2015ESASP.730..101S

TURB3D: NEW ROCKET-BORNE MULTI-SENSOR SYSTEM TO STUDY THREE-DIMENSIONAL STRUCTURES OF MESOSPHERIC TURBULENCE

B. Strelnikov[1], F.-J. Lübken[1], M. Rapp[2], G. Krein[3], H. Henkel[3] and H.-J. Heckl[1]

[1]*Leibniz Institute of Atmospheric Physics, Schloßstraße 6, 18225 Kühlungsborn, Germany, Email: strelnikov@iap-kborn.de*
[2]*German Aerospace Center Institute of Atmospheric Physics (IPA), Oberpfaffenhofen, 82234 Wessling, Germany, Email: markus.rapp@dlr.de*
[3]*von Hoerner & Sulger GmbH, Schloßplatz 8, 68723 Schwetzingen, Germany, Email: krein@vh-s.de, henkel@vh-s.de*

ABSTRACT

Leibniz Institute of Atmospheric Physics (IAP) at the Rostock University in Kühlungsborn, Germany together with the company von Hoerner and Sulger GmbH (vH&S) in Schwetzingen, Germany develop a new instrumental setup for 3-dimensional in-situ turbulence and temperature measurements in the mesosphere and lower thermosphere (MLT) region. The setup consists of a mother payload carrying a new generation CONE instrument and three identical daughter payloads that will be ejected from the main payload at a predefined altitude. When ejected, all the payloads measure densities of neutral air and one of the plasma species, either electrons or ions. Each payload has its own telemetry and positioning system and sends all the data directly down to the ground. The new measurements will thereby yield four simultaneously measured profiles of neutral and plasma densities, neutral air temperature, and turbulence energy dissipation rate, separated by up to some hundreds of meters. Important for turbulence studies, these measurements will infer spectra information that cover a wide range of spatial scale characteristics for MLT turbulence in both horizontal and vertical directions.

Key words: turbulence, in-situ, turb3d.

1. INTRODUCTION

The mesosphere and lower thermosphere (MLT) region (approx.50–130 km) attracts more scientific interest during last decades since its importance was recognized to be crucial for understanding the whole Earth's atmospheric system. For example, long term changes of thermal and dynamical structure of this region is believed to be indicator of anthropogenic impact on the Earth's atmosphere. The cooling of the atmosphere in the altitude region between ∼50–80 km observed during last 40 years reaches value of 20 K [BP08], whereas at Earth's surface it is about 0.5 K [SQM^{+}07]. Figure 1 demonstrates that the modern climate models, like WACCM which is described in [GMK^{+}07] and shown as black line, cannot properly reproduce the measurements (shown as red line).

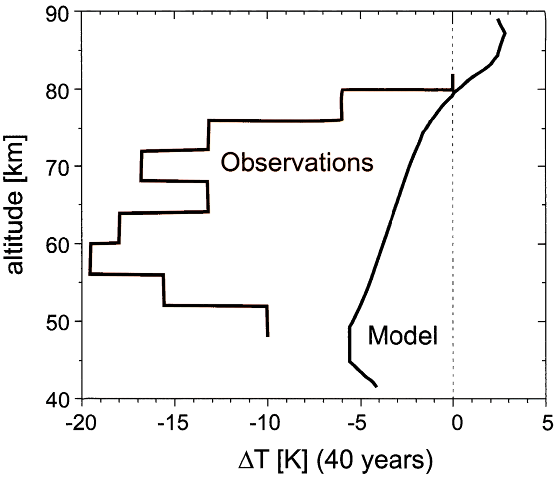

Figure 1: Comparison of the observed (red line) and modeled (black line) temperature changes between years 1960–2000. Red line: from phase hight measurements in Kühlungsborn, 55 °N [BP08]. Black line was derived from WACCM climate modell (adapted from [GMK^{+}07]).

