MEASUREMENTS OF THE D-REGION PLASMA USING ACTIVE FALLING PLASMA PROBES

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ABSTRACT

MEDUSA is the acronym for MEasurements of the D-region plasma USing Active falling plasma probes. The scientific scope of MEDUSA is measuring small scale fluctuations in the plasma density of the D-region. The measurements enable investigations on the physics of the atmospheric phenomenon of polar mesospheric winter echoes (PMWE), which are radar echoes in the range of 55-80 km. To observe the turbulence in that height region, we measure positive ion density and neutral density with our experiment. The MEDUSA experiment, as a part of the REXUS/BEXUS project, develops a new in-situ technique probing the lower ionosphere plasma by two free falling units (FFU). These identical FFUs contain a sensitive structure that is exposed to the atmosphere. This structure consists of a grid, which surrounds an ion collector that is connected to a electrometer. The collector has a negative potential, the measured current at the electrometer is proportional to the ion density measurements. The positively charged grid shields the collector from ambient electrons. Acceleration sensors inside each payload can be used to derive neutral gas density profiles from the FFU's equation of motion. These neutral density profiles can be used to investigate possible correlations with the plasma densities. From this density profile, assuming hydrostatic equilibrium one can integrate a temperature profile. A GPS receiver on each FFU provides in-situ horizontal information of all three physical quantities (ion, neutral density and temperature) that has not been available in this scientific field before. During the REXUS 15/16 campaign a sounding rocket will bring the two probes up to approximately 90 km, which are then ejected from the main payload. During descend, the FFU will measure the ion density. The data will be stored on the FFU directly and will also be sent to a ground station in case a recovery of the probe is not possible. The rocket launch is supported by ground based instruments and model studies at winter polar latitudes.

Key words: FFU; Rocket Payload; Mesosphere; Turbulence; D-Region; Ion Density.

1. INTRODUCTION

The Earth atmosphere is mostly influenced by solar radiation. It drives dynamical, chemical micro and macro physical processes like turbulence and ionization in the whole atmosphere. In the field of atmospheric research the polar summer mesopause region holds a prominant position since it is the coldest place in the Earth's atmosphere. Here, the phenomena noctilucent clouds (NLC) and polar mesospheric summer echoes (PMSE) are observed by ground based [e.g. 3] and in-situ measurements [e.g. 6]. The ionospheric state in this altitude region plays an important role for the PMSE phenomena and other effects which are associated with enormous interest in nowadays geophysics. Besides the resonably known NLC and PMSE the small-scale structure of the lower D-region plasma at the high latitude ionosphere is connected to the phenomena of polar mesosphere winter echoes (PMWE). PMWE are radar echoes which occur in the altitude range from 55-85 km during the polar winter. The formation process is not fully understood, but theoretical approaches explain the formation by either turbulent or non-turbulent conditions. High electron densities are likely to be essential for the echo formation process. These conditions are often fulfilled during high solar activity causing enhanced ionization in the atmosphere [e.g. 2, and references therein]. Since at least ions are connected to neutral gas dynamics [7], it is believed that breaking gravity waves and the resulting shear winds and turbulence play an important role in the formation of local high plasma densities [4].

MEDUSA (Measurements of the D-region plasma using active falling plasma probes) is an experiment which is going to be flown on the REXUS 15 rocket in March 2014.

The aim of MEDUSA is to get a better understanding of turbulent processes in the mesosphere. In case of PMWE conditions during the rocket flight we can actually gain information about the role of turbulence in PMWE physics. Ground based radar measurements will give reasonable information if these conditions are fulfilled. The MEDUSA experiment consists of two autarc free falling units (FFU). By applying two probes it is also possible to gain information about the horizontal dimensions of turbulence and PMWE.

This paper covers the description of the MEDUSA experiment design and its components. In the following sections we present the concept of the experiment, the used sensors, the mechanical design and the electronics.

2. CONCEPT OF THE EXPERIMENT

The concept of the MEDUSA experiment is described in this section. See Fig. 1 for the conceptional overview.

