OFFSHORE WIND R&D Conference 2018

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Optmization of Jacket Substructures Considering Detailed Cost and Load Assumptions

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Content

- Motivation
- Optimization problem
- Cost function
- Constraints
- Results
- Conclusion

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Jackets are appropriate substructures for intermediate water depths and/or turbines with high rated power

But: Costs are still high

Smarter designs are a key to cheaper structures!

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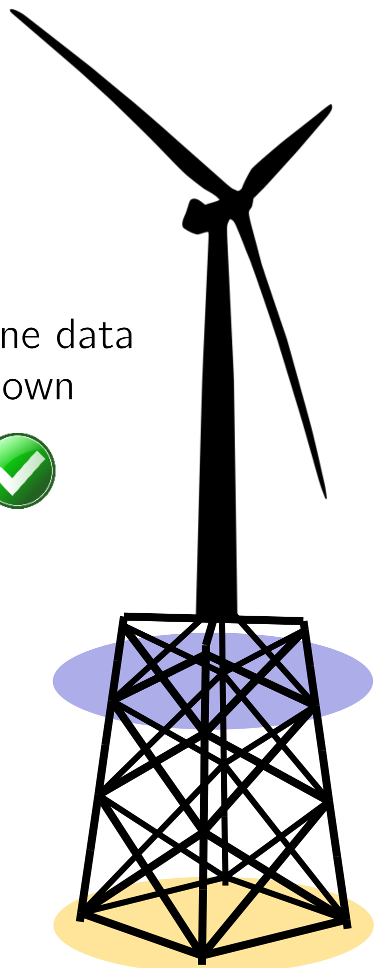
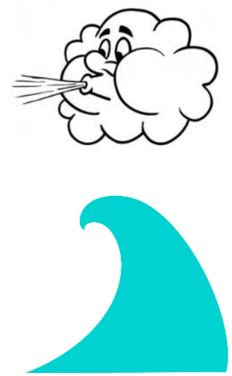
Motivation

