International Conference on Space Optics—ICSO 1997

Toulouse, France

2–4 December 1997

Edited by George Otrio

High stability carbon/carbon telescope structure

Bruno Bailly, Jean-Louis Cornu, Bernard Capdepuy, Frédéric Leleu, et al.

International Conference on Space Optics — ICSO 1997, edited by Georges Otrio, Proc. of SPIE Vol. 10570, 105701T · © 1997 ESA and CNES · CCC code: 0277-786X/18/$18 · doi: 10.1117/12.2326580

HIGH STABILITY CARBON/CARBON TELESCOPE STRUCTURE

Bruno BAILLY[1], Jean-Louis CORNU[1], Bernard CAPDEPUY[2], Frédéric LELEU[2], Michel KORNMANN[3], Alain PRADIER[4]

(1) AEROSPATIALE Espace & Défense - Satellites Operations
100 Boulevard du Midi - 06 322 Cannes la Bocca, France

(2) AEROSPATIALE Espace & Défense Industrial Operations
33 165 Saint Médard en Jalles, France

(3) M3D - BATTELLE
7, route de Drize CH-1227 Carouge Genève, Suisse

(4) ESA - ESTEC
P.O. Box 299 - 2200 AG Noordwijk, The Netherlands

ABSTRACT *- Current and future space telescope programmes require ever higher dimensionally stable structures. Typical structure stability requirements are about a few microns for dimensions of 0.5 meter. "Conventional" materials like CFRP present a good structural performance but are limited in terms of long term dimensional stability due to effects like moisture desorption. In the frame of an ESTEC project supported by an internal development, AEROSPATIALE has designed, manufactured and tested a very high dimensional stability telescope structure for precision optical systems using the advanced Carbon/Carbon composite combining high dimensional stability and good structural performance.*

The Carbon/Carbon material developed and manufactured in AEROSPATIALE facilities presents :
- a high thermoelastic stability (CTE < 10^{-7} K^{-1}) and moisture unsensitivity
- a process optimizing the cycles in terms of cost, schedule and performances
- a high potentiality for future programmes thanks to industrial facilities up to 2.5 m.
The Telescope structure is based on the SILEX (Semi-conductor Laser Intersatellite Link Experiment) configuration.
A detailed characterization programme has been carried out with regard to Carbon/Carbon composite and junction techniques, giving satisfactory results. The Telescope is built around a Carbon/Carbon external cylinder. The primary mirror baseplate consists in a fully Carbon/Carbon honeycomb sandwich and the secondary mirror support is also made of Carbon/Carbon composite. The manufacturing and the assembly of the Carbon/Carbon structure have been successfully performed. Structural and thermal analyses have been carried out to verify stiffness and strength requirements, to set-up the performance budget and to make the test predictions.

The satisfactory results achieved during the test sequence have confirmed the potentiality of the Carbon/Carbon technology for high stability instruments.

Keywords *Space telescope, Lightweight structures, Dimensional stability, Carbon/Carbon (C/C)*

1 - INTRODUCTION

There is an ever higher demanding need for very high dimensionally stable structures for future earth observation and scientific payloads. Thus, there is a high interest to use more advanced materials than conventional CFRP combining high long term dimensional stability and good mechanical performance. The objective of the study consists in the development and the qualification of a telescope structure using the selected Carbon/Carbon (C/C) technology in a representative architectural configuration
The main results of the programme (material characterization, design, analyses, manufacturing & assembly of the telescope structure, test results and exploitation) are presented.

2 - MAIN REQUIREMENTS

In table 1 are presented the main requirements of the *Dimensionally Stable Structures* project [1].
The long term (L.T.) stability, which is specified in terms of misalignment of mirrors M1 and M2, is the most stringent requirement, in particular w.r.t. the Defocus. Long Term is defined as the lifetime starting from the final ground alignment until the end of the mission (≈ 10 years).

