Assessment of the Single Perturbation Load Approach on composite conical shells

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DLR

Outline

- Structural models
- Buckling mechanism of cone with SPLA
- Comparison SPLA with other imperfections
- Influence of the material, height and semi-vertex angle on the buckling with SPLA
- Empirical formula for the minimum perturbation load and design load
- Summary and next steps

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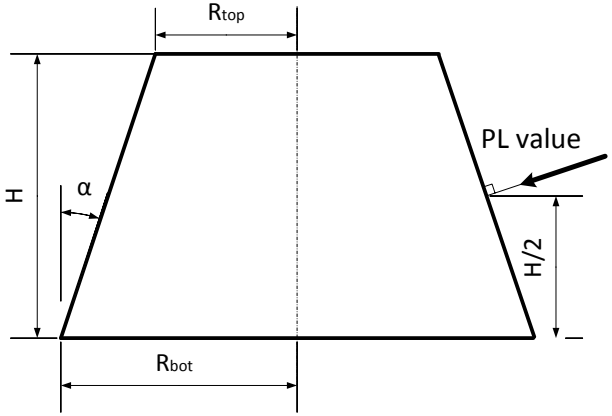
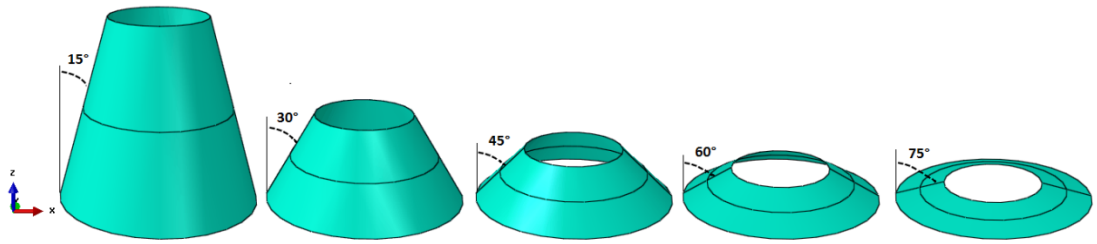
Structural models

- Study cases: **top and bottom radius fixed**

Top radius R_{top}	200 mm
Bottom radius R_{bot}	400 mm
Semi-vertex angle α	5°, 10°, 15°, 30°, 45°, 60°, 75°
Orthotropic	[+30/-30/-60/+60/0/+60/-60/-30/+30]





