Analysis of the suitability of the Auriga™ Star Tracker for Very Low Earth Orbit Missions

***Abstract*—This article presents the key design drivers specific to the Very Low Earth Orbit (VLEO) environment, in particular the necessary resistance to the heavy ion ATOX fluence and the tolerance to Total Ionizing Dose, and also presents how the design choices made on the Auriga™ Star Tracker make it a perfect choice for VLEO missions.**

I. Introduction

AURIGA™ is a compact, reliable, standardized, and ready-to-use star tracker provided by Sodern. The Auriga™ star tracker is presented in Fig 1, and its technical characteristics are listed in [1] .

The Auriga™ star tracker was initially developed for the needs of the Eutelsat OneWeb constellation, flying at an altitude of 1200 km. As of today, Auriga™ cumulates 38 million hours of faultless in-flight operations and 10% of the delivered models already achieved their expected in-flight life time, which confirms its lifetime duration and reliability. In addition to its use on the OneWeb constellation, it has flown on a wide variety of missions, ranging from Low Earth Orbit (LEO) to Medium Earth Orbit (MEO) missions, and it will soon have a heritage on Geostationary orbit.

This article presents the key design choices which also makes it suitable for use on Very Low Earth Orbit (VLEO) missions, with a studied altitude range from 250 to 350 km. In particular, radiation and atomic oxygen issues will be explored.

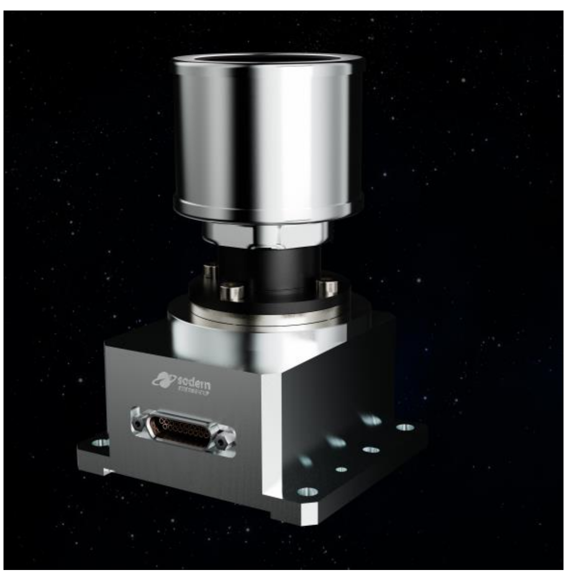

Fig. 1. View of the Auriga™ Star Tracker in a 35° baffle configuration.

II. Radiation Constraints

A. Context

Radiation effects are sometimes considered to be a lesser concern in the VLEO environment, since most of the missions fly at altitudes which are too low to be significantly exposed to Van Allen trapped proton radiation belt. Nevertheless, satellites flying on polar orbits are exposed to galactic cosmic rays when they cross Earth's poles. In consequence, radiation effects can still have practical consequences on spacecraft flying on VLEO orbits. The accumulation of Total Ionizing Dose (TID) through the satellite lifetime can eventually cause electronic failures. Likewise, the exposure to heavy ions during the crossing of Earth's poles can cause destructive Single Event Effects (SEE) in non-radiation-tolerant electronics, especially during solar flares.

B. Environmental Constraints on Typical Missions

Table I presents the TID levels behind 2 mm of aluminum shielding for typical VLEO mission profiles. For this analysis, the AE8MAX, AP8MIN and ESP 85% confidence level environment models were used, in conformance with [2] . For the longest VLEO mission considered (315 km altitude, 10 years lifetime), the TID level rises to 14 krad [Si], which is not a negligible level.

Table I
Total Ionizing Dose Behind 2 mm of Aluminum Shielding

Altitude (km)	Lifetime (years)	Total Ionizing Dose (krad [Si])
250	1	1.2
250	2	2.4
315	1	1.4
315	10	14.0
350	1	1.6
350	2	3.2

Orbit inclination of 98° considered

C. Design and Validation of the Auriga™ Star Tracker

Being designed for the LEO and GEO environments which are characterized by higher radiations constraints, Auriga™ is perfectly suited to the radiation environment of the VLEO missions listed in section II.B. Its minimum TID tolerance is higher than 35 krad, which is considerably higher than the dose listed in Table I.

Furthermore, it is immune to proton-induced and heavy-ion induced destructive Single Event Effects up to a LET of 60 MeV.cm²/mg, making the crossing of Earth's poles and its associated cosmic ray exposure safe in any circumstance.

