almatech	REQUEST FOR ~~WAIVER~~ / DEVIATION (~~RFW~~/RFD)	PRODUCT ASSURANCE

RFD/RFW Number:	FLX-RFD-ALM-CU-0012	Issue	1.0

Spacecraft / Project	FLORIS	Originator's Name	Thomas Gandy	
System / Experiment / Model	FLEX	Signature / Date	Digitally signed by Thomas Antoine David Gandy (Authentication) Date: 2019.01.31 19:45:46 +01'00'	
Sub-System		Request Type (Highlight applicable request)	~~Waiver (RFW)~~	Deviation (RFD)
Assembly	EQM/PFM	Organisation	Almatech	
Sub-Assembly	Calibration Unit	Ref. Doc. / Drwg No.	ALM-PRO-4170	
Item	-	References	-	
Serial No.	EQM, PFM			

RFW/RFD Title	Coating performance measurement at operational conditions

End Items(s) Affected (Hardware, Software)		
Name	CI-Number	Model(s)
Calibration Unit		EQM, PFM

Requirement / Interface Documents Affected				
Specification/Drawing Title	Number	Issue	Date	App. Paragraph
FLORIS Instrument General design and interface requirements (GDIR)	FLX-RS-FNM-INS-0029	3	10.03.2017	6.4.4

Description of Deviation / Discrepancy / Non-Conformance

FLO-INS-GDI-REQ-3070 says :
Coating performance shall be measured at operational conditions (e.g. Temperature and incident angle) on ground, and they shall be maintained in space environment within its required limits.

Almatech is not compliant with this requirement as the performances of the coating were measured at room temperature.

Other Items or Requirements (Potentially) Affected

None

Need for RFW/RFD and Rationale for Acceptance

The test was performed according to Black coating test plan (FLX-PL-ALM-CU-0008 rev 1.0) attached and summarized in the test report (FLX-TRR-ALM-CU-0001 Rev 2.0) attached. This was presented during PDR.

RFD/RFW Number:	FLX-RFD-ALM-CU-0012	Issue	1.0

RFW/RFD CLOSED	Name	Sign & Date	
		Approved	Rejected
Project Manager / Engineering: (Sub System)	Gianluigi Capo	Digitally signed by Gianluigi Capo (Authentication) Reason: Project Manager Date: 2019.02.01 13:29:14 +01'00'	
Engineering: (Almatech)	Marco Lai	Digitally signed by Marco Lai (Qualified Signature) Date: 2019.01.31 19:04:22 +01'00'	
Product Assurance: (Almatech)	Thomas Gandy	Digitally signed by Thomas Antoine David Gandy (Authentication) Date: 2019.01.31 19:46:00 +01'00'	
Project Manager: (Leonardo)			
Engineering: (Leonardo)			
Product Assurance: (Leonardo)			
Engineering (ESA)			
Contract Manager (ESA)			

Continuation sheet:

FLORIS Calibration Unit

Black Coating Test Plan

Doc :	FLX-PL-ALM-CU-0008
Issue:	1:0
Date :	26.04.2018
DRD Code :	IN-11/QV-01/QV-02

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Released by:	G. Capo		

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Internal reference: ALM-PRO-3667

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M. Lai	Almatech	C
J. Martín	Almatech	C
M. François	ESA	C
A. Capanni	Leonardo	A

A = Approval
C = Copy
I = Information
O = Original
R = Review

Change Record

Modification	Page	Iss.	Rev.	Date
First Issue	all	1	0	26.04.2018

Contents

1 Introduction

1.1 Project Overview

The Earth Explorer - Fluorescence Explorer (FLEX) mission will map vegetation fluorescence to quantify photosynthetic activity.

The conversion of atmospheric carbon dioxide and sunlight into energy-rich carbohydrates through photosynthesis is one of the most fundamental processes on Earth – and one on which we all depend.

Information from FLEX will improve our understanding of the way carbon moves between plants and the atmosphere and how photosynthesis affects the carbon and water cycles.

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Mission objectives can therefore summarized as follows:

- To assess the quality of fluorescence-derived photosynthesis data against classical optically-based methods (i.e. from fraction of absorbed photosynthetically active radiation times Light Use Efficiency).
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- To identify and characterize the effects of different types of stress on fluorescence and photosynthesis (especially drought and freezing air temperatures).
- To indicate potential applications of the novel fluorescence observations.

Mission orbit:

- Orbit: Sun-synchronous
- Measurement altitude: 815 km

The FLEX Space Segment consists of a single satellite carrying the FLuORescence Imaging Spectrometer (FLORIS) push-broom instrument. This high-resolution imaging spectrometer will acquire data in the 500– 780 nm spectral range, with a sampling of 0.1 nm in the oxygen bands (759–769 nm and 686–697 nm) and 0.5–2.0 nm in the red edge, chlorophyll absorption and Photochemical Reflectance Index bands.

The monthly global maps will have an on-ground spatial resolution of 300 × 300 m2 with a swath width of 150 km.

1.2 Scope of the Document

The aim of this document is to present the foreseen activities to characterize the total hemispherical reflectance of different black coating options to be applied on the following elements of the FLORIS CU:

- Nadir Baffle
- Sun View Baffle
- Black Target
- External Surfaces

The reflectance measurement of the Sun Diffuser is not part of this test plan, but addressed in the AIT Plan (FLX-PL-ALM-CU-0006).

2 Applicable and Reference Documents

2.1 Applicable Documents

Ref.	Title	Reference	Iss.	Date
AD 103	Floris Calibration Unit User Requirement Specification	FLX-RS-FNM-INS-0006	4D2.3	26.03.2018
AD 211	FLEX List of Acronyms and Abbreviations	FLX-LI-FNM-INS-0003	2	29.11.2016

2.2 Reference Documents

Ref.	Title	Reference	Iss.	Date
[RD01]	FLORIS Calibration Unit Almatech Proposal	17-10S-225	1.0	15.06.2017
[RD02]	Leonardo Clarification Letter	FLX-LET-FNM-INS-0009	--	18.10.2017
[RD03]	Floris CU Negotiation Meeting #1 between Leonardo and Almatech	FLX-MIN-FNM-INS-0041		15.11.2017

2.3 Acronyms and Abbreviations

The abbreviations and acronyms used in this document are in accordance with [AD 211].

3 Reflectance Requirements

The total hemispherical reflectance requirements that apply to the FLORIS CU elements under the scope of the present document are summarized in Table 1:

Table 1: Reflectance requirements.

Element	Criterion	Wavelength [nm]	Reference
Nadir Baffle	Total hemispherical reflectance < 5% (TBC)	300-1000	FLO-CU-URD-REQ-0580
Sun Baffle	Total hemispherical reflectance < 9%	480-800	FLO-CU-URD-REQ-0680
External Surfaces	Total hemispherical reflectance < 9%	480-800	FLO-CU-URD-REQ-0583
Black Target	Reflectance < 9% $\left(BRDF < \frac{9\%}{\pi}\right)$ with $\pm \frac{0.5\%}{\pi}\left[\frac{1}{sr}\right]$ of accuracy.	500-780 (perpendicular to the target)	FLO-CU-URD-REQ-0690

4 Test Plan Overview

In order to assess the capability of the different black coatings to meet the requirements presented in the previous section, the following test plan is established:

1) Machine the samples

2) Prepare the surface prior to coating

3) Black coating

4) Reflectance measurement: Total Integrated Scatter (TIS)

5) Reflectance measurement: Bidirectional Reflectance Distribution Function (BRDF)

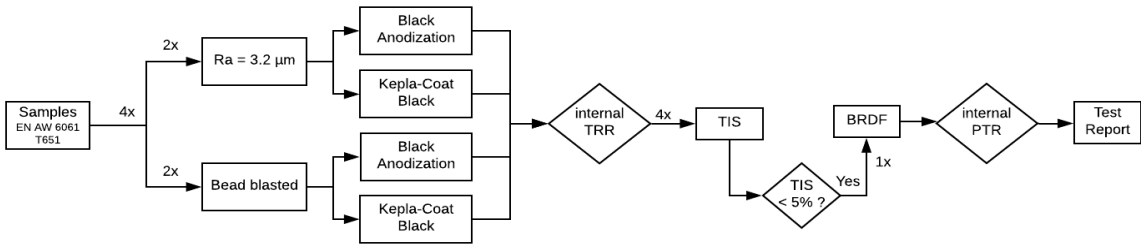


Figure 1: Test sequence.

