ESA's ADM-AEOLUS Wind Lidar Mission – Status and Development

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Abstract: The European Space Agency (ESA) is developing a direct detection Doppler Wind Lidar for measuring wind profiles from space. The pulsed UV Lidar instrument, ALADIN, will deliver horizontally projected single line-of-sight wind profiles from its molecular and particle channels. The development of the ADM-Aeolus mission has reached a major milestone with the integration of the full instrument and its functional and performance tests in April 2016. A 6-month life test of the spare UV laser transmitter is being performed with all relevant performance parameters adequate and stable at present (more than half of the required test duration). Launch readiness is expected in 4th quarter of 2017.

Keywords: Direct Detection, Doppler wind lidar, UV, high spectral resolution, line-of-sight wind profiles, backscatter and extinction profiles

1. Introduction

The primary objectives of ADM-Aeolus [1] is to provide global observations of line-of-sight wind profiles in clear air and particle rich air (aerosol layers and transparent clouds) down to the ground or top of optically dense clouds, for the improvement of Numerical Weather Predictions (NWP) and climate model parameterization. Aeolus observational data will be delivered in near-real time (NRT, e.g. within 3 hours) and quasi-real time for regions close to the data downlink station (QRT, e.g. within 30 minutes) for direct processing and ingestion into operational numerical weather prediction (NWP) models. From observation impact experiments, it was demonstrated that both the accuracy and spatial distribution of the wind observations are critical for the improvement of weather forecasts, whereas the provision of a single horizontal wind component instead of full vector information was of lower criticality. Therefore, a single viewing geometry had been adopted, avoiding the need for a complex scanning mechanism. A subset of the Aeolus observation requirements described in [2] are listed in Table 1.

Table 1. Subset of the Aeolus Observational Requirements

Requirements	Planetary Boundary Layer	Troposphere	Stratosphere
Vertical domain	0 - 2 km	2 - 16 km	16 - 20 km
Vertical resolution	0.5 km	1 km	2 km
Coverage	Global		
Horizontal accumulation length	3 km (20 pulses)		
Horizontal integration length	< 100 km		
Random error	1 m/s	2.5 m/s	3 m/s
Systematic error	0.7 m/s		
Observational dataset length	3 years		

2. Space Segment and Payload

The Aeolus spacecraft will fly in a sun-synchronous dusk-dawn polar orbit, with a 6 pm local ascending node crossing time, an inclination of approximately 97º, and a mean orbital height of approximately 400 km. A lower altitude of 320 km is being considered to benefit from the low solar activity during the mission lifetime. During nominal operation, the spacecraft will be tilted by 35º with respect to the orbit plane, while the instrument will view the atmosphere in the cross-track, anti-sun direction, as illustrated in Figure 1. A quasi-global coverage is achieved daily (with around 16 orbits) and the repeat cycle is 7 days (109 orbits). The satellite will also be periodically oriented to nadir for calibration purposes.

