Heliostat Field Flux Evaluation – PHLUX Tool

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Exceptional service in the national interest

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Background

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- A beam characterization system (BCS) is typically used to evaluate a flux distribution from a collector
  - It consists of a digital (e.g., CCD) camera (with neutral density filter), flux gauge or calorimeter and a water-cooled Lambertian target panel
- **PHLUX** uses only a digital camera (DSLR) and an image of the sun to scale the flux distribution from a surface of known reflectance

PHLUX Method

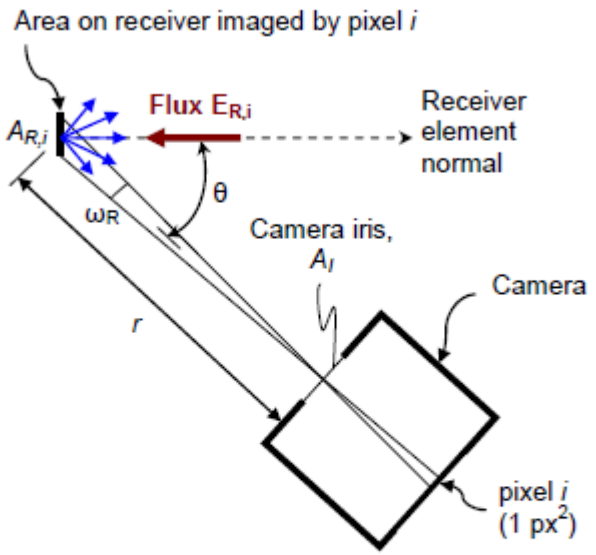

Figure 1. Reflection of irradiance on a small portion of a diffuse receiver toward a CCD camera. The area on the receiver, $A_{R,i}$, corresponds to the area captured by one pixel on the CCD.

Image of heliostat beam on the tower. Tower wall has

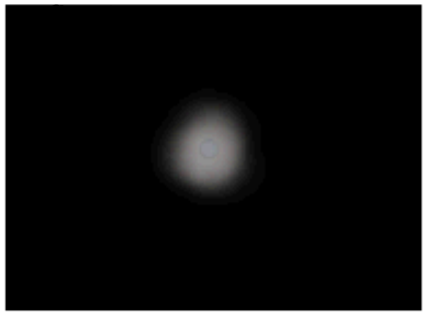

Image of the sun with extra neutral density filters on the camera

Irradiance:

$$E_{R,i} = \frac{(V_{CCD,i} - V_{CCD,i\_ambient})E_{DNI}}{\rho_{R,i}\tan^2(\gamma/2)} \frac{\pi r_{sun\_pixels}^2}{\sum_{sun} V_{CCD\_sun,i}}$$

Ho, C.K. and S.S. Khalsa, 2012, A Photographic Flux Mapping Method for Concentrating Solar Collectors and Receivers, *Journal of Solar Engineering*, 134(4).

DSLR Cameras and Parameters Used

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Parameter	Nikon D90	Nikon D3300
Lens focal length	300 mm	300 mm
Shutter speed	1/4000	1/4000
f-number	f/32	f/32
Image format	RAW (NEF)	RAW (NEF)
White balance	Direct Sunlight	Direct Sunlight

Receiver with Target Panel (Equipped with Kendall Radiometer) to Measure Flux Levels

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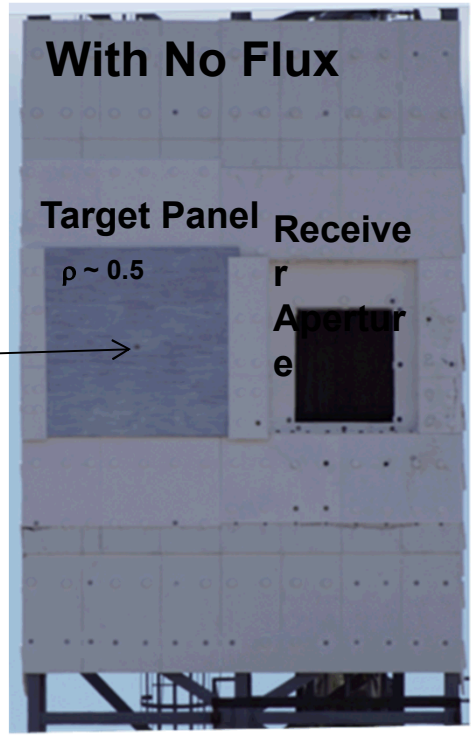
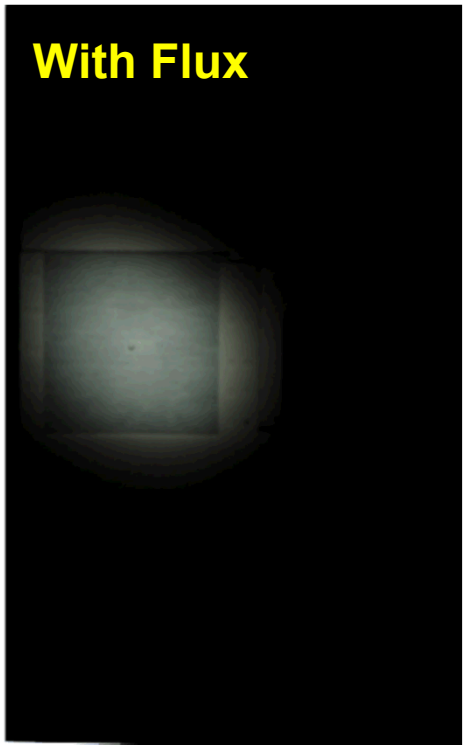
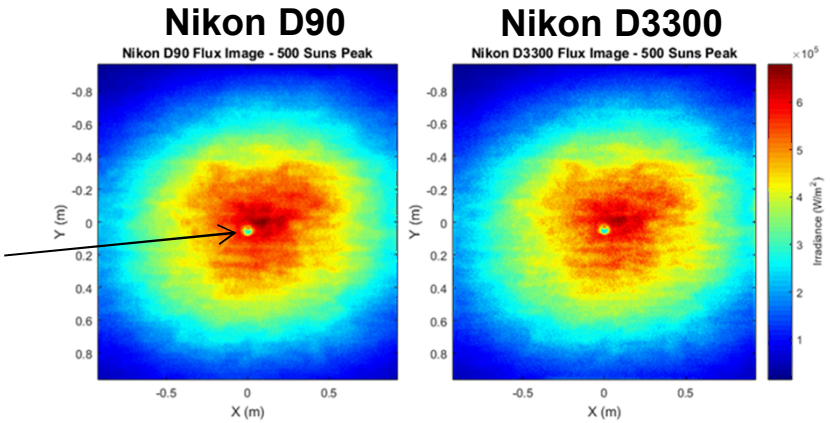
Kendall radiometer





