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Hélène Ducollet

Christian du Jeu

Jean-Jacques Fermé

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MANUFACTURING & CONTROL OF THE ASPHERICAL MIRRORS FOR THE TELESCOPE OF THE SATELLITE PLEIADES

Hélène Ducollet, Christian du Jeu, Jean-Jacques Fermé

SESO-P.A. Aix les Milles 305, rue Louis Armand-CS 30504-13593 Aix-en-Provence Cedex 3-France
T. + 33 4 42 16 85 04 - F. + 33 4 42 16 85 85 - E-mail: info@seso.fr

ABSTRACT

For the Pleiades space program, SESO has been awarded the contract (fully completed), for the manufacturing of the whole set of telescope mirrors (4 mirrors, 2 flight models). These works did also include the mechanical design, manufacturing and mounting of the attachment flexures between the mirrors and the telescope main structure. This presentation is focused on the different steps of lightweighting, polishing, integration and control of these mirrors as well as a presentation of the existing SESO facilities and capabilities to produce such kind of aspherical components/sub-assemblies.

Key-words: Aspherical mirrors, Lightened mirrors, Space telescope

1. INTRODUCTION - A FEW WORDS ABOUT PLEIADES AND THE SESO CONTRIBUTION

Pleiades is the last generation of French satellites for earth observation, coming just after the product line of SPOT satellites (from SPOT1 to SPOT5). The PLEIADES telescope is based on a Korsch Concept with 4 mirrors (Figure 1):

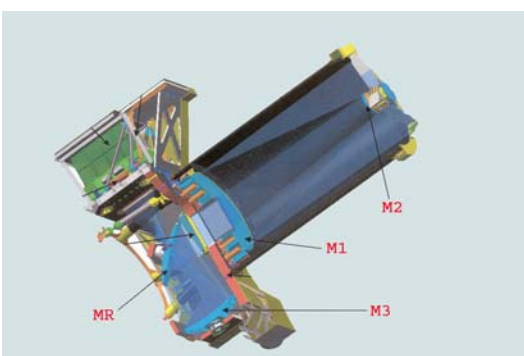


Fig. 1: Pleiades Telescope

- An on-axis Cassegrain Telescope with a primary Mirror (M1- Elliptical Concave, close to a parabola, CA 660 mm) and a Secondary Mirror (M2-Hyperbolic Convex)
- A tertiary off-axis mirror (M3- Elliptical Concave off-axis)
- A folding flat mirror (MR), for purpose of overall volume limitations

For this space program PLEIADES, SESO has been awarded from THALES ALENIA SPACE the contract for the manufacturing of the whole set of telescope mirrors (i.e. M1+M2+M3+MR) with different models (EM, QM and FM). These works did also include the complete lightening design of the mirrors as well as the mechanical design, manufacturing and mounting of the attachment flexures (MFDs) between the mirrors and the telescope main structure. The preliminary design was made in close collaboration between SESO and THALES ALENIA SPACE. The contract started in November 2003 and was fully completed end 2006 so within less than 3 years.

2. MANUFACTURING and CONTROL OF THE MIRRORS ASSEMBLIES

The primary mirror has been grinded/lightened with undercutting technique; other mirrors have been lightened with an open-back-concept. With these lightening techniques, SESO is able to lighten mirrors with weight reducing level up to 70%-80%.

2.1 Primary mirror M1

Primary has a 675 mm diameter, with a concave radius of 3185.44 and a conic coefficient of –0.9784. Because the deviation from the best fit sphere is not so important (about 12µm), the primary mirror was (Figure 2):

- First lightened, grinded and polished spherical using a conventional machine with a large size polishing tool
- Then aspherized by polishing using one of our large diameter capacity Computer Controlled Polishing machine

