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CHARACTERIZATION OF THE DIESEL SPRAY

Fábio Jairo Dias - fabioj.dias@outlook.com
Pedro Teixeira Lacava - placava@ita.br
Instituto Tecnológico de Aeronáutica
Divisão de Engenharia Mecânica
Praça Marechal Eduardo Gomes, 50
São José dos Campos - SP, 12.228-900, Brasil

Abstract. There are some parameters that significantly influence the performance of diesel engines, such as: spray angle, lift-off length and liquid length. For the development of this work, we searched the literature for recent equations for the characterization of diesel spray. The equation related to these parameters were programmed in the Mat Lab and compared with experimental results in the literature. Using this model, it is possible to characterize the diesel spray according to the diameter of the injection hole installed in the engine and also the pressure that will be injected into the fuel.

***Keywords**: Injector Nozzle Characterization, Spray, Diesel Engine*

1. INTRODUCTION

The internal combustion engine, led by the reduction of consumption limits and polluting emissions, brings with it the need to design increasingly complex engines and new sophisticated technologies, capable of managing all possible operating conditions. In order to meet the requirements of standards and customers, surveys are carried out using current projects using computational resources that allow the development of several engine simulations. An important point for these simulations are the spray characteristics provided by the injector nozzle, such as spraying, lift-off length and liquid length.

In this context, the present work describes the models for obtaining these spray parameters based on recent literature. To provide the calculation and comparison with experimental data from the literature, a Mat Lab code was developed to organize the equations and present the results of the simulation. The use of this model allows the user to know the characteristics of the nozzle, such as spray angle, lift-off length and liquid length. These parameters are important for choosing the injector nozzle for better engine configuration and performance.

Spray Angle

When a high-pressure jet is developed in a gaseous environment (combustion chamber), an opening occurs in the jet, which is called the spray angle. this angle is due to the turbulent effect of the penetration of ambient gas in the liquid flow that was injected. Figure 1 adapted from (Reitz & Bracco 1979) shows an ideal spray.

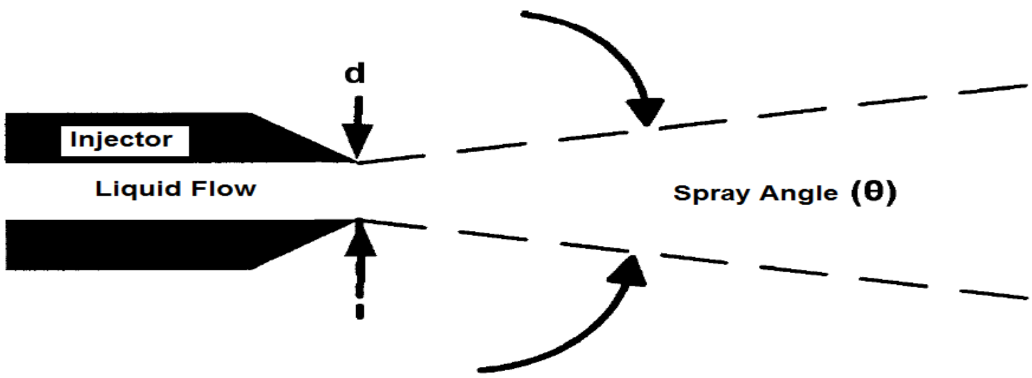

Figure 1 – Spray Angle adapted (Reitz & Bracco 1979).

The spray angle is affected by the ratio between the specific masses of air and fuel, and also by the appearance of the injector, such as the length of the injection port and its diameter. Increasing the ratio between the specific mass of the gas and that of the liquid, or as the specific mass of the gas rises relative to that of the liquid, obtains greater spray angles (Reitz e Bracco, 1979). In this way, a greater angle will result in a greater mass of gas penetrating the spray as the jet moves away from the injector (Naber & Silbers, 1996).

Lift-off Length

In classic diesel combustion, the fuel-air mixture self-ignites after a short ignition delay, and a high diffusion flame sets up at a certain distance from the injector. This distance between the injector nozzle and the first location downstream of the diffusion flame is called the lift-off length of a diesel jet. The distance between the nozzle of the injector and the first downstream location of the diffusion flame is defined as the lift-off length of a diesel jet. The lift-off length is an important characteristic since air-entrainment into the central, soot-forming region of the jet is only feasible up to the lift-off position. For a given fuel, the soot formation rate is therefore largely determined by the temperature and the equivalence ratio of the fuel-air mixture at the lift-off position. The understanding of the physical processes governing the lift-off length and its stabilization during the quasi-steady phase of combustion is therefore essential for predicting soot formation rates (Guillaume et al 2015). In Figure 2 adapted from (Muller et. al. 2015) we can see the lift-off length.