This means that the dynamical and chemical processes of that region are not fully understood. The neutral dynamics which is one of the key player in the energy budget of the MLT region, is essentially influenced by turbulence that, in turn, is permanently generated by breaking gravity waves [e.g., FA03]. As a result e.g., turbulence in the polar mesosphere leads to maintaining such temperature structure that the mesopause reaches temperatures of 130 K, and is thereby the coldest place in the Earth's atmosphere. Advances in turbulence measurements in the MLT region made in the last 20 years significantly contributed to our understanding of the dynamics of the atmospheric system. The most reliable to date technique

Proc. '22nd ESA Symposium on European Rocket and Balloon Programmes and Related Research',
Tromsø, Norway, 7–12 June 2015 (ESA SP-730, September 2015)

to measure turbulence in the MLT is the in-situ measurements with ionization gauges. This technique yields precise measurements of the turbulence energy dissipation rates with altitude resolution of $\sim$100 m and resolves wide range of spatial scales of turbulence from several centimeters up to several kilometers [SRL11]. However, these measurements are only capable of sounding turbulent structures in a single dimension and yield only vertical profiles of the energy dissipation rates.

It is already for long time known that turbulence is highly variable and intermittent in both time and space. It also could be anisotropic at some scales. This rises the questions how representative are the so far gained turbulence climatologies for the middle atmosphere, how precise are the models of turbulence and turbulent parametrization in atmospheric models. To address these questions three dimensional (3D) soundings of turbulent structures is required. This motivated us to develop a new instrument for 3D turbulence measurements in the middle atmosphere which is called TURB3D.

In this paper we introduce the newly developed TURB3D system, describe its basic properties and measurement capabilities.

2. SYSTEM DESCRIPTION

The TURB3D system consist of a main module shown in Figure 2 where three daughter-payloads are integrated and an additional (fourth) "daughter-payload" mounted on the symmetry axis of the front or rear deck of the main payload and, thereby contributing to a conventional payload configuration replacing its predecessor - CONE instrument.

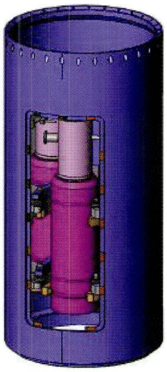

Figure 2: Main module of TURB3D with an opened hatch for daughter-payload ejection.

The daughter-payloads will be ejected at a predefined phase of a rocket flight and will perform the in-situ turbulence measurements independently along their trajectories. Such a system will therefore yield four profiles of the turbulence energy dissipation rates, ε. Figure 3 shows schematics of a TURB3D-flight. The daughter-payloads on this schematics were ejected at around the apogee. They move parallel to each other and the horizontal distance between them, as well as to the main payload, is gradually increasing during the measurement phase.

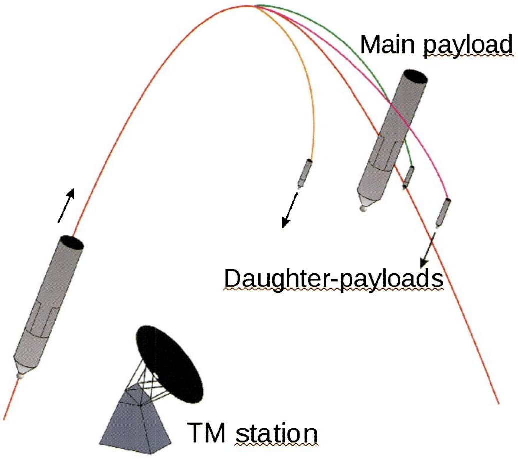

Figure 3: Schematics of a TURB3D-sounding.

The entire system is designed to work under conditions typical for a sounding rocket flight, namely spin rate of the main payload between 2 and 5 Hz, lift-off acceleration up to 40 g, it accepts power supply of 28 V for the housekeeping electronics of the main module and the fourth daughter-payload mounted on the main mother-payload.

