Local Analysis-Test Correlation for Tow-Steered Composite Shells with Small Cutouts

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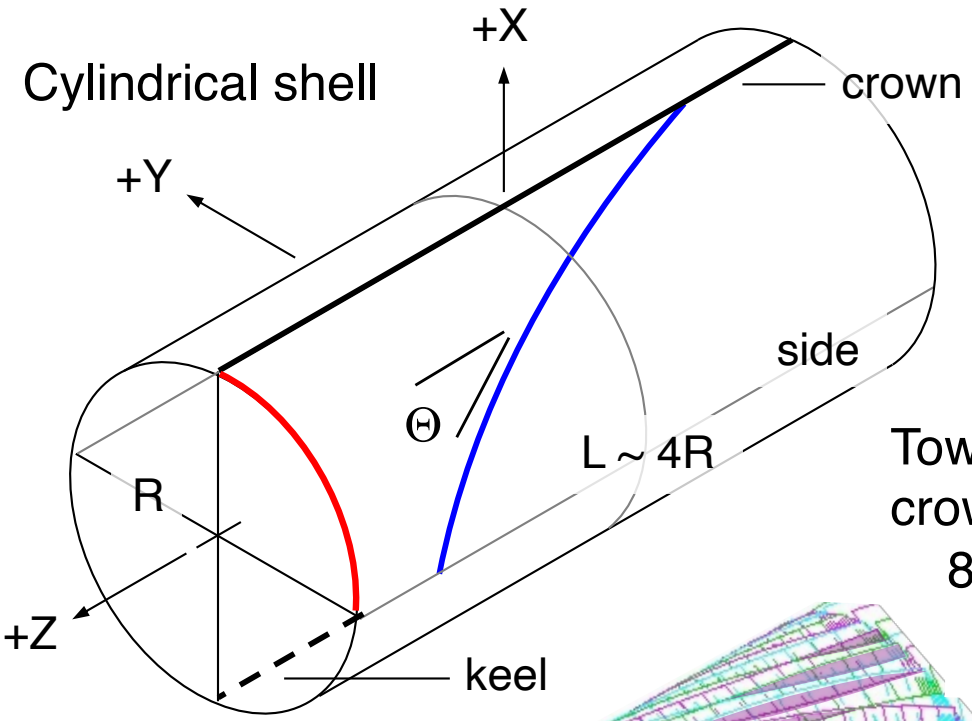
Talk Outline

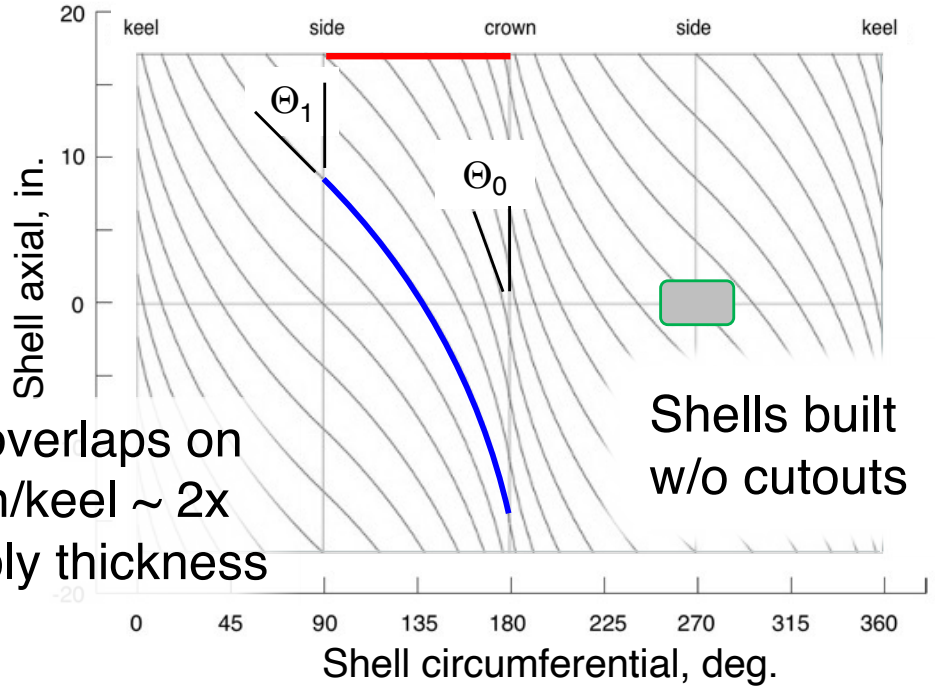
- Introduction
  - Shell design and manufacturing
  - Analyses and tests without cutouts
- Shells with small cutouts
  - Cutout description
  - Structural analyses
  - Compression tests
- Comparison of analysis and test results
  - Crown and keel
  - Cutout top edge
  - Cutout left edge
- Summary and concluding remarks

Study Objectives

- Assess structural performance of two tow-steered composite shells with small cutouts
  - Shells with and without tow overlaps
  - Same nominal layup
- Apply nonlinear finite element analyses
  - Shell prebuckling deflections and strains
  - Shell postbuckling deflections and strains
- Compare modeled shell structural response with corresponding test results
  - Discrete locations on shell planform
  - Measured analog (LVDT, strain gage) and digital image correlation (DIC) deflections and strains
  - Shell postbuckling behavior

Tow-Steered Shell Concept

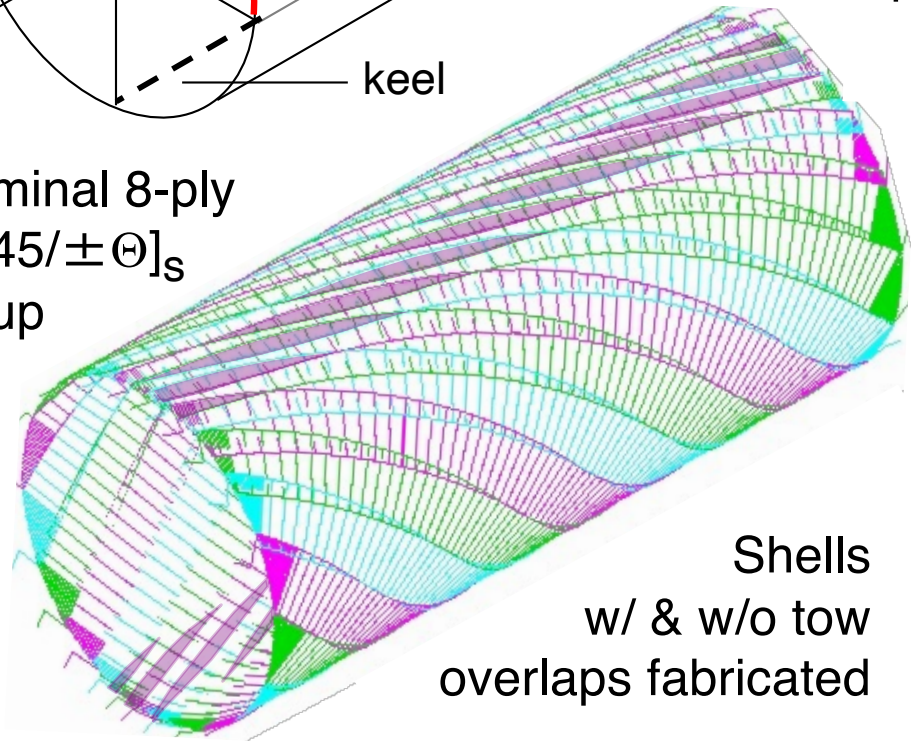




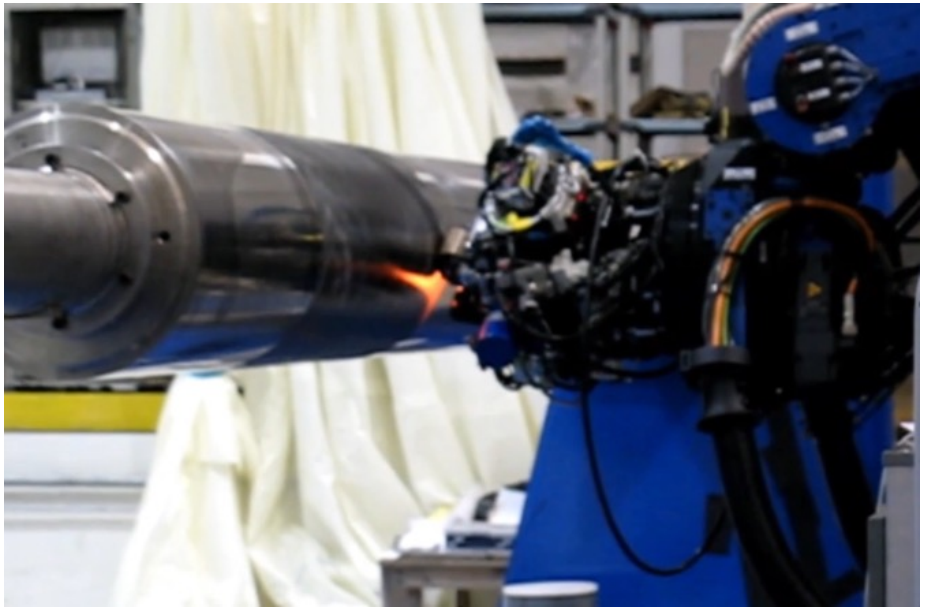
Tow overlaps on crown/keel ~ 2x 8-ply thickness

