POST-BUCKLING ANALYSIS IN THIN-WEB LAMINATED COMPOSITE BEAMS

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Agenda

- Introduction
- Objectives
- Methodology
- Results and Discussion
- Conclusion

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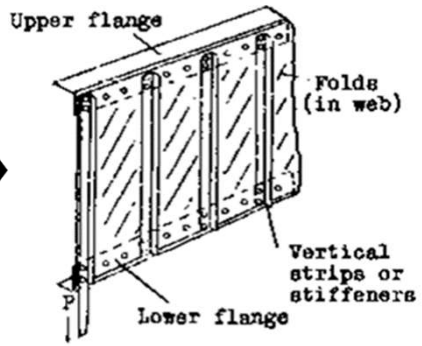
Introduction

Aeronautic Industry Main Goals

Increase the efficiency and reduce the costs of the aircrafts



Post-buckling capacity of composite materials reinforced panels

Panel's buckling
Diagonal folds
Shear forces

Tension by the diagonal folds
Compression in the stiffeners

Lighter structure

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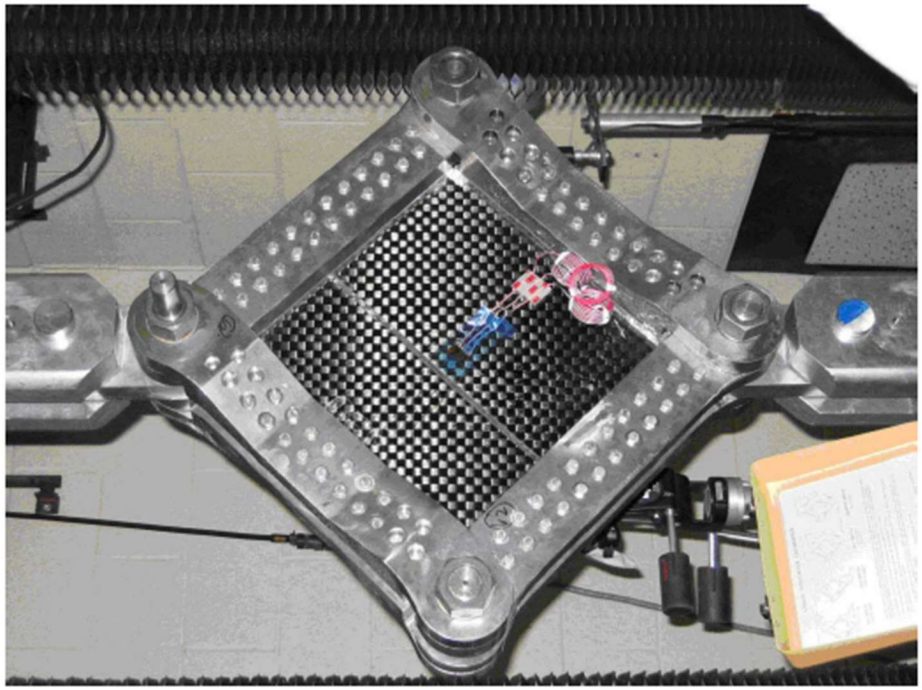
Objectives

For the metallic reinforced panel there is a consolidated methodology developed by NASA to calculate the panel's diagonal tension, NACA TN2661. This semi-empiric method was developed based in several tests performed with aluminum panels using different geometries and loads and is widely used by aircrafts manufactures.

Objectives

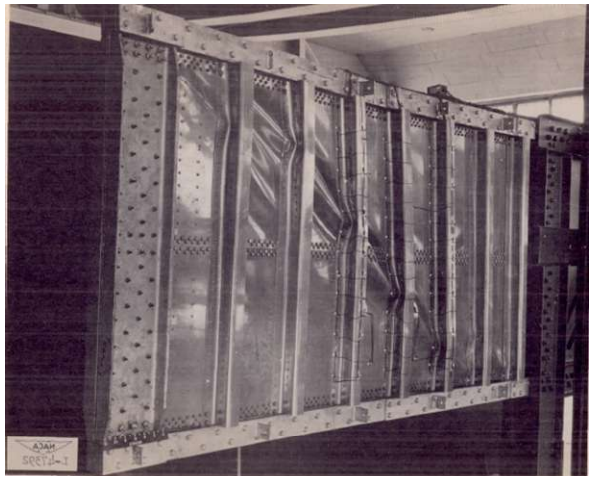
For a method for the panel's post-buckling behavior in composite reinforced panels is still in development. There are some researches trying to adapt the NACA TN-2661 method for composite materials making it account for the anisotropy of the material and corroborate the results with tests. Other studies were based in modeling the reinforced panel in finite elements and compared the results with tests data. Yet it was used a one bay panel with unidirectional load.

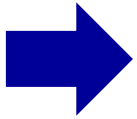


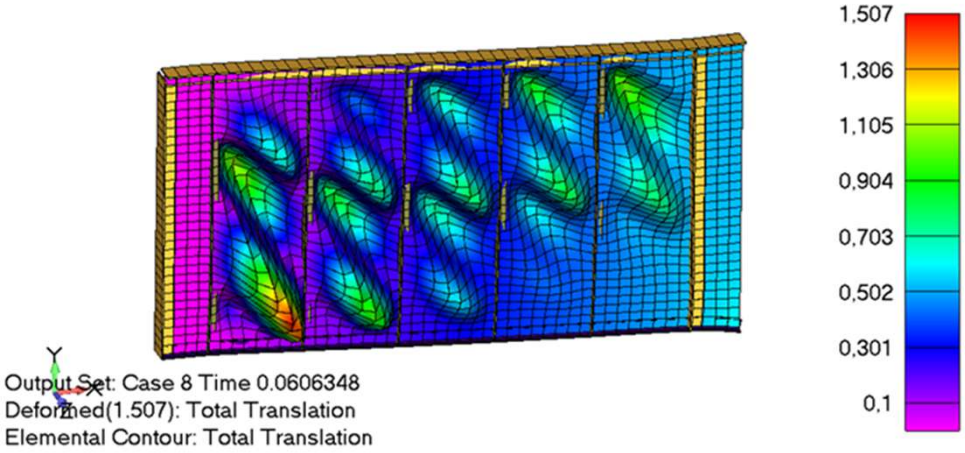
HERRERO, J. Buckling, post-buckling, and progressive failure analysis of hybrid composite shear webs using a continuum damage mechanism model. 2007. 208 f. Dissertation (Master of Science in mechanical engineer) – Whichita State University, Orone, 2007.

Objectives

- **The first main goal is to develop a method to build a FEM to represents the post-buckling behavior of the composite reinforced panel in order to avoid having to use experimental results in future projects.**







Objectives

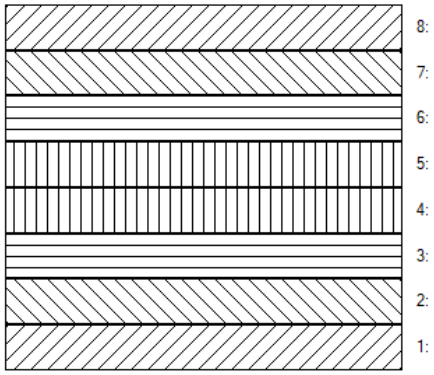
- **The second main goal is to study the influence of stacking sequence in post-buckling behavior.**

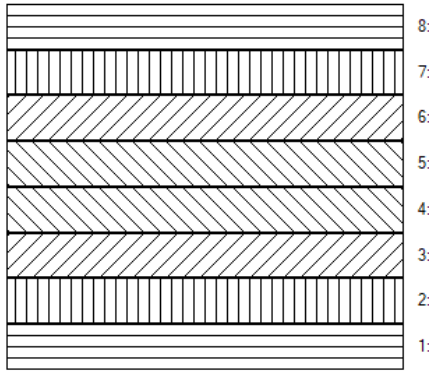
Lay-up1	45°
Lay-up2	-45°
Lay-up3	0°
Lay-up4	90°

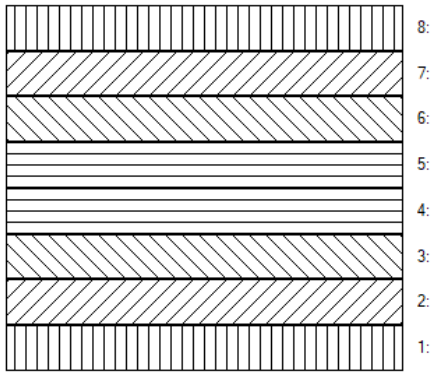
Lay-up1	0°
Lay-up2	90°
Lay-up3	45°
Lay-up4	-45°

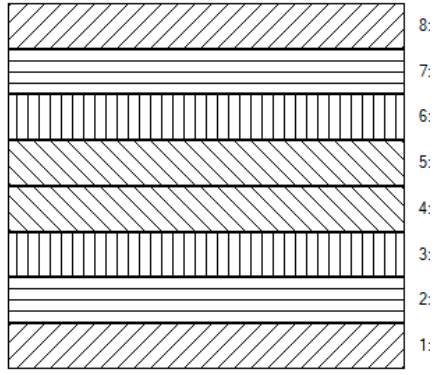
Lay-up1	90°
Lay-up2	45°
Lay-up3	-45°
Lay-up4	0°

Lay-up1	-45°
Lay-up2	-0°
Lay-up3	90°
Lay-up4	45°







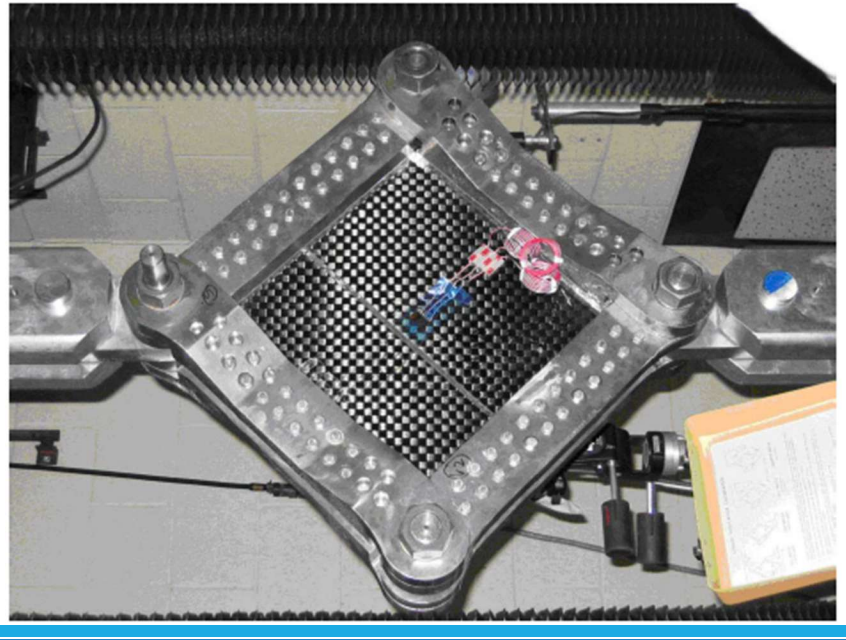


Objectives

- **The third main goal was to choose the reinforced panel that have the best behavior during the post-buckling analysis: metallic or composite.**

Metallic???

Composite???