Turbine data known





Loads and environmental conditions known

Site known

Jacket design

Ideal jacket design by optimization

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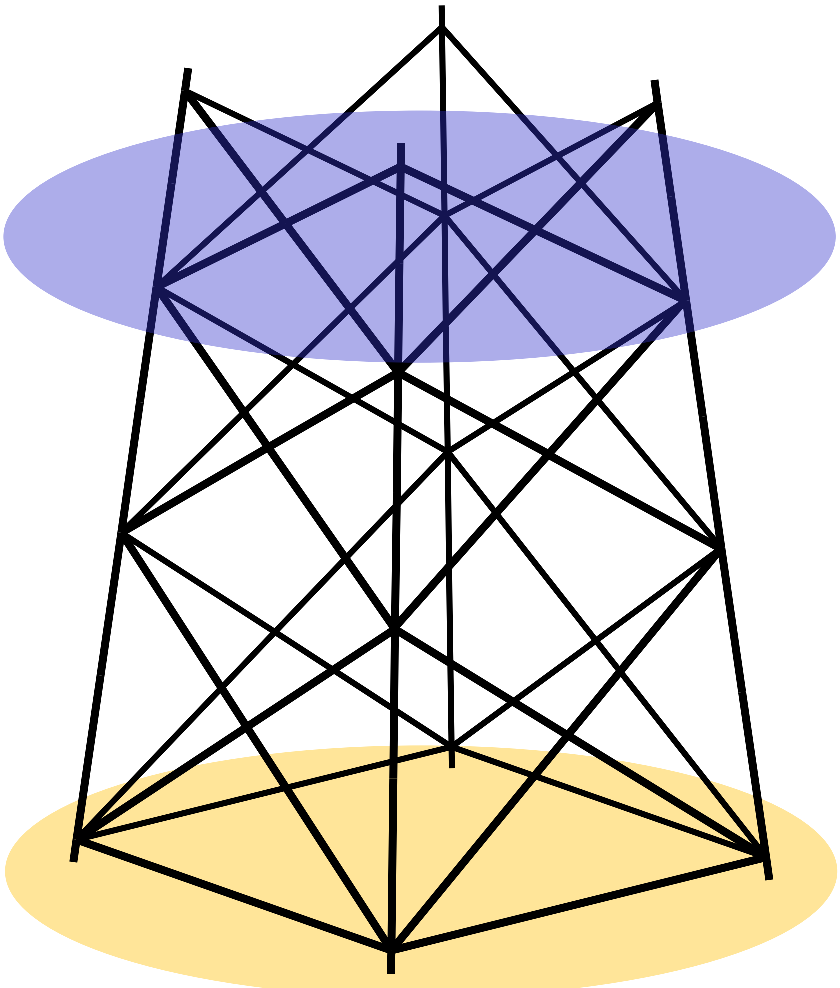
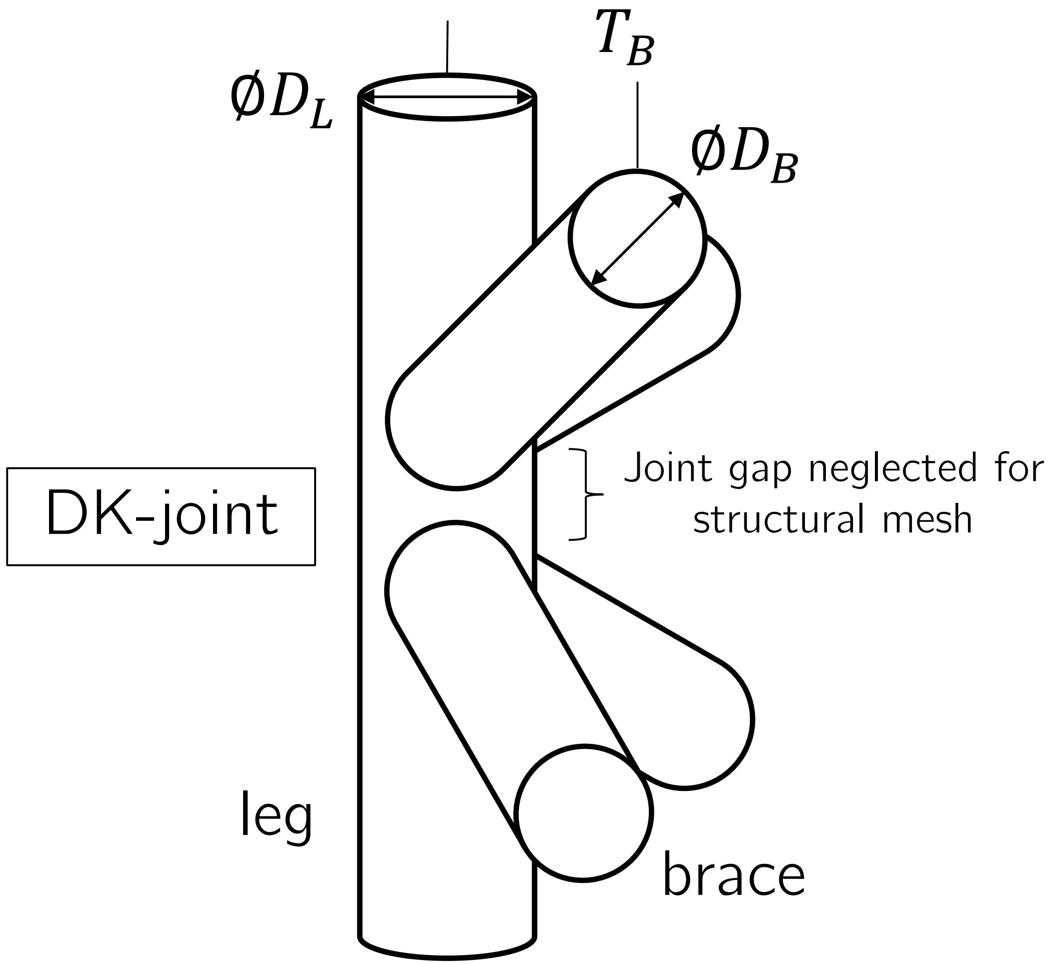
Optimization problem



