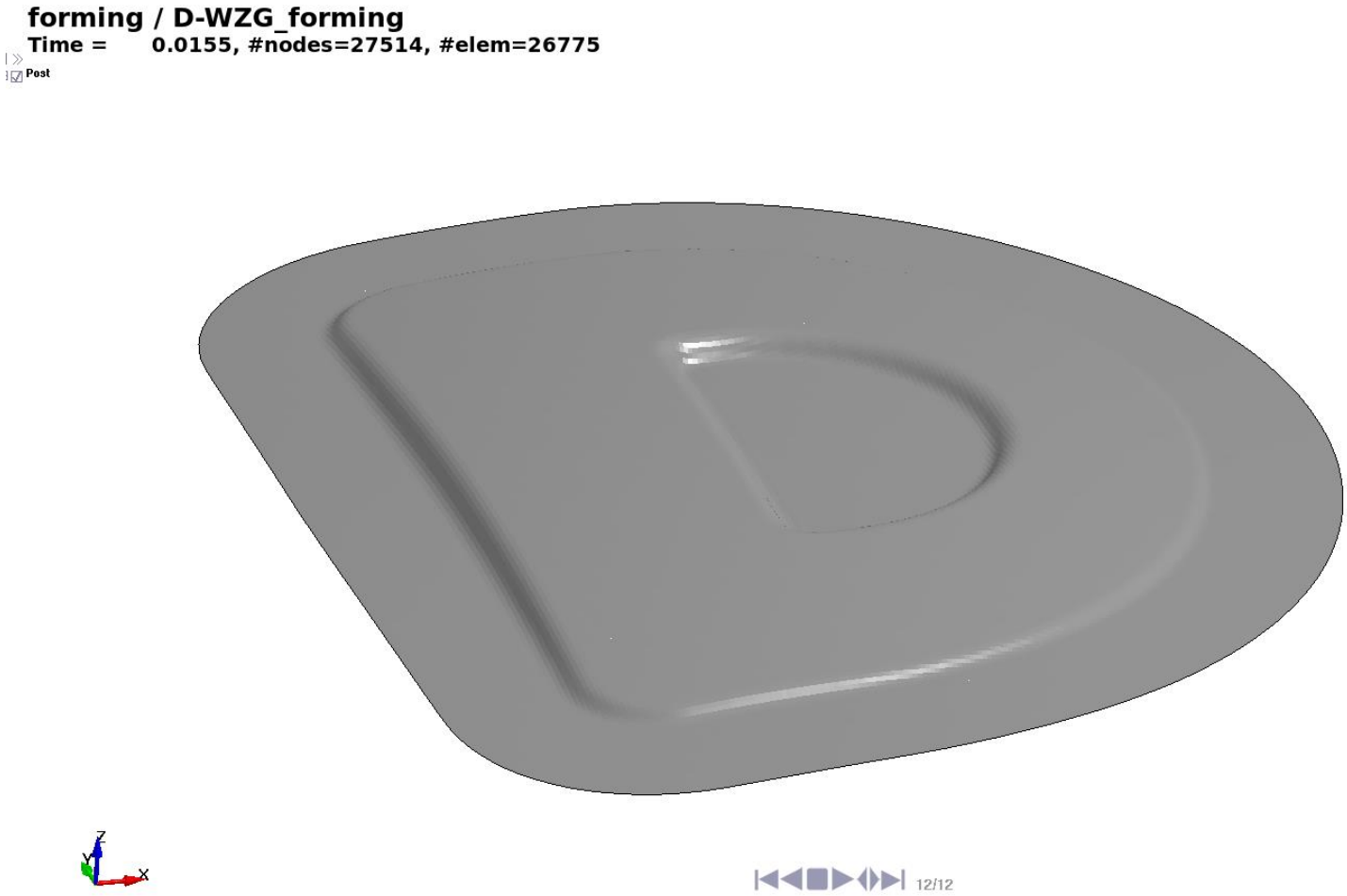
# Stage 2 – Deep drawing

- Standard Finite Elements



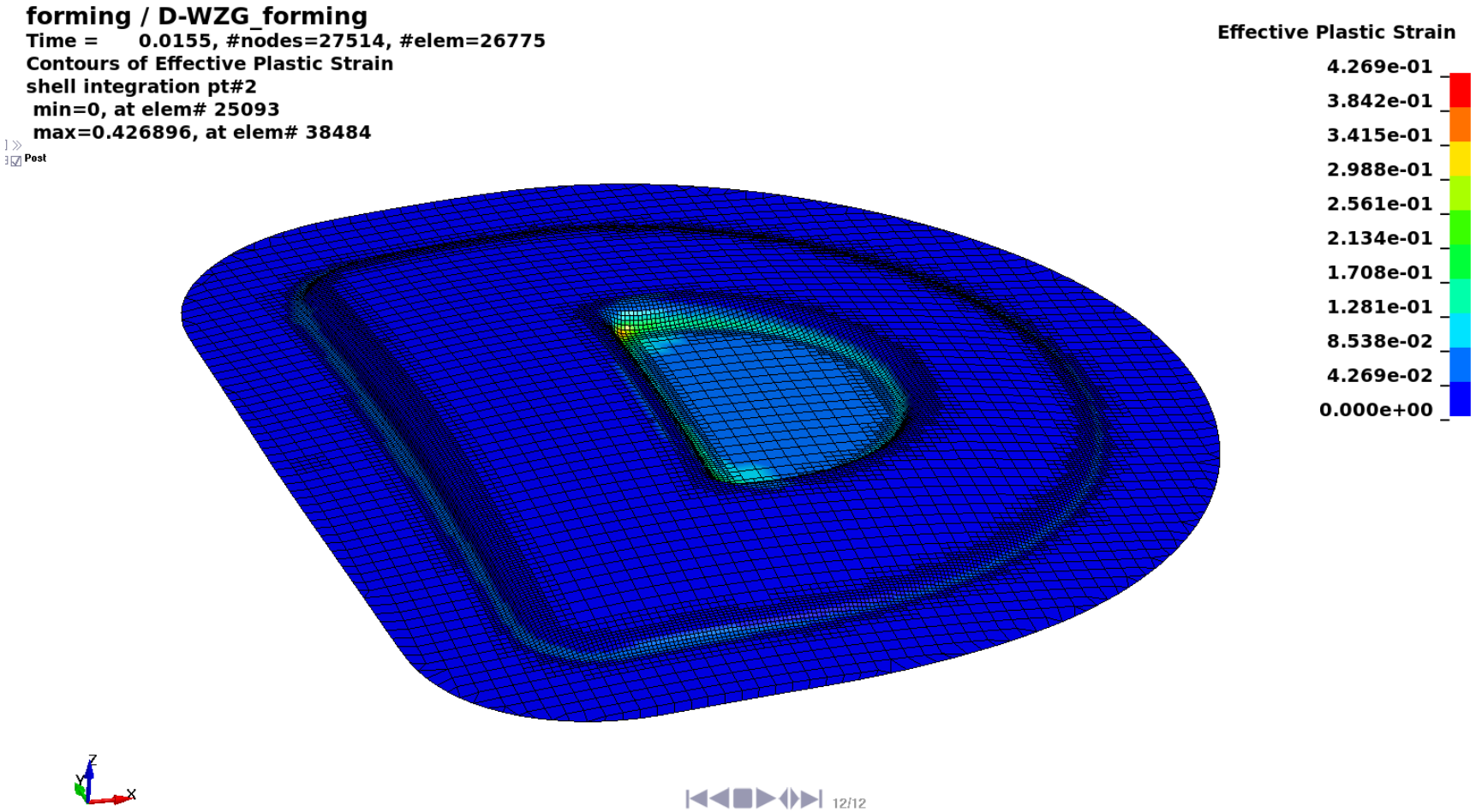
# Stage 2 – Deep drawing

- Standard Finite Elements



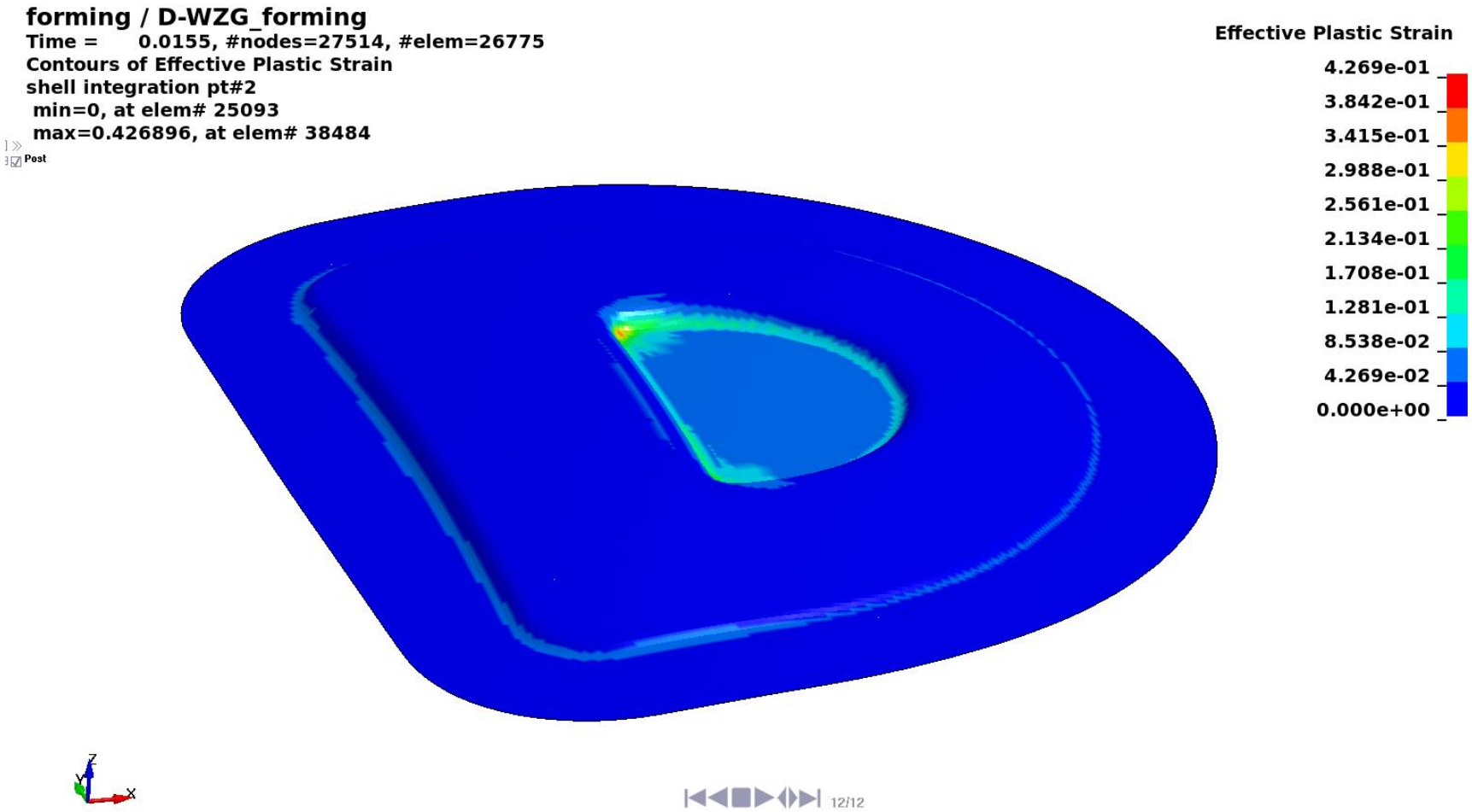
# Stage 2 – Deep drawing

- Standard Finite Elements



