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Computer Modeling of a Liquid Fuel Spray

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OPPORTUNITY FOR UNDERGRADUATE RESEARCH PROJECT REPORT

"COMPUTER-MODELING OF A LIQUID FUEL SPRAY"

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ABSTRACT

This project was designed to find an accurate and convenient method of computing fuel spray parameters. The project centers around an experimental setup which basically fires a laser beam through a fuel spray mist. A concentric ring detector then measures energy from the scattered light.

A computer code was written which solves a governing equation to give computed values of the energy from scattered light. Comparison of the experimental energy and the computed energy tells how well the fuel parameters of the computer model matches those of the real spray of the experiment. An iteration technique then manipulates the computer model until the unknown parameters are solved for.

The computer code designed here works very well with calibration or known data. However, actual test data causes the computer code to crash. New techniques and approaches are currently being employed to salvage the code.

A specific liquid fuel spray exits a specific type of injector with certain repeatable and consistent parameters. The overall objective of this project is to repeatedly measure these characteristics with a high degree of accuracy and convenience.

Fuel sprays studied here are modeled as "Rosin-Rammler" (RR) distributions. The RR distribution is given as:

$$V(D) = \frac{\delta D^{\delta - 1}}{D\delta} \; Exp\left\{-(D/\bar{D})^{\delta}\right\} \tag{1}$$

where $\bar{D}$, the mean droplet diameter, and δ, the distribution width parameter, are constants for a particular fuel spray as mentioned above. These parameters are the points of interest here.

When a fuel spray exits an injector, the spray is made up of spherical droplets, ranging normally from 5 to 200 microns in diameter. The mean droplet diameter, as the name implies, is more or less an average droplet diameter. The distribution width parameter is a dimensionless relative gauge of the size of each class of droplets.

The project centers around the experimental setup of Figure 1. In this experiment, a laser beam is directed through a projected fuel spray flow, scattering light. This scattered light is detected by a flat, concentric ring detector (Figure 2) which detects the light as energy, given by:

$$Energy = L_{ik} = C\int_0^{\infty}\left\{ \left[J_o^2 + J_1^2\right] \alpha\theta^i - \left[J_o^2 + J_1^2\right]\alpha\theta_k\right\}\frac{1}{D}V(D)dD \tag{2}$$

This expression gives the energy incident upon the i^{th} ring.

(Note: For a more complete and in-depth discussion of the above points, see Dr. J.A. Drallmeier's M.S. and PhD. theses.)

The energy given by Equation 2 is measurable and is recorded data. Note, however, the containment of V(D), the size distribution, in the integral of Equation 2. The distribution is unknown and, to be solved for, must be assumed. Several distributions have been suggested by various researchers. As noted, this project assumed the function to be a Rosin-Rammler distribution, given by Equation 1. This is a widely accepted assumption.

Note also in Equation 2 the α term. α is given by:

$$\alpha = \frac{\pi D}{\lambda} \tag{3}$$

The dependence of α upon drop diameter, D, makes equation 2 all the more complicated (λ is wavelength of the laser light, a known constant). In addition, α is an argument of the Bessel functions, complicating matters further still. Also, note the θ term in Equation 2. (θ_i - θ_k) is the angle from the bottom of the ring to the top of the ring.

The anticipated method of solving for $\bar{D}$ and δ is to begin by making educated guesses for these two parameters. These values will be inserted into Equation 2 and the corresponding energies calculated. After comparison of the calculated energy values and those obtained from experiment, adjustments will be made in $\bar{D}$ and δ and the process repeated. Eventually, computed energy values and experimental energy values should match and thus, $\bar{D}$ and δ of the fuel spray is known.

Although this appears as a cookbook operation, Equation 2 is a difficult equation to solve. A computer code was written which accomplished this. The energy values produced by the code were checked against energy data obtained from a calibration reticle. A calibration reticle is a very thin gold foil slide which has been precisely etched. The gold is etched away to leave a known number of known diameter particles, thereby simulating fuel drops an a slide. With all numbers of particles and particle diameters known, the $\bar{D}$ and δ parameters of the RR distribution equation are also known.

The code written solved Equation 2 by representing the integral with a Simpson Rule approximation from calculus. The code also computes Bessel functions as needed. Bessel function values were checked against those of a CRC handbook. The integral is evaluated from a minimum diameter to a maximum diameter, instead of zero to infinity.

