CASR
FAA Center for Aviation Systems Reliability

Developer Studies

Lisa Brasche, Rick Lopez, David Eisenmann, Allison Wright, and Jason McReynolds

Center for Nondestructive Evaluation

Iowa State University

lbrasche@cnde.iastate.edu

(515) 294-5227

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Engineering Assessment of FPI

- Provide engineering data to support decisions regarding the safe application and relevant use of FPI
- Includes data to support changes in specifications
- Generate tools for use by airlines and OEMS that improve FPI processes
- Strong industry team with extensive experience

BOEING
Delta
delta.com
D&W Enterprises, LTD.
Consulting Services
General Electric Company
Honeywell
IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY
MAGNAFLUX
Met-L-Chek
Pratt & Whitney
A United Technologies Company
Rolls-Royce
SHERWIN
INCORPORATED
UNITED

Goals

- Define areas where engineering data is deficient due to:
  - Change in process or materials
  - Change in applications
  - Data not available in the public domain
- Perform studies to provide quantitative assessment of performance
  - Indication luminance measurements
  - Digital recording of UV-A indication
  - Probability of detection
- Complete study using either lab or shop facilities
- Distribute results through use of web
- Support changes to industry specifications as warranted
- Utilize results to update/create guidance materials

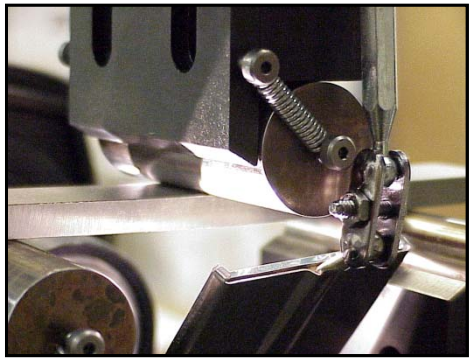
www.cnde.iastate.edu/faa-casr/fpi/index.html

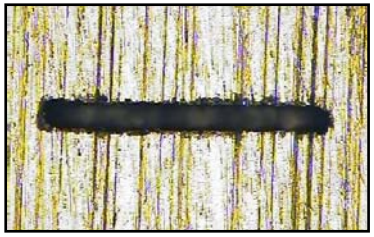
Brightness Measurement

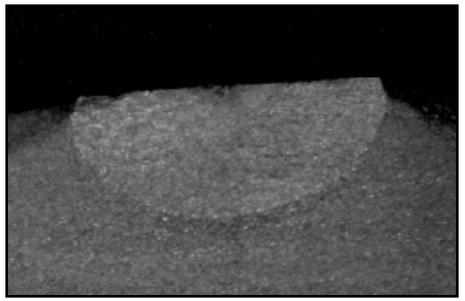
- Used rigid fixturing to assure repeatability with transportability for brightness measurements
- Photo Research PR-880 Photometer used to record indication brightness in ft-Lamberts

Sample Fabrication

- Materials:
  - Titanium 6Al-4V
  - Inconel 718
  - Aluminum 6061-T6511
- EDM notches used as starter defects
- Three point bending at 0.1 R-ratio gave 2.5:1 aspect ratio
- Lengths from 20 to 180 mils, centered at 80 mils







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Developer Questions

- Do penetrants self-develop?
- How does dry powder developer compare to non aqueous wet developer?
- How do different penetrant/developer families compare?
- How do developer application methods compare (dust chambers, bulb, spray wand, electrostatic)?
- How do different developer forms compare?

Developer Chamber Characterization

- Dry powder developers qualified using dip/drag
- Indication luminance is high with dip/drag, and results are repeatable, but not realistic for shop floor

- Team evaluated four dust storm cabinets and a spray wand applicator at two field locations
- Penetrant process and chemistry was held constant while samples developed with cracks facing up, sideways, or downward

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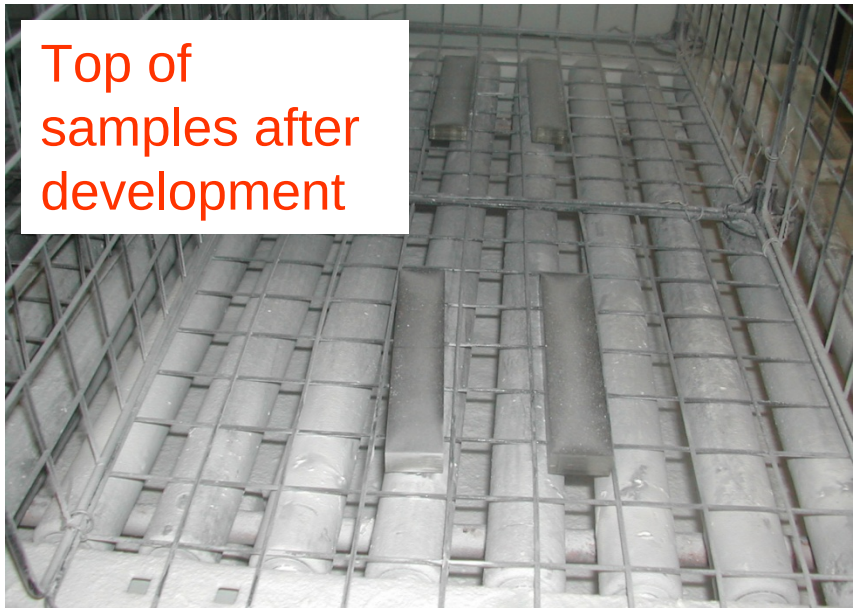
Field Studies

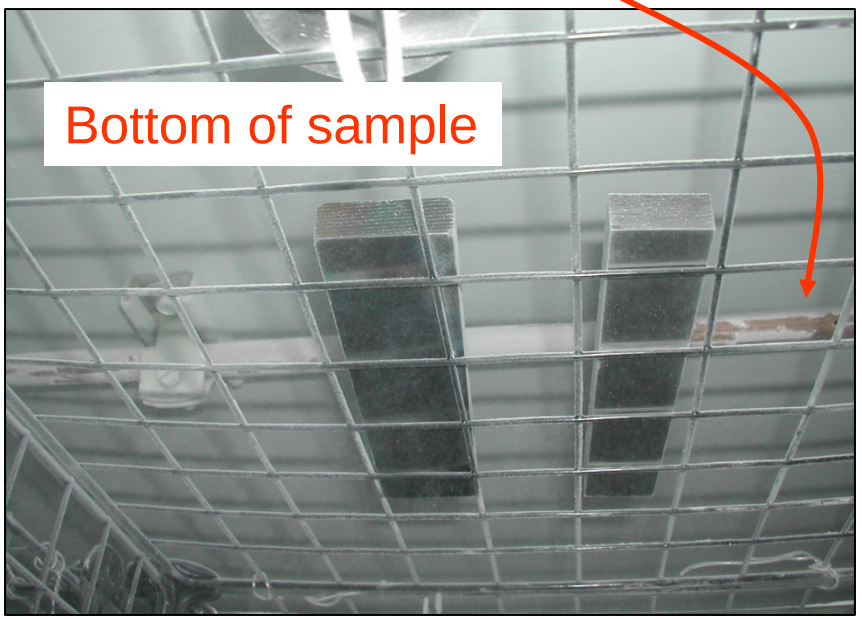
- 15 - 20 samples per basket
- 20 minute penetrant dwell
- 90 second pre-wash
- 120 seconds emulsifier contact with vertical motion
- Two 30 second cycles of air agitated water rinse, then a 90 second post-wash
- Samples dried for 8 minutes at 150ºF
- Drag-through application of developer
- 10 minute development time
- Brightness reading using Spotmeter
- Length reading using UVA and image analysis software