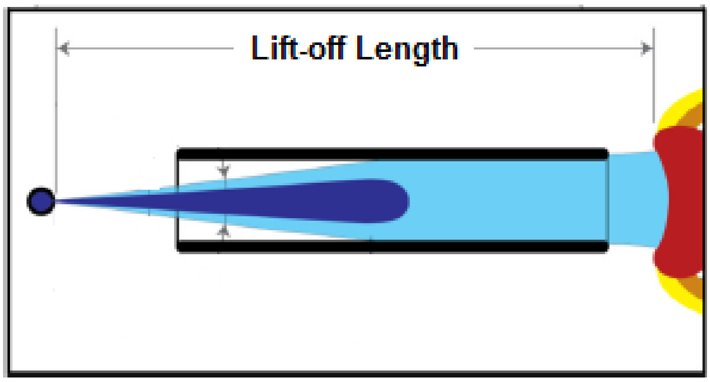

Figure 2 – Lift-off Length adapted (Muller et. al. 2015).

Liquid Length

The knowledge on spray penetration is useful for engine design and the development of computational models used as engine design and optimization tools. The liquid length is the distance from the injector that fuel remains in the liquid phase (droplets) in the combustion chamber. One practical concern liquid length measurements address is the potential for wall wetting, particularly in small-bore engines.

The penetration length is one of the important parameters affecting mixture characteristics within the combustion chamber of diesel engines. If the penetration is too long, wetting of the chamber wall or/and piston crown will occur, resulting in high levels of soot formation and low fuel economy. On the other hand, if the penetration is too short, mixing efficiency and optimum combustion will be compromised.

2. DEVELOPMENT OF THE MODEL

Spray Angle

The spray angle formulation is one of the basic research studies for diesel spray. As the physical relationships between several other spray injection parameters are included in the spray angle equation, it becomes a fundamental "tool equation" for the analysis of the angle being injected into the combustion chamber (Arai, 2018).

Equation 1 describes the spray angle calculation, as presented by (Arai 2018), which represents the most recent model for this parameter. Russell (2018) presented the experimental results of the spray angle for a typical diesel engine injector with an injection orifice diameter of 0.138 mm, Figure 3 compares the results obtained using the equation cited by (Arai, 2018) with the results experimental data obtained by (Russel, 2018).

$$\theta = 0.017\left(\frac{Dn^2.\rho a.\Delta p}{\mu a^2}\right)^{0.25} \tag{1}$$

Where:

Dn is the nozzle diameter [mm];
ρa is the air specific mass [kg/m³]
Δp is the pressure difference between "Injection pressure - Ambient pressure (Chamber)" [Mpa].
μa is the air viscosity [Pa.s]

