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TITLE: SprayVision: 2020's "Best New Idea" Opens the Window to Improved Aerospace Finishes

INTRODUCTION

The demand for perfection in aerospace applications is well established, which makes sense – lives are in the balance. This quest for excellence drives down to the finest detail – including the finish on the part. This paper examines how CFAN, a supplier of jet engine turbine blades to GE Aerospace, employed the SprayVision system, voted "Best Idea of 2020", to investigate the unique traits of their automated blade painting system with the goal of refining their plan extend First Time Yield (FTY) percentage from <90% to >95%.

THE PLAYERS

This work represents a collaboration between three companies: CFAN, SprayVision, and Saint Clair Systems, each bringing unique equipment, knowledge, perspective and talent to the problem of automated finishing of CFAN's various turbine blades.

CFAN: The Coolest Company You've Never Hear Of…

CFAN was founded in 1991 as a 50/50 joint-venture between two of the world's leading aerospace companies: GE Aircraft Engines and SAFRAN. The company name "CFAN" is literally derived from "composite fan blades", as CFAN produced the world's first FAA-conforming composite fan blade. These are used in various GE Aircraft Engines, which power a variety of Boeing aircraft such as the 747 and the 787 Dreamliner.

Figure 1: CFAN Jet Engine Turbine Blade

Turbine fan blades create thrust by extracting energy from the high pressure and temperature generated by the jet engine's combustor. Shown in Figure 1, the fan blade exhibits a uniquely complex geometry from the convex to concave side of the component. As you might imagine, this application exerts extreme forces on the blade surfaces, so each blade is constructed of a combination of titanium and composites to provide the required strength. CFAN builds fan blades in strict accordance with the Engineering and Quality specifications derived directly from GE Aviation. Exterior paint is no exception. It poses a significant challenge to bond to these different surfaces while maintaining consistent cured-coating characteristics from side-to-side. Moreover, the coating must be capable of withstanding a battery of severe tests, including ASTM D 4541adhesion testing and rain erosion. This all starts with the primer, making it the logical starting point for this exercise.

The primer selected for this application is a PPG CA7502E. It is a 2K solvent borne epoxy with a higher solids content than what is found in comparable primer packages. The range specified for viscosity of this material is between 20 – 50 seconds using a #2 Zahn Signature cup. This elevated viscosity range is an excellent indicator that this is a difficult material to work with. We have learned that maintaining a stable fluid temperature is critical for optimal results.

CFAN relies heavily upon GE's engineering specification to determine conformity of the finished coating. Dimensional characteristics are measured to determine defect size such as foreign materials (dirt), runs, etc. in the coating. After completion, the fan blade must be able to pass a CMM profile conformity evaluation. Surprisingly, aesthetic appearance is extremely important! There are exceptionally high standards for the cosmetic quality of each fan blade. It is fair to say that the aesthetic quality of the fan blade is typically better than what you would observe on the exterior of a commercial aircraft.

With so many blades in each engine, consistency and repeatability are essential. This is the reason automating the coating process is so important.

Saint Clair Systems

Saint Clair Systems (SCS) was founded in 1990 and is located in Romeo, Michigan. For its entire 30-year history, SCS has been focused on controlling and stabilizing viscosity at the point-of-application in industrial fluid dispensing processes, including paints & coatings, sealers & adhesives, inks, etc. This is usually accomplished by accurately controlling fluid temperature all the way to the point-of-dispense. With more than 3500 active installations worldwide across myriad industries, it is known as a leader in advanced fluid process control strategies and technologies.

Michael Bonner, SCS' VP of Engineering & Technology said, "*In 2020, we signed on as SprayVision's exclusive North American distributor because we were impressed with their innovative technology, which allows you to 'see' the defects in your coating process before you paint your first part. This is complementary to SCS' technology, which is designed to maintain the consistency of your process from the first part to the last.*"

SprayVision (Speaking of Companies You've Never Heard Of…)

Located in Ostrava in the Czech Republic, SprayVision was founded in 2017 on the idea of providing a means for paint applicators to literally see the outcome of their painting process before they paint the first part, thus reducing defects and improving overall quality, reducing cost by reducing setup time and paint usage while increasing first pass yield (FPY) to reduce rework, rejects, and scrap. This is not a simulation, it is a measurement of the actual film pattern being dispensed.

The system was first introduced at PaintExpo 2018, held in Karlsruhe, Germany, and was voted "Best Idea of 2020" out of 171 entries at Vodafone's Idea of the Year contest! By the end of 2020, they had already achieved a base of more than 35 installations worldwide.

THE SYSTEMS UTILIZED

The SprayVision System

The primary reason this investigation was scheduled in the first place, is the SprayVision system, which is built around the SprayCapture Unit shown in Figure 2. It is available in two sizes. The larger A2 system (not shown) is commonly used for bell applications, and the smaller A3 system (shown) is more commonly used for gun spray applications. One of the most innovative features of this capturing technology is that it is designed to accept capture films while they are still wet, which allows for immediate analysis without waiting until after the curing process as is common in traditional paint quality systems.

Figure 2: SprayCapture A3 Unit

This capturing hardware is combined with their proprietary SprayVision software, which performs various measurement and analysis functions on the captured image, displaying it in the popular color "heat map" format used in Finite Element Analysis (FEA) and thermal photography and shown in Figure 3. In addition to the numerical measurements available, the color representation allows you to "see" and quickly, visually assess what is really happening in your paint process.