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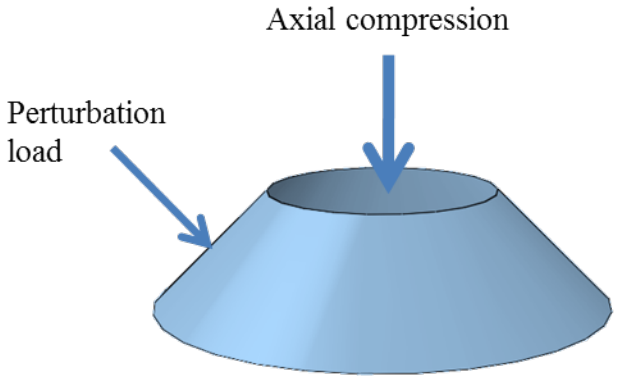
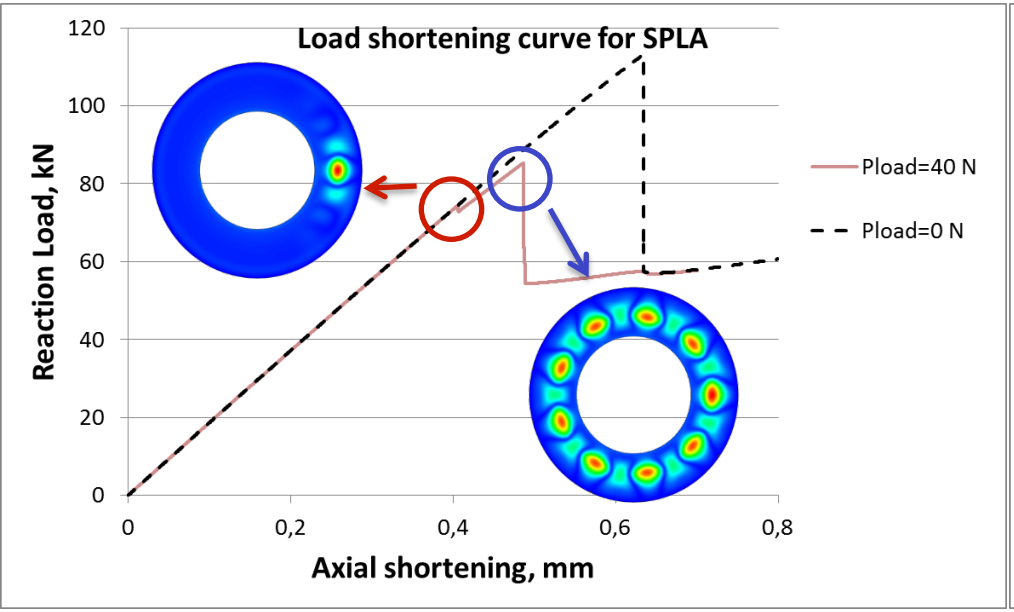
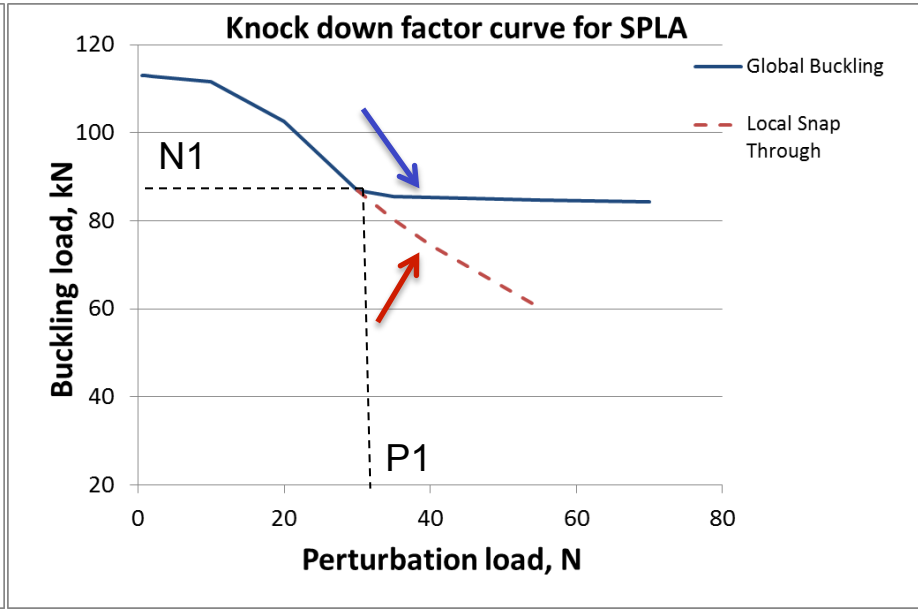
Buckling mechanism of cone with SPLA