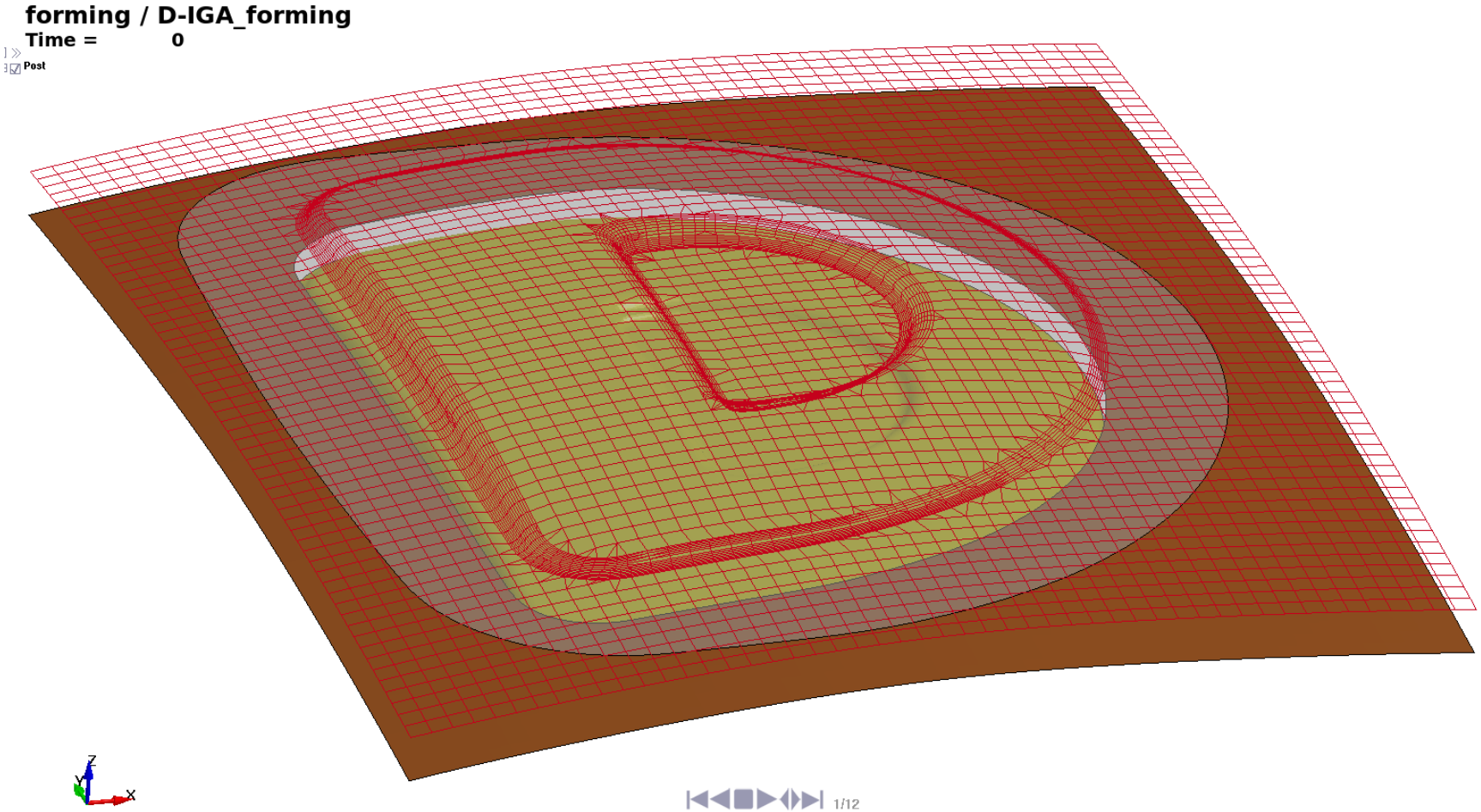
# Stage 2 – Deep drawing

- Standard Finite Elements



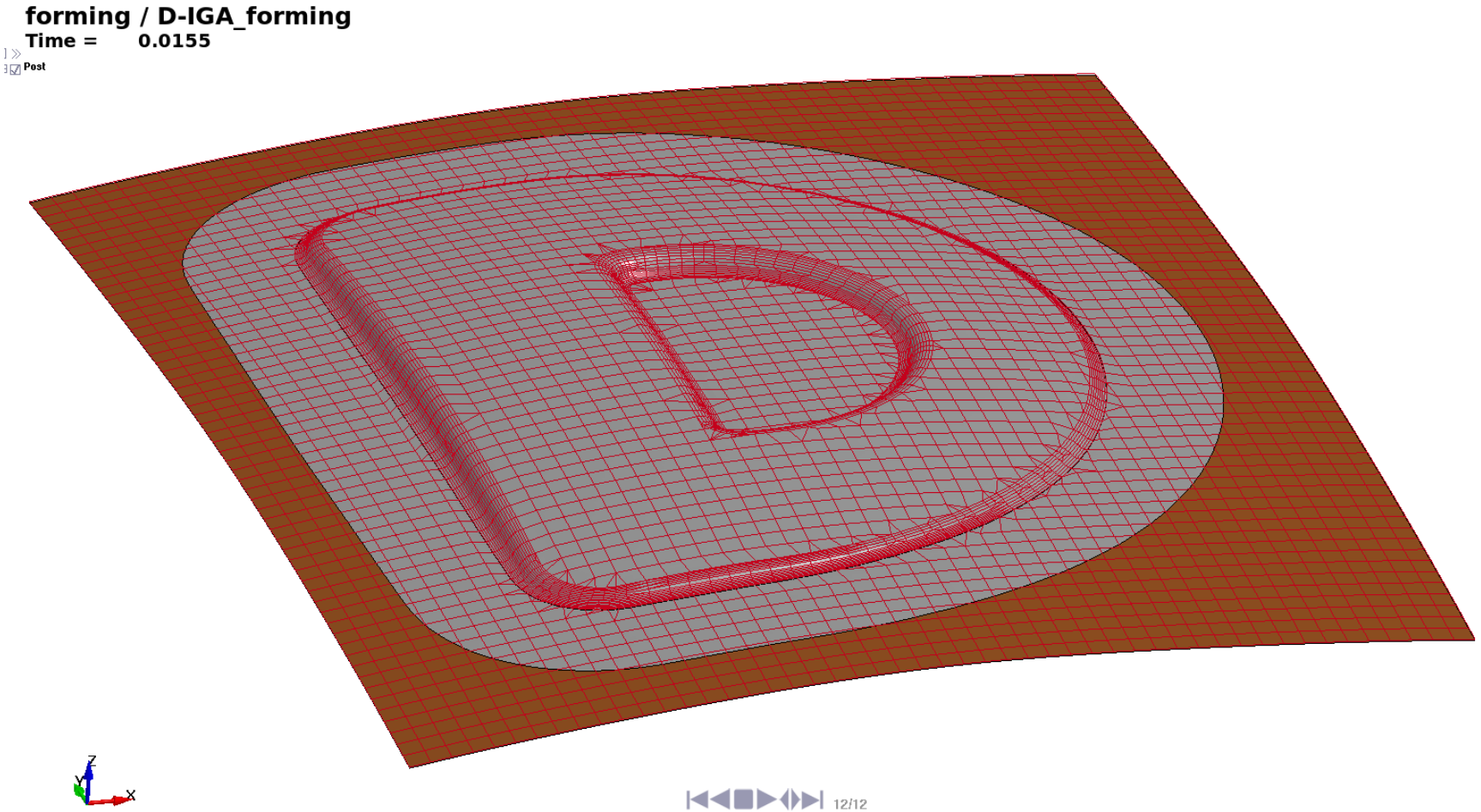
# Stage 2 – Deep drawing

- Isogeometric Elements



# Stage 2 – Deep drawing

- Isogeometric Elements

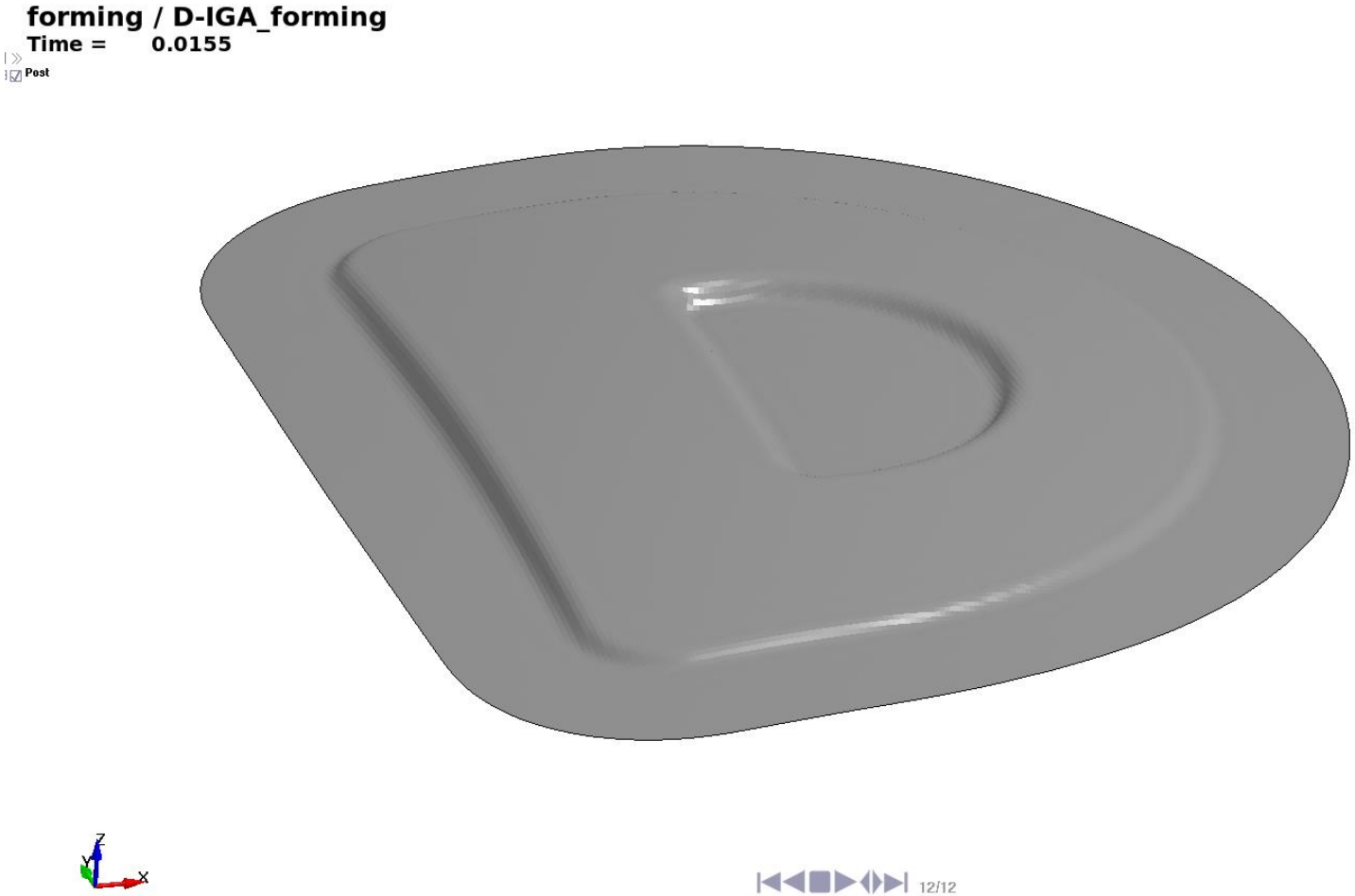


# Stage 2 – Deep drawing

- Isogeometric Elements