More details are given in the following chapters.

5 Samples Description

The test samples will be made out of aluminum EN AW 6061 T651. In particular, 4 samples with dimensions 50mm x 50mm x 1mm will be machined with a surface roughness of Ra <= 3.2 µm.

Two of these samples will follow a controlled bead blasting before applying the black coating. The goal is to investigate whether this surface finish could have a positive effect on the final reflectance of the black surface.

Two different black coatings will be then applied:

- Black Anodization, provided by Steiger Galvanotechnique SA (Switzerland), following a modified procedure of the Standard ECSS-Q-70-03B, according to the ESA technical note D-TOS/QMC Report: 00/055 05.05.2000.
- Kepla-Coat® Black, provided by AHC Surfac (Germany).

The reflectance of these two coatings is expected to be less than 5% in the spectral range of 300-1000 nm, which would fulfil all the requirements stated in Table 1.

This sample strategy is summarized in Table 2:

Table 2: Sample strategy.

Sample	Surface roughness (after machining)	Surface preparation (prior to coating)	Black coating
ALM-DES-225-6001	Ra = 3.2 µm	None	Black Anodization
ALM-DES-225-6002	Ra = 3.2 µm	None	Kepla-Coat Black
ALM-DES-225-6003	Ra = 3.2 µm	Bead blasting	Black Anodization
ALM-DES-225-6004	Ra = 3.2 µm	Bead blasting	Kepla-Coat Black

6 TIS Measurement

The first test to be performed in order to characterize the total hemispherical reflectance of the 4 samples is the measurement of the Total Integrated Scatter (TIS). The TIS is the fraction of the total reflected radiant power that is scattered out of the specularly reflected beam:

$$TIS = \frac{diffuse\ reflectance}{total\ reflectance} = \frac{diffuse\ reflectance}{specular\ reflectance + diffuse\ reflectance}$$

This test will be performed at the Institute for Solar Technology (SPF), in Switzerland, by means of a FTIR spectrometer with an integrating sphere, at an incident angle of 10° and covering a wavelength range from 300 nm to 1100 nm. For more details on the instrument, please refer to Appendix A.

Only the sample with the lowest total hemispherical reflectance will undergo the second test.

Figure 2: Imaging sphere for scatter and appearance measurement.

7 BRDF Measurement

The second test consists on a BRDF measurement, which quantifies the radiance scattered into all directions from a surface illuminated by a source from any direction above the hemisphere of the material. The BRDF characterizes thus the directional scatter in detail.

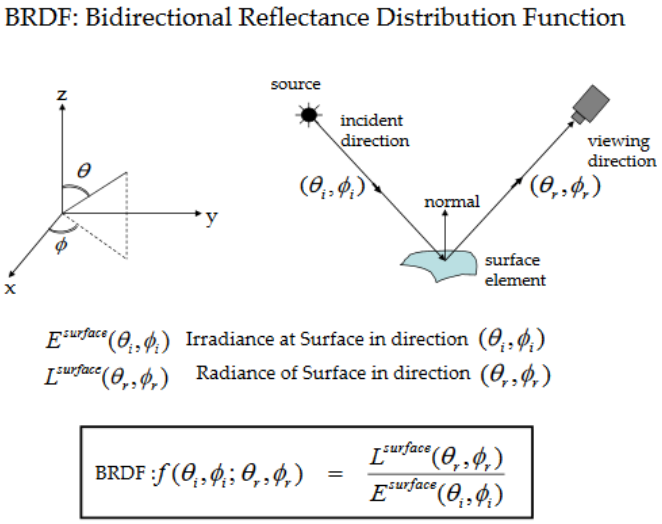


Figure 3: BRDF measurement.

In particular, a source angle up to 60° will be considered, since this is the maximum incidence angle the straylight can achieve through the vans with respect to the normal of the Black Target surface (Figure 4).

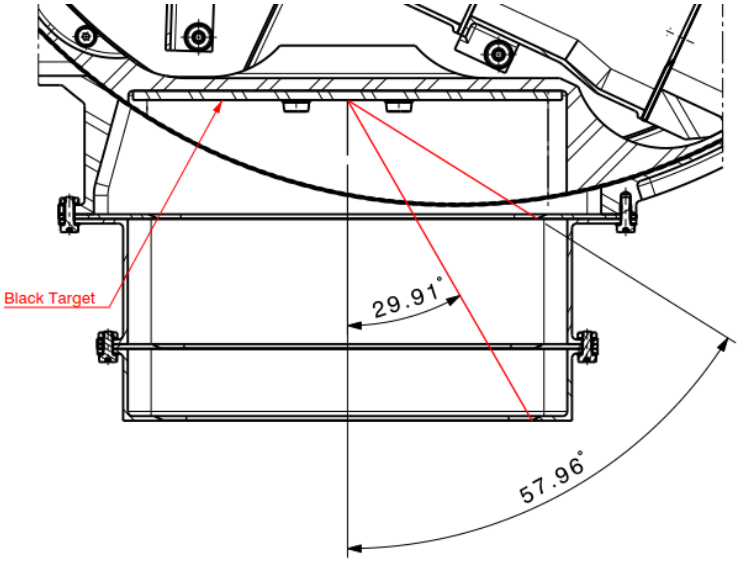


Figure 4: Angle of incidence of interest w.r.t. the Black Target.

The BRDF measurement plan is shown in Table 3. A total of 525 points are foreseen.

Table 3: BRDF measurement parameters.

Parameter [units]	**Range**		**Resolution**	**# of points**
	Min	**Max**		
Wavelength [nm]	500	800	50	7
Incident angle, θ_i [°]	0	60	15	5
Elevation scattering angle, θ_s [°] (1)	-60	60	-	15
Azimuth incident angle, φ_i [°]	0	-	-	1
Azimuth scattering angle, φ_s [°]	0	-	-	1
TOTAL				525

These measurements will be performed at the Netherlands Organisation for Applied Scientific Research (TNO) TBC, which can reach an accuracy of 0.5% as requested by the client (see the error budget presented in Appendix B).

[1] The scattering angles at ±10° from the incident direction of study are not measured due to physical reasons.

8 Conclusion

The Test Plan presented in this document proposes two methods to determine the optical performances of two black coatings, each applied in turn on two samples with a different surface finishing (4 samples in total).

The first method consists in measuring the total integrated scatter (TIS) to compare the performance of different samples in terms of reflectance. The one delivering the best results (if reflectance < 5%) will then follow the second test.

The second method consists in measuring the BRDF to consolidate the reflectance values in a more detailed and precise way. It allows the characterization of the total hemispherical reflectance along the desired wavelength range and for different incident angles.

The final results will confirm if the chosen black coating and surface finish combination can meet the reflectance requirements defined by the client.

Appendix A
SPF Radiant Imaging Sphere

Radiant Zemax

Imaging Sphere for Scatter and Appearance Measurement

IS-SA™

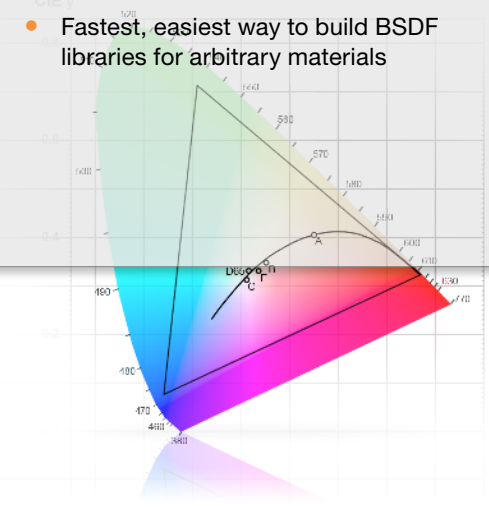
Fast, flexible system for comprehensive BRDF, BTDF, and TIS measurement

Applications

- BRDF (bi-directional reflectance distribution function) measurement
- BTDF (bi-directional transmission distribution function) measurement
- Material characterization and classification based on scatter for metals, plastics, paper, textiles and more
- Surface treatment characterization and classification based on scatter for cleaners, polishes, paints, coatings, and more
- Quality control sampling
- Generation of accurate and complete appearance models for optical design and rendering applications

Benefits

- Complete BSDF and TIS measurement in seconds for many materials
- Cost effective solution for a broad range of related measurement applications
- Fastest, easiest way to build BSDF libraries for arbitrary materials



The IS-SA™ provides rapid, comprehensive measurement of scatter distribution functions for almost any material, including films, metals, plastics, papers, textiles, and surface treatments such as cleaners, polishes, coatings, and paints. It is designed for use in both R&D and production quality control applications for material characterization and quality assessment, and for generating libraries of BSDF measurements for computer modeling and rendering.

