MONDARO STUDENT EXPERIMENT ON THE REXUS SOUNDING ROCKET

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ABSTRACT

The German Aerospace Center (DLR, Deutsches Zentrum für Luft- und Raumfahrt) and the Swedish National Space Board (SNSB) are jointly carrying out the REXUS/BEXUS program to support the younger generation of engineers and scientists. A new experiment MONDARO (Measuring Of Neutral-gas Density in the Atmosphere by ROcket) is developed by students from Rostock University under support of Leibniz-Institute of Atmospheric Physics (IAP). The MONDARO experiment comprises three identical Pirani gauges mounted on the same ram deck of the payload. One gauge to be placed on the symmetry axis of the payload and the other two sensors has to be symmetrically mounted behind the shock front. Pirani is a sensor that utilizes thermal conductivity principle for gas density measurements. The measurements of the central gauge will yield the first successful high-resolution density measurements using a cost-effective rocket-borne instrument. The measured densities of the neutral atmosphere will then be integrated assuming hydrostatic equilibrium, yielding the temperature profiles. An aerodynamical correction factors have to be applied to the density measured inside the gauges because of the shock front that arises due to the high speed of the sounding rocket. For the central sensor placed on the symmetry axis of the payload, these factors have to be calculated using the direct simulation Monte Carlo technique (DSMC). Comparison of the measurements made by the central sensor with the side-mounted ones will yield an experimental ram correction factors for such hardware configuration. These experimental ram correction factors can further be compared with the factors calculated using the DSMC. The launch of the REXUS rocket with the MONDARO experiment is scheduled for March 2010 from the Esrange Space Center (Kiruna, Sweden). In the present paper we will explain the MONDARO project in detail.

Key words: MONDARO, REXUS, PIRANI.

1. INTRODUCTION

The polar mesosphere in summer is host to a number of fascinating geophysical phenomena that are primarily caused by its extra-ordinary thermal structure. Owing to the gravity wave driven mean meridional circulation with upwelling and adiabatically expanding air masses above the summer polar regions, mean minimum temperatures of $\sim$130 K are attained at the mesopause at around 88 km [Lüb99]. These extremely low temperatures marginally allow ice particles to form and grow at altitudes between $\sim$80 and 90 km, hence forming ice clouds being $\sim$75 km higher than ordinary clouds in the upper troposphere. Under favourite conditions the largest of these ice particles (with radii larger than $\sim$20 nm) can even be visually observed in the form of noctilucent clouds (NLC) which have been discovered as early as 1883 [Jes85]. In addition, the smaller ice particles efficiently modify the ionospheric plasma at these altitudes and give rise to very strong radar echoes nowadays known as polar mesosphere summer echoes or PMSE [EB81, HHR88]. For further reading on the subject of NLC and PMSE we refer the reader to the review articles by [Tho91, RL04], respectively.

In recent years, these high atmospheric ice clouds have reached a considerable scientific interest since it was suspected that the mesopause environment should change due to anthropogenic activity [RD89, TJO$^+$89, TODS03, von03]. However, it is evident that for a scientifically based judgement about these issues we require a detailed and rigorous understanding of the physical processes involved. Despite this obvious desire to understand the basic physical processes involved in the formation of these ice clouds, it is astonishing how little is known in fact on a variety of crucial processes like, for example, the initial formation of the particles (nucleation) and the action of gravity wave induced temperature variations at the altitudes of the ice clouds. For a better understanding of these processes the ability to precisely measure the temperature profile in the altitude range where the ice particles exist is of utmost importance. Unfortunately, remote sensing techniques fail exactly in the relevant altitude region. Hence, techniques for a precise temperature measurement at NLC and PMSE altitudes must rely on sounding rockets. In the past, the two most common

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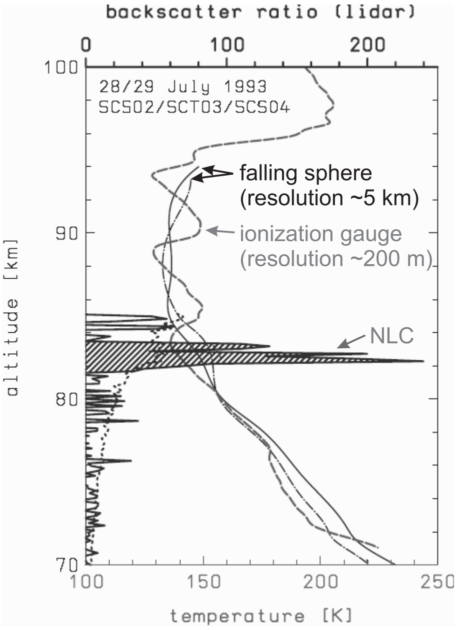

