Microsatellite Star Tracking Baffles: Validation and Testing

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Purpose

- Star tracker baffles are designed to attenuate light originating from bright celestial objects that lie outside of a sensor field of view (FOV).
- Baffles scale independently with the size of the parent satellite.
- For small satellites with limited payload space, baffles compete with other subsystems.
- Baffle size must be minimized while preserving an avoidance angle.

- Demands an accurate method to characterize a baffle's performance.

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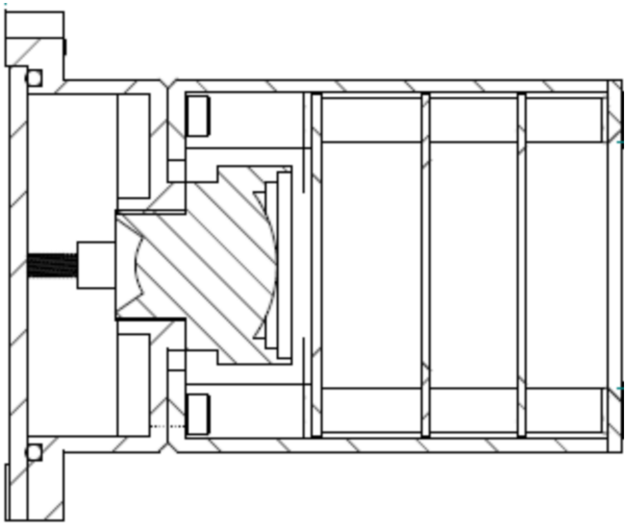
Baffle Design

- Design and analysis performed using non-sequential ray-tracing software like Zemax, FRED, or ASAP.
- Surface properties crucial to accurate results.
  - BRDF/BSDF/BDRF often important for ‘black’ materials.
  - May not be known or only poorly characterized.
- Experimental validation is required to obtain confidence in the system.



Validation Issues

- On-orbit validation would be ideal if neglecting the resulting high costs.
- Must look towards atmospheric based validation.

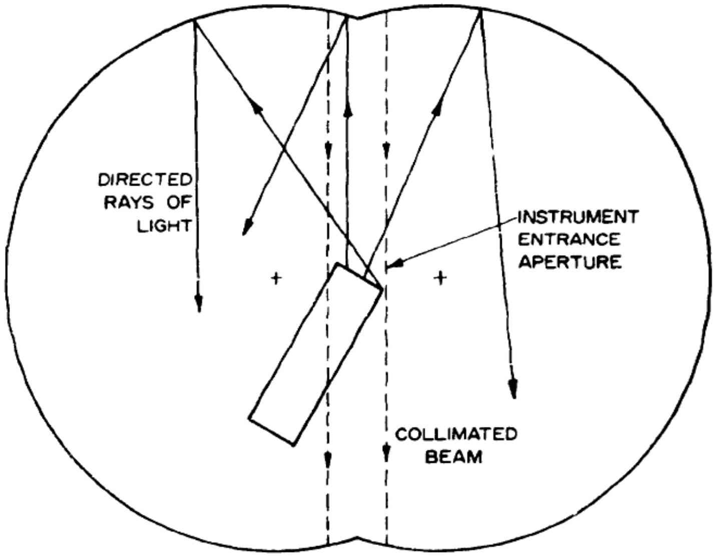
- Difficult to replicate very bright off-axis illumination and dim background scene within the same FOV.
- Light illuminating the volume of air in front of the sensor will contribute unwanted scattered photons to enter the optical system.