The MEDUSA experiment consist of two autarc free falling units (FFU) mounted inside a REXUS module. These FFUs will be transported inside of the rocket payload up to an altitude of 80 to 90 km. Here the ejection mechanism will be activated and both FFU will leave the REXUS rocket payload. Just after ejections of the FFUs

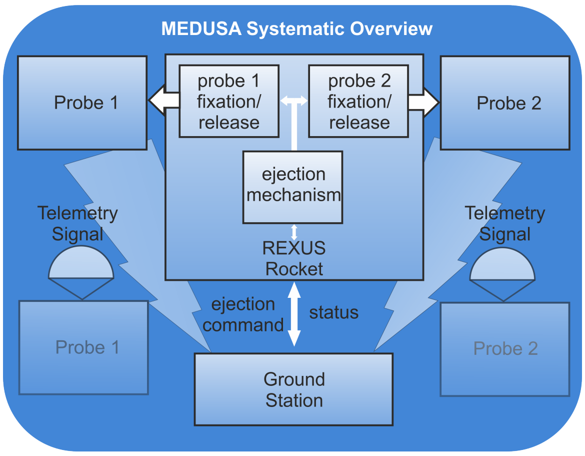

Figure 1. Concept drawing of the MEDUSA experiment

they start their measurements. Both FFUs carry identical sensors, in order to receive receive horizontally resolved measurements. Due to the fact that we can only measure during the downleg of the rocket flight, it is crucial to obtain all data from both FFUs. Since a recovery of the FFU after landing is not 100 percent secure, we use a telemetry system inside the FFU to send our data to the ground. For reasons of redundancy the data is also saved onboard.

Below 30 km the FFU will leave the region of scientific interest, since this altitude region below is also accessible by balloon systems. The FFU recovery system will release a parachute at an altitude of approximately 5 km. To reduce possible drift of the FFU due to the atmospheric wind, we will initiate the recovery system at this low altitude. The time for data transmission in this case is limited, since we expect to loose the telemetry signal at an altitude of approximately one kilometer.

In Tab. 1 a timeline of our experiment during the rocket flight is shown. The main reason to eject our FFU before the apogee is that the tumbling of the rocket is minimal in this timeframe. During ejection we need to have a very upright rocket orientation, since our sensors, situated in the front of our FFU, has to point downwards to perform reliable measurements.

Table 1. Timeline for countdown and flight

Event	**Time** (T±t)
Monitoring	-600s
Lift-off	+0.00s
Burn-out	+26.00s
Yo-Yo despin	+75.00s
Hatches open	+76.00s
Experiment Ejection	+76.50s
Start measurement	+77.00s
Activate wireless modem	+79.00s
Motor Separation	+80.00s
Apogee	+140.00s
Parachute release	+270.00s
Switch Off System	∼+730.00s
Landing	∼+800.00s

After the successful flight, we aim at a successful recovery of both FFU by a helicopter team. Since we can hand over the latest received GPS data, we expect a good chance of finding the landed FFU.

3. SENSORS

Two main sensors are used inside of each FFU. Firstly we use an electrostatic probe for the measurement of the ion density in the D-region. Secondly, we use a three axis accelerometer in each FFU to measure the atmospheric drag.

The electrostatic probe consists of a spherical grid around a solid electrode. The grid is biased on payload potential while the electrode is biased negatively, thus the grid shields the electrode from ambient electrons and negative ions. At the same time positive ions are attracted by the electrode. The current of positive ions reaching the electrode is proportional to the positive ion density [e.g. 7]. This current is measured by a highly sensitive electrometer inside the FFU.

The used accelerometer applies a capacitive method to measure the atmospheric drag. By solving the equation of motion of the FFU one can derive the atmospheric neutral density ρ.

$$\rho = -2m\frac{(a_z + g)}{C_D \cdot A \cdot v \cdot V_z} \quad (1)$$

Here, m is the mass of one FFU, a_z is the acceleration in z direction, g is the gravitational acceleration, C_D is the

FFU´s drag coefficient, A is the effective FFU crosssection, v the is the FFU´s absolute velocity and V_z the FFU velocity in vertical direction only. Under the assumption of hydrostatic equilibrium one can also integrate the temperature profile along the flight path of both FFU.