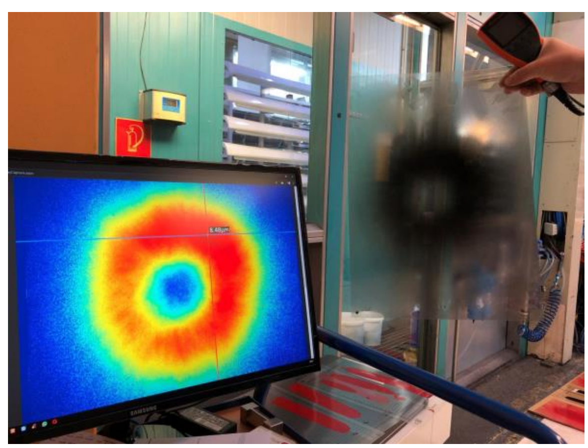

Figure 3: A Sprayed Foil and Its Captured Image Displayed in "Heat Map" Format

The CFAN Painting System

Figure 4: Conveyorized Robotic Paint Application

CFAN's automated paint system is a tightly controlled modern conveyorized paint line built around an ABB/IRB580 paint robot equipped with standard Iwata HVLP guns as shown in Figure 4. The mix room, shown in Figure 5, is located directly adjacent to the paint booth to minimize paint travel. The meter and mix system is fed by pressure pots which allow the resin, catalyst, and solvent components to be closely monitored for quality before being loaded into the system. The flow of each component is carefully controlled by its own Elwood-Gettys AC servo-motor driven gear pump to assure the proper ratio is delivered to the static mixer located in the booth just prior to delivery to the robot.

Figure 5: Mix Room Adjacent to Booth

The ambient environment in both the mix room and spray booth is tightly controlled by the same make-up air system to assure a consistent 75°F and 50% RH as shown by the Booth Monitoring Stack in Figure 6. Even the blades are thermally preconditioned to assure that they also enter the booth at 75°F as shown in the thermal scan in Figure 7.

Figure 6: Booth Monitoring Stack Showing 75.8°F and 49.7% RH

The critical nature of the specialized coatings used in this process require that their viscosity be maintained within a very narrow window. This requires dispensing them at a very tightly controlled temperature. Variations in paint temperature at delivery was documented as an issue in 2019 which resulted in the installation of an SCS Temperature Control System in February 2020.

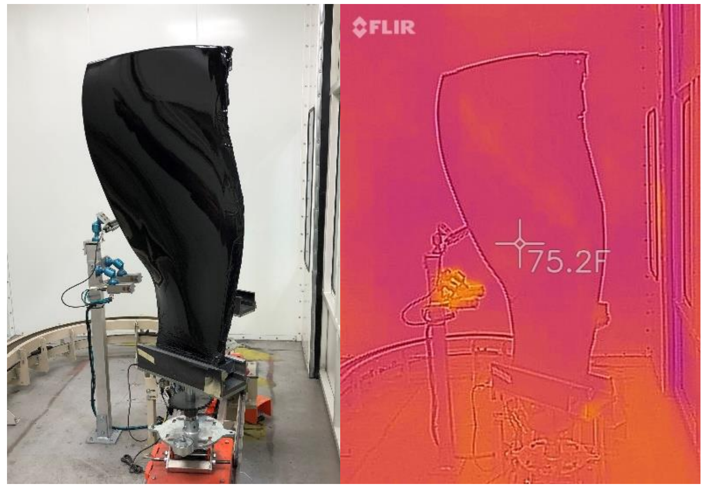

Figure 7: Turbine Blade Entering Booth at 75.2°F

The SCS Temperature Control System

The temperature control system is comprised of the AT-5900S Heat/Cool Temperature Control Unit (TCU), shown in Figure 8. This performs the control functions to assure that the paint is dispensed at the desired temperature by circulating temperature conditioned thermal transfer fluid to and from the process. The actual thermal transfer function is performed by SCS' patented Recorable Coax Hose System, shown in Figure 9 in place on the CFAN robot. This is installed around the existing paint line, creating a path for the thermal transfer fluid and converting the paint line into a flexible heat exchanger.

Figure 8: AT-5900 TCU

Figure 9: Recorable Coax System in Place on Robot

Placing the temperature sensor on the robot arm just before the gun whip line extends temperature control to the point-of-application, as shown in the thermal scan in Figure 10, and compensates for any exotherm produced by the 2K mix. Because it uses the original paint line, it adds no volume or pressure drop to the system and therefore no significant changes must be made to the system or system settings to implement temperature control.

In short, the CFAN automated painting operation is a, tightly integrated blend of the most modern control technologies available.

THE TESTING PROTOCOL

Calibration

The first step in any testing protocol is to calibrate the system, in this case to the CFAN primer. With the SprayVision system, this involves doing drawdowns on a special calibration film which is then captured and fed to the SprayVision software before being cured in a lab oven.

The SprayVision Calibration Tool provides a step-by-step procedure that creates a calibration profile that correlates the SprayCapture intensity measurements to CFAN's Standard DeFelsko Positector 6000 film thickness measurements, as shown in Figure 11. The accuracy of the calibration is confirmed by checking other films throughout the process with both the SprayVision software and the DeFelsko Unit.

Figure 10: Thermal Scan Showing Control to Point of Dispense

Create Test Film Sets

One of the goals of this exercise was to establish the effect of changes in viscosity on the performance of paint process outcomes. This required the creation of a set of test films under controlled conditions from which to gather performance data.

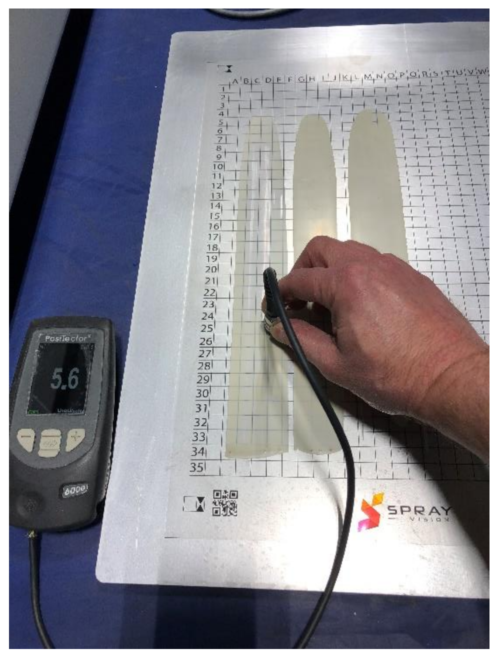

Figure 11: Measuring Drawdowns to Calibrate SprayVision System

The first step was to create a robot program to produce the films using the standard coating parameters used to prime blades. Then, the following procedure was followed:

1) Set TCU to target temperature and allow to stabilize
2) Draw 500 cc of primer into a cup
3) Check viscosity with the CFAN's Standard #2 Zahn Signature Cup
4) Spray Static Pattern film
5) Spray Dynamic Pattern film
6) Capture both wet films for both Pattern and Droplet analysis

This procedure was repeated for temperatures from 70°F – 120°F in 5°F increments. The result was the set of 22 films (11 static and 11 dynamic) shown in Figure 12, each sprayed with the same coating, program, and settings. The only difference was the temperature-based viscosity variation in the primer itself.