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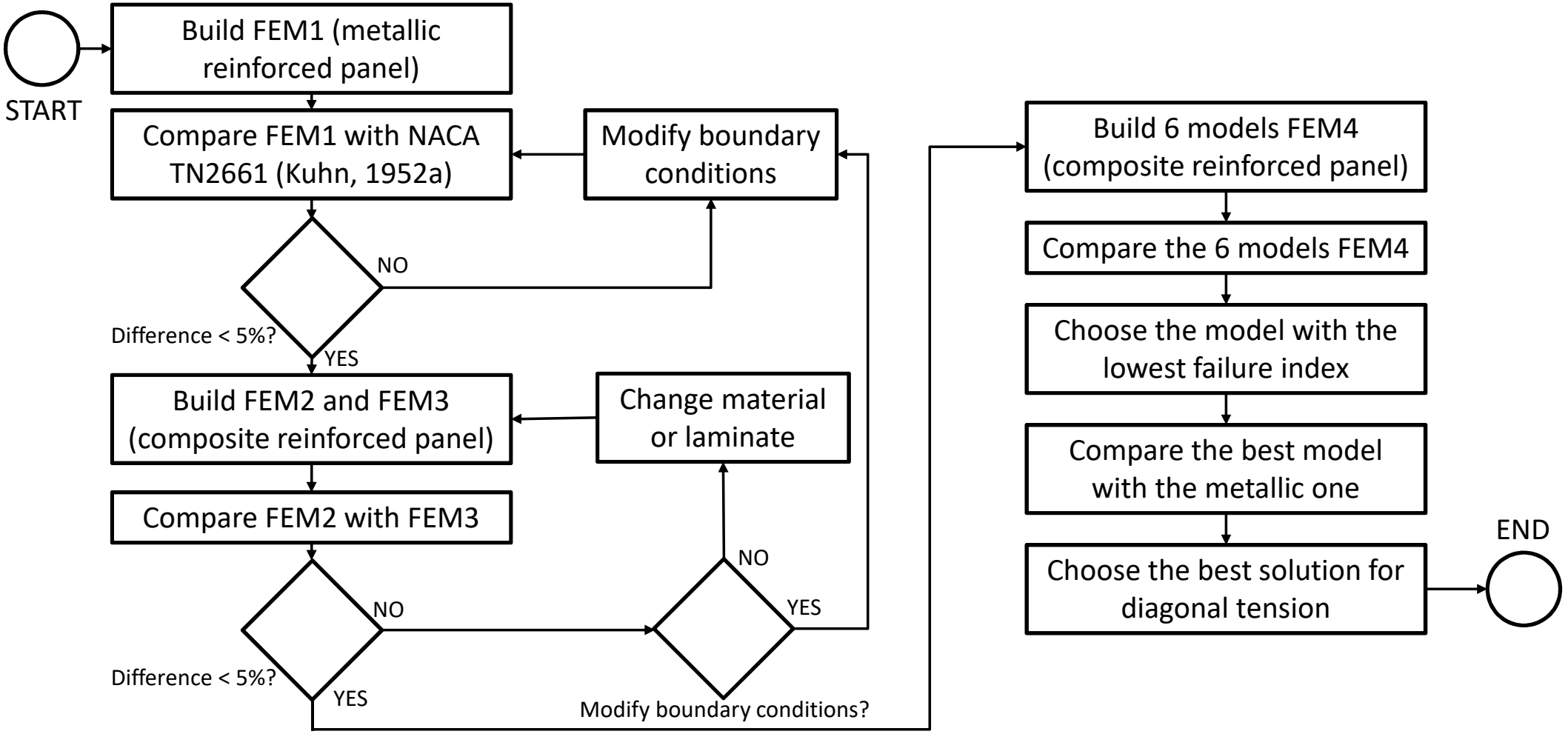
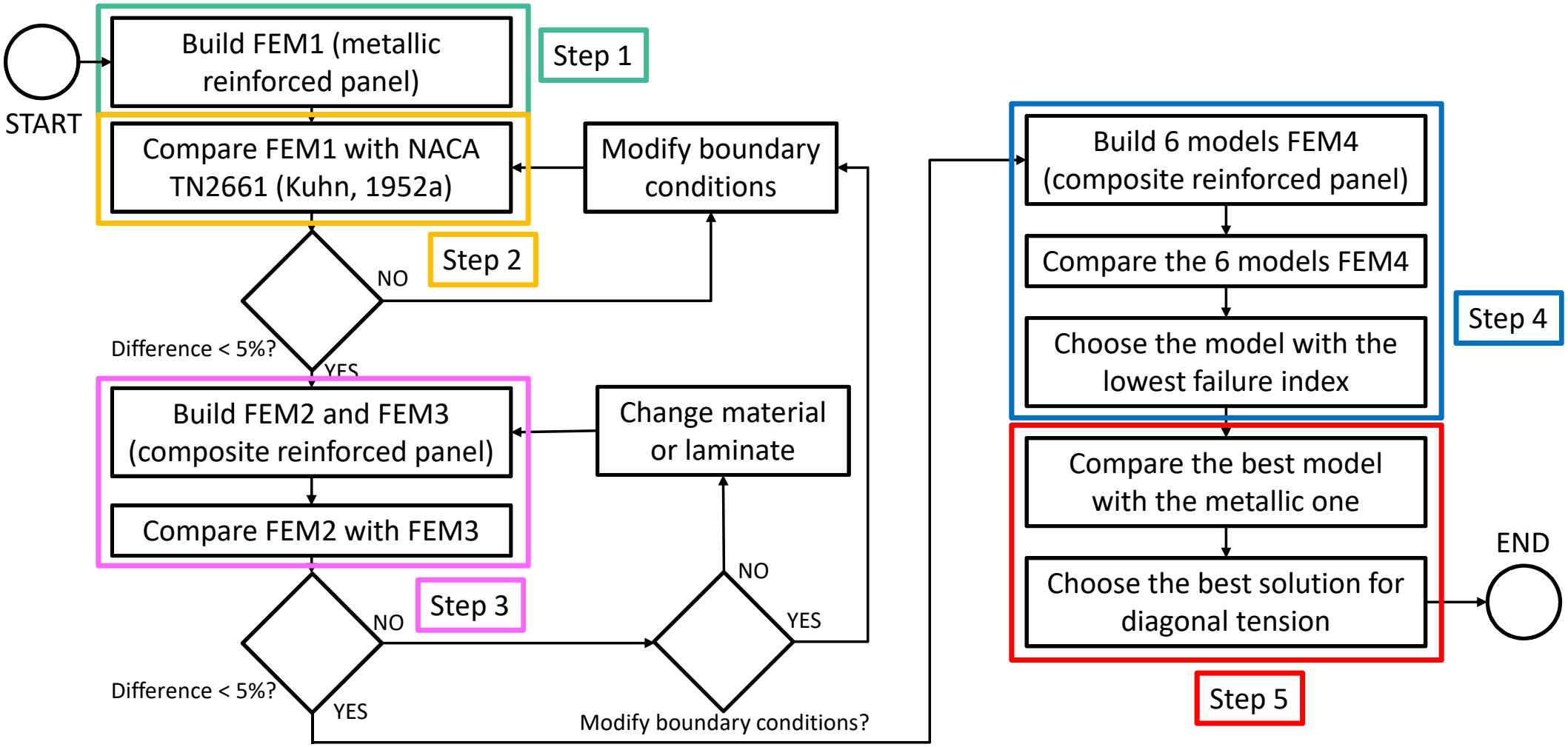
Methodology



Methodology



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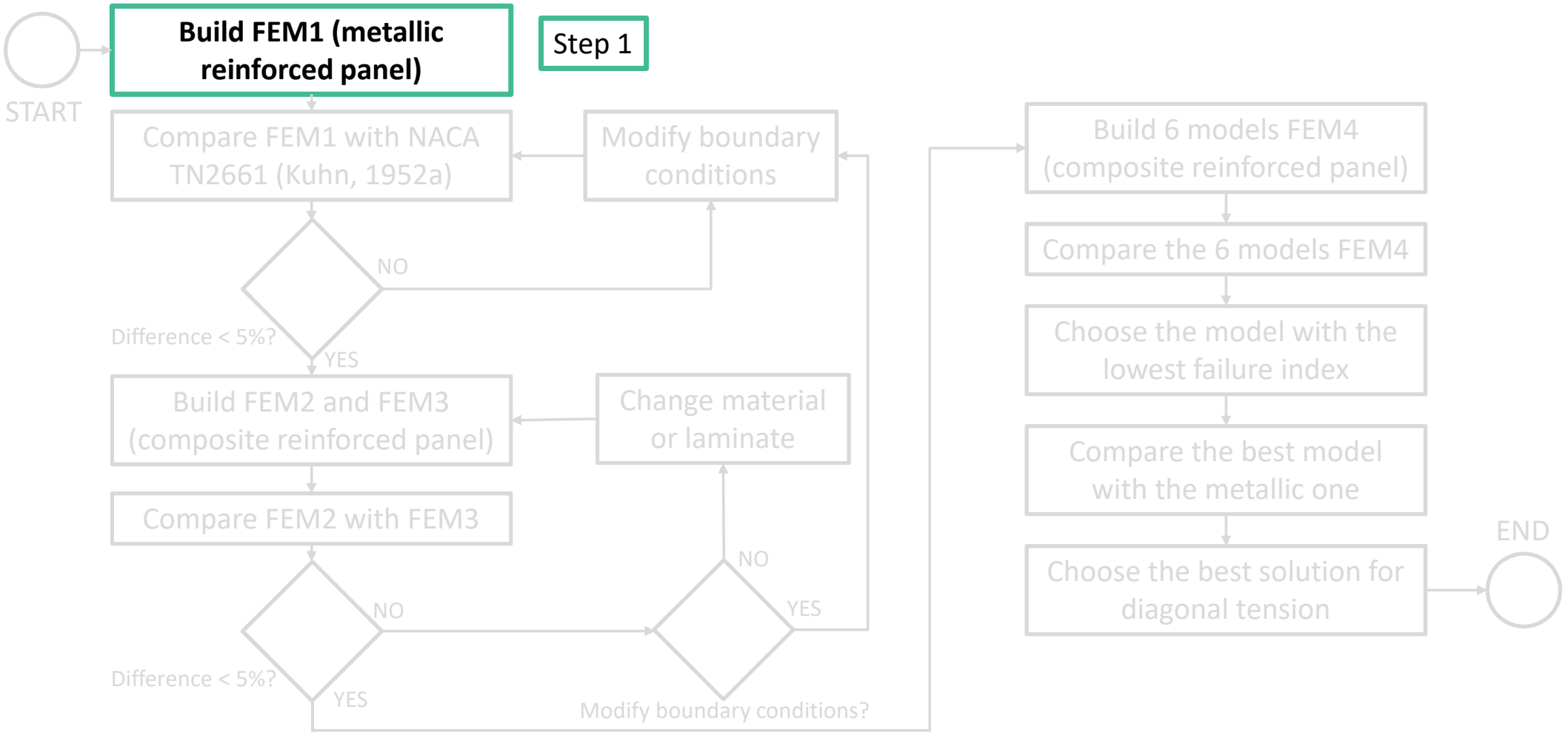
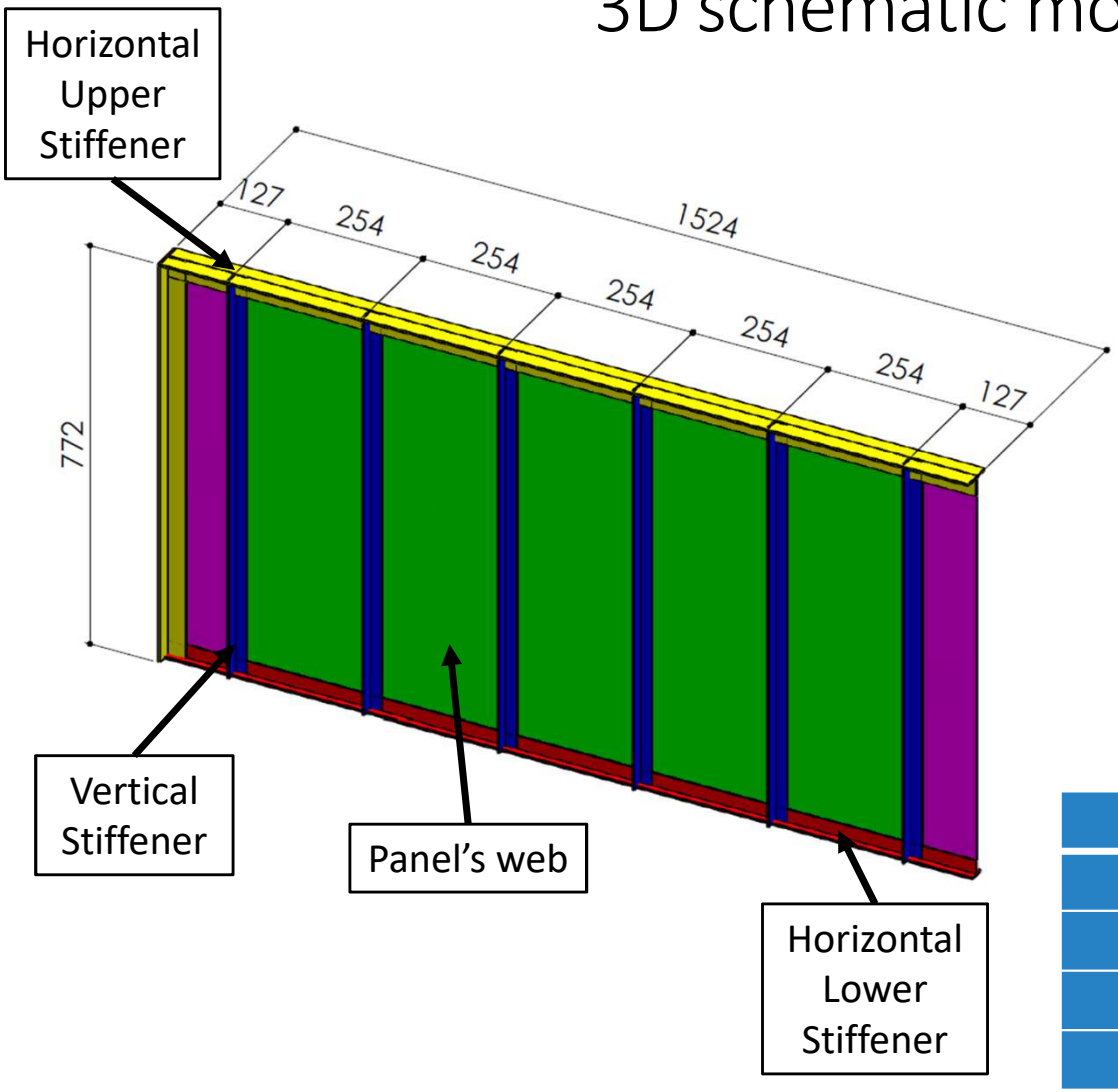
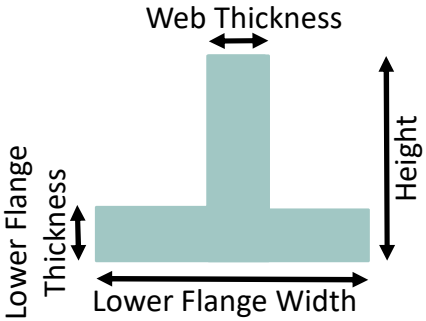
Results and Discussion



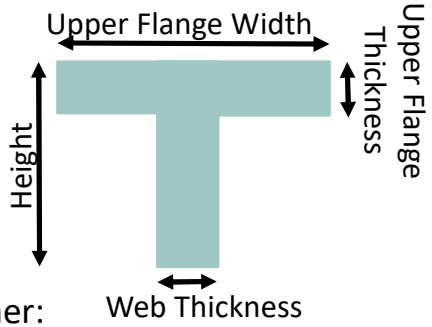
3D schematic model and material



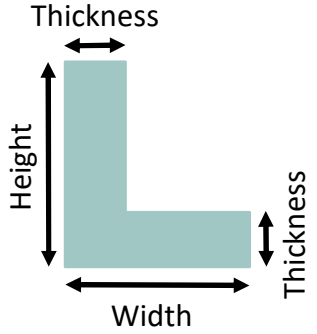
Horizontal Lower Stiffener:



Horizontal Upper Stiffener:



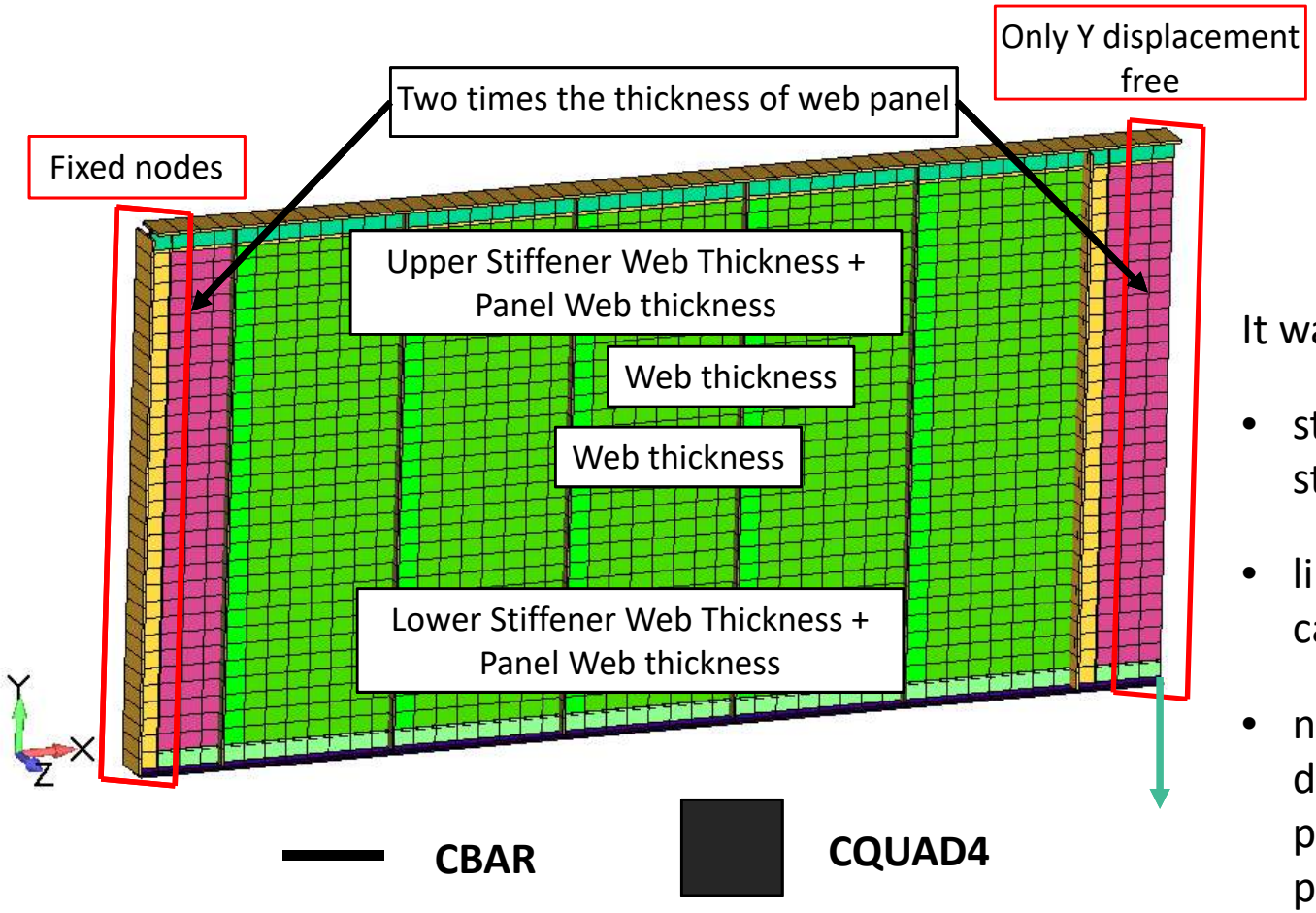
Vertical Stiffener:



Material	
Web	Aluminum 2024 T3
Horizontal Upper Stiffener	Aluminum 7075-T3 Extruded
Horizontal Lower Stiffener	Aluminum 7075-T3 Extruded
Vertical Stiffener	Aluminum 7075-T3 Extruded

All dimensions are in millimeter

Metallic reinforced panel FEM final model



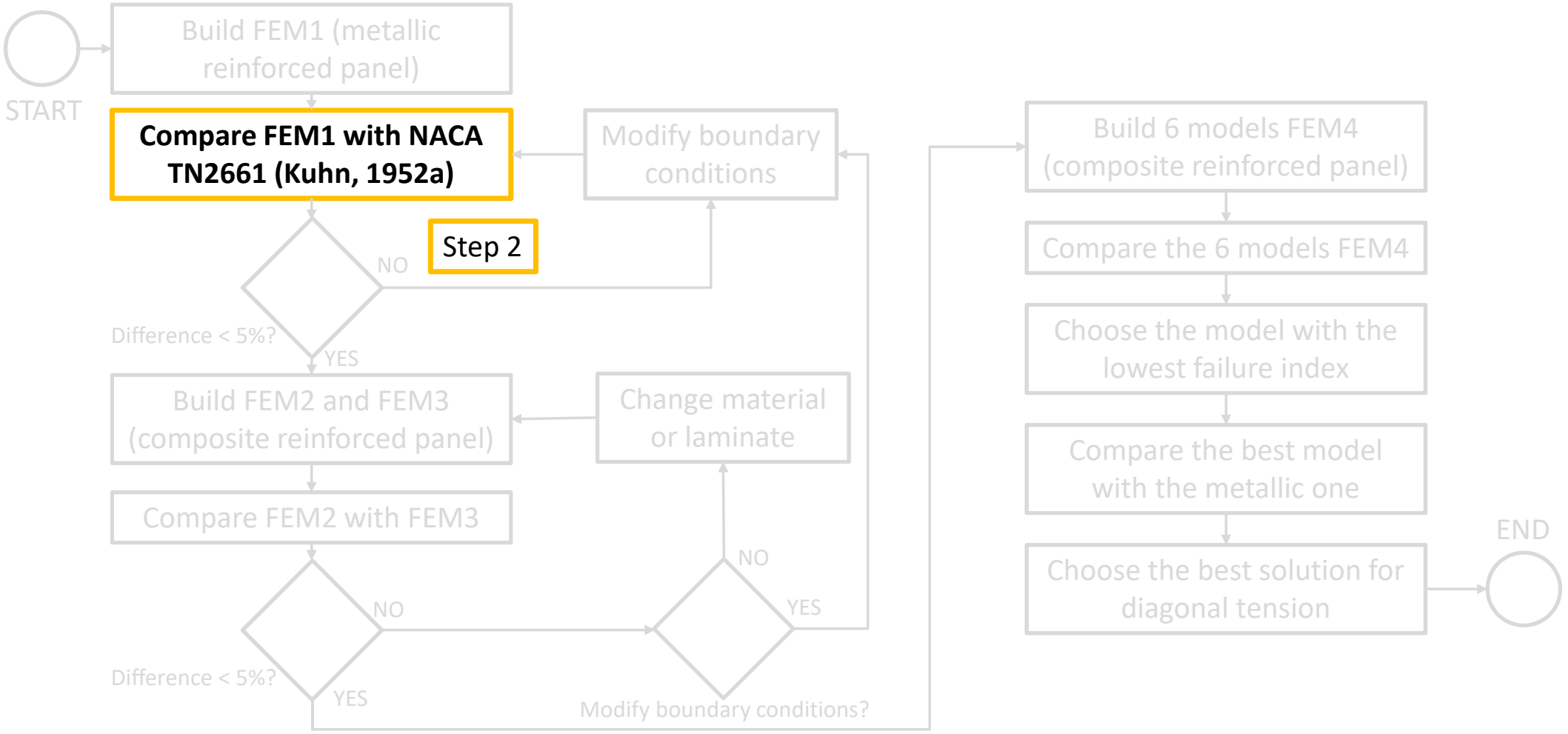
Pre/Post processor: Femap 11.2®

Solver: NASTRAN®

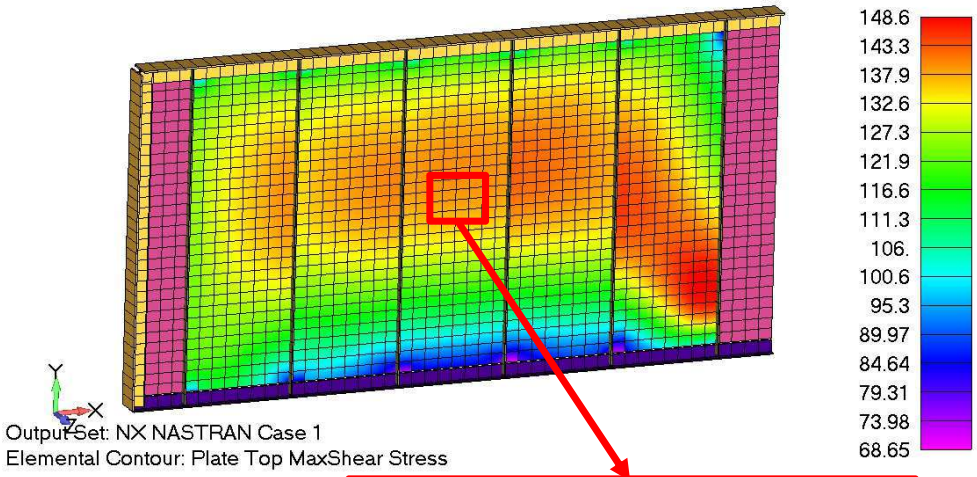
It was performed:

- static analysis (SOL101) to evaluate the stress in the panel's web;
- linear buckling analysis (SOL105) to calculate the buckling load;
- non-linear analysis including large displacement and elastic material properties (SOL106) to evaluate the post-buckling behavior of the structure.

Results and Discussion



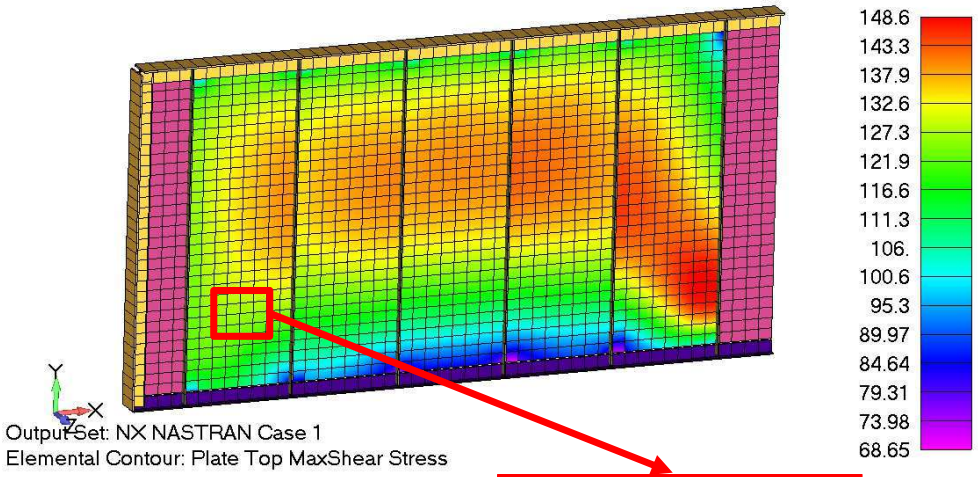
Linear Analysis (SOL101): Maximum stress in the middle of panel



138.5	138.67	138.73	138.68
137.55	137.71	137.77	137.73
136.27	136.42	136.48	136.45

FEM shear stress	NACA TN2661 (Kuhn, Peterson and Levin, 1952a) shear stress (f_{smax})	Difference
137.58 MPa	134.21 MPa	2.51%

Linear Analysis (SOL101): average shear stress in the web (region of first eigenvalue buckling mode)

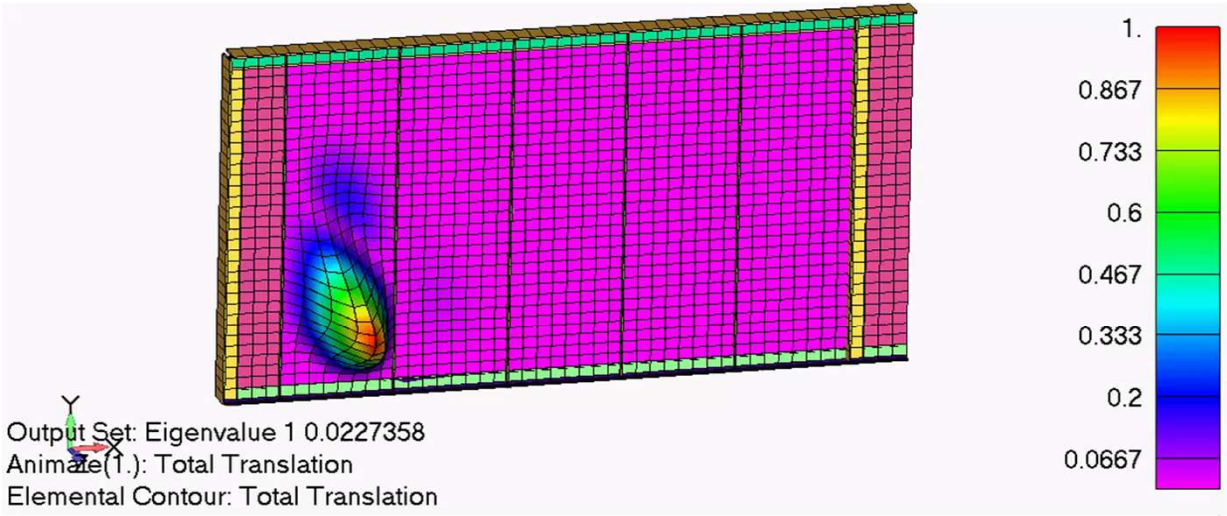


127.68	128.05
126.51	126.4
125.13	124.47

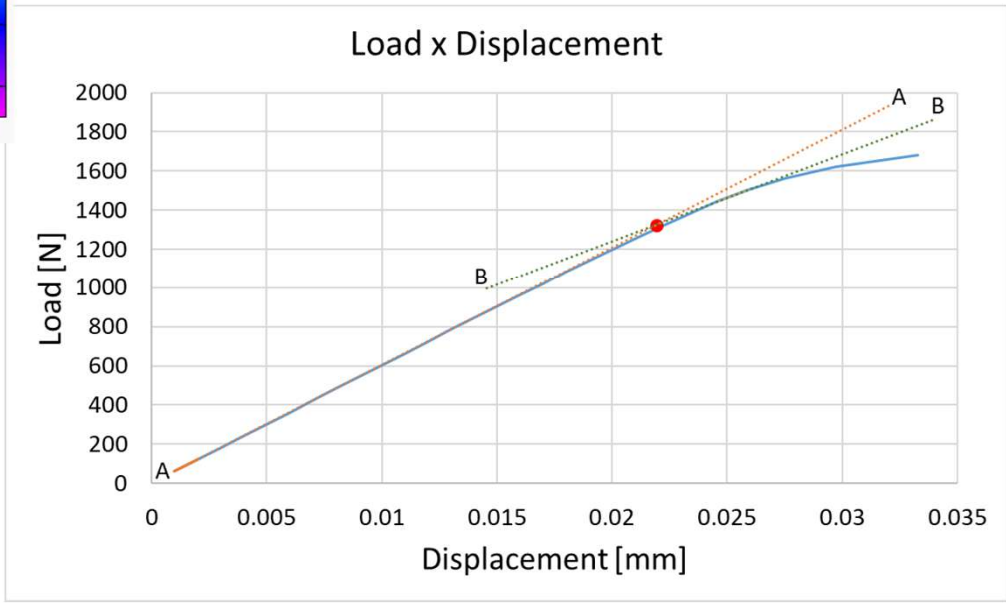
FEM shear stress	NACA TN2661 *Shear nominal stress in the web (f_s)	Difference
126.37 MPa	126.42 MPa	0.04%

* (Kuhn, Peterson and Levin, 1952a)

