# 2013 UTSR Gas Turbine Industrial Fellowship Program

Final Report:

UNS N08020

&

Spray Angle Characterization

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WOODWARD

## Table of Contents

## Summer Projects Introduction

Woodward integrates leading-edge technologies into fuel, combustion, fluid, actuation, and electronic control systems for the aerospace and energy markets.[1] Woodward has 10 offices in the United States of America, and 27 other offices around the world. Woodward, Greenville is located in South Carolina, and is focused primarily on fuel delivery and ignition. A few of the products manufactured here are: injectors, nozzles, swirlers, and igniters. This report will focus on two projects. The first project, UNS N08020, was focused on the improvement of Woodward products through a change the material. And the second project, Spray Angle Characterization, was focused on improving the productivity of Woodward procedures by standardizing the method of measuring spay angle.

## UNS N08020

The components that Woodward manufactures are exposed to extremely harsh environments within the gas turbines, making the material composition of the components critical. In an effort to improve the quality and cost of their products, Woodward has started to incorporate UNS N08020 into the design of various projects. UNS N08020 is a nickel-chromium alloy designed specifically for these harsh and corrosive environments. Its material characteristics are superior to those of 300 series stainless steels, and though it is inferior to other high nickel alloys such as Hast-X or Inco 625, it is much more cost efficient.

### Objective

The purpose of the UNS N08020 project is to research the material, compile an engineering report on any pertinent information, and to begin weld trials in an effort to familiarize Woodward with the material. A better understanding of UNS N08020 is crucial to the success of projects that require this material in various components. This report will only include a summary of the results found.

### Material Characteristics

The following tables of material characteristics compare the following metals: UNS N08020, Stainless Steel 316, Hastelloy X and Inconel 625.

***Specified Chemistry***

| Alloy | Ni | Cr | Cu | Mo | Mn | Nb | Si | P | S | C | Fe | Al | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **8020** | 32-38 | 19-21 | 3-4 | 2-3 | 0-2 | 0-1 | 0-1 | 0-0.025 | 0-0.002 | 0-0.07 | 30-45 | - | - |
| **316** | 10-14 | 16-18 | 0-0.75 | 2-3 | 0-2 | - | 0-1 | 0-0.045 | 0-0.03 | 0-0.08 | 61-72 | - | 0.5-2.5 Co, 0.2-1 W |
| **Hast X** | 49-50 | 20.5-23 | 0-0.5 | 8-10 | 0-1 | - | 0-1 | 0-0.04 | 0-0.03 | 0.05-0.15 | 17-20 | 0-0.5 | 0-1.5 Co, 0.6 W |
| **Inc 625** | 58-61 | 20-23 | - | 8-10 | 0-0.5 | 3.6 | 0-0.5 | 0-0.015 | 0-0.015 | 0.05 | 0-5 | 0.2 | 0-1 Co, 0.2 Ti |

Data taken from Rolled Alloys, Inc. and compared to other sources.

### *Mechanical Properties*

| Alloy | Density ($lbs/in^3$) | Modulus of Elasticity (Msi) | Ultimate Strength (ksi) | Yield Strength (ksi) | Elongation (%) | Melting Point (°F) | Hardness, Brinell | Hardness, Rockwell B |
|---|---|---|---|---|---|---|---|---|
| **8020** | 0.278 | 28 | 80 | 35 | 30 | 2525-2630 | 217 | 95 |
| **316** | 0.285 | 29 | 75 | 30 | 40 | 2500-2650 | 217 | - |
| **Hast X** | 0.297 | 30 | 110 | 56 | 45 | 2300-2470 | - | 92 |
| **Inc 625** | 0.305 | 30 | 120 | 60 | 44 | 2350-2460 | - | - |

Data taken from Rolled Alloys, Inc. and compared to other sources.

### *Thermal Properties*

| **Thermal Expansion** | **Expansion Coefficient ($10^{-6}$/°C)** | | | |
|---|---|---|---|---|
| **20°C to:** | **N08020** | **316*** | **Hast X*** | **Inc 625*** |
| **100** | 14.7 | 16.5 | 13.0 | 12.8 |
| **200** | 15.1 | 17.0 | 13.5 | 13.1 |
| **350** | 15.7 | 17.5 | 14.0 | 13.7 |
| **450** | 15.9 | 17.8 | 14.5 | 14.1 |
| **900** | 17.2 | 19.3 | 16.4 | 16.0 |

*Data interpolated from A to Z of Materials, http://www.azom.com/

| **Temperature** | **Thermal Conductivity (W/m·K)** | | | |
|---|---|---|---|---|
| **(°C)** | **N08020** | **316 SS*** | **Hast X*** | **Inc 625*** |
| **50** | 12.2 | 14.6 | 9.9 | 10.2 |
| **100** | 13.1 | 16.3 | 10.9 | 11.0 |
| **200** | 14.8 | 17.2 | 12.9 | 12.5 |
| **300** | 16.5 | 18.7 | 14.9 | 14.0 |
| **400** | 18.1 | 20.1 | 16.9 | 15.5 |

*Data interpolated from A to Z of Materials, http://www.azom.com/

## Machining

UNS N08020 requires more power than carbon steels to machine. General recommendations from Rolled Alloys for machining UNS N08020 are listed below.