Figure 1. Near common volume measurements of a noctilucent cloud (NLC) by lidar and temperature profiles by different sounding rocket techniques. The dashed line shows a high resolution measurement with an ionization gauge, the solid and dash-dotted lines show accompanying measurements obtained with the falling sphere technique. After [RLM+02].

in situ techniques applied to measure these temperatures have been so called falling spheres and active ionization gauges [e.g. Lüb99, RGL01]. While falling spheres only provide information on the mean background thermal structure at the mesopause because of a rather coarse altitude resolution (i.e., $5 - 10$ km at 85 km altitude; and are not commercially available any more), ionization gauges are principally an ideal tool for a density and temperature measurement in the mesopause region since they provide temperatures at sufficient accuracy ($\sim 3\,\%$) and altitude resolution $\sim 100 - 200$ m [RGL01]. Most interestingly, the measurements show that the NLC occurred at the altitude of a local gravity wave induced temperature minimum, and based on these observations and model simulations it was argued that gravity waves play indeed a general crucial role for the formation of these clouds [JT94, RLM+02]. However, rocket launches with active ionization gauges have been rather rare, among other reasons, because of the very high costs of such instruments (∼several hundreds of kEuro).

2. NEW TECHNIQUE

In 2004 [Rap04] made an attempt to develop a cost-effective technique for in situ temperature measurements in the middle atmosphere using Pirani pressure gauge, which is available on the free market. Unfortunately, the rocket failed during first few seconds after take off and the technique was not established. The two Pirani pressure gauges were also mounted on the ECOMA payloads [SRS+09] that were launched during three sounding rocket campaigns in 2006, 2007, and 2008. However, due to a rather complicated aerodynamics, interpretation of the measurements is far from trivial and have not been finished yet. The main complication is to derive correction factors that have to be applied to the measured air density/pressure to eliminate the influence of the shock front that appears due to the high speed of the rocket.

2.1. PIRANI pressure gauge

The PIRANI pressure gauge is a robust thermal conductivity gauge widely used in vacuum systems and is available on the free market. It is suitable for pressure measurements in the range from $5 \cdot 10^{-4}$ to 10^{1} mbar.

In the Pirani technique, a tungsten wire is heated with a constant heating power. Being in contact to the gas whose pressure is to be measured, the tungsten wire changes its temperature and, hence, its resistance depending on the number of collisions with gas molecules (and hence the pressure). So the pressure measurement reduces to a resistance measurement that can be done very precisely and with a fast repetition rate.

Importantly, the time resolution of the gauge is only 10 ms such that at typical rocket speeds of ∼800 m/s, a spatial resolution of better than ∼10 m will be achieved.

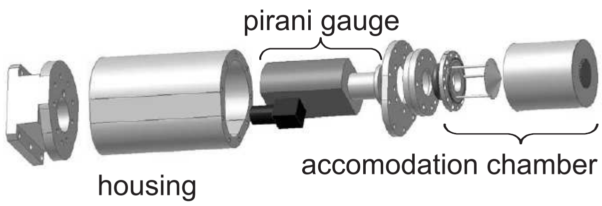

Figure 2. Drawing of the Pirani instrument that includes complete electronics, accommodation chamber (Pitot-chamber), and housing (including mounting).

Fig. 2 shows a schematic of the instrument that includes complete electronics and the accommodation chamber. This chamber is necessary to ensure that the temperature of the gas inside the sensor is known, i.e., due to collisions with the walls of the accommodation chamber it will be at the temperature of the chamber walls so that measured pressures can be converted to absolute densities applying the ideal gas law. The temperature of the accommodation chamber will be precisely measured with a Pt-1000-thermistor. In addition, the accommodation chamber provides the significant advantage that the density sensor will have a well defined geometry, similar to a standard Pitot-tube. This, in turn, has the advantage that aerodynamic effects due to the supersonic motion of the sounding rocket will be easy to correct applying either continuum fluid-theory (i.e., below altitudes of 70 km) or direct simulation Monte Carlo techniques [i.e., above 70 km; see Gum01, RGL01, for details] provided that the aerodynamics of the instrument is well defined. This means that for the instrument mounted on the front deck in the symmetry axis of the payload we can precisely derive the ram correction factors for the density measurements. The corrected absolute atmospheric number densities will be converted to temperatures assuming hydrostatic equilibrium [see RGL01, for details].

