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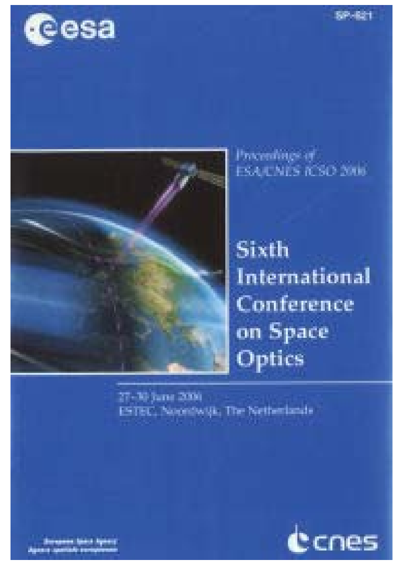

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ALADIN, THE FIRST WIND LIDAR IN SPACE: DEVELOPMENT STATUS

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ABSTRACT

The Atmospheric LAser Doppler INstrument (ALADIN) is the payload of the ADM-AEOLUS mission [1], which aims at measuring wind profiles as required by climatology and meteorology users. ALADIN belongs to a new class of Earth Observation payloads and will be the first Wind Lidar in space. The instrument comprises a high energy laser and a direct detection receiver operating on aerosol and molecular backscatter signals in parallel.

ALADIN is now in its final construction stage: the Opto-Structural-Thermal-Model (OSTM) has been completed and successfully tested, most of the flight equipments have been delivered and the integration of Flight Model (FM) has started. The Aeolus satellite is developed for the European Space Agency with EADS Astrium as prime contractor for the satellite and the instrument.

1. INSTRUMENT DESIGN

1.1 Overview

The ALADIN instrument emits laser pulses towards the atmosphere and measures the Doppler shift of the return signal, backscattered from different altitudes in the atmosphere. The instrument emits the pulses at the 355 nm wavelength with a high power solid-state laser featuring high efficiency and high reliability. Both the emitter and receiver use a large telescope. The receiver analyses the backscattered signal from the atmosphere: the receiver combines a fringe-imaging channel (analyzing low altitude aerosols and clouds) and a double-edge channel (analyzing air molecules). The two scattering mechanisms have different properties and allow coverage of the full range of altitudes. The instrument is designed to pave the way for potential future operational missions.

ALADIN is composed of two blocks: the instrument core which is located outside the platform and the remote electronics located inside. The instrument core includes the main structures and baffle, the telescope, the laser heads, the receiver optics and detectors, and two mechanisms (laser redundancy switch and Laser Chopper). The Core is fixed onto the Nadir side of the platform. The opto-mechanical architecture is based on a mono-static concept: the transmit and receive beams propagate through the same telescope. This architecture allows to limit the field-of-view, hence to improve the daytime performance, and to relax the telescope and optics stability requirement. The optical protection of the receiver during laser emission is ensured by a chopper mechanism, located at the receiver entrance. The ALADIN instrument view is shown in figure 1.

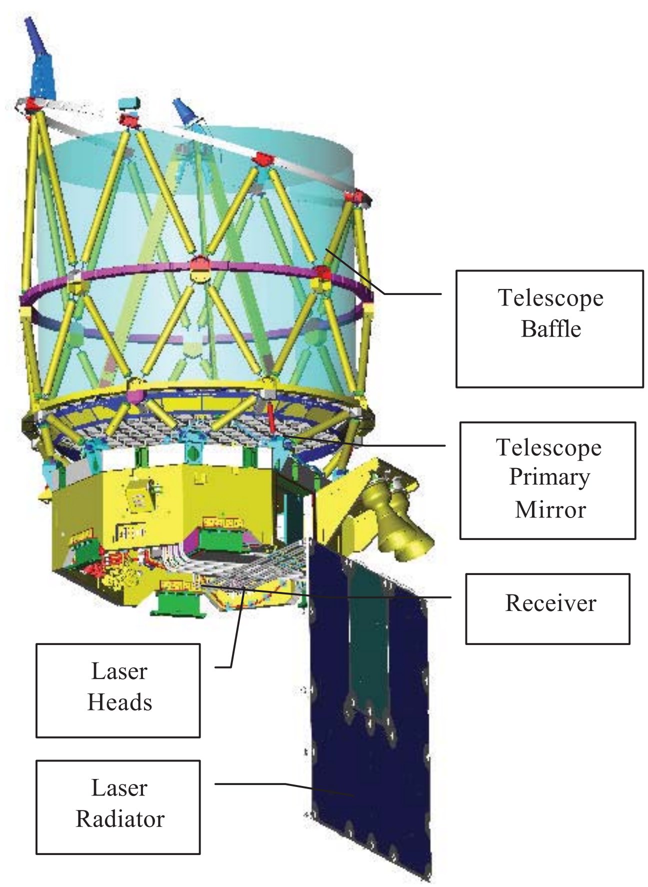

Fig 1. ALADIN Instrument View

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1.2 Transmitter

The Transmitter is based on a Power Laser Head (PLH), seeded by a Reference Laser Head (RLH). The laser beam divergence is adjusted in order to fit the eye safety requirement. The PLH emits in “burst” mode: 12 s bursts every 28 s. The PLH is a diode-pumped Q-switched Nd:YAG laser working in the third harmonic. This laser emits a single axial mode, obtained via injection seeding. The PLH and RLH are cooled by two radiators mounted on the anti-sun side of the platform connected via a set of heat pipes. The routing of the heat pipes is designed to allow on-ground testing of each PLH. Two sets of laser heads are implemented on the main structure (cold redundancy), the switching being performed by a FFM (Flip-Flop Mechanism).

