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Partitioned Solution Strategies for Strongly-Coupled Fluid-Structure Interaction Problems in Maritime Applications

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Partitioned Solution Strategies for Strongly-Coupled Fluid-Structure Interaction Problems in Maritime Applications

Vom Promotionsausschuss der Technischen Universität Hamburg zur Erlangung des akademischen Grades Doktor-Ingenieur (Dr.-Ing.)

genehmigte Dissertation

von Marcel König, M.Sc.

> aus Pinneberg

> > 2018

Vorsitzender des Prüfungsausschusses

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Tag der mündlichen Prüfung: 6. Juli 2018

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König, Marcel Partitioned Solution Strategies for Strongly-Coupled Fluid-Structure Interaction Problems in Maritime Applications

Fortschr.-Ber. VDI Reihe 18 Nr. 351. Düsseldorf: VDI Verlag 2018. 278 Seiten, 130 Bilder, 21 Tabellen. ISBN 978-3-18-335118-3, ISSN 0178-9457, € 95,00/VDI-Mitgliederpreis € 85,50.

Keywords: Multifield Problems – Fluid-Structure Interaction – Partitioned Solution Approach – Maritime Applications – Floating Offshore Wind Turbines – Landing Maneuver of Crew Transfer Vessels to Offshore Structures

Many engineering applications are governed by coupled multifield phenomena. In this thesis, a partitioned solution approach is followed to solve these kind of problems, which does not only enable the use of different discretization schemes for each of the subproblems but also allows to reuse specialized and efficient solvers, which enhances modularity, software reusability, and performance. A framework for the partitioned analysis of general multifield problems is proposed and implemented in the generic software library comana, which is verified against various benchmark problems and successfully applied to sophisticated fluid-structure interaction problems from the maritime industry.

Bibliographische Information der Deutschen Bibliothek

Die Deutsche Bibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliographie; detaillierte bibliographische Daten sind im Internet unter <u>www.dnb.de</u> abrufbar.

Bibliographic information published by the Deutsche Bibliothek

(German National Library)

The Deutsche Bibliothek lists this publication in the Deutsche Nationalbibliographie (German National Bibliography); detailed bibliographic data is available via Internet at <u>www.dnb.de.</u>

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Als Manuskript gedruckt, Printed in Germany. ISSN 0178-9457 ISBN 978-3-18-335118-3

> https://doi.org/10.51202/9783186351180-I Generiert durch IP '18.222.95.7', am 11.05.2024, 16:14:13. Das Erstellen und Weitergeben von Kopien dieses PDFs ist nicht zulässig.

Acknowledgements

The present thesis has emerged from the joint program Maritime safety aspects regarding installation and maintenance of offshore wind turbines, funded by the Hamburg Research and Science Foundation, and the research project Fluid-structure interaction and optimization of floating platforms for offshore wind turbines, financed by the Federal Ministry for Economic Affairs and Energy, which I conducted at the Institute for Ship Structural Design and Analysis at Hamburg University of Technology from July 2013 to June 2017. Many great people have contributed to my work and I would like to say "thank you" to those without whom this thesis would not have been possible.

First and foremost, I would like to express my gratitude to Prof. Dr.-Ing. habil. Alexander Düster for the supervision of my PhD thesis. His broad expertise, his helpfulness, and our fruitful discussions guided me through my time at university during the past years. I would also like to thank Prof. Dr.-Ing. Moustafa Abdel-Maksoud for acting as a cosupervisor for this thesis.

Moreover, I am much obliged to the *Hamburg Research and Science Foundation* and the *Federal Ministry for Economic Affairs and Energy* for providing the necessary funding for the projects I have been working on and for sharpening the scope of my research.

I also owe credits to my colleagues at the Institute of Ship Structural Design and Analysis who have always been an inspiration for my work and who made my four years at the institute a pleasure. In particular, I would like to thank my colleague Lars Radtke for our lively discussions, his constant helpfulness, and his willingness to share his knowledge.

