

Contents

1. <u>Introduction</u>	1
1.1. Energy and environment challenges for automotive engines.	1
1.2. R&D context.	6
1.3. Motivation.	8
1.4. Outline of the Thesis	9
Bibliography	11
2. <u>General context and historical background</u>	12
2.1. Introduction	12
2.2. The race for power	12
2.2.1. Context	
2.2.2. The pre-War period	
2.2.3. The close pre-war and the war periods: the aeronautic experience	
2.2.4. The post-war period	
2.3. The race for fuel economy	18
2.3.1. Context	
2.3.2. The development of the Diesel for automotive applications	
2.3.3. The gasoline lean burn and stratified engines	
2.4. The race for low emissions	22
2.4.1. Regulations	
2.4.2. The challenge of the Diesel engine	
2.4.3. The CO2 reduction	
2.5. Conclusion	25
Bibliography	27

3. <u>The spray structure and its impact on combustion</u>	28
3.1. Introduction	28
3.2. Macroscopic interaction between the spray and the Diesel combustion	28
3.3. Detailed analysis for Diesel applications	30
3.3.1. Global structure of the spray	
3.3.2. Internal flow in the hole	
3.3.3. Primary, secondary atomization and air entrainment	
3.3.4. Lift-off length	
3.3.5. Pollutant formation	
3.4. The high pressure gasoline injection	40
3.4.1. The “inwardly opening needle”	
3.4.2. The “outwardly opening needle”	
3.4.3. General remarks	
3.5. Conclusion	43
Bibliography	44
4. <u>Tools and methodologies</u>	46
4.1. Introduction	46
4.2. Engine tests	46
4.2.1. Bench overview	
4.2.2. Indicated values	
4.2.3. Testing methodologies	
4.3. Visualization	48
4.3.1. General overview	
4.3.2. Spray and combustion visualization for gasoline direct injection	
4.3.2.1. Free jet in atmospheric conditions	
4.3.2.2. Jet in the motored engine	
4.3.2.3. Visualization of the combustion	
4.3.3. Visualization of the mixture preparation for gasoline direct injection	
4.3.3.1. Background with homogeneous mixtures	

4.3.3.2.	Introduction of direct injection	
4.4.	Simulation	57
4.4.1.	Historical background	
4.4.2.	Dedicated methodology for the aerodynamics simulation	
4.4.3.	Dedicated methodology for the Diesel spray simulation	
4.5.	Conclusion	60
	Bibliography	61
5.	<u>The MID3S spray guided stratified engine</u>	65
5.1.	Introducion	65
5.2.	General design and patents	66
5.2.1.	Specifications and requirements	
5.2.2.	General design origins and description	
5.2.2.1.	Thermodynamic roots	
5.2.2.2.	State of the art	
5.2.2.3.	Choice of the general design	
5.3.	Ignition and injection systems	79
5.3.1.	The ignition system	
5.3.2.	The injection system	
5.3.2.1.	Design and hydraulic performances	
5.3.2.2.	Spray behavior	
5.3.2.3.	Spray atomization	
5.4.	Mixture preparation	84
5.4.1.	Experimental set-up	
5.4.2.	Mixture preparation results	
5.4.2.1.	Macroscopic observation of the films	
5.4.2.2.	Explanation of the physics	
5.4.3.	Conclusion	
5.5.	Combustion	90
5.5.1.	Full load results	
5.5.1.1.	Global results	

5.5.1.2.Injection timing	
5.5.1.3.Ignition timing	
5.5.1.4.Effect of the injection pressure	
5.5.2. Part load results	
5.5.2.1.Choice of the injection pressure	
5.5.2.2.Choice of the ignition timing	
5.5.2.3.Optimization of the ignition timing	
5.5.2.4.Influence of the equivalence ratio	
5.5.3. Conclusions	
5.6. Conclusions	102
5.6.1. Methodologies and tools	
5.6.2. Physics	
Bibliography	104
6. <u>The K5M air guided stratified engine</u>	106
6.1. Introduction	106
6.2. General design and patents	107
6.2.1. Specifications and requirements	
6.2.2. General design origins and description	
6.2.2.1.Thermodynamic roots	
6.2.2.2.State of the art	
6.2.2.3.The K5M engine	
6.3. Ignition and injection systems	118
6.3.1. The ignition system	
6.3.2. The injection system	
6.4. Optimization of the mixture preparation	119
6.4.1. Methodology	
6.4.2. First estimation of the spray and tumble characteristics	
6.4.3. Aerodynamics optimization	
6.4.3.1.Choice of the system	
6.4.3.2.Detailed flow analysis : CFD	
6.4.3.3.Detailed flow analysis : PIV	
6.4.4. Mixture preparation	

6.4.4.1.Spray parameters setting	
6.4.4.2.Mixture preparation analysis	
6.4.5. Combustion at 2000 rpm	
6.4.6. Conclusion	
6.5. Conclusion	142
6.5.1. Methodologies and tools	
6.5.2. Physics	
 Bibliography	 144
 7. <u>The Lifted Flame Diffusion Controlled (LFDC) Combustion</u>	 147
7.1. Introduction	147
7.2. General design	148
7.2.1. Specifications and requirements	
7.2.2. Background of low emissions concepts	
7.2.2.1.Physics of the Diesel combustion	
7.2.2.2.Emergence of HCCI	
7.2.2.3.HCCI concepts	
7.2.2.4.Mild HCCI combustion	
7.2.3. Proposal for an improved diffusion controlled combustion	
7.2.4. Basis of the Lifted Flame Diffusion Controlled (LFDC) combustion	
7.2.4.1.Lift-off length definition and soot formation mechanism	
7.2.4.2.First strategy contributing to a low soot formation	
7.2.4.3.Second strategy for a low soot formation	
7.2.5. Basic experiment concerning a non sooting diffusion controlled combustion	
 7.3. Development of the Lifted Flame Diffusion Controlled Combustion (LFDC)	 169
7.3.1. Definition of the injection system	
7.3.2. Spray investigation: effect of the nozzle definition	
7.3.2.1.Air entrainment	
7.3.2.2.Spray evaporation	
7.3.2.3.Lift-off length	
7.3.3. Spray investigation: effect of the injection pressure	
7.3.3.1.Spray evaporation	
7.3.3.2.Lift-off length	

7.3.4. Lift-off length: effect of the oxygen content	
7.4. Tests on a single cylinder engine	180
7.4.1. Operating points and reference configuration	
7.4.2. Full load points	
7.4.2.1. Peak power at 4000 rpm	
7.4.2.2. Maximum torque at 1500 rpm	
7.4.2.3. Conclusion for full load performances	
7.4.3. Part load operating points	
7.4.3.1. LTC Mild HCCI conditions	
7.4.3.2. LFDC operating points	
7.4.3.3. Thermodynamic analysis at 2250 rpm 9.4 bars IMEP in LFDC mode	
7.4.3.4. 3D analysis at 2250 rpm 9.4bars IMEP in LFDC mode	
7.4.4. Conclusion	
7.5. Conclusion	198
Bibliography	199
8. <u>Conclusion</u>	202
8.1. Threatens and potential for the internal combustion engine	203
8.1.1. Potential solutions for the SI powertrain	
8.1.2. Potential solutions for Diesel	
8.2. Tools development	206
8.2.1. Spray characteristics	
8.2.2. Mixture preparation	
8.3. R&D context	208
Bibliography	210