Shells built w/o cutouts

Nominal 8-ply $[\pm 45/\pm\Theta]_s$ layup

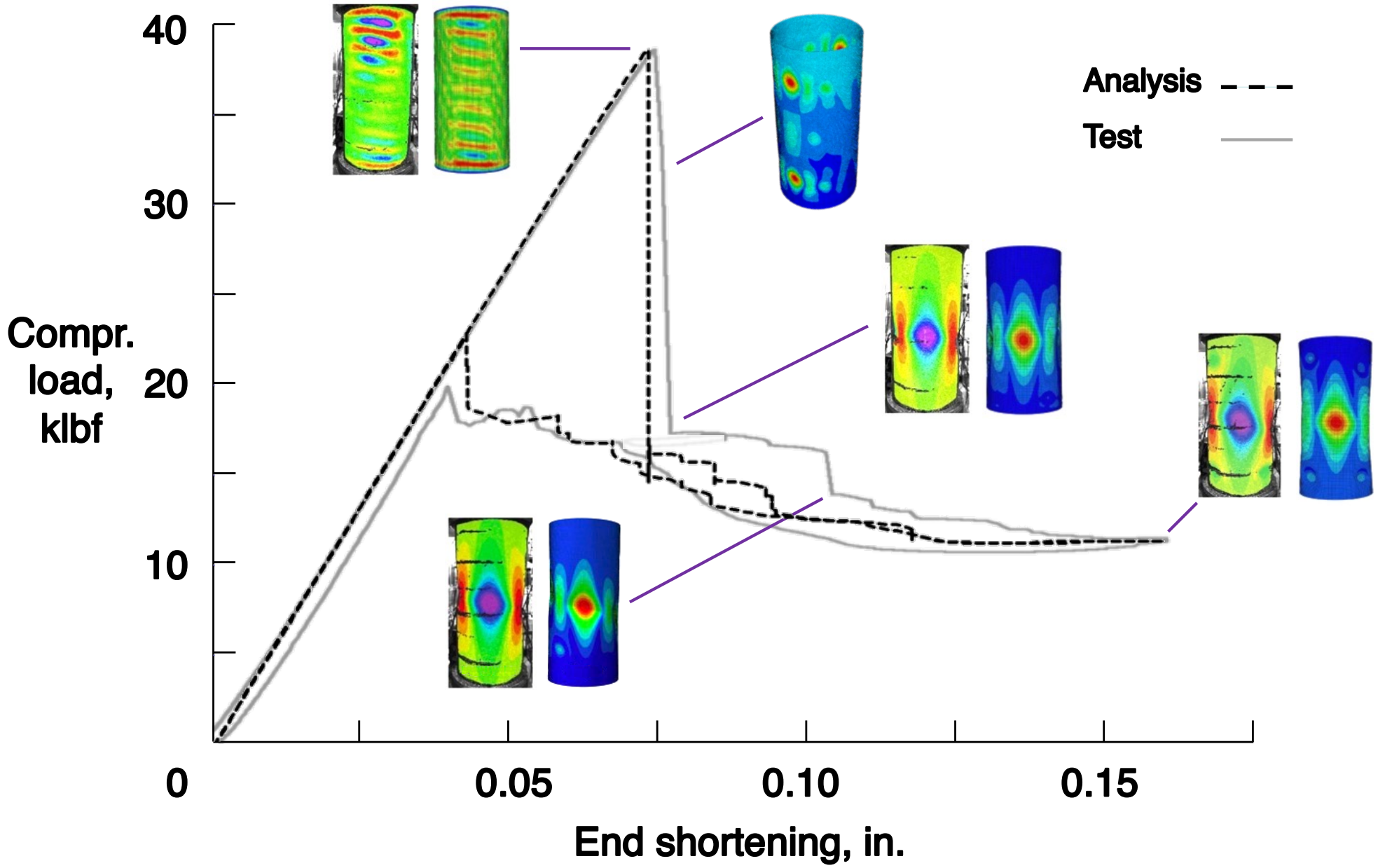


Shells w/ & w/o tow overlaps fabricated



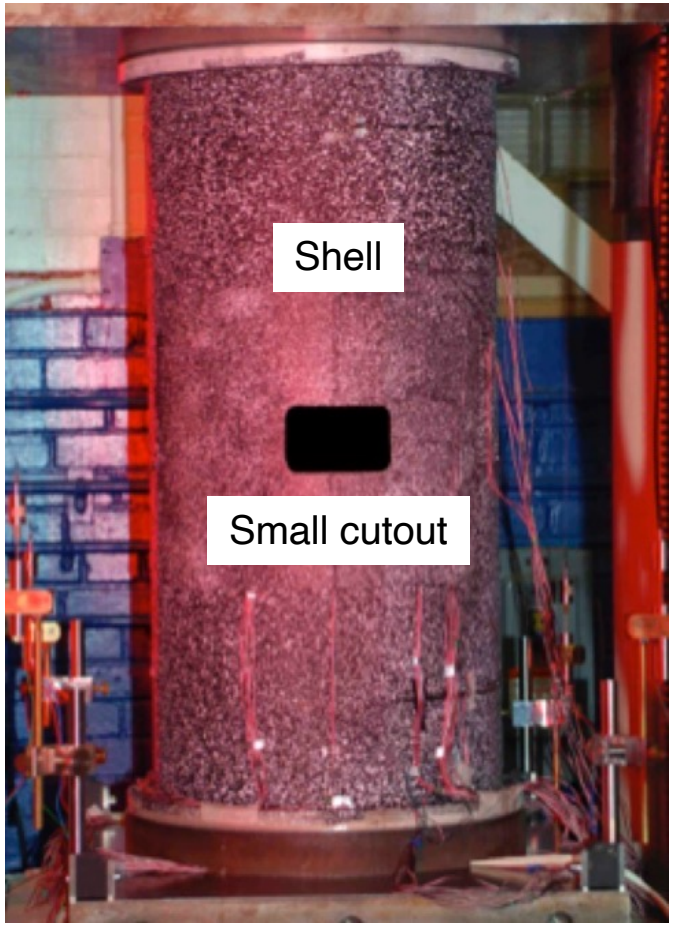
Baseline Shell w/o Cutout Test and FEA

(Shell with Overlaps shown)



Description of Small Cutouts

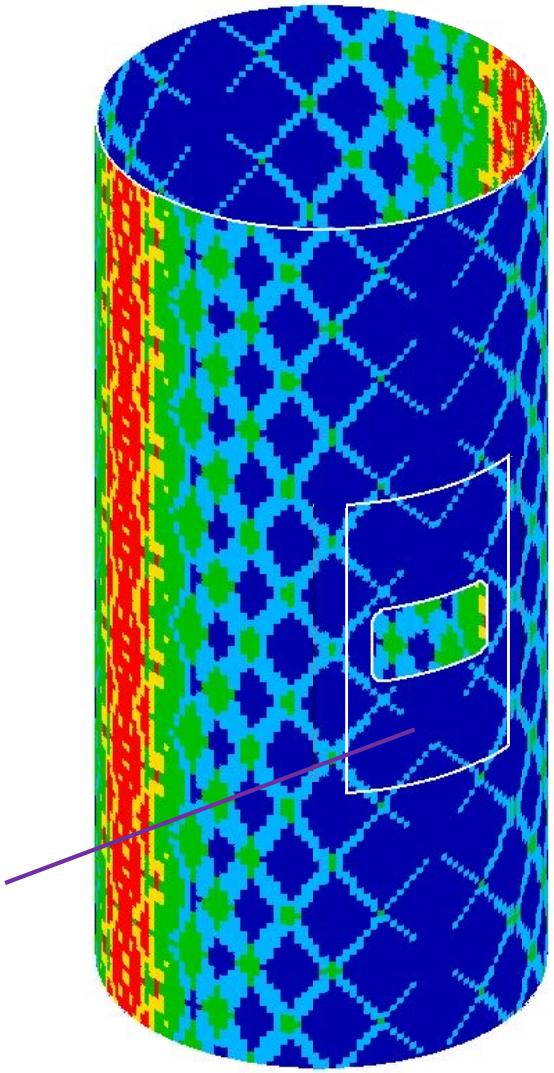
- Small cutouts scaled to represent passenger doors on commercial aircraft fuselage barrel
- Cutouts are 3 in. (axial) x 4.88 in. (circumferential), with 0.50-in. corner radii
- Unreinforced cutouts machined into center of one side of each shell (layup ~ $[\pm 45]_{2S}$)
- 20 back-to-back strain gage pairs around cutout perimeter
- Digital image correlation (DIC) used for full-field visualization



Shell with small cutout installed in test stand

Finite Element Models

- ABAQUS analyses performed
  - Geometrically nonlinear analyses
  - Axial end shortening applied / removed
- S4R shell elements used
  - Acreage elements ~ 0.25 in.-square
  - Each constant thickness and fiber angles
  - Measured IM7/8552 material properties and predicted ply thickness
- Refined FE mesh around small cutouts
  - Parametric mesh refinement studied
  - Refined elements surrounding cutout are ~ 0.083 in.-square (1/3 nominal)
  - Refinements have same thickness and layup as parent element

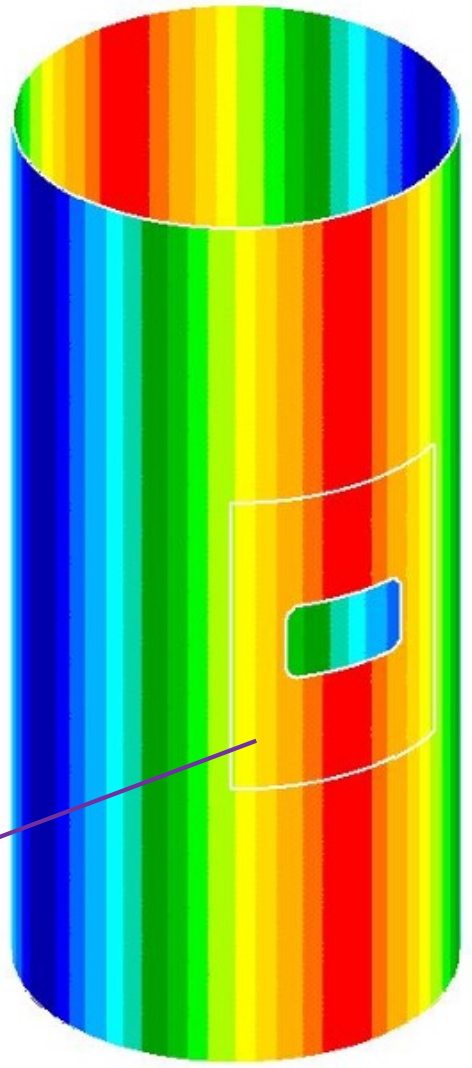


Shell with overlaps laminate thicknesses

8 16
plies

Finite Element Models (2)

- ABAQUS analyses performed
  - Geometrically nonlinear analyses
  - Axial end shortening applied / removed
- S4R shell elements used
  - Acreage elements ~ 0.25 in.-square
  - Each constant thickness and fiber angles
  - Measured IM7/8552 material properties and predicted ply thickness
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Steered ply 3 fiber orientation angles