Mass (Telescope Structure)	**< 2.2 Kg** with - optics : 2.7 Kg - thermal control : 0.4 Kg
Stiffness (Equipped Telescope)	**> 150 Hz** (first frequency)
Strength (sizing loads)	**30 g** (applied simultaneously on each axis : X, Y, Z)
L.T. Stability	**Defocus ≤ 2 µm** **Decenter ≤ 10 µm** **Tilt ≤ 45 arcsecond**
Thermal environment	**- 10°C to + 40°C**

Table 1 : Main requirements

At the beginning of the study, a preliminary breakdown was given for the Defocus allocation which is the most severe term (Table 2). The Defocus allocation (**2 µm**) has been shared into two terms, 1.7 µm for the telescope structure and 0.3 µm for the mirrors fixation devices. In order to set up the tolerance budget, the following summation philosophy (2.1) was selected :

$$\text{L.T. STABILITY} = \sqrt{\text{Cont.}1^2 + \text{Cont.}2^2 + \text{Cont.}6^2} + \text{Cont.}3 + \text{Cont.}4 + \text{Cont.}5 + \text{Cont.}7 \quad (2.1)$$

	CONTRIBUTORS	**Allocations**
Contributor 1	Distortions at telescope interface	0.1 µm
Contributor 2	Ground testing & launch	0.6 µm
Contributor 6	Ageing of material	0.25 µm
	Quadratic sum	**0.65 µm**
Contributor 3	Gravity release effects	0.2 µm
Contributor 4	Moisture release effects (when applicable)	0.8 µm
Contributor 5	L.T. thermal variations	for both contributors
Contributor 7	Microvibrations effects	
TOTAL	**Arithmetic sum**	**1.7 µm**

Table 2 : L.T. stability tolerance budget

This **Defocus** allocation breakdown shows the low values to be allocated for each contributor and confirms the criticality of defocus L.T. stability.

3 - MATERIAL & TELESCOPE ARCHITECTURE SELECTION

After having examined the advanced materials under technical and industrial criteria, the Carbon/Carbon (C/C) composite has been selected due to the following reasons :

- **high thermoelastic stability** : CTE close to zero in a quasi-isotropic lay-up configuration
- **moisture unsensitivity**
- concept authorizing a **simple thermal design**
  preferred versus design based on a "compensation" phenomenon (e.g. "all SiC telescope"), sensitive to thermal gradients and risky if a complex thermal control is not implemented
- **various architectural possibilities** offered (cylinder, honeycomb sandwich ...)
- **industrial maturity and growth potential** with industrial facilities up to 2.5 m
  AEROSPATIALE has gained a large background with the development of re-entry bodies parts (HERMES nose cap, CASSINI/HUYGENS front shield ...).

Various mechanical architectures of Telescope have been studied for this application (external cylinder, truss, tripod). According to the trade-off results, the **C/C cylinder** concept (see Figure 2) has been selected. This concept presents :

- a high technical performance, in particular w.r.t. the stability, which enables to consider the less sophisticated thermal control level (N°2 ; see § 5.2)
- an interesting architectural configuration (minimum optical obscuration, direct external baffling and upper spider for M2 support which increases the "lever arm" for M1/M2 adjustment)
- a high growth potential w.r.t. future applications (this kind of architecture covering the other ones in terms of structural parts and performances).

4 - FEASIBILITY & CHARACTERIZATION

4.1 - C/C reference process

The selected carbon/carbon process (combination of two main routes, liquid and vapour), dedicated to complex shapes and thin wall parts, enables to optimize the cycles in terms of cost, schedule and performances. This mixed route consists in a rigidification of the fiber preform by resin polymerization and pyrolysis, followed by a Chemical Vapour Infiltration (CVI). The first step is realized with prepregged fabric according to current manufacturing technologies used with CFRP. The CVI is then performed on selfstanding parts without tooling. The process is summarized in Figure 1.

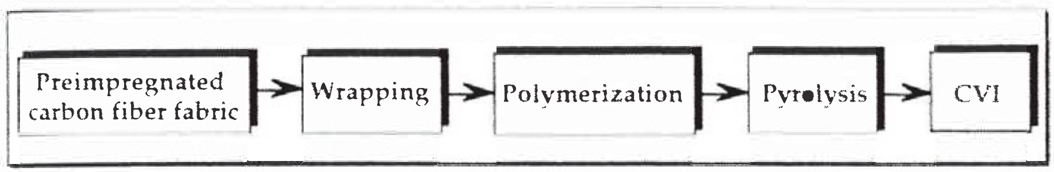

Figure 1 : Selected C/C process

The process duration (after fiber preform wrapping) is 3 weeks. It allows the manufacturing of large and complex shaped parts with low durations and reduced costs.
AEROSPATIALE CVI facilities can accommodate parts up to **2.5 meters** in diameter and height.

4.2 - Feasibility

The phase 2 feasibility activities objectives were :

- to freeze the manufacturing processes
- to manufacture representative parts of the Demonstration Model in order to optimize the definition of toolings and the wrapping method
- to select and validate appropriate NDI methods
- to ensure the traceability of the processes.