The IS-SA™ takes advantage of a novel optical configuration to measure 2ϖ steradians (a full hemisphere) of scattered light at once, dramatically reducing the time required to obtain a BSDF measurement. The IS-SA™ comes with Radiant Zemax' sophisticated IS-SA™ control and analysis software providing flexible measurement set-up and intuitive operation. Extensive data analysis and display functions, including isometric plots, cross-sectional graphs, radar plots, bit maps and color graphs, are also available.

With an optional tunable light source, the IS-SA™ can be used to measure BSDF as a function of wavelength. Other options include a Transmission Arm attachment for BTDF (transmission) measurement, and a goniometric positioning system to automatically move and rotate the material sample. Software options allow the IS-SA™ user to perform view angle performance measurement for displays or luminous intensity distribution measurement for small light sources; additional software allows the IS-SA™ ProMetric® Imaging Colorimeter to be used in stand-alone mode for other applications.

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Web site: RadiantZemax.com

Imaging Sphere for Scatter and Appearance Measurement

IS-SA™

Key Features

- Photopic and colorimetric measurement capabilities
- Full, automated control over illumination angle of the light source
- Extensive configuration options for light source and sample control
- Easy to use control and analysis software interface
- Data can be exported for use in optical design and rendering tools

Specifications*

Optical Specifications

CCD Type	Full-frame, cooled and temperature stabilized CCD
CCD Bit Depth	16-bit (65,536:1) dynamic range
Resolution	Either 512x512 or 1024x1024 pixel CCD options
Field of View	Approximately 2ϖ steradians
Color Measurement	CIE 1931 matched XYZ filters (photopic only and spectral options also)
Neutral Density Filters	ND0, 1, and 2 standard
Standard Illumination Angle	Continuous to 80°
Illumination Source	Metal Halide or Halogen
Sensitivity	Less then 5% reflectivity
System Accuracy	BRDF: ±5% TIR: ±5%
Minimum Measurement time	Photopic: 1 sec Color: 5 sec

Mechanical Specifications

Overall Size (WxHxD)	88cm x 66cm x 110cm
Orientation	Rotatable to vertical, face-down or face-up positions
Angular Resolution	0.5°
Weight	120 kg
Construction	Integrated imaging dome and imaging colorimeter
Maximum Sample Size	Unlimited x Unlimited (for reflectance measurement)
Illumination Area	10 mm or 20 mm

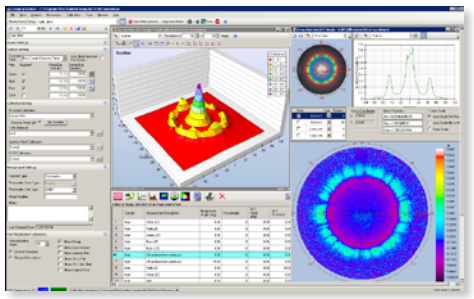
Control and Analysis Software Specifications

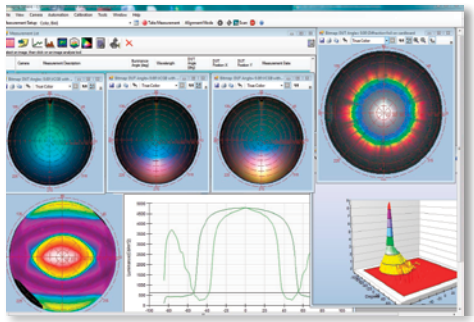
Measurement Capability:	BRDF, CCBRDF, BTDF, CCBTDF TIR (Total Integrated Reflectance) TIS (Total Integrated Scatter), Gain Relative Color: CCT; CIE x,y; u',v'; E
IS 1.x Software	Measurement set-up and image capture control Gray-scale and false color display Cross-Sections of scatter & relative color 3D surface plot of scatter & relative color Isometric plot of scatter & relative color Graph and image comparison for multiple captures Export BSDF data to optical design & rendering tools Reports of TIS, TIR, and color Process measurements (rotate, add, subtract, threshold, etc.)

Optional Equipment

Transmission Arm for BTDF measurement
XYPhi Stage for automated sample positioning and rotating
Automated specular light removal
Calibration Samples
Aperture Mask Calibration Device
Monochromator for automated spectrally tunable illumination

* *Specifications subject to change without notice*





System Requirements

- 2.0 GHz or faster processor
- 1GB or greater RAM
- Windows® 7, Vista or XP
- USB 2.0 interface

Radiant Zemax

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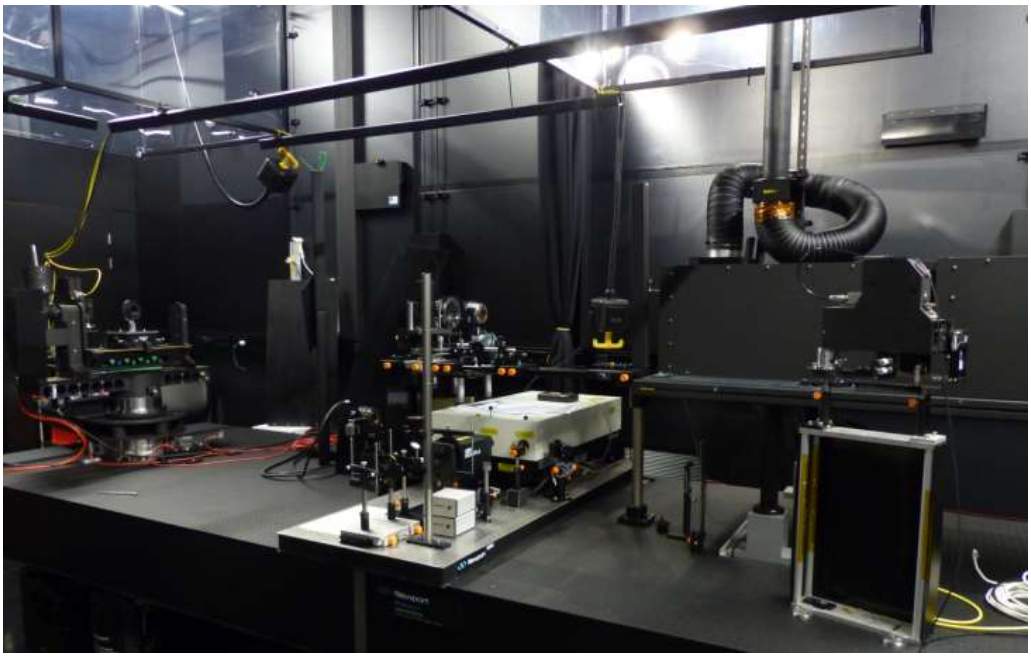
Appendix B
TNO BSDF Measurement
Error Budget

Draft error budget BSDF measurements for FLORIS Flight Spare Diffuser



	Name	Date	Signature
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Checked by:			
Verified by:			
Approved by:	Sanneke Brinkers	30-11-2017	

Contents

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Person	Organization	Distribution
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Change log

Changes with respect to last issues:

Version	Date	Number of pages	Remarks / Changes	Page
1			Creation	All

1 Error Budget

This section summarizes the different error contributions and predicted uncertainties. When performing BSDF measurements the following error sources are considered:

- **Noise**

Every measurement contains a noise level. The noise level depends on several parameters, such as measurement time, angular configuration, wavelength, bandwidth and the diffuser itself. Ultimately the required or desired noise level defines the measurement time and can thus be adjusted accordingly.

- **Linearity**

A linearity test was performed in order to determine the response function of the individual detectors within the predicted signal strength regime that is predicted for the measurements.

- **Detector Field of View Determination**

A field of view determination is executed for the Si- detector. The uncertainty of this determination is included in the uncertainty budget.

- **Residual Polarization**

Residual polarization can be caused by different components:

- ARCF related components
  - Beam residual polarization
  - Detector polarization sensitivity
- Diffuser related components
  - Diffuser residual polarization

The total BSDF uncertainty due to residual polarisation is a combination of the above described contributions.

