International Conference on Space Optics—ICSO 2004

Toulouse, France

30 March–2 April 2004

Edited by Josiane Costeraste and Errico Armandillo

ALADIN: the first european lidar in space

Didier Morançais, Frédéric Fabre, Marc Schillinger, Jean-Claude Barthès, et al.

International Conference on Space Optics — ICSO 2004, edited by Errico Armandillo, Josiane Costeraste, Proc. of SPIE Vol. 10568, 1056802 · © 2004 ESA and CNES
CCC code: 0277-786X/17/$18 · doi: 10.1117/12.2307984

ALADIN: THE FIRST EUROPEAN LIDAR IN SPACE

Didier Morançais[(1)], Frédéric Fabre[(1)], Marc Schillinger[(1)], Jean-Claude Barthès[(1)]
Martin Endemann[(2)], Alain Culoma[(2)], Yannig Durand[(2)]

[(1)]EADS Astrium, 31 rue des cosmonautes 31402 Toulouse Cedex France, didier.morancais@astrium.eads.net
[(2)]ESA-ESTEC,Postbus 299, 2200 AG Nordwijk, The Netherlands, martin.endemann@esa.int

ABSTRACT

The Atmospheric LAser Doppler INstrument (ALADIN) is the payload of the ESA's ADM-AEOLUS mission, which aims at measuring wind profiles as required by the climatology and meteorology users. ALADIN belongs to a new class of Earth Observation payloads and will be the first European Lidar in space. The instrument comprises a diode-pumped high energy Nd:YAG laser and a direct detection receiver operating on aerosol and molecular backscatter signals in parallel. In addition to the Proto-Flight Model (PFM)., two instrument models are developed: a Pre-development Model (PDM) and an Opto-Structure-Thermal Model (OSTM). The flight instrument design and the industrial team has been finalised and the major equipment are now under development. This paper describes the instrument design and performance as well as the development and verification approach. The main results obtained during the PDM programme are also reported. The ALADIN instrument is developed under prime contractorship from EADS Astrium SAS with a consortium of thirty European companies.

1. INTRODUCTION

The European Space Agency has awarded EADS Astrium the Aeolus satellite contract which includes the development of the Atmospheric Laser Doppler Lidar Instrument (ALADIN), the sole instrument on the Aeolus mission. Designed to measure wind fields, Aladin will enhance meteorologists' understanding of climate conditions to improve weather forecasting models.
Aeolus will be placed in a Sun-synchronous orbit at an altitude of 400 kilometers, enabling it to collect information from anywhere on the planet. The ALADIN lidar (laser detection and radar) instrument will measure wind profiles showing the relative strength and direction of winds at different altitudes. ALADIN will be the first spaceborne wind Lidar offering global coverage. Measurements are averaged over 7-second periods (during which the satellite travels 50 kilometres) to obtain a wind profile every 28 seconds (or 200 km) for altitudes from 0 to 30 kilometres.

The instrument is based on the Direct Detection Doppler Wind Lidar concept, which operates in the near UV band (355 nm) and uses a large telescope (1.5 meter) made of silicon carbide for both emission and reception. ALADIN is an active instrument which fires laser pulses towards the atmosphere and measures the Doppler shift of the return signal, backscattered at different levels in the atmosphere. A high energy solid-state laser acts as the source [1]. The receiver combines a fringe-imaging channel (analysing aerosol and cloud backscatter) and a double-edge channel (analysing molecular backscatter). The two scattering mechanisms have different spectral properties and wavelength dependencies. ALADIN's receiver enhanced performance capabilities are based on technology breakthroughs in detection (accumulation CCD) and optics (sequential filters), developed and tested in R&D programs.
The launch is scheduled in 2007 for a three-year mission. This will be the first time that a Doppler Wind Lidar (DWL) be flown in space.

Figure 1: Artist's view of AEOLUS satellite

2. ALADIN DESIGN AND PERFORMANCE

ALADIN is made of two functional 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 emit/receive telescope, the laser heads, the receiver optics and detectors, and two mechanisms (laser redundancy switch and Laser Chopper). To

ensure the AEOLUS mission, 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 propagates through the same telescope. This architecture allows to limit the field-of-view, hence to ameliorate the daytime performance, and to relax the telescope and optics stability requirement. The optical isolation of receiver during laser emission is ensured by the Laser Chopper Mechanism (LCM), placed at the receiver entrance.

