Appendix N

Spatial Infra-red Objective thermal analysis

Jean-Baptiste Meurisse Salem Belmana Remi Gazin
(Sodern, France)

Abstract

The aim of that thermal analysis is to calculate accurately the thermal gradient in all the lenses of a spatial infra-red objective facing a cryo-cooler. The issues of that work are to calculate the optical performances of the objective (stability, defocus ...) thanks to thermal predictions, to predict the appropriate flight adjustment shims and to accurately assess the heat flux radiated to the cryo-cooler so as to avoid overdimensioning. The difficulty of that analysis consists in taking into account the spectrally dependant thermo-optical properties of the lenses. Indeed, the functional bandwidth of that objective (around 10μm) being inside the "thermal bandwidth" ($\sim$[2μm;50μm] with a peak of luminance at 10μm) a strong semi-transparent effect had to be considered. A spectral calculation has been performed thanks to NX7.5 software and allows us to accurately calculate the flux radiated to the cryo-cooler. Its shows particularly the filtering (or semi-transparent) effect of the lenses on each other: the heat flux radiated by the internal lenses being way smaller than the one from the lens facing the cryo-cooler.

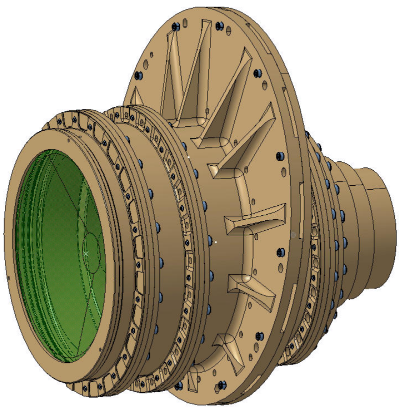
Spatial InfraRed Objective Thermal Analysis

8th and 9th november 2011

JB. Meurisse (jean-Baptiste.meurisse@sodern.fr)
S. Belmana (salem.belmana@sodern.fr)
R. Gazin (remi.gazin@sodern.fr)

Equipment presentation

- **Equipment presentation**
  - **Infrared objective for space application (observation)**
    - High performances required
    - Accurate temperature gradient assessment required
  - **Fonctionnal bandwith inside [2µm;12µm]**
    - High transparency of the lenses inside this bandwith
    - Opacity/reflectivity above 12-20µm

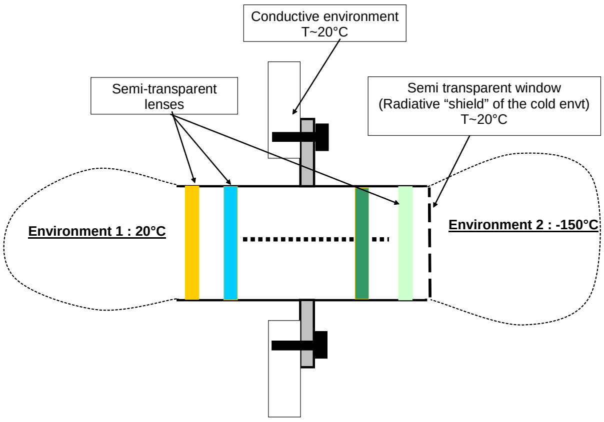


SODERN - 16 novembre 2011 P. 2

SODERN

Technical challenges

- **Verification of the thermal gradients in a semi-tranparent and spectrally dependant environment**



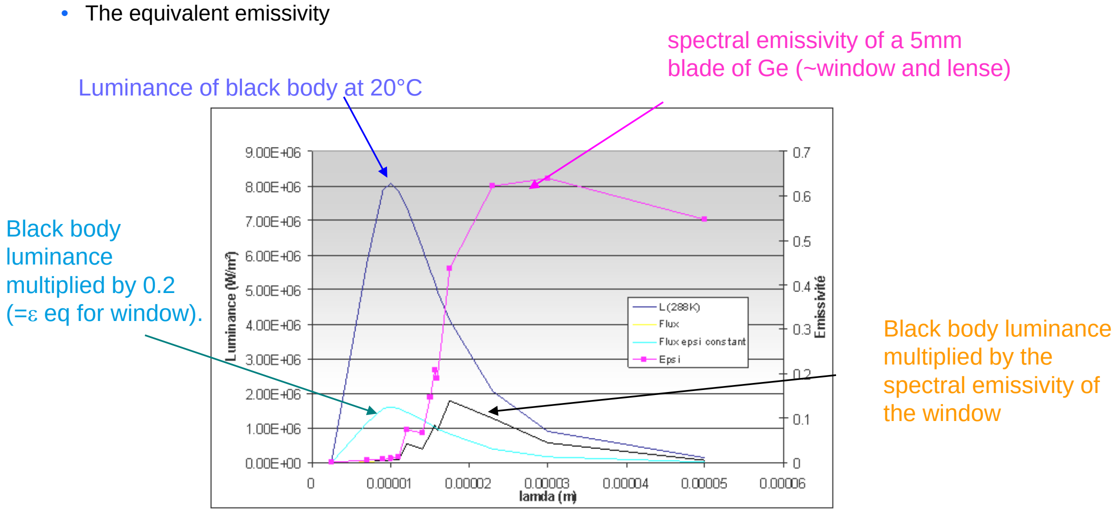
- **Determination of in-flight focusing shim thickness by calculation only**
  - **Thermal gradient assessment thanks to NX7.5**
  - **Calculation of optical de-focus due to thermal gradient**
  - **Determination of the relevant shim**

