UNIVERSITY OF PATRAS
ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ

Diploma’s Thesis Presentation

Investigation and numerical modelling of buckling and post-buckling behaviour of stiffened aircraft fuselage panels

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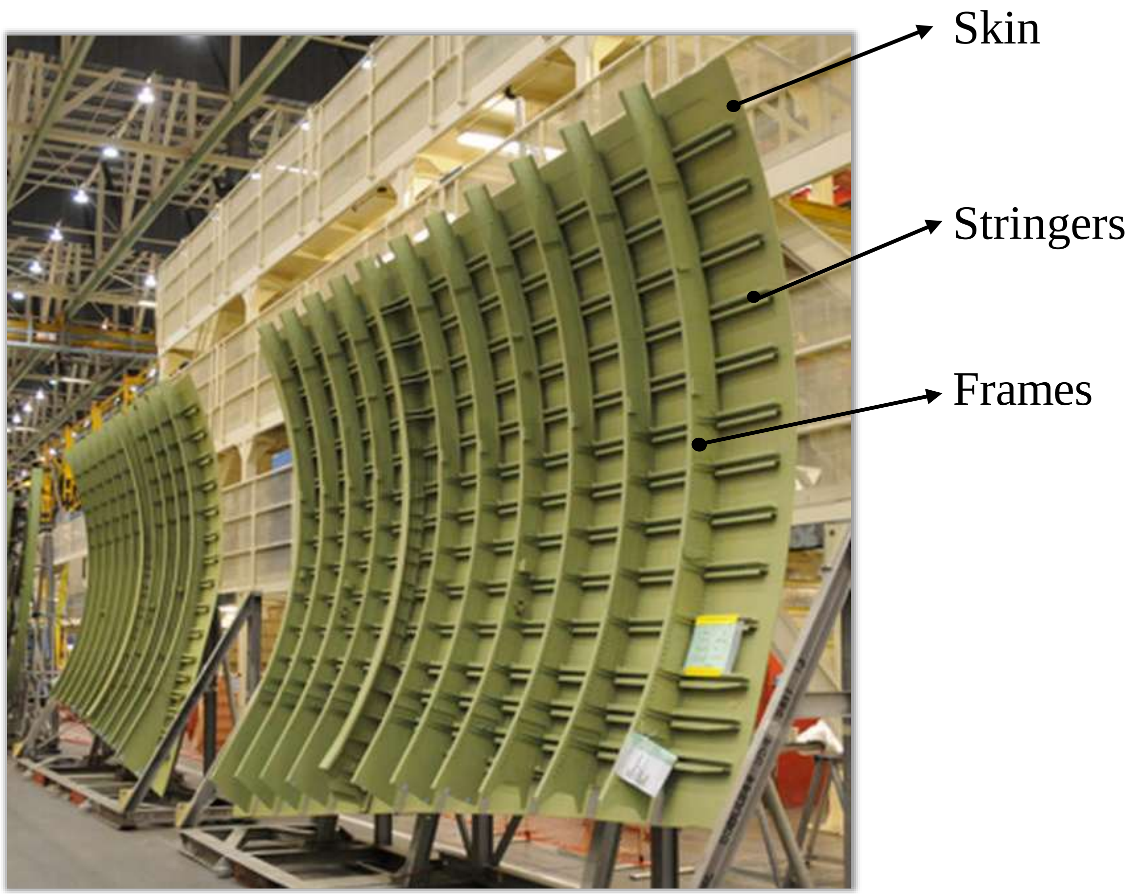
Πάτρα, 13/07/2022

Contents

Introduction (1/2) – Stiffened panels

The fuselage is subjected to:
- ❖ Axial tensile loads
- ❖ Axial compressive loads
- ❖ Combination of tensile/compressive loads

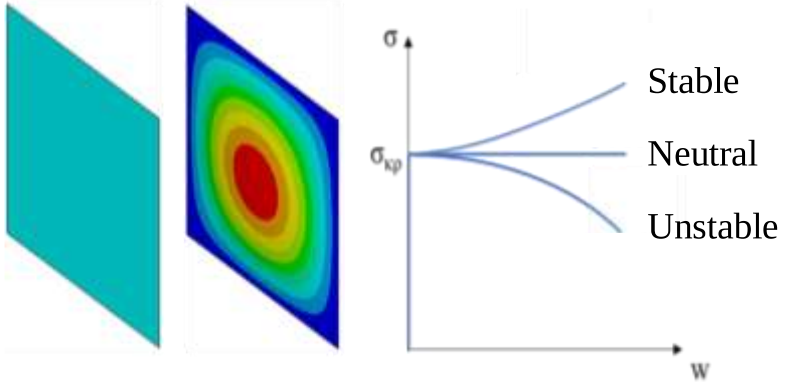
They are primarily constructed from:
- ❖ Aluminum alloys
- ❖ Multilayer carbon fiber–reinforced polymer (CFRP) composites

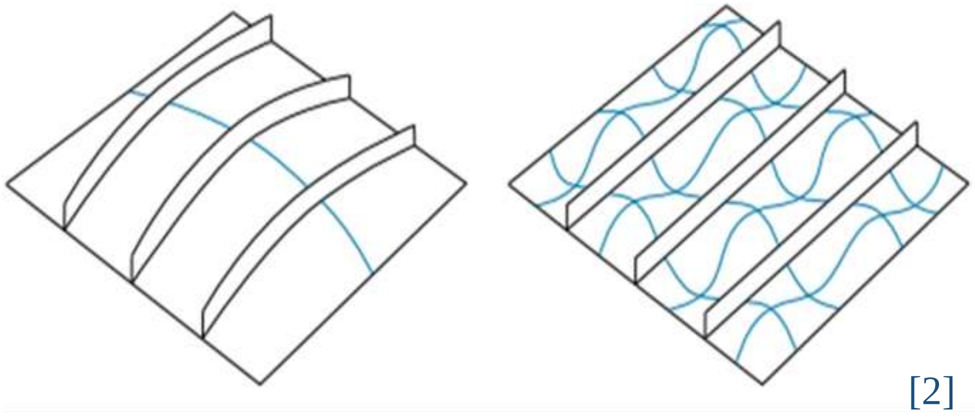


Stiffened Panel - Boeing 747-800 [1]

Introduction (2/2) - Buckling

Buckling ● The loss of a structure's ability to retain its configuration when subjected to external loads, leading to abrupt deformations and significant displacements.