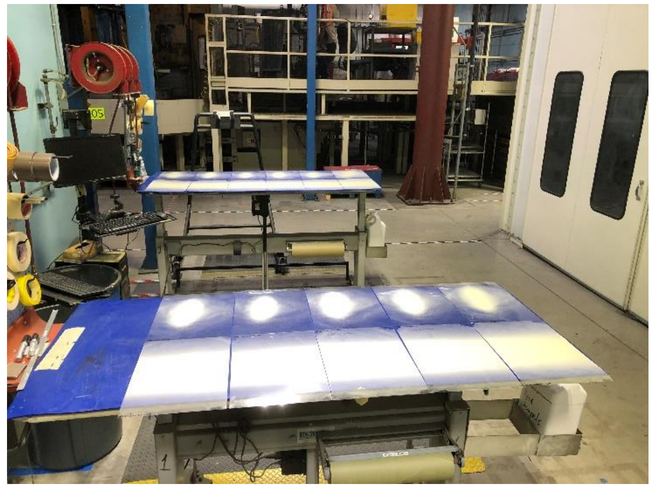

Figure 12: Set of 11 Static and 11 Dynamic Films to Analyze Viscosity Impact on Painting Process

ANALYSES

Coating Viscosity

CFAN has established the target viscosity for this primer to be 22 seconds in #2 Zahn Signature Series Cup. This is generally considered high for a primer. One advantage of this is the ability to cover in a single coat, instead of having to apply multiple coats.

As with all modern coatings, viscosity changes as a function of temperature. The plot of the viscosity readings taken for each of the 11 temperatures between 70°F and 120°F is shown in the Viscosity vs. Temperature Chart in Figure 13. It shows a change of >2:1 over this range.

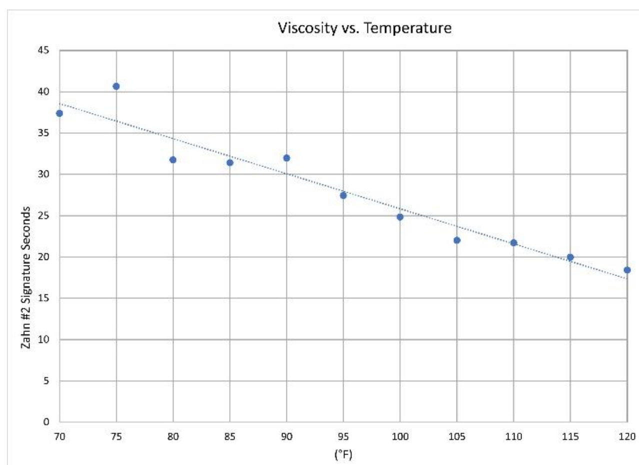

Figure 13: Viscosity vs. Temperature Plot

The importance of this knowledge starts with the minimization of solvents added to the coating. Reducing added solvent has been documented to improve surface finish with regard to gloss and orange peel – not generally considered an issue with primer – but important from cure consistency, environmental, and health and safety perspectives. To meet this objective, CFAN has been running the primer at 100°F.

Next, we analyze the film sets to determine the impact of temperature-based viscosity changes on spray parameters.

Static Pattern Analysis

It is common to do "test shots" on paper before painting. Doing this test on SprayVision foils then capturing the film makes the characteristics and quality of the spray pattern much easier to interpret.

Some explanation is in order here. First is the static pattern. This is a brief shot from the gun to establish the spray pattern and droplet distribution. Figure 14 shows the comparison of the film sprayed at 95°F and its captured color map.

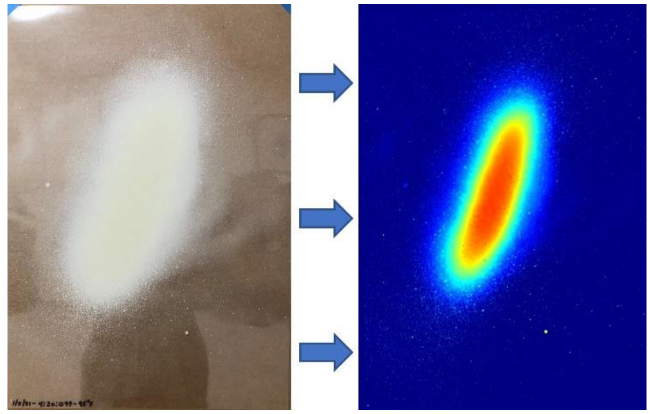

Figure 14: 95°F Static Sprayed Film vs. Captured Color Map View

The color map shows the density and volume of the pattern. The darker the color, the greater the thickness of the paint in that area. Though it may appear that the color map is smaller than the sprayed area on the film, this is an optical illusion. To show that these are actually scaled correctly simply pick discreet droplets on the film and draw straight, parallel lines to the corresponding dots on the capture as shown in Figure 15. Of course, these large droplets also indicate an issue with atomization. This was confirmed to be occurring at gun trigger and turn off, and also occurred at every viscosity (see Figure 16), which indicates an issue that must be addressed in the setup.

