Chemical Methods for Decreasing Jet Fuel Flammability

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Background

- During the 1970's and 80's scientists used physical methods to reduce fuel flammability in the event of a catastrophic fuel release.
- The fuel releases of interest, were those that occurred when an aircraft wing or jet fuel tank failed as the result of a ground crash situation.
- Atomized fuel release in the presence of an ignition source cause intense fires and explosions.
- Intense fires and explosions greatly reduce post crash survivability.
- Gelled fuel program and the Antimisting kerosene program (AMK).
- High molecular weight polymers were used to increase fuel viscosity and thus inhibit the fuel atomization.
- Small scale programs were very successful.
- Programs required modification of plane with degraders.
- Controlled impact demonstration (Boeing 720) failed.

Dryden Flight Research Center EC84-31805 Photographed 12/84
CID

http://www.dfrc.nasa.gov/gallery/photo/CID/HTML/index.html

Known

- Atomization of jet fuel can produce highly flammable, extremely explosive fuel air mixtures.
- The flammability characteristics of atomized jet fuel are dependent on the number density and droplet size of the fuel.
- Smaller droplets exhibit greater flammability.

Aviation Fuels with Improved Fire Safety: A Proceedings, NMAB-490; National Academy Press: Washington, DC. 1997; 1-141.

Objectives

- Develop an understanding of critical mechanisms that control aerosol production
- Model aerosol production mechanisms
- Correlate flammability characteristics with aerosol parameters
- Reduce fuel flammability by the addition of chemical additives

Non-Flammable Fuel?

Jet engine combustion: atomization is in a controlled environment

- adjust pressure, temperatures, and nozzles

Safety: leak or rupture under atmospheric conditions

- chemical additives ideally prevent fuel from burning

Aerosol Dynamics

Chemical and physical parameters of aerosol production

- Liquid surface tension
- Liquid molecular interactions
- Viscosity
- Vapor pressure
- Liquid density

Fuel Characteristics

MIL-DTL-5624M (JP5) and MIL-DTL-83133B (JP8)

- Hydrocarbon content C_9-C_{16}
- 55% Aromatic, 45% Alkanes
- Flashpoint 38 ^{0}C (JP8), 60 ^{0}C (JP5)
- Boiling point 150-290 ^{0}C
- Autoignition temperature 229 ^{0}C
- Several thousand components
- Maximum sulfur of 0.5%, sulfides, disulfides, thiols
- Nitrogen in 10 to 15 ppm range

Fuel Storage

Chemical additives to control fuel flammability must be stable

- Military fuels can be in storage for one/two years
- Low molecular weight acid compounds, alcohols, and aldehydes promote jet fuel degradation
- Fuel degradation is measured in terms of sediment formation that can plug nozzles and filters

Mushrush, G. W. Fuel Instability 1: Organo-Sulfur Hydroperoxide Reactions. Fuel Science and Technology INT'L **1992**, 10, 1523-1560.

Watkins, J. M. Jr.; Mushrush, G. W.; Hazlett, R. N.; Beal, E. J. Hydroperoxide Formation and Reactivity in Jet Fuels, Energy and Fuels **1989**, 3, 231-236.

Proposed Chemical Fuel Additives

Chemical structures stable in fuels

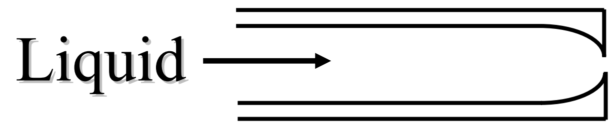
- Esters (methyl linoleate – C_{18} and methyl palmitate –C_{16})
- Hydrocarbon polymers (polyisobutylene and polyisoprene)
- Methacrylates
- High molecular weight ethers (polyoxyethylene isooctylcyclohexyl ether)
- Aromatic alkyl substituted phenols
- Anticing compounds (NRL patent)

Little, R. C.; Pratt, R.; Romans, J. B. The Effects of Additives on the Aerosolization of JP-5 Jet Fuel. Fire Safety journal **1983**, *5*, 145-156.

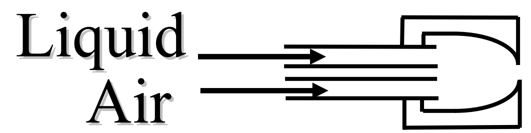
Mannheimer, R. J. *Degradaton and Characterization of Antimisting Kersosene (AMK),* DOT/FAA/CT-82/93, National Technical Information Service: Springfield VA, 1985; 1-77.

Atomizers

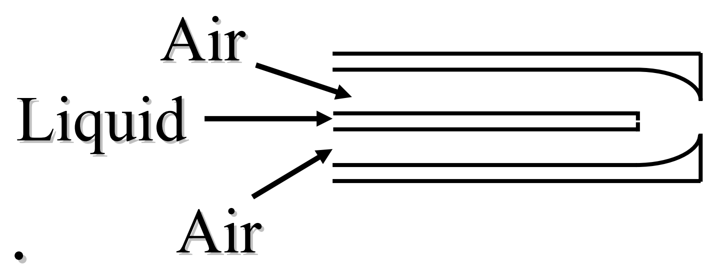
- Pressure atomizers (nozzles)



- Air-Assist atomizers



- Airblast atomizers



- Rotary atomizers to be used in this study

Lefebvre, A. H. *Atomization and Sprays;* Hemisphere Publishing Corporation: Philadelphia, 1988.