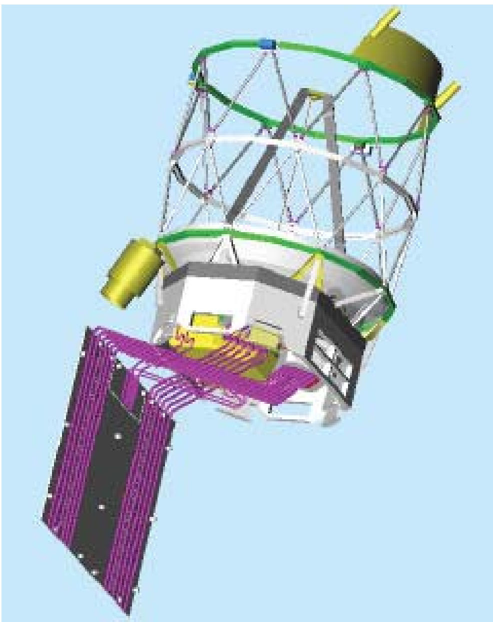

Figure 2 : ALADIN instrument Core

The telescope, developed by EADS Astrium, is a 1.5 m diameter afocal Cassegrain telescope, made of Silicon Carbide, allowing low mass (75 kg) and high stiffness to be reached. The focus is thermally adjusted by means of controlled heaters. This design prevents from implementing a refocusing mechanism.

The Transmitter is based on a Power Laser Head (PLH), seeded by a Reference Laser Head (RLH). The laser beam divergence is adjusted thanks to an aberration generator in order to fit the eye safety requirement. The PLH emits in UV (355 nm) in “burst” mode : 12 s bursts every 28 s. 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 with high thermal representativeness. Two sets of laser heads are implemented on the main structure (cold redundancy), the switching being performed by a FFM (Flip-Flop Mechanism).

The optical bench assembly is the receiver function. It features a Transmit/Receive Optics (TRO) which includes a passive diplexer, using a polarising beam splitter, relay optics with two focal points (one for the LCM, one for the field stop), and a narrow bandwidth filter to limit the Earth radiometric background. The Mie receiver is based on the fringe imaging technique : a Fizeau interferometer (MSP) coupled with an array detector. The Rayleigh receiver is based on the double edge technique with a sequential Fabry-Pérot (RSP). The spectral separation between the Mie and Rayleigh signals is performed by using the reflection on interferometers and polarisation optics. Two identical Detection Front-end Units (DFU) are used for both channels. They include optics, detector and proximity electronics. The detector is an Accumulation CCD (ACCD) optimised for UV sensitivity (thinned and back-side illuminated). The analogue accumulation process together with the ACCD die cooling allows the noise per shot to be dramatically reduced, hence allowing quasi photon-counting.

The remote Electronics include the Detection Electronic Units (DEU), the Transmitter Laser Electronics (TLE) and the ALADIN control and data management units (ACDM). The redundancy scheme 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.

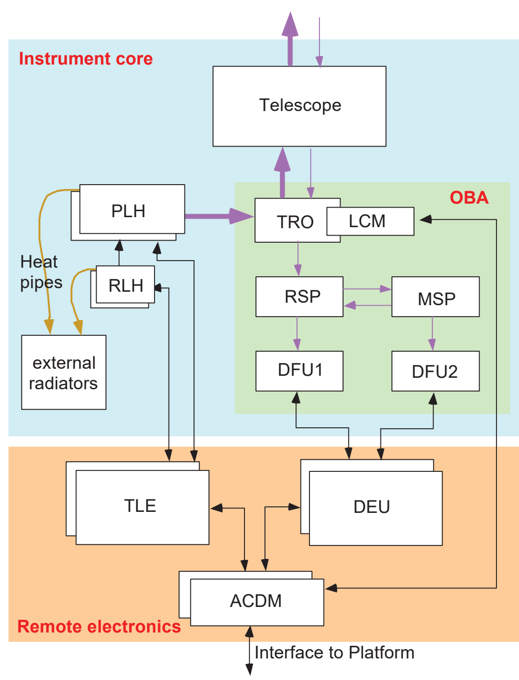

Figure 3 : ALADIN functional block diagram

The instrument main characteristics are summarised in the table below :

Parameter	***Value***
Mission parameters	
Mean altitude	408 km
Nadir angle	35 degrees
Horizontal wind velocity range	+/- 150 m/s
Vertical resolution	≥ 0.25 km
Wind measurement random error : - between 0 and 2 km altitude - between 2 and 16 km altitude	 < 1 m/s < 2 m/s
Wind unknown bias (offset)	< 0.4 m/s
Wind proportional error (slope error)	< 0.7 %
Instrument parameters	
Mass	450 kg
Power consumption	800 W
Operating wavelength	355 nm
Emitted power	150 mJ/pulse
Pulse repetition frequency	100 Hz
Telescope diameter	1.5 m
Total instrument field of view (full angle)	22 µrd
Receiver equivalent bandwidth	< 1 nm
Emitter frequency tunability	+/- 12.5 GHz
Mie interferometer frequency tunability	None
Rayleigh interferometer frequency tunability (thermal tuning)	+/- 1.1 GHz
Mie interferometer resolution	< 135 MHz
Rayleigh interferometer 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 (0.6 e-/p/shot)

