MERTIS - Reflective baffle design and manufacturing

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ABSTRACT

Optical instruments for remote sensing applications frequently require measures for reducing the amount of external, unwanted stray light in the optical instrument path. The reflective planet baffle design and manufacturing process for the thermal infrared imaging spectrometer MERTIS onboard of ESA's cornerstone mission BepiColombo to Mercury is presented. The baffle has to reflect the unwanted solar flux and scattered IR radiation, and minimize the heat load on the instrument.

Based on optical stray light simulations and analyses of different baffle concepts the Stavroudis principle showed the best performance and the smallest number of internal reflections. The setup makes use of the optical properties of specific conic sections of revolution. These are the oblate spheroid, generated by rotating an ellipse about its minor axis, and the hyperboloid of one sheet, obtained by the rotation of a hyperbola around its conjugate axis. Due to the demanding requirements regarding surface quality, low mass and high mechanical stability, electroforming fabrication was selected for the baffle. During manufacturing, a layer of high strength nickel alloy is electrodeposited onto a diamond turned aluminum mandrel. The mandrel is subsequently chemically dissolved. Not only the baffle, but also the baffle support structure and other mating components are electroformed. Finally, the baffle and support structure are assembled and joined by an inert gas soldering process. After the optimum baffle geometry and surface roughness has been realized, the remaining total heat flux on the baffle is only dependent on the selection of the appropriate, high reflective coating.

Keywords: Baffling, Stavroudis, stray light, Mercury, MERTIS, BepiColombo

1. INTRODUCTION

Baffles are placed on the front of optical instruments like telescopes, cameras or spectrometers to shade the interior from solar and planetary radiation. A good survey can be found in Ref. 1. Based on optical stray light simulations and analyses of different baffle concepts the Stavroudis principle shows the best performance and the smallest number of internal reflections.

2. BAFFLE GEOMETRY

The setup makes use of the optical properties of specific conic sections of revolution. These are the oblate spheroid, generated by rotating an ellipse about its minor axis, and the hyperboloid of one sheet, obtained by the rotation of a hyperbola around its conjugate axis.

In both cases, the foci are also rotated about the axis of the conic, generating a circle in a plane perpendicular to that axis[2]. The working principle is shown in Figure 1.

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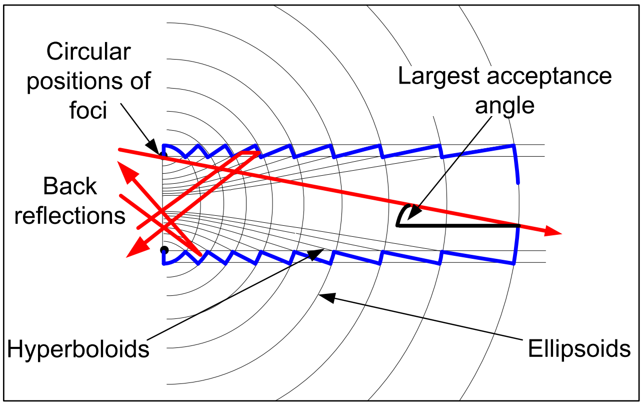


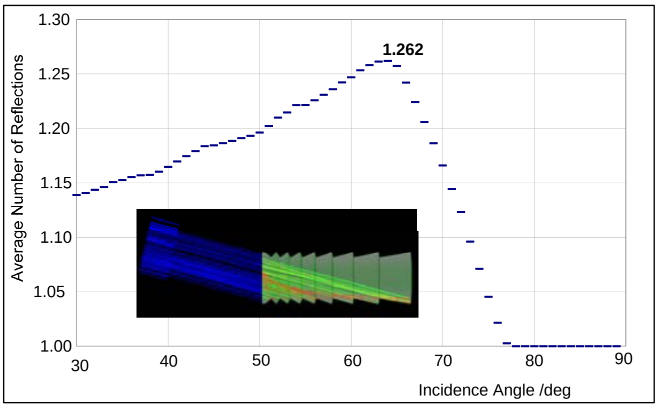


Figure 1: Consecutive ellipsoids and hyperboloids are leading to a minimum number of reflections.