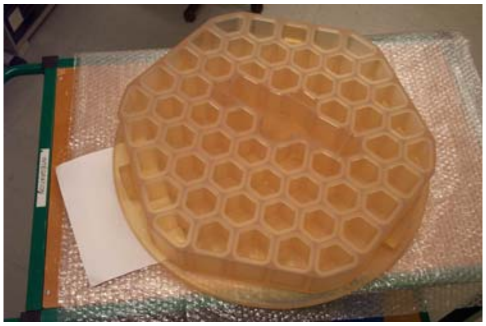
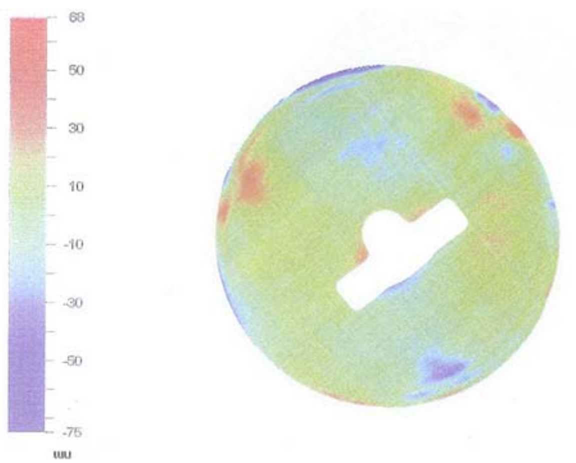


Fig. 2: M1 lightweighting

After polishing and gluing of flexures, a comparison was done between measurements of gravity effect and calculations. This demonstrates that FEM analysis was very good, local irregularities were similar on both wavefront maps (Figures 3 and 4):



Zernike Polynom. able

Poly Fit	Fit Error	Zernike Polynomial Coefficients (wv)				
2 Term	0.028	0.207	-0.657			
3 Term	0.022	0.207	-0.659	0.030		
8 Term	0.019	0.207	-0.659	0.031	0.011	-0.017
		0.012	0.018	-0.000		
16 Term	0.016	0.207	-0.658	0.029	0.011	-0.016
		0.013	0.018	0.002	-0.010	-0.000
		-0.014	0.023	0.007	0.010	-0.008
24 Term	0.012	0.207	-0.658	0.030	0.011	-0.016
		0.014	0.019	0.001	-0.011	-0.000
		-0.013	0.023	0.007	0.008	-0.006
		-0.009	0.028	-0.006	-0.001	0.003
		-0.009	0.004	0.021	0.002	
36 Term	0.011	0.207	-0.658	0.026	0.011	-0.018
		0.014	0.019	0.004	-0.011	-0.000
		-0.014	0.024	0.007	0.010	-0.011
		-0.009	0.028	-0.006	-0.001	0.003
		-0.008	0.004	0.019	0.006	0.002
		0.003	0.000	-0.003	-0.000	0.003
		-0.010	0.001	0.001	0.006	-0.010
		0.004				

Fig. 3: Gravity effect measured

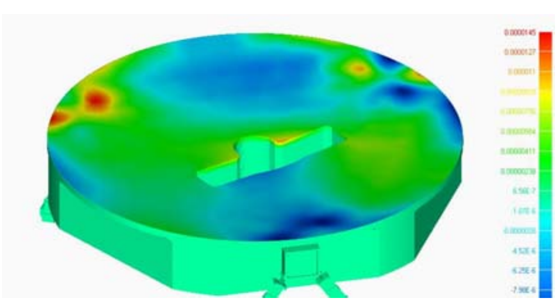


Fig. 4: Gravity effect from FEM analysis

To control the high level of WFE quality for such aspherical mirror, we have developed an interferometric test bench using a home-made (design + manufacturing) Offner corrector (see Figure 5). Of course, all interferograms (before and after cut) have been recorded and mirror control fully documented. The final WFE performances were **22 nm RMS** (for a requirement of less than 28nm RMS).