PHLUX Comparison to Kendall Radiometer

Kendall radiometer



Example of **PHLUX**-analyzed flux distributions (at 500 suns level) from the two cameras

PHLUX Analyzed Images		Kendall Radiometer (kW/m^2)
D90 (kW/m^2)	D3000 (kW/m^2)	
350 (0.11)	294 (0.07)	315
564 (0.13)	547 (0.09)	500
1140 (0.10)	1051 (0.02)	1035

Irradiance at the Kendall Radiometer location.
% Errors from the Kendall Radiometer are in parentheses.

PHLUX Uncertainties

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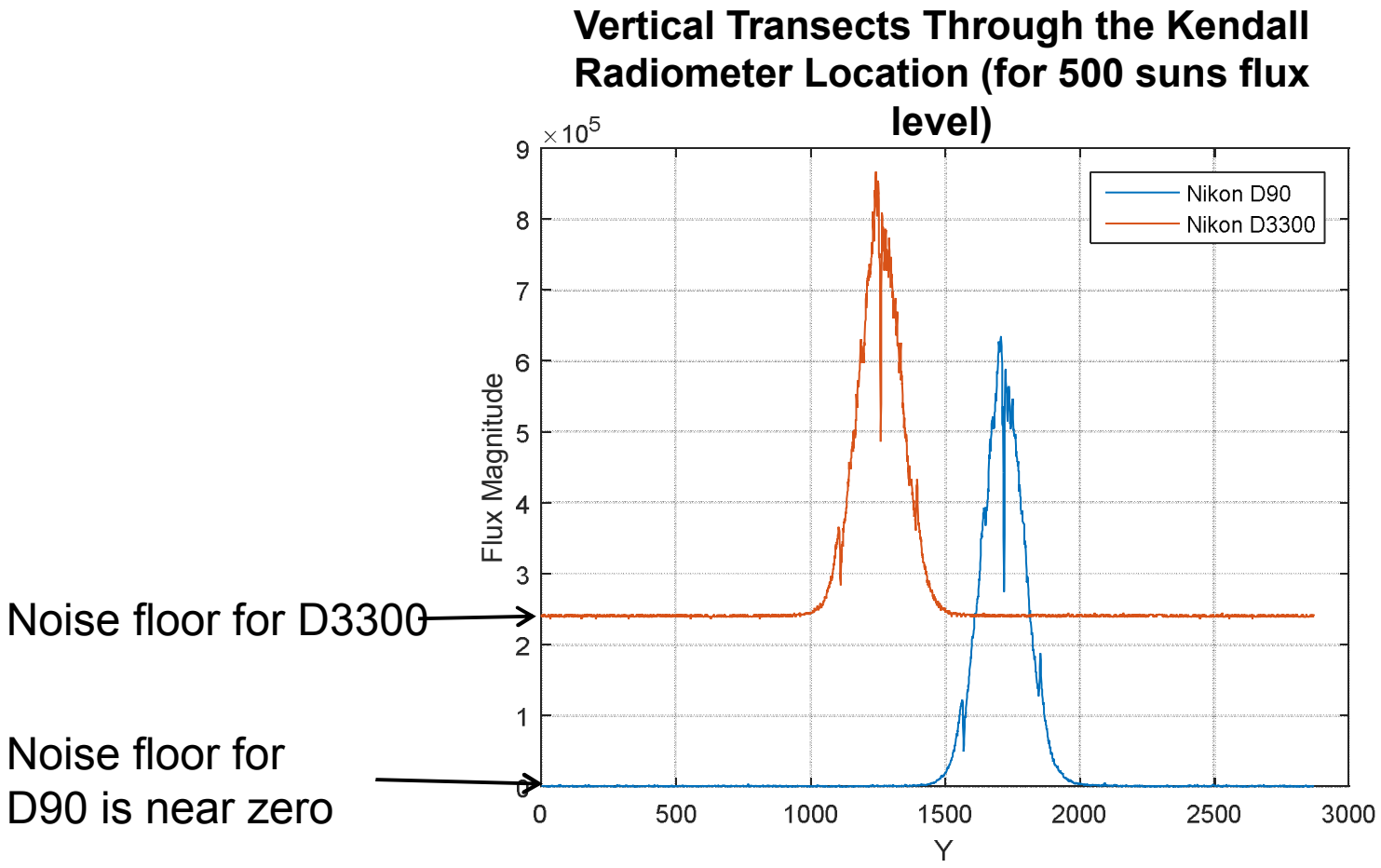
- Target surface reflectance variations
- Accuracy of DNI measurement
- Sunshape
- Filter attenuation variations
- Camera lens focus
- Camera responses (linearity, noise, spectral)
- Atmospheric attenuation over long distances