The majority of rays is leaving the baffle with one single internal reflection (i.e. minimum absorbed power), only some rays with two.

3. MANUFACTURING PROCESS

The design of the stray light baffle requires pristine surface quality with a roughness of 20 nm RMS or better, low mass of 0.25 kg or better and high mechanical stability and stiffness due to the extreme mechanical loads during launch. The first mechanical eigen mode of the baffle structure shall be above 150 Hz.

The net-shape electroforming fabrication process[3], developed by NiCoForm, Inc., in combination with the mechanical properties of its proprietary alloy, NiColoy®, as well as the design of the electroformed baffle support structure provide the best solutions to meet the demanding requirements of the assembly.

Electroforming begun with a diamond machined mandrel that has the exact surface finish, dimensions and geometry desired of the inside of the finished part, cf. Figure 2. The mandrel was cleaned and a layer of NiColoy® - a proprietary Nickel-Cobalt alloy, was electrolytically deposited onto it. The plated layer was then laser cut on the ends to make the required orifices which define the instrument's FOV.

Finally, the aluminum mandrel was chemically dissolved in a caustic solution that does not attack NiColoy®. The result is shown in Figure 3: An 0.2 mm thick NiColoy® shell that has the desired net-shape of the baffle. Since plating is an atomic level process, exact replication of the optical surfaces was achieved. Additionally, internal stress of the deposit was kept close to zero, which eliminated geometric distortions of the optics.

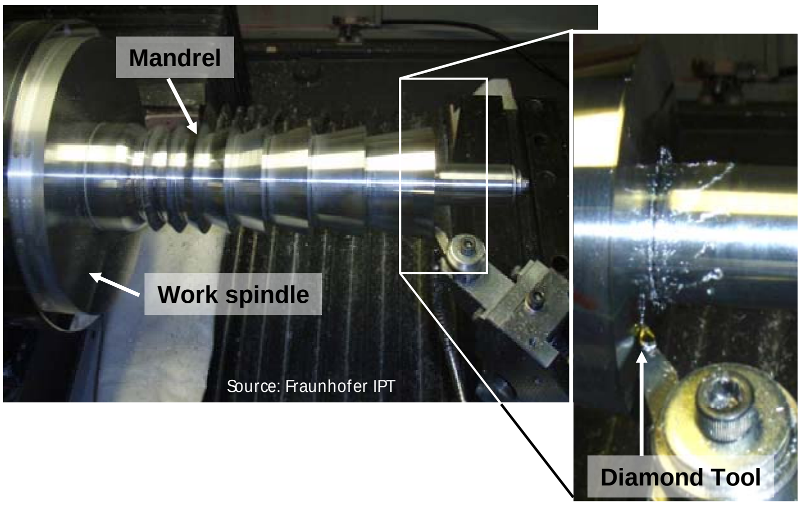


Figure 2: Diamond turning of mandrel. By courtesy of Fraunhofer IPT/Aachen.

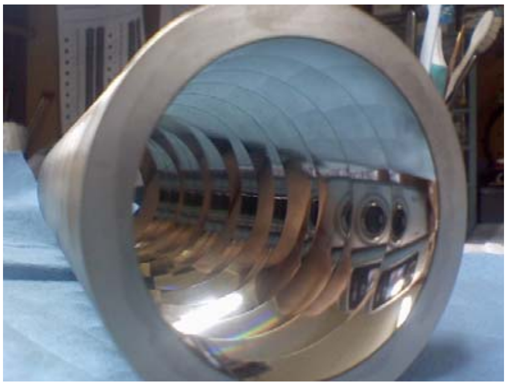


Figure 3: Replication of the diamond turned mandrel on the inside of the electroformed baffle.

4. MATERIAL SELECTION

The baffle, being a flight component, requires a low mass and high strength material. NiColoy® has a density of 8.88 g/cm^3, which is relatively high compared to traditional aerospace materials, like Titanium Alloys[4] (~4.5 g/cm^3).