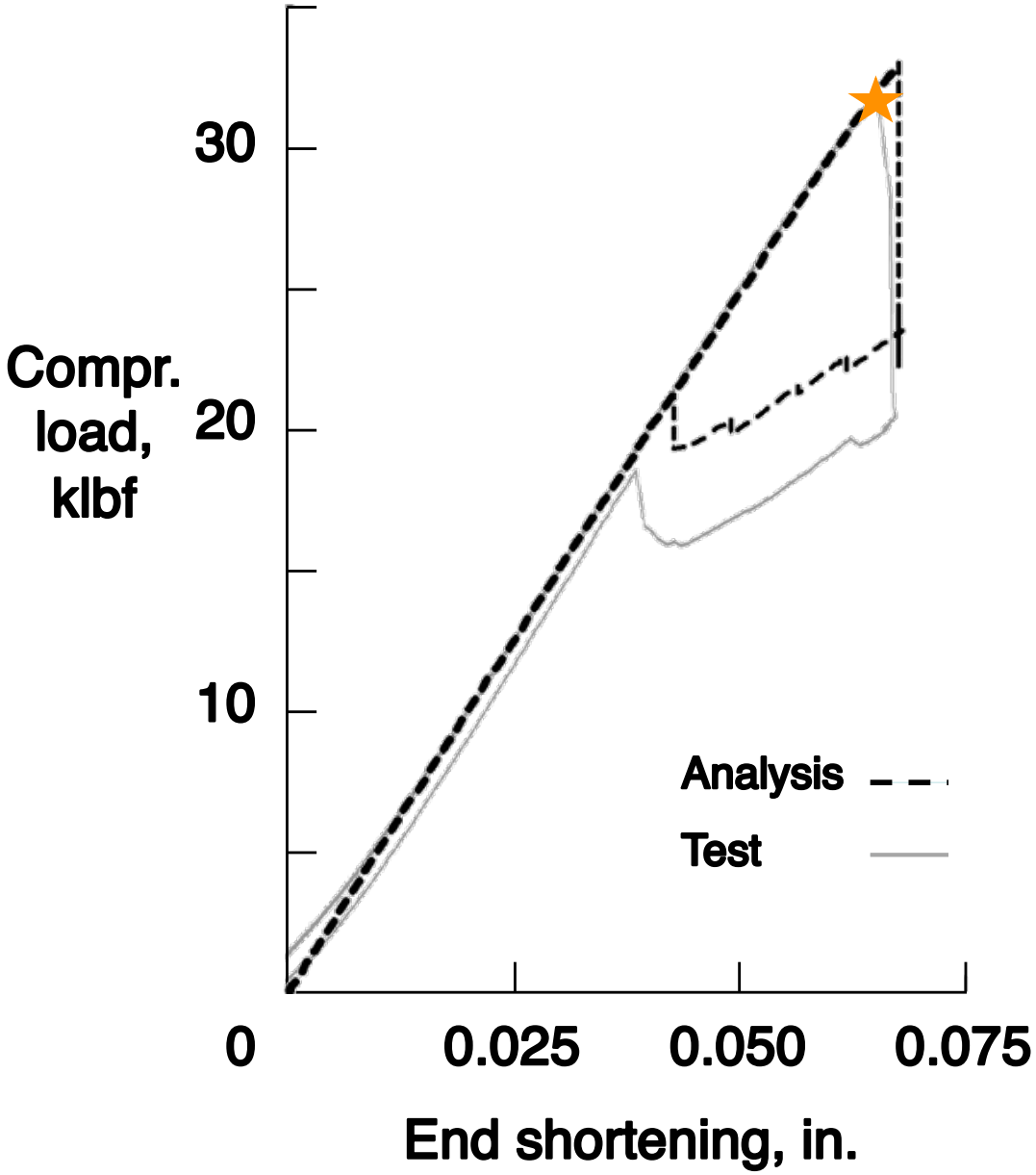
10 45
degrees

Shells with Small Cutouts

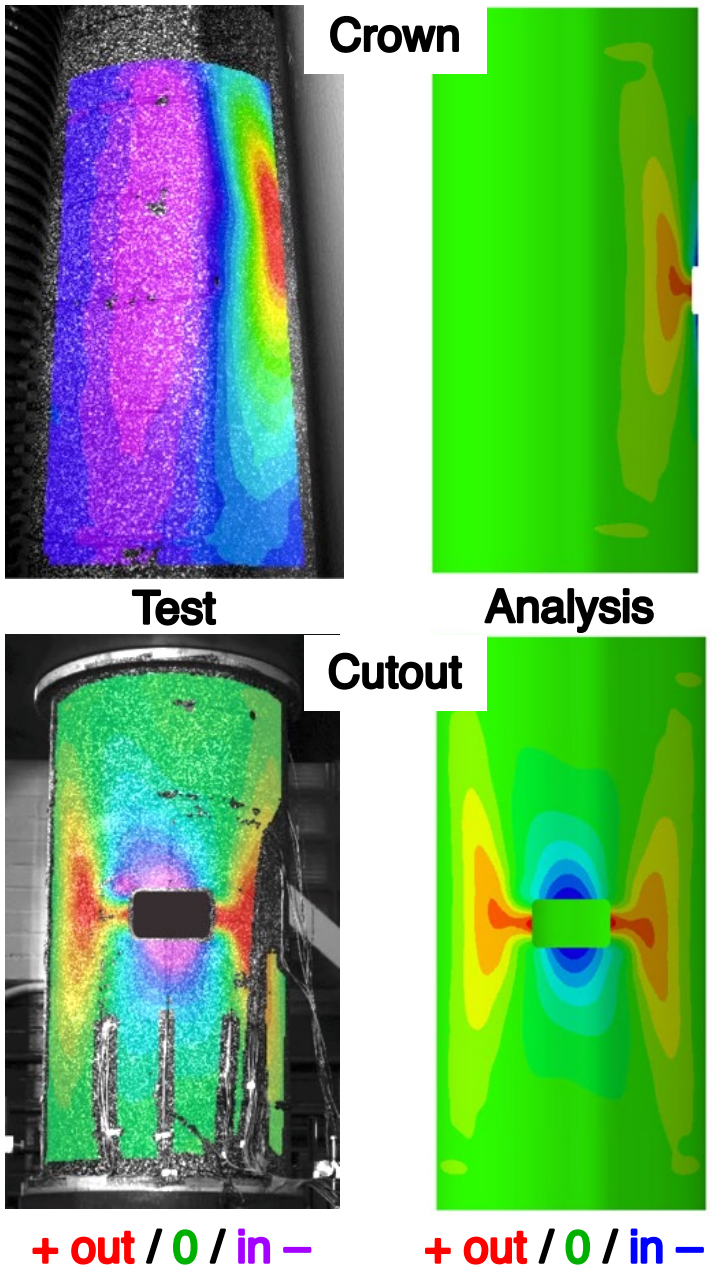
Shell with Overlaps

Shell with Overlaps Test and FEA

(Buckling DIC shown)

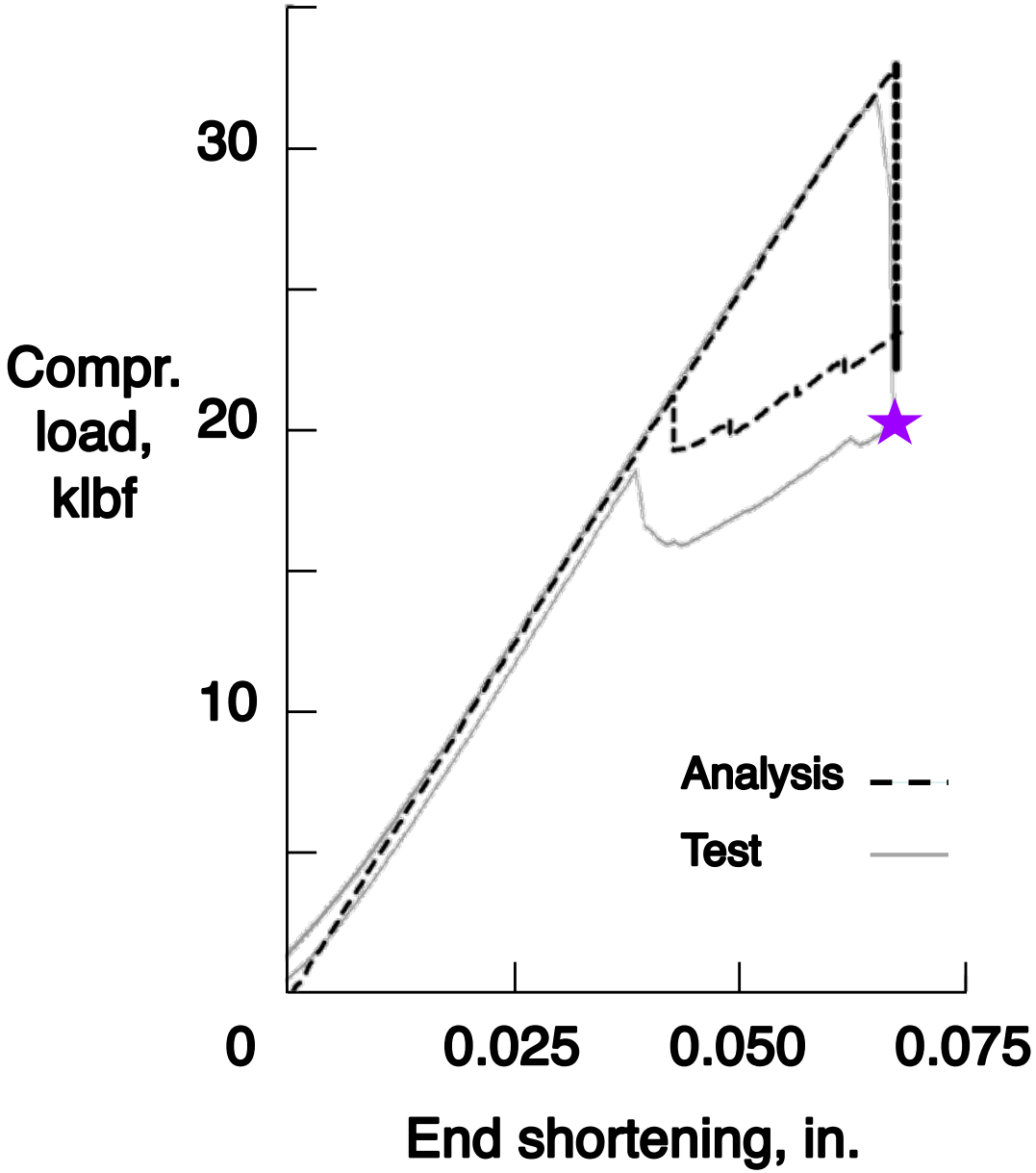


Shell radial deflections

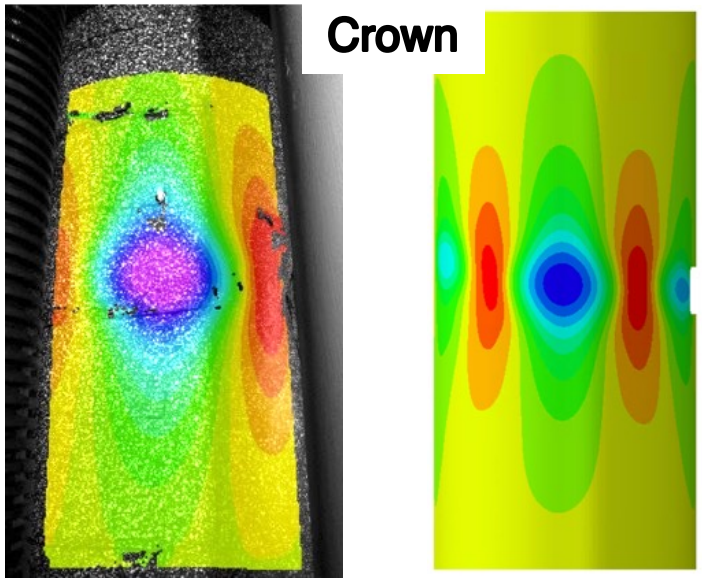


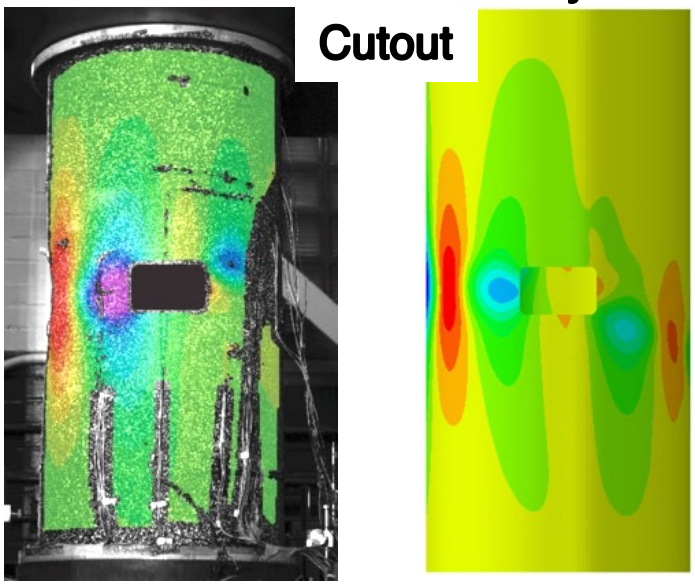
Shell with Overlaps Test and FEA (2)

(Postbuckling DIC shown)