- The SPLA applied to Cone 45







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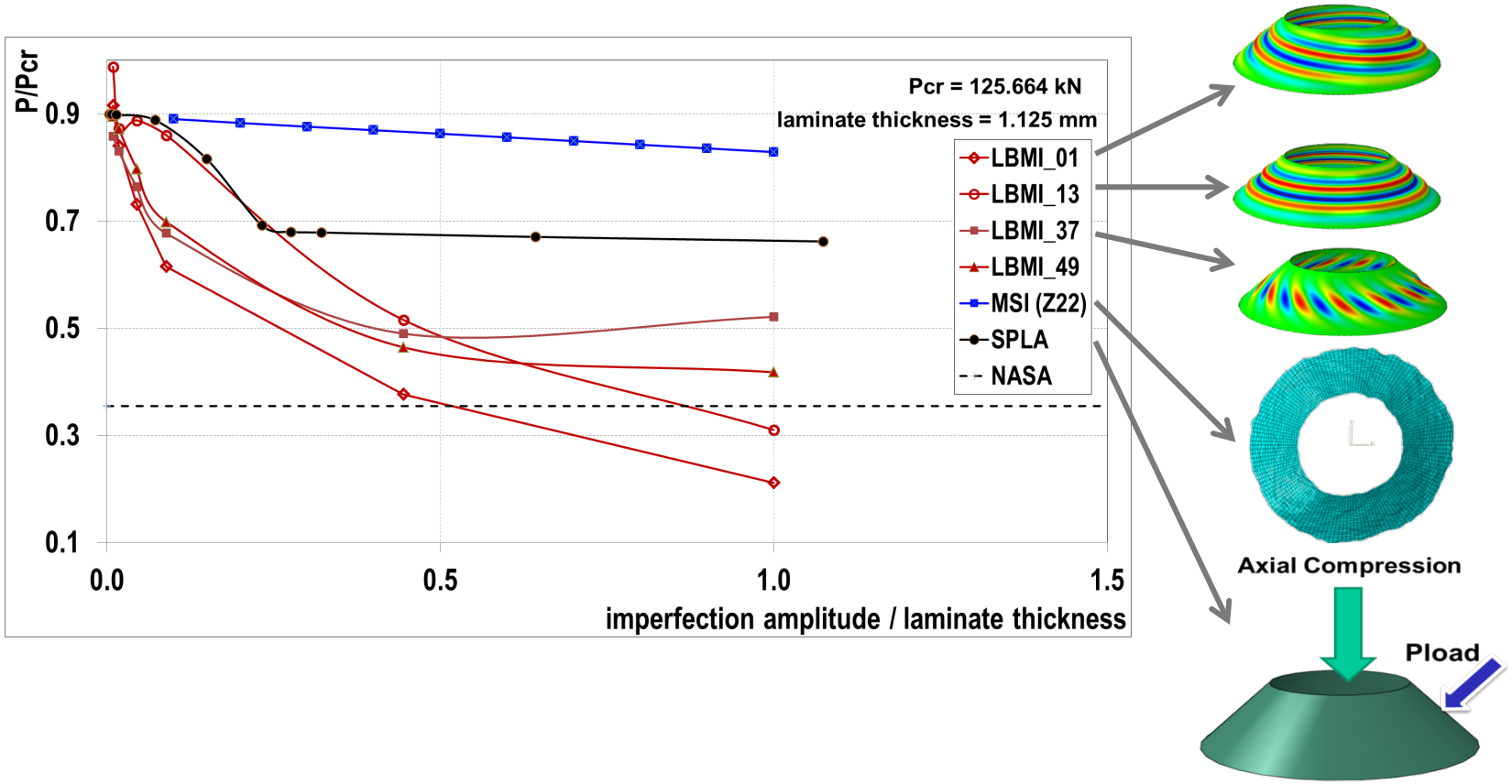
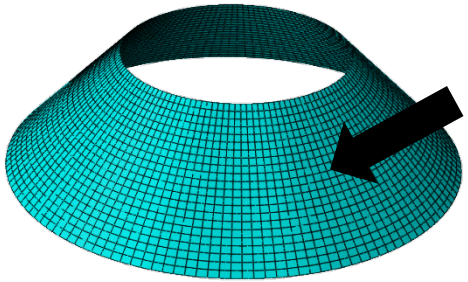
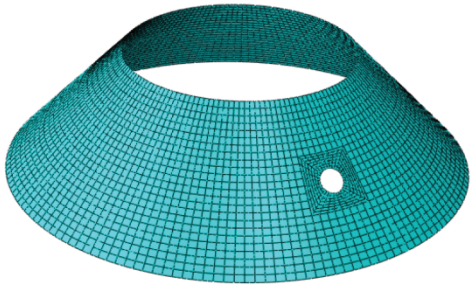
Comparison SPLA with other imperfections