- **Straylight**

Possible straylight contributions are to be viewed twofold:

- External straylight, i.e. possible facility straylight contributions
- Detector or internal straylight, i.e. possible straylight contributions caused within the detecting system

- **Source wavelength uncertainty**

Uncertainties in the wavelength of the source are fed into the uncertainty of the BSDF determination and are characterized by the diffuser and its BSDF slope under investigation. In the present case a strong center wavelength and bandwidth dependency is not expected.

- **Source beam homogeneity**

It is in the nature of artificial light sources that in-homogeneities occur in the beam intensity profile and induce accordingly errors in the BSDF determination. For this purpose a beam homogeneity measurement is performed and an according correction applied on the results. The number given in the final error budget is the residual error after applying the correction factor.

- **Angular Alignment Uncertainty**

The alignment error depends on the alignment sensitivity of the diffuser and thus the BSDF slope under investigation. In the present case a strong angular dependence is not expected.

➢ **Detector irradiance**

Not applicable for the present spectral range

The following table summarizes the predicted individual error contributions.

	Error Contribution	Predicted Contribution 500nm – 780nm (% 1σ)
Stochastic	Noise	0.3
Setup	Linearity	0.15
	Detector spatial dependence	0.01
	Detector field dependence	0.1
	Detector FOV knowledge	0.2
	Detector Irradiance	-
	Residual polarization	0.1
	Straylight external	0.12
	Straylight detector	0.12
	Source wavelength uncertainty	0.1
	Source beam homogeneity	0.2
Alignment	Angular alignment uncertainty	0.1
	TOTAL RSS	0.48

Table: Predicted absolute error budget on BSDF measurements

Please note that the table above contains only the predicted values, a comparison with the achieved results will be discussed after the campaign.

FLORIS Calibration Unit

Black Coatings Optical Test Report (Total Hemispherical Reflectance)

Doc :	FLX-TRR-ALM-CU-0001
Issue:	2:0
Date :	13.11.2018
DRD Code :	QV-05

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Reviewed by:	M. Lai		
Approved by:	T. Gandy		
Released by:	G Capo		

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Internal reference: ALM-PRO-3887

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G. Capo	Almatech	O
M. Lai	Almatech	C
M. François	ESA	C
A. Capanni	Leonardo	A

A = Approval
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R = Review

Change Record

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First Issue	all	1	0	03.09.2018
PDR-CU-AI#064: Raw data of Total hemispherical reflectance measurements updated with & without tolerances	appendix C , §7, §8	2	0	13.11.2018
Results discussion & conclusion updated.	§7-8			
Document Title changed as "Black coating Optical Test Report (Total Hemispherical Reflectance)" instead of "Black coating Optical Test (TIS) Report"	Title			

Contents

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The monthly global maps will have an on-ground spatial resolution of 300 × 300 m2 with a swath width of 150 km.

1.2 Scope of the Document

This document presents the results of the optical tests (TIS) performed on samples with black coatings for FLORIS Calibration Unit.

2 Applicable and Reference Documents

2.1 Applicable Documents

Ref.	Title	Reference	Iss.
AD 105	Cover Letter	FLX-LET-FNM-INS-0003	3
AD 106	Special Condition of Tender	FLX-OF-FNM-INS-0001	4
AD 100	Contract for FLEX Unit/sub-system	Draft Contract	
AD 101	Generic Statement of Work for FLEX Unit/sub-system	FLX-SOW-FNM-INS-0001	2
AD 102	Specific Statement of Work	FLX-SOW-FNM-INS-0005	2
AD 103	Floris Calibration Unit User Requirement Specification	FLX-RS-FNM-INS-0006	5
AD 201	FLORIS Radiation Environment RS	FLX-RS-FNM-INS-0016	4
AD 202	FLEX FEMM Requirements Specification	FLX-RS-FNM-INS-0023	1
AD 203	FLEX GMM &TMM Requirements Specification	FLX-RS-FNM-INS-0024	1
AD 204	FLEX CAD Model Requirements Specification	FLX-RS-FNM-INS-0025	1
AD 205	FLEX Cleanliness Requirements for Sub-contractors	FLX-RS-FNM-INS-0028	3
AD 206	FLEX Instrument General Design Interface Requirements	FLX-RS-FNM-INS-0029	3
AD 208	FLEX PA Requirements for Subcontractors	FLX-RS-FNM-INS-0021	2
AD 209	FLEX PA SW Requirements for Subcontractors	FLX-RS-FNM-INS-0022	1
AD 210	FLEX Configuration Control and Documentation Management Plan	FLX-PL-FNM-INS-0001	3
AD 211	FLEX List of Acronyms and Abbreviations	FLX-LI-FNM-INS-0003	2

2.2 Reference Documents

Ref.	Title	Reference	Iss.	Date
[RD01]	FLORIS Calibration Unit Almatech Proposal	17-10S-225	1.0	15.06.2017
[RD02]	Leonardo Clarification Letter	FLX-LET-FNM-INS-0009	--	18.10.2017
[RD03]	Floris CU Negotiation Meeting #1 between Leonardo and Almatech	FLX-MIN-FNM-INS-0041		15.11.2017
[RD04]	ESA Evaluation of Aluminium black anodizing process	D-TOS/QMC Report: 00/055	--	05.05.2000
[RD05]	FLORIS CU, Black Coating Test Plan	FLX-PL-ALM-CU-0008	1.0	26.04.2018

2.3 Acronyms and Abbreviations

The abbreviations and acronyms used in this document are in accordance with [AD 211].

3 Introduction

Several black coatings combined with surface treatments are potential candidates to be applied for Calibration Unit. A test campaign is performed on representative samples in order to evaluate their optical properties over a spectral range.

4 Test Objective

The objectives of the optical tests are to:

- Measure the direct (10°) total hemispherical spectral reflectance in the spectral range (300 nm to 1100 nm).
- Compare the optical measurements of each sample to choose the suitable coating for CU.

5 Facility

The direct total hemispherical spectral reflectance is measured with an FTIR spectrometer with an integrating sphere at an incident angle of 10° and covering a wavelength range from 300 nm to 1100 nm.

6 Samples Description

The samples used have an optical surface of 50mm x 50mm and a thickness of 1mm. Each sample is unique in terms of surface treatment and black coating as described in Table 1.

Each sample is identified with its drawing number and the drawings are available in Appendix B.

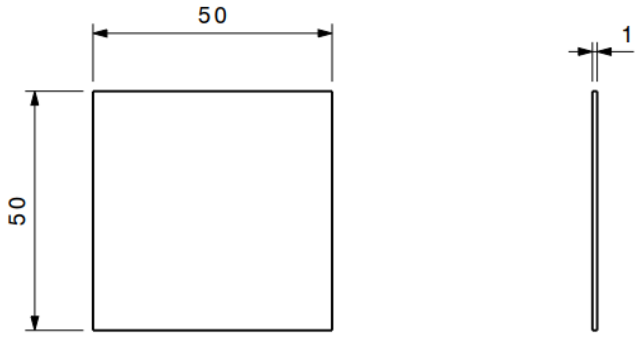


Figure 1: Sample dimensions

Table 1: Samples List

Drawing Reference	Qty	Substrate	Surface treatment before coating	Coating
ALM-DES-225-6001	1	AW 6061 T651	No treatment	Black anodisation[1]
ALM-DES-225-6002	1	AW 6061 T651	No treatment	Kepla-Coat Black[2]
ALM-DES-225-6003	1	AW 6061 T651	Bead blasting	Black anodisation
ALM-DES-225-6004	1	AW 6061 T651	Bead blasting	Kepla-coat Black

As different identifications were used by the supplier, Table 2 lists all references used per sample.

Table 2: Samples Cross-references

Samples Drawing reference	Samples used by supplier	Sample number used by supplier
ALM-DES-225-6001	ALMA1808001	Sample 1
ALM-DES-225-6002	ALMA1808002	Sample 2
ALM-DES-225-6003	ALMA1808003	Sample 3
ALM-DES-225-6004	ALMA1808004	Sample 4

[1] Anodization performed by Steiger Galvanotechnique SA (Switzerland) according to [RD04]
[2] Kepla-coat Black treatment performed by AHC Surfac (Germany)

7 Results Discussion

The optical measurements are performed at SPF on the 31.08.2018 and the results are showed in Figure 2. The raw data are available in Appendix C.