Chamber A Characterization

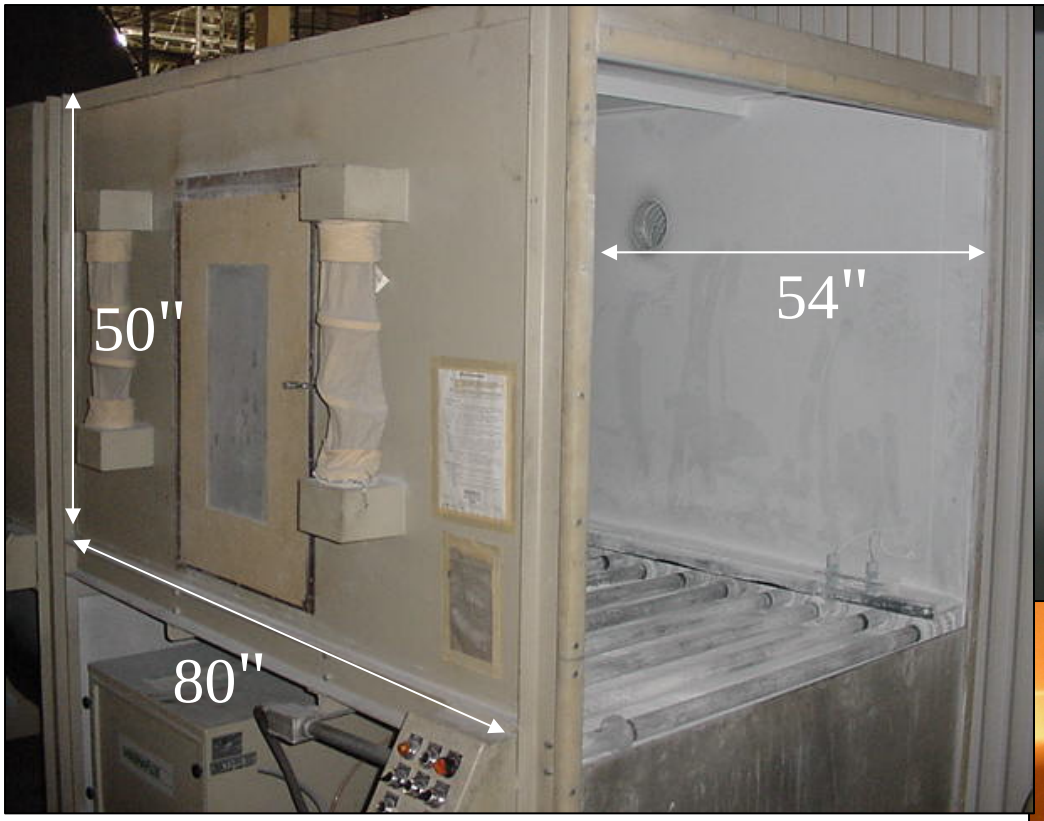
Applied through linear diffusers at top and bottom of chamber

Linear diffusers



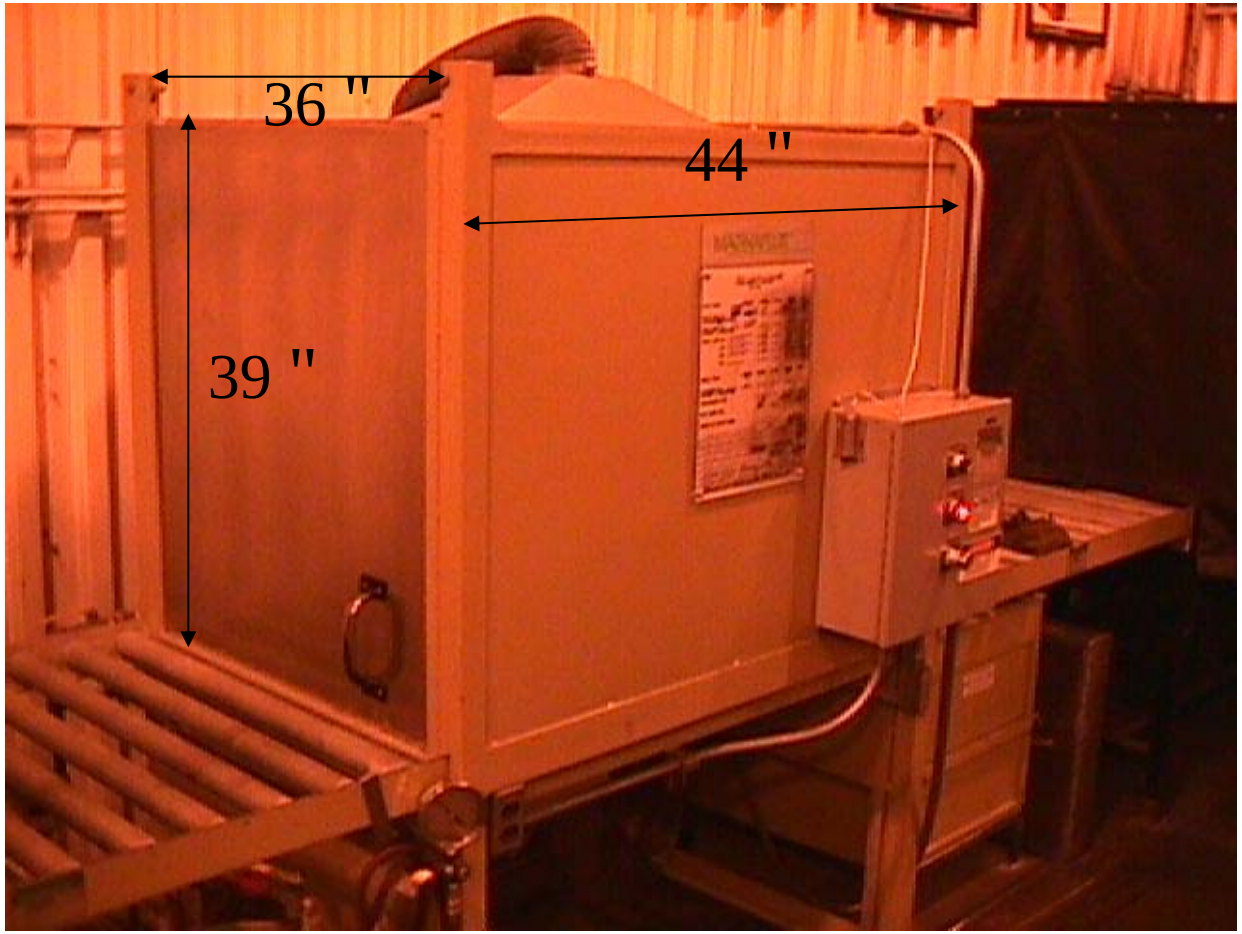


Chamber B



- Circular diffusers at top and bottom of chamber
- Evacuation in upper, center region of chamber