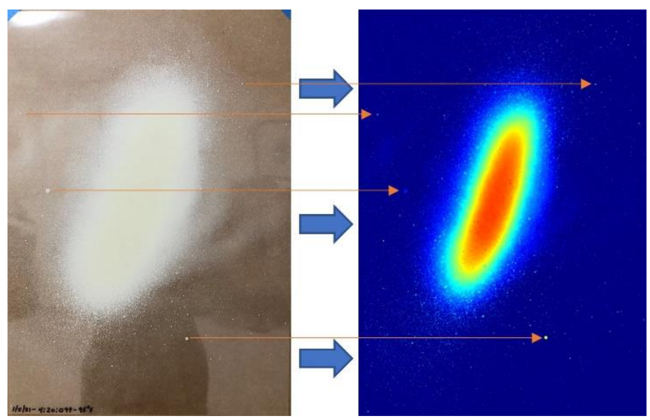

Figure 15: Correlating Sprayed Film to Captured Color Map View

Another issue is the "backward C" shape of the pattern, which also indicates that the atomization and shaping air are out of balance for this viscosity of primer. This was not observed for patterns at other viscosities, which reinforces the importance of viscosity and its impact on system setup.

Yet another important feature of the software is the ability to compare captures as shown below in Figure 16. Though all of the spray parameters are the same, these two patterns are clearly quite different. These differences are the result of the temperature-based viscosity variations described above.

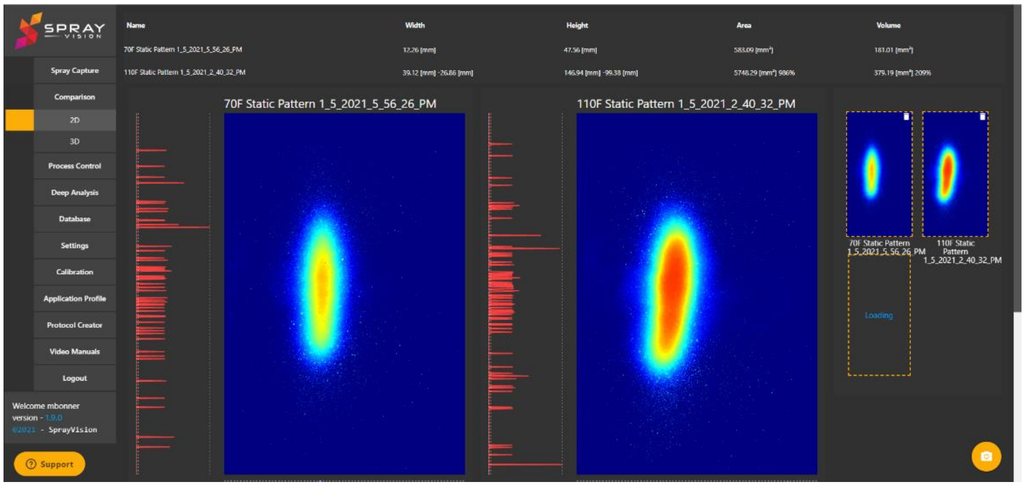

Figure 16: Comparison of 70°F and 110°F Static Patterns

Note the dimensions of the patterns at the top of the screen. Of particular importance to the quality of the process outcome is the width, height, and distribution of the paint through the pattern.

The change in pattern size as a function of viscosity is shown in the chart in Figure 17. Probably most important is the change in height, as it relates to the pattern overlap in the robot program. We see a 25% change (200mm – 150mm), which is roughly shrinking from 8" – 6" over this range. You can imagine the impact this would have on surface finish if the same overlap pattern were used, and the striping and other film related defects that would result.

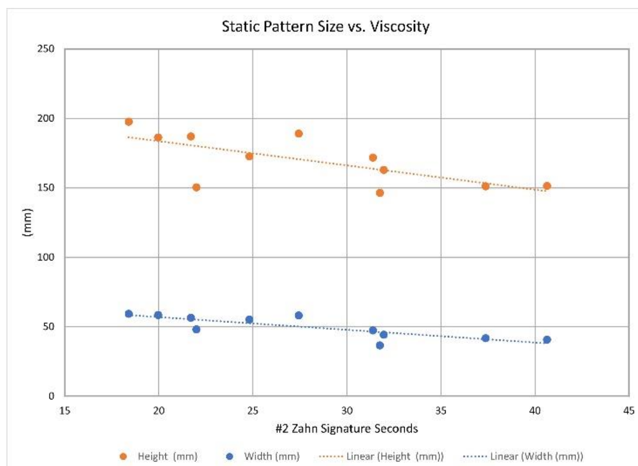

Figure 17: Static Pattern Size vs. Viscosity

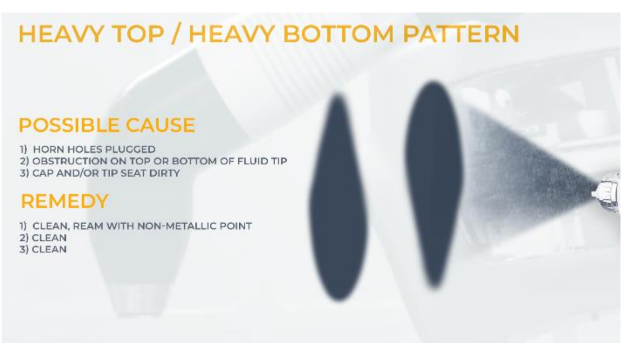

Figure 18: SprayVision Troubleshooting Guide for Pattern Distribution

As noted, paint distribution through the pattern is another important factor to consider. In both patterns in Figure 16, the distribution of paint is greater toward the top of the pattern. Though harder to distinguish in the 70°F pattern, in the 110°F pattern this is quite evident. Turning to SprayVision's troubleshooting guide, shown in Figure 18, this may be as simple as correcting the gun alignment so it is perpendicular to the surface, or it can be yet another symptom of an imbalance between atomization and shaping air. This can be caused by an incorrect adjustment, or by an occlusion in one or more of the air lines or passages.