- Machine tools should be rigid and used to no more than 75% of their rated capacity. Both work piece and tool should be held rigidly; tool overhang should be minimized.

- Tools, either high speed steel or cemented carbide, should be sharp, and reground at predetermined intervals. Turning operations require chip curlers or breakers.

- Feed rate should be high enough to ensure that the tool cutting edge is getting under the previous cut thus avoiding work-hardened zones. Slow speeds are generally required with heavy cuts. Approximate speeds for turning with high speed steel tools are 0.33 - 0.38 surface meter/second and for drilling 0.23 - 0.28

m/s. Lubricants, such as sulfur-chlorinated petroleum oil, are suggested. Such lubricants may be thinned with paraffin oil for finish cuts at higher speeds.

- The tool should not ride on the work piece as this will work harden the material and result in early tool dulling or breakage.

- Band sawing suggestion: Lenox® Matrix 2 blade, variable pitch 12.7-8.5mm (2-3 teeth per 25mm) for large billet, 8.5-6.35mm pitch (3-4 teeth per 25mm) for smaller bar. The coolant mix should be rich, about 5:1 water to solvent. Blade set up should be rigid, with no gap. Speeds about 0.38-0.41 meter/second.

## Welding

A fundamental issue when welding UNS N08020 is hot tears or cracking during solidification. Listed below are basic recommendations from the suppliers to prevent hot tears when welding UNS N08020.

### *Weld Materials*

(The welding information in this section pertains primarily to TIG welding.)

- Use high purity raw materials when manufacturing the weld fillers (minimize dilution). In addition, cleanliness of the weld materials should be highly stressed.

- Reduction of phosphorus, sulfur and silicon in the chemistry of UNS N08020 improves the weldability.

- Corrosion Materials specifies using ER320LR filler metal for TIG welding UNS N08020, and AWS ERNiCrMo-3 for TIG welding to other metal alloys such as 316, C276 and Alloy 22.

- The nickel alloy weld filler used with UNS N08020 gives a more viscous weld pool than is the case with conventional stainless fillers. Do not raise the welding current to improve fluidity, it is ineffective.

### *Heat Input and Interpass Temperature*

- Welding heat input should be as low as feasible for the joint involved.

- Interpass temperatures should be kept below 100°C. Low interpass temperature minimizes the chances of nickel alloy weld bead solidification cracking.

# Spray Angle Characterization

The spray angle of a given atomizer is the angle formed by two straight lines which are tangent to the outer edge of the sprayed cone and drawn from the discharge orifice to a specified distance downstream of the nozzle.[2] This angle is very important for the quality assurance of various Woodward products.

## Objective

The purpose of a spray angle characterization study was to standardize the procedures Woodward uses to measure the cone angle of sprayed liquid fuel. This study includes data gathered on all of the measurement methods, a comparison of these methods and a final recommendation of how Woodward should conduct the spray angle measurements in the future.

## Method Descriptions

The four methods that Woodward uses to obtain the spray angle are: measuring by hand, taking pictures, using the Habco vision system, and using a vertical flow apparatus (production method). The vertical flow apparatus is not included in this study due to constraints on equipment and time. The remaining three methods are described below along with some general pros and cons based on experience with using the three different methods.

*Note:* Throughout this report a flow stand is mentioned; the flow stand is the equipment in which the atomizers are flowed. The flow stand holds the atomizer in place, keeps the fuel moving at a constant pressure, captures and recycles/disposes of the fuel that is flowed through the atomizers, and takes various measurements of the test apparatus such as mass flow rate and temperature of the fuel.

### *Hand*

Measuring the spray angle by hand was the least technical of the methods. First, the flow stand apparatus is set up (set up procedures not included in this report), and the fuel was brought to the prescribed pressure and mass flow rate. Then, a protractor was held inside the flow stand as close to the spray cone as possible without touching the cone, this is shown below in Figure 1.