The electroforming process gives the ability to deposit a thin but uniform wall of material which allows for fabrication of a low mass component. Examining the material options that are available through electroforming, NiColoy® proved to have a higher strength than pure electroformed Nickel[5]. Moreover, compared to Titanium Alloys, NiColoy® has similar Yield Strength, Ultimate Tensile Strength and Modulus of Elasticity. Based on these values and detailed structural analysis for the component, it was determined that NiColoy is a suitable material for baffle fabrication. See the comparison in Table 1 below.

Table 1: Comparison of Mechanical Properties

Material	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Modulus of Elasticity (ksi)	Elongation at Break (%)
NiColoy®	96-120	125-150	20000-22000	2.5-7.5
Titanium Alloys[4]	110-205	120-229	15200-17800	4-18
Electroformed Nickel[5]	60-80	90-120	21000	10-20

5. MATING COMPONENTS AND ASSEMBLY

The extreme loads and intense vibrations that the planetary baffle will experience during launch required the additional design of a support structure for the baffle. The use of electroforming enabled the design of a single, thin walled sleeve-type support structure as opposed to an eight piece “rib-like” structure which was originally proposed. This single component structure simplified the assembly process and further reduced the overall weight of the component as compared to alternative designs. Assembly of the baffle, support structure, aperture and flange was completed in an inert gas soldering process. Since all mating components were fabricated with the same material, the coefficient of thermal expansion is the same from component to component, making for a more stable assembly.

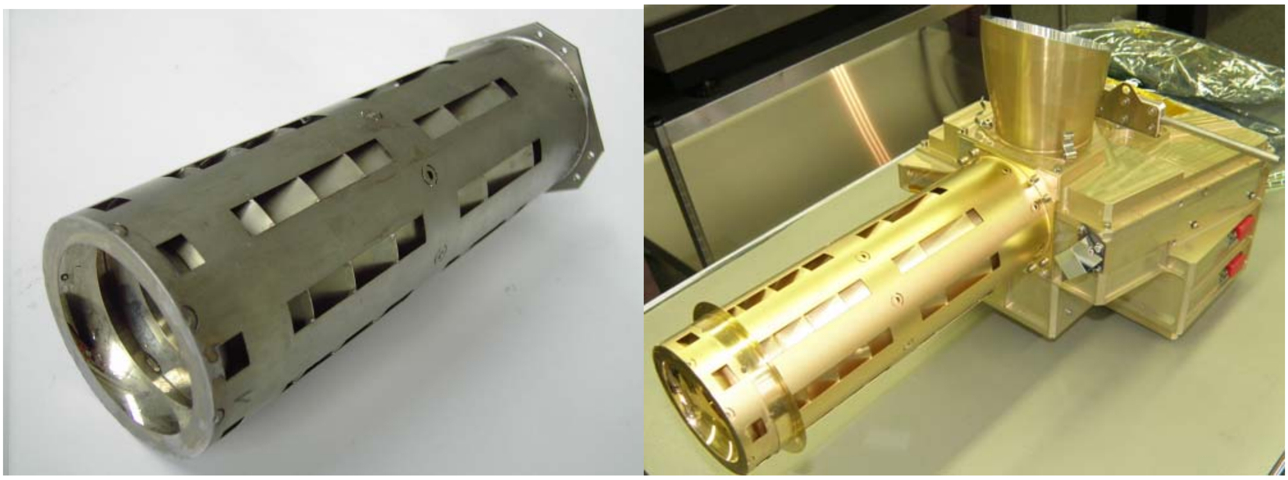


Figure 4: Bare planetary baffle assembly (left, length/diameter 220 mm/70 mm) and coated baffle integrated in the MERTIS Structural Thermal Model STM (right).

6. OPTICAL COATING

To limit the thermal load of the baffle to the instrument and spacecraft, irradiance outside the FOV has to be reflected to the highest possible degree. In addition to the basic design of the baffle the absorbance of the baffle material resp. the coating material is crucial. Therefore a model of different coating materials has been developed to simulate the thermal impact of the absorbance of the materials. The materials bare nickel, gold, aluminum, silver and the protected variants have been evaluated.