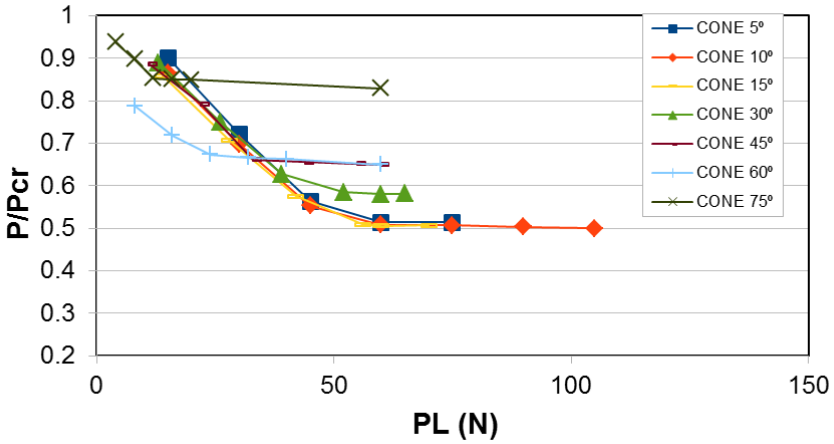


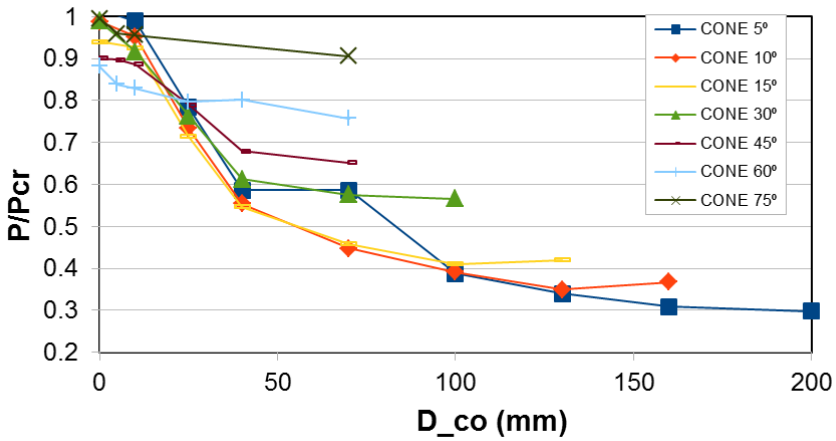
- LBMI depends on the eigenmode chosen; for (ξ/t)>0.5 the LBMIs may be more conservative than the NASA SP-8007
- SPLA is more conservative than MSI and less than conservative the LBMI and NASA

Comparison SPLA with other imperfections









- The less the conical semi-vertex angle is, the more sensitive to imperfections (PL and cut-out) the cone is

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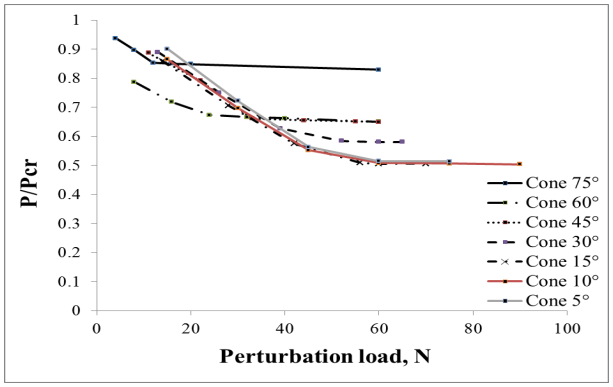
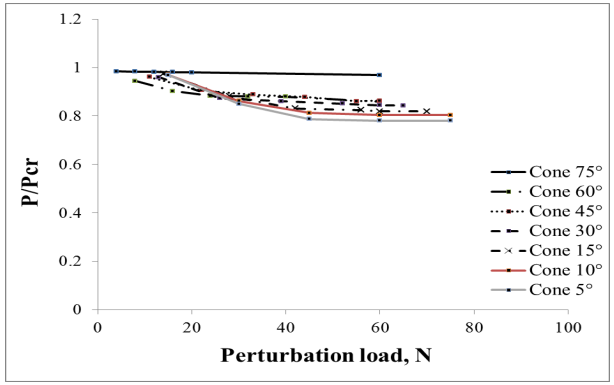
Effect of the material, height and semi-vertex angle on the SPLA KDF