Table 1 : ALADIN main characteristics

3. ALADIN DEVELOPMENT PLAN

The model philosophy aims at reducing the development risk while maintaining a short planning duration compared to previous instruments with similar complexity. Two instrument models are developed: an Optical-Structural-Thermal Model (OSTM) and a Proto-Flight Model (PFM). The OSTM allows to perform mechanical and thermal qualification of the Core Instrument and will be tested under quasi-static, sinusoidal and acoustic environment as well as thermal vacuum. A Shack-Hartman configuration is used to measure the telescope wavefront error. The OSTM is delivered to the satellite for integrated mechanical tests. The PFM is delivered in two parts, instrument core including opto-mechanics, laser, receiver, heat pipes and the remote electronics to be integrated within the satellite bus. In addition to the environmental tests, the PFM is submitted to performance tests in order to verify the wind performance. The receiver and transmitter complete optical trains (including telescope) are verified with dedicated optical ground support equipment. In particular, a device simulating a variety of wind profiles has been developed (see photo).

In order to mitigate the development risks on the critical transmitter and receiver units of ALADIN, elegant breadboards have been developed. This includes an engineering model of the Optical Bench Assembly (PDM), a Laser Test Bed (LTB) and some specific ground support equipment. In order to support the platform avionics development, an instrument electrical functional model (EfM) is developed and delivered to the Prime.

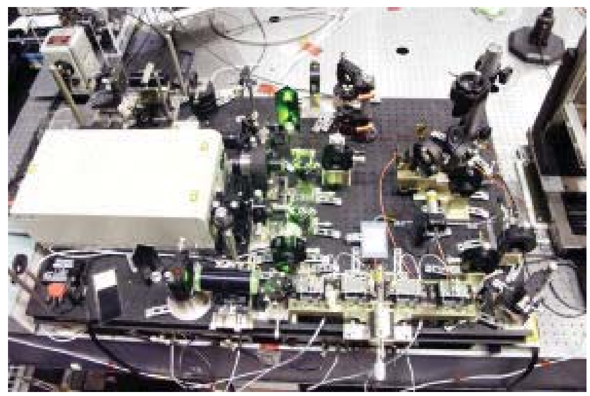

Figure 4: Wind profile simulator for instrument tests

The instrument development has started in July 2002 with the Phase B completed in July 2003. The development programme is now in Phase C/D for a delivery planned in autumn 2006.

4. ALADIN PRE-DEVELOPMENT RESULTS

In order to reduce the development risk of the flight model, it has been decided to undertake a Pre Development Model (PDM) [2].

This PDM program aims at validating all critical technologies relevant to the receiver with the development of EM units. It also validates the delta processes or materials as needed. A sketch of the receiver configuration is shown in figure 5.

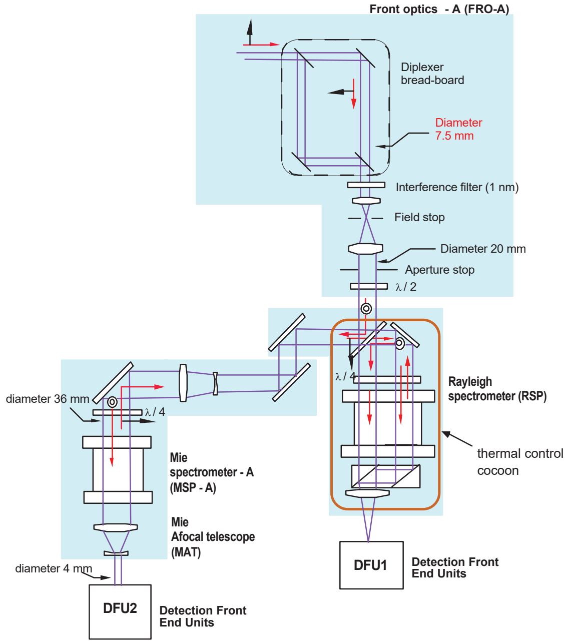

Figure 5 : PDM principle sketch.

