NAVAL POSTGRADUATE SCHOOL

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THESIS

EFFECT OF PRESSURE AND TEMPERATURE ON OIL MIST SPRAYS USED FOR BLADE EXCITATION IN HIGH CYCLE FATIGUE TESTING

by

Andrew P. Thompson

June 2006

Thesis Advisor: Raymond Shreeve
Second Reader: Garth Hobson

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The flow patterns of two oil mist nozzles used in rotor blade excitation experiments were characterized using a Laser Doppler Velocimeter (LDV). Both nozzles were operated in a vacuum test chamber and velocity measurements were taken at three axial distances from the nozzle exit, at three or four different pressures, at three different temperatures. The 4 gallon per hour "mini-mist" nozzle produced a "referenced velocity" consistent with a hollow cone at each axial location, pressure, and temperature. The temperature of the oil flowing through the 4 gallon per hour nozzle did not affect the nozzle's performance. The 6 gallon per hour "standard" nozzle produced a "solid" cone structure at each axial location, pressure, and temperature. The temperature of the oil flowing through the 6 gallon per hour nozzle did affect the nozzle's performance. The spray pattern quantification can be used to design blade excitation experiments in high cycle fatigue (HCF) vacuum spin tests.

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EFFECT OF PRESSURE AND TEMPERATURE ON OIL MIST SPRAYS USED FOR BLADE EXCITATION IN HIGH CYCLE FATIGUE TESTING

Andrew P. Thompson
Ensign, United States Navy
B.S., United States Naval Academy, 2005

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June 2006

Author: Andrew P. Thompson

Approved by: Dr. Raymond Shreeve
Thesis Advisor

Dr. Garth Hobson
Second Reader

Dr. Anthony Healey
Chairman
Department of Mechanical and Astronautical Engineering

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ABSTRACT

The flow patterns of two oil mist nozzles used in rotor blade excitation experiments were characterized using a Laser Doppler Velocimeter (LDV). Both nozzles were operated in a vacuum test chamber and velocity measurements were taken at three axial distances from the nozzle exit, at three or four different pressures, at three different temperatures. The 4 gallon per hour “mini-mist” nozzle produced a “referenced velocity” consistent with a hollow cone at each axial location, pressure, and temperature. The temperature of the oil flowing through the 4 gallon per hour nozzle did not affect the nozzle’s performance. The 6 gallon per hour “standard” nozzle produced a “solid” cone structure at each axial location, pressure, and temperature. The temperature of the oil flowing through the 6 gallon per hour nozzle did affect the nozzle’s performance. The spray pattern quantification can be used to design blade excitation experiments in high cycle fatigue (HCF) vacuum spin tests.

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I would like to thank Dr. Garth Hobson for his kindness in showing me how to use the LDV system. None of my thesis would have been possible without his assistance.

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Lastly, I would like to thank my mother and father for their continuing support throughout my educational experience. Without their support, none of this would have been possible.

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I. INTRODUCTION

Oil jet excitation (OJE) has been recently developed successfully to excite rotor blade resonance in vacuum spin tests (References 1, 2). The purpose of such tests is to examine high cycle fatigue (HCF) tolerance to blade damage, and to progressively develop new blade resonance damping techniques. The OJE technique is able to produce excitation forces large enough to verify structural integrity at resonance to 10^7 cycles.

The OJE technique in early tests showed that discrete jets gave the desired excitation magnitudes, but eroded the blade past the erosion threshold before a 10^7 cycle test was completed (Reference 1). Conversely, oil mist nozzles, when arranged in a similar manner as the discrete jets, produced lower excitation amplitudes, but the erosion effects were not expected to be a problem. Therefore, studies were conducted on discrete jets with smaller diameters to extend the erosion threshold, and on oil mist nozzles to improve the excitation amplitudes (Reference 3). Moreno was able to develop discrete jet nozzles with extremely small diameters (Reference 3). It was later found that oil mist nozzles could in fact produce excitation amplitudes sufficient for endurance testing (Reference 2). Consequently, more studies were conducted in an effort to quantify oil-mist spray patterns in order to permit the desired design of an excitation arrangement in any new rotor test (Reference 4).

A study conducted by Vonderheide using Laser-Doppler Velocimetry (LDV) of two nozzles used in vacuum spin tests quantified the spray patterns at three axial locations at three different supply pressures. A four gallon per hour “mini-mist” Hago nozzle, the type used at the Rotor Spin Research Facility at the Naval Postgraduate School (NPS), and a six gallon per hour “standard” Hago nozzle, the type used in the Rotor Spin Facility at the Naval Air Warfare Center’s Propulsion and Power Center at Patuxent River, Maryland, were studied. It became evident during the study that the oil pumping system produced a temperature rise in the oil, which in turn affected the nozzle performance (Reference 4). Thus, the initial goal of the present study was to quantify the temperature effect on the spray from the two nozzles. After initial tests to establish techniques successfully, a program of 63 tests was conducted using one 4 gph mini mist nozzle and one 6 gph standard Hago nozzle. Laser Doppler Velocimetry (LDV) was used to map the velocity at three axial displacements from the nozzle exit, and the results were empirically correlated to equations that describe a simple conical flow pattern.

II. BACKGROUND

A. ROTOR SPIN RESEARCH FACILITY

The Rotor Spin Research Facility at the Turbopropulsion Laboratory (TPL) at NPS was established to support the HCF testing program at the Naval Air Systems Command facility in Patuxent River, MD.

An air turbine drives the test rotor in a pressure vessel which is lined with 10 inches of steel and 4 inches of lead brick. A near vacuum is maintained in the pit so that the air turbine is able to use very little energy while operating at very high speeds (Reference 4). However, with no air present, an alternate source of excitation of the blades is necessary. This excitation has been generated successfully using the oil-mist nozzles which are the focus of the present study.

Figure 1 shows a schematic diagram of the spin pit pressure vessel and oil injection and recovery system. Figure 2 shows one installation of the mist nozzles in the spin pit. Of note is the position of the nozzles under the rotor so that the spray impacts the undersurface of the blade tips. Strain gauges are used to measure the blade response to the mist impact, and the electrical lead wires are fed through a high-speed slip ring.

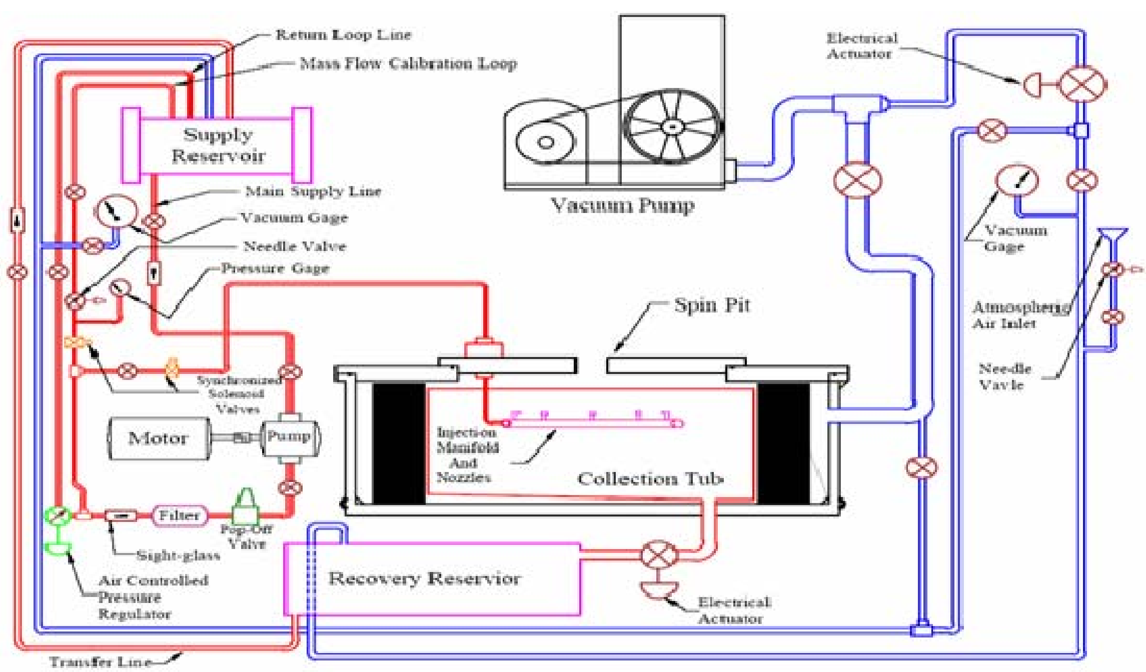

Figure 1. Spin pit and oil injection and recovery system.

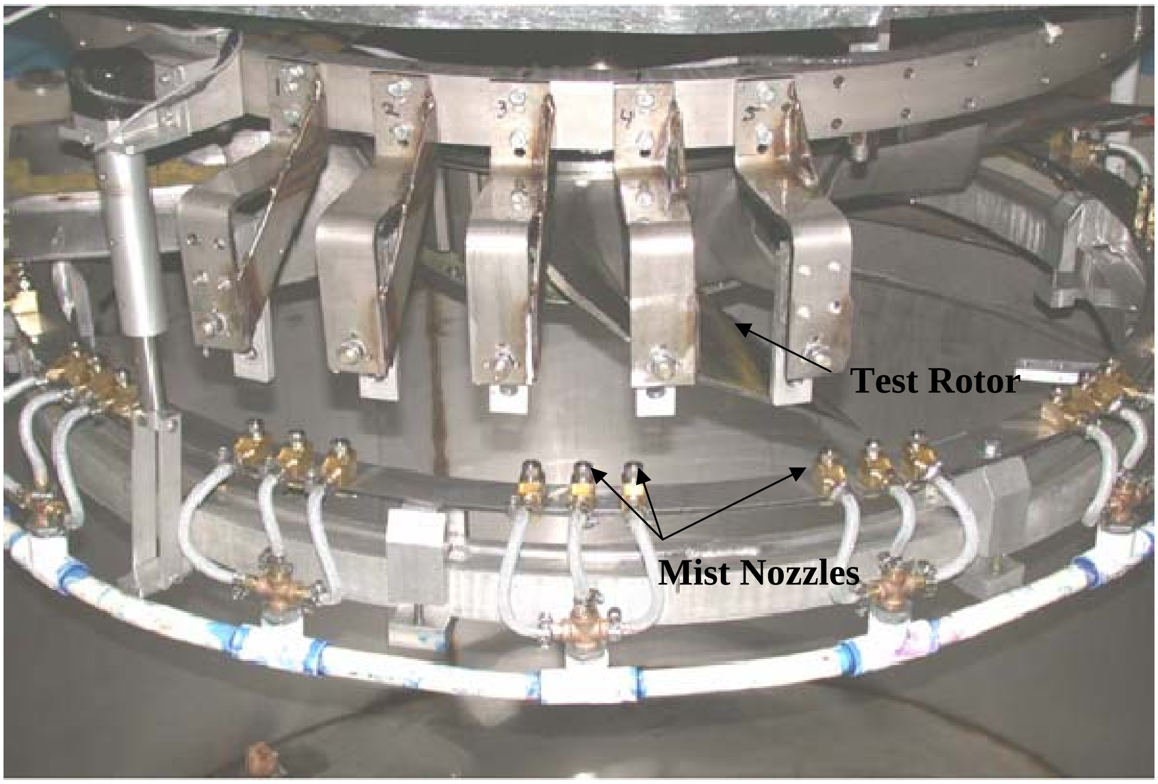

Figure 2. Test rotor and one arrangement of oil-mist nozzles

B. BLADE EXICTATION USING OIL

Discrete oil jets were initially used because of their large excitation amplitudes (Reference 1). However, it was found that discrete jets eventually eroded the blade surfaces (Reference 3). Mist nozzles were expected to produce less erosion, and when it was shown that adequate excitation amplitudes could be generated it became important to be able to quantify the excitation which was produced by a given arrangement of nozzles.

Figure 3 shows the radial view of the rotor blade of Figure 2 and the penetration of the oil spray if there were one, six, or eleven empty blades spaces in the partially bladed rotor (Reference 4). Figure 4 shows the spread of oil across the blade surface and the modal lines of the targeted oscillation (Reference 4). (Figure 5 shows the experimental set-up of discrete jets discharging radially inwards to produce the 'discrete jet pattern' shown in Figure 4).

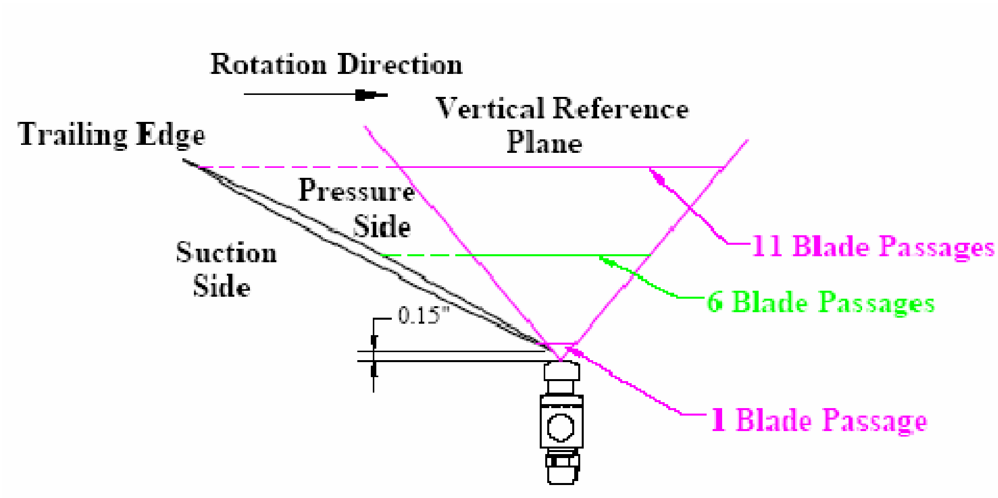

Figure 3. Radial view of rotor blade showing oil penetration distance.

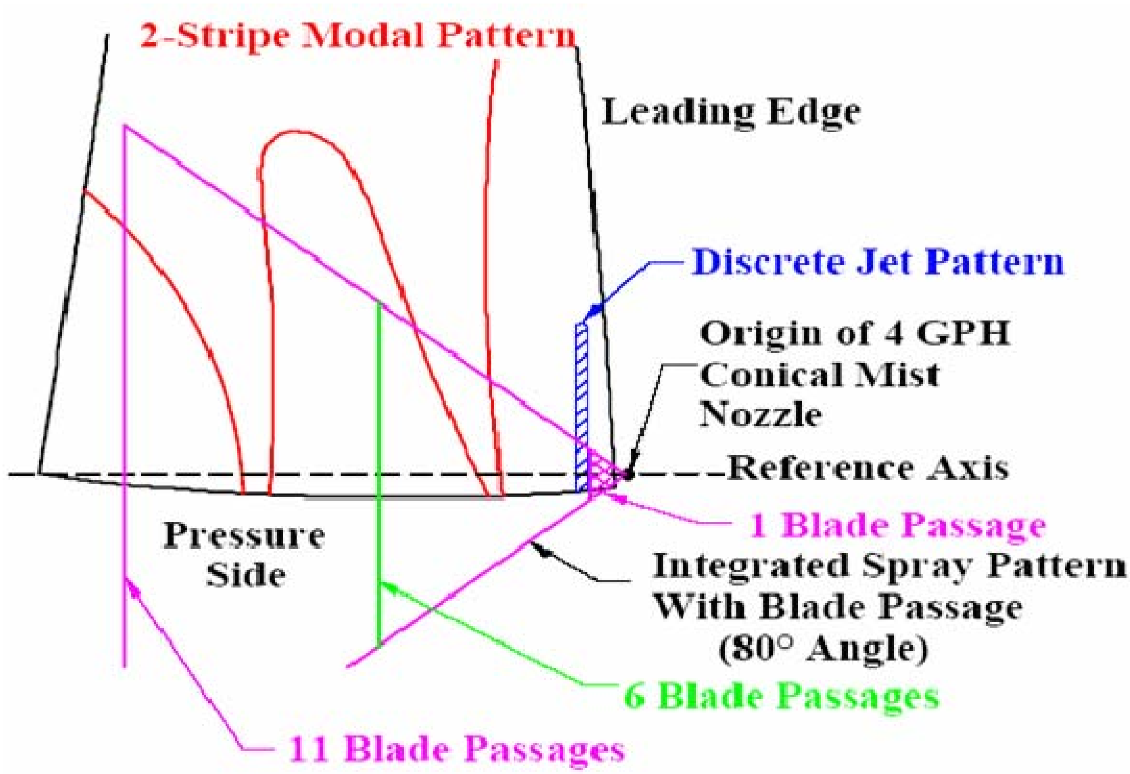

Figure 4. Blade surface showing oil spread and projected modal lines

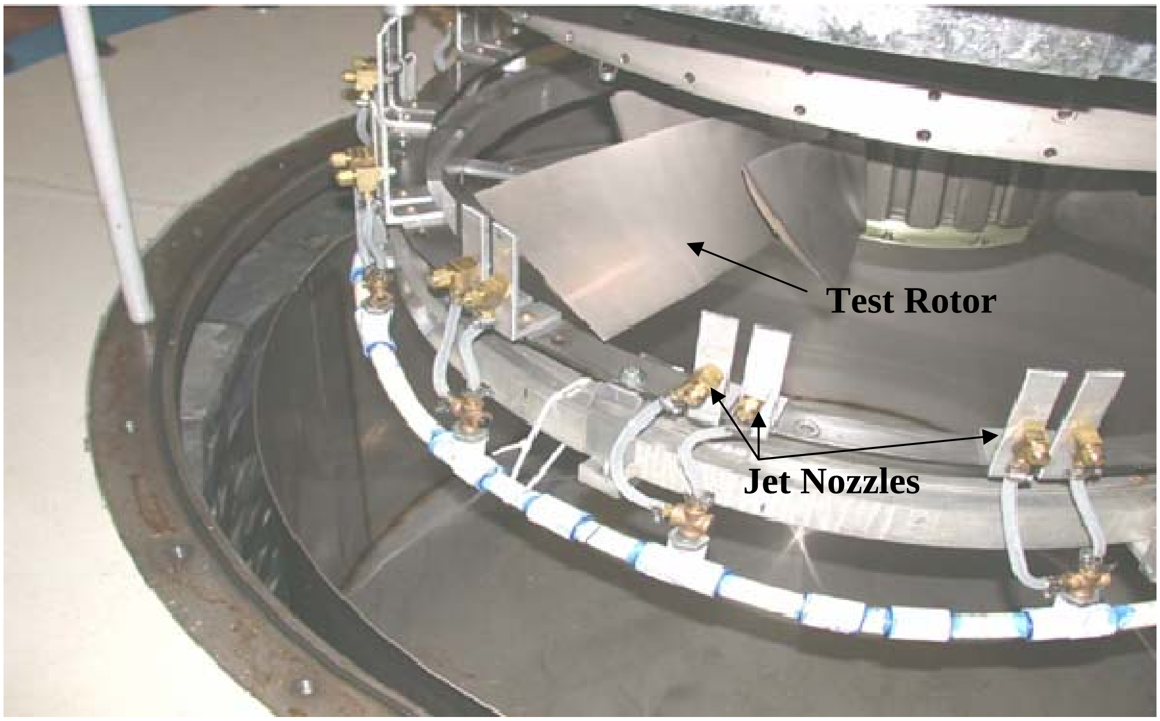

Figure 5. Experimental set-up of discrete jet nozzles for radial inward discharge.

C. IMPACT QUANTIFICATION AND APPROACH

In order to quantify the excitation 'impact' of the spray on the rotating blade surface, the geometry of and velocity within the spray pattern must be known in terms of the injection pressure and temperature, for the particular oil that is used.

Such information cannot be derived from the available manufacturer's technical literature for the nozzles. Thus, mapping the velocity field of the mist pattern was a requirement. Vonderheide successfully mapped a 4 gph nozzle and the parameters needed to quantify the mist were developed in terms of pressure (Reference 4). He was not able to obtain consistent results with a 6 gph standard nozzle. The present study followed a similar approach. However, the mist patterns were to be quantified at three different temperatures over the full range of pressures for the 6 gph standard Hago nozzle as well as the 4 gph mini mist nozzle.

The parameters needed for the quantification are shown in Figure 6. Combining these parameters with the oil mass flow rate, the force conveyed on the rotating blade can be determined. The rotor velocity and oil flow rate are needed to determine the momentum the oil will have and where it impacts the blade. The angles in Figure 6 determine the area over which the impact is distributed. The required velocity and angle information can be derived from LDV flow surveys of the oil spray discharging into vacuum.

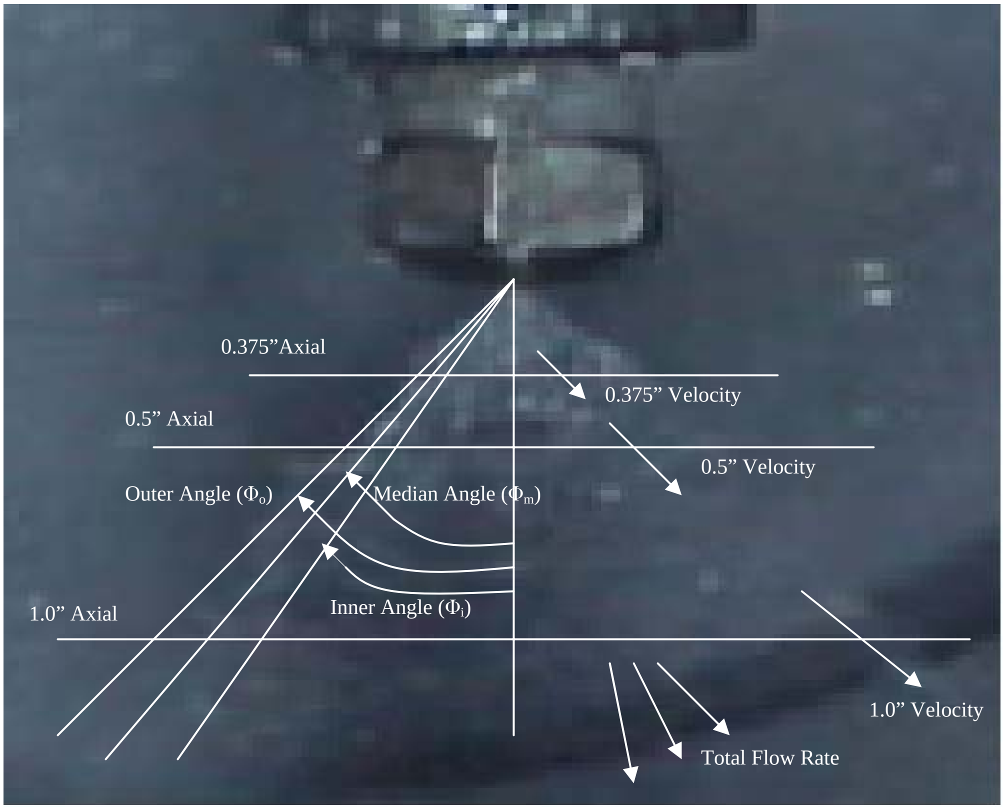

Figure 6. Parameters for mist quantification.

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III. APPARATUS AND PROCEDURE

A. APPARATUS DESCRIPTION

1. Vacuum Test Chamber

The vacuum test chamber used in the present study was that described by Vonderheide (Reference 4) and is shown in Figures 7 and 8. Built from PVC piping by technicians at the Turbopropulsion Laboratory, the vacuum chamber has two windows on either side to allow laser beams to pass through the chamber while maintaining the vacuum. Modifications to the chamber were made during the course of the present testing.

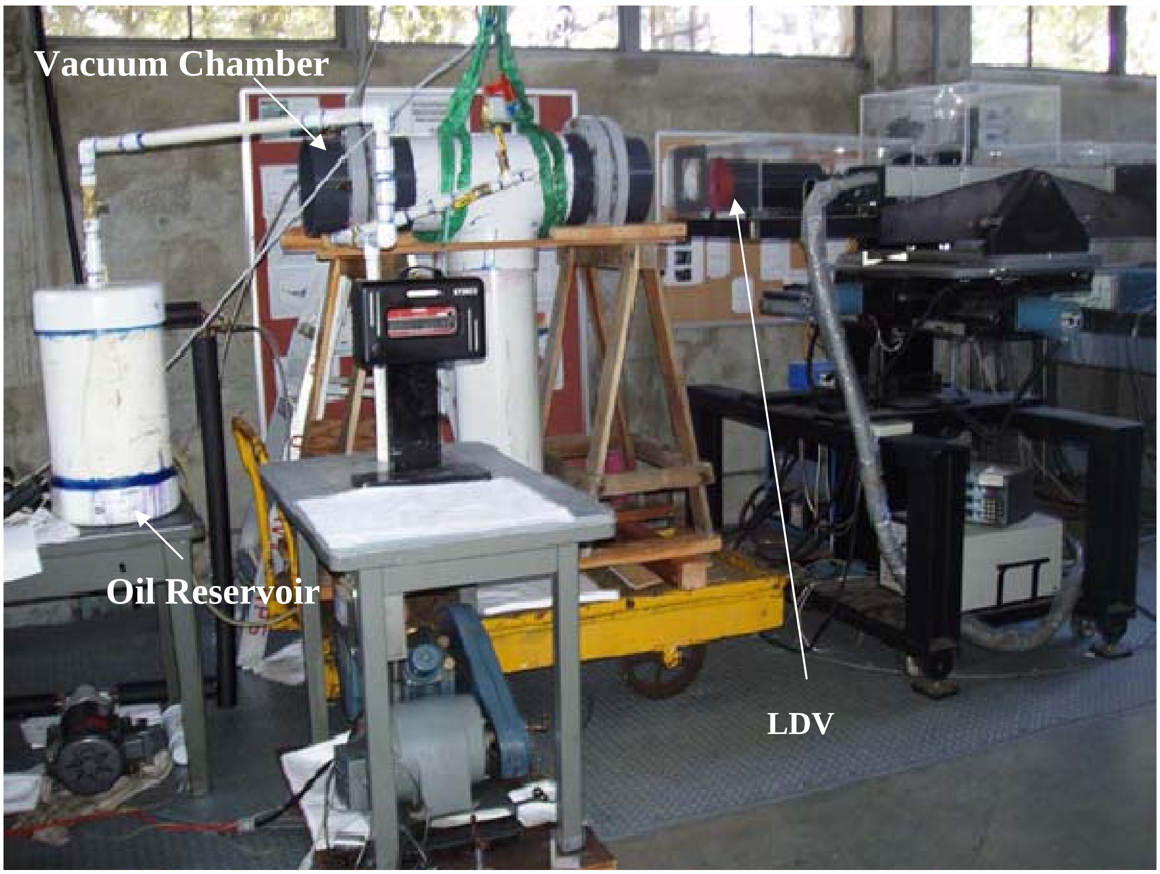

Figure 7. Side view of vacuum chamber and LDV system.

Figure 8. End view of vacuum chamber showing windows and nozzle.

First, the bypass 'loop' in the oil pump line was wrapped with heating tape, as shown (in the final configuration) in Figure 9. In the beginning stages of the experiment, the loop was configured as in Figure 10. Two thermocouples were attached to the system: one on the inside of the loop and one just before the nozzle. The two readings were extremely different as the heaters were only applied to the piping inside the loop. Thus, when the oil finally got to the nozzle head, the oil flowed through relatively "cold" pipes. This made the temperature near the nozzle much lower than the "loop" reading, and not constant. Therefore, a modification was made which is illustrated in Figure 11. The loop was made larger, eliminating the long line to the nozzle, and separate thermocouples. The single thermocouple now indicated the temperature of the oil flowing through the nozzle, the measurement needed in the analysis.

Figure 9. Heating tape installed on oil pumping return loop.

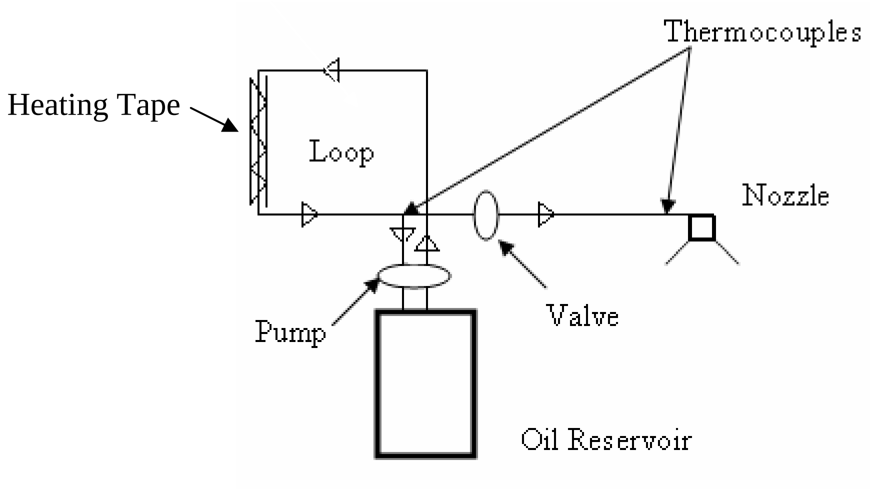

Figure 10. Apparatus before “loop” modification.

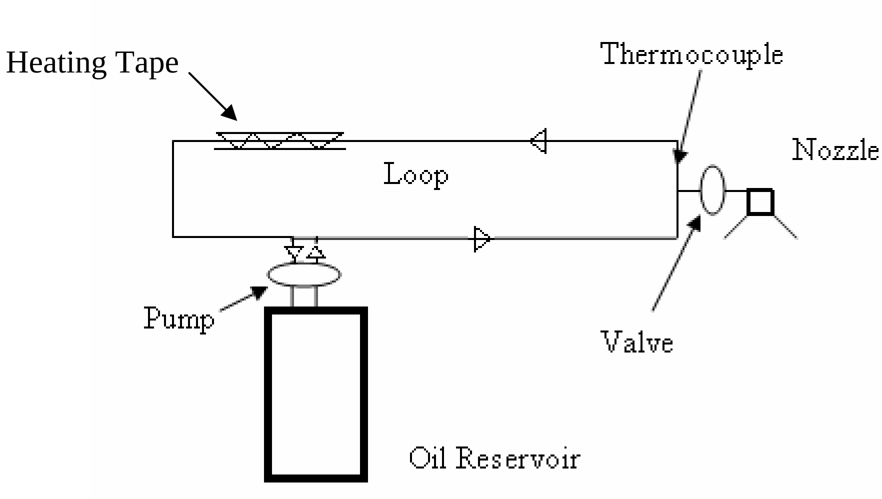

Figure 11. Apparatus after "loop" modification.

The oil used in the experiment was MARCOL 5, a light mineral oil, produced by Exxon Mobil. The Material Safety Data Sheets (MSDS) for the oil can be found in Appendix A.

2. LDV System

The traversing Laser Doppler Velocimeter (LDV) used in the present study is shown in Figure 7, as documented by Vonderheide (Reference 4). The LDV system included two sets of two laser beams: a vertical set and a horizontal set. This allowed measurements to be taken of both the vertical and horizontal components of the spray (Reference 4). The measurement of velocity is based on the following principle: a set of two parallel laser beams split from the same source are focused by a lens to cross at a specified distance from the lens. The angle of the crossing beams produces a pattern of interference fringes. Since the beam crossing angle and the wavelength of light are already known, the fringe separation is determined. As a fluid particle passes through the beam crossing, a light and dark return is seen by the detector, and since the fringe spacing at the crossing is known, the frequency derived from the reflected signal is a measure of the particle velocity. Because two pairs of two beams crossing at right angles are used, two components of velocity can be determined from the exact same measurement volume, which has the shape of an ellipsoid. The LDV's data acquisition program was computer controlled while the traversing mechanism was manually controlled (Reference 4).

B. FLOW MAPPING TECHNIQUE

Some effort was expended to ensure a constant temperature was maintained during a run. Since the temperature was controlled by wire rheostats, which could be set to percentages of full power, achieving a constant temperature at a required level was difficult. The relationship between the required power setting and resulting temperature was established through experience. The temperature in the reported tests fluctuated no more than two to three degrees in a given run.

The laser table was first adjusted visually to ensure that the laser beams crossed at the tip of the nozzle. This point became the reference zero point for the vertical and horizontal displacements. The table was then traversed vertically downwards to the required survey station. Data points were taken by traversing horizontally across the flow with an interval originating where the first high data rate was found. This interval was a function of cone width. The recorded data were a horizontal "x position" and both vertical (V) and horizontal (U) velocity components. From U and V, the total velocity of the oil droplets and the flow direction angle could be calculated (Reference 4). Tests were conducted as shown in Table 1. The 4 gallon per hour nozzle was mapped at three axial distances (0.375", 0.5", and 1.0"), at four gauge pressures (60, 80, 100, and 120 psig), at three temperatures (80, 100, and 120°F). The 6 gallon per hour nozzle was mapped at the same three axial distances, at three gauge pressures (60, 80, and 100 psig), at three temperatures (80, 100, and 120°F). The pressures were measured using Heise gauge in the feed line about 30 inches upstream of the nozzle. The temperature was measured using a digital temperature meter connected to a thermocouple, inserted into the loop and only inches from the nozzle feed line.

		Temperature (°F)		
Hago Nozzle	**Pressure (psig)**	**80**	**100**	**120**
4 gph Mini-mist	**60**	x	x	x
	80	x	x	x
	100	x	x	x
	120	x	x	x
6 gph Standard	**60**	x	x	x
	80	x	x	x
	100	x	x	x

Table 1. Program of tests (surveys conducted at 0.375", 0.5", and 1.0" at each temperature and pressure).

IV. EXPERIMENTAL RESULTS

A. FOUR GALLON PER HOUR NOZZLE

The Hago 4 gallon per hour (gph) “mini mist” nozzle showed a very consistent flow pattern at each pressure and temperature combination. Three axial locations were surveyed at the specified pressures and temperatures. Figures 12 – 14 show the pictures of each pressure and temperature combination of the study while Figures 15 – 26 show the flow maps of all the pressure and temperature combinations at each axial distance.

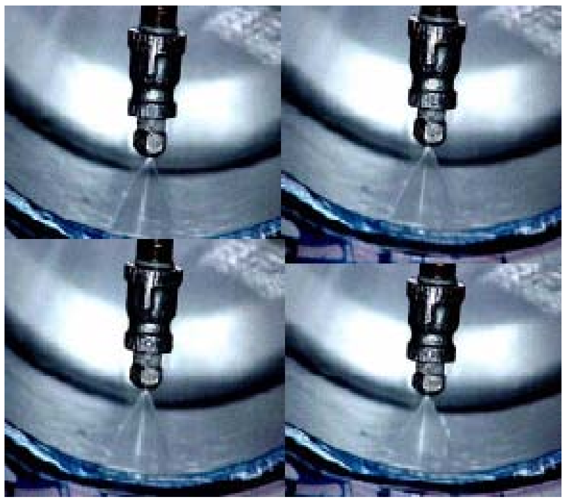

Figure 12. Hago 4 gph nozzle (80°F). Clockwise from top left: 60psig, 80 psig, 100 psig, 120 psig.

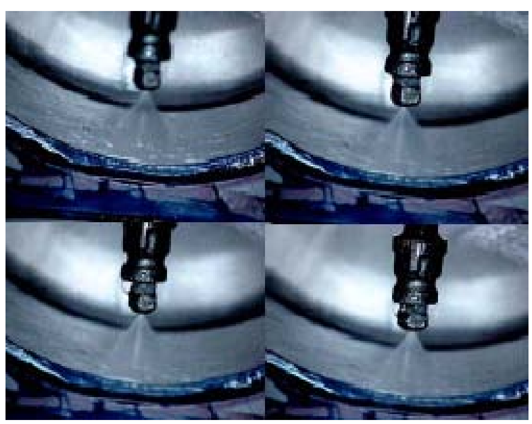

Figure 13. Hago 4 gph nozzle (100°F). Clockwise from top left: 60 psig, 80 psig, 100 psig, 120 psig.

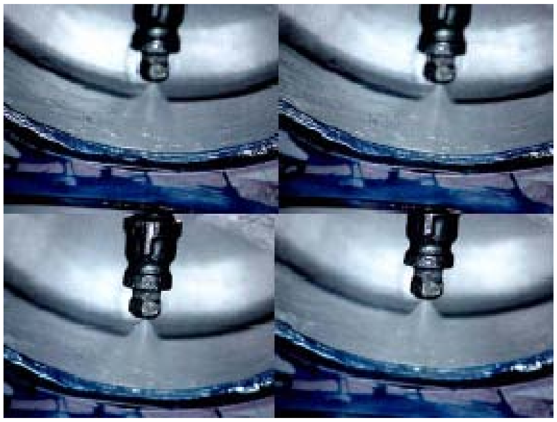

Figure 14. Hago 4 gph nozzle (120°F). Clockwise from top left: 60 psig, 80 psig, 100 psig, 120 psig.

It can be seen from Figures 12 – 14 that as the pressure and temperature rise, the mist becomes finer, causing an initial expectation that there was an effect of temperature on the 4 gph “mini mist” nozzle.

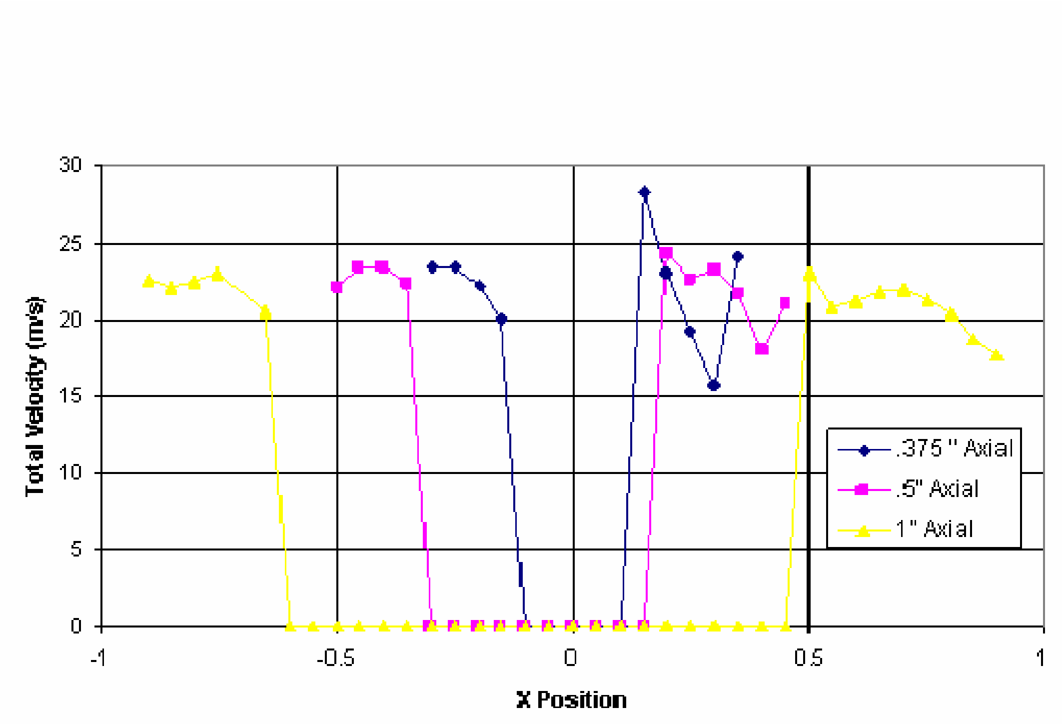

Figure 15. Flow map: 4gph, 60 psig, 80°F.

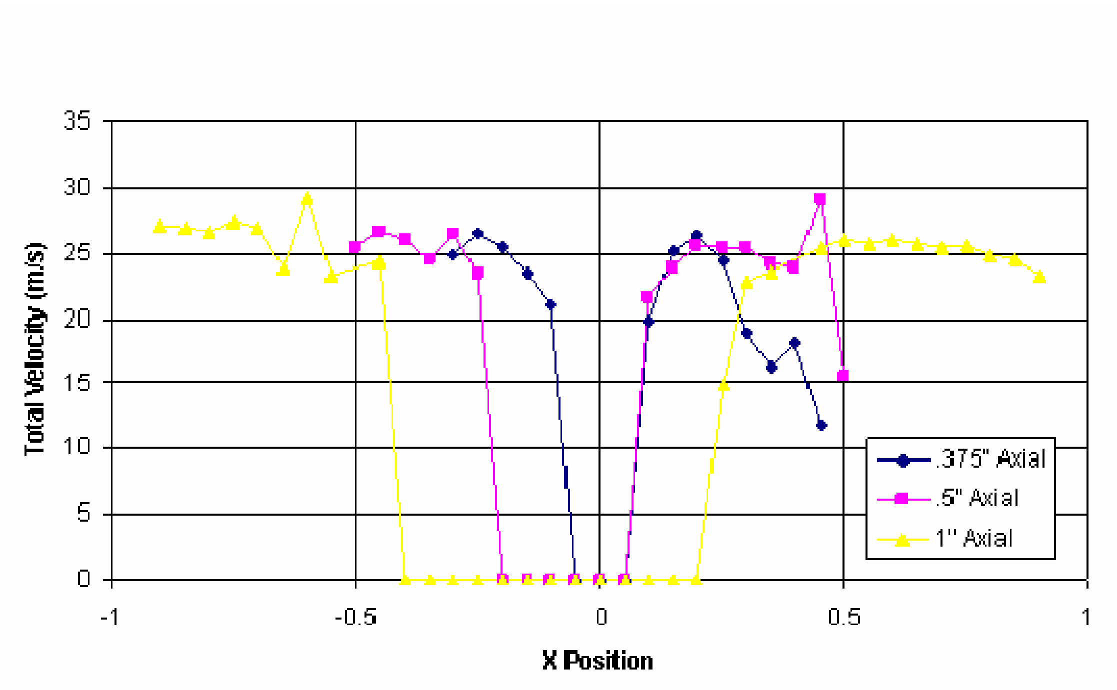

Figure 16. Flow map: 4gph, 80 psig, 80°F.

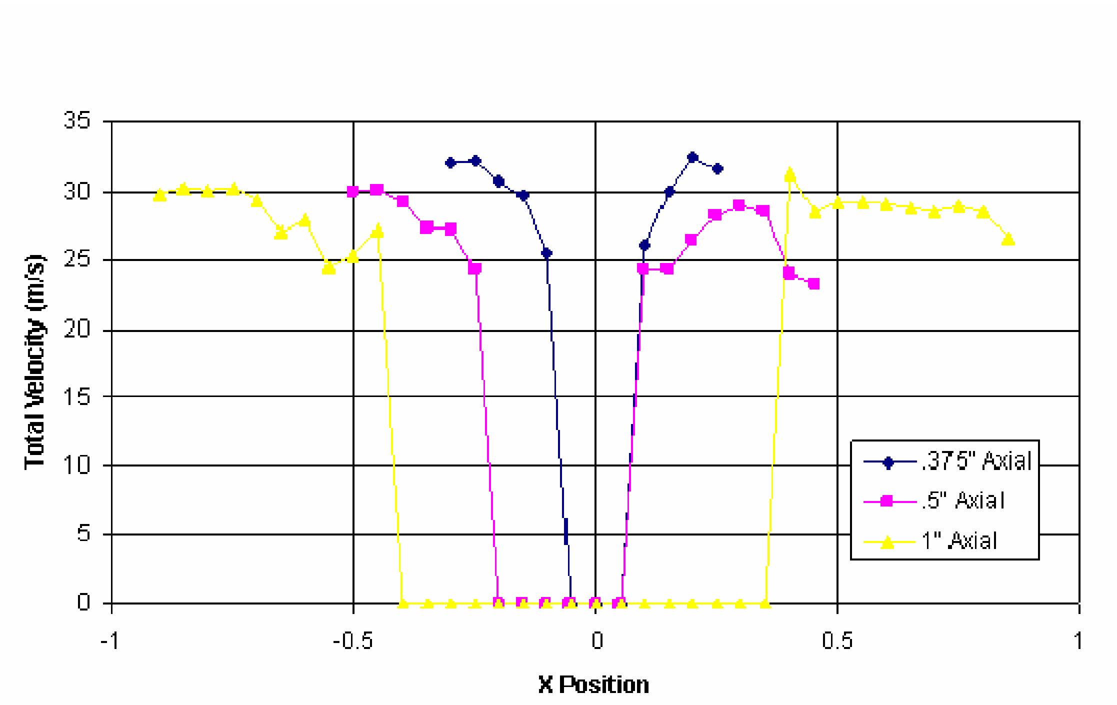

Figure 17. Flow map: 4gph, 100 psig, 80°F.

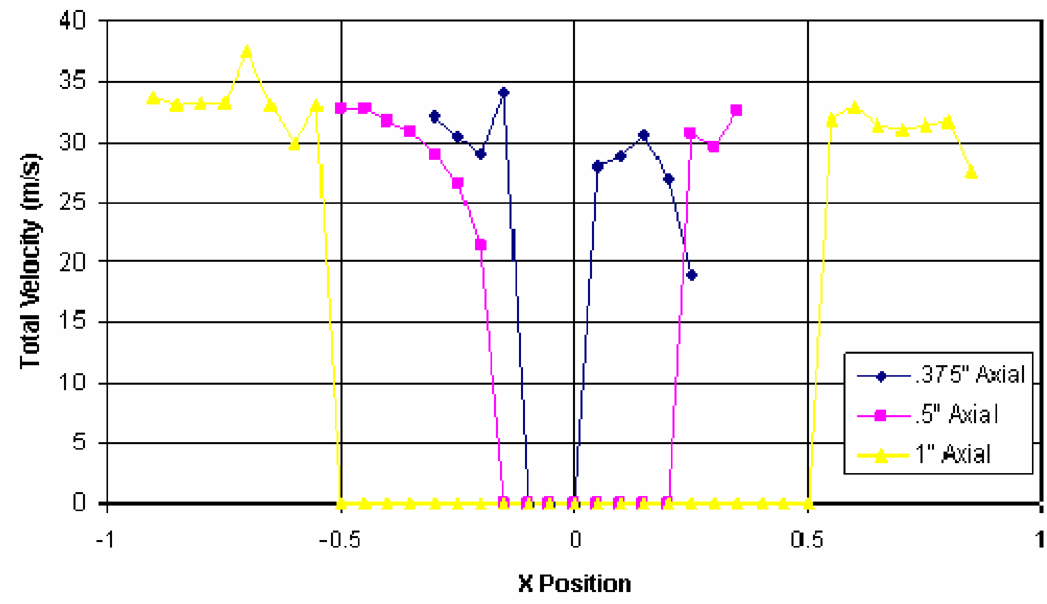

Figure 18. Flow map: 4gph, 120 psig, 80°F.