Image Noise Floor



Impacts of High Image Noise Floor
Particularly from the Nikon D3300

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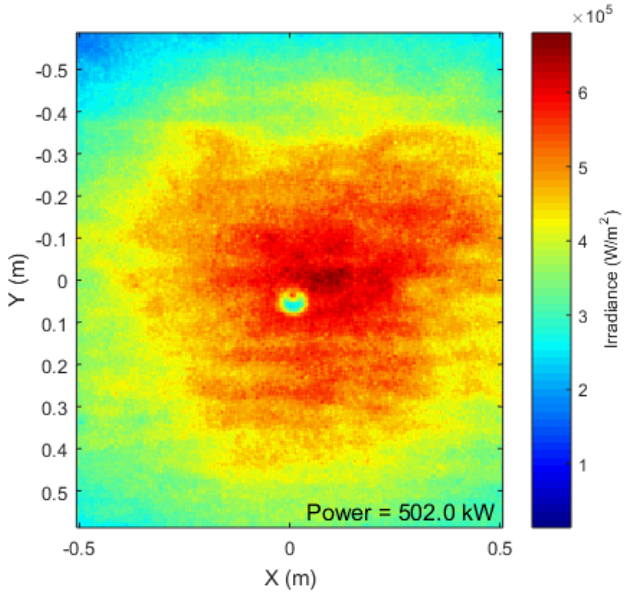
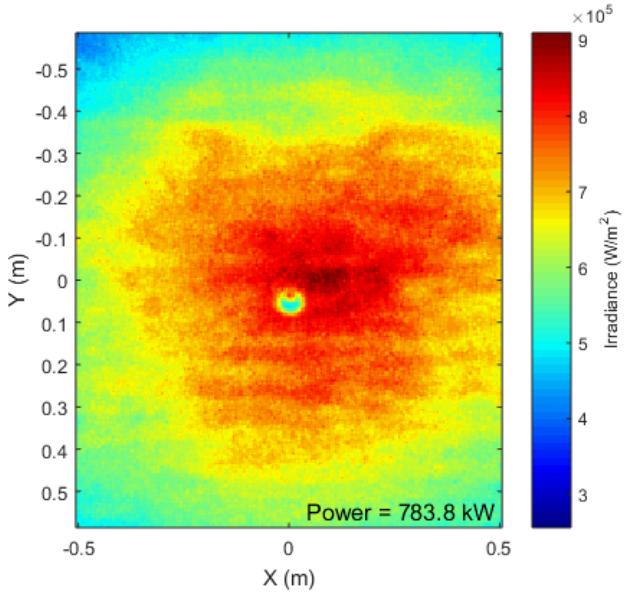
PHLUX Analysis on a Nikon D3300 Image



Flux map <u>with the noise floor removed</u> over the receiver aperture size and the calculated power.



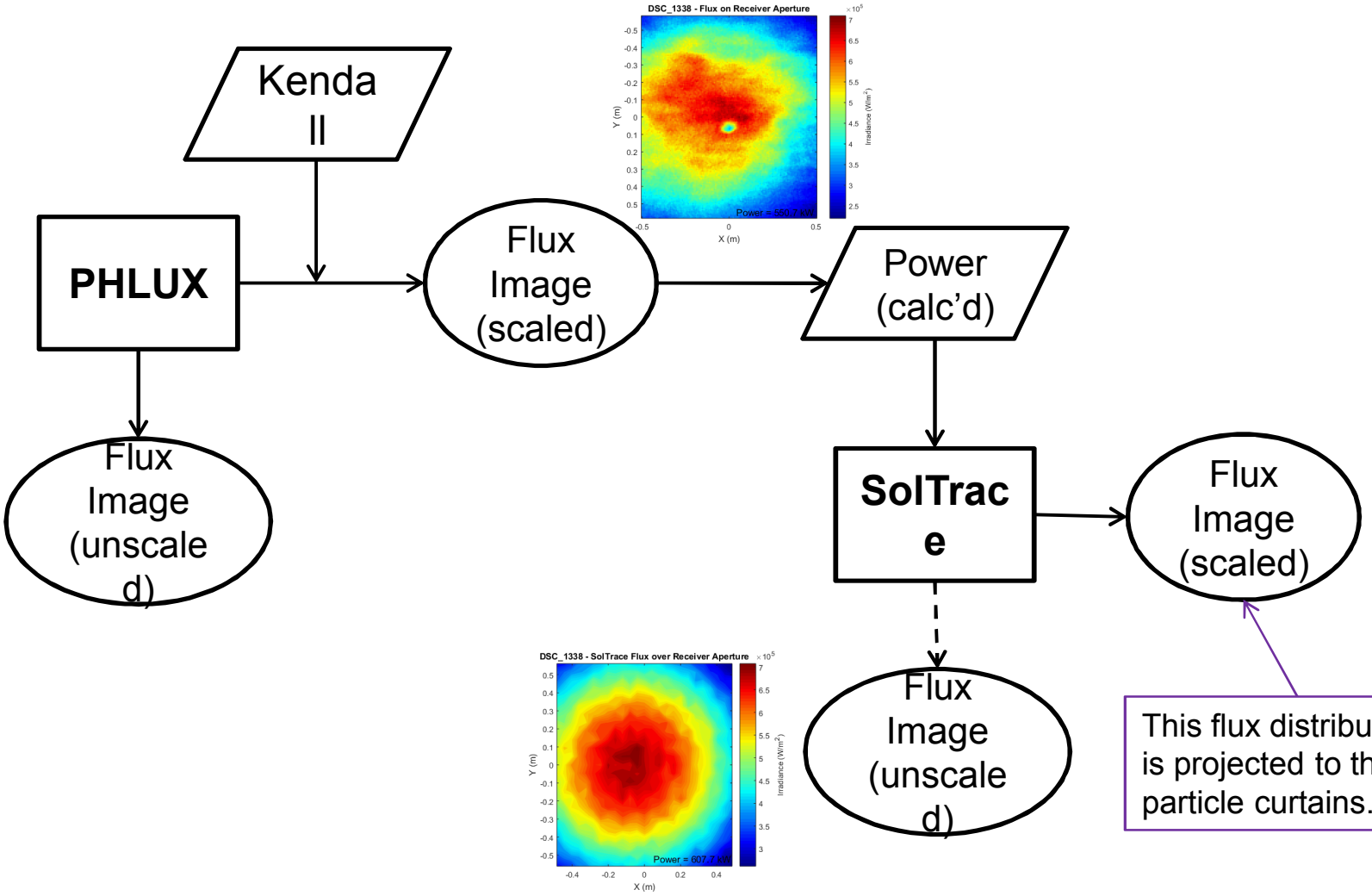
Flux map <u>with the noise included</u> over the receiver aperture size and the calculated power.