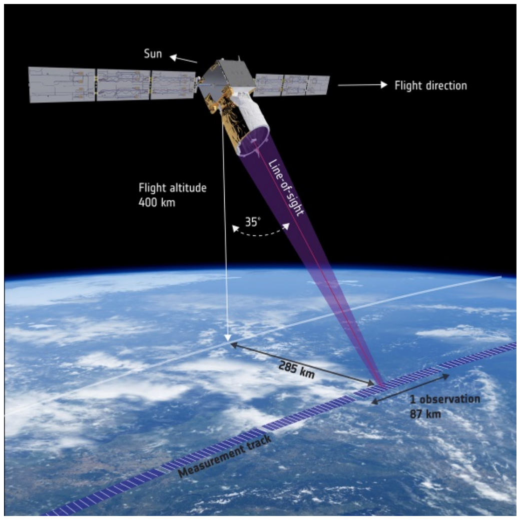

Figure 1. Aeolus orbit, pointing and sampling characteristics

Aeolus will embark a single payload, the ALADIN high spectral resolution Doppler wind lidar, which comprises a laser transmitter, a 1.5 m diameter Cassegrain afocal telescope, an optical bench assembly and the instrument control electronics. The laser transmitter is based on a diode-pumped, frequency tripled Nd:YAG laser, comprising two seeding Reference Laser Heads (RLH) and two Power Laser Heads (PLH) in cold redundancy. Each laser head can be switched to the transmit path by means of a flip-flop mechanism. A chopper mechanism is used to isolate the receiver input from the transmit path during pulse emission. The laser transmitter will be operated at e pulse repetition frequency of 50 Hz and a nominal laser output pulse energy of 80 mJ. The telescope, used in a monostatic configuration, is based on all silicon carbide structure (primary, secondary mirrors and tripod legs) resulting in a low mass (75 kg) and high overall stiffness. Its thermal re-focusing capability will allow adjustment of the focal spot while maintaining the overall telescope wavefront error within 350 nm. The transmit/receive optics use a passive diplexer/polarizer to separate emitted and received signals, and a narrowband interference filter for rejecting the broadband background signal.

The backscattered signal is analyzed in two separate spectrometers, allowing independent recording of the aerosol (Mie) and molecular (Rayleigh) components. The Mie receiver, based on the fringe imaging technique, uses a Fizeau interferometer, whereas the Rayleigh receiver, based on the double edge technique, uses two Fabry-Perot interferometers, implemented sequentially for an improved optical efficiency. Both receivers are equipped with identical detection units (e.g. accumulation charge-coupled devices ACCD of 16x16 pixels), providing on-chip accumulation over a configurable number of laser pulses. With typically 20 accumulations per readout, 35 independent signal acquisitions will be needed in order to form observations that can provide the wind velocity profiles with the required random error. The vertical sampling will be controlled by a programmable range gating that can be set individually for both receivers. In total, 24 Mie and 24 Rayleigh samples will be available. With a range bin resolution between 250 m and 2 km, backscattered signals will be acquired in both channels, covering typically in overall height interval between 0 and 30 km. The instrument control electronics comprise the Detection Electronics Units (controlling the ACCD readout and post-processing), the Transmitter Laser Electronics and the ALADIN Control and Data Management Unit which will provide the overall synchronization of laser emitter and detection chain as well as all data exchange between the instrument and the platform.

3. Ground Segment and Data Products

The Aeolus Ground Segment will perform all tasks related to the commanding and monitoring of the spacecraft, as well as the acquisition, processing and dissemination of science data. Its two main components are the Flight Operations Segment (FOS) and the Payload Data Ground Segment (PDGS).

The FOS will include the S-band station located in Kiruna (Sweden), for spacecraft tracking, telemetry reception and commanding tasks, as well as the Flight Operations Control Centre (FOCC) located at ESA/ESOC in Darmstadt (Germany), in charge of spacecraft monitoring, telemetry acquisition, flight dynamics analysis and telecommand data uplink to the spacecraft throughout the mission. The PDGS will be in charge of the science data reception via X-band and of various processing, archiving and product dissemination tasks. It will include the X-band acquisition station located in Svalbard (Norway), the Aeolus Processing Facility (APF) located in Tromso (Norway) for the processing and dissemination of the Level 1B and Level 2A products, and the Level 2 Processing Facility (L2/Met PF) hosted by the European Centre for Medium Range Weather Forecast (ECMWF) in Reading (UK).

The primary data product of the mission will be the Level 1B data set, comprising calibrated wind velocity observations for both Mie and Rayleigh channels, with various additional annotation parameters. The observation horizontal integration length is approximately 90 km, with less than 1% data gap between successive observations. The different values provided in Table 1 correspond to the horizontal integration length that needs to be considered in order to meet the wind velocity random error requirement. The Level 1B products will be globally delivered to a number of meteorological service centres within 3 hours after sensing (NRT service) and for selected regions within 30 minutes after sensing (QRT service).