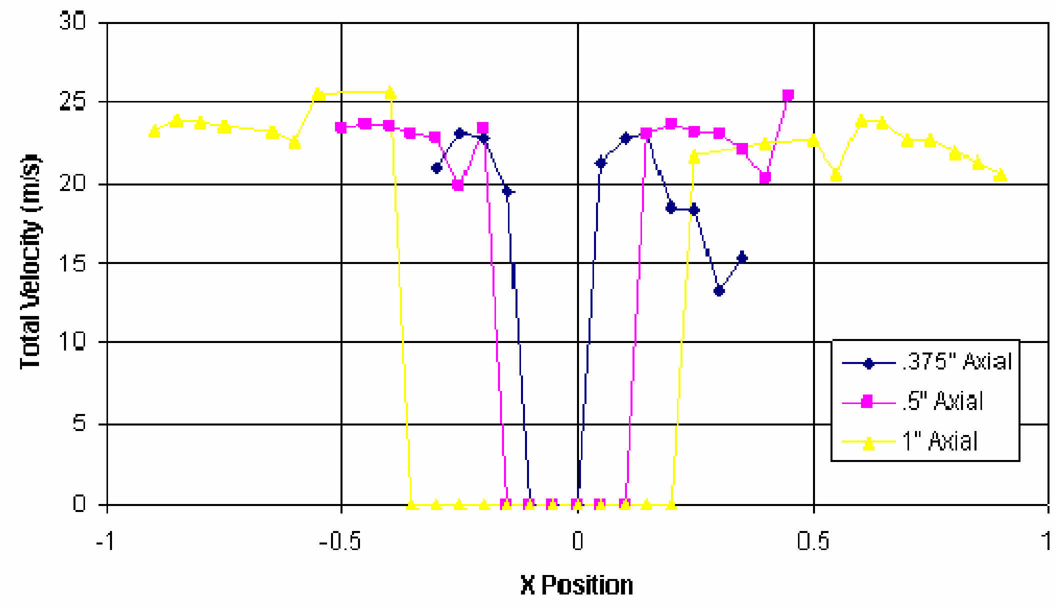

Figure 19. Flow map: 4gph, 60 psig, 100°F.

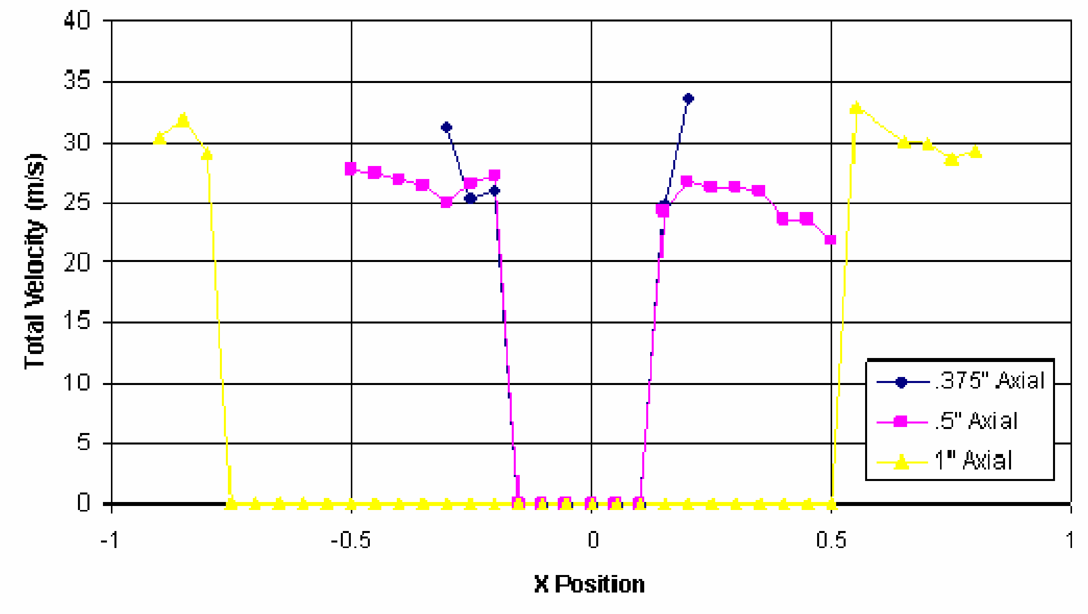

Figure 20. Flow map: 4gph, 80 psig, 100°F.

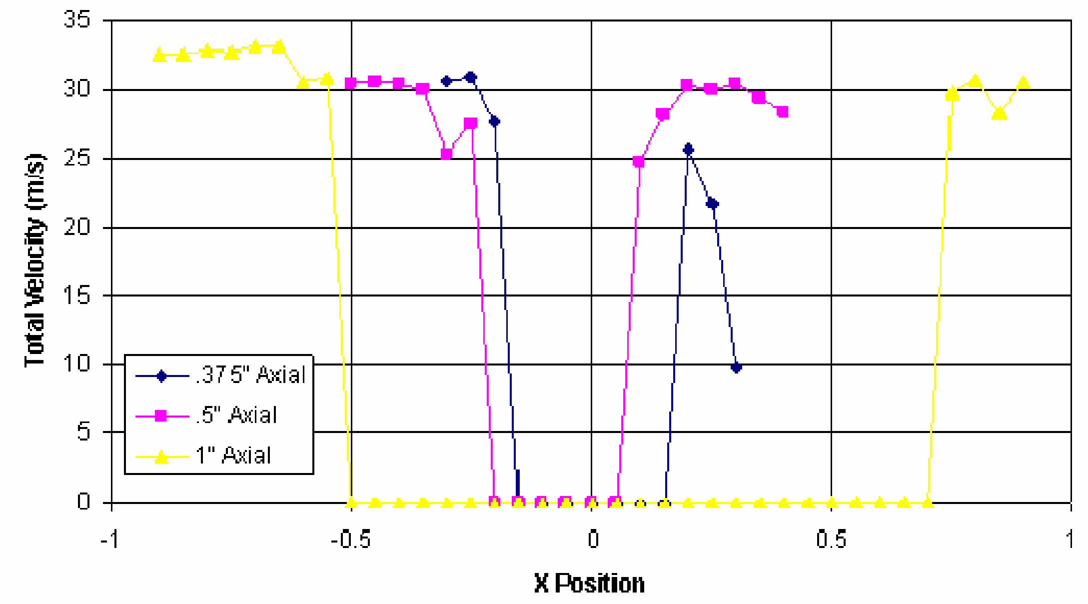

Figure 21. Flow map: 4 gph, 100 psig, 100°F.

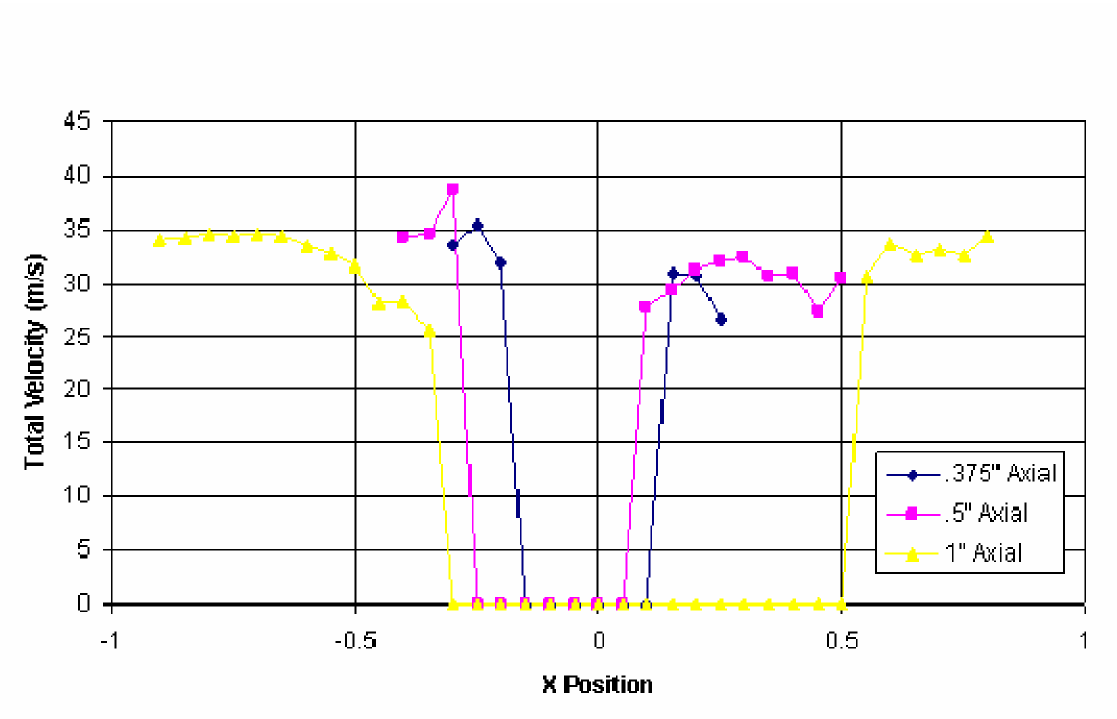

Figure 22. Flow map: 4gph, 120 psig, 100°F.

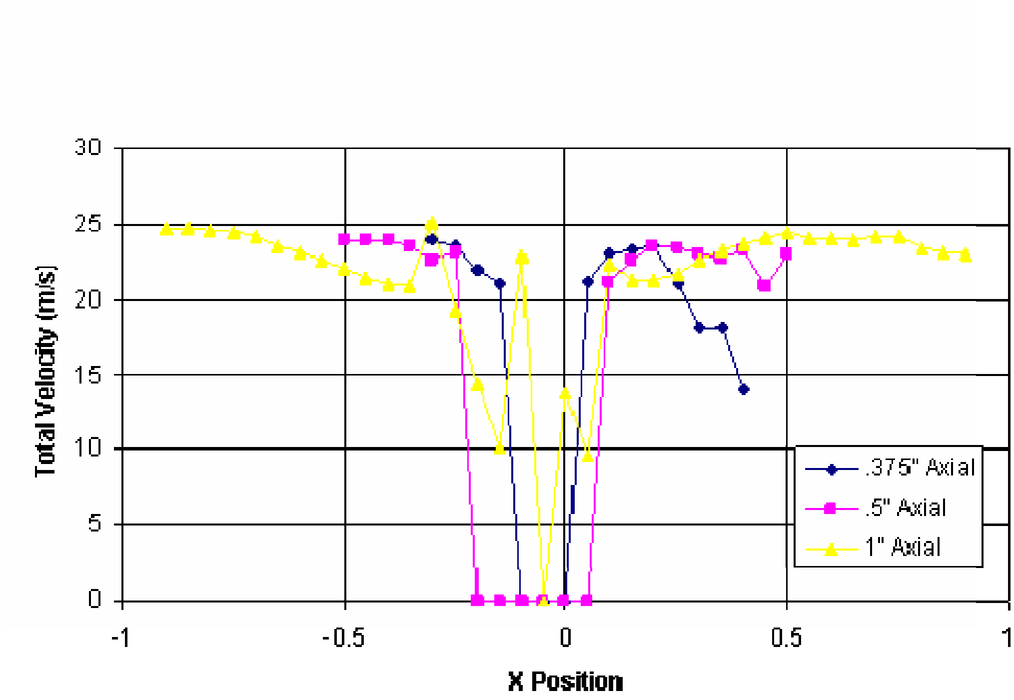

Figure 23. Flow map: 4gph, 60 psig, 120°F.

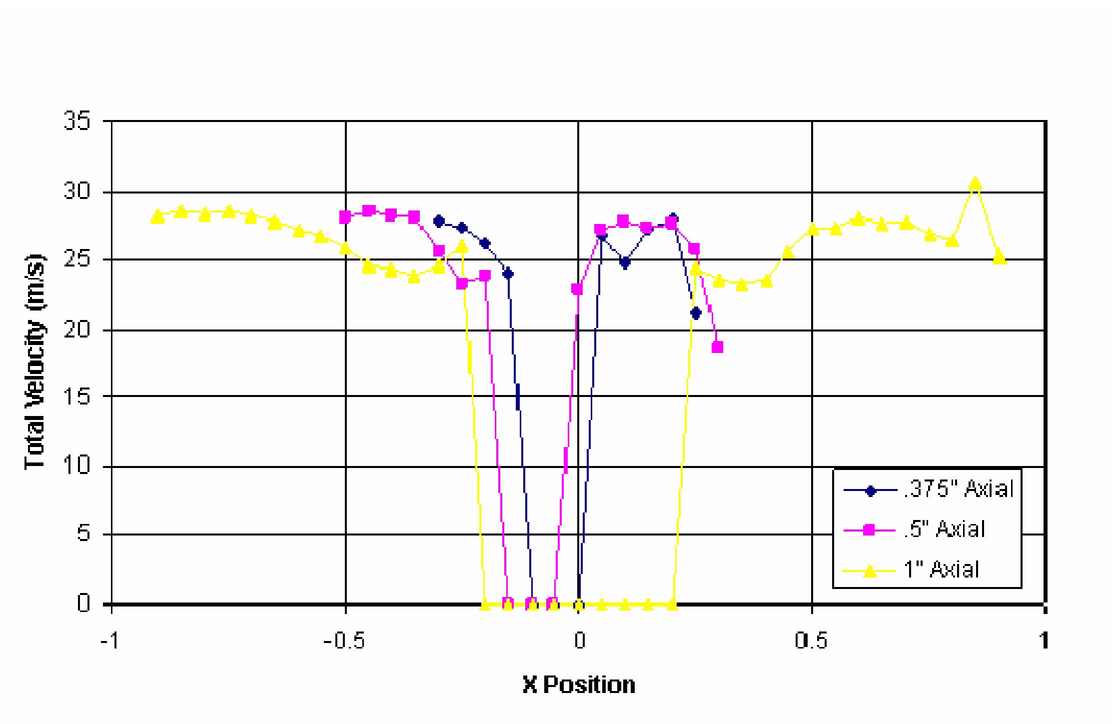

Figure 24. Flow map: 4gph, 80 psig, 120°F.

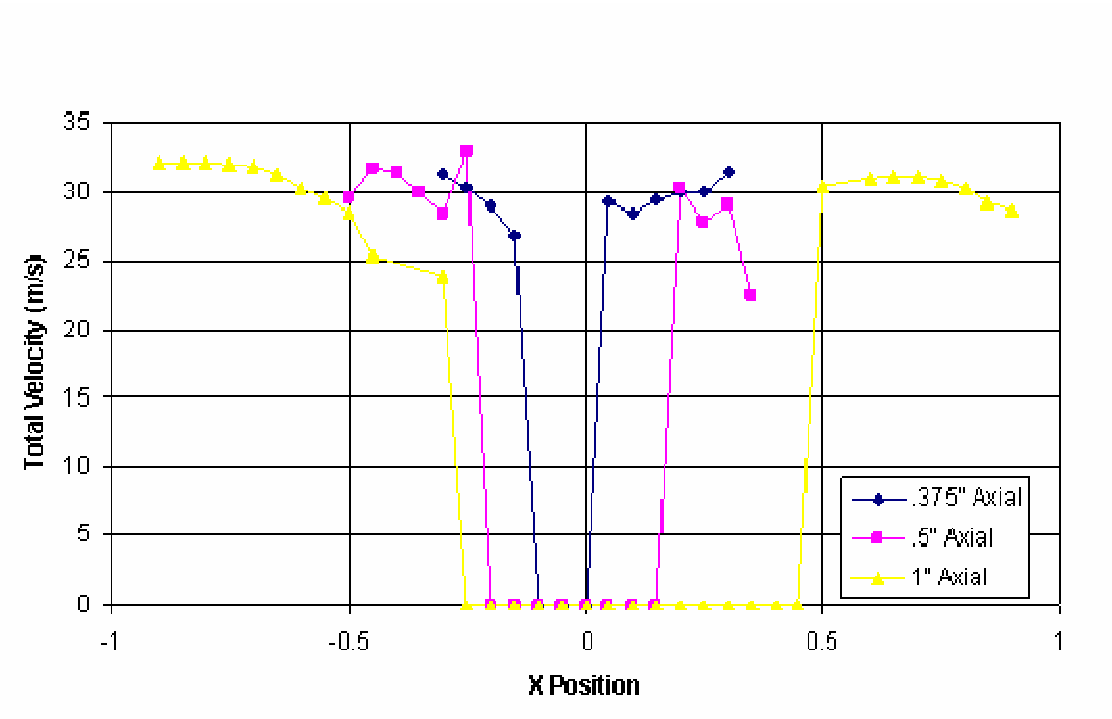

Figure 25. Flow map: 4gph, 100 psig, 120°F.

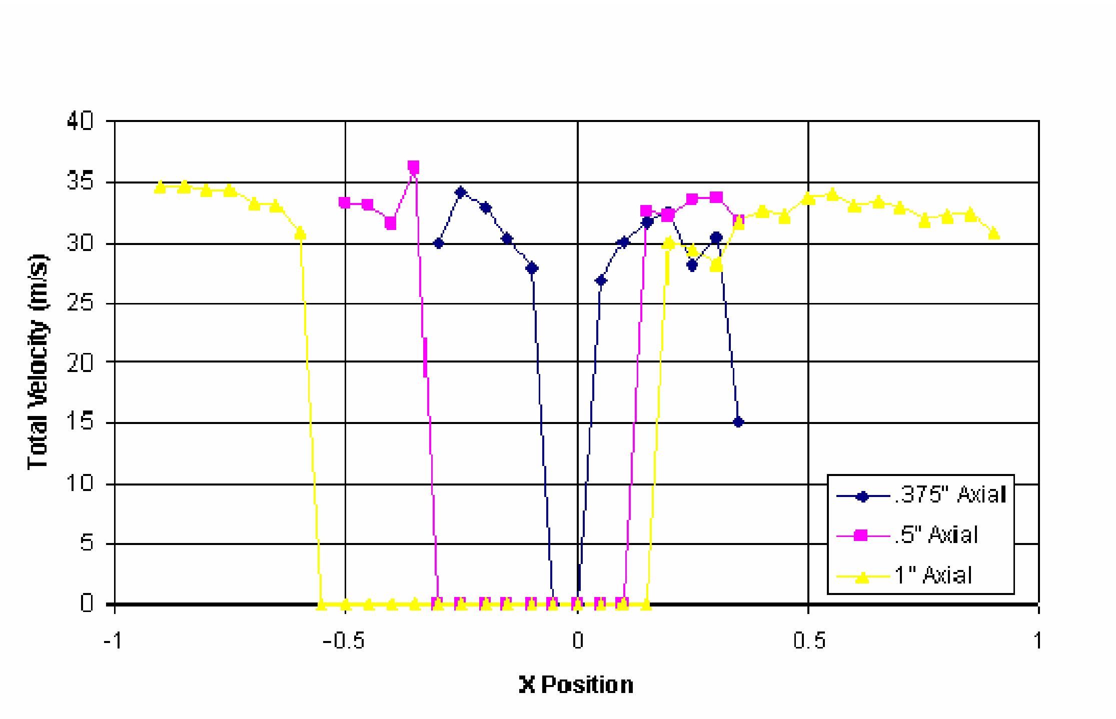

Figure 26. Flow map: 4gph, 120 psig, 120°F.

The measurements were taken at intervals from the edge of the spray to the point where the data rate sharply dropped. From the figures, it can be seen that the 4 gph nozzle produced a hollow cone mist structure with thickness varying with axial position.

The twelve plots show that the flow velocities were highest at the outer edge of the cone and decreased towards the inner edge, consistent with Vonderheide (Reference 4). Also, the maximum velocities were relatively constant at the three axial positions, for each pressure and temperature combination.

The flow rate of the 4 gph nozzle was also measured. The Hago mini mist nozzles were characterized by the manufacturer using water (Reference 4). The MARCOL 5 had a different viscosity, therefore giving a somewhat different flow rate. The flow rate was measured at each pressure and temperature combination by collecting and measuring the amount of oil sprayed from the nozzle during a set time interval. The oil was sprayed into a container open to the atmosphere during this measurement. Therefore the data were plotted against gauge pressure during the measurement, corresponding to absolute pressure into vacuum.

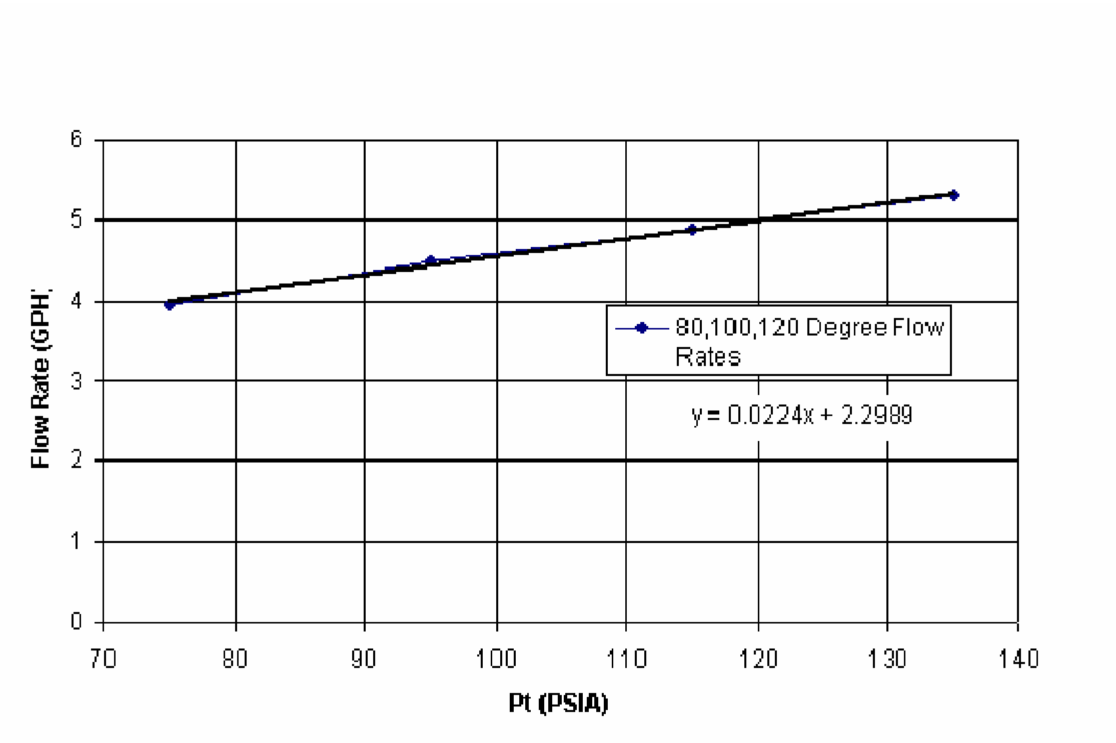

Figure 27. Measured flow rates at various pressures and temperatures (4gph).

It can be seen from the plot that the flow rate increased in a nearly linear fashion as the pressure was increased. It can also be seen that the temperature did not affect the flow rate at each pressure. The flow rate was only dependent on pressure.

B. SIX GALLON PER HOUR NOZZLE

The 6 gph nozzle was initially to be tested at the same four pressures and three temperatures as the 4gph nozzle (60, 80, 100, 120 PSI and 80, 100, and 120°F, respectively). However, the 120 PSI test resulted in the window of the vacuum chamber rapidly fogging, making measurements with the LDV virtually impossible. Thus, the 6 gph nozzle was measured at 60, 80 and 100 PSI at 80, 100, and 120°F at three axial distances. Figures 28 – 30 show the pictures of each pressure and temperature combination of the present study while Figures 31 – 39 show the flow maps of all the pressure and temperature combinations at each axial distance.

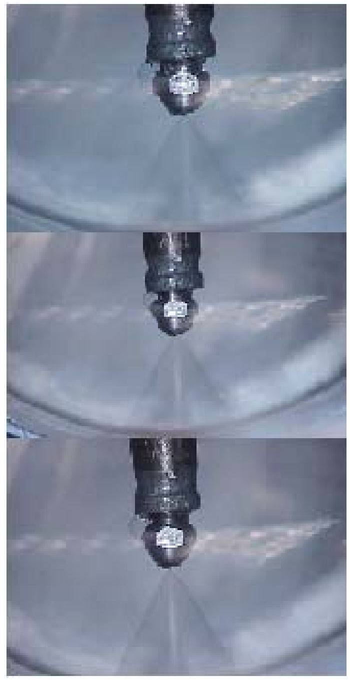

Figure 28. Hago 6 gph nozzle (80°F). From top: 60 psig, 80 psig, 100 psig.

Figure 29. Hago 6 gph nozzle (100°F). From top: 60 psig, 80 psig, 100 psig.

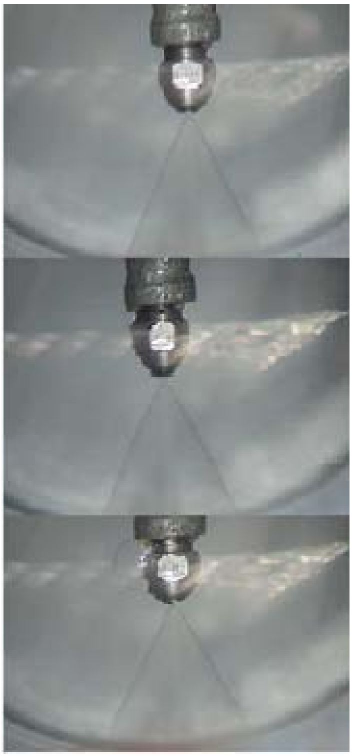

Figure 30. Hago 6 gph nozzle (120°F). From top: 60 psig, 80 psig, 100 psig.

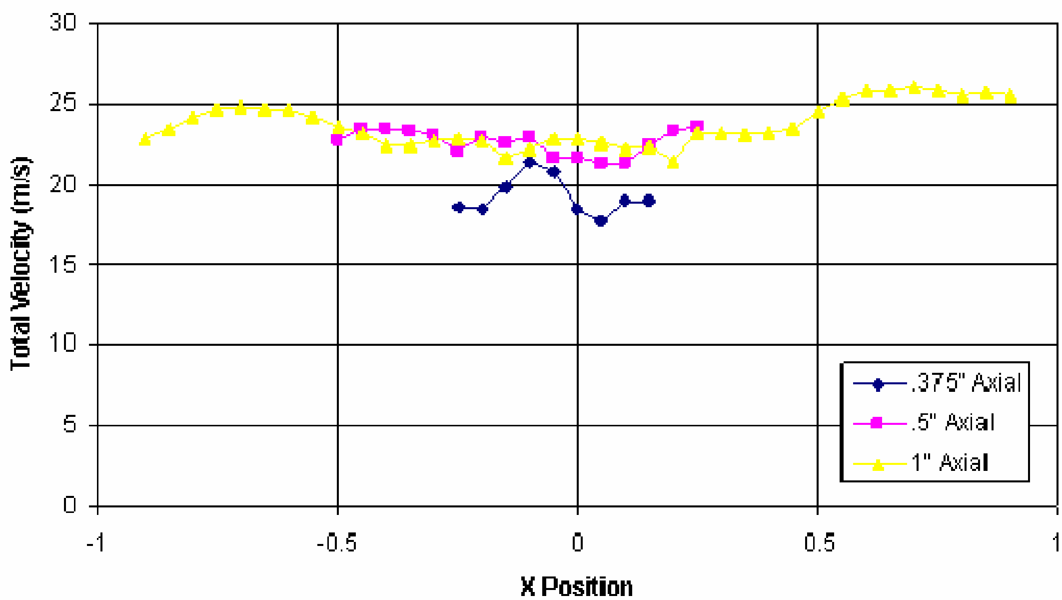

Figure 31. Flow map: 6gph, 60 psig, 80°F.

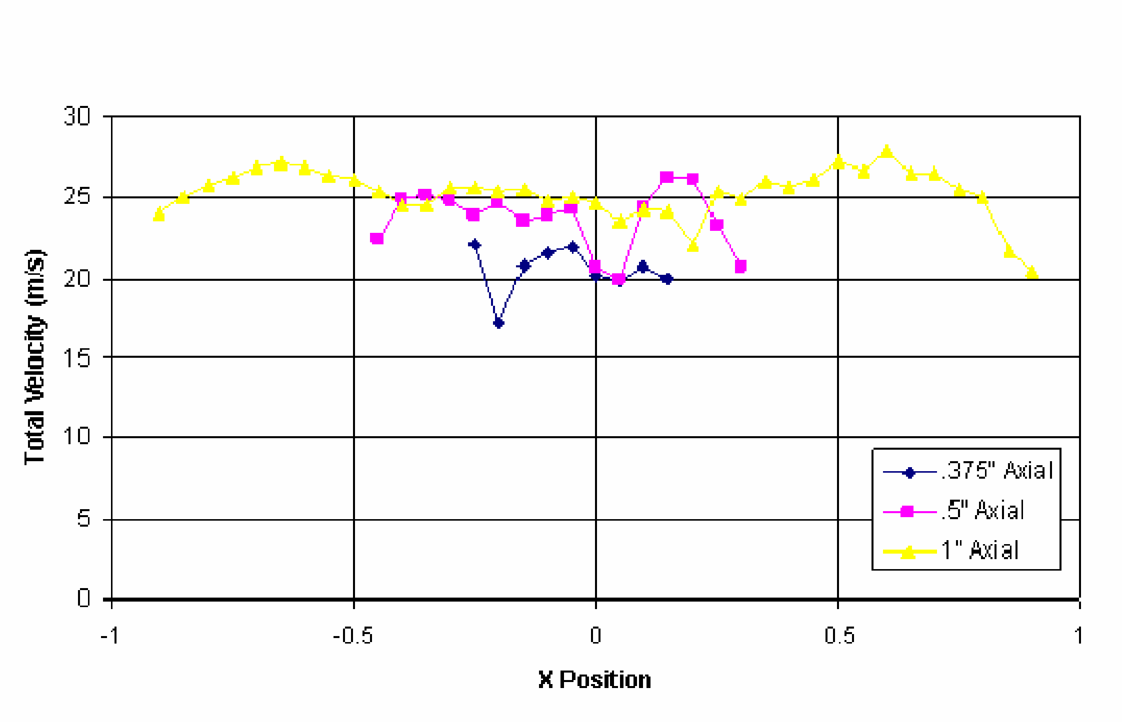

Figure 32. Flow map: 6gph, 80 psig, 80°F.

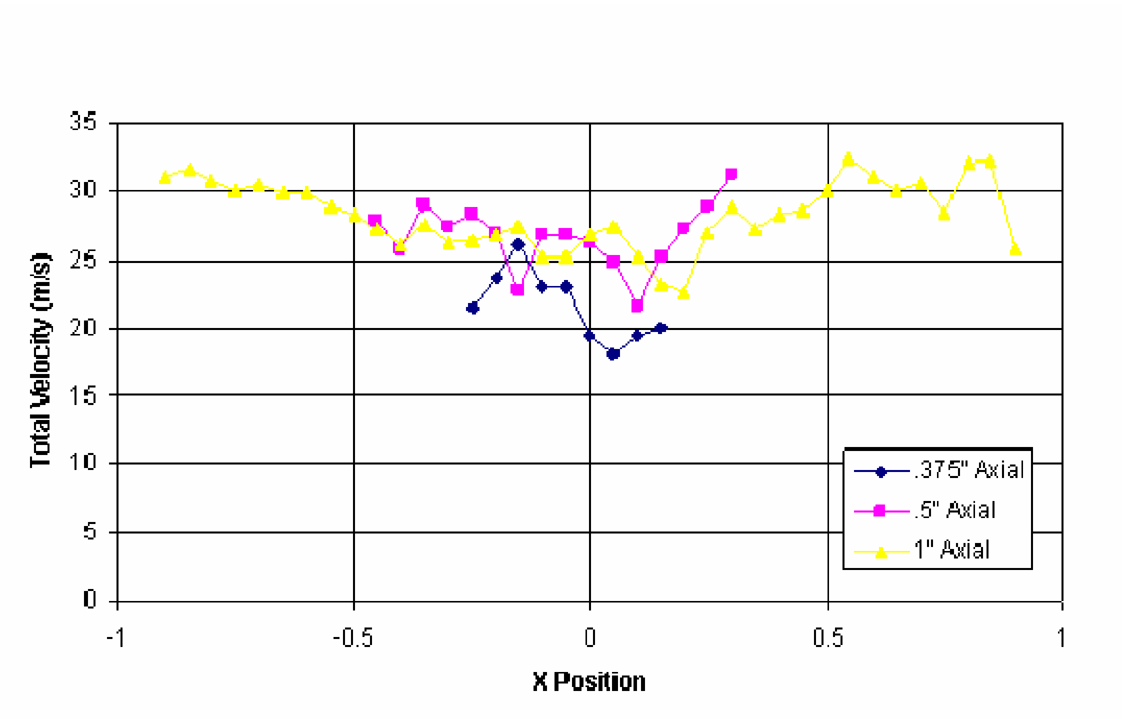

Figure 33. Flow map: 6gph, 100 psig, 80°F.

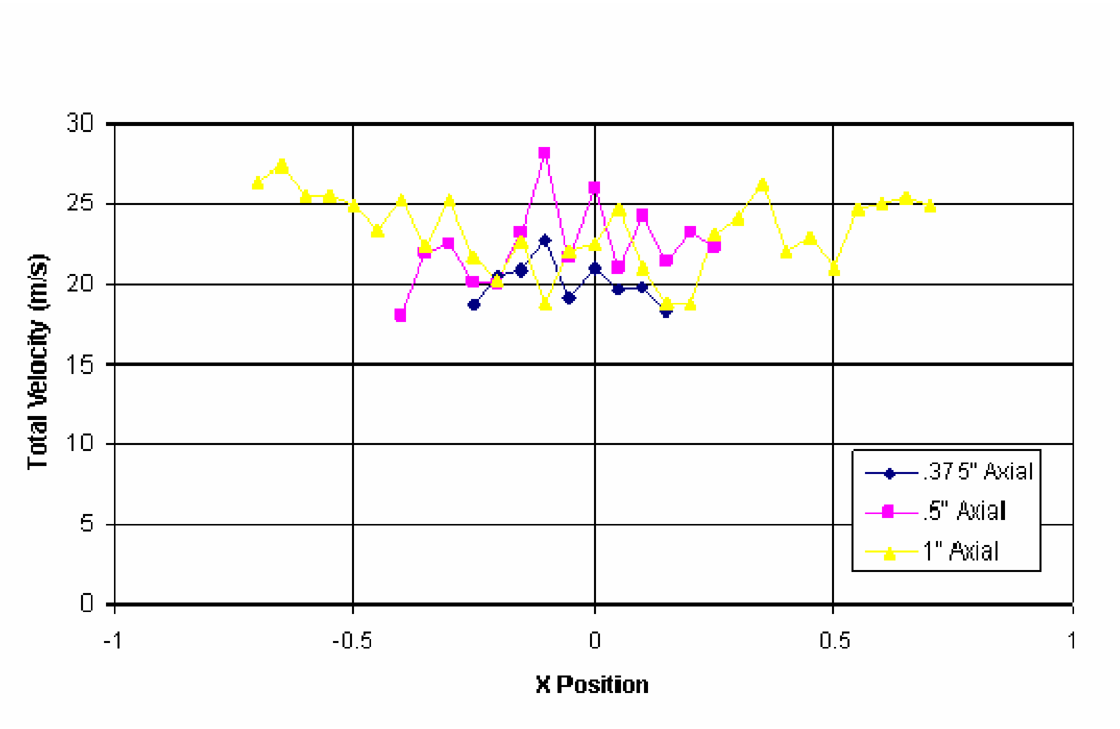

Figure 34. Flow map: 6gph, 60 psig, 100°F.

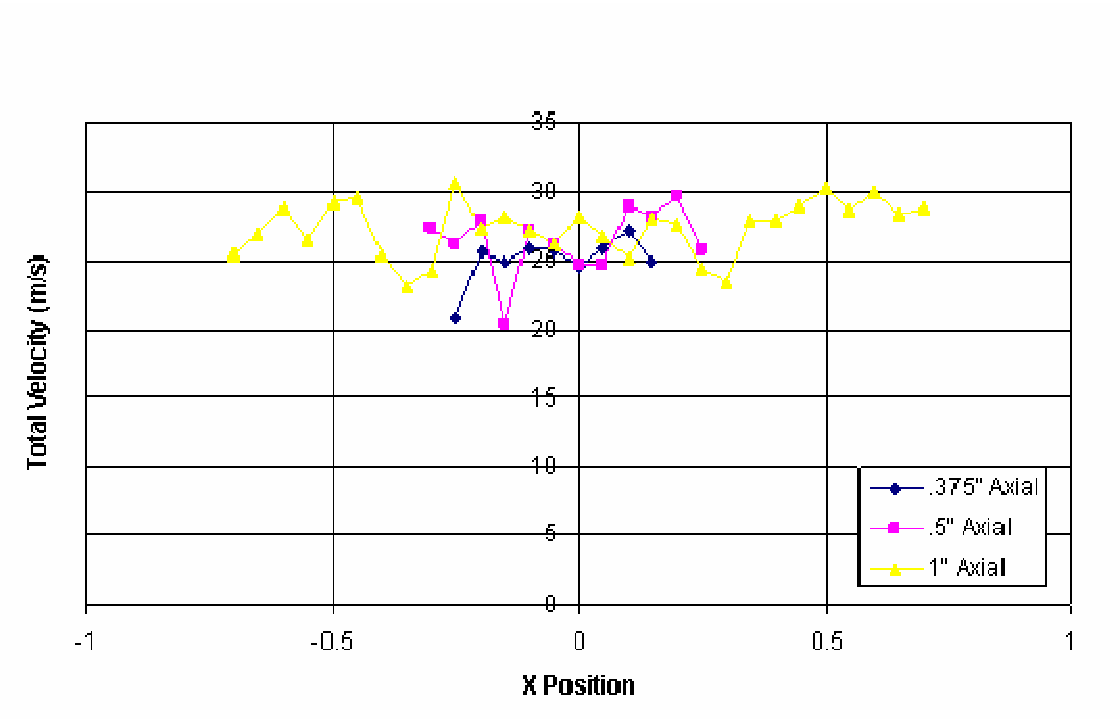

Figure 35. Flow map: 6gph, 80 psig, 100°F.

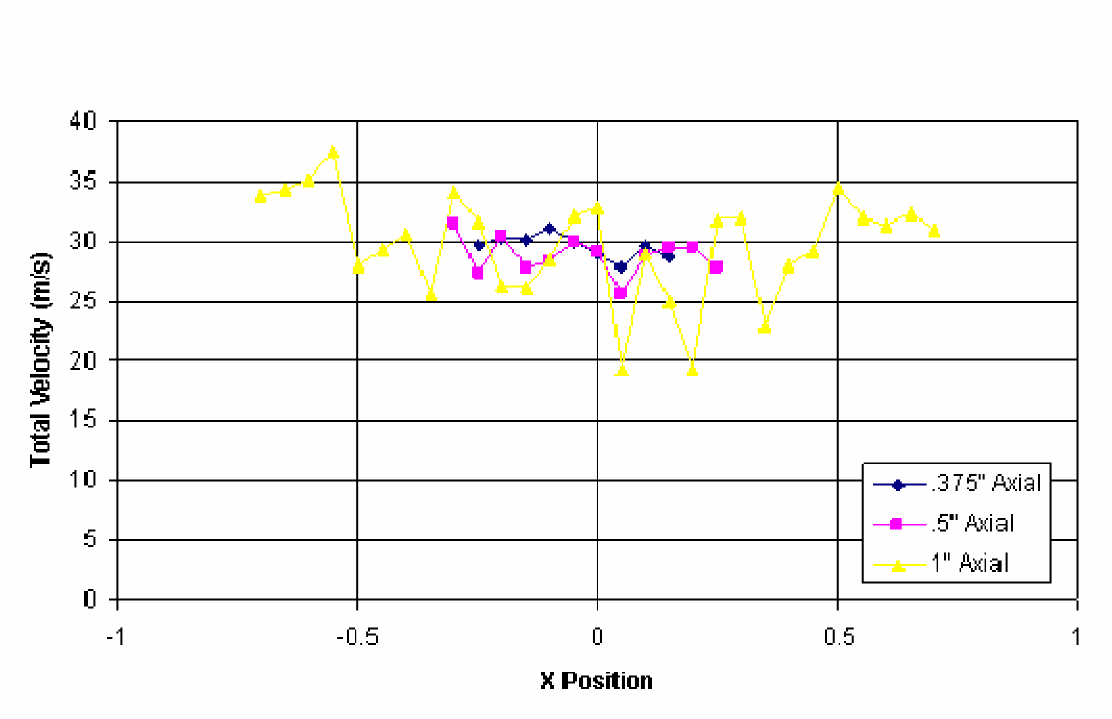

Figure 36. Flow map: 6gph, 100 psig, 100°F.

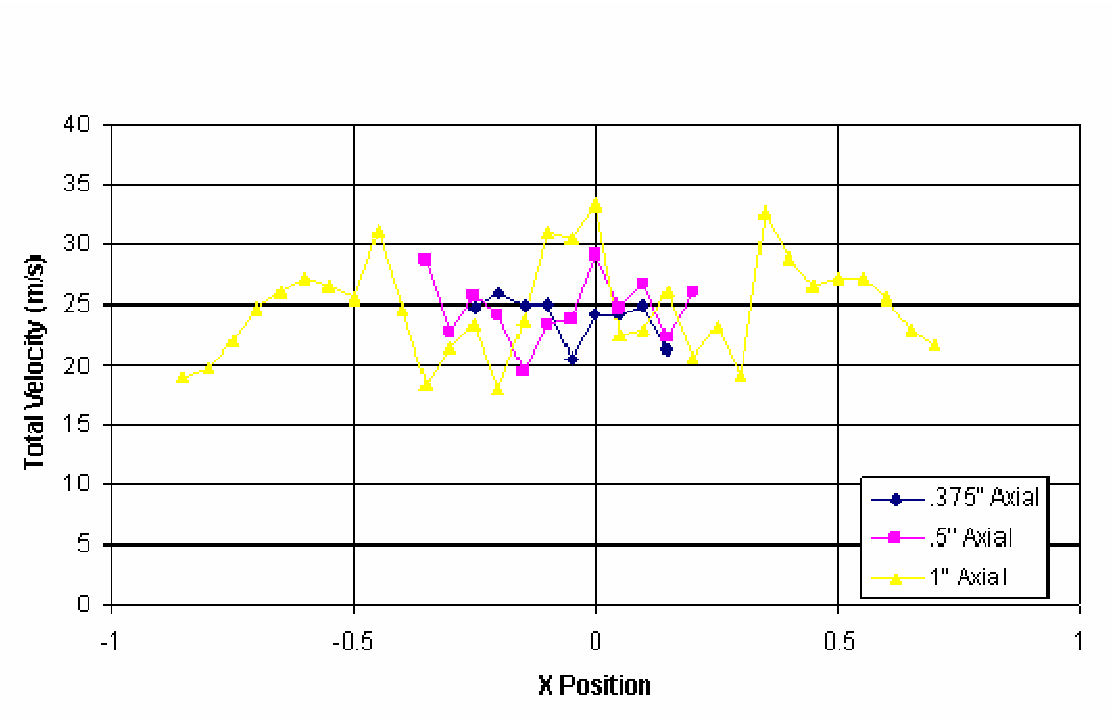

Figure 37. Flow map: 6gph, 60 psig, 120°F.

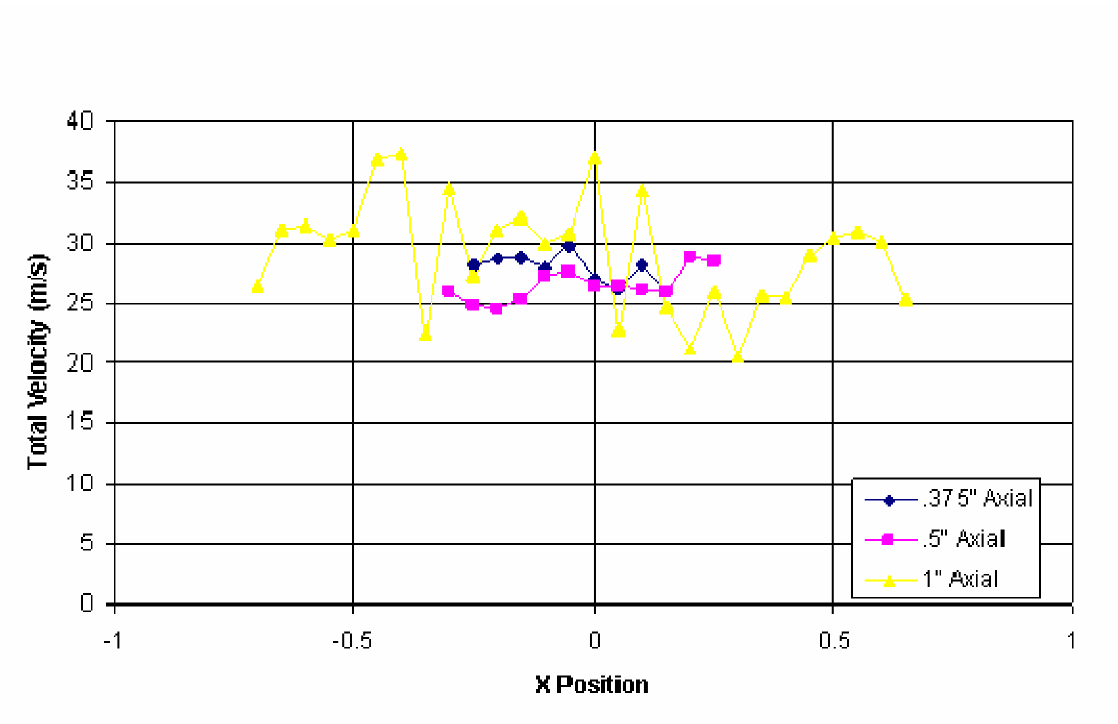

Figure 38. Flow map: 6gph, 80 psig, 120°F.