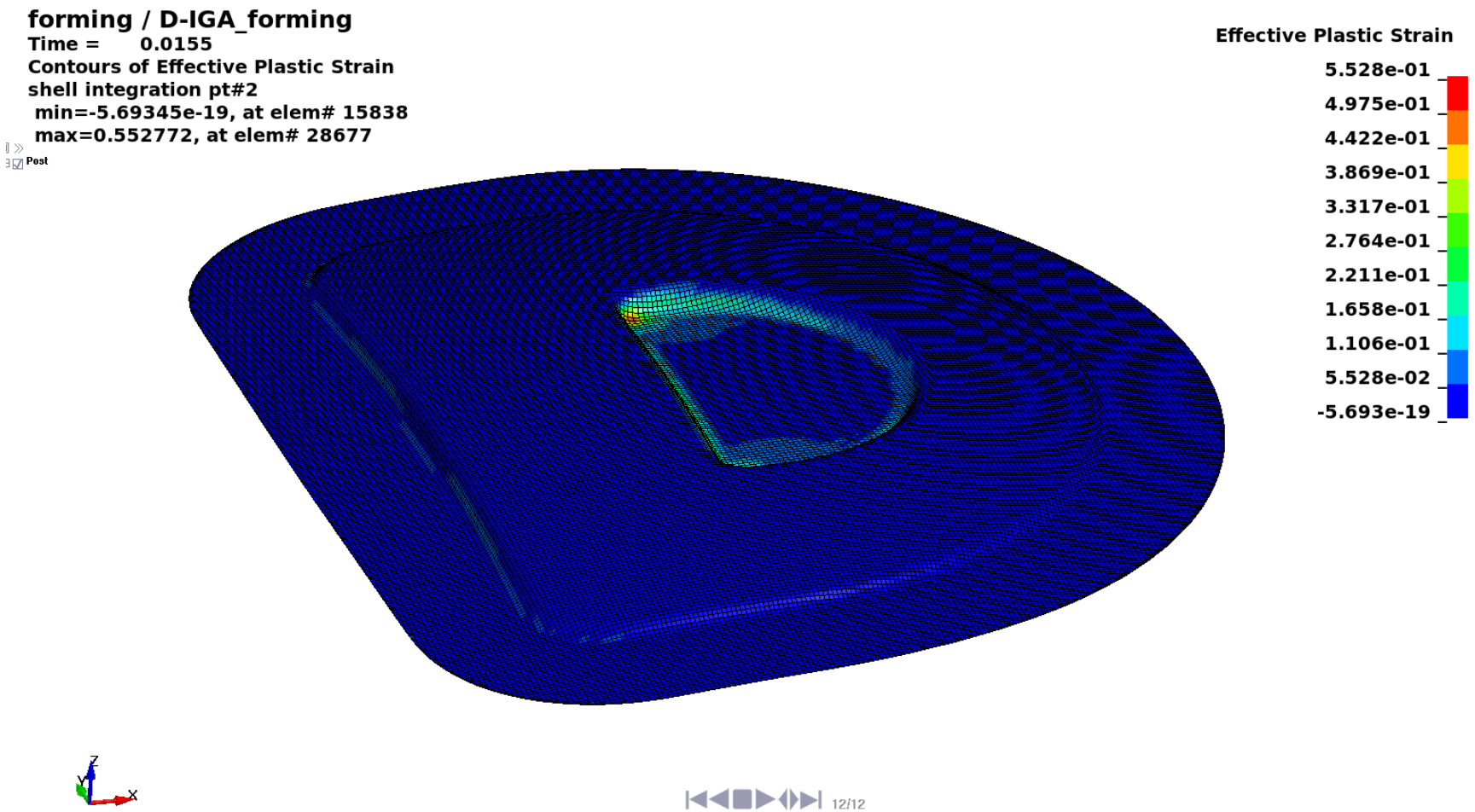
# Stage 2 – Deep drawing

- Isogeometric Elements



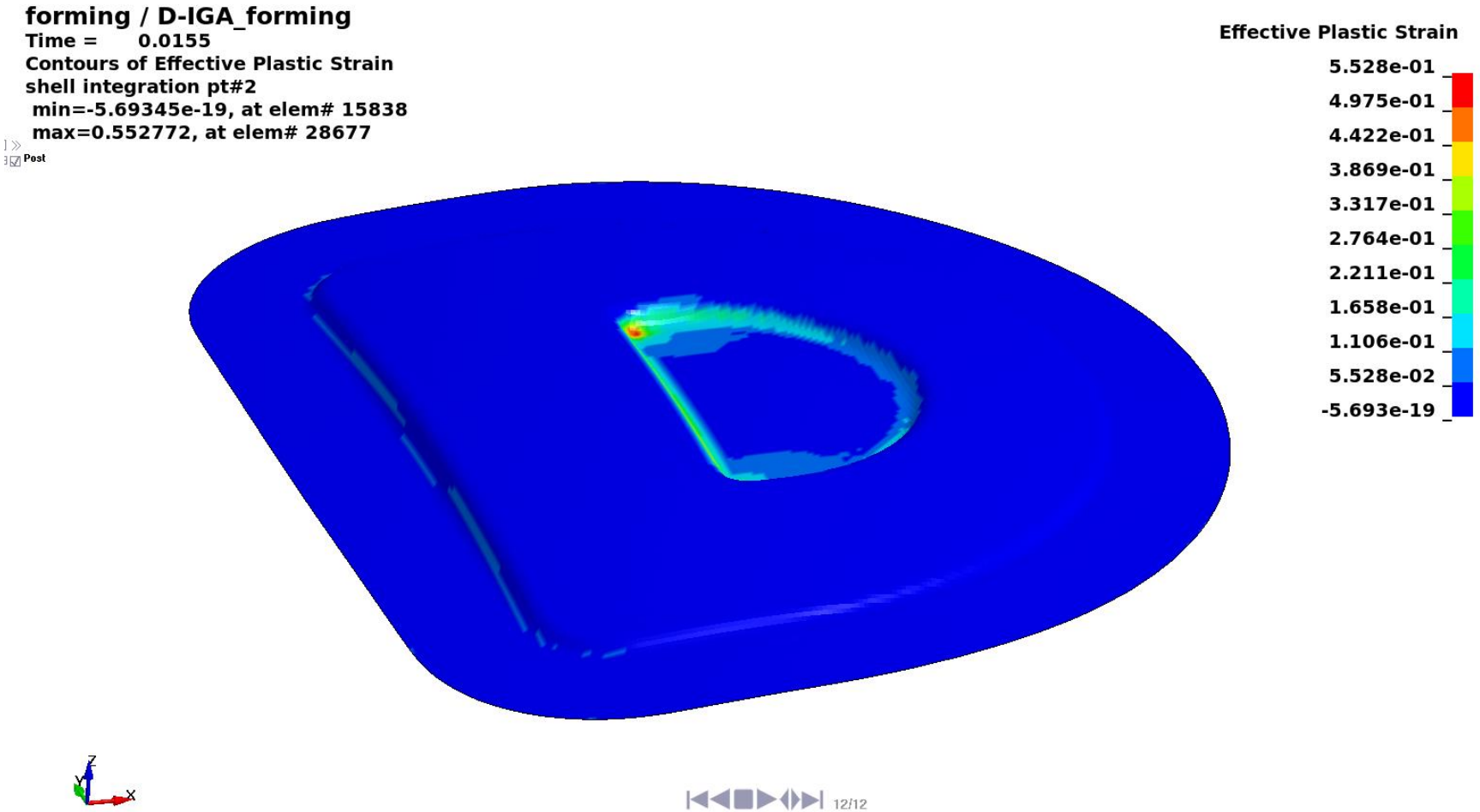
# Stage 2 – Deep drawing

- Isogeometric Elements



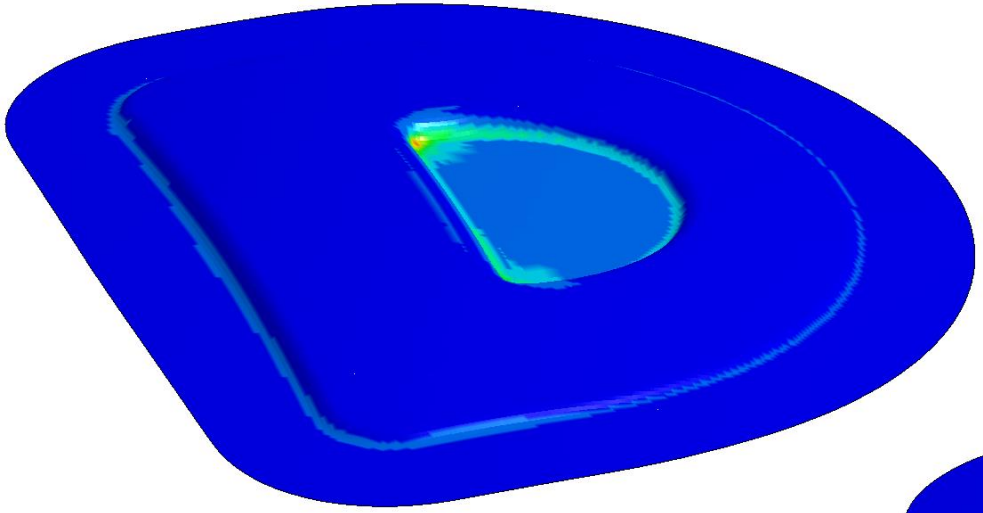
# Stage 2 – Deep drawing

- Isogeometric Elements