3. REXUS SOUNDING ROCKET PROGRAM

Under a bilateral Agency Agreement between the German Aerospace Center (DLR) and the Swedish National Space Board (SNSB) the REXUS/BEXUS programme is realized. The REXUS/BEXUS programme (Rocket/Balloon-borne EXperiments for University Students) gives an opportunity to students from universities and higher education colleges across Europe to carry out scientific and technological experiments on research rockets/balloons. The REXUS and BEXUS payloads are launched from the Esrange Space Center (SSC) in northern Sweden, i.e. at high northern latitude. Each year, two rockets and two balloons are launched, carrying up to 20 experiments designed and built by student teams. REXUS experiments are launched on a unguided, spin-stabilized rocket powered by an Improved Orion Motor with 290 kg of solid propellant. It is capable of taking 40 kg of student experiment modules to an altitude of approximately 100 km. The vehicle has a length of approx. 5.6 m and a body diameter of 35.6 cm. For more details the reader is referred to the official Web-site of the REXUS/BEXUS project: http://www.rexusbexus.net/.

4. MONDARO PROJECT

MONDARO states for Measuring Of Neutral gas Density in the Atmosphere by Rocket. A group of students from Rostock University came up with an idea to approve the proposed by [Rap04] method and, additionally, to derive empirical ram correction factors for the aerodynamics of the ECOMA payload.

4.1. Timing and organization

The MONDARO-team consists of three physics students (Diplom), one mechanical engineering student (Bachelor), and one electrical engineering student (Diplom). The REXUS project is not an obligatory part of their education but an additional project on a voluntary basis that extends skill and experience of the students.

The time table of the ongoing MONDARO-REXUS project is sketch in Fig. 3. The students decided to use the opportunity provided by the REXUS programm and applied for the launch that should take place in March 2010. On a workshop that took place in February 2009 the MONDARO-team had to defend their project and the review panel of the REXUS/BEXUS programme accepted the MONDARO experiment to be a part of the REXUS rocket.

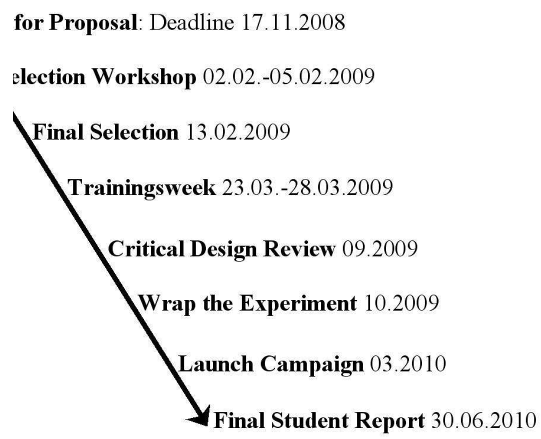

Figure 3. Schedule

After that, the students with help of experts from the European Space Agency (ESA), SSC and the Mobile Rocket Base (MORABA) of DLR run through a usual procedure that constitutes a development and conducting experiment on a sounding rocket. The rocket launch is scheduled on March 2010.

4.2. Instrumentation

The MONDARO experiment comprises three Pirani gauges that should be mounted on the front deck of the payload as shown in Fig. 4.

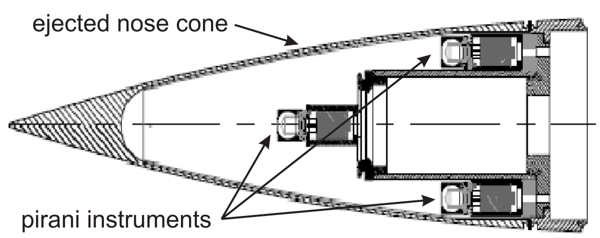

Figure 4. PIRANI sensors on the REXUS payload

The nose cone will be ejected after the rocket will pass the dense atmosphere, i.e. at ∼60