The energy values given by the code matched very well with experimental energy measurement of the calibration reticle. For this reason it was decided that output of the code was plausible and the code should be integrated into a larger code, with the purpose of performing the iterative solving procedure.

Since there are two unknowns at hand, namely $\bar{D}$ and δ, the iterative solution procedure is required to be a "non-linear" best fit routine. The method employed in this project is that laid out in chapter 14 of Numerical Recipes, by B.P. Flannery, et al. This method is basically a statistical analysis of the energy data and the two unknown parameters we seek. The analysis was realized with computer code by computing an error residual and partial derivatives of the particular function with respect to the unknown parameters. With these values, the analysis is designed to compute incremental values of $\bar{D}$ and δ which are used to create a better fit to the inputted experimental data. In short, the code constantly reduces the error residual and drives $\bar{D}$ and δ to values which most agree with the inputted energy curve.

The code was completed and was tested again with calibration reticle data. This was done by using energy data from the reticle as a data base and inputting $\bar{D}$ and δ values which were known to be incorrect. The code performed superbly and quickly iterated to the correct $\bar{D}$ and δ values. The code has not, however, proved successful with real test data. The iteration code "blows up" or crashes most of the time it encounters real test data.

The code's success with calibration data provides us with confidence that it's defects can be cured. We are currently trying a couple of different things, such as normalized data and a different, although still Rosin-Rammler, distribution function.