The beam is spatially filtered by a field stop at the level of a second intermediate focus. The beam diameter is increased to 20 mm at this level, thus reducing its divergence to be compatible with the Rayleigh Fabry-Perot etalon required performance. A narrow band filter, 1 nm FWHM, limits the earth and atmospheric background to an acceptable level. The linearly polarized beam is then directed by a polarizing beam splitter to the Mie spectrometer, where part of the Mie signal is transmitted to the corresponding detector. At the Fizeau etalon level, the beam diameter is again increased to 36 mm by a dedicated beam expander to further reduce the beam divergence and thus achieve the required fringe finesse. Fringe imaging is achieved by a telecentric 2 lens afocal arrangement, insensitive to focus variations (not shown in the figure). The other part of the signal is reflected back to the polarizing beam-splitter. A quarter-wave plate located between the polariser and the spectrometer allows the polarization vector of the reflected beam to be turned by 90°. Thus, the beam can now be directed to the Rayleigh double edge spectrometer and the corresponding detector. At spectrometer level, a similar polarizing beam-splitter/ quarter-wave plate arrangement (patented) allows the 2 sides of the Rayleigh signal to be fully transmitted without loss to the corresponding part of the detector. Focusing of the beam is achieved by a beam combiner based again on polarization beam splitter / λ/4 plate arrangement and a single lens.

The PDM underwent a comprehensive test campaign : thermal vacuum and mechanical tests. The thermal vacuum (TV) was dedicated to performance measurements in terms of spectral and thermo-elastic stability and also to validate the thermal regulation. Performance tests were carried out in the operational temperature range (20 to 25 °C) , as well as non operational temperature range (-15°C to + 50 °C).

The thermal regulation performances were perfectly in line with the Flight model need; in steady state stabilities of a few mK at spectrometer level were achieved. The extensive testing of the PDM showed that the major performance drivers were in line with the Flight model needs : receiver stability of a fractions of a MHz were measured. Concerning the detection chain performance, photon noise limited performances were demonstrated with a quantum efficiency exceeding 85 %.

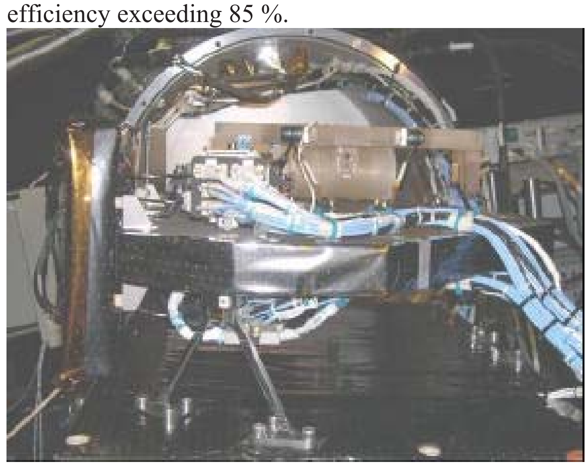

Figure 6 : Optical bench assembly in front of vacuum chamber.

The aim of mechanical tests was to verify the PDM mechanical behaviour in terms of strength and stability against qualification loads (25 g for quasi static and 5g rms for random loads). The units sustained these loads without failure. The main goal of this test was to qualify the optical contacting mechanical strength , this technique being used to guaranty a high stability assembly for both Rayleigh and Mie spectrometers. Indeed both spectrometers have passed these tests without integrity degradation, demonstrating the proper sizing of the optical contacting and isostatic mounts. Figure 6 shows the Mie spectrometer fixed on the optical bench during the vibration tests. Moreover it is now demonstrated that the high stability of the receiver equipments is in line with the Flight model needs.

The PDM is designed and manufactured to engineering models standards. The whole receiver was tested successfully against thermal vacuum and mechanical environments. The results are compatible with the FM specifications. It is a major step for securing the flight model units development.

Figure 7: Optical Bench Assembly during mechanical tests.

5. CONCLUSION on ESA's AEOLUS instrument

The ALADIN instrument will be the first European Lidar and the first Doppler Wind Lidar in space. This challenging programme has progressed well with satisfactory results from the pre-development programs, consolidation of the flight design, selection of the complete industrial consortium and start of the flight equipment development.

The major activities that will happen in the near future are the development and tests of the OSTM as well as the development of the flight equipment. The transmitter qualification, planned in early 2005, will be a major milestone for the program.

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

6. REFERENCES

1. Cosentino A., et al., High energy, single frequency, tunable laser source operating in burst mode for space-based lidar applications, *these proceedings.*

2. ALADIN: the LIDAR instrument for the Aeolus mission., Schillinger, M.; et. al. Conference: Sensors, Systems, and Next-Generation Satellites VI., *Proceedings of the SPIE - The International Society for Optical Engineering (2003) vol.4881, p.40-51.*