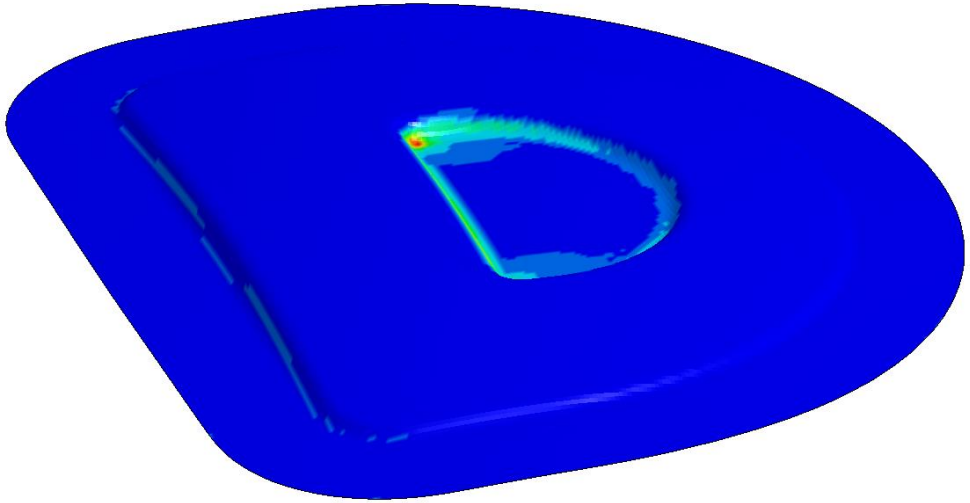


# Comparison of results after deep drawing

- Effective plastic strain



Standard Finite Elements



Isogeometric Elements

# Stage 3 – Trimming

- ***CONTROL_FORMING_TRIMMING**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Card 1 | **PSID** | | **ITYP** | | | | | |