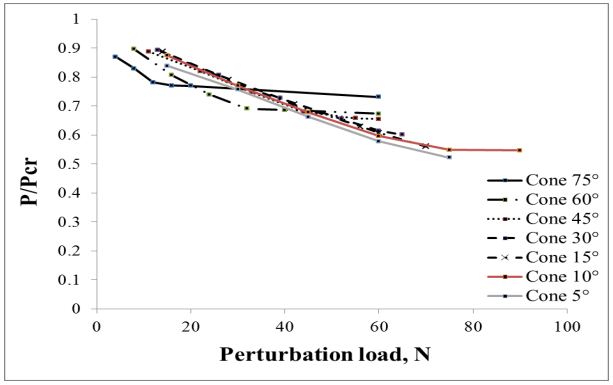
Orthotropic layup



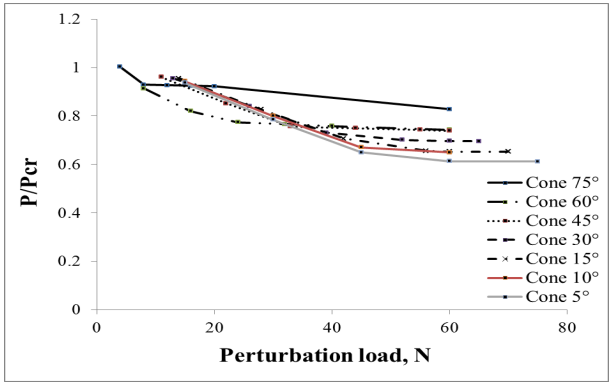
Cross-ply layup



Aluminium



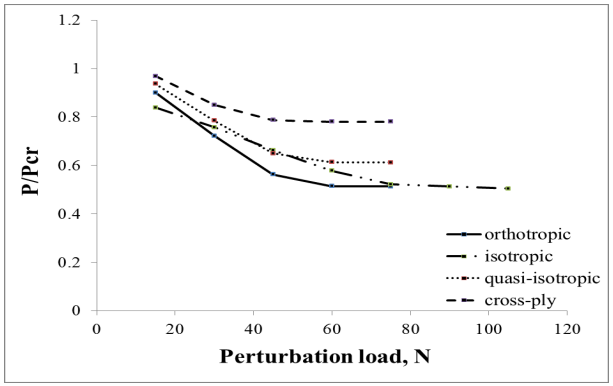
Quasi-isotropic layup



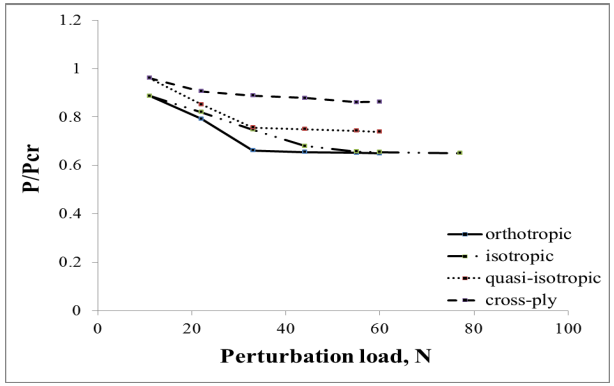
- Cross-ply layup is less imperfection sensitive; no clear P1-N1 transition point for high α