Jacket topology parameters	
N_L	Number of legs
N_X	Number of bays
R_{foot}	Foot radius
ξ	Head radius / foot radius
L	Total jacket length
L_{OSG}	Distance ground – first layer
L_{MSL}	Distance MSL – TP
L_{TP}	Distance TP – last layer
q	Segment ratio
x_{MB}	Mud brace flag (Boolean)

Optimization problem



$$\beta = \frac{D_B}{D_L} \qquad \beta_b = \frac{D_{Bb}}{D_L} \qquad \beta_t = \frac{D_{Bt}}{D_L}$$

$$\gamma = \frac{D_L}{2T_L} \qquad \gamma_b = \frac{D_L}{2T_{Lb}} \qquad \gamma_t = \frac{D_L}{2T_{Lt}}$$

$$\tau = \frac{T_B}{T_L} \qquad \tau_b = \frac{T_{Bb}}{T_{Lb}} \qquad \tau_t = \frac{T_{Bt}}{T_{Lt}}$$

(according to DNV GL RP-C203)

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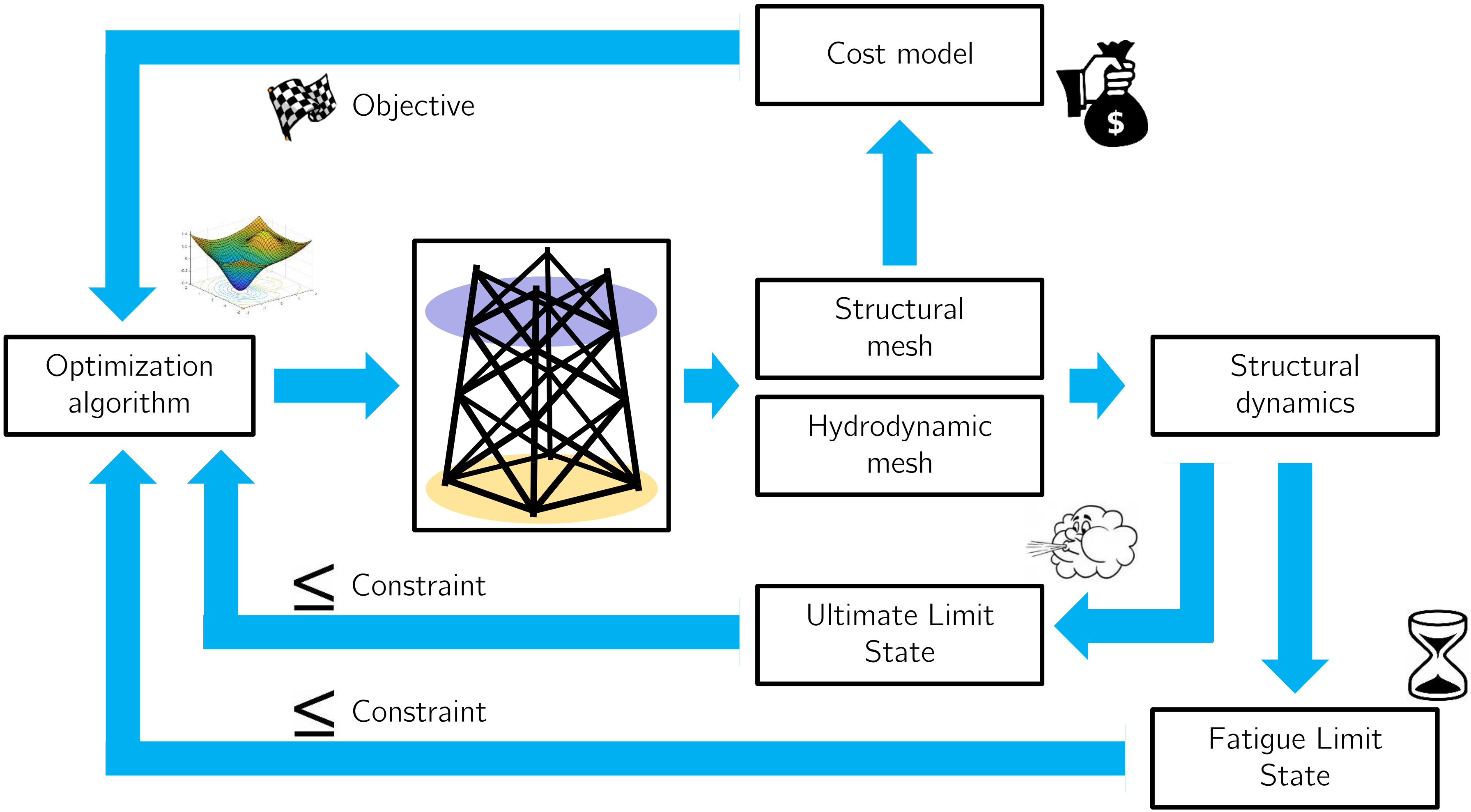
Optimization problem