4. MECHANICS

In this section we describe the mechanical design of the MEDUSA experiment. In Fig. 2 the assembly of the MEDUSA experiment is shown. Since both FFUs are

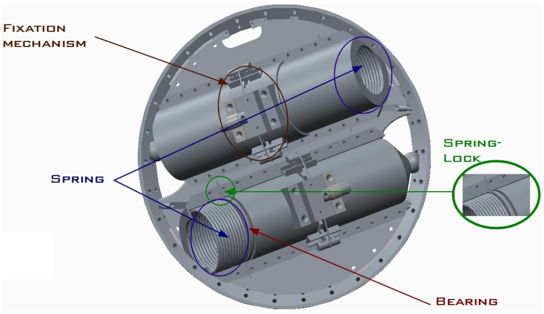

Figure 2. Experiment FFU mounted inside a rexus module

mounted inside a REXUS rocket module, an ejection mechanism is used to liberate the FFU from the rocket module. Each FFU has a cylindrical form with a diameter of 80 mm and a length of 220 mm. The FFU framework has bolts on the outside that fit into the channel of the rifled barrel that covers each FFU. For ejection we use a spring that pushes the FFU out of the module. While the spring acts, the bolts are guided along the channels of the riffled barrels. In that way the spring forces the FFU to gain translational and rotational speed at the same time. Since the spring cannot rotate, there is a bearing between the spring and FFU. The strength of the spring is designed that after ejection the FFU has a spinning frequency of 12 Hz and absolute speed of 1.8 m/s. The FFU are pointing downwards with an limb angle of 27°, because we want that the electrostatic probe to point downwards while the FFU falls to the ground. Pointing downwards reduces the turbulent influence on the positive ion density measurement.

Each FFU is fixed inside the rocket by three stamps (see Fig. 3). These stamps are locked by a wire around the complete FFU. At the point of ejection the wire is cut by a pyrocutter. Now a spring pushes the stamps out of the grooves in the FFU hull.

Since the rocket has to be sealed during takeoff, we have also designed a system that allows to open a hatch so that the FFU to leave the rocket module (see Fig. 4). The hatch opening system works as follows. There is a hatch on each side of the rocket module, one for each FFU. The hatches are locked during the start of the rocket, to avoid aerodynamical disturbances. The lock mechanism

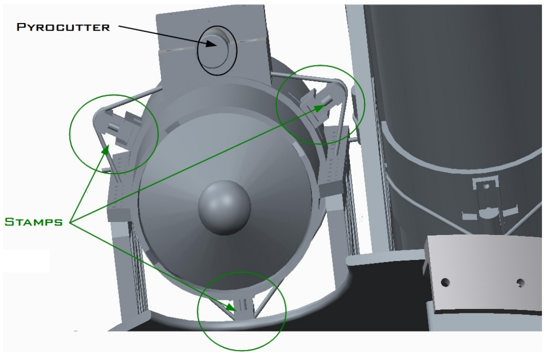

Figure 3. Fixation mechanism of the FFU inside of the rocket module

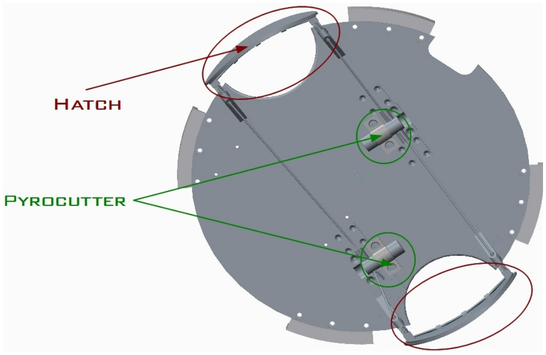

Figure 4. Ejection mechanism of the hatches, which cover the holes in the rocket module, the lock mechanism is realised by a wire locking the hatches until ejection of the FFU

is again realized by a wire that holds both hatches against the rocket module wall. This wire is cut by a pyrocutter just before the FFU are released. Then springs, which are mounted right behind the hatches, can push the hatches out of the rocket modules outer structure.

