PROGRESS WITH ADM-AEOLUS, THE SPACEBORNE DOPPLER WIND LIDAR

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ABSTRACT

The Atmospheric Dynamics Mission ADM-Aeolus, usually called Aeolus, will make the first ever global wind profile measurements. The Satellite, to be launched in 2008, carries a direct detection lidar operating at 355 nm. The instrument, ALADIN, is a monostatic lidar, with a frequency tripled Nd: YAG laser as transmitter and CCD detectors.

The mechanical and thermal qualification of the satellite, including instrument is complete. The flight model structures and mirrors have been delivered. Deliveries of flight electronics are on-going.

The Engineering Qualification Model of the laser is under test. The component test programme for Laser Induced Damage in vacuum is substantially complete. Work continues to satisfactorily understand issues associated with contamination from the very small quantities of organic materials located close to the high energy laser beams.

A number of studies have been completed by user groups demonstrating the expected utility of the data from the satellite. Work is underway to prepare for the assimilation of the wind data into Numeric Weather Prediction models.

1. MISSIONS AND PERFORMANCES

"The primary aim of the *Atmospheric Dynamics Mission (ADM-Aeolus)* of the European Space Agency is to provide global observations of vertical wind profiles. Presently, knowledge of the 3D wind fields over large parts of the Tropics and major oceans is quite incomplete. This leads to major difficulties both in studying key processes in the coupled climate system and in further improving the numerical forecast systems. Progress in climate modeling is intimately linked to progress in numerical weather prediction (NWP). The wind profile measurements provided by ADM-Aeolus are expected to demonstrate improvements in such atmospheric modeling and analysis.

These advances will, in turn, enhance the long-term databases being created by NWP data assimilation system to serve the climate research community. As such, ADM-Aeolus promises to also provide data that are needed to address some of the key concerns of climate research, including climate variability, validation and improvement of climate models, and process studies that are relevant to climate change." [1]

Numerical Weather Prediction (NWP) models assimilate wind averages over a resolution grid. Measurements with higher spatial resolution than the grid size lead in general to data representativity errors. For global NWP models in the next few years, a grid size of about 50 km is expected. Aeolus will average measurements in the flight direction over 50 km, some spatial representativity error for the cross dimension remains.

Fig. 1. Artist Impression of Aeolus in-orbit

NWP models have a correlation radius of about 200 km; if information with higher resolution is fed into the model along a single track, instabilities in the cross direction can occur. It was therefore decided to measure average winds over 50 km with a spacing of 200 km. This results in a burst measurement cycle, where the lidar operates over 50 km stretches and then is switched off for the next 150 km. With the average orbital velocity of 7.2 km/s, the lidar measures for 7s during a 28s burst cycle.

The Satellite measures wind velocity along the line of sight of the instrument telescope. Doppler shifts of backscattered light due both to Rayleigh scattering from molecules in the upper atmosphere, and Mie scattering from aerosols at lower altitudes are measured by the instrument. The measurement accuracy is about 2 m/s throughout the Troposphere and lower Stratosphere. Measurements up to 30 km are possible.

The Satellite will be in a sun-synchronous dawn/dusk 400 km orbit. This type of orbit provides adequate solar energy and a benign thermal environment. Wind measurements with full accuracy are possible on both the illuminated and dark sides of the orbit.

2. DEVELOPMENT PROGRAME

The Aeolus Satellite and instrument are being designed and manufactured by EADS Astrium. The laser is designed and manufactured by Selex (ex Galileo Avionica).

The design of the instrument and spacecraft were outlined at the ILRC in 2004 [2].

As is usual with Spacecraft programmes the development of Aeolus has made use of a number of development models, each of which has a progressively higher degree of fidelity to the final flight article. The main development models are as follows:

2.1 Receivers

Representative Pre-Development Models of the Mie and Rayleigh receivers demonstrated the required performance in vacuum as well as their ability to withstand launch environments. This work was completed in late 2003.

2.2 Laser Pump Diodes

Pump Diodes from Thales Laser Diodes (now Nuvonyx-Europe) have been selected for flight. Preliminary testing on typical diodes demonstrated that some could achieve the 3.5×10^9 shots expected for flight, and that their performance was unaffected by vacuum. The full set of flight diodes, procured to a stringent screening specification, has now been delivered. Part of the delivered lot will be subject to lifetime testing under precisely the optical and electrical conditions of flight.