Obviously, the importance of the static pattern is really in how the paint is distributed when the gun is moving through its path. This is the purpose of the Dynamic Pattern.

Dynamic Pattern Analysis

The dynamic pattern is more representative of how the system will perform when spraying parts. It puts the static pattern in motion in the form of a single pass across the width of the film.

As with the static pattern, it is hard to visually distinguish the important features of the spray pass. As shown in Figure 19, however, after the SprayVision capture, the details become readily apparent.

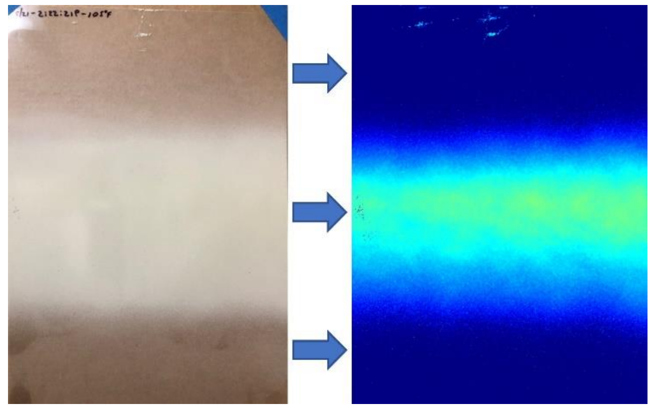

Figure 19: 105°F Dynamic Sprayed Film vs. Captured Color Map View

Here we can see the effect of the "lopsided" spray, with the concentration of paint shifted to the top of the pattern. This means uneven "overspray" areas as shown in Figure 20, with the lower overspray area larger than the upper overspray area. This will certainly have a negative impact on coverage using a standard 50% overlap. Striping would be the most common defect.

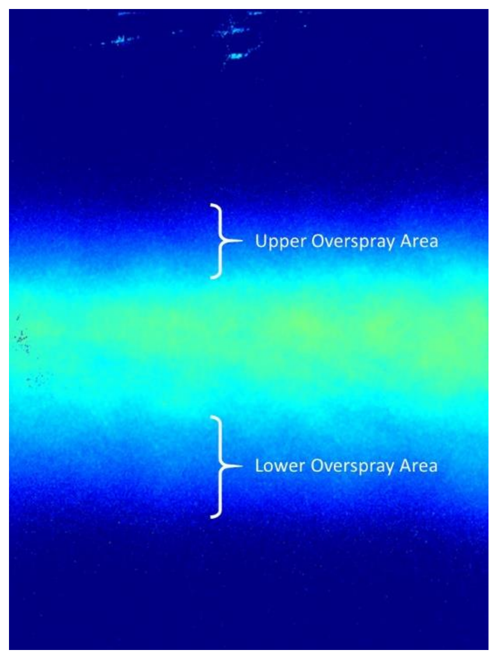

Figure 20: Overspray Areas

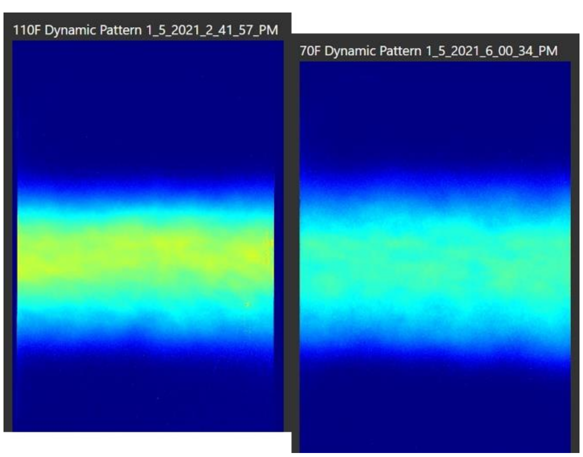

Figure 21: Comparison of Low Viscosity and High Viscosity Dynamic Patterns

One of the important factors in coverage and transfer efficiency is the volume being dispensed on each pass. Again, using SprayVision's comparison features as shown in Figure 21, we can compare the volume being dispensed at lower (110°F) vs. higher (70°F) viscosities. Note that these have been cropped and shifted in position to make it easier to compare the effect of viscosity on the pattern and the volume being dispensed. From this comparison we can also see that the pattern is much more stable, with smaller overspray areas at the lower viscosity than at the higher viscosity. These trends are easier to see when plotted against viscosity.

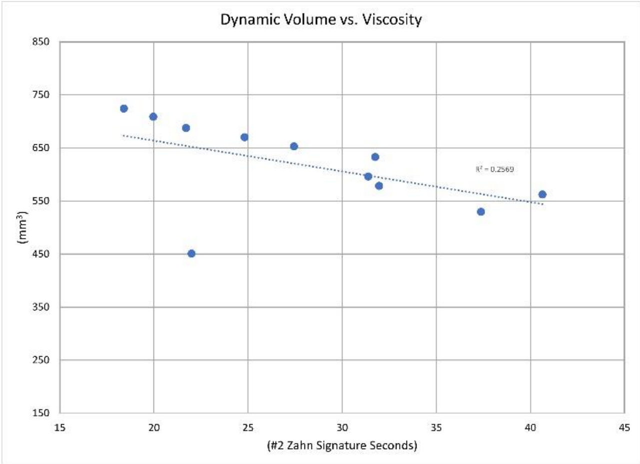

Figure 22: Dynamic Pattern Volume vs. Viscosity

The change in pattern volume as a function of viscosity is shown at right in Figure 22. This exhibits the inverse relationship, with volume decreasing as the viscosity increases.

We can also see that there is an outlier at 450mm³ that is shifting the trendline. Though we were unable to determine the exact source of the outlier and did not have sufficient time to repeat the test, it was clear that if we remove that outlier, as shown in Figure 23, the trend more closely correlates to the remaining points, which matches the behavior that we saw in the system.