Higher level products will include information on clouds and aerosols optical properties (Level 2A), as well as consolidated horizontal line-of-sight wind observations (Level 2B), after temperature/pressure corrections and scene classification of the measurements within one observation. The assimilation of Level 2B data in the ECMWF operational forecast model will provide the so-called Aeolus assisted wind products (Level 2C). A further detailed description of Aeolus wind retrievals and data delivery can be found in Tan et al. 2008 [3]. For the Level 2A processing and products, a detailed description is given in Flamant et al. 2008 [4]. A summary overview of all products is given in Table 2.

Table 2. Aeolus Data products

Product	Contents	Typical size per orbit
Level 1B	Engineering calibrated wind velocity data (preliminary one component wind observations), including viewing geometry, scene geolocation and ground echo data	~87.5 Mbytes
Level 2A	Supplementary data product for cloud and aerosol optical properties (layer backscatter and extinction coefficient, backscatter-to-extinction ratio,…), including viewing geometry, scene geolocation data and error quantifiers	~20 Mbytes
Level 2B	Consolidated geolocated wind observations after atmospheric corrections and scene classification, including additional geophysical parameters and error quantifiers	~42 Mbytes
Level 2C	Aeolus assisted wind data, result of NWP assimilation processing, including vertical wind vector profiles (u & v components) and supplementary geophysical parameters	~46 Mbytes

4. Recent achievements and future prospects

During the Aeolus development phase, a number of technical challenges for the Aeolus system have appeared and have been tackled. These include laser diode performance, optical mounting stability, laser induced damage on the IR and UV coatings, laser-induced contamination (LIC) in vacuum, and long-term UV energy drift. To mitigate these risks, the laser housing is maintained at a low pressure of 0.6 mbar.

The two flight laser transmitters have been delivered, after successful qualification including mechanical, thermal vacuum, EMC test and burn-in during 4 weeks (> 100 Mshots). The third (spare) laser is undergoing a long-duration endure test of 6 months (780 Mshots). Up to 13 June, the laser has run for 135 days, corresponding to 587 Mshots. The degradation measured by the laser UV photodiode is lower than 4 %. A higher degradation is observed in the external elements of the test equipment because of LIC effects in the vacuum chamber.

The two lasers have been integrated in the instrument and full-instrument tests have been performed in ambient conditions. In particular, a dedicated optical test equipment was developed to characterize the outgoing laser beam and generate synthetic atmospheric echoes which can be modulated in shape, amplitude and frequency. Detailed correlation of test results with predicted performance is being analysed. Initial results show that random errors extrapolated from test are within 5% of expectations for the Mie and Rayleigh channels. The response slopes in both channels have been verified. A short endurance test on the emission path of the instrument showed good stability.

The next steps will be the delivery of the instrument to the satellite prime contractor. The integrated spacecraft will be transported to test facilities end of 2016. Mechanical and thermal vacuum tests are planned for first half 2017. In particular, mechanical tests will cover sine, acoustic and shocks tests. Later thermal vacuum test, including full performance in vacuum. Flight readiness is expected in 4th quarter 2017.

5. Summary

The development of the Aeolus mission is getting close to completion after about 15 years of development challenges, during which invaluable experience has been gained. The ambitious mission and instrument concept led to a difficult development requiring time-consuming iterations in critical elements, particularly the laser. This careful step-by-step development recently culminated in the integration of the instrument and the testing of its performance in ambient conditions. The instrument will soon be integrated on the satellite and all satellite-level testing, including instrument in thermal vacuum, will be performed during the 1st half of 2017, to be ready for a launch in the 4th quarter of 2017.

The development took much more time than initially anticipated, but the mission remains unique and eagerly expected by user communities anticipating break-through in weather forecast and climate research.

6. References

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