The two major stray light sources are the direct sun light (incident angle at baffle aperture between 35 to 90 deg) and the outside FOV IR radiation from Mercury. The spectral range of both sources is different. While the sun emits largely in the visible spectra with a peak at about 500 nm (black body equivalent temperature of 5776 K: 200…2.8 µm) the Mercury emits in the IR range with a maximum at a wavelength of 4µm. With respect to the baffle material / coating there is a trade between the impact of direct sun illumination and the rejection of the IR irradiance of the mercury background.

It turned out that a bare nickel surface (i.e. the uncoated baffle) exhibits the highest thermal load (temperature maximum at the baffle tip: 263 °C), gold a medium thermal load (211 °C) and protected silver or protected aluminum the lowest thermal load (165 °C) on the baffle. Since the reflectivity stability (tendency for aging effects) of silver and aluminum in a harsh environment is lower compared to gold, gold was chosen as a best coating material for the baffle. Figure 5 is showing the simulated, thermal loads on a gold coated baffle during three orbits and the temperature gradient from the tip to the end of baffle.

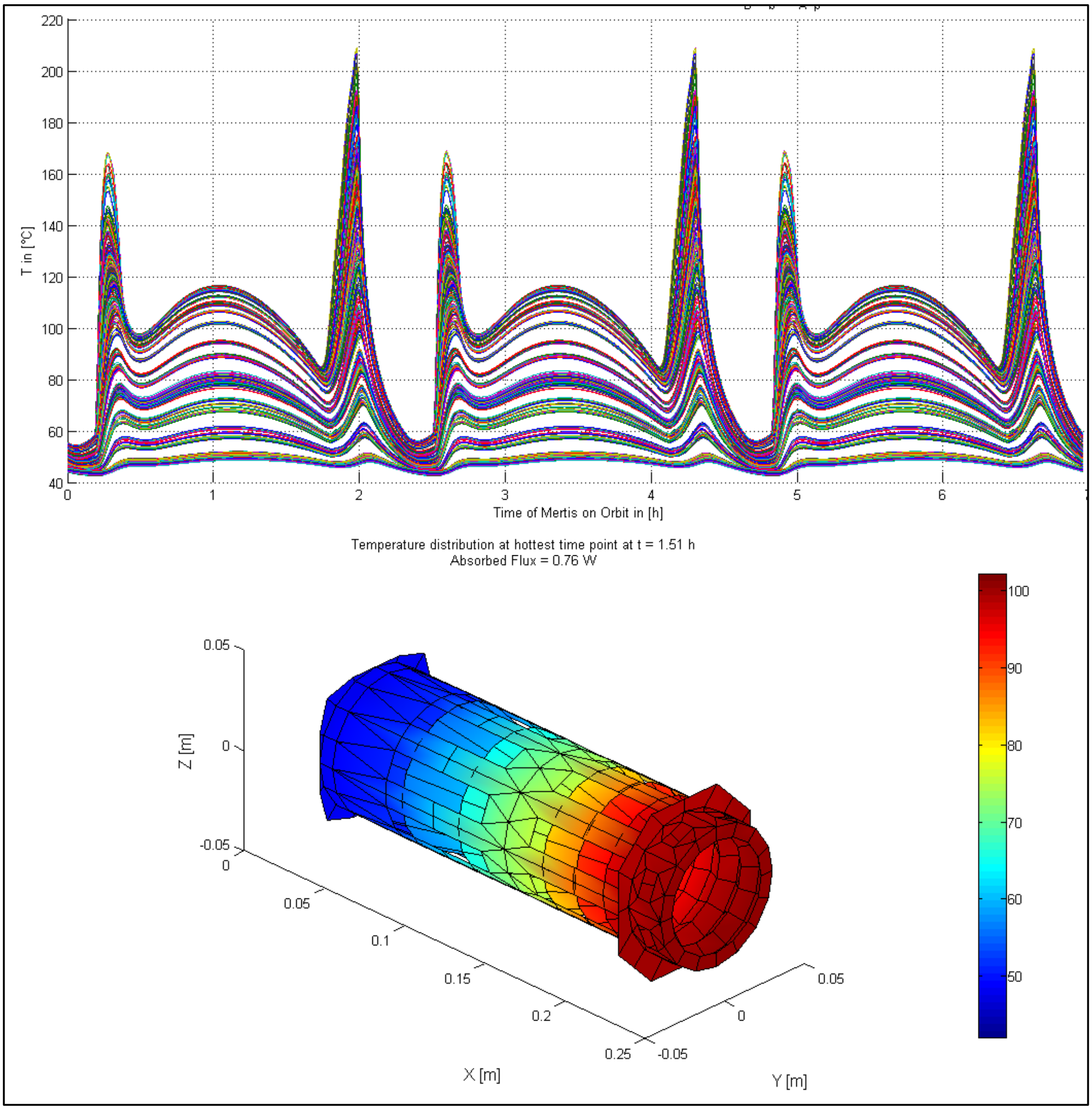


