Optimisation strategies applied to advanced Ariane 5 Upper Stage concepts with specific focus to mass reduction of stringer stiffened cylinder shells

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Overview

- Introduction
- Problem definition
- Analysis Method
  - Design Choices
  - Design Optimisation
  - Verification
- Result and Discussion
- Summary
- Significance of Work

Introduction

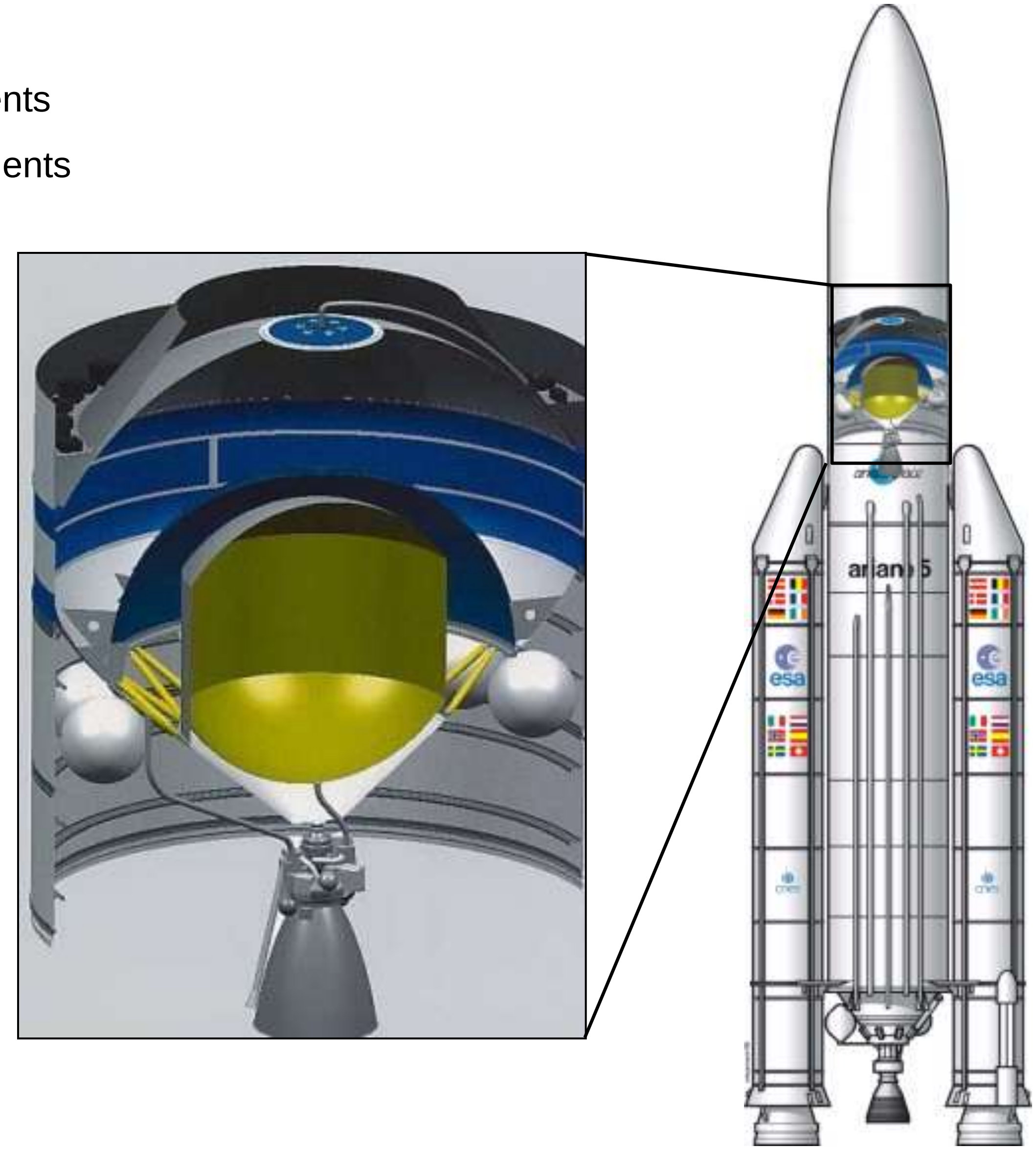
- Motivation of the investigations
  - Europe is in need of an improved Upper Stage to face uprising competitions and commercial demands in the launcher business
    - New Upper Stage for A5 (A5 ME) post A5
    - Different Launcher and Upper Stage configurations are under investigations by an European industrial expert team financed by ESA (FLPP)

