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ATOMIC OXYGEN MONITOR SYSTEM ON BOARD A SUPER-LOW-ALTITUDE TEST SATELLITE

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JAXA proposed a brand-new concept of low-Earth-orbit (LEO) satellites, super-low-altitude satellites which orbit at an altitude of under 250 km. High resolution optical observation and reduced emission power of active sensors such as radar are expected in Earth observation from the super-low-altitude orbit. A super low altitude test satellite (SLATS) has been developed as the first demonstration satellite at this altitude. The Atomic Oxygen Monitor (AMO) is one of the missions of the SLATS and comprises two missions: the Materials Degradation Monitor (MDM) and the Atomic Oxygen Fluence Sensor (AOFS). The MDM will observe the degradation of candidate materials for use as super-low-altitude satellites in future. AOFS will obtain AO environment data while in SLATS orbit. The results thus obtained by the AMO will be used to develop future super-low-altitude orbit satellites. This paper presents a summary of the AMO mission development status.

I. INTRODUCTION

One of the problems in low-Earth orbit is an Atomic Oxygen (AO) degradation of the materials used on the satellite surface. The oxygen molecules in the upper air are dissociated from the sun by ultraviolet rays, and there is a tendency toward high concentration, which means low altitude AO collides with exposed materials at high velocities of about 8 km/s, thereby eroding their surfaces. Such AO attacks transform the exposed surfaces of polymer materials into a needle-like form[1]. Polymers used for spacecraft suffer chemical and physical damage from this space environment, which alters the surface characteristics and degrades the mechanical properties.

Meanwhile, JAXA has proposed a brand-new concept of low-Earth-orbit (LEO) satellites, namely the super-low-altitude satellite[2]. High resolution optical observation and reduced emission power of active sensors such as radar are expected in Earth observation from super-low-altitude orbit. Super-low-altitude satellites are supposed to be operated in orbits of less than 250 km in altitude where air drag can no longer be considered negligible. However, the high propellant efficiency of ion thruster systems allows air drag to be compensated and maintains the altitude of the satellite throughout the entire mission.

However, AO fluence in super-low-altitude orbit is expected to far exceed that in low-Earth orbit, hence the severe material degradation from AO. Moreover, it is very difficult to evaluate the materials used in these satellites because it takes so long to irradiate AO on the ground. With regard to the AO environment, there are very few examples of direct AO detection performed in a super-low-altitude orbit, and such precious survey data is needed to help design super-low-altitude satellites.

The Super Low Altitude Test Satellite (SLATS), which JAXA is now developing, is a unit aiming to demonstrate technology while in super-low-altitude orbit below an altitude of 250 km[2, 3]. The result obtained from the satellite operation will then be leveraged when designing a future low-altitude orbit satellite. The Atomic Oxygen Monitor (AMO) is one of the missions of the SLATS. AMO comprises two missions: the Materials Degradation Monitor (MDM) and Atomic Oxygen Fluence Sensor (AOFS). MDM will observe the degradation of candidate materials for super-low-altitude satellites in future, while AOFS will obtain AO environment data in the SLATS orbit. This paper presents a summary of the AMO mission development status.

II. OUTLINE OF AMO

AMO comprises MDM and AOFS, both of which are checked in the early operation phase. Moreover, in the super low-Earth-orbit phase, which is below 250km, both MDM and AOFS are operated in over three months.

II.I MATERIAL DEGRADATION MONITOR (MDM)

MDM is a system which qualitatively monitors the extent to which the material is deteriorated by AO from visual observation. MDM comprises two components, MDM-S (Fig. 1), which mainly carries material samples, and MDM-C (Fig. 2), which has a camera system. Both components are carried in the +Z side panel of the SLATS satellite body structure (Fig. 3). A material sample mount side is carried in the direction of the +X side, which is in the direction of movement of the satellite, while MDM-S evaluates material degradation based on an AO collision from the direction of movement of a satellite.