- **Is there a way of validating baffle performance in the atmosphere using modest equipment?**

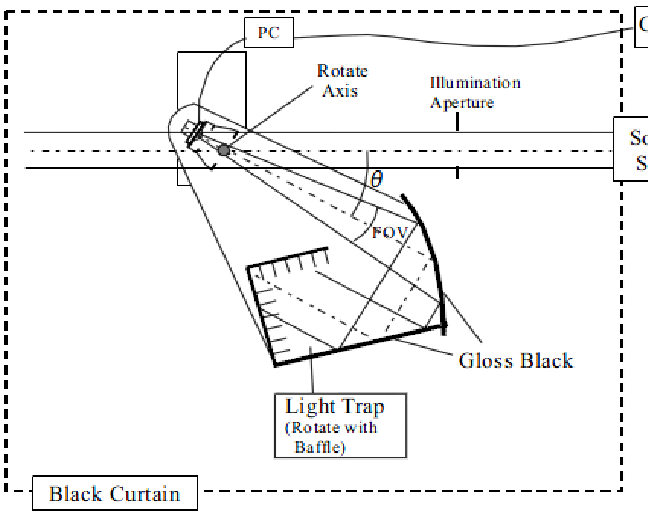
Previous Methods

	Schenkel (1972)	Kemp and Wyatt (1976)	Bock et. Al (1995)	Kawano et. Al (2005)
Test Environment	12 ft. long light tunnel.	Custom designed chamber.	Testing performed on rooftop.	Black curtain enveloping the test area.
Beam Management	Interior of tunnel is baffled to reduce reflections.	Internal chamber designed to deflect scattered rays away from the sensor boresight.	Beam reflection and scattering dumped into open space (Unlikely to ever return to the sensor).	Light trap constructed to absorb reflected light.
Atmospheric Management	None. Although the thought is reasoned with. Suggests a sophisticated vacuum chamber	Chamber is well ventilated and filtered to remove particles.	Atmospheric scattering was isolated using a blocked beam approach.	Dust and particles are removed via HEPA filter.

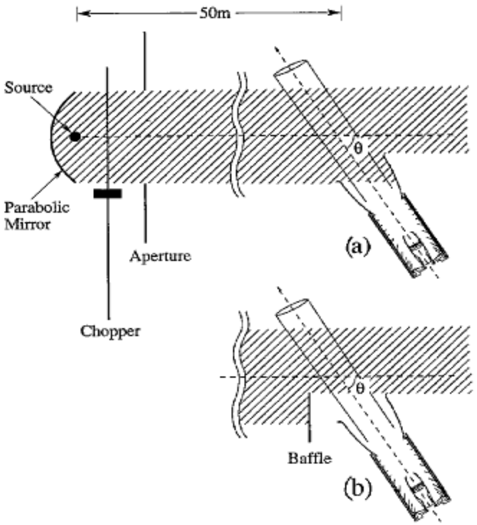
Previous Methods Cont.



Kemp and Wyatt (1976)

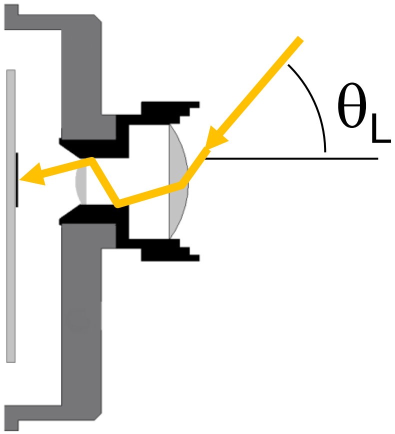


Kawano, et al. (2005)

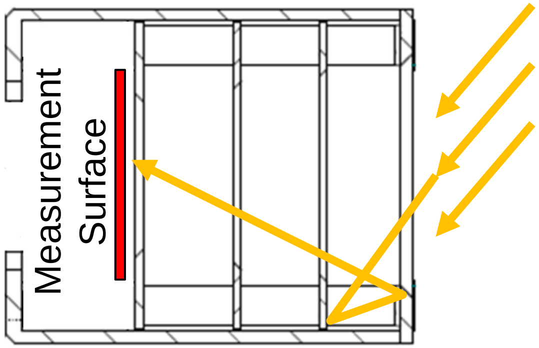


Bock, et al (1995)

Our Approach



separate problem



Lab Testing: Wide-Angle Lens Response

Ray Tracing: Baffle Analysis

- Difficult to be confident in ray tracing alone
  - Materials uncertainty
  - Lens Uncertainty
  - End-to-end ray-tracing non-trivial
- Separate problem in two
  - Lab testing to determine wide angle lens response [Arnoux]
  - Ray-tracing predicts ray intensity and incidence angles
- Use blocked-beam approach (Bock, et al) for lab testing

