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DESIGN AND FUNCTIONAL TESTS OF THE EUCLID GRISM MOUNT

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ABSTRACT

The Euclid mission selected by ESA in the Cosmic Vision program is dedicated to understand dark energy and dark matter. One of the probes based on detection of Baryonic Acoustic Oscillations required the redshift of millions of galaxies. This massive spectroscopic survey relies on the Near Infrared SpectroPhotometer (NISP) using grism in slitless mode. In this Euclid NISP context, we designed a cryogenic mount for the four grisms of the spectroscopic channel. This mount has to maintain optical performances and alignment at the cryogenic temperature of 120K and to survive launch vibrations. Due to a very small mass and volume budget allowed in the Grism Wheel Assembly our design relies on a weight relief Invar ring glued to the grism by tangential flexures. Tangential flexures have the advantage of small height but the drawback of less decoupling capabilities than bipods. We will present the design of the mount and the integration and functional tests to stay within the 60 nm RMS transmitted wavefront error budget allowed to the grism.

I.   INTRODUCTION

Euclid space mission selected in 2011 by ESA is dedicated to study the dark universe. One of the probes used is Baryonic Acoustic Oscillations (BAO) which requires redshift measurements of millions of galaxies by the acquisition of their emitted spectra. Near Infrared SpectroPhotometer (NISP) instrument of Euclid uses low resolution grisms in slitless mode to perform this massive redshift measurement.

A grism is a grating imprinted on the hypotenuse of a prism to make the light undeviated at a chosen wavelength. In our case, the prism is made of a silica blank with approximately 2 degree wedge. The grating is imprinted into a thin resin layer by a photolithographic process.

The NISP Grism Sub-Unit (NI-GSU) is a critical part of the NISP instrument of EUCLID mission. To maintain optical performances in cryogenic environment and survive during launch vibration, we designed a weight relief Invar ring which has to fit in a small mass and volume budget allowed by the Grism Wheel Assembly (GWA). The mount validation has been done first using a bare prism without grating or filter (protoprism).

II.   NI-GSU OVERVIEW

In NISP, there are 4 grisms mounted on a Grism Wheel Assembly (NI-GWA):

- 1 "blue" with a 1.9° prism angle transmitting in spectral band [950-1300] nm: BGS-Y
- 3 "red" with a 2.1° prism angle transmitting in spectral band [1300-1850] nm: RGS+Z, RGS-Z, RGS-Y.

For the red spectral band, the three similar grisms (except for the curvature radius of the filter face) are rotated 90° with respect to each other.

Each NI-GSU is composed of the following subassemblies:

- the grism itself (the optical element) [1]
- the grism mechanical mount which maintains the grism optical element in cryogenic environment on the wheel.

▮ *NI-GSU optical element*

Error! Reference source not found. shows the NI-GSU profile view layout. It contains three elements:

- a silica Suprasil 3001 prism including a convex first surface
- a grating (imprinted on a resin layer) on the prism hypotenuse
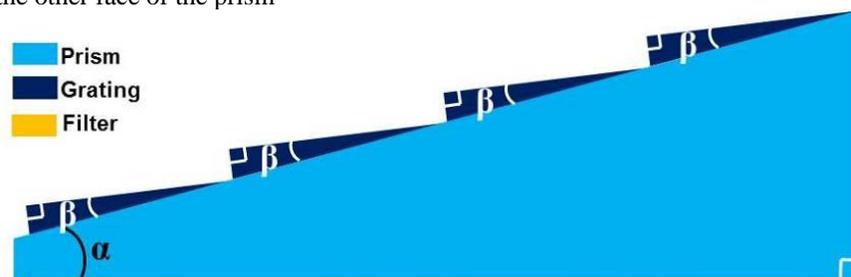- a filter on the other face of the prism

