DEVELOPMENT OF AN AIRBORNE DEMONSTRATOR FOR ADM-AEOLUS AND CAMPAIGN ACTIVITIES

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ABSTRACT

The Atmospheric Dynamics Mission ADM-Aeolus of the European Space Agency ESA will be the first lidar mission to sense the global wind field from space. It is based on an incoherent Doppler lidar operating at 355 nm with a two-interferometer receiver for aerosol and molecular return. The launch is planned for October 2007 and the nominal operation time is 3 years. An airborne instrument demonstrator is under development for ground and airborne campaigns envisaged in the years 2005 and 2006. An overview of the ADM, the campaign objectives, and the results of the development of the airborne demonstrator are shown.

1. INTRODUCTION

The determination of the atmospheric flow at different heights is a basic requirement in meteorology, both scientifically for the documentation and understanding of dynamic structures, and operationally as initial state for numerical weather prediction. The current observing system lacks the global coverage of wind profiles. Spaceborne Doppler lidars offer the unique potential to sense the clear-air and partially cloudy atmosphere. Hence a significant improvement of numerical weather prediction from a satellite Doppler lidar is expected [1,2].

2. THE ATMOSPHERIC DYNAMICS MISSION

In 1999 the European Space Agency ESA decided to establish a Doppler lidar wind mission named Atmospheric Dynamics Mission ADM-Aeolus [3]. The mission provides profiles of one component of the horizontal wind vector from ground up to the stratosphere with 0.5-2 km vertical resolution and accuracy for the component of the horizontal wind of 1-2 ms^{-1} depending on altitude. A wind profile will be obtained every 200 km with a horizontal averaging length of 50 km. Currently the mission is in Phase C and the launch is foreseen for October 2007.

The ADM instrument ALADIN (Atmospheric Lidar Doppler Instrument) is based on an incoherent Doppler lidar operating at 355 nm. The receiver consists of two interferometers, which sense the Doppler shift from aerosol as well as from molecular return, yielding profiles of the line-of-sight LOS wind speed throughout the whole troposphere and part of the stratosphere. The molecular channel uses the double-edge technique with a sequential Fabry-Perot interferometer, whereas the aerosol channel is based on a Fizeau interferometer [4].

3. CAMPAIGNS

Several ground campaigns have been performed in the past to validate the incoherent Doppler Lidar technology through comparisons of wind measurements from rawinsondes with direct detection lidars based on double edge technique at 355 nm [5,6]. Extensive comparisons of wind measurements from direct detection Doppler lidars with coherent Doppler lidars and other sensors were made in Europe [7] and USA [8]. Up to now no direct detection Doppler lidar was operated onboard an aircraft, whereas airborne validations of coherent Doppler lidars were performed during the last years [9,10].

The instrument concept of ALADIN combines new techniques, like a novel combination of the molecular and aerosol receiver, and the use of an accumulation CCD to improve detection sensitivity. There is a need to validate these features from ground and from aircraft, which is the more comparable to the downward looking geometry from space. Ground and airborne campaigns are foreseen with an ALADIN type instrument - the ALADIN Airborne Demonstrator A2D. The objectives are to validate the predicted instrument performance and to obtain a dataset of atmospheric measurements, which will be used before launch to test and validate the algorithms and quality control scheme for the on-ground data processor development. The ground campaign is planned for spring 2005 at the meteorological observatory of the German Weather Service DWD in Lindenberg close to Berlin, Germany. The main reference instruments for comparison will be the 2µm Doppler lidar from DLR [11,12] and the 482 MHz windprofiler from DWD [13]. Airborne campaigns with the 2µm Doppler lidar and the A2D onboard the DLR Falcon aircraft are envisaged for end 2005 and 2006. The A2D and the 2µm Doppler lidar will be deployed above 2 aircraft fuselage windows, which are separated by only 0.5 m. Both systems will look downward with an angle of 20° nadir, and perpendicular to the aircraft flight direction to minimize the contribution of the aircraft ground speed to the Doppler shift. The same atmospheric volume will be sampled with this unique instrumental setup by a coherent detection lidar sensitive to aerosol backscatter and an incoherent detection lidar sensitive to aerosol and molecular backscatter.