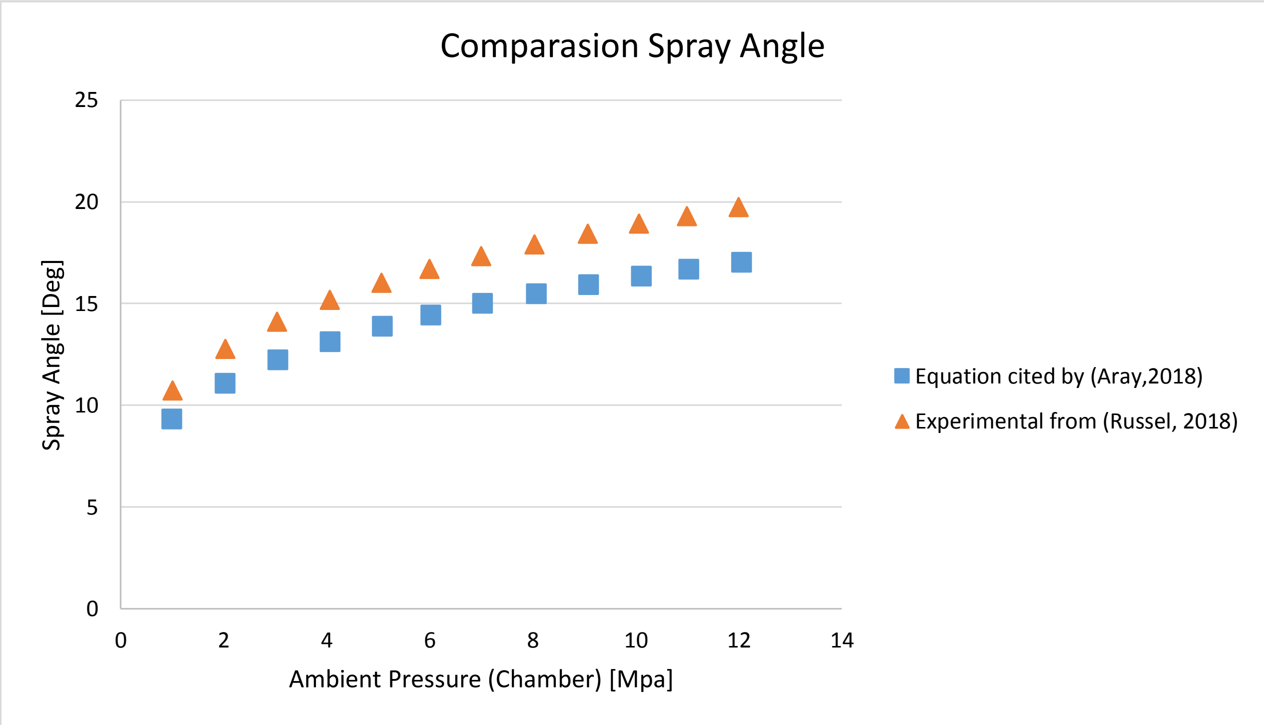

Figure 3 – Comparison of the spray angle experimental with equation cited by (Aray, 2018).

Lift-off Length

The lift-off length represents the distance between the nozzle exit and the start of combustion. In general, it is important to observe the fuel jet travel before the ignition (Dennis, et. al 2000). The equation presented by (Guillaume e.t al 2015) calculates the lift-off length, one time equation went developed based on an optical heavy-duty Diesel engine experiments.

$$H = A.T^{-1.43}.\rho^{-0.83}.d^{0.41}.U^{0.48}.Z_{zt}^{-0.75} \tag{2}$$

Where:

H = Length of lift-off [mm]
A = Constant 3.34x10³
T = Temperature [K]
ρ = Air specific mass [kg/m³]

d = Nozzle diameter [µm]
U = Injection velocity [m/s]
Zst = Stoichiometric fraction

Figures 4 and 5 show the comparison between the equation cited by (Guillaume et al 2015) and the experimental and theoretical results cited by (Argachoy 2004) for a Diesel injector with an injection orifice diameter of 0.180 and 0.246 mm. It is possible to notice that an adopted equation shows good agreement with the experimental results, where a better result can be seen in the combination of lower injections, in relation to the theoretical model cited by Argachoy, 2004.