Fig. 1. NI-GSU profile view layout

■ *NI-GSU mechanical mount design approach*
The following picture shows the principle of the opto-mechanical mount:
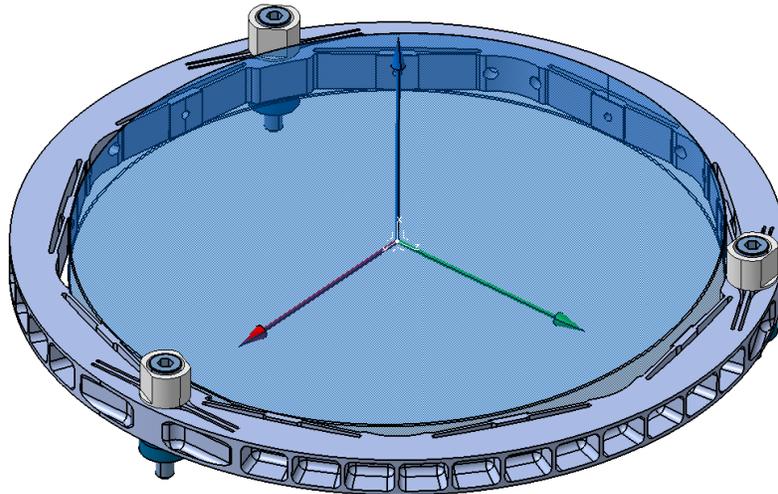

Fig. 2. 3D view of the opto-mechanical mount

Each grism is glued through 9 flexible blades [2] with 3M 9323-2 glue on an Invar ring. This ring is manufactured thanks to Electro Discharged Machining. This mount is fixed to the Invar Grism Wheel Assembly (NI-GWA) with 3 blades enabling it to minimize stresses in the optical element due to thermal differences (from 300 K to 100 K).

The bonding technique of Silica on Invar has already been approved by LAM with a bonding surface of about 49 mm2. The gluing total area and number of blades are determined by the quasi static accelerations (60 g Design Load Level) the system has to support. The radial compliance of the 9 blades enables to compensate the small difference of Coefficient of Thermal Expansion (CTE) between Invar and silica 3001 (even if these CTE are very close).

Length and thickness of the two stages of flexures are optimized to ensure the integrity of the assembly during thermal cycles and vibration tests.

■ *Interface with the wheel*
The interface with NI-GWA corresponds to 3 M4 threaded holes with brass helicoïl. Each grism will be delivered with its three Titanium M4 screws with 3 Invar spherical washers and 3 aluminum thermal compensation washers.

The proposed interface with the wheel is to have 3 M4 points positioned differently on the wheel depending on the grism orientation through the optical path. The philosophy is to always glue the grism in its mount with the same orientation as illustrated by Fig. 2, but to change the interface point positions on the wheel. Positions of the interface points are given by the referential attached to each grism configuration. Thus orientation of the grism (+ or - Z or - Y) is done on the mechanical interface with the wheel, not by the gluing in the mount. It allows to have the same procedure for the gluing and to design the same mechanical mount for all the components.

III.   Tests methodology
■ *Tests campaign*
The tests campaign of the NI-GSU protoprism (mock-up of the Engineering Model of the blue grism) was performed in LAM Test Building under the responsibility of LAM NI-GSU team, between September and mid-October 2013. It consisted in a first run of vibration "signature" tests on our LDS shaker (35 kN in sine mode) at the beginning of September 2013. Then the NI-GSU protoprism has been submitted to 8 thermal cycles between 323 and 105 K in our vacuum chamber in the last two weeks of September. In October, sine qualification and random tests have been performed on the prototype, in order to ensure that the thermal qualification did not change the behavior of the prototype, and to validate the design of the NI-GSU.

Vibration signature tests
Vibration tests conducted on the protoprism are firstly a low level sine (0.1 g from 20 to 2500 Hz), in order to know the first eigenfrequencies and to update the Finite Element Model.

Thermal tests

After the vibration "signature" tests campaign, the protoprism has been cycled 8 times between 323 K and 105 K in one of our vacuum chambers. Procedure for cooling down was the following:

- The mean temperature slope was about 10°C/hour (for cooling down and warming).
- There were 8 cycles during 10 days.

Vibration tests after cooling down

36 hours after the cooling down, sine qualification and random vibration tests have been performed on the protoprism in order to see if any changes did occur in its behavior. Firstly a low level sine vibration test (0.1 g between 20 and 2000 Hz) has been performed all axes in order to compare with the signature tests made before thermal cycles. Then, qualification sine has been conducted on each axis before the random tests.