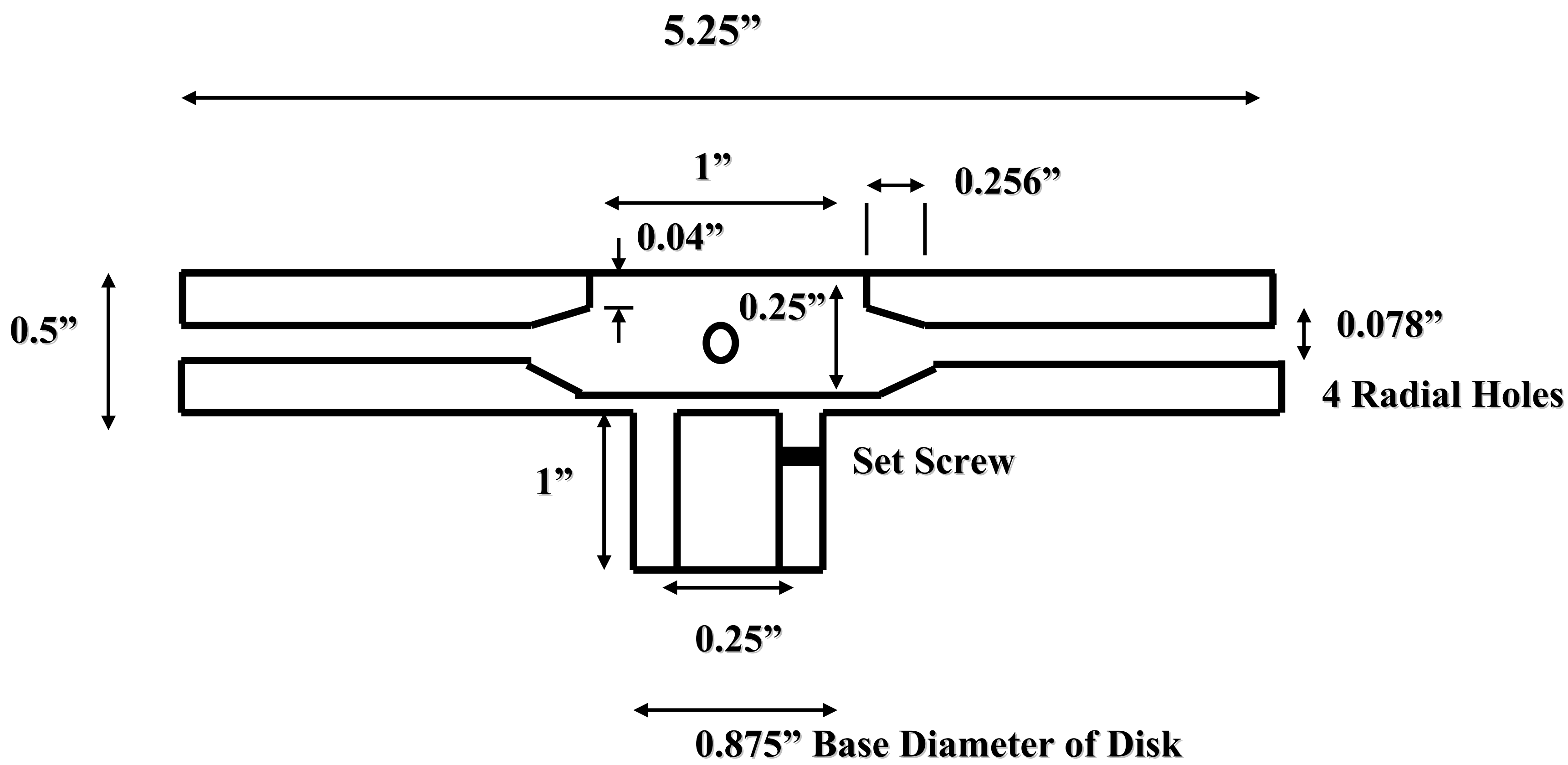
Rotary Atomizer

- Simulate droplet linear velocities associated with aircraft landing in crash situations.
- Drop sizes of the fuel formed in the flat spray pattern easily controlled by the rotational speed of the atomizer.
- Simulate shearing forces and their effects on additives associated with droplet formation.

Lefebvre, A. H. *Atomization and Sprays;* Hemisphere Publishing Corporation: Philadelphia, 1988.

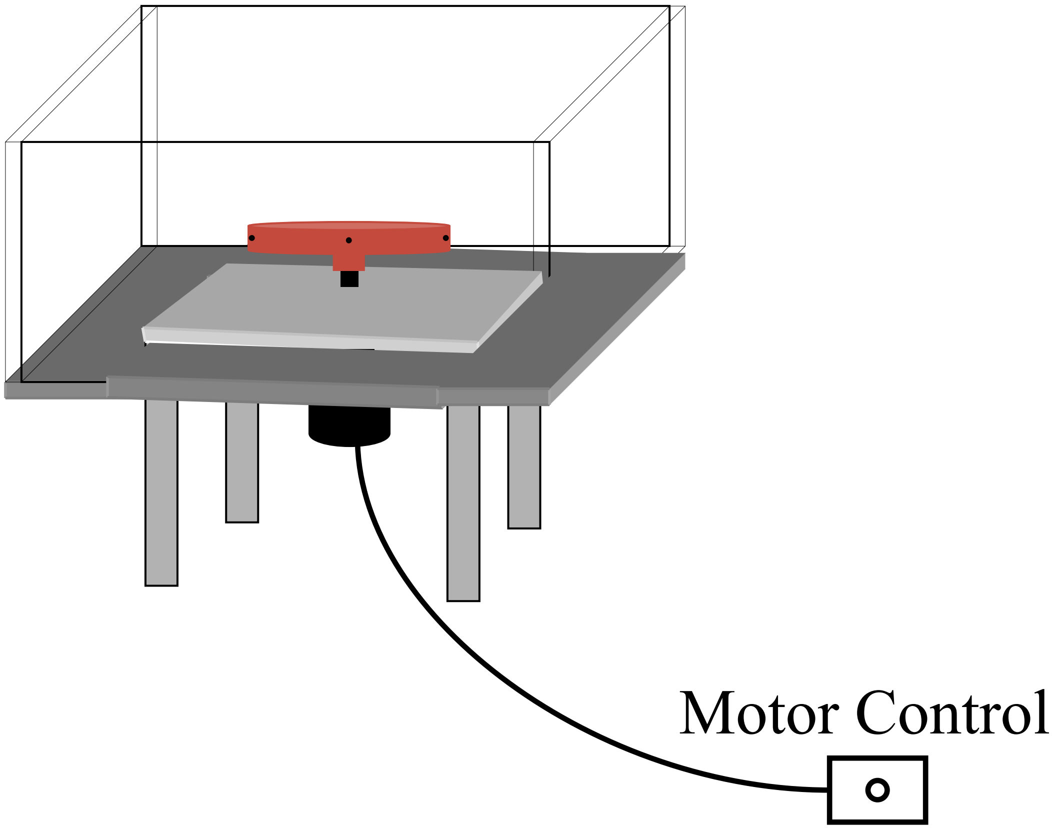
Mannheimer, R. J. Real-*Time Quality Control of Antimisting Kerosene (AMK),* DOT/FAA/CT-85/5, National Technical Information Service: Springfield VA, 1985; 1-47.