- Focus of the investigation
  - Reduce the specific Launcher costs by either increased performance or decrease the recurring costs
    - Redesign of the Upper stage (A5 ME)
    - Identification and introduction of cost efficient new technologies (FLPP)
    - Design studies and trade off's for different Upper Stage design options
    - Manufacturing processes

Problem definition

- Initial work
  - Identification of cost driving components
  - Identification of mass driving components

- Upper Skirt
- Upper Dome
- Upper Y-Ring
- Cylinder
- Lower Y-Ring
- Lower Dome
- Inter-tank Structure
  - Common Bulkhead
  - Inter-tank Ring (X-, K-, …)
  - Inter-tank Interfaces (cylinder, struts, …)
- (Elongated) Lower Skirt



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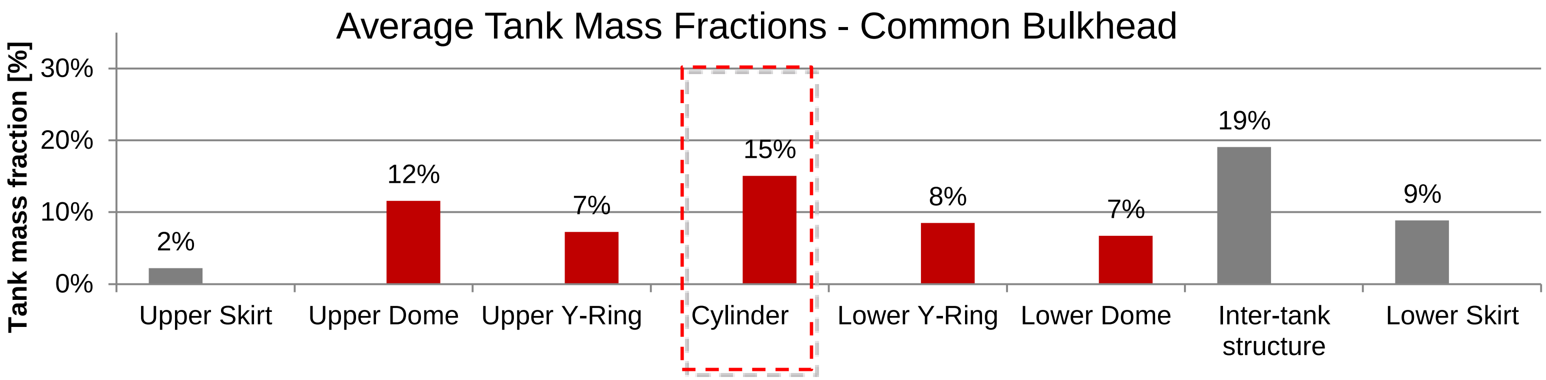
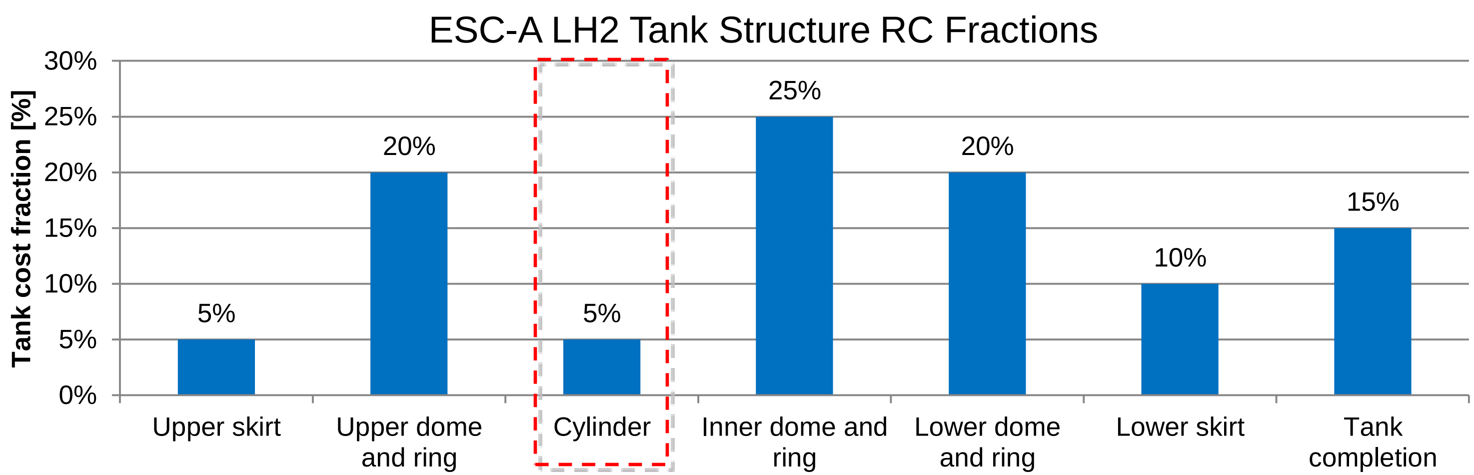
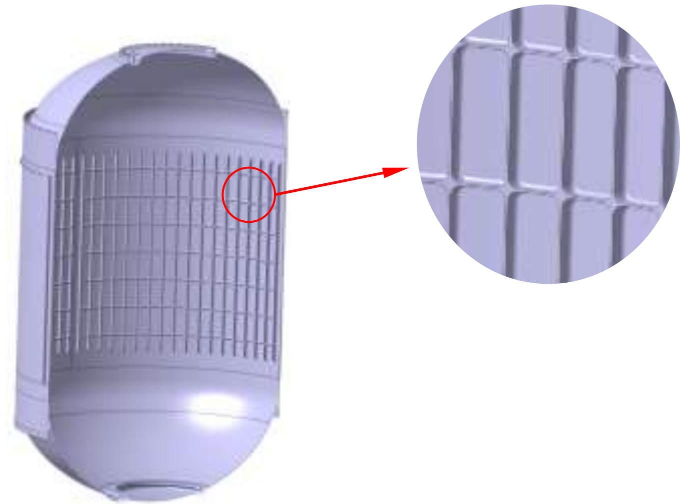
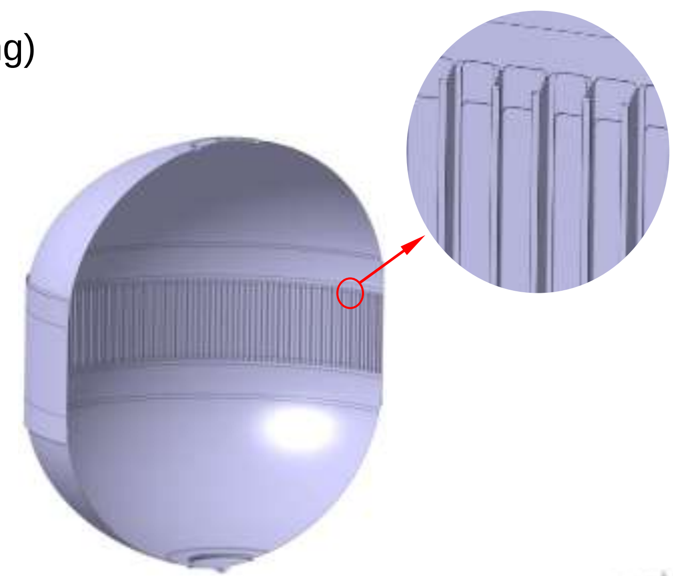