The 2D Carbon/Carbon composite and the C/C sandwich skins consist in a quasi-isotropic lay-up. With regard to the C/C honeycomb sandwich, the manufacturing is based on the same principle as the one presented in § 4.1 :

- the C/C honeycomb and the 2D C/C skins are densified during the same CVI cycle. Therefore, the honeycomb sandwich is a fully C/C one, without any organic component.

With regard to the severe requirements of the dimensionally stable structures, any delamination inside C/C parts has to be detected. Non Destructive Inspection (NDI) is systematically performed after pyrolysis and after CVI (US dry coupling method and XRays for local inspection such as evolutive thickness zones of the cylinder). The physical properties of the C/C and their range of variation have been settled and are controlled in order to reach the expected thermoelastic performances and to guarantee the good health of the material (volumic fractions, density and thicknesses). The microstructure was recorded, using Scanning Electronic Microscopy and optical microscopy facilities.

As a conclusion, the feasibility activities have demonstrated the capability to manufacture the Demonstration Model and validated the NDI methods as well as the expected material physical properties objective and associated variation range.

4.3 - Characterization

A complete characterization programme was performed on the 2D C/C composite, the C/C honeycomb sandwich technology and the junctions techniques :

- mechanical characterization of the 2D C/C and the C/C honeycomb sandwich
- measurement of the Coefficient of Thermal Expansion (CTE)
- measurement of thermal, thermo-optical and electrical properties
- material characterization under space environment (outgassing, cleanliness ...)
- junctions characterization : screwed junctions : tg(φ) and bonded junctions
- microyield ($\sigma 10^{-6}$) and material microcreep (load applied during a long time).

The CTE and microyield measurements have been performed on high accurate AEROSPATIALE test devices. A good correlation between measurements and predictions (issued from the technological model) has been achieved. Main characterization results are summarized in Table 3.

2D C/C	E (Young's modulus)	60 GPa
	ρ (density)	1.5 Kg/m^3
	ν (Poisson's ratio)	0.27
	Tensile strength	193 MPa
	Compressive strength	187 MPa
	ILSS (InterLaminar Shear Strength)	15 MPa
	G (In plane shear modulus)	20 MPa
	$\sigma 10^{-6}$ (Microyield)	> 20 MPa (*)
		-0.1x10^{-6} K^{-1}
	Thermal conductivity	7 W/m°C
	Optical properties : . Emissivity . Solar absorptivity	0.4 0.7
	Electrical properties : . Surface impedance . Surface resistivity	5 mΩ 120 mΩ
	Cleanliness : . Molecular (after "hand" cleaning) . Particular	< 10^{-8} g/cm^2 < 50 ppm
Junctions	Tg(φ) C/C - Invar	> 0.2
	Cold bonding (double shear strength)	> 18 MPa
C/C Honeycomb Sandwich	C/C sandwich Mechanical properties	> Alu Honeycomb
	Insert (M5) strength	> 5000 N (⊥ and //)

Table 3 : Main C/C properties

(*) This value has to be considered as a minimum due to micro-bending effects occured during the microyield test (not stiff enough sample). This value can be largely increased after mechanical load application (sample unfolding).

Various CTE measurements (performed on different samples and directions) were performed and showed the very low sensivity of the C/C composite to manufacturing parameters, as predicted with the technological model.

A microcreep test was performed by M3D-BATTELLE. The aim of this test is to evaluate the long term stability of the C/C composite under permanent mechanical load (internal stresses).

Although internal stresses level is low, a loading up to 2 x microyield strength (2 x $\sigma 10^{-6}$) was applied in order to increase the accuracy of the measurement and to correlate the microyield behaviour of the material. No intrinsic insability (within the measurement accuracy) was observed for the C/C material (for durations higher than 300 hours) even with high loads corresponding to equivalent 100 g applied to the structure. Moreover, this test corroborates that the microyield is higher than the initially measured one.

As a conclusion of this paragraph, a complete characterization programme was performed and the results are satisfactory. Furthermore, the reproducibility of mechanical and thermal properties has been demonstrated through the different CVI cycles.

5 . DESIGN & ANALYSES

5.1 - Telescope structure design

On the basis of the selected architectural configuration, the detailed design was carried out. The Telescope structure is defined in Figure 2. The overall sizes of the Telescope structure are :

- overall height ≈ 600 mm
- outer diameter ≈ 330 mm.