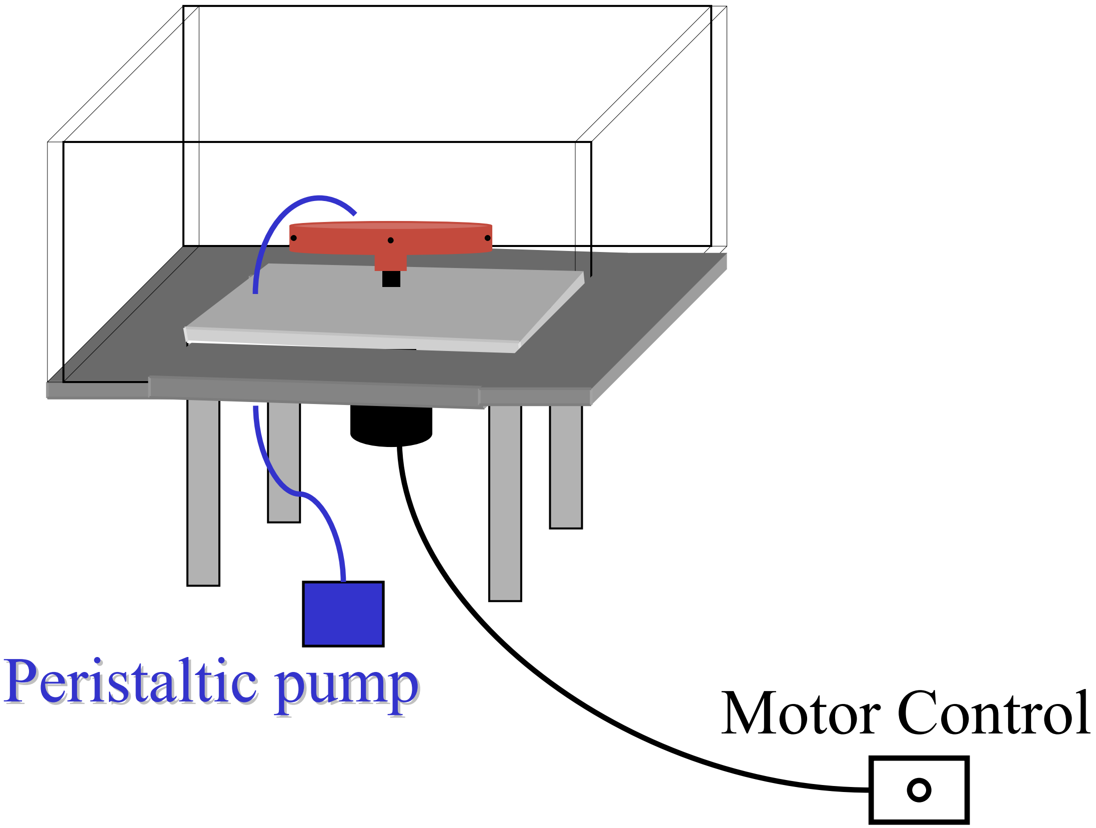
Cross-section of Rotary Atomizer Disk

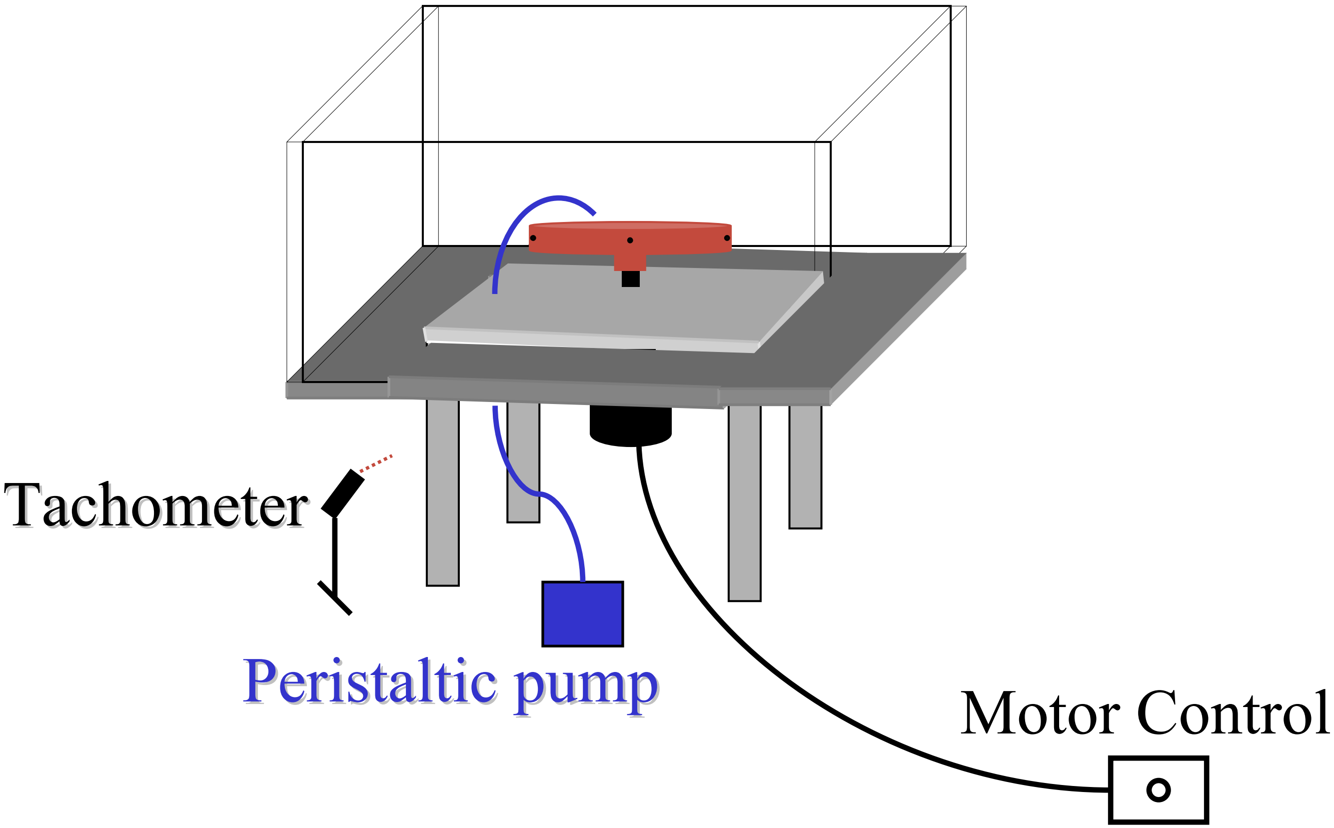


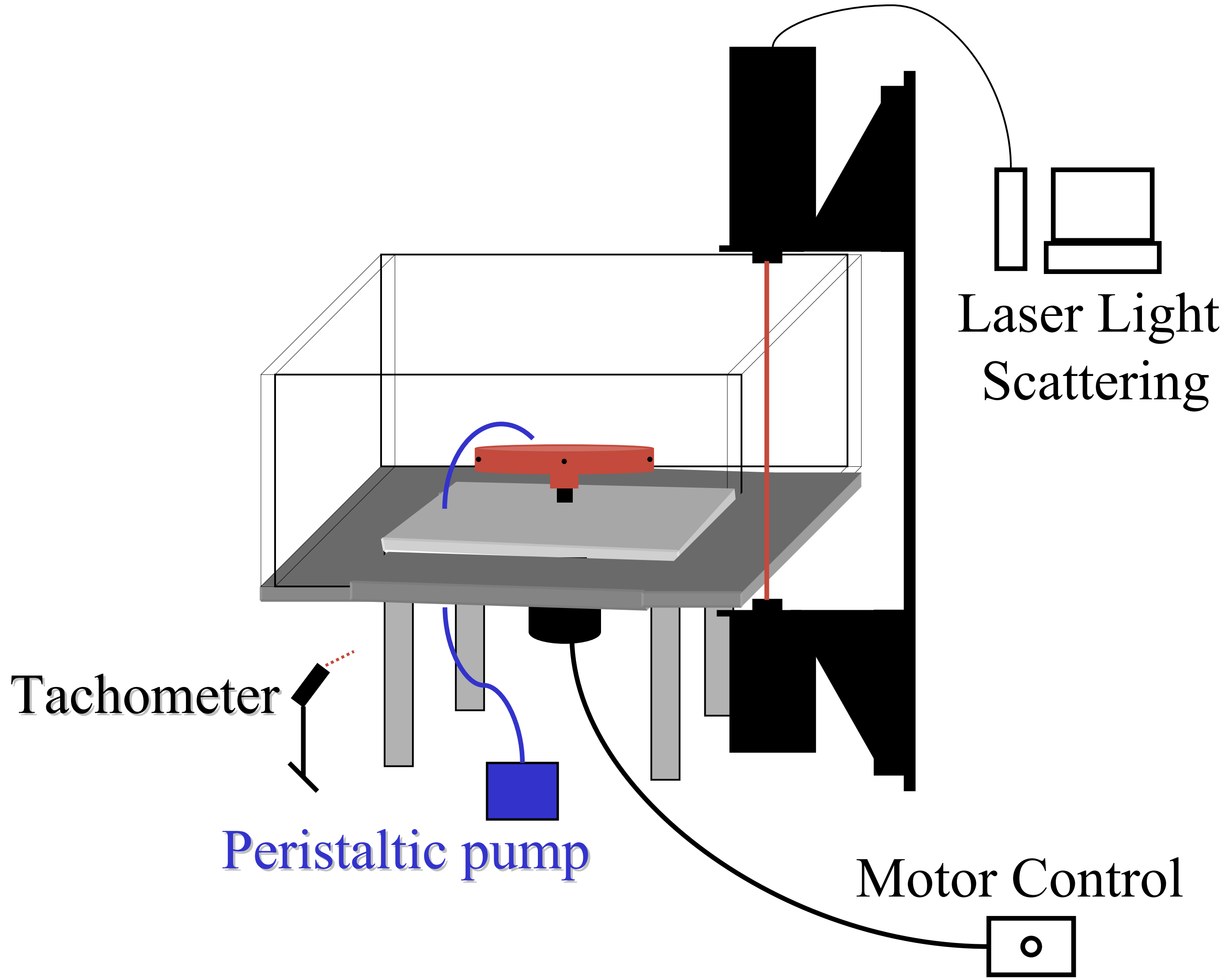
Mannheimer, R. J. *Degradaton and Characterization of Antimisting Kersosene (AMK),* DOT/FAA/CT-82/93, National Technical Information Service: Springfield VA, 1985; 1-77.