3. MAIN MODULE

The main module is designed to be integrated in a standard 14-inch payload, is of 82 cm long and weights about 100 kg. It includes

- Doors eject mechanism
- Vacuum caps with pumping system to support vacuum inside the sealed sensors which are basically ionization gauges
- Launch lock mechanism for satellites to hold the daughter-payloads until their ejection and to lift up the vacuum sealing before ejection
- Vacuum caps lift mechanism
- Motor driven spinning-up system to assure that the ejected sub-payloads acquire spin rate needed for stabilization of their flight
- Daughter-payloads ejection mechanism
- Housekeeping module to monitor and control the system's life-cycle which includes 28 V DC power interface and Ethernet data interface

The active spinning-up of the daughter payloads is done by a brushless DC motor. The daughter-payload spin rate is programmable from 0 to 5 turns per second to stabilize the daughter payload eject and flight. TURB3D also uses four pyrotechnic cable cutters to trigger the following actions:

- Doors eject mechanism
- Vacuum caps lift mechanism
- Daughter-payloads launch lock release mechanism
- Daughter-payloads ejection mechanism

To avoid ignition of the pyros by operator error a flight mode and a non flight mode bit is used which are stored non-volatile within the TURB3D. If the flight mode bit is not set the pyros are blocked. The operator has to set the flight mode bit before launch. The mechanism activities are monitored by switches which are analyzed and transmitted via Ethernet by the central electronic unit. The spinning rate of each daughter-payload is sensed directly with reed contacts and measured by the central electronic unit.

The main module central electronic unit supports charging of the daughter-payloads rechargeable batteries. The electrical contact from central unit to daughter-payloads is achieved by the usage of spring contacts. The daughter payloads are pressed against the spring contacts by the launch lock mechanism.

The main module also supports a digital camera to monitor the ejection of the daughter-payloads. Video data is stored on a memory card and an analog video signal is supplied to the rocket telemetry.

Three ion getter pumps (IGP) including a high voltage power supply are used to preserve the vacuum in the vacuum caps. This ensures low outgassing during flight measurements and the possibility to make pre-launch tests on the launch pad with the ionization gauges.

A 3-axis gyro and an accelerometer are included in the central electronic unit to monitor the flight. A precision altimeter is used to detect leakages in the central unit electronic box during leakage tests and flight.

The TURB3D main module is designed for reuse, but mechanics will need service after launch due to contamination with salt water.

The central electronic unit and the daughter-payload use a reprogrammable logic and parameters. This enables the operator to change selected parameters just before launch by the GSE GUI software. Parameters are stored in an nonvolatile memory, so that no configuration is necessary after power cycling.

The main module needs a trigger signal from the rocket for ejection of the daughter payloads. Trigger signal must be given at a defined altitude and the central electronic unit starts ejecting the daughter-payloads by an automated predefined procedure.

4. DAUGHTER-PAYLOAD

Each sub-payload is a stand-alone system and its block-diagram is shown in Figure 4.

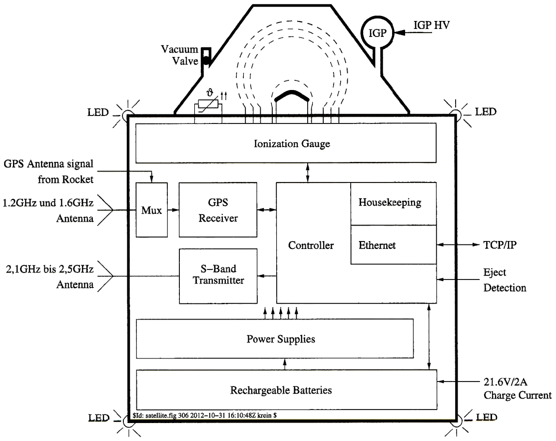

Figure 4: Block-diagram of the daughter-payload.

As it is seen from the Figure 4, the daughter-payloads consist of:

- ionization gauge (the upper part)
- system to determine position and attitude of the flying units: GPS, gyro, accelerometer.
- Telemetry system (TM) that will send all the data directly to a ground TM-station.
- Own power supply with rechargeable batteries.

The LEDs on the sub-payloads will help to control the ejection phase by build-in cameras from the main section. The LEDs also serve as a status display, indicating the different operating modes of the daughter-payload by being off, flashing or permanently on. A detailed hardware layout of a daughter-payload is shown in Figure 5 and is described in more detail further below.

In addition to the ionization gauge described in section 4.1 the daughter payload has a housekeeping module to monitor supply currents, supply voltages and temperatures. A 3-axis gyro and an accelerometer are included to monitor flight stability and spin rate during flight. The precision altimeter is used to determine leakages during test or flight. A recovery system for the daughter-payloads is not provided.