Chamber C

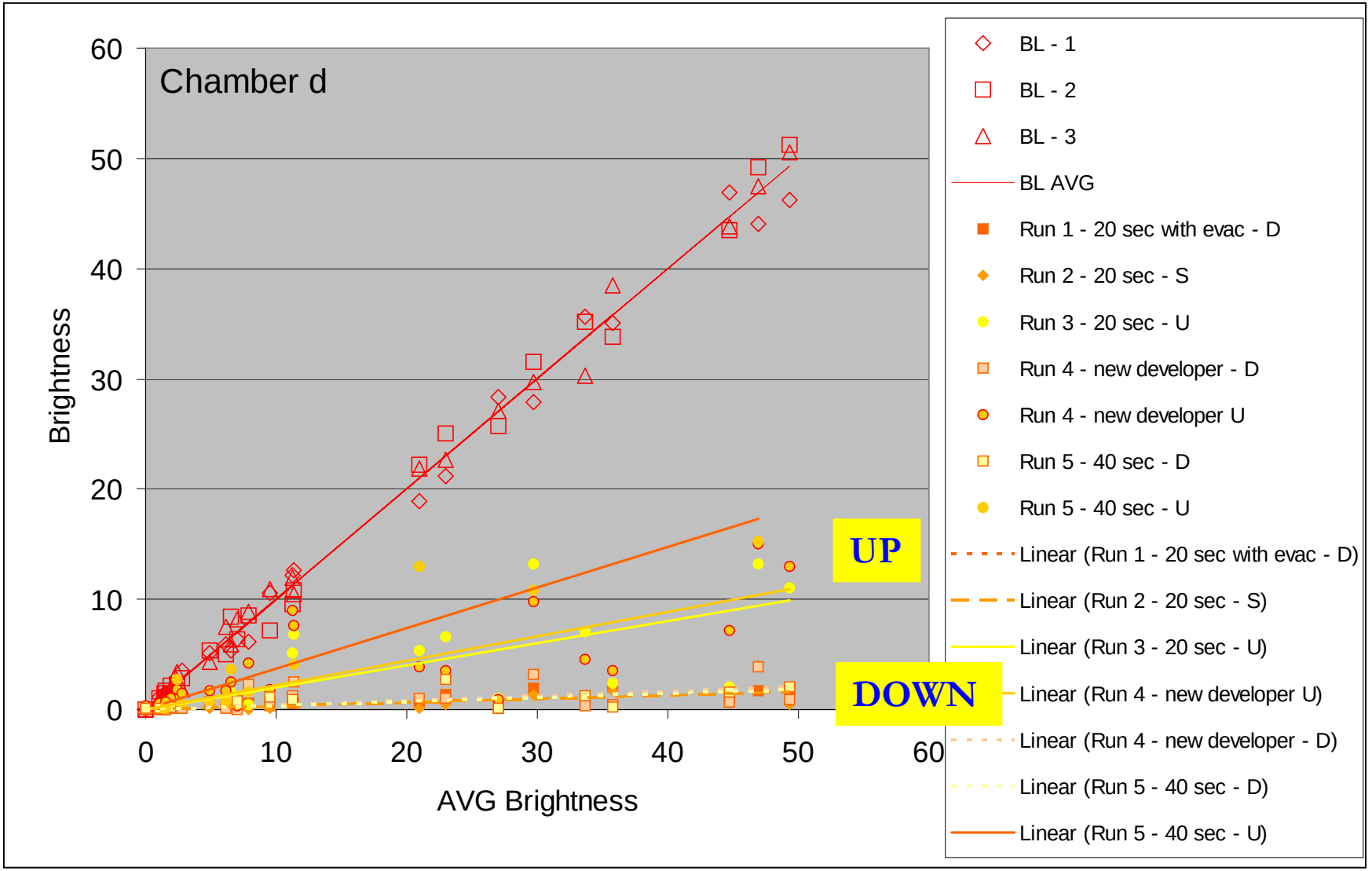


Circular diffuser located in top of chamber

Chamber D Characterization

- Chamber contains two jets, at approximately ¼ and ¾ of the chamber length
- Jets located below rollers
- Typical operation of 5 sec developer application followed by 10 min dwell in chamber

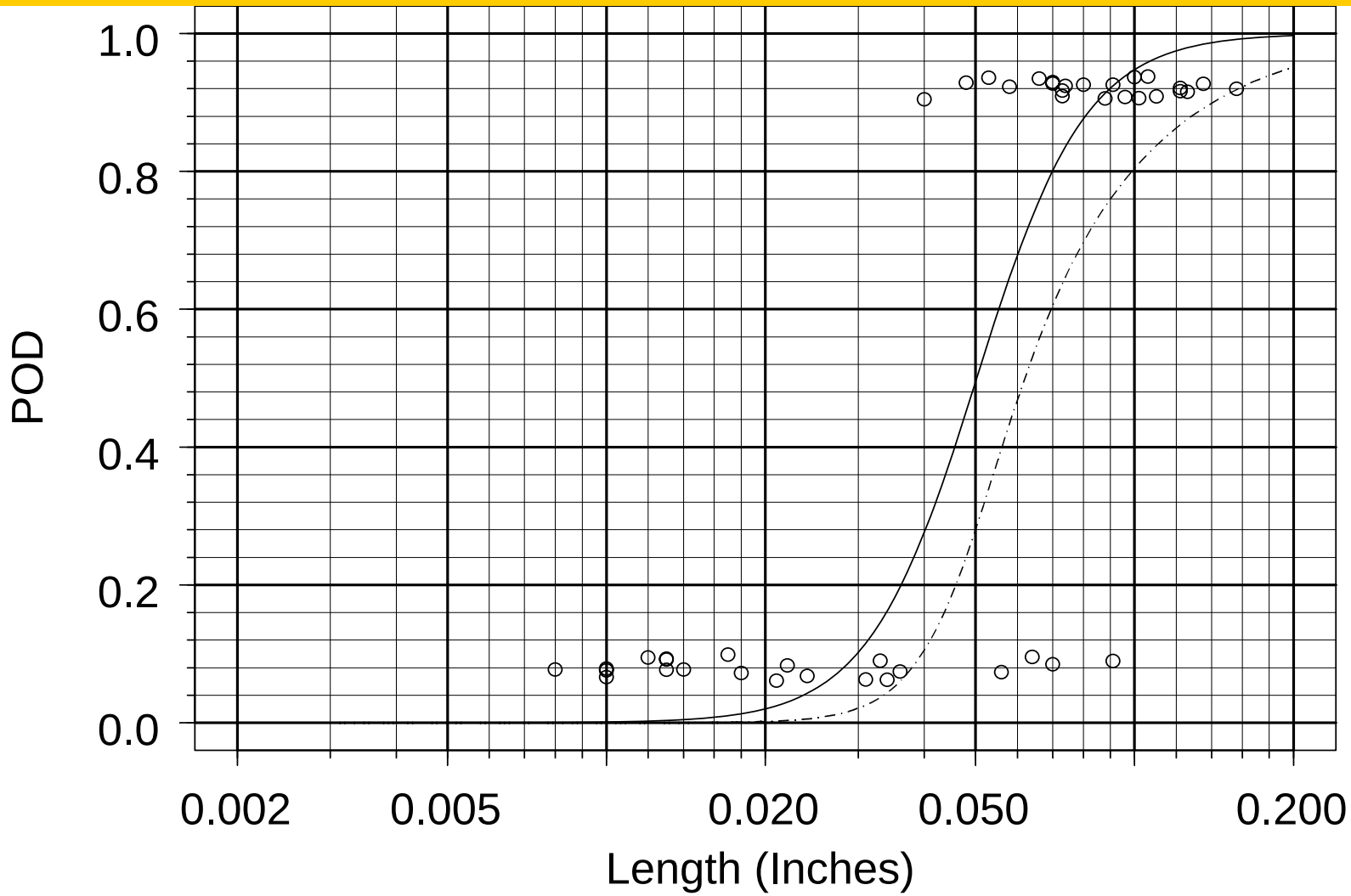
Chamber D Characterization



Developer Application Method

R3.I2.5kuva.0fc
Hit-Miss POD with 95% lower confidence bound

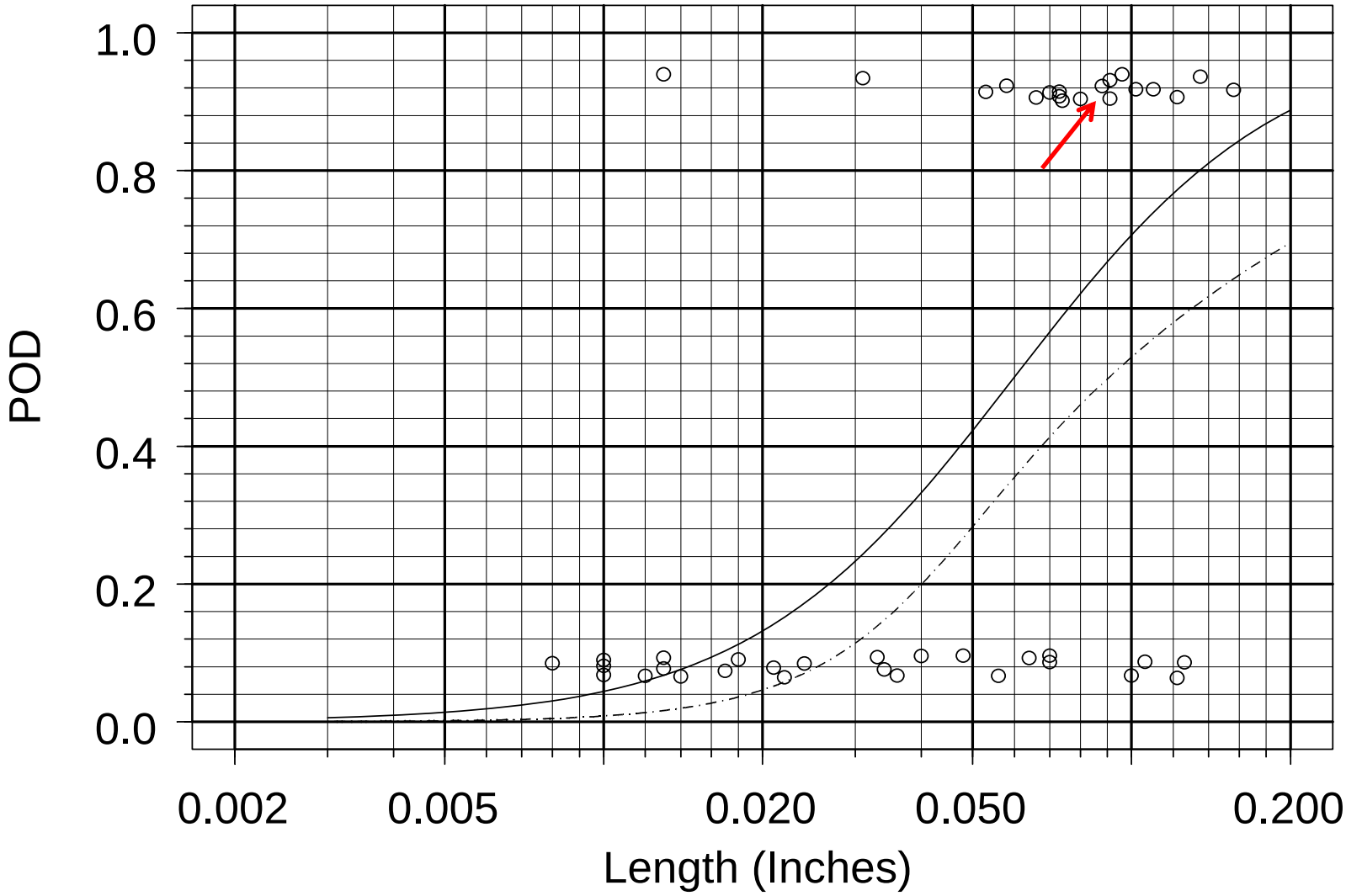
POD results for samples processed using **dip/drag**, 5,000 UVA, no white light contamination



