FAILURE ANALYSIS ON OPTICAL FIBER ON SWARM FLIGHT PAYLOAD

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I. INTRODUCTION

Failure analysis on optical components is usually carried-out, on standard testing devices such as optical/electronic microscopes and spectrometers, on isolated but representative samples. Such analyses are not contactless and not totally non-invasive, so they cannot be used easily on flight models. Furthermore, for late payload or satellite integration/validation phases with tight schedule issues, it could be necessary to carry out a failure analysis directly on the flight hardware, in cleanroom.
Therefore, the CNES (Centre National d'Etudes Spatiales) department "Laboratories & expertise" has explored the capability to bring classical imaging and physical characterization measurement systems close to the payloads. The goal is to get as soon as possible a maximum of non-invasive information in parallel with laboratory analyses and simulations, to help project teams to take good decisions.
The optical fiber of SWARM instrument (SWARM is the ESA "Earth explorers" program: constellation of 3 satellites to study the magnetic field) "FM1A" (Flight Model 1A), guiding the light from the laser to the magnetometer, has been damaged during assembling and testing operations. This paper summarizes observations and analysis that have been carried-out at CNES (France), and also on the flight model at IABG (Germany) with the collaboration of ESA (European Space Agency).

II. FLIGHT MODEL INSPECTION

A damage on a flight model optical fiber of SWARM instrument has been observed "Fig 1" when the instrument was about to leave the assembling site at IABG Munich. The change of the overall optical cable would have strongly affected the scheduled planning and called into question the qualification. So the only way to make a decision on the need to change the optical fiber or not, was to work directly on the payload, reproduce the defect in the laboratory for further investigations, and then better understand the function of each layer of the optical fiber. Therefore and in case no degradation of the core was demonstrated, protections had to be setup to keep safe the optical fiber in the damaged area and preserve its performance during the life time of the instrument.
Radiometric measurements have been carried out first, on the payload and demonstrated that the optical fiber was not broken. But the problem is that a part of the energy is sensitive to the variation of polarization. So it was not possible to make a strict comparison to previous measurements.

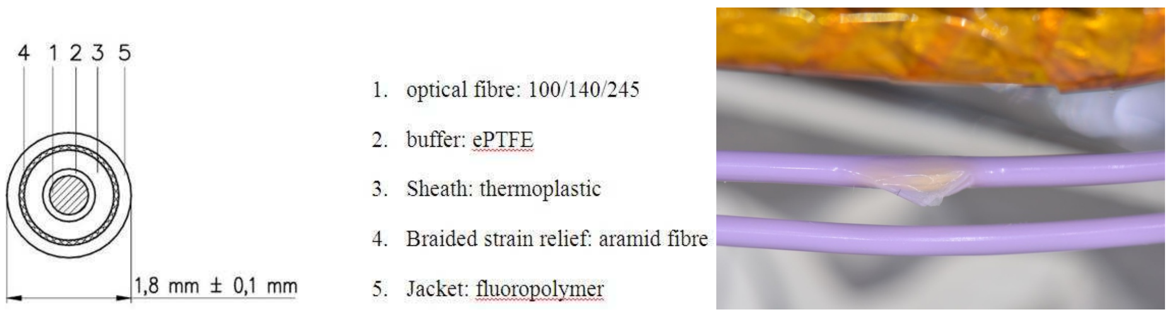

Fig 1: On the left: description of the layers of the optical cable; on the right, the damaged area

It was not possible on the flight model to control the fiber by X-ray imaging. Therefore, only UV, visible and IR wavelengths have been used to collect information.

A fluorescence imaging at two wavelengths

Absorption and emission tests have been performed under UV/visible light on the different layers of the optical cable and it turned out that the jacket was an excellent absorbent at 450 nm and quite transparent at 365 nm for low thickness. In addition, the aramid fibers have a very good fluorescent yield at 365 nm with a yellow reemission, and the third thermoplastic layer (sheath) is fluorescent in the red part of the spectrum.
On the following pictures and from two different views, the jacket absorbs the 450 nm excitation light, and then behaves as a source at higher wavelengths “Fig2”. It is no longer transparent. This confirms that a thin film of fluoropolymer is still covering the aramid fibers.