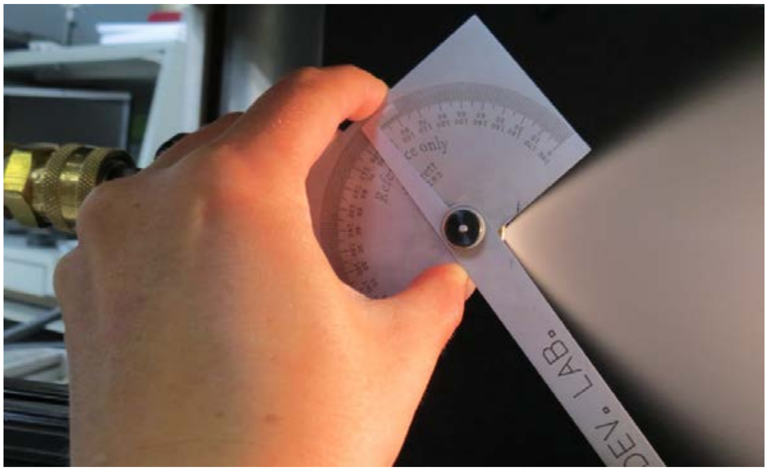



**Figure 1: Measuring Spray Angle by Hand**

Markings on the protractor were visual indicators of what portion of the protractor should be parallel with the edges of the spray cone; this ensured that the measurement was consistent with the defined spray angle. Note: the define spray angle will be discussed in the Method

Comparison section. Once the protractor was parallel with the edges of the spray cone, the angle is recorded.

Pros and cons of hand measurements:

- \- Tedious Work (without good precision)
- \- Operator Dependent
- \- Errors
- \- Visual Fatigue
- \+ Alignment

### *Picture*

The picture method of measuring spray angle was first used at Woodward as a system to verify the hand measurements of the spray angle. For this method, after the flow stand is set up, a camera is secured perpendicular to the direction of flow and the lens was placed about one foot away from the exit orifice of the atomizer. After ensuring that the camera was focusing on the fuel cone, a picture was taken. The picture was saved on the computer, sized correctly (not distorted), printed out, lines parallel to the cone edge were drawn, and then the angle was measured using a protractor. See Figure 2 for an example of this process.

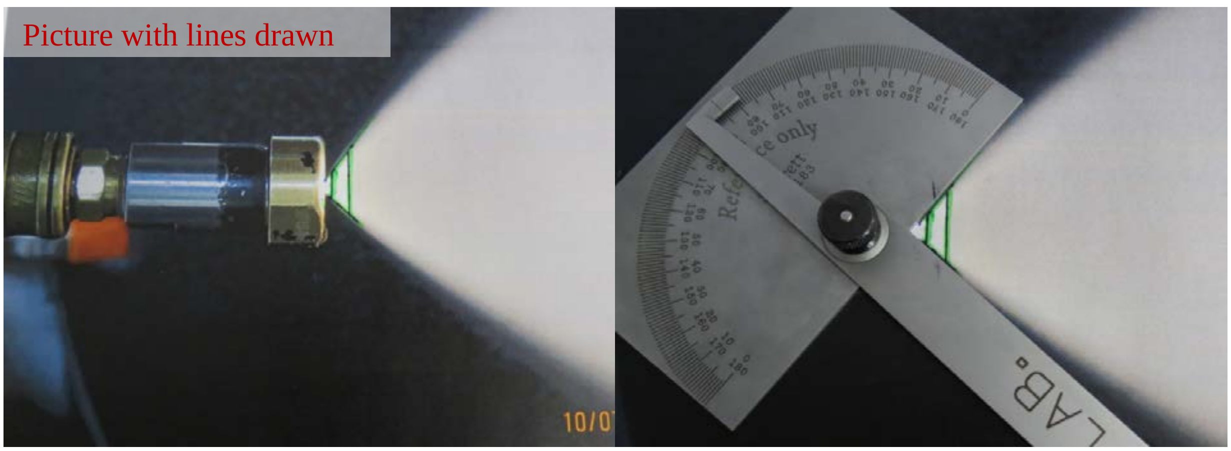



**Figure 2: Measuring Spray Angle by Pictures**

This method is very time consuming and not practical for production use, but it was beneficial to the study to be able to compare another method of measuring the spray angle.

Pros and cons of picture measurements:

- \- Time Consuming
- \- Camera Settings Vary
- \- Operator Dependent
- \+ Consistent Specific Procedure
- \+ Visualize Lighting Variations (with proper camera settings)

### *Habco*

Habco is a vision system Woodward has integrated into the flow stand apparatus, but had not been extensively used for measuring the spray angle due to lack of training with the software and camera. Figure 3 is the camera secured to the flow stand and, similar to the picture method, is set up to be perpendicular to the direction of the fuel flow.