Analysis Method

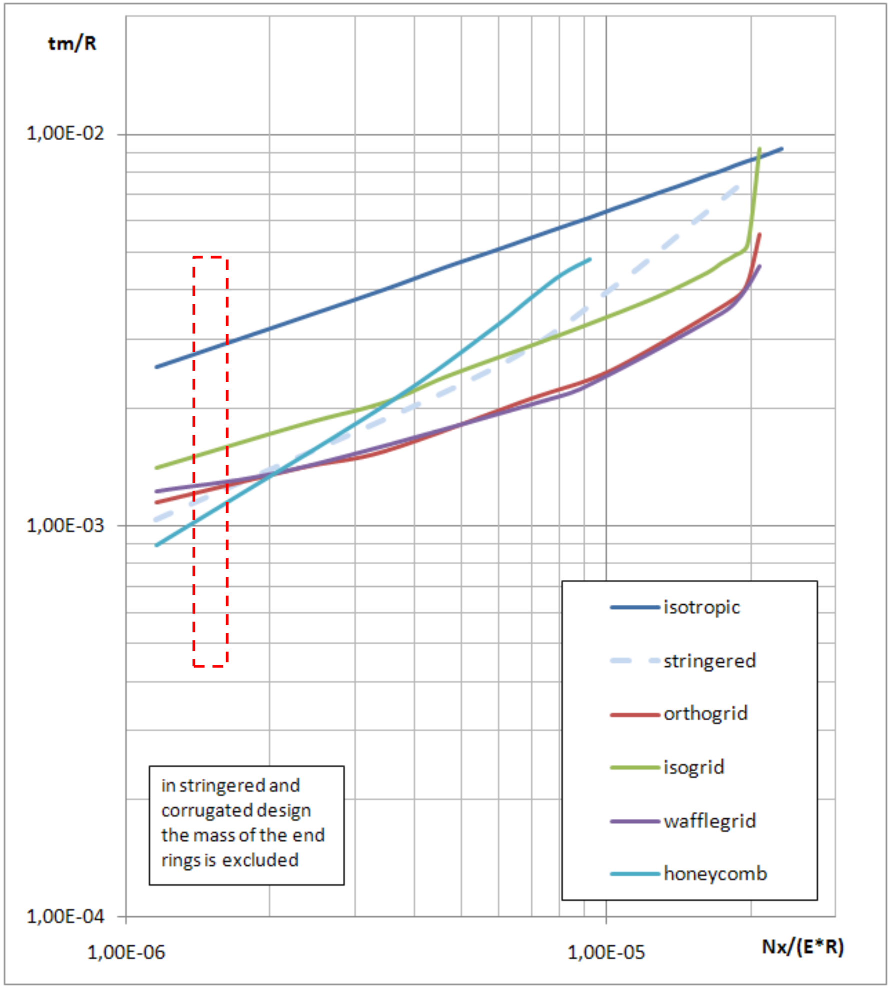
- A methodology for the design investigations is derived
- Chose stiffening options (Phase I)
  - Analytic analysis of chosen options
    - Global and Local buckling
  - Define initial design
    - Initial stiffening designs
    - Preliminary optimisation (Analytical methods)
  - Identification of best design choices
- Optimisation of design OptiStruct (Phase II)
    - FEM based optimisation Methods
  - Optimisation of design HyperStudy/ASTRA (Global, Local buckling)
    - Local criteria
    - Stringer Shape
    - KDF
    - Number of Stringers
- Verification based on HyperMesh FEM analysis (Phase III)





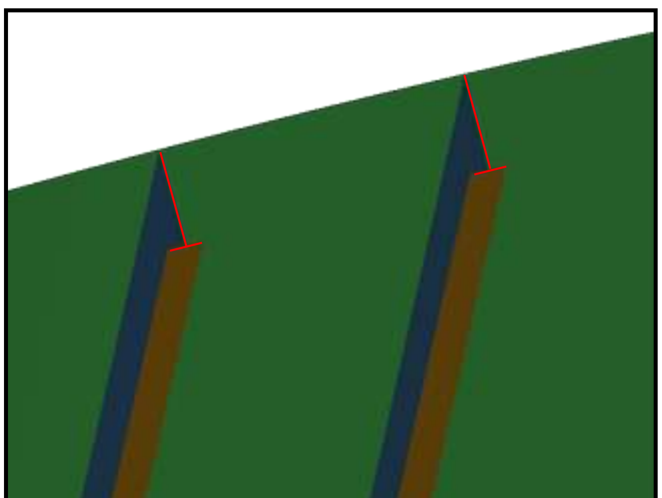
Chose stiffening options (Phase I)