Calculated power over the aperture = 502 kW

Calculated power over the aperture = 784 kW

56% Error!

Flux Image Analysis Flowchart



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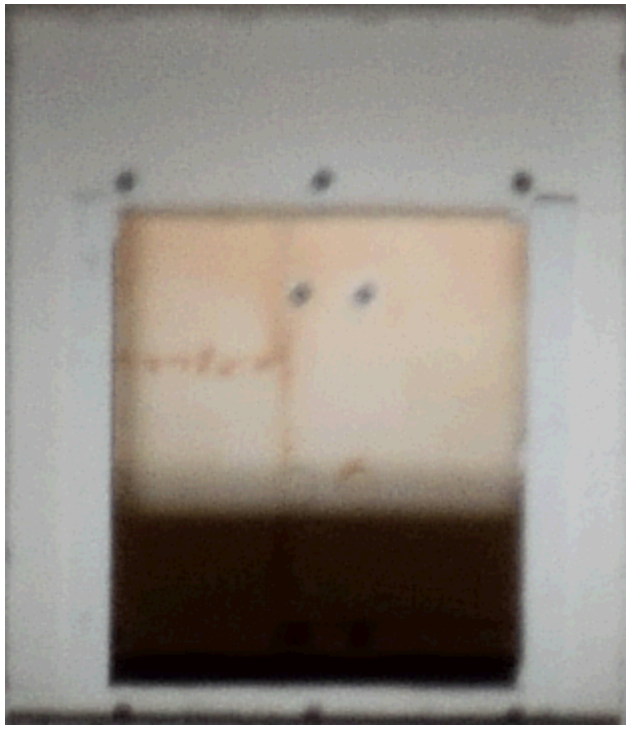
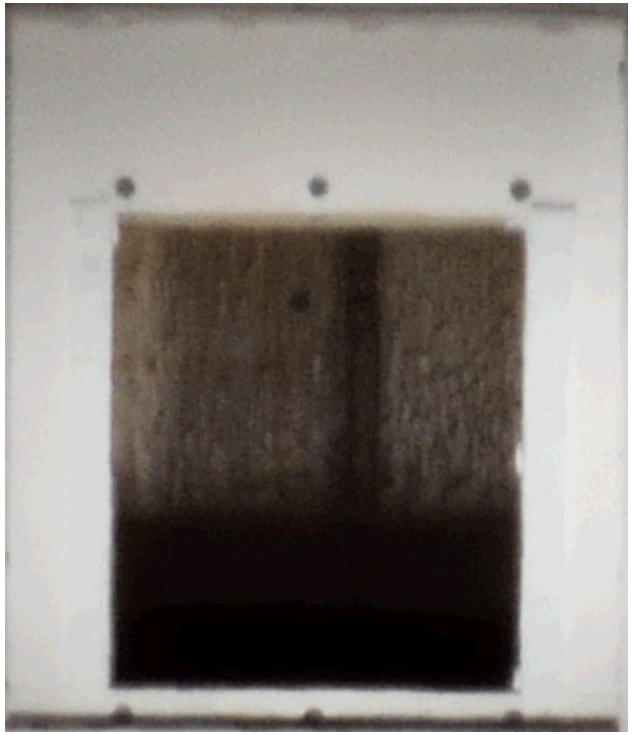
PARTICLE CURTAIN TRANSMITTANCE TEST

