Characterization of the Reflectivity of Various White Materials

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ABSTRACT

We present total reflectance measurements and Lambertian characterization of various materials that are commonly (and uncommonly) used as a screen for imaging system calibration (such as flat fielding). We measure the total reflectance of the samples over a broad wavelength range (250 nm $< \lambda <$ 2500 nm) that is of interest to astronomical instruments in the ultraviolet, visible, and near-infrared regimes. A Helium-Neon laser was used to determine how closely the various materials' diffuse reflectance characteristics match that of a Lambertian surface.

Keywords: Optical instrumentation, infrared instrumentation, calibration

1. INTRODUCTION

The development of various calibration systems (DECal,[1] TCal[2]) by our lab has initiated a complimentary characterization program to our investigation of the reflectivity of black materials (Marshall et al.[3] and paper 10706-195[4] also presented at this conference). We report on the characterization of various white materials that are candidates for use as calibration or general projection screens.

The material choice for a calibration screen can have a significant impact on the quality and ease with which calibration data is obtained. Desirable characteristics include reflectivity across a broad range of wavelengths, a high level of reflectivity to ensure the maximum amount of calibration light is reflected and a Lambertian reflectance profile. A Lambertian screen ensures that every position on a detector will see light reflected with the same angular profile regardless of where the light source is placed and will be insensitive to misalignment of the screen surface to the optical axis of the optical system being calibrated. We also are interested in practical considerations such as durability, ease of mounting, and manufacturing limitations that make construction of large screens difficult.

In this paper we share our methodology and results as they relate to our choice of screen material for TCal,[2] a project with the additional requirement that the screen be easily transported. Rigid coated panels have proven to work well[1] in permanently installed locations, but are not practical for any but the smallest aperture telescopes in a portable system.

2. MATERIALS TESTED

Table 1 is a list of white materials in our sample library. Those that have been tested are primarily commercial screen materials as they are most relevant to our current lab projects (see paper 10706-119[2] as an example). Testing is ongoing, so samples to be tested in the near future are listed as well.

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Table 1. Sample list, if a sample has been tested it has a sample code.

Code	**Sample**
WP01	Duraflect
WF01	Da-Lite Da-Mat
WF02	Da-Lite High Contrast Matte White
	Da-Lite Matte White
	Da-Lite High Contrast Da-Mat
	Stewart SnoMatte 100
	Stewart StudioTek 100
WF05-1	Stretchy Screens Fabric Swatch
WF05-2	Stretchy Screens Fabric Swatch + flat mylar
WF05-3	Stretchy Screens Fabric Swatch + textured mylar
WF06-1	Stretch Shapes White Trapeze Plus Fabric Sample
WF06-2	Stretch Shapes White Trapeze Plus Fabric Sample + flat mylar
WF06-3	Stretch Shapes White Trapeze Plus Fabric Sample + textured mylar
	Edmunds White Balance Reflectance Target #58-609
	Thorlabs EDU-VS1 Post-Mountable White Polystyrene Viewing Screen
	White Construction Paper
	White Felt
	White Velcro
	White Velvet
	White foam board
	White printer paper
	White cotton t-shirt
	White Styrofoam
	Rust-Oleum 2X Ultra Cover Primer Spray
	Valspar Premium Enamel Spray Paint
	Polyken 510 Gaffer's Tape White
	Insignia – 32 Collapsible Light Reflector – White/Silver
	Quantaray 5 in 1 Portable Reflector - White
	Quantaray 5 in 1 Portable Reflector - Silver
	Quantaray 5 in 1 Portable Reflector - Sunlight (zig-zag gold & silver pattern)
	Quantaray 5 in 1 Portable Reflector - Translucent

3. TOTAL REFLECTANCE MEASUREMENTS

Texas A&M University maintains a Materials Characterization Facility (MCF) that includes a wide range of instrumentation for investigating material properties. We used the Hitachi High-Tech U-4100 UV-Visible-NIR Spectrophotometer and obtained reflectance profiles for the samples.

