Advanced Sizing Strategies for Preliminary Design of Orthotropic Grid Stiffened Shell Structures

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Integration in DESICOS project

Objective of WP3:
- development of new design approaches

Our study structures:
- stiffened aluminium shells (with TU Delft)

Two challenges when designing stiffened shells:
1. taking imperfections into account using the SPLA
   - key questions:
     1. same characteristics as for unstiffened shells?
     2. more or less conservative design compared to emp. KDF?
2. deriving a suitable stiffening pattern by developing a sizing strategy
Overview stiffened shell

- Dimensions acc. to a DESICOS test structure:
  \[ R = 400 \text{ mm}, \; L = 1000 \text{ mm} \]

- Stiffened shell structures studied:
  \[ n_{\text{Str}} = 30, \; 45, \; 90, \; 126 \]
  \[ n_{\text{Str}} = 90, \; n_R = 36 \]
SPLA
Numerical modelling

- FE-models:
  - discrete/detailed finite element models
  - smeared models
- Variation of point of SPL introduction
  - at a stiffener
  - between stiffeners
SPLA - results
Pre-buckling regime

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SPLA - results
Local snap-through
SPLA - results
Global collapse

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SPLA - results
Comp. to emp. KDF

- Stringer stiffened shells
- Normalized design load SPLA: $\rightarrow 0.613$
- Emp. knock down factor Almroth $\rho_{90\%}$: $\rightarrow 0.626$
Orthogrid stiffened shells

Normalized design load SPLA:
\[ \rightarrow 0.772 \]

Emp. knock down factor Almroth \( \rho_{90\%} \):
\[ \rightarrow 0.745 \]

Summary: SPLA design loads were similar to the results obtained using Almroth’s \( \rho_{90\%} \) empirical KDF
Sizing strategy
General idea

- Buckling modes:
  - local buckling skin sections
  - local buckling stringers
  - global buckling

- All failure modes occur at the same load
  - as suggested in the isogrid design handbook

- Stiffener height is determined such that it buckles locally at the same stress as the skin section
  - constant relation between stiffener height and stiffener spacing
  - number of stringers as initial variable
**Sizing strategy**

**Procedure**

- \( t = t_{\text{Str}} = t_{\text{Skin}} \)
- \( n_{\text{Str}} = n_{\text{Str,init}} + i \)

Buckling stress of skin section, \( \sigma_{\text{cr,skin}} \)

- Height of stringer such that: \( \sigma_{\text{cr,skin}} = \sigma_{\text{cr,stringer}} \)

Buckling load causing local buckling, \( F_{\text{crit,loc}} \)

Smeared stiffness properties and global buckling load, \( F_{\text{crit,gl}} \)

- \( F_{\text{crit,loc}} = F_{\text{crit,gl}} = F_{\text{max}} \) ?
  - no
  - yes

Adapt wall thickness, for:
  - \( F_{\text{req}} > F_{\text{max}} \), increase \( t \)
  - \( F_{\text{req}} < F_{\text{max}} \), decrease \( t \)

- \( F_{\text{max}} = F_{\text{req}} \) ?
  - no
  - yes
Sizing strategy
Structural models

→ local buckling: analytical methods - buckling of plates
→ global buckling: AstrA / Tennyson
Sizing strategy
Stringer stiffened shell

- Buckling load vs. number of stringers

→ good agreement betw. discrete FEM and analytical methods
Sizing strategy
Orthogrid stiffened shell

- Buckling load vs. number of stringers

→ good agreement betw. discrete FEM and analytical methods
Sizing strategy
Summary

The sizing process presented in conjunction with the structural models chosen allows:

- deriving initial configurations
- for stringer stiffened and orthogrid stiffened shells
- in the case of a axial compressive forces

Manufacturing restraints are currently not considered

Drawbacks due to current structural models:

- combined loading and inner pressure can recently not be taken into account
- composite materials can recently not be taken into account
Weight strength curves

- Isotropic
- Isogrid
- Sandwich
- Corrugated Shell

With rings inside and outside.
Weight strength curves

- Isotropic
- Stringer Stiffened
- Isogrid
- Orthogrid
- Sandwich
- Corrugated Shell Rings Inside
- Rings outside

$h/R$

$\frac{N_x}{R \cdot E}$
Summary and conclusion

- SPLA applied to stiffened shells led to similar results than using empirical knock down factors.

- The sizing approach allows to derive preliminary design efficiently:
  - Mathematical optimization algorithms are not needed.
  - The configurations derived can be considered as starting point for detailed design of stiffened shells.

- The general idea of the sizing approach can also be implemented using numerical structural models:
  - Deriving weight strength curves for pressurized cylinders and composite stringer and orthogrid stiffened shells.
Thank you for your attention!

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