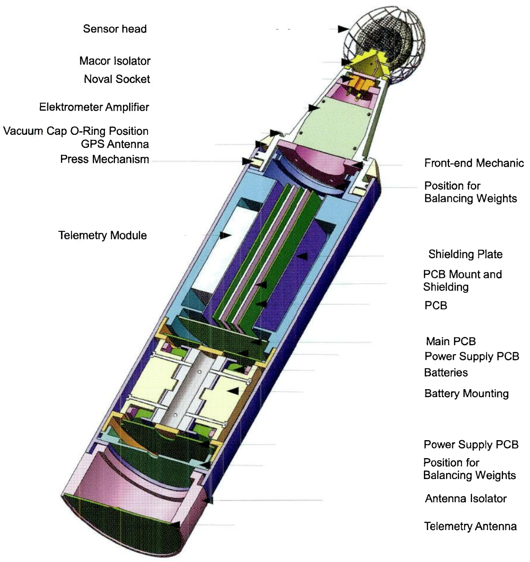

Figure 5: Main module of TURB3D with an opened hatch for daughter-payload ejection.

4.1. Scientific instrument

The scientific instrument incorporated in each sub-payload is a new generation of the CONE instrument [GLN93]. It consists of an ionization gauge surrounded by two screening grids fixed biased at plus and minus three to six volt.

Similar to the CONE's design, the TURB3D sensor is directly mounted on the electronics to reduce noise that can be introduced to the measured currents before they reach the electronics. The sensor must be covered by a vacuum-tight cap (seen in Figure 2) under which a high vacuum ($\sim 10^{-8}\ mbar$) is permanently supported by a small ion getter pump (IGP). Such design allows to run the instrument on the ground before lift-off of the sounding rocket and, thereby to ensure that instrumental parameters such as emission current, anode and shielding voltages, and electrometer's noise level have their nominal values and are stable. For turbulence measurements it is especially important to ensure that the emission current from the filament, that is the electron source for the ionization gauge, is constant. The filament (cathode) used for thermal electron emission in ionization gauges can only survive under pressures below ~1 mbar. The scientific instruments can be switched-on several minutes before and the IGP will be automatically switched-off during the lift-off of the rocket. The vacuum caps of the daughter-payloads will be opened inside the main module shortly before their ejection.

The outer fixed biased grids are connected to sensitive electrometers and, thereby utilize a well known technique widely used on sounding rockets to measure electron or ion density with very high altitude resolution and precision. Such a probe is described in detail elsewhere [BTA90, GLN93]. In case when the outermost grid will be positively biased, it will measure electron density. This grid can also be connected to the housing and, thereby be under the floating potential of the ambient plasma. In such configuration the second negatively biased grid, which is also connected to a sensitive electrometer, will yield measurements of positive ion densities.

The electronics of the ionization gauge consists of two main modules: Emission current regulator and ion collector electrometer (ELM). The ion collector of the ionization gauge is connected to the autoranging electrometer amplifier that yields the neutral density measurements. The electrometer's amplifier automatically switches between two ranges with a digital programed hysteresis changing the sensitivity by a factor of 32. The low current range measures currents up to 0.5 uA and the high current range currents up to 16 μA. All the measured voltages and currents are internally digitized with 24 bit resolution. The analog-digital converter sample rate is 3.33k samples per second with a noise level (RMS) of about 1.6pA in the lower measurement range and a noise level (RMS) of about 10pA in the higher measurement range. Such low noise level and high speed of operation make it possible to measure tiny density fluctuations of a magnitude of $\sim 0.05\ \%$ at spatial scales down to 30 cm. An increase of ADC sample rate is possible but will result in increased noise. A change in sample rate needs also hardware modification of the anti aliasing filter in front of the ADC. The measurement ranges are variable by replacing the two feedback resistors in the front-end amplifier. With the above described configuration a SNR of 110dB for the low current range is achieved and 124dB for the high current range.