Shell radial deflections

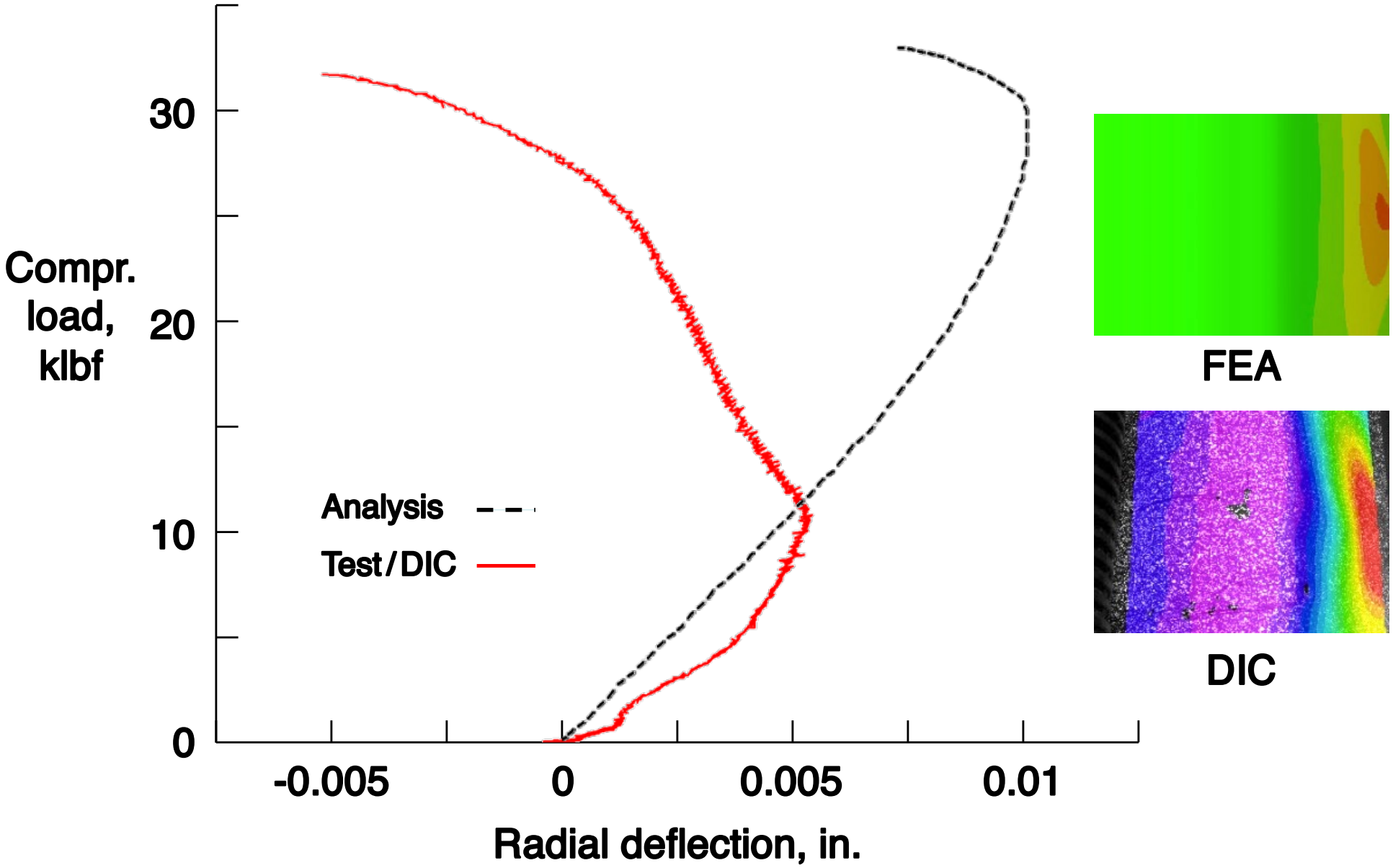




+ out / 0 / in – + out / 0 / in –

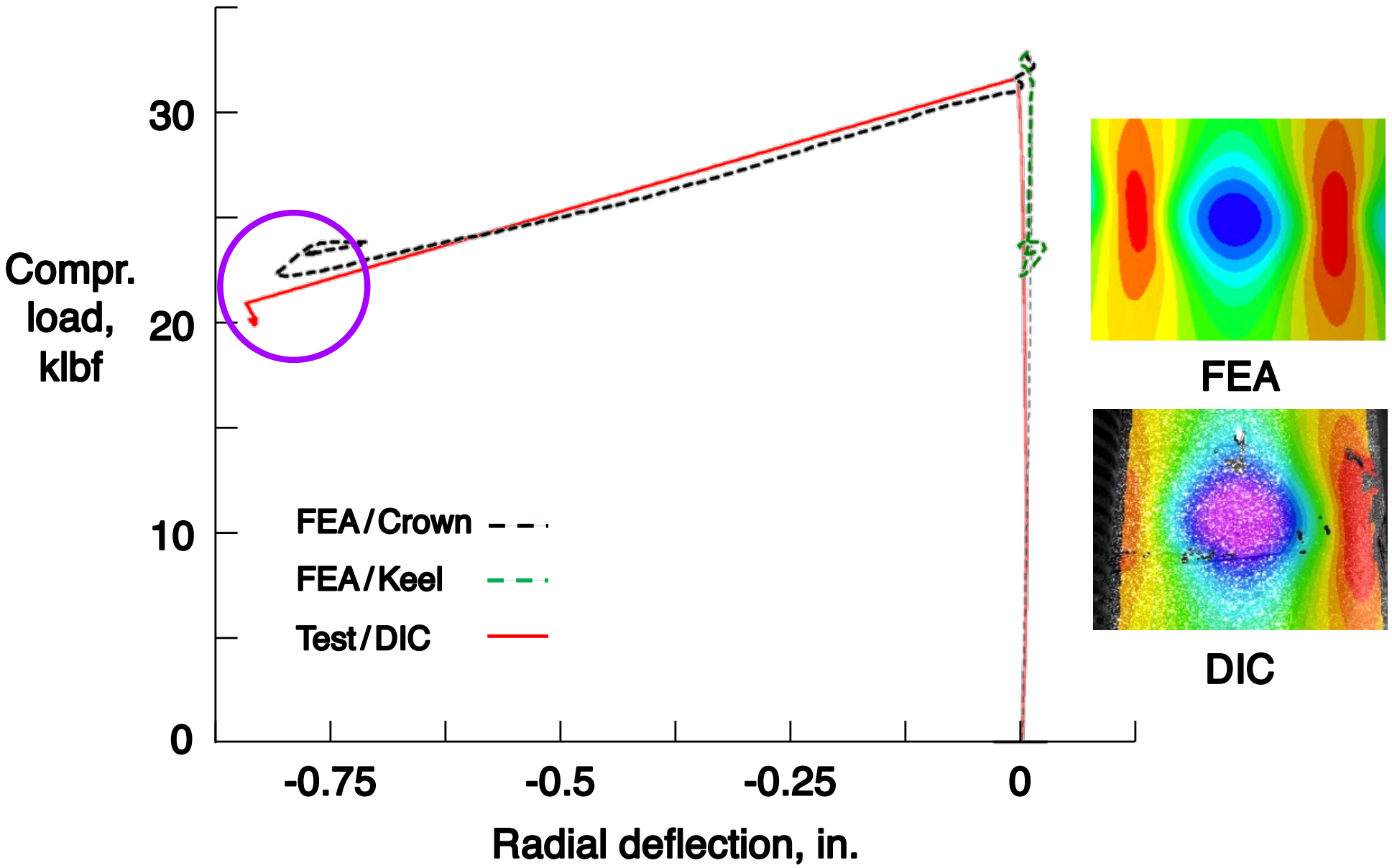
Shell with Overlaps Crown & Keel Deflections

(Prebuckling results shown)



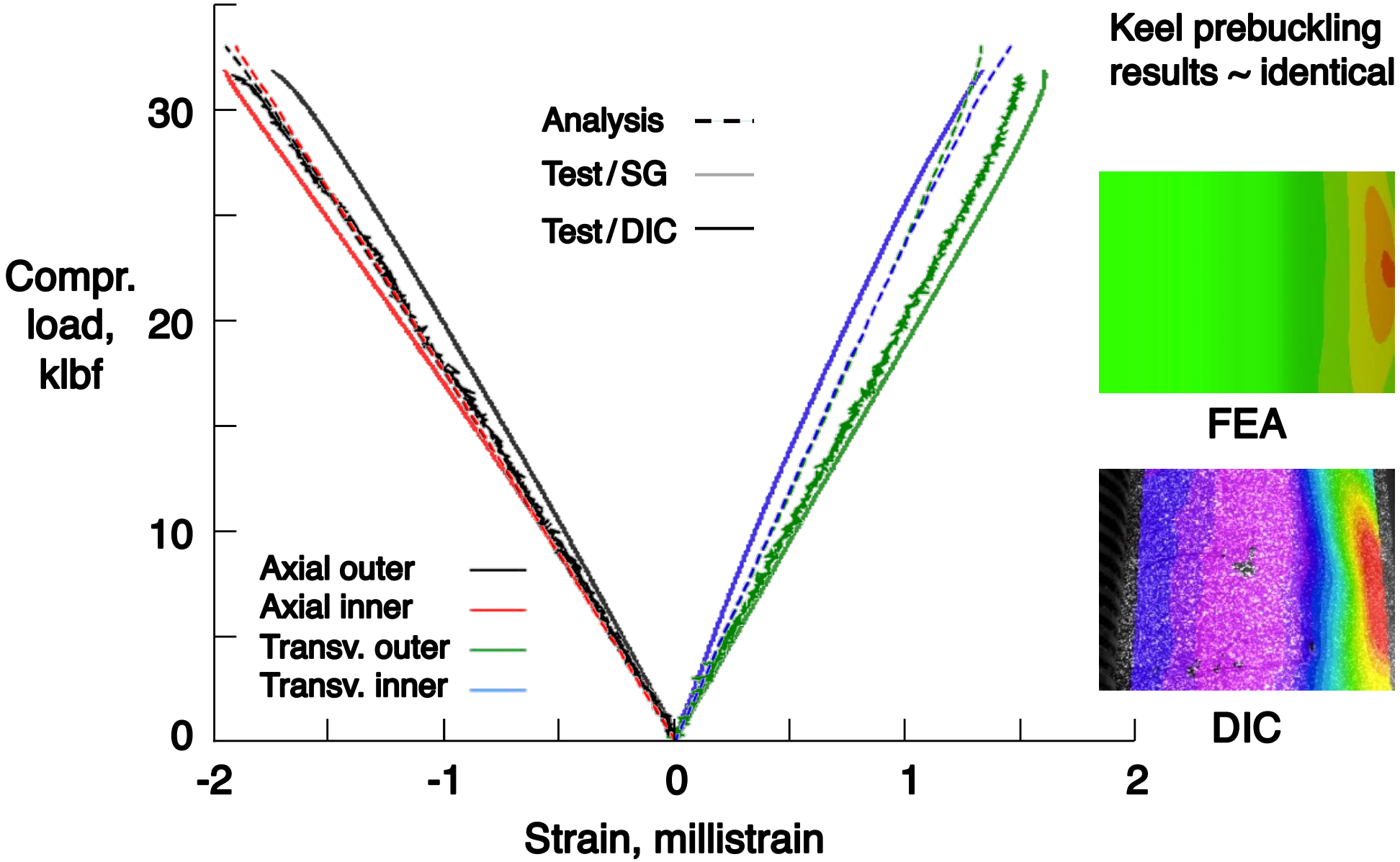
Shell with Overlaps Crown & Keel Defl. (2)