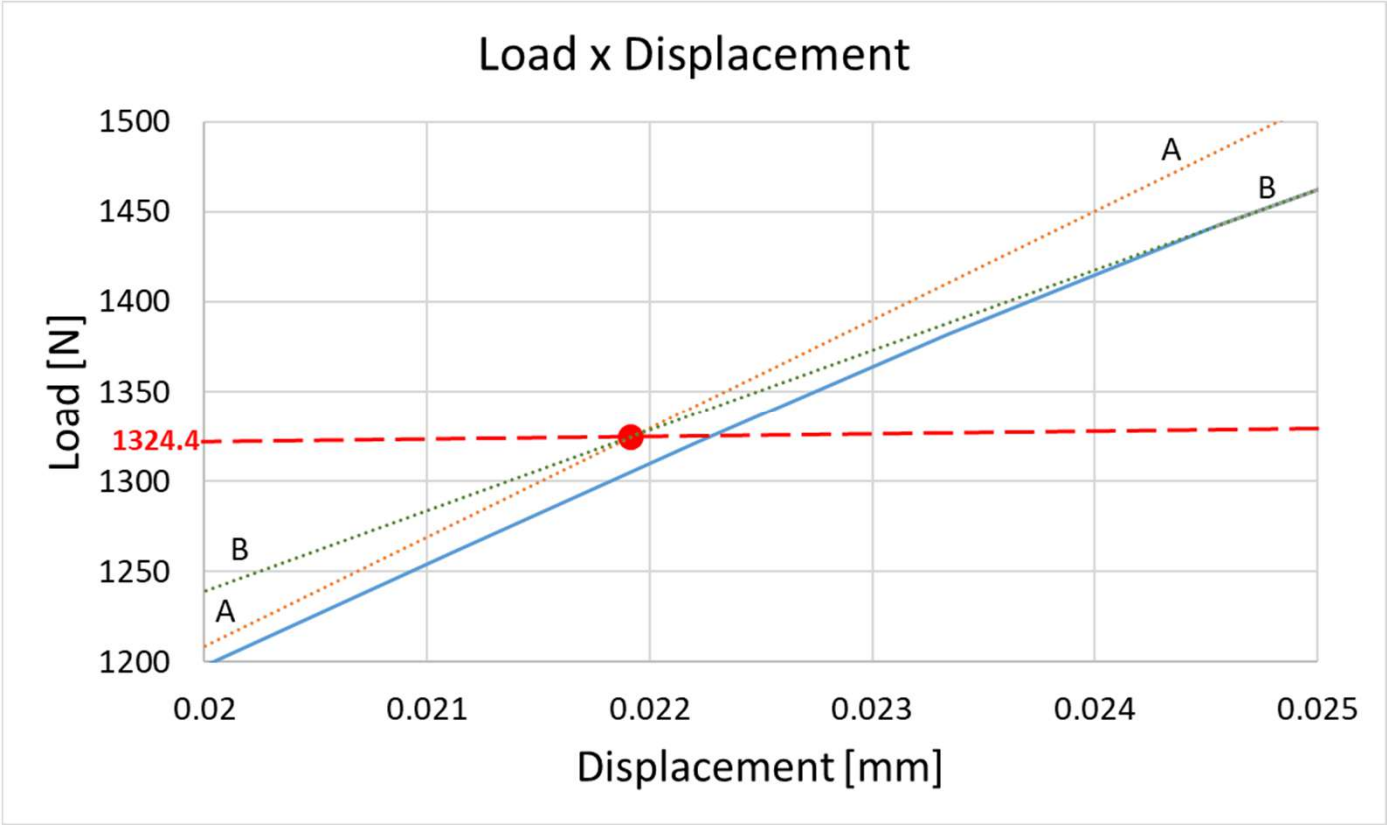
Linear Buckling Analysis (SOL105) *vs*. Non-linear analysis (SOL106)



Buckling Load: 0.0227358 x 60075N = 1365.9N

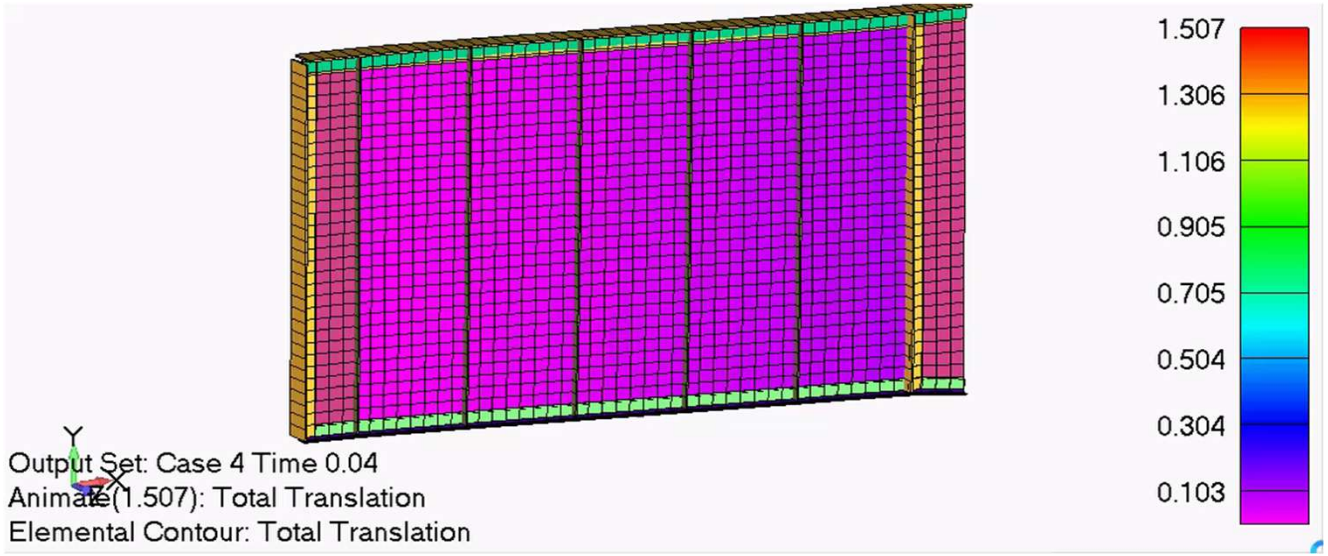


Linear Buckling Analysis (SOL105) *vs*. Non-linear analysis (SOL106)

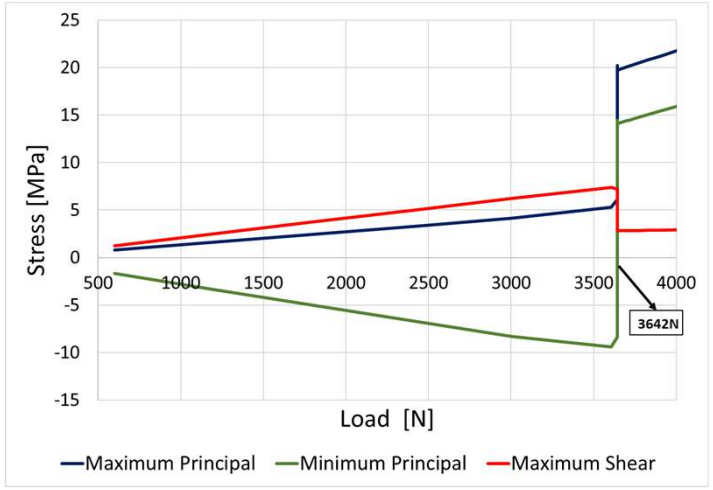


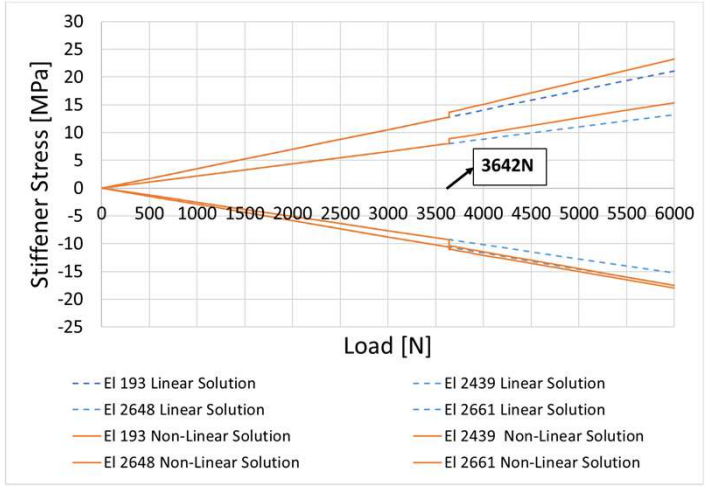
Linear buckling analysis	Non-linear analysis	Difference
1365.85 N	1324.36 N	3.13%