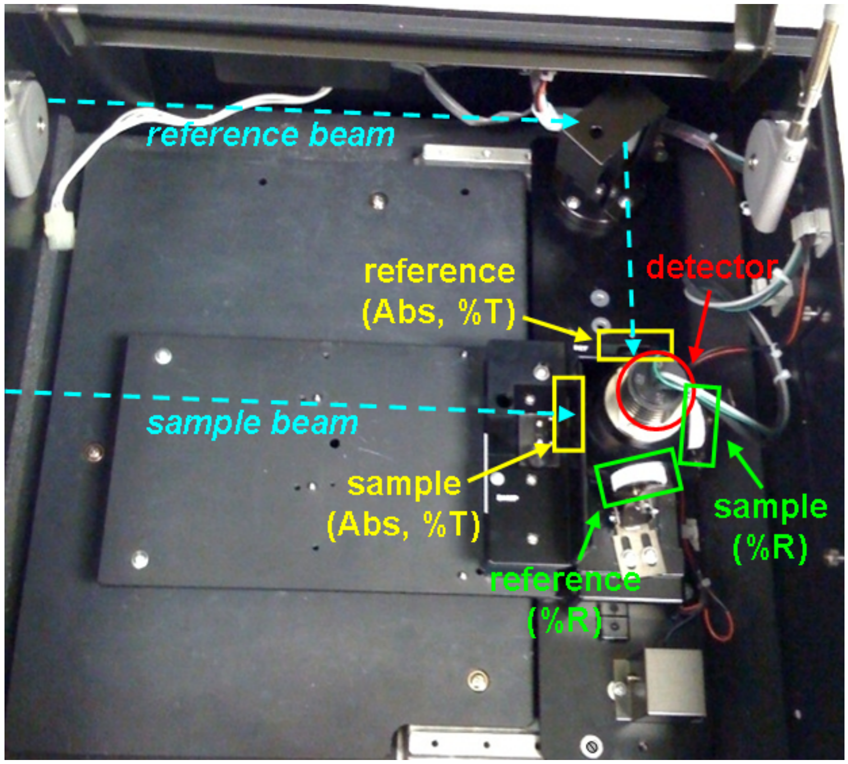

Figure 1. Internal view of the U-4100 UV-Visible-NIR Spectrophotometer. Test samples are placed at the 3 o'clock position.

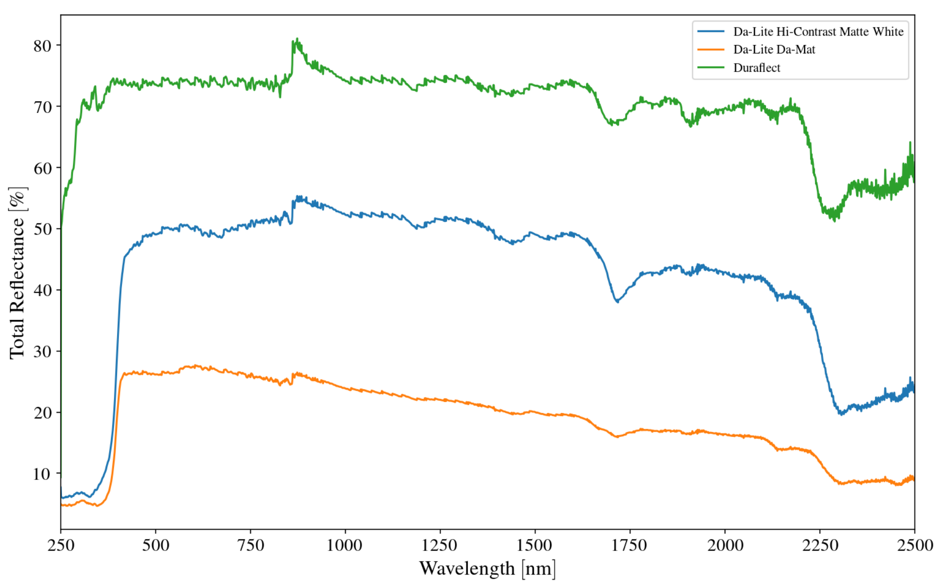

Figure 2. Total reflectance measurements of two different Da-Lite screens compared to a Duraflect screen.