Effect of the material, height and semi-vertex angle on the SPLA KDF

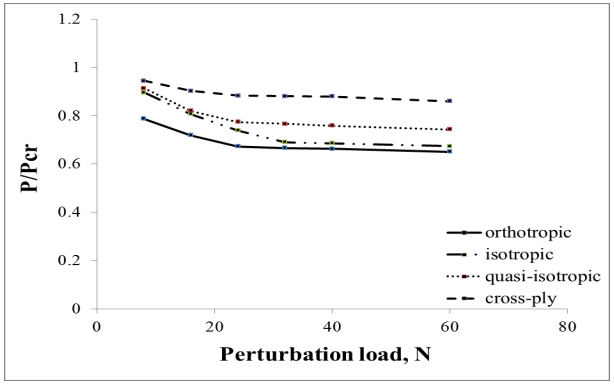
Cone 5°



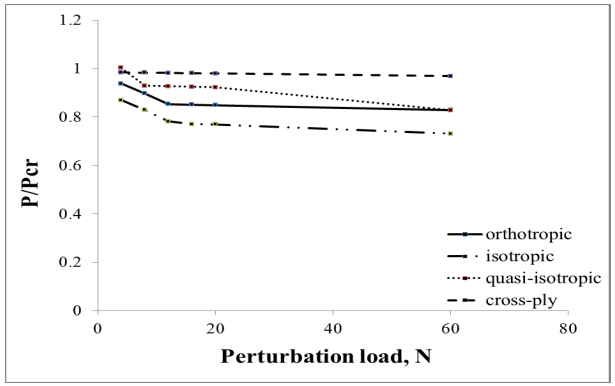
Cone 45°



Cone 60°

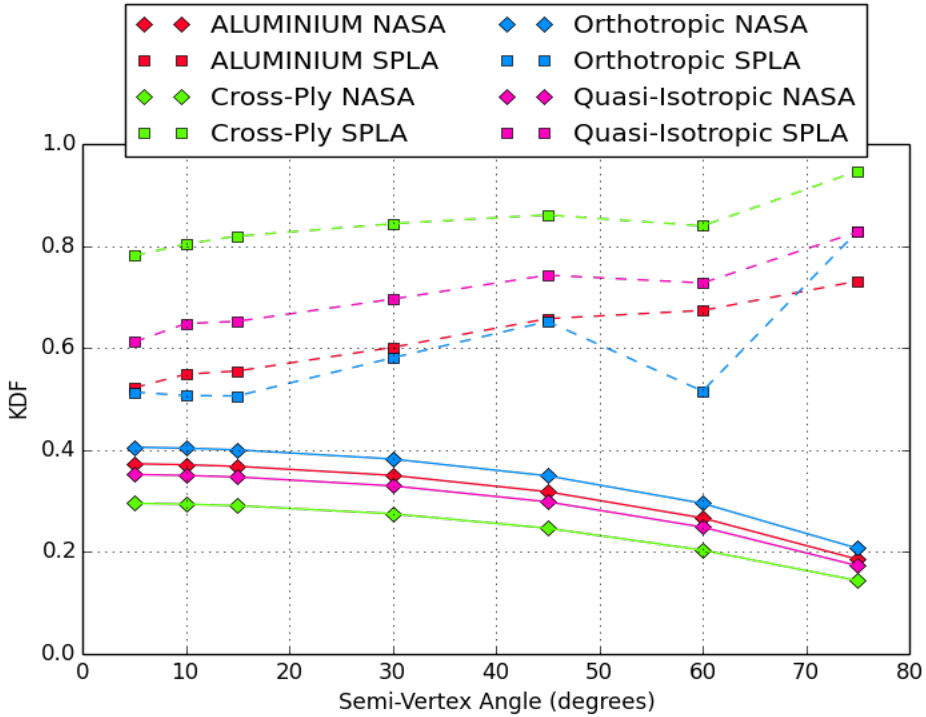


Cone 75°



- As the geometry becomes closer to a cylinder, it becomes more imperfection sensitive

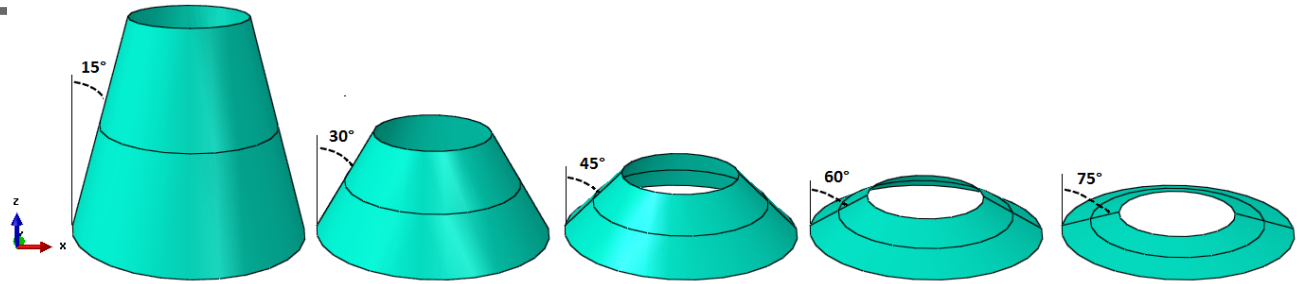
Effect of the material, height and semi-vertex angle on the SPLA KDF