Front Curtain Particle Flow

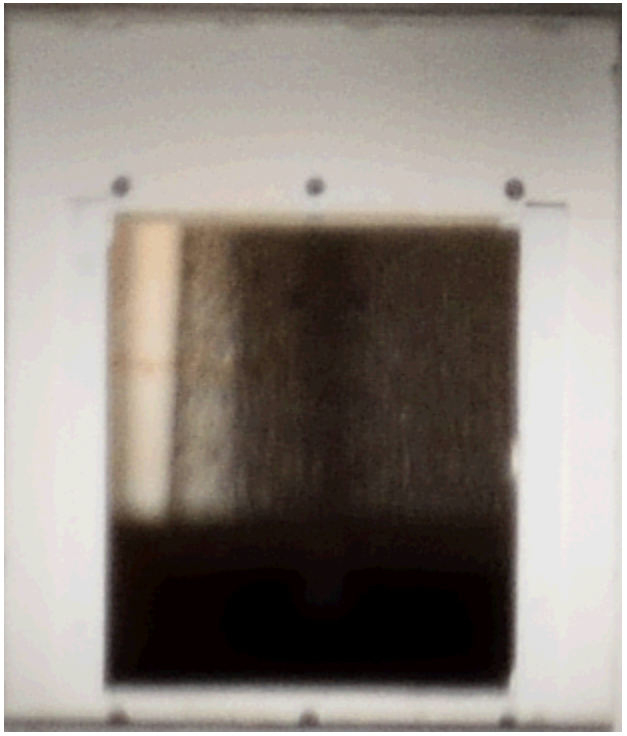
Front Illumination





3/8” steel plates
23 Hz
Illumination from 4 heliostats

Back Curtain Particle Flow
Front Illumination

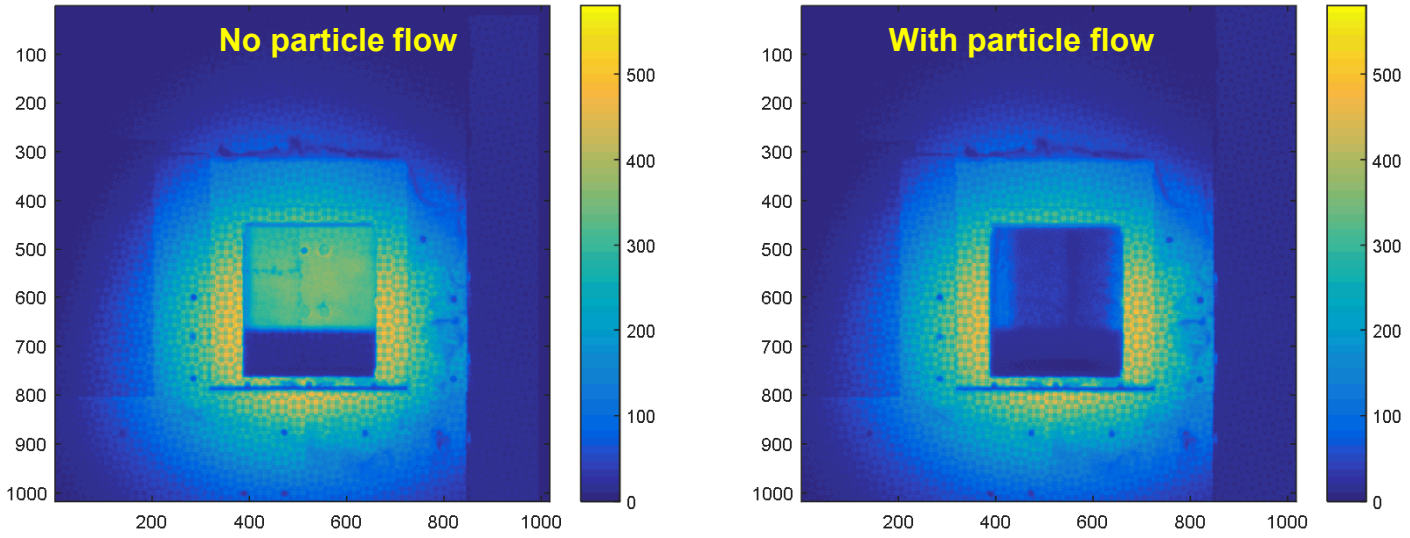


3/8” steel plates
26 Hz
Illumination from 2 heliostats

Front Curtain Particle Flow

Front Illumination

Images processed in Matlab.



xx" steel plates – not recorded in the data logsheet
23 Hz
Illumination from 8 heliostats

Front Curtain Particle Flow
Back Illumination

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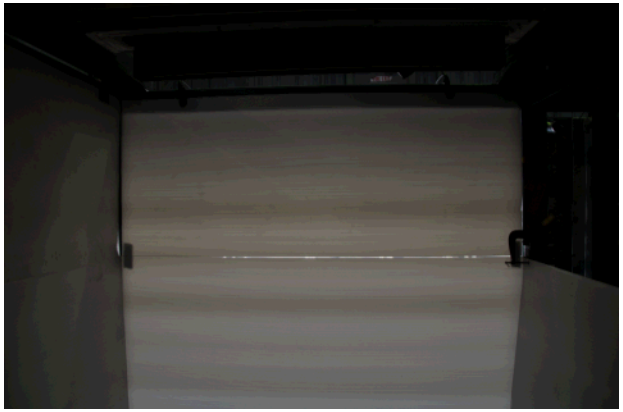
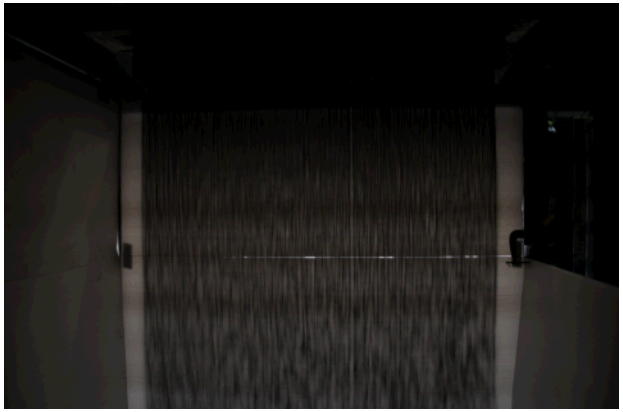
Frame Set for Shutter Speed Setting 1/60

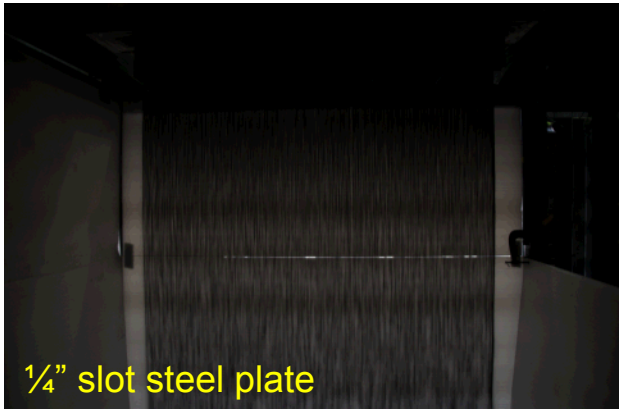
Frame #435 (no particles)



Frame #444 (w/ particles)

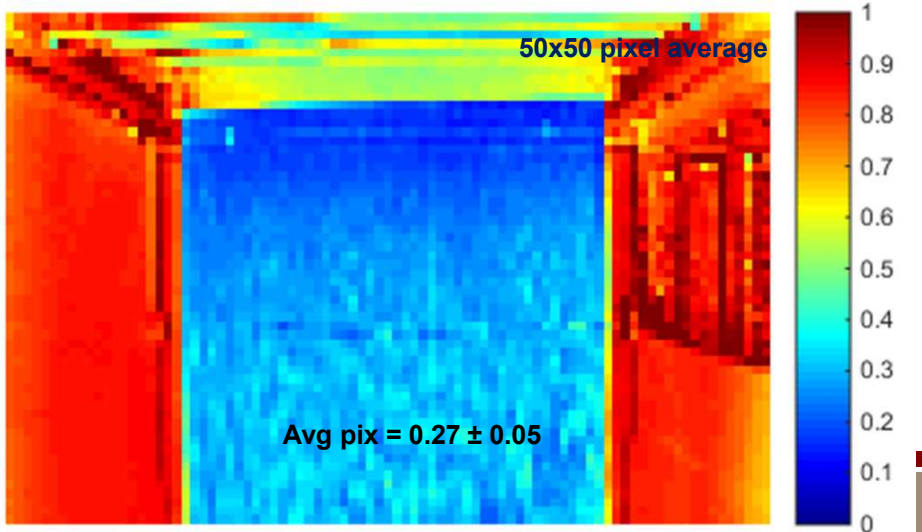


Frame #445 (w/ particles)