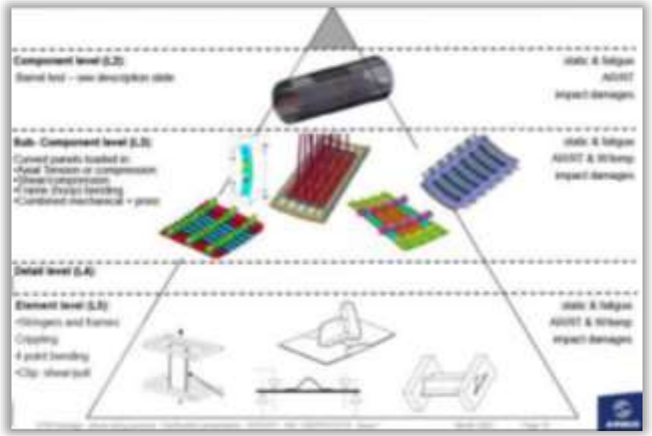




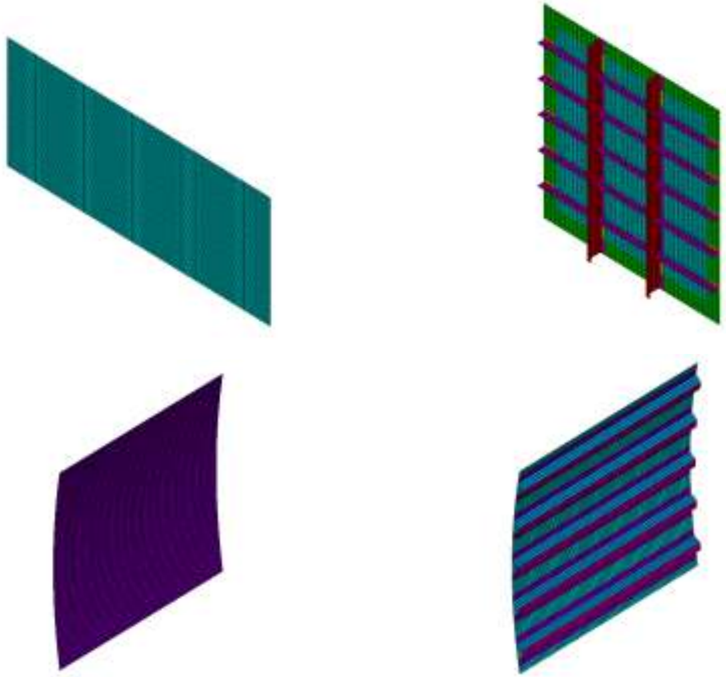
α) Global buckling β) Local buckling

Purpose of study

Validation of fuselage design



1. Analytical equations
2. Experimental methods
3. FEM

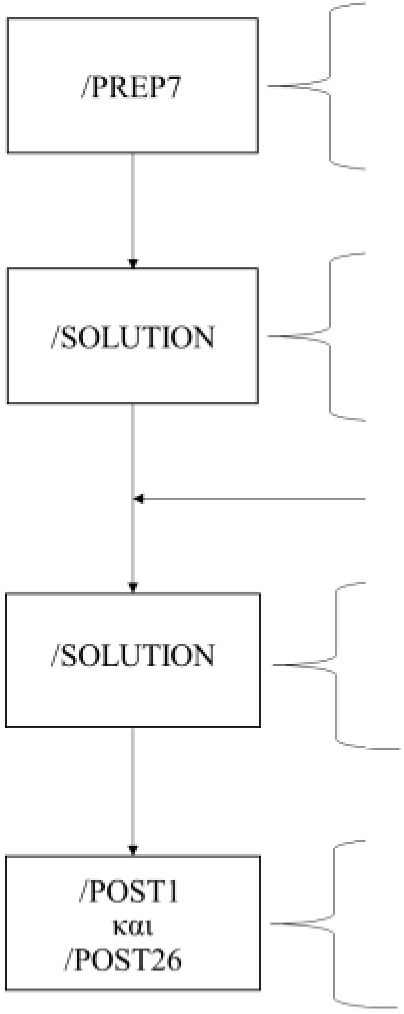


Main goals

- Investigation of numerical methods for predicting the buckling of stiffened shells
- Parametrization of the problem
- Validation of numerical models
- Study of combined compression/shear buckling in stiffened fuselage panels

Load cases:
1. Axial compression
2. In-plane shear
3. Combined compression/shear

Development of numerical models



1. Geometry definition
2. Element type definition
3. Material characterization
4. Meshing

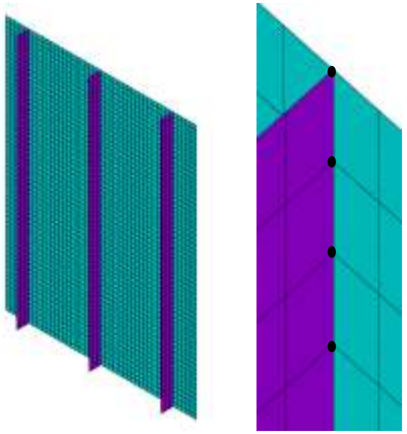
5. Boundary conditions
6. Loads
7. Buckling linear analysis solvers
8. Solution

9. Introduction of initial imperfections

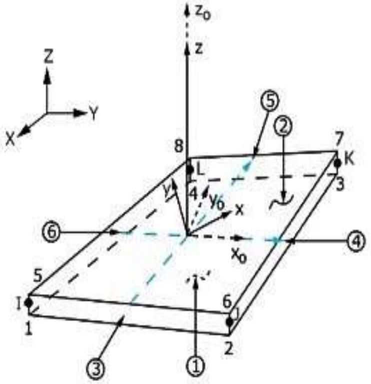
10. Boundary conditions
11. Loads
12. Buckling non-linear analysis solvers
13. Solution

14. Investigation of results
15. Comparison and validation of results

Method of Shared Nodes



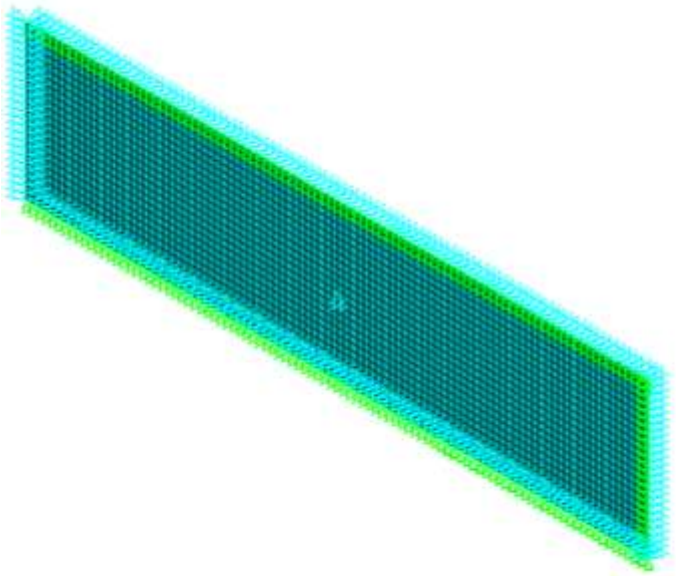
SHELL181



Validation of numerical models (1/9)

1. Axial compression load case

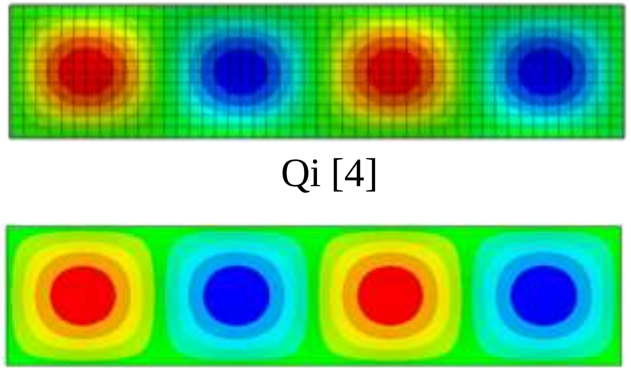
i. Plate



Timoshenko Analytical Equation [3]