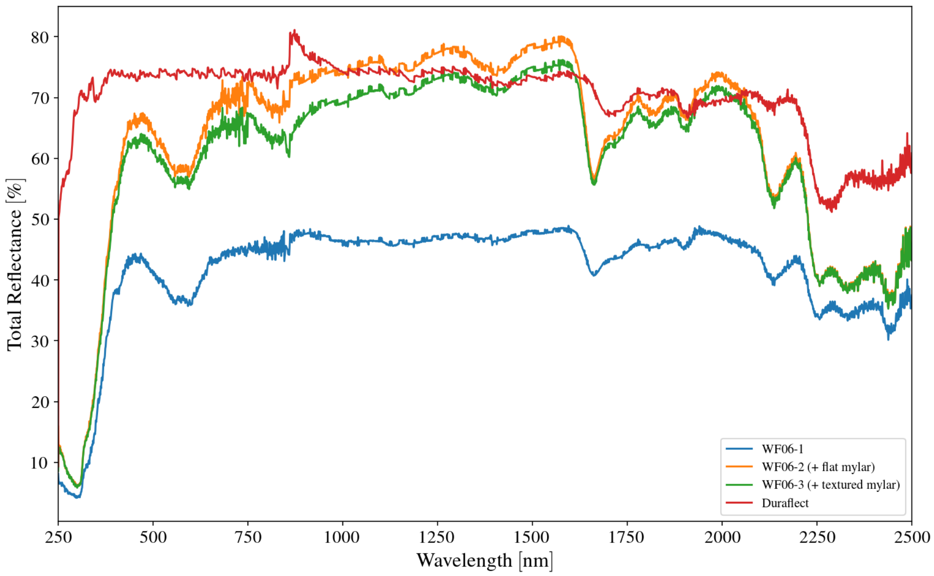

Figure 3. Total reflectance measurements of various screen combinations using a polyester-spandex material from stretchshapes.net compared to a Duraflect screen.

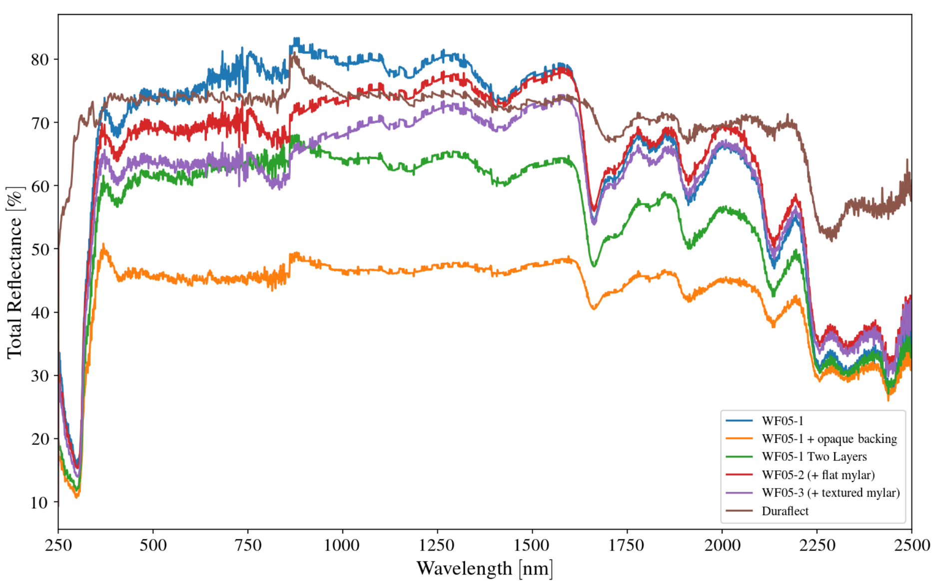

Figure 4. Total reflectance measurements of various screen combinations using a nylon-spandex material from stretchyscreens.com compared to a Duraflect screen. Our first measurement of this fabric is labeled WF05-1 and appears much more reflective than it actually is (as shown by WF05-1 + opaque backing). This is due to the small gaps in the weave of the fabric when stretched that allow the $BaSO_4$ backing material to reflect back through and artifically raise the overall reflectance.

The U-4100 dual beam spectrophotometer uses two different lamps to cover a wide range of wavelengths. A deuterium lamp covers the far UV (< 345 nm), and a tungsten lamp for UV, visible, and near-IR measurements. The U-4100 is capable of measuring both reflectance and transmittance of solid and liquid samples. With this system we measured precise reflectance values at each wavelength (in 1 nm steps) for the wavelength range 250 nm $< \lambda <$ 2500 nm. Figure 1 shows the instrumental setup of the Hitachi High-Tech U-4100 UV-Visible-NIR Spectrophotometer. The reference and test sample are placed in the 6 o'clock and 3 o'clock positions of the integrating sphere, respectively. The data acquisition procedure involves obtaining a baseline measurement at each wavelength of the reference $BaSO_4$ wafers ($\sim$ 100% reflectance) in both the reference and sample slots of the dual beam spectrophotometer. We then measure a second reference sample having 5% reflectivity (Labsphere SRS-05), and measure the reflectivity of the test sample. We compare the 5% reflectance reference sample to the values provided by the manufacturer and use this ratio to construct the absolute reflectivity of the test sample as a function of wavelength. During each day of testing the SRS-05 standard is measured to ensure measurements from different test days are tied to a common reference.