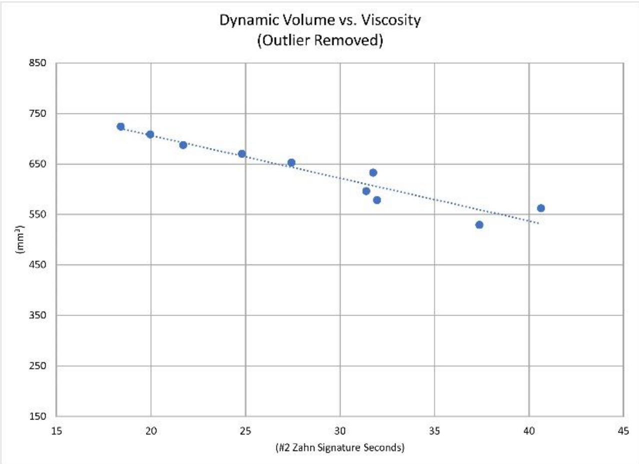

Figure 23: Dynamic Pattern Volume vs. Viscosity with Outlier Removed

The change in the overspray pattern as a function of viscosity is shown in the chart in Figure 24. In contrast, this exhibits a direct relationship with overspray increasing as the viscosity increases. As the pattern becomes less stable with increasing viscosity, it becomes more difficult to get reliable measurements, which accounts for the outliers. This is important again as it points out how essential viscosity is to a stable and repeatable spray process.

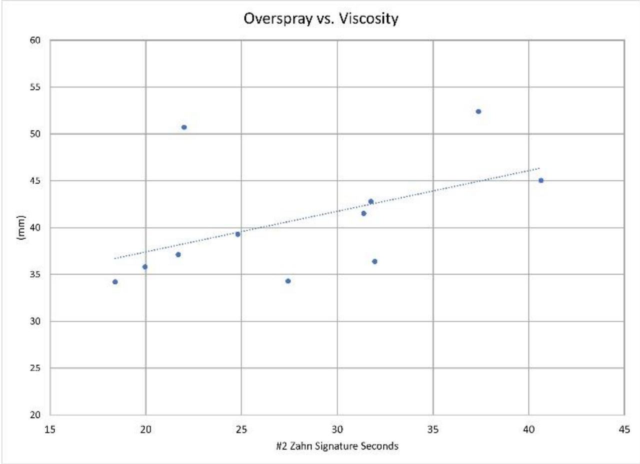

Figure 24: Overspray Pattern vs. Viscosity

Droplet Analysis

Another important feature of the SprayVision system is its ability to capture and analyze patterns at the droplet level. Shown in Figures 25 through 27 this allows a small, select area to be captured and processed with extremely fine detail. Once the capture is completed, the captured area is broken down into nine (9) smaller sub-areas which can then be viewed and analyzed separately.

In Figure 25 we can see the total Droplet Analysis pattern, and the top center frame in the "Zoomed Area". Here, in the overspray area, the droplets are small and mostly separated.