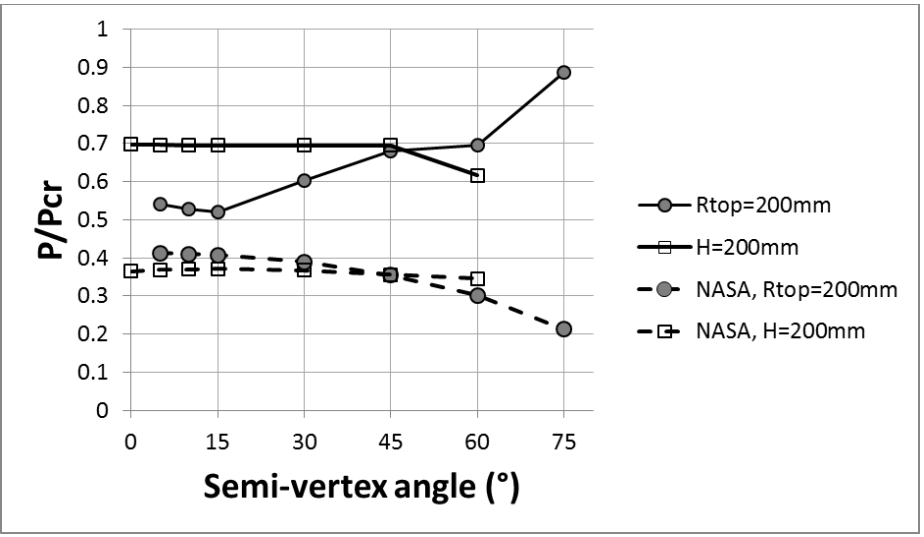


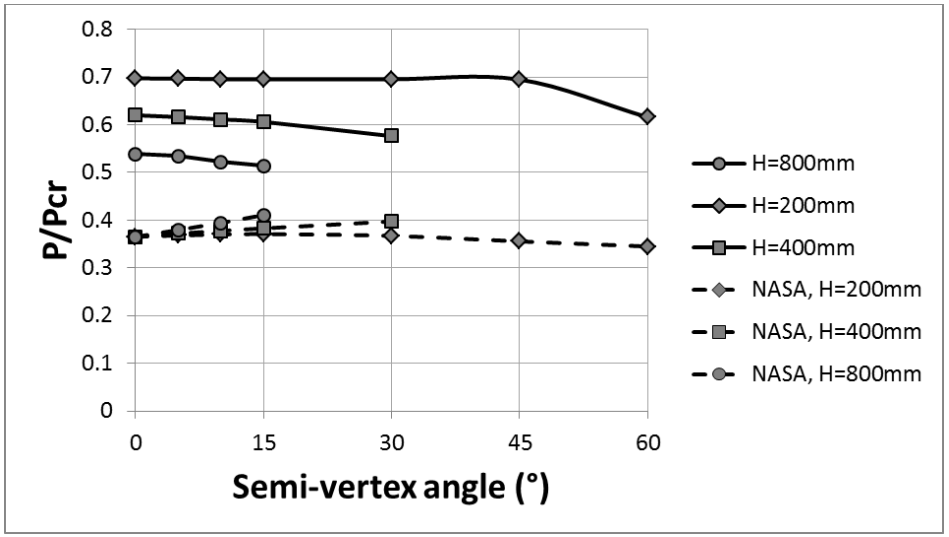
- In all cases the NASA KDF is more conservative than the SPLA KDF, and the SPLA KDF increase with increasing semi-vertex angle.
- It is well known that cylinders are much more imperfection sensitive than plates. This behavior is reflected by the SPLA KDF, but not by the NASA ones.

Effect of the material, height and semi-vertex angle on the SPLA KDF

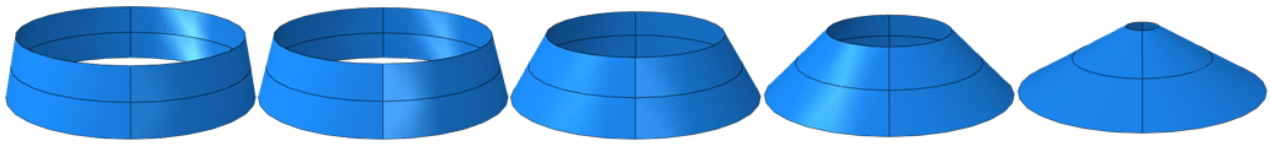
- R_{top} = 200 mm







- H = 200 mm



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Empirical formula for the design load