(Postbuckling results shown)



Shell with Overlaps Crown Strains

(Prebuckling results shown)



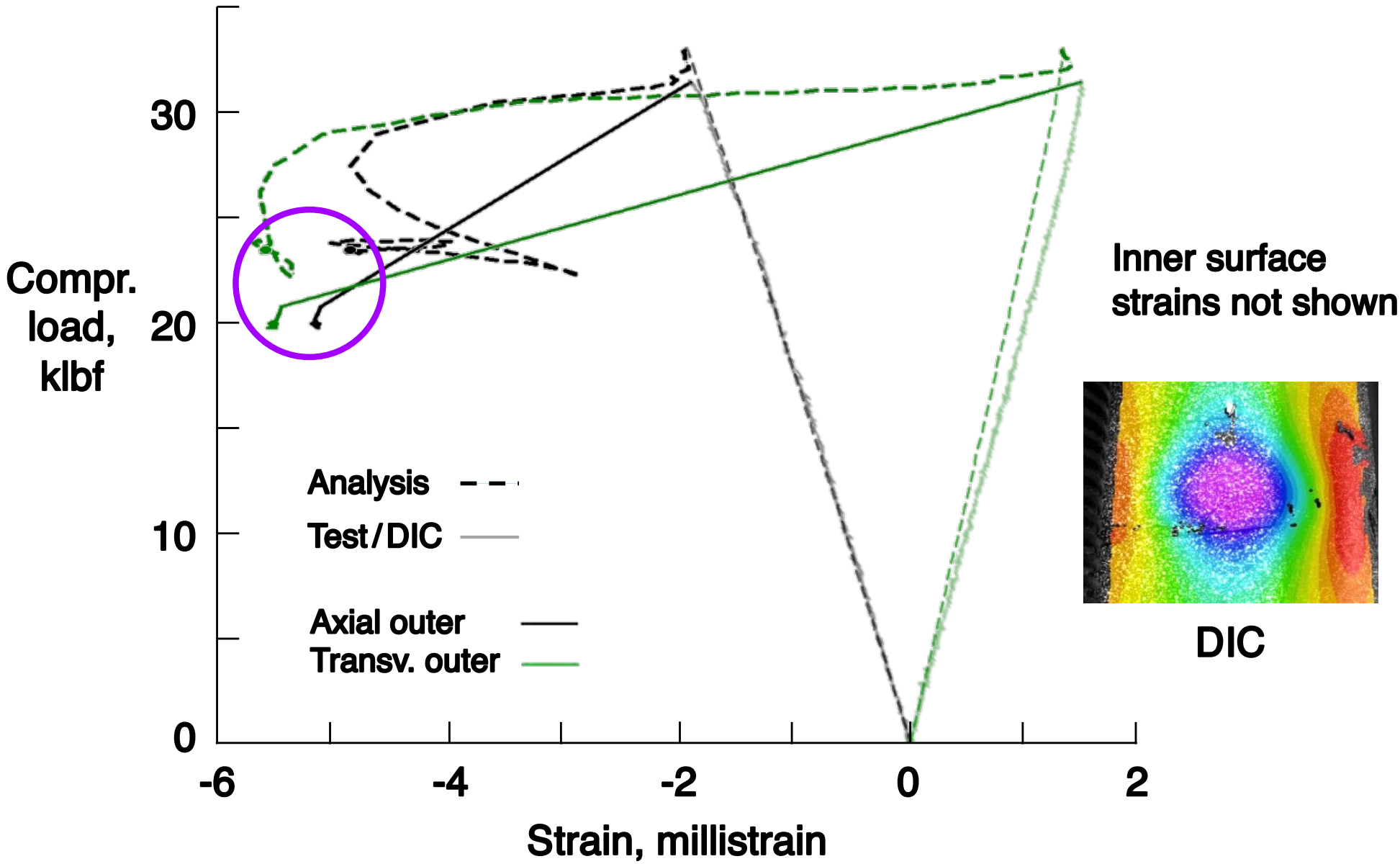
Keel prebuckling results ~ identical

FEA

DIC

Shell with Overlaps Crown Strains (2)

(Postbuckling results shown)

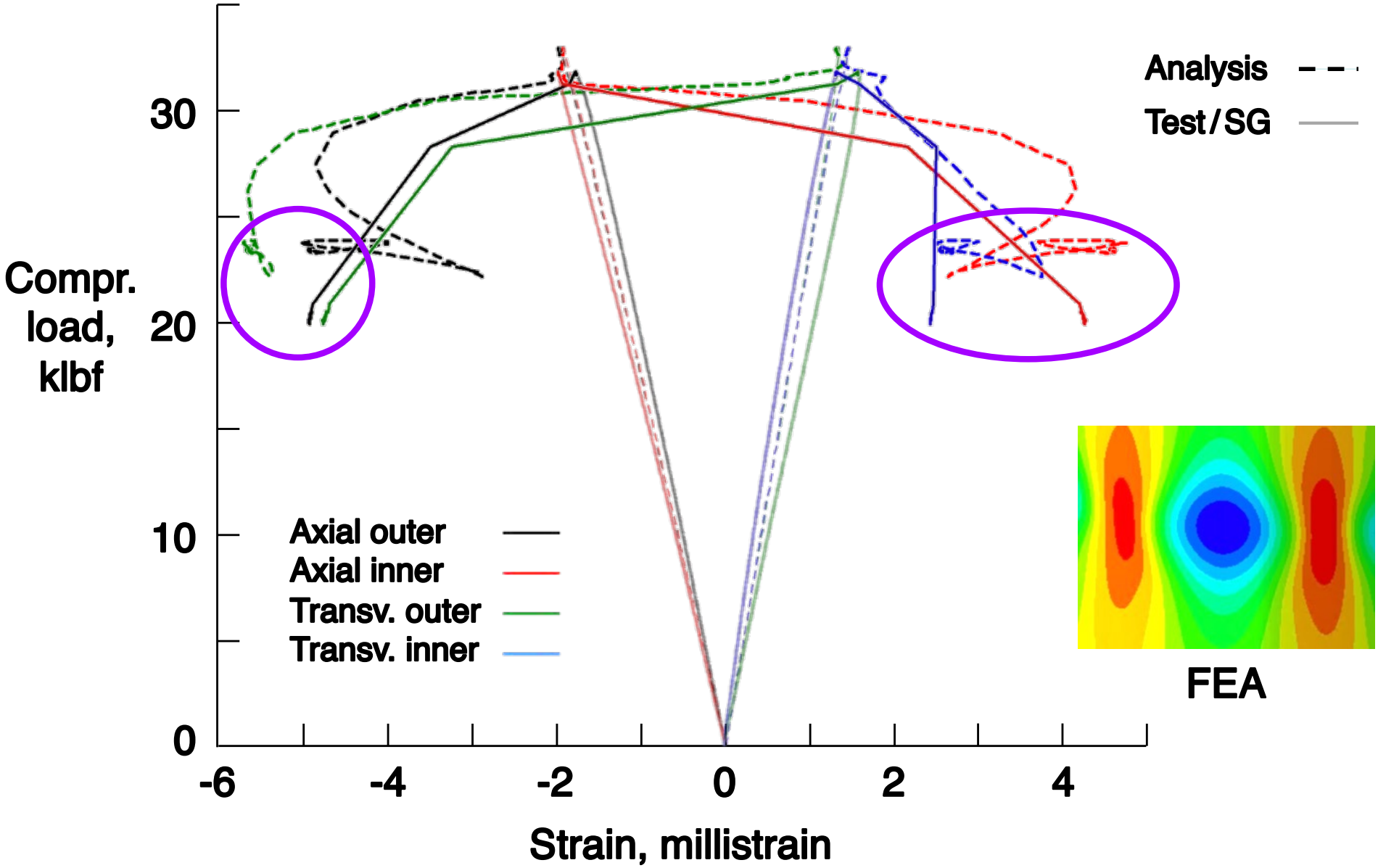


Inner surface strains not shown

DIC

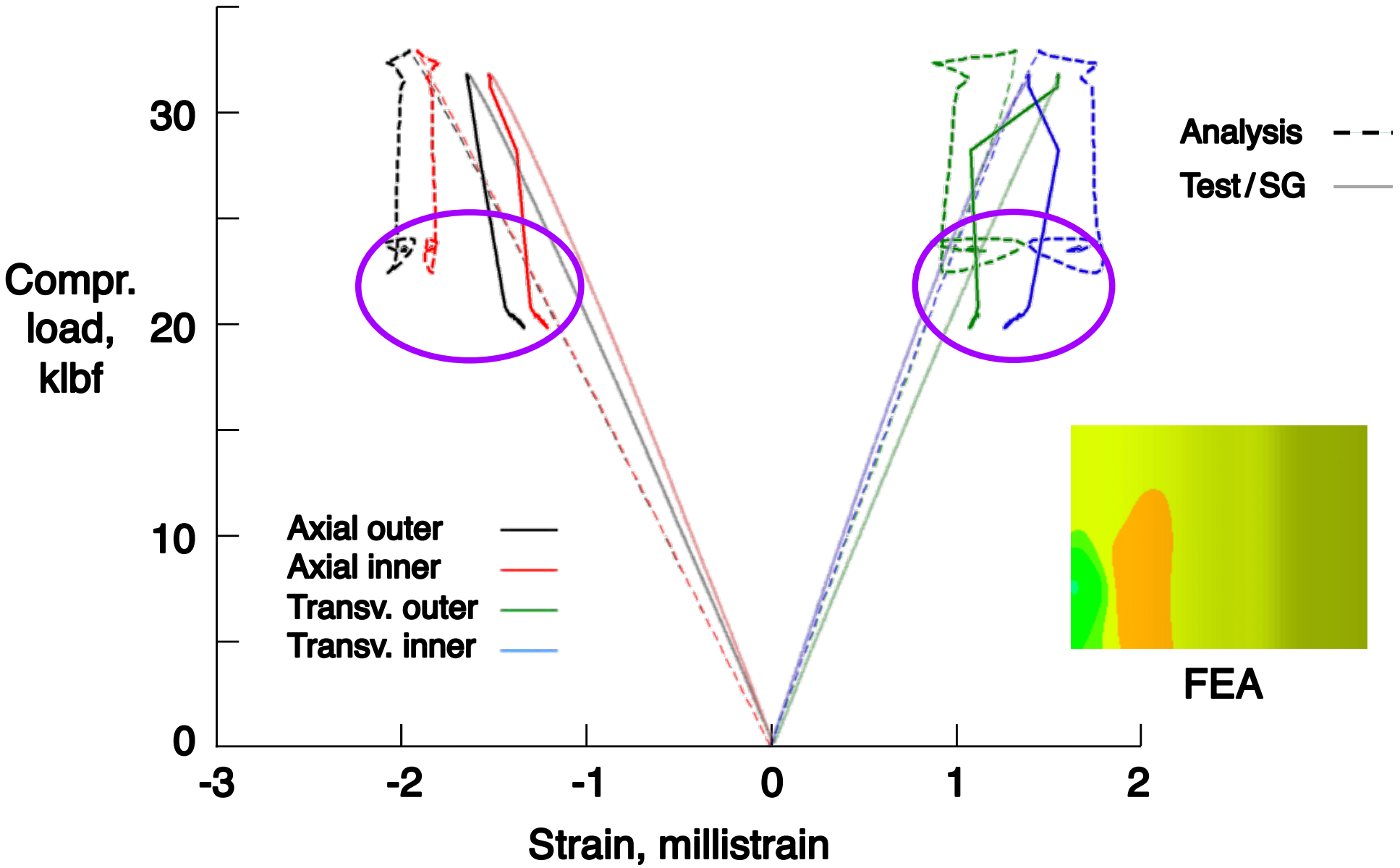
Shell with Overlaps Crown Strains (3)