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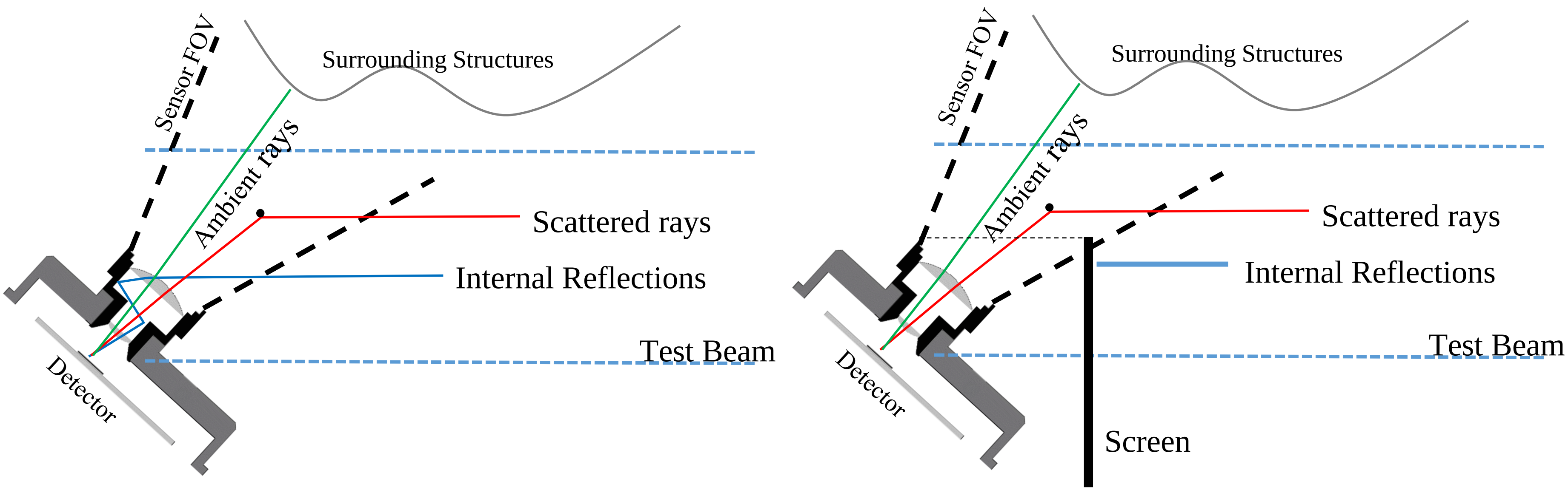
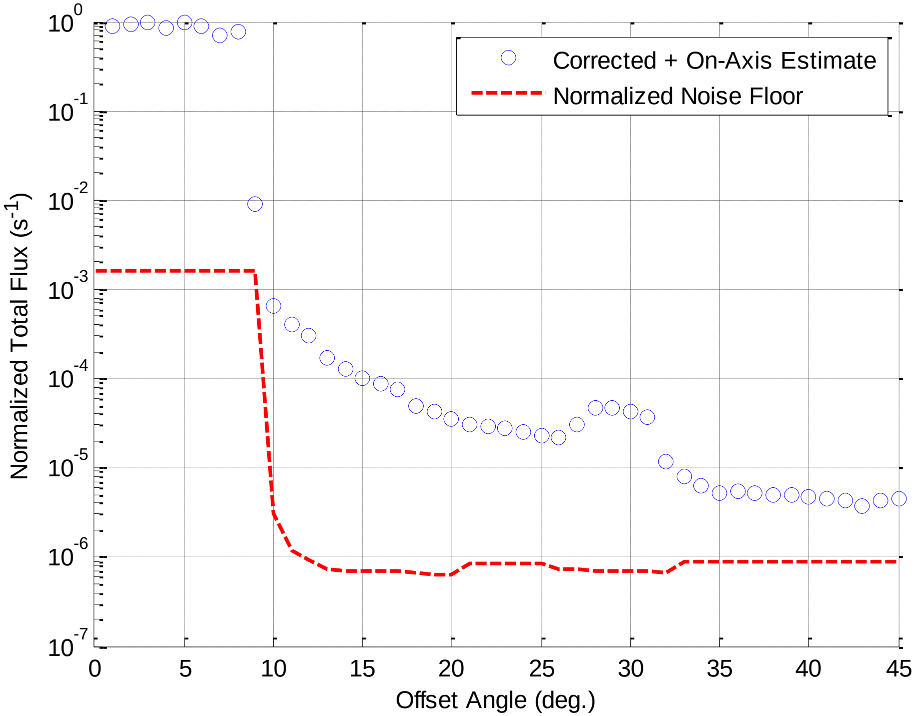
Wide-Angle Lens Testing