The main structural parts consist of :

❶ ***C/C external cylinder with upper ring***

. Equipped with Invar edge inserts
. Thickness =1.6 mm (ring : 3.2 mm)

❷ ***M1 Baseplate (C/C honeycomb sandwich)***

. Equipped with Invar inserts
. Baseplate thickness = 37 mm

The baseplate is made of a fully C/C honeycomb sandwich (C/C core and C/C skins). This part concept presents a high interest in terms of stability (thermoelastic stability in three dimensions and moisture unsensitivity).

❸ ***Spider :*** **3 C/C blades**

. Blade section : 20 - 30 x 1.6 mm

❹ ***Spider / Cylinder brackets (Invar)***

M2 support : ❺ ***C/C hexagon***

. Wall thickness : 3.2 mm

❻ ***C/C M2 plate***

. Thickness : 4.8 mm

❼ ***Telescope Fixation Devices (TFD)***

These INVAR parts enable to well decouple the telescope from all instabilities occuring at Telescope / Carrier Structure interface.

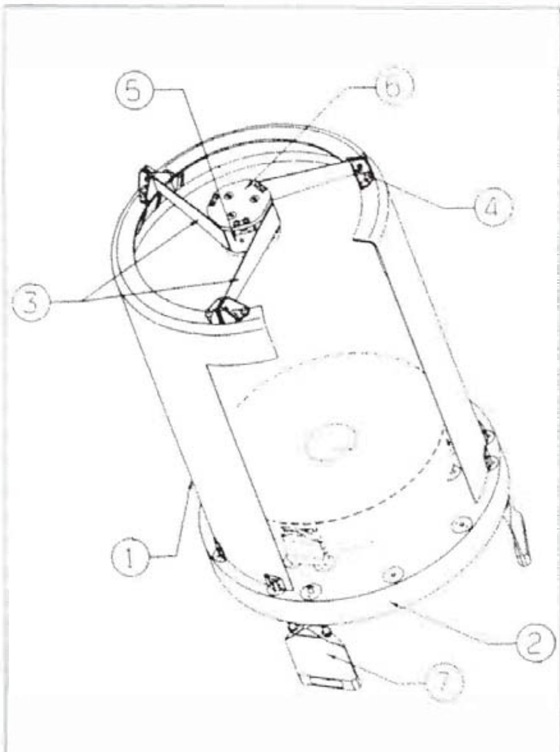

Figure 2 : Telescope Structure Design

5.2. Thermal design

The envisaged thermal architectures were defined. A basic thermal control is generally implemented and consists of :

- an efficient thermal protection (MLI) of the overall telescope (no heat dissipation)
- a protection towards solar illumination by means of entry baffle (when possible)
- the implementation of a simple heating system monitored by bistable thermostats (on/off heating).

The resulting temperature range (level N°1) is typically close to (-10°C,+40°C) on low altitude orbits, avoiding any degradation of structural and optical parts, especially in non-operational modes. In addition to this basic thermal control, different performance levels can be obtained for operational modes (levels n°2 to n°4). The main characteristics and performances are summarized in Table 4.

Level	Performance		Monitoring type	Type of sensor	Electronic function
	T level	ΔT			
N°2	20°C ± 6	< 12°C	ON/OFF	bistable thermostats	
N°3	20°C ± 3	< 6°C	ON/OFF	thermistors	acquisition of T° & comparison with tresholds
N°4	20°C ± 1	< 2°C	PID regulation	Pt sensors	acquisition of T° & algorithm calculation

Table 4 : Thermal control levels

For simplicity reasons and due to the very low CTE of the C/C material, the thermal control **level 2** was selected as the **baseline**.

A thermal mathematical model was performed in order to define the temperature level variations and the thermal gradients observed by the structure for typical "in-orbit" cases.
The thermal load cases (sun in different areas of the structure) were then implemented in the structural model to analyse the thermoelastic behaviour of the telescope structure. This model was also used for the predictions of the holographic test (non uniform heating).

5.3 - Mechanical analyses

The design is analysed with a detailed mathematical model (Figure 3) in order to verify stiffness requirements, general and local strength and to establish the stability budget. The main sizing criteria are summarized in Table 5.