Figure 3: Habco Camera on the Flow Stand

This camera is not the same camera that is used in the picture method. This camera is directly connected to the computer in the flow lab and has all of the software necessary. This software is already being used to take measurements of the pressure, temperature and mass flow rate of the fuel in standard procedures. In other words, if this method were to be incorporated at Woodward there would be no additional costs. The Habco system captures live feed of the spray cone, converts the image into a binary image (has an adjustable brightness threshold which will determine whether each pixel is "on" or "off"), and then calculates what the spray angle is for a specified portion of the binary image.

Pros and cons of the Habco vision system:

- Requires a Master
+ Consistent
+ Quick
+ Ability to Quantify Lighting
+ Potential for Production Applications

## Method Comparison

During the spray angle study, the method which was most accurate, precise, time efficient and repeatable was sought for. First, a specified spray angle had to be defined in order to be consistent in taking measurements and to better quantify the characteristics of each study. A ruler was used to measure the distance from the exit orifice where the spray angle was measured at. See Figure 4 and 5 for pictures of the limits which were set to measure the spray angle.

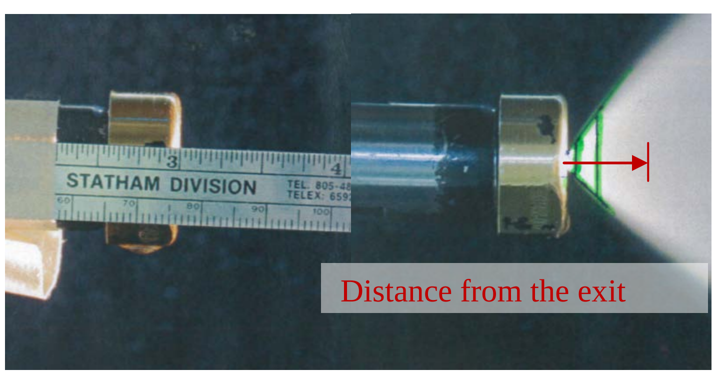


Figure 4: Limits Set on the Picture Method

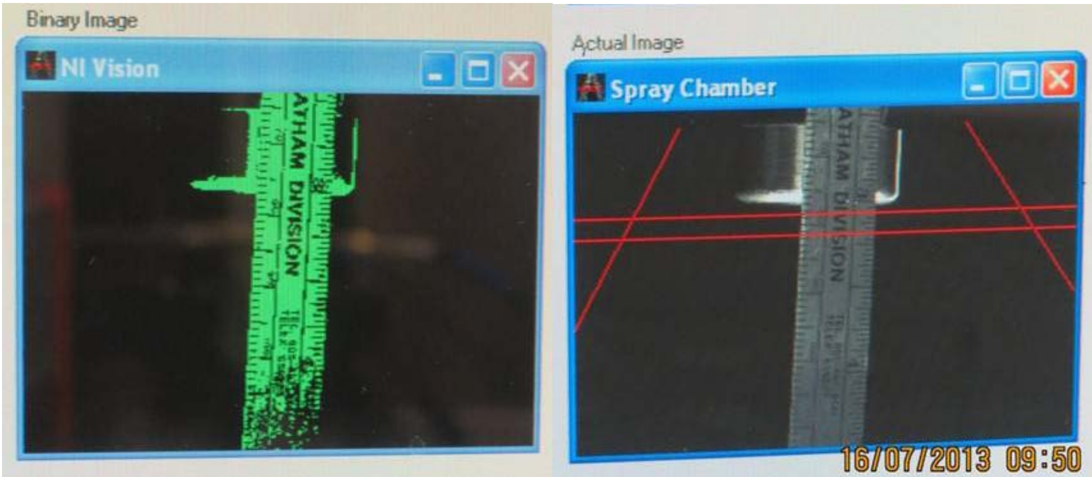



**Figure 5: Limits Set in the Habco System**

The limit specified within the study was set in order to minimize the effects of various spray densities as well as curved cone boundaries. These two factors become more of a problem the further from the exit orifice the measurement is taken, this is apparent in Figure 6.