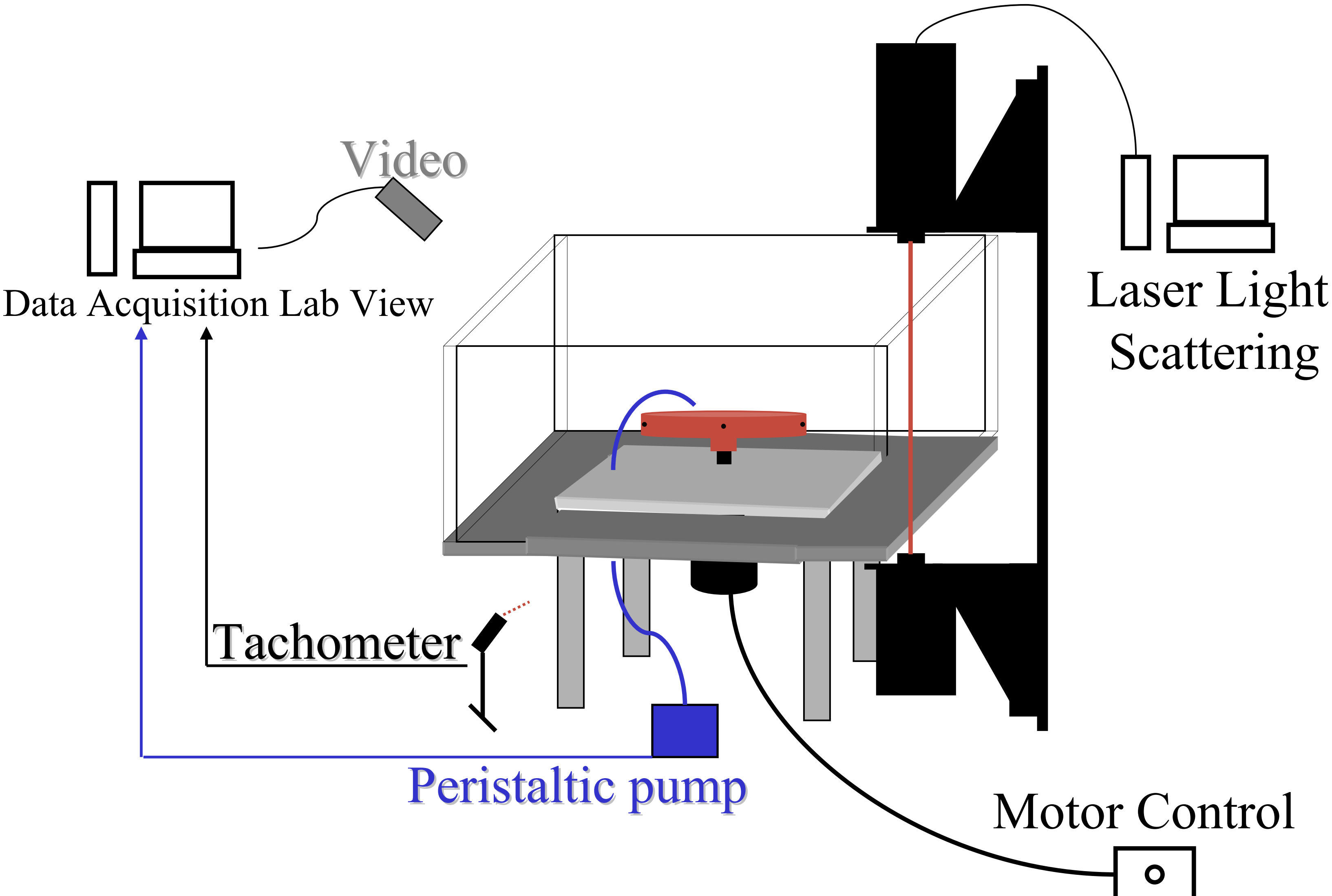
Little, R. C.; Pande, S.; Romans, J. B. *Evaluation of Polyisobutylene (PIB) Formulations in JP-5 Jet Fuel: The Effect of PIB Concentration on Fuel Mist Flammability,* NRL Memorandum Report 5195; Naval Research Laboratory: Washington, DC, September 1983; 1-24.

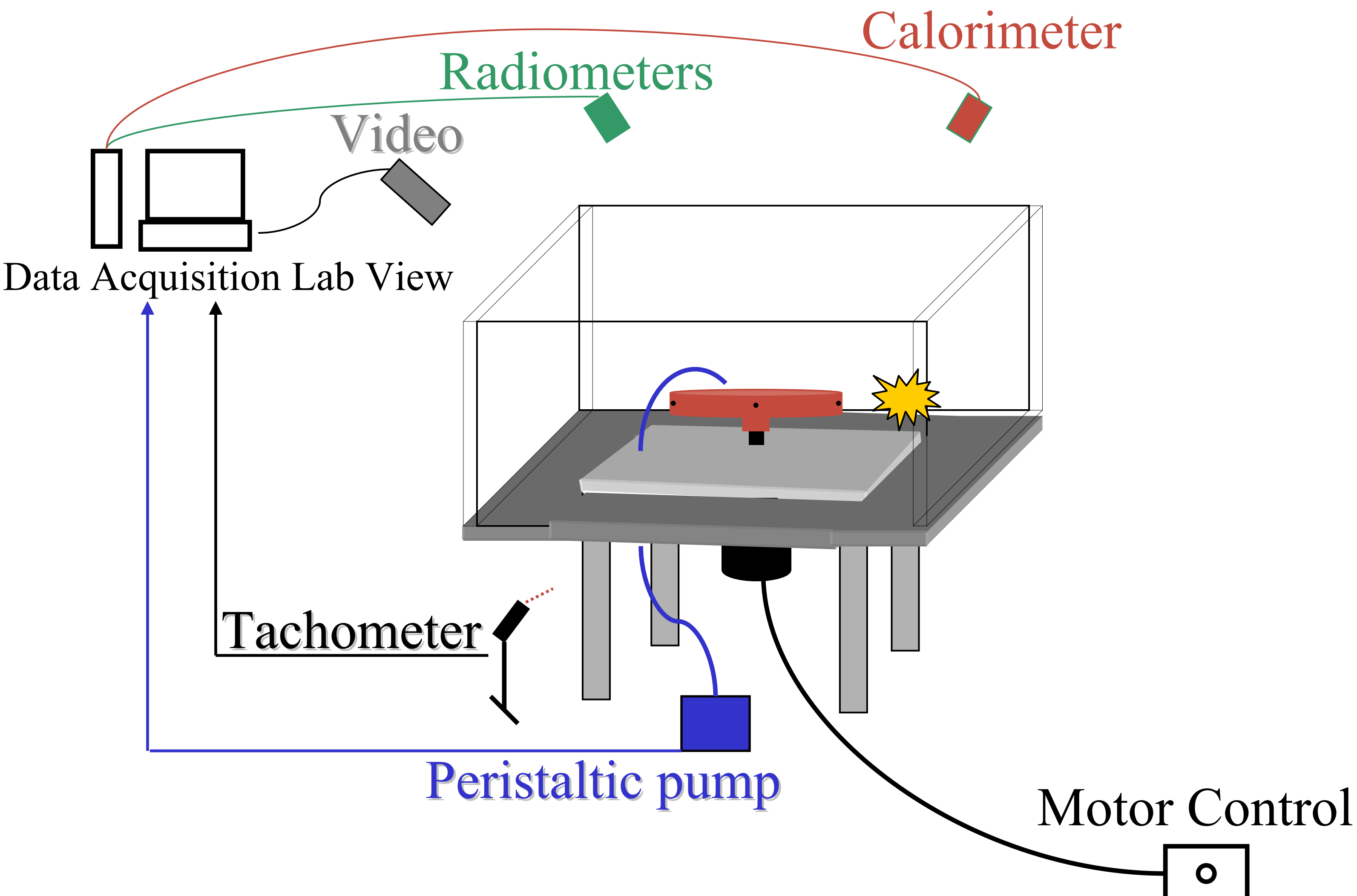

Motor Control


Peristaltic pump
Motor Control


Tachometer
Peristaltic pump
Motor Control


Laser Light
Scattering
Tachometer
Peristaltic pump
Motor Control


Video
Data Acquisition Lab View
Laser Light Scattering
Tachometer
Peristaltic pump
Motor Control


Calorimeter
Radiometers
Video
Data Acquisition Lab View
Tachometer
Peristaltic pump
Motor Control

Rotary Atomizer

Video of Rotary Atomizer

Rotary Atomizer Instrumentation

- LabVIEW data acquisition system for automated control and data collection.
- Video monitor for the ignition of fuel mist and propagation of ignited flame.
- Control of disk speed is achieved by a variable frequency speed controller.