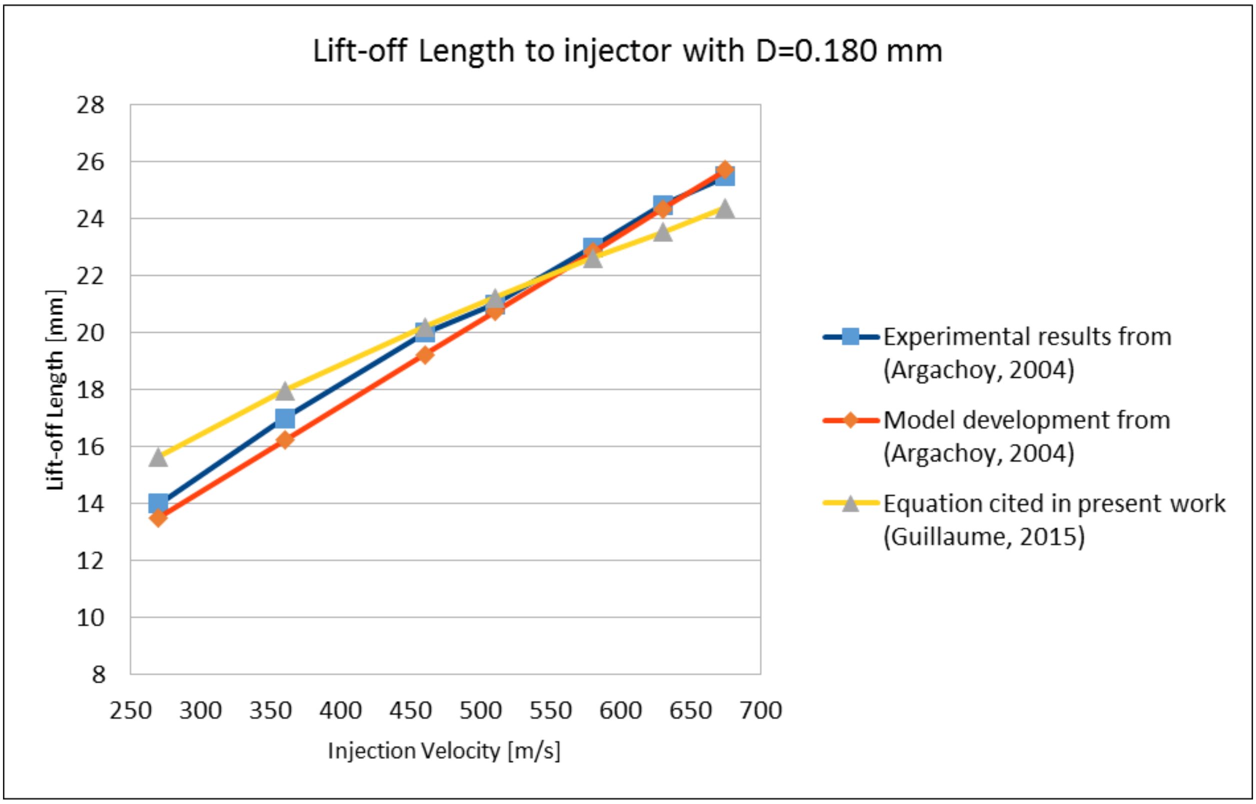

Figure 4 - Comparison between the experimental and theoretical results from (Argachoy 2004) for lift-off length and the equation cited in the present work.