1.3 Detection and electrical architecture

The remote Electronics include the Detection Electronic Units (DEU), the Transmitter Laser Electronics (TLE) and the ALADIN control and data management units (ACDM). The design includes a full redundancy for the remote electronics, with box-redundancy for the ACDM and TLE and internal redundancy for the DEU. All the electrical units are implemented inside the satellite bus. This provides thermal and mechanical decoupling from the instrument core. The DEU operates the Detector Front-end Units: timing sequence (main clocks), secondary power and video signal digitisation functions. The TLE operates the two laser heads and provides power supplies and control functions. The ACDM operates the DEU and TLE, and provides control (synchronisation) of all equipments, power and data buses to these units and interface with the platform.

1.4 Receiver

The optical bench assembly is the receiver function. It features a Transmit/Receive Optics (TRO) which includes a passive diplexer using a polarizing beam splitter, relay optics with two foci (one chopper, one field stop), and a small bandwidth filter to limit the Earth radiometric background.

The aerosols (“Mie”) receiver is based on a Fizeau interferometer. The incoming beam from the Rayleigh receiver is linearly polarized. A quarter-wave plate rotates the reflected beam polarization by 90° back to the Rayleigh receiver. The fringes generated at the output of the Fizeau interferometer are imaged on the CCD detector unit with an afocal lens.

The molecules (“Rayleigh”) receiver is based on a double edge sequential Fabry-Perot interferometer. The input beam is sequentially routed to the two parts of the Fabry-Perot, which slightly differ in spacing by applying a thin vacuum deposited silica layer of controlled thickness on the inner surface of one end plate. The two end plates are optically contacted to a cylindrical silica spacer. Spectral tuning of the Rayleigh spectrometer is achieved by slightly varying the temperature of the assembly.

The detector for both Rayleigh and Mie receivers is the Accumulation CCD (ACCD), a small area detector with a 16x16 useful image zone and two interleaved memory zones (Astrium patent). This geometry and a specific sequencing of charge transfer allow on-chip accumulation of laser shots without mixing the vertical samples. The vertical wind profile is built-up in the memory zone and read-out at low frequency after accumulation; hence the read-out noise occurs only one time for the cumulated shots. This concept adds the benefits from quasi photon counting mode operation and high quantum efficiency as provided by thinned and back-illuminated devices. This detector provides quasi-perfect detector performance, high dynamic range, operation versatility, and makes the detection chain electronics design and operation simple and robust.

Table 1. ALADIN main characteristics

Feature	Value
Wind altitude	0-30 km
Wind accuracy	0.5-2 m/s
Altitude resolution	0.25-2 km
Mass	500 kg
Power consumption	840 W
Operating wavelength	355 nm
Transmitted energy	150 mJ per pulse
Pulse repetition frequency	100 Hz
Telescope diameter	1.5 m
Total instrument field of view (full angle)	22 µrd
Transmitter frequency tunability	+/- 12.5 GHz
Rayleigh spectrometer frequency tunability	+/- 1.1 GHz
Mie spectrometer resolution	< 135 MHz
Rayleigh spectrometer characteristics : - filter spacing - filter FWHM	 5.5 GHz 1.6 GHz
CCD quantum efficiency	> 75 %
Detection chain resolution	16 bits
Detection chain noise for 50 accumulated shots.	4 e-/p rms

1.5 Telescope

The instrument uses a very lightweight telescope made of silicon carbide: this technology allows to select a large diameter while keeping a low mass and high stiffness; hence improving the overall performance. The Silicon Carbide (SiC) material offers a significant mass saving advantage over conventional technologies, especially when the complete telescope, mirror and tripod structure, is made with the same material.

The Aladin telescope, is a 1.5 m diameter afocal Cassegrain telescope, with low mass (75 kg) and high first frequency (60Hz). The focus is thermally adjusted by means of heaters. This design avoids implementing a refocusing mechanism. The secondary mirror is fixed via a tripod structure. The telescope is fixed on the main structure via titanium. Telescope fixations are located at two thirds of the primary mirror diameter. The architecture allows a direct transfer of telescope loads to the platform interface and also optimize both the load spreading in the M1 and its stiffness.

The driving parameters for the telescope design are the focus-fit (overall inter-mirror M1-M2 distance) that shall be maintained within a few microns. Due to the use of the same material, the focus is not sensitive to a uniform temperature variation. In addition, the high conductivity of the SiC material avoids thermal gradients detrimental to the stability and optical performances.