  - **PSID** Part set ID for trimming (***SET_PART**)

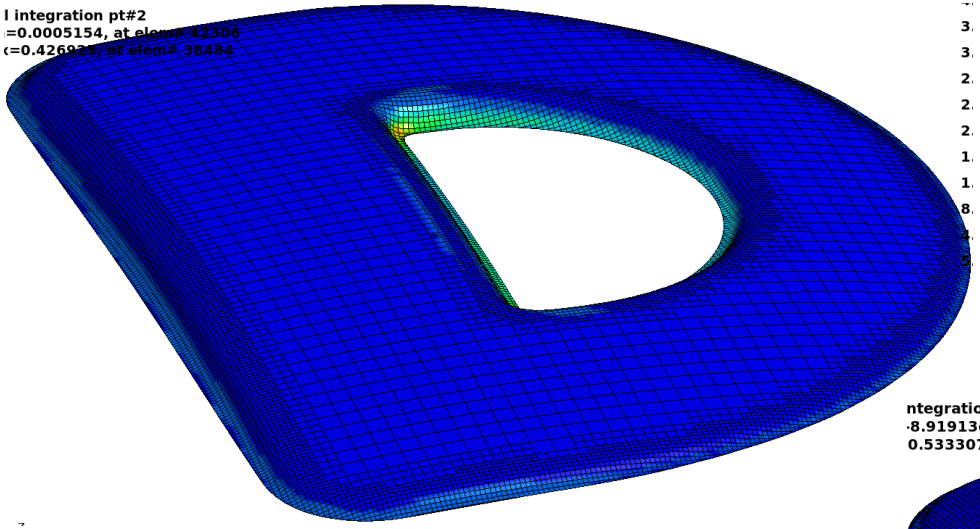
- ***DEFINE_CURVE_TRIM_3D**

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| Card 1 | **TCID** | **TCTYPE** | **TFLG** | **TDIR** | **TCTOL** | **TOLN** | **NSEED1** | **NSEED2** |
| Card 2 | **CX** | | **CY** | | **CZ** | | | |