It is observed that the reflectivity curves of samples coated with black kepla-coat (ALM-DES-225-6002/6004) are identical although the surface treatments before coating are different. Their reflectivity curves exceed the limit of 5% at ~0.65 μm and then, they increase exponentially with the wavelength until to reach 10% at 1.0 μm. Consequently, the kepla-coat coating is not compliant with the requirement of 5% in the spectral range of 0.3-1.0 μm [FLO-CU-URD-REQ-0580, AD103].

The samples coated with black anodization (ALM-DES-225-6001/6003) present reflectivity curves below the requested 5% in the range of 0.3-1.0 μm which is compliant with the requirement [FLO-CU-URD-REQ-0580, AD103]. The sample ALM-DES-225-6003 with the bead blasting treatment before coating shows the lowest reflectivity over the wavelength and is a candidate for CU.

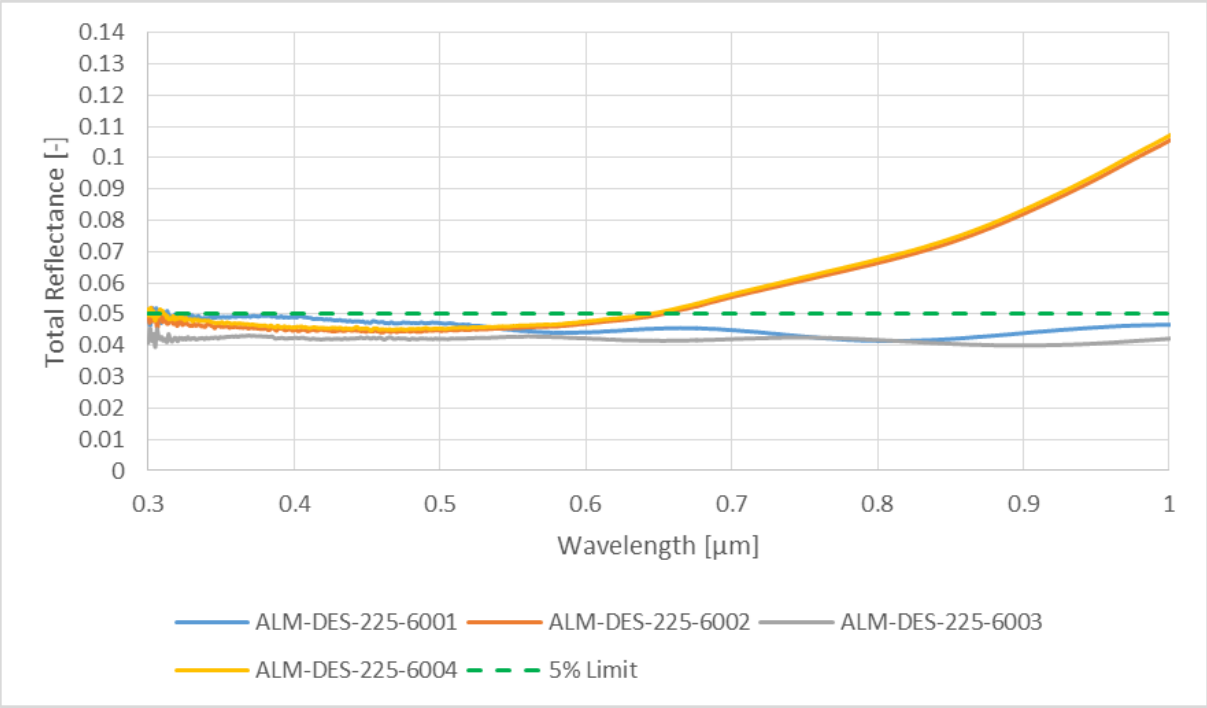


Figure 2: Total direct (10°) total hemispherical spectral reflectance measurements

The two potential coating candidates are the black anodization with and without bead blasting (ALM-DES-225-6001/6003) and their reflectivity curves are plotted in Figure 3 including their measurement errors in the spectral range of 0.3-1.0 μm. The measurement accuracy is 0.3% (abs) in the band from 0.5 μm to 2.0 μm and 0.5% (abs) out of this band. It is observed that the reflectivity curves with tolerances are well below the

requested 5% from 0.34µm to 1µm. A zoom in the spectral range from 0.30-0.34µm is plotted in Figure 4 and 4 peaks exceeding the requested 5% are identified for the black anodization without pre-coating treatment (ALM-DES-225-6001). The peaks exceed at most 4.4% over a maximal range of 1.8 nm (Table 3) which is considered as negligible compared to the total requested spectrum. Thus, the black anodization coating with and without bead blasting are considered as having suitable optical properties for Calibration unit.

Although the black coating with bead blasting shows the lowest reflectivity curve, the process is more difficult to control and the bead blasting could locally damage the sharp edge of the baffle, that's why the black anodization without bead blasting is preferred and selected for calibration unit.

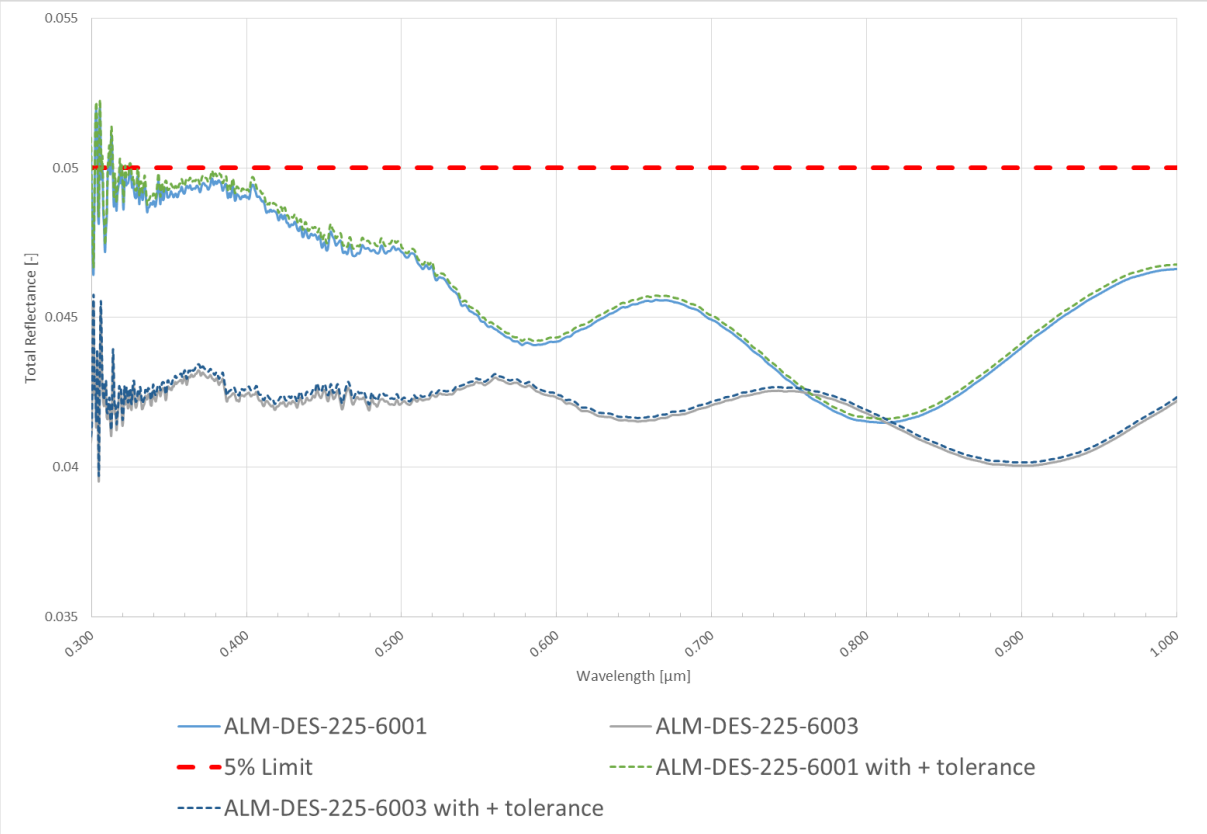


Figure 3: Total direct (10°) hemispherical spectral reflectance measurements including measurement errors