(Postbuckling results shown)



Shell with Overlaps Keel Strains

(Postbuckling results shown)

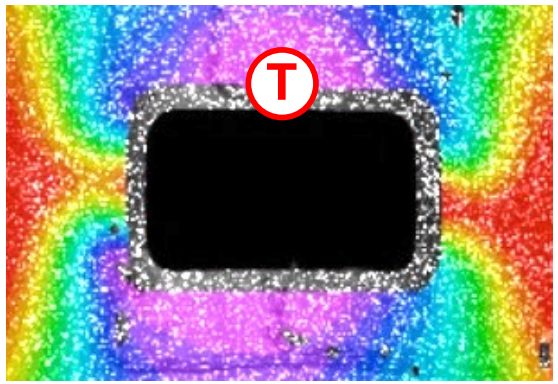


Shells with Small Cutouts

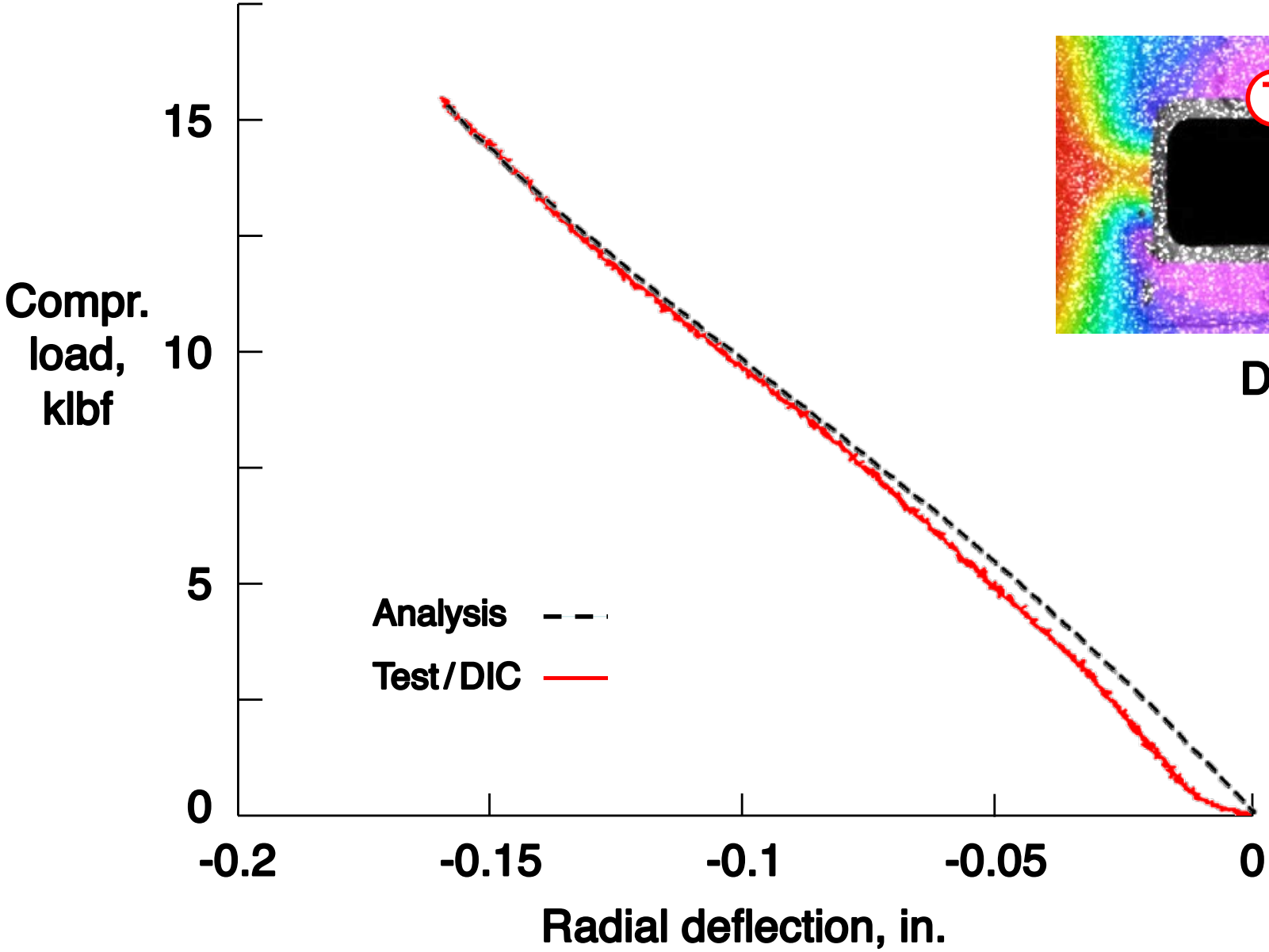
Shell w/o Overlaps

Shell w/o Overlaps Cutout Top Edge Deflections

(Prebuckling results shown)

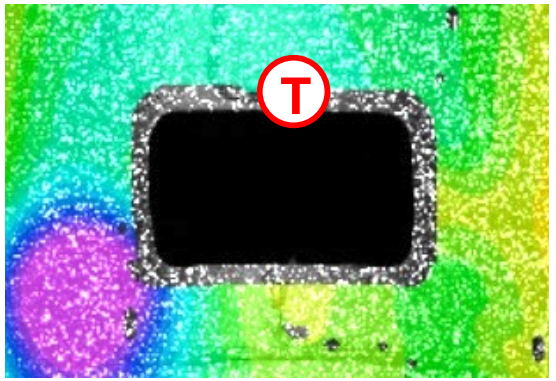


DIC

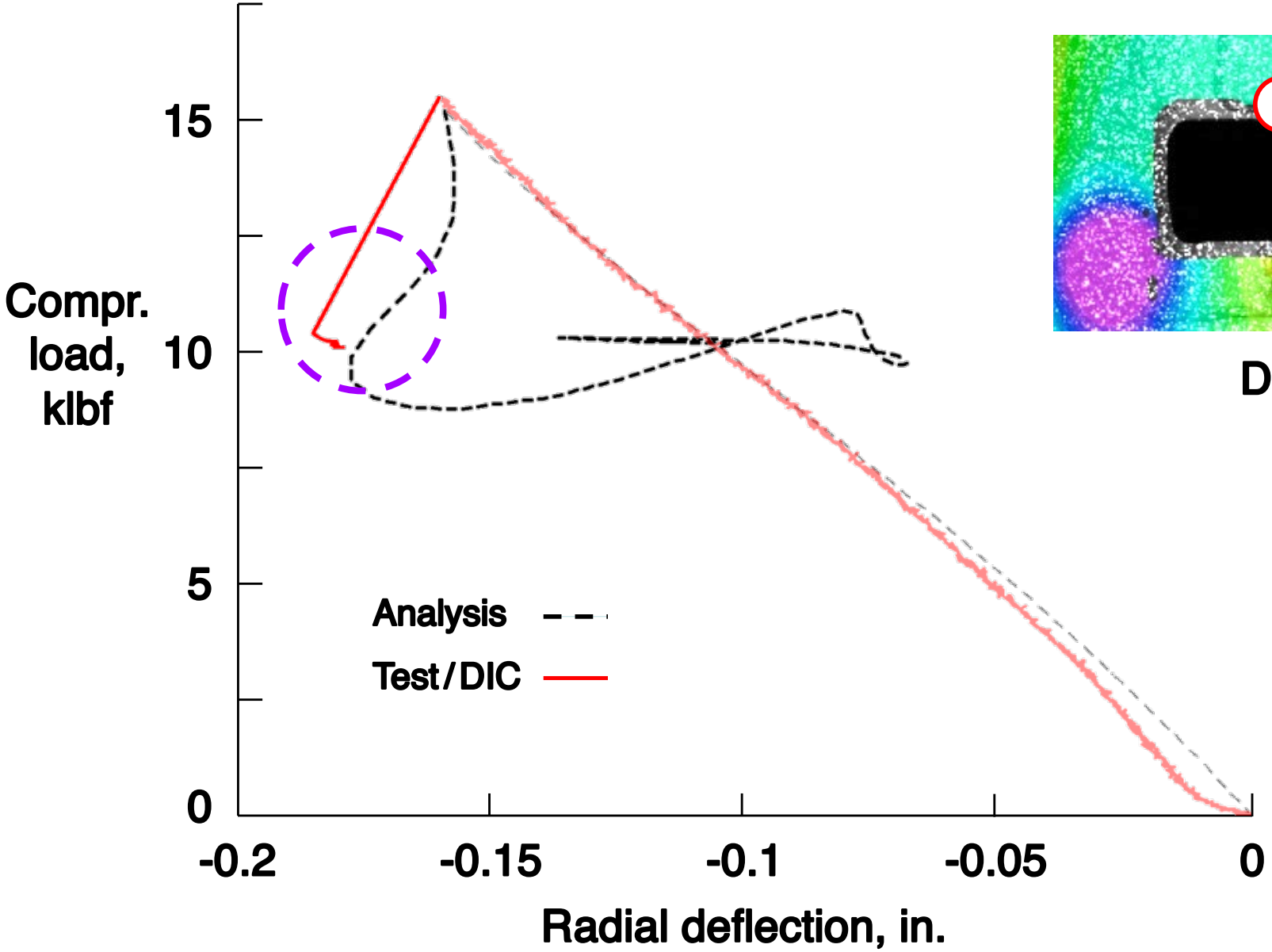


Shell w/o Overlaps Cutout Top Edge Defl. (2)

(Postbuckling results shown)