Developer Application Method

R4.I2.DevCh.5kuva.0fc
Hit-Miss POD with 95% lower confidence bound

POD results for **dust storm chamber** processing, 5,000 UVA, no white light contamination



Manual Spray Application

Increasing spray time from 5 to 25 sec offered significant indication luminance improvements

Preliminary Conclusions

- POD was related to indication luminance
- Team found that:
  - Increasing UV-A from 1,000 to 3,000 $\mu W \bullet cm^{-2}$ was not a significant change
  - Crack orientation within chamber affects POD, with a 0.010” deficit when facing downward
  - Use of 5,000 $\mu W \bullet cm^{-2}$ resulted in a 0.015” POD improvement
  - Increasing white light contamination led to over a 0.100” reduction in 90/95 point POD
  - A characterization method for chambers is needed

Lessons Learned – So Far

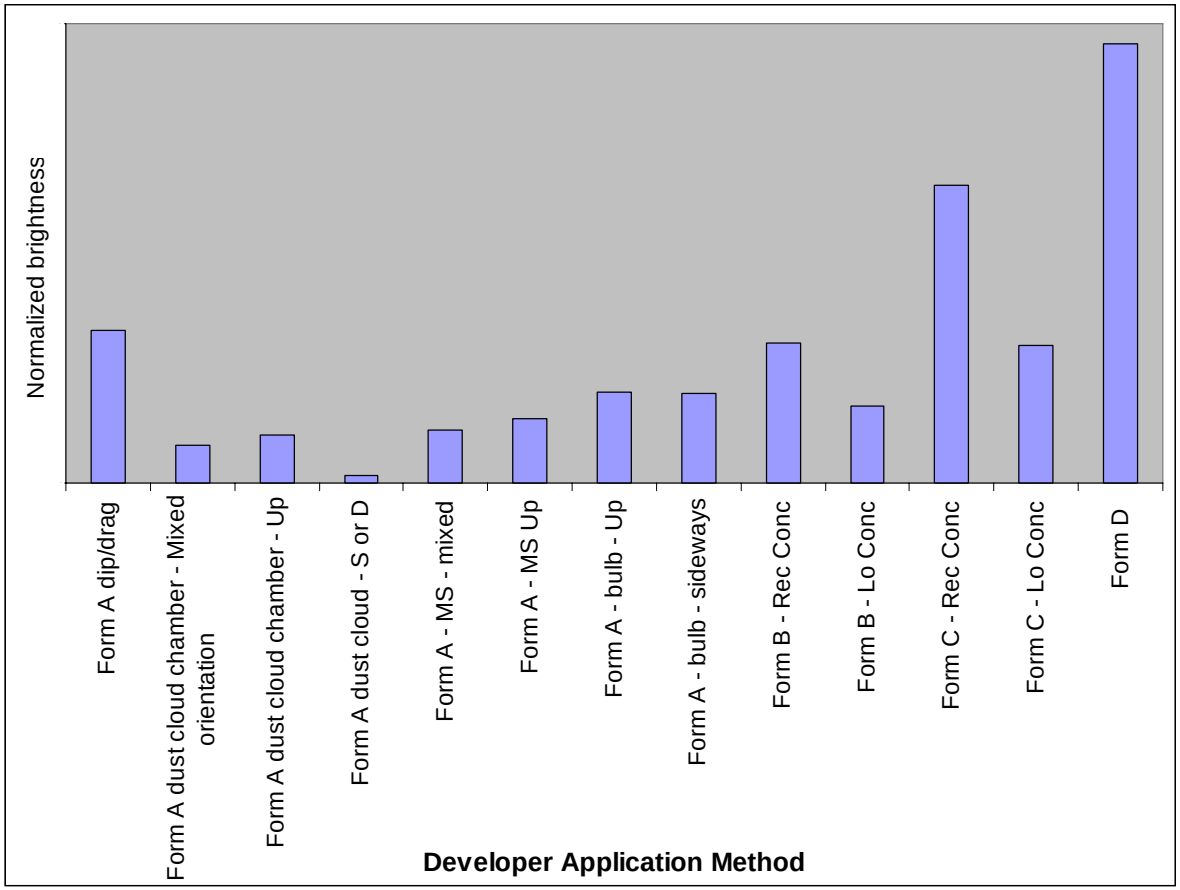
- Developer application is critical to overall FPI performance
- Crack orientation matters
  - Avoid barriers that prevent direct application of the developer
  - Ensure chamber configuration or part handling fixtures (rollers, baskets, etc.) don't hamper application
  - No metal-to-metal contact
  - May require multiple trips through the chamber to ensure adequate coverage on all surfaces

Developer Form Comparison

- Form a - Dry Powder Developer
- Form b - Aqueous Soluble Developer
- Form c - Aqueous Suspendable Developer
- Form d - Nonaqueous Wet Developer (NAWD)

Developer Form Comparison

- Brightness comparison normalized to Form A dip/drag
- Only samples common to all runs were used which leads to a small sample set (10 samples)
- Form D brightness results from more “spread-out” nature of the indication



Electrostatic Application of Developer

- Electrostatic spray machines impart a negative charge to the developer particles while electrically grounding the specimen.
- Particles ejected from the gun are attracted by this charge, which increases transfer efficiency over standard spray applications
- Electrostatic spray, as with any chosen method, is not without challenges

Note: This study is not intended to be a qualification process study. Rather its purpose is to provide data on the feasibility of the electrostatic application method for typical aerospace usage.

Equipment Used

How Was It Performed

As with any manual process, there are many variables to be considered

Introduction

Electrostatic spray of developer has several operator-controlled variables:

- Fluidizing Air (0 – 1.0 Nm^3/hr)
- Powder Output (0 – 100%, in steps of 10%)
- Total Air Volume (0 – 6.5 Nm^3/hr)
- Conveying Air Volume (0 – 5.4 Nm^3/hr)
- Supplementary Air Volume (0 – 4.5 Nm^3/hr)
- Spray Current (0 – 100 micro-Amps)
- Charge Voltage (0 – 100 kilovolts)
- Spray Time
- Gun to Specimen Distance
- Gun to Specimen Angle
- Gun motion
- Specimen grounding direct versus basket

Nm^3/hr = normal cubic meters per hour

Introduction

There are also variables not necessarily under the operator's control:

- Ambient humidity
- Ambient temperature
- Airflow rate within the spray booth
- Compressed air quality

What Work Was Done

Varying -

- Spray Time
- Gun to Specimen Distance
- Location of Flaw with respect to Spray Direction
- Airflow