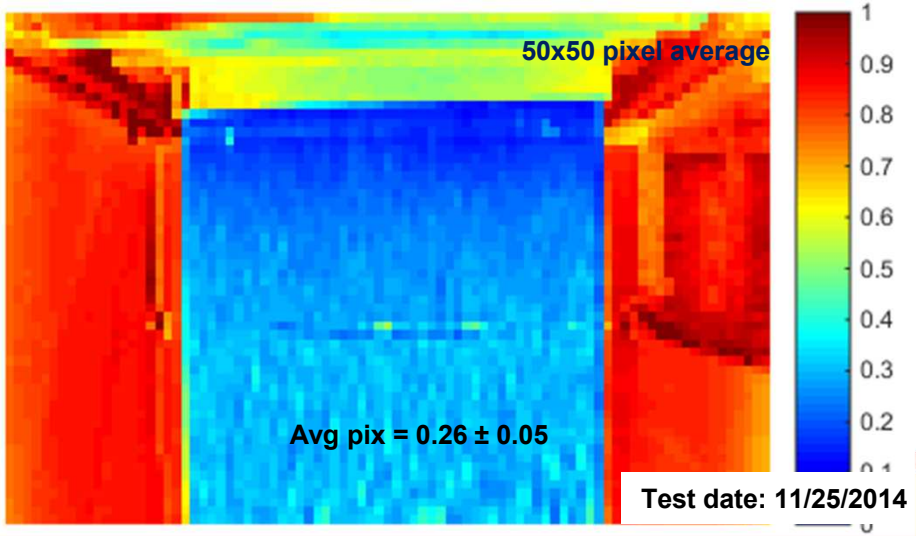


RATIOED FRAMES

Frame 444 / Frame 435



Frame 445 / Frame 435



Test date: 11/25/2014

Front Curtain Particle Flow
Back Illumination

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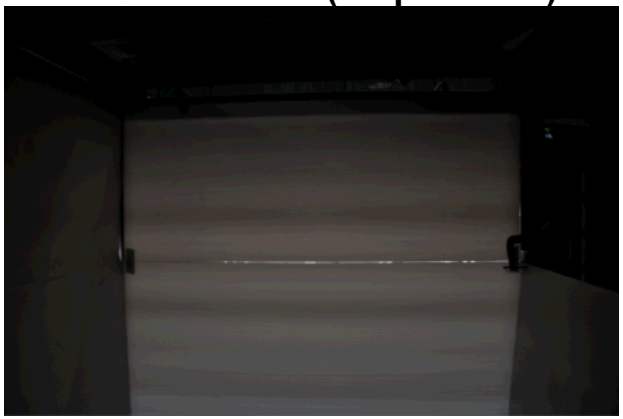
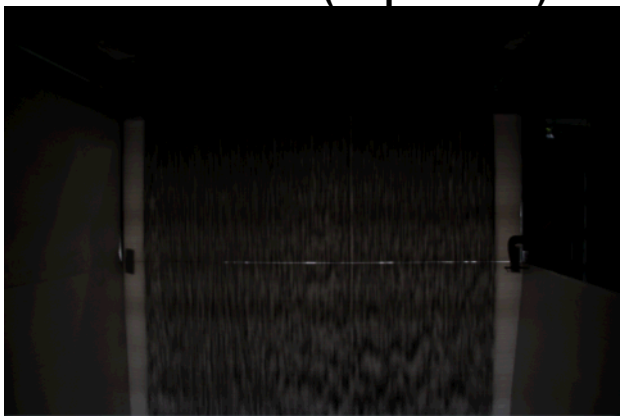
Frame Set for Shutter Speed Setting 1/100

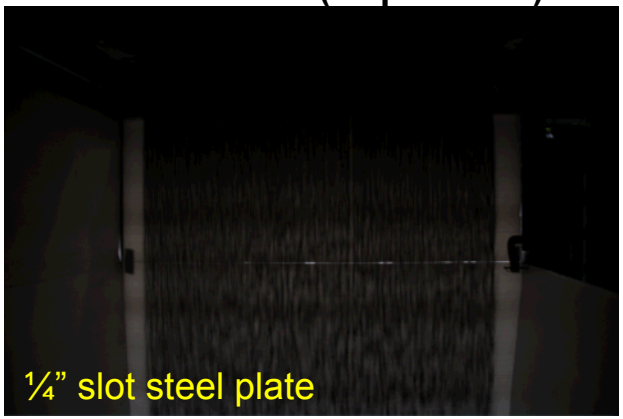
Frame #436 (no particles)



Frame #440 (w/ particles)