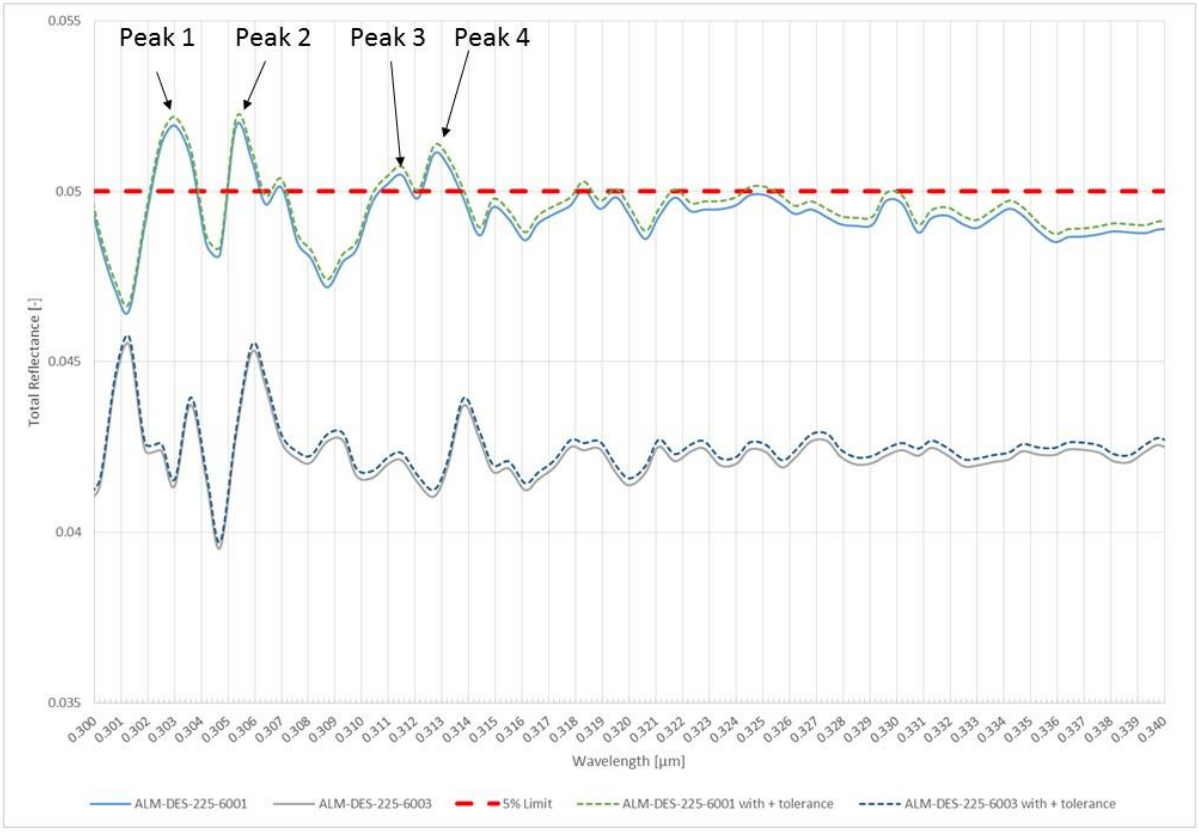


Figure 4: Zoom in the spectral range 0.3-0.34 µm of Figure 3

Table 3: Peak values extract from Figure 4

Peak	Peak out of tolerances [%]	over a range of [nm]
Peak 1	+4.4%	1.8 nm
Peak 2	+4.3%	1.4 nm
Peak 3	+1.5%	1.1 nm
Peak 4	+2.7%	1.6 nm

8 Conclusion

The samples coated with black anodization (ALM-DES-225-6001/6003) are compliant with the requirement [FLO-CU-URD-REQ-0580, AD103].

The sample (ALM-DES-225-6003) having a bead blasting treatment before black anodization shows the lowest reflectivity curve. However, the latter process is more prone to introduce local damages at the sharp baffles edges. Therefore, the black anodization without bead blasting is selected for Calibration Unit.

Appendix A
Optical Equipment Datasheet

Radiant Zemax

Imaging Sphere for Scatter and Appearance Measurement

IS-SA™

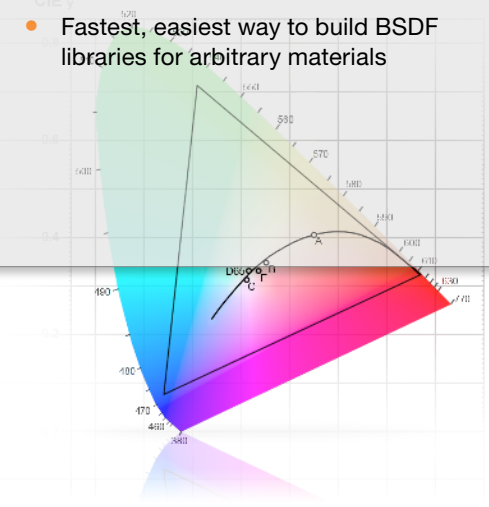
Fast, flexible system for comprehensive BRDF, BTDF, and TIS measurement

Applications

- BRDF (bi-directional reflectance distribution function) measurement
- BTDF (bi-directional transmission distribution function) measurement
- Material characterization and classification based on scatter for metals, plastics, paper, textiles and more
- Surface treatment characterization and classification based on scatter for cleaners, polishes, paints, coatings, and more
- Quality control sampling
- Generation of accurate and complete appearance models for optical design and rendering applications

Benefits

- Complete BSDF and TIS measurement in seconds for many materials
- Cost effective solution for a broad range of related measurement applications
- Fastest, easiest way to build BSDF libraries for arbitrary materials



The IS-SA™ provides rapid, comprehensive measurement of scatter distribution functions for almost any material, including films, metals, plastics, papers, textiles, and surface treatments such as cleaners, polishes, coatings, and paints. It is designed for use in both R&D and production quality control applications for material characterization and quality assessment, and for generating libraries of BSDF measurements for computer modeling and rendering.

The IS-SA™ takes advantage of a novel optical configuration to measure 2ϖ steradians (a full hemisphere) of scattered light at once, dramatically reducing the time required to obtain a BSDF measurement. The IS-SA™ comes with Radiant Zemax' sophisticated IS-SA™ control and analysis software providing flexible measurement set-up and intuitive operation. Extensive data analysis and display functions, including isometric plots, cross-sectional graphs, radar plots, bit maps and color graphs, are also available.

With an optional tunable light source, the IS-SA™ can be used to measure BSDF as a function of wavelength. Other options include a Transmission Arm attachment for BTDF (transmission) measurement, and a goniometric positioning system to automatically move and rotate the material sample. Software options allow the IS-SA™ user to perform view angle performance measurement for displays or luminous intensity distribution measurement for small light sources; additional software allows the IS-SA™ ProMetric® Imaging Colorimeter to be used in stand-alone mode for other applications.

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Sales and marketing: sales@radiantzemax.com
Technical support: support@radiantzemax.com
Web site: RadiantZemax.com

Imaging Sphere for Scatter and Appearance Measurement

IS-SA™

Key Features

- Photopic and colorimetric measurement capabilities
- Full, automated control over illumination angle of the light source
- Extensive configuration options for light source and sample control
- Easy to use control and analysis software interface
- Data can be exported for use in optical design and rendering tools

Specifications*

Optical Specifications

CCD Type	Full-frame, cooled and temperature stabilized CCD
CCD Bit Depth	16-bit (65,536:1) dynamic range
Resolution	Either 512x512 or 1024x1024 pixel CCD options
Field of View	Approximately 2ϖ steradians
Color Measurement	CIE 1931 matched XYZ filters (photopic only and spectral options also)
Neutral Density Filters	ND0, 1, and 2 standard
Standard Illumination Angle	Continuous to 80°
Illumination Source	Metal Halide or Halogen
Sensitivity	Less then 5% reflectivity
System Accuracy	BRDF: ±5% TIR: ±5%
Minimum Measurement time	Photopic: 1 sec Color: 5 sec

Mechanical Specifications

Overall Size (WxHxD)	88cm x 66cm x 110cm
Orientation	Rotatable to vertical, face-down or face-up positions
Angular Resolution	0.5°
Weight	120 kg
Construction	Integrated imaging dome and imaging colorimeter
Maximum Sample Size	Unlimited x Unlimited (for reflectance measurement)
Illumination Area	10 mm or 20 mm