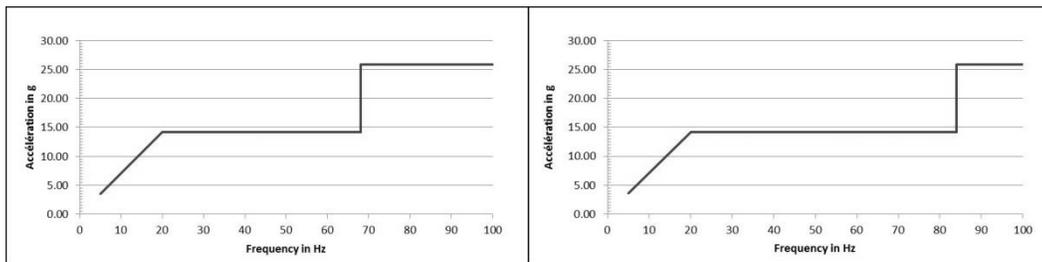Sine qualification spectra are a little bit different in X and Y or Z axes (see following images).

Fig. 3. Sine qualification spectrum in X direction (left) and in Y or Z directions (right)

Taking into account the fact that the frequencies of the grism are far from the one of the Grism Wheel Assembly, the project agreed to notch the random vibrations on the main frequencies of the grism for this model (protoprism). Thus random vibrations have been done with notches (depending of the vibration axes) on the resonant frequencies of the grism.

At this stage of instrument development, the random qualification levels at interface points with NI-GWA were not completely defined. Thus the random level was calculated to produce same stress in bonding pads than 60 g static; we obtained 10.7 g rms. Our assumption was 4.2σ of occurrence probability which has been seen on the time recording file during random tests at lower level (6g rms).

This random qualification level of 10.7 g rms has been achieved by means of progressive steps going from 4 g rms to 6 g rms up to 10.7 g rms. First intermediate random level (4 g rms) lasted 1 min at 0 dB, while the second intermediate level at (6 g rms) and the final one (10.7 g rms) lasted 2 min and 30 seconds at 0 dB in order to be able to study the time file.

Following images show the spectra for X and Y random qualification. Z axis random qualification spectrum is very close to Y axis spectrum.
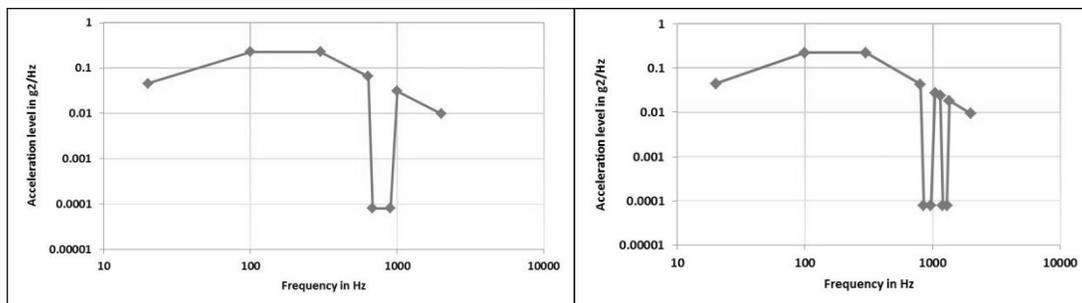

Fig. 4. X axis (left image) and Y axis (right image) random qualification spectra

Vibration and accelerometer axes

The vibration tests [3] have been performed along the three NI-GSU protoprism axes.

X axis is the optical axis, it goes from the plane face of the prism (filter side) to the prismatic face of the prism (grating side), Y axis goes from the flat part of the optics to the thickest part of the prism (XY plane is the symmetry plane of the NI-GSU), and Z axis completes the direct trihedron.

Three monoaxial accelerometers were positioned on the prism upper face, a PCB triaxial sensor was positioned in the middle part of the prism, and two aluminum cubes of 1 cm^3 equipped with 3 monoaxial