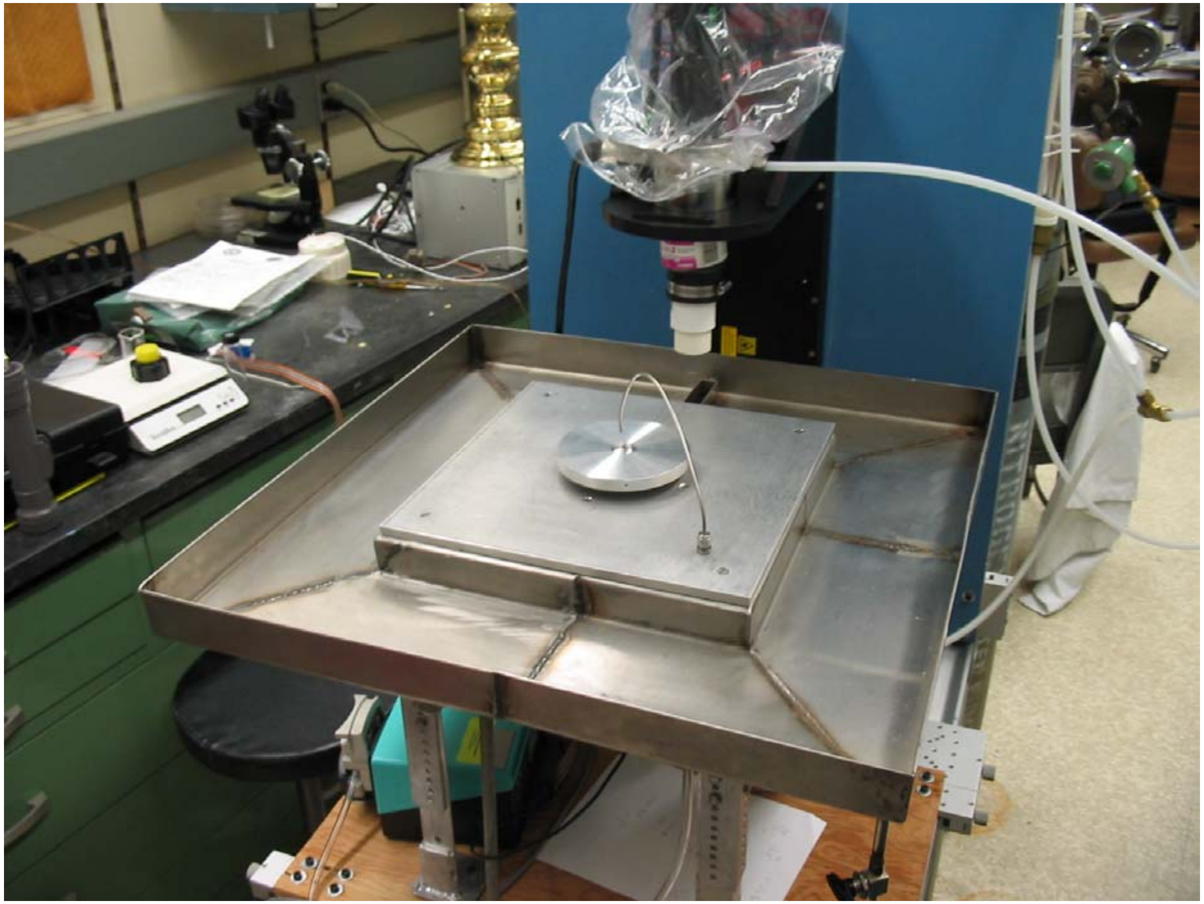
Drop Size Measurements

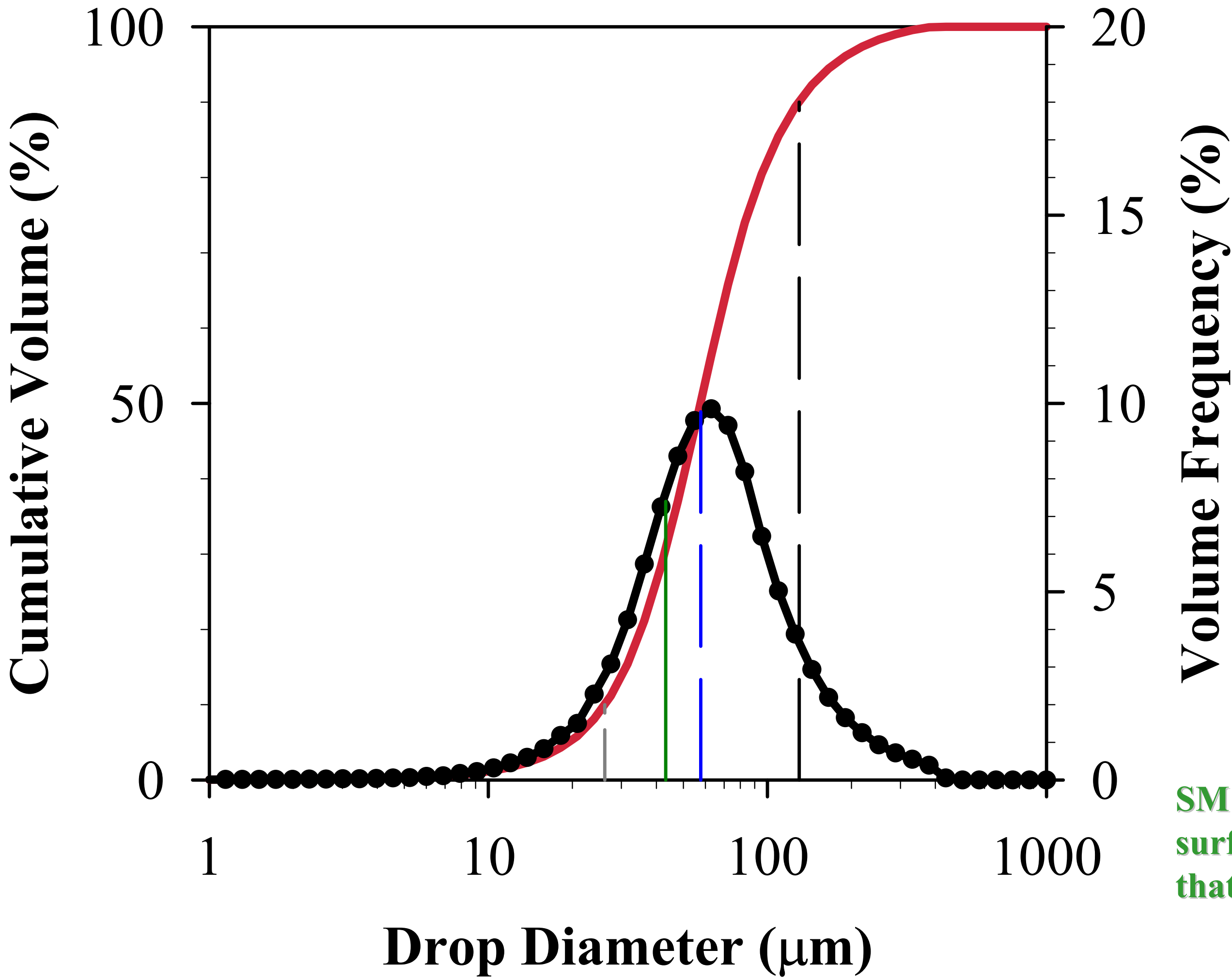
- Malvern Spraytech
- Laser forward light scattering
- 670 nm diode laser
- 10 mm beam diameter (other sizes available)
- Real time measurements 1 to 2500 Hz
- Size range 1.0 µm to 850 µm (other size ranges available)