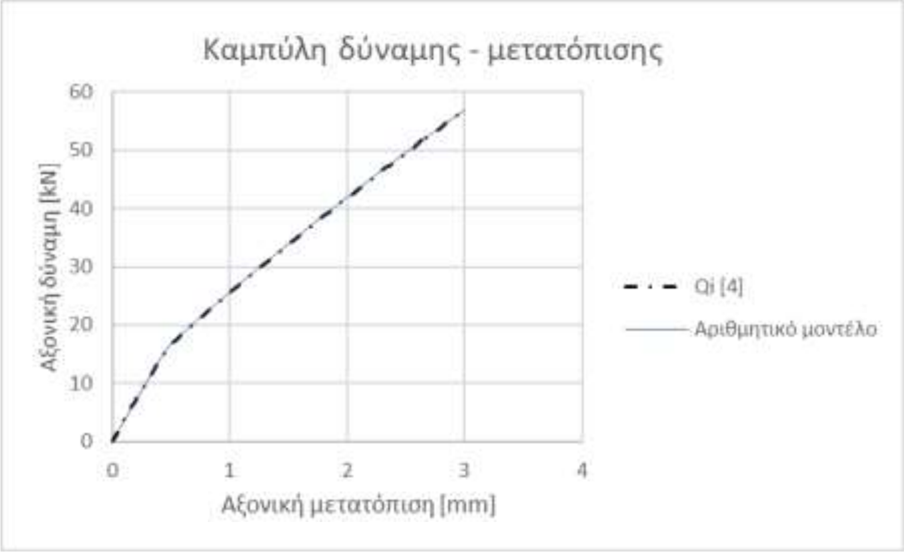
$$\sigma_{cr} = \kappa \frac{\pi^2 E}{12(1-\nu^2)} \left(\frac{t}{b}\right)^2$$

$N_{cr,FE}$	$N_{cr,an}$	ε
kN	kN	%
17.08	17.05	0.15



Qi [4]

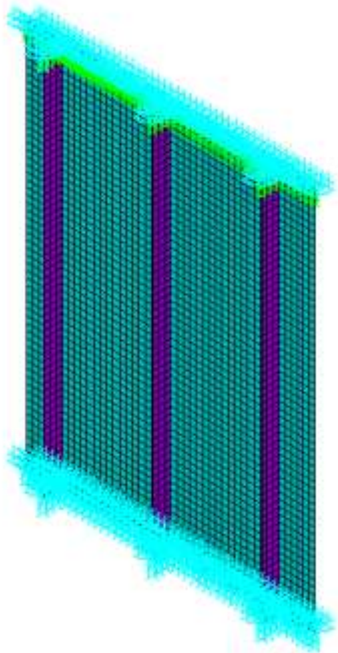
Αριθμητικό μοντέλο

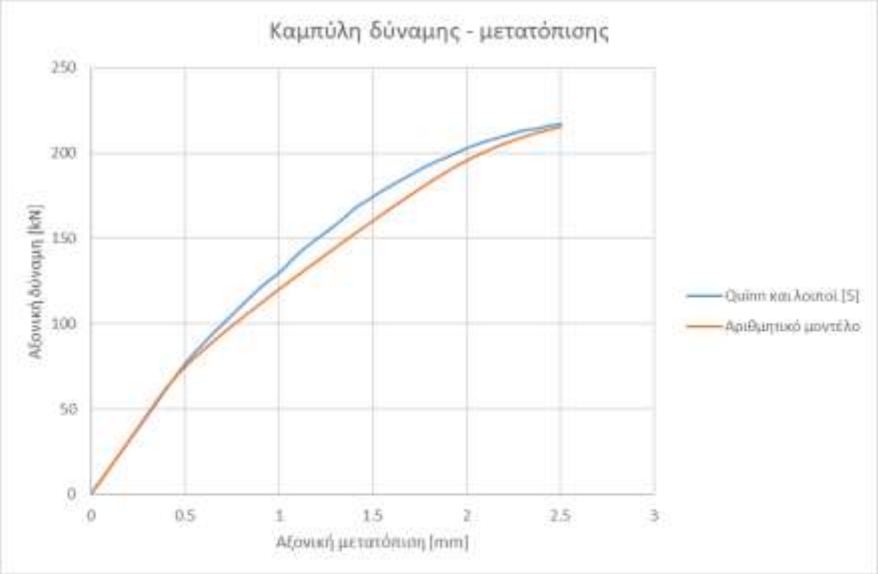


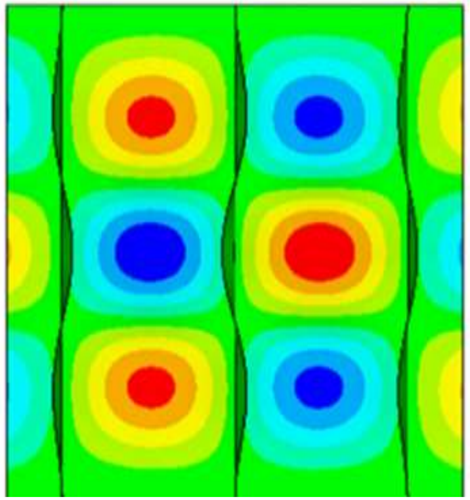
Validation of numerical models (2/9)

1. Axial compression load case

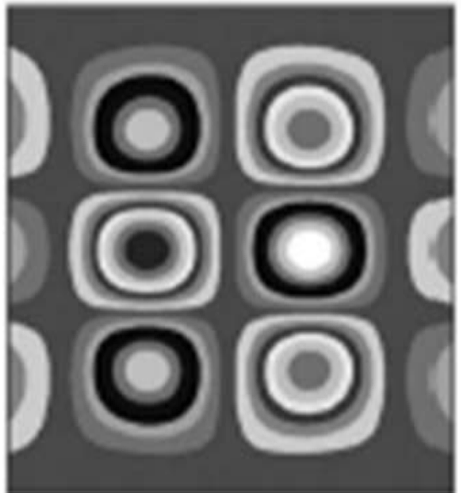
ii. Stiffened plate







Numerical model

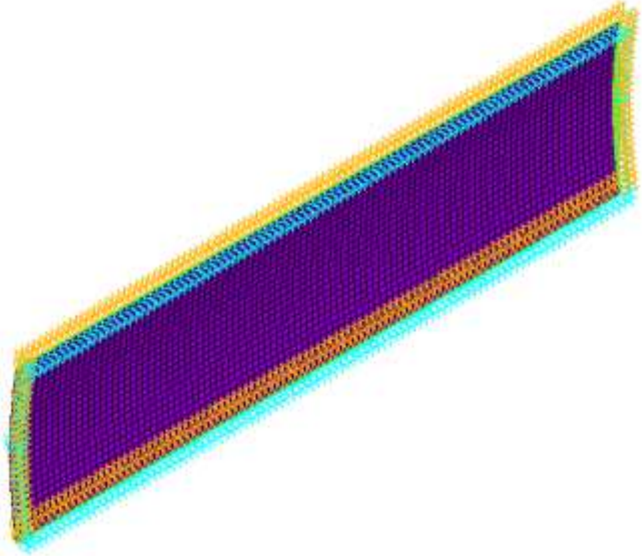


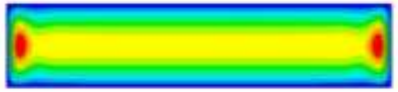
Quinn et al[5]