	Topology parameters		Geometry and material parameters
⚠ N_L	Number of legs (discrete)	D_L	Leg diameter
⚠ N_X	Number of bays (discrete)	β_b	D_{Bb}/D_L
R_{foot}	Foot radius	β_t	D_{Bt}/D_L
ξ	Head radius / foot radius	γ_b	$D_L/2T_{Lb}$
L	Total jacket length	γ_t	$D_L/2T_{Lt}$
L_{OSG}	Distance ground – first layer	τ_b	T_{Bb}/T_L
L_{MSL}	Distance MSL – TP	τ_t	T_{Bt}/T_L
L_{TP}	Distance TP – last layer	E	Material Young's modulus
q	Segment ratio	G	Material shear modulus
⚠ x_{MB}	Mud brace flag (Boolean)	ρ	Material density

Optimization problem



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Cost function

CAPEX =

	$1.0\ \mathrm{kg}^{-1}$	$\times$	Structural mass [kg]	(Material costs)
+	$4.0 \times 10^{6}\ \mathrm{m}^{-3}$	$\times$	Weld volume $\left[\mathrm{m}^3\right]$	(Fabrication costs)
+	$100.0\ \mathrm{m}^{-2}$	$\times$	Outer surface area $\left[\mathrm{m}^2\right]$	(Coating costs)
+	$2.0 \times 10^{4}\ \mathrm{m}^{-1}$	$\times$	Head radius [m]	(TP costs)
+	2.0×10^{5}	$\times$	Number of legs [–]	(Transport costs)
+	$2.0\ \mathrm{kg}^{-1}$	$\times$	Structural mass [kg]	(Installation costs)
+	2.0×10^{5}			(Fixed costs)

(valid for 5 MW scale and concept without prefabricated joints, unquantifiable impacts, especially on T&I costs, neglected)