Measurement of Aerosol Size Distribution

Malvern Spraytech Coupled to Atomizer

- Drop size distribution
- Number density
- Specific surface area





Dv(10) = 26 µm
SM = 43 µm
Dv(50) = 58 µm
Dv(90) = 130 µm

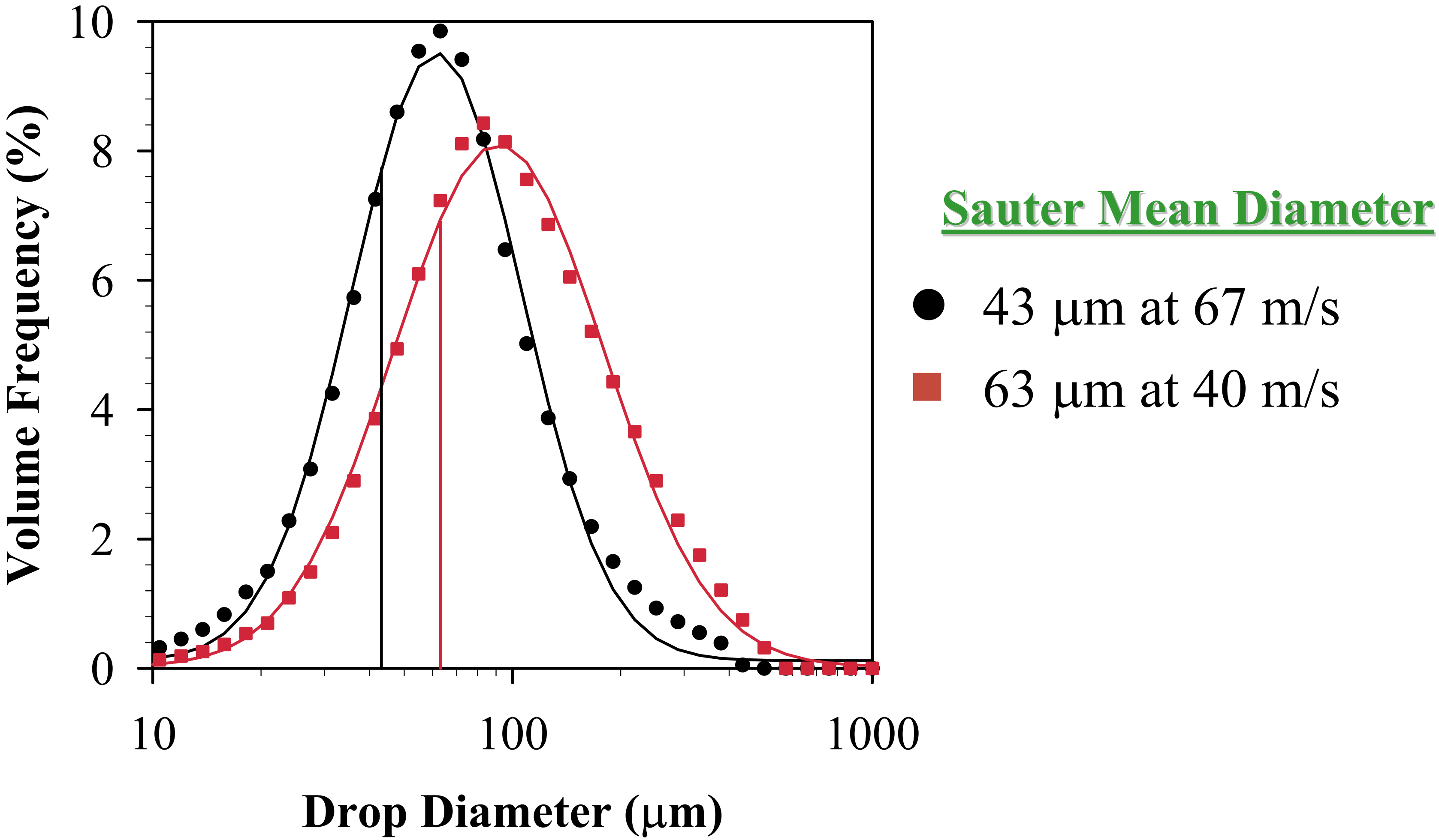
SM = Diameter of a droplet whose surface to volume ratio is equal to that of the entire spray.

Rotary Atomizer Size Distribution for a Water Aerosol at Flow of 410 mL/min and Disk Tangential Velocity of 67 m/s

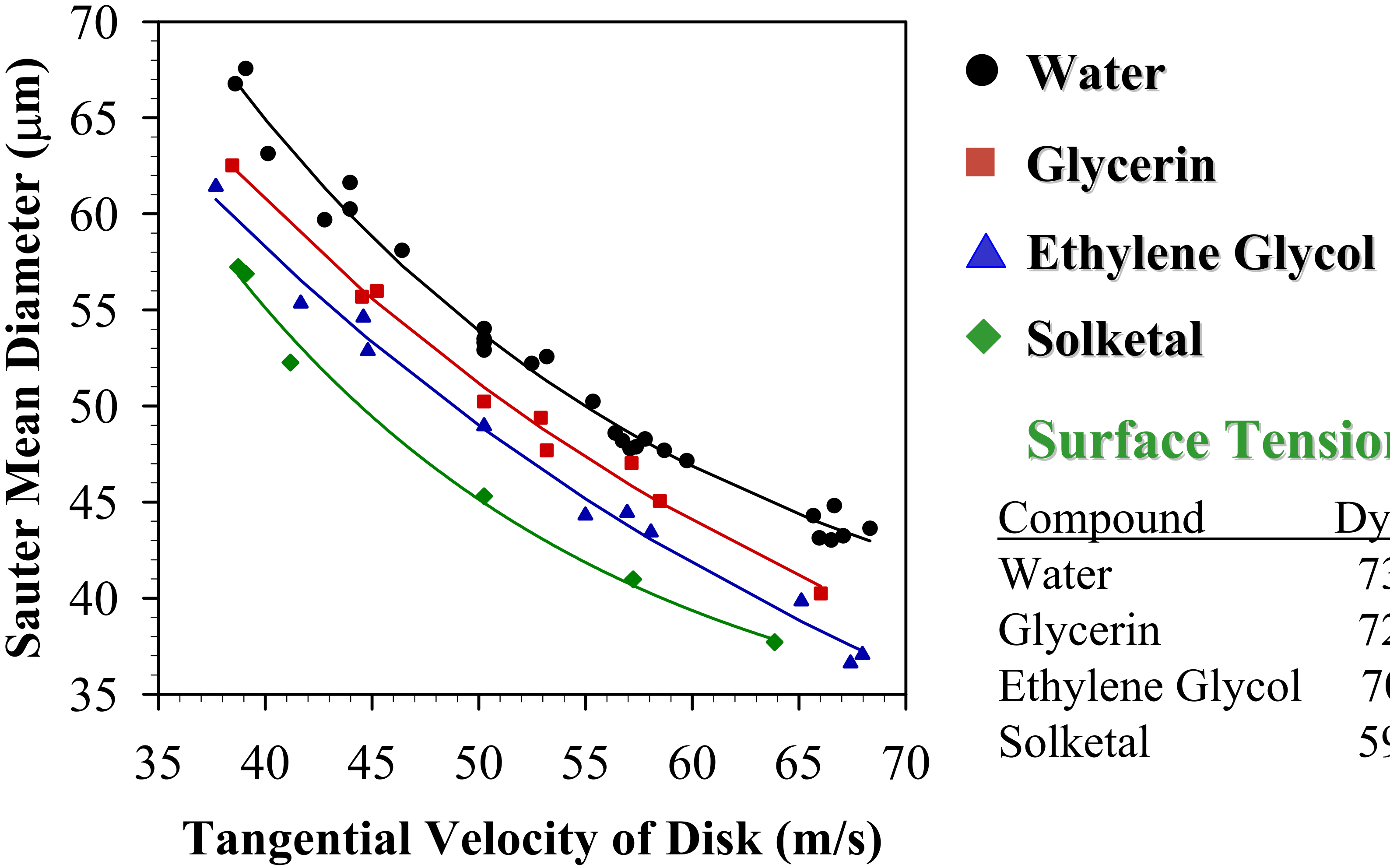
Aerosol Systems

- Water aerosols
- Water/additives aerosols

- Dodecane aerosols
- Fuel aerosols
- Fuel/additives aerosols



Drop Size Distribution for a Water Aerosol at a Flow of 410 mL/min and Disk Tangential Velocities of 67 m/s and 40 m/s