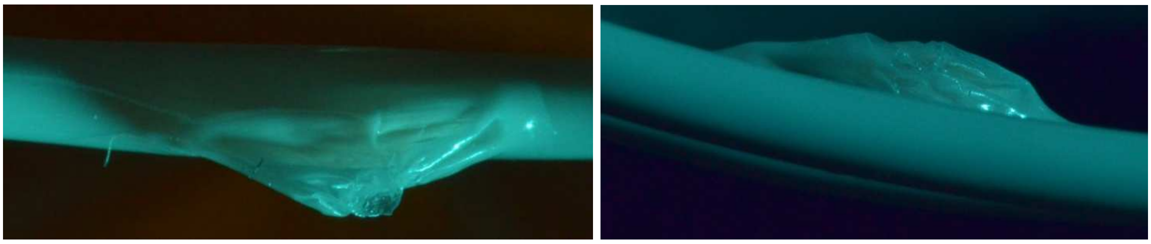

Fig 2: 450nm excitation wavelength.

At 365 nm radiation excitation “Fig3”, the fluorescence yield is very high for the aramid fibers and low for the fluoropolymer. This confirms that the aramid fibers are not broken despite an important shifting (extension) in the damage jacket; nevertheless, this may involve tensions in the optical fiber.

Fig 3: 365 nm excitation wavelength.

Results of the visual inspection on FM (Flight Model):
- A thin film of fluoropolymer is still covering the aramid fibers.
- The aramid fibers have been displaced 1.5 mm over the jacket. They seem to remain braided however, they are not broken.
- We do not see anything from deeper internal materials.

B Infrared imaging of the backscattered light in the optical fiber

The following pictures “Fig 4” show the IR InGaAs 14 bits camera over “FM1A” optical cable and the IR image with the Viton protection to prevent from bending the optical cable over few centimeters.

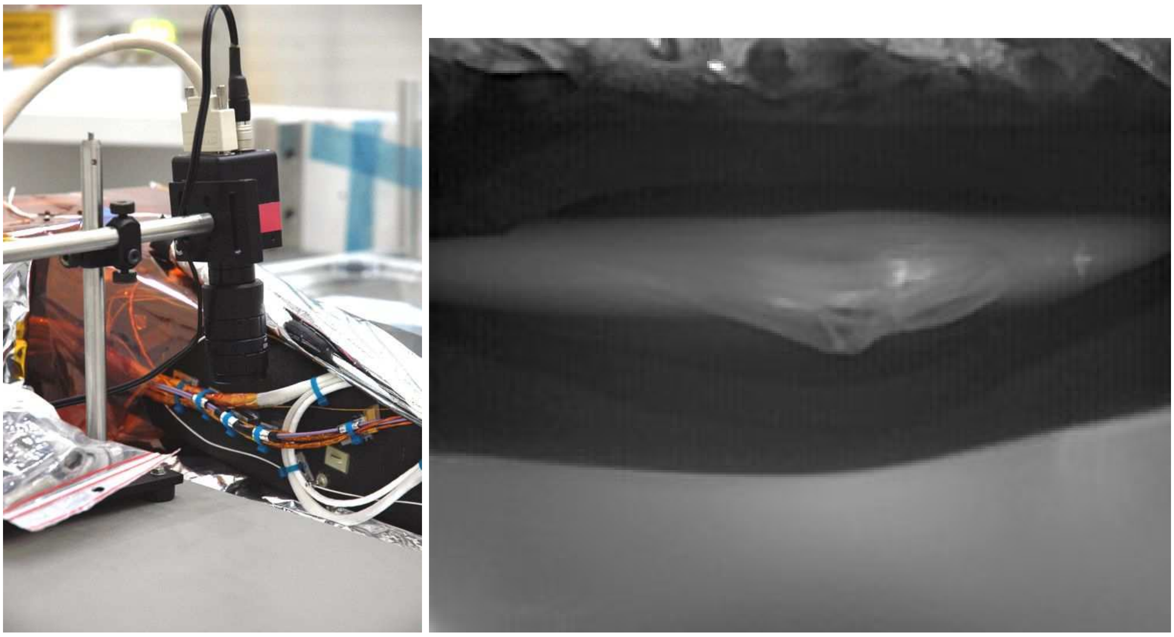

Fig 4: IR imaging of the damaged optical fiber under room light (laser off).