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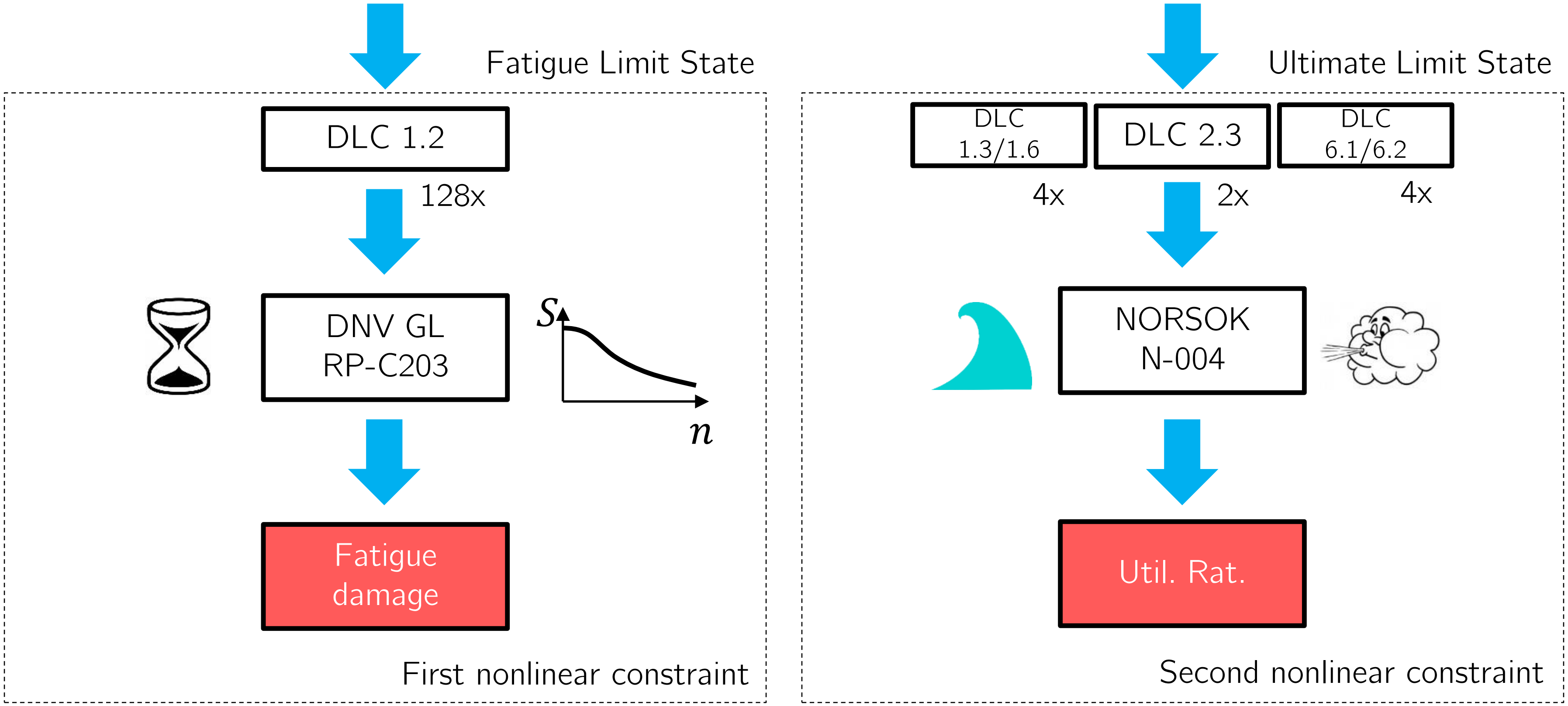
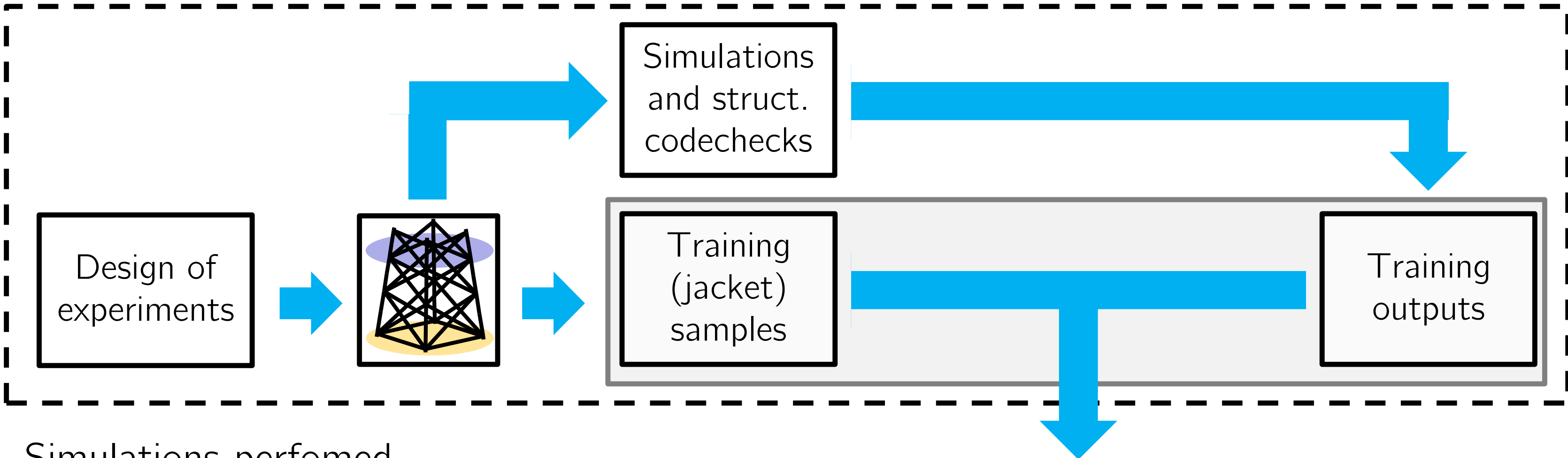
Jacket design variables	N_L	N_X	R_{foot}	ξ	L	L_{OSG}	L_{MSL}	L_{TP}	q	x_{MB}
	D_L	β_b	β_t	γ_b	γ_t	τ_b	τ_t	E	G	ρ