III. Atomic Oxygen Constraints

A. Context

The most salient environmental constraints specific to the VLEO environment is the high atomic oxygen (ATOX) flux encountered along the orbit. ATOX is one of the most abundant chemical species present on altitudes lower than 500 km. It is mainly created through the breakage of O_2 molecules by ultraviolet radiation emitted from the sun. On VLEO orbits, spacecraft surfaces perpendicular to the movement of the spacecraft (ram direction) are impacted by an ATOX flux with a typical energy of 4.5 to 5 eV [3] . ATOX interacts with spacecraft equipment materials through oxidation effects and erosion, and can significantly degrade materials directly exposed to the flux on external surfaces, and even internal cavities [4] . Carbon-based materials like Kapton show a very high sensitivity to ATOX erosion, however other materials can also show a significant sensitivity [5] .

B. Environmental Constraints on Typical Missions

Table II shows the ATOX fluxes and fluences on surfaces perpendicular to the spacecraft ram direction for typical polar VLEO orbits and mission profiles. The fluences have been computed using the NRLMSISE-00 model [6] , which is the reference atmospheric model for estimating ATOX abundance. For this computation, the daily A_P value and the $F_{10.7}$ flux model parameters were set to respectively 15 and 10^{-20} W·m^{-2}·Hz^{-1}, giving average results relevant to the current solar cycle.

It can be observed that the ATOX flux rises rapidly with decreasing altitude, reaching a value of 8.6×10^{15} atoms/cm²/s. For a 5-year mission, this corresponds to a total ram fluence of 1.3×10^{23} atoms/cm². In more general terms, most considered mission profiles are characterized by a ram fluence above 5.0×10^{21} atoms/cm², which is considerably higher than the fluence commonly observed on helio-synchronous LEO missions. For reference, a 7.5-year, 800 km mission is exposed to an ATOX ram fluence of 1.4×10^{19} atoms/cm².

TABLE II
ATOMIC OXYGEN FLUENCES FOR TYPICAL POLAR VLEO MISSIONS

Altitude (km)	ATOX Flux (atoms/cm²/s)	Lifetime (years)	ATOX Fluence (atoms/cm²)
250	8.6×10^{15}	1	2.7×10^{22}
250	8.6×10^{15}	2	5.5×10^{22}
315	2.3×10^{14}	1	7.2×10^{21}
315	2.3×10^{14}	10	7.2×10^{22}
350	1.2×10^{14}	1	3.7×10^{21}
350	1.2×10^{14}	2	7.3×10^{21}

Orbit inclination of 98° considered

C. Design and Validation of the Auriga™ Star Tracker

Several design choices make the Auriga™ Star Tracker particularly resilient to high ATOX fluence. Whereas polymer-based thermal control materials such as Kapton (polyimide) and FEP Teflon show a high sensitivity to ATOX erosion and can contaminate optics of sensitive instruments, the Auriga™ star tracker external structure is completely made of aluminum, which is practically insensitive to ATOX erosion [7] .

The anti-reflective coatings of lenses can also be eroded by ATOX, which is a concern on star trackers. In the case of high-performance multilayer coatings which are commonly used on such applications, the erosion of the outermost layers of the anti-reflective coating can effectively cause a reduction of their efficiency, since they rely on a stack of layers with finely optimized thicknesses to create destructive interference to reflected light. As a mitigation technique on Auriga™, no anti-reflective coating is used on the external side of first lens element.

On a star tracker, the optical absorption properties of the baffle elements are critical to achieve a low Sun Exclusion Angle (SEA). As such, these parts are often painted in black. Depending on the nature of the paint, exposure to ATOX can oxidize its constituents and cause an optical degradation. Non-silicone-based paints are particularly sensitive to these effects. The Auriga™ star tracker only uses an inorganic, oxide-based optical black coating, which by nature should be very resilient to ATOX exposure. This theoretical resilience has been experimentally tested by exposing coating samples up to a fluence of 5.5×10^{21} atoms/cm² at the European Space Agency LEOX facility (Low Earth Orbit Atomic Oxygen Facility), which uses a hot plasma of oxygen atoms generated by Laser Pulse Induced Breakdown to simulate the space environment [9] . This facility is currently among the most representative of the world, generating a plasma with an energy close to 5.5 eV. No significant change of absorption or reflectivity was measured on Auriga™'s baffle black coating after this exposure.