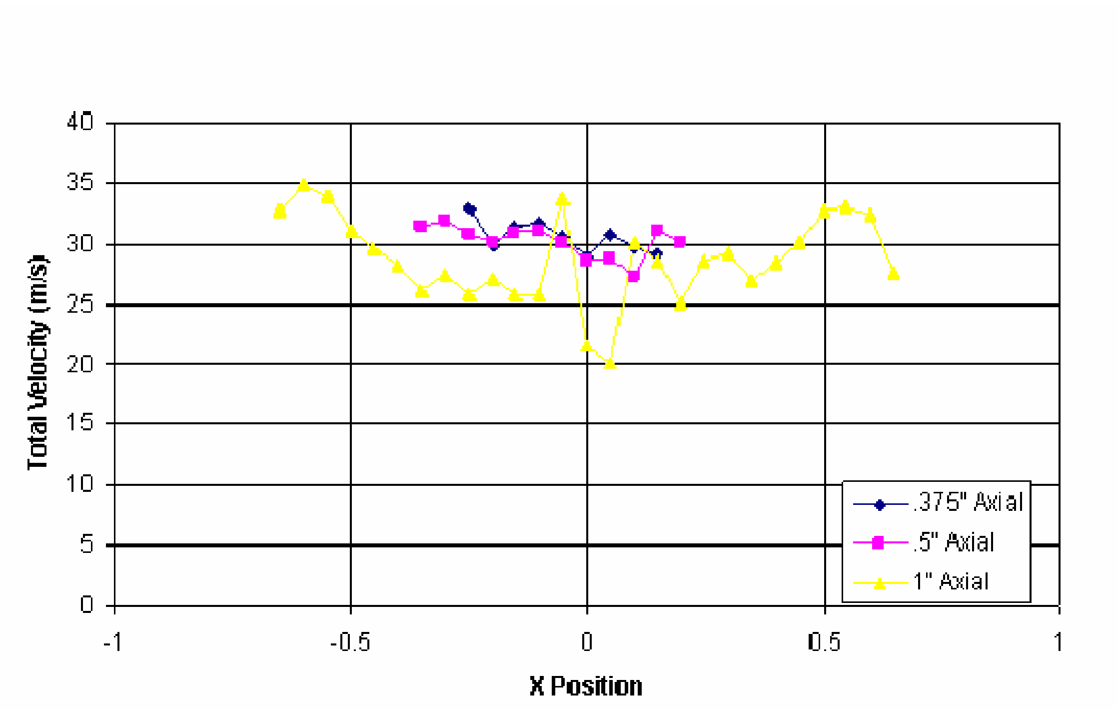

Figure 39. Flow map: 6gph, 100 psig, 120°F.

It can be seen that the 6 gph nozzle produced a solid symmetrical cone structure at each pressure and temperature combination. The plots also show more of a variation in flow velocities at each axial position than the 4 gph nozzle. It can also be seen that as the temperature increased at each axial position, the behavior of the flow became more and more erratic, most notably in Figures 37 – 39 (120°F flow maps). Also, as the temperature increased, the velocities decreased with increasing axial distance. Comparing Figures 33 and 39 (100 psig at 80°F and 120°F, respectively), one can see that the 1" axial distance at 80°F had the highest velocity and the 0.375" axial distance the lowest. The 1" axial distance at 120°F had the lowest velocity while the 0.375" axial distance had the highest. This "inversion" was not expected since the 4 gph nozzle showed a logical progression of velocity as the pressure and temperature were varied.

The flow rate of the 6gph nozzle was also measured in the same manner as the 4 gph nozzle. The oil was sprayed into a container for a specified time interval at each pressure and temperature combination and a volume measurement was taken. Figure 40 shows the results for the flow rate measurement.

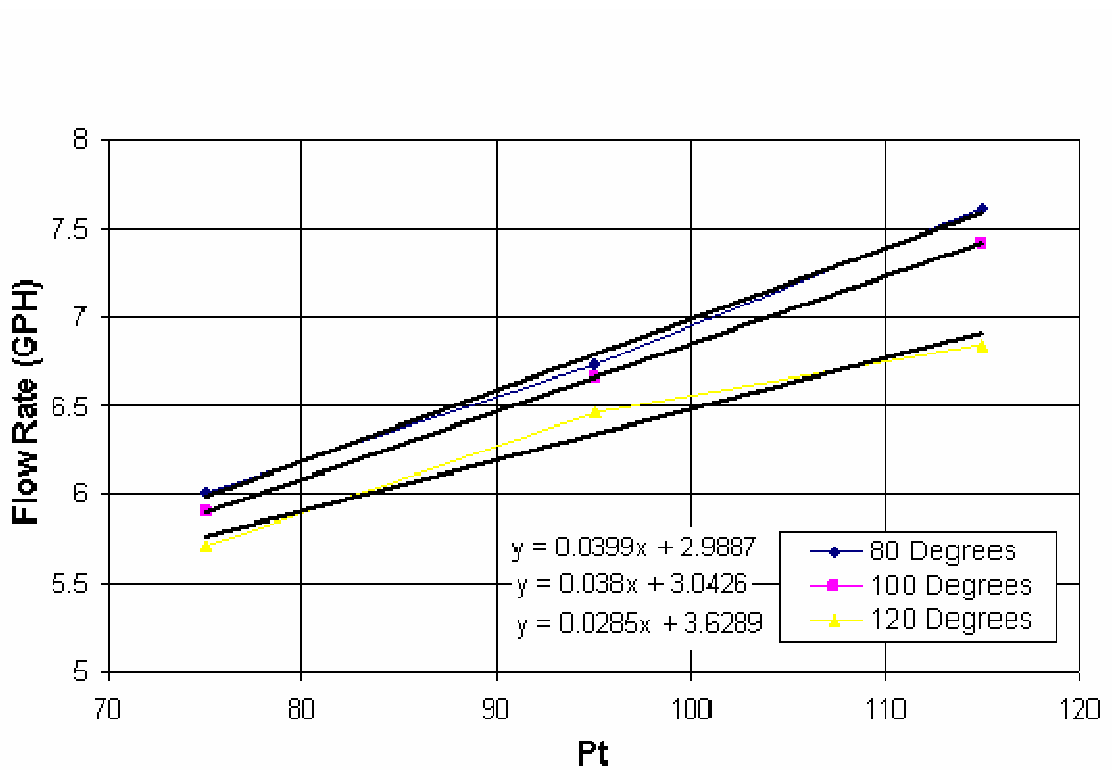

Figure 40. Measured flow rates at various pressures and temperatures (6gph nozzle).

From the plot it can be seen that as the temperature increased at each pressure, the flow rate decreased. The largest change occurred between 100°F and 120°F. The trend lines were added to show the near linear nature of the flow rates at each temperature.

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V. DATA ANALYSIS

A. FOUR GALLON PER HOUR NOZZLE

1. Velocity Reduction

After the data were mapped, an empirical correlation of the data was sought. The first property investigated was the velocity. Figures 41 – 52 show the velocities at each pressure and temperature combination at each axial location.

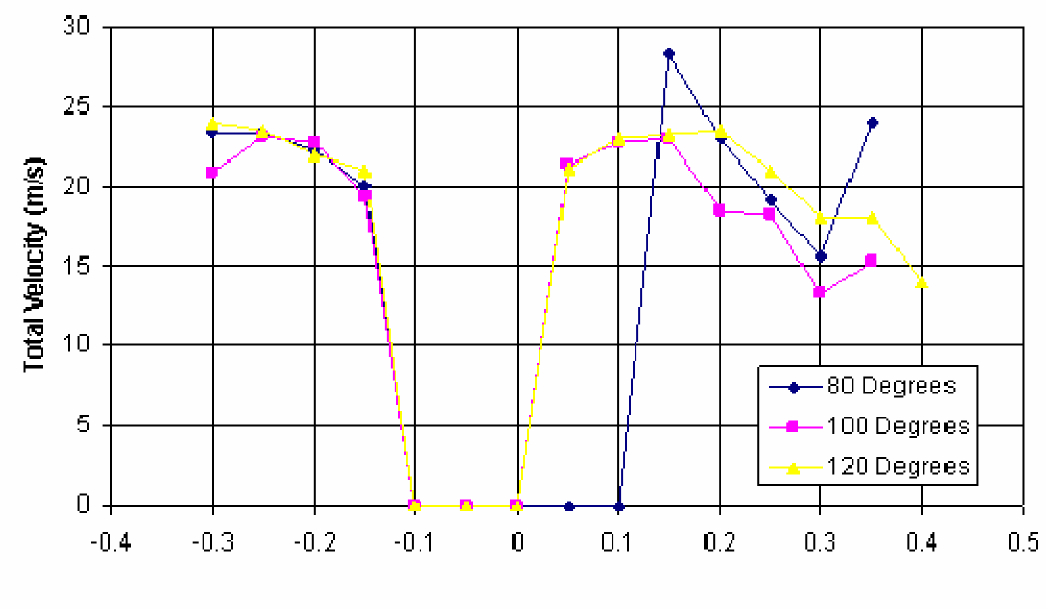

Figure 41. Velocities at 60 psig, 0.375” axial position, for three temperatures (4 gph).

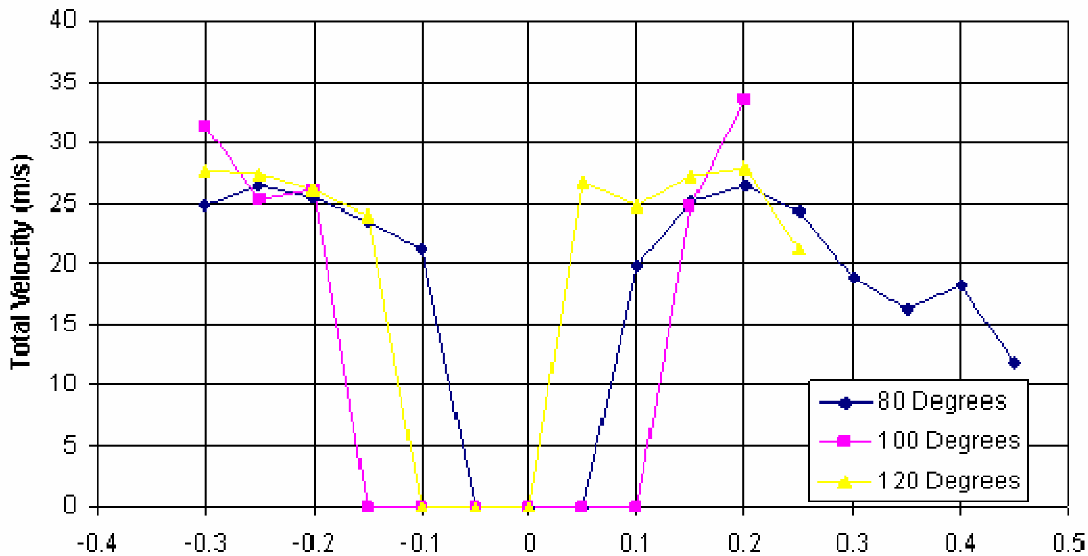

Figure 42. Velocities at 80 psig, 0.375” axial position, for three temperatures (4 gph).

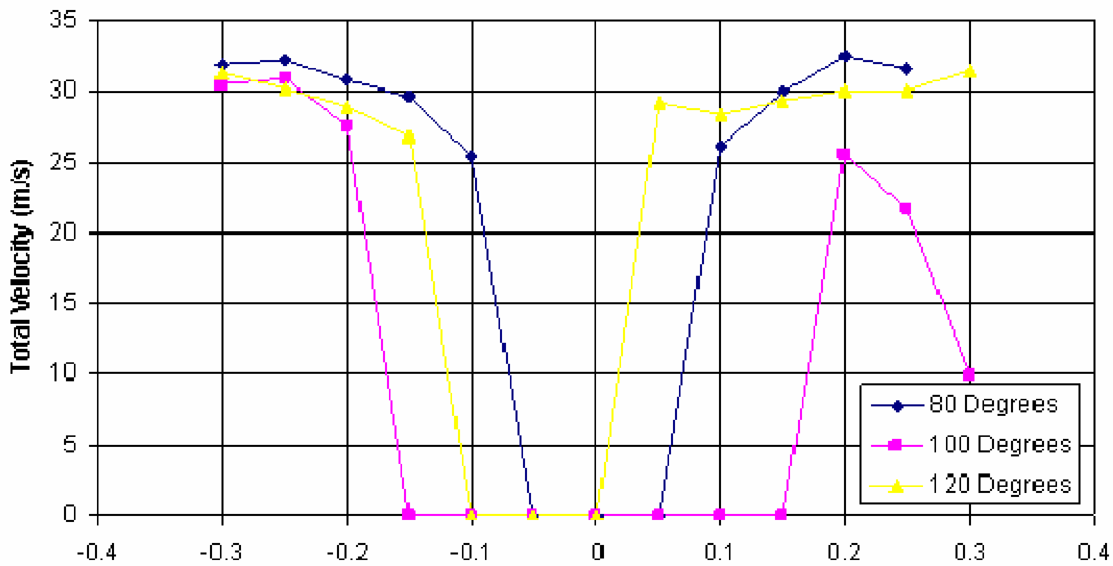

Figure 43. Velocities at 100 psig, 0.375” axial position, for three temperatures (4 gph).

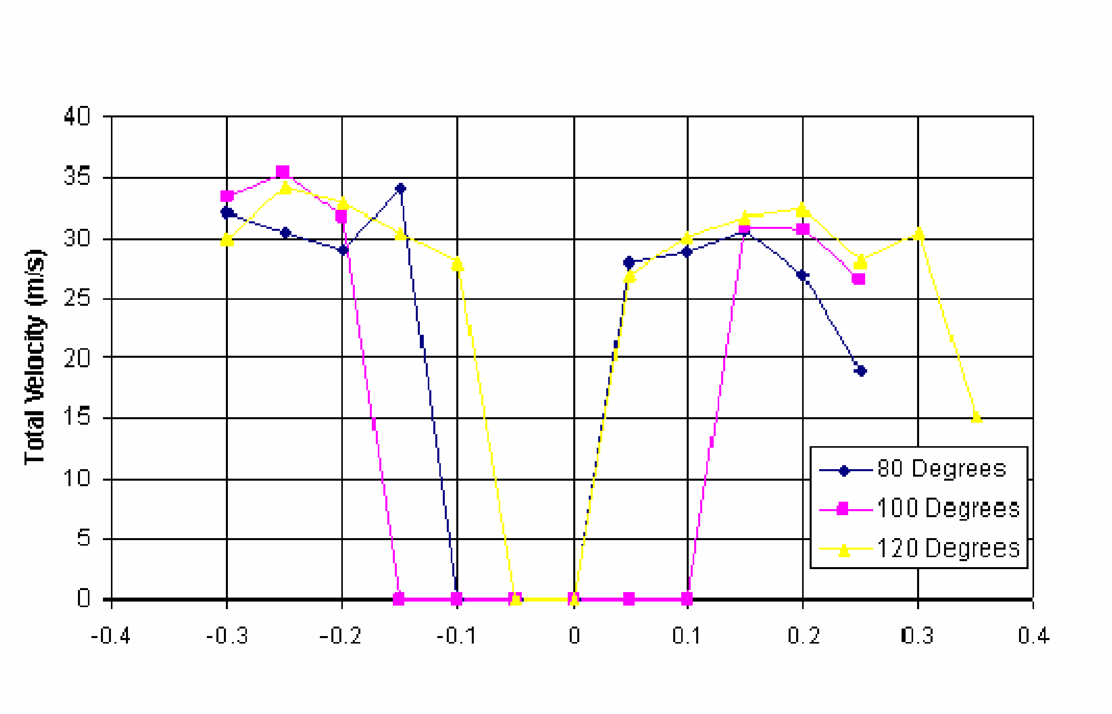

Figure 44. Velocites at 120 psig, 0.375”axial position, for three temperatures (4 gph).

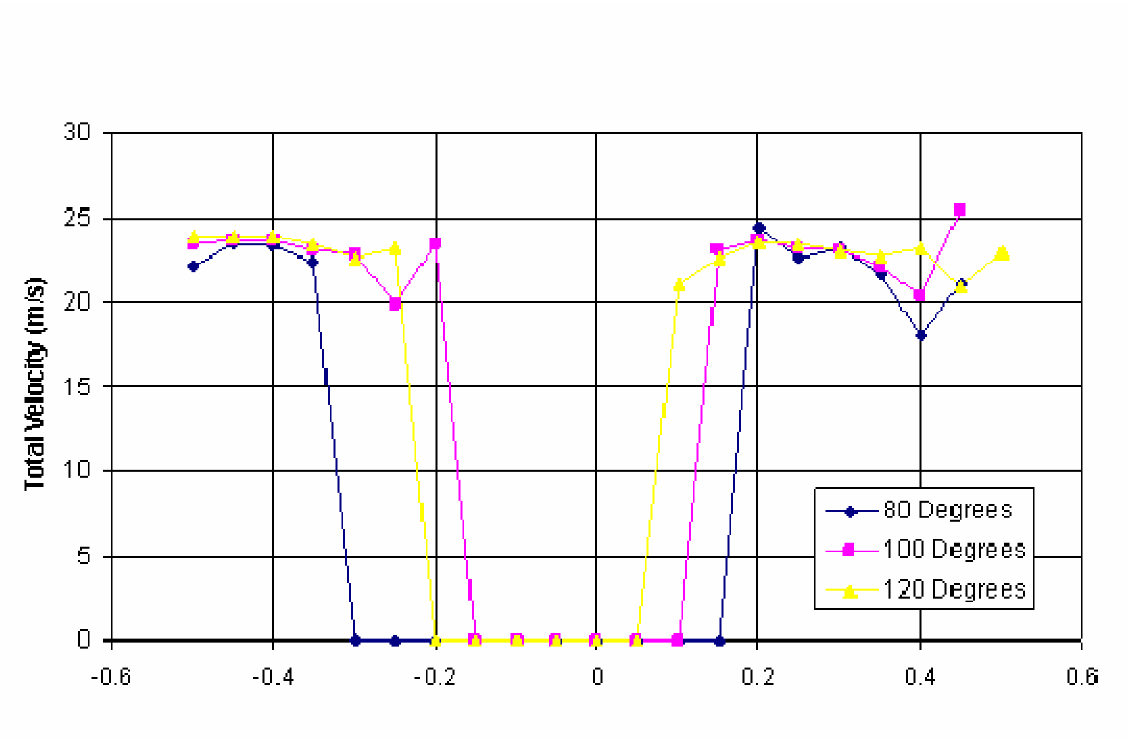

Figure 45. Velocities at 60 psig, 0.5” axial position, for three temperatures (4 gph).

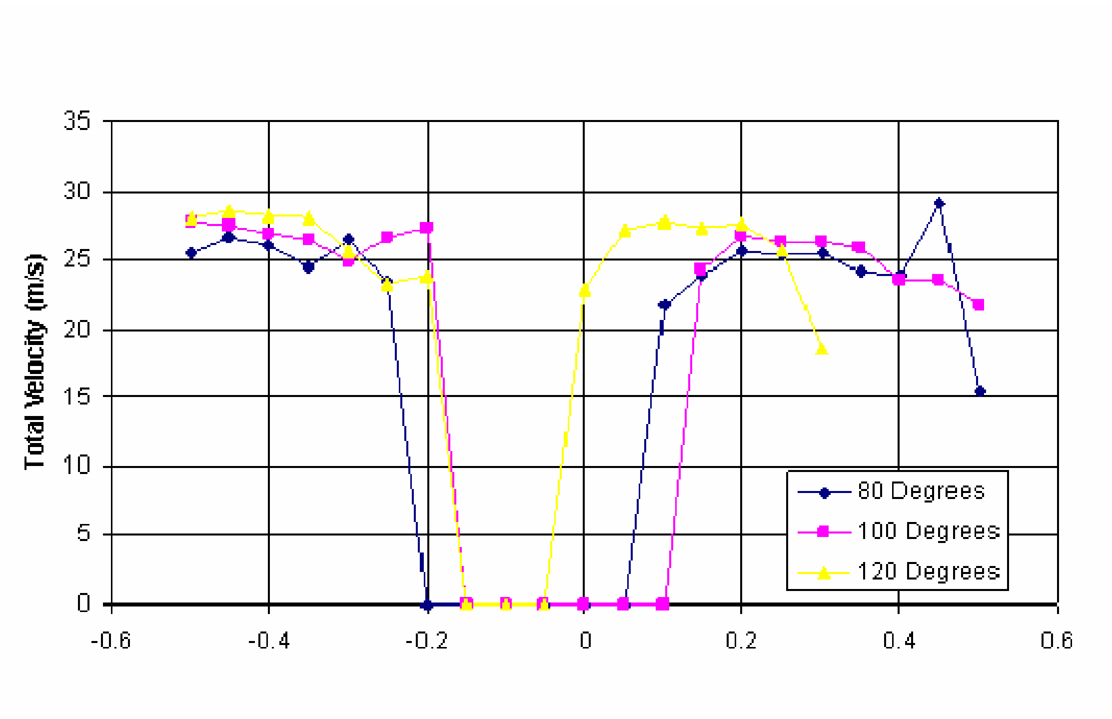

Figure 46. Velocities at 80 psig, 0.5" axial position, for three temperatures (4 gph).

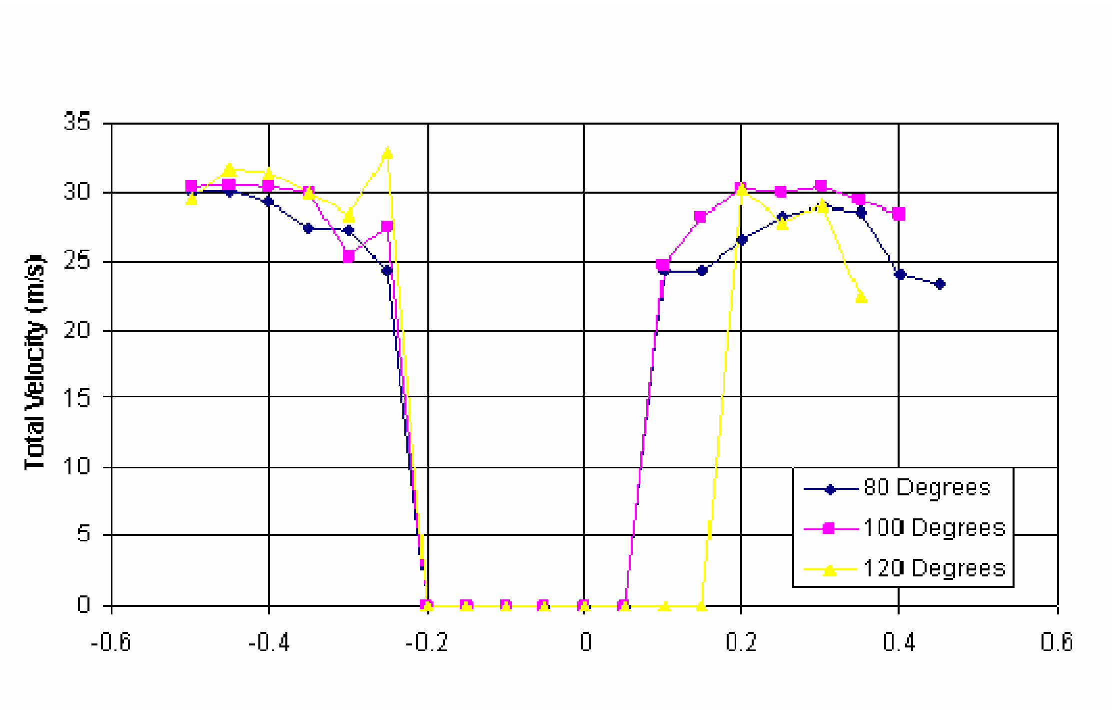

Figure 47. Velocities at 100 psig, 0.5" axial position, for three temperatures (4 gph).

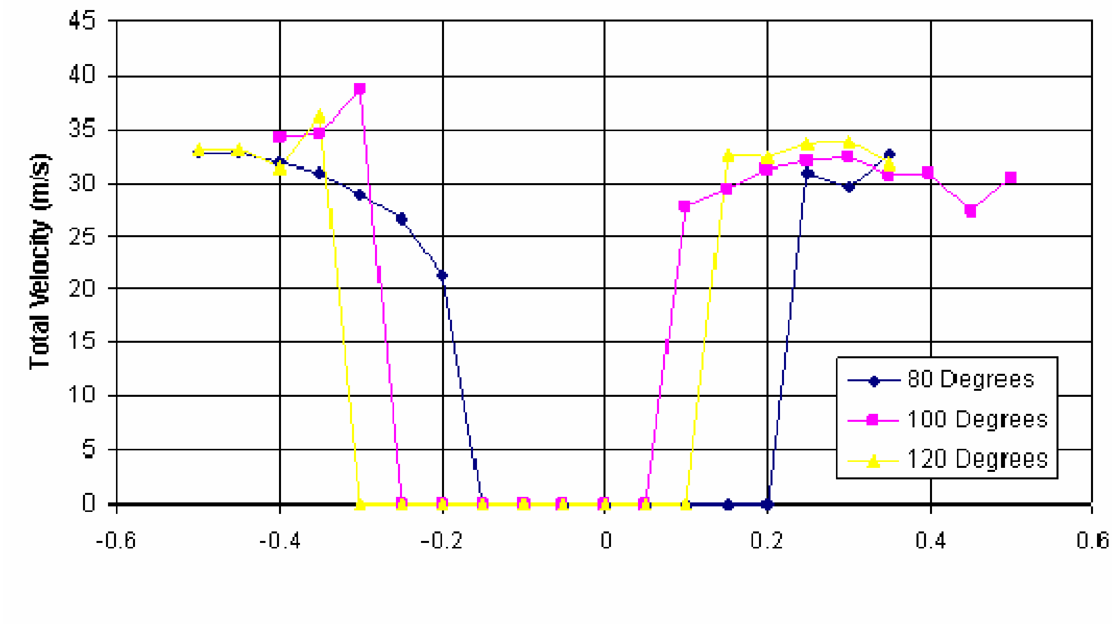

Figure 48. Velocities at 120 psig, 0.5” axial position, for three temperatures (4 gph).

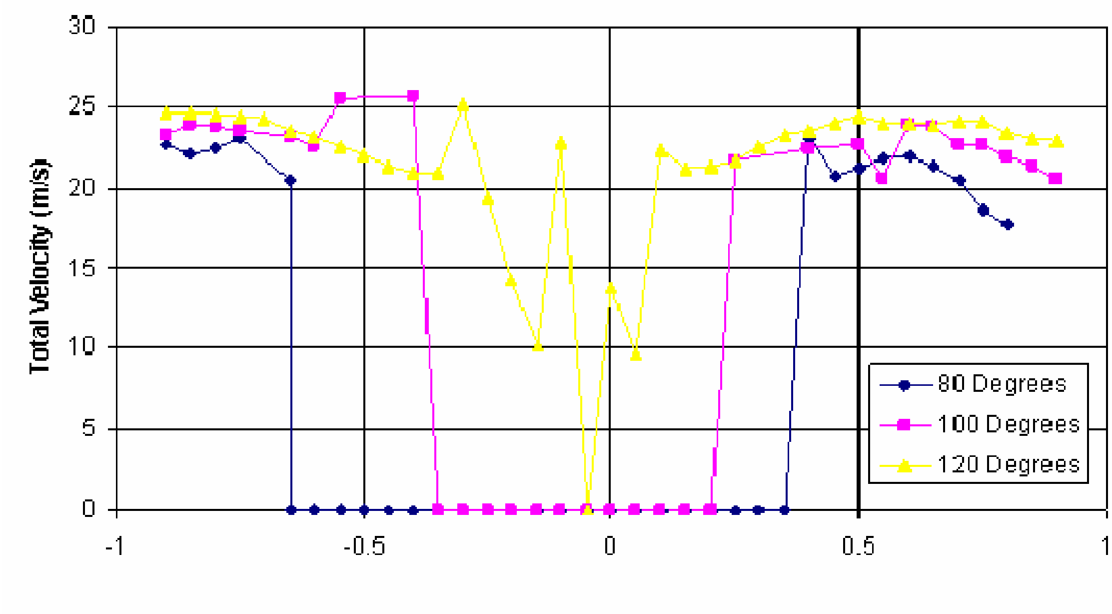

Figure 49. Velocities at 60 psig, 1” axial position, for three temperatures (4 gph).

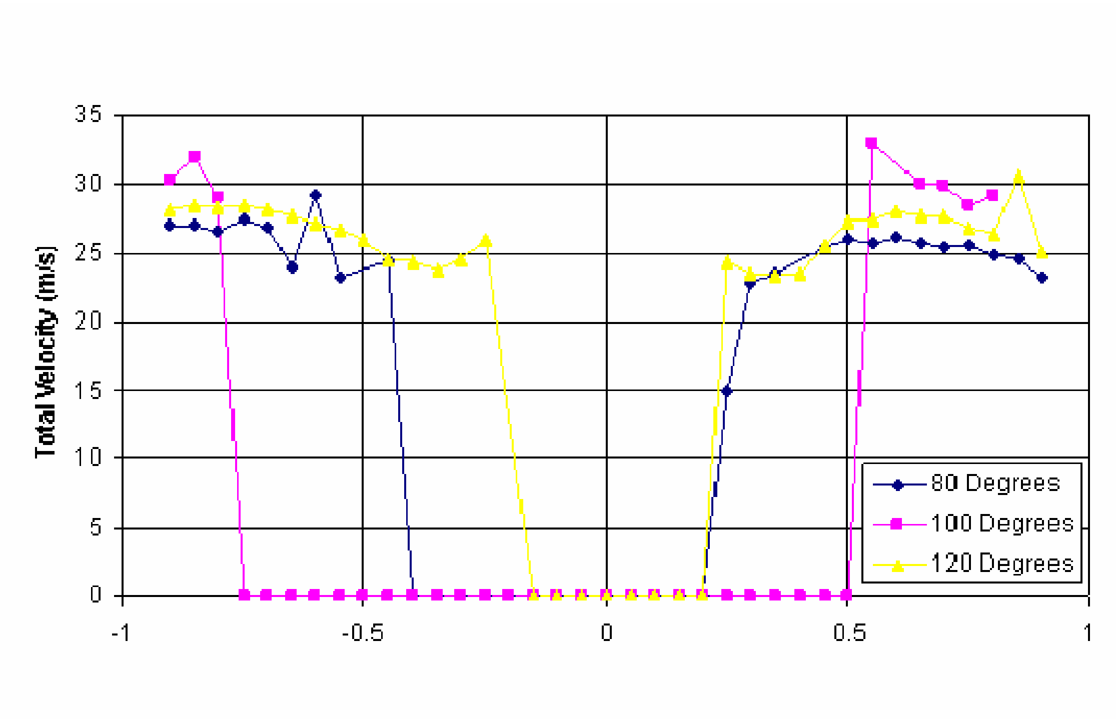

Figure 50. Velocities at 80 psig, 1" axial position, for three temperatures (4gph).

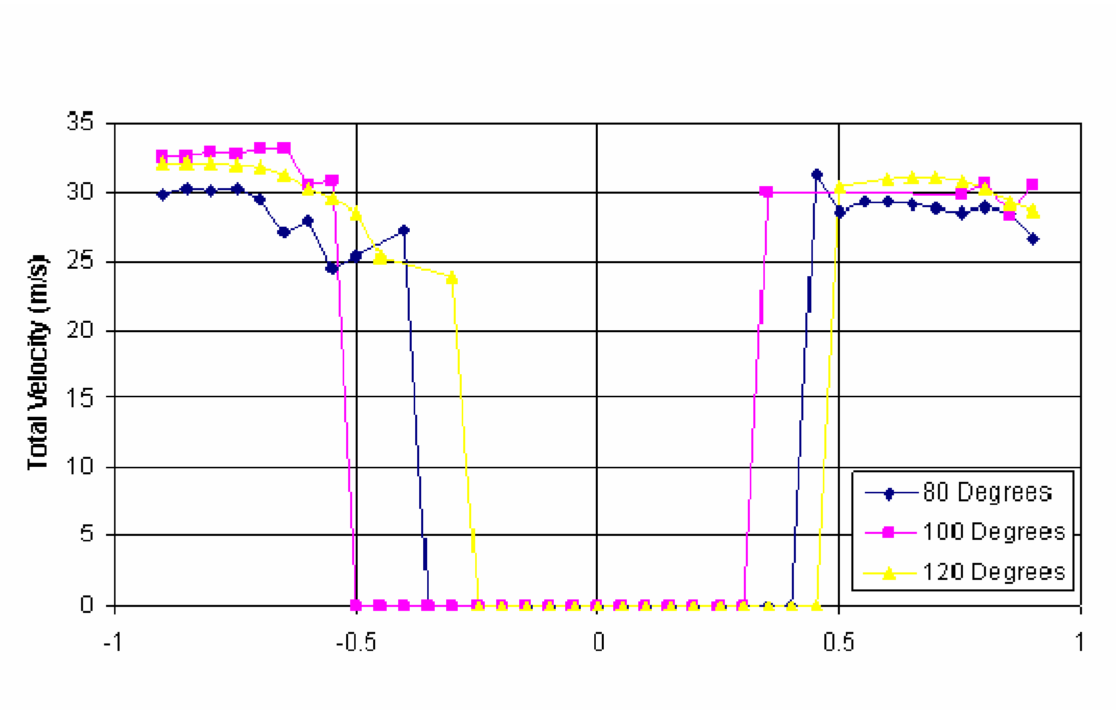

Figure 51. Velocities at 100 psig, 1" axial position, for three temperatures (4gph).

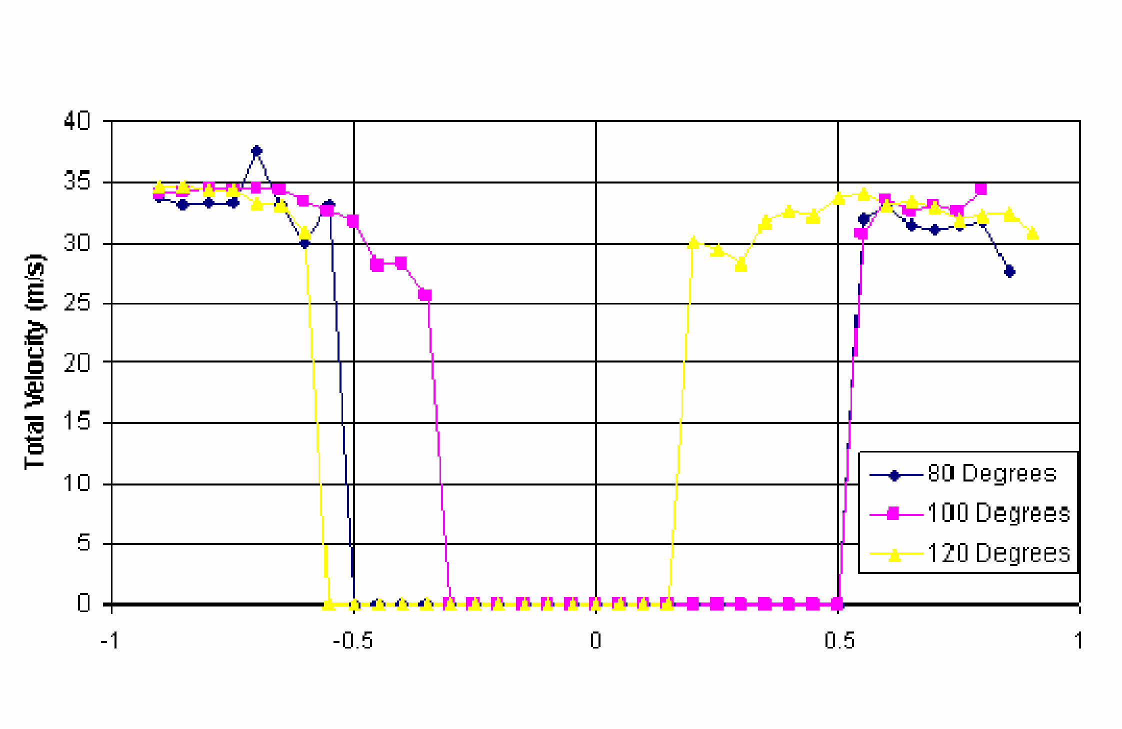

Figure 52. Velocities at 120 psig, 1" axial position, for three temperatures (4gph).

Figures 41 – 52 show no consistent trend in varying the temperature at the four pressures in the study. However, the velocities match Vonderheide (Reference 4) in that the velocities increase with pressure. In Vonderheide (Reference 4), the oil flow at the nozzle exit was assumed to follow Bernoulli's equation. If Bernoulli is written to relate the oil nozzle exit velocity (V_e) to the exit stagnation pressure (P_{te}) and the exit static pressure (P_e), then

$$V_e \propto \sqrt{P_{te} - P_e}$$

Since the exit is to a vacuum,

$$\frac{V_e}{\sqrt{P_{te}}} = const. \qquad (1)$$

V_e is not the same as the droplet velocity (*V*), and P_{te} is lower than the stagnation pressure P_t measured in the feed line to the nozzle. A correlation of the measurements in terms of the "referenced velocity,"

$$\frac{V}{\sqrt{\delta}} \equiv V_{ref} \qquad (2)$$

was examined where

$$\delta \equiv \frac{P_t}{P_{tref}} \qquad (3)$$

and where P_{tref} is a chosen reference stagnation pressure. The reference pressure used in the present study was 100 psia.

Each point within the hollow spray cone was plotted against α, which is a fraction of the spray cone angle from the inner edge to the outer edge. The equation of α is

$$\alpha = \frac{\varphi - \varphi_i}{\varphi_o - \varphi_i} \qquad (4)$$

where φ_i and φ_o are the innermost and outermost angles of the spray, respectively. Figures 53 – 61 show the referenced velocities at each axial location at each pressure and temperature combination.

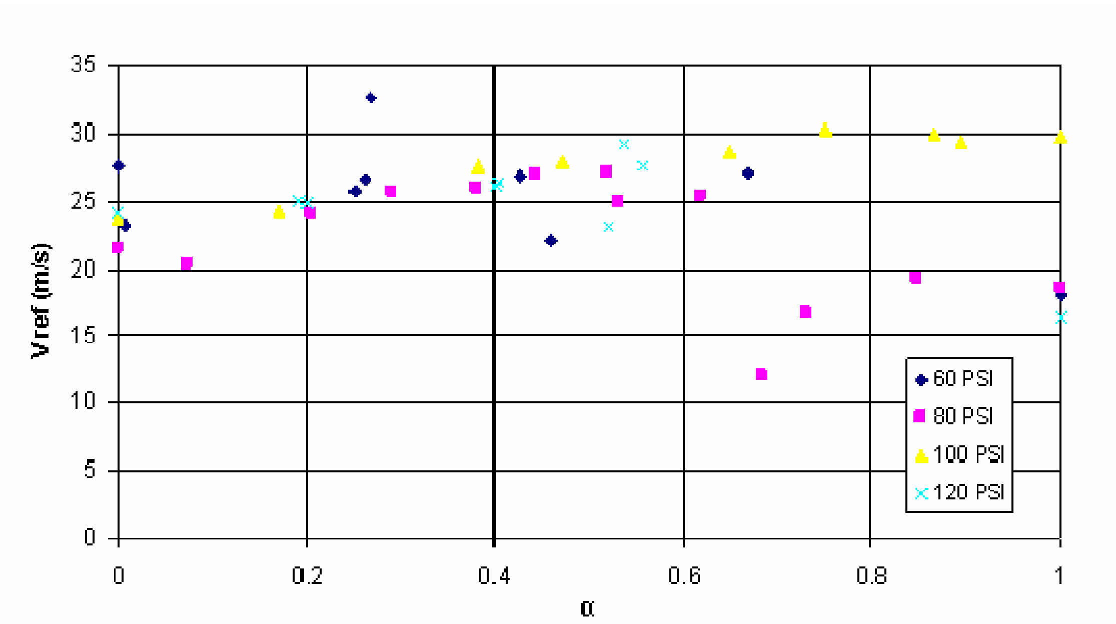

Figure 53. Referenced velocity at 0.375” axial position for four pressures at 80°F (4 gph).

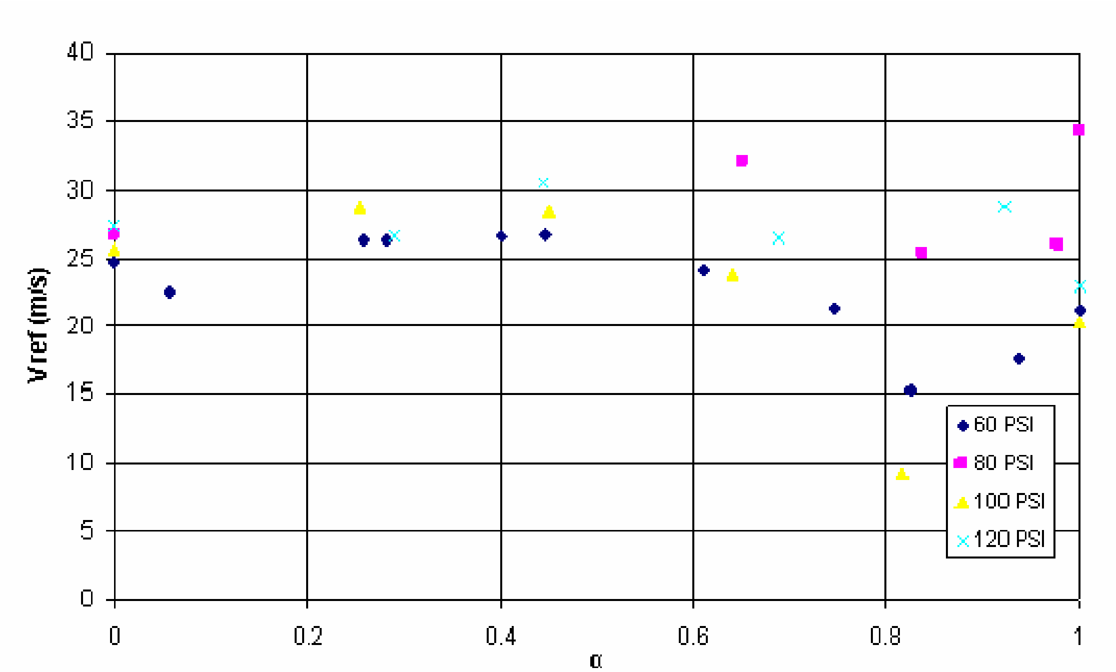

Figure 54. Referenced velocity at 0.375” axial position for four pressures at 100°F (4 gph).

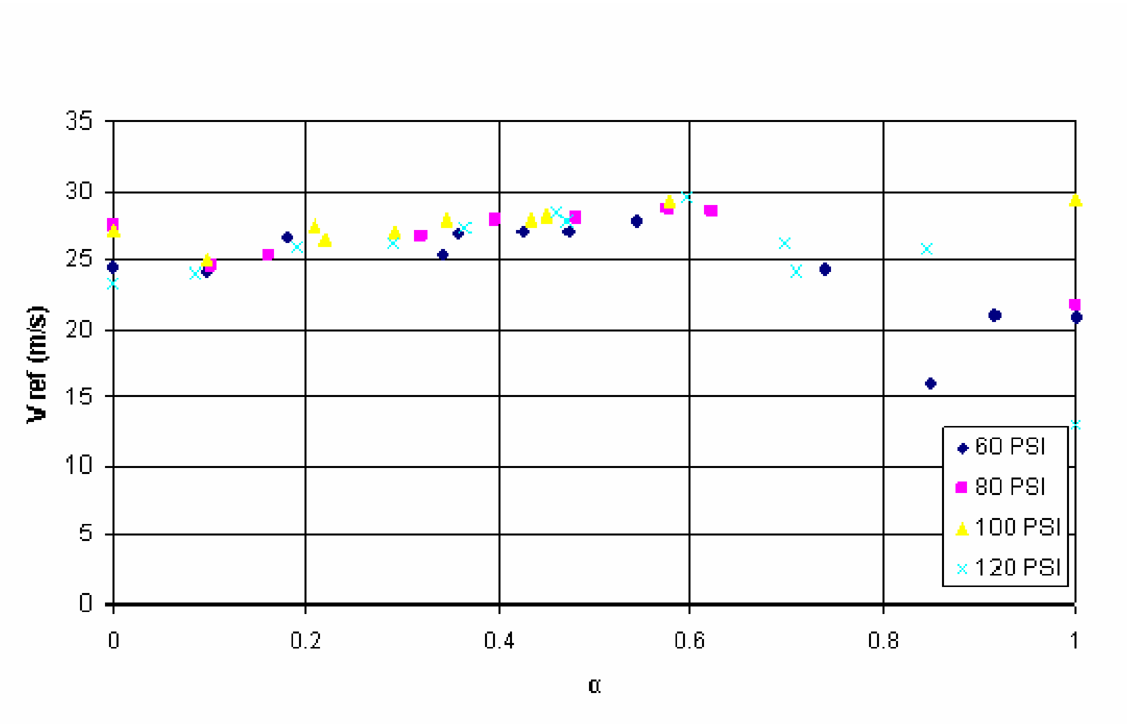

Figure 55. Referenced velocity at 0.375” axial position for four pressures at 120°F (4 gph).

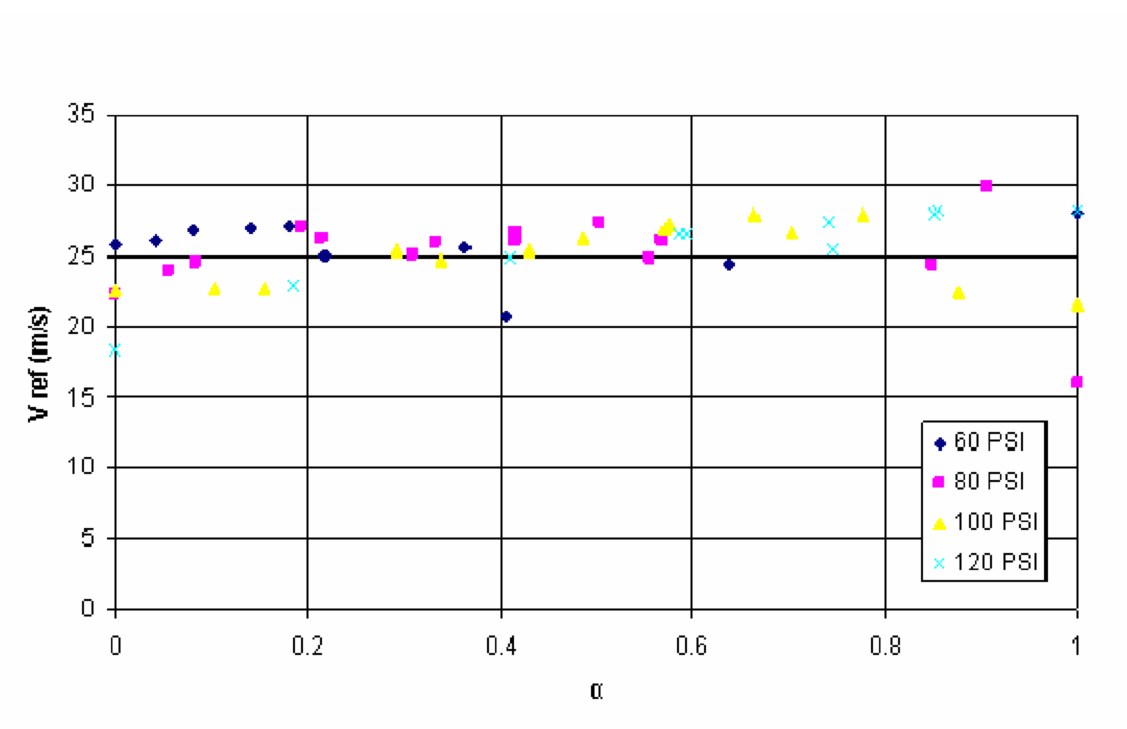

Figure 56. Referenced velocity at 0.5” axial position for four pressures at 80°F (4 gph).