4. ALADIN AIRBORNE DEMONSTRATOR

The ALADIN Airborne Demonstrator A2D is currently under development at EADS-Astrium, France, EADS-Astrium, Germany, and DLR, Germany. A pre-design study was finished in January 2004, the design and manufacturing phase started recently and will be finished by begin 2005. The main component of the A2D is the receiver breadboard developed within the ESA pre-development program. The optical and mechanical design of this breadboard will be very similar to the satellite instrument, except for some changes in the front optics of the receiver. An electro-optical modulator has been introduced to attenuate the near field signal next to the aircraft. The dynamical range and altitude dependence of the signal differs strongly from the satellite operating from 408 km compared to the aircraft with a flight level of 10 km. Tab. 1 summarises the main instrument specifications of the airborne demonstrator compared to the satellite instrument.

The receiver unit will compromise a Fizeau interferometer for detection of the aerosol signal and a sequential, double-edge Fabry-Perot interferometer for the molecular signal (Fig. 1). An accumulation CCD with quantum efficiency of 85 % will be used, which allows the on-chip accumulation of the return signal from several laser pulses. The signal from the telescope will be transmitted through a spectral interference filter to attenuate solar background and then directed via a polarizing beam splitter to the Fizeau interferometer. The reflected signal from the Fizeau will be passed to one channel of the double edge Fabry Perot. Then the reflected signal from the first channel of the Fabry-Perot will be transmitted through the second Fabry Perot channel.

The transmitter unit, which is developed by EADS-Astrium, Germany, consists of a frequency-tripled, diode-pumped, pulsed Nd:YAG laser with an output energy of 70 mJ at 355 nm. The oscillator stage of the laser will use injection seeding from a reference laser head signal to achieve a frequency stability of better than 4 MHz (rms) at 355 nm. In addition the laser transmitter must be tunable in frequency over a large spectral range of ±5 GHz to calibrate the spectral response of the two interferometers.

The receiver unit will be integrated on top of an aircraft frame, and will be covered by a temperature controlled half dome (Fig. 2). The laser transmitter will be mounted within the same aircraft frame. Shock mounts for vibration damping connect the aircraft frame to the aircraft seat rails. The electronic devices will be integrated in 3 separate aircraft racks.

Tab. 1: System specifications of satellite and airborne versions of ALADIN instrument.

	satellite	**airborne**
transmitter	Nd:YAG, tripled, diode-pumped	
wavelength	355 nm	
operation	burst-mode	continuous
repetition rate	100 Hz	50 Hz
energy / pulse	150 mJ	70 mJ
laser linewidth	< 50 MHz (FWHM)	
freq. stability	4 MHz rms over 7s	
telescope ∅	1.5 m	0.2 m
receiver FOV	15 µrad	100 µrad
receiver aerosol	fringe imaging Fizeau interferometer, 16 channels	
receiver molecules	double edge Fabry-Perot, 2 channels, sequential	
detection	accumulation CCD, quantum efficiency 0.85	
nadir angle	35°	20°
altitude	408 km	10 km
min. vertical resolution	250 m	300 m
platform speed	7600 ms^{-1}	200 ms^{-1}

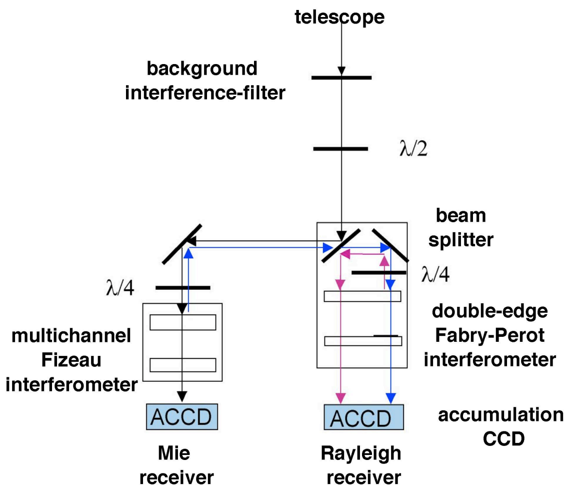

Fig. 1: Principle of the ALADIN two-interferometer receiver.