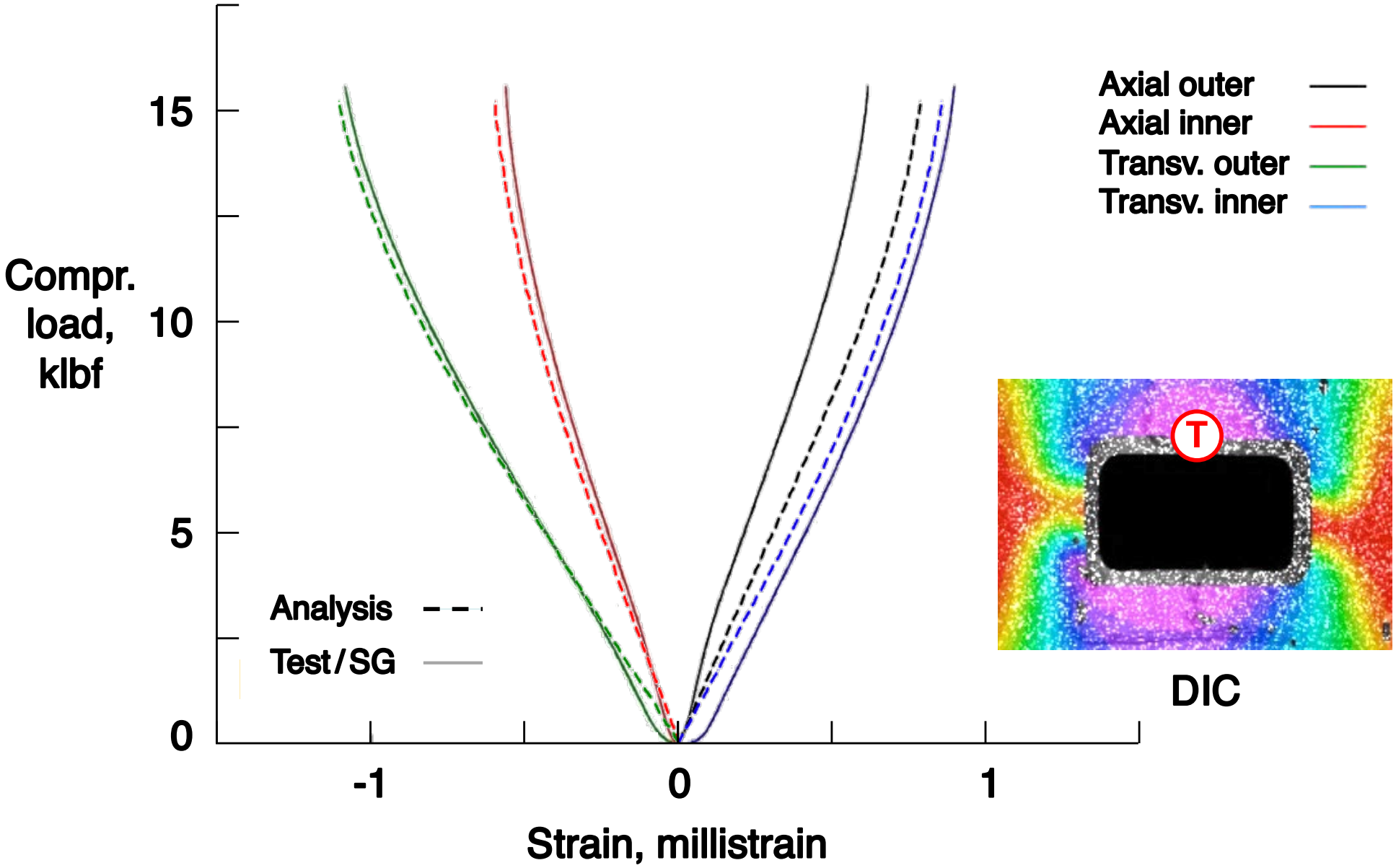


DIC



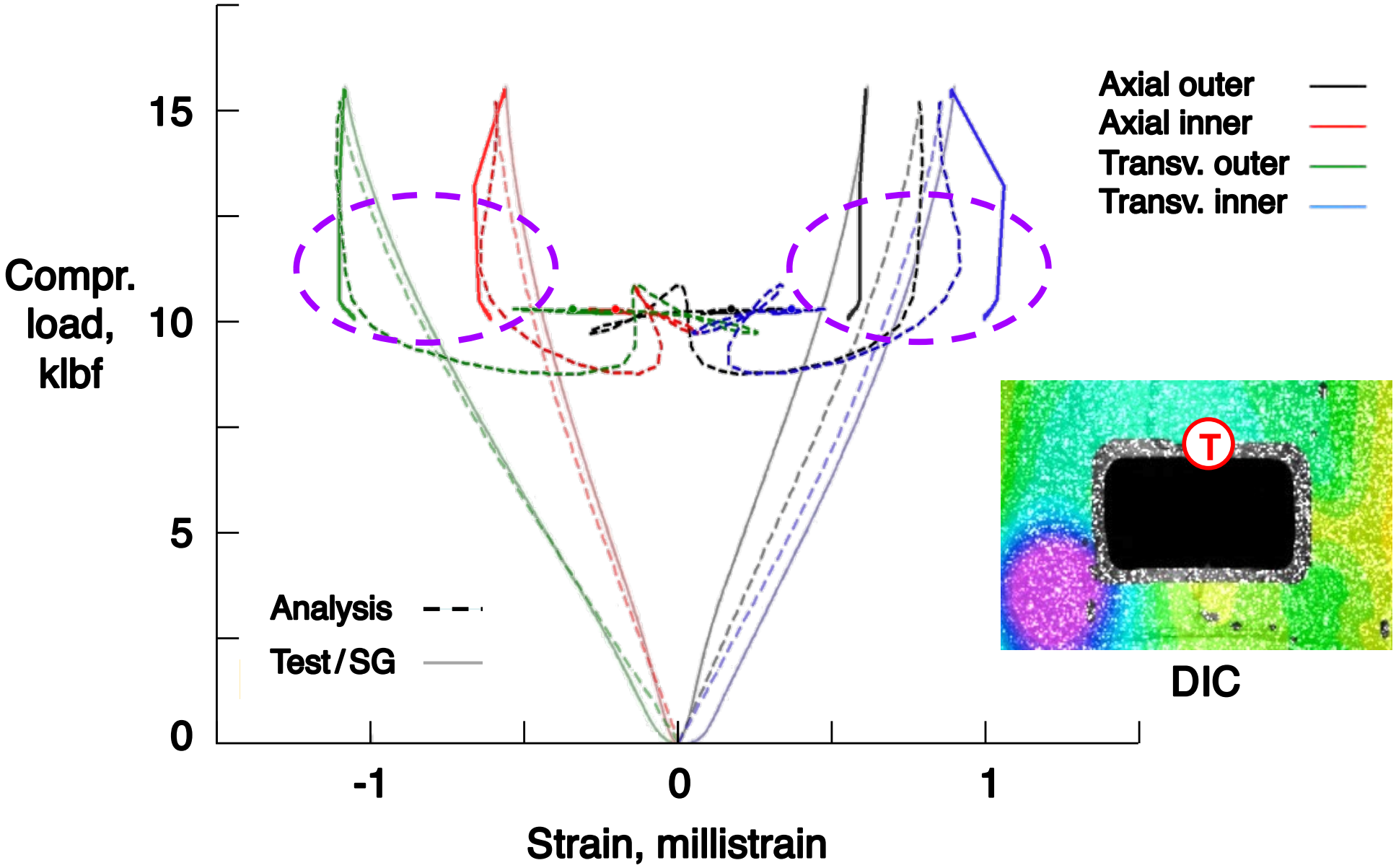
Shell w/o Overlaps Cutout Top Edge Strains

(Prebuckling results shown)



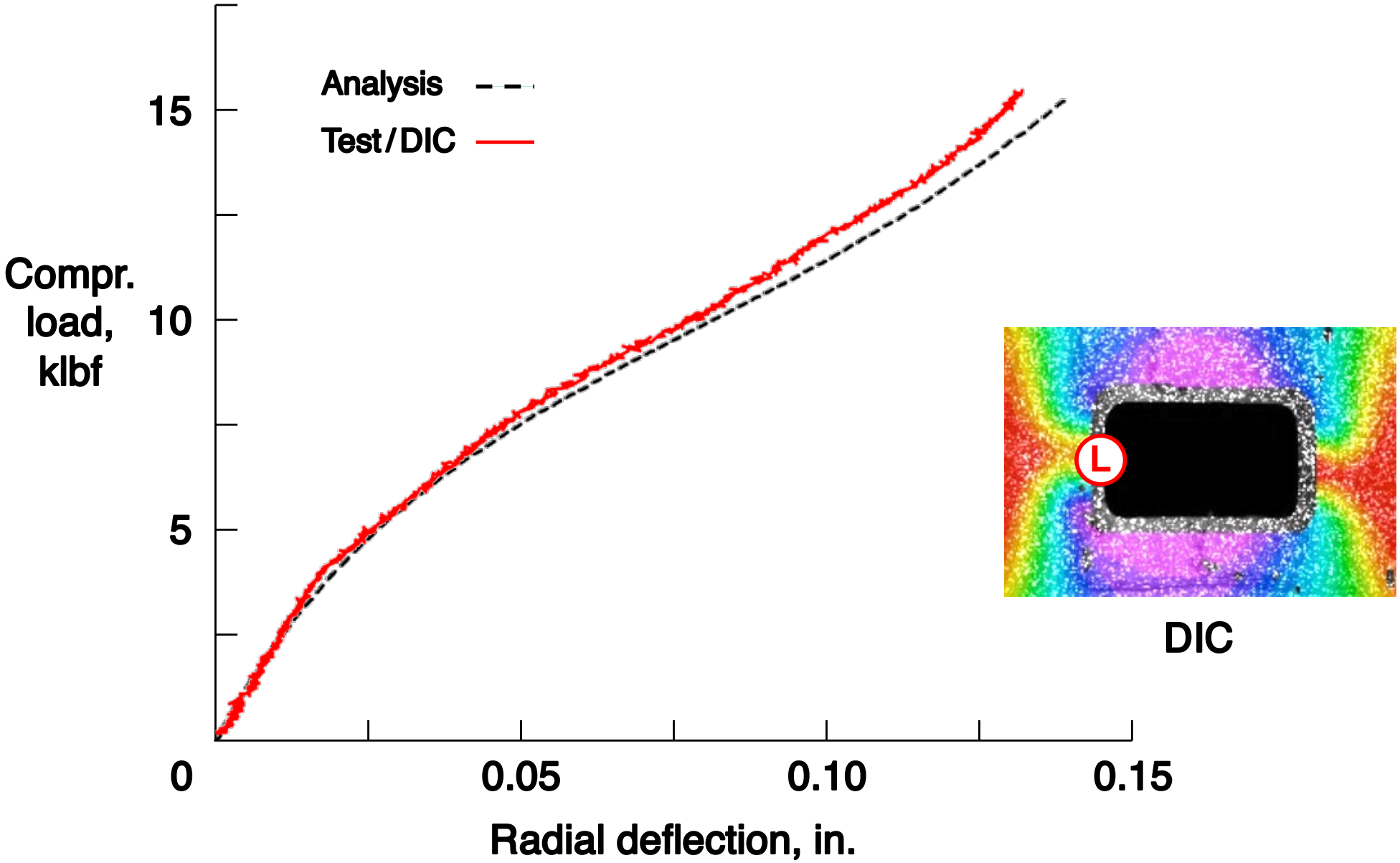
Shell w/o Overlaps Cutout Top Edge Strains (2)

(Postbuckling results shown)