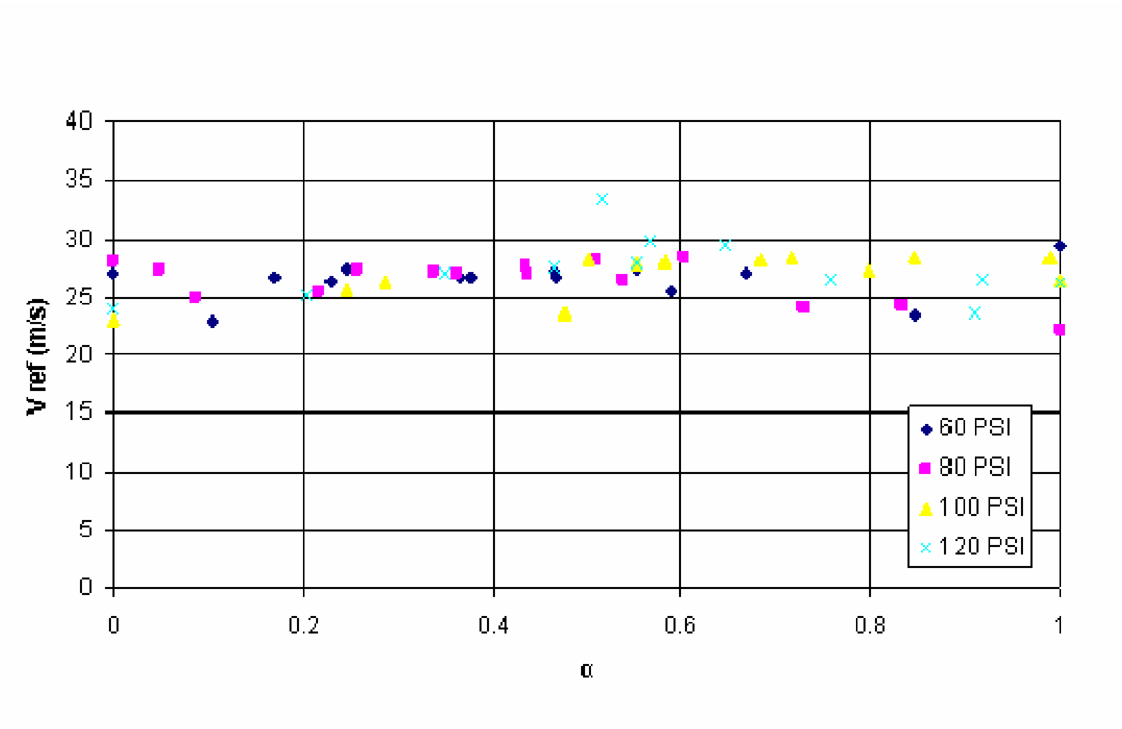

Figure 57. Referenced velocity at 0.5” axial position for four pressures at 100°F (4 gph).

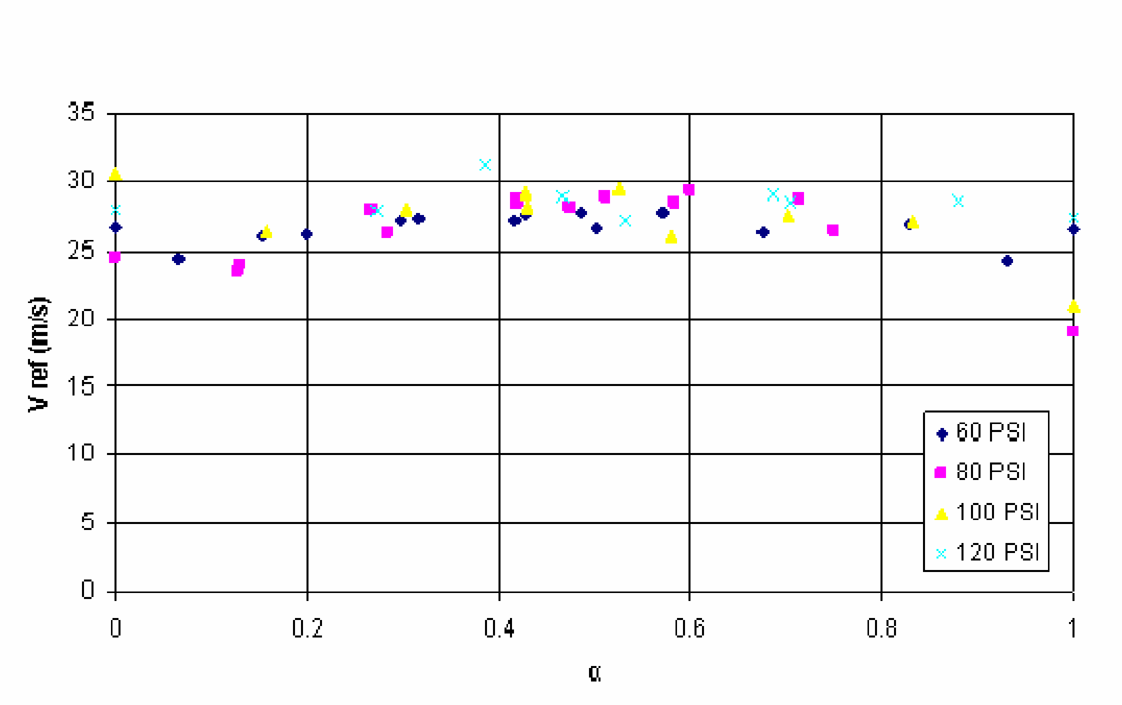

Figure 58. Referenced velocity at 0.5” axial position for four pressures at 120°F (4 gph).

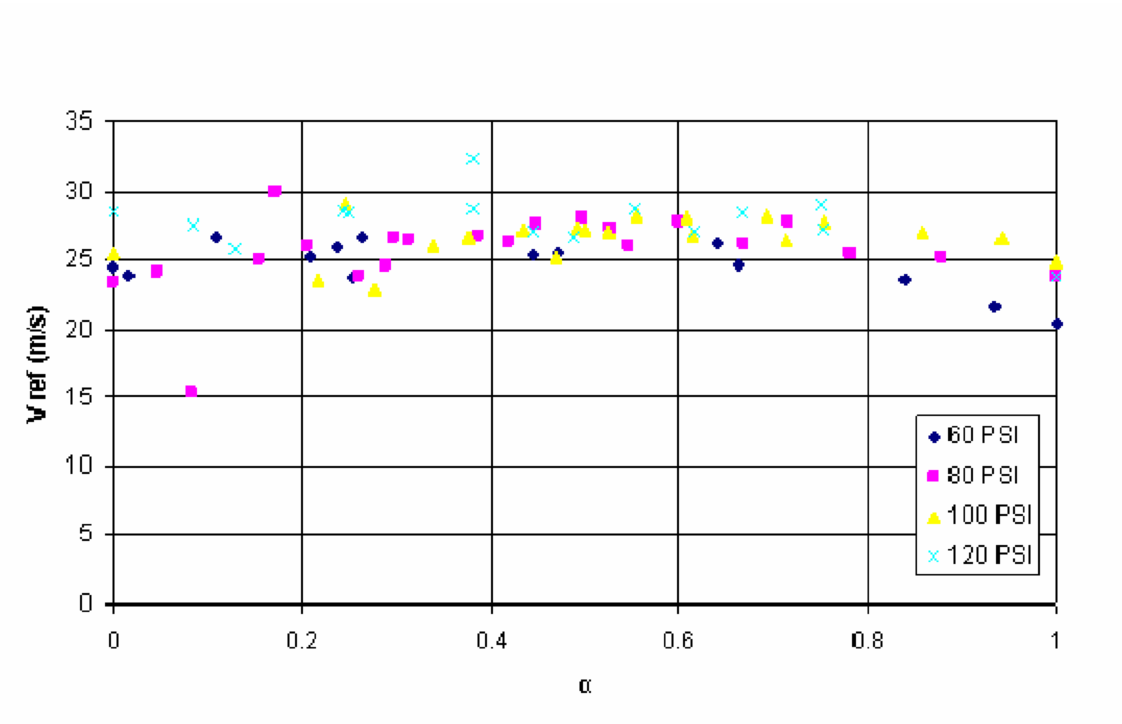

Figure 59. Referenced velocity at 1” axial position for four pressures at 80°F (4 gph).

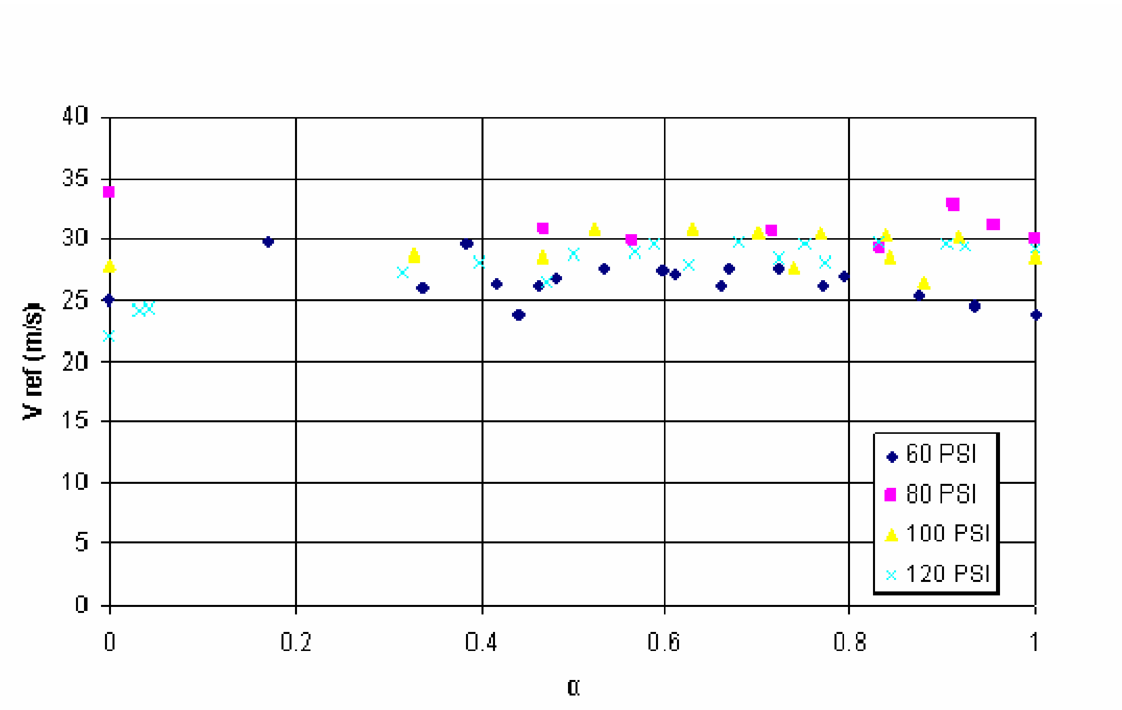

Figure 60. Referenced velocity at 1” axial position for four pressures at 100°F (4 gph).

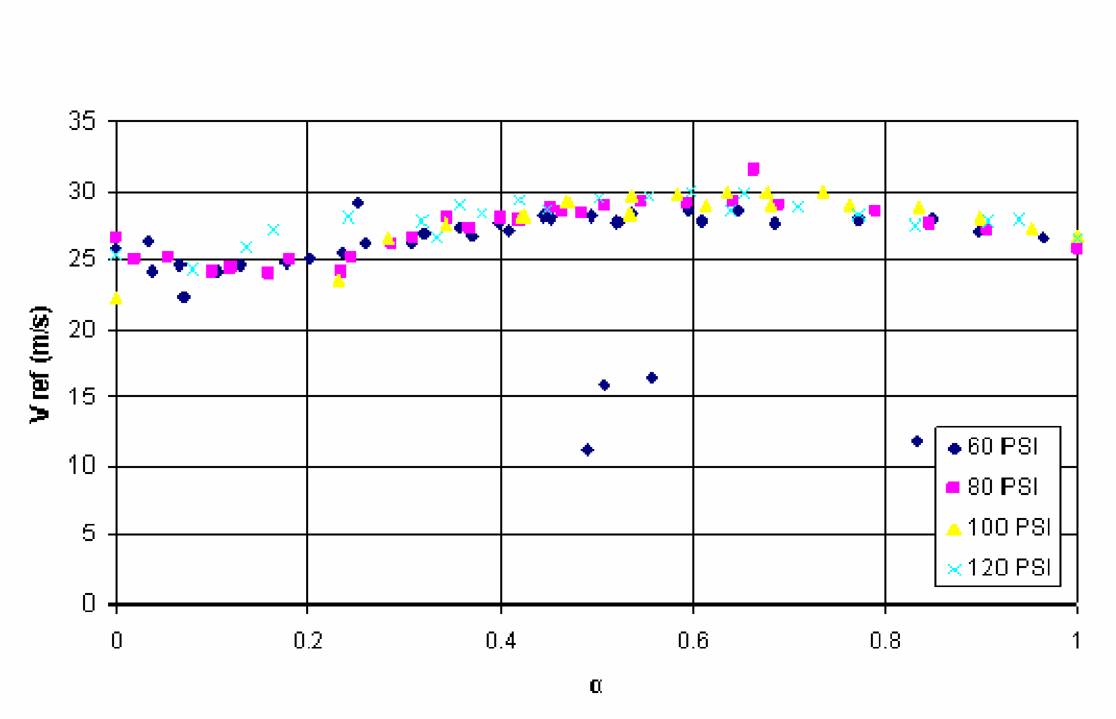

Figure 61. Referenced velocity at 1" axial position for four pressures at 120°F (4 gph).

These nine plots show that the referenced velocity was nearly constant and independent of pressure, temperature, or axial position of the flow. According to the graphs, V_{ref} was within 25 – 30 m/s and was constant throughout the region occupied by the spray.

2. Flow Angle Reduction

The spread (Δ) of the mist cone at each pressure and temperature combination, or the difference between the angles of the inner and outer boundaries, can be characterized by

$$\Delta = \varphi_o - \varphi_i \tag{5}$$

and the results are shown in Figure 62 for the three temperatures.

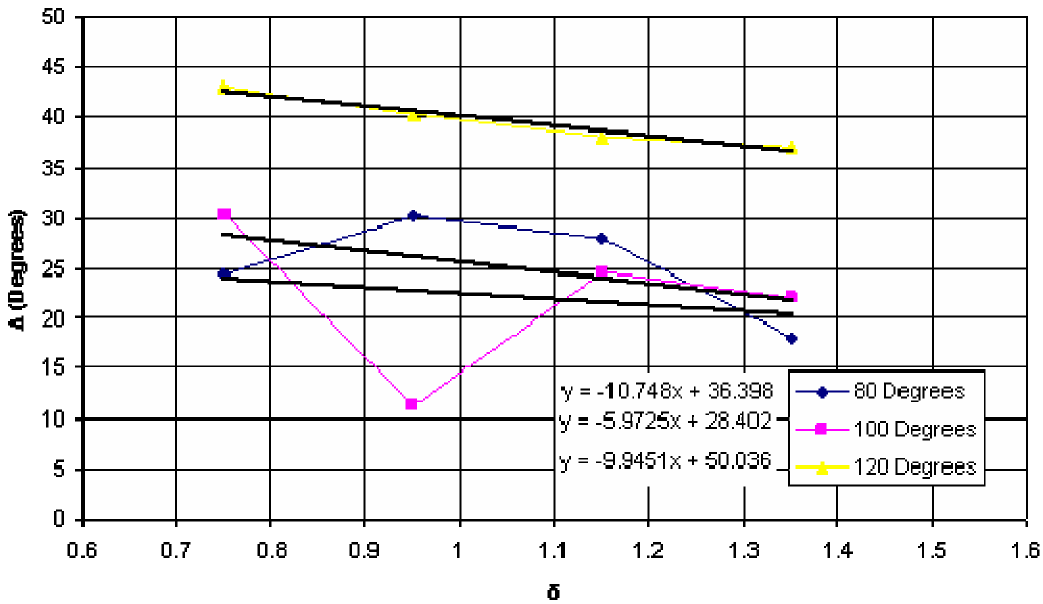

Figure 62. Flow angle spread for three temperatures at referenced pressure (4 gph).

Figure 62 shows an almost linear relationship between the average spread of the spray cones at each temperature, with one suspect data point. The results show a decrease in spread as the pressure increased, which is not in agreement with Vonderheide (Reference 4). Also, because the spread does not vary monotonically, it cannot be concluded that the spread is a function of temperature for this nozzle. Thus, the analysis of spread was repeated using the geometric angle of the spray derived from the axial and x-positions at the spray edges. Figure 63 shows the results.

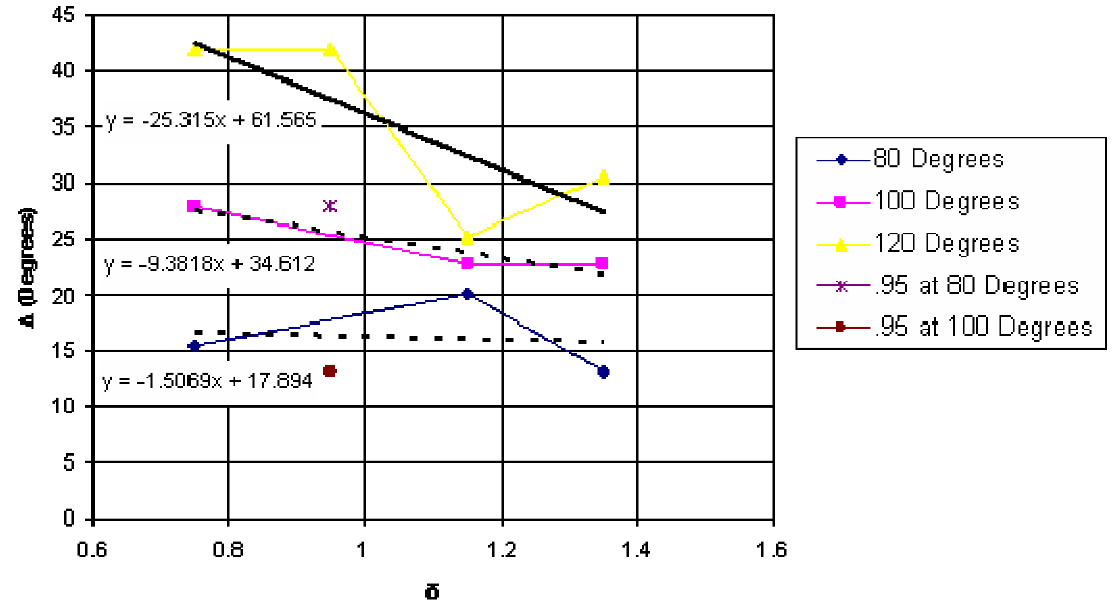

Figure 63. Geometric angle spread for three temperatures at referenced pressure (4 gph).

At δ = .95 at both 80°F and 100°F, the data are again suspect. Thus, they are shown on the graph, but were not used in deriving the correlation. A trend line was added to the remaining data, giving the following results:

80°F: $\Delta = -1.5069\delta + 17.894$ (6)

100°F: $\Delta = -9.3818\delta + 34.612$ (7)

120°F: $\Delta = -25.315\delta + 61.565$ (8)

3. Flow Rate Reduction

As with the velocity, the flow rate data were referenced to the flow rate that results from an absolute pressure of 100 psia (P_{tref}). The reference flow rate (G_{ref}) was calculated using the relationship between stagnation pressure and flow rate given in Figure 27. The measured flow rates (G) were divided by G_{ref} and plotted versus δ. Because the flow rates were only dependent on pressure, a temperature variation in Figure 64 is not present. Thus, Figure 64 represents the flow rates at all temperatures and pressures, giving

$$\frac{G}{G_{ref}} = 0.0988\delta + 0.7781 \qquad (9)$$

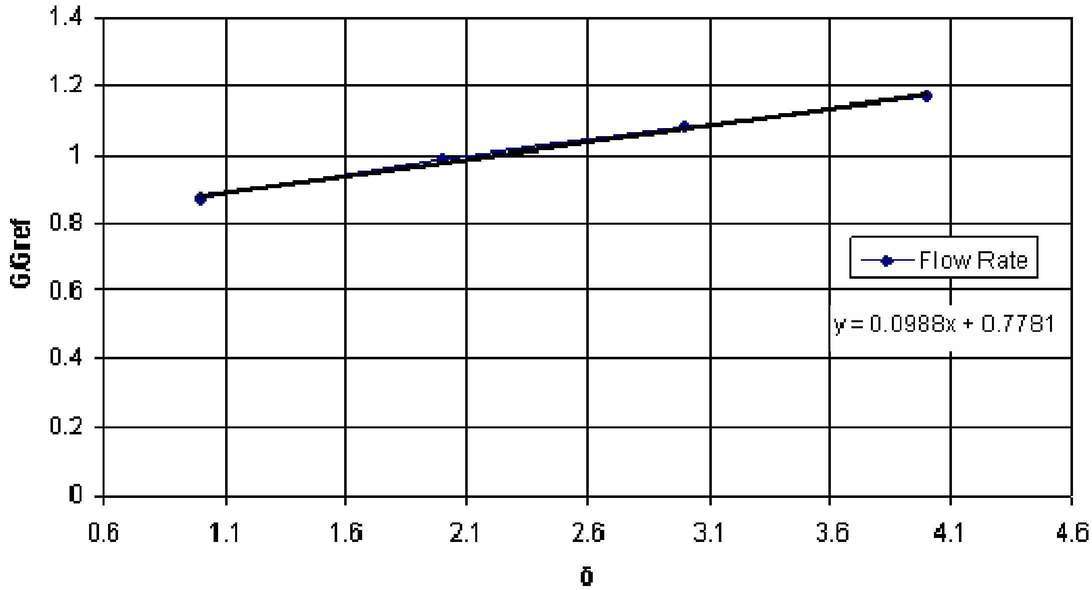

Figure 64. Referenced flow rate, G/G_{ref} with referenced pressure of the 4 gph nozzle at three temperatures.

4. Summary

The 4 gph "mini mist" nozzle flow pattern was described quantitatively by the expressions

$$\frac{V}{\sqrt{\delta}} = V_{ref} = const., \text{ where } \delta = \frac{P_t}{P_{tref}}$$

$$\Delta = \varphi_o - \varphi_i = a\delta + b, \text{ where } a \text{ and } b \text{ are constants.}$$

$$\varphi_m = \frac{\varphi_o + \varphi_i}{2} = const.$$

and the flow rate (G) was described by

$$\frac{G}{G_{ref}} = c\delta + d, \text{ where } c \text{ and } d \text{ are constants and } G_{ref} \text{ is the flow rate at } P_{tref}.$$

For the 4 gph nozzle, using P_{tref} = 100 psia, the following values were obtained:

V_{ref} = 26 m/s (for all pressure and temperature combinations)

a = -1.5069 and *b* = 17.894 (for 80°F)

a = -9.3818 and *b* = 34.612 (for 100°F)

a = -25.315 and *b* = 61.565 (for 120°F)

φ_m = 32.4° (for 80°F)

φ_m = 31.2° (for 100°F)

φ_m = 24.5° (for 120°F)

c = 0.0988 and *d* = 0.7781 (for all pressure and temperature combinations)

The correlations of the above constants (*a*, *b*, and φ_m, respectively) with respect to temperature are shown in Figures 65 – 67. A reference temperature, T_{ref} = 530°R (70°F), was used in the correlations.

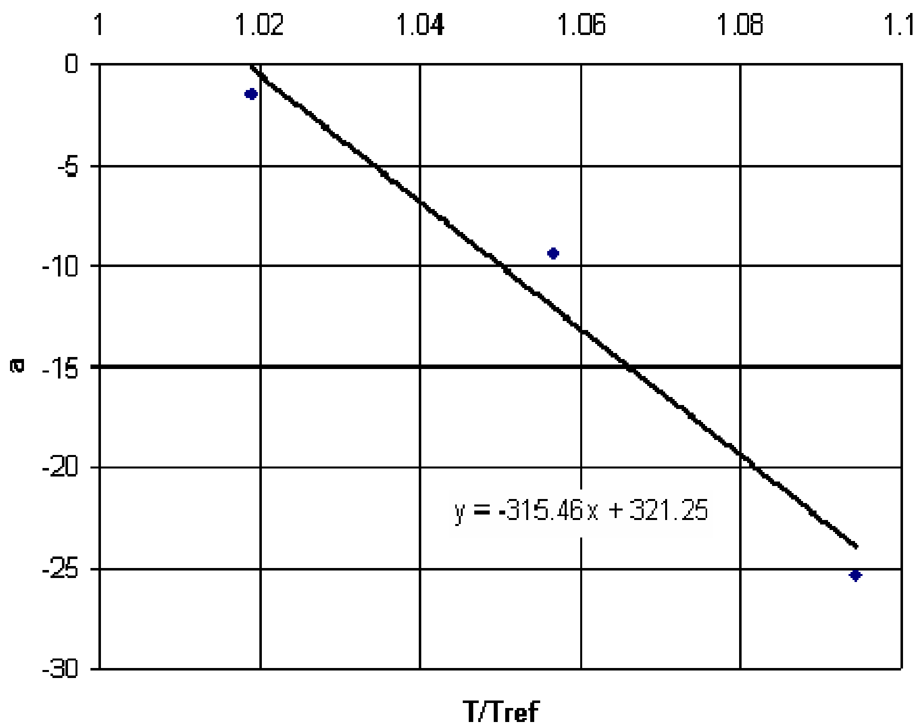

Figure 65. Coefficient *a* correlation (4 gph).

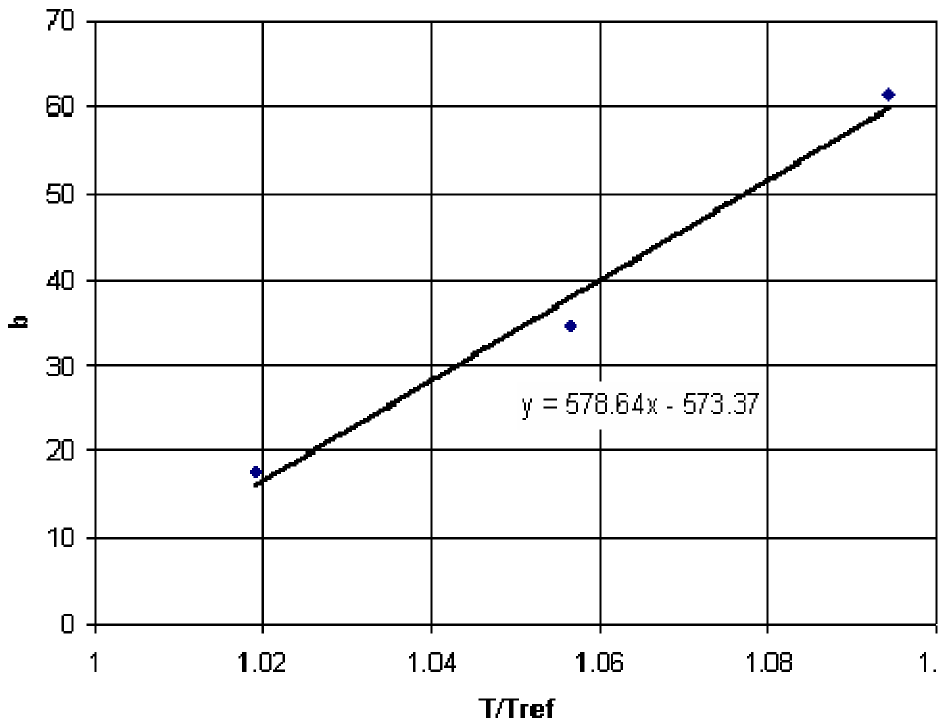

Figure 66. Coefficient *b* correlation (4 gph).

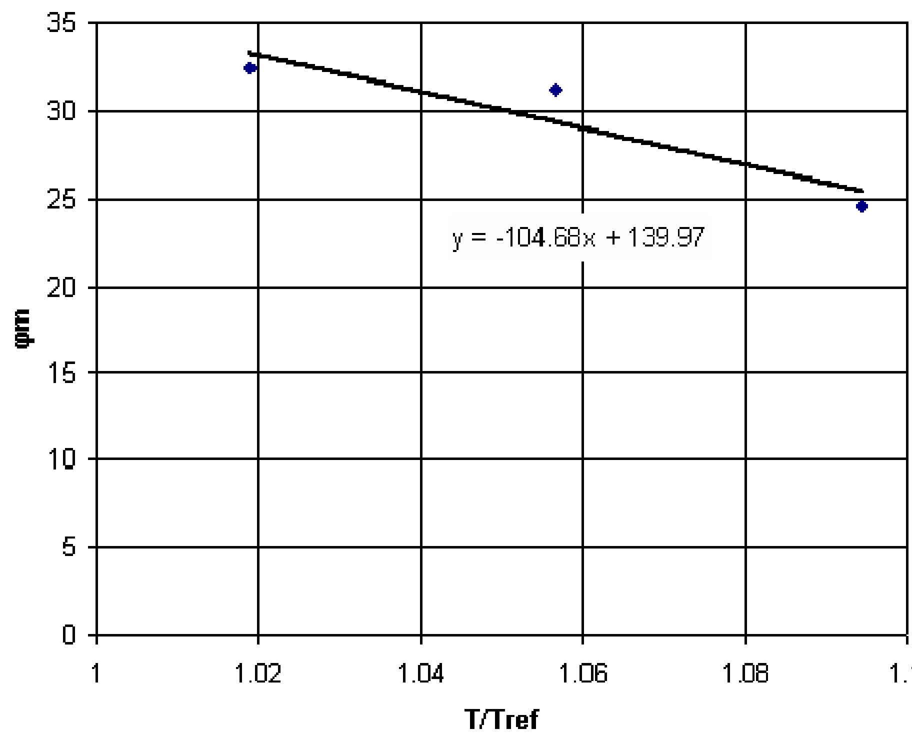

Figure 67. φ_m correlation (4gph).

B. SIX GALLON PER HOUR NOZZLE

1. Velocity Reduction

The Hago 6 gph "standard" nozzle was characterized in the same manner as the 4 gph "mini mist" nozzle. Figures 68 – 76 show the temperature effect on the 6 gph nozzle at each temperature and axial station.

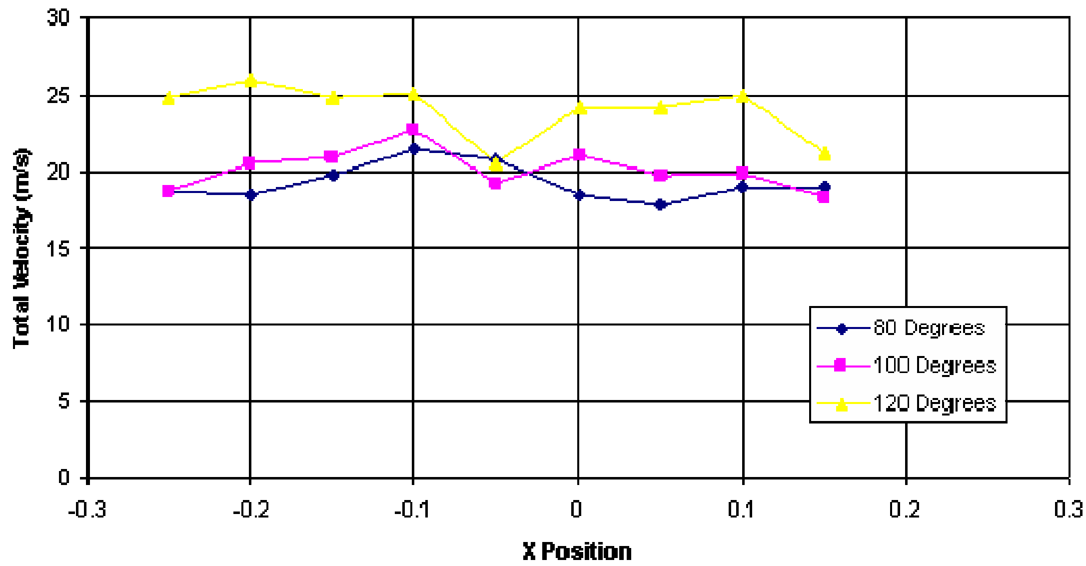

Figure 68. Velocities at 60 psig, 0.375" axial position, for three temperatures (6gph).

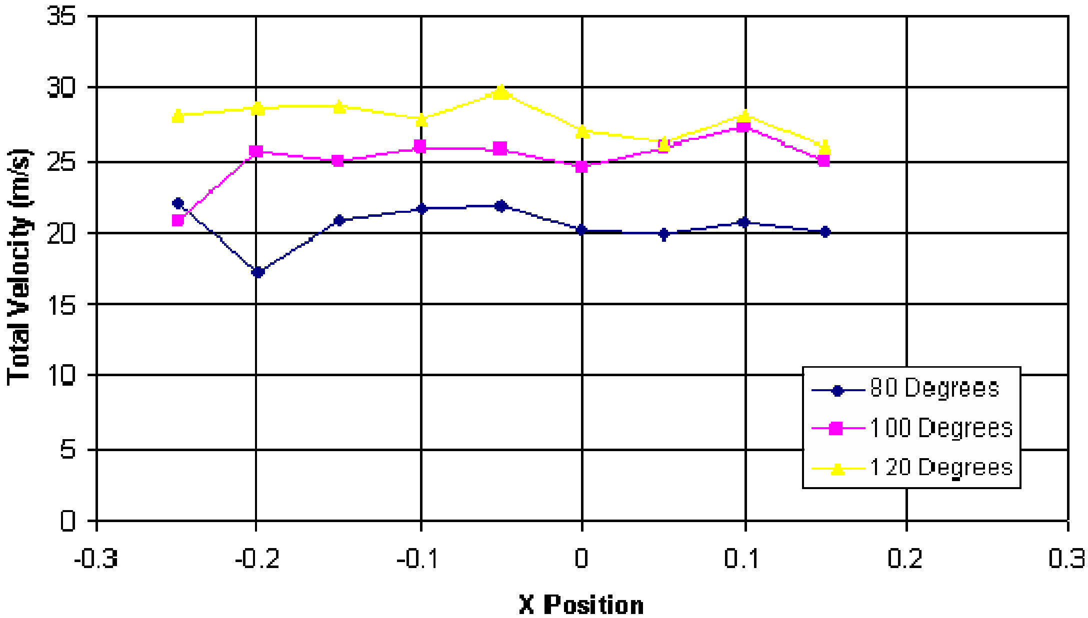

Figure 69. Velocities at 80 psig, 0.375” axial position, for three temperatures (6gph).

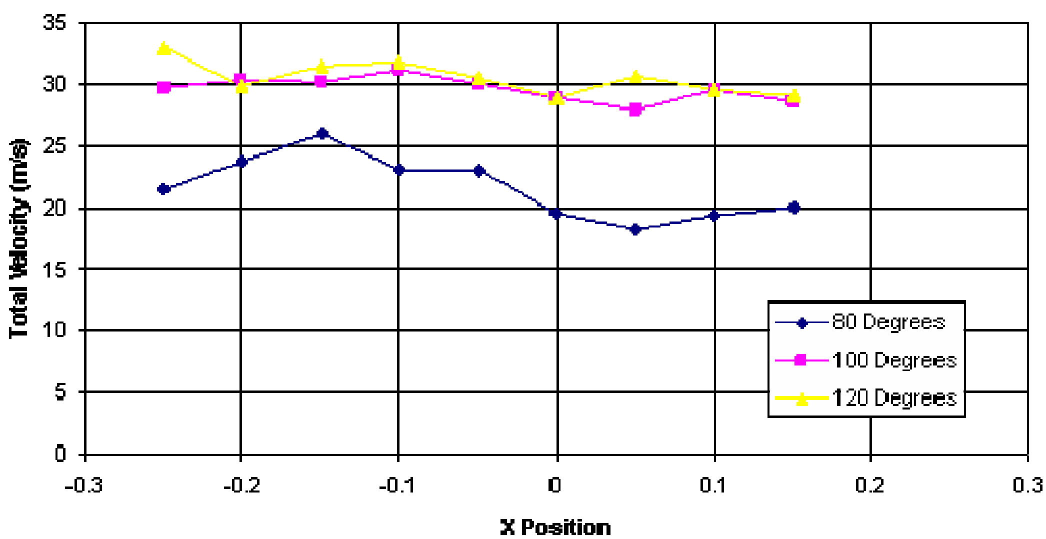

Figure 70. Velocities at 100 psig, 0.375” axial position, for three temperatures (6gph).

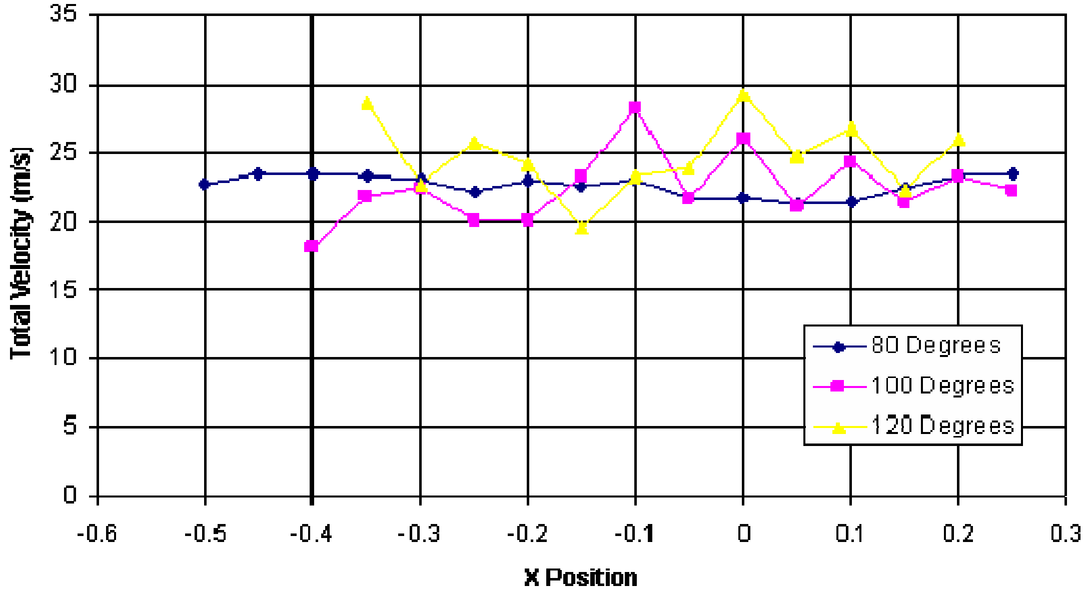

Figure 71. Velocities at 60 psig, 0.5” axial position, for three temperatures (6gph).

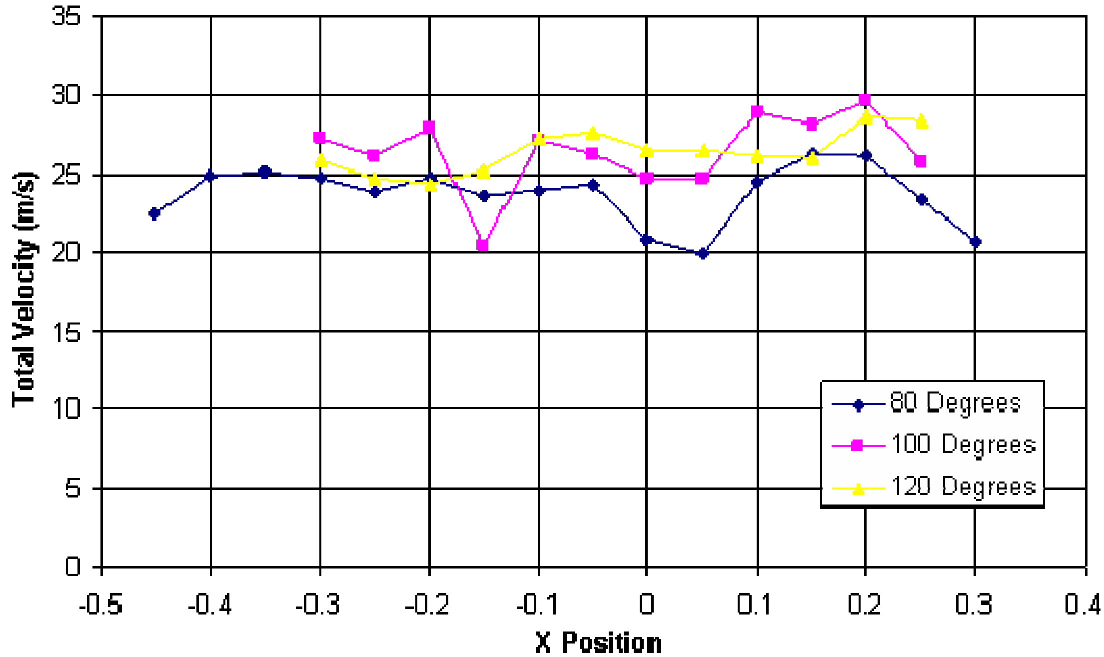

Figure 72. Velocities at 80 psig, 0.5” axial position, for three temperatures (6gph).

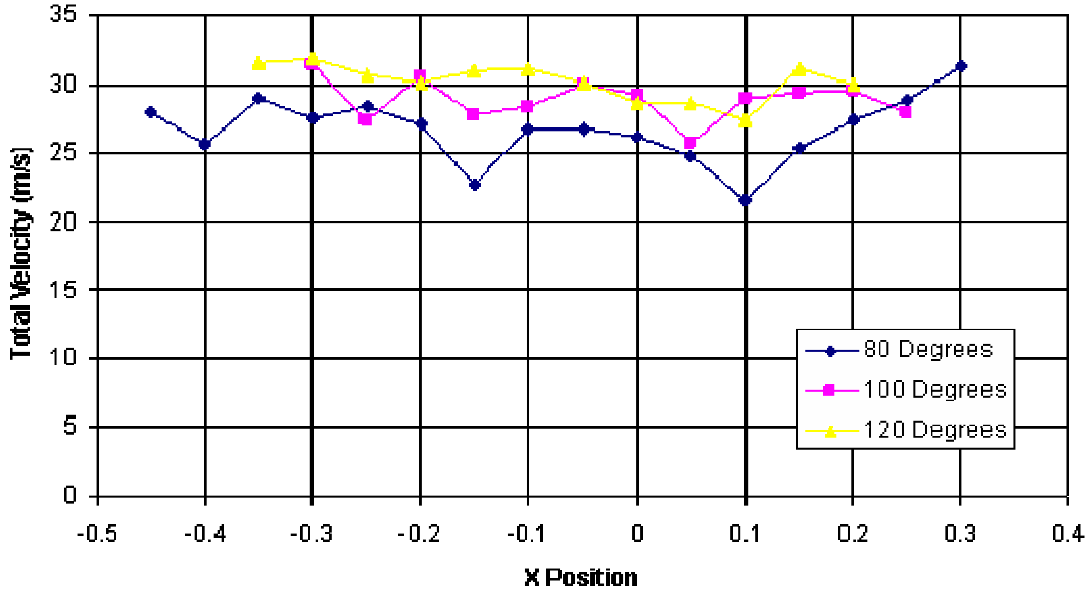

Figure 73. Velocities at 100 psig, 0.5" axial position, for three temperatures (6gph).

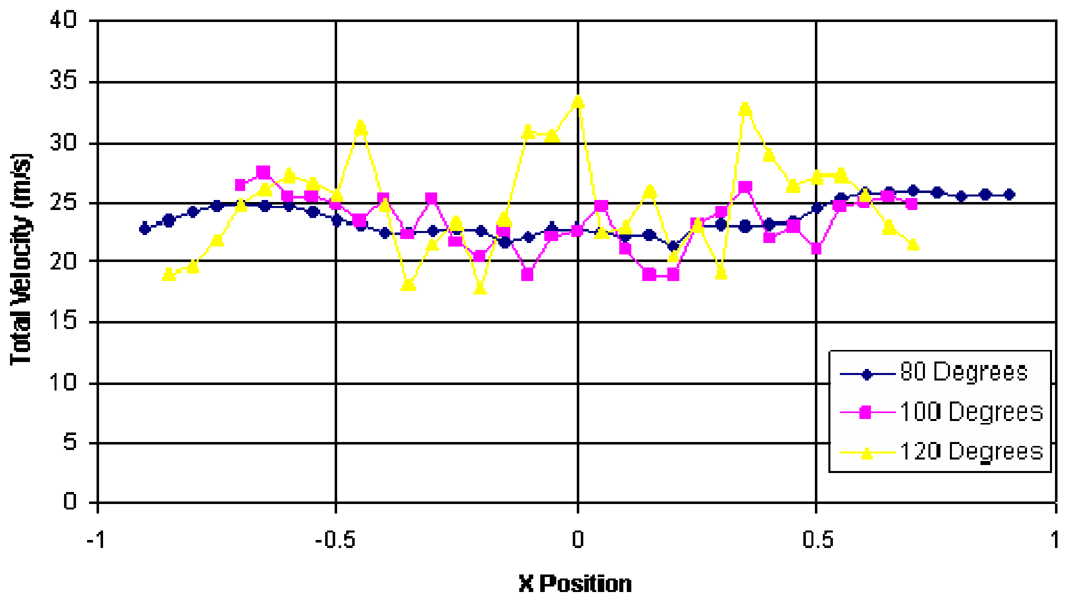

Figure 74. Velocities at 60 psig, 1" axial position, for three temperatures (6gph).

