

Contents

1	Numerical RANS/URANS simulation of combustion noise	1
	Bernd Mühlbauer, Berthold Noll, Roland Ewert, Oliver Kornow and Manfred Aigner	
1.1	Introduction	2
1.2	Theoretical Background	2
1.2.1	RANS/URANS approach	3
1.2.2	Boundary conditions	4
1.2.3	RPM-CN approach	4
1.3	Results and Analysis	9
1.3.1	Indirect combustion noise	9
1.3.2	Direct combustion noise	19
1.4	Conclusions	26
	References	28
2	Measurement and Simulation of Combustion Noise emitted from Swirl Burners	33
	C. Bender, F. Zhang, P. Habisreuther, H. Büchner and H. Bockhorn	
2.1	Introduction	33
2.2	Theoretical Background	35
2.2.1	Experimental Setup	35
2.2.2	Numerical Methods	37
2.3	Results and Analysis	41
2.3.1	Experiment	41
2.3.2	Numerical Simulation	49
2.4	Conclusions	59
	References	60
3	Modeling of noise sources in combustion processes via Large-Eddy Simulation	63
	Anna Schwarz, Felix Flemming, Martin Freitag and Johannes Janicka	
3.1	Introduction	63

3.2	Theoretical Background	64
3.2.1	Non-Premixed Flames	65
3.2.2	Partially Premixed Flames	67
3.2.3	Premixed Flames	68
3.2.4	LES/CAA Hybrid Approach	70
3.3	Results and Analysis	73
3.3.1	Open, Non-Premixed Jet Flames	73
3.3.2	Model Combustor (Partially Premixed Flames)	77
3.3.3	Tecflam Burner (Premixed Flames)	81
3.3.4	LES/CAA Coupling	83
3.4	Summary and Conclusions	85
	References	86
4	Modelling of the Sound Radiation from Flames by means of Acoustic Equivalent Sources	89
	Rafael Piscoya, Haike Brick, Martin Ochmann and Peter Költzsch	
4.1	Introduction	89
4.2	Theoretical Background	90
4.2.1	Hybrid Approach	90
4.2.2	Equivalent Source Method (ESM)	92
4.2.3	Boundary Element Method (BEM)	93
4.2.4	Numerical Simulation of the Flames	95
4.3	Results and Analysis	95
4.3.1	Numerical Aspects of the Hybrid Method	95
4.3.2	Location of the Control Surface	102
4.3.3	Inclusion of Ground Effects	102
4.3.4	Measurement of the Flame	104
4.3.5	Results of the Simulation and Comparison with the Measurement	105
4.3.6	Sound Propagation in a Non-Homogeneous Medium	107
4.4	Conclusions	119
	References	120
5	Investigation of the Correlation of Entropy Waves and Acoustic Emission in Combustion Chambers	125
	Friedrich Bake, André Fischer, Nancy Kings and Ingo Röhle	
5.1	Introduction	126
5.2	Theoretical Background, Test Specification and Data Analysis	126
5.2.1	Test Specification and Data Analysis	129
5.3	Results and Discussion	134
5.3.1	Entropy Wave Generator Test Rig (EWG)	134
5.3.2	Combustor Test Rig	137
5.4	Conclusions	141
	References	142