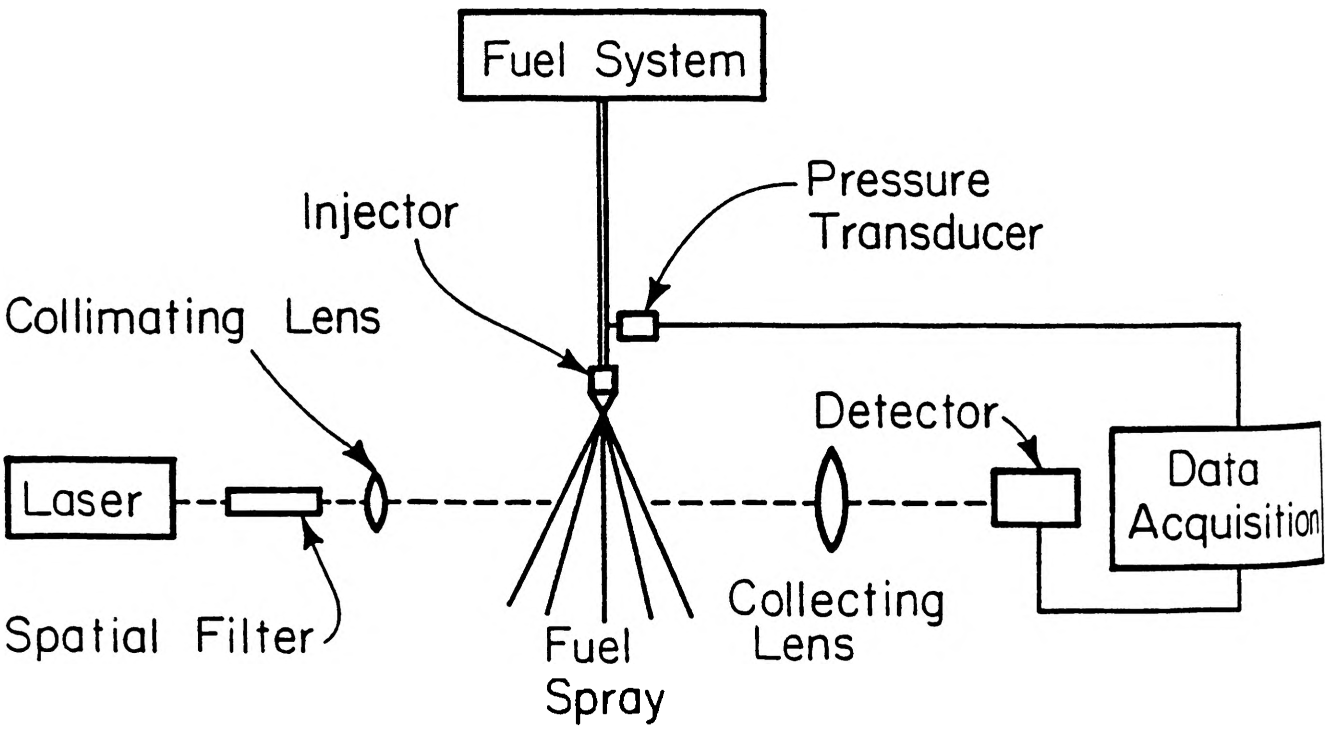

Figure 1) Experiment Setup

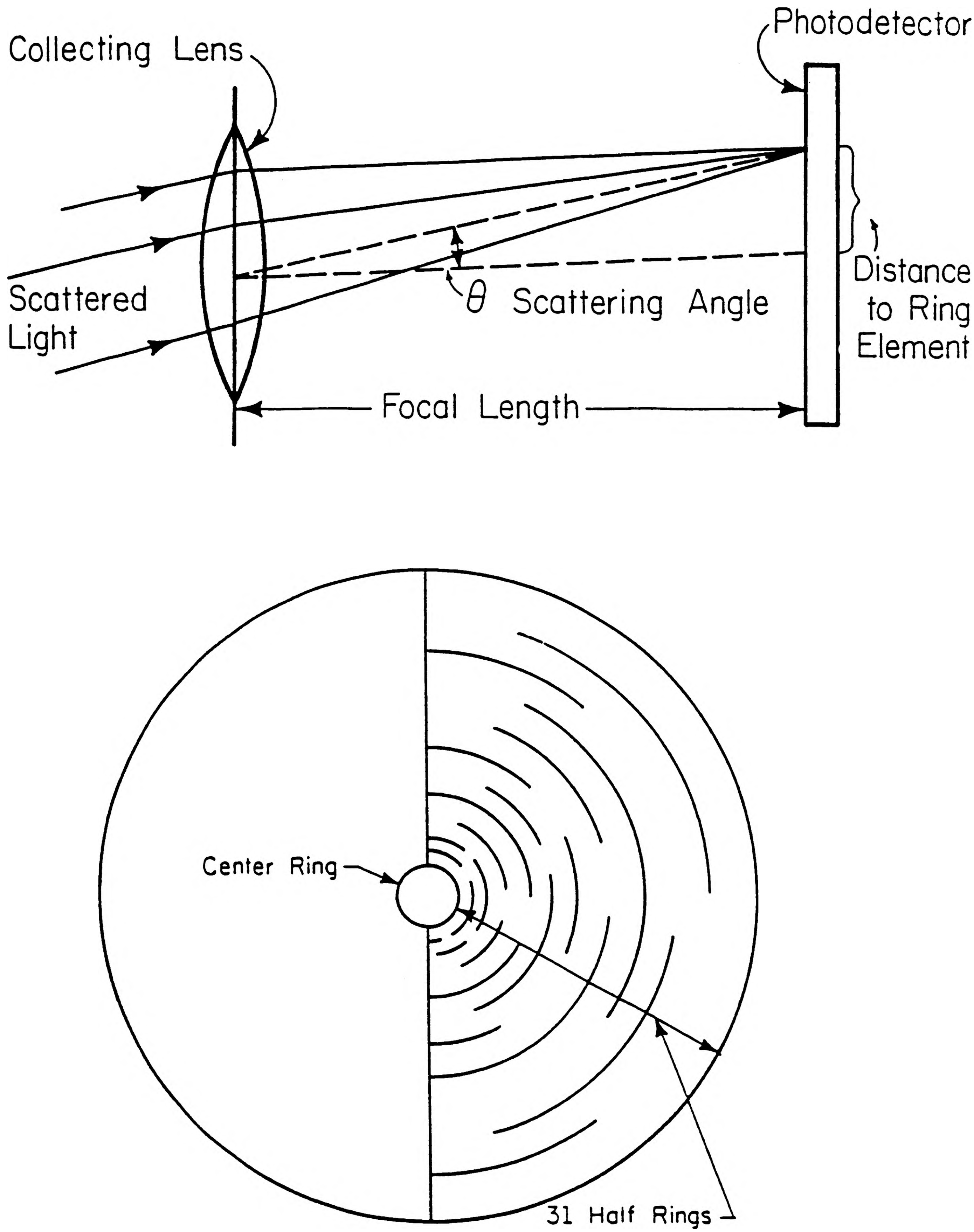

Figure 2) Ring Detector