4. LAMBERTIAN REFLECTANCE

A good screen material must not only have good total reflectance across a broad range of wavelengths, the nature of the reflection is important as well. A highly specular screen would be very sensitive to alignment of the telescope, screen, and calibration light source and would have a variable angular illumination profile as a function of field position. A Lambertian surface is ideal as it has the same apparent brightness as the viewing angle is changed and is therefore insensitive to alignment errors and illumination source offset from the optical axis. A summer Research Experience for Undergraduates (REU) project at Texas A&M developed MADLaSR[5] (Multi-Angle Detection of Lambertian and Specular Reflectivity). MADLaSR consists of a HeNe laser and Gentec photodiode mounted on movable arms that allow for testing the reflected power of the laser off of a sample at variable angles. Figure 5 shows MADLaSR in Lambertian mode where the laser source is fixed perpendicular to the sample surface and the detector arm moves between 10° and 90°.

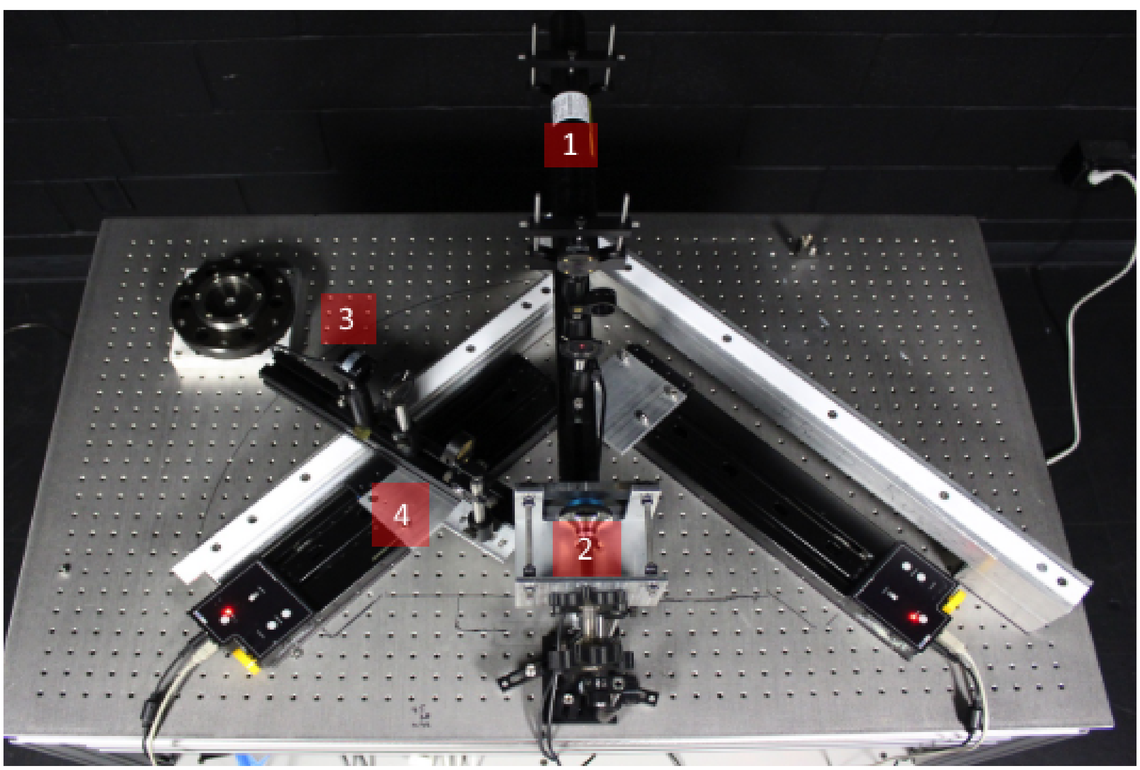

Figure 5. MADLaSR in Lambertian mode. The laser light source (1) is fixed perpendicular to the sample surface (2). The reflected power is measured by a photodiode (3) as the moveable arm (4) travels between 10°and 90°.