Validation of numerical models (3/9)

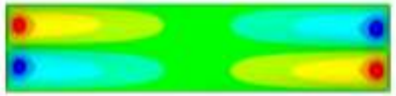
1. Axial compression load case

iii. Shell

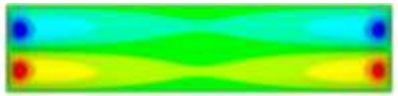




1st eigenmode



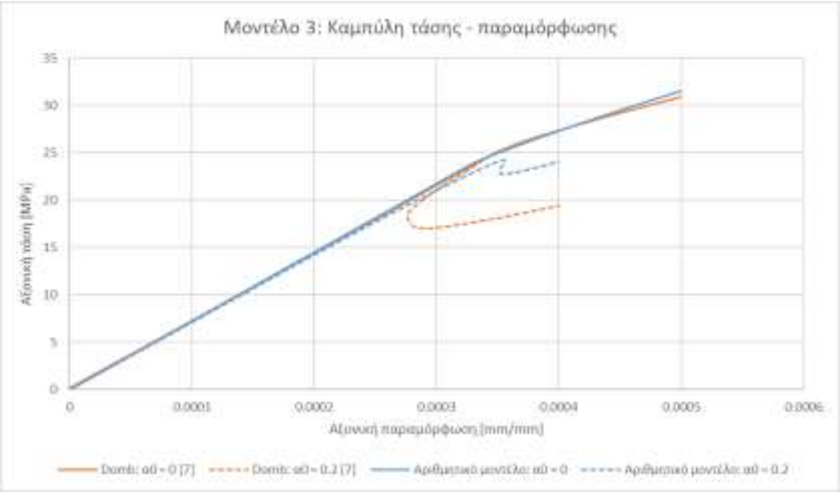
2nd eigenmode



3rd eigenmode

4th eigenmode

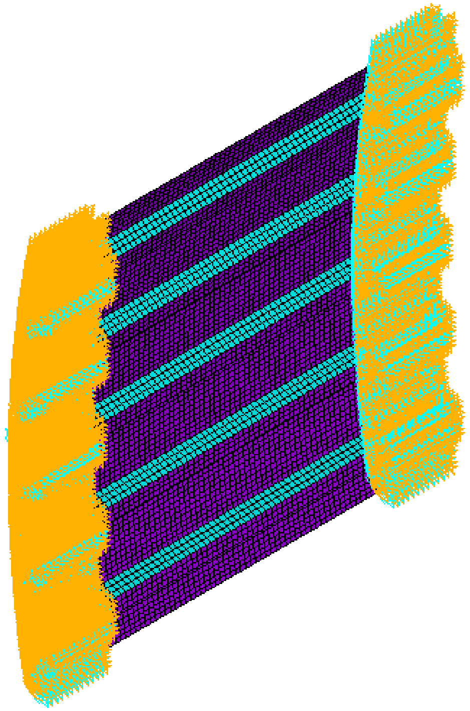
The eigenmodes agree with Tran's observations [6]

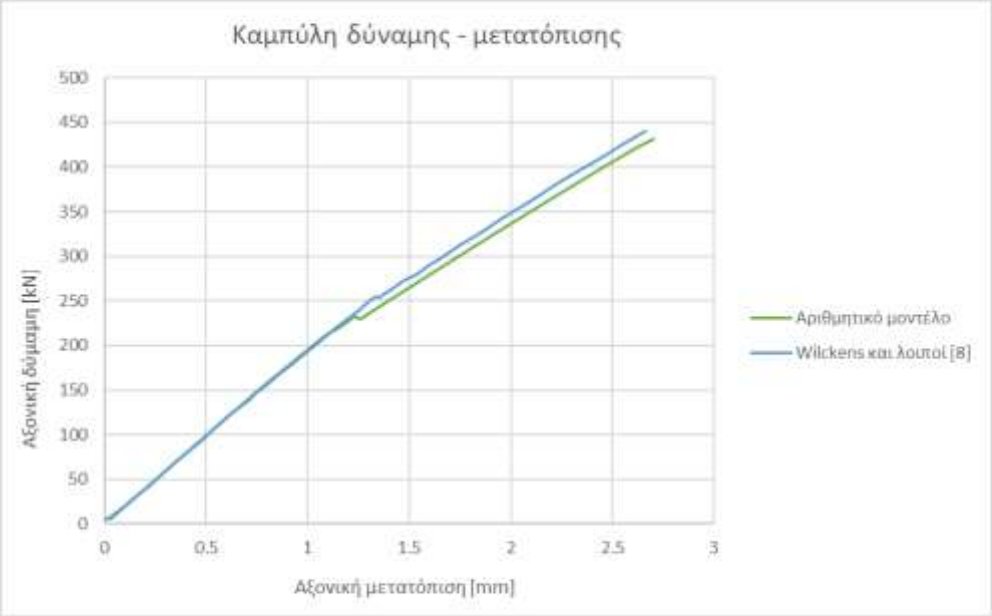


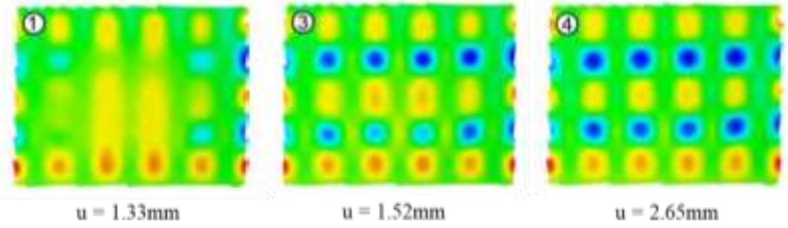
Validation of numerical models (4/9)

1. Axial compression load case

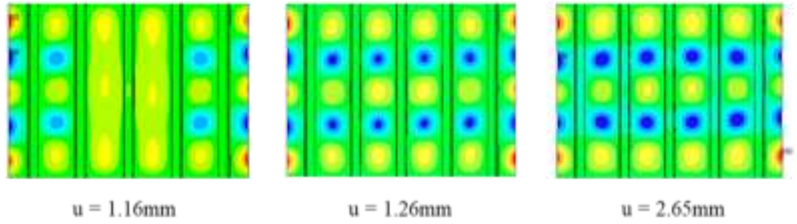
iv. Stiffened panel







Wilckens et al[8]