The following infrared pictures (900 – 1700 nm) have been acquired in the same conditions, in the dark, so that they can be directly compared in terms of power, in grey levels. A very small amount of light is escaping from the jacket and can be seen on "Fig 5" on FM1A SWARM instrument. The power of the laser in the optical fiber is 4 times higher (2mW) on the flight model compared to the 460 µW in our sample at CNES. Anyway, the flux going out of the fiber is insignificant on flight model. The 4th picture "Fig 5" is acquired strictly in the same conditions of integration time, working distance, aperture, cooling and resolution concerning the InGaAs camera. An optical power of 460 µW is injected in the optical fiber bended with a 6 cm radius of curvature with the same laser source as the flight model. Only the power is 4 times less that the image on flight model. Approximately 5 ppm of light escapes from the jacket, each centimeter, with this radius of curvature. The camera can easily acquire this light with a 350 ms integration time and a subtraction of the dark. It confirms the insignificant amount of light escaping from the jacket on flight model.

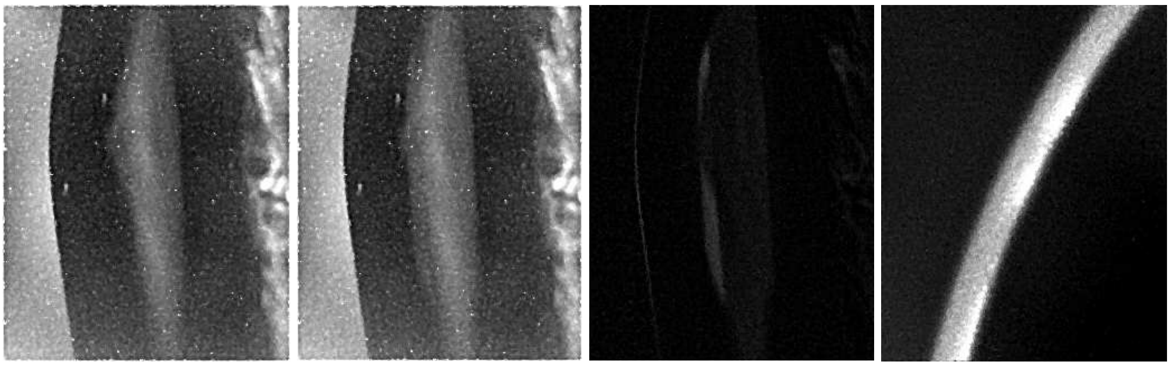

Fig 5: IR long exposure image of the optical fiber: laser off, laser on, and the difference between the two. The last image is the reference for the quantification of the flux taken in the same conditions in our laboratory.

To conclude concerning the UV, visual, IR inspection, we know that the optical fiber is not affected by latent cracks. They would involve a measurable loss of light escaping form the core with this InGaAs camera. These cracks have also been reproduced in our laboratory and the amount of light is much more important than what we can see on the flight model.
The fluorescence imaging shows that the jacket is affected but not totally removed and that the aramid fibers, supposed to prevent from high temperatures (about 400°C), are not broken. Therefore, the goal of the following studies in our laboratory was to reproduce strictly the same damage and to evaluate the integrity of the low protecting layers of the fibers.

III. LABORATORY TEST AND EXPERTISES

IABG mentioned a possible incident due to the use of a hot air gun too close to the optical fiber. We performed different tests and reproduced the damage. The following tomography “Fig 6” and cross-sections “Fig 7” images show that at these temperatures (about 500°C / 20 seconds) the shape of the sheath is preserved. It means that the optical fiber is still free to move in the sheath and thanks to the Aramid fibers; the excess of heat has been dissipated along the cable. The ePTFE also plays a role in this dissipation.