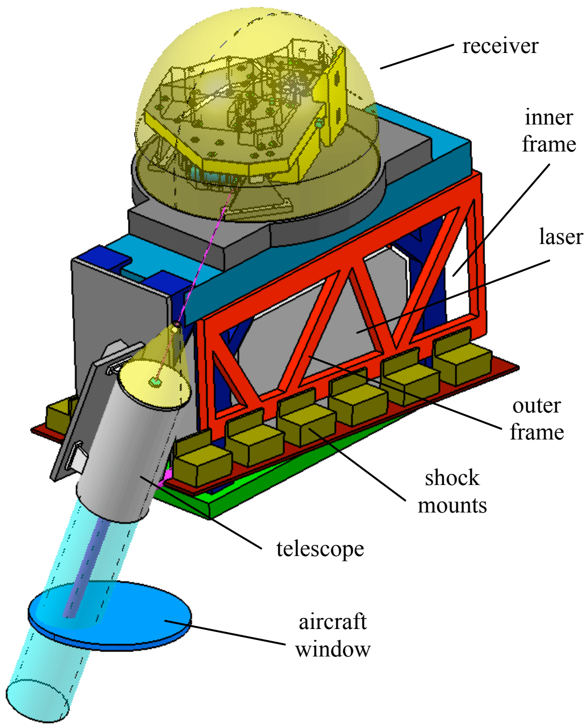

Fig. 2 ALADIN Airborne Demonstrator A2D main unit (courtesy of EADS-Astrium)

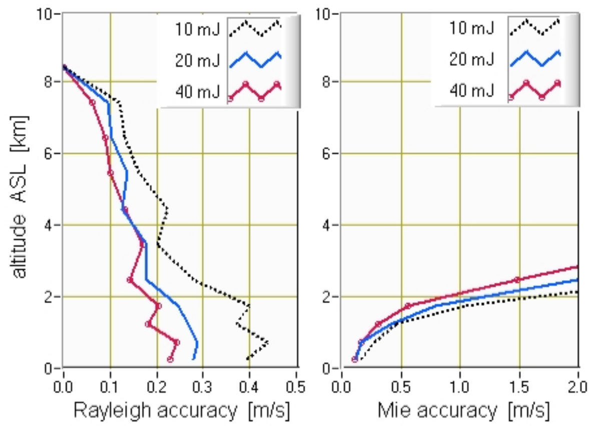

Fig. 3. Performance simulations for the LOS wind speed accuracy from the airborne A2D Rayleigh channel depending on laser energy (10, 20, 40 mJ); telescope diameter 20 cm, 200 averaged shots, aircraft flight level 10 km, nadir angle 20°, reference atmosphere model without clouds.

The end-to-end simulator developed for the satellite instrument during previous studies [14,15] has been adopted for the airborne demonstrator. The simulator is based on a Monte-Carlo simulation for the propagation of every single photon throughout the atmosphere, with different spectral response of aerosols and molecules. The transmission of the photons through the Fizeau and Fabry-Perot interferometers, as well as the noise characteristic of the CCD is simulated. The end-to-end simulator can use standard profiles for atmospheric parameters (backscatter, temperature, pressure, extinction, clouds) or use data from a atmospheric numerical model as input (e.g. Local Model of the German Weather Service), which allows to include temporal or horizontal inhomogeneities of the atmosphere. The atmospheric input parameters to the simulation are derived on a vertical resolution of 15 m, which is much smaller than the vertical resolution of the airborne instrument (300 m at 20° nadir angle). Thus the influence of atmospheric inhomogeneities within one range gate can be simulated.

Simulations have been performed to assess the influence of different instrument parameters and atmospheric conditions on the accuracy (Fig. 3). The accuracy of LOS wind speed derived from the Rayleigh receiver is better than 0.5 m/s even for laser energy of 10 mJ. The accuracy of the Mie receiver is better than 1 m/s below 2 km within the atmospheric boundary layer. In case of high-level clouds the accuracy of the Mie receiver is in the same order (not shown).

5. CONCLUSION

EADS-Astrium and DLR are developing an airborne demonstrator A2D for the first space-borne wind lidar ALADIN of ESA´s ADM-Aeolus mission. The instrument is based on a Doppler Lidar operating at 355 nm with an aerosol and molecular sensitive receiver, which is similar to the satellite instrument. The A2D development will be finished at the begin of 2005, and a first ground based campaign at the site of the Meteorological Observatory Lindenberg, Germany, is planned for spring 2005. An aircraft deployment together with a coherent 2µm Doppler lidar on the DLR Falcon aircraft is foreseen for early 2006.

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