2. OSTM QUALIFICATION RESULTS

The instrument has been tested against mechanical loads and thermal vacuum environment by means of the Opto-Structural and Thermal Model (OSTM). This model is fully representative of the flight model from the mechanical and thermal design and includes some of the optical functions. The OSTM is a full-size instrument including all the structural elements and the telescope with small mirrors mounted on the primary mirror. This allows to measure the wavefront error versus various environmental temperature with a Shack-Hartman instrument.

The thermal vacuum tests of the OSTM have been performed in the Focal 5 chamber of the Centre Spatial de Liège (CSL). These tests have demonstrated the instrument design complies to the required thermal environment. The instrument thermal control performance and power consumption have been verified at this stage. In particular, the laser cold plate stability, controlled via heat pipes and radiator, has been verified to be stable within +/- 1°C, as required to operate the laser in optimal conditions. The thermo-elastic stability has also been verified to be very good during these tests. The defocus stability has been measured to be better than +/- 1 µm and the line-of-sight stability better than 15 µrad. The wavefront error has also been measured in all cases and is compliant with the requirements. The laser / receiver co-alignment stability has also been measured as predicted and confirmed that no co-alignment mechanism is needed.

Fig 2. OSTM instrument in vacuum chamber

The OSTM has then been mounted on the satellite Structural Model and submitted to acoustic and sinus tests at ESTEC facilities. A launcher shock test has also been performed with the Eurockot tester. The measured instrument frequency content is in line with the predictions. This test campaign has also allowed to verify that the random loads generated by the launcher acoustic environment are below the equipment specifications.

Fig 3. OSTM instrument during vibration test

3. DEVELOPMENT STATUS

3.1 Telescope development

The ALADIN telescope is developed by EADS Astrium, The flight model of the primary mirror has been polished and coated with a custom coating with high reflectivity (> 98%) in the UV. The wavefront error has been verified to be better than 200 nm rms.

The telescope secondary mirror structure (tripod) has been tested against launch loads vibrations up to 50 g, both on the OSTM and the flight model.

Fig 4. Coated primary mirror in SiC

3.2 Transmitter development

The transmitter Engineering and Qualification Model has been assembled and tested [2]. The measured performance, especially the energy in UV and the spectral characteristics are in line with the predictions. The environmental tests on the EQM are on-going and the two FM lasers are being constructed. The qualification of coatings and laser diodes are well advanced.

Fig 5. Power Laser Head EQM (open box)

3.3 Optics & electrical equipment

The construction of the main optical units (Transmit / Receive Optics [3]and Spectrometers [4]) is also close to be completed and these equipment will soon be delivered. The Spectrometers development has taken benefit from the instrument pre-development program which validated the technologies and performance of a complete receiver Engineering Model.

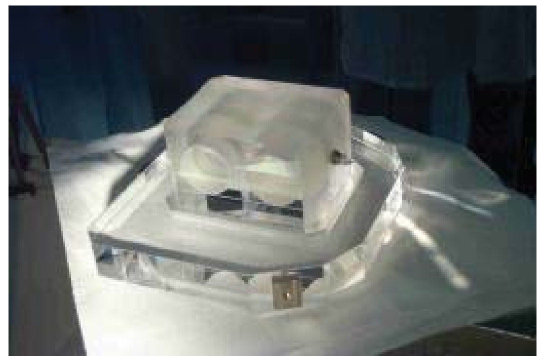

Fig 6. Rayleigh Spectrometer

The ACCD detectors, Detection Front-End Units nd the Detection Electronics have also been delivered. They have been electrally coupled and performance tests are currently on-going at Astrium Toulouse.

The first flight model of the ACDM has been delivered and is currently used together with the detection chain. The two mechanisms of the instrument (flip-flop and chopper) have been delivered to Astrium and will be functionally coupled to the ACDM.

Finally, all structural and thermal hardware (Structures, Laser Control System with heat pipes, MLI) have been delivered and are being prepared for the final instrument integration.

4. INSTRUMENT INTEGRATION STEPS

The ALADIN flight model integration is performed first in three parallel steps: a) Electrical & Detection integration, b) Telescope integration and c) Receiver integration. The electrical integration is performed first without laser and then with the transmitter. The telescope integration is performed directly on the instrument main structure and the wavefront error is measured at several integration steps. The receiver integration is performed on a dedicated optical bench and its performances are tested at sub-assembly level.

The final integration step includes the laser heads and receiver alignment on the instrument as well as performance tests in air and in vacuum and environmental test campaigns. The instrument electronics are kept on a separate panel as they will be later integrated within the platform.

5. CONCLUSION

The ALADIN instrument will be the first Doppler Wind Lidar in space. This challenging programme has achieved satisfactory results with the completion of pre-development programs, completion of the flight design, completion of the OSTM model environmental tests and manufacture of the flight equipments.

The major activities that will happen in the near future are the delivery of the last flight equipments and the integration of the flight instrument The transmitter qualification will also be a major milestone for the program.

The development of this instrument will continue to be an exciting but difficult challenge that EADS Astrium and all theirs partners place significant efforts upon in order to deliver a working instrument in-orbit.

6. REFERENCES

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