sensors (one in each direction) were stuck close to each other, one on the thickest part of the prism and the second one on the Invar mount (see Fig. 5).
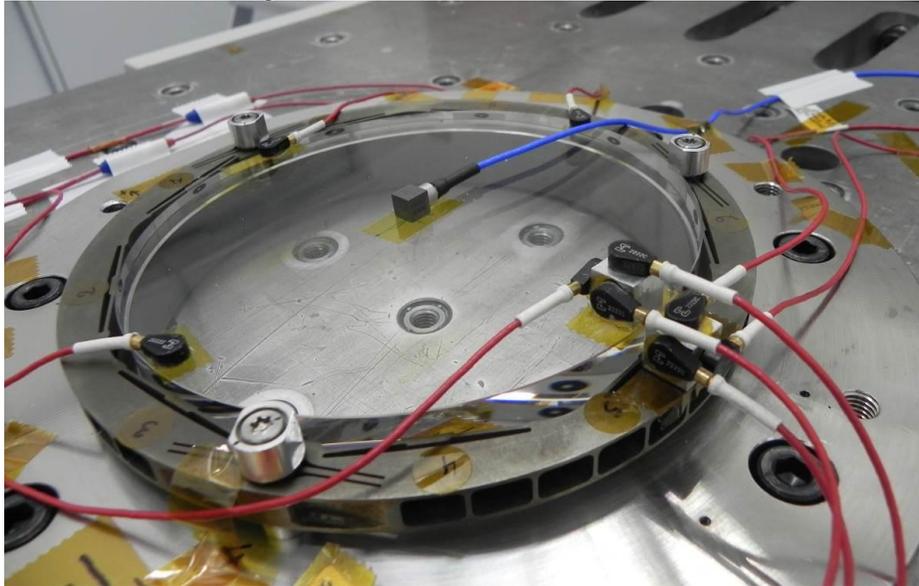

Fig. 5 .Photo of the NI-GSU protoprism equipped with its sensors and fixed on its vibration interface

The idea of using so many sensors for the protoprism vibration tests is linked to the need to know quite precisely the behavior of the specimen. Indeed, when we will qualify the complete Engineering Model (with filter and grating on the prism), we won't be able to put any sensor on the optics.

IV.   FEA AND TESTS CORRELATION
Aim

Finite Element Analyses [4] (modal, static, frequency responses and random) have been performed in order to have tests prediction before beginning the tests campaign. Comparison between FEA and vibration tests results for interesting sensors will be presented in the sub-chapters below, in order to show the good concordance between the Finite Element Model and the protoprism tested.

Thermal tests

The protoprism has been cycled 8 times between 323 K and 105 K at the end of September 2013. One cycle lasted about 34 hours. The protoprism was equipped with thermal sensors at different positions (center and edge of the optics and on the Invar mount) in order to register the evolution of the temperature with time.

In order to check that the dynamic behavior of the protoprism is the same before and after thermal cycles, that means that there is no influence of the thermal cycles on the behavior of the protoprism, we have compared sine responses of typical sensors in each direction before and after thermal cylces.

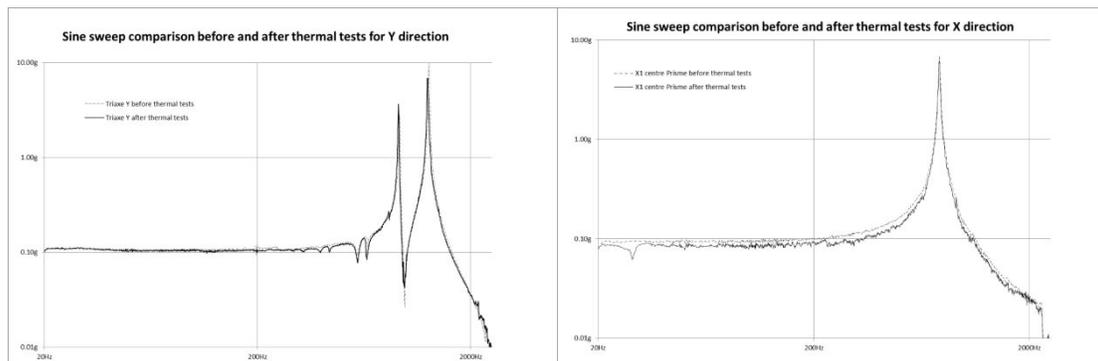Hereafter are presented some interesting curves for X and Y axes tests for different sensors.

Fig. 6. Sine sweep comparison between before and after thermal cycles for X1 sensor at the center of the prism (left image) and for Y sensor at the center of the prism (right image)

As all curves have very good reproducibility for all typical sensors (X for X axis vibration, Y for Y axis vibration and Z for Z axis vibration) between before and after thermal cycles, we concluded that thermal cycles have not changed the behavior of the protoprism or the behavior of the glue itself.