Part	Sizing criteria
Cylinder	Thermoelastic stability Microyield in current section Rings strength (local bending stress)
M1 Baseplate	Inserts strength Stiffness Thermoelastic stability
Spider blades	Stiffness Thermoelastic stability
M2 support	Stiffness Thermoelastic stability
Junctions	Bonding microcreep & microyield Microsliding of screwed junctions Local strength and stiffness Thermoelastic stability

Table 5 : Sizing criteria

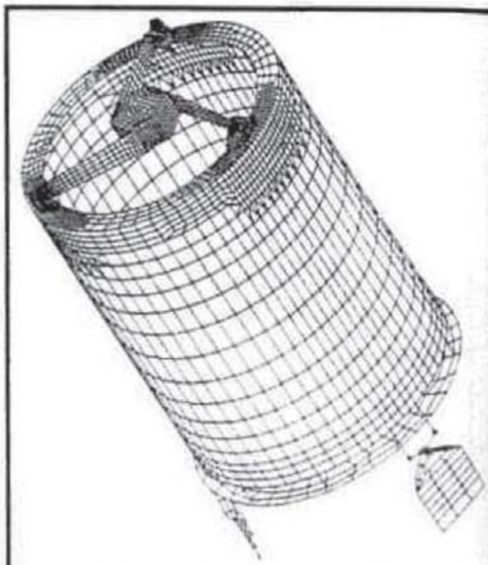

Fig. 3 : Telescope Structure F.E.M.

The structure sizing is driven by the stability performance, i.e. microyield in current section, micro sliding for screwed junctions and microcreep for bonded linkages. The values taken into account for junctions stability sizing are issued from AEROSPATIALE experience in high resolution instruments.
The main analyses results are presented hereafter and are compliant with the requirements :

- Telescope first eigenmode = **170 Hz** (specification : > 150 Hz)
- Current stress under combined 30 g : < $\sigma 10^{-6}$
- Theoretical L.T. stability budget : **Defocus = 1.2** µm (including all contributors defined in § 2) with the following elements :
  . simplified thermal control level : **20°C ± 6°C**
  . horizontal optical axis for ground measurements
  . **without "Zero g" devices**

6 - DEMONSTRATION MODEL

On the basis of the feasibity results and the detailed design, the manufacturing of the Demonstration Model was performed.

The C/C parts were firstly manufactured. The control results (material investigations, geometrical inspection, NDI and mechanical & CTE tests on "witness" samples) were satisfactory.

Then, the C/C parts were equipped with Invar inserts in order to be able to perform the final assembly of the Telescope structure.

Finally, the assembly of the Demonstration Model was performed on the same principle as the AIT sequence which would be applied for a Telescope equipped with optics (but of course with a lower accuracy : assembly tool instead of a control loop).

As a conclusion of this paragraph, the assembly of the Demonstration Model has been successfully performed (see Figure 4) and the final controls were satisfactory.

Figure 4 : C/C Telescope

7 - VERIFICATION PROGRAMME

7.1 - Test sequence

The verification logic defined for the Demonstration Model is presented in Figure 5.
The tests sequence, performed by M3D-BATTELLE with the support of EPFL (Ecole Polytechnique Fédérale de Lausanne), is focused on both following axes :

- ***verification of the mechanical behaviour*** :
  . modal test on the bare structure
  . static test under qualification loads
- ***verification of the dimensional stability*** :
  . after thermal cycles application
  . under gravity
  . after load relaxation (residual deformation)
  . under thermal environment

With regard to the verification of the dimensional stability performance, the measurement devices were defined after having analysed the achievable accuracy. Indeed, for each instability contributor, displacements about a few tenths of microns have to be measured. The selected high accuracy measurement devices consist of :

- **holographic measurement** for a non uniform heating :
  . measurement of the structure deformation and correlation of the structural and thermal models
- **capacitive sensors,** with the use of a Zerodur reference structure, for the following tests :
  . thermal cycling, residual static test and gravity test (deformation under low load)
- **interferometry in vacuum** for a homogeneous temperature evolution
  . measurement of the defocus.

The test results and test exploitation are presented for each phase of the test sequence