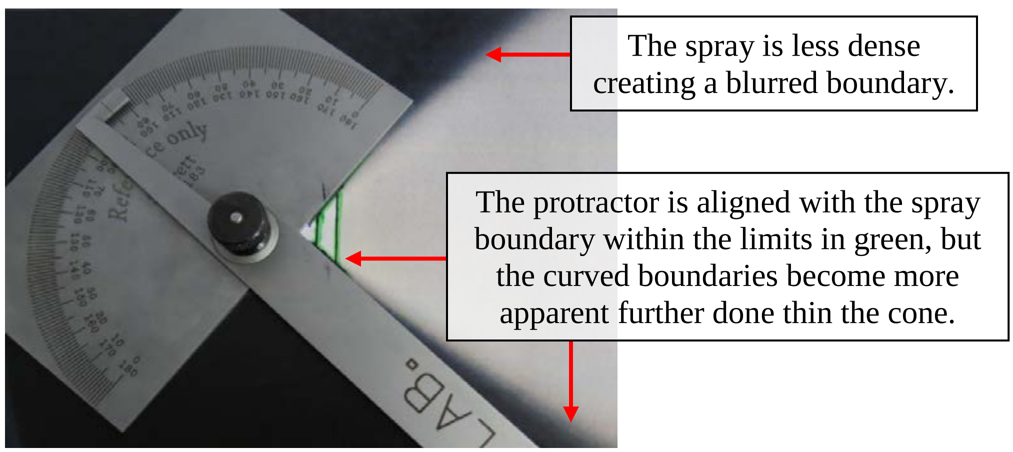



**Figure 6: Spray Cone Characteristics**

## *Data Collection*

In this Spray Angle Characterization Study, 25 of the same atomizer were used. The parts were labeled 1 through 25 on the atomizer itself in order to track consistency of the various measurements. The atomizer used had a specification that required the spray angle to be within 80° to 100°. For an initial experiment on the different methods, each atomizer was measured three separated times using each of the methods. Figure 7 (on page 10) shows the data that was collected.

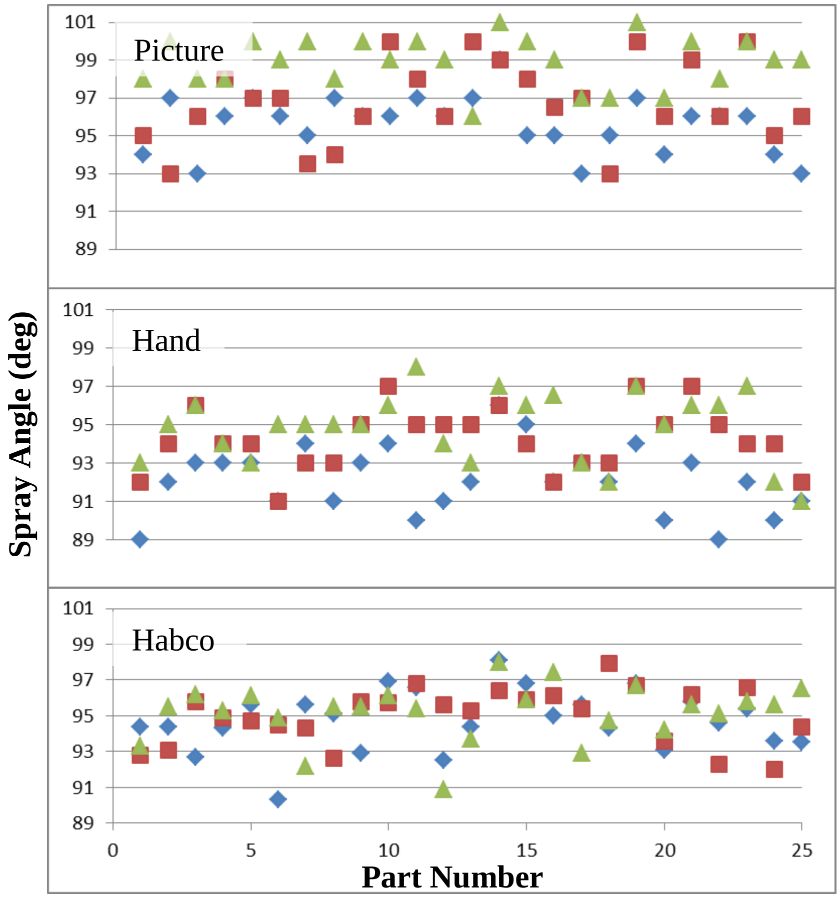



Figure 7: Data Comparison of Methods

This data was useful for completing a general comparison on the various pros and cons of each method (listed in Method Descriptions starting on page 6). Also, the data recorded by the Habco vision system was more condensed and repeatable compared to the other two methods. Though most of the data is within the specification of 80° to 100° degrees, it is clear that when measuring by taking pictures, the angle measurements all seem to be shifted higher while the data taken by hand and the Habco system are relatively more consistent with each other.

### *Timed Data Collection*

In a production facility such as Woodward, it is extremely beneficial to consider how long a process takes verses the information that is gathered. An experiment was conducted to consider any time savings that a particular method might have. This experiment consisted of measuring the spray angle of five atomizers with each of the methods. The flow stand apparatus was set up identically for each method, and there were three fiber optic lights pointing into the center of the cone (lighting effects are discussed in more detail in Effects of Lighting starting on page 11). The start time was recorded, five spray angle measurements were taken and then the end time was recorded. The results are shown in Figure 8.