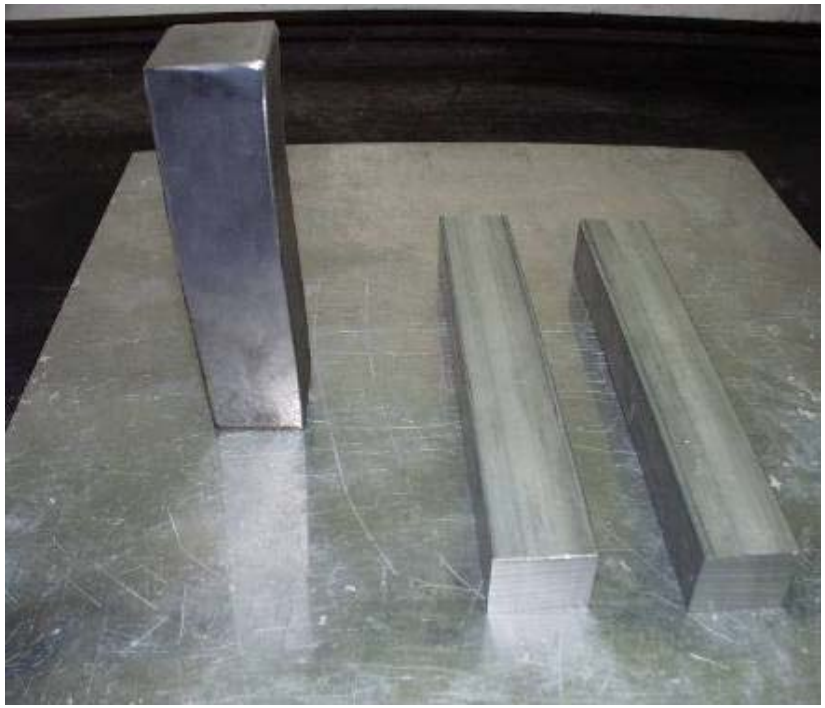
Holding constant –

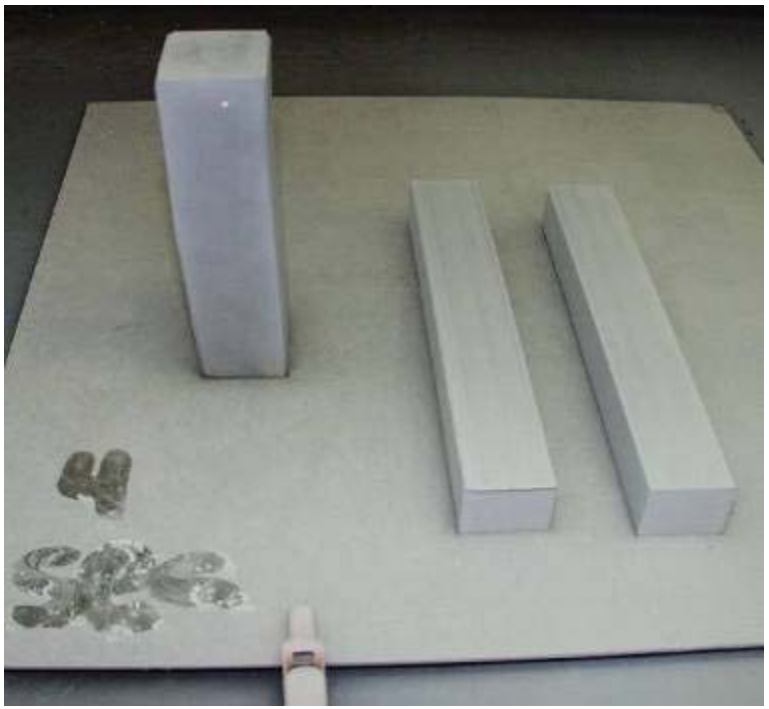
- Powder Output (25%)
- Total Air Volume (4.0 Nm^3/hr)
- Spray Current (100 micro-Amps)
- Charge Voltage (100 kilovolts)
- Gun to Specimen Angle (~0˚)
- Gun motion (none)
- Specimen grounding method

How Was It Performed

Initial experimentation with equipment:

- With so many variables to control early work has simply used pre-programmed values for flat geometry components
- Two aluminum blocks, and a steel block were placed atop a grounded sheet of aluminum and sprayed for a given duration
- Coating thickness was evaluated as spray time was increased

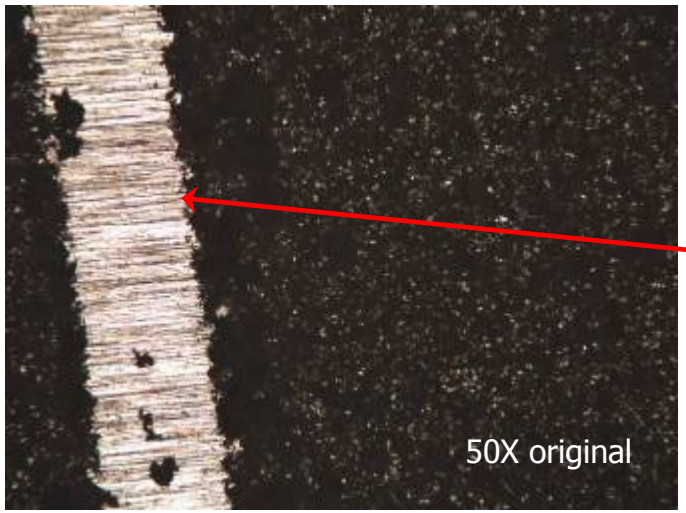




Coating Thickness

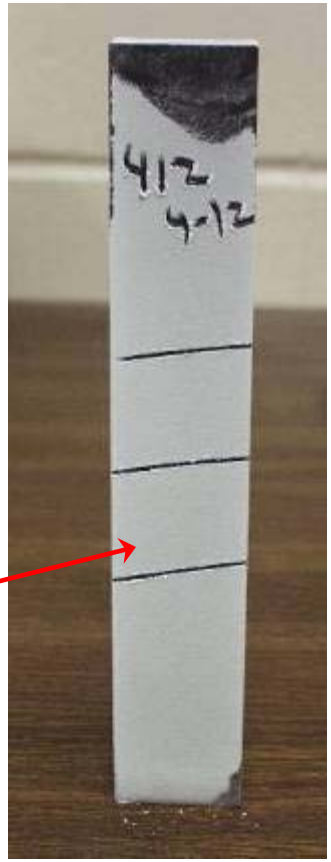
Initial experimentation with equipment:

- Developer coating thickness was estimated by clearing away a narrow path, and then measuring the elevation difference with an inverted microscope under moderate magnification
- As expected, coating thickness increased with spray time, and inversely with distance



Titanium sample sprayed for 4 seconds at a 12” distance

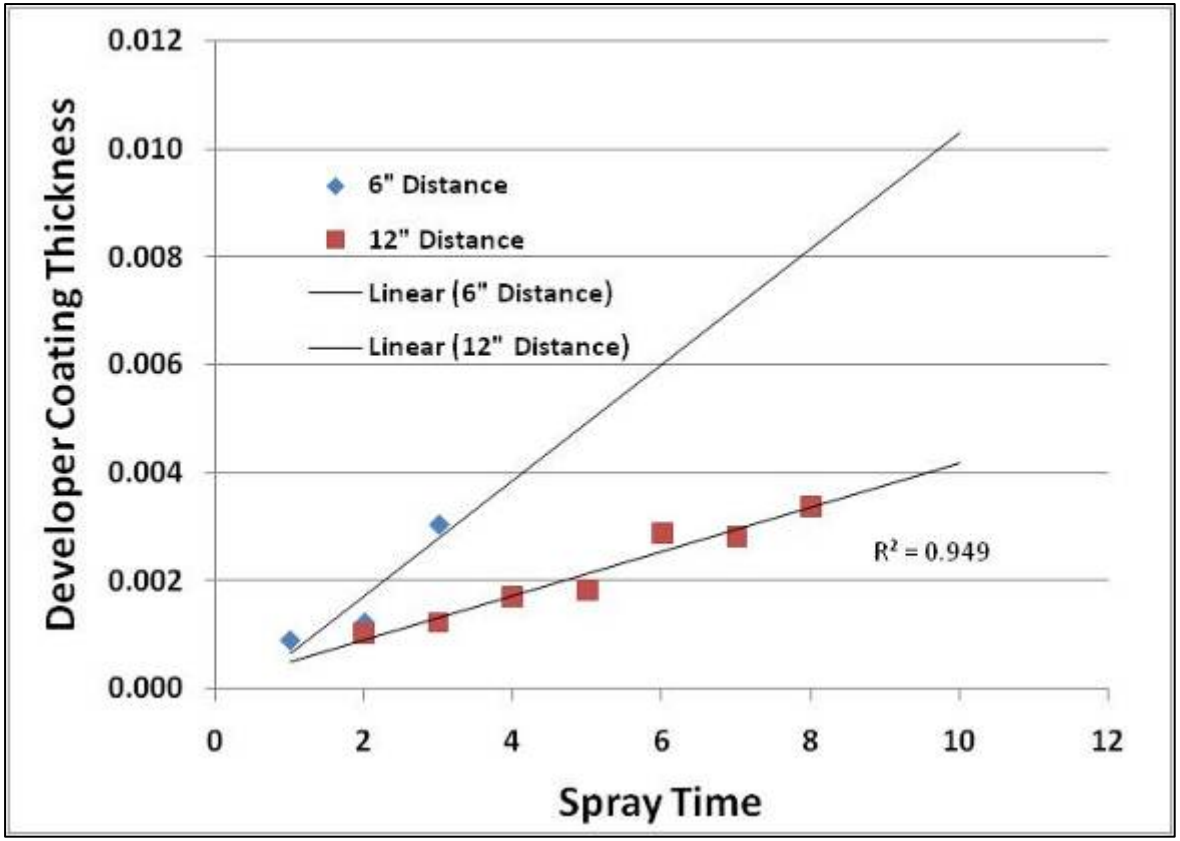
Thickness Evaluation Areas



Coating Thickness

- Gun-side layer thickness increased rapidly when the gun was closer, and in all cases increased with spray duration (below)
- Comparison of a few data points showed that layer thickness on the gun side of the sample was 1.6 – 1.9 times thicker than that deposited on an adjacent side with the gun at 6”