Finite element model updated with sine results

All finite element Analyses have been carried out using MSC/NASTRAN software. The protoprism mount Finite Element Model has been designed and analyzed thanks to Patran 2012 64 bit version (pre-post processor) and MD Nastran 2011.1 (solver).

All elements used in the FEM are volumic hexahedral. There are **210166** nodes and **160704** elements in the model. Some concentrated masses have also been added to simulate the mass of the vibration sensors.

Material characteristics of Invar M93, Invar 36, Suprasil 3001 (a type of Silica) and 3M-9323-2 glue have been entered in the model. The boundary conditions used for this model are 3 local zones under the spherical washers completely blocked in X, Y and Z directions, corresponding to the three screw fixations of the mount to the Grism Wheel Assembly.

Modal analysis of this model has shown five modes between 1000 and 2500 Hz.

The first mode with F1=780.7 Hz is a translation mode in X direction (optical axis direction).

The second and third modes with F2=954.8 Hz and F3 = 988.4 Hz are respectively rotation modes around Z and Y axes.

The fourth and fifth modes with F4=1337.5 Hz and F5=1344.6 Hz are respectively translation modes along Y and Z axe.
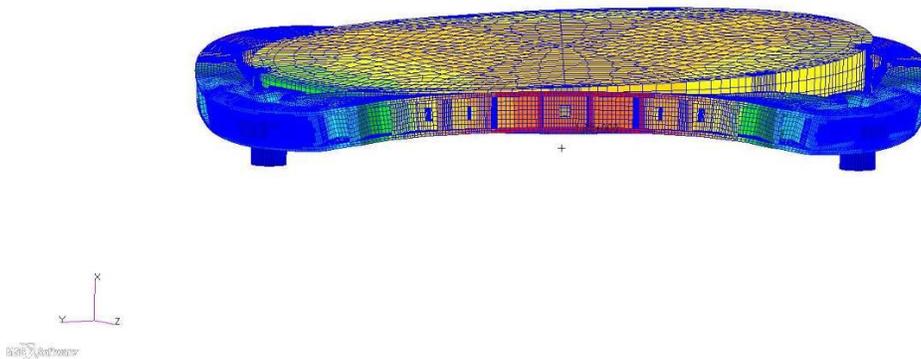

Fig. 7. First mode of vibration of the protoprism: side view: grism translation along optical axis (X direction) – F1=780.7 Hz

Harmonic analyses have been done on that model using a sine sweep load (on blocked nodes) of 0.1g between 20 and 2000 Hz. Material damping has been added to the model in order to get closer to the peaks of principal modes (depending of the direction of vibration) which appear at about 10g for the first mode (see Fig. 8). Values of damping introduced in the FEM were taken from literature [5] and from other real tests.
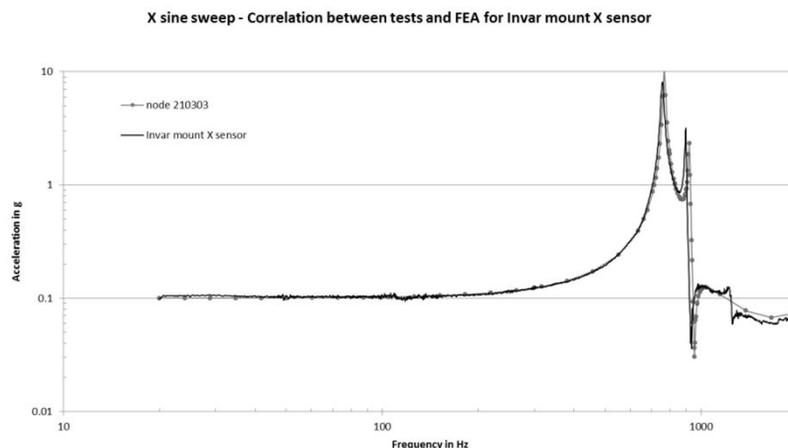
Fig. 8. Example of a comparison (Invar mount X sensor) between tests and FEA for X sine sweep

■ Tests and simulation correlation for random vibration
As said before, Random Qualification tests (with notches at the resonant frequencies of the protoprism) at 10.7g rms level with 2 min and 30 seconds at 0 dB were completed in X, Y and Z directions without any problem.