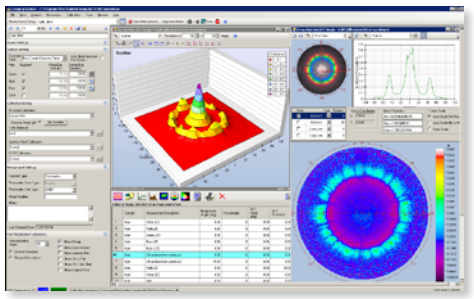
Control and Analysis Software Specifications

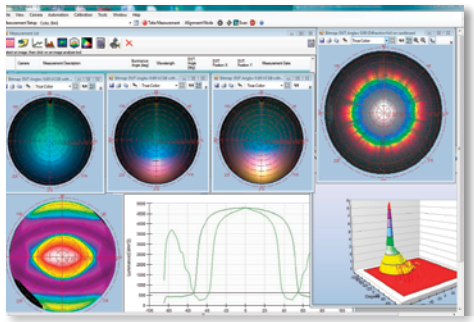
Measurement Capability:	BRDF, CCBRDF, BTDF, CCBTDF TIR (Total Integrated Reflectance) TIS (Total Integrated Scatter), Gain Relative Color: CCT; CIE x,y; u',v'; E
IS 1.x Software	Measurement set-up and image capture control Gray-scale and false color display Cross-Sections of scatter & relative color 3D surface plot of scatter & relative color Isometric plot of scatter & relative color Graph and image comparison for multiple captures Export BSDF data to optical design & rendering tools Reports of TIS, TIR, and color Process measurements (rotate, add, subtract, threshold, etc.)

Optional Equipment

Transmission Arm for BTDF measurement
XYPhi Stage for automated sample positioning and rotating
Automated specular light removal
Calibration Samples
Aperture Mask Calibration Device
Monochromator for automated spectrally tunable illumination

* *Specifications subject to change without notice*





System Requirements

- 2.0 GHz or faster processor
- 1GB or greater RAM
- Windows® 7, Vista or XP
- USB 2.0 interface

Radiant Zemax

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SphereOptics

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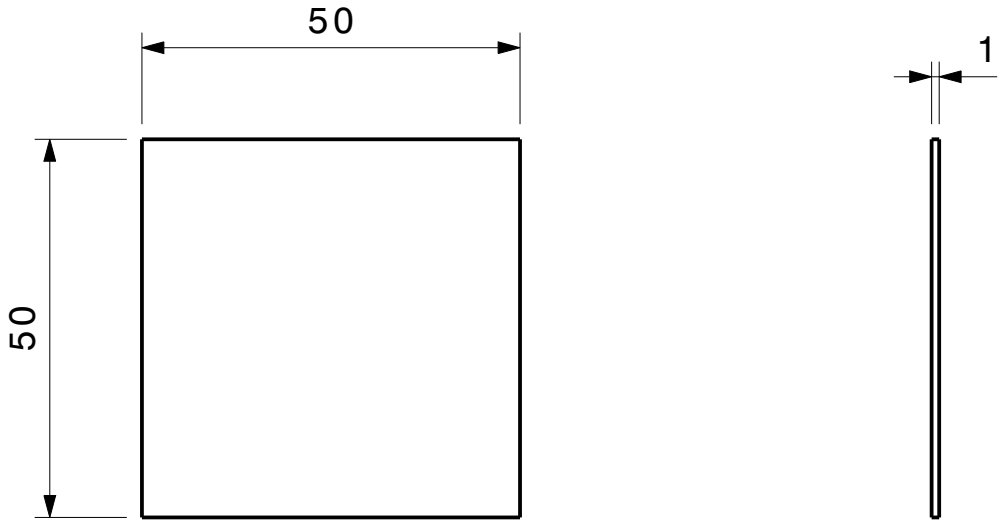
Fax +49 7556 966 562-22
E-Mail info@sphereoptics.de
www.sphereoptics.de

Appendix B
Samples Drawings

A	23.04.2018 JM	First issue



Isometric view
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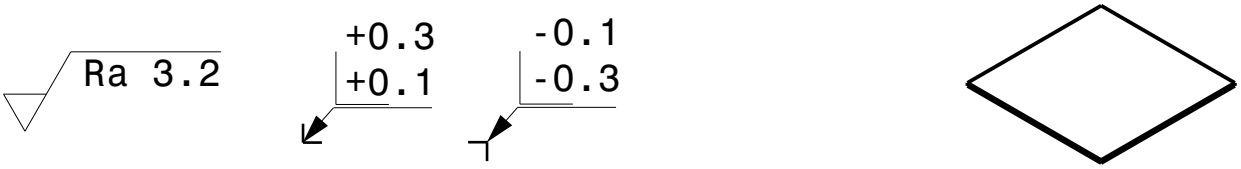

NOTES :

Machining overlengths to be defined by the subcontractor.
Machining overthicknesses to be defined by the subcontractor.

Surface treatment: Black Anodizing (modified procedure according to ESA technical note D-TOS/QMC Report : 00/055 05.05.2000)

#	Qty	Identification Number	Title	Material Code
1	1	ALM-DES-225-6001	Black Coating Sample Type I	EN AW 6061 T651

General tolerances / Tolérances générales (ISO 2768-f)									Angular dimensions				N-Class roughness Classe de rugosité N (Ra in μm)			
Linear dimesions (in mm)																
Nominal dimension	≥ 0.5 ...3	> 3 ...6	> 6 ...30	> 30 ...120	> 120 ...400	> 400 ...1000	> 1000 ...2000	> 2000 ...4000	...10	> 10 ...50	> 50 ...120	> 120 ...400	N10 N9 N8 N7	12.5 6.3 3.2 1.6	N6 N5 N4 N3	0.8 0.4 0.2 0.1
Tolerance	± 0.05	± 0.05	± 0.1	± 0.15	± 0.2	± 0.3	± 0.5	-	± 1°	± 30'	± 20'	± 10'				

Project	17-10P-225	Drawn	Jaime Martin Lopez (Authentication) 2018.05.02 08:51:06 +02'00'		Scale 1:1
Seperate RPL Nb	-	Checked			
Internal Drawing Nb	ALM-DES-225-6001	Release			

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Tot. Mass	Sheet N°/Nb	Format
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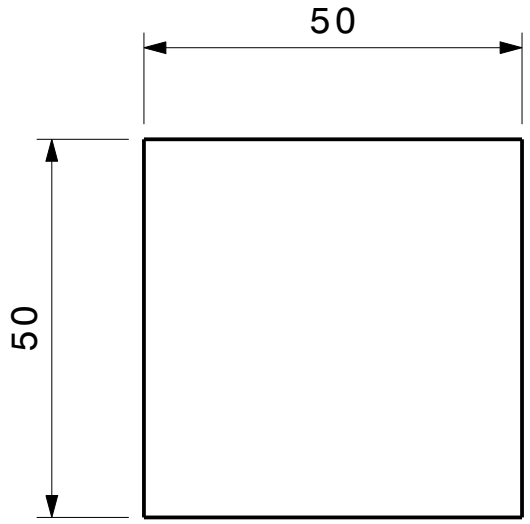
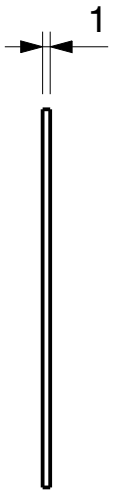
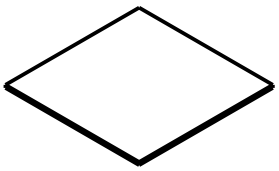
Title	Drawing Number	Revision
Black Coating Sample Type I	ALM-DES-225-6001	A

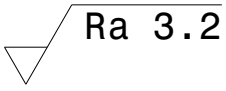
A	23.04.2018 JM	First issue

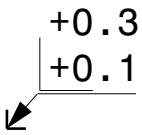


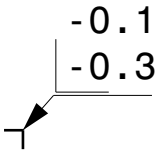


Isometric view
Scale: 1:2









NOTES :

Machining overlengths to be defined by the subcontractor.
Machining overthicknesses to be defined by the subcontractor.

Surface treatment: Kepla-Coat Black.

