Toward standardization of the DBI diagnostic

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Introduction

- Extinction imaging isolates attenuation by scattering and absorption
- Diffused lighting
- Many optical setups aimed at imaging extinction
- Diffused lighting is a diffuse description
DBI applied within ECN

- Liquid (Sandia Spray A)
- Soot (CMT Spray G)
- Liquid (Sandia Spray G)

New DBI setup performance

Liquid

Soot

(Sandia
Spray A)

(CMT
Spray G)
Toward standardization of the DBI diagnostic

DBI applied within ECN

25.4 mm 30°
eng. diff. 150 mm Fresnel lens
f=150 mm

LED
Parabolic reflector

Focal plane
Acceptance cone

50 mm f/1.2 lens w/ 2 diopter close-up lens

Liquid
Soot

(Sandia Spray A)
(Liquid (CMT Spray G)

(Sandia Spray G)

Liquid
Soot

(Sandia Spray A)

Toward standardization of the DBI diagnostic
DBI applied within ECN

25.4 mm 30° eng. diff.
150 mm Fresnel lens
f=150 mm

Parabolic reflector

L
>150 mm

Focal plane

Acceptance cone

50 mm f/1.2 lens w/ 2 diopter close-up lens

(Caterpillar Spray D)

(C Sandia Spray D)

Toward standardization of the DBI diagnostic
Beam steering effect
Lighting characteristics

• 3 fundamental refractive scenarios

Parallel faced

Non-parallel faced

Lens

Non-planar faced

Extended light source

Refracting media

Lens diagram

n²ΩA and n²L are conserved
Dimensioning for high speed

- Lambertian emitters are inefficient
- High light throughput required for high speed imaging
- Light throughput maximized with engineered diffuser
- Dimensioning according to collection optics and geometrical constraints

\[ \beta \geq 2\alpha_{\text{max}} + 2\zeta \]
\[ D \geq S + 2\tan(\alpha_{\text{max}} + \zeta)L \]
Characterization of DBI setup

- Characterize the angles being collected from the source
- The largest angle, $\alpha_{\text{max}}$, is collected at in the periphery

- Measure the magnitude of beamsteering $\zeta$

- Characterize spatial and angular uniformity
- Angular uniformity in image plane depends on angular and spatial uniformity
Revisit the CAT/Sandia measurements

Illumination pattern
LED+parabolic reflector
Extinction imaging

150 mm Fresnel lens 
f=150 mm

100 mm 15° eng. diff.

50 mm f/1.2 lens w/ 2 diopter close-up lens

Collimated input to diffuser

I [W, sr⁻¹]

0  0.2  0.4  0.6  0.8  1

-20 -15 -10 -5  0  5  10  15  20

Angle [deg]

LED

Focal plane

Acceptance cone

L

0

150 mm
Extinction imaging
Extinction imaging

\[ KL = -\ln \left( \frac{I}{I_0} \right) \]
Extinction imaging

Toward standardization of the DBI diagnostic
**Extinction imaging**

![Diagram](image)

Toward standardization of the DBI diagnostic
Summary

- A theoretical description of the lighting characteristics needed to eliminate beam steering
- Guide to designing an optical setup suited for high speed application
- Methods for characterizing the setup
- Respective institutions should characterize a setup suitable for application in their respective vessels
Thanks for paying my salary

Thanks for your attention!
Revisit the measurements with previous setup

Ghandhi et al 2009

Collimated light

Eng. diffuser

Field lens

Image plane

Camera
Perceived optical thickness

- Ideal source with limited angular distribution
- Solid angle of collection matching illumination
- Beam steering through non-parallel refracting media
- Larger collection angle can potentially reduce perceived optical thickness

\[ K_{L\text{app}} = -\ln \left( \frac{I_0 - I_\zeta}{I_0} \right) \]
Extinction imaging of soot

- Transmission consists of sequential and reference images
- Moving flame luminosity introduces error
- High temporal resolution and spectral filtering reduces error
- Clever post processing can further reduce error

\[
\tau = \frac{I_f - I_{f,i-1}}{I_0 - I_{f,i+1}}
\]
Extinction imaging of soot

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\[
\tau = \frac{I_f - I_f}{I_0 - I_0}
\]

Flame and source image
Flame image
Source image

\(I_0\)
\(I_{f,i-1}\)
\(I_i\)
\(I_{f,i+1}\)
Beam steering effect