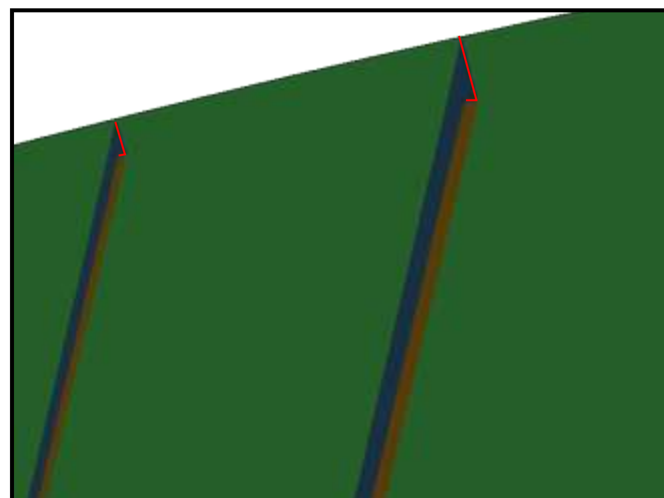
- As an example for a typical design trade off during early design phases the cylindrical components are investigated
  - Different stiffening concepts are taken into considerations
    - Isotropic
    - Orthogrid/ Waffel Grid
    - Isogrid
    - Sandwich
    - Stringer & Ring stiffeners (high nr. of parameters)
- Analytic analysis of different stiffening concepts
  - Buckling global / local criterias [R1]
    - Local buckling [R1-R3]
    - Plastic correction (Neuber) [R1]
    - KDF Assessment [R1-R3]
    - Global buckling [R1-R3]
  - Manufacturing aspects
    - Limitations due to raw material
  - The most promising candidates are chosen
    - Stringer stiffened
    - Orthogrid



Optimisation of design OptiStruct (Phase II)

- Optimisation of stringer shape
  - Objective : Minimise Mass
  - Constrain : $\lambda_{FEM} > \lambda_{min}$ / KDF
- Optimisation by shape and size variables to represent:
  - Amount of stringers acc. to initial design
  - Simple flange profile
  - I-Profile
  - T-Profile
  - Z-Profile
- OptiStruct clearly chooses Z-Profiles as most efficient