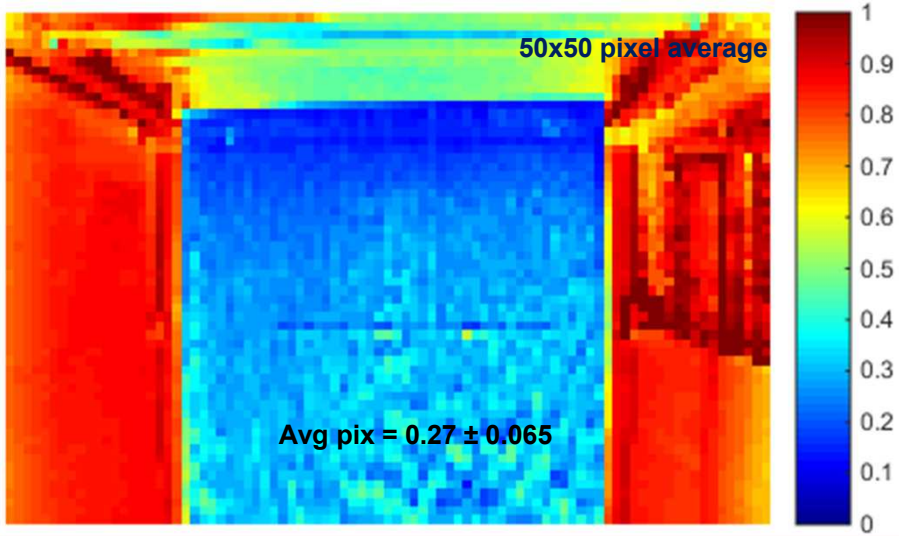


Frame #441 (w/ particles)

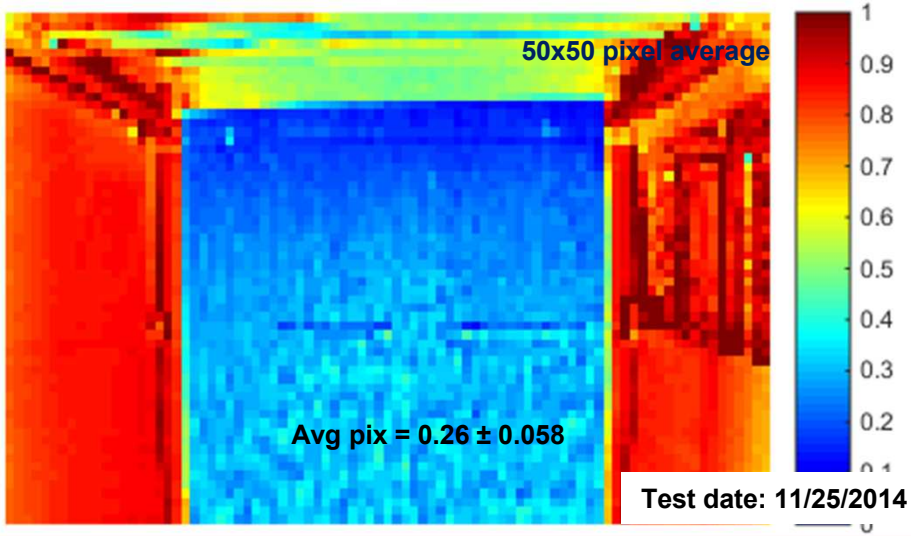


RATIOED FRAMES

Frame 440 / Frame 436



Frame 441 / Frame 436



Test date: 11/25/2014

Front Curtain Particle Flow
Back Illumination

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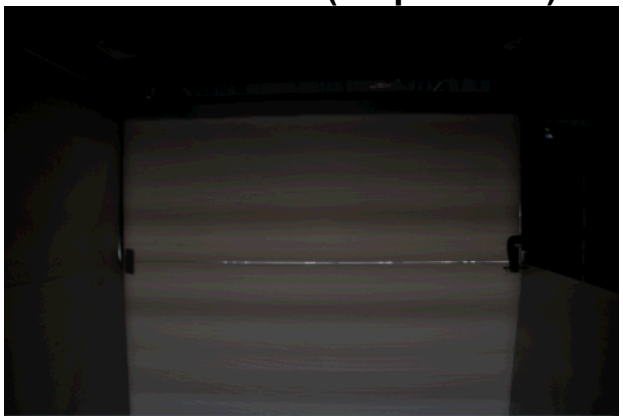
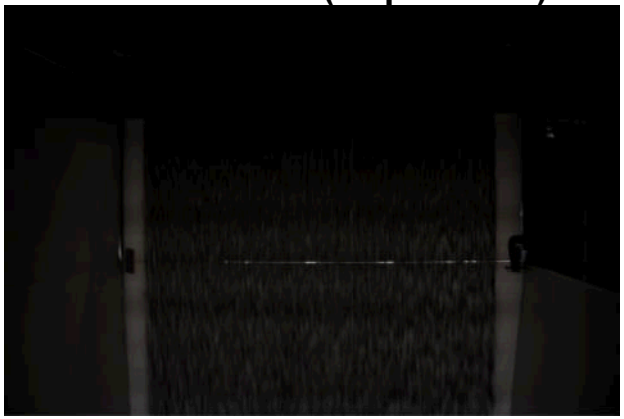
Frame Set for Shutter Speed Setting 1/125

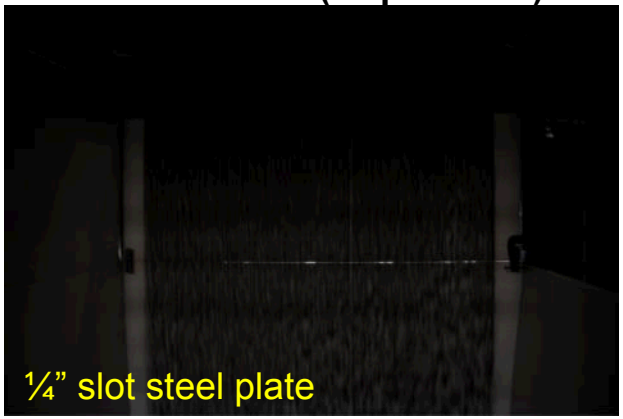
Frame #437 (no particles)



Frame #438 (w/ particles)