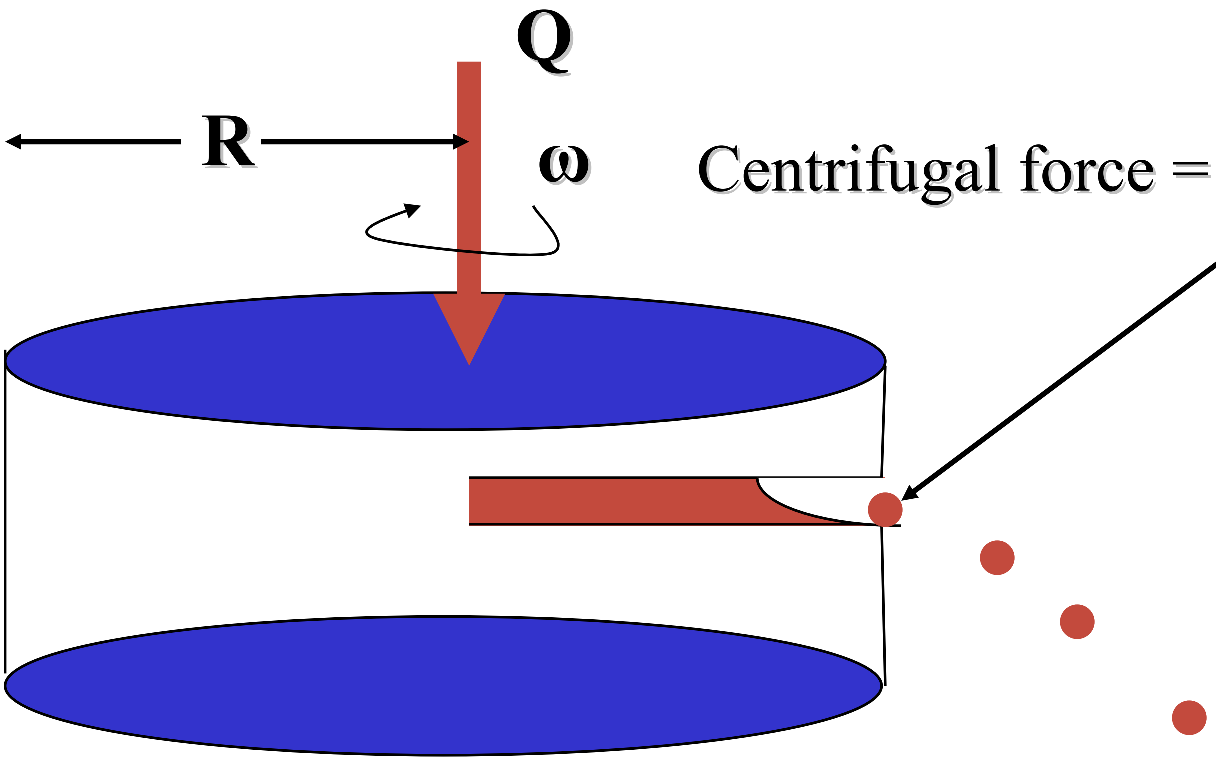


Surface Tension

Compound	Dynes/cm
Water	73
Glycerin	72
Ethylene Glycol	70
Solketal	59

Sauter Mean Diameter vs. Disk Tangential Velocity for a 5% (v/v) Additive/Water Aerosol at Flow of 410 mL/min

Droplet Formation at Low Flow Rates, Q



Centrifugal force = surface tension force

$$\frac{d}{R} = \frac{c}{\sqrt{W_e}}$$

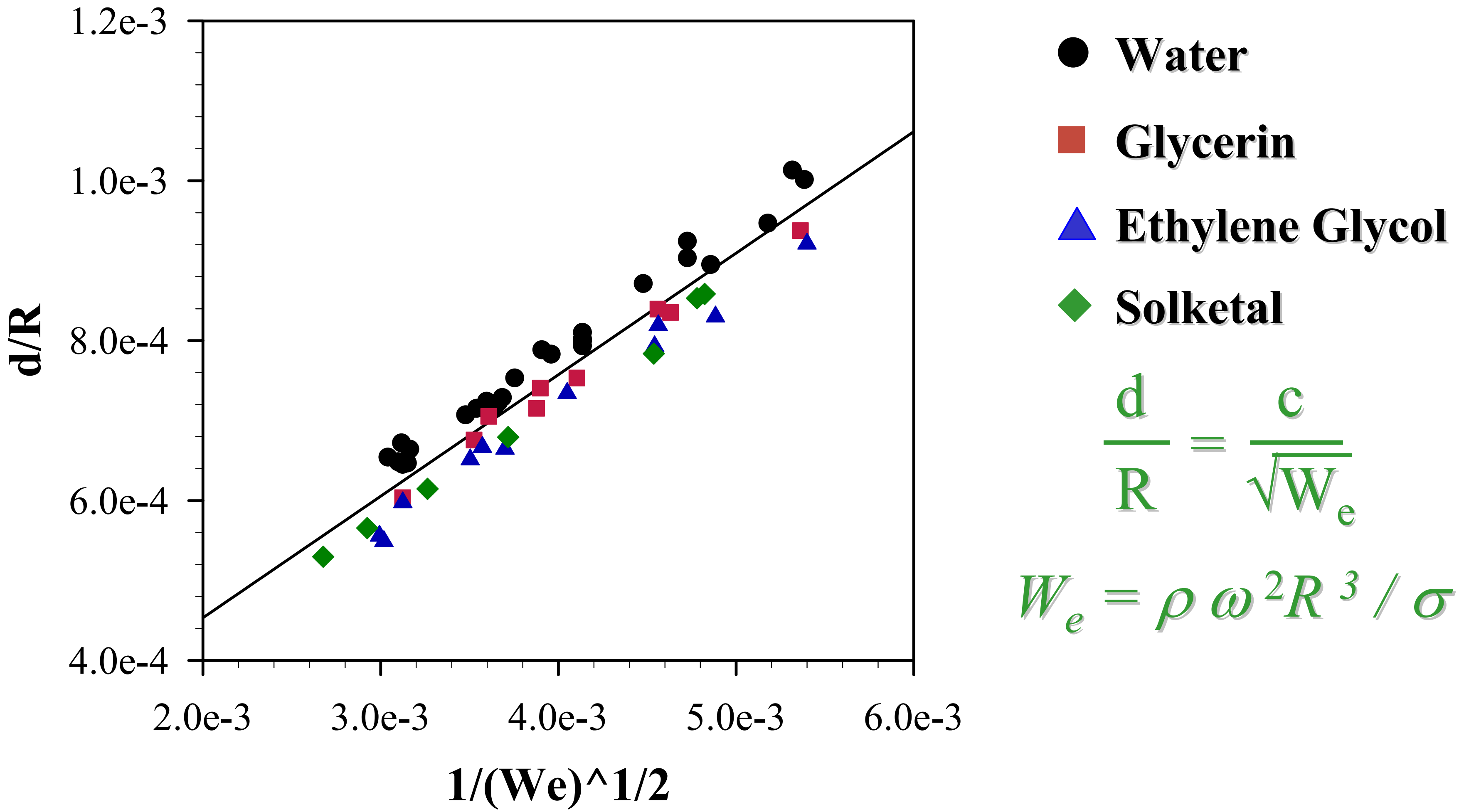
$$W_e = \rho\,\omega^2 R^3 / \sigma$$

$$(\pi d^3 \rho / 6)(\omega^2 R) = c(\sigma \pi d)$$

(Drop Mass) (Acceleration) (Surface tension) (Circumference)

Drop diameter (d) and ω are independent of Q

Lefebvre, A. H. *Atomization and Sprays;* Hemisphere Publishing Corporation: Philadelphia, 1988.