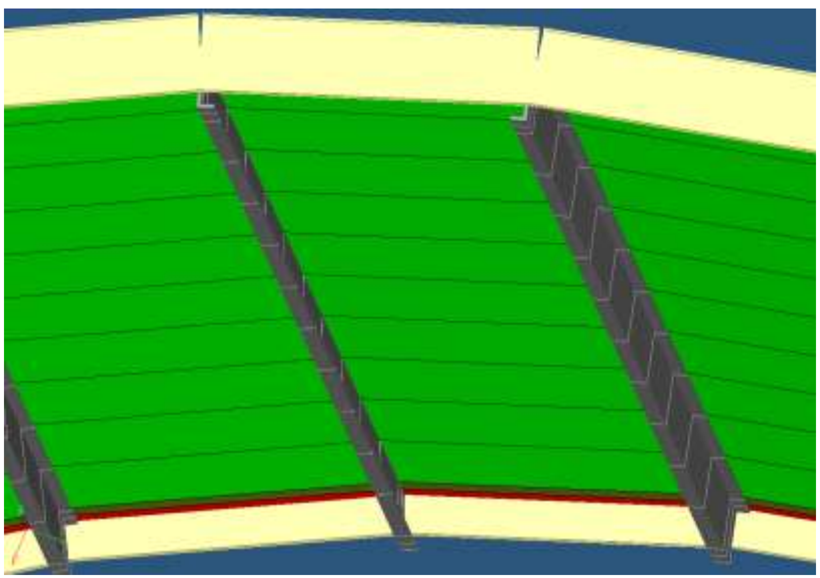


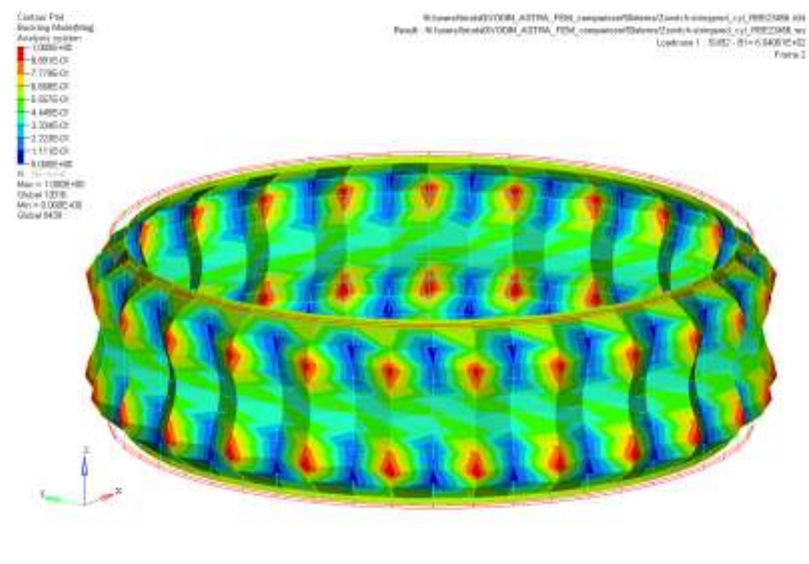
Optimisation of design HyperStudy/ASTRA

- Optimisation of buckling modes based on HyperStudy/ASTRA (Phase II)
- ASTRA
  - Free available program code
  - Good agreement between FEM based linear buckling analysis and ASTRA
  - ASTRA utilizes an ASCII input/output deck
  - Short analysis time (30 sec- 1min)
  - Only global modes can be reflected
- HyperStudy
  - Z-Profile dimensions as **parameter:**
    - Web-/Flange thickness
    - Web- /Flange High
    - Pos. Of CoG
  - **Objective :** minimise Mass (Output ASTRA)
  - **Constrain (Global):** $\lambda_{ASTRA} > \lambda_{min}$ / KDF (Output ASTRA)
  - **Constrain (Local):** Analytical implementation to HyperStudy
    - Stringer crippling
    - Local stringer buckling
    - Skin buckling
  - **Constrain (Local):** Stress in Stringers< R_{p02}
  - **Constrain Manufacturing limitations**
    - Max. raw part thickness→ max. Stringer dimensions
    - Min. wall thickness due to manufacturing process

Verification based on HyperMesh FEM analysis (Phase III)