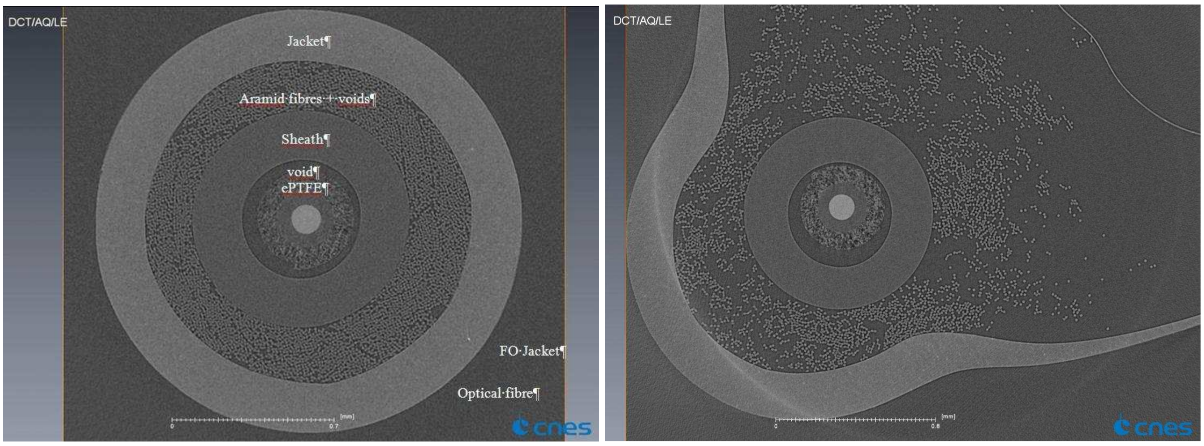

Fig 6: X-ray pictures extracted from tomography videos showing the different protection layers in order to assess the depth of damage

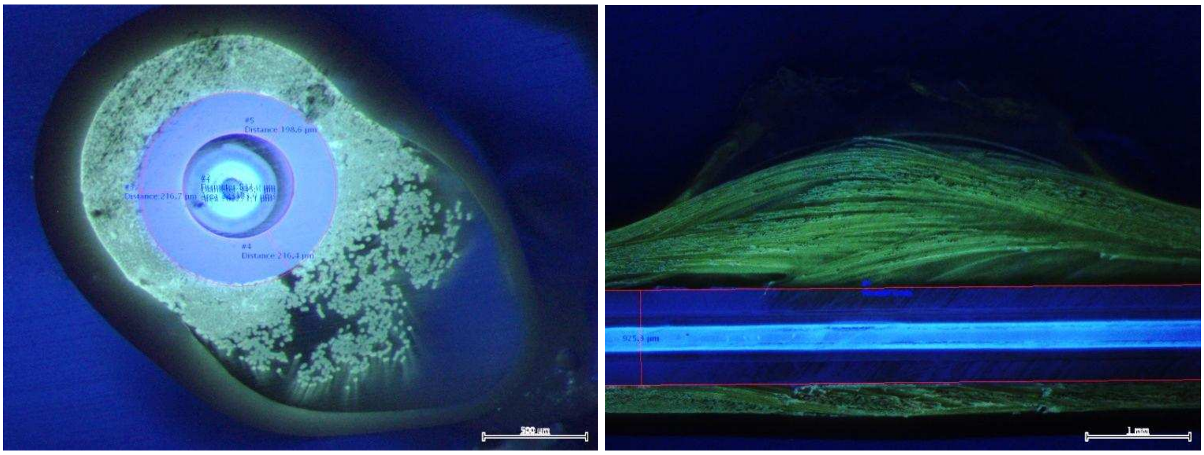

Fig 7: Cross-section under UV light to identify the 5 protection layers and the depth of damage

Other characterizations have been carried out like thermal shocks. Considering that heat could have created evolutionary micro-cracks in the optical fiber, we performed a 10 cycle thermal test (+45°C / -50°C) to simulate thermal shocks on a damaged area. The temperatures were measured with a thermocouple and the optical transmission of the fiber with a laser and a photodiode.

Under vacuum environment, two damaged samples have been observed with stereomicroscope, before and after 12 hours storage in a 6.10-7 Torr vacuum chamber. We did not see any evolution of the jacket bubble and aramid fibers with this “all or nothing” test.

In addition, differential Scanning Calorimetry measurement on the sheath “Fig 8” showed that the glass transition temperature at a rather high temperature is the same for the heated and the unheated overall optical cable.