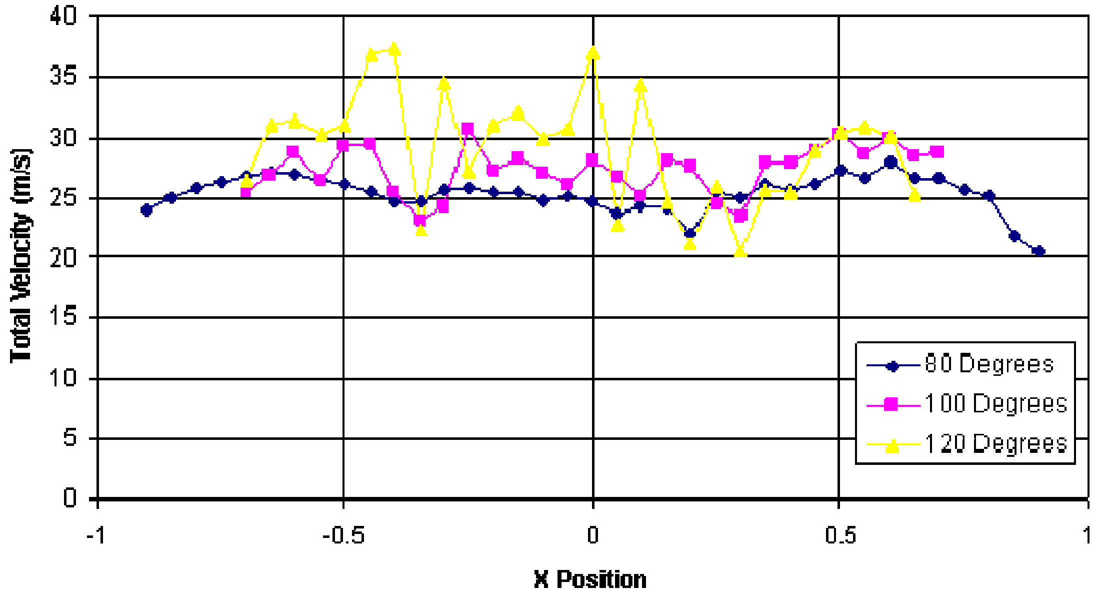

Figure 75. Velocities at 80 psig, 1" axial position, for three temperatures (6gph).

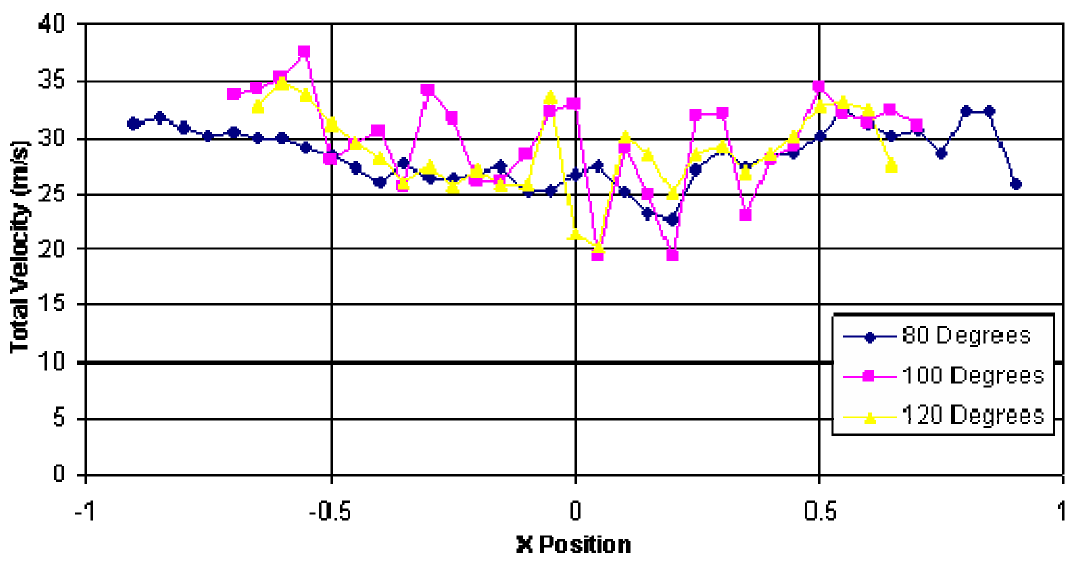

Figure 76. Velocities at 100 psig, 1" axial position, for three temperatures (6gph).

As can be seen from Figures 68 – 76, an effect with temperature was evident in that as the temperature increased, the total velocity increased at each axial position.

The same reference velocity reduction based on the Bernoulli relationship was achieved as with the 4 gph nozzle. Figures 77 – 85 show the results. Note that the inner angle of the spray, $\varphi_i = 0$.

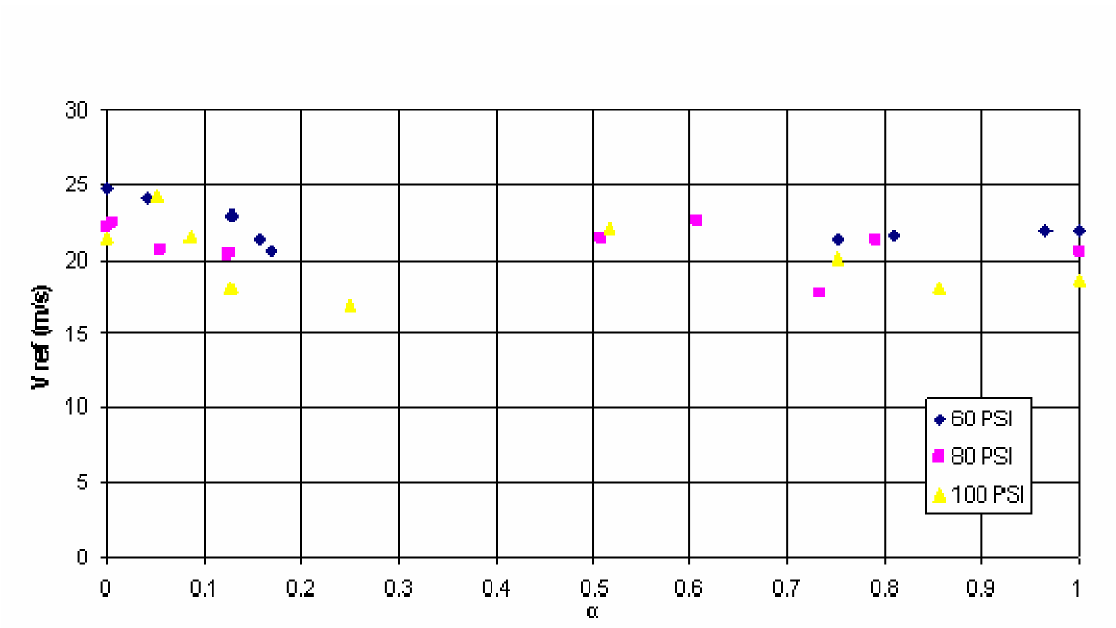

Figure 77. Referenced velocity at 0.375” axial position for three pressures at 80°F (6 gph).

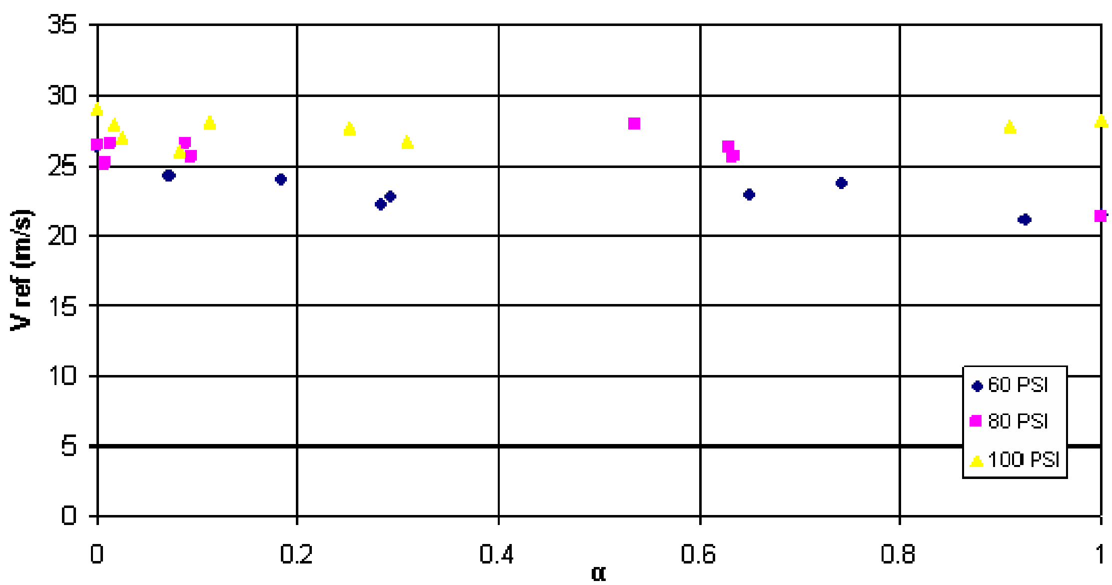

Figure 78. Referenced velocity at 0.375” axial position for three pressures at 100°F (6 gph).

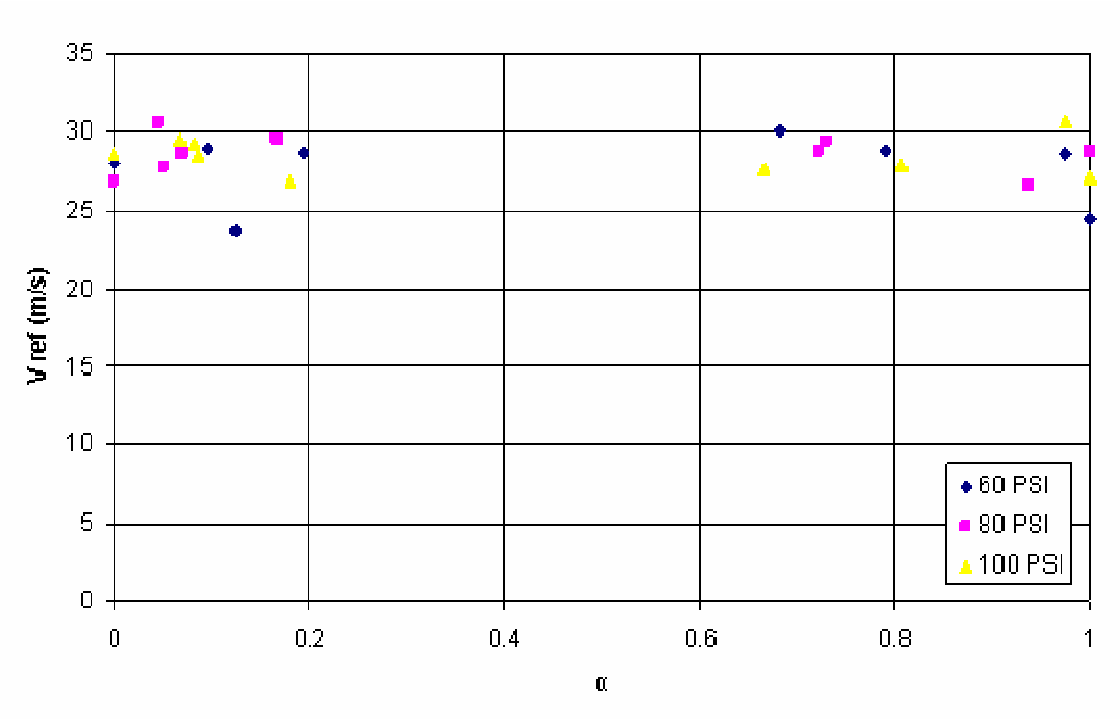

Figure 79. Referenced velocity at 0.375” axial position for three pressures at 120°F (6 gph).

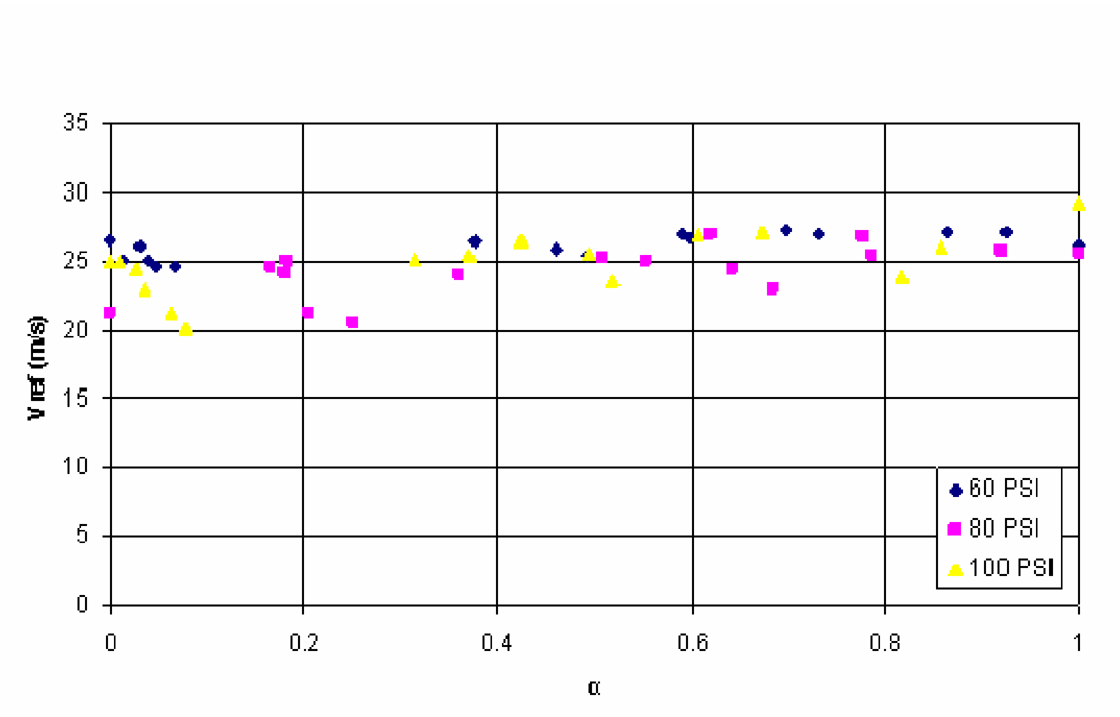

Figure 80. Referenced velocity at 0.5” axial position for three pressures at 80°F (6 gph).

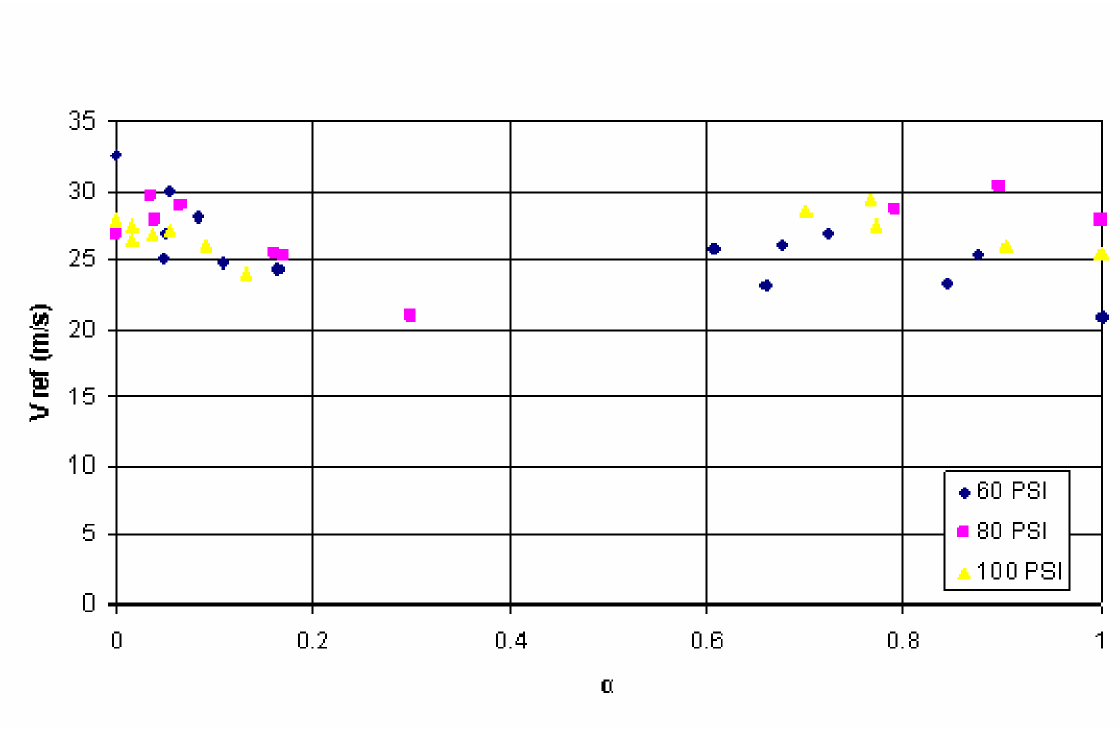

Figure 81. Referenced velocity at 0.5" axial position for three pressures at 100°F (6 gph).

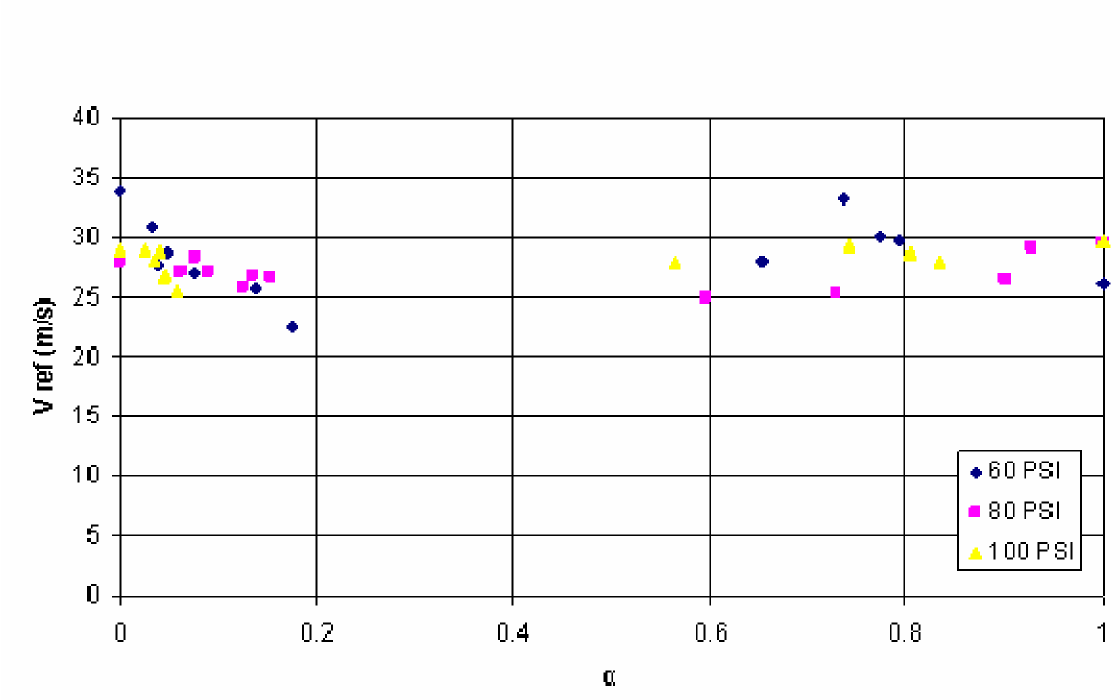

Figure 82. Referenced velocity at 0.5" axial position for three pressures at 120°F (6 gph).

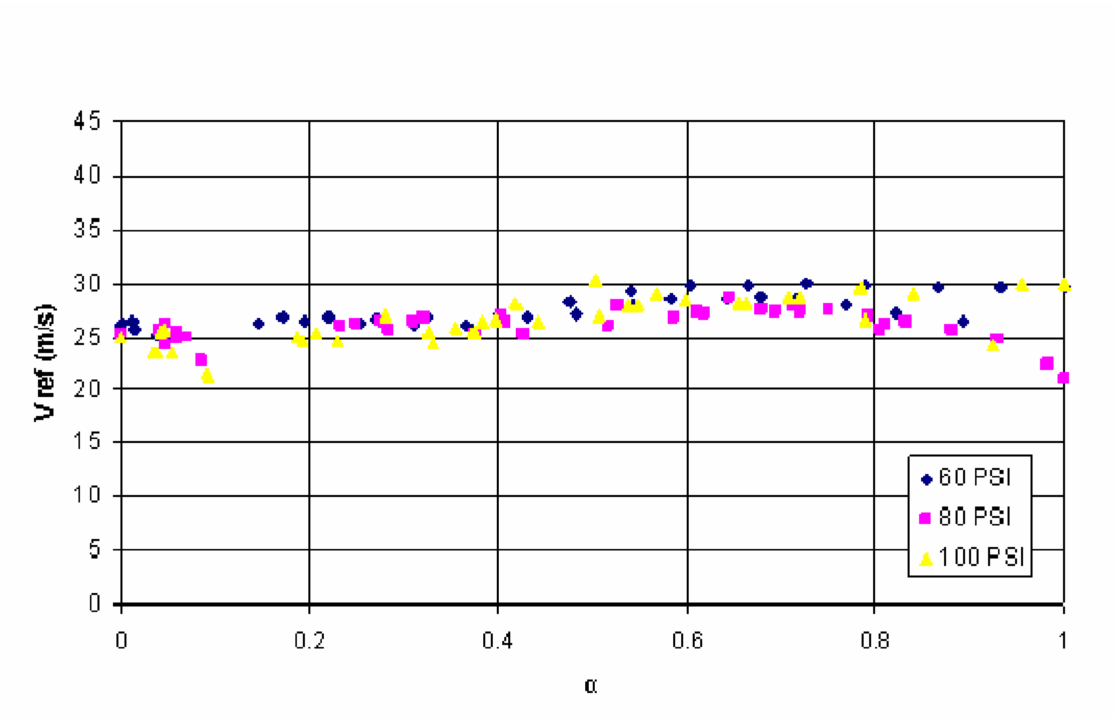

Figure 83. Referenced velocity at 1” axial position for three pressures at 80°F (6 gph).

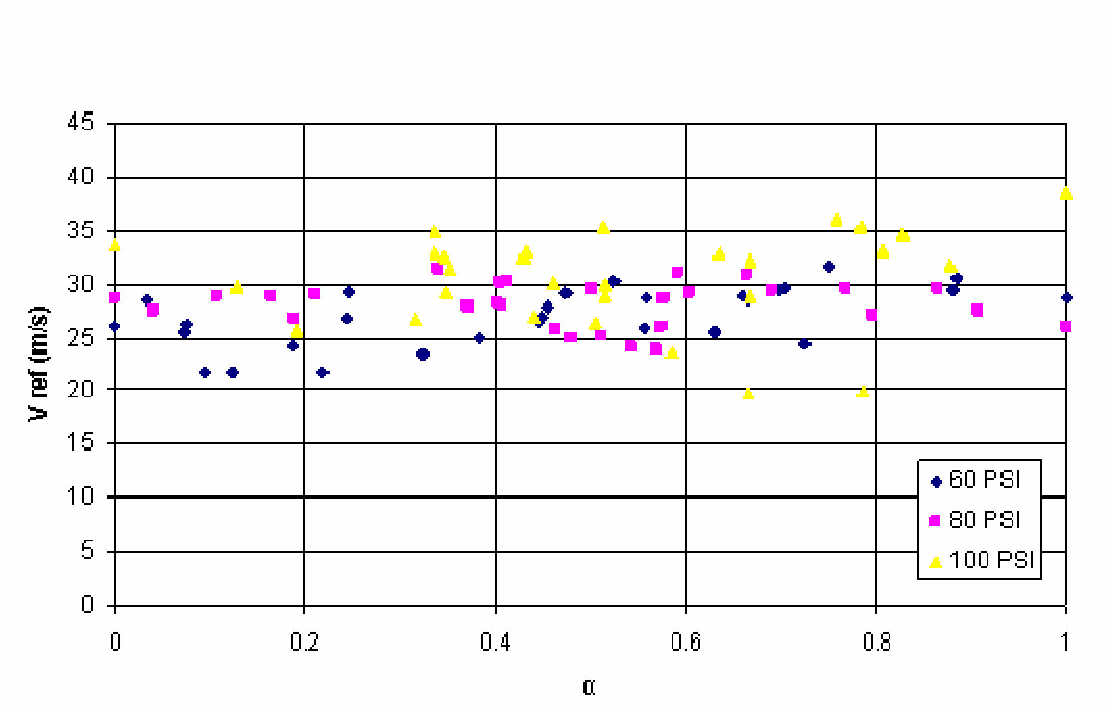

Figure 84. Referenced velocity at 1” axial position for three pressures at 100°F (6 gph).

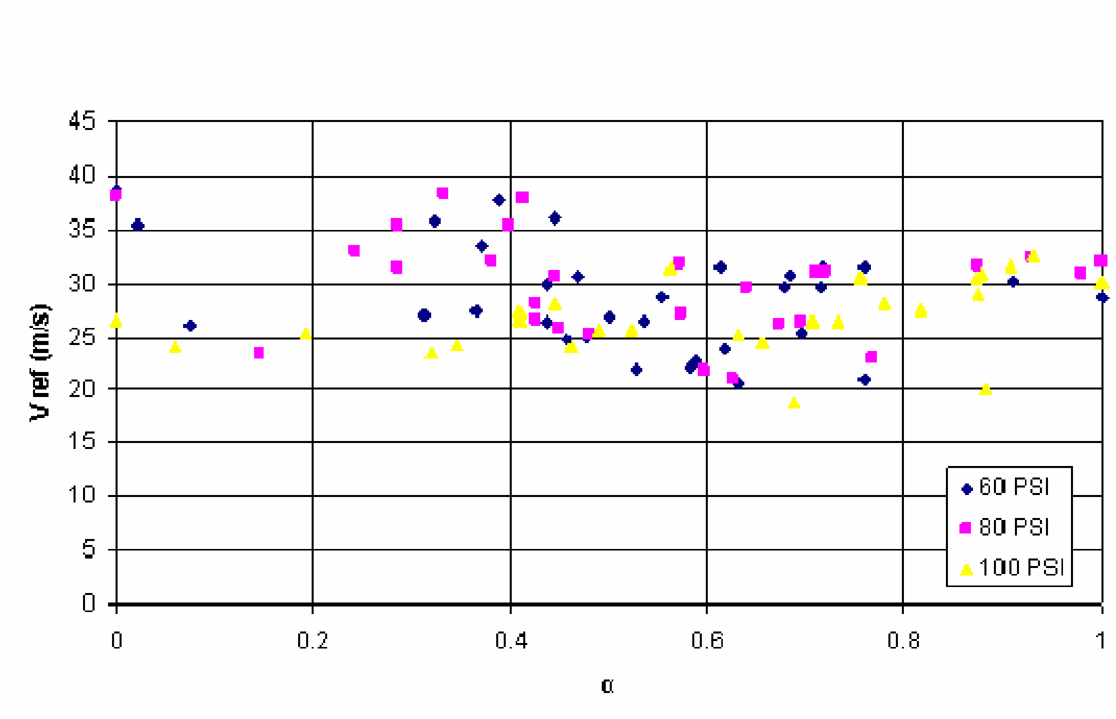

Figure 85. Referenced velocity at 1” axial position for three pressures at 120°F (6 gph).

The referenced velocities consistently increased with temperature at each axial distance for each pressure. The reference velocities of each individual pressure at each temperature and axial distance were consistently the same. From the graphs, the referenced velocities for 80, 100, and 120°F were 25, 27, and 29 m/s, respectively.

2. Flow Angle Reduction

The measured flow angle spread was reduced in the same manner as the 4 gph nozzle. The results are shown in Figure 86.

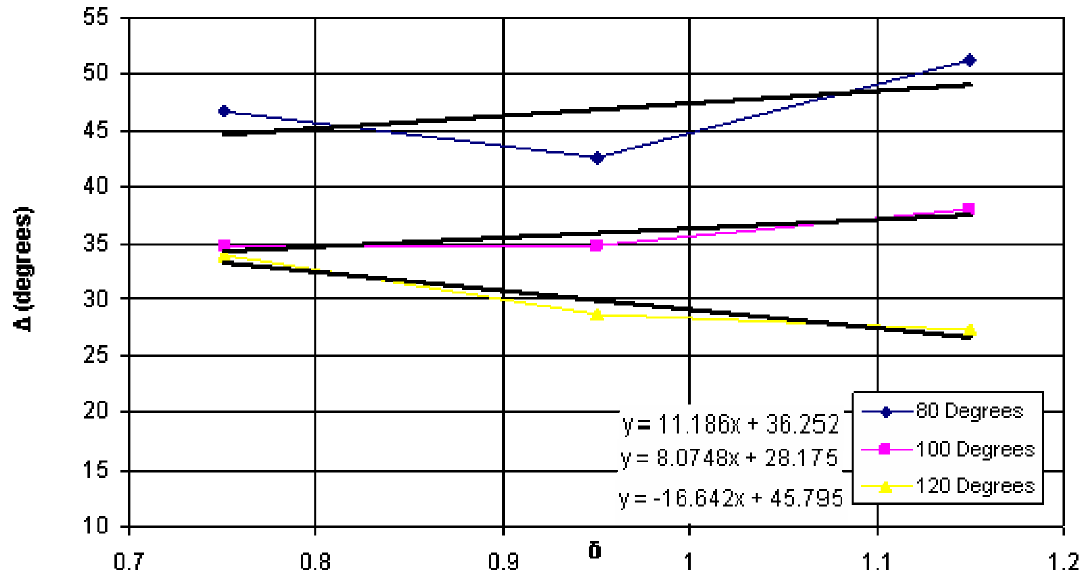

Figure 86. Measured flow angle spread for three temperatures at referenced pressures (6 gph).

Clearly there is an effect of temperature on the 6 gph nozzle. The flow angle spread determined by measurement decreased with an increase in temperature. The geometric angle spread determined from the two coordinates at the spray edges was also analyzed for each pressure and temperature. Figure 87 shows the results of this analysis.

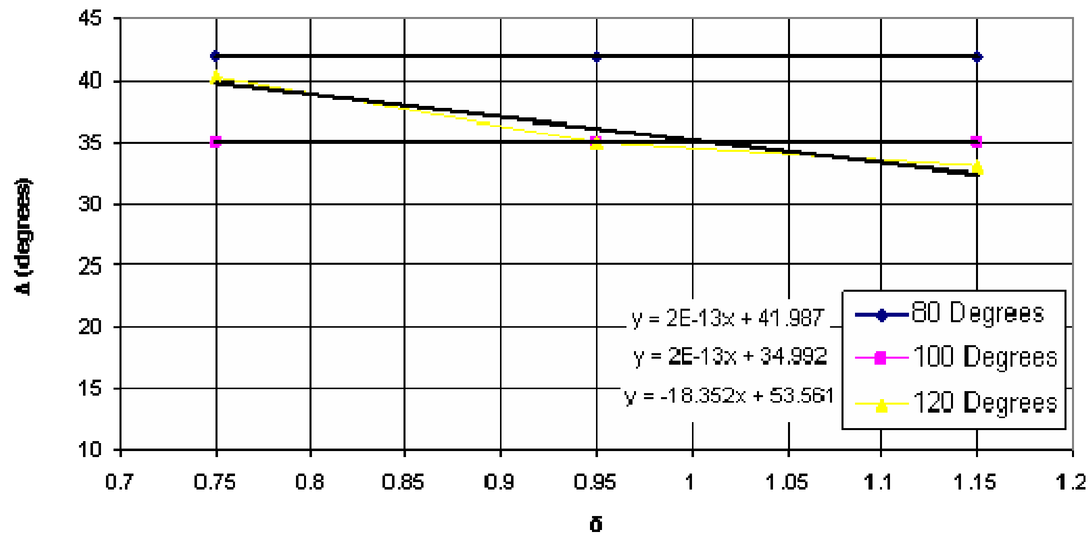

Figure 87. Geometric angle spread for three temperatures at referenced pressures (6 gph).

Since the geometric angle gave a much better fit of the empirical model to the data, the equations for each temperature from Figure 87 were used; namely:

$$80°F: \quad \Delta = 41.987 \tag{10}$$

$$100°F: \quad \Delta = 34.992 \tag{11}$$

$$120°F: \quad \Delta = -18.352\delta + 53.561 \tag{12}$$

3. Flow Rate Reduction

The flow rate was reduced in the same manner as the 4 gph nozzle. The results are shown in Figure 88, giving:

$$80°F: \quad \frac{G}{G_{ref}} = 0.5722\delta + 0.4283 \tag{13}$$

$$100°F: \quad \frac{G}{G_{ref}} = 0.5558\delta + 0.4447 \tag{14}$$

$$120°F: \quad \frac{G}{G_{ref}} = 0.4403\delta + 0.5601 \tag{15}$$

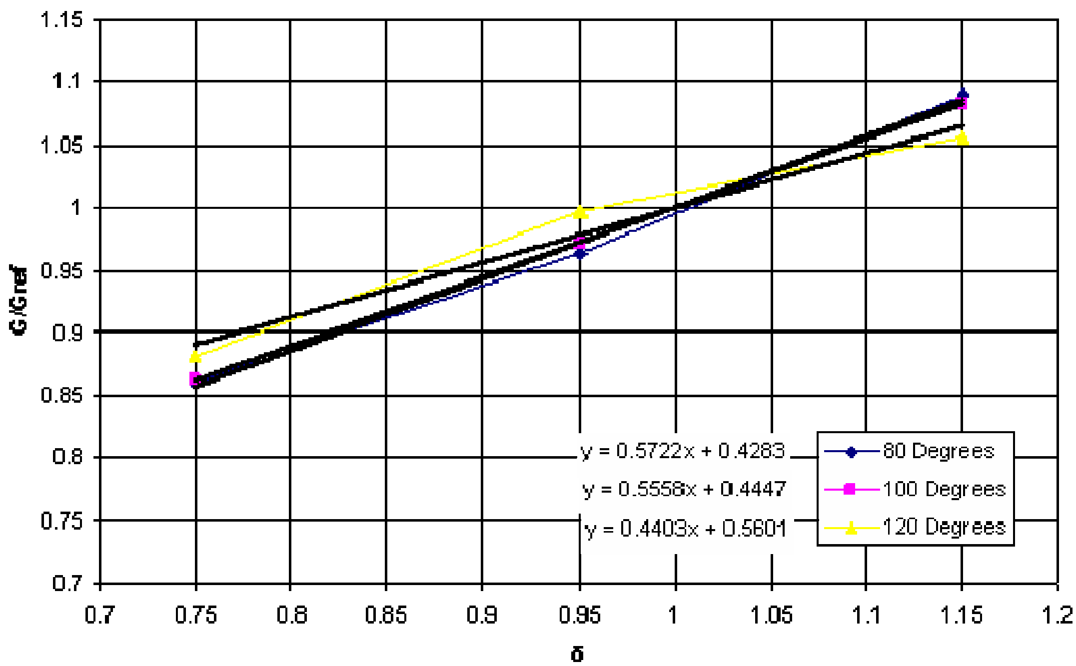

Figure 88. Referenced flow rate, G/G_{ref}, with referenced pressure of the 6 gph nozzle at three temperatures.

4. Summary

The 6 gph "standard" nozzle flow pattern was described quantitatively in the same manner as the 4 gph nozzle. The following values, using P_{tref} = 100 psia, were obtained:

80°F: V_{ref} = 25 m/s

100°F: V_{ref} = 27 m/s

120°F: V_{ref} = 29 m/s

80°F: a = 0 and b = 41.987

100°F: a = 0 and b = 34.992

120°F: a = -18.352 and b = 53.561

80°F: c = 0.572 and d = 0.428

100°F: c = 0.556 and d = 0.445

120°F: c = 0.440 and d = 0.5601

φ_m = 21° (for 80°F)

φ_m = 17.5° (for 100°F)

φ_m = 18.1° (for 120°F)

C. REPEATABILITY

The flow surveys were conducted on one specific 4 gph nozzle and one specific 6 gph nozzle. To ensure that the results were generally valid, one other 4 gph nozzle and one other 6 gph nozzle were tested at a selected pressure and temperature combination. Figures 89 – 92 show how the two other nozzles compared with the nozzles tested in the present study. Nozzle 1 denotes the nozzle used in the present study while Nozzle 2 denotes a second nozzle used to establish repeatability.

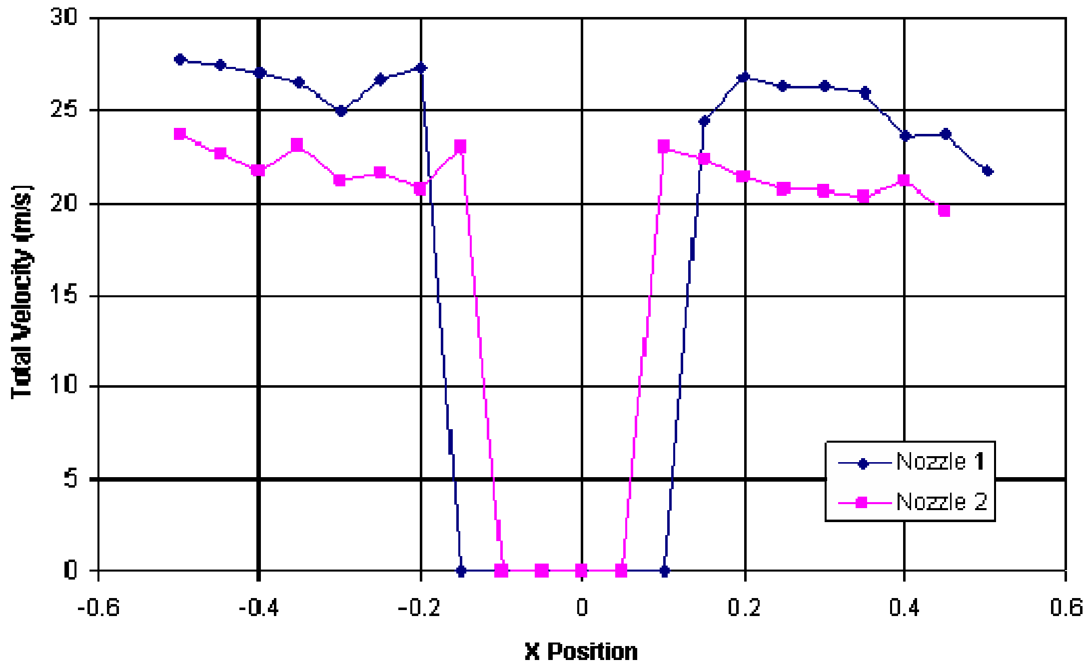

Figure 89. Flow map for 0.5” axial position, 80 psig, 100°F for repeated nozzle (4gph).

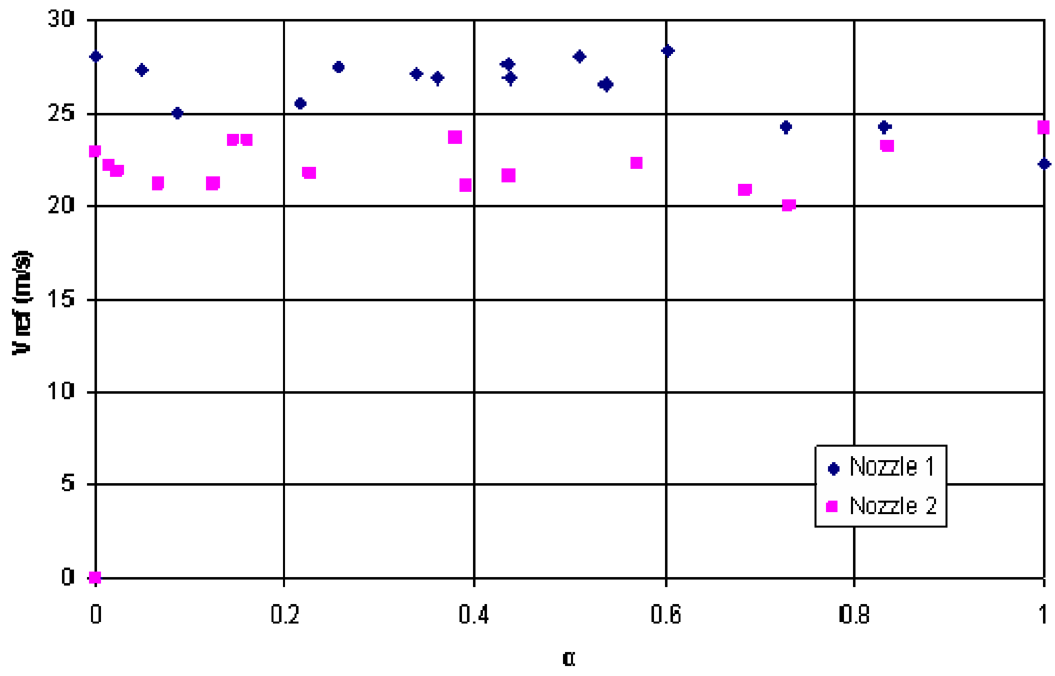

Figure 90. Referenced velocity for 0.5” axial position, 80 psig, 100°F for repeated nozzle (4 gph).

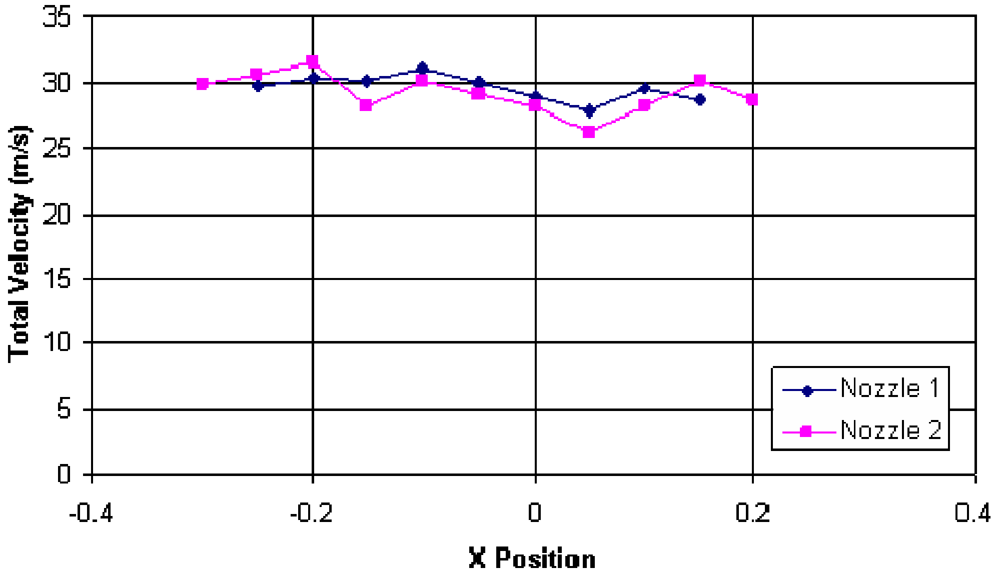

Figure 91. Flow map for 0.375” axial position, 100 psig, 100°F for repeated nozzle (6gph).

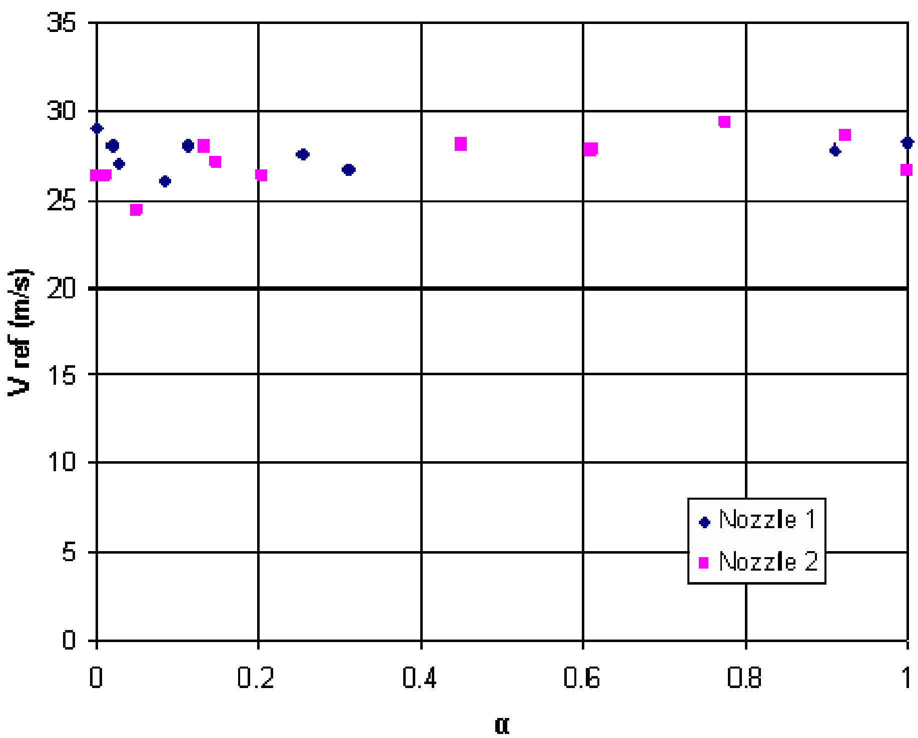

Figure 92. Referenced velocity for 0.375” axial position, 100 psig, 100°F for repeated nozzle (6 gph).

It can be seen from the graphs that the second nozzles compared reasonably well to the nozzles surveyed extensively in the present study. The largest difference occurred with the 4 gph nozzle in that the referenced velocity was higher for the nozzle in the present study than in the repeated nozzle. The repeated 6 gph nozzle velocity, on the other hand, was virtually identical to the nozzle used in the present study.

D. EXPERIMENTAL VS. CORRELATED RESULTS

1. 4 Gallon Per Hour Nozzle

The final step was to compare the analytical results to the experimental data in an effort to verify the empirical model. Figure 93 shows the empirical model at a specified pressure and temperature combination using the measured flow angles. It is clear that the model does not match the width of the experimental data very well. The reason for the discrepancy can be seen in Figure 94, which shows a comparison of the measured flow angle and geometric angle at the point in the spray for a specified pressure and temperature combination. The flow angles and geometric angles are different by up to 10 degrees at some x-positions. The trend was evident to some degree throughout the data. Therefore, the models for the angle of spread was produced solely from the geometric angle of the spray. Figures 95 – 103 show the resulting empirical model at each pressure. The edge values are shown as four points at each pressure, denoting the inner and outer edges of the spray cone at both the positive and negative displacement sides of the nozzle head. The points are connected as a horizontal line across the data to emphasize the velocity magnitude. The values are presented in ascending order at 60, 80, 100, 120 psig from bottom to top of each graph.