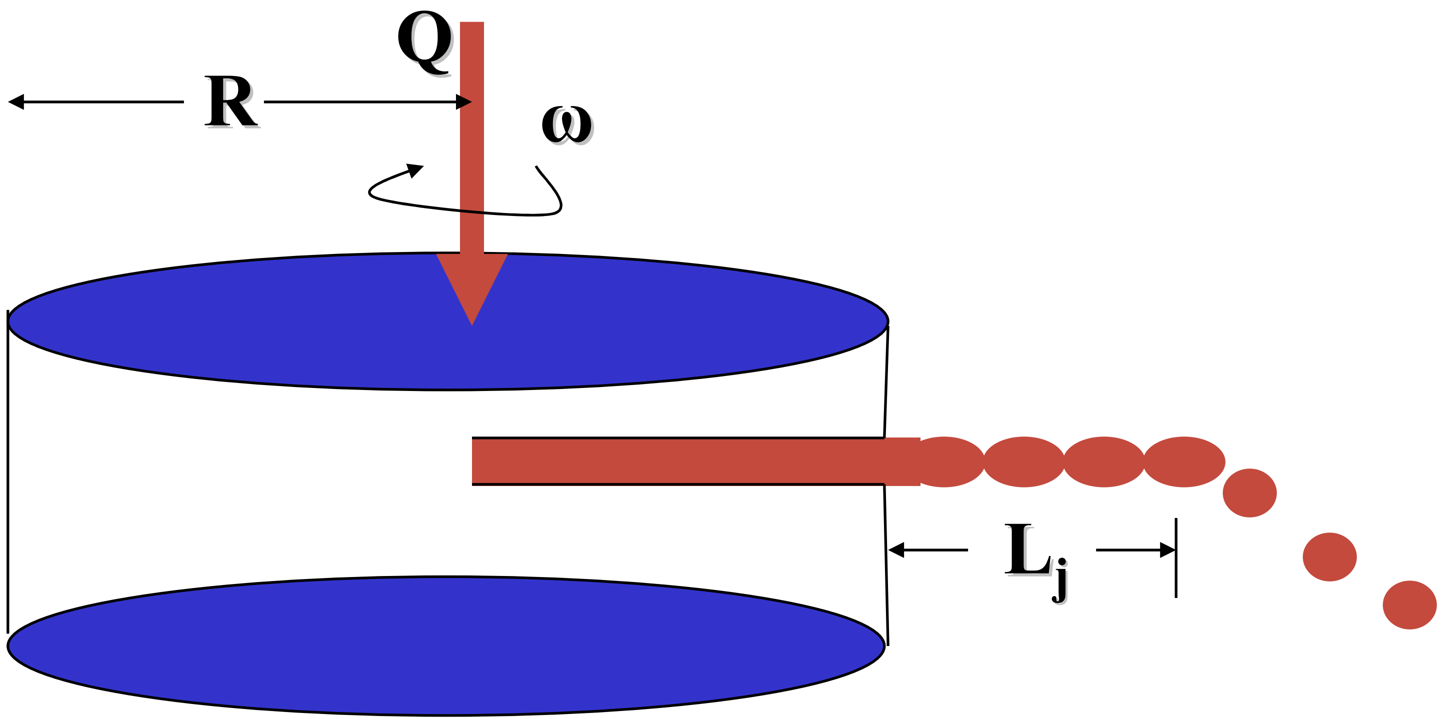


$$\frac{d}{R} = \frac{c}{\sqrt{W_e}}$$

$$W_e = \rho\,\omega^2 R^3 / \sigma$$

The Ratio of Drop Diameter to Disk Radius vs. the Inverse of the Weber Number for a 5% (v/v) Additive/Water Aerosol

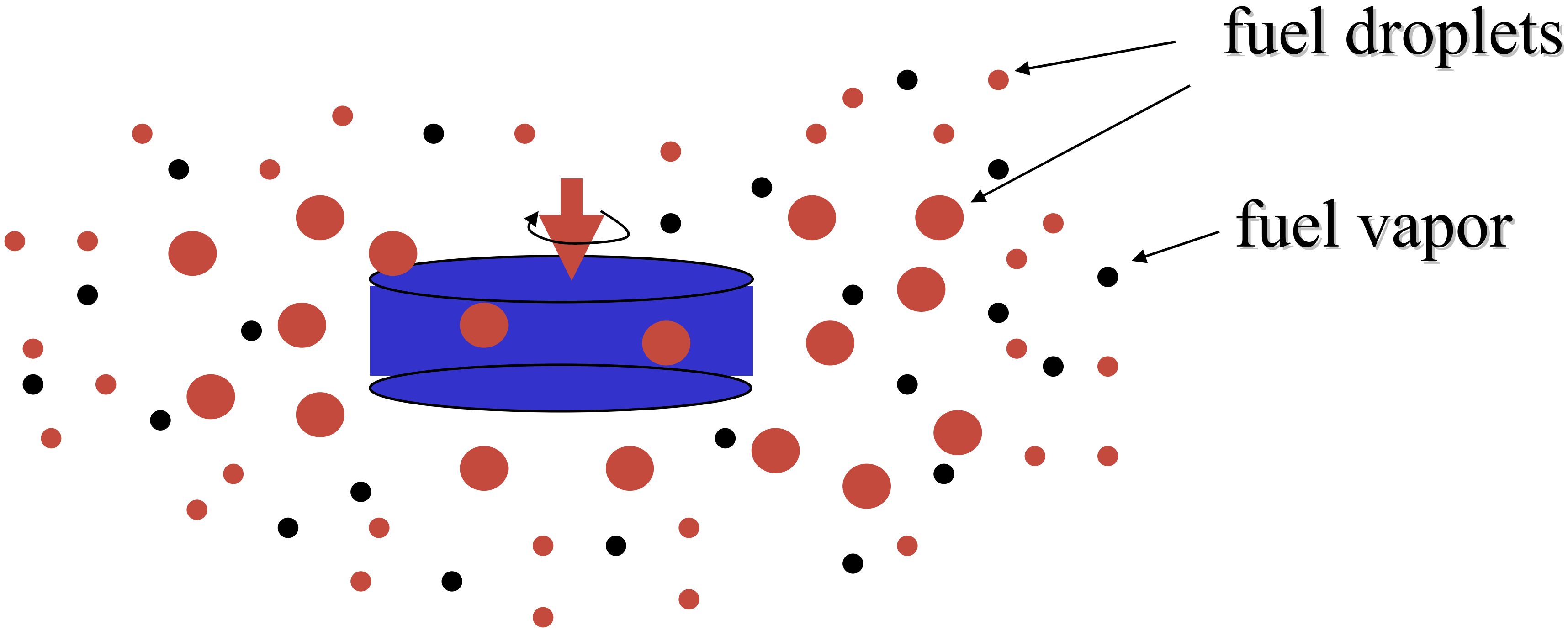
Droplet Formation at High Flow Rates, Q



- Growth of shear induced instabilities on the jet is opposed by the surface tension forces
- Jet breakup length, L_j depends on Q, W_e, R_e
- Drop diameter depends on We and Re

Lefebvre, A. H. *Atomization and Sprays;* Hemisphere Publishing Corporation: Philadelphia, 1988.

Droplet Transport



- Droplet evaporation
- Droplet coalescence

Fuel Aerosol Flammability

For defined aerosol liquid parameters

- Heat flux measurements
- Flame propagation

Flammability

Ignition Sources

- Electrical sparks or arcs
- Lasers
- Hot Surfaces (frictional sparks, heated wires, rods, or fragments, heated vessels or tubes)
- Pilot or burner flames

Conclusion

- Apparatus characterization is in progress.
- Additives with water are shown to behave in reproducible and predictable fashion.
- Efforts to begin fuel analysis are underway.

Benefits of Research

Successful research will benefit both military and civilian sectors

- Increased fuel safety aboard both military and civilian aircrafts
- Increased safety aboard military aircraft carriers
- Improved safety for all middle distillate fuel applications
- Research may be applied to other potential flammable fluids used aboard Navy vessels

Acknowledgements

- Frederick W. Williams
- George G. Mushrush
- Ramagopal Ananth
- John B. Hoover
- Jean L. Bailey
- Bradley A. Williams
- Naval Research Laboratory (YIP Funding)
- Office of Naval Research

The Fourth Triennial International Aircraft Fire and Cabin Safety Research Conference