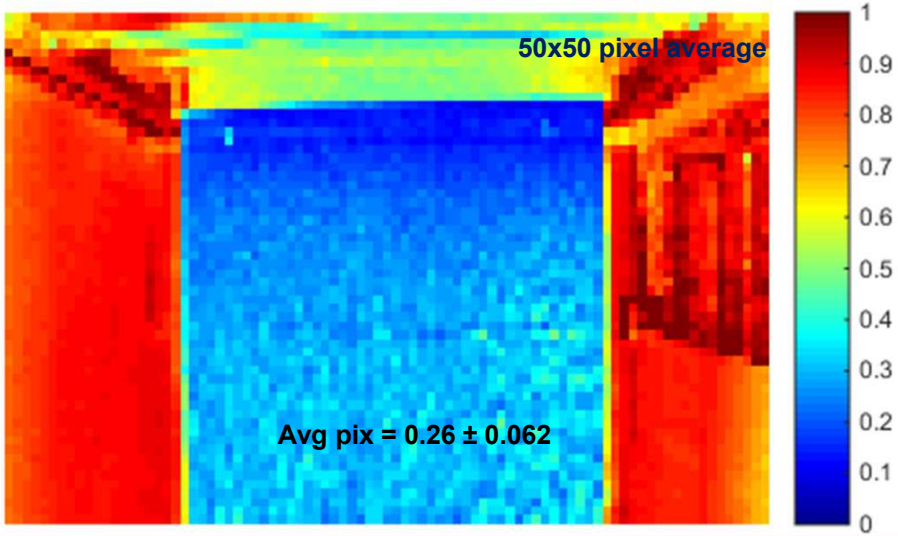


Frame #439 (w/ particles)

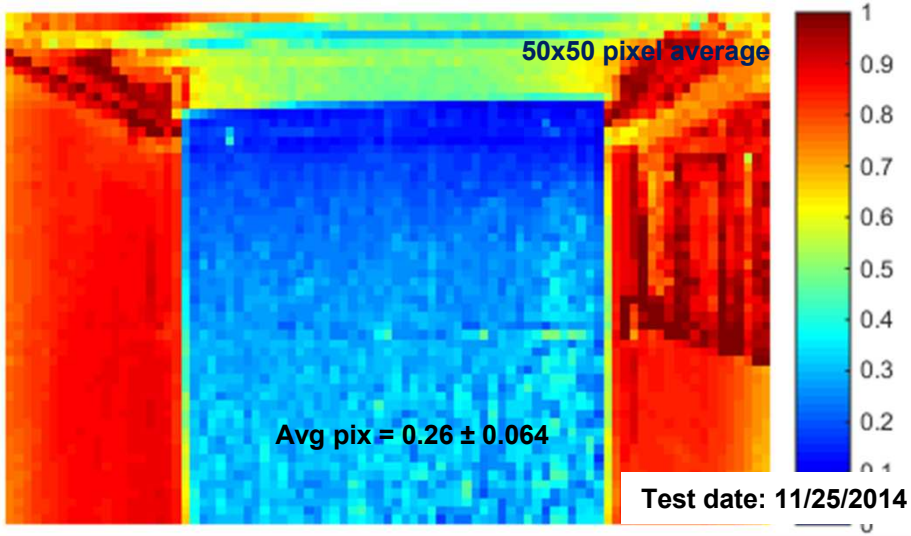


RATIOED FRAMES

Frame 438 / Frame 437

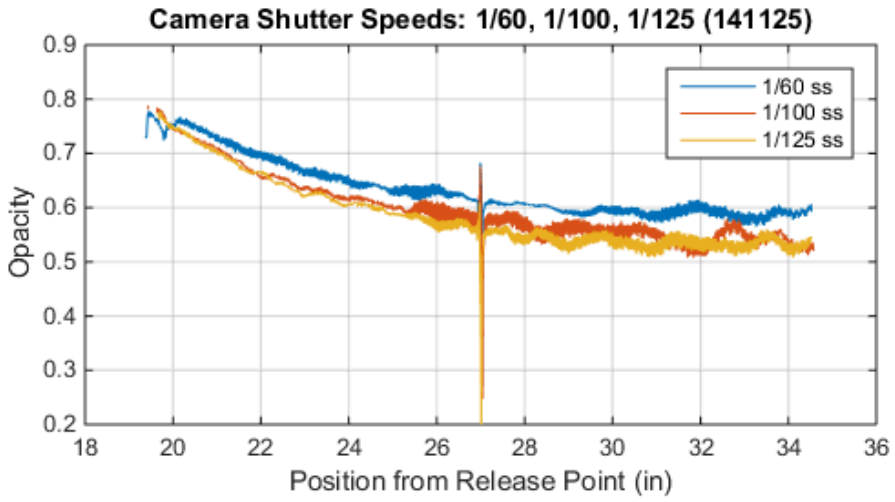


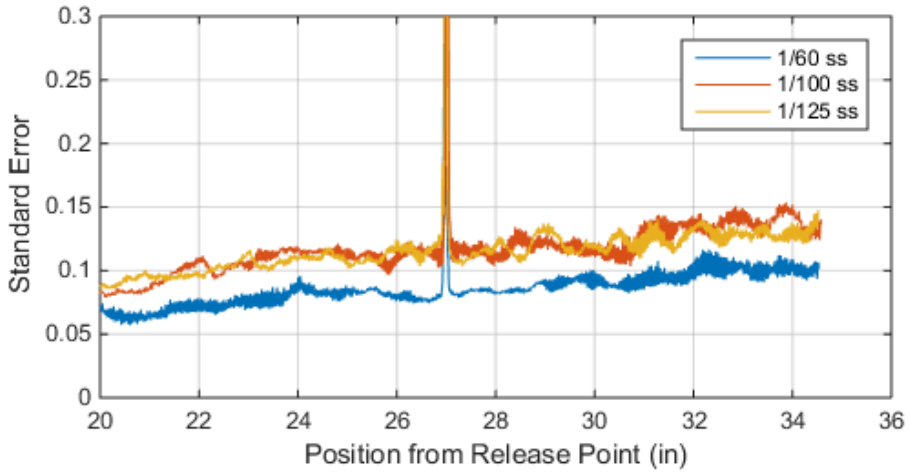
Frame 439 / Frame 437



Test date: 11/25/2014

Opacity Using Back-Lit Particle Flows





¼” slot steel plate

Test date: 11/25/2014

Opacity Calculations from Back-Lighting the Particle Flows

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