Constraints



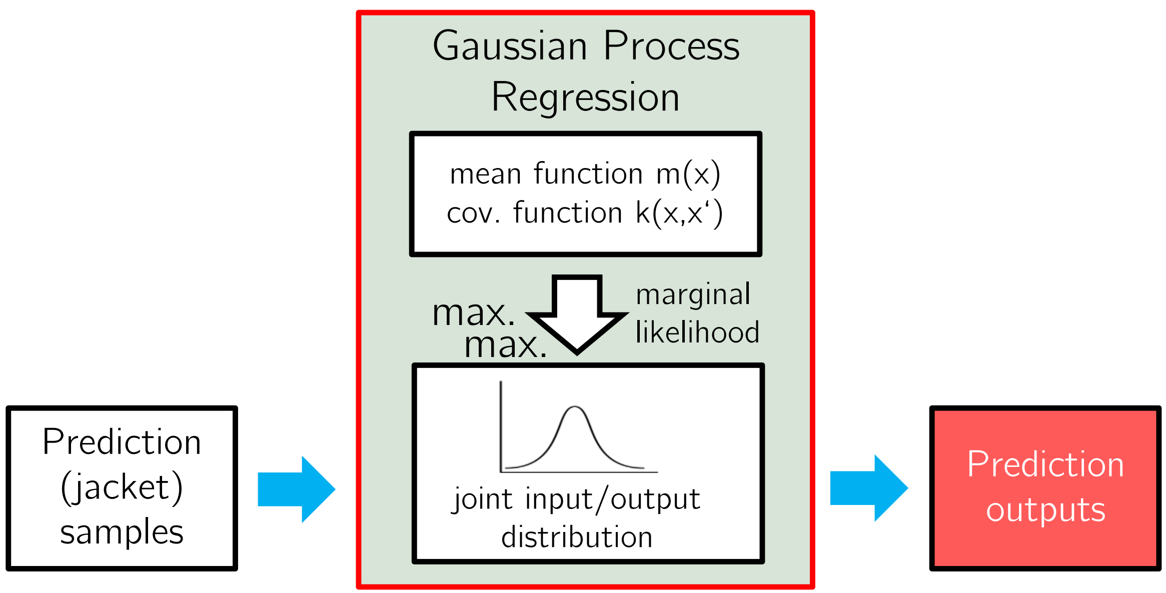
Simulations perfomed on high-performance compute cluster with FAST v8

Number of simulations:

FLS: 240 x 128 = 30.720

ULS: 240 x 10 = 2.400

33.120



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Results

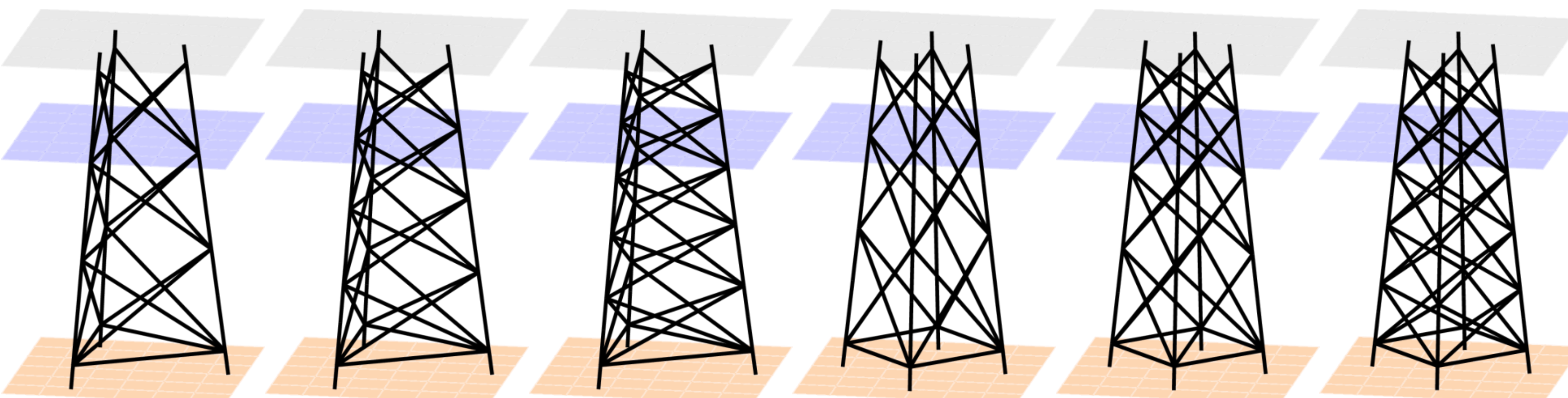
Setup

- NREL 5MW reference turbine
- FINO3 environmental data
- 50m water depth
- OC3 soil conditions
- continuous design variables -/+ 20% w.r.t OC4 jacket
- all time domain simulations performed with FAST v8
- Matern 5/2 kernel for GPR (surrogate models)

Problem is solved using

- two different gradient-based optimization algorithms (sequential quadratic programming/interior-point methods)
- gradients obtained by finite differences
- 100 random starting points
- fixed discrete design variables to avoid a mixed-integer problem (six sub-problems)

Cost and mass comparison

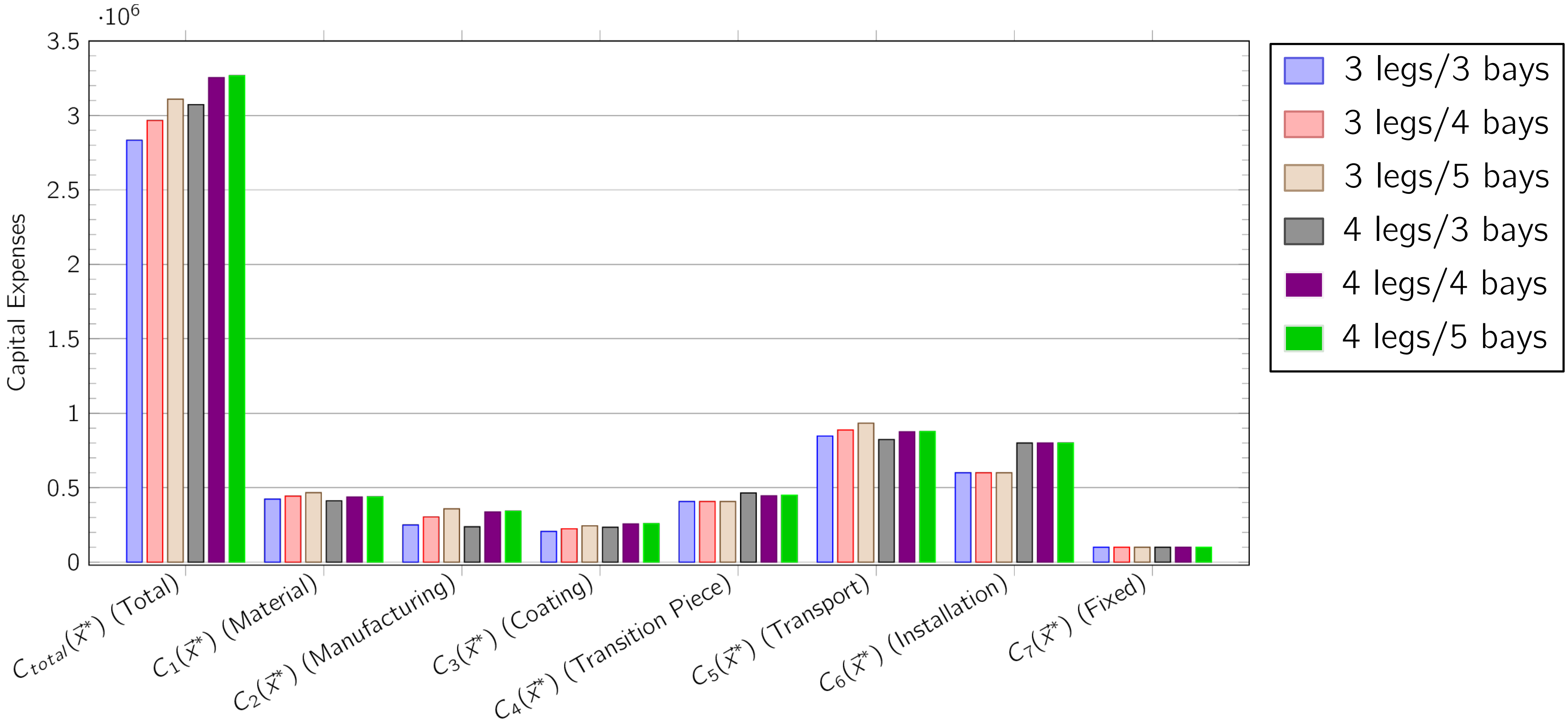


3 legs 3 bays	3 legs 4 bays	3 legs 5 bays	4 legs 3 bays	4 legs 4 bays	4 legs 5 bays
2 831 000	2 965 000 +4,7%	3 112 000 +9,9%	3 069 000 +8,4%	3 162 000 +11,7%	3 266 000 +15,4%
423t +2,7%	444t +7,8%	467t +13,3%	412t	438t +6,3%	439t +6,5%

Optimal design variables

N_L	3	3	3	4	4	4
N_X	3	4	5	3	3	3
R_{foot} in m	12.735	12.735	12.735	10.894	10.459	10.549
ξ	0.533	0.533	0.533	0.533	0.533	0.533
q	0.937	0.941	0.936	0.813	0.809	0.977
D_L in m	1.021	1.021	1.023	0.960	0.960	0.960
β_b	0.800	0.800	0.800	0.800	0.799	0.787
β_t	0.800	0.800	0.800	0.800	0.800	0.800
γ_b	12.000	12.000	12.000	12.680	12.259	12.000
γ_t	16.165	16.029	15.928	18.000	18.000	18.000
τ_b	0.513	0.505	0.493	0.497	0.493	0.478
τ_t	0.472	0.466	0.454	0.383	0.387	0.383

Cost breakdowns



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Conclusion

Approach

- Improvement of state of the art in multiple ways
- Intended for conceptual and pre-design studies
- Numerically efficient by surrogate modeling
- To be combined with tube sizing approaches

Results

- Three-legged jackets seem to be slightly advantegous compared to four-legged ones from an economical point of view
- Light jackets are not necessarily cheap jackets
- Transport and installation costs may drive the design of jackets significantly

INSTITUT FÜR STATIK
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Thank you for your attention!

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