4.1. Finite element method analysis

During a rocket flight the experiments are exposed to accelerating forces that are in the order of 20 times the gravitational acceleration. This extreme force during the rocket's liftoff puts an immense stress on the FFU and the inner structure parts of our experiment. To test the stability of our experiment during a rocket flight we have applied an finite element method (FEM) analysis. FEM is a numerical technique that can be used to simulate the stress on a structure generated by a disruption, e.g. a rocket start. In Fig. 5 we show the results of a FEM analysis where the FFU is mounted on the rocket payload. The force that acts on the module and FFU has been set to 20 g, comparable to the force that act during an Improved Orion start. The derived quantity is the tension acting on the FFU and rocket module during the rocket start. The tension is colorcoded and given in units of MPa.

The tension on the wall mounted brackets holding the

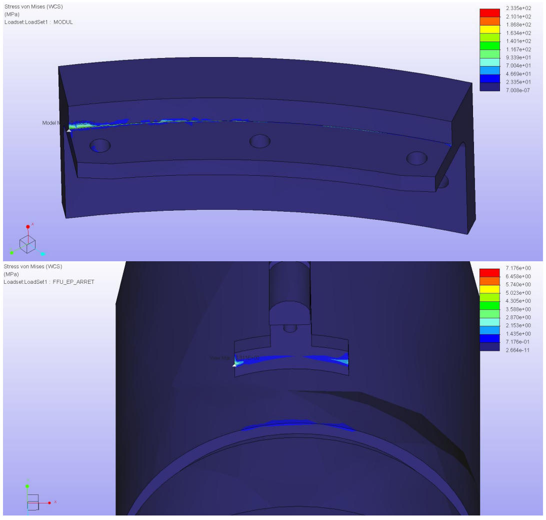

Figure 5. Finite elements method analysis of the rocket module and the FFU, applied acceleration force is 20 g, result is the tension of the structure in MPa

experiments bulkhead is about one order of magnitude higher than the tension acting on the FFU. The tension on the brackets is apporximately 230 MPa which is a the limit what steel can withstand. Further investigations on more robust material is needed. On the contrary, the tension on the FFU stamps is only in the order of 10 MPa. This is due to the very light weight design of the FFU, resulting in a minimum of stress on the FFU structure.

5. ELECTRONICS

In this section we describe the electronical system that controls the MEDUSA experiment. At first there is a Onboard Communication Unit (OCU) mounted on the bulkhead of the rocket module. The OCU has the purpose to communicate with the REXUS service module and to check the status of the FFU. Another part of the OCU is a gyroscope which monitors the attitude of the rocket. We need the attitude of the rocket during the moment of ejection, since the knowledge about the fall direction of the FFU is crucial for the MEDUSA experiment.

Each FFU itself contains overall six sensors. The main sensors are the positive ion probe, the accelerometer and the GPS module. Onboard each FFU we have also an addtional gyroscope, temperature sensors and a pressure sensor. In Fig. 6 you can see the inner parts of the probe covered by the glas fiber. We use glas fiber as cover material since it is transparent to the electro-magnetic telemetry signal. This material is necessary since we want to send our data down to a groundstation by telemetry.

The ion density sensor is primarily a sensitive two channel current to voltage converter circuit. It amplifies currents from a couple of nano amps up to 50 micro amps. The measuring range covers the typical ion currents measured by electrostatic probes in the lower ionosphere. The two channels provide two different amplifications of the measured current. The output voltage will be converted by analog digital converter (ADC) and the digital signal will then be processed and send to the ground station by telemetry as well as stored onto a flash drive on board the FFU.