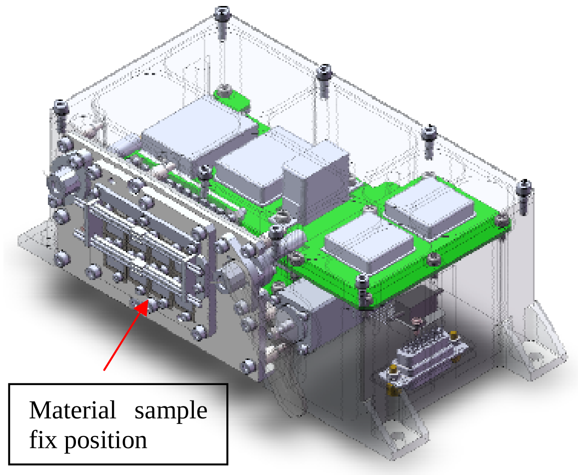

Fig. 1: Overview of MDM-S

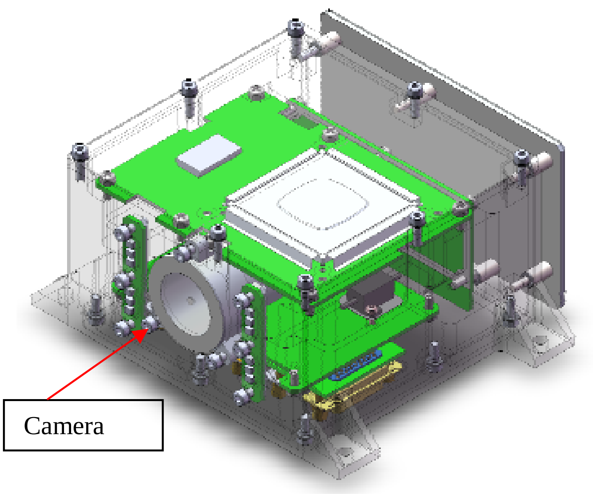

Fig. 2: Overview of MDM-C.

Material sample name	Application
Atomic Oxygen Protective Coating/Polyimide(UPILEX-R)/Al	MLI
Polysiloxane Block Polyimide(BSF-30)/Al	MLI
UV Protective Coating/Polysiloxane Block Polyimide (BSF-30)/Al	MLI
ITO Coating/Polyimide(Kapton®)/Al	MLI
Beta cloth/Al	MLI
Expanded PTFE cable (3 types)	Cable
ETFE cable	Cable
ITO Coating/FEP Film (5mil)/Ag	OSR
FEP Film (1mil)/Ag	OSR
FEP Film (5mil)/Ag	OSR

Table 1: MDM material sample list

The mount sample has selected two kinds of electric wire cables, such as a solar paddle exposed to eight kinds and the satellite body structure external surface in films mainly used for thermal control materials, such as a thermal blanket (Table 1). Films are selected, including those carried in SLATS, focusing on those considered potentially usable in future super-low-altitude orbit satellites, and data is acquired concerning the validity of AO-proof coating and the AO tolerance of the base film itself, etc. Moreover, a reduced thickness of covering material is observed, presuming the use of an electric wire cable for the electric power line from a photovoltaic cell in respect of a solar paddle etc. These results can be used to determine the covering thickness required for the external exposure electric wire of a future super-low-altitude orbit satellite, and the required examination of the effect against AO.

The monitoring material used to determine the number of AO collisions other than on the experiment sample is carried in MDM. Monitoring material carries the processed sample so that the bulk polyimide material, from which the thickness differs, could observe signs of gradual disappearance in the form of corrosion of AO. This monitors the number of AO having collided with the MDM sample loading side on a semi-quantitive basis.

A hole resembling a pinhole is initially expected due to AO material degradation, followed by a tear expanding from this starting point. A CCD camera with more than 380,000 pixels and capable of observing the details of such degradation is used to observe the loading sample of MDM.

MDM loading lighting is used and under stable lighting conditions, material sample photography of MDM is performed. Moreover, as well as front lighting, the material is also backlit and the design is expected to be one allowing even observation of the minute hole expected to emerge in the early stages of degradation of a thin film. Photography is performed using both front and back lights on a weekly basis. After the orbit data is transmitted to the ground, image analysis is conducted. The quantity linked to the upward tendency in the area of a tear and the portion turned over are determined, and this information is converted as material degradation data.