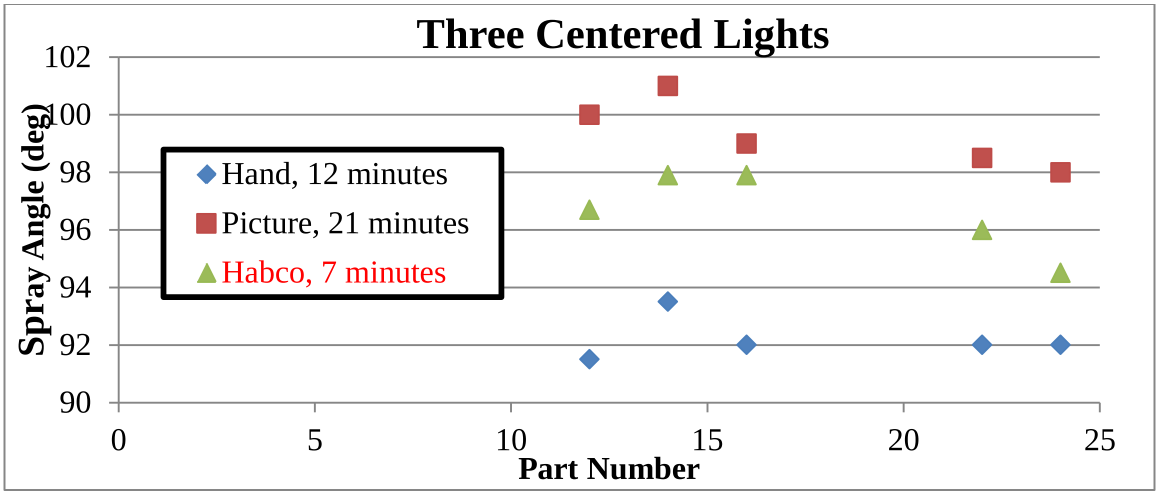



**Figure 8: Data from Timed Experiment**

There is a shift in the data for each of the methods. But if just the trends are considered, the angles recorded were consistent for each atomizer. The consistent data shows that enough time was taken to produce useful results. It is important to see the time saved by using the Habco vision system; the Habco method took 7 minutes while by hand took 12 minutes and the pictures took 21 minutes. Times could vary depending on the operator, but each test was kept consistent.

### *Effects of Lighting*

Another important consideration for taking spray angle measurements is the lighting within the flow stand. For all of the light configurations fiber optic lighting was used; there were three different set ups originally considered. The three configurations are illustrated in Figure 9.

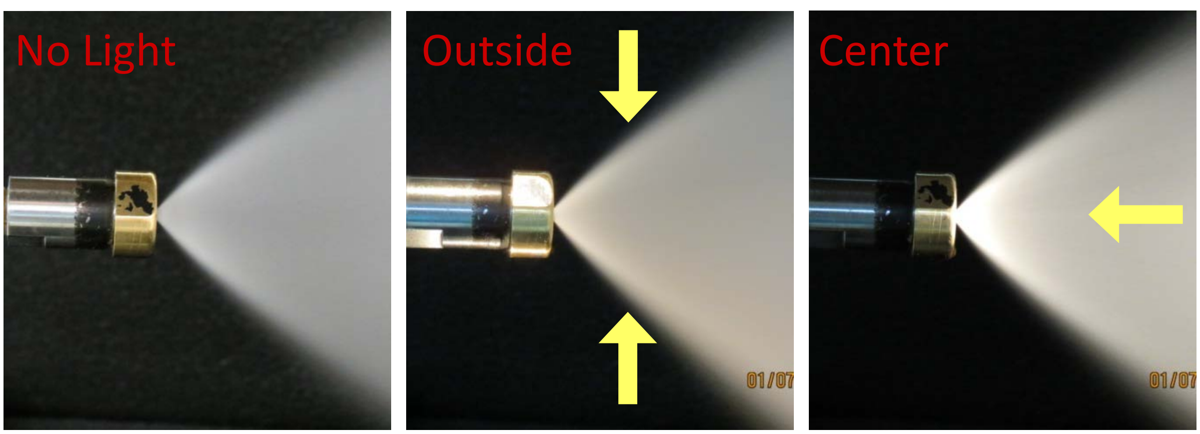
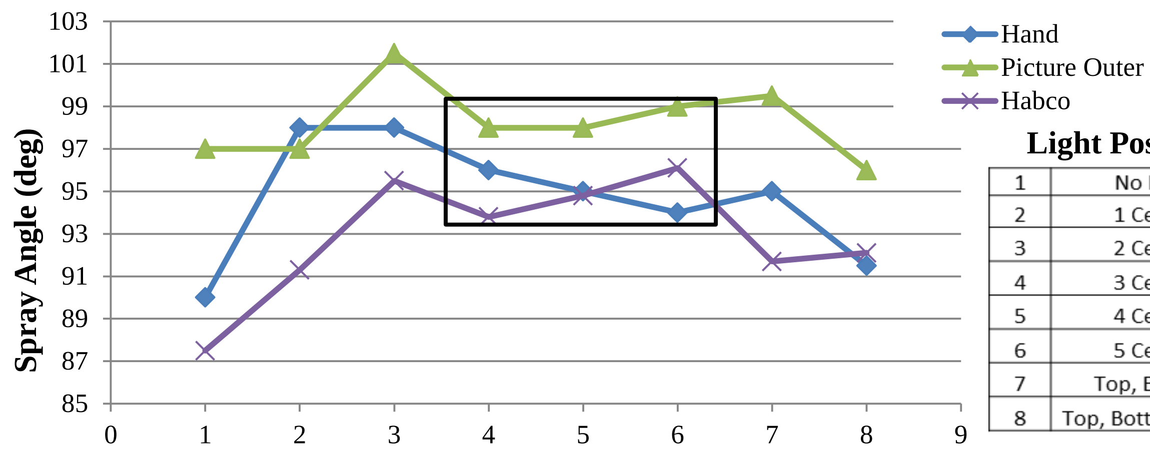