The electrometer ADC is a 20 bit single channel ADC operating at about 850kHz which is expanded by digital filtering to 24 bit. In the above configuration the lowest 3.3 bit are lost in the noise for the high current range and the lowest 6.8 bit are lost in the noise for the low current range

Some basic characteristics of the ionization gauge electronics' are as follows:

- ELM data resolution: 24 bit
- ELM measurement ranges: 2
- Filament ionization current ADC resolution: 24 bit
- Anode Voltage ADC resolution: 24 bit

- Negative Shield grid current: 24 bit
- Positive Shield grid current: 24 bit
- Sampling rate: 3.33 kHz
- 16 bit DAC for anode voltage, grid voltage, and emission current programming.

The emission current regulation and measurement is also improved in comparison to the CONE instrument. The emission current regulator uses a two stage regulation to speed up regulation when filament is hot and slows down regulation when the filament is cold. The emission current is set via the multi channel DAC and measured via the 24 bit multi channel ADC.

Both electrometer amplifier and emission current sense amplifier are located directly in the nose cone of the daughter-payload to avoid EMI coupling into the measured currents.

4.2. Service module

The position, i.e. trajectory vs time, of the sub-payloads will be precisely determined via different redundant systems, an onboard GPS and tracking radar. If both fails flight trajectories can also be calculated by simulation and known ejection point.

The TM-transmitter on each daughter-payload is designed to send the data via S-band directly to a ground-based receiver. Each daughter uses a data bandwidth of 380 kbit/s with a RF transmitter power of 5W.

Additionally, the entire data stream can be transmitted via the built-in Fast Ethernet interface for configuration and pre-launch operations. For ground support operation only a laboratory power supply and a PC with the TURB3D software is necessary to operate the TURB3D system. All TURB3D Ethernet interfaces are operated in socket server mode. A commercial 5 port Fast Ethernet switch is used inside the central electronic unit to collect all Ethernet ports to one global Ethernet line. On rocket side or ground side, socket clients needs to be setup to send or receive data from the TURB3D system.

The Transmitted data frames via RF Transmitter and Ethernet also include a frame counter, header and a checksum.

5. SUMMARY

In this paper we introduced a new measurement system called TURB3D. It is designed for use aboard sounding rockets for measurements of absolute neutral densities, neutral temperatures, turbulence energy dissipation rates, and plasma density with very high altitude resolution and covering three spatial dimensions. The system will be tested in a real sounding rocket flight in a nearest future and aims at bringing new and unique scientific results.

ACKNOWLEDGMENTS

This work was funded by the German Space Agency (DLR) under grant 50 OE 1201 (Project TURB3D).

REFERENCES

[BP08] J. Bremer and D. H. W. Peters. Influence of stratospheric ozone changes on long-term trends in the meso- and lower thermosphere. 70:1473–1481, 2008.

[BTA90] T. A. Blix, E. V. Thrane, and Ø. Andreassen. In situ measurements of the fine-scale structure and turbulence in the mesosphere and lower thermosphere by means of electrostatic positive ion probes. 95(D5):5533–5548, April 1990.

[FA03] D. C. Fritts and M. J. Alexander. Gravity wave dynamics and effects in the middle atmosphere. 41(1):3/1–64, April 2003.

[GLN93] J. Giebeler, F.-J. Lübken, and M. Nägele. CONE - a new sensor for in-situ observations of neutral and plasma density fluctuations. ESA-SP-355:311 – 318, 1993.

[GMK+07] R. R. Garcia, D. R. Marsh, D. E. Kinnison, B. A. Boville, and F. Sassi. Simulation of secular trends in the middle atmosphere, 1950–2003. 112(D9), May 2007.

[SQM+07] S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller. Climate change 2007: The physical science basis. Contribution of Working group I to the Fourth Assessment Report. Technical report, Intergovernmental Panel on Climate Change, Cambridge, UK, May 2007.

[SRL11] B. Strelnikov, M. Rapp, and F.-J. Lübken. In-situ density measurements in the mesosphere/lower thermosphere region with the TOTAL and CONE instruments. In K. Oyama, editor, *Rocket and satellite in situ instrumentation*. Terra Publishers, 2011. accepted.