2.3 Laser

A Laser Test Bed demonstrated the functional performance of the optical and electrical design of the laser, although with a mechanical layout not subject to flight constraints. This work was complete in early 2004.

An Engineering Qualification Model of the laser has been built. This is representative of the optical, electrical and mechanical design of the flight article.

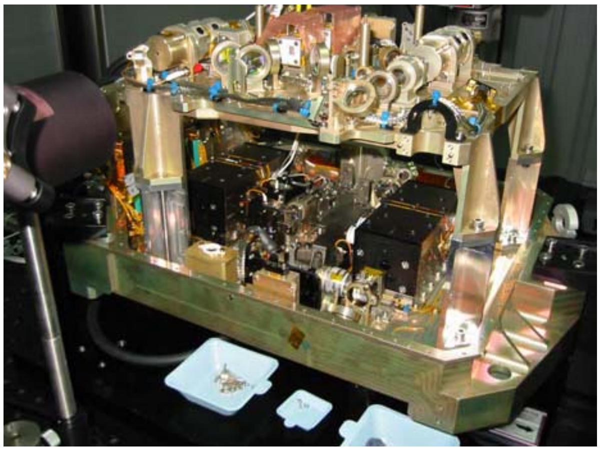


Fig. 2. Engineering Qualification Model of Power Laser Head (Upper optical bench mounted on temporary stand-offs)

The laser generates 120 mJ per pulse of output power at 355 nm from 420 mJ of Infra Red at 1064 nm. This has been packaged in an enclosure about 50 x 35 x 20 cm weighing 30 kg. The EQM is working well and stably in air. At the time of writing it is about to be subject to vibration and vacuum testing.

2.4 Instrument

The instrument includes a 1.5 meter telescope based on silicon carbide mirrors, an equipment bay, containing the essential electronics as well on lasers and detectors, and support mechanical and thermal hardware. An Optical/Structural/Thermal (OSTM) model of this has been built and tested. This has shown that the thermal control of the instrument is appropriate and that the telescope focus is unaffected by the thermal condition of orbit.

The Flight Model Instrument Structure is presently being integrated with the Flight Model mirrors. Instrument electronic units are arriving for integration.

2.5 Platform

The spacecraft platform is a new design for Aeolus. Although some pointing requirements are quite stringent the design is conventional. It has an aluminum honeycomb structure, hydrazine propulsion system and triple junction Gallium Arsenide solar array.

The Flight Model Structure was built into a Structural Model Satellite with the addition of the OSTM instrument and some dummy units. This model has successfully survived Acoustic, Shock and Sinus vibration testing to simulate mechanical environment of launch.

Fig.3. Structural Model Satellite being prepared for vibration testing

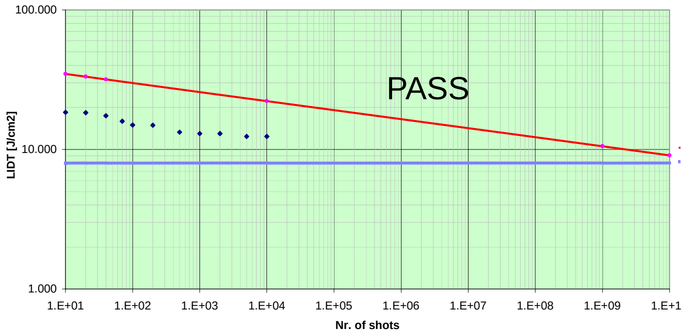
The platform structure has been refurbished for flight and is now integrated with the flight propulsion system. Installation of flight electronics units will begin shortly.

3. LASER INDUCED DAMAGE

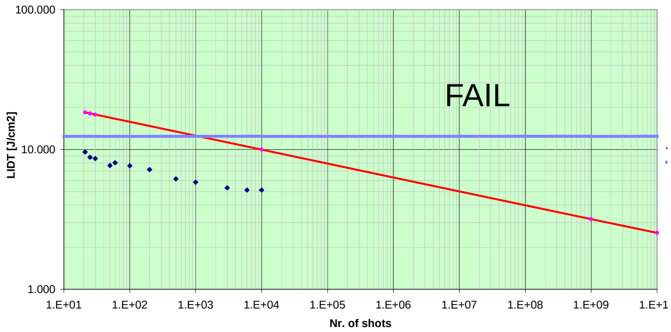
An extensive programme of test for Laser Induced Damage is nearing completion. Flight lots of all relevant coatings and components, including YAG slabs and LBO tripler crystals have been subject to S-on-1 testing [3], in vacuum, at various numbers of pulses up to 1 million. In all cases the characteristic damage curve shows a typical decay, although the decay rate and curvature very widely between test samples. The worst case decay as predicted by theory follows a power law of the form:

$$D_n = D_o \, . \, n^{-\alpha}$$

where D_n is the laser damage threshold at n shots, D_o is the single shot damage threshold, and α is the decay coefficient. This power law has been used to approximate the decay of the tested optics over the lifetime of the laser. Plotting the results of the S-on-1 tests on a log/log scale, the power law results in a straight line. This log/log curve has been extrapolated linearly (in the log/log domain) to predict the damage threshold at end of life. The linear extrapolation gives a pessimistic conclusion. Use of this technique has allowed rejection of a number of unsuitable coatings and components.



Element #10(W01) (waveplate)



Element #14(W01) (piezo mirror)

Fig.4. Typical LIDT curves. Blue line is pass criteria. Red line is scaled extrapolated lifetime.

A number of scaling laws used in the test methodology have been demonstrated. Tests are on-going using a 1 Khz laser to prove that extrapolation to several billion pulses is valid.

4. CONTAMINATION

The instrument and laser have been designed to operate in vacuum. A outline design does exist, however, to allow the laser to be pressurized if necessary.

The laser will be purged on-ground via a baffled purge pipe. Materials selection inside the laser, and in the instrument close to high power UV fields has been stringent to avoid known outgassing offenders. Further from the instrument the materials have been selected according to normal European practice for optical spacecraft.

Despite careful selection and sparing use some problem materials remain, at present, in the laser. The most significant of these is probably soluthane used in very small quantities to lock screw threads against launch vibrations.

An extensive laboratory test campaign is underway to ensure, before flight, that effects due to contamination are acceptable. It is possible that this campaign may lead to some design changes.

5. PREPARATIONS FOR DATA USE

All Aeolus measurements will reach meteorological processing centers within three hours from sensing. In sensitive regions, in particular over the North Atlantic this will be achieved within 30 minutes. Data will be downlinked to a primary ground station at Svalbard, Spitzbergen, located at 78°13 N, which has a line of sight to almost every orbit. Additional ground stations may be used to receive data provided the antenna is at least 2.4 m in diameter.

Aeolus has been designed to explore the path to operational use. It has a very low cost of operations. The orbit repeats with a seven day repeat cycle and commanding is only necessary once per week. The satellite is designed to survive for at least five days even in one failure situations, so manning requirements in the control centre are minimal.

In order to test the benefit of Aeolus for Numerical Weather Prediction, ensembles of data assimilations have been used to assess separately the impact of conventional radiosonde observations and of ADM-Aeolus observations[4]. It has been demonstrated that the new observation technique will provide observations of comparable benefit to the existing radiosonde and wind-profiler network. It was also shown that the impact is highest over oceans and in the tropics.

An independent study focusing on the tropics supported the conclusions regarding the tropics[5]. It was found that wind fields provide valuable complementary information to mass fields to describe a tropical atmosphere for NWP purposes.

A more recent study by Stoffelen et al. looked into the added value of Aeolus data in numerical weather prediction (NWP) to enhance the predictive skill of high-impact weather systems. For this purpose, the presently envisaged data properties as well as modified properties of possible later versions of Aeolus were used. Different scenarios including those of multiple satellites for potential follow-on missions were investigated.

The most important conclusions were:

(a) There is benefit if Aeolus observations are used
(b) The performance of two Aeolus satellites with the same line of sight is on average superior to a single dual perspective satellite.

These results were verified with 48 hour forecasts and will be published soon.

Arrangements are in place with the European Centre for Medium Range Weather Forecasting, who will assimilate Aeolus data and produce wind products. ECMWF is also producing software for other meteorological services to produce wind products for themselves using their own temperature and pressure fields. Finally and very importantly ECMWF will measure the impact of the availability of Aeolus data on their weather predictions.

6. OUTLOOK

The various qualification programmes will be summarized in a Qualification Review to be held in the Spring of 2007. Launch of the Satellite is expected in September 2008. A three month in-orbit commissioning phase will be followed by a three year nominal lifetime.

7. REFERENCES

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