Following results will focus on X axis random vibration (the direction which shows the less margins in all components). Fig. 9 below shows very good correlation between tests and FEA for nearly all sensors.
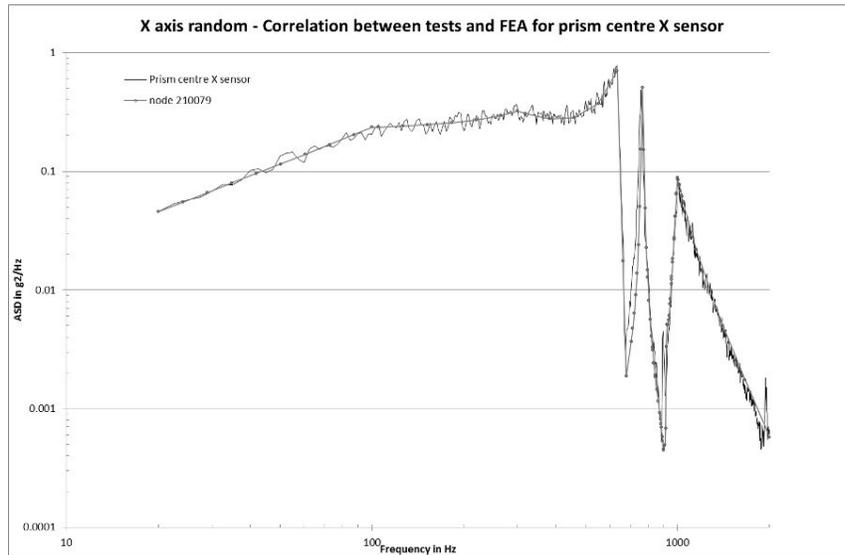

Fig. 9. Comparison (prism center X sensor) between tests and FEA for X-axis random qualification

We have a very good match between the experimental response of prism center X sensor and the analytical one given by the FEM (on node 210079). The random acceleration level seen by the center of the optical component during tests is about 14.7 g rms while the one predicted by the updated FEM is about 16.7 g rms. Thus we can say that the updated Finite Element Model behaves quite comparably to the real protoprism after the cooling down process.

Table 1 shown below presents the results of stresses with an occurrence probability of **3σ** and the margins encountered in all components of the protoprism for the X random qualification vibration load case.

Table 1. Summary of results for X axis random qualification

Parts	VM Stress in MPa	Margin / Yield	Margin / Ult
	X axis random: 10.7 g RMS		
Ring/Blade flexures	42.38	2.3	6.1
Optical component	5.31		2.1
Silica/Invar bonded joint	8.21		0.2

By looking at these results, we can say that 10.7 g rms of random acceleration level is not critical for any of the components of the protoprism.

V. EFFECT OF THE MOUNT DEFORMATION ON THE GRISM
We investigated two cases where the distortion of the mount could induce a deformation of the grism thus degrading the transmitted wavefront.

■ A Mount at 120K operational temperature
The first case corresponds to the cool down of the mount from room temperature to the 120K operational temperature. We modeled on Patran/NASTRAN (Fig. 10) the shrinking of the Invar mount relative to the silica prism due to the difference of CTE between Invar and silica. The mount shrinking produces a radial force of 16