Non-linear analysis - diagonal tension initiation

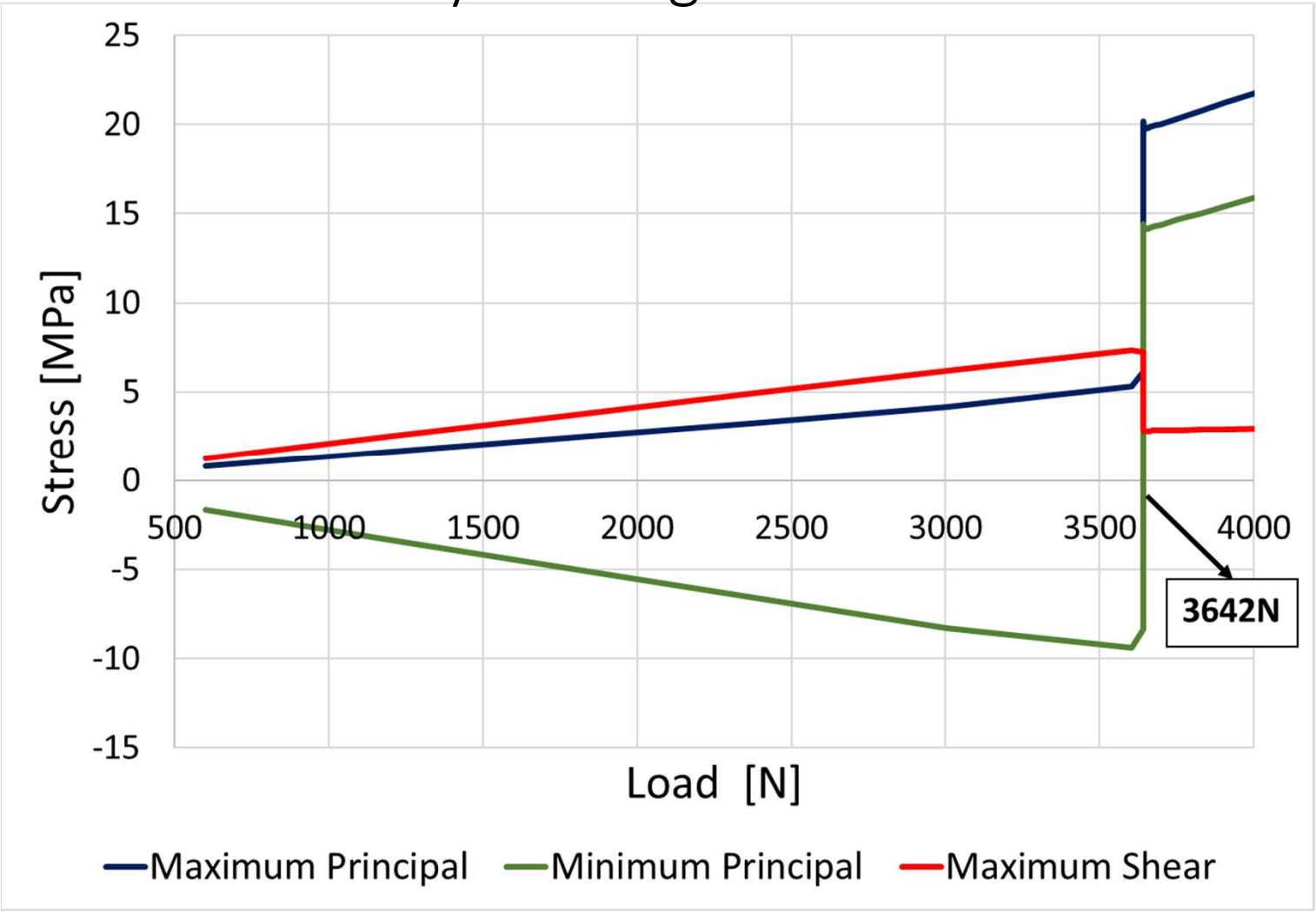


$$0.0606348 * 60075N = 3642.64N$$

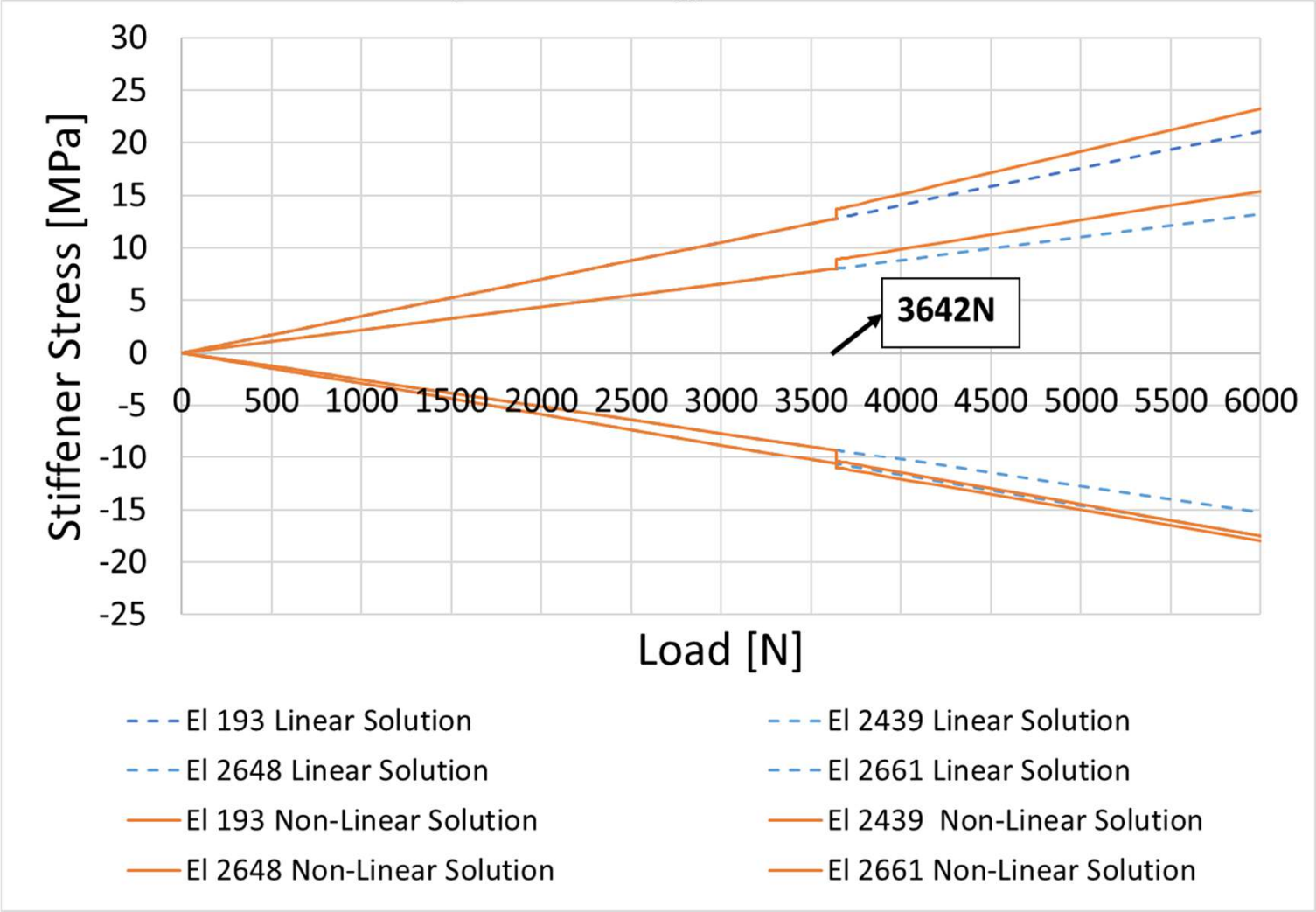




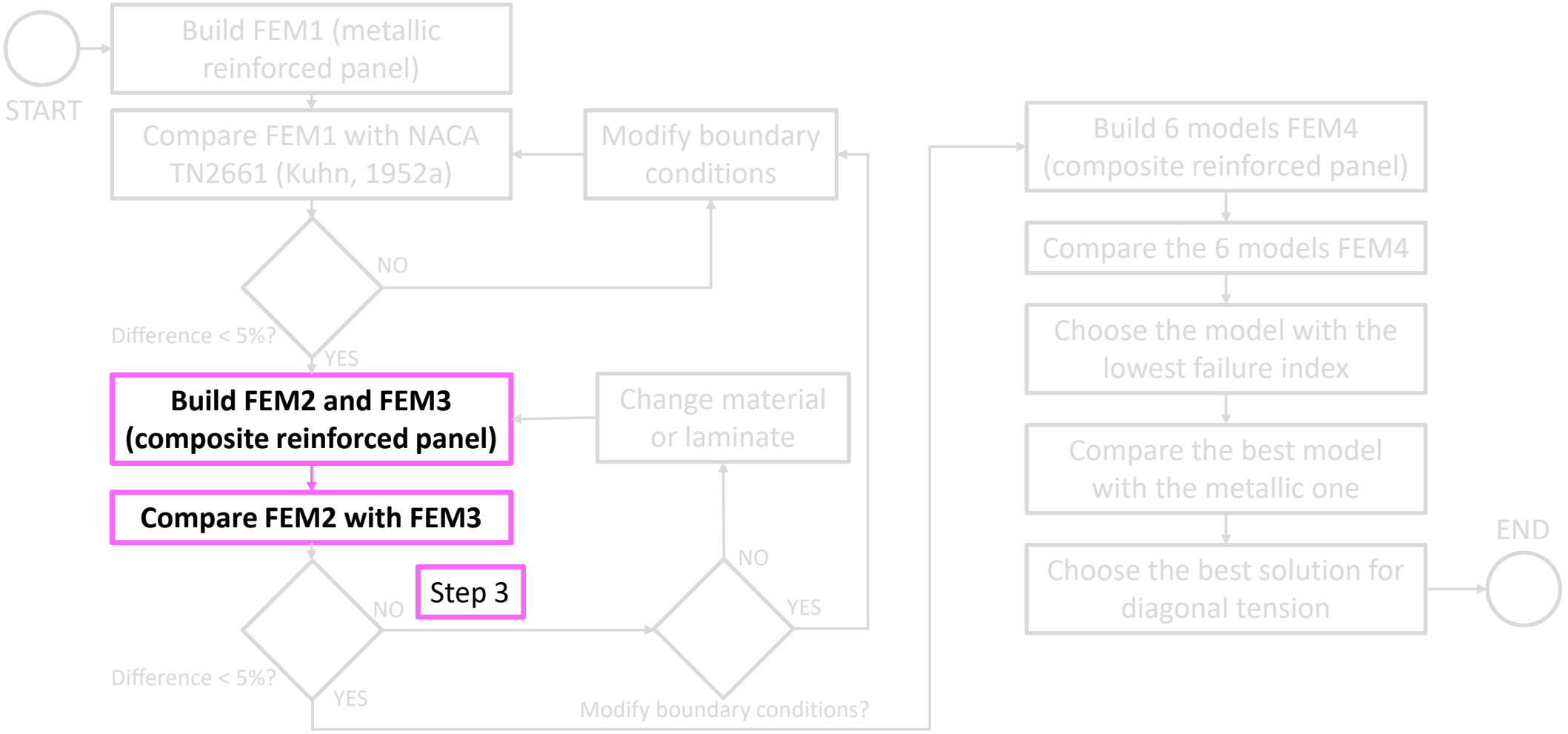
Non-linear analysis - diagonal tension initiation



Non-linear analysis - diagonal tension initiation

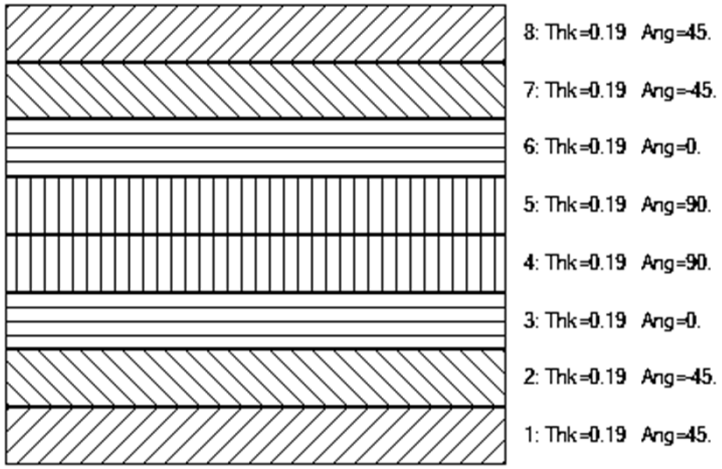


Results and Discussion



Model 1: modeling each layer and entering tape's material properties

carbon/epoxy $[45/-45/0/90]_S$



Model 2: equivalent properties for the layup selected

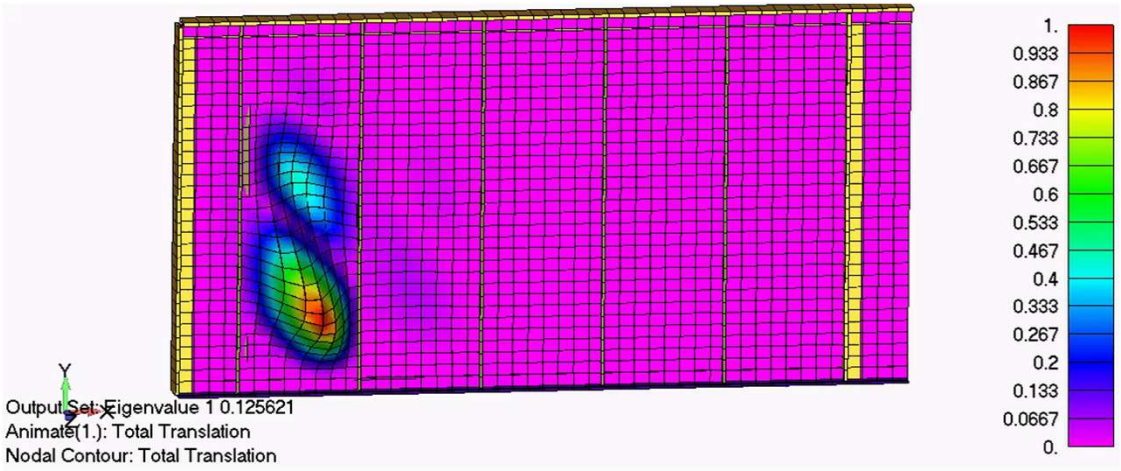
Carbon/epoxy $[45/-45/0/90]_S$ Equivalent Properties	
Ex = Ey = E	56675.5 [MPa]
Gxy	22039.8 [MPa]
nxy = nyx	0.286

Material	
FEM2	Tape carbon/epoxy $[45/-45/0/90]_S$
FEM3	NA (it was used the Young's modulus equal to the composite model) E = 56675.5 MPa
Horizontal Upper Stiffener	Steel 4043
Horizontal Lower Stiffener	Steel 4043
Vertical Stiffener	Steel 4043

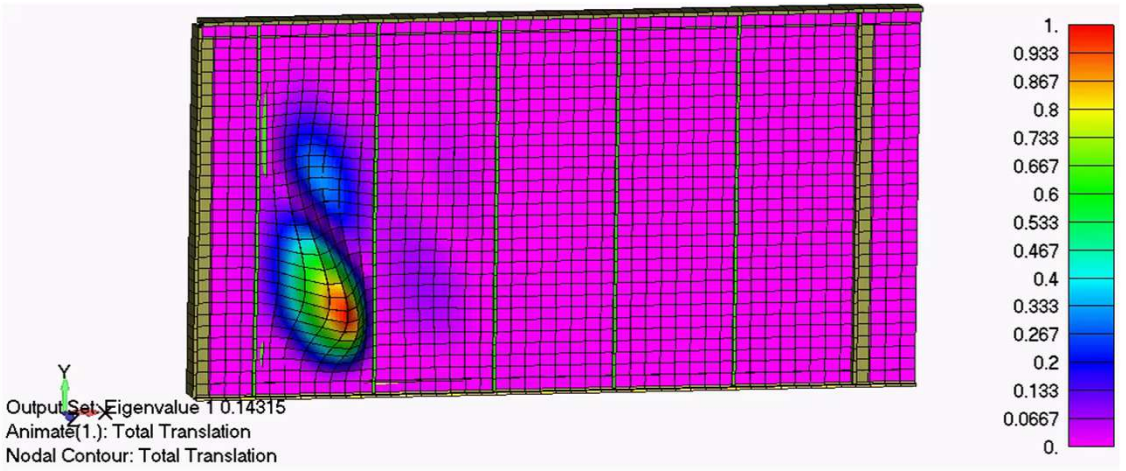
P.S.: the 0 angle ply is in X direction global coordinate system.

Isotropic and Laminate models: First eigenvalue (linear buckling analysis) comparison

Isotropic Model



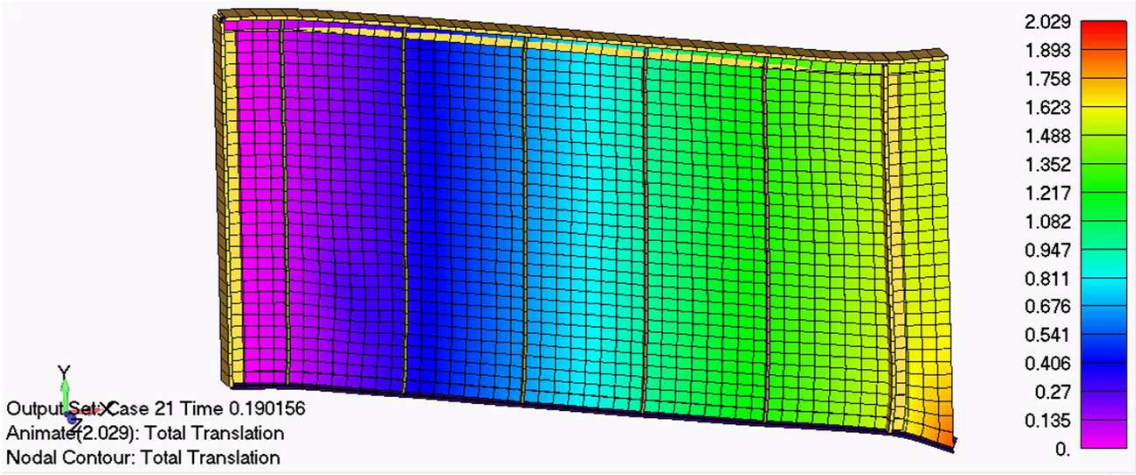
Laminate Model



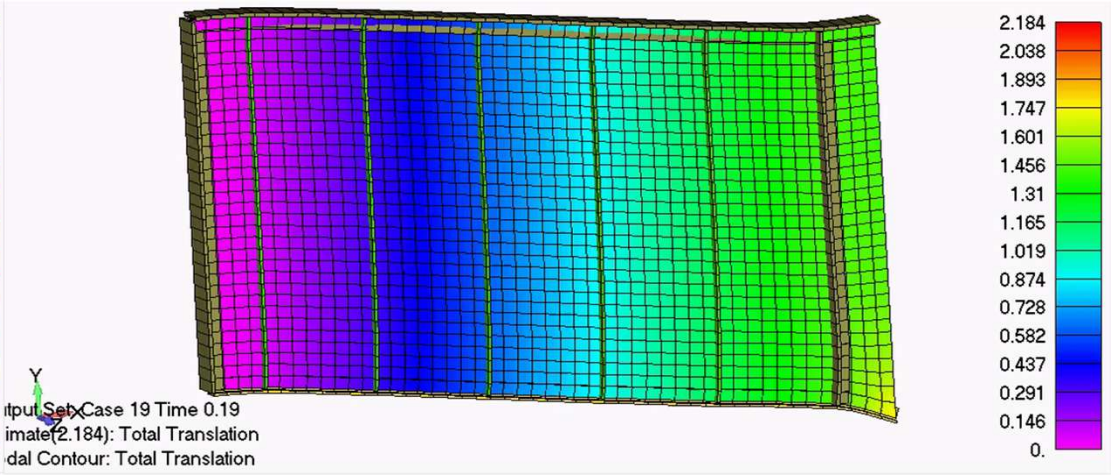
	First Eigenvalue
Isotropic Equivalent Model	0.125621
Laminate Model	0.14315
Difference	1.75%

Isotropic and Laminate models:
Diagonal tension first occurrence (non-linear analysis) comparison

