

Contents

List of figures

List of tables

List of abbreviations

List of publications

1	Introduction	1
1.1	Background	1
1.2	Objectives and scope	9
1.3	Outline	10
2	Previous work and literature review	13
2.1	Origin of the Virtual Engine Model	13
2.2	Engine heat transfer	15
2.2.1	Convective heat transfer	17
2.2.2	Measurement of engine heat transfer	32
2.2.3	Lumped heat transfer	40
2.2.4	Multizone heat transfer	51
2.3	Modeling of ancillary thermal systems	62
2.4	Thermal codes integrated into global engine models	68

3	Modeling tools	75
3.1	Virtual Engine Model (VEMOD)	75
3.2	CALMEC: Combustion diagnosis	77
3.3	Initial model of heat transfer in the engine block	80
3.4	Heat transfer in the turbocharger	89
3.5	Heat transfer in gas ducts	91
4	Heat transfer in the engine block	93
4.1	Qualitative evaluation of the initial model	94
4.2	Quantitative evaluation of the initial model	97
	4.2.1 Methods	97
	4.2.2 Results	125
4.3	Multizone model of in-cylinder convection	141
	4.3.1 In-cylinder gas motion	143
	4.3.2 Thermal analysis	170
4.4	Heat rejection to coolant and lubricant	188
4.5	Transient behavior	193
4.6	Adaptation for integration into VEMOD	201
5	Heat transfer in ancillary systems	211
5.1	Model of heat exchangers	212
	5.1.1 Model structure	213
	5.1.2 Effectiveness-NTU method	215
	5.1.3 Definition of heat exchangers	218
5.2	Thermo-hydraulic model	221
	5.2.1 Description of objects	223
	5.2.2 General workflow	227
	5.2.3 Circuit definition	229
	5.2.4 Circuit creation	231
	5.2.5 Hydraulic network analysis	242
	5.2.6 Thermal state of the circuit	255
6	Heat transfer in the global engine model	273
6.1	Validation methods	274
	6.1.1 Experimental tests	275
	6.1.2 Simulation methods	279
6.2	Validation results	287
	6.2.1 Validation in steady state	287
	6.2.2 Validation in WLTP driving cycle	288
6.3	Concluding remarks	295

7 Conclusions and future work **297**
7.1 Main contributions 298
7.2 Suggestions for future work 302

Bibliography **307**