N on each of the nine pads and thus induces a deformation of the grism. The FEM gives us the displacements of the about 2000 nodes of the model on both faces of the prism.
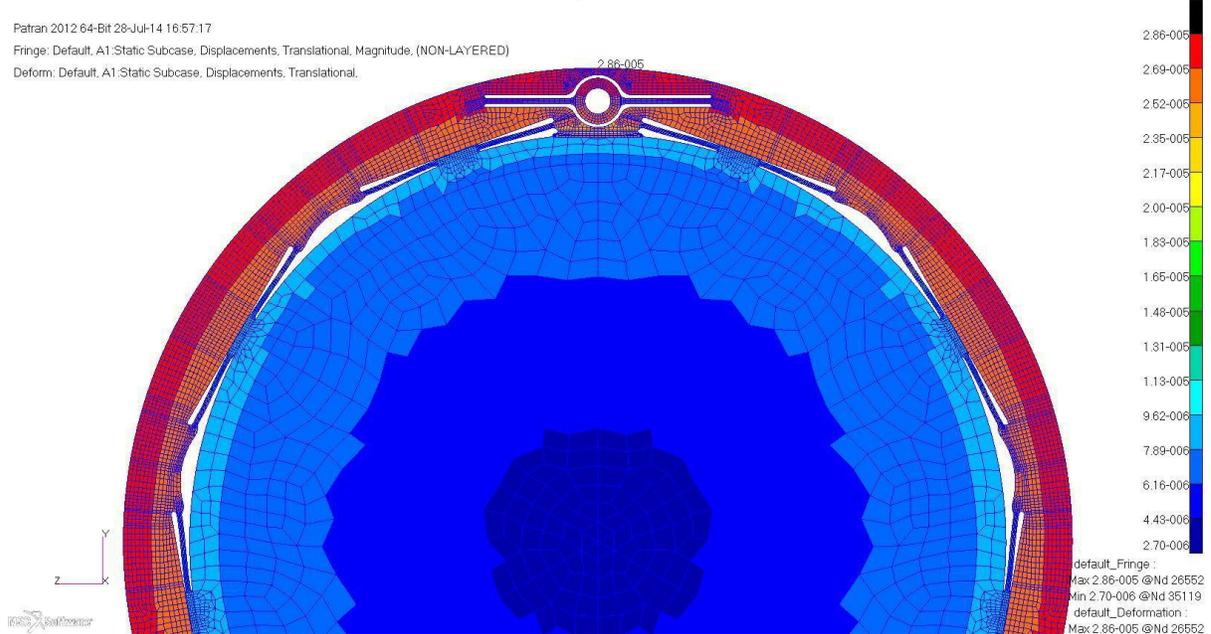

Fig. 10. Thermoelastic deformation of the mount due to the 218 K difference of temperature

A 3D plot using IDL (Fig. 11) reveals the amplitude and type of deformation of both faces which could be decomposed in the classical Zernike terms for further optical analysis.
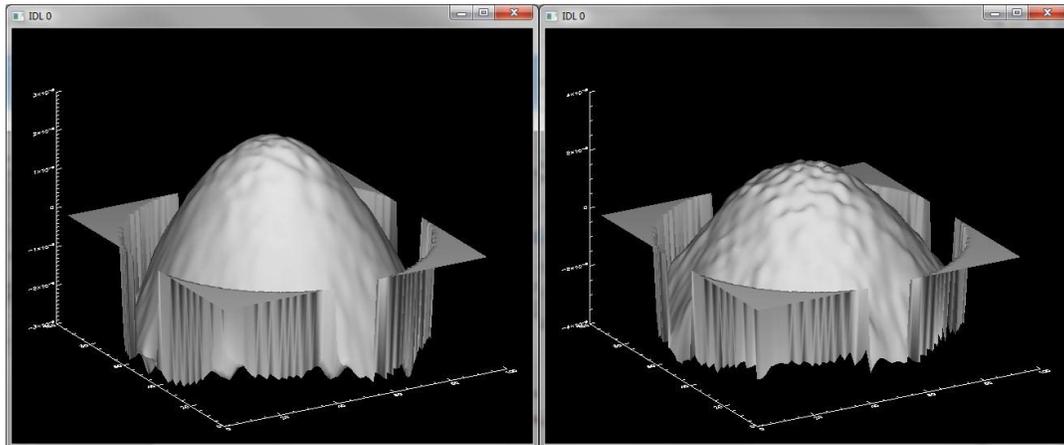

Fig. 11. A 3D fit using IDL gives 50 nm PV deformation (mainly focus) on both faces of the grism (left image is the filter face and right image hypotenuse face)

Since the grism is used in transmission we anticipated that the effect of the grism deformation on the transmitted WFE will be negligible. A Zemax analysis on a simplified model confirms that the induced deformation (50 nm PV on each face) will produce 1.6 nm PV WFE in transmission which corresponds for focus to 0.5 nm RMS to be compared to the total budget of 60 nm RMS.