#	Qty	Identification Number	Title	Material Code
1	1	ALM-DES-225-6002	Black Coating Sample Type II	EN AW 6061 T651

General tolerances / Tolérances générales (ISO 2768-f)									Angular dimensions				N-Class roughness Classe de rugosité N (Ra in μm)			
Linear dimesions (in mm)																
Nominal dimension	≥ 0.5 ...3	> 3 ...6	> 6 ...30	> 30 ...120	> 120 ...400	> 400 ...1000	> 1000 ...2000	> 2000 ...4000	...10	> 10 ...50	> 50 ...120	> 120 ...400	N10	12.5	N6	0.8
													N9	6.3	N5	0.4
													N8	3.2	N4	0.2
Tolerance	± 0.05	± 0.05	± 0.1	± 0.15	± 0.2	± 0.3	± 0.5	-	± 1°	± 30'	± 20'	± 10'	N7	1.6	N3	0.1

Project	17-10P-225	Drawn		Jaime Martin Lopez (Authentication) 2018.04.27 16:26:35 +02'00'	Scale
Seperate RPL Nb	-	Checked			1:1
Internal Drawing Nb	ALM-DES-225-6002	Release			

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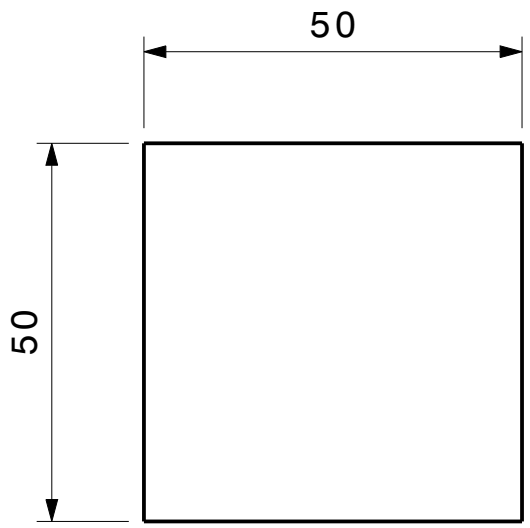
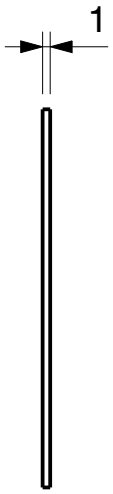
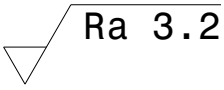
Tot. Mass	Sheet N°/Nb	Format
6.8 g	1/1	A4

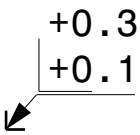
Title	Drawing Number	Revision
Black Coating Sample Type II	ALM-DES-225-6002	A

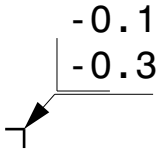
A	23.04.2018 JM	First issue



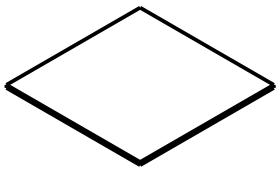








Isometric view
Scale: 1:2



NOTES :

Machining overlengths to be defined by the subcontractor.
Machining overthicknesses to be defined by the subcontractor.

Surface treatment 1: Bead blasting prior to black coating

Surface treatment 2: Black Anodizing (modified procedure according to ESA technical note D-TOS/QMC Report : 00/055 05.05.2000)

#	Qty	Identification Number	Title	Material Code
1	1	ALM-DES-225-6003	Black Coating Sample Type III	EN AW 6061 T651

General tolerances / Tolérances générales (ISO 2768-f)									Angular dimensions				N-Class roughness Classe de rugosité N (Ra in μm)			
Linear dimesions (in mm)																
Nominal dimension	≥ 0.5 ...3	> 3 ...6	> 6 ...30	> 30 ...120	> 120 ...400	> 400 ...1000	> 1000 ...2000	> 2000 ...4000	...10	> 10 ...50	> 50 ...120	> 120 ...400	N10 N9 N8 N7	12.5 6.3 3.2 1.6	N6 N5 N4 N3	0.8 0.4 0.2 0.1
Tolerance	± 0.05	± 0.05	± 0.1	± 0.15	± 0.2	± 0.3	± 0.5	-	± 1°	± 30'	± 20'	± 10'				

Project	17-10P-225	Drawn		Jaime Martin Lopez (Authentication) 2018.05.02 08:51:58 +02'00'	Scale
Seperate RPL Nb	-	Checked			1:1
Internal Drawing Nb	ALM-DES-225-6003	Release			

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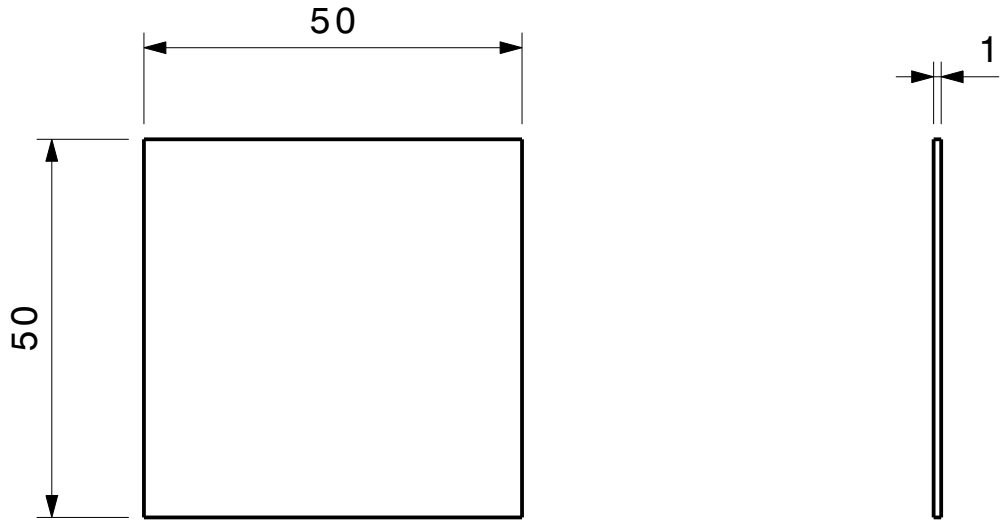
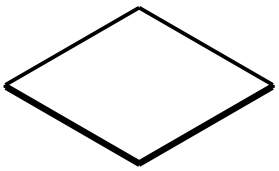
Tot. Mass	Sheet N°/Nb	Format
6.8 g	1/1	A4

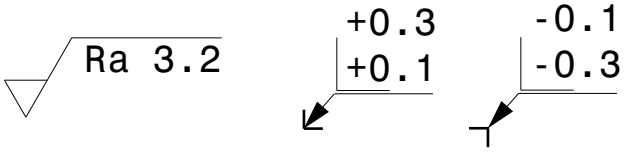
Title	Drawing Number	Revision
Black Coating Sample Type III	ALM-DES-225-6003	A

A	23.04.2018 JM	First issue



Isometric view
Scale: 1:2





NOTES :

Machining overlengths to be defined by the subcontractor.
Machining overthicknesses to be defined by the subcontractor.

Surface treatment 1: Bead blasting prior to black coating.
Surface treatment 2: Kepla-Coat Black.

#	Qty	Identification Number	Title	Material Code
1	1	ALM-DES-225-6004	Black Coating Sample Type IV	EN AW 6061 T651

General tolerances / Tolérances générales (ISO 2768-f)									Angular dimensions				N-Class roughness Classe de rugosité N (Ra in μm)			
Linear dimesions (in mm)																
Nominal dimension	≥ 0.5 ...3	> 3 ...6	> 6 ...30	> 30 ...120	> 120 ...400	> 400 ...1000	> 1000 ...2000	> 2000 ...4000	...10	> 10 ...50	> 50 ...120	> 120 ...400	N10 N9 N8 N7	12.5 6.3 3.2 1.6	N6 N5 N4 N3	0.8 0.4 0.2 0.1
Tolerance	± 0.05	± 0.05	± 0.1	± 0.15	± 0.2	± 0.3	± 0.5	-	± 1°	± 30'	± 20'	± 10'				

Project	17-10P-225	Drawn		Jaime Martin Lopez (Authentication) 2018.04.27 16:27:32 +02'00'	Scale
Seperate RPL Nb	-	Checked			1:1
Internal Drawing Nb	ALM-DES-225-6004	Release			

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Tot. Mass	Sheet N°/Nb	Format
6.8 g	1/1	A4

Title	Drawing Number	Revision
Black Coating Sample Type IV	ALM-DES-225-6004	A

Appendix C
Total hemispherical Reflectance Raw data

The raw data of the total hemispherical reflectance (10°) are available in the excel file named "FLX-TRR-ALM-CU-0001-Black Coating Optical Test - Raw Data.xlsx" embedded in this document.