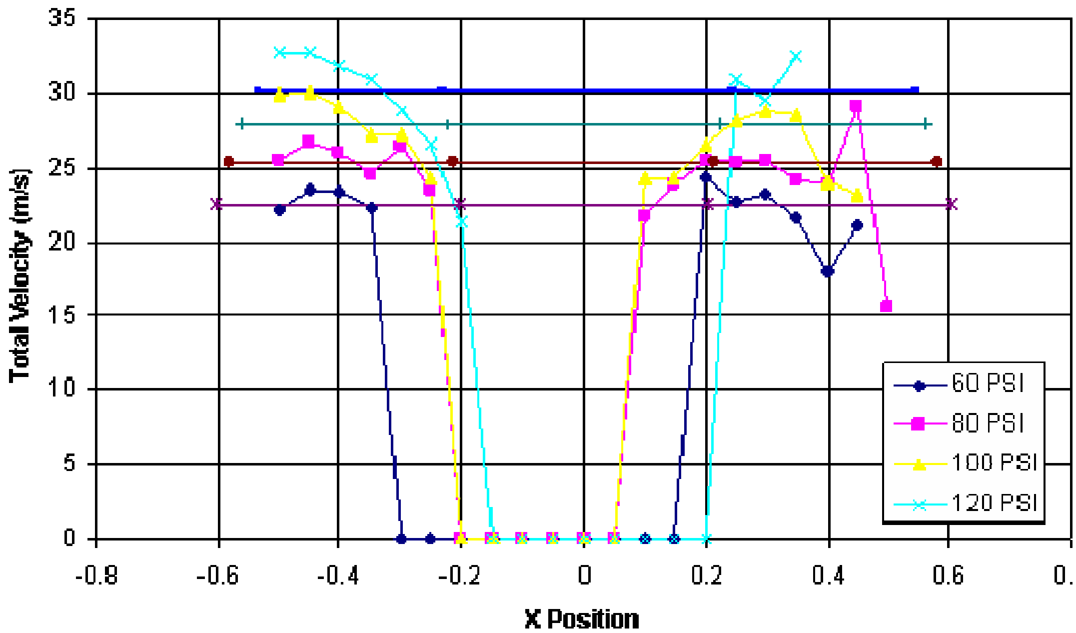

Figure 93. Empirical model for 0.5” axial position at 80°F for four pressures using measured flow angle (4 gph).

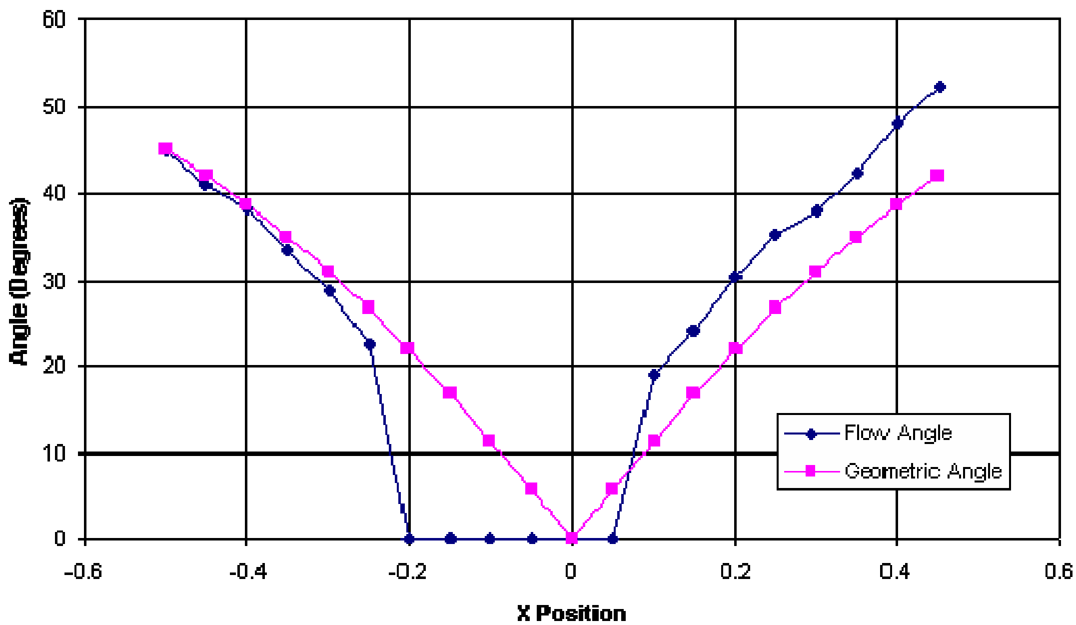

Figure 94. Flow angle and geometric angle comparison at 0.5” axial position, 100 psig, 80°F (4 gph).

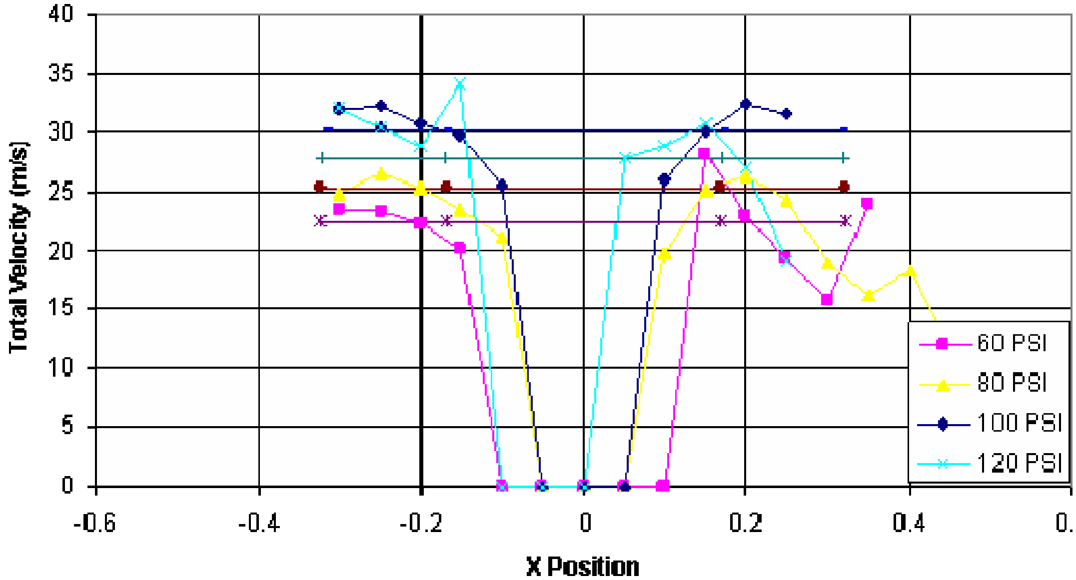

Figure 95. Empirical model for 0.375” axial position at 80°F for four pressures (4 gph).

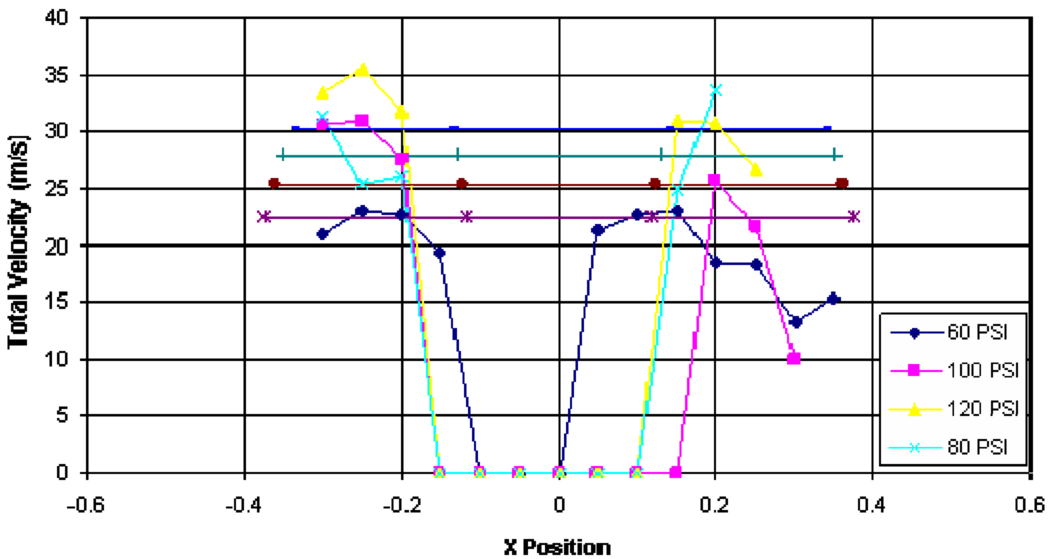

Figure 96. Empirical model for 0.375” axial position at 100°F for four pressures (4 gph).

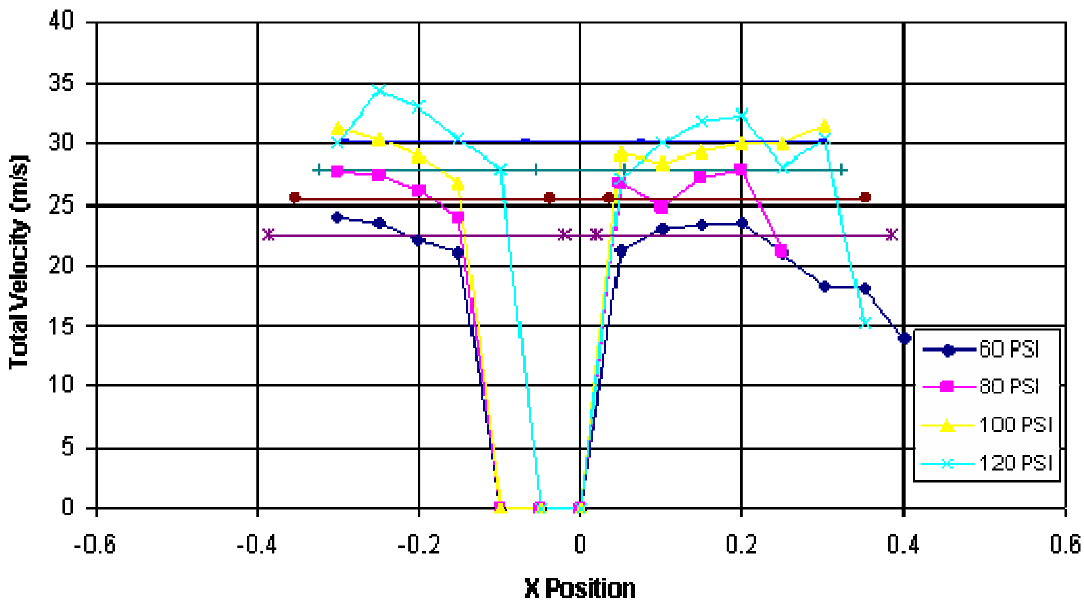

Figure 97. Empirical model for 0.375” axial position at 120°F for four pressures (4 gph).

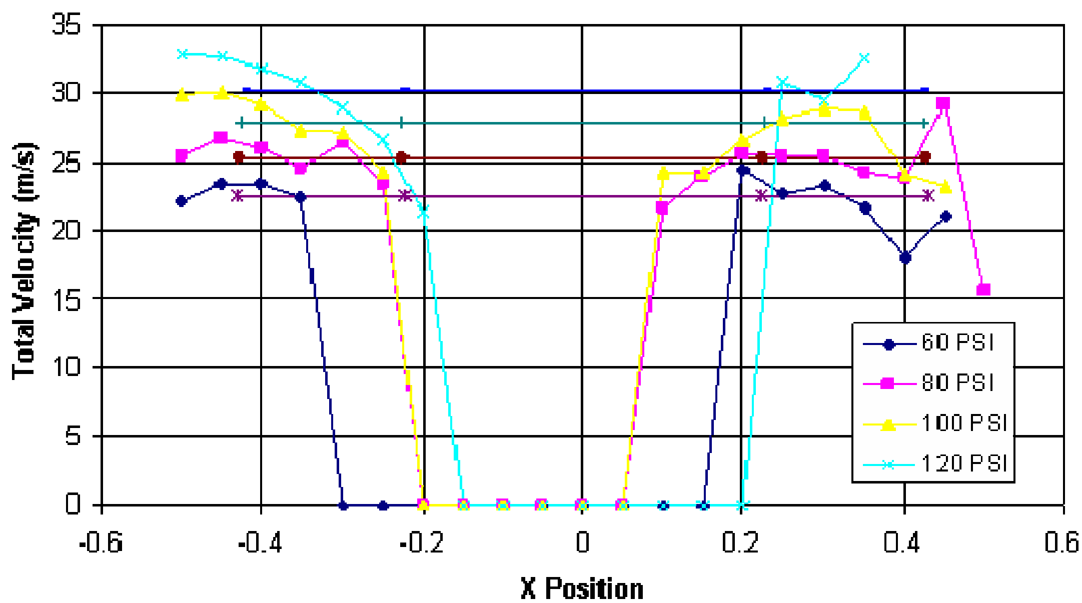

Figure 98. Empirical model for 0.5” axial position at 80°F for four pressures (4 gph).

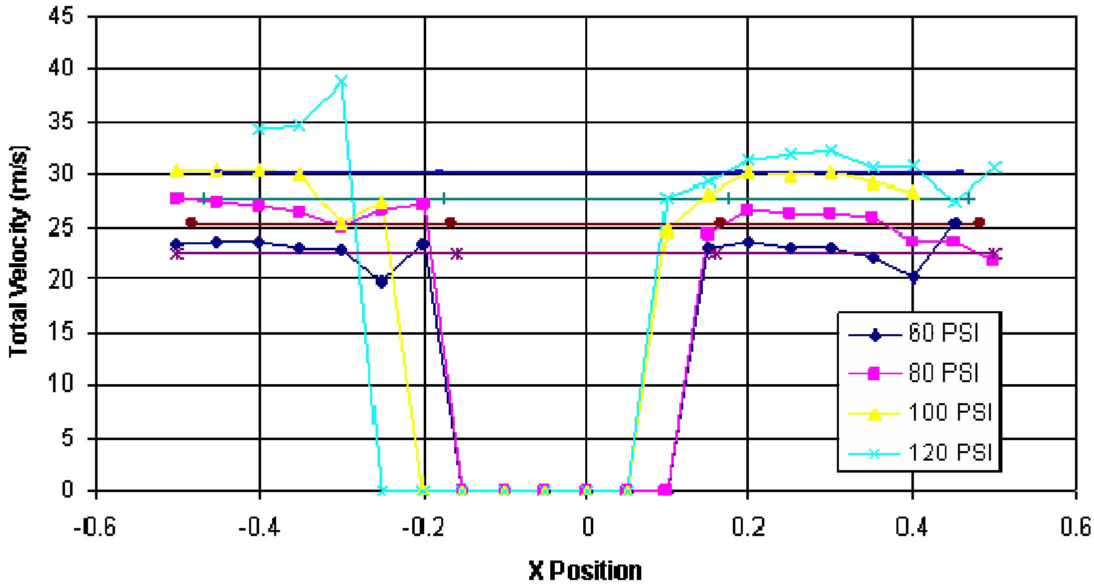

Figure 99. Empirical model for 0.5” axial position at 100°F for four pressures (4 gph).

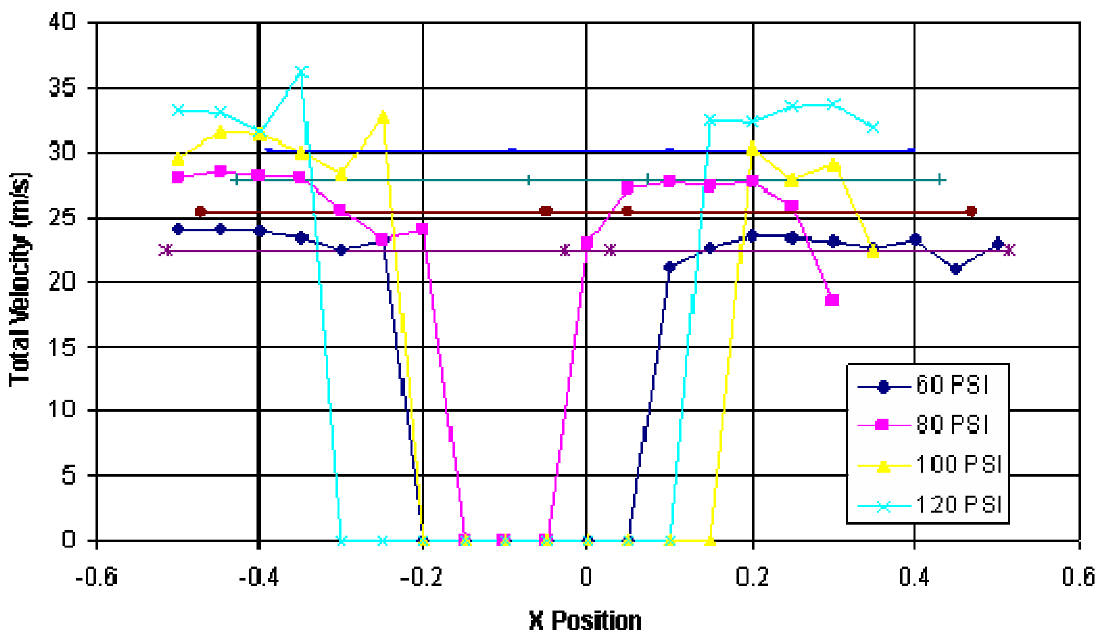

Figure 100. Empirical model for 0.5” axial position at 120°F for four pressures (4 gph).

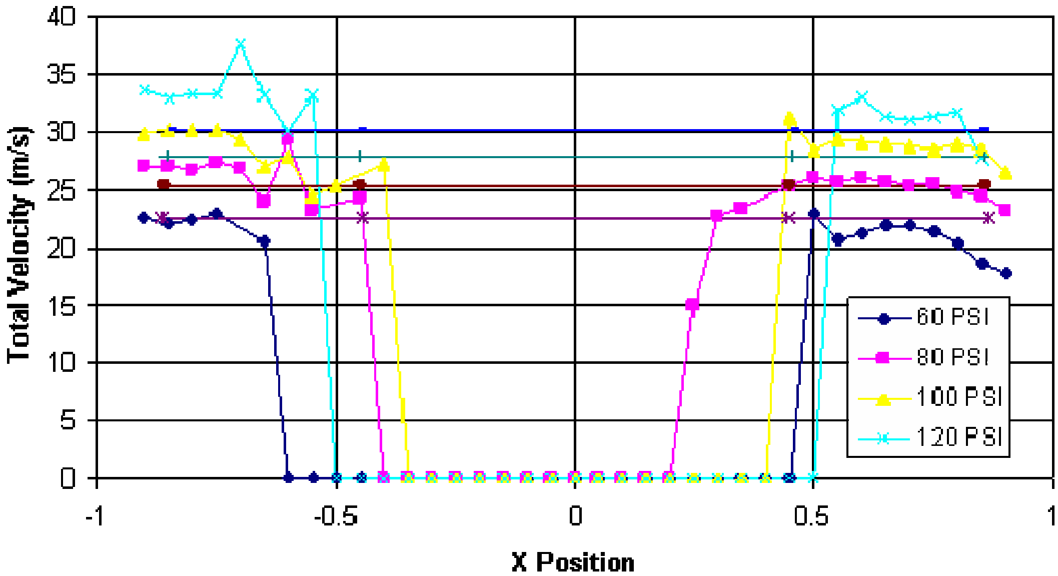

Figure 101. Empirical model for 1” axial position at 80°F for four pressures (4 gph).

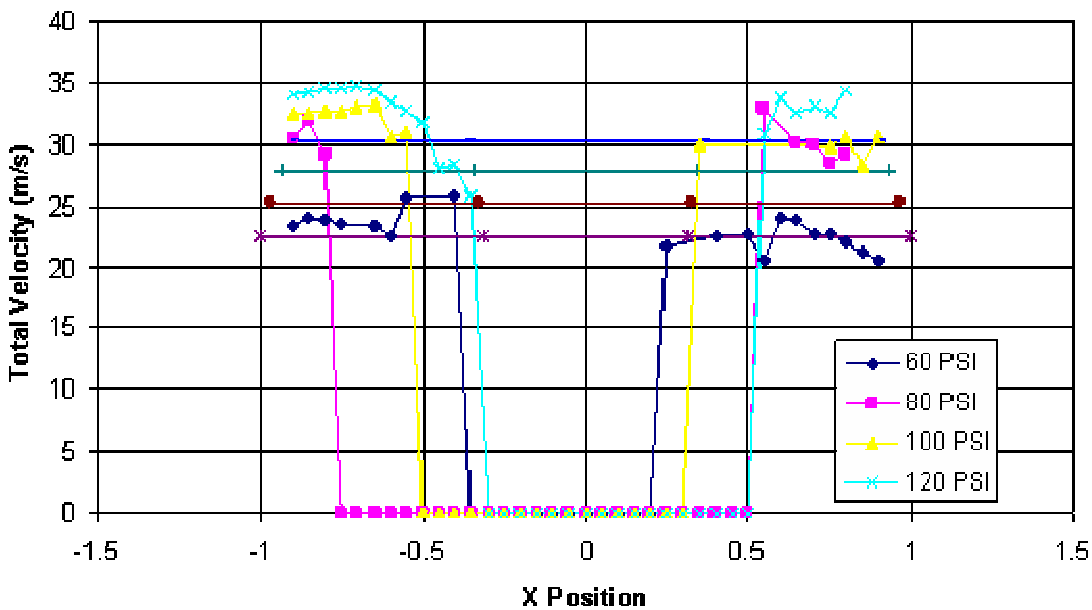

Figure 102. Empirical model for 1” axial position at 100°F for four pressures (4 gph).

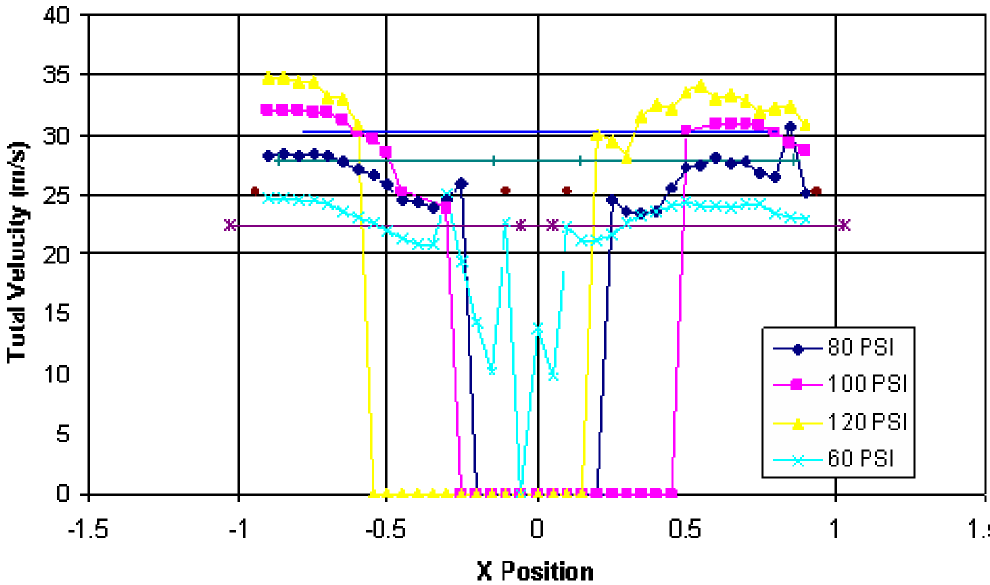

Figure 103. Empirical model for 1" axial position at 120°F for four pressures (4 gph).

It can be seen from Figures 95 – 103 that the empirical model matches the experimental results fairly well. However, the spray area of the model is slightly larger, most notably at 120°F. In Figure 104, a comparison is shown of Vonderheide's model and the one of the present study for the flow at the 1 inch station.

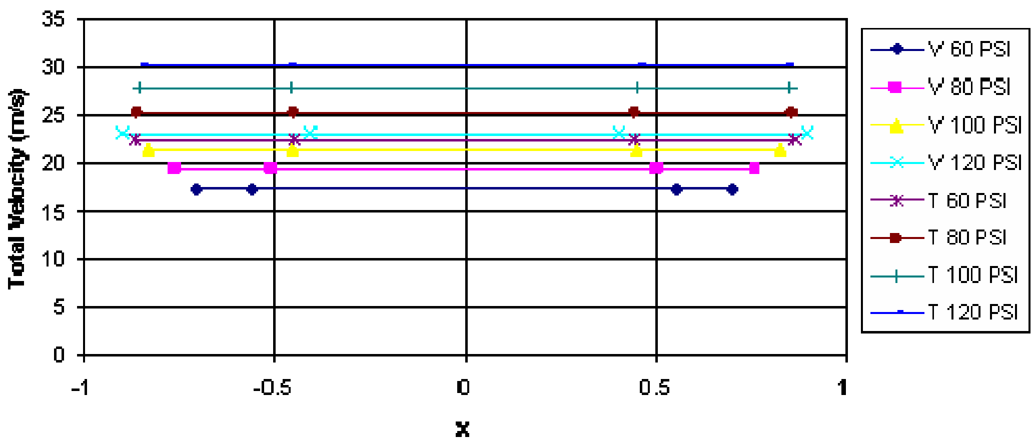

Figure 104. Comparison of empirical models of Vonderheide and the present study at 1" station at 80°F for three pressures.

It can be seen that Vonderheide predicted a spray area narrower than the one found in the present study, and a lower velocity. While it is possible that some differences could occur as a result of LDV settings, it is also possible that the mini-mist nozzles are much less repeatable than the 6 gph standard nozzles.

2. 6 Gallon Per Hour Nozzle

The 6 gph nozzle empirical model was compared to the experimental results in a similar manner to the 4 gph nozzle. Figure 105 shows the analytical model of the velocities at each temperature using the measured flow angle of the spray. It is clear that the area predicted by the model using the flow angles predicts a larger area than the data cover. The reason for this discrepancy is shown in Figure 106. The figure shows that, at specified pressure, temperature, and axial position, the flow angle and geometric angle disagreed by as much as 10 degrees at some locations. Figures 107 – 115 show the results of using the geometric angle in the empirical model at each temperature, pressure and location. The empirical model values are shown with four points at each temperature, denoting the inner and outer edges of the spray cone on both the positive and negative displacement sides of the nozzle head. Since the spray was a solid cone, the innermost edges are at zero for each plot. The points are connected as a horizontal line across the data. The values are presented in ascending order at 80, 100, 120°F from the bottom to top of each graph. The figures show that the analytical model matches the experimental data quite well.

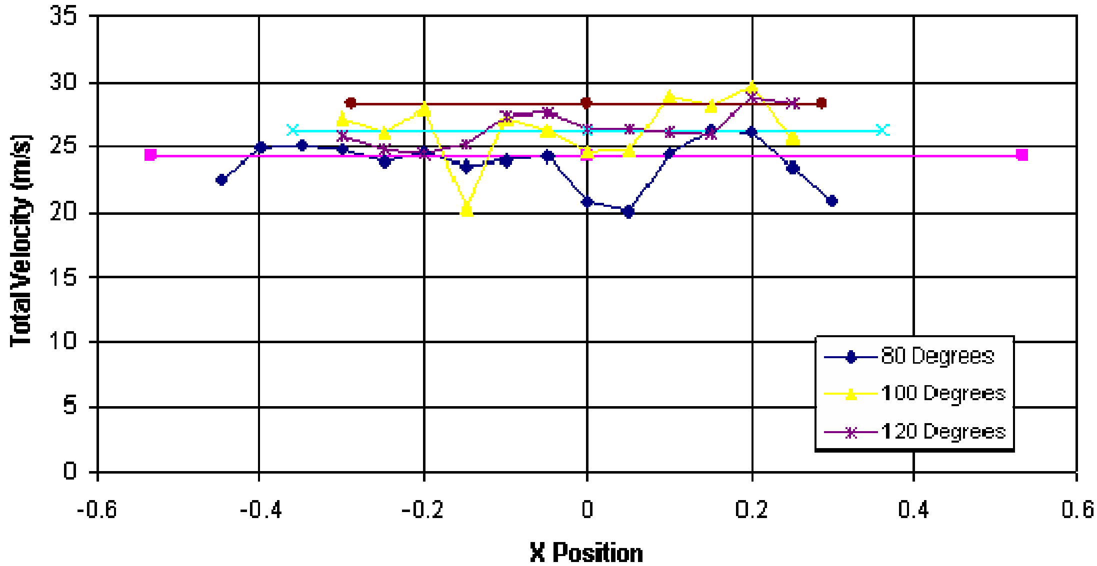

Figure 105. Empirical model for 0.5” axial position at 80 psig for three temperatures using flow angle (6gph).

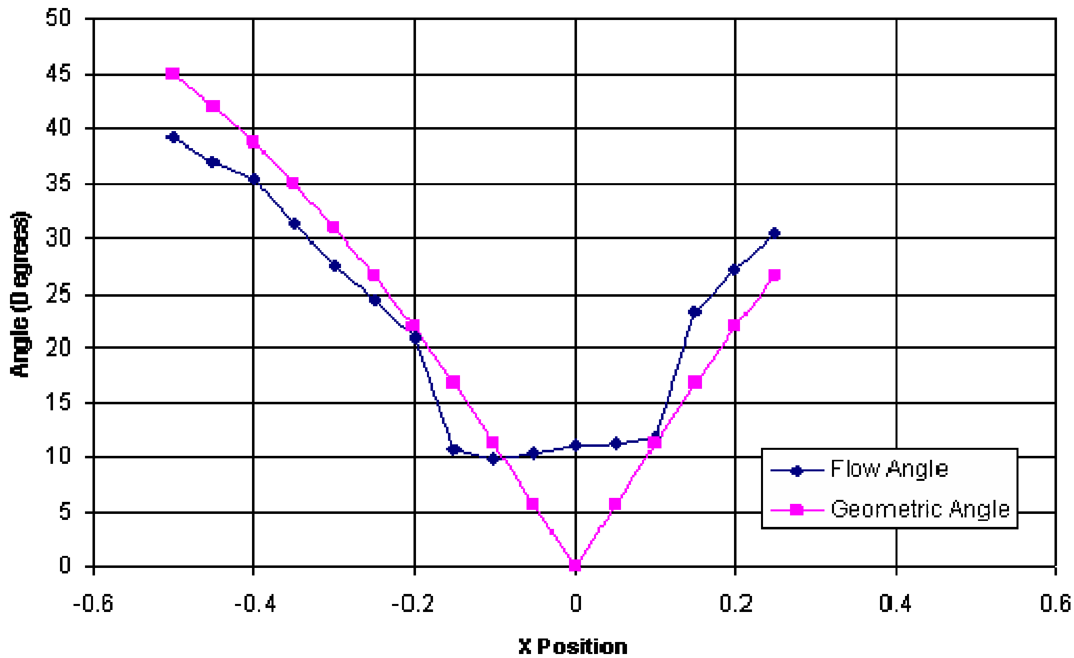

Figure 106. Measured flow angle and geometric angle comparison at 0.5” axial position, 60 psig, 80°F (6 gph).

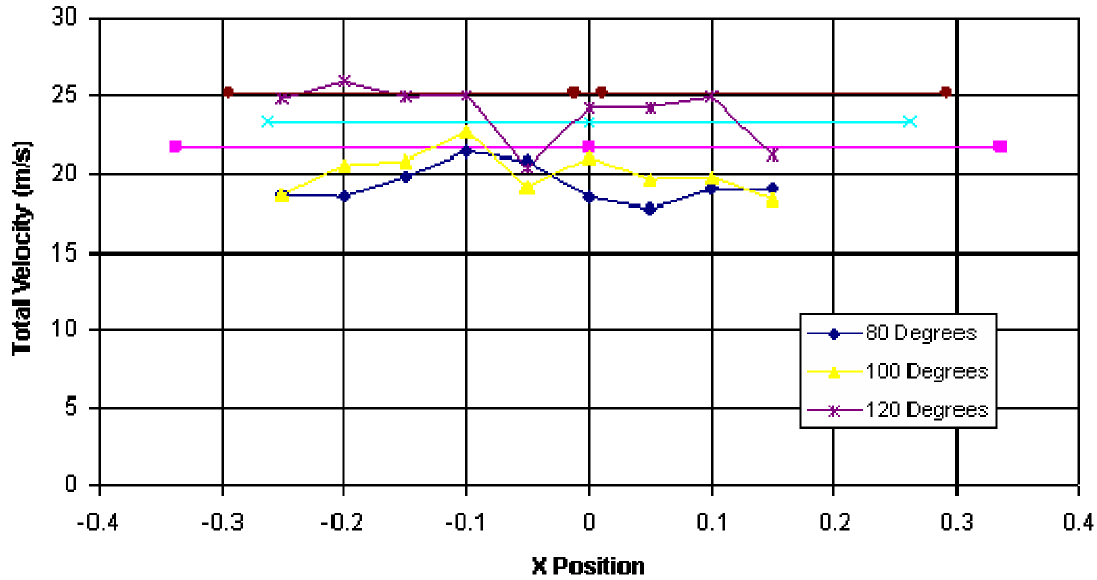

Figure 107. Empirical model for 0.375” axial position at 60 psig for three temperatures (6 gph).

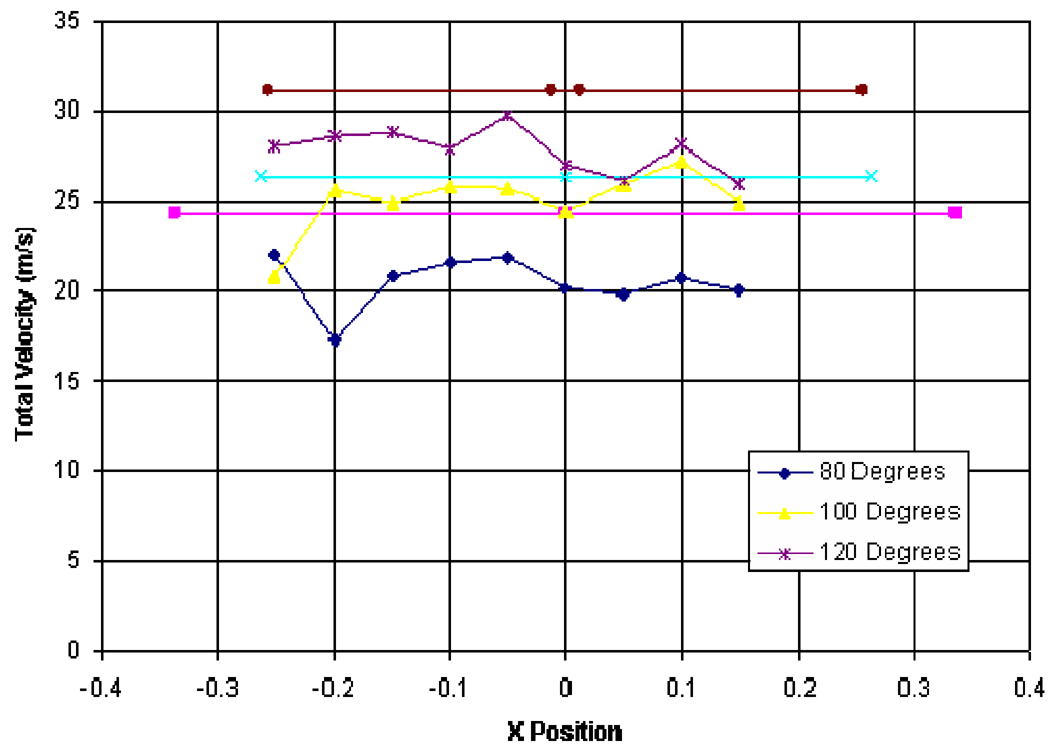

Figure 108. Empirical model for 0.375” axial position at 80 psig for three temperatures

(6 gph).

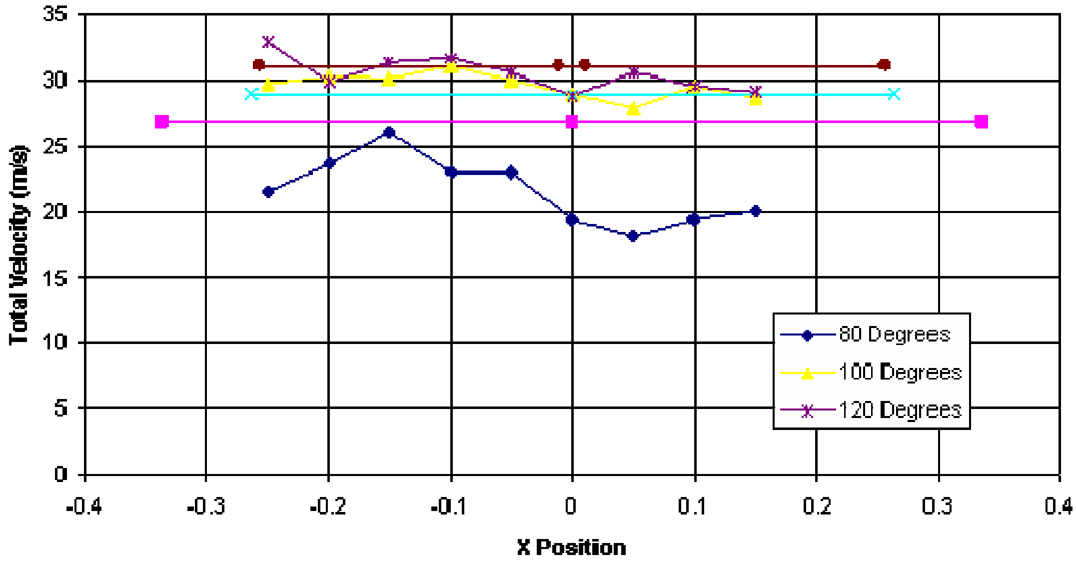

Figure 109. Empirical model for 0.375” axial position at 100 psig for three temperatures (6 gph).

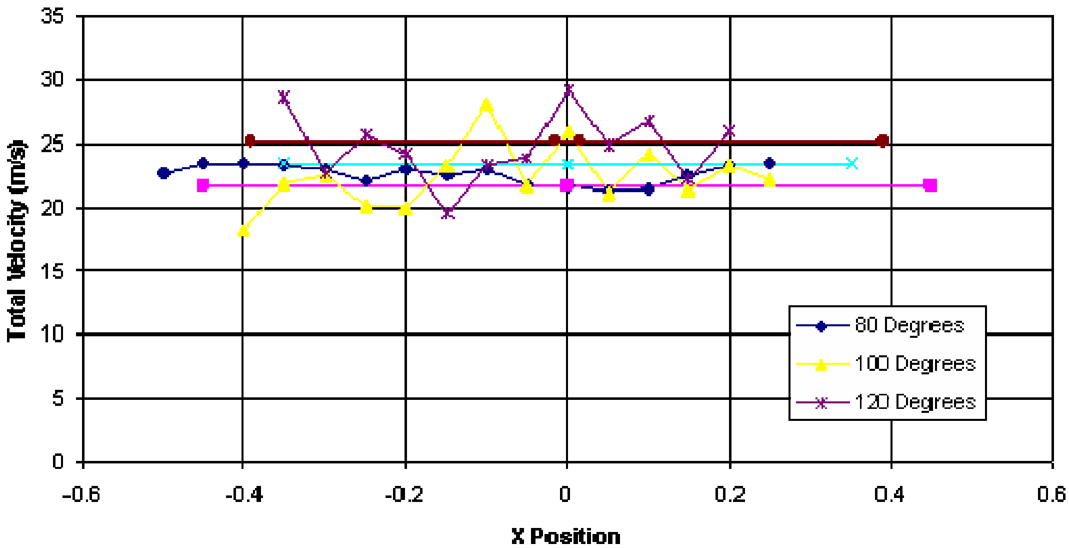

Figure 110. Empirical model for 0.5” axial position at 60 psig for three temperatures (6 gph).

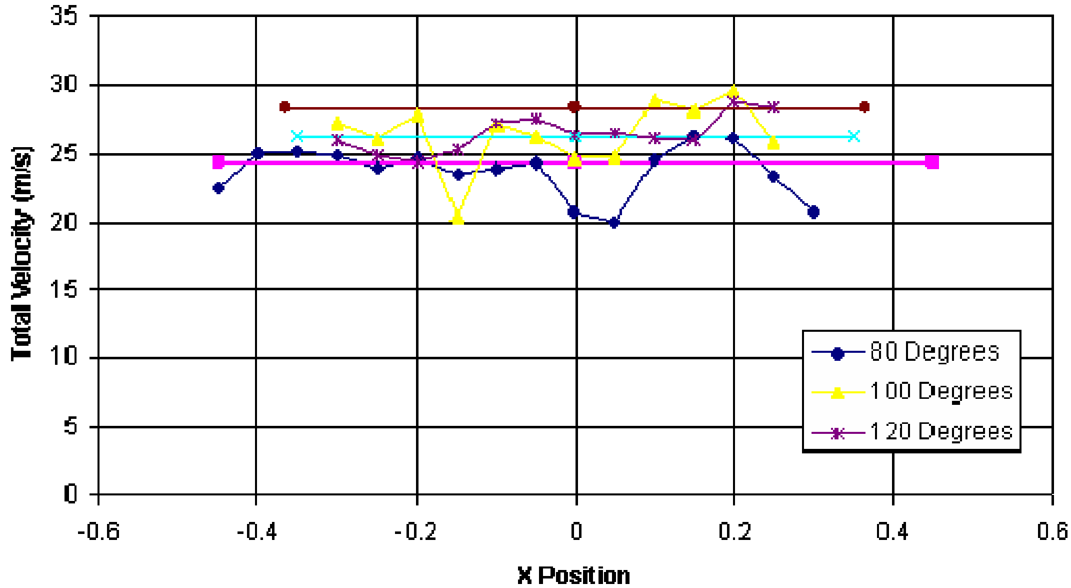

Figure 111. Empirical model for 0.5” axial position at 80 psig for three temperatures (6 gph).

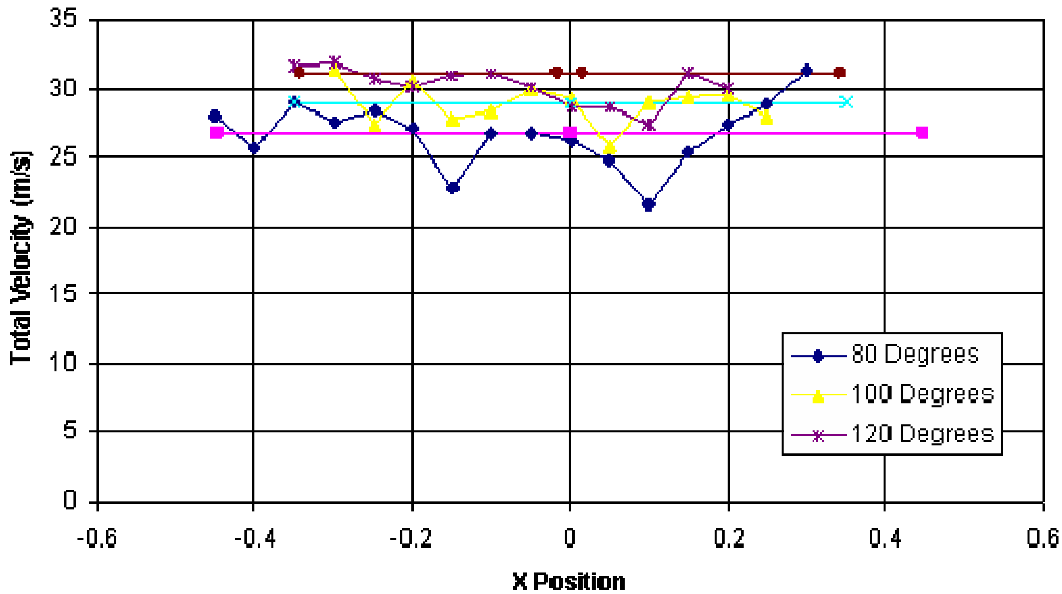

Figure 112. Empirical model for 0.5” axial position at 100 psig for three temperatures (6 gph).

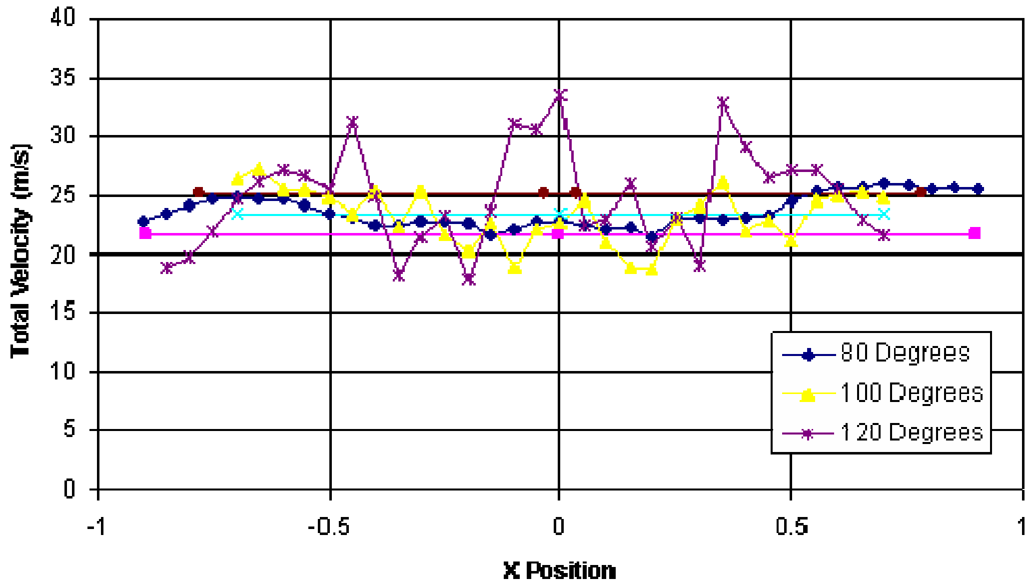

Figure 113. Empirical model for 1” axial position at 60 psig for three temperatures (6 gph).

