

# Project “Computer Experiments”

Fallstudien II / Case Studies II

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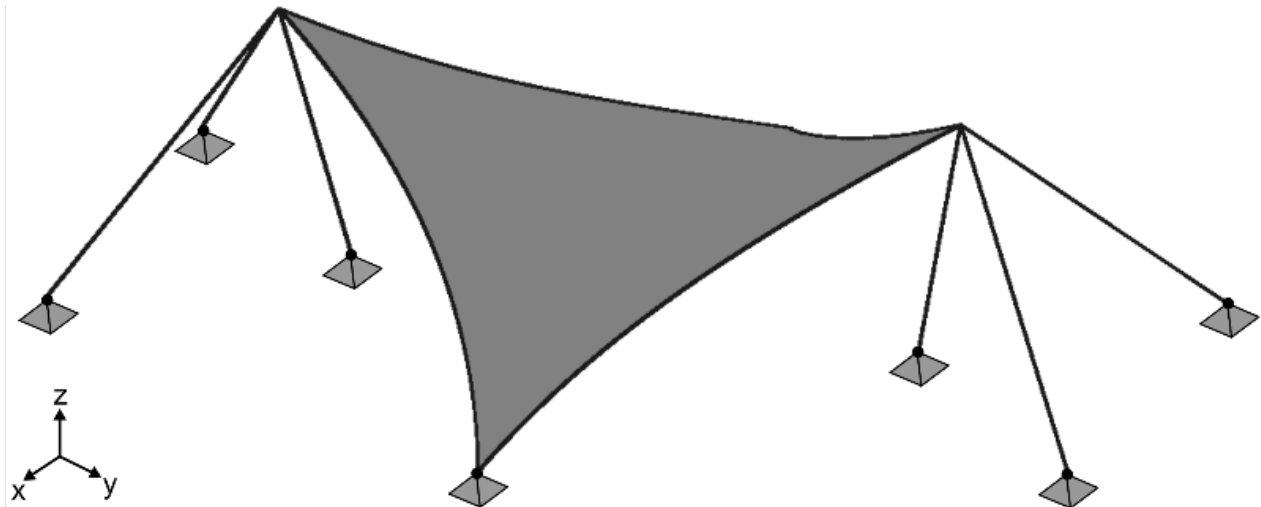
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## Computer Model: Sun Sail

- Structure parts of the sun sail: membrane, truss, edge and support cables
- Membrane structure with hyperbolic paraboloid shape
- Base area of membrane is  $6\text{ m} \times 6\text{ m}$  and a height of  $3\text{ m}$
- Structure is supported by elastic trusses, which are braced by pre-stressed cables