The maximum flux of this facility is around 1×10^{20} atoms/cm^2/day. In consequence, it is not practically possible to reach the highest fluences listed in section III.B for the 250 km altitude missions. In consequence, a scanning electron microscope (SEM) analysis has been performed on the black coating samples exposed to ATOX, in order to better understand their potential degradation mechanisms at higher fluences. The results are presented in Fig. 2. At a magnification factor of 5000, no sign of erosion is observed on the fine structure of the black coating. As such, there is no indication that higher fluence levels would degrade the coating, and its use should be suitable for ATOX fluences at least an order of magnitude higher (5.5×10^{22} atoms/cm²) without any practical effect. This covers most of the missions presented in section III.B.

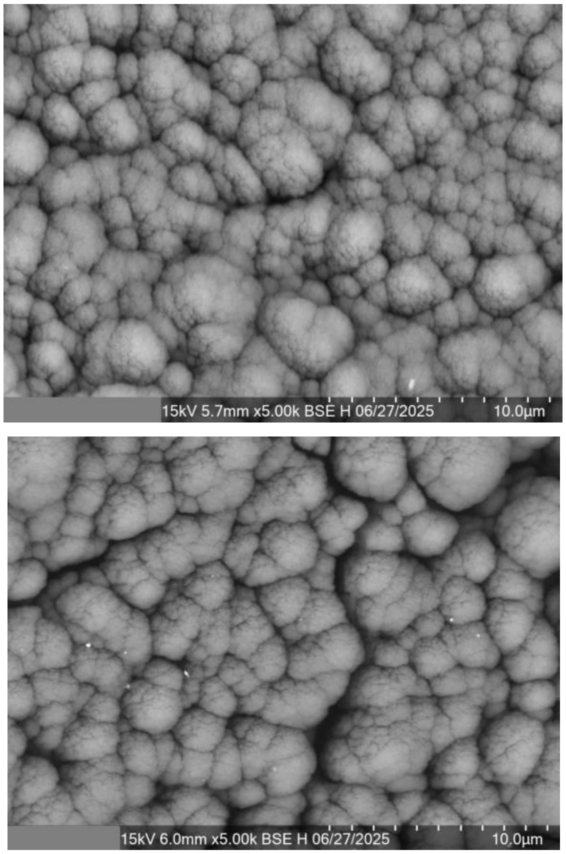

Fig. 2. SEM pictures (magnification x5000) of Auriga™'s baffle black coating. Before ATOX exposure (top) and after exposure to 5.5×10^{21} atoms/cm² (bottom)

IV. Conclusion

The VLEO environment is very challenging, in particular considering the ATOX fluence and the Total Inonizing Dose. The Auriga™ Star Tracker includes specific design features that provide a strong resistance to this environment. These features, associated to Auriga™'s large flight heritage, make it perfectly suited to VLEO missions with altitudes ranging from 250 km to 350 km.

References

[1] Auriga™ general description and performance characteristics, https://sodern.com/wp-content/uploads/2025/02/AURIGA_CP.pdf

[2] ECSS-E-ST-10-04C Rev.1 – Space environment

[3] J. A. Dever, "Low Earth Orbital Atomic Oxygen and Ultraviolet Radiation Effects on Polymers", NASA Technical Memorandum 103711, February 1991.

[4] B. Banks, S. K. R. Miller, K. K. de Groh, and R. Demko, "Atomic Oxygen Effects on Spacecraft Materials," NASA report NASA/TM-2003-212484, June 2003.

[5] B. Banks et al., "Issues and Effects of Atomic Oxygen Interactions With Silicone Contamination on Spacecraft in Low Earth Orbit," NASA report NASA/TM-2000-210056, May 2000.

[6] J. M. Picone, A.E. Hedin, D. P. Drob, A. C. Aikin, "NRLMSISE-00 empirical model of the atmosphere: Statistical comparisons and scientific issues", *Journal of Geophysical Research (Space Physics)*, Vol. 107, Is. A12, DOI: 10.1029/2002JA009430

[7] D. Dooling, M. M. Finckenor, "Material Selection Guidelines to Limit Atomic Oxygen Effects on Spacecraft Surfaces" NASA report NASA/TP-1999-209260, June 1999.

[8] B. Banks, R. Demko, "Atomic Oxygen Protection of Materials in Low Earth Orbit", NASA report NASA/TM-2002-211360, February 2002.

[9] ESA Materials & Electrical Components Laboratory, https://technology.esa.int/lab/materials-electrical-components-laboratory