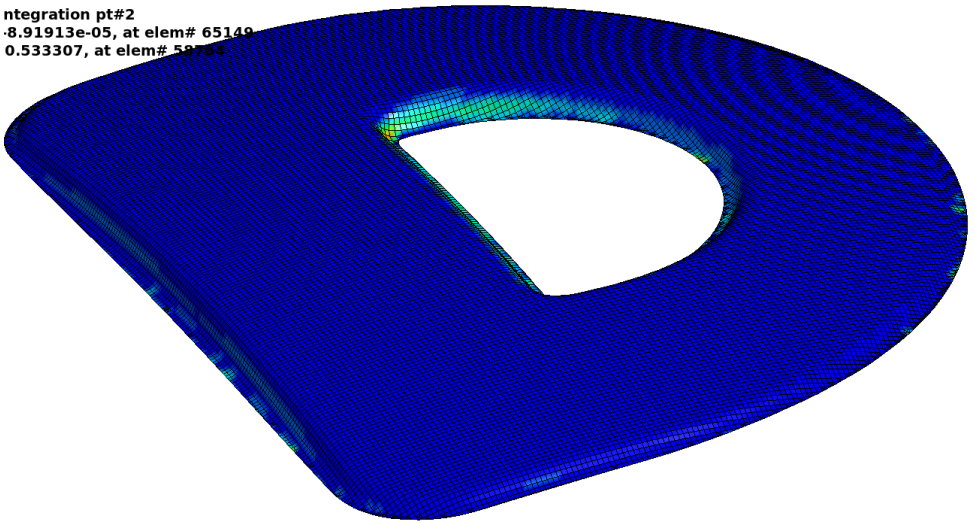
  - Currently only 3D-trimming (trimming curve defined in 3D physical space)
  - Map 3D-physical points into parametric space of NURBS-patch to define new trimmed NURBS-patch
  - Map the results data (stress, strain, …) from original patch to trimmed one