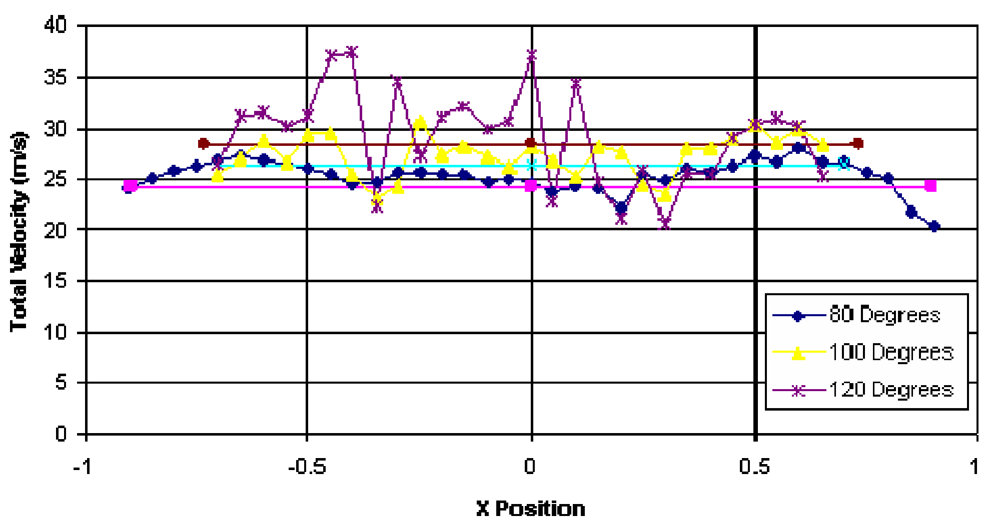

Figure 114. Empirical model for 1” axial position at 80 psig for three temperatures (6 gph).

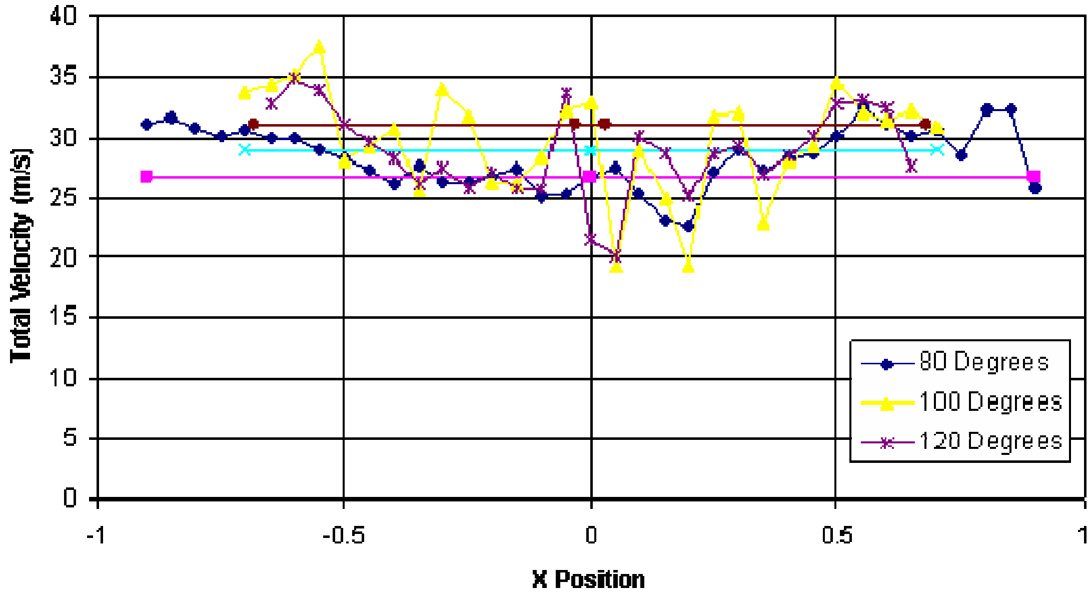

Figure 115. Empirical model for 1” axial position at 100 psig for three temperatures (6 gph).

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VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Two mist nozzles were tested within a vacuum chamber at various pressure and temperature combinations. It was found that the 4 gph mini mist nozzle displayed a hollow cone structure while the 6 gph nozzle displayed a solid cone structure. Both nozzles showed a uniform spray pattern at each pressure and temperature combination.

The 4 gph nozzle was quantified using the parameters set forth in Figure 6, using defined referenced quantities. A referenced velocity of 26 - 27 m/s was found at each pressure and temperature combination at each axial position. The flow angle spread and flow rate were successfully correlated with respect to pressure, but did not show a significant trend with increase in temperature.

The 6 gph nozzle was quantified in the same manner as the 4 gph nozzle and the referenced velocity was found to be 25, 27, and 29 m/s at 80, 100, and 120°F, respectively. The flow angle spread and flow rate were both correlated with respect to non-dimensionalized pressure and both parameters decreased with an increase in temperature. Thus, the temperature of the oil clearly affected the performance of the 6 gph nozzle.

B. RECOMMENDATIONS

The present study was conducted only at selected pressures, temperatures, and axial positions. Further surveys should be conducted at various other pressure and temperature combinations if the nozzle is to be used outside the range of the present study.

Ensuring the temperature was constant while oil was flowing through the nozzle was the most significant difficulty encountered during the study. The apparatus should be modified to allow the temperature to be maintained constant more easily. One way of accomplishing this is by adding a bypass tube (with its own valve) around the tube leading to the nozzle. This would allow the oil to flow at a constant temperature throughout the entire system while still flowing through the nozzle.

The discrepancy between the measured flow angle variation and the geometrical angle, in what appears to be a simple conical geometry, needs to be resolved. Also, the LDV system only measured two components of the droplet velocity of the oil spray. The spray is actually a three dimensional swirling flow. In the future, LDV surveys need to be taken traversing axially, normal to the chamber window, through the center of the spray. The additional velocity component will give a better analysis of the flow pattern for each nozzle.

APPENDIX A: MSDS FOR MARCOL 5

ExxonMobil

7332901-00 MARCOL 5
MATERIAL SAFETY DATA BULLETIN

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1. PRODUCT AND COMPANY IDENTIFICATION

PRODUCT NAME: MARCOL 5
SUPPLIER: EXXON MOBIL CORPORATION
3225 GALLOWS RD.
FAIRFAX, VA 22037

24 - Hour Health and Safety Emergency (call collect): 609-737-4411
24 - Hour Transportation Emergency (Primary) CHEMTREC: 800-424-9300
(Secondary) 281-834-3296
Product and Technical Information:
Lubricants and Specialties: 800-662-4525 800-443-9966
Fuels Products: 800-947-9147
MSDS Fax on Demand: 713-613-3661
MSDS Internet Website: http://www.exxon.com, http://www.mobil.com

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2. COMPOSITION/INFORMATION ON INGREDIENTS

CHEMICAL NAMES AND SYNONYMS: WHITE MINERAL OIL (PETROLEUM)

GLOBALLY REPORTABLE MSDS INGREDIENTS:

None.

OTHER INGREDIENTS:

Substance Name	Approx. Wt%
WHITE MINERAL OIL (PETROLEUM) (8042-47-5)	100

See Section 8 for exposure limits (if applicable).

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3. HAZARDS IDENTIFICATION

Under normal conditions of use, this product is not considered hazardous according to regulatory guidelines (See section 15).

EMERGENCY OVERVIEW: Clear Water White Liquid. DOT ERG No. : NA

POTENTIAL HEALTH EFFECTS: Low viscosity material - if swallowed may enter lungs and cause lung damage. Excessive exposure may result in eye, gastrointestinal, or respiratory irritation.

For further health effects/toxicological data, see Section 11.

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4. FIRST AID MEASURES

EYE CONTACT: Flush thoroughly with water. If irritation occurs, call a physician.

SKIN CONTACT: Wash contact areas with soap and water. Remove and clean oil soaked clothing daily and wash affected area. (See Section 16 - Injection Injury)

INHALATION: Not expected to be a problem. However, if respiratory irritation, dizziness, nausea, or unconsciousness occurs due to excessive vapor or mist exposure, seek immediate medical assistance. If breathing has stopped, assist ventilation with a mechanical device or mouth-to-mouth resuscitation.

INGESTION: Seek immediate medical attention. Do not induce vomiting.

NOTE TO PHYSICIANS: Material if aspirated into the lungs may cause chemical pneumonitis.

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5. FIRE-FIGHTING MEASURES

EXTINGUISHING MEDIA: Carbon dioxide, foam, dry chemical and water fog.

SPECIAL FIRE FIGHTING PROCEDURES: Water or foam may cause frothing. Use water to keep fire exposed containers cool. Water spray may be used to flush spills away from exposure. Prevent runoff from fire control or dilution from entering streams, sewers, or drinking water supply.

SPECIAL PROTECTIVE EQUIPMENT: For fires in enclosed areas, fire fighters must use self-contained breathing apparatus.

UNUSUAL FIRE AND EXPLOSION HAZARDS: None.

COMBUSTION PRODUCTS: Fumes, smoke, carbon monoxide, sulfur oxides, aldehydes and other decomposition products, in the case of incomplete combustion.

Flash Point C(F): 154(310) (ASTM D-92).

Flammable Limits (approx.% vol.in air) - LEL: 0.9%, UEL: 7.0%

NFPA HAZARD ID: Health: 0, Flammability: 1, Reactivity: 0

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6. ACCIDENTAL RELEASE MEASURES

NOTIFICATION PROCEDURES: Report spills/releases as required to appropriate authorities. U.S. Coast Guard and EPA regulations require immediate reporting of spills/releases that could reach any waterway including intermittent dry creeks. Report spill/release to Coast Guard National Response Center toll free number (800)424-8802. In case of accident or road spill notify CHEMTREC (800) 424-9300.

PROCEDURES IF MATERIAL IS RELEASED OR SPILLED:
LAND SPILL: Shut off source taking normal safety precautions. Take

measures to minimize the effects on ground water. Recover by pumping or contain spilled material with sand or other suitable absorbent and remove mechanically into containers. If necessary, dispose of adsorbed residues as directed in Section 13.
WATER SPILL: Confine the spill immediately with booms. Warn other ships in the vicinity. Notify port and other relevant authorities. Remove from the surface by skimming or with suitable absorbents. If permitted by regulatory authorities the use of suitable dispersants should be considered where recommended in local oil spill procedures.

ENVIRONMENTAL PRECAUTIONS: Prevent material from entering sewers, water sources or low lying areas; advise the relevant authorities if it has, or if it contaminates soil/vegetation.

PERSONAL PRECAUTIONS: See Section 8

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7. HANDLING AND STORAGE

HANDLING: No special precautions are necessary beyond normal good hygiene practices. See Section 8 for additional personal protection advice when handling this product.

STORAGE: Keep containers closed when not in use. Do not store in open or unlabelled containers. Store away from strong oxidizing agents and combustible materials. Do not store near heat, sparks, flame or strong oxidants.

SPECIAL PRECAUTIONS: Prevent small spills and leakages to avoid slip hazard.

EMPTY CONTAINER WARNING: Empty containers retain residue (liquid and/or vapor) and can be dangerous. DO NOT PRESSURIZE, CUT, WELD, BRAZE, SOLDER, DRILL, GRIND OR EXPOSE SUCH CONTAINERS TO HEAT, FLAME, SPARKS, STATIC ELECTRICITY, OR OTHER SOURCES OF IGNITION; THEY MAY EXPLODE AND CAUSE INJURY OR DEATH. Do not attempt to refill or clean container since residue is difficult to remove. Empty drums should be completely drained, properly bunged and promptly returned to a drum reconditioner. All containers should be disposed of in an environmentally safe manner and in accordance with governmental regulations.

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8. EXPOSURE CONTROLS/PERSONAL PROTECTION

OCCUPATIONAL EXPOSURE LIMITS:

When mists/aerosols can occur, the following are recommended: 5 mg/m3 (as oil mist)- ACGIH Threshold Limit Value (TLV), 10 mg/m3 (as oil mist) - ACGIH Short Term Exposure Limit (STEL), 5 mg/m3 (as oil mist) - OSHA Permissible Exposure Limit (PEL)

VENTILATION: If mists are generated, use adequate ventilation, local exhaust or enclosures to control below exposure limits.

RESPIRATORY PROTECTION: If mists are generated, and/or when ventilation is not adequate, wear approved respirator.

EYE PROTECTION: If eye contact is likely, safety glasses with side shields or chemical type goggles should be worn.

SKIN PROTECTION: If prolonged or repeated skin contact is likely, oil impervious gloves should be worn. Good personal hygiene practices should always be followed.

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9. PHYSICAL AND CHEMICAL PROPERTIES

Typical physical properties are given below. Consult Product Data Sheet for specific details.

APPEARANCE: Liquid
COLOR: Clear Water White
ODOR: Odorless
ODOR THRESHOLD-ppm: NE
pH: NA
BOILING POINT C(F): NE
MELTING POINT C(F): NA
FLASH POINT C(F): 154(310) (ASTM D-92)
FLAMMABILITY (solids): NE
AUTO FLAMMABILITY C(F): NE
EXPLOSIVE PROPERTIES: NA
OXIDIZING PROPERTIES: NA
VAPOR PRESSURE-mmHg 20 C: < 0.1
VAPOR DENSITY: > 2.0
EVAPORATION RATE: NE
RELATIVE DENSITY, 15/4 C: 0.84
SOLUBILITY IN WATER: Negligible
PARTITION COEFFICIENT: > 3.5
VISCOSITY AT 40 C, cSt: 8.0
VISCOSITY AT 100 C, cSt: NE
POUR POINT C(F): -9(15)
FREEZING POINT C(F): NE
VOLATILE ORGANIC COMPOUND: NE
DMSO EXTRACT, IP-346 (WT.%): <3
NA=NOT APPLICABLE NE=NOT ESTABLISHED D=DECOMPOSES

FOR FURTHER TECHNICAL INFORMATION, CONTACT YOUR MARKETING REPRESENTATIVE

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10. STABILITY AND REACTIVITY

STABILITY (THERMAL, LIGHT, ETC.): Stable.
CONDITIONS TO AVOID: Extreme heat and high energy sources of ignition.
INCOMPATIBILITY (MATERIALS TO AVOID): Strong oxidizers.
HAZARDOUS DECOMPOSITION PRODUCTS: Product does not decompose at ambient temperatures.
HAZARDOUS POLYMERIZATION: Will not occur.

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11. TOXICOLOGICAL DATA

---ACUTE TOXICOLOGY---

ORAL TOXICITY (RATS): Practically non-toxic (LD50: greater than 2000 mg/kg). ---Based on testing of similar products and/or the components.
DERMAL TOXICITY (RABBITS): Practically non-toxic (LD50: greater than

2000 mg/kg). ---Based on testing of similar products and/or the components.

INHALATION TOXICITY (RATS): Practically non-toxic (LC50: greater than 5 mg/l). ---Based on testing of similar products and/or the components.

EYE IRRITATION (RABBITS): Practically non-irritating. (Draize score: 0 or greater but 6 or less). ---Based on testing of similar products and/or the components.

SKIN IRRITATION (RABBITS): Practically non-irritating. (Primary Irritation Index: 0.5 or less). ---Based on testing of similar products and/or the components.

---REPRODUCTIVE TOXICOLOGY (SUMMARY)---

Oral exposure of pregnant rats to white mineral oil did not cause adverse effects in either the mothers or their offspring.

---CHRONIC TOXICOLOGY (SUMMARY)---

Repeated and/or prolonged exposure may cause irritation to the eyes or respiratory tract. Overexposure to oil mist may result in oil droplet deposition and/or granuloma formation. This product is severely solvent refined and/or severely hydrotreated. Chronic mouse skin painting studies of white mineral oils showed no evidence of carcinogenic effects.

---SENSITIZATION (SUMMARY)---

Not expected to be sensitizing based on tests of this product, components, or similar products.

---OTHER TOXICOLOGY DATA---

Low viscosity white oils have been tested in sensitive rat species (Fischer 344) and after feeding relatively high doses (2% of diet) for 90 days, displayed some minimal hematological changes and liver microgranuloma. Similar effects were not observed to the same degree in other rodent strains or in other species. Medium to high viscosity white oils have been tested in numerous subchronic and chronic feeding, dermal, and inhalation toxicity studies. A number of test species and strains have been used, and most of the studies have shown minimal to no toxicities. Oil that is absorbed is retained in various tissues to some degree, but no clinical disease has been observed in the animal tests. Multiple chronic studies did not show any chronic toxicity, cancer, or reproductive effects. Humans exposed to white oils with biopsy/autopsy evaluations have confirmed the presence of oil in tissues with no clinical disease or long term effect on health. ***Meets requirements of European Pharmacopoeia*** ***Meets requirements of U.S. Pharmacopoeia XXIII***

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12. ECOLOGICAL INFORMATION

ENVIRONMENTAL FATE AND EFFECTS:

ECOTOXICITY: Available ectoxicity data (LL50 >1000 mg/L) indicates that adverse effects to aquatic organisms are not expected from this product.

MOBILITY: When released into the environment, adsorption to sediment and soil will be the predominant behavior.

PERSISTENCE AND DEGRADABILITY: This product is expected to be inherently biodegradable.

BIOACCUMULATIVE POTENTIAL: Bioaccumulation is unlikely due to the very low water solubility of this product, therefore bioavailability to aquatic organisms is minimal.

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13. DISPOSAL CONSIDERATIONS

WASTE DISPOSAL: Product is suitable for burning in an enclosed, controlled burner for fuel value. Such burning may be limited pursuant to the Resource Conservation and Recovery Act. In addition, the product is suitable for processing by an approved recycling facility or can be disposed of at an appropriate government waste disposal facility. Use of these methods is subject to user compliance with applicable laws and regulations and consideration of product characteristics at time of disposal.

RCRA INFORMATION: The unused product, in our opinion, is not specifically listed by the EPA as a hazardous waste (40 CFR, Part 261D), nor is it formulated to contain materials which are listed hazardous wastes. It does not exhibit the hazardous characteristics of ignitability, corrosivity, or reactivity. The unused product is not formulated with substances covered by the Toxicity Characteristic Leaching Procedure (TCLP). However, used product may be regulated.

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14. TRANSPORT INFORMATION

USA DOT: NOT REGULATED BY USA DOT.

RID/ADR: NOT REGULATED BY RID/ADR.

IMO: NOT REGULATED BY IMO.

IATA: NOT REGULATED BY IATA.

STATIC ACCUMULATOR (50 picosiemens or less): YES

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15. REGULATORY INFORMATION

US OSHA HAZARD COMMUNICATION STANDARD: Product assessed in accordance with OSHA 29 CFR 1910.1200 and determined not to be hazardous.

EU Labeling: Product is not dangerous as defined by the European Union Dangerous Substances/Preparations Directives.

Symbol: Not applicable.

Risk Phrase(s): Not applicable.

Safety Phrase(s): S62.
If swallowed, do not induce vomiting: seek medical advice immediately and show this container or label.

Governmental Inventory Status: All components comply with TSCA and METI.

U.S. Superfund Amendments and Reauthorization Act (SARA) Title III:
This product contains no "EXTREMELY HAZARDOUS SUBSTANCES".

SARA (311/312) REPORTABLE HAZARD CATEGORIES: None.

This product contains no chemicals subject to the supplier notification requirements of SARA (313) toxic release program.

THIS PRODUCT MEETS THE REQUIREMENTS OF FDA REGULATIONS(S): 172.878 178.3620(a)

The following product ingredients are cited on the lists below:

CHEMICAL NAME	CAS NUMBER	LIST CITATIONS *
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*** NO REPORTABLE INGREDIENTS ***

--- REGULATORY LISTS SEARCHED ---

1=ACGIH ALL	6=IARC 1	11=TSCA 4	16=CA P65 CARC	21=LA RTK
2=ACGIH A1	7=IARC 2A	12=TSCA 5a2	17=CA P65 REPRO	22=MI 293
3=ACGIH A2	8=IARC 2B	13=TSCA 5e	18=CA RTK	23=MN RTK
4=NTP CARC	9=OSHA CARC	14=TSCA 6	19=FL RTK	24=NJ RTK
5=NTP SUS	10=OSHA Z	15=TSCA 12b	20=IL RTK	25=PA RTK
			26=RI RTK	

* EPA recently added new chemical substances to its TSCA Section 4 test rules. Please contact the supplier to confirm whether the ingredients in this product currently appear on a TSCA 4 or TSCA 12b list.
Code key:CARC=Carcinogen; SUS=Suspected Carcinogen; REPRO=Reproductive

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16. OTHER INFORMATION

USE: MULTI-PURPOSE MINERAL OIL

NOTE: PRODUCTS OF EXXON MOBIL CORPORATION AND ITS AFFILIATED COMPANIES ARE NOT FORMULATED TO CONTAIN PCBS.

Health studies have shown that many hydrocarbons pose potential human health risks which may vary from person to person. Information provided on this MSDS reflects intended use. This product should not be used for other applications. In any case, the following advice should be considered:
INJECTION INJURY WARNING: If product is injected into or under the skin,

or into any part of the body, regardless of the appearance of the wound or its size, the individual should be evaluated immediately by a physician as a surgical emergency. Even though initial symptoms from high pressure injection may be minimal or absent, early surgical treatment within the first few hours may significantly reduce the ultimate extent of injury.

Precautionary Label Text:

WARNING!

LOW VISCOSITY MATERIAL-IF SWALLOWED, MAY BE ASPIRATED AND CAN CAUSE SERIOUS OR FATAL LUNG DAMAGE. EXCESSIVE EXPOSURE MAY RESULT IN EYE, GASTROINTESTINAL, OR RESPIRATORY IRRITATION.

FIRST AID: In case of contact, wash skin with soap and water. Remove contaminated clothing. Call a physician if irritation persists. Wash or dispose of contaminated clothing. If swallowed, seek immediate medical attention. Do not induce vomiting. Only induce vomiting at the instruction of a physician.

For industrial use only. Not intended or suitable for use in or around a household or dwelling.

Refer to product Material Safety Data Sheet for further safety and health information.

****
For Internal Use Only: MHC: 0* 0* 0* 0* 0*, MPPEC: A, TRN: 7332901-00, CMCS97: 97P849, REQ: PS+C, SAFE USE: L
EHS Approval Date: 13AUG2002
****

Prepared by: ExxonMobil Oil Corporation
Environmental Health and Safety Department, Clinton, USA

APPENDIX B: LDV VELOCITY DATA TABLES

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	14.8846	18.0405	23.38826538	50.47512473
-0.25	17.2903	15.6647	23.33103727	42.17601016
-0.2	17.9375	13.1075	22.21622071	36.15678391
-0.15	17.7132	9.32912	20.01973862	27.77470662
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	22.6485	16.894	28.25529664	36.72004387
0.2	18.4449	13.6761	22.96192603	36.55534467
0.25	13.9591	13.1471	19.1755759	43.28414666
0.3	7.36505	13.8104	15.65155295	61.92911732
0.35	21.2637	11.0659	23.97079641	27.49304249

Table 2. 4 gph mini mist nozzle at 0.375” axial position, 60 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	17.3045	17.6765	24.73670092	45.60928008
-0.25	19.9732	17.3394	26.44964103	40.96233612
-0.2	20.8786	14.3871	25.35556318	34.57008807
-0.15	21.0083	10.4006	23.44186744	26.33867712
-0.1	20.1725	6.07585	21.06764604	16.76202267
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	18.5898	6.83021	19.80485882	20.1741942
0.15	21.6688	12.6971	25.11480125	30.36869497
0.2	20.9007	16.0481	26.35110575	37.51798977
0.25	18.2217	16.1349	24.33855684	41.52415776
0.3	10.4437	15.716	18.86964562	56.394905
0.35	10.2354	12.5894	16.22517814	50.88829242
0.4	8.11639	16.2686	18.18084521	63.48543229
0.45	7.82524	8.9118	11.85978753	48.71440013

Table 3. 4 gph mini mist nozzle at 0.375” axial position, 80 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	22.6012	22.579	31.94722965	44.97184682
-0.25	24.2675	21.1155	32.16793274	41.026998
-0.2	25.2599	17.4775	30.71686107	34.67962853
-0.15	26.4734	13.4051	29.67385404	26.85588012
-0.1	24.5052	6.86411	25.44839549	15.6480005
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	24.3745	9.19413	26.05087862	20.66661659
0.15	26.105	14.7498	29.98378937	29.46723854
0.2	25.6427	19.8096	32.40321459	37.68694575
0.25	23.5092	21.0774	31.57434521	41.87812113

Table 4. 4 gph mini mist nozzle at 0.375” axial position, 100 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	22.9634	22.3162	32.02078266	44.18110355
-0.25	23.9243	18.751	30.3969099	38.08806319
-0.2	25.0904	14.3812	28.91966607	29.8202738
-0.15	24.7242	23.4089	34.04794656	43.43470732
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	25.8132	10.5487	27.88541493	22.22763808
0.1	24.8884	14.4666	28.78740992	30.16766987
0.15	24.0884	18.9354	30.63984967	38.17016608
0.2	19.7843	18.2837	26.93904624	42.74263014
0.25	9.02589	16.7941	19.06589849	61.74445526

Table 5. 4 gph mini mist nozzle at 0.375” axial position, 120 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	14.011	15.5369	20.92136187	47.95621805
-0.25	17.4038	15.1726	23.08895938	41.08185665
-0.2	18.8374	12.7888	22.76842208	34.17276847
-0.15	17.6371	8.16848	19.43685576	24.85083128
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	19.7176	8.15115	21.33600235	22.45993862
0.1	19.037	12.482	22.76417565	33.25167523
0.15	17.8718	14.5367	23.03729329	39.1244777
0.2	10.9561	14.8503	18.45447201	53.58122134
0.25	7.98701	16.4788	18.31237773	64.14127619
0.3	7.24833	11.0817	13.24169033	56.81206129
0.35	7.32034	13.4487	15.3119205	61.43984867

Table 6. 4 gph mini mist nozzle at 0.375” axial position, 60 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	25.6826	17.8991	31.304532	34.87398605
-0.25	19.6969	15.9049	25.31666869	38.92026415
-0.2	23.1896	11.7308	25.98786672	26.83323803
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	19.7591	14.9799	24.79555276	37.1667351
0.2	25.9457	21.1575	33.47863729	39.19562792

Table 7. 4 gph mini mist nozzle at 0.375” axial position, 80 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	21.7307	21.4727	30.54996183	44.65784787
-0.25	24.0134	19.3993	30.87031292	38.93311916
-0.2	23.5026	14.4096	27.56825673	31.51273794
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	16.3607	19.6775	25.59055511	50.25844171
0.25	10.603	18.9396	21.70557664	60.75848843
0.3	5.62828	8.15173	9.905969804	55.37725127

Table 8. 4 gph mini mist nozzle at 0.375” axial position, 100 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	23.8774	23.3423	33.39151389	44.3507443
-0.25	28.2305	21.3665	35.40463886	37.1205751
-0.2	27.4178	16.073	31.78170993	30.37989828
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	25.3738	17.6123	30.88726012	34.76504126
0.2	23.2453	20.0856	30.72092608	40.82935933
0.25	18.6666	19.0328	26.658759	45.5565355

Table 9. 4 gph mini mist nozzle at 0.375” axial position, 120 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	17.3883	16.5217	23.98581972	43.53607439
-0.25	18.476	14.4824	23.47557211	38.09109877
-0.2	18.1414	12.3453	21.94349166	34.23545408
-0.15	19.3072	8.19692	20.97516315	23.00377125
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	20.0204	6.69145	21.10904828	18.4812557
0.1	20.5302	10.3795	23.00485019	26.81989592
0.15	19.0965	13.3658	23.30924542	34.98849617
0.2	17.9067	15.1664	23.46635025	40.26352816
0.25	12.8023	16.684	21.02985357	52.49953197
0.3	8.88935	15.7885	18.11897557	60.6193192
0.35	7.77978	16.3367	18.09455011	64.53551411
0.4	7.49828	11.7777	13.96203496	57.51710574

Table 10. 4 gph mini mist nozzle at 0.375” axial position, 60 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	19.9775	19.2617	27.75092058	43.95492847
-0.25	21.5145	16.9041	27.3609632	38.1569796
-0.2	22.269	13.669	26.12948377	31.54214025
-0.15	22.0993	9.19598	23.93627182	22.59321408
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	25.412	8.44815	26.77948809	18.38924571
0.1	22.4083	10.4641	24.73114024	25.03136532
0.15	22.3206	15.4511	27.14674337	34.69233698
0.2	20.7164	18.74	27.93486762	42.13240914
0.25	10.6932	18.174	21.08646016	59.52833824

Table 11. 4 gph mini mist nozzle at 0.375” axial position, 80 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	22.0528	22.1698	31.27020978	45.15158744
-0.25	23.3348	19.2538	30.25263138	39.52641503
-0.2	24.445	15.5463	28.96973367	32.45515878
-0.15	24.495	10.8033	26.77155797	23.79944729
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	27.5509	9.71847	29.21473515	19.43009056
0.1	24.7487	13.8558	28.36338036	29.24270688
0.15	25.7928	14.1615	29.42476192	28.76892447
0.2	24.6215	17.157	30.00968029	34.86994109
0.25	23.4052	18.7761	30.00575475	38.73725412
0.3	13.7884	28.2725	31.45559141	64.00166924

Table 12. 4 gph mini mist nozzle at 0.375” axial position, 100 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	16.4715	24.999	29.93760701	56.61965789
-0.25	24.3375	24.0638	34.22543465	44.67600689
-0.2	25.8994	20.4054	32.97209835	38.23356873
-0.15	26.2962	15.1883	30.36732769	30.01010102
-0.1	26.1971	9.60718	27.90315315	20.13934304
-0.05	0	0	0	0
0	0	0	0	0
0.05	25.9531	7.48355	27.01049648	16.08486263
0.1	27.1743	12.8434	30.05653846	25.29684138
0.15	26.4609	17.6069	31.78336289	33.63951972
0.2	25.2319	20.2261	32.33796374	38.71595184
0.25	18.0074	21.5709	28.09929148	50.14485109
0.3	19.7036	23.0905	30.35462145	49.52518965
0.35	6.63468	13.6572	15.18348084	64.08947697

Table 13. 4 gph mini mist nozzle at 0.375” axial position, 120 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.5	14.9998	16.2339	22.10279415	47.2626829
-0.45	17.8194	15.1865	23.41283406	40.4391398
-0.4	18.1372	14.6836	23.3359408	38.9931023
-0.35	18.5722	12.3867	22.32390982	33.7012434
-0.3	0	0	0	0
-0.25	0	0	0	0
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	7.88659	23.0204	24.33386772	71.0889834
0.25	18.4476	13.0511	22.59745908	35.2782125
0.3	18.5969	13.8937	23.21378016	36.7633216
0.35	16.11	14.4367	21.6321614	41.8645613
0.4	11.8011	13.5158	17.94276486	48.8746947
0.45	11.3243	17.7939	21.0917673	57.5267242

Table 14. 4 gph mini mist nozzle at 0.5” axial position, 60 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.5	18.3229	17.6644	25.45112359	43.9517118
-0.45	19.9607	17.6725	26.65983497	41.5205458
-0.4	20.4452	16.0232	25.97593389	38.0863143
-0.35	20.3	13.7328	24.50876977	34.0780609
-0.3	22.9646	13.0677	26.42229431	29.6414643
-0.25	21.3538	9.67913	23.4450492	24.3835681
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	20.0663	8.21767	21.68378417	22.2703716
0.15	21.6075	10.2661	23.92230895	25.4132078
0.2	22.018	12.9295	25.53359149	30.4224822
0.25	20.8017	14.5111	25.36301926	34.8993202
0.3	20.0216	15.6856	25.43427833	38.0763523
0.35	17.5587	16.6414	24.19181968	43.4636062
0.4	13.8012	19.4358	23.83743785	54.6217557
0.45	15.929	24.4017	29.14062463	56.8642052
0.5	7.65864	13.4865	15.50936649	60.4088601

Table 15. 4 gph mini mist nozzle at 0.5” axial position, 80 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.5	21.2605	21.0596	29.92516687	44.7280102
-0.45	22.6553	19.6932	30.01807363	40.998917
-0.4	22.9386	17.9784	29.14450611	38.0879951
-0.35	22.8013	14.9805	27.28213082	33.3049945
-0.3	23.854	13.0922	27.21064161	28.7600564
-0.25	22.4578	9.32405	24.31646951	22.5472923
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	22.94	7.94645	24.27734886	19.1061613
0.15	22.1654	9.96682	24.30313679	24.2113846
0.2	22.9137	13.3824	26.53537785	30.2864185
0.25	23.0787	16.2232	28.21025721	35.1053473
0.3	22.7877	17.7706	28.89763824	37.9482807
0.35	21.1143	19.1986	28.53769273	42.2793073
0.4	16.1075	17.8674	24.05609152	47.9652714
0.45	14.2706	18.3262	23.22713135	52.0921313

Table 16. 4 gph mini mist nozzle at 0.5” axial position, 100 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.5	23.1141	23.2423	32.77905014	45.1584528
-0.45	24.5686	21.6449	32.74321001	41.3800034
-0.4	24.8826	19.7165	31.74719129	38.3926371
-0.35	25.4784	17.4042	30.85538922	34.3368372
-0.3	25.0696	14.3275	28.87493897	29.7483516
-0.25	24.3056	10.7659	26.58320511	23.8904245
-0.2	20.2029	6.97409	21.37276537	19.044798
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	0	0	0	0
0.25	25.3609	17.4577	30.78874044	34.5423843
0.3	23.1187	18.373	29.53034742	38.4750302
0.35	24.4275	21.4274	32.49363364	41.2567047

Table 17. 4 gph mini mist nozzle at 0.5” axial position, 120 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.5	16.458	16.6321	23.39855796	45.3014528
-0.45	17.8911	15.5397	23.69754703	40.9766508
-0.4	18.6469	14.4537	23.59271759	37.7802001
-0.35	19.1499	12.9293	23.10596175	34.0257574
-0.3	19.9449	11.0195	22.78658413	28.9205243
-0.25	18.1157	8.15909	19.86829978	24.2462195
-0.2	21.913	8.1165	23.36786557	20.3244568
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	20.6182	10.3769	23.08224913	26.71558
0.2	20.5676	11.6484	23.63707664	29.5249197
0.25	19.0857	13.0851	23.14052261	34.434421
0.3	18.186	14.1229	23.02578773	37.8322302
0.35	16.3563	14.9032	22.12767317	42.3385177
0.4	12.5207	15.9927	20.31094241	51.9425744
0.45	13.5669	21.4858	25.41063512	57.7302254

Table 18. 4 gph mini mist nozzle at 0.5” axial position, 60 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.5	19.6375	19.5636	27.71941289	44.8919889
-0.45	20.6614	18.0082	27.40782219	41.0749714
-0.4	21.2306	16.6035	26.95207949	38.0273681
-0.35	21.903	14.8102	26.44018595	34.0654652
-0.3	21.7642	12.1066	24.90482213	29.08553
-0.25	24.6555	10.0788	26.63598862	22.2340104
-0.2	25.6263	9.45959	27.31649858	20.2609191
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	22.2913	9.82119	24.35893735	23.7775217
0.2	22.961	13.6487	26.71131844	30.7285065
0.25	21.4996	15.0737	26.25736529	35.0348876
0.3	20.6627	16.2038	26.25852825	38.1037324
0.35	19.1939	17.3858	25.89733266	42.1702269
0.4	15.14	18.0671	23.572011	50.0374205
0.45	13.8119	19.1735	23.63031282	54.2323782
0.5	10.5234	19.0259	21.74228181	61.0526158

Table 19. 4 gph mini mist nozzle at 0.5” axial position, 80 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.5	21.2806	21.7668	30.44104989	45.6471012
-0.45	22.7485	20.3463	30.5199308	41.8095076
-0.4	23.8708	18.8802	30.4347999	38.3416304
-0.35	24.6687	17.0836	30.00656843	34.7034258
-0.3	21.4656	13.3559	25.28145661	31.889881
-0.25	24.7145	11.8729	27.41846576	25.6597317
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	23.4387	8.08964	24.79546194	19.0416177
0.15	25.1601	12.6773	28.17347276	26.741947
0.2	25.4774	16.2717	30.23021885	32.5652283
0.25	24.8042	16.6862	29.89444109	33.9293811
0.3	24.0755	18.4404	30.32619416	37.4499655
0.35	22.3087	19.058	29.34084968	40.5067863
0.4	19.6965	20.3526	28.3227901	45.9385579

Table 20. 4 gph mini mist nozzle at 0.5” axial position, 100 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.4	24.6136	23.7536	34.20618099	43.9813514
-0.35	26.1558	22.6003	34.56731742	40.8291336
-0.3	30.1808	24.2777	38.73354368	38.8135039
-0.25	0	0	0	0
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	26.3763	8.62364	27.75024988	18.1049775
0.15	26.2556	12.9953	29.29563711	26.3332681
0.2	26.5093	16.6409	31.29956133	32.1180618
0.25	25.6399	19.1819	32.02108305	36.8011522
0.3	24.6482	20.9029	32.31818361	40.2996029
0.35	20.333	22.9972	30.69693954	48.518458
0.4	17.737	25.2592	30.86467809	54.923485
0.45	15.834	22.268	27.32360481	54.5846916
0.5	16.0897	25.9612	30.54279541	58.2110423

Table 21. 4 gph mini mist nozzle at 0.5” axial position, 120 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.5	17.4308	16.4071	23.93795562	43.2671559
-0.45	18.4272	15.2782	23.93710707	39.6625114
-0.4	19.0306	14.4857	23.91650562	37.2776422
-0.35	19.9356	12.3639	23.4583497	31.8068591
-0.3	20.2892	9.81071	22.53667383	25.8057852
-0.25	21.8511	7.67111	23.15850815	19.3442806
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	19.5268	7.95135	21.08364022	22.1562464
0.15	20.0194	10.5263	22.61812035	27.7356167
0.2	19.8377	12.7005	23.55497912	32.6282003
0.25	18.7681	14.0431	23.44035484	36.8054164
0.3	17.5509	14.9195	23.03531139	40.3668771
0.35	15.2904	16.741	22.67283426	47.5929715
0.4	13.6442	18.7699	23.20502833	53.9858785
0.45	10.9916	17.7943	20.91536237	58.2962328
0.5	11.0429	20.1204	22.95160423	61.2402156

Table 22. 4 gph mini mist nozzle at 0.5” axial position, 60 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.5	19.0643	20.6023	28.06959743	47.220427
-0.45	21.3192	18.9604	28.53077386	41.6485489
-0.4	22.365	17.0849	28.14404081	37.3766568
-0.35	23.5783	15.2147	28.06106425	32.8335064
-0.3	22.9053	11.3158	25.54799596	26.2905418
-0.25	22.0028	7.48875	23.24230162	18.7962333
-0.2	23.367	5.18707	23.93579713	12.5157298
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	21.6971	7.33565	22.90362219	18.6800646
0.05	24.605	11.7116	27.25009357	25.4537268
0.1	23.3056	15.0516	27.74349751	32.8558376
0.15	22.2778	15.9076	27.37429653	35.5289672
0.2	20.9368	18.1026	27.6776755	40.8476998
0.25	16.928	19.4487	25.78389256	48.9639377
0.3	8.94649	16.1793	18.48808892	61.059204

Table 23. 4 gph mini mist nozzle at 0.5” axial position, 80 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.5	18.0665	23.3138	29.49460447	52.2269183
-0.45	22.398	22.304	31.60915722	44.8795178
-0.4	23.6777	20.5117	31.32671885	40.9019809
-0.35	24.2918	17.5583	29.97307869	35.8596928
-0.3	24.5692	14.0995	28.3273982	29.850174
-0.25	30.1465	12.9771	32.82097784	23.2903254
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	22.8326	19.8407	30.24865285	40.9894552
0.25	18.8886	20.3619	27.77383988	47.1496353
0.3	15.6451	24.5656	29.1245233	57.5081519
0.35	9.68302	20.2882	22.48047899	64.486094

Table 24. 4 gph mini mist nozzle at 0.5” axial position, 100 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.5	23.387	23.5412	33.18342759	45.1882658
-0.45	24.7022	22.0466	33.10968524	41.7487652
-0.4	24.7054	19.5682	31.516206	38.3813947
-0.35	29.4629	21.0302	36.19850533	35.5187075
-0.3	0	0	0	0
-0.25	0	0	0	0
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	28.6776	15.2564	32.48326466	28.0128479
0.2	26.9894	17.7555	32.3061216	33.3396936
0.25	26.7892	20.2643	33.59022315	37.1051523
0.3	25.3281	22.3258	33.76320475	41.3950052
0.35	21.4768	23.4615	31.80715203	47.5288247

Table 25. 4 gph mini mist nozzle at 0.5” axial position, 120 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	16.5641	15.4321	22.63888511	42.973766
-0.85	17.1807	13.8533	22.070124	38.880246
-0.8	18.8192	12.2963	22.48024204	33.160248
-0.75	19.1109	12.8089	23.0063995	33.831596
-0.7	0	0	0	0
-0.65	17.0951	11.343	20.51599603	33.565207
-0.6	0	0	0	0
-0.55	0	0	0	0
-0.5	0	0	0	0
-0.45	0	0	0	0
-0.4	0	0	0	0
-0.35	0	0	0	0
-0.3	0	0	0	0
-0.25	0	0	0	0
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	0	0	0	0
0.25	0	0	0	0
0.3	0	0	0	0
0.35	0	0	0	0
0.4	0	0	0	0
0.45	0	0	0	0
0.5	19.9168	11.5344	23.01567521	30.076384
0.55	18.3268	9.66385	20.71862918	27.802995
0.6	18.7804	9.72101	21.14713833	27.366746
0.65	18.4151	11.7113	21.82362151	32.454802
0.7	17.2591	13.5767	21.9591283	38.190009
0.75	15.4731	14.7062	21.34687663	43.544344
0.8	13.7101	15.1184	20.40913669	47.796731
0.85	11.9467	14.3101	18.6414217	50.143388
0.9	10.951	13.8839	17.68296017	51.735201

Table 26. 4 gph mini mist nozzle at 1” axial position, 60 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	20.2462	17.9299	27.04422172	41.527887
-0.85	21.2776	16.6322	27.0067832	38.013904
-0.8	21.6028	15.6011	26.64723793	35.836045
-0.75	22.4501	15.6991	27.39468435	34.964657
-0.7	22.4681	14.841	26.9271387	33.446218
-0.65	20.9949	11.4634	23.92060546	28.634928
-0.6	26.4881	12.3937	29.24420013	25.074748
-0.55	20.617	10.8684	23.30628258	27.796279
-0.5	0	0	0	0
-0.45	22.1737	10.127	24.37681482	24.54676
-0.4	0	0	0	0
-0.35	0	0	0	0
-0.3	0	0	0	0
-0.25	0	0	0	0
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	0	0	0	0
0.25	13.855	5.70515	14.98364981	22.380665
0.3	21.4543	7.76842	22.81743495	19.904892
0.35	21.9011	8.55404	23.51233254	21.334414
0.4	0	0	0	0
0.45	22.8159	11.1743	25.40531978	26.093734
0.5	22.7256	12.5318	25.95185748	28.87409
0.55	22.4669	12.6326	25.77487494	29.348006
0.6	22.2347	13.6586	26.09481247	31.562076
0.65	21.6167	13.8145	25.65389111	32.581267
0.7	20.461	15.0844	25.42029985	36.398639
0.75	19.4912	16.441	25.49928153	40.147928
0.8	17.9777	17.0674	24.78898627	43.512071
0.85	16.8824	17.7633	24.50612692	46.456486
0.9	14.9263	17.8521	23.26997864	50.100704

Table 27. 4 gph mini mist nozzle at 1” axial position, 80 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	22.603	19.4353	29.8098389	40.690751
-0.85	23.5148	19.0216	30.24511672	38.9701
-0.8	24.1811	17.9707	30.12758961	36.618673
-0.75	24.71	17.3985	30.22071975	35.149669
-0.7	24.5119	16.1365	29.3465479	33.357426
-0.65	22.7159	14.6199	27.01395174	32.765238
-0.6	24.4404	13.6148	27.97670337	29.120486
-0.55	21.6948	11.2297	24.42888678	27.367066
-0.5	22.8118	10.9865	25.31958533	25.716153
-0.45	0	0	0	0
-0.4	25.6414	9.14477	27.22330274	19.628309
-0.35	0	0	0	0
-0.3	0	0	0	0
-0.25	0	0	0	0
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	0	0	0	0
0.25	0	0	0	0
0.3	0	0	0	0
0.35	0	0	0	0
0.4	0	0	0	0
0.45	27.9439	13.9288	31.22295656	26.494228
0.5	24.6237	14.3072	28.47845806	30.158032
0.55	24.8582	15.3691	29.22566239	31.727293
0.6	24.2776	16.1304	29.14775576	33.600657
0.65	23.9847	16.3663	29.03655644	34.308227
0.7	22.9896	17.1983	28.71068148	36.799811
0.75	21.9365	18.1176	28.45096592	39.55368
0.8	20.9821	19.9697	28.96614297	43.583837
0.85	19.8429	20.5031	28.53274943	45.937473
0.9	17.9597	19.6359	26.61051283	47.552842

Table 28. 4 gph mini mist nozzle at 1” axial position, 100 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	25.2619	22.2586	33.66910848	41.383711
-0.85	25.3228	21.1795	33.01235254	39.908459
-0.8	26.2764	20.4135	33.27401658	37.84277
-0.75	27.3308	18.9816	33.27572339	34.780487
-0.7	30.8043	21.3903	37.50266434	34.775855
-0.65	27.9584	17.6839	33.08160289	32.313663
-0.6	25.8464	15.0691	29.91845865	30.243259
-0.55	29.1847	15.4722	33.03234304	27.930194
-0.5	0	0	0	0
-0.45	0	0	0	0
-0.4	0	0	0	0
-0.35	0	0	0	0
-0.3	0	0	0	0
-0.25	0	0	0	0
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	0	0	0	0
0.25	0	0	0	0
0.3	0	0	0	0
0.35	0	0	0	0
0.4	0	0	0	0
0.45	0	0	0	0
0.5	0	0	0	0
0.55	27.7732	15.6726	31.89014	29.436324
0.6	27.8188	17.6745	32.95866477	32.42958
0.65	25.4014	18.4036	31.36755673	35.923752
0.7	24.8619	18.5227	31.003298	36.686977
0.75	24.4024	19.7592	31.3990941	38.99791
0.8	23.7262	20.9595	31.65806701	41.457074
0.85	19.2629	19.871	27.67518667	45.890245