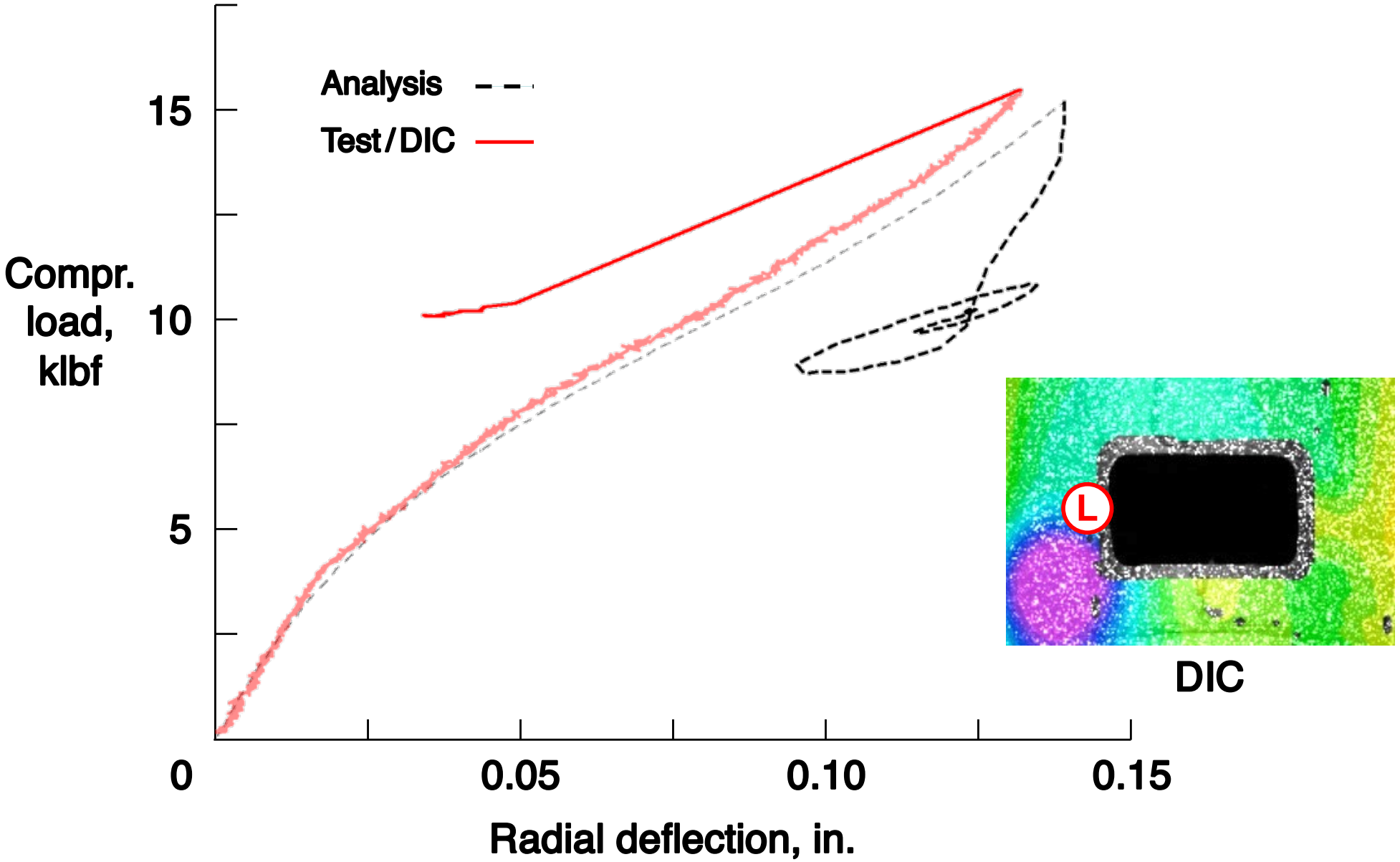
Shell w/o Overlaps Cutout Left Edge Deflections

(Prebuckling results shown)



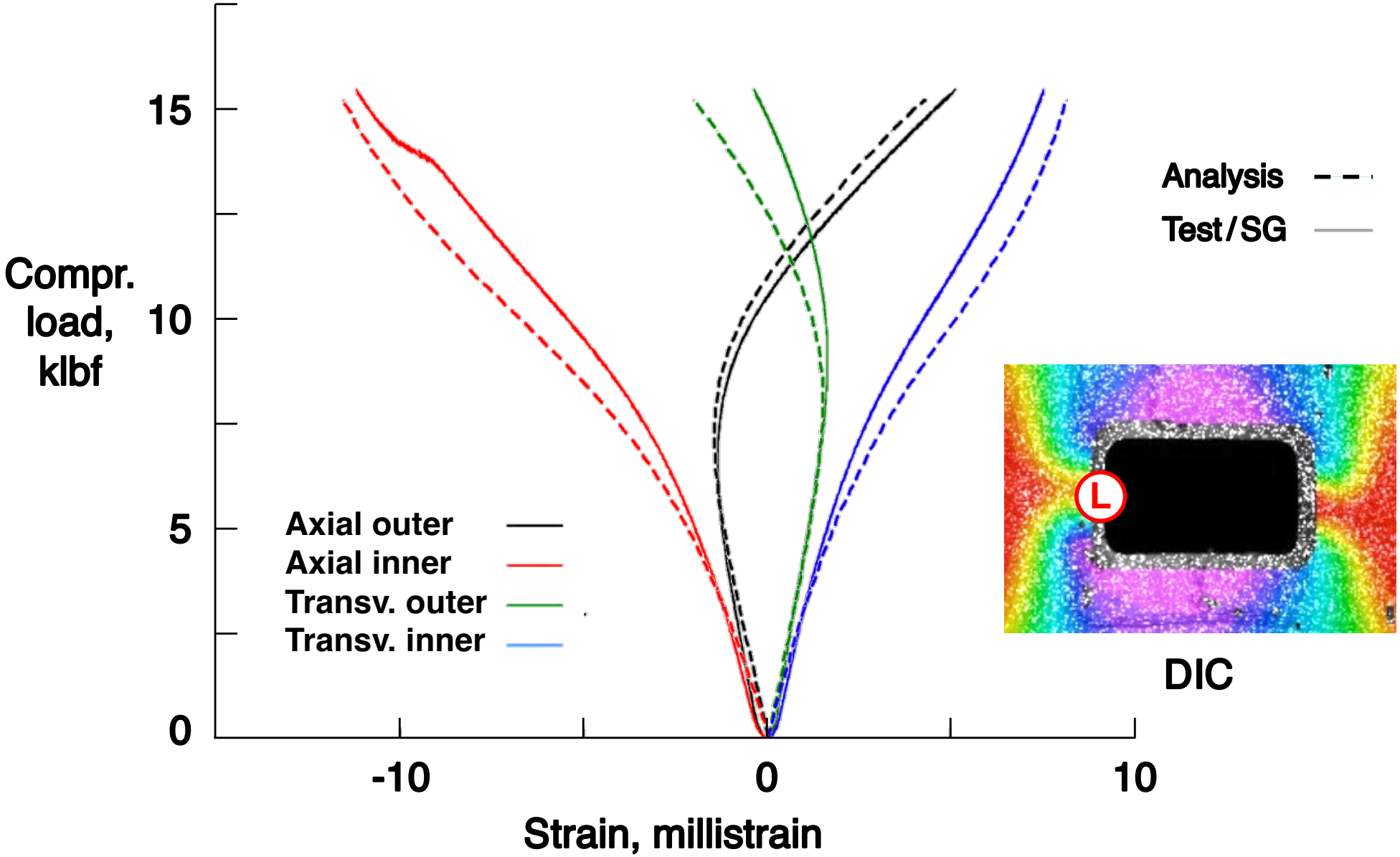
Shell w/o Overlaps Cutout Left Edge Defl. (2)

(Postbuckling results shown)



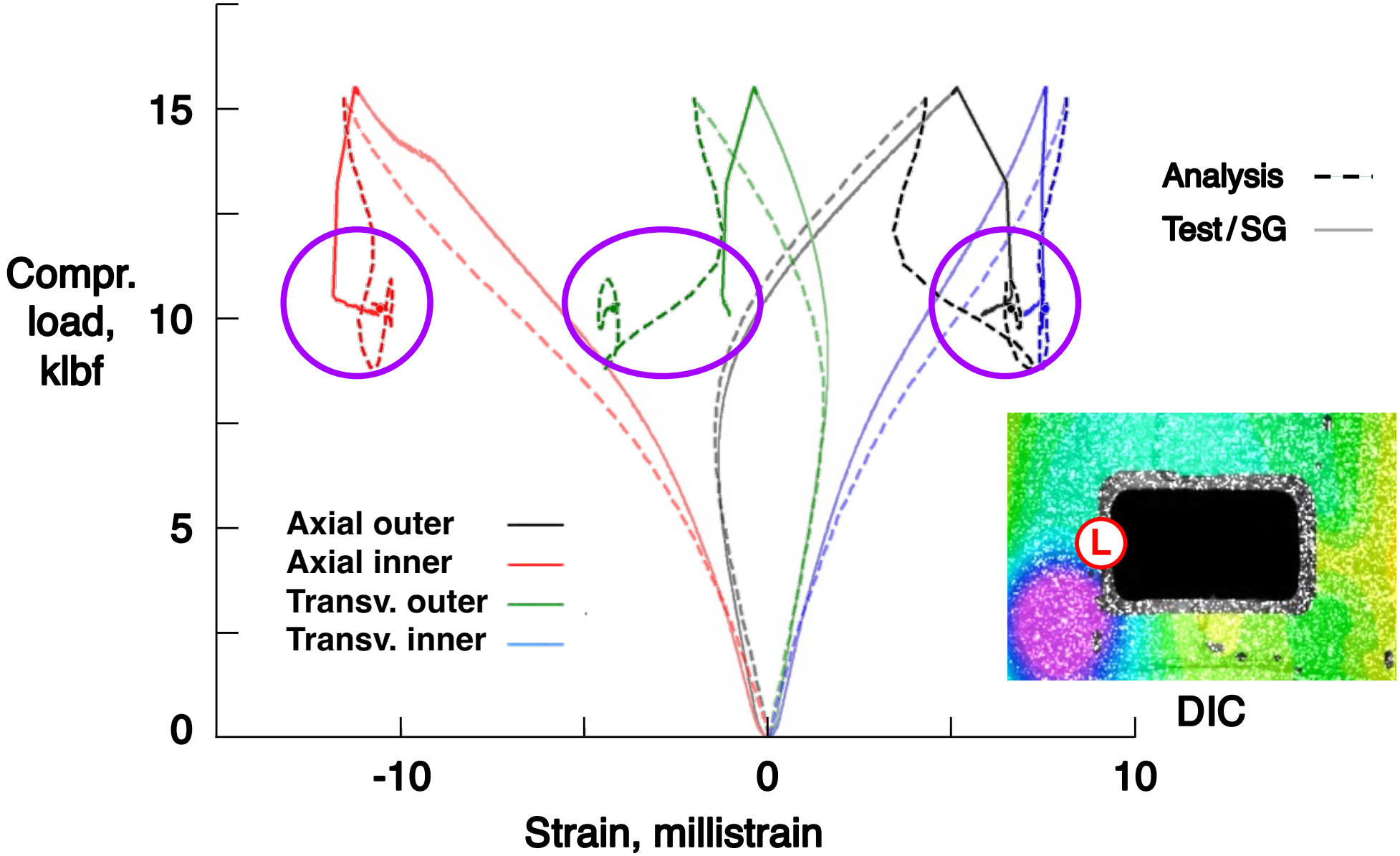
Shell w/o Overlaps Cutout Left Edge Strains

(Prebuckling results shown)



Shell w/o Overlaps Cutout Left Edge Strains (2)

(Postbuckling results shown)



Results Summary

- Discrete locations on shells with small cutouts
  - Crown/keel center
  - Cutout top and left edges
- Deflections and strains computed using geometrically nonlinear finite element analyses
- Corresponding results measured during compression tests to stable postbuckling
  - Digital image correlation
  - Displacement transducer
  - Strain gage
- Excellent prebuckling correlation between FEA and test
- Very good to good correlation at stable postbuckling

Concluding Remarks

- Structural performance of two tow-steered composite shells with small cutouts compared using tests and analyses
- Shells tested in end compression through global buckling, into stable postbuckling, and elastic unloading
- Geometrically nonlinear finite element analyses performed for detailed comparisons with test results
- Local comparisons of radial deflections and strains performed from prebuckling to stable postbuckling
- Future plans for similar detailed investigations of local behavior for shells with large cutouts