At 25% powder output, 40 Nm^3/hr air volume, 100 µA, 100 kVp



Coating Thickness

- It was obvious that coating thickness could be varied dramatically, but the effect of thickness on penetrant indications was not known.
- The next series of experiments utilized low-cycle fatigue crack blocks to monitor indication brightness versus developer layer thickness.

Steel block after electrostatic spray

Front

Back

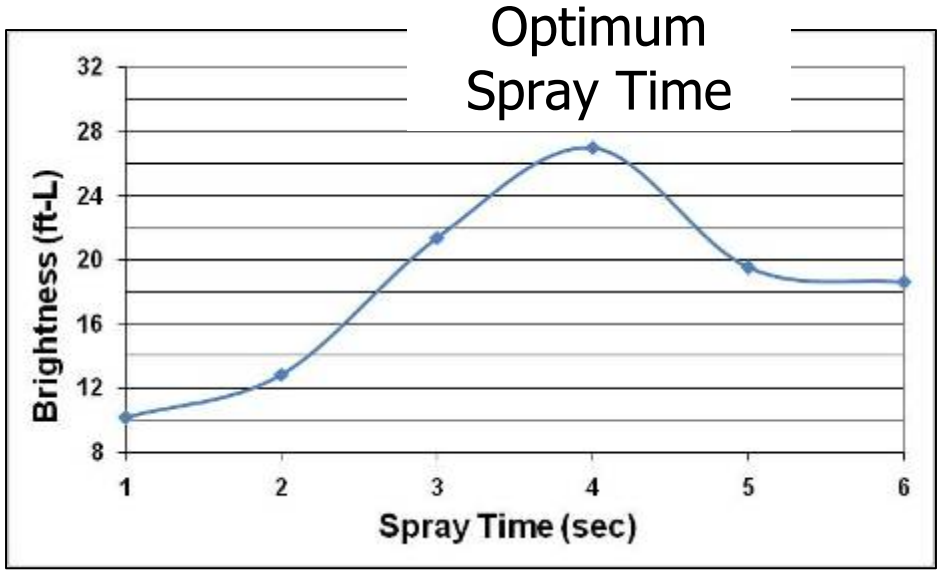
Optimum Spray Time

- To establish an ideal spray time 6 samples were chosen from the 20 by the excellent repeatability of their baseline run results
- These 6 blocks were re-processed several times while varying the electrostatic spray time
- Results suggested that 3.5 – 4.0 seconds was ideal in our setup

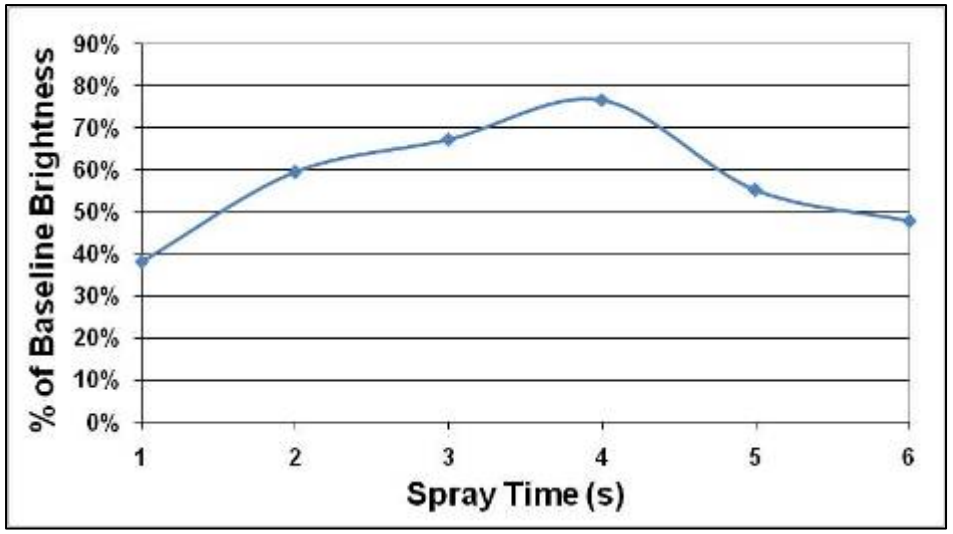
An inconel 718 block being developed at a distance of 12” while standing on a grounded aluminum sheet