Isotropic Model

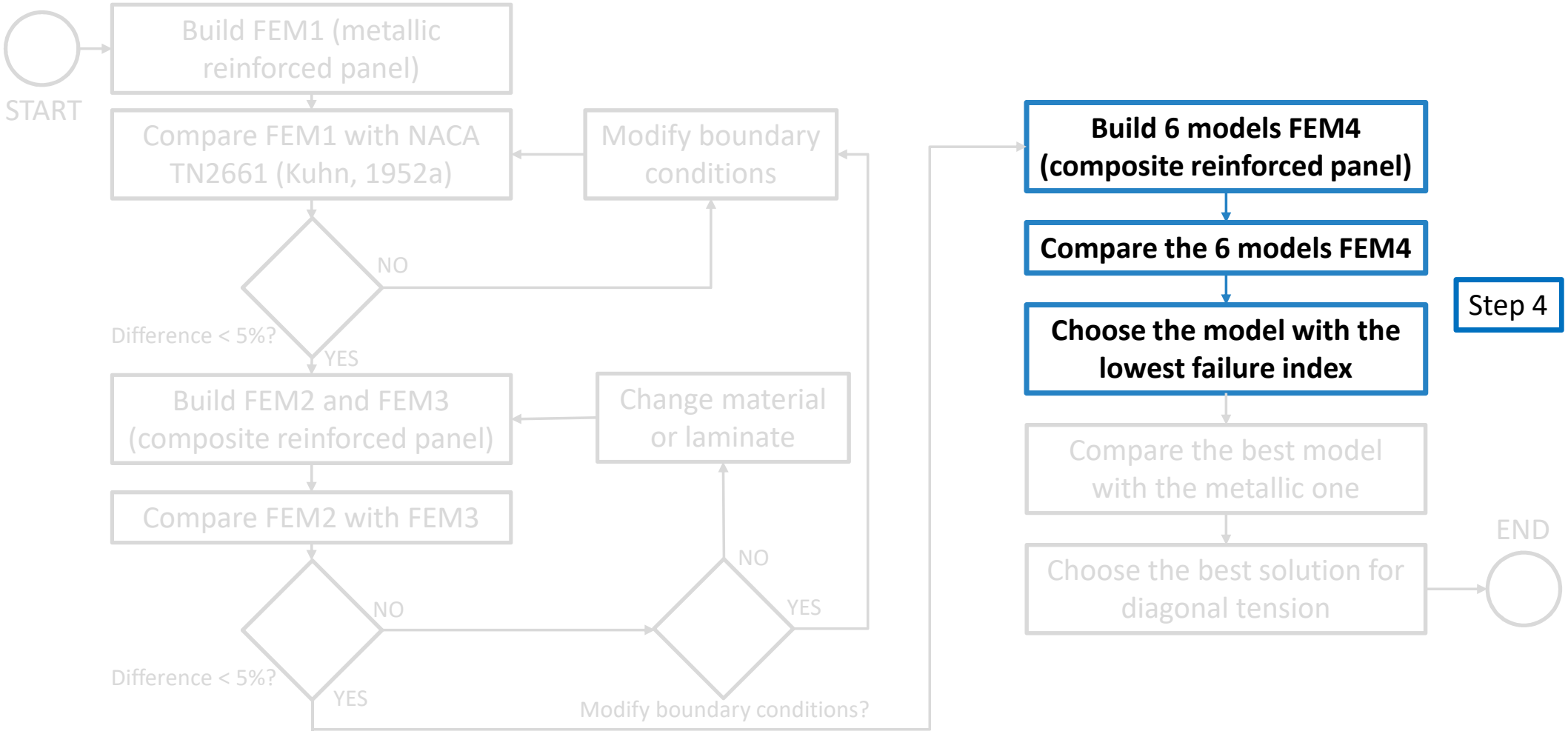


Laminate Model



	First occurrence of Diagonal Tension
Isotropic Equivalent Model	0.190313
Laminate Model	0.20751
Difference	1.72%

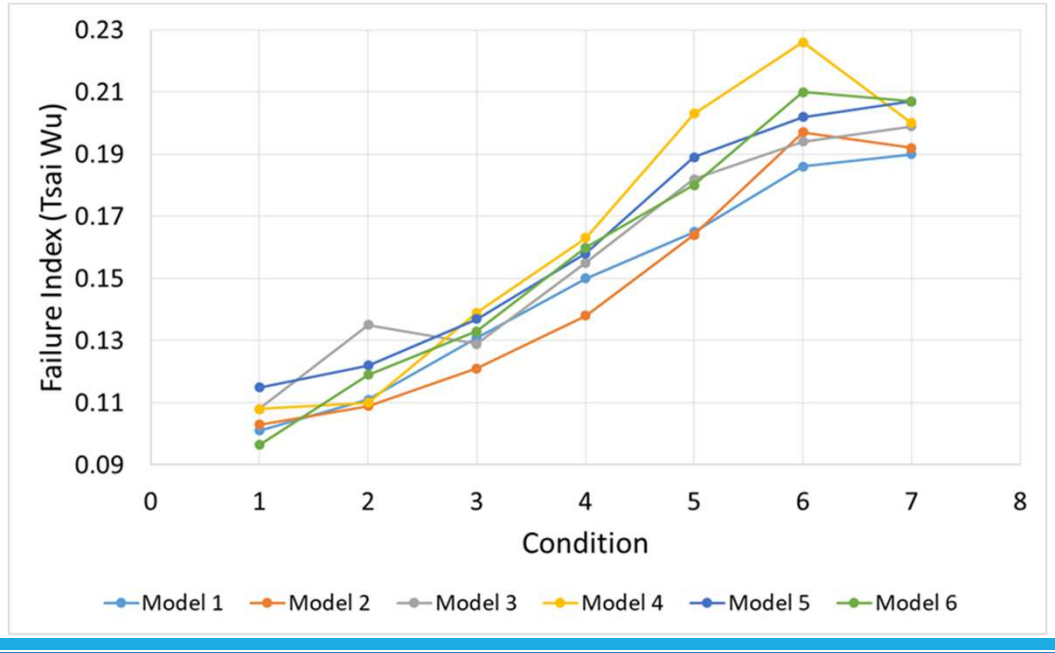
Results and Discussion

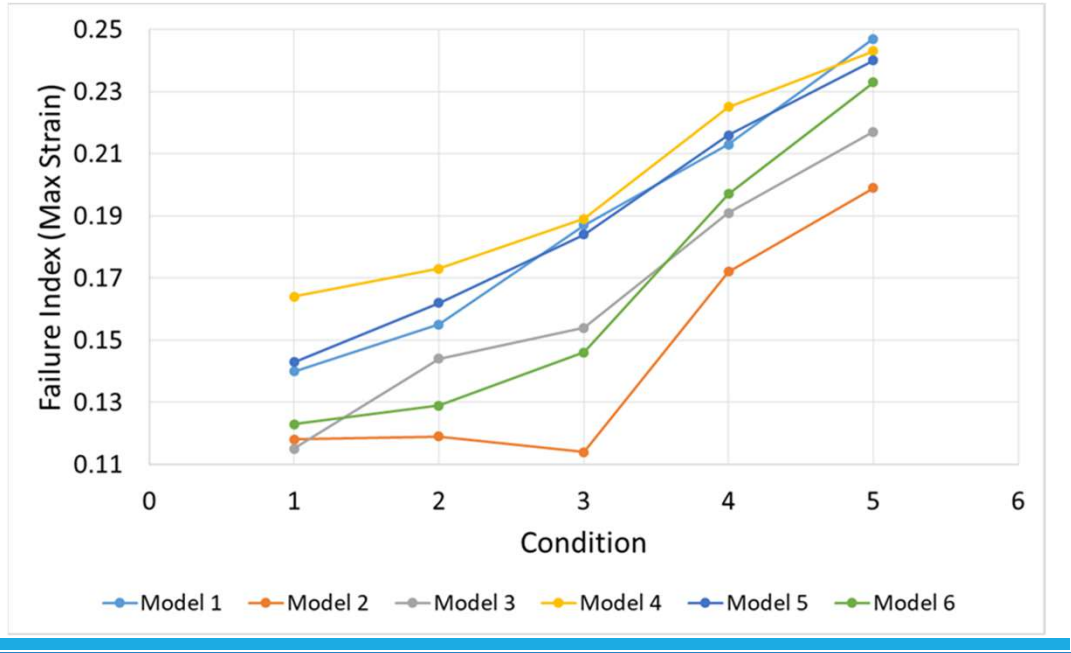


Composite Reinforced Panel: FEM comparison

Carbon/epoxy tape	
Model 1	$[0/90/45/-45]_S$
Model 2	$[45/-45/0/90]_S$
Model 3	$[45/0/90/-45]_S$
Model 4	$[0/45/-45/90]_S$
Model 5	$[0/45/90/-45]_S$
Model 6	$[45/0/-45/90]_S$

	Condition						
	1	2	3	4	5	6	7
Tsai-Wu	5500 N	100000 N	160000 N	310000 N	500000 N	700000 N	800000 N
Maximum Strain	5500 N	100000 N	160000 N	310000 N	480000 N	700000 N	900000 N





Composite Reinforced Panel: FEM comparison

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Model 5	$[0/45/90/-45]_S$
Model 6	$[45/0/-45/90]_S$

	Condition						
	1	2	3	4	5	6	7
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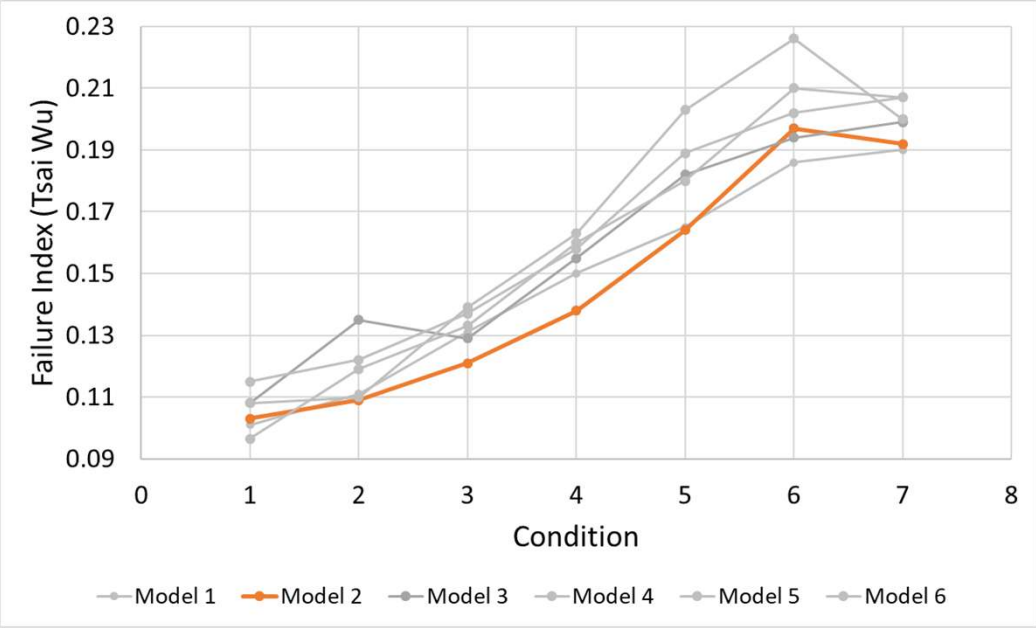