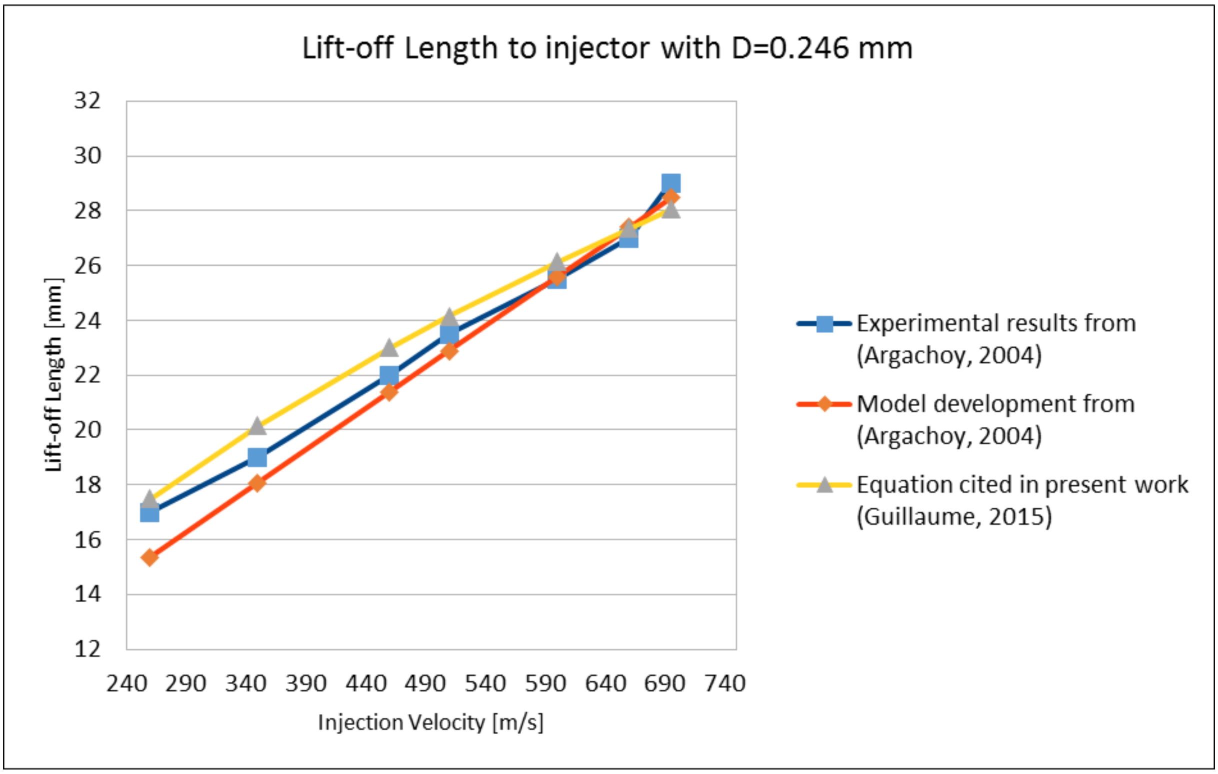

Figure 5 - Comparison between the experimental and theoretical results from (Argachoy 2004) for lift-off length and the equation cited in the present work

Liquid Length

Differently than the lift-off length, the spray length is associated with the continuous or stationary fuel injection regime. It represents the distance between the nozzle exit until the point where the atomization takes place or the point of first droplets formation (Hiroyasu and Haiyan, 1978). In literature, this length is called by some authors as spray penetration. The present study adopted the equation cited by (Whitelaw et al. 2002) to calculate this parameter.

$$LL = 6.47.D_n^{0.56}.\rho_a^{-0.27}.P_{inj}^{0.23}.C_d^{0.08}.t^{0.5} \tag{3}$$

Where:

Dn = Nozzle diameter [mm];
ρa = Air specific mass [kg / m³];
Pinj = Injection pressure [Bar];
Cd = discharge coefficient;
t = Injection time [µs];

Figures 6 and 7 compare the results of the spray length equation cited by (Whitelaw et al. 2002) and the experimental results by (Guillaume et. al. 2005) for an injector with an injection hole diameter of 0.170 mm and injection pressure of 700 and 300 Bar with different injection times.

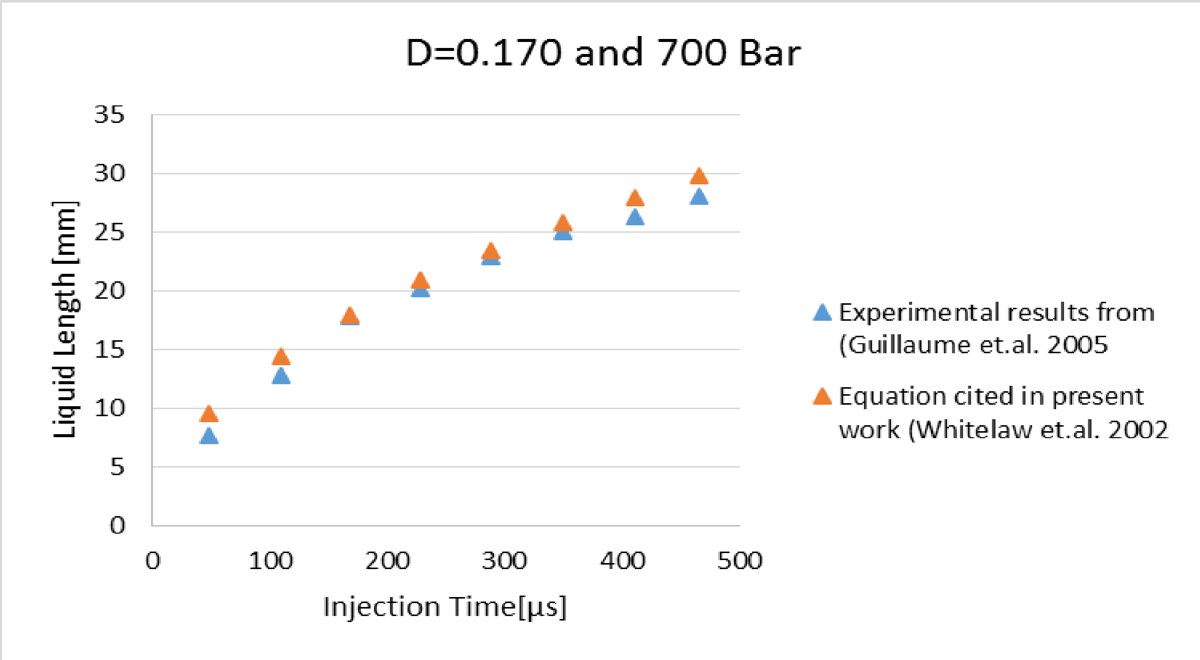

Figure 6 - Comparison of the liquid length experimental with equation cited by (Whitelaw et al. 2002).