SODERN - 16 novembre 2011 P. 3

SODERN

Spectral approach required (1/2)

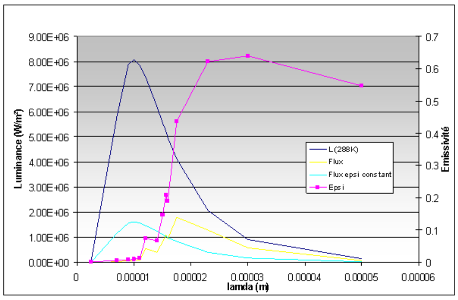
- **Importance of the spectral aspects in the thermal exchanges:**
  - **Benchmark on the emittance of the window radiated to the lenses, when considering**
    - The actual spectral thermo-optical properties
    - The equivalent emissivity



SODERN - 16 novembre 2011 P. 4

Spectral approach required (2/2)

- **The integral of the yellow and the light blue curves (i.e the energy [W] emitted by the window) are similar due to the equivalent emissivity definition**



- **The spectral fluxes are not centered on the same wavelength.**
  - **Lenses will absorb differently the two fluxes**
  - **In particular, the actual flux (yellow) will be more absorbed as it is centered on a high absorption wavelength ($\varepsilon_{window} \sim \varepsilon_{lense}$).**
- **The equivalent emissivity approach is too severe and does not allow the focus shim prediction**

SODERN - 16 novembre 2011 P. 5

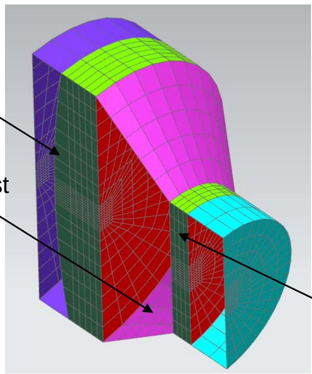
Choosen solution: NX7.5

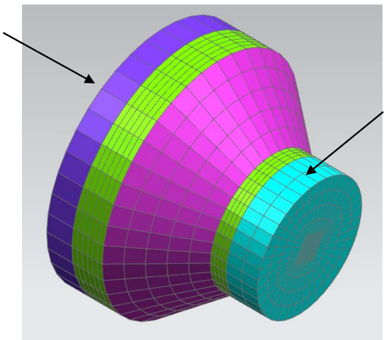
- **Solving the spectrally dependent problem requires an adapted software that allows the semi-transparent resolution.**
- **NX7.5 has been choosen:**
  - **The spectral module is available since 2010**
  - **It is adapted to a fine meshing required to assess the lenses thermal gradient with good accuracy**
- **A validation campaign has been performed on the NX7.5 spectral module**
  - **Validation on a thin single window**
    - The maximum error on these cases is 4%
  - **Validation on a simplified (2 lenses) objective**

SODERN - 16 novembre 2011 P. 6

Spectral module validation (1/3)

- **Simplified 2 lenses objective**
  - **Aims at validating thermal couplings between two lenses**
  - **Allows for preliminary analysis of the cavity between the last lens and the window**
- **Model presentation**

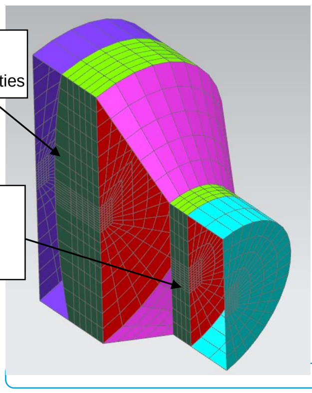


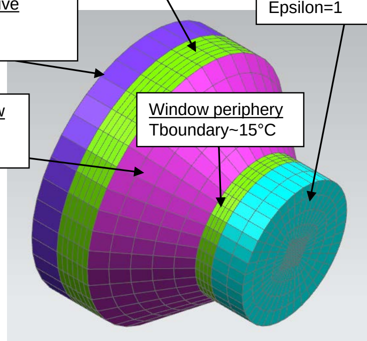


SODERN - 16 novembre 2011 P. 7

Spectral module validation (2/3)