- Two off axis tests are required.
  - Full beam encompasses every type of ray.
  - Blocking the beam removes the direct rays.
- Secondary considerations:
  - Manage dark response
  - Estimate noise floor
  - Account for saturation

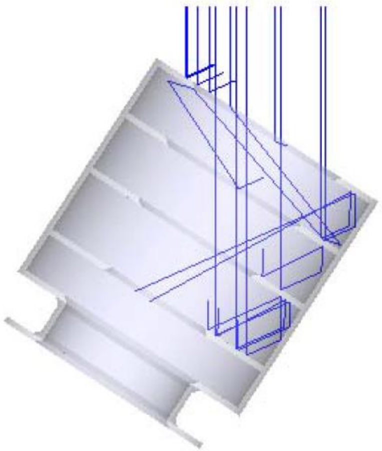
Lens-only Results

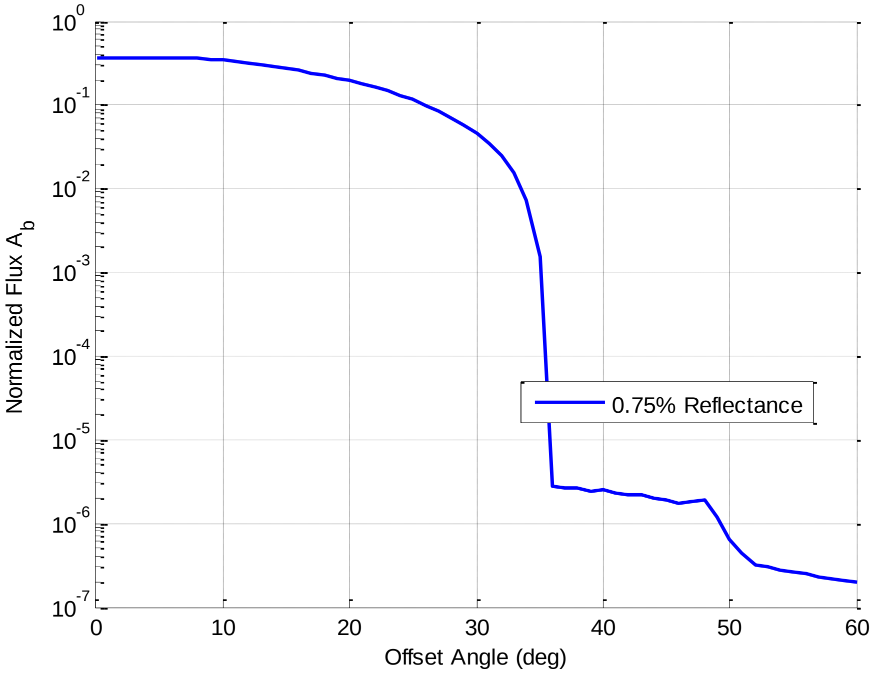
- What does this mean?
  - We characterize the light response of the sensor as a function of offset angle. Observe lens-only attenuation.
- We can also apply this method to baffle + sensor configurations.



Ray Tracing

- Non-Sequential Ray tracing software is used to determine initial baffle performance.
- Initial designs can be refined based on sensor size and can be tested in the software.
- Surface properties are subject to assumptions and lab testing reinforces surface properties.





