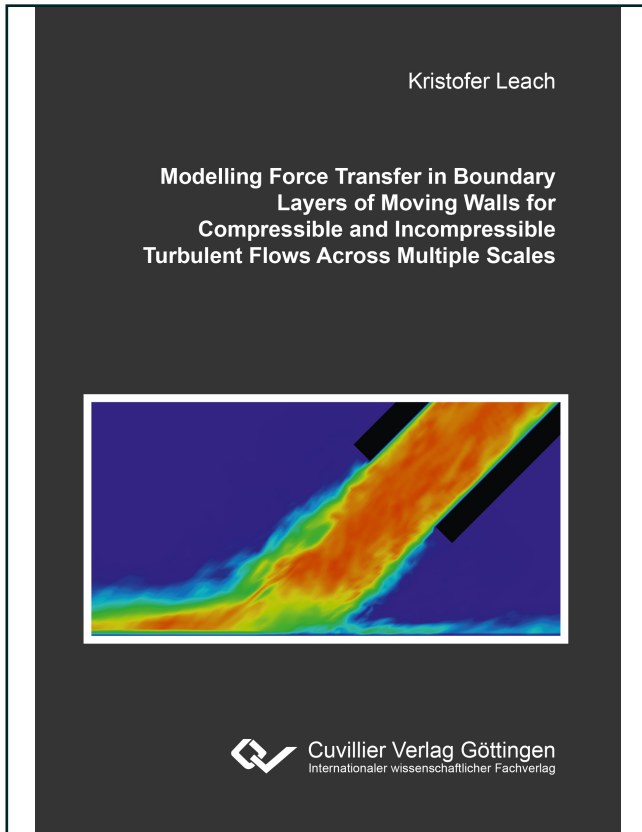




Kristofer Leach (Autor)

Modelling Force Transfer in Boundary Layers of Moving Walls for Compressible and Incompressible Turbulent Flows Across Multiple Scales



<https://cuvillier.de/de/shop/publications/6886>

Copyright:

Cuvillier Verlag, Inhaberin Annette Jentzsch-Cuvillier, Nonnenstieg 8, 37075 Göttingen, Germany

Telefon: +49 (0)551 54724-0, E-Mail: info@cuvillier.de, Website: <https://cuvillier.de>



Contents

1	Introduction	1
1.1	Motivation	1
1.2	Basic setup	3
1.3	Goals and limitations	4
2	Governing equations	7
2.1	Conservation of mass	7
2.2	Conservation of momentum	8
2.3	Motion and deformation of a fluid element	10
2.4	Deformation law for a Newtonian fluid	13
2.5	Mechanical and thermodynamic pressure	15
2.6	The Navier-Stokes equations	16
2.7	The energy equation	16
2.8	The perfect gas	19
2.9	Sutherland's viscosity model	21
2.10	Incompressible flow	21
2.11	Summary	22
3	Computational methods	25
3.1	Discretisation methods	25
3.1.1	Finite Difference Method	26
3.1.2	Finite Volume Method	27
3.1.3	Finite Element Method	29
3.2	Interpolation schemes	30
3.2.1	Upwind interpolation scheme	30
3.2.2	Linear upwind interpolation scheme	31
3.2.3	Linear interpolation scheme	31
3.2.4	Other interpolation schemes	33
3.3	Boundary conditions	33
3.4	Unsteady problems	34
3.4.1	Explicit (forward) Euler Method	36
3.4.2	Implicit (backward) Euler Method	38
3.4.3	Crank-Nicolson Method	39
3.4.4	Other methods	40



3.5	Solving the Navier-Stokes equations	40
3.5.1	SIMPLE	41
3.5.2	PISO	42
3.5.3	PIMPLE	44
3.6	Large Eddy Simulation	45
3.6.1	Filtered Navier-Stokes equations	47
3.6.2	Smagorinsky model	48
3.6.3	Dynamic Smagorinsky model for incompressible flow	50
3.6.4	Law of the Wall	51
3.7	Summary	53
4	Developing a prototype grinding tool	55
4.1	Parametric study	55
4.1.1	Variable parameters	56
4.1.2	Simulation setup	57
4.1.3	Forces	62
4.1.4	Evaluation	64
4.2	Computational results	72
4.2.1	Simulation Setup	72
4.2.2	Reynolds and Mach numbers	74
4.2.3	Temperature variation	75
4.2.4	Normal forces	76
4.2.5	Tangential forces	78
4.2.6	Flow analysis	79
4.2.7	Grinding force dependency	81
4.2.8	Grinding power	83
5	Empirical validation of simulated data	87
5.1	Experimental setup	88
5.2	Simulation setup	89
5.3	Empirical and computational results	90
6	Developing a fully functional 8 mm grinding tool	93
6.1	Determination of an adequate propulsion fluid	93
6.1.1	Cavitation: limiting factor of liquids	93
6.1.2	Oil viscosity study	95
6.2	Optimisation of geometric parameters	97
6.2.1	Gap height	97
6.2.2	Co-duct position	98
6.2.3	Duct diameter	99
6.2.4	Main duct offset	100
6.2.5	Final adjustments	101



6.2.6	Summary	103
6.3	Optimisation of the computational grid	105
6.3.1	Test setup	106
6.3.2	Results for air	106
6.3.3	Results for oil	108
6.4	Computational Results	108
6.4.1	Reynolds and Cavitation numbers	109
6.4.2	Normal forces	109
6.4.3	Tangential forces	112
6.4.4	Grinding power	114
7	Modelling force transfer across multiple scales	117
7.1	Simulation Setup	117
7.2	Computational results	121
7.2.1	Normal forces	121
7.2.2	Tangential force	125
7.2.3	Grinding power	131
7.3	Non-dimensional analysis	136
7.3.1	Normal forces	137
7.3.2	Tangential forces	138
7.3.3	Grinding power	142
7.4	Single duct vs. triple duct geometry	143
7.5	Air vs. oil propulsion	146
8	Conclusion	149
8.1	Summary	149
8.2	Limitations	151
8.3	Future research possibilities	153
	Appendix	155
A	Theorems & formulae	155
A.1	Divergence theorem	155
A.2	Leibnitz integral rule	155
A.3	Reynolds transport theorem	156
A.4	Grinding angle and corresponding abrasion force	156
A.5	Extrapolation of standard deviation	157
A.6	Sigmoid function	158
B	Advanced Meshing Techniques	161
B.1	Meshing a cylinder with hexahedra	161
B.2	Automatic Mesh Generation	164



B.3	Selective Grid Refinement	174
C	Supplemental results	177
C.1	40mm GrindBall prototype (Chapter 4)	178
C.2	Dynamometer validation (Chapter 5)	180
C.3	8mm hydraulic grinding tool (Chapter 6)	180
C.4	Scale Analysis (Chapter 7)	185
D	OpenFOAM settings	189
D.1	40mm GrindBall parametric study (Chapter 4)	189
D.2	40mm GrindBall prototype (Chapter 4)	191
D.3	Dynamometer validation (Chapter 5)	192
D.4	Propulsion fluid study (Chapter 6)	194
D.5	Simulations using ISO VG46 oil (Chapter 6)	195
D.6	Scale Analysis (Chapter 7)	196
	Bibliography	199