- **Case 1: Nominal case boundary conditions**
  - **Last lens**
    - Boundary T° on its periphery : 20°C (radial conduction implemented)
    - Actual thermo-optical properties
  - **Window:**
    - Boundary T°~15°C
    - Actual thermo-optical properties without reflexion ($T=T_{\text{réelle}}+R_{\text{réelle}}$; $A=A_{\text{réelle}}$)
  - **Cavity lens-window:**
    - T~15°C
    - Epsilon=1
  - **Inside of the objective (representative of the other lenses)**
    - T=20°C
    - Epsilon=1





SODERN - 16 novembre 2011 P. 8

Spectral module validation (3/3)

- **Validation cases**
  - **The monitored value is the heat flux emitted towards cold environment**
    - Cause for the radial gradient in the lenses
    - Cause for the decrease of the average temperature of the equipment

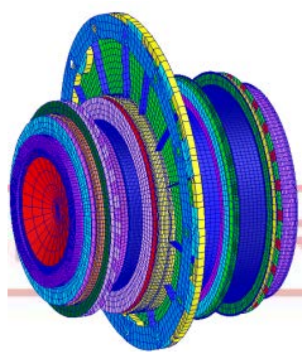
Computation case	Flux emitted to the cold envt (=$\Phi_{emitted} - \Phi_{absorbed}$)	
	Theoretical value	Calculated value
Case 1 – Nominal case (no reflective window)	24.2mW	24.5mW (error:1.5%)
Case 2 – Impact of the window's reflection Actual thermo-optical properties of the window	16.0mW 33% decrease of the flux emitted to the cold envt	15.9mW (error:1.0%)
Case 3 – Addition of a lense The inside objective has diffuse node and represent the additionnal lens	25.8mW	26.7mW (erreur:3.6%)

- **The spectral reflexion has a strong impact of the results**
- **The filtering of the lenses w.r.t the cold environment is important too**
- **The calculated error in these cases is below 4%**

SODERN - 16 novembre 2011 P. 9

Preliminary results on the equipement

- **The thermal model of the equipment:**
  - **Meshing of the parts (lenses, mechanical structre, environments…)**
  - **Implementation of materials properties (thermo-optical properties, conductivity, heat capacity)**
  - **Boundary conditions implemented**
  - **Definition of the bandwidth for analysis and its discretisation, which depends on**
    - The temperature levels expected
    - The thermo-optical properties of the materials
    - The accuracy required



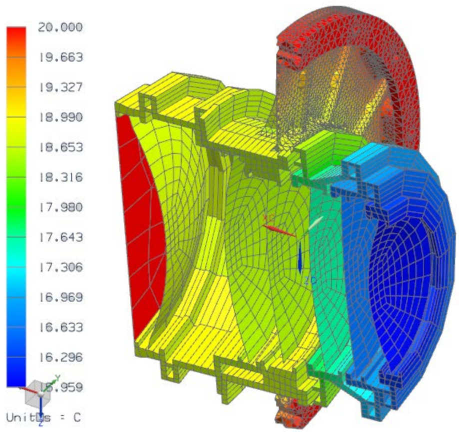
SODERN - 16 novembre 2011 P. 10

SODERN

Preliminary results on the equipement

- **Preliminary results**

Half view of the model



➔Cold environment has strong impact on lenses.

➔Filtering effect is correclty taken into account

SODERN - 16 novembre 2011 P. 11

SODERN

Next steps

- **Consolidation of the results by sensitivity analysis**
  - **Hand calculation to be compared to computed values**
  - **Physical sensitivity**
    - Thermo-optical properties
    - Type of reflexion (diffuse / specular)
    - …
  - **Numerical sensitivity**
    - Number of emitted rays for the GR calculation
    - Discretisation of the spectral bandwidth
    - …
- **Finalize the thermal analysis:**
  - **Steady-state calculation**
    - Assessment of the thermal gradient in the lenses
    - Computation (CodeV optical software) of the associated optical performance
    - Prediction of the adapted shim to fit with location of focal plane
- **Transient calculation**
  - **Assessment of the thermal gradient stability due to environment variations**
  - **Computation (CodeV optical software) of the variation of focal plane location and the associated performances**

SODERN - 16 novembre 2011 P. 12

Conclusion

- The spectral dependent thermal aspects on our infra-red objective is the main issue of the analysis and of the design
- The problem is analyzed thanks to NX7.5 for which the appropriate module has been validated on simple cases
- The preliminary results are extremely encouraging as they are physically consistent and partially validated by hand calculation
- Sensitivity analysis has to be performed so as to:
  - Assess the optical performances in flight conditions
  - Compute the in-flight shim thickness

SODERN - 16 novembre 2011 P. 13