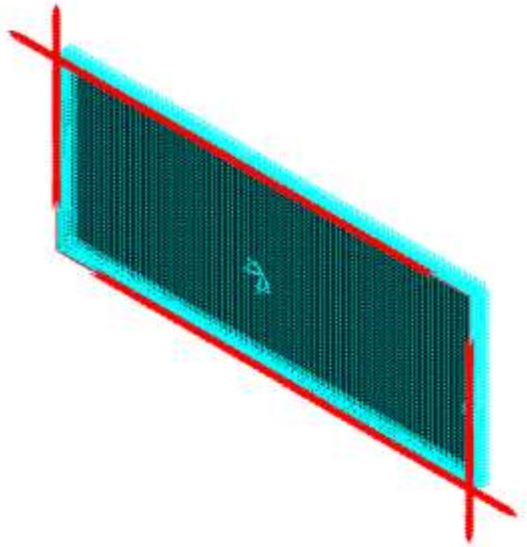


Numerical model

Validation of numerical models (5/9)

2. In-plane shear load case

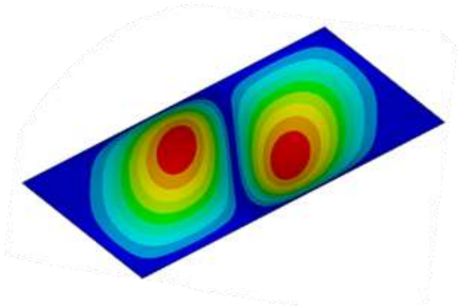
i. Flat plate



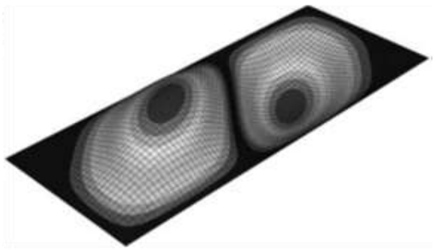
Timoshenko analytical equation [3]

$$\sigma_{cr} = \kappa_s \frac{\pi^2 \mathrm{D}}{b^2 t}$$

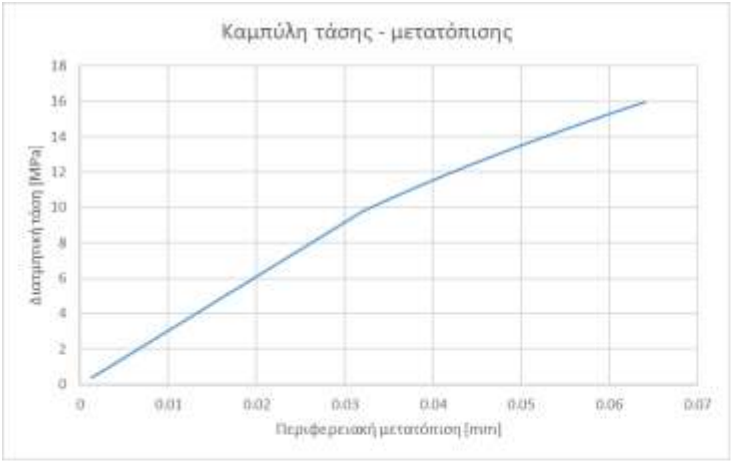
$\sigma_{cr,FE}$	$\sigma_{cr,an}$	ε
MPa	MPa	%
9.83	9.74	0.86



Numerical model



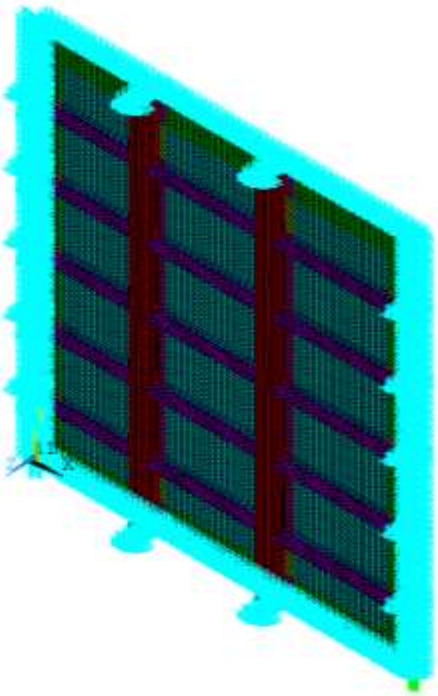
Amani et al [9]

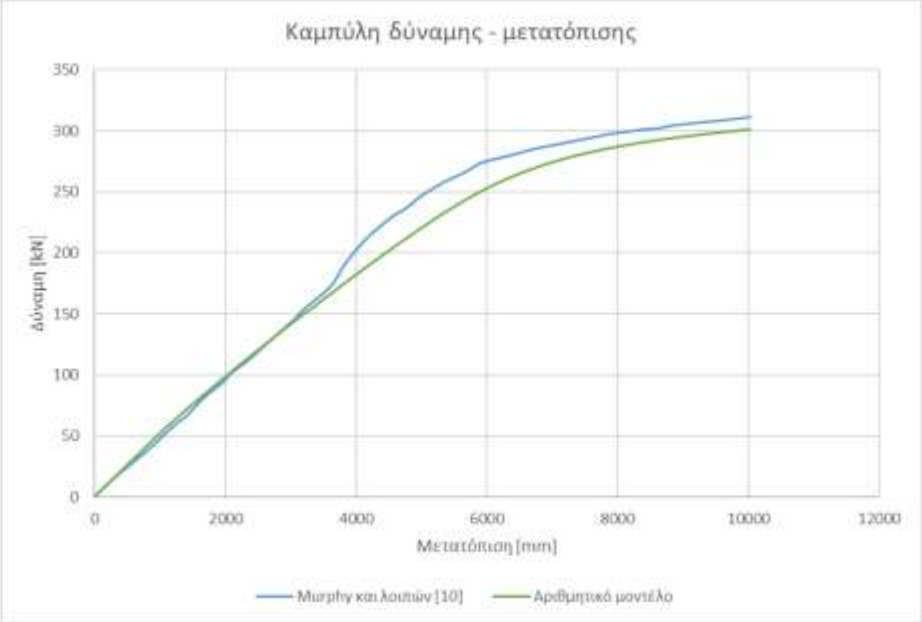


Validation of numerical models (6/9)

2. In-plane shear load case

ii. Stiffened plate





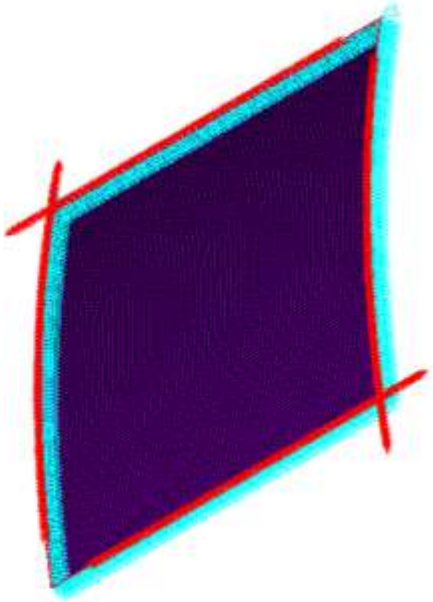
Αριθμητικό μοντέλο

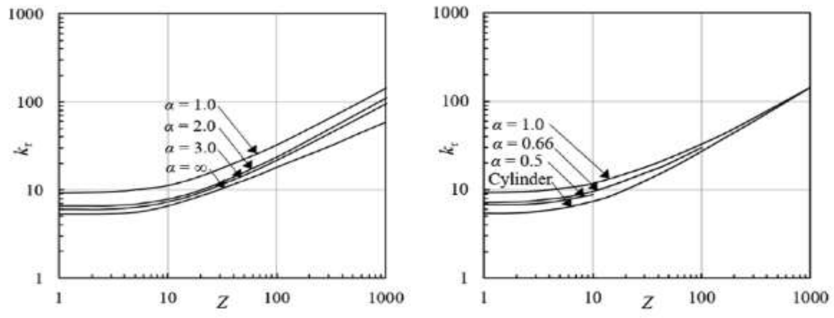
Murphy et al [10]