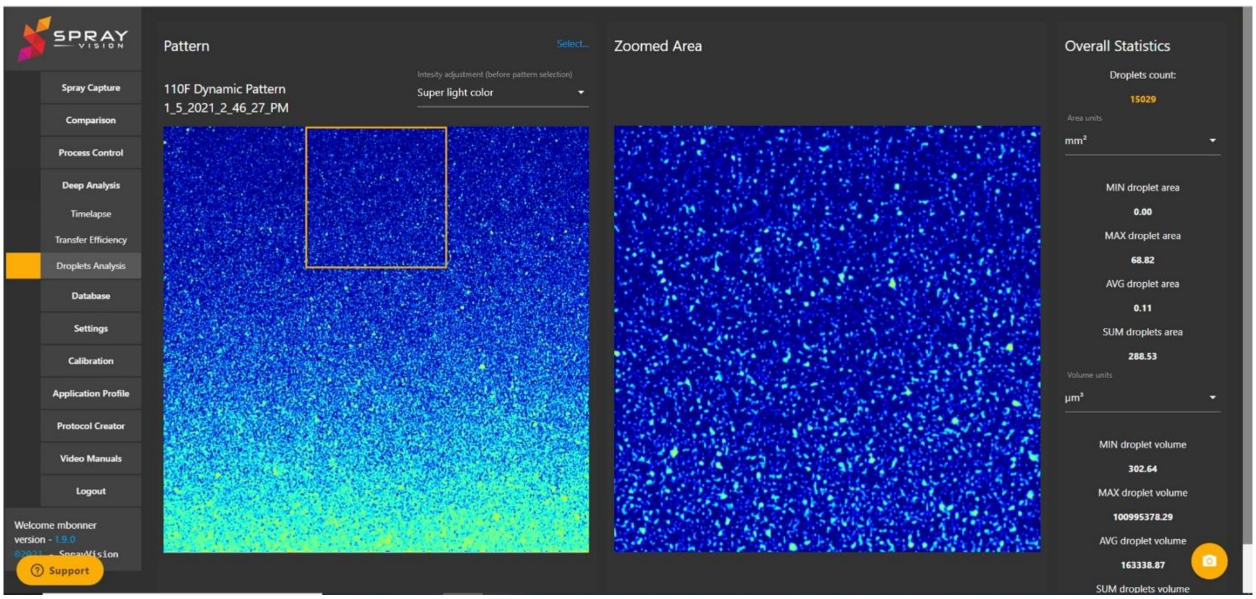

Figure 25: Droplet Analysis in Overspray Area

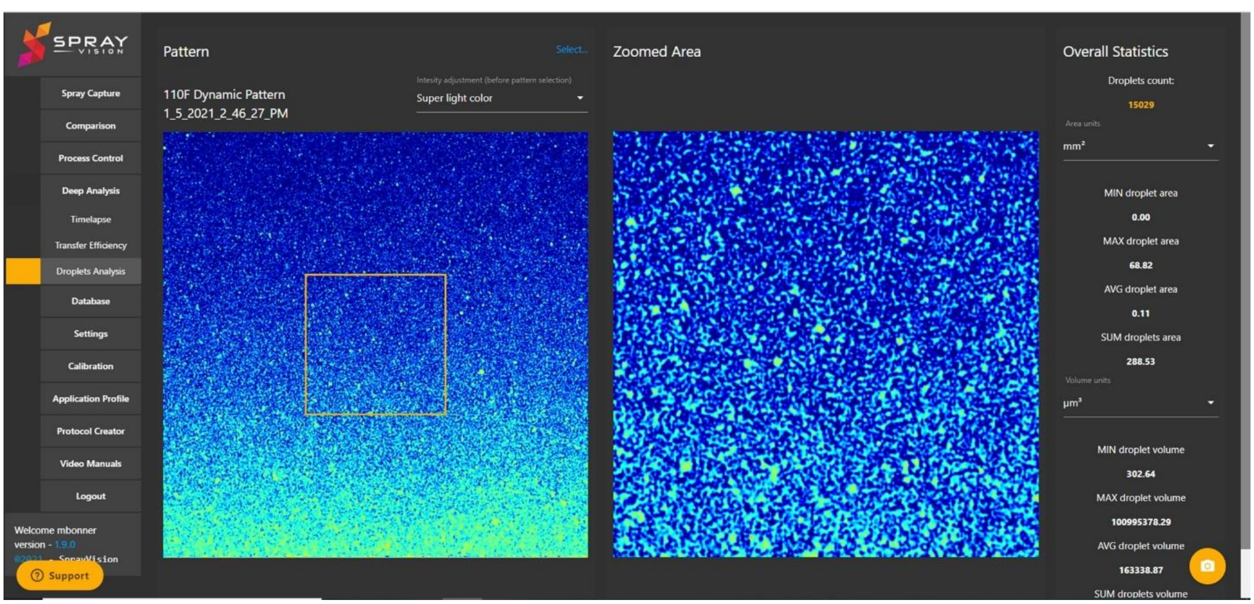

Figure 26: Droplet Analysis in Overspray Area – Closer to Main Spray Area

As we move closer to the main spray area, in Figure 26, we see the droplet pattern getting denser and the droplets getting larger. In addition, we also see droplets merging to form larger areas of coverage.

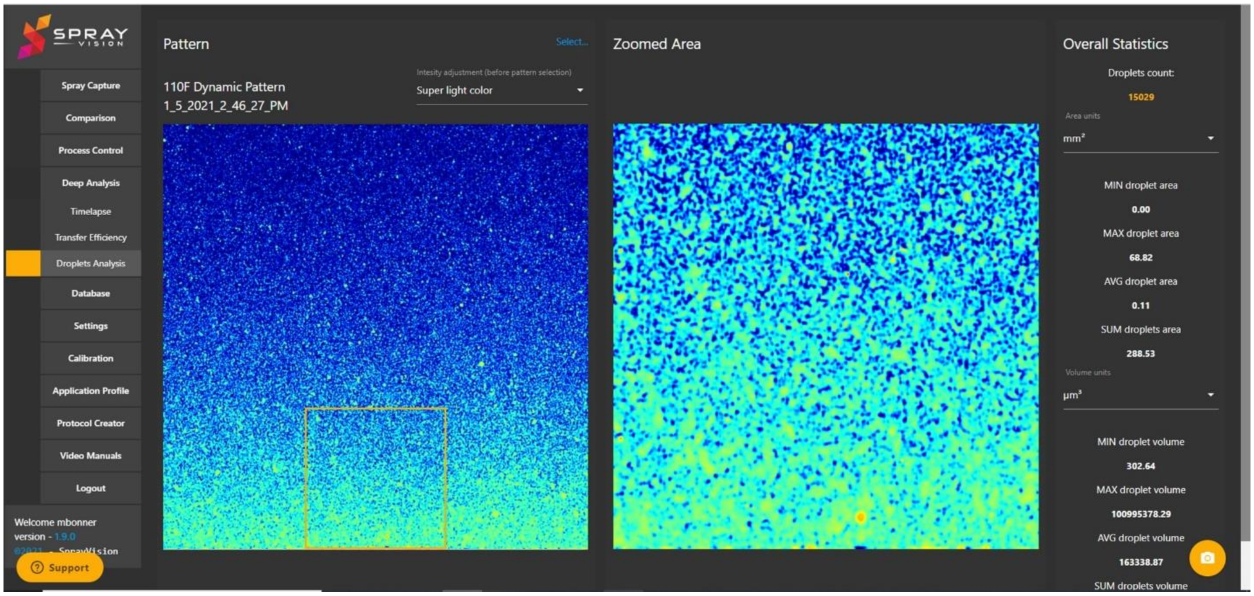

Figure 27: Droplet Analysis in Overspray Area – On the Edge of the Main Spray Area

And in Figure 27, on the edge of the main spray area, we see the main painting activity we all think of with the droplets joining one another to form a continuous film.

At each step in this process, the software allows the measurement of the droplets as shown in Figure 28, where you can compare the statistics for the droplets in the Zoomed Area to the Overall Statistics shown at the right of the screen.