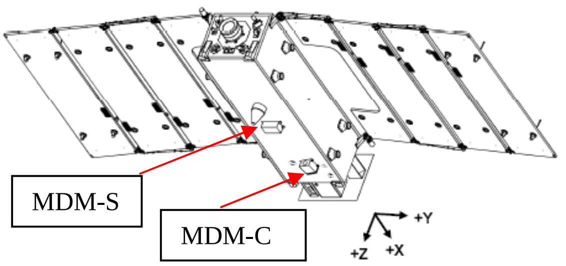

Fig. 3: Orbital configuration of SLATS and MDM

MDM is scheduled to shift to manufacture after a critical design review.

Moreover, picture observation with a camera due to the AO irradiation test on the ground is planned.

II.II ATOMIC OXYGEN FLUENCE MONITOR (AOFS)

The AOFS is a system which measures the number of collisions involving AO colliding with SLATS during satellite deployment, and is scheduled to install eight sensors in/on SLATS. In AOFS, the number of collisions involving AO is calculated based on the minute mass change accompanying AO and corroding a substance. The Thermoelectric Quartz Crystal Microbalance (TQCM) is installed as a sensor, which quantitatively measures the minute mass loss of substance adhering to the crystal electrode surface, and can set a crystal oscillator as an arbitrary temperature. The number of AO collisions is measured using the mass loss phenomenon, whereby a polyimide coating is applied to the crystal oscillator electrode side of TQCM, following a reaction with AO. Since the amount of erosion at the time of one oxygen atom colliding with polyimide has data as “reaction efficiency [$3x10^{-24}$ cm^3/atom]”, AO fluence can be calculated by the polyimide coating mass loss, which was measured by TQCM. A sensor using such polyimide as a material to be eroded has been established as a proven system within the JAXA AO irradiation facility. As for change of mass, telemetry data is obtained as a change of frequency. However, a limit applies when applying the mass of the polyimide coating to TQCM and it is exposed to be measured until only $1.0x10^{20}$ [atoms/cm^2] if the unadornment sensor is exposed. It is impossible to observe the number of AO collisions in a SLATS mission period (it is predicted as $2.6x10^{22}$ [atoms/cm^2] in respect of +X). It is therefore designed as a structure which prepares an opening-and-closing type shutter mechanism at the front of TQCM to limit the number of AO collisions (Fig. 4).

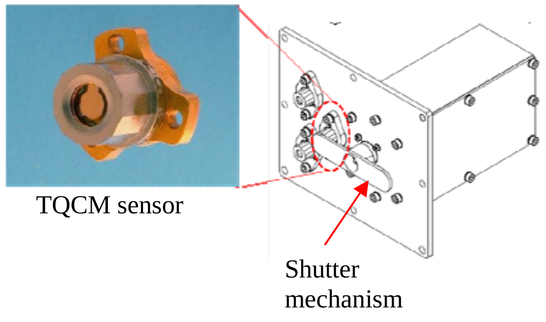

Fig. 4: AOFS sensor (+X)

In addition, the TQCM sensor is carried in a position which can measure the number of AO collisions based on the direction of movement of a satellite and can be kept warm at a high temperature rather than the ambient temperature, to prevent contamination due to adhesion. Furthermore, TQCM, which lacks any polyimide coating, is installed next to the polyimide coating TQCM sensor with a shutter because the effect of contamination is also observed.

III. Schedule

AMO is being manufactured and completion is scheduled for within the current financial year.

Moreover, the ground evaluation of material samples and proofreading of a mounted sensor, etc. are scheduled to be performed in parallel. For the ground evaluation, the initial degradation situation picture of MDM material samples or the monitoring material is checked using the JAXA AO irradiation facility. In addition, a ground evaluation test, which is specialized for super-low-Earth orbit is researched in Kobe University[4].

Moreover, the mass decrease tendency measurement by AO of the TQCM sensor with a polyimide coating is checked for AOFS.

IV Conclusion

The result obtained through AMO missions is expected to be useful in selecting material for a satellite employed in future super-low altitude.

Currently, steady progress will continue to manufacture a flight model and conduct a ground examination.

References

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