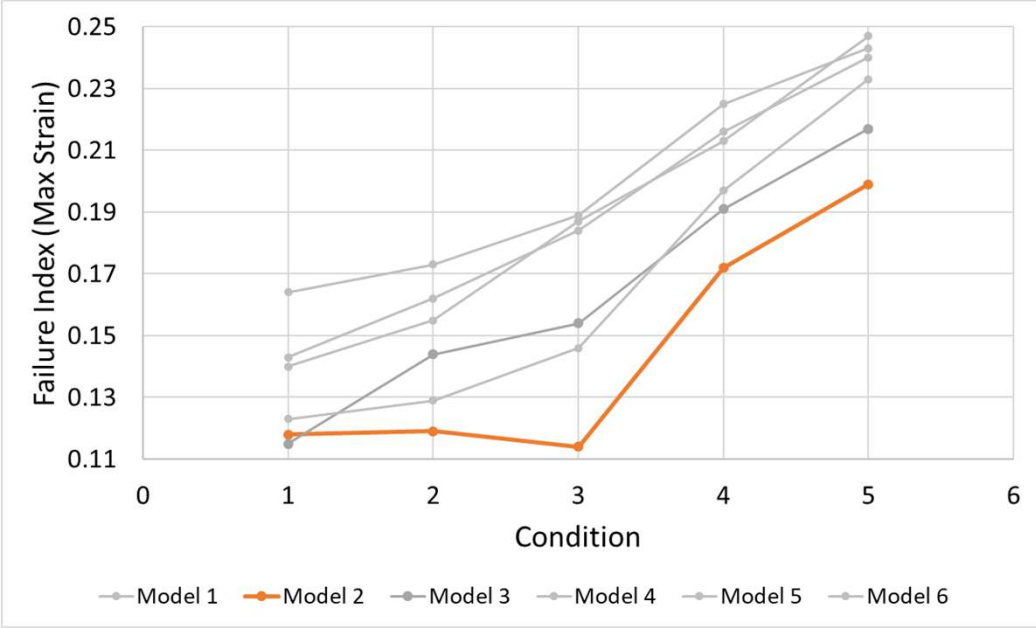

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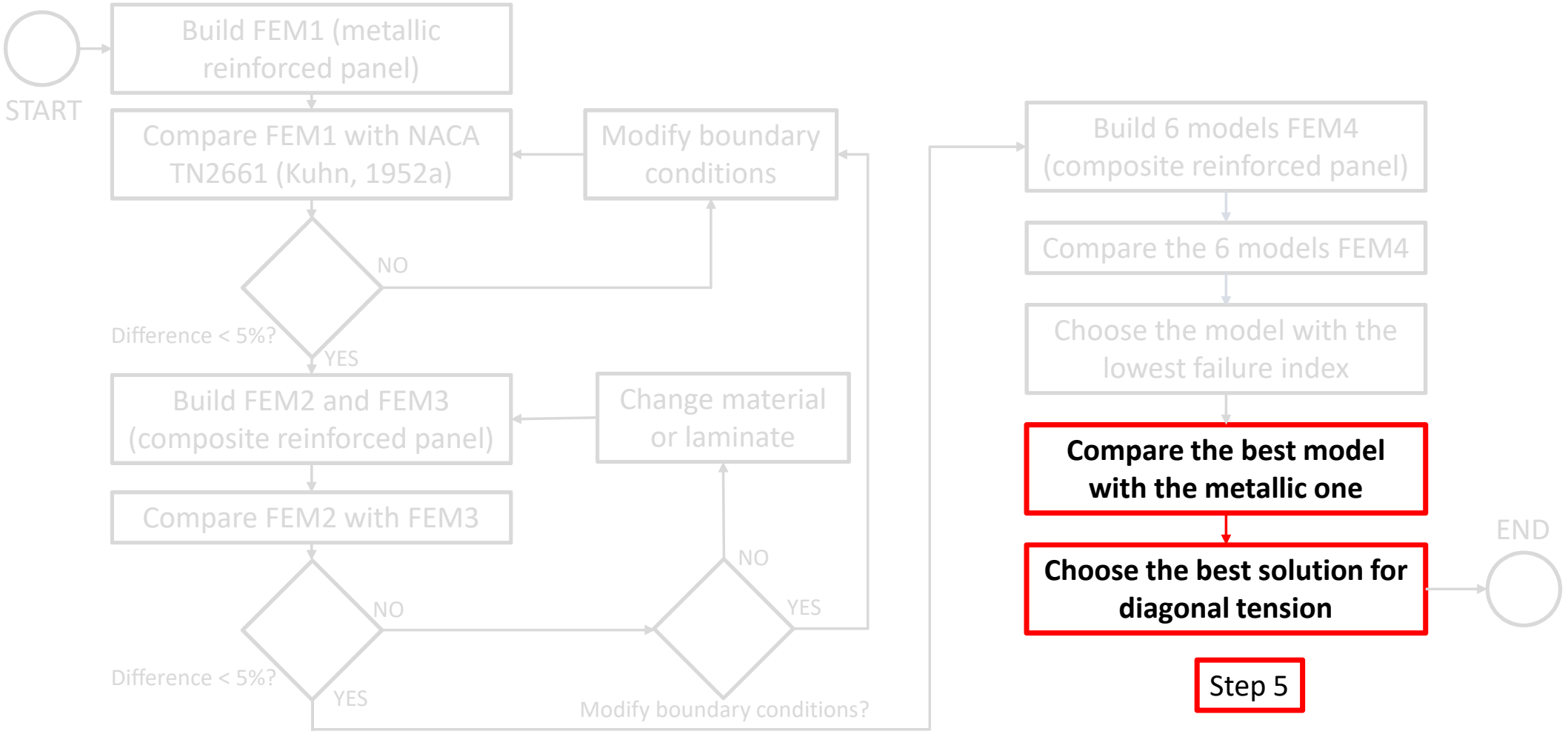
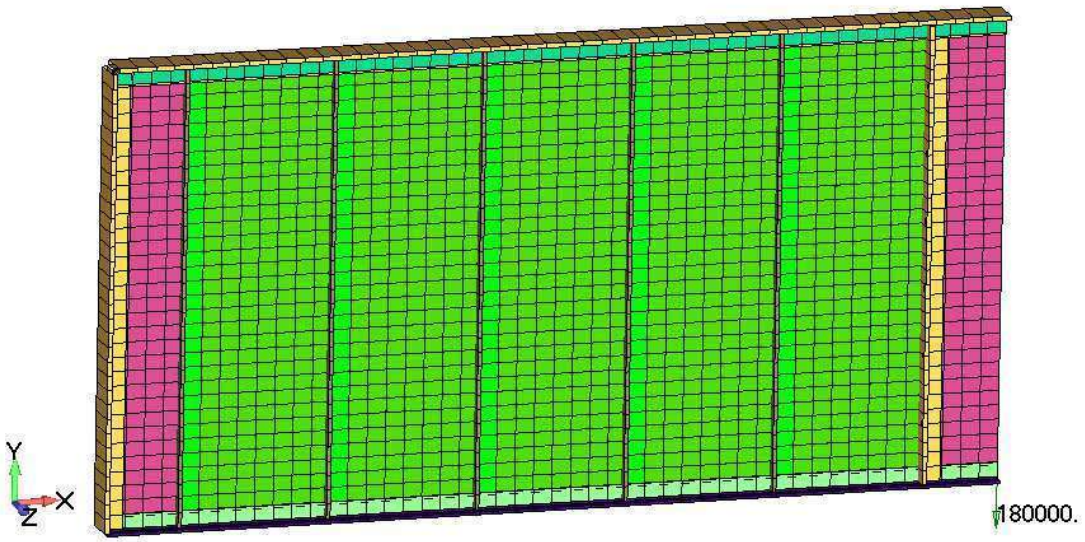
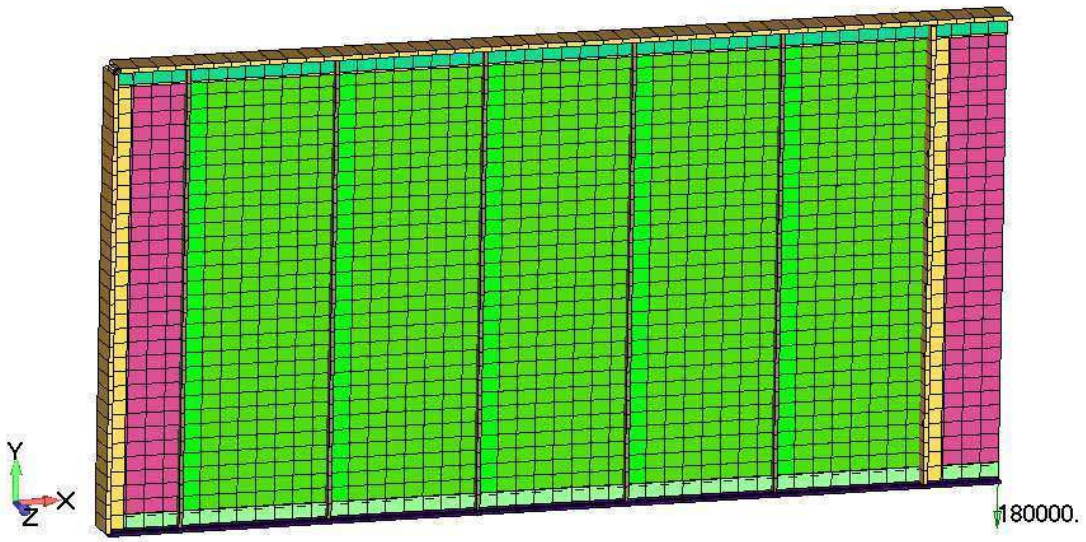


Composite Reinforced Panel *vs.* Metallic Reinforced Panel

Carbon/epoxy tape $[45/-45/0/90]_S$



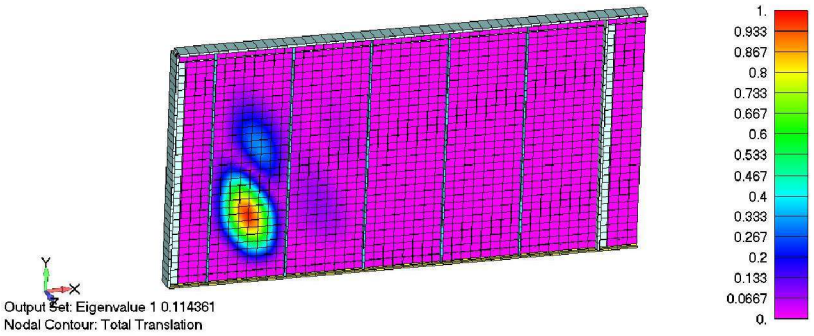
Aluminum 2524 T3



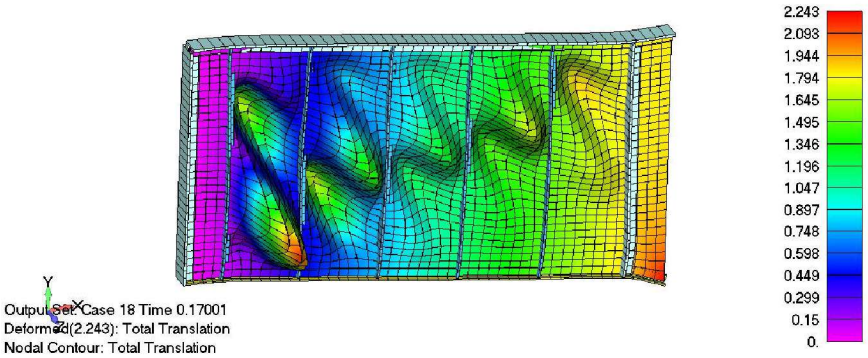
	Composite Panel	Metallic Panel	Difference
Web's thick	1.52 mm	0.701 mm	-53.87%
Total Mass	14.330 kg	14.330 kg	0.00%

Composite Reinforced Panel *vs.* Metallic Reinforced Panel

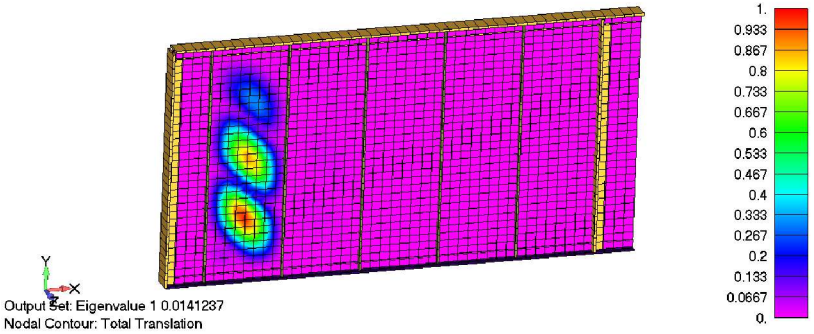
Model - Carbon/epoxy tape $[45/-45/0/90]_S$



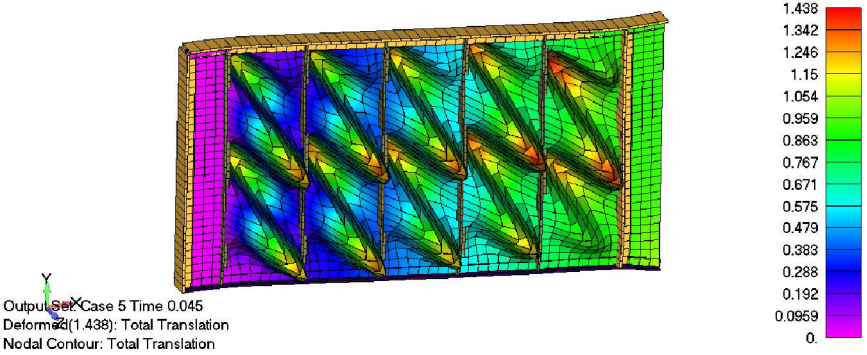
Model - Carbon/epoxy tape $[45/-45/0/90]_S$



Model - Aluminum 2524 T3

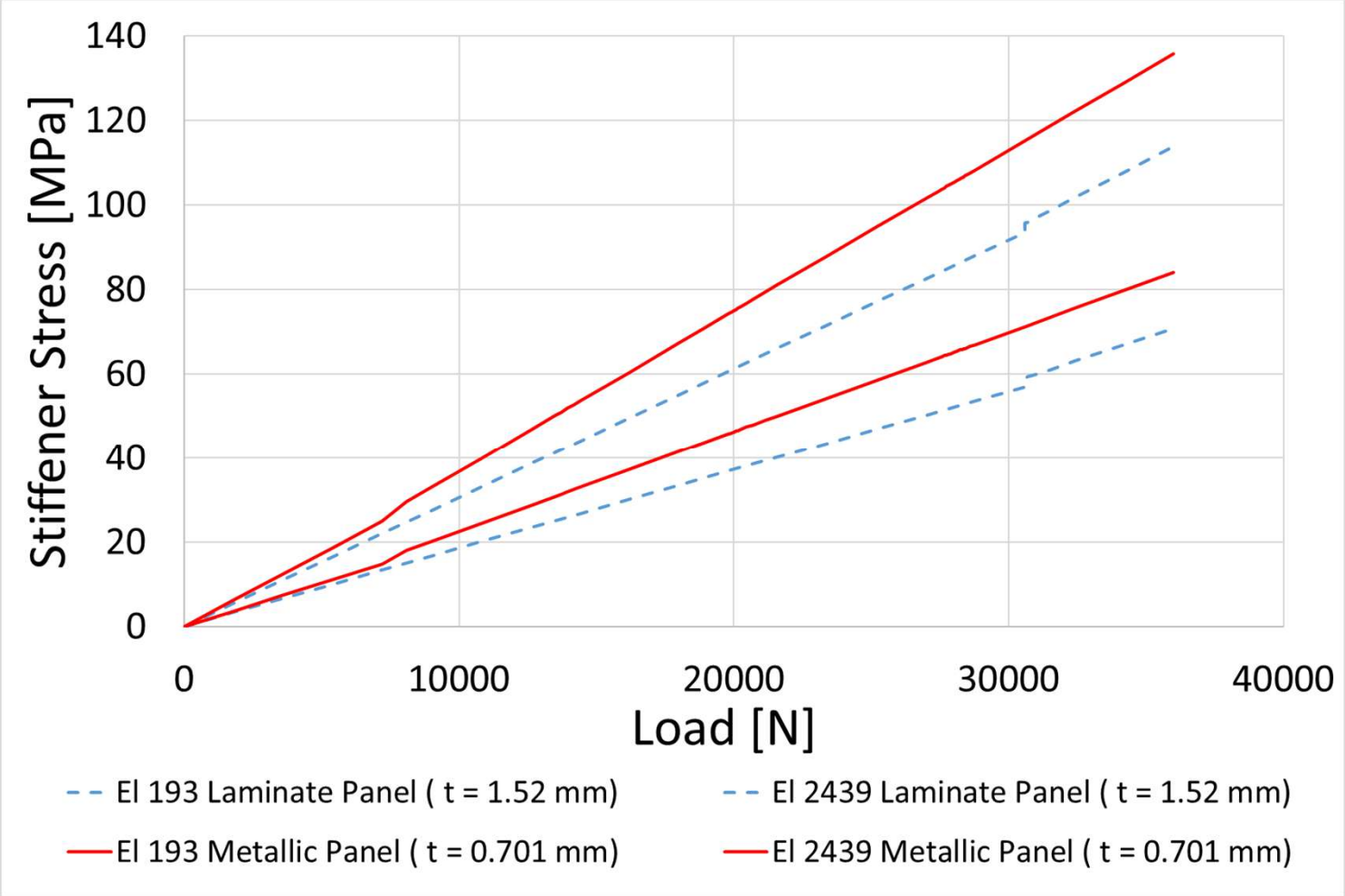


Model - Aluminum 2524 T3



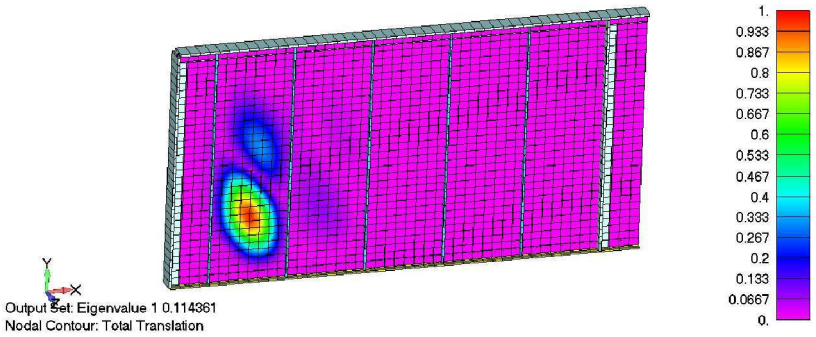
	Eigenvalue	Diagonal Tension
Composite Model	0.114361	0.17001
Metallic Model	0.014123	0.04500