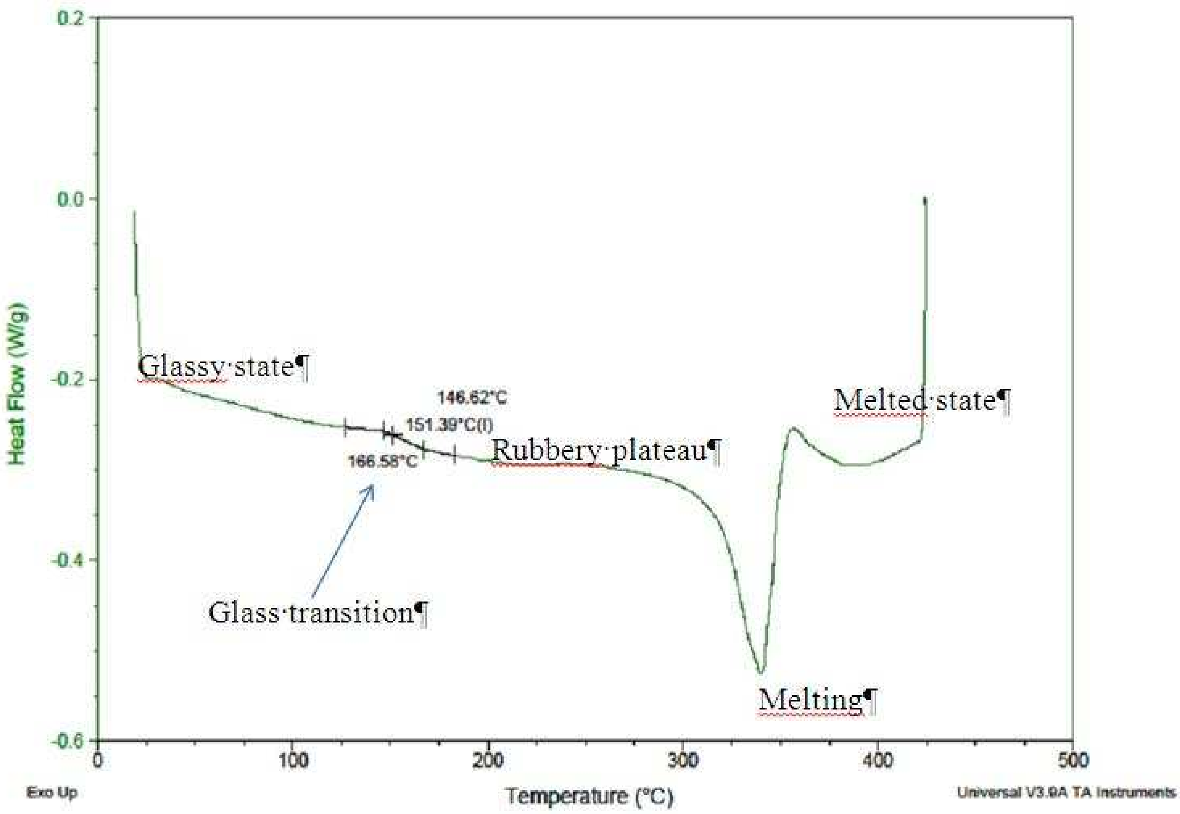

Fig 8: Differential Scanning Calorimetry measurement on the sheath

IV CONCLUSION

The laser of SWARM "FM1A" still has a nominal performance in orbit presently, and we are quite confident for the future.

Most of the tests we can carry out in cleanrooms during assembling and testing phases are mainly "all or nothing" tests. But in addition to more formal or analytical measurements in a laboratory which are time-consuming, they are really helpful for projects to take decisions or to mitigate the risks.

At CNES "Laboratories & Expertise" department, thanks to the miniaturization of technologies, we think it is important in case of failures to export instruments from the laboratory to the cleanrooms where the satellites are integrated. This failure analysis case study shows us that there is an interest to control and choose the lighting conditions and to select the cameras adapted to the spectral range of the sources. We can notice that fluorescence is a technique, among others, that has to be further explored. That is why we are developing a new instrument to analyze the fluorescence of materials from 300 to 700 nm.