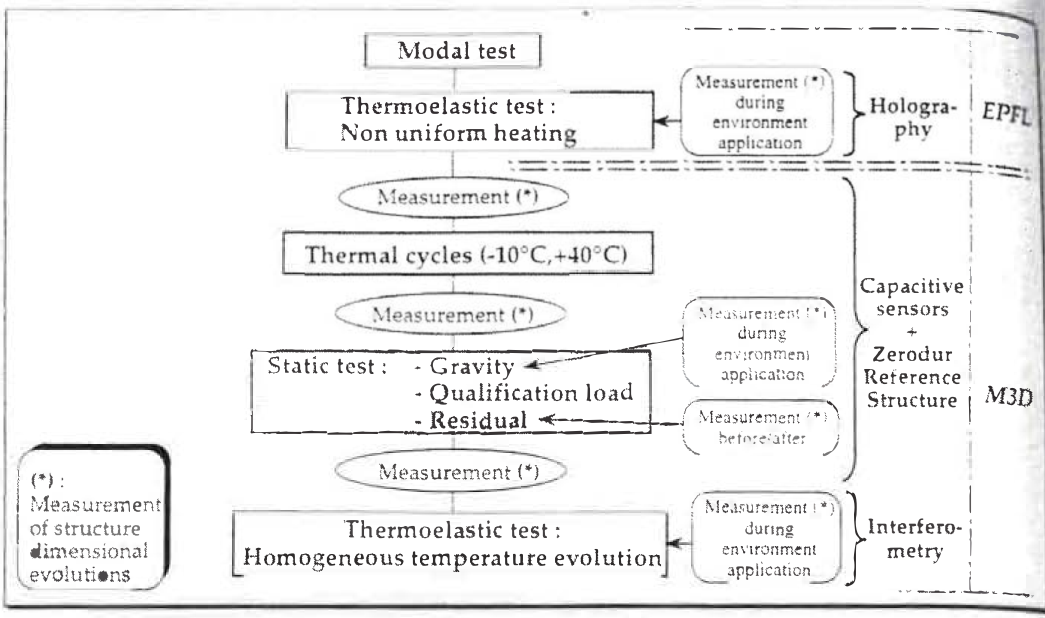

Figure 5 : Test sequence

7.2. Modal test

The aim of the test is to measure the three main eigenfrequencies and mode shapes of the bare Telescope structure. The principle is to apply a low level sine vibration to the specimen support interface, by means of an electrodynamic shaker (see Figure 6), along two axes (axial and transverse ones).

The test results are presented in Table 6.

Mode shape	Frequency (bare structure)
Global bending (Cylinder & TFD)	241 Hz
Ovalizing of cylinder	509 Hz
Axial mode of spider	561 Hz

Table 6 : Measured frequencies

The Demonstration Model presents a low damping (<1%), mostly due to sizing with regard to stability which limits dissipations in structural parts and junctions. The main modes (cylinder ones) are in accordance with the predictions issued from the F.E. model. The measured spider mode is higher than measured. This mode which presents a low effective mass is sensitive. The F.E. model has been updated in spider area (in particular w.r.t. junctions) and is now in accordance with the test results.

The modal test allowed to confirm the prediction of the first eigenfrequency of the equipped telescope structure and so to ensure the specification compliance :

→ f1 = 177 Hz > 150 Hz (requirement)

Figure 6 : Modal test

7.3 - Holographic test

The aim of the test (performed in EPFL premises) is to measure the deformation of the Telescope structure under non-uniform heating, as a simulation of unfavorable flight conditions. The principle of the test consists in heating one side of the external cylinder and in measuring the associated deformation of the structure by holography. For this purpose, heaters have been implemented inside the cylinder. The temperature maps were obtained with an IR TV camera calibrated by an appropriate location of thermocouples for emissivity correction. In addition, an auxiliary diffuser was used to check the influence of the convection (change of the air refractive index) in front of the heated surface. Several calibrations were carried out before the final test in order to improve the measurement.

Two configurations were tested :

- vertical optical axis ⇒ Cylinder deformation measured.
- horizontal optical axis ⇒ Relative displacement between M1 and M2 recorded.

The thermal gradients applied on the cylinder were increased up to 20° C. Associated holographic measurements of the out-of-plane deformation of the cylinder and of the M1/M2 displacement were recorded. The holographic technique was very accurate (< 0.25 µm) and reproducible. The test results underline the high thermoelastic stability of the structure under large thermal gradients :

- the **CTE** of the C/C composite (**-0.1 x 10^{-6} K^{-1}**) is confirmed by the correlated (F.E. model) low local deformations of the cylinder in the heated area (about 1 µm PtV for $\Delta T = 20°C$)
- **Defocus < 0.25 µm for ΔT = 20°C** applied on one side of the cylinder.

7.4 - Thermal cycling, gravity and statictest

For this test, the capacitive measurement device (with the Zerodur reference structure) is used. It enables to measure the M1/M2 displacements (Defocus, Decenter and partial Tilt). Before starting the test sequence, a complete calibration of the system (reproducibility of measurement after repositionning, stability versus time and influence of temperature variations) was carried out and enabled to validate the accuracy of the system (Defocus : 0.2 µm & Decenter : 0.5 µm).