**Figure 9: Fiber Optic Light Configurations**

When there were no lights used the initial set up time is obviously decreased, but without any light added the data collection becomes less accurate. Though there was no experiment conducted to quantify the decrease in accuracy, it is recommended to use lights. Without light, it was more difficult to visually pick up on the edges of the cone which makes the eye fatigue much faster when taking hand measurements. Also, the Habco measurements had a greater tendency to jump around without any lights.

Experiment set-up is easier to control and much quicker when the light is in the center, as opposed to around the outside. Having the light around the outside was less consistent, easily bumped, harder to reach, and often created shadows on the spray if it was not at the correct location or was slightly skewed from the correct direction. An additional benefit is the center light illuminates the dense inner part of the cone. A short experiment was conducted to observe the angle measurements for all of the lighting positions, and is shown by Figure 10.




**Light Position**

| | |
|---|---|
| 1 | No Light |
| 2 | 1 Center |
| 3 | 2 Center |
| 4 | 3 Center |
| 5 | 4 Center |
| 6 | 5 Center |
| 7 | Top, Bottom |
| 8 | Top, Bottom, Front |

**Figure 10: Light Position Experiment**

Though it is not a substantial improvement, the measurements were most consistent with three to five center lights. With the center lighting as the preferred lighting set up, the light intensity also had to be considered. How many fiber optic lights should be used and how far away should they be positioned from the exit orifice? An experiment was conducted using only center lighting and the Habco system as the only measurement method. There were 6 different light locations tested; the fiber optic light source started at 6 inches away from the exit orifice and measurements were taken every 2 inches up to 16 inches away. At each location the number of fiber optic lights used varied from one to four lights.