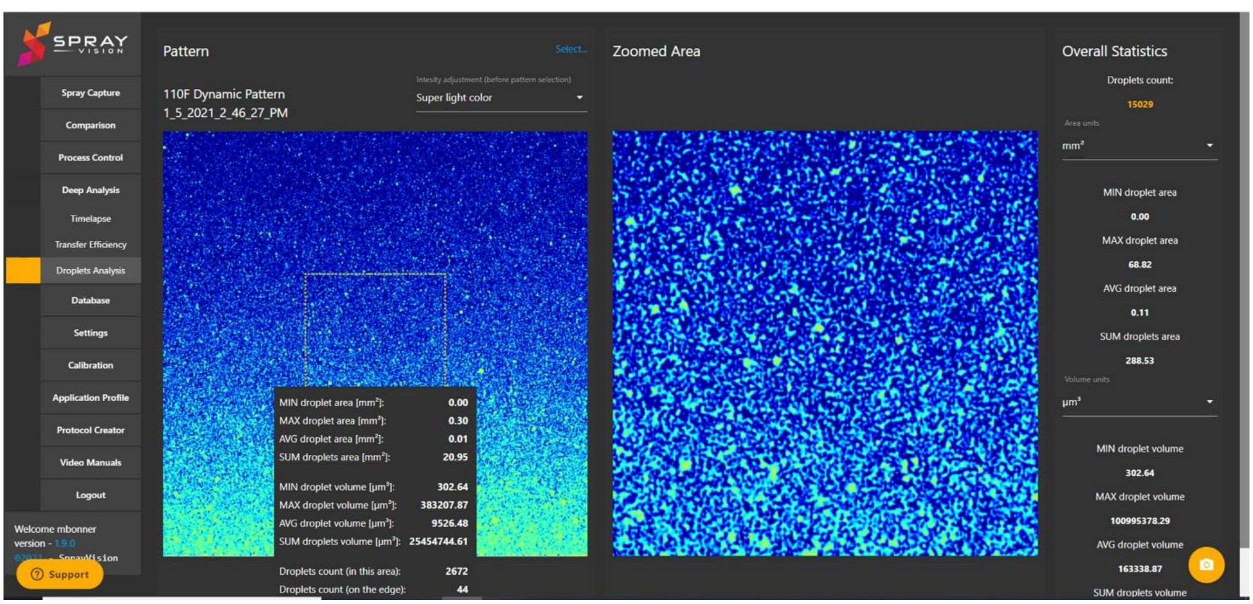

Figure 28: Droplet Analysis in Overspray Area with Zoom Analysis Panel

To be fair, this requires some care in the setup for capturing to gather data in the proper location, and the instability in the patterns we were working with made it difficult to get comparable data from capture to capture. Still, as shown in Figure 29, and as we would expect, as the viscosity of our paint increases, so does the size of our atomized particles.

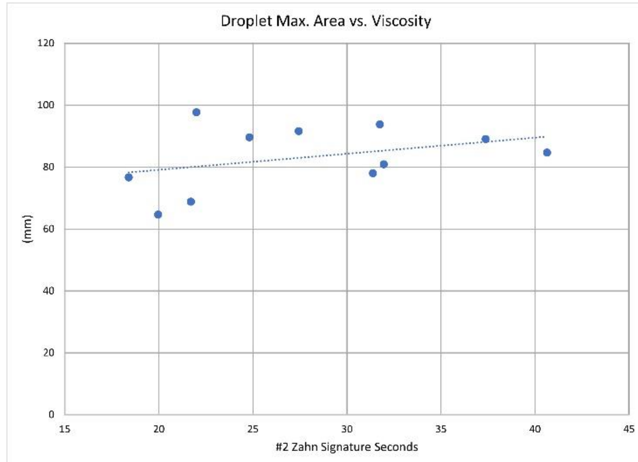

Figure 29: Max. Droplet Size vs. Viscosity

CONCLUSIONS

The SprayVision System turned out to be an extremely useful tool in analyzing the automated prime process. There were many "lessons learned", though in many cases they might be better defined as "beliefs reinforced by objective data".

First is that the primer viscosity varies widely as a function of temperature. Though we had already established this in 2019 and instituted means to control the fluid temperature at dispense in early 2020, this effort really pointed out all the areas with regard to gun setup and robot programming where stable viscosity is essential. It was clear that utilizing temperature instead of adding solvent was a much smarter move.

Next, improving the overall finish outcome begins with the primer. Improving this layer requires finer atomization, and the SprayVision system revealed that a dispense temperature of 110°F produced better atomization and improved primer finish quality than did the 100°F that we had been using. It also allowed us to identify issues with the air balance between the atomizing air and the shaping air, which arose from the investigation of nozzle alignment to the part. While not resolved during this exercise, the groundwork for future improvement was laid. This is important, because the complex geometry of the blades requires strict control of the robot path – particularly with regard to distance and angle to the surface, and the imbalance of air pressures can produce the same effect as gun misalignment.

The large droplets produced at gun firing and turn-off were already known and were dealt with by triggering well off the part. In the development of the routine to generate the dynamic foils, however, we established an issue with timing of the air and fluid valves because of the air valve being located outside of booth and generating delay and pressure variation at the nozzle. There are several ways to address this issue, which will be part of near-term improvements.

ANTICIPATED BENEFITS

From this work we can project that utilizing these technologies in the future will produce:

- A 20-30% reduction in paint usage per part
- A two-point improvement in orange peel on the ACT scale
- A 5-7 GU improvement in gloss (on a 60° geometry)
- A 3 - 5% increase in First Time Yield (FTY)
- > 2.5% reduction in rework
- Detection of system & equipment failure prior to spraying parts

AUTHOR BIOGRAPHIES

Matt Thomas is a Coatings Process Engineer who has served CFAN for the last eight of his twenty-five-year career in aerospace coatings operations. Matt began his career on the shop floor at Cessna Aircraft Company prepping and applying coatings to business jets and learned aircraft paint operations from the ground up, while completing his formal university education. Matt has previously served other notable aerospace companies such as Gulfstream, Honda Aircraft Company, and StandardAero in various professional capacities. Additionally, he is highly involved with SAE International's G8 Committee dedicated to Organic Aerospace Coatings and continues to be a strong advocate for the training and development of Aerospace Coatings Applicator Specialist (ACAS) personnel.

Michael Bonner is the Vice President of Engineering & Technology for Saint Clair Systems, Inc., a leading supplier of process temperature and viscosity control equipment for industrial fluid dispensing systems. A degreed electrical engineer, over the years he has spent time in a wide variety of industries including audio systems, medical equipment, HVAC and appliance controls, metal stamping, even the manufacture of gasoline pumps. For the last 20+ years, however, he has focused on the science of point-of-use temperature and viscosity control in fluid dispensing operations.