Επιβεβαίωση αριθμητικών μοντέλων (7/9)

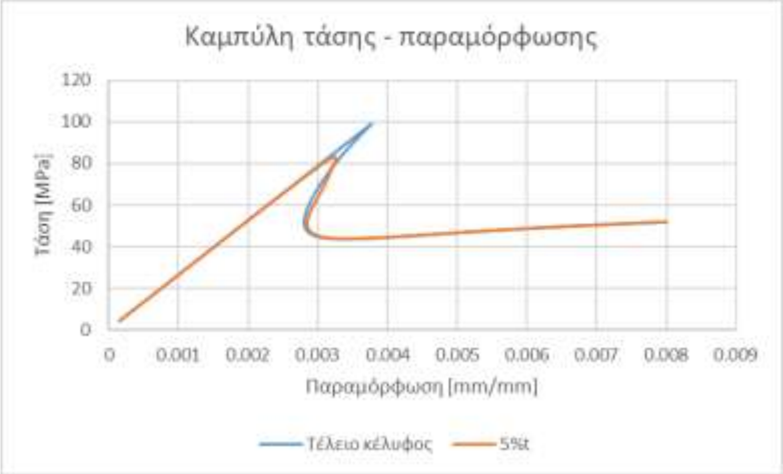
2. In-plane shear load case

iii. Shell





NACA design curves [11]



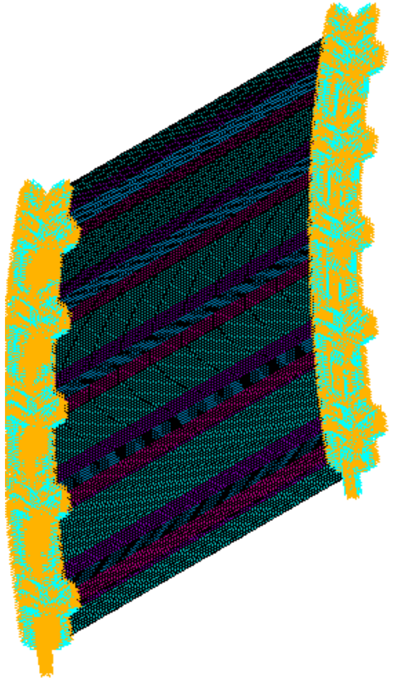
$\sigma_{cr,FE}$	$\sigma_{cr,an}$	ε
MPa	MPa	%
100.1	103.3	3.16

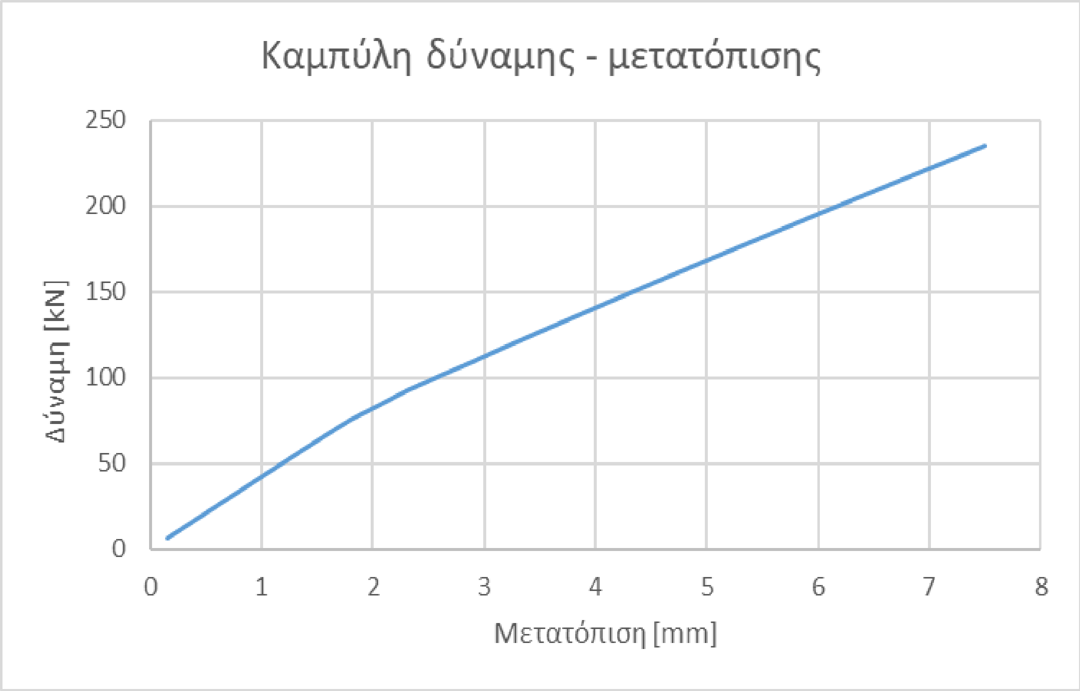
$\sigma_{cr,FE}$	$\sigma_{cr,Domb}$ [11]	ε
MPa	MPa	%
83.3	84.4	1.3

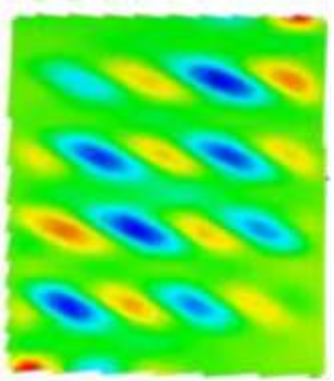
Validation of numerical models (8/9)

2. In-plane shear load case

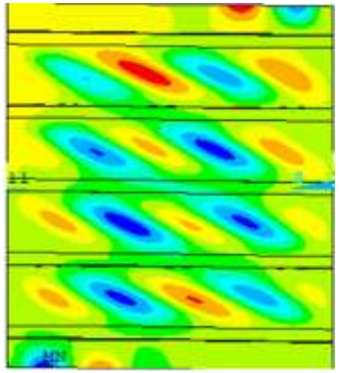
iv. Stiffened panel







Odermann and Kling [12]