Composite Reinforced Panel *vs.* Metallic Reinforced Panel

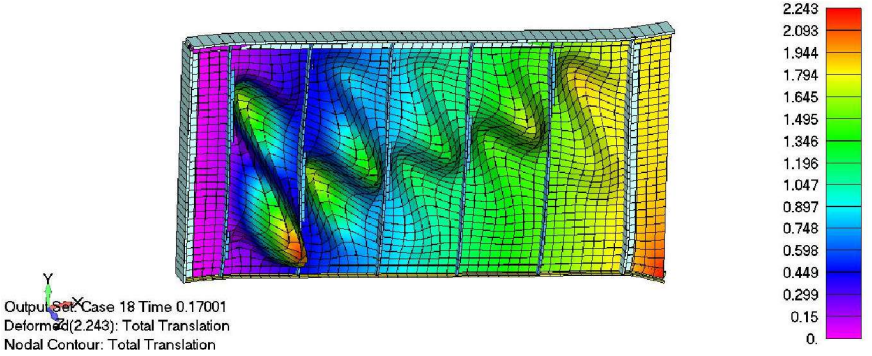


Composite Reinforced Panel *vs.* Metallic Reinforced Panel

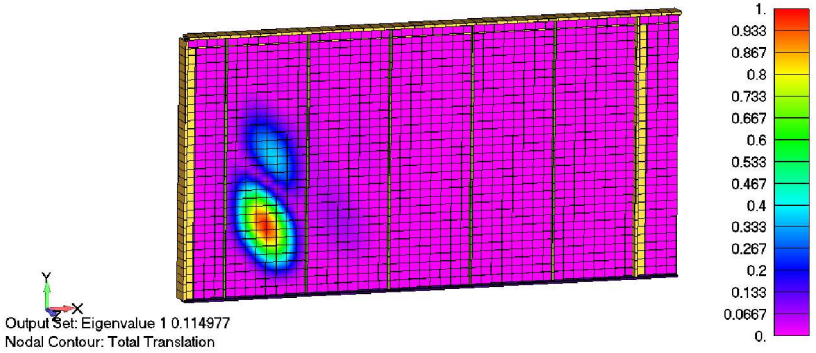
Model - Carbon/epoxy tape $[45/-45/0/90]_S$



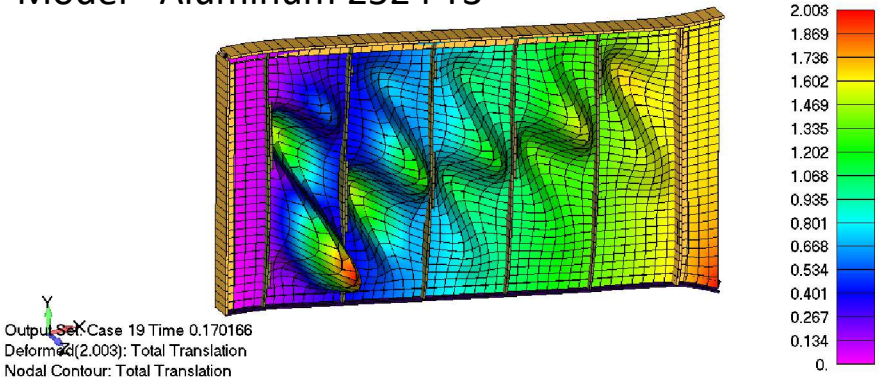
Model - Carbon/epoxy tape $[45/-45/0/90]_S$



Model - Aluminum 2524 T3



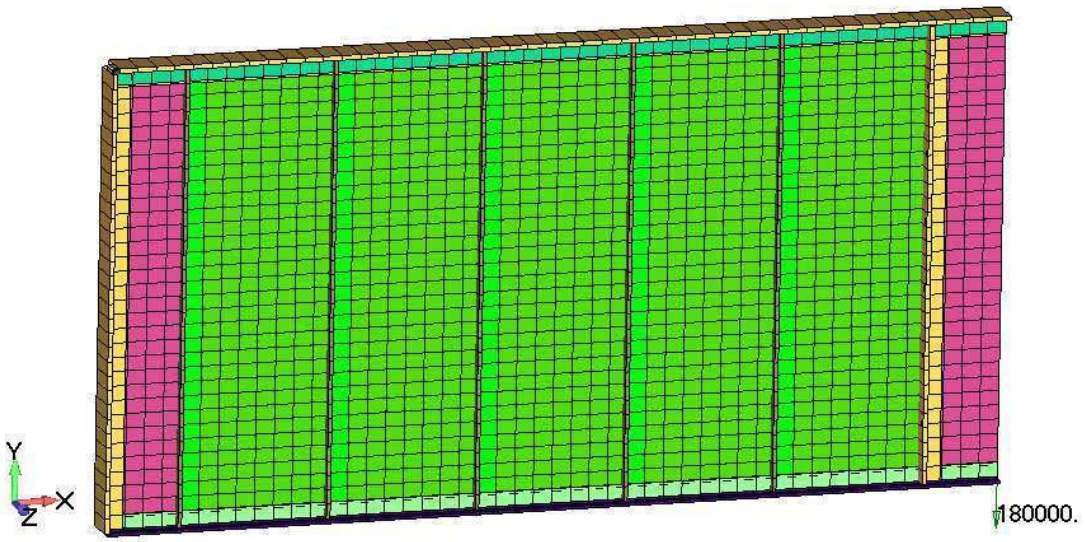
Model - Aluminum 2524 T3



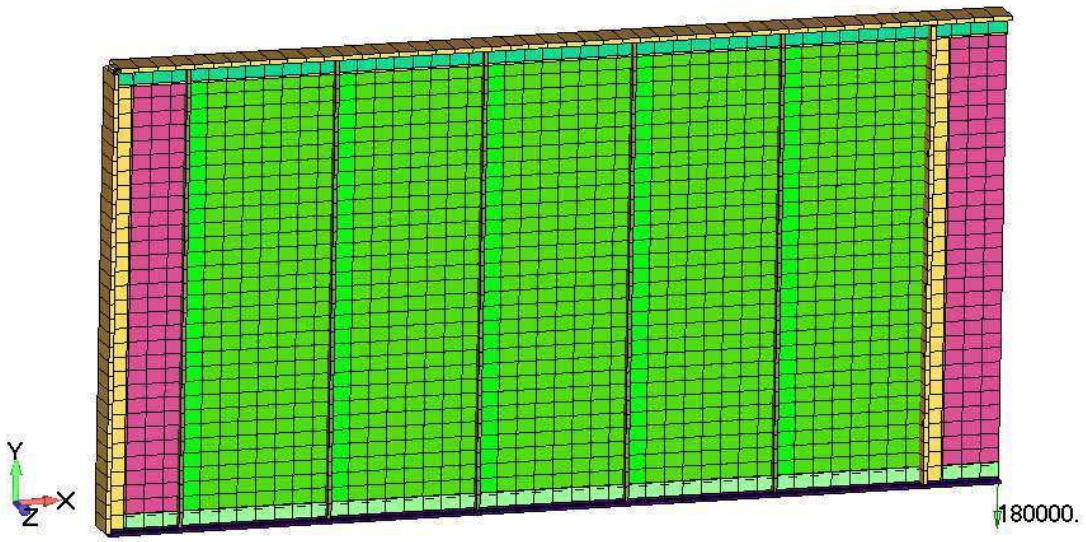
	Eigenvalue	Diagonal Tension
Composite Model	0.114361	0.17001
Metallic Model	0.114977	0.170166

Composite Reinforced Panel *vs.* Metallic Reinforced Panel

Carbon/epoxy tape $[45/-45/0/90]_S$



Aluminum 2524 T3



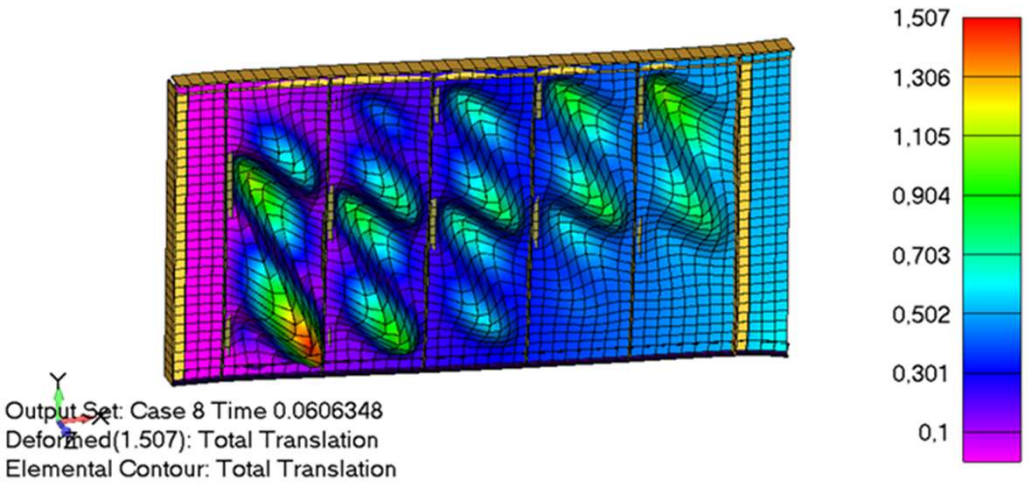
	Composite Panel	Metallic Panel	Difference
Web's thick	1.52 mm	1.51 mm	-0.82%
Total Mass	14.330 kg	17.368 kg	21.20%

Agenda

- Introduction
- Objectives
- Methodology
- Results and Discussion
- Conclusion

Conclusion

1. **To build a FEM to represents the post-buckling behavior of the composite reinforced panel without having to use experimental results:**
   a) The results have shown that it was possible to represent the behavior of the composite reinforced panel during post-buckling using the FEM developed.

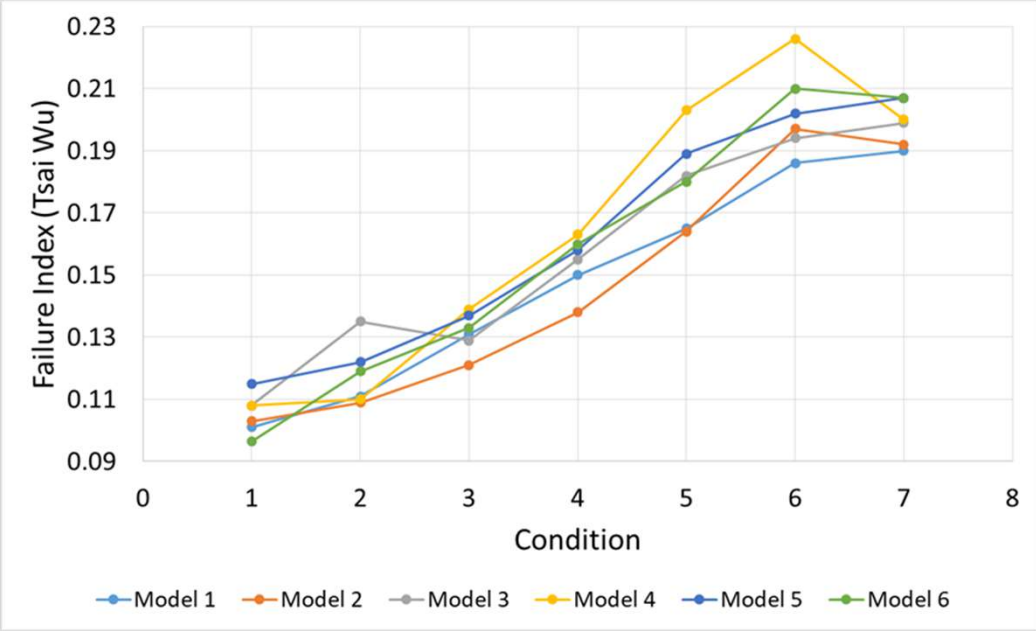


Conclusion

2. Study the influence of stacking sequence in post-buckling behavior:

b) The six lay-ups presented different failure index in the moment when first occurs the diagonal tension. And the conclusion was that the model that had better results, or lower failure index, was the one with +45 and -45 at the outside layers.

Carbon/epoxy tape	
Model 1	$[0/90/45/-45]_S$
Model 2	$[45/-45/0/90]_S$
Model 3	$[45/0/90/-45]_S$
Model 4	$[0/45/-45/90]_S$
Model 5	$[0/45/90/-45]_S$
Model 6	$[45/0/-45/90]_S$

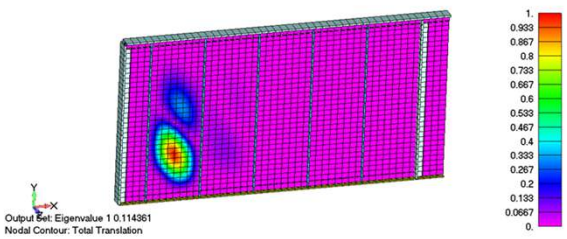


Conclusion

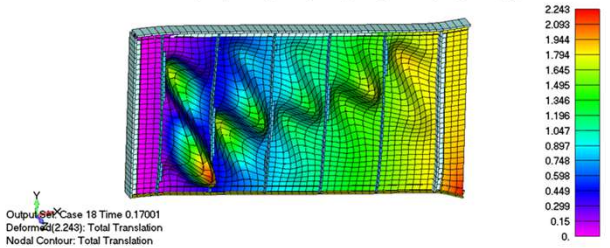
3. **Choose the reinforced panel that have the best behavior during the post-buckling analysis, metallic or composite:**
   c) The comparison between buckling analysis and post-buckling behavior shown that the web of the composite reinforced panel withstands to greater loads than the metallic one, and consequently redistributes less load for the stiffeners. Therefore, it is possible to conclude that the composite reinforced panel presents the best behavior during the post-buckling event.

	Composite Panel	Metallic Panel	Difference
Web's thick	1.52 mm	1.51 mm	-0.82%
Mass	14.330 kg	17.368 kg	21.20%

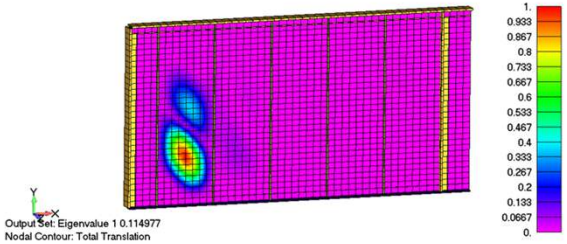
Model - Carbon/epoxy tape $[45/-45/0/90]_S$



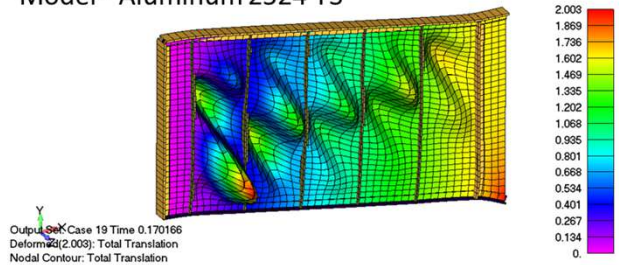
Model - Carbon/epoxy tape $[45/-45/0/90]_S$



Model - Aluminum 2524 T3



Model - Aluminum 2524 T3



Thank you

Take the first step in faith.

You don't have to see the whole staircase, just take the first step.

Martin Luther King Jr