Thermal cycling

The aim of the thermal cycling test consists in applying to the Demonstration Model the extreme specified temperature variations (**-10°C,+40°C**) and in checking its dimensional stability after such thermal cycles. The test results are the following :

⇒ Defocus = 0.5 µm after the first cycle

⇒ **Defocus < 0.2 µm** after 4 more cycles (within measurement accuracy)

A thermal environment similar to in-orbit non-operational conditions was applied to the Telescope structure. A slight geometrical adaptation had initially been measured, that may be due to junctions behaviour. Stabilization occured very rapidly and the structure remained very stable after thermal cycling.

Gravity test

The aim of this test consists in measuring the deflection of the M2 Mirror interface under a small known load similar to the M2 gravity one. This allows to simulate the defocus or decenter occuring after release in space of the gravity. Two directions (corresponding to different ground measurement configurations) were considered, loading of M2 interface in axial direction (along optical axis) and in lateral direction.

The gravity test results are :

	Defocus	Decenter
Axial loading	0.8 µm / 100 g	≈ 0
Lateral loading	≈ 0	0.3 µm / 100 g

The axial gravity measurement confirms the spider stiffness increase, as observed during the modal test. In case of a horizontal optical axis ground measurement (usually preferred configuration), the Defocus is negligible and the Decenter remains very low, authorizing to not use "Zero G" devices.

9

Static test

The purpose of this test (see Figure 7) is to apply the specified qualification launch loads (52 g separately on each axis) to the Demonstration Model in order to :

- verify strength requirements (strain measurement)
- check stiffness (displacement measurement)
- check stability (measurement before and after loading).

The Telescope structure was instrumented with strain gauges and LVDT displacement sensors. The qualification loads were applied along two directions, axial and lateral. Specific interface parts were fitted for introduction of local or distributed loads by sub-assemblies with same resultants as acceleration loads.
The main test results are presented hereafter for both loading cases :

- measured stresses in agreement with the predictions issued from the F.E.M. Model
- spider deformation well correlated
- very high stability after mechanical loading (axial and lateral 52 g) :
  - **Defocus < 0.2 µm** (within measurement accuracy)
  - **Decenter < 0.5 µm** (within measurement accuracy)

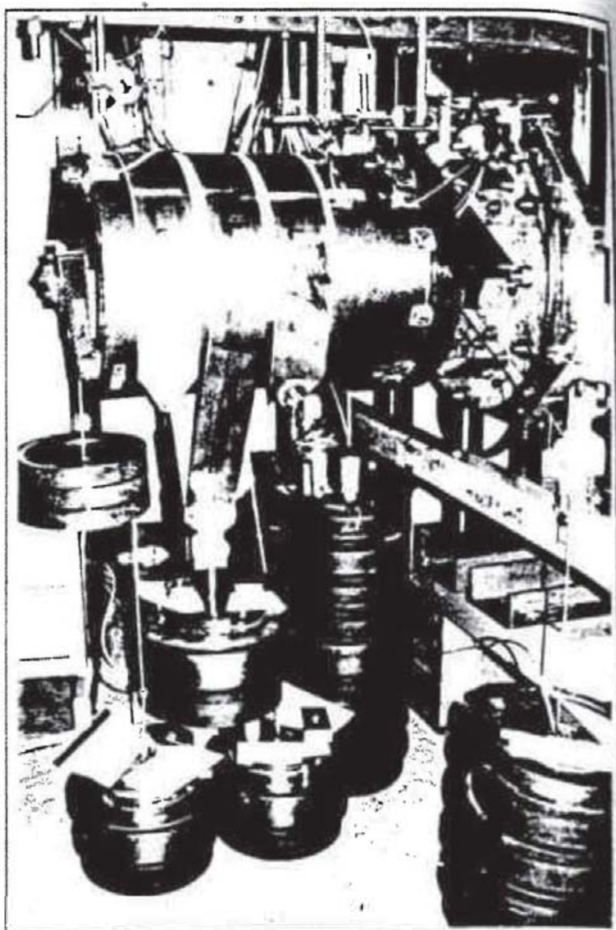

Figure 7 : Lateral static test

The static test has demonstrated the excellent mechanical behaviour of the Telescope structure, showing in particular a very high residual stability after loading.

7.5 - Thermoelastic test

The aim of this test (see Figure 8) consists in applying an uniform temperature variation to the Demonstration Model and in measuring the associated Defocus. The long term variation thus simulated (±6°C) corresponds to the selected thermal control level (N°2).