Results

Average indication brightness of 6 selected samples versus spray time

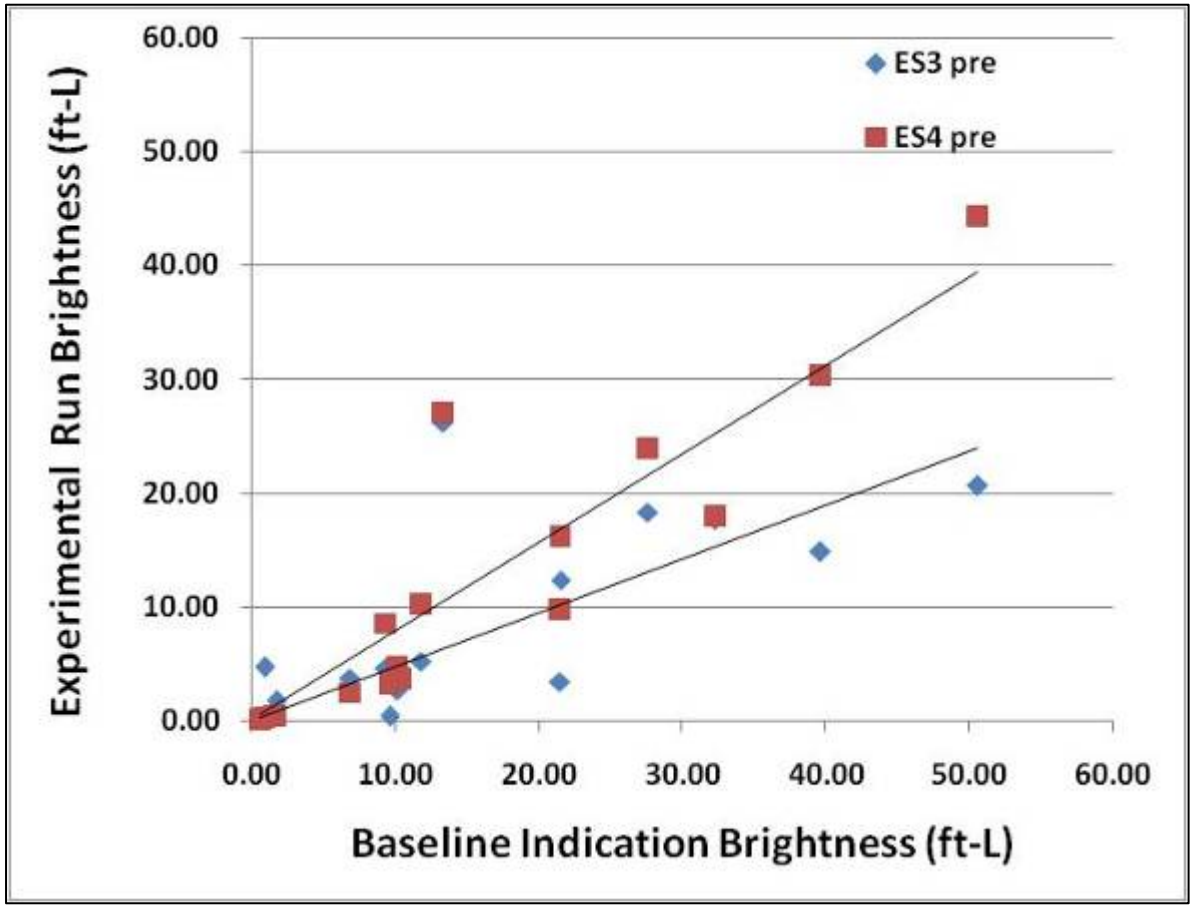


Same data set, but in terms of comparative brightness



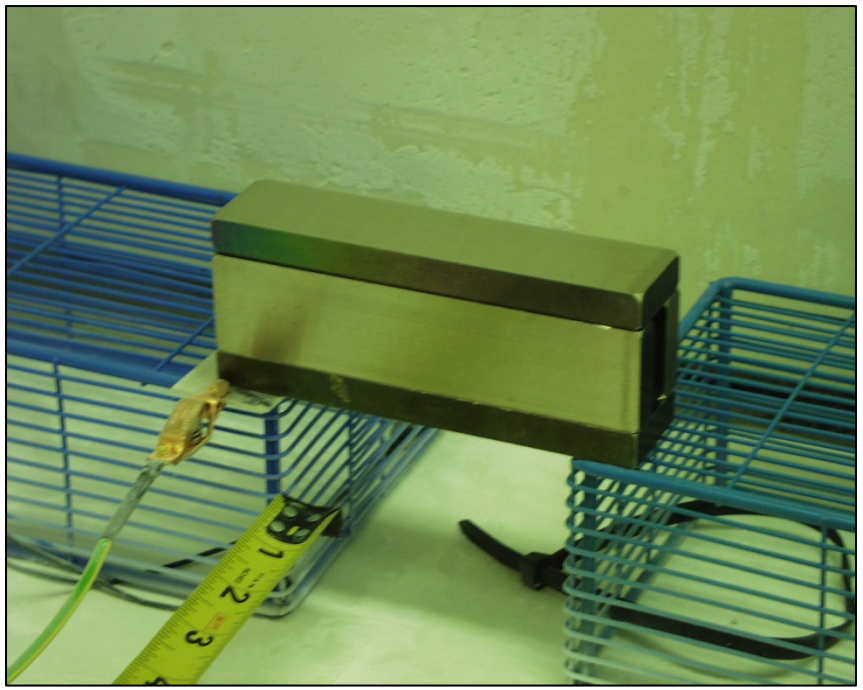
Optimum Spray Time

- The full set of 20 blocks was processed using 3 seconds and 4 seconds of electrostatic spray time to determine the relative effect on a larger sample set
- Processing parameters were the same as those used on the 6-sample runs



Effect of Position

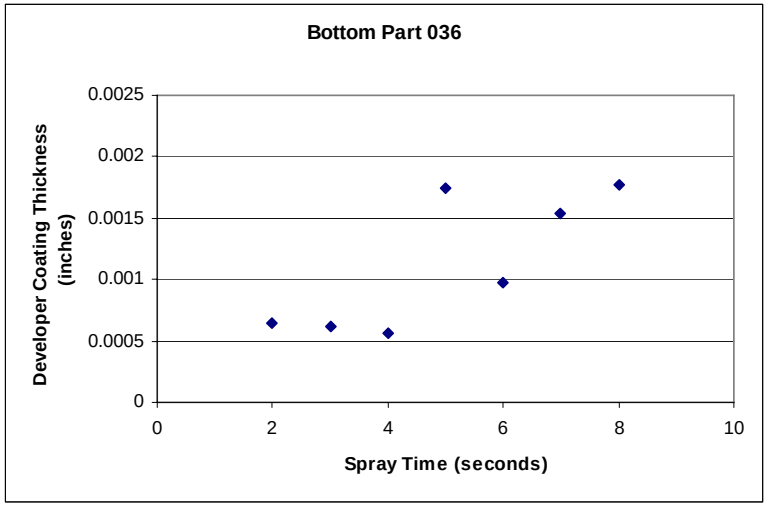
- Four samples chosen that produced similar indication luminance
- Stacked such that crack is facing front, back, top or bottom
- Processed parts in rotation- each sample saw each position
- Sprayed for 3 seconds at 12” stand-off

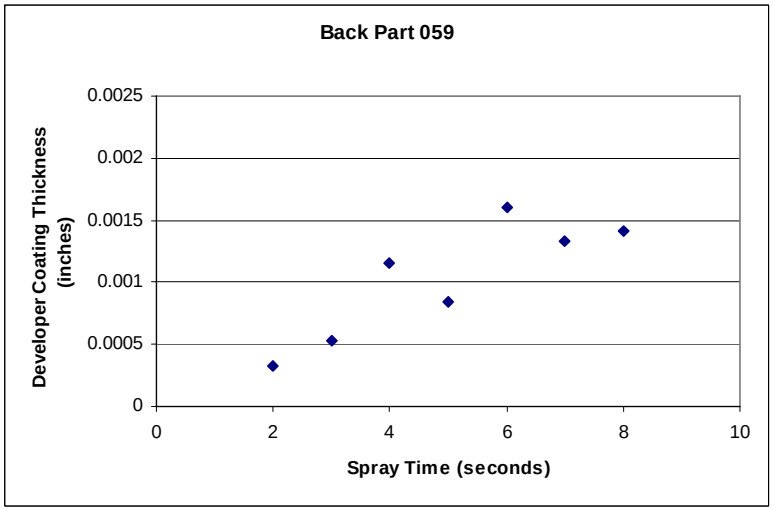


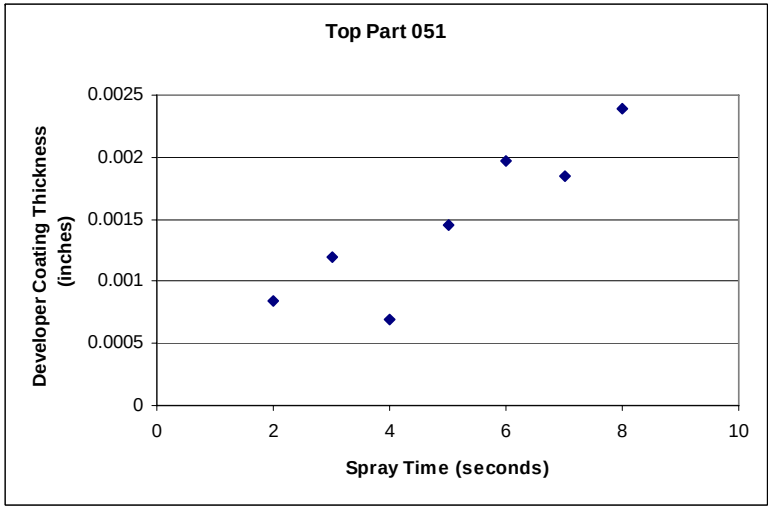
Found that coating thickness and luminance were greatest on front and top surfaces of cluster using this setup.

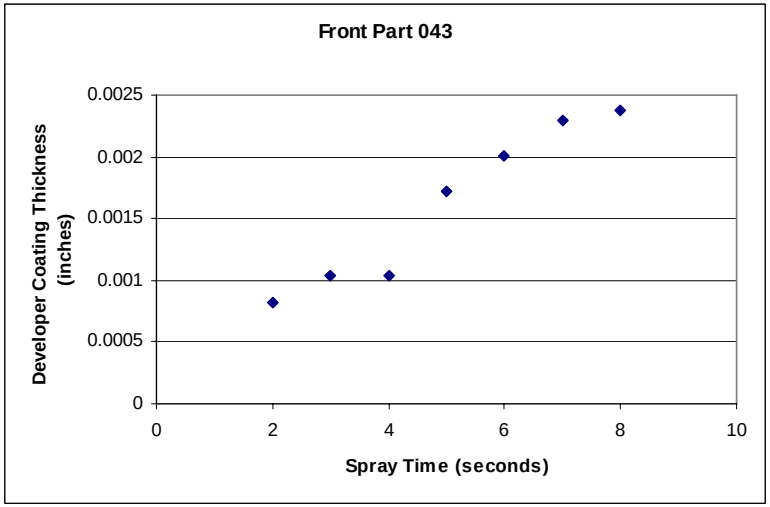
What effect does position have?