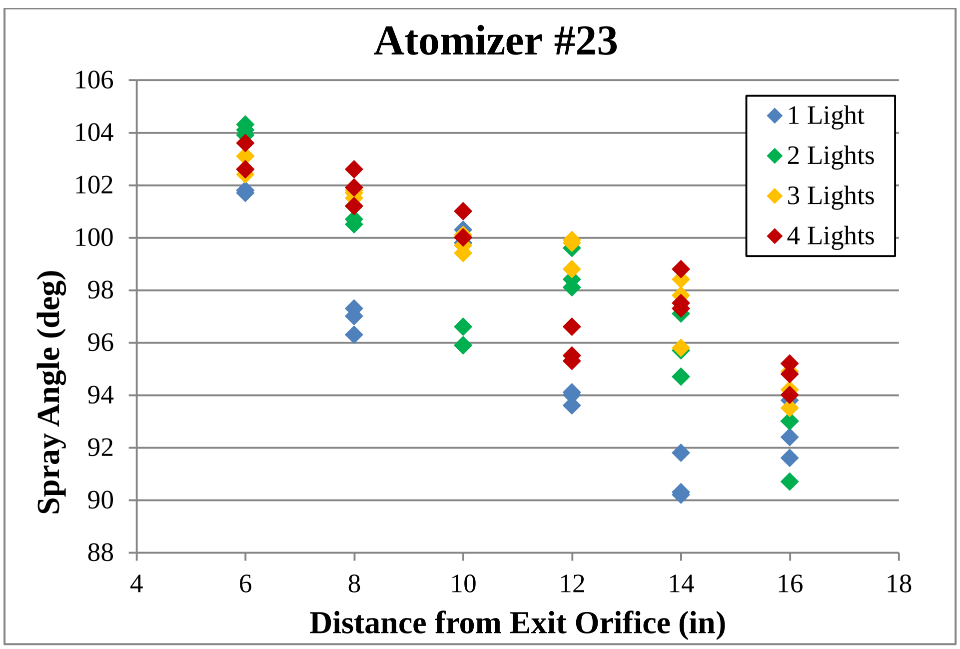



**Figure 11: Light Intensity Experiment**

When observing trends of the data, using three or four of the fiber optic light tended to be more linear in the angle measurements. This means that as the distance between the exit orifice and the light source increased, the angle decreased more linearly than when using one or two lights. It is possible that this is more ideal for being able to predict how the flow stand apparatus affects the spray angle as well as being more confident about the measurements Woodward is taking.

Another factor that was recorded in this study was the spread of the data. Spread in this case is caused by variations in the angle while it is being recorded. The angle the Habco software reports is continuously being recalculated until the angle is "accepted" by the observer, so there is always a minimum and a maximum angle that the system reports. For example, while watching the screen, the angle could be continuously fluctuating between 90° and 95°, but the angle recorded or accepted by the operator could be 94°. Figure 11 displays the minimum, maximum, and recorded angle for each light setting at each of the distances. Figure 12 shows the spread or range of these light settings (max – min).

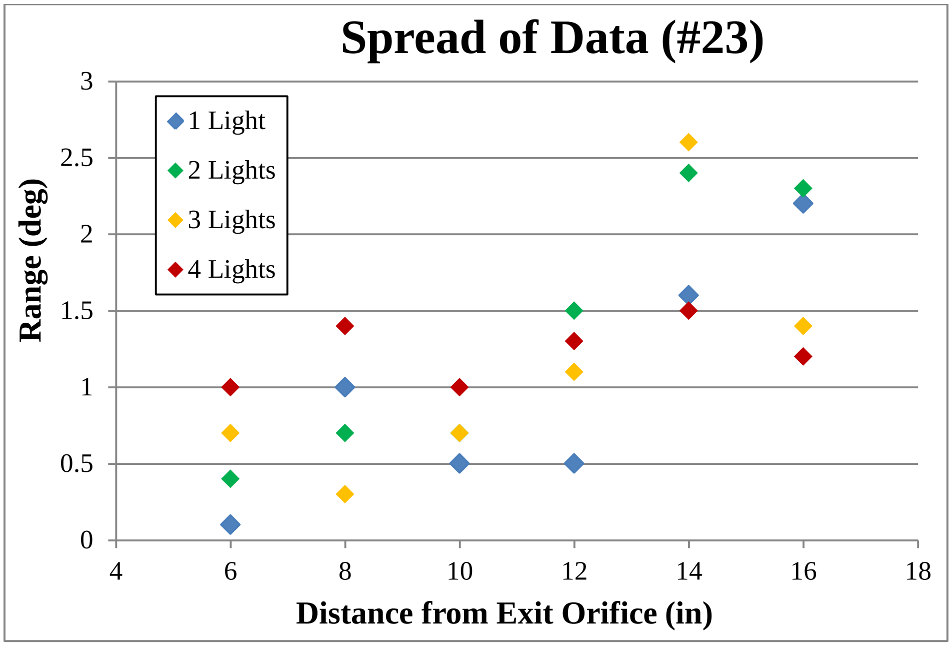



Figure 12: Spread in Angle Reported Using Habco

The variation in angle measurements increased as the light source got further from the exit orifice. It is recommended to keep the light source within 12 inches of the exit orifice. One factor that contributed to this spread in data is that turbulence began to be visible and was illuminated by the fiber optic lights when the lights were further than 12 inches from the exit orifice.

## Recommendations

After extensive work in measuring spray angles of atomizers, it is recommended that Woodward use the Habco vision system as their primary method. It saves time, improves accuracy, removes a number of human errors and can increase confidence in the data being reported to Woodward's customers. It is also strongly recommended to obtain a spray angle master so that Woodward can continue to have confidence in the Habco system. With a master, a more optimal light apparatus could be specified.

## Works Cited

[1] About Woodward. Web. 08 Aug 2013. http://www.woodward.com/AboutWoodward.aspx

[2] A. H. & Ballal, D. R. (2010). *Gas Turbine Combustion: Alternate Fuels and Emissions*: Taylor and Francis Group, LLC.