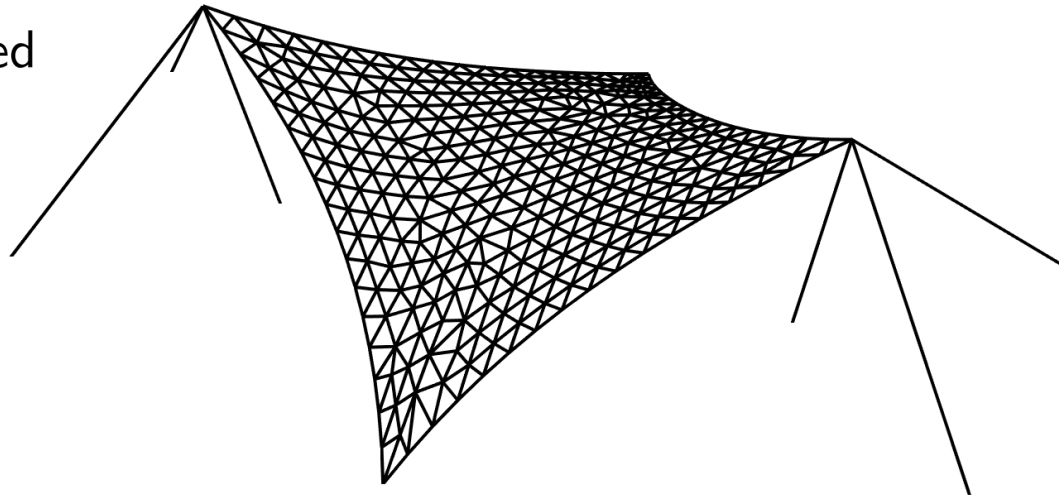


## Computer Model: Sun Sail

- Assume an isotropic pre-stress  $\sigma_{\text{mem}}$  for the membrane
- Edge and support cables are pre-tensioned by  $\sigma_{\text{edg}}$  and  $\sigma_{\text{sup}}$
- Membrane is modeled with a linear elastic, isotropic material law defined by Young's modulus  $E_{\text{mem}}$  and Poisson's ratio  $\nu_{\text{mem}}$
- Winkling deformation due to tension loss is taken into account
- Sun sail is subjected to a snow load  $f_{\text{mem}}$
- Model response: Maximal Cauchy stress in the membrane  $\sigma_{\text{mem}, \text{max}}$
- Structure fails when the maximum stress in the membrane  $\sigma_{\text{mem}, \text{max}}$  exceeds the rupture stress  $\sigma_{\text{mem}, y}$

## Computer Model: Sun Sail

- Pre-stressed membrane structure is represented by a finite element model
- Finite element mesh with 690 elements
- Structural analysis is performed with the open-source multi-physics software Kratos<sup>1,2</sup>
- Computer model depends on a set of (uncertain) material parameters



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<sup>1</sup>Dadvand, P., Rossi, R., Oñate, E. (2010). An Object-oriented Environment for Developing Finite Element Codes for Multi-disciplinary Applications. *Archives of Computational Methods in Engineering*, **17**(3):253–297. <https://doi.org/10.1007/s11831-010-9045-2>.

<sup>2</sup>Ferrándiz, V. M., Bucher, P., Zorrilla, R., et al. (2023). *KratosMultiphysics/Kratos: Release 9.3*. <https://doi.org/10.5281/zenodo.7681287>.

## Model Input Parameters

$\sigma_{\text{mem,max}}$  : Maximal Cauchy stress

Part	Quantity	Symbol	Unit	Distrib.	Mean	Std.
Membrane	Young's modulus	$E_{\text{mem}}$	[GPa]	Lognormal	0.6	0.09
	Poisson's ratio	$\nu_{\text{mem}}$		Uniform	0.4	0.0115
	thickness	$t_{\text{mem}}$	[mm]	Deterministic	1	
	pre-stress	$\sigma_{\text{mem}}$	[MPa]	Lognormal	4	0.8
	surface loading	$f_{\text{mem}}$	[kPa]	Gumbel	0.4	0.12
	rupture stress <sup>1</sup>	$\sigma_{\text{mem,y}}$	[MPa]	Lognormal	11	1.650
Truss	Young's modulus	$E_{\text{tru}}$	[GPa]	Deterministic	205	
	cross sectional area	$A_{\text{tru}}$	[cm <sup>2</sup> ]	Deterministic	25	
Edge cable	Young's modulus	$E_{\text{edg}}$	[GPa]	Deterministic	205	
	diameter	$d_{\text{edg}}$	[mm]	Deterministic	12	
	pre-stress	$\sigma_{\text{edg}}$	[MPa]	Lognormal	353.678	70.735
Support cable	Young's modulus	$E_{\text{sup}}$	[GPa]	Deterministic	205	
	diameter	$d_{\text{sup}}$	[mm]	Deterministic	12	
	pre-stress	$\sigma_{\text{sup}}$	[MPa]	Lognormal	400.834	80.166

<sup>1</sup> No parameter of the structural analysis model.

## Finite Element Methode

1. Definition of continuous governing equations (usually partial differential equations) and boundary conditions
2. Discretisation of the entire domain into a finite number of small elements connected by nodes
3. Reformulating the original differential equations in a “weak form” for each element
4. Assemble equations from all elements into a global system of equations that represents the entire domain and apply boundary conditions
5. Solve the large global system of linear equations

## Surrogate Model

- Computationally expensive deterministic model not sustainable
- Surrogate model: Approximate time-consuming computer model by a computationally cheaper model

*What is a suitable choice for a surrogate model?*

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- Computer model runs are required to train a surrogate model

## Design of Computer Experiments

*How to select “optimal” design points for evaluating the computer model?*

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*How to select “optimal” design points for evaluating the computer model?*

- Simplifying assumptions:
  - Homogeneously distributed material parameters across the membrane
  - Stochastically independenten material parameters
- Limited budget for computer model runs  $n_{\max} \leq 200$

## Analysis of Computer Experiments

*What could be possible research questions?*

⇒  $\tau_{\text{mem, max}} \mid \text{parameters}$