# Stage 3 – Trimming: Comparisson of results

- Effective plastic strain after trimming



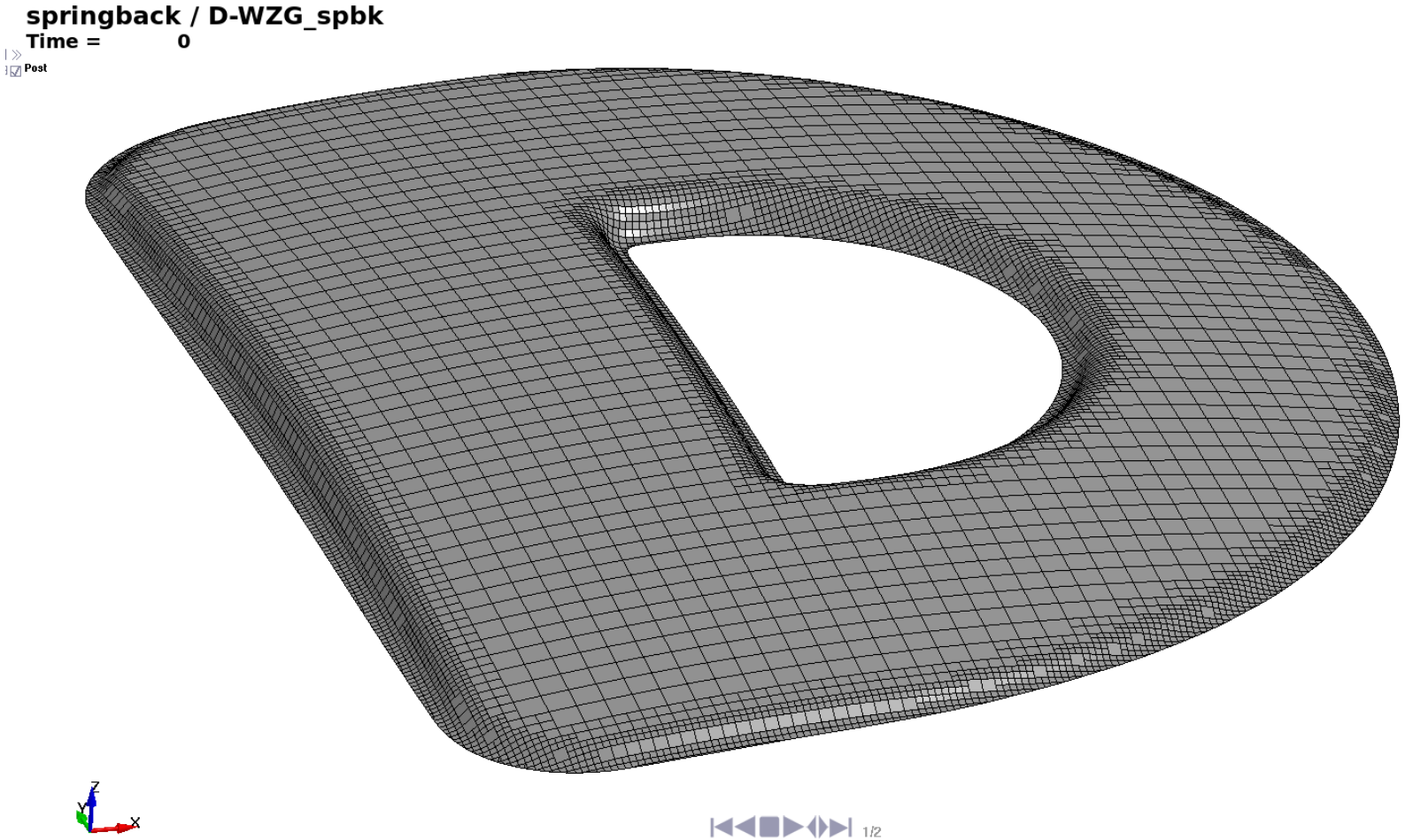

Standard Finite Elements




Isogeometric Elements

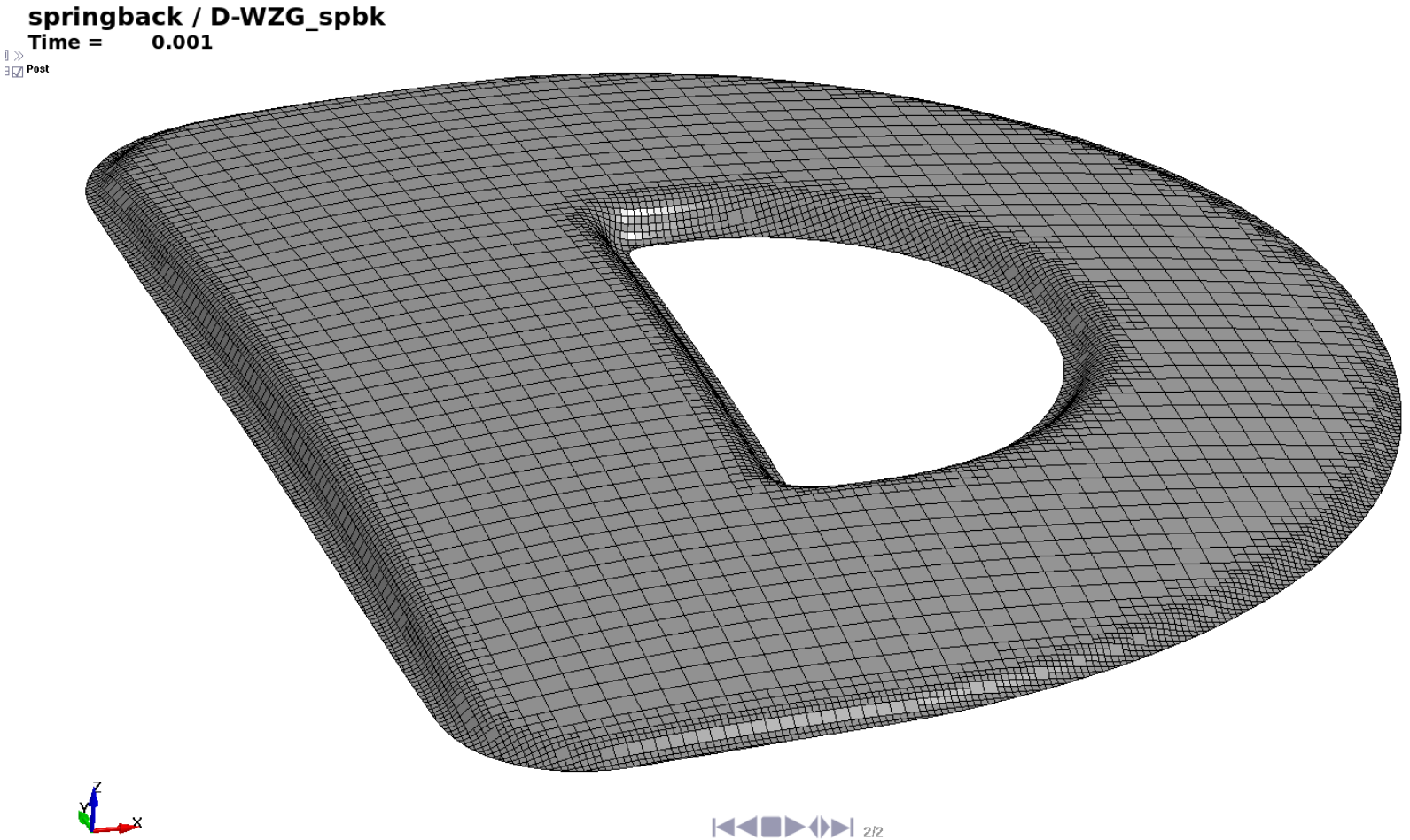
# Stage 4 – Springback analysis

- Standard Finite Elements



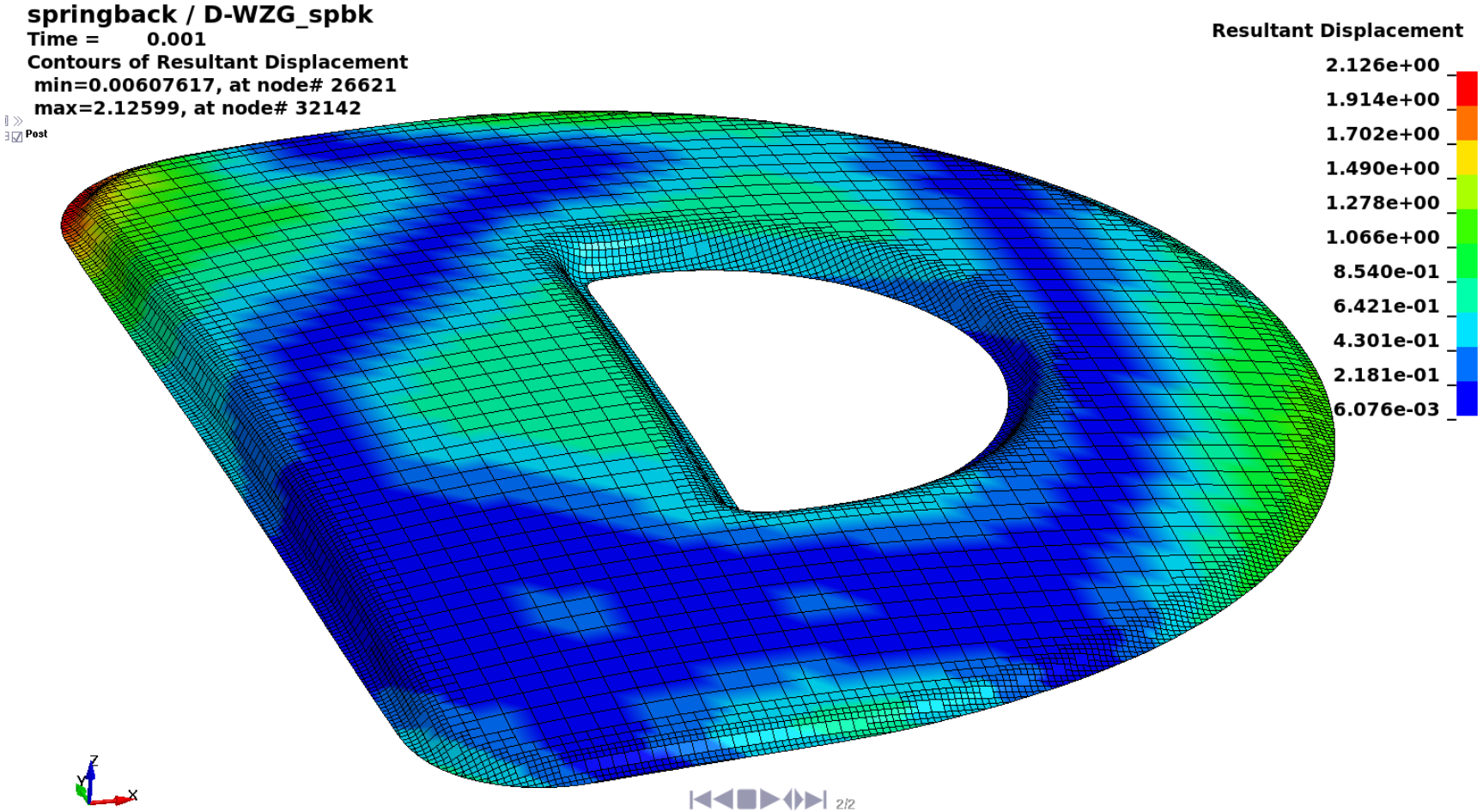
# Stage 4 – Springback analysis

- Standard Finite Elements



# Stage 4 – Springback analysis

- Standard Finite Elements



# Stage 4 – Springback analysis

- Isogeometric Elements
  - … not yet ready
  - … work in progress

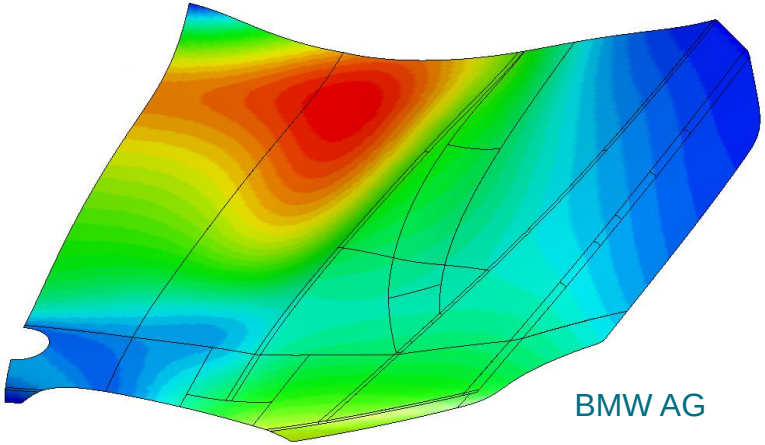
# Outline

- Introduction to IGA in LS-DYNA
  - Motivation & Definition
  - NURBS-based finite elements in LS-DYNA
  - Analysis capabilities
- A multistage sheet metal forming process
  - Stage 1 – Gravity
  - Stage 2 – Deep drawing
  - Stage 3 – Trimming
  - Stage 4 – Springback analysis
- **Summary and Outlook**

## Summary

- IGA in LS-DYNA allows the mapping of results data to enable multistep sheet metal forming analysis by supporting
  - ***INTERFACE_SPRINGBACK_LSDYNA**
  - ***INITIAL_*STRESS/STRAIN*_SHELL_NURBS_PATCH**

- Still missing / To-Do:
  - Enabling springback analysis
  - Adaptivity
  - … and a bunch of other things



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## Outlook

- We are constantly working to increase features for IGA in various areas, like
  - Robust coupling of trimmed NURBS patches (explicit and implicit)
  - Better integration of IGA with Pre- and Post-Processing
  - … what customers are requesting

# Thank you!