███ *Mount bolted on the grism wheel.*

This second case analyses the deformation of the mount when bolted on the three interfaces points. To minimize this effect we used three Invar spherical washers thus relaxing the specification of the ring flatness on the Grism Wheel Assembly side. But despite the use of spherical washers the first interferometric tests in reflection (highly sensitive) for different tightening torques show a significant astigmatism (up to 700 nm RMS) on the prism. These tests also reveal that the mount permanently deforms the grism (300 nm RMS of astigmatism in reflection) at rest without any torque applied. All these test results lead us to suspect the efficiency of our spherical washers with probably inadequate surface finish of the two antagonist curved surfaces. We decided to polish again the same set of spherical washers and to conduct a second run of interferometric tests. A drastic improvement is shown in Fig. 12 where the wavefront error decreases from 715

nm RMS down to 182 nm RMS after the repolishing process. In both cases the three interface points are tightened at full torque (4 Nm).
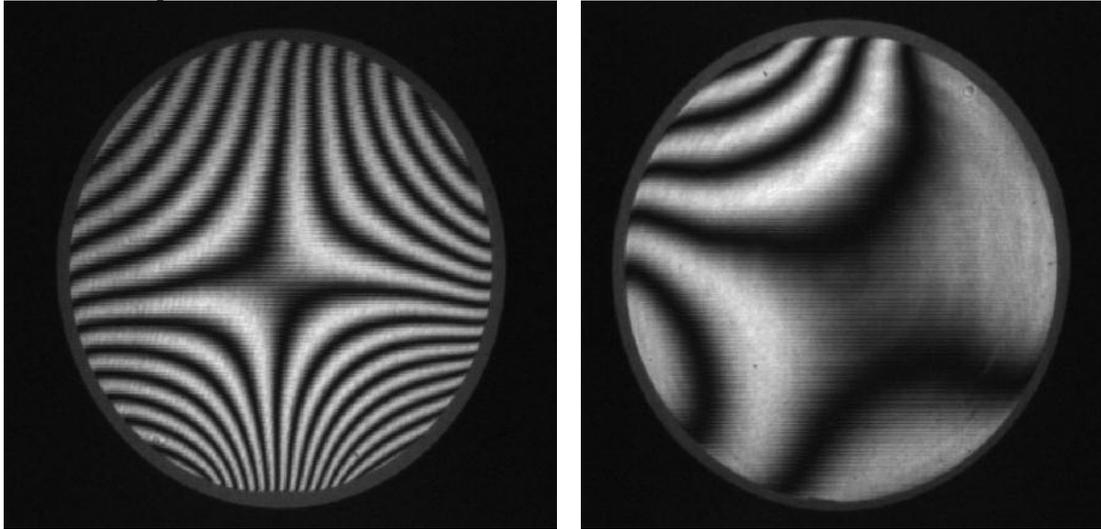

Fig. 12. Interferograms by reflection on one face of the prism when a 4 Nm torque is applied on the 3 point interface. Left image: "not well polished" spherical washers (715 nm RMS) and right image: repolished spherical washers (182 nm RMS)

The permanent deformation could be explained by the fact that during the gluing process the same "not well polished" spherical washers have been used to tighten the mount on the bonding setup. The prism has then been bonded on a pre-stressed mount. For the Engineering Model (foreseen for December 2014) we will control the shape of the grism just after the bonding.

We simulated on Zemax the effect on the transmitted wavefront of the astigmatism deformation of the two optical faces. This simulation demonstrates that an astigmatism of 1000 nm PV on each face will produce 30 nm PV of transmitted wavefront error which corresponds for astigmatism to 6 nm RMS. It will be a small contributor to the total allocated budget of 60 nm RMS for the grism.

VI. CONCLUSIONS

This paper shows that design of the mechanical mount enables the Euclid NISP grism to survive the severe environments of the mission. The qualification procedure in thermal and in vibration (up to 10.7 g rms with notches on the frequencies of the protoprism) has shown the integrity of the protoprism (and especially the glued zones and the silica Optics).

The deformation results on the protoprism obtained either by modelisation or interferometric tests show that the effect on the transmitted wavefront is well below the allocated budget.

As the project still goes on, we foresee to have a complete grism Engineering Model (grating and filter on each side of the prism) glued on its mechanical mount, by the end of year 2014. Systematic interferometric tests will be performed before and after thermal cycling and at cryogenic temperature.

VII. REFERENCES

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