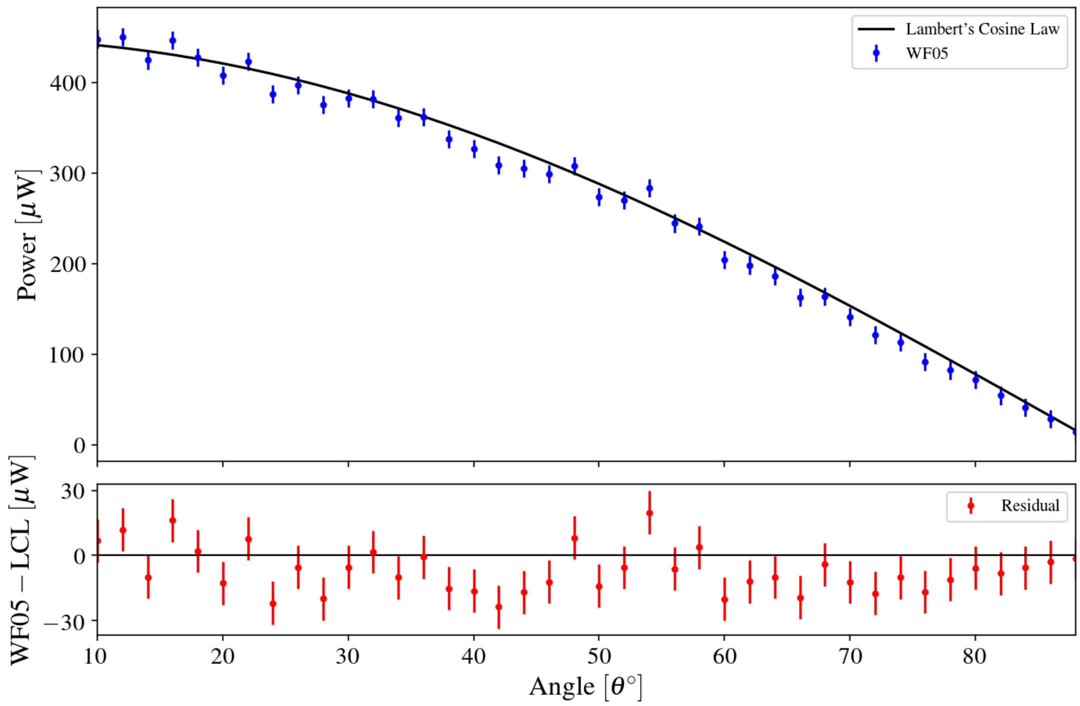

Figure 6. Lambertian characterization of the WF05 material from stretchyscreens.com compared to a perfect Lambertian surface scaled to the detected power level.