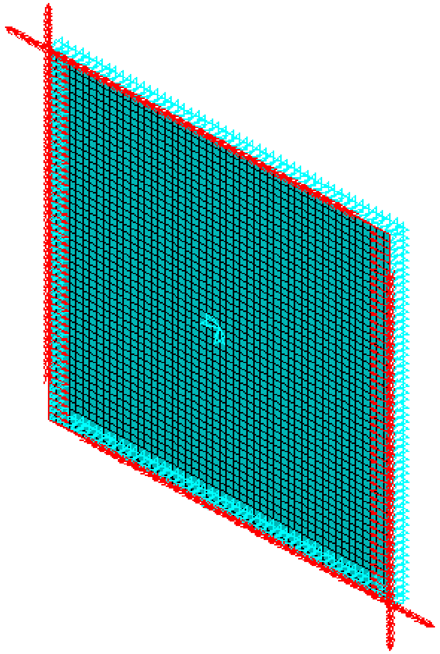
Numerical model

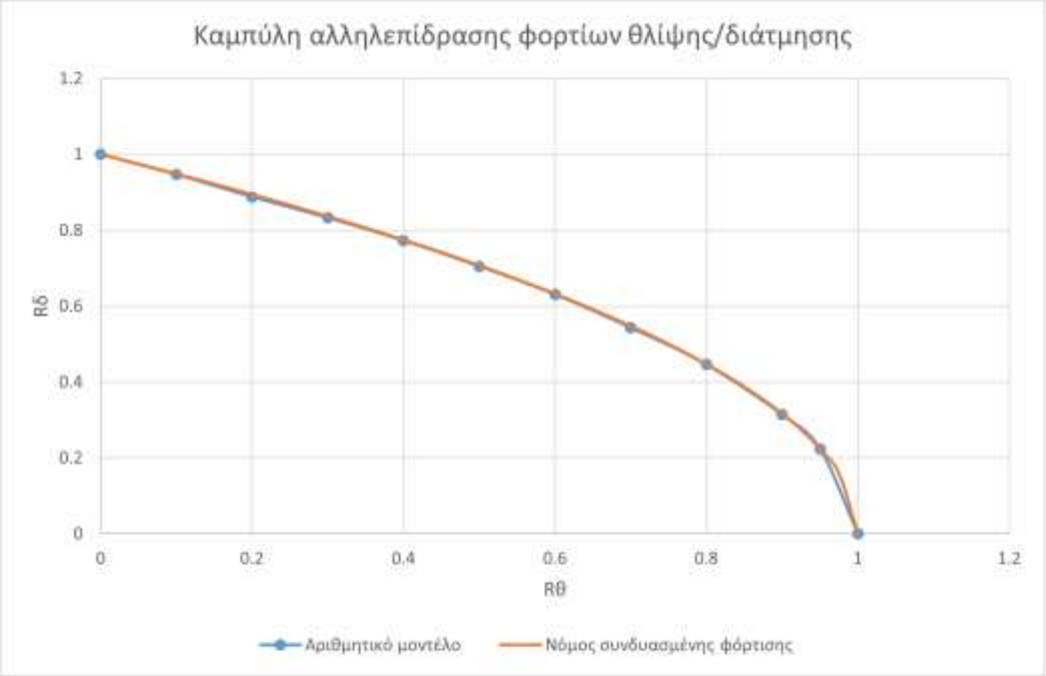
Validation of numerical models (9/9)

3. Combined compression/shear load case

i. Flat plate

Buckling compression and shear interaction curve: $R_c + R_s^2 = 1$, where $R_i = \dfrac{\sigma_i}{\sigma_{cr,i}}$

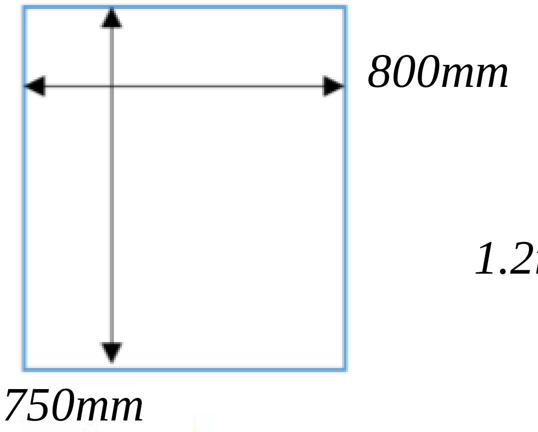


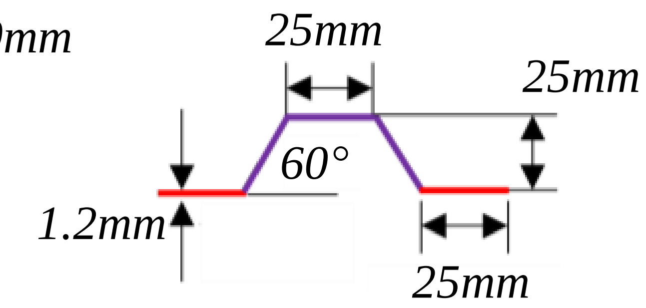


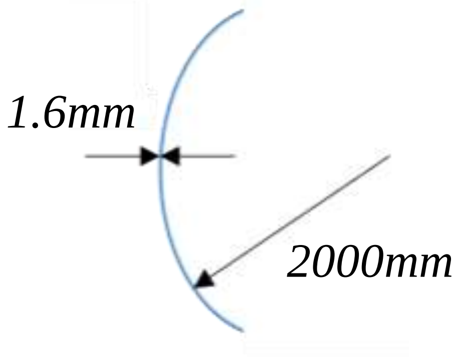
Numerical models of stiffened fuselage panels (1/3)

Geometry

Shell	Stringers







- 5 stringers
- Distance of *150mm* between them
- Length of *600mm*

Material properties

Isotropic		Orthotropic	
Aluminum Alloy		**CFRP**	
E	70GPa	**E_{11}**	131GPa
ν	0.33	**E_{22}**	11.2GPa
		ν_{12}	0.33
		G_{12}	5.3GPa
		G_{13}	5.3GPa
		G_{23}	3.95GPa

Ply sequencing of orthotropic material

Shell	Stringers
$[45,-45,0,90,-45,45,0]_s$	$[45,0,-45,0,90]_s$

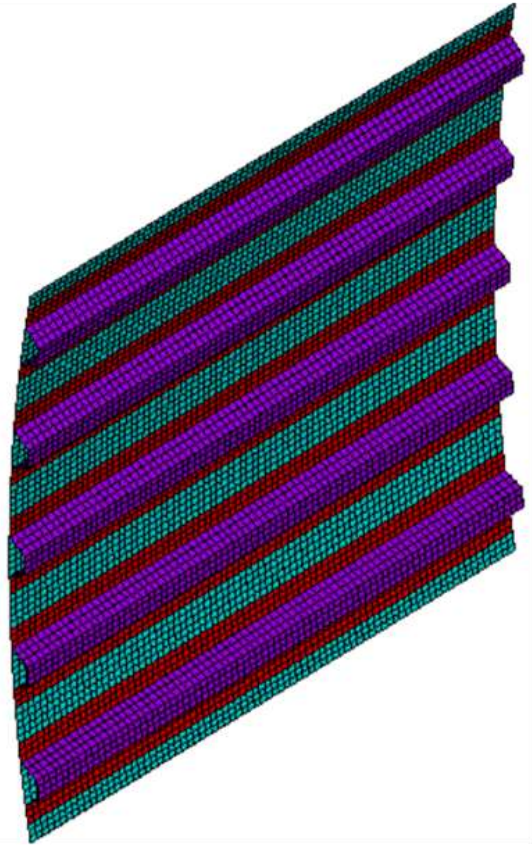
Numerical models of stiffened fuselage panels (2/3)