The Demonstration Model is implemented in a vacuum chamber in vertical position and uniformely heated at different temperature steps. The control of the temperature homogeneity is carried out via thermocouples fitted on the Telescope structure.

The Defocus measurement is performed thanks to a high stable differential interferometer and two stable Zerodur mirrors, one fixed inside the M2 support and the other being implemented at the center of the M1 Baseplate via a stable Invar spider.

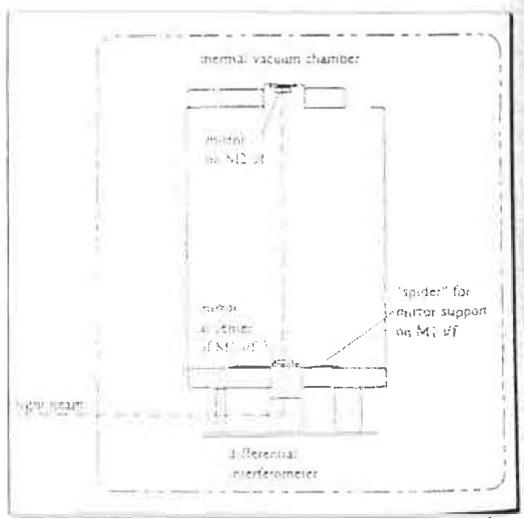

Figure 8 : Thermoelastic test principle

During the test, a local instability was observed at the level of the top of the cylinder (in cylinder / spider area). The other heated areas (M1 baseplate, lower part of the cylinder, M2 support) showed a quasi-negligible influence within the measurement accuracy which confirms the stability of the C/C material and the other junctions. In order to identify the origin of the measured local instability, a sensitivity analysis was performed with the F.E. model and showed a complex local behaviour in cylinder / spider area, and in particular a thermal expansion of the bonding of the cylinder stiffeners which leads to a thermoelastic contribution not representative of the material stability. Design improvement has been identified to reduce strongly this local instability.

As a conclusion, the test sequence enabled to validate the performance of the AEROSPATIALE Carbon/Carbon telescope :

- **excellent mechanical behaviour :**
  . negligible residual deformation after high launch load (52 g)
  . high gravity stability with an increased spider stiffness
- **high L.T. stability :**
  . no microcreep phenomenon after application of high loads during a long period
  . negligible residual deformation after thermal cycling
- **high thermoelastic performance :**
  The local instability, not linked to the C/C technology, does not challenge the global thermoelastic peformance of the Telescope structure.

8. CONCLUSION

The results achieved during this programme confirm the strong interest of the AEROSPATIALE Carbon/Carbon material for high stability instruments and have enabled to bring this technology to flight standard through a reprensentative Telescope configuration.

The very high thermoelastic stability of the C/C material (CTE $< 10^{-7}$ K^{-1} in quasi-isotropic lay-up configuration) associated to its moisture unsensitivity enables, depending on the applications, to withstand severe thermal environments, to simplify the thermal control or to not use "refocusing" device.

A high growth potential is offered with AEROSPATIALE industrial facilities up to 2.5 m.

9. REFERENCES

{ 1 } " Dimensionally Stable Structures" - ESTEC/Contract n° 11241/94/NL/PP(SC)

{ 2 } O. FRANC, J.L. MACRET, "Oxidation resistant carbon/carbon materials", Symposium *Space applications of advanced structural materials*, ESA SP-303, Noordwijk, March 1990

{ 3 } J.L. MACRET, P. LAUTISSIER, "High temperature composites in Aerospatiale activities", Symposium *Advanced materials for lightweight structures*, ESA SP-336, Noordwijk, March 1992

{ 4 } B. BAILLY, JL CORNU, B. CAPDEPUY, F. LELEU, M. KORNMANN, A. PRADIER, "Dimensionally stable structures", *Conference on spacecraft structures, materials & mechanical testing*, ESA SP-386, Noordwijk, March 1996

{ 5 } B. CAPDEPUY, F. LELEU, F. BOURSEREAU, P. PARROT, B. BAILLY, JB RITI, JL CORNU, "Space optical payloads, new application area for high temperature composites", *47th International Astronautical congress*, Beijing, October 1996

{ 6 } A. PRADIER, P. GUIGUE-JOGUET, J.A. MASSONI, M. NIVET, B. CAPDEPUY, J. PORA, "Dimensionally stable structures for scientific programmes", ESA symposium *Scientific satellites achievment and prospect in Europe*, Paris, November 1996