Fig. 5: M1 after coating

2.2 Secondary mirror M2

Secondary has a 175 mm diameter, a convex radius of 724.89 and a conic coefficient of –1.972. This mirror has been first polished as a sphere, using conventional spherical polishing and then polished aspherical using CCPM. What was challenging onto that mirror was mainly the interferometric control as the WFE requirement is very tight and the part is a convex, we have developed an interferometric test bench using a home-made (design + manufacturing) Hindle corrector Globally, the allocation of tolerance of the test set-up, was less than 10 nm rms wfe. The final WFE performances were **8nm RMS** (for a requirement of less than 17nm RMS)

The final WFE performances got onto M1-M2 optical combination (tested as an on-axis Cassegrain Telescope) was **22 nm rms** (for a requirement of less than 28nm RMS). The global WFE of M1 + M2 was quite exactly the interferogram (Figure 6) of M1 alone, meaning that:

- The secondary was quite perfect,

- Both correctors used for M1 and M2 measurements were very good.

Fig.6: M1-M2 combination with interferometric test

2.3 Tertiary mirror M3

Tertiary mirror is a rectangle of 115*431 mm with a concave radius of 927.87 and a conic coefficient of –0.5712 and an off-axis of 69.8 mm. Among all, this mirror was the most challenging one because of its “funny” external shape and outer cuts and the fact that it is an off-axis mirror and highly aspherical (deviation from best fit sphere is more than 130µm over the complete parent on-axis mirror). This M3 mirror is a concave ellipsoidal so that testing at conjugates, without any null-lens. The WFE of the mirror was tested in double pass with the interferometer located at the longest stigmatic point, and after reflection onto a small reference spherical concave mirror, located at the longest stigmatic point (Figure 7).

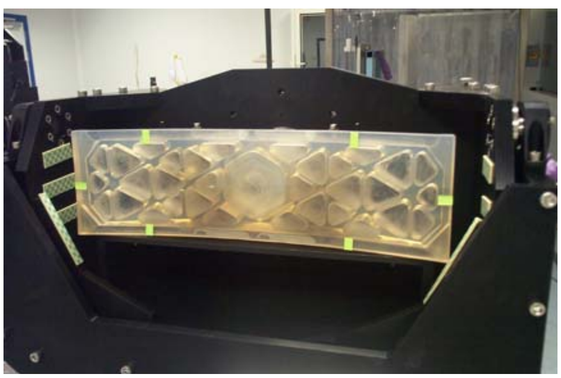


Fig. 7: M3 during interferometric test before coating

The final WFE performances was 18nm RMS for 100% of the useful aperture and in the range of **6-8nm RMS** for any sub aperture of 61mm diameter inside CA (for a requirement of less than 20nm RMS) (Figure 8).

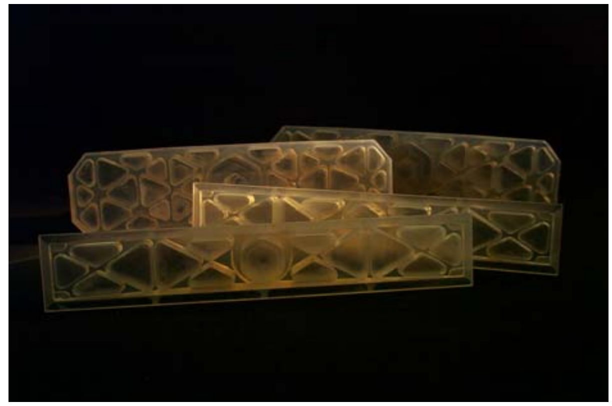


Fig. 8: M3 and MR mirrors (M1 and FM2) before coating

3. CONCLUSIONS

The production of PLEIADES mirrors presented in this report, for which the complete SESO program was completed in quite less than 2 years (from design to final delivery of flight models including qualification tests as vibrations and thermal vacuum, passing through engineering and qualification models) and with fully successful final results is a typical example of the SESO know-how and a full-scale demonstration of what the company is able to do (Figure 9).

Fig. 9: M2 during vibration tests

We would like to conclude this report with a specific acknowledgement to THALES ALENIA SPACE, EADS ASTRIUM, and CNES (FRANCE) for their confidence in SESO about this PLEIADES program.