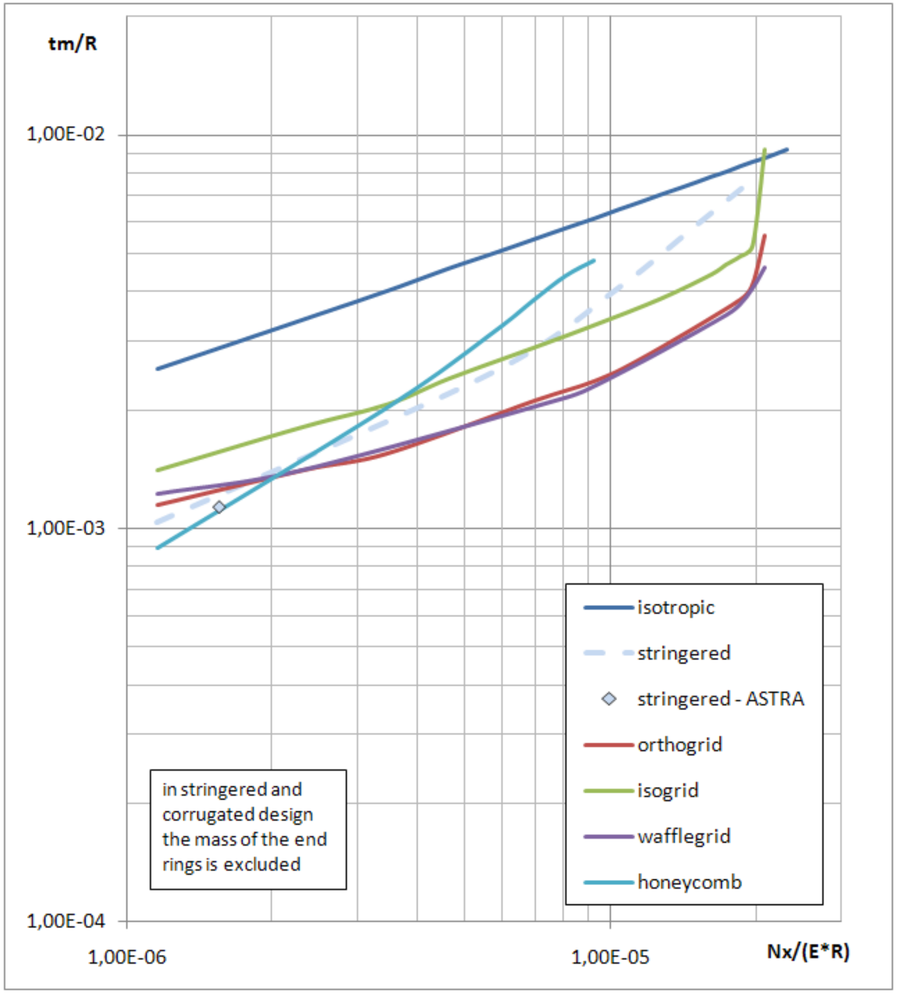
- Verification based on HyperMesh FEM analysis (Phase III)
  - A linear buckling analysis is performed via HyperMesh
  - Stringers and rings are represented by bar elements to avoid local buckling modes
  - A coarse mesh for the cylindrical shell is chosen to avoid local Skin buckling modes





Result and Discussion

- Verification based on HyperMesh FEM analysis (Phase III)
  - Global criteria by linear FEM and KDF approach
  - Analytical approach for KDF acc. to [R1]
  - Local criteria acc. to [R1]
- Mass reduction compared to isotropic design (no Inner Pressure considered)
  - <50% remaining mass
- Mass reduction compared to preliminary optimized design
  - 16%
- All constraints are met (all MoS positive)



Summary

- A method for a optimisation strategy for stringer stiffened cylinder designs is presented
  - Identification of design options based on analytical relationships
  - A preferred shape of stringer is identified (Z-Shape)
    - Generally the Z-Shaped stringer design is very efficient
    - The Z-Shape leads to reduced stringer high→ dimensions of the raw material
  - Optimisation with seven variables is performed
    - 5 Variables to describe the stringer profile
    - 1 Variable for the shell thickness
    - <u>1 Variable for the amount of stringers</u>
  - A linear buckling analysis is performed via HyperMesh
  - Analytical approach for KDF acc. to [R1]
  - Local criteria acc. to [R1]
- Mass reduction compared to isotropic design (no Inner Pressure considered)
  - >50%
- Mass reduction compared to preliminary optimised design
  - 16%

Significance of WORK

- Significance of the performed work
  - Even during early design phases optimisation tools in combination with quick responding analytic solver software provide optimised design choices
  - Basing on these results further FEM analysis can be “speedup” as the number of time consuming redesign loops can be reduced
  - Due to reasonable close agreement of HyperStudy/ASTRA investigations compared to FEM the level of reliability of pre-dimensioning phases is increased
  - HyperStudy/ASTRA analysis time (exemplarily for Stringer stiffened structure)
    - 1/2 Day setup of an sufficient ASTRA input deck
    - 1 Day implementation of local criteria in HyperStudy
    - 1/2 Day calculation time (genetic algorithm 7 variables, 4 constrains)

References

	Reference	Issue	Rev.	Title
R1	Space Engineering- Buckling of Structures	10.03.2009	-	ECSS-E-HB-32-24
R2	NASA SP 8007	08.68	-	Buckling of Thin-Walled Circular Cylinders
R3	Isogrid Design Handbook	1973	A	NASA CR-124075 1973