Mesh convergence check

Aluminum			CFRP		
Element size	**N_{cr}**	**ε**	**Element size**	**N_{cr}**	**ε**
mm^2	kN	%	mm^2	kN	%
50x50	338.6	-	50x50	408.9	-
25x25	238.7	41.8	25x25	296.7	37.8
12.5x12.5	220.7	8.17	12.5x12.5	270.8	9.55
10x10	218.7	0.90	10x10	268.7	0.78
5x5	217.5	0.56	5x5	266.1	0.98

- Element size selected is *10x10mm²*

Numerical model and boundary conditions



Numerical models of stiffened fuselage panels (3/3)

Results

$$R_c + R_s^n = 1$$

$$R_i = \frac{\sigma_i}{\sigma_{cr,i}}$$

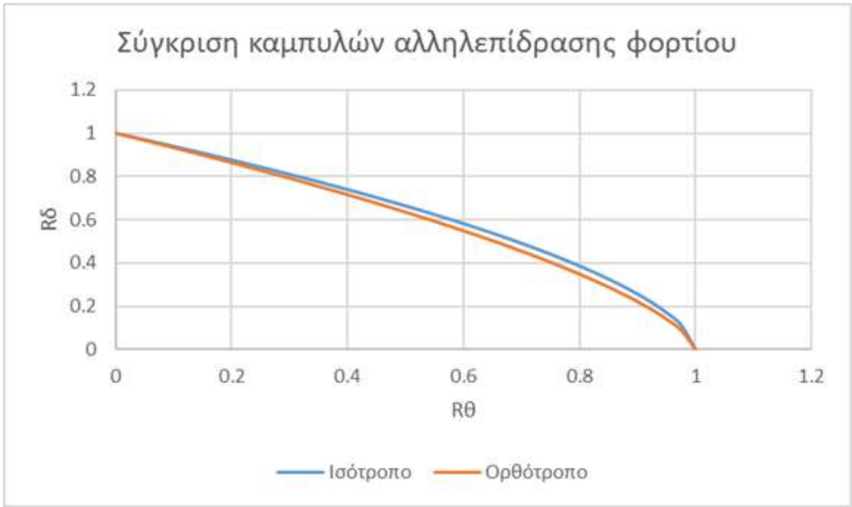
	$\sigma_{cr,c}$ [kN]	$\sigma_{cr,s}$ [kN]
Aluminum	416.3	229.1
CFRP	322.7	142.4
ε (%)	**29**	**60**

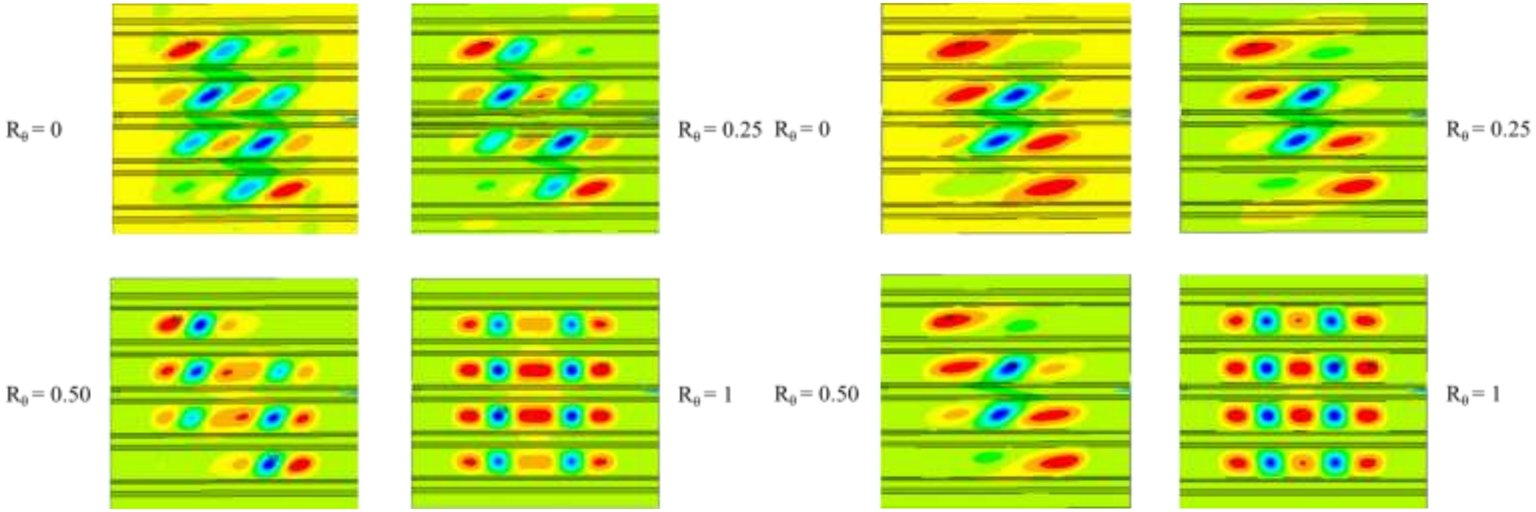
For the aluminum fuselage panel it is calculated:

$$R_c + R_s^{1.694} = 1$$

For the CFRP fuselage panel it is calculated:

$$R_c + R_s^{1.529} = 1$$





Conclusions

Αριθμητικά μοντέλα

- The critical buckling load, the pre-buckling stiffness, the resulting mode shapes, and the failure mechanism are predicted with high accuracy.
- The post-buckling behavior of the structures is computed with satisfactory accuracy.
- The numerical models are fully parametric.

Deviations in the post-buckling regime are due to:

- Initial imperfections.
- Plasticity models.
- The modeling approach of the interface between the skin and stiffeners.

Σύνθετη φόρτιση ενισχυμένων κελυφών

- In stiffened shells, the load interaction curve has the form: $R_c + \mathrm{R}_s^n = 1$
- Since $n_{orthotropic} < n_{isotropic}$, orthotropic stiffened shells are more sensitive to shear loads than their isotropic counterparts, highlighting the need for careful design of fuselage panels made from orthotropic materials compared to conventional aluminum panels.

Future work

Further development of numerical models

- Validation for additional loading cases.
- Incorporation of nonlinear phenomena for more accurate prediction in the post-buckling regime.
- Parametric study of the effect of geometry, material properties, and ply orientation on the interaction curve.

Validation of fuselage panel results

- Experimental investigation for the validation and enhancement of numerical model accuracy.

References

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[12] F. Odermann και A. Kling, «Shear-Compression Buckling Test Method on Curved Stiffened Composite Panels,» σε European Conference on Composite Materials, Seville, Spain, 2014

Thank you for your attention!