Figure 5: Simulated, thermal loads on a gold coated baffle during three orbits (upper curve). The upper, multiple curves show multiple thermal nodes on the baffle. The lower figure shows a snap-shot temperature distribution to show the gradient from the tip to the end of baffle.

7. OPTICAL VERIFICATION

The electromagnetic radiation which incidences the baffle is reflected, transmitted and absorbed by the surfaces of the baffle inner walls. At a given temperature the surface emits radiation, which is dependent on the absorbed radiation. The reflectance (ρ), transmittance (τ), absorption (α) and hemispherical emittance (ε) can be calculated from measured spectra as follows:

$$\rho_{refl}(\lambda) = \frac{\int_{\lambda} R(\lambda) S(\lambda) d\lambda}{\int_{\lambda} S(\lambda) d\lambda} \quad (1)$$

$$\tau_{trans}(\lambda) = \frac{\int_{\lambda} T(\lambda) S(\lambda) d\lambda}{\int_{\lambda} S(\lambda) d\lambda} \quad (2)$$

$$\alpha_{abs}(\lambda) = \frac{\int_{\lambda} A(\lambda) S(\lambda) d\lambda}{\int_{\lambda} S(\lambda) d\lambda} \quad (3)$$

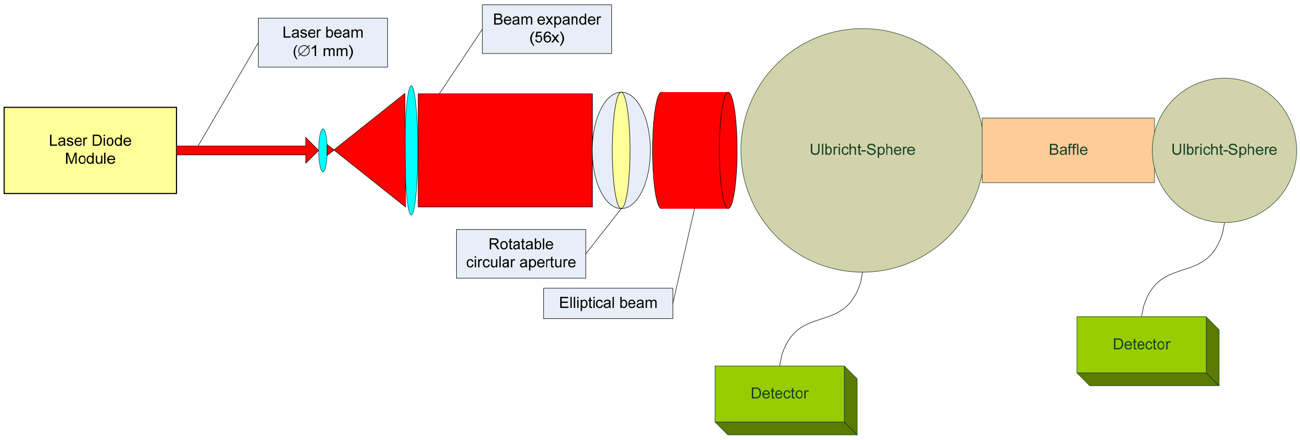
$$\varepsilon_{emitt}(\lambda) = \frac{\int_{\lambda} E(\lambda) S(\lambda) d\lambda}{\int_{\lambda} S(\lambda) d\lambda} \quad (4)$$