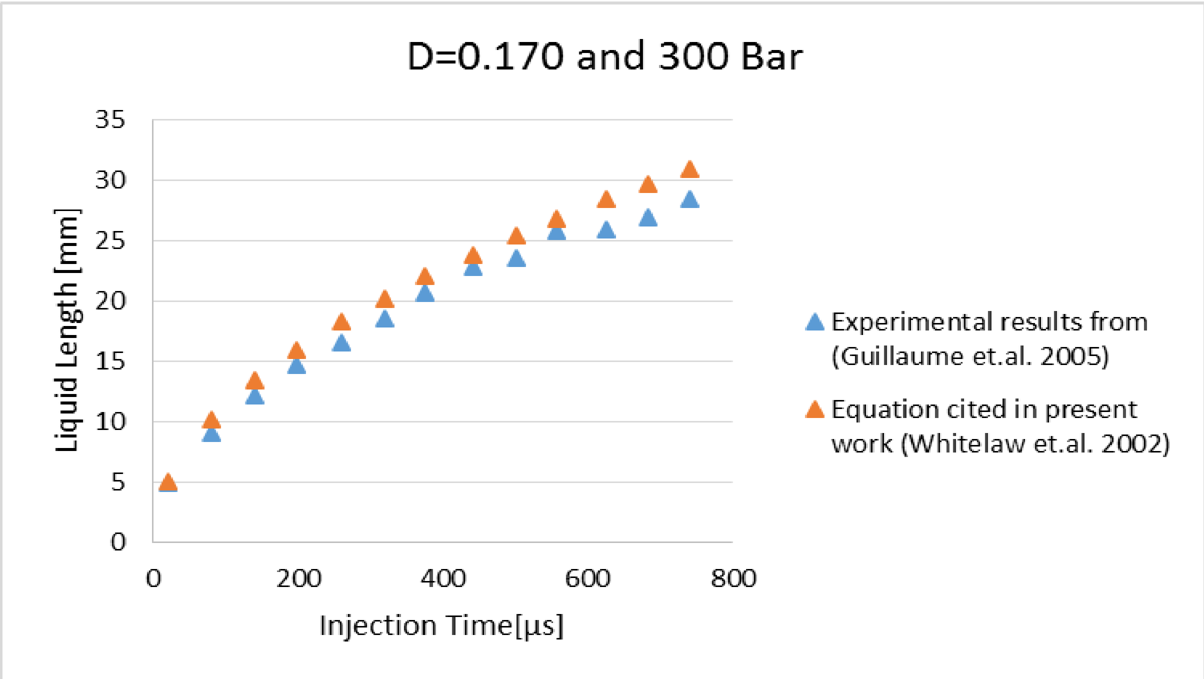

Figure 7 - Comparison of the liquid length experimental with equation cited by (Whitelaw et al. 2002).

3. CONCLUSION

The present work compared the recent literature on phenomenological models related to the characterization of diesel engine spray with experimental results. It can be seen in the spray angle graph that the curve generated by the model using the equation cited by (Aray, 2018) has a small deviation from the experimental curve, and it can be concluded that the equation used has a good representation of the experimental results .

The lift-off length was compared with the theoretical and experimental model cited by (Argachoy, 2004) so that it can be seen that the use of the equation cited for this parameter has a satisfactory representation of the theoretical and experimental model.

The equation used to define the Length of the Liquid also presents a small deviation from the experimental results, which can be seen in Charts 6 and 7, where the injection pressure is different.

We can conclude that the equations presented in this work show an acceptable agreement for the characterization of a spray. Therefore, it is possible to point out that the results of these equations can feed more complex models to describe the combustion process or define preliminarily the characteristics of the injector or injection condition.

4. ACKNOWLEDGEMENTS

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6. RESPONSIBILITY NOTICE