6	Influence of boundary conditions on the noise emission of turbulent premixed swirl flames	147
	Fabian Weyermann, Christoph Hirsch and Thomas Sattelmayer	
6.1	Introduction	148
6.2	Theory and Methods	149
6.2.1	Calculation of the acoustic power spectrum	149
6.2.2	Modeling of the spectral heat-release	152
6.2.3	Coherence volume	156
6.2.4	Acoustic power spectrum of an unconfined flame	157
6.2.5	Simulation of confined flames	157
6.2.6	Experimental setup and measurement techniques	161
6.3	Results and Analysis	166
6.3.1	Validation of the noise-model for unconfined flames	166
6.3.2	Adiabatic flames	168
6.3.3	Unconfined flames, modeling based on CFD-data	168
6.3.4	Sound emission from a complex combustion system into the environment	169
6.4	Conclusions	170
	References	171
7	Theoretical and Numerical Analysis of Broadband Combustion Noise	175
	Thanh Phong Bui and Wolfgang Schröder	
7.1	Introduction	175
7.2	Aeroacoustic theories to compute combustion generated noise	178
7.2.1	Acoustic analogies based on a scalar wave equation	178
7.2.2	Acoustic perturbation equations for reacting flows (APE-RF)	179
7.2.3	Summary of the APE-RF formulation	182
7.2.4	Source term formulations	183
7.2.5	Rayleigh's criterion for acoustic wave amplification	186
7.3	Hybrid CFD/APE-RF method to simulate combustion noise	187
7.3.1	CFD/CAA interface conditions	187
7.3.2	Numerical methods used in the CAA	196
7.4	Results and Analysis: Application of the APE-RF system to open turbulent flames	197
7.4.1	H3 Flame: A non-premixed open turbulent flame	197
7.4.2	Premixed Methane Flame	199
7.4.3	DLR-A Flame: A non-premixed open turbulent flame	204
7.5	Summary and Conclusions	209
7.6	Acknowledgments	211
	References	211

8	Investigations Regarding the Simulation of Wall Noise Interaction and Noise Propagation in Swirled Combustion Chamber Flows	217
	Christoph Richter, Łukasz Panek, Verina Krause and Frank Thiele	
8.1	Introduction	217
8.2	Theoretical background	220
8.2.1	Mathematical models	220
8.2.2	Numerical Method	221
8.2.3	Intensity-based analysis of the result	225
8.3	Results and Discussion	227
8.3.1	The entropy wave generator (EWG) model experiment	227
8.3.2	Swing-off response of a premixed swirl combustor flow	231
8.3.3	10 kW model combustion system with 17 mm exit nozzle	233
8.4	Conclusion	235
	References	237
9	Direct Numerical Simulations of turbulent flames to analyze flame/acoustic interactions	239
	G. Fru, H. Shalaby, A. Laverdant, C. Zisl, G. Janiga and D. Thévenin	
9.1	Introduction	239
9.2	Theoretical Background, Numerical methods and procedure	242
9.2.1	DNS code family <i>Parcomb</i>	243
9.2.2	DNS code family π^3	245
9.2.3	Steps involved by the computational procedure	246
9.2.4	Modeling of chemical reactions	247
9.3	Flame/acoustics interactions investigated with DNS	253
9.3.1	Local Rayleigh's criterion	254
9.3.2	Examples of results and discussion	255
9.4	Post-processing challenge: AnaFlame	261
9.4.1	Introduction	261
9.4.2	Content of the post-processing toolbox AnaFlame	262
9.5	Conclusions and perspectives	263
	References	266
10	Localization of Sound Sources in Combustion Chambers	269
	Christian Pfeifer, Jonas P. Moeck, C. Oliver Paschereit and Lars Enghardt	
10.1	Introduction	269
10.2	Theoretical Background	271
10.2.1	Theory of Nearfield Acoustic Holography	271
10.2.2	Sound Pressure Field in the Combustion Chamber without Mean Flow	272
10.2.3	Modal Composition of G	273
10.2.4	Sound Pressure Field in the Combustion Chamber with Mean Flow	275
10.2.5	Reflection at the Combustion Chamber Outlet	276
10.2.6	Reconstruction of Sound Sources	277

- 10.3 Results and Analysis 280
 - 10.3.1 Optimization of the Sensor Arrangement 281
 - 10.3.2 Effect of Noise on the Reconstruction Accuracy 284
 - 10.3.3 Reconstruction of Sound Sources not located on
assumed Source Distribution 285
 - 10.3.4 Effect of Reflection at the Combustion Chambers Outlet . 287
 - 10.3.5 Effect of Mean Flow 288
- 10.4 Conclusion 289
- References 290