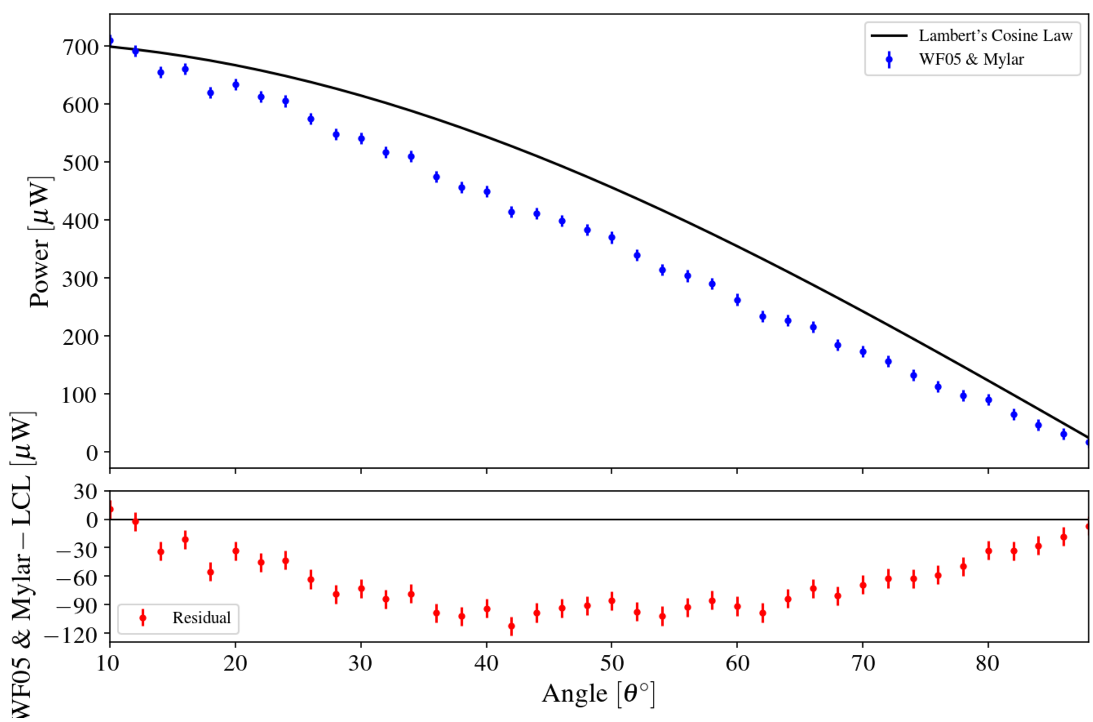

Figure 7. Lambertian characterization of the WF05 material from stretchyscreens.com with a flat mylar sheet behind it compared to a perfect Lambertian surface scaled to the detected power level. A clear deviation from a Lambertian surface is apparent in the residual.

MADLaSR measures the reflected power in two degree intervals; errorbars in Figures 6 and 7 are $\pm 10\mu W$, the manufacturer quoted accuracy (2%) of the power meter at the power measurement range used.

If the total reflectance was the sole consideration in the design of a white screen, adding a mylar backing to increase the amount of light reflected would be the obvious choice. However, as Figures 6 and 7 show, although the reflected power does increase (from $450\mu W$ to $700\mu W$ at 10°) with the addition of a backing, the mylar makes the screen more specular. The measurements are compared to the ideal case of Lambert's Cosine Law,

$$I = I_0 cos(\theta) \tag{1}$$

Where I_0 is the radiant intensity (W/sr). The solid angle seen by the photodiode is a constant so the measured power follows the same profile. We scale this relation to the measured power at 10° and look at the residual between the two curves to determine if a surface is Lambertian or not. The deviation from a Lambertian reflectance profile is clearly seen in Figure 7.

5. DISCUSSION

We use Duraflect as our performance standard as it is a commercial product specifically designed to have high reflectance and a Lambertian reflectance profile. Our particular need at this time is a portable calibration screen. Duraflect is a coating that can be placed on a variety of substrates, but none of them are very flexible. Developing a large portable screen would require tiling multiple panels together and would result in traveling with a very heavy and cumbersome screen.

This led us to investigate various more flexible screen materials. The Da-Lite screens are flexible enough to be rolled up into a tube, but have poor reflectance below 400 nm (Figure 2). Our requirements are good reflectivity between 320 nm and 1000 nm. We next investigated several stretchy screen materials, a nylon-spandex material from stretchyscreens.com (Figure 4) and a polyester-spandex material from stretchshapes.net (Figure 3). Each had better reflectivity into the UV than the Da-Lite products, however the nylon-spandex material performed the best with 27% reflectivity at 320 nm compared to 9% for the polyester-spandex material.

One issue we noticed with these stretchy materials is that when stretched the gaps in the weave of the fabric allow light to pass through and in the case of the total reflectance measurement allow the $BaSO_4$ backing to reflect back through, artificially raising the overall reflectance. The performance and light leak issue can be improved simply by using two layers (see Figure 4, green vs. orange lines). We also added reflective mylar backing to the samples, both a smooth mylar and a textured mylar. This did serve to raise the overall reflectance, but resulted in a less Lambertian surface as shown in Figures 6 and 7.

Our current selection for a traveling calibration screen is the WF05-1 nylon-spandex fabric. Not only does it have adequate reflectance qualities, it can be packed into a small bag for travel. The frame is a tubular aluminum frame, produced by the vendor and purchased with the screen that can be broken down into three sections and if the screen becomes dirty, it can be washed in a standard washing machine. These conveniences outweigh the reduction in performance as compared to a Duraflect screen.

Information about all of the samples including reflectivity plots and text files of the calibrated data are available at `http://instrumentation.tamu.edu/reflectance.html`. We are in the process of updating the plots to be interactive, allowing a user to zoom in on a particular region of interest and then save it as an image as well as better features for comparing materials. The same page includes information on how to suggest or submit a sample for testing. Due to resource availability no guarantee is made on sample testing turn around time and results will be made public on our website. We are also unable to return any samples that are submitted for testing.

6. CONCLUSIONS

We have presented measurements of the amount of total reflectance as well as Lambertian characterization of various materials that have been or may be used as calibration or projection screens. The combination of these measurements provide a quantitative basis for selecting a screen material that will match the performance requirements of a particular experiment.

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