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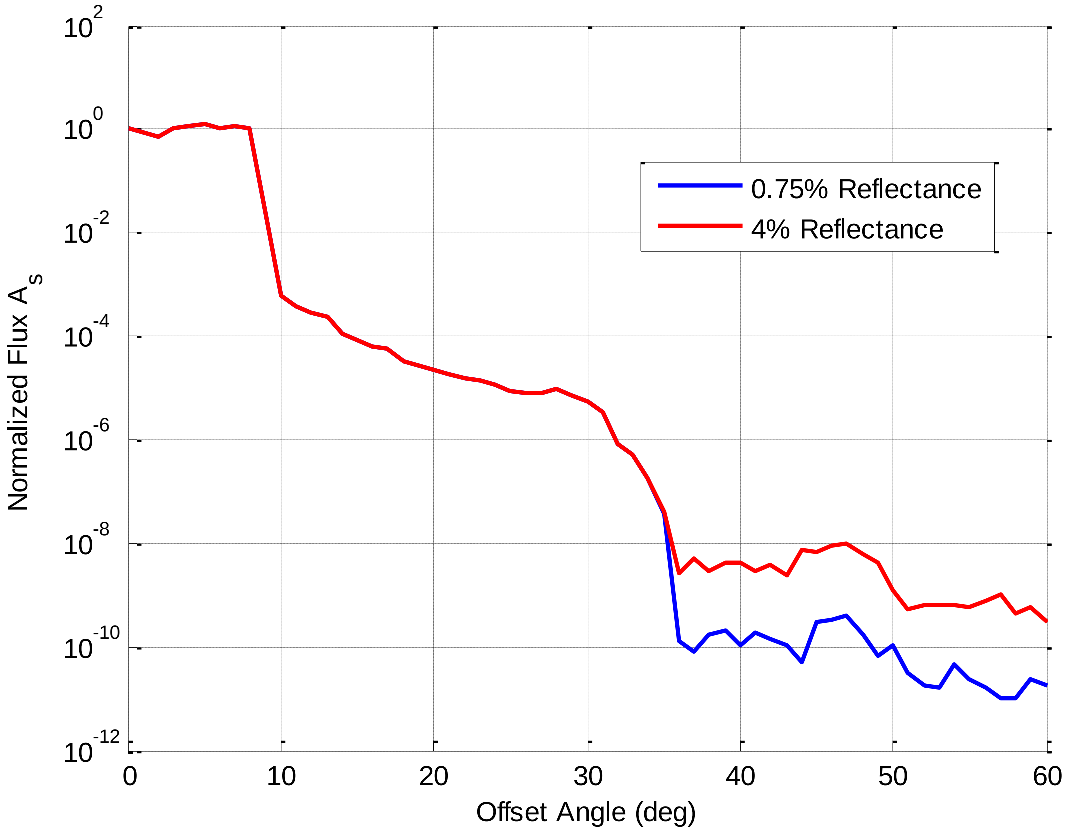
Integration

- To refine baffle performance predictions, both baffle ray tracing and lens response data must be combined to generate total system performance predictions.
- A total attenuation of 10^{-8} is required.



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Summary

- Surveyed terrestrial stray light testing techniques.
  - Long history, but takes a little digging
- Devised testing strategy suitable for modest test facility
  - Small beam
  - Simple beam management
  - No clean requirements
- Facility cannot test over whole attenuation range; hybrid approach needed
  - Ray trace baffle analysis
  - Wide-angle lens characterization
- Lens testing shows variety of behaviours
  - Attenuation
  - Internal reflections and other spatial effects (see paper)
- Full system analysis suggests ~35° exclusion angle for ST16

Future Work

- Explore other methods to apply lens attenuation within Zemax.
- Account for spatial lens effects in addition off-axis alone.
  - Rays behave differently based on where it strikes the lens.
- Perform total system analysis using the proposed stray light test with a more capable facility.
  - Allow us to validate our ray tracing assumptions.