Last but not least, I am indebted to my wonderful wife Marieke, and I would like to express my deepest thanks to her – for her endless support, her patience, and her love.

https://doi.org/10.51202/9783186351180-I Generiert durch IP '18.222.95.7', am 11.05.2024, 16:14:13. Das Erstellen und Weitergeben von Kopien dieses PDFs ist nicht zulässig

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List of Acronyms

AAA	Almost always use auto
AABB	Axis-aligned bounding box
ALE	Arbitrary Lagrangian-Eulerian
APDL	ANSYS parametric design language
API	Application programming interface
BEM	Boundary element method
BMWi	Bundesministerium für Wirtschaft und Energie (Federal Ministry for
	Economic Affairs and Energy)
\mathbf{CFD}	Computational fluid dynamics
COG	Center of gravity
CPU	Central processing unit
\mathbf{FE}	Finite element
FEM	Finite element method
FSI	Fluid-structure interaction
\mathbf{FV}	Finite volume
\mathbf{FVM}	Finite volume method
HF	High frequency
HyStOH	Hydrodynamische und strukturmechanische Optimierung eines
	Halbtauchers für Offshore-Windenergieanlagen (Hydrodynamic and
	structural optimization of a floating platform for offshore wind turbines)
JONSWAP	Joint North Sea Wave Project
\mathbf{LF}	Low frequency
MPI	Message passing interface
MVP	Most vexing parse
ODR	One definition rule
OWT	Offshore wind turbine
\mathbf{pImpl}	Pointer to implementation
POD	Plain old data
RAII	Resource acquisition is initialization
RANS	Reynolds-averaged Navier-Stokes
RAO	Response amplitude operator
\mathbf{RBF}	Radial basis function
RVO	Return value optimization
SFINAE	Substitution failure is not an error
VOF	Volume of fluid

List of Symbols

Nomenclature

In this thesis, the following notation for the distinction of scalars, vectors, tensors, and matrices is introduced. Scalars *s* are denoted in italic font. Vectors *v* from the Euclidean space as well as second-order tensors *T* defined as linear maps between vector spaces are typeset in bold italic font. Bold calligraphic symbols are used to represent tensors *C* of order higher than two. While "short" local discrete vectors *v* and matrices *M* are typeset in bold italic font, "long" global discrete vectors *v* and matrices *M* are denoted by an upright bold symbol.

Symbol	Description
$\operatorname{card}(\mathcal{S})$	Cardinality of the set \mathcal{S}
${oldsymbol{\Phi}}\circ{oldsymbol{\Psi}}$	Composition of the transformations ${oldsymbol \Phi}$ and ${oldsymbol \Psi}$
${oldsymbol{\varPhi}}^{-1}$	Inverse of the transformation $\boldsymbol{\Phi}$
δu	Variation of u
Δu	Increment of u
u_0	Initial value of u
$u_{\rm ref}$	Reference value of u
$u _{x=x^{*}}$	u evaluated at $x = x^*$
\bar{u}	Prescribed value of u (Chapter 2, 3)
	Mean value of u (Chapter 4, 6)
$oldsymbol{u}^{\mathrm{T}}$	Transpose of the vector or tensor \boldsymbol{u}
\mathbf{v}^{-1}	$:= \mathbf{v} / \ \mathbf{v}\ _2^2$, Moore-Penrose inverse of the vector \mathbf{v}
$\mathrm{D}u\cdotoldsymbol{v}$	Directional derivative of u in the direction of the vector \boldsymbol{v}
$\partial u / \partial x$	Partial derivative of u with respect to x
$\partial u / \partial t _{\mathbf{X}}$	Derivative of u with respect to time $t,$ with the material coordinate \boldsymbol{X} held
	fixed
$\partial u/\partial t _{\chi}$	Derivative of u with respect to time $t,$ with the referential coordinate $\pmb{\chi}$ held
	fixed
$\mathrm{D}u/\mathrm{D}t$	$:= \partial u / \partial t _{\mathbf{X}}$, material derivative of u
\dot{u}	$:= \mathrm{D}u/\mathrm{D}t$
ü	$:= \mathrm{D}^2 u / \mathrm{D} t^2$
$\operatorname{grad} s$	$:= \sum_{i=1}^{d} \partial s / \partial x_i \boldsymbol{e}_i$, gradient of the scalar s
$\operatorname{Grad} s$:= $\operatorname{grad}_{\boldsymbol{X}} s$, gradient of the scalar s in the reference configuration
$\operatorname{grad} \boldsymbol{v}$	$:= \sum_{i,j=1}^{d} \partial v_j / \partial x_i \boldsymbol{e}_i \otimes \boldsymbol{e}_j$, gradient of the vector \boldsymbol{v}
$\operatorname{Grad} \boldsymbol{v}$:= $\operatorname{grad}_X v$, gradient of the vector v in the reference configuration
$\operatorname{curl} oldsymbol{v}$	$:= \boldsymbol{e}_1(\partial v_3/\partial x_2 - \partial v_2/\partial x_3) + \boldsymbol{e}_2(\partial v_1/\partial x_3 - \partial v_3/\partial x_1) + \boldsymbol{e}_3(\partial v_2/\partial x_1 - \partial v_1/\partial x_2),$
	curl of the vector \boldsymbol{v}
$\operatorname{div} \boldsymbol{v}$	$:=\sum_{i=1}^{d} \partial v_i / \partial x_i$, divergence of the vector \boldsymbol{v}
$\operatorname{Div} \boldsymbol{v}$:= $\operatorname{div}_{\boldsymbol{X}} \boldsymbol{v},$ divergence of the vector \boldsymbol{v} in the reference configuration