- Coating thickness follows linear trend of increasing thickness with increasing time with least variation in the “front” sample





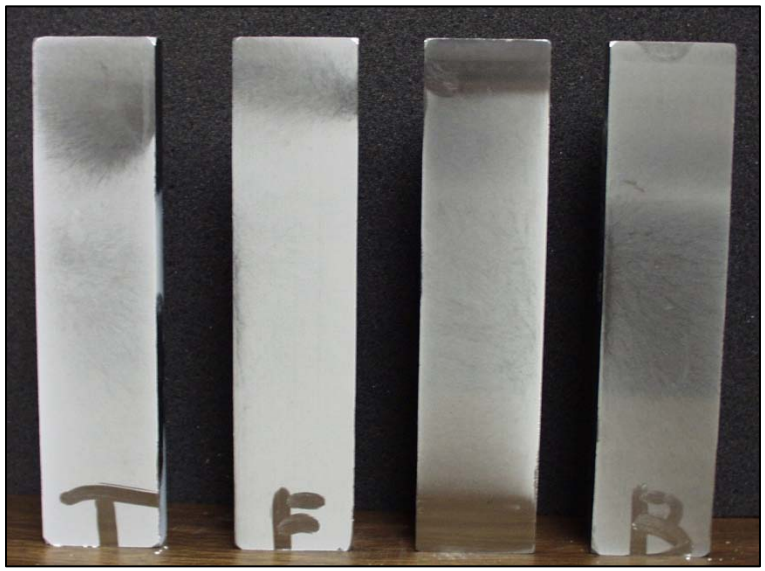




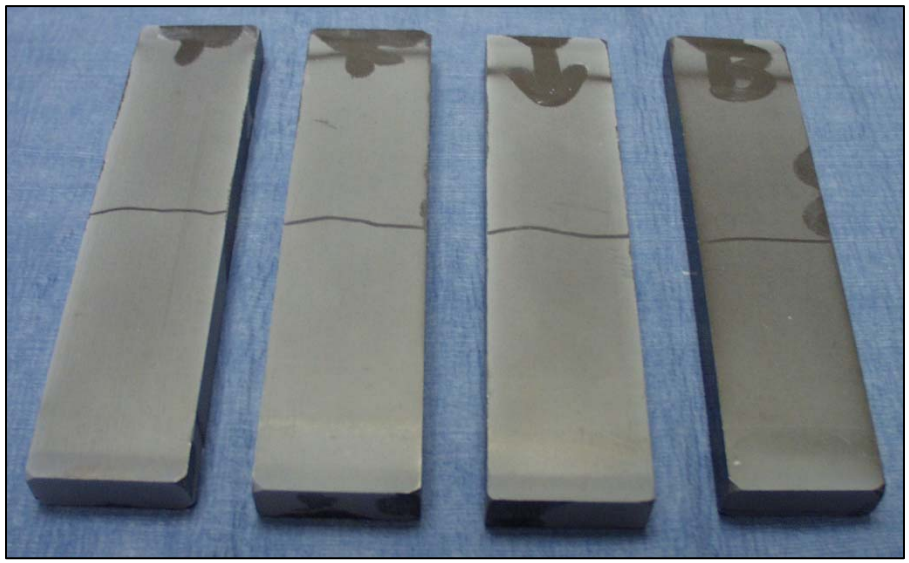
Effect of Position

- 3 sec spray at 24” and 12” with no airflow
- Decreased indication luminance due to increased spray distance
- More even distribution coating thickness around all sides
  - Potential airflow effect

Effect of Position



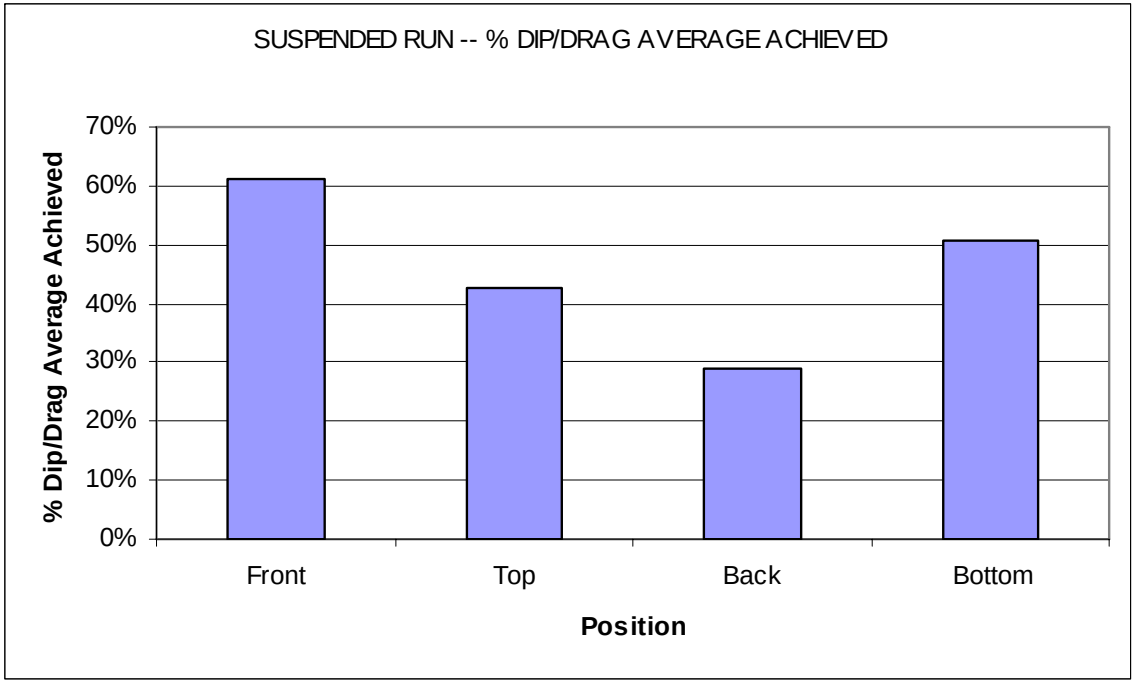
VS.



Performance: Electrostatic vs. Dip/Drag

SUSPENDED RUN -- % DIP/DRAG AVERAGE ACHIEVED

	02-057	*02-058*	*02-066*	*02-090*	*AVERAGE*	*STD DEV*
Front	119.13%	40.66%	28.99%	55.09%	**60.97%**	0.402195
Top	90.58%	12.79%	38.61%	28.75%	**42.68%**	0.336582
Back	27.16%	18.41%	30.31%	40.41%	**29.07%**	0.090781
Bottom	135.51%	20.04%	31.82%	15.85%	**50.80%**	0.568758
					45.88%	



Indication luminance for suspended cycle averaged 46% of the baseline value when results were analyzed by sample and position

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Summary

- Self-development of indications does not occur and use of developer is required to produce optimal indication luminance.
- Variation within chambers evaluated in this study are expected to be representative
  - Recommend that measurements be made of operational chambers to ensure inspectors are aware of any deficient regions.
- Arbitrarily reducing powder volume within a dust storm cabinet, to avoid a mess or reduce powder usage, is not a good choice when seeking the most sensitive inspection possible.
- Obstacles impeding developer motion to sample's surface, such as stacking of baskets, fixtures, rollers, and slings should be noted and avoided when feasible.
  - Additional developer should be applied to affected areas using a dusting bulb, spray wand, or nonaqueous wet developer to ensure adequate and complete coverage of all surfaces.
- In most cases, the location of a crack, i.e., top vs. bottom, is unknown.
  - Recommend processing of parts twice, inverting the part on the second run so that the other surface has the opportunity to be in the most sensitive "up position" during developer application.
  - Add supplemental developer to the lower surface and other critical areas of the component.

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Summary

- In most training programs, the inspector is taught to use a light coat of developer because of concerns with masking indications. While this can be an issue, it is important to ensure that adequate developer is applied.
- When using manual spray wands the inspector should make an effort to apply powder to all surfaces rather than holding the wand near a single location and expecting developer to reach all surfaces.
- Use of evacuation systems too early in the development process can reduce the developer contact with the surface and potentially lead to missing indications.
- In use of Form B and/or Form C developers, it is important to use the manufacturers recommended concentration. In use of immersion systems, care should be taken to ensure pooling of the developer around geometrical features (in crevices and cavities), does not occur. In spray applications, it is important that developer be applied to all surfaces.
- For electrostatic application of developer, a performance characterization study of the system prior to routine use and at periodic intervals is recommended.
- Time necessary to arrive at an optimal coating thickness for the typical part-to-gun distance should be established.
- Given that thickness variation (and resulting indication luminance variations) can occur with respect to the impinging direction of the spray, care should be taken to encircle the part with the spray gun when feasible.