where *R(λ)* – is the spectral reflectance, *T(λ)* the spectral transmittance, *A(λ)* the spectral absorbance, *E(λ)* the spectral emittance, *S(λ)* the spectral solar irradiance. Apparently, form the energy conservation law it is valid that

$$\rho_{refl}(\lambda) + \tau_{trans}(\lambda) + \alpha_{abs}(\lambda) = 1. \quad (5)$$

The wavelength depended coating properties were measured with a spectrophotometer (PerkinElmer, LAMBDA 950 UV/Vis/NIR) on flat samples manufactured of the same substrate material and coating.

A test setup to measure the Point Source Transmittance (PST) and point source Reflectance (PSR) was built up. For simplicity reasons, the test setup contains a light source (laser diode) radiating at one single test wavelength of 650 nm. The setup shall enable different beam angles to verify the baffle performance that strongly depends on the beam angle of incidence. The principal test configuration is illustrated in Figure 6. The optimization of the setup is not yet completed but first measurement results are showing a good correlation with the simulation results.



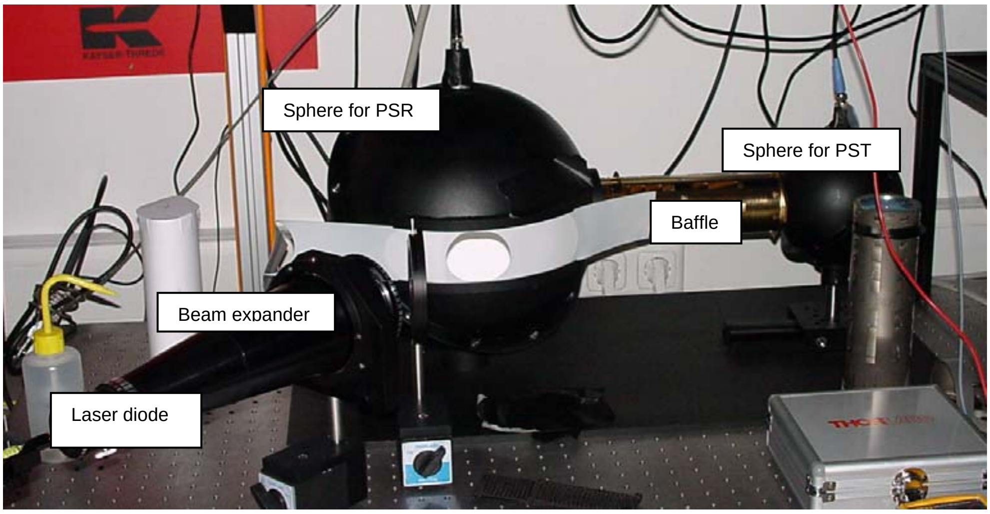


Figure 6: Test setup to measure the Point Source Transmittance (PST) and point source Reflectance (PSR).

SUMMARY AND CONCLUSIONS

Electroforming of NiColoy® has been implemented in manufacturing the planetary baffle that takes advantage of the Stavroudis geometry to reflect radiation at incidence angles outside the MERTIS instrument field of view. The high strength of NiColoy® and the replication capabilities of electroforming enabled the manufacturing of this baffle which cannot be made by any other method. By manufacturing the mating components from NiColoy®, a strong and rigid component with a first eigenfrequency at 323 Hz, a low mass of 0.232 kg and uniform thermal properties has been achieved.

It turned out that gold coating is a most appropriate material when reflectivity and stability in a harsh environment is required.

The test setup to measure the Point Source Transmittance (PST) and point source Reflectance (PSR) is not yet optimized but first measurement results are showing a good correlation with the simulation results.

ACKNOWLEDGEMENTS

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