Table 29. 4 gph mini mist nozzle at 1” axial position, 120 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	17.6724	15.2114	23.31738432	40.720004
-0.85	18.6825	14.8991	23.89600358	38.571997
-0.8	19.0521	14.327	23.83789931	36.942822
-0.75	19.2215	13.549	23.51683361	35.17954
-0.7	0	0	0	0
-0.65	19.8634	12.0704	23.24326173	31.285811
-0.6	19.4059	11.5177	22.56648772	30.689782
-0.55	22.4694	12.1174	25.52851972	28.337299
-0.5	0	0	0	0
-0.45	0	0	0	0
-0.4	23.8242	9.55648	25.66941401	21.85695
-0.35	0	0	0	0
-0.3	0	0	0	0
-0.25	0	0	0	0
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	0	0	0	0
0.25	20.7381	6.18615	21.64110079	16.609778
0.3	0	0	0	0
0.35	0	0	0	0
0.4	20.0559	10.178	22.49068271	26.906955
0.45	0	0	0	0
0.5	19.7816	11.1245	22.69506992	29.351923
0.55	17.8191	10.3126	20.58810442	30.059621
0.6	20.0846	12.9896	23.91904817	32.892537
0.65	19.5177	13.5581	23.76473625	34.786033
0.7	18.1416	13.5231	22.62723766	36.701559
0.75	17.3554	14.5802	22.6669835	40.03348
0.8	15.9997	15.0177	21.94360302	43.186641
0.85	15.0419	15.0332	21.26630804	44.983426
0.9	14.0335	15.0754	20.5962814	47.049923

Table 30. 4 gph mini mist nozzle at 1” axial position, 60 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	23.1957	19.6605	30.40683737	40.284358
-0.85	24.5516	20.4523	31.95430547	39.795424
-0.8	23.5673	17.0201	29.07062836	35.83649
-0.75	0	0	0	0
-0.7	0	0	0	0
-0.65	0	0	0	0
-0.6	0	0	0	0
-0.55	0	0	0	0
-0.5	0	0	0	0
-0.45	0	0	0	0
-0.4	0	0	0	0
-0.35	0	0	0	0
-0.3	0	0	0	0
-0.25	0	0	0	0
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	0	0	0	0
0.25	0	0	0	0
0.3	0	0	0	0
0.35	0	0	0	0
0.4	0	0	0	0
0.45	0	0	0	0
0.5	0	0	0	0
0.55	28.7109	16.1705	32.95149236	29.389001
0.6	0	0	0	0
0.65	24.7102	17.144	30.07508471	34.753012
0.7	23.766	18.2746	29.9797225	37.558081
0.75	22.2053	17.9028	28.52342188	38.877147
0.8	22.1259	19.0923	29.22449948	40.790703

Table 31. 4 gph mini mist nozzle at 1” axial position, 80 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	23.7404	22.1536	32.47135022	43.019769
-0.85	24.5188	21.4013	32.54515625	41.116169
-0.8	25.3383	20.7727	32.76483652	39.345389
-0.75	25.8894	20.0178	32.72572916	37.711356
-0.7	26.7644	19.4134	33.06377484	35.955033
-0.65	27.6923	18.2449	33.16232584	33.378642
-0.6	25.9215	16.1802	30.55688195	31.97241
-0.55	27.0902	14.7643	30.85228501	28.590614
-0.5	0	0	0	0
-0.45	0	0	0	0
-0.4	0	0	0	0
-0.35	0	0	0	0
-0.3	0	0	0	0
-0.25	0	0	0	0
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	0	0	0	0
0.25	0	0	0	0
0.3	0	0	0	0
0.35	28.0789	10.4734	29.96859578	20.455462
0.4	0	0	0	0
0.45	0	0	0	0
0.5	0	0	0	0
0.55	0	0	0	0
0.6	0	0	0	0
0.65	0	0	0	0
0.7	0	0	0	0
0.75	23.2911	18.6498	29.83773415	38.685179
0.8	23.0308	20.1747	30.61758104	41.217965
0.85	21.0793	19.0427	28.40706447	42.09415
0.9	21.5702	21.6371	30.55221145	45.088714

Table 32. 4 gph mini mist nozzle at 1” axial position, 100 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	24.6711	23.352	33.97026758	43.426593
-0.85	25.513	22.7477	34.18144269	41.720583
-0.8	26.5642	22.0201	34.50422475	39.656658
-0.75	27.1457	21.1513	34.41317364	37.924895
-0.7	27.8735	20.5027	34.60191771	36.336804
-0.65	28.3955	19.4136	34.3975622	34.359862
-0.6	28.2145	17.9212	33.42495205	32.422772
-0.55	28.2184	16.3981	32.63703084	30.16146
-0.5	27.8643	15.0339	31.66129125	28.34863
-0.45	26.0173	10.554	28.07644592	22.08009
-0.4	26.2143	10.7584	28.33606704	22.313342
-0.35	23.9158	9.36221	25.68299955	21.378628
-0.3	0	0	0	0
-0.25	0	0	0	0
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	0	0	0	0
0.25	0	0	0	0
0.3	0	0	0	0
0.35	0	0	0	0
0.4	0	0	0	0
0.45	0	0	0	0
0.5	0	0	0	0
0.55	26.1575	16.2057	30.77075753	31.780002
0.6	27.9313	18.7405	33.6357527	33.859628
0.65	26.5862	18.7399	32.52706385	35.178983
0.7	26.3324	20.0568	33.10091413	37.295713
0.75	25.5128	20.1991	32.54084517	38.36951
0.8	25.8517	22.707	34.40811302	41.294654

Table 33. 4 gph mini mist nozzle at 1” axial position, 120 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	18.4035	16.4041	24.65326163	41.712458
-0.85	19.0236	15.6764	24.6504944	39.490233
-0.8	19.6087	14.7321	24.52622853	36.917694
-0.75	19.9859	14.0909	24.45382714	35.185446
-0.7	20.2414	13.3511	24.24801322	33.408593
-0.65	20.0985	12.3353	23.58197041	31.539202
-0.6	20.0553	11.5048	23.12088842	29.840904
-0.55	20.1228	10.3198	22.61471538	27.150618
-0.5	20.1681	8.96857	22.07232442	23.974278
-0.45	19.8725	7.83891	21.36269567	21.52726
-0.4	19.8677	6.65445	20.95249885	18.517661
-0.35	20.1546	5.60133	20.91847984	15.53158
-0.3	22.8434	10.5049	25.14306758	24.696087
-0.25	18.4864	5.63791	19.3270022	16.960453
-0.2	11.2443	8.7647	14.25672643	37.93568
-0.15	6.61594	7.78831	10.21902318	49.653079
-0.1	21.9977	6.04575	22.81337104	15.367491
-0.05	0	0	0	0
0	11.1769	8.04325	13.77014757	35.739982
0.05	7.95072	5.55818	9.700892404	34.956582
0.1	21.6407	5.36824	22.29658936	13.9317
0.15	20.3305	6.12219	21.23229711	16.758796
0.2	20.0985	7.09795	21.31503217	19.451091
0.25	20.0207	8.32099	21.68103556	22.568715
0.3	20.4843	9.57013	22.60959829	25.041672
0.35	20.6065	10.7911	23.26103354	27.639907
0.4	20.5901	11.5578	23.61217819	29.306718
0.45	20.5888	12.4028	24.03597581	31.064978
0.5	20.4427	13.2953	24.38583575	33.038731
0.55	19.4303	14.2625	24.10301774	36.279933
0.6	18.3702	15.5209	24.04917015	40.194318
0.65	17.3996	16.4369	23.93570057	43.370287
0.7	16.4317	17.6779	24.13522143	47.09238
0.75	15.3861	18.6157	24.15111508	50.425859
0.8	14.2618	18.5669	23.41214887	52.471039
0.85	13.1325	19.0112	23.10602263	55.364175
0.9	12.5379	19.2456	22.96937212	56.917028

Table 34. 4 gph mini mist nozzle at 1” axial position, 60 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	20.831	18.9638	28.17013084	42.313612
-0.85	21.661	18.4048	28.42420771	40.353709
-0.8	22.1542	17.5751	28.27883869	38.425243
-0.75	22.8312	16.9235	28.41950995	36.547486
-0.7	23.1061	16.1846	28.21051461	35.009208
-0.65	23.2422	15.245	27.79586095	33.261629
-0.6	23.2013	14.1944	27.19892117	31.458016
-0.55	23.2621	13.0773	26.68597144	29.343473
-0.5	23.0968	11.7863	25.93027262	27.035227
-0.45	22.3697	10.1569	24.56758221	24.420292
-0.4	22.6104	9.06176	24.35868803	21.839847
-0.35	22.4755	7.90229	23.8242374	19.371457
-0.3	23.4839	7.07378	24.52614773	16.763262
-0.25	25.1362	6.54666	25.97474365	14.598229
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	0	0	0	0
0.25	23.5664	6.48544	24.44250685	15.386829
0.3	22.2805	7.51439	23.5135437	18.637351
0.35	21.7991	8.38389	23.35573532	21.036643
0.4	21.5111	9.57537	23.54602161	23.995579
0.45	22.9355	11.2496	25.54585407	26.127422
0.5	24.0489	13.0259	27.35002124	28.441846
0.55	23.5607	13.9758	27.39396959	30.675685
0.6	23.5743	15.16	28.02807914	32.743984
0.65	22.9211	15.5022	27.67119495	34.071621
0.7	19.1449	20.0588	27.72873335	46.335413
0.75	17.7498	20.1645	26.86377599	48.644153
0.8	16.6573	20.5912	26.48514982	51.028791
0.85	23.0566	20.2223	30.66835863	41.253096
0.9	14.4863	20.5327	25.12856257	54.796137

Table 35. 4 gph mini mist nozzle at 1” axial position, 80 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	23.5871	21.7446	32.0808185	42.672503
-0.85	24.439	20.8271	32.10969971	40.437886
-0.8	24.9995	20.1407	32.10331442	38.856451
-0.75	25.5444	19.1822	31.94484572	36.904191
-0.7	26.0957	18.2858	31.86465189	35.019728
-0.65	26.3973	16.8204	31.30085148	32.50535
-0.6	26.0163	15.5035	30.28541527	30.791343
-0.55	26.1807	13.7246	29.56000165	27.664691
-0.5	25.7623	12.2386	28.52156081	25.410454
-0.45	23.1716	10.0178	25.24439271	23.380323
-0.4	0	0	0	0
-0.35	0	0	0	0
-0.3	23.0728	6.02326	23.84604288	14.630798
-0.25	0	0	0	0
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	0	0	0	0
0.25	0	0	0	0
0.3	0	0	0	0
0.35	0	0	0	0
0.4	0	0	0	0
0.45	0	0	0	0
0.5	24.8631	17.3822	30.33668766	34.958027
0.55	0	0	0	0
0.6	24.4186	19.1317	31.020799	38.078302
0.65	23.5915	20.201	31.05864249	40.572882
0.7	22.4393	21.5116	31.08490179	43.790801
0.75	21.241	22.3179	30.81020515	46.416226
0.8	19.8355	22.7276	30.1660548	48.887189
0.85	18.4208	22.708	29.24002628	50.950929
0.9	17.3177	22.8034	28.63385732	52.785692

Table 36. 4 gph mini mist nozzle at 1” axial position, 100 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	26.2959	22.5883	34.6656264	40.662731
-0.85	27.1702	21.6695	34.75323004	38.573992
-0.8	27.5447	20.6887	34.44898846	36.910047
-0.75	28.1324	19.7156	34.35311941	35.023337
-0.7	27.848	18.1011	33.21386646	33.023723
-0.65	28.4229	16.7397	32.98603948	30.496008
-0.6	27.0466	14.8346	30.84775403	28.744019
-0.55	0	0	0	0
-0.5	0	0	0	0
-0.45	0	0	0	0
-0.4	0	0	0	0
-0.35	0	0	0	0
-0.3	0	0	0	0
-0.25	0	0	0	0
-0.2	0	0	0	0
-0.15	0	0	0	0
-0.1	0	0	0	0
-0.05	0	0	0	0
0	0	0	0	0
0.05	0	0	0	0
0.1	0	0	0	0
0.15	0	0	0	0
0.2	27.9683	10.9535	30.03672697	21.387289
0.25	28.1856	8.31077	29.38531853	16.428612
0.3	26.6894	9.35178	28.28037944	19.310106
0.35	29.2387	12.1329	31.65610273	22.53651
0.4	29.4379	13.946	32.57423633	25.348928
0.45	28.4201	15.2125	32.23541903	28.158922
0.5	29.2356	16.6399	33.63936057	29.647047
0.55	28.8903	18.0302	34.05491956	31.96795
0.6	25.3128	21.3197	33.09482515	40.105752
0.65	24.5117	22.6364	33.36510216	42.72228
0.7	23.2043	23.2254	32.83075911	45.026038
0.75	21.7003	23.4194	31.92759491	47.181964
0.8	20.6885	24.6573	32.18689913	50.001952
0.85	20.3245	25.2345	32.40162481	51.151159
0.9	18.361	24.7817	30.84248654	53.464897

Table 37. 4 gph mini mist nozzle at 1” axial position, 120 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.25	16.9364	7.82217	18.65550826	24.7901152
-0.2	16.9341	7.44712	18.49927942	23.73848372
-0.15	19.3485	4.22476	19.80436945	12.3172562
-0.1	21.111	3.69547	21.43200456	9.928997363
-0.05	20.4586	3.86209	20.81994364	10.69025814
0	18.0021	4.09896	18.4628567	12.82718487
0.05	17.2767	4.00335	17.73446289	13.04630492
0.1	16.7114	8.99732	18.97953258	28.29776247
0.15	16.802	8.80382	18.96877567	27.65339337

Table 38. 6 gph mist nozzle at 0.375” axial position, 60 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.25	20.2781	8.70848	22.06895928	23.24122345
-0.2	15.5353	7.5957	17.29277897	26.05547309
-0.15	19.4437	7.472	20.82998449	21.02121856
-0.1	21.331	3.57804	21.62900671	9.522089831
-0.05	21.592	3.6778	21.90298329	9.666510167
0	19.805	3.76558	20.15980203	10.76531039
0.05	19.3762	4.23458	19.83352702	12.32790117
0.1	18.3935	9.52045	20.71134497	27.36602103
0.15	16.9529	10.6277	20.00871874	32.083422

Table 39. 6 gph mist nozzle at 0.375” axial position, 80 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.25	19.6315	8.76248	21.49829872	24.05349823
-0.2	22.345	7.73401	23.6455902	19.09166544
-0.15	25.6984	4.15394	26.03196074	9.181983019
-0.1	22.7329	3.97911	23.07851942	9.928330279
-0.05	22.8124	3.23861	23.04114122	8.080119684
0	19.1003	3.64085	19.44420862	10.79210649
0.05	17.6551	4.20397	18.14871675	13.39364871
0.1	17.357	8.56503	19.3552367	26.26461503
0.15	17.4342	9.79671	19.99817133	29.33271379

Table 40. 6 gph mist nozzle at 0.375” axial position, 100 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.25	17.1866	7.36471	18.69807939	23.19584241
-0.2	19.4538	6.70267	20.57610555	19.01103035
-0.15	20.5437	3.64541	20.86462614	10.06220395
-0.1	22.5887	2.82423	22.7645699	7.126620959
-0.05	18.7937	3.879	19.18983587	11.66202648
0	20.8383	3.03165	21.05767434	8.277574455
0.05	19.2988	4.03423	19.71595022	11.8071134
0.1	18.9045	5.97453	19.82612239	17.53848714
0.15	17.0012	6.8488	18.32885329	21.94165394

Table 41. 6 gph mist nozzle at 0.375” axial position, 60 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.25	18.7415	9.1822	20.86999327	26.10205588
-0.2	24.1371	8.46152	25.57727345	19.31866384
-0.15	24.6008	4.10618	24.94113219	9.476023859
-0.1	25.6061	3.61315	25.85976044	8.031698492
-0.05	25.4645	3.47757	25.70086095	7.776515699
0	24.2971	3.3867	24.53199554	7.935160633
0.05	25.5244	4.21144	25.86950371	9.369197165
0.1	25.9512	8.23039	27.22506384	17.59635798
0.15	23.4988	8.27198	24.91223102	19.39294149

Table 42. 6 gph mist nozzle at 0.375” axial position, 80 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.25	28.1584	9.59653	29.74876264	18.81937867
-0.2	28.4392	10.3632	30.26853169	20.02166122
-0.15	29.7706	4.3442	30.08588869	8.302146677
-0.1	30.8741	3.68297	31.09299469	6.802664982
-0.05	29.777	3.68067	30.00361746	7.046463964
0	28.7067	3.59962	28.9315034	7.147187605
0.05	27.5622	3.82078	27.82576555	7.892267455
0.1	29.1206	5.21201	29.58334654	10.14736562
0.15	28.0878	5.40557	28.60322877	10.89353307

Table 43. 6 gph mist nozzle at 0.375” axial position, 100 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.25	22.761	9.87405	24.81048134	23.45189527
-0.2	24.6665	8.12169	25.9691754	18.2246427
-0.15	24.4876	4.11841	24.83150931	9.546860007
-0.1	24.805	3.39496	25.03624929	7.793419414
-0.05	20.2686	2.96416	20.48419856	8.320179945
0	24.0682	2.56563	24.20455966	6.084656945
0.05	24.0682	2.56563	24.20455966	6.084656945
0.1	23.3756	8.58404	24.90189587	20.16435753
0.15	19.361	8.58404	21.1786228	23.91094659

Table 44. 6 gph mist nozzle at 0.375” axial position, 60 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.25	26.2843	9.83125	28.06274939	20.50755959
-0.2	27.4372	8.09176	28.6055331	16.43180588
-0.15	28.5483	4.00874	28.82837889	7.993186486
-0.1	27.697	3.17765	27.87868843	6.544873251
-0.05	29.5778	3.19984	29.750382	6.174464084
0	26.8662	2.94899	27.02756453	6.264040041
0.05	26.0451	2.50288	26.16508441	5.489149701
0.1	26.9579	7.89302	28.08964466	16.31953526
0.15	24.4431	8.69003	25.94189197	19.57135699

Table 45. 6 gph mist nozzle at 0.375” axial position, 80 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.25	30.7456	11.5422	32.84074147	20.57662823
-0.2	28.3682	9.20958	29.82567912	17.98573674
-0.15	31.2092	3.73304	31.43166798	6.820938979
-0.1	31.4842	3.65635	31.69580012	6.624248687
-0.05	30.3368	3.66185	30.55700541	6.882676866
0	28.5432	4.18143	28.84785301	8.334250738
0.05	30.533	2.98172	30.67824544	5.577571126
0.1	28.4597	8.0716	29.58217792	15.83413595
0.15	27.1843	10.4192	29.1126415	20.97083185

Table 46. 6 gph mist nozzle at 0.375” axial position, 100 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.5	17.5506	14.2965	22.63655169	39.16583093
-0.45	18.7525	14.0997	23.46183702	36.93891096
-0.4	19.1719	13.5236	23.46166035	35.1986276
-0.35	19.8798	12.0829	23.26376841	31.29114487
-0.3	20.417	10.589	22.99958282	27.41289953
-0.25	20.1304	9.08294	22.08467349	24.2851411
-0.2	21.4505	8.19227	22.96164711	20.90261215
-0.15	22.1586	4.23304	22.55930366	10.81512093
-0.1	22.6265	3.95088	22.96884749	9.904726945
-0.05	21.3415	3.88185	21.69166618	10.30894543
0	21.2645	4.1503	21.66573217	11.04387129
0.05	20.8521	4.15854	21.26272629	11.2785416
0.1	20.894	4.4033	21.35294563	11.9006396
0.15	20.593	8.89497	22.43194464	23.36151669
0.2	20.7261	10.6365	23.29605875	27.16660027
0.25	20.2798	11.8716	23.49904625	30.34429586

Table 47. 6 gph mist nozzle at 0.5” axial position, 60 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.45	20.5375	9.11111	22.46778208	23.9236474
-0.4	20.9695	13.4594	24.91737102	32.69462121
-0.35	21.6607	12.7585	25.13891897	30.49876794
-0.3	22.1375	11.1528	24.78817973	26.7388158
-0.25	22.0295	9.25251	23.89367723	22.78267103
-0.2	23.3204	8.05061	24.67090143	19.04556953
-0.15	23.1895	4.09454	23.54820944	10.01343164
-0.1	23.6127	3.98428	23.94648384	9.577566198
-0.05	23.9736	4.24565	24.34664332	10.04277675
0	20.3802	3.85064	20.74078061	10.69935188
0.05	19.537	4.12981	19.96871803	11.93570821
0.1	22.9349	8.48503	24.45414836	20.30253341
0.15	24.3397	9.90646	26.27848827	22.14673129
0.2	23.3558	11.6562	26.10288092	26.5224483
0.25	22.5501	6.03633	23.34404185	14.98589132
0.3	20.6531	1.80148	20.73151875	4.985044366

Table 48. 6 gph mist nozzle at 0.5” axial position, 80 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.45	22.9455	15.8805	27.90495029	34.68697243
-0.4	21.3921	14.0874	25.61399581	33.36621563
-0.35	25.3968	13.9827	28.99160826	28.83583348
-0.3	25.259	10.8346	27.48464368	23.21643755
-0.25	26.4299	10.1404	28.30843207	20.99038585
-0.2	25.7234	8.15456	26.98499873	17.5891053
-0.15	22.4099	3.80152	22.73004998	9.627759828
-0.1	26.563	3.71708	26.821813	7.965929369
-0.05	26.5682	3.55681	26.80522614	7.625117844
0	25.9083	3.86183	26.19453645	8.477953071
0.05	24.4361	3.74057	24.72073719	8.703027057
0.1	21.1985	3.77118	21.53133068	10.08729927
0.15	23.0871	10.2631	25.26549837	23.96697895
0.2	25.7982	9.02601	27.33159307	19.28339802
0.25	25.7147	12.9833	28.80645544	26.78911776
0.3	24.232	19.7457	31.25831877	39.17523158

Table 49. 6 gph mist nozzle at 0.5” axial position, 100 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.4	15.7696	8.82683	18.07189011	29.23735757
-0.35	19.5704	9.74966	21.86450151	26.48175106
-0.3	20.8399	8.45207	22.48863978	22.07607348
-0.25	18.1352	8.76017	20.14016031	25.78276719
-0.2	18.6265	7.42114	20.05043194	21.72324621
-0.15	23.0472	3.36103	23.29098432	8.297096285
-0.1	27.926	3.51296	28.14608967	7.169879159
-0.05	21.4211	3.09981	21.64422203	8.234015002
0	25.711	3.7862	25.98828258	8.377164303
0.05	20.6923	3.94364	21.06474723	10.79030847
0.1	23.9784	3.80702	24.27873695	9.021477808
0.15	21.0855	3.56343	21.38448839	9.592298174
0.2	21.4494	9.15979	23.32334696	23.1245069
0.25	20.8227	7.82081	22.24297427	20.5857055

Table 50. 6 gph mist nozzle at 0.5” axial position, 60 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	25.8739	8.59823	27.26514736	18.38231137
-0.25	24.8053	8.27219	26.14827022	18.44275797
-0.2	26.8118	7.69626	27.89453418	16.01599314
-0.15	20.0642	3.69627	20.40182672	10.43811931
-0.1	26.94	3.54008	27.17159853	7.486121839
-0.05	26.0507	3.22014	26.24896707	7.046615198
0	24.3742	3.85347	24.67692964	8.983892152
0.05	24.4782	3.82065	24.77457652	8.871362219
0.1	28.6335	3.7397	28.87668053	7.441040107
0.15	27.8872	3.80872	28.14608804	7.777106601
0.2	28.3277	8.7701	29.65422805	17.20223708
0.25	24.3997	8.23401	25.75158793	18.64766517

Table 51. 6 gph mist nozzle at 0.5” axial position, 80 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	29.7886	10.0292	31.43160102	18.60730544
-0.25	25.281	10.4068	27.33917422	22.3742758
-0.2	29.1206	9.21731	30.5445273	17.56372411
-0.15	27.5884	3.74106	27.84089339	7.722356021
-0.1	28.2107	3.23369	28.39542825	6.539067228
-0.05	29.7774	3.27035	29.95644738	6.267480855
0	29.0063	3.63862	29.23362781	7.149972897
0.05	25.4205	3.74427	25.69477336	8.379037276
0.1	28.6954	3.4518	28.90226469	6.859212459
0.15	29.2297	3.35278	29.42136122	6.543489557
0.15	29.2297	3.35278	29.42136122	6.543489557
0.2	27.9345	9.44198	29.48706965	18.67547231
0.25	26.0867	9.90797	27.90490614	20.79724035

Table 52. 6 gph mist nozzle at 0.5” axial position, 100 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.35	26.9877	9.62962	28.65424109	19.63716968
-0.3	20.7381	9.27982	22.71967981	24.10741157
-0.25	24.0539	9.04856	25.69954364	20.61522054
-0.2	22.9809	7.57194	24.19619888	18.23645211
-0.15	19.1854	3.42006	19.4878522	10.10758293
-0.1	23.1061	3.41561	23.35718838	8.408731316
-0.05	23.6855	3.24789	23.90714746	7.808025752
0	29.0063	3.63862	29.23362781	7.149972897
0.05	24.5303	3.42993	24.76893292	7.959732163
0.1	26.4948	3.58942	26.73683532	7.715252963
0.15	21.9247	3.65962	22.22802935	9.476314791
0.2	24.3732	8.98588	25.97689199	20.23785684

Table 53. 6 gph mist nozzle at 0.5” axial position, 60 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.3	24.0333	9.6321	25.89163686	21.83999549
-0.25	23.4264	8.0566	24.77307047	18.97866452
-0.2	23.3603	7.04723	24.40014481	16.78727571
-0.15	24.9149	3.90684	25.21935052	8.911830494
-0.1	27.1047	3.26242	27.30033235	6.863311064
-0.05	27.343	3.89542	27.61908662	8.108081362
0	26.1947	3.61595	26.44309745	7.85951206
0.05	26.2277	3.84291	26.50773858	8.335723579
0.1	25.8333	4.13004	26.16135737	9.083166339
0.15	25.6283	4.25024	25.97834292	9.416324618
0.2	26.3319	11.4517	28.71428896	23.50414289
0.25	26.2287	10.7561	28.34851656	22.29799198

Table 54. 6 gph mist nozzle at 0.5" axial position, 80 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.35	29.5048	10.9768	31.48052352	20.40693144
-0.3	28.8277	13.5455	31.85148125	25.16779561
-0.25	28.571	11.2611	30.71016793	21.51160224
-0.2	28.7374	8.83634	30.06524677	17.09191521
-0.15	30.6266	3.96708	30.88246025	7.380459422
-0.1	30.7853	3.83701	31.02349661	7.104578394
-0.05	29.8762	3.81514	30.1188084	7.27718827
0	28.3869	3.71348	28.6287622	7.452921958
0.05	28.4577	3.74668	28.70328031	7.500302241
0.1	27.05	3.6759	27.29862159	7.738679395
0.15	30.8709	3.59299	31.07928641	6.638649979
0.2	27.8081	11.2758	30.00723398	22.0718738

Table 55. 6 gph mist nozzle at 0.5" axial position, 100 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	16.7637	15.5301	22.85181926	42.81240593
-0.85	17.9145	15.1507	23.46216147	40.22196073
-0.8	18.9616	14.9429	24.14192484	38.24027079
-0.75	19.9086	14.6179	24.69889379	36.28799626
-0.7	20.3685	14.2211	24.84180906	34.92239221
-0.65	20.5055	13.6298	24.62208314	33.61158737
-0.6	21.002	12.8238	24.60759741	31.40819688
-0.55	20.9423	12.075	24.17406781	29.96707114
-0.5	20.8343	10.9196	23.52245142	27.65977437
-0.45	20.8668	10.0677	23.16855467	25.75612652
-0.4	20.6295	8.93305	22.48056166	23.41372605
-0.35	20.9373	8.20813	22.48875117	21.40685977
-0.3	21.4387	7.48314	22.70716279	19.24144992
-0.25	21.7796	6.70744	22.78904841	17.11720613
-0.2	21.8525	5.99307	22.65940521	15.33634636
-0.15	21.2577	4.27363	21.68302845	11.36717013
-0.1	21.7731	4.04213	22.1451281	10.51710672
-0.05	22.402	3.96991	22.7510393	10.04918819
0	22.4195	4.11189	22.79345563	10.3929333
0.05	22.1751	3.88637	22.51308357	9.940603787
0.1	21.7973	4.03853	22.16826587	10.49654188
0.15	21.8877	4.04015	22.25745321	10.45824807
0.2	20.9478	4.37875	21.40055552	11.80662146
0.25	22.2274	6.47306	23.15076276	16.23660804
0.3	22.0397	7.18064	23.17994752	18.04585802
0.35	21.6256	7.83457	23.00102307	19.91455036
0.4	21.5332	8.64029	23.20201098	21.86333829
0.45	21.2367	9.75839	23.37142705	24.67906252
0.5	21.7474	11.3064	24.51089733	27.46976944
0.55	21.9683	12.617	25.33367115	29.86993836
0.6	21.7741	13.7002	25.72560808	32.17798266
0.65	21.2298	14.5518	25.73828454	34.42838293
0.7	20.8313	15.5226	25.97872534	36.69191444
0.75	20.0639	16.2357	25.81003754	38.97977067
0.8	19.0259	17.0251	25.53113591	41.82339152
0.85	18.3721	17.8925	25.64518697	44.24230644
0.9	17.5031	18.604	25.54343997	46.74639859

Table 56. 6 gph mist nozzle at 1” axial position, 60 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	18.323	15.5253	24.01597945	40.27501058
-0.85	19.559	15.5787	25.00500699	38.53724377
-0.8	20.6338	15.4829	25.79678071	36.88331275
-0.75	21.3849	15.2121	26.24351223	35.42605823
-0.7	22.2701	14.9989	26.85003455	33.9602446
-0.65	22.8628	14.646	27.15166551	32.64378502
-0.6	22.9041	14.0396	26.86462665	31.50718201
-0.55	23.0424	13.0026	26.45788738	29.43561035
-0.5	22.9978	12.3553	26.10655555	28.24639697
-0.45	22.8834	11.1005	25.43366068	25.87754248
-0.4	22.6491	9.50144	24.56133329	22.75835586
-0.35	22.9593	8.81148	24.59210516	20.99615108
-0.3	24.3321	8.20917	25.67959428	18.64337901
-0.25	24.5165	7.72772	25.70557194	17.49510488
-0.2	24.4663	6.99378	25.4462727	15.95277547
-0.15	25.1388	4.21381	25.48951667	9.515557991
-0.1	24.382	4.26215	24.75172411	9.915528717
-0.05	24.7253	4.02663	25.0510321	9.249682135
0	24.4539	3.37748	24.68604052	7.863724763
0.05	23.2802	3.87662	23.60076047	9.454148376
0.1	23.9076	4.2966	24.29061772	10.18826212
0.15	23.7842	4.14714	24.14305158	9.890958625
0.2	21.6663	4.14956	22.06008622	10.8420759
0.25	24.4182	7.25302	25.47262826	16.54317597
0.3	23.7493	7.57352	24.92764441	17.68719379
0.35	24.6437	8.50625	26.07044761	19.04310507
0.4	23.8024	9.6402	25.68049263	22.04841895
0.45	24.2938	9.79106	26.19262443	21.95077101
0.5	24.4336	12.0037	27.22296131	26.16388967
0.55	23.2878	12.9709	26.65644154	29.11704714
0.6	24.0611	14.0612	27.86851052	30.30182548
0.65	22.5294	14.0724	26.56325105	31.98988162
0.7	22.2955	14.4393	26.56280679	32.92842304
0.75	20.6737	15.0818	25.59028259	36.1113585
0.8	20.3021	14.6845	25.05613307	35.87819919
0.85	16.1374	14.5768	21.74623593	42.09128141
0.9	15.0135	13.8381	20.41808497	42.66708819

Table 57. 6 gph mist nozzle at 1” axial position, 80 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.9	22.3492	21.62	31.09519482	44.04987462
-0.85	23.6454	20.9903	31.61799543	41.59584188
-0.8	23.9648	19.2675	30.7497674	38.79899237
-0.75	24.2222	17.7477	30.0282505	36.23037813
-0.7	25.4828	16.7615	30.50116355	33.33521475
-0.65	25.5598	15.4293	29.85576451	31.11748892
-0.6	25.7843	15.2459	29.95442527	30.59523778
-0.55	25.2367	14.1624	28.93898064	29.30038755
-0.5	25.3058	12.566	28.25398856	26.40743232
-0.45	25.0005	10.7821	27.22643349	23.32934693
-0.4	24.2748	9.52089	26.07514643	21.41575277
-0.35	25.5253	10.5668	27.6260421	22.48826301
-0.3	25.1567	7.61273	26.28332576	16.83646727
-0.25	25.4189	6.96046	26.35466715	15.31391521
-0.2	25.8504	6.92229	26.76118979	14.99109952
-0.15	27.1047	4.17581	27.42448087	8.758254788
-0.1	24.8917	3.66147	25.15955269	8.367972197
-0.05	24.963	3.6258	25.2249439	8.264245445
0	26.6091	3.1325	26.79284903	6.714121938
0.05	27.0591	4.08983	27.36643203	8.594878296
0.1	24.8975	4.0211	25.22012592	9.174400511
0.15	22.7245	4.30542	23.12876005	10.7281906
0.2	22.2618	4.27601	22.66874502	10.87285526
0.25	25.9945	7.44	27.03826234	15.97188379
0.3	27.2632	9.43568	28.84985496	19.09052386
0.35	25.4282	9.85362	27.27062857	21.18172662
0.4	25.8697	11.3926	28.26716669	23.7679212
0.45	26.018	11.7917	28.56537262	24.38065923
0.5	27.1248	12.8568	30.01752957	25.36033913
0.55	28.3244	15.7678	32.41751305	29.1040789
0.6	26.3623	16.5029	31.10171329	32.04672261
0.65	24.3948	17.6222	30.09398943	35.84341516
0.7	24.0738	18.976	30.65348956	38.24669192
0.75	21.1863	18.9592	28.43080323	41.8247308
0.8	20.1367	25.0635	32.15067214	51.22065426
0.85	21.0142	24.3658	32.1759042	49.22398654
0.9	17.3122	19.2025	25.85436665	47.96345351

Table 58. 6 gph mist nozzle at 1” axial position, 100 psig, 80°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.7	22.5201	13.838	26.43189641	31.5696142
-0.65	24.2304	12.7942	27.40079995	27.83506873
-0.6	22.8395	11.4159	25.53361575	26.55732409
-0.55	22.8411	11.3488	25.5051193	26.42088525
-0.5	22.9587	9.54834	24.86509003	22.58203599
-0.45	22.0565	7.80085	23.3953511	19.477454
-0.4	23.7578	8.72782	25.31023316	20.17164128
-0.35	20.6462	8.55991	22.35033856	22.51888545
-0.3	24.5698	6.06679	25.30772635	13.87006606
-0.25	20.6299	6.56828	21.65029044	17.66076869
-0.2	19.5228	5.61448	20.31408638	16.04448371
-0.15	22.3851	3.62298	22.6763905	9.193477578
-0.1	18.5609	3.17415	18.83035414	9.704430652
-0.05	21.8091	3.50669	22.08922175	9.134417634
0	22.4054	2.79122	22.57859292	7.101208475
0.05	24.4518	3.44503	24.69329372	8.019653787
0.1	20.5035	4.45906	20.98277218	12.26951632
0.15	18.5411	3.44357	18.85816968	10.52145003
0.2	18.3211	4.2726	18.81270358	13.12713148
0.25	22.4451	5.51547	23.11283028	13.80583715
0.3	22.7779	8.14284	24.18963769	19.67139177
0.35	24.3765	9.65989	26.2207404	21.61737272
0.4	20.0032	9.12559	21.98645954	24.52278025
0.45	21.6013	7.60809	22.90194741	19.40252834
0.5	18.7402	9.6219	21.06599287	27.17761267
0.55	22.2959	10.6443	24.70644206	25.52030613
0.6	22.6297	10.7174	25.03928882	25.3421815
0.65	21.6597	13.2548	25.39354893	31.46483015
0.7	20.414	14.158	24.84311494	34.74299676

Table 59. 6 gph mist nozzle at 1” axial position, 60 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.7	20.846	14.5003	25.39319626	34.82214567
-0.65	22.7635	14.3235	26.89497322	32.17937543
-0.6	25.3513	13.5921	28.76514547	28.19798514
-0.55	23.1919	12.8558	26.5167083	29.00060457
-0.5	27.8886	8.92947	29.28326219	17.75420911
-0.45	28.0276	9.13228	29.47787136	18.04725046
-0.4	23.4404	9.78243	25.39976946	22.65234095
-0.35	21.3805	8.8617	23.1442327	22.51282391
-0.3	22.8693	8.30441	24.33039473	19.95721497
-0.25	29.4911	8.40089	30.6643104	15.90023213
-0.2	25.9848	8.35754	27.29575619	17.82944606
-0.15	27.5822	5.99909	28.22705861	12.270644
-0.1	25.9602	7.86244	27.124711	16.84973191
-0.05	25.6253	5.24773	26.1571151	11.57341755
0	27.6179	5.34586	28.13052825	10.95498249
0.05	26.6049	3.42901	26.82496624	7.344159476
0.1	23.7612	8.40975	25.20552559	19.49028853
0.15	27.7264	4.52463	28.09315813	9.268316067
0.2	26.3173	8.41943	27.63126998	17.74051242
0.25	22.8238	8.6895	24.42198306	20.8428802
0.3	21.7967	8.68131	23.46191114	21.71667631
0.35	27.7935	3.02047	27.95714365	6.202301635
0.4	25.8135	10.8014	27.98226267	22.7063829
0.45	27.0678	10.1376	28.90392241	20.53224112
0.5	27.8416	11.8906	30.27442913	23.12637535
0.55	25.7174	12.5236	28.60463633	25.96468866
0.6	27.1396	12.7829	29.99934034	25.220692
0.65	26.0361	11.299	28.38214059	23.45960759
0.7	24.6849	14.8308	28.79751581	30.99763919

Table 60. 6 gph mist nozzle at 1” axial position, 80 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.7	28.6958	17.7831	33.75925922	31.78694631
-0.65	29.687	17.2826	34.35121878	30.20627569
-0.6	30.6769	17.1767	35.15837335	29.24546502
-0.55	29.5422	23.0584	37.47574404	37.97289719
-0.5	25.2135	12.2913	28.04989551	25.98871719
-0.45	27.7935	9.30851	29.3108683	18.51656321
-0.4	29.7076	7.7138	30.69273869	14.55583136
-0.35	24.0958	8.82463	25.66089773	20.11429897
-0.3	33.0899	8.22305	34.0963346	13.95566903
-0.25	30.7552	7.85574	31.74263659	14.32857621
-0.2	25.0006	8.01776	26.2547991	17.78118624
-0.15	25.4267	6.00261	26.12562726	13.28291055
-0.1	27.556	7.08133	28.45133337	14.41199926
-0.05	30.7611	9.64704	32.23834137	17.41203363
0	32.8641	1.05179	32.88092655	1.833081244
0.05	16.7009	9.7306	19.32885504	30.22675709
0.1	28.7949	3.24456	28.97711917	6.428873942
0.15	24.7378	3.79055	25.02652629	8.711620051
0.2	17.344	8.42083	19.28016374	25.89742324
0.25	30.3566	9.48593	31.80418261	17.35315198
0.3	31.1148	7.74033	32.06311725	13.96972468
0.35	21.1197	8.94109	22.93435891	22.94551945
0.4	26.2698	9.82614	28.04737812	20.50815944
0.45	27.3853	10.2268	29.23255196	20.4777049
0.5	32.326	11.9962	34.48012602	20.35992334
0.55	29.0751	13.4142	32.02034044	24.76689228
0.6	28.1595	13.7575	31.34048893	26.03811149
0.65	27.6813	16.6478	32.30175869	31.02310566
0.7	25.7842	17.0989	30.93860616	33.55051417

Table 61. 6 gph mist nozzle at 1” axial position, 100 psig, 100°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.85	17.7251	6.68404	18.94348333	20.6611899
-0.8	18.2176	7.50231	19.70191882	22.38267703
-0.75	19.7861	9.38814	21.90038643	25.38347805
-0.7	20.5084	13.8083	24.72374606	33.95237145
-0.65	22.3032	13.5975	26.12134638	31.36923679
-0.6	24.1889	12.4261	27.19394867	27.19005686
-0.55	24.0891	11.272	26.59591553	25.07627932
-0.5	23.1821	10.7612	25.55803564	24.90086918
-0.45	29.6018	9.80175	31.1823807	18.32074341
-0.4	23.0579	9.03553	24.76504704	21.39835817
-0.35	16.186	8.3052	18.19238695	27.16281716
-0.3	20.3521	6.8846	21.48501086	18.68937617
-0.25	22.6108	5.88071	23.36302692	14.5787306
-0.2	16.3901	7.14196	17.87856176	23.54508802
-0.15	22.7321	6.53564	23.65296938	16.0403187
-0.1	29.9409	7.92671	30.97241069	14.82858596
-0.05	30.4001	3.42054	30.59192988	6.419770821
0	33.2621	3.36507	33.43188587	5.776861153
0.05	22.267	3.08638	22.47988057	7.89136198
0.1	21.4207	8.17003	22.92587575	20.8772598
0.15	24.7229	8.07126	26.00705717	18.08025441
0.2	18.9006	8.10093	20.56350523	23.2003137
0.25	21.7733	7.88393	23.15670411	19.90489833
0.3	17.6877	7.21051	19.10094725	22.17859651
0.35	31.2922	9.41654	32.67832625	16.7477448
0.4	27.7942	8.08694	28.94678138	16.22276809
0.45	25.0677	8.61035	26.5052393	18.9567687
0.5	25.0061	10.6382	27.17492109	23.04607514
0.55	24.4952	11.9197	27.24140362	25.94818927
0.6	22.9895	11.1785	25.5631761	25.93104687
0.65	21.7614	7.11167	22.89398131	18.09749774
0.7	20.3517	7.11085	21.55819753	19.25932943

Table 62. 6 gph mist nozzle at 1” axial position, 60 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.7	25.1517	8.06675	26.41364171	17.78228474
-0.65	27.283	14.9421	31.10672663	28.70822967
-0.6	28.0745	14.2379	31.47849022	26.89171064
-0.55	28.0815	11.0593	30.18076803	21.49594272
-0.5	29.5314	9.43873	31.00311613	17.72475034
-0.45	35.8458	8.70698	36.88811297	13.65279098
-0.4	36.5914	7.50753	37.35362848	11.59458225
-0.35	20.6085	8.63194	22.34324642	22.72653779
-0.3	33.5554	7.93547	34.48095929	13.30535189
-0.25	26.4697	6.59751	27.27951899	13.99566442
-0.2	30.3295	6.92416	31.1098467	12.86010469
-0.15	31.6091	5.17444	32.02983035	9.296913116
-0.1	28.8994	7.46029	29.84679626	14.47471856
-0.05	30.1904	5.53168	30.69299164	10.38293322
0	37.0321	1.99577	37.08584	3.084855656
0.05	22.566	2.7053	22.72758245	6.836215493
0.1	33.8237	6.20263	34.3877202	10.39151003
0.15	23.7546	6.5237	24.63411624	15.35648258
0.2	20.0837	6.68254	21.16627852	18.40406403
0.25	25.1498	6.26077	25.91736254	13.97902276
0.3	19.3903	6.72598	20.52370681	19.1303017
0.35	23.9636	9.14018	25.64755379	20.87781745
0.4	23.9113	8.85133	25.4969863	20.31321783
0.45	27.2028	9.61598	28.85237251	19.46810862
0.5	28.2677	11.0068	30.33500469	21.27480798
0.55	27.8649	13.2852	30.86987514	25.49049216
0.6	26.5822	14.2582	30.16470825	28.2082852
0.65	24.4489	6.37498	25.26636264	14.61430463

Table 63. 6 gph mist nozzle at 1” axial position, 80 psig, 120°F.

X (in)	U mean (m/s)	V mean (m/s)	Total Velocity (m/s)	Angle (deg)
-0.65	29.7376	13.6994	32.74138687	24.73439182
-0.6	31.3832	15.2353	34.88580812	25.89473575
-0.55	30.5619	14.5307	33.84037491	25.4288194
-0.5	28.2385	13.0395	31.10372072	24.78575477
-0.45	27.1078	11.8432	29.58199126	23.60016574
-0.4	26.1883	10.5374	28.22877708	21.91840079
-0.35	24.4167	9.07184	26.04752426	20.38216763
-0.3	26.2789	8.05681	27.48622878	17.04494017
-0.25	24.6753	7.28778	25.72901412	16.45435636
-0.2	26.6453	5.21884	27.15158012	11.08186024
-0.15	25.5093	3.78275	25.78824508	8.434868861
-0.1	25.0627	6.31452	25.84592993	14.14129112
-0.05	31.9541	10.7061	33.69992706	18.52322977
0	19.4997	9.05867	21.50111165	24.91742861
0.05	18.7931	7.21981	20.13221955	21.01544962
0.1	28.8688	8.35012	30.05215662	16.13218241
0.15	28.351	3.58091	28.57625093	7.198698646
0.2	24.4525	5.93497	25.16244474	13.64268727
0.25	27.5482	7.59369	28.57564437	15.41092474
0.3	28.2373	7.78825	29.29167031	15.41961574
0.35	25.3763	9.18487	26.98737554	19.89755982
0.4	26.4514	10.3752	28.41340066	21.41691551
0.45	27.7237	11.6779	30.08283381	22.84201517
0.5	30.3277	12.4954	32.80098182	22.39228706
0.55	30.0022	13.91	33.0699275	24.87397958
0.6	28.7249	14.8232	32.32409532	27.29554804
0.65	26.275	8.37388	27.57711898	17.67715461

Table 64. 6 gph mist nozzle at 1” axial position, 100 psig, 120°F.

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LIST OF REFERENCES

1. Shreeve, R.P., Seivwright, D.L., Hobson, G.V., "HCF Spin-Testing with Oil-Jet Excitation," Proceedings of the 9th National Turbine Engine High Cycle Fatigue (HCF) Conference, Pinehurst, NC, March 16-19, 2004.

2. Shreeve, R.P., Seivwright, D.L., Hobson, G.V. and Moreno, O.R., "Oil-Jet Excitation in Rotor Spin Testing," Proceedings of the 10th National Turbine Engine High Cycle Fatigue (HCF) Conference, New Orleans, LA, March 8-11, 2005.

3. Moreno, O.R. "Investigation and Development of Oil-Injection Nozzles for High-Cycle Fatigue Rotor Spin Test," Thesis, Naval Postgraduate School, Monterey, CA March 2005.

4. Vonderheide, C.M. "Laser Velocimetric Flow Mapping and Characterization of Oil Mist Nozzles Used for Blade Excitation in High Cycle Fatigue Testing," Thesis, Naval Postgraduate School, Monterey, CA September 2005.

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