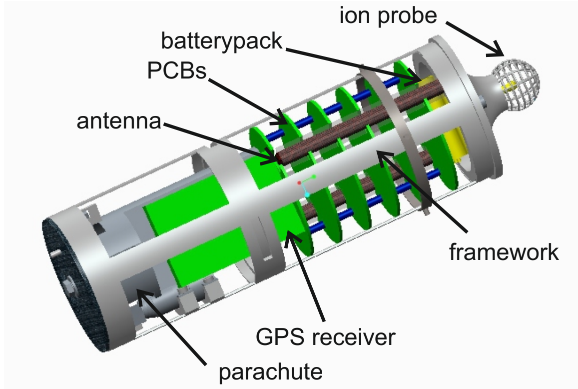

Figure 6. Inner structure of the FFU, batteries in the front, electronics on circuit boards and parachute in the rear of the FFU

The accelerometer is assembled on a circuit board inside the FFU (green plates in Fig. 6). Details on the performance and the details of the control electronics of the sensor can be found in [5].

The GPS module will be used, to get the actual position of the probes, which is needed, to reconstruct the trajectory for the flight results. Additionally, the position will be used to track the satellite during its fall with the telemetry antenna of the ground station. This tracking achieves the best possible signal strength for the data communication. Caused by the CoCom formalities, most GPS-receiver are limited in speed, acceleration and altitude that can be measured. That is why a module must be chosen that can be unlocked by the manufacturer, to work in the desired altitude of 30 km to about 80 km and velocities of more than 500 m/s. The OEM615 by Novatel fulfils these requirements. It is a combined L1/L2 receiver with an update rate of up to 50 Hz. Due to its dimension, it has to be mounted vertically into the system. The module can stand accelerations of up to 40 g and vibrations up to 7.7 grms. Additionally it can be operated in a temperature range of -40°C to +85°C.

Temperature sensors will be used on different points within the system, e.g. near the batteries and the accelerometer. Monitoring the temperature is an important part of analyzing the housekeeping data. Using these sensors, e.g. the charging of the batteries can be interrupted if they get too warm. Additionally, by logging this value, the temperature dependance of the sensors can be corrected while analyzing their data. For that purpose the ”ADT7310” from ”Analog Devices” has been chosen. This sensor uses a SPI-Interface, which makes it easiy to be integrated into the MEDUSA system. Additionally it guarantees an accuracy of $\pm 0.5°$ and can interrupt the supervised part of the experiment if it exceeds a pre-defined temperature limit.

The pressure sensor will be used for the control of the parachute release. In cas of a failure of the GPS module, the measurement data of the pressure sensor will be used to open the parachute in a predefined altitude. An absolute pressure sensor will be chosen to measure the atmospheric pressure. Its data will be compared with a look-up-table that contains the air pressure in relation to the altitude and is stored in the microcontroller. "Freescale Semiconductors" offers a wide range of pressuresensors that could be used for that application. Their pressure sensors can be operated in a temperature range of -40°C to 85°C minimum and have a digital output. Their measurement range start from 200 hPa, which corresponds to approximately 10 km altitude.

6. CONCLUSION AND OUTLOOK

We present the MEDUSA experiment design for the REXUS 15/16 student sounding rocket campaign, which will be flown in March 2014. This experiment includes two autonomous FFU which will be ejected from the rocket payload at maximum altitude. These FFU will be able to measure ion and neutral density in the altitude range from 80 - 50 km. The experiment focusses on the turbulent processes in the mesosphere and D-region ionosphere. Within that scope, we want to improve the understanding of processes in the mesosphere, like PMWE, which need further investigation on dynamics and coupling between the plasma and the neutral state of the atmosphere.

Our experiment consists of a mechanism, that ejects the FFU from the rocket payload, a positive ion sensor, an acceleremter and a GPS module. By combining all three measured quantities, the positive ion density, neutral density and position information we can gain an insight into the nature of the processes of the mesosphere. To gain horizontal information about the turbulence is a major advance in this field.. Horizontal changes in the turbulent structure of neutral and charged ionosphere hasn't been analyzed in the studies of [7], [1] and others. We want to focus on these horizontal changes with our MEDUSA experiment.

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