- Existing empirical formula for P1 for metallic cylinders:

$$P_1 = 0.81 \cdot \frac{Et^3}{12(1-\nu^2)} \cdot \frac{1}{R^{0.8}} \qquad (0 < t < 0.8)$$

$$300 \le R/t \le 2000$$

$$P_1 = 0.69 \cdot \frac{Et^3}{12(1-\nu^2)} \cdot \frac{1}{R^{0.8}} \qquad (0.8 \le t \le 1.5)$$

$$300 \le R/t \le 2000$$

R/t	t, mm	R, mm	H, mm	α,°	E, MPa	ν	P1-compute, N	P1-formula, N	Difference [%]
800	0.5	400	300	0	70000	0.33	5.8	5.49	5.3
533.3	0.75	400	300	0	70000	0.33	16	15.8	1.25
400	1	400	300	0	70000	0.33	35	37.42	6.4
454	0.5	227	300	30	70000	0.33	6	8.64	30.5
302.6	0.75	227	300	30	70000	0.33	17	24.8	31.4
227	1	227	300	30	70000	0.33	40	58.9	32

Empirical formula for the design load

- **Improved** empirical formula for **P1** for metallic cylinders and cones:

$$P1(K(t,E,\nu),R,\alpha,R/r) = 2.14 \cdot D/R \cdot (R/r)^{1/3} \cdot \cos(\alpha),$$

where $D = 2.14 E \cdot t^3 / 12(1-\nu^2)$

- **New** empirical formula for **N1** for metallic cylinders and cones:

$$N1 = 2.29 \cdot Et^2 / (1-\nu^3) \cdot (R/H)^{0.06} \cos^2(a)$$

- For the ranges: $200 \leq R/t \leq 2000$, $0.2 \leq R/H \leq 2$

Empirical formula for the design load

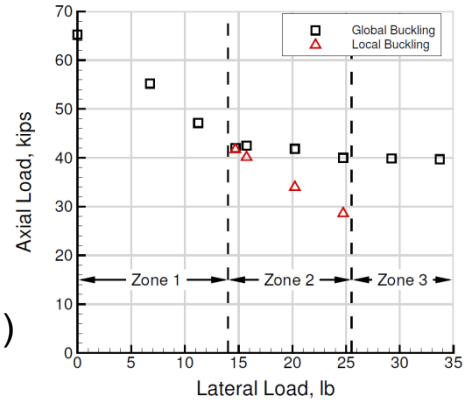
- Validation of the empirical formulas for P1 and N1
- NASA metallic cylinders TA01, TA02 and TA06

Test article	PL	Predicted buckling load (FEM)	Measured buckling load
TA01	65.38 N (14.7 lb)	186.8 kN (42 kips)	**169 kN (38 kips)**
TA02	109,87 N (24.7lb)	177.9 kN (40 kips)	**168.6 kN (37.9 kips)**
TA06	65.38 N (14.7 lb)	186.8 kN (42 kips)	**162.8 kN (36.6 kips)**

- Predicted by empirical formula
  - **P1=65.63 N**
  - **N1=164.51 kN**

a)

b)



a) Test set-up, b) KDF curve [W. T. Haynie and M. W. Hilburger, „Validation of Lower-Bound Estimates for Compression-Loaded Cylindrical Shells"]

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Summary

- The imperfection sensitivity of the cones with applied SPL and cut-outs has a similar trend. However, the KDFs obtained with the SPLA and cut-outs are not exactly the same;

- The SPLA applied to the cones with higher semi-vertex angle and the cross-ply layup does not give a clear indication where P1 is and therefore the KDF can't be identified, showing the limitation of the SPLA for cones with high semi-vertex angles and cross-plied layups
- According to the NASA approach, the value of the KDF gets smaller within growing semi-vertex angle α. However, the SPLA calculations show that the conical shells become less imperfection sensitive when α becomes bigger. Thus, the SPLA results deserves more confidence than the NASA results
- These results are based on numerical studies. They need further corroboration, in particular by experiments which are planned as next steps in the research

- Empirical formula for the minimum perturbation load P1 and the design load N1 for metallic cylinders and cones were developed, verified and validated

Thank you!

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DESICOS 8th meeting – WP3 – DLR: Model and parameters

- ABAQUS Standard 6.11 (Implicit) was employed
- The following parameters for the non-linear analysis were used:

Type of parameter	Value
Nonlinear solver	Newton-Raphson with artificial damping stabilization
Boundary conditions	Both edges clamped
Element type	S8R
Element size	20 mm
Damping factor	Range between 1.e-6 and 4.e-7
Initial increment	0.001
Maximum increment	0.001
Minimum increment	1.e-6
Maximum number of increments	10000