$\operatorname{div} T$	$:= \sum_{i,j=1}^{a} \partial T_{ij} / \partial x_i e_j$, divergence of the tensor T
$\operatorname{Div} \boldsymbol{T}$	$:= \operatorname{div}_{\boldsymbol{X}} \boldsymbol{T}$, divergence of the tensor \boldsymbol{T} in the reference configuration
Δs	:= div grad s, Laplacian of the scalar s
$oldsymbol{u}\cdotoldsymbol{v}$	$:=\sum_{i=1}^{d} u_i v_i$, scalar product of the vectors \boldsymbol{u} and \boldsymbol{v}
$m{S}\cdotm{T}$	$:= \sum_{i=1}^{d} S_{ii}T_{ii}$, scalar product of the second-order tensors S and T
$\boldsymbol{v}\cdot \boldsymbol{T}$	$= \sum_{i=1}^{d} v_i T_{ii} e_i$, dot product of the vector \boldsymbol{v} and the second-order tensor \boldsymbol{S}
T_{ii}	$\Sigma_{i,j=1}^{d}$, $T_{i,j}$, $r_{i,j}$, $r_{$
$1 \circ$	$\sum_{i,j=1}^{n} i_{ij} j_{j} j_{i}$, and product of the second of derivers \mathcal{D} and the vector \mathcal{D} $= u u^{T}$ dvadic product of the vectors u and u
a o u	$= \mathbf{x}^d$, dyadic product of the vectors \mathbf{x} and \mathbf{y}
	$\sum_{i,j,k=1}^{j} S_{ij} T_{jk} e_i \otimes e_k$, tensor product of the second-order tensors S and T
	Determinant of the tensor \mathbf{I}
$\operatorname{tr} \boldsymbol{T}$	$:=\sum_{i=1}^{a}T_{ii}$, trace of the tensor T
$\ oldsymbol{x}\ _p$	$:= \left(\sum_{i=1}^d x_i ^p\right)^{\gamma_r}$, <i>p</i> -norm of the vector $oldsymbol{x}$
$\boldsymbol{H}^1(\varOmega)$	Sobolev space of component-wise weak differentiable functions in $L^2(\Omega)$ with derivatives in $L^2(\Omega)$
$\pmb{H}_0^1(\varOmega)$	Set of functions in $H^1(\Omega)$ with vanishing trace on the Dirichlet boundary of Ω
$L^2(\Omega)$	Hilbert space of component-wise Lebesgue-measurable functions with integrable squares over \varOmega
0	Zero vector
a	Axis
a	Acceleration vector
da	Area element in the current configuration
d a	:= n da, directed area element in the current configuration
A_k	Initialize coefficient
d 4	Area element in the reference configuration
d <i>A</i> d <i>A</i>	Area element in the reference configuration $= \mathbf{N} \mathbf{d} \mathbf{A}$ directed area element in the reference configuration
dA dA A	Area element in the reference configuration := N dA, directed area element in the reference configuration Convergence acceleration scheme
dA dA A b	Area element in the reference configuration $:= \mathbf{N} dA$, directed area element in the reference configuration Convergence acceleration scheme Body force vector
$dA \\ dA \\ A \\ b \\ B_k$	Area element in the reference configuration $:= \mathbf{N} dA$, directed area element in the reference configuration Convergence acceleration scheme Body force vector Influence coefficient
$dA \\ dA \\ \mathcal{A} \\ \boldsymbol{b} \\ B_k \\ \mathcal{B}$	Area element in the reference configuration := N dA, directed area element in the reference configuration Convergence acceleration scheme Body force vector Influence coefficient Set of bounding boxes
$dA \\ dA \\ \mathcal{A} \\ \boldsymbol{b} \\ \mathcal{B}_k \\ \mathcal{B} \\ \boldsymbol{B} \\ \boldsymbol{B} \\ \boldsymbol{\beta} \\ $	Area element in the reference configuration := N dA, directed area element in the reference configuration Convergence acceleration scheme Body force vector Influence coefficient Set of bounding boxes := FF^{T} , left Cauchy-Green deformation tensor
$dA \\ dA \\ \mathcal{A} \\ \mathcal{B} $	Area element in the reference configuration := N dA, directed area element in the reference configuration Convergence acceleration scheme Body force vector Influence coefficient Set of bounding boxes := FF^{T} , left Cauchy-Green deformation tensor := $J^{2/3}I$, dilatational (i.e., volume-changing or volumetric) part of the left
$dA \\ dA \\ A \\ b \\ B_k \\ B \\ B \\ \hat{B} \\ B$	Area element in the reference configuration := N dA, directed area element in the reference configuration Convergence acceleration scheme Body force vector Influence coefficient Set of bounding boxes := FF^{T} , left Cauchy-Green deformation tensor := $J^{2/3}I$, dilatational (i.e., volume-changing or volumetric) part of the left Cauchy-Green deformation tensor B
$dA \\ dA \\ \mathcal{A} \\ \boldsymbol{b} \\ \mathcal{B} \\ \mathcal{B} \\ \boldsymbol{B} \\ \boldsymbol{B}$	Area element in the reference configuration := N dA, directed area element in the reference configuration Convergence acceleration scheme Body force vector Influence coefficient Set of bounding boxes := FF^{T} , left Cauchy-Green deformation tensor := $J^{2/3}I$, dilatational (i.e., volume-changing or volumetric) part of the left Cauchy-Green deformation tensor B := $J^{-2/3}B$, distortional (i.e., volume-preserving or isochoric) part of the left Cauchy Cracen deformation tensor B
$dA \\ dA \\ A \\ B \\ $	Area element in the reference configuration := N dA, directed area element in the reference configuration Convergence acceleration scheme Body force vector Influence coefficient Set of bounding boxes := FF^{T} , left Cauchy-Green deformation tensor := $J^{2/3}I$, dilatational (i.e., volume-changing or volumetric) part of the left Cauchy-Green deformation tensor B := $J^{-2/3}B$, distortional (i.e., volume-preserving or isochoric) part of the left Cauchy-Green deformation tensor B Speed of sound (Chapter 2)
$dA \\ dA \\ \mathcal{A} \\ \boldsymbol{b} \\ \mathcal{B} \\ \mathcal{B} \\ \boldsymbol{B} \\ \boldsymbol{C} \\ \boldsymbol{C} $	Area element in the reference configuration := N dA, directed area element in the reference configuration Convergence acceleration scheme Body force vector Influence coefficient Set of bounding boxes := FF^{T} , left Cauchy-Green deformation tensor := $J^{2/3}I$, dilatational (i.e., volume-changing or volumetric) part of the left Cauchy-Green deformation tensor B := $J^{-2/3}B$, distortional (i.e., volume-preserving or isochoric) part of the left Cauchy-Green deformation tensor B Speed of sound (Chapter 2) Damping constant (Chapter 4, 5)
$dA \\ dA \\ dA \\ \mathcal{A} \\ \mathcal{B} \\$	Area element in the reference configuration := N dA, directed area element in the reference configuration Convergence acceleration scheme Body force vector Influence coefficient Set of bounding boxes := FF^{T} , left Cauchy-Green deformation tensor := $J^{2/3}I$, dilatational (i.e., volume-changing or volumetric) part of the left Cauchy-Green deformation tensor B := $J^{-2/3}B$, distortional (i.e., volume-preserving or isochoric) part of the left Cauchy-Green deformation tensor B Speed of sound (Chapter 2) Damping constant (Chapter 4, 5) Specific heat capacity
$dA \\ dA \\ dA \\ \mathcal{A} \\ \mathcal{B} \\$	Area element in the reference configuration := N dA, directed area element in the reference configuration Convergence acceleration scheme Body force vector Influence coefficient Set of bounding boxes := FF^{T} , left Cauchy-Green deformation tensor := $J^{2/3}I$, dilatational (i.e., volume-changing or volumetric) part of the left Cauchy-Green deformation tensor B := $J^{-2/3}B$, distortional (i.e., volume-preserving or isochoric) part of the left Cauchy-Green deformation tensor B Speed of sound (Chapter 2) Damping constant (Chapter 4, 5) Specific heat capacity Child of a tree node (Chapter 4)
$dA dA dA A A B B_k B B B B B B B B C C C_p C$	Area element in the reference configuration := N dA, directed area element in the reference configuration Convergence acceleration scheme Body force vector Influence coefficient Set of bounding boxes := FF^{T} , left Cauchy-Green deformation tensor := $J^{2/3}I$, dilatational (i.e., volume-changing or volumetric) part of the left Cauchy-Green deformation tensor B := $J^{-2/3}B$, distortional (i.e., volume-preserving or isochoric) part of the left Cauchy-Green deformation tensor B Speed of sound (Chapter 2) Damping constant (Chapter 4, 5) Specific heat capacity Child of a tree node (Chapter 4) Center of gravity (Chapter 6, 7)
$dA \\ dA \\ dA \\ \mathcal{A} \\ \mathcal{B} \\$	Area element in the reference configuration := N dA, directed area element in the reference configuration Convergence acceleration scheme Body force vector Influence coefficient Set of bounding boxes := FF^{T} , left Cauchy-Green deformation tensor := $J^{2/3}I$, dilatational (i.e., volume-changing or volumetric) part of the left Cauchy-Green deformation tensor B := $J^{-2/3}B$, distortional (i.e., volume-preserving or isochoric) part of the left Cauchy-Green deformation tensor B Speed of sound (Chapter 2) Damping constant (Chapter 4, 5) Specific heat capacity Child of a tree node (Chapter 4) Center of gravity (Chapter 6, 7) Influence coefficient

\hat{C}	$:= J^{2/3} I$, dilatational (i.e, volume-changing or volumetric) part of the right
	Cauchy-Green deformation tensor C
$ar{C}$	$:= J^{-2/3} C$, distortional (i.e., volume-preserving or isochoric) part of the right
	Cauchy-Green deformation tensor C
С	Fourth-order material tensor
С	Damping matrix
d	Dimension of space (Chapter 3)
	Distance (Chapter 4, 5)
d	Displacement vector
d	Discrete displacement vector
D	Diameter
D	Rate-of-strain tensor
e	Error
e	Cartesian basis vector
E	Young's modulus
\boldsymbol{E}	Green-Lagrange strain tensor
f	Generic function
f	External force vector
f	Discrete external force vector
F	External force
F	Deformation gradient (Chapter 3)
	Distance function (Chapter 4)
\hat{F}	$:= J^{1/3} I$, dilatational (i.e., volume-changing or volumetric) part of the defor-
	mation gradient F
$ar{F}$	$:= J^{-1/3} \mathbf{F}$, distortional (i.e., volume-preserving or isochoric) part of the de-
	formation gradient F
q	Gravitational acceleration
g	Nonlinear field equation
G	Weak form (Chapter 3)
	Shear modulus (Chapter 6)
h	Height
H	Height
H	Displacement gradient
I_T, II_T, III_T	Invariants of the second-order tensor T
\mathcal{I}	Interpolation scheme
Ι	Identity mapping (Chapter 2)
	Second-order identity tensor (Chapter 3)
\mathcal{I}	Fourth-order identity tensor
I	Identity matrix
j	Time step
J	$:= \det F$, Jacobian determinant (Chapter 3)
	Advance ratio (Chapter 6)
J	Jacobian matrix
J	Discrete Jacobian matrix
k	Spring constant (Section 4.3)
	Iteration (Chapter 4 (except Section 4.3), 5, 6)

	Wave number (Chapter 7)
$k_{ m t}$	Thrust coefficient
k _a	Torque coefficient
\vec{K}	Bulk modulus
К	Tangent stiffness matrix
\mathbf{K}_{m}	Material stiffness matrix
K.	Initial stress matrix
l	Tree level (Chapter 4)
	Length (Chapter 6)
l	Angular momentum
L	Length
	Number of finite volumes (Section 2.1)
	Number of boundary elements (Section 2.2)
	Number of finite elements (Chapter 3)
	Number of subdomains (Section 4.1, 4.2, Section 5.1)
	Number of query points (Section 4.5, 5.4, 5.5)
	Mass (Section 212, 312, 43, Chapter 6, 7)
m_{-}	Number of boundary segments (Chapter 2)
nu _s	Number of finite element surfaces (Chapter 3)
\overline{m}	Specific mass
m	External moment
Ma	Mach number
M	Mass matrix
<i>n</i>	Number of nodes (Chapter 3)
10	Number of time steps (Section 4.4)
	Number of source points (Section 4.5)
	Rotational speed (Chapter 6)
	Number of mooring lines (Chapter 7)
\boldsymbol{n}	Outer unit normal in the spatial or current configuration
N	Shape function (Chapter 3)
	Tree node (Chapter 4)
N	Outer unit normal in the reference configuration (Section 3.1.1, 3.1.2)
	Vector of shape functions (Section 3.1.5)
p	Pressure (Chapter 2, 6, 7)
r	Polynomial order (Chapter 4, 6)
n	Linear momentum (Chapter 3)
F	Source point (Chapter 4, 5)
P	Point
\mathcal{P}	Predictor scheme (Section 4.2, 4.4)
	Set of source points (Section 4.5, Chapter 5)
P	First Piola-Kirchhoff stress tensor
q	Torque (Section 6.14)
*	Heat flux (Section 6.17)
a	Query point
$\dot{\mathcal{Q}}$	Set of query points
r	Radius
r	Moment arm

r	Residual or out-of-balance vector
R_{φ}	Joule heating term
$\mathcal{R}^{'}$	Set of nearest neighbor or nearest bounding box candidates
R	Rotation tensor
s	Shrink factor (Chapter 4)
	Scaling factor (Chapter $6, 7$)
S	Sequence
\tilde{S}	Transformed sequence
S	Solver
$oldsymbol{S}$	Second Piola-Kirchhoff stress tensor
t	Time (except Section 6.14)
	Thrust (Section 6.14)
t'	Ramp time
t	Traction
T	Final time
u	Generic scalar-valued quantity
\boldsymbol{u}	Generic scalar-, vector-, or tensor-valued quantity
u	Generic discrete quantity
U	Dilatational part of the strain energy density U
$oldsymbol{U}$	Right stretch tensor
v	Volume in the current configuration (Chapter 3)
	Velocity (Chapter $2, 6, 7$)
v	Velocity
$\hat{m{v}}$	Mesh velocity
$ ilde{m{v}}$	$:= \boldsymbol{v} - \hat{\boldsymbol{v}}$, convective velocity
V	Volume in the reference configuration
V	Left stretch tensor
w	Interpolation weight
\boldsymbol{w}	Material velocity in the referential configuration
W	Strain energy density (Section 3.1.3)
	Virtual work (Section 3.1.4)
_	Width (Chapter $6, 7$)
W	Distortional part of the strain energy density W
\mathcal{W}	Set of interpolation weights
\mathbf{W}	Interpolation matrix
$oldsymbol{x}$	Particle in the spatial or current configuration
$oldsymbol{x}'$	Collocation point
X	Particle in the material or reference configuration
y	State vector
α	Angle of attack
α_{ϑ}	Thermal expansion coefficient
α_{φ}	Linear temperature coefficient
β	Newmark parameter
γ	Diffusion coefficient (Chapter 2)
	Newmark parameter (Chapter $3, 6, 7$)

	Peak enhancement factor (Chapter 7)
Г	$:= \partial \Omega$, boundary of the domain Ω
Δ	Thickness (Chapter 6)
	Draft (Chapter 7)
ε	Tolerance (except Section 6.17)
	Emissivity (Section 6.17)
ε	Linear strain
ζ	Wave elevation
η_0	Efficiency
$\tilde{\eta}$	Test function
'n	Discrete test function vector
θ	Angle between cell normals (Chapter 4)
	Misalignment angle θ (Chapter 7)
θ	Temperature
Θ	Inertia tensor in the inertial frame
Â	Inertia tensor in the body frame
$\tilde{\lambda}_{a}$	Thermal conductivity
λ_{i}	Electrical conductivity
λ	Weighting vector
11	Dynamic viscosity (Section 2.1, Chapter 6)
r-	Doublet strength (Section 2.2)
ν	Kinematic viscosity
έ. έ	Coordinate in the parameter space of a finite element
ρ	Density
ρ_{∞}	Spectral radius
ρ	Quaternion
σ	Source strength
$\sigma_{ m sb}$	Stefan-Boltzmann constant
$\sigma_{\rm v}$	von Mises stress
σ	Cauchy stress
ϕ	Generic scalar quantity (Chapter 2)
	Electric potential (Chapter 6)
	Phase angle (Chapter 7)
φ	$:= \boldsymbol{\Phi} \circ \boldsymbol{\Psi}^{-1}$, bijective transformation from the material or reference configu-
	ration Ω_X to the spatial or current configuration Ω_x (Chapter 2, 3)
	Vector storing rotations about $x, y, and z$ (Chapter 4)
Φ	Generic extensive property (Section 2.1)
	Velocity potential (Section 2.2)
Φ	Bijective transformation from the referential configuration Ω_{χ} to the spatial
	configuration Ω_x
χ	Particle in the reference configuration
Ψ	Bijective transformation from the referential to the material configuration
ω	Relaxation factor (Chapter $4, 6$)
	Angular frequency (Chapter $6, 7$)
ω	Angular velocity pseudo-vector
Ω	$\subset \mathbb{R}^d$, domain in <i>d</i> -dimensional space \mathbb{R}^d

 $\partial \Omega \subset \mathbb{R}^{d-1}$, boundary of the domain $\Omega \subset \mathbb{R}^d$ in d-dimensional space \mathbb{R}^d

Abstract

A broad range of engineering applications are governed by coupled multifield phenomena. Due to their highly nonlinear nature, fluid-structure interaction problems belong to the most challenging problems in this area. Prominent examples for such problems can, in particular, be found in the maritime industry. In this thesis, emphasis is placed on the numerical investigation of the fluidstructure interaction of a floating offshore wind turbine and of the landing maneuver of a crew transfer vessel to an offshore wind turbine. Due to the ever increasing computational resources, even such highly complex problems have become amenable to a numerical analysis, which helps to provide a deeper insight into the governing physical processes, to reduce the number of expensive experiments, to increase the confidence in the final product, and, last but not least, to reduce costs by shortening the product development cycle.

In the present work, a partitioned solution approach is followed in order to split a coupled problem into separate subproblems, which are coupled by iteratively exchanging the relevant field quantities within a time increment. This procedure enables the use of different spatial and temporal discretization schemes in each of the subdomains. Existing specialized and efficient solvers can then be reused to solve the subproblems – which significantly enhances modularity, software reusability, and also performance. However, these advantages come at the expense of reduced stability of the solution process. Appropriate measures must hence be taken to circumvent stability problems and to accelerate the convergence of the partitioned solution procedure. Therefore, different predictors are proposed so as to provide a reasonable initial guess for the solution in the current time increment and to help to reduce the number of implicit iterations. Regarding the transfer of the relevant field quantities between possibly non-conforming discretizations, several mesh-independent and mesh-dependent interpolation schemes are presented and assessed with respect to accuracy and computational efficiency. Moreover, efficient convergence acceleration schemes, which are suitable to stabilize and accelerate the coupling procedure, are discussed in detail.

In order to simplify the computer implementation of customized coupling strategies for various kinds of multifield problems, the C++ software library *comana* is presented. It offers a vast range of modular and well-tested algorithmic building blocks, which can easily be combined to create a coupling algorithm tailored to the specific problem under consideration. Based on a master/slave architecture, *comana* allows the user to select from plenty of solvers for different physical phenomena and to simply exchange them in a black-box manner. Shared- and distributed-memory parallelized solvers can be integrated into a coupled computation without difficulty rendering even large computations possible. Preparing a solver for a coupled simulation only requires an adapter module and very little modifications in the solver code. Adapters for various solvers for thermodynamics, fluid and structural dynamics are readily provided; adapters not yet available can be implemented with little effort.

In the last part of this work, the software library is verified by means of numerous benchmark problems – and it is also applied to several advanced applications from the maritime industry. Exploiting the full versatility of the software library *comana*, it is demonstrated that the partitioned solution approach is well suited to solve even highly complex and strongly coupled problems efficiently. Particular focus is placed on the fluid-structure interaction of a floating offshore wind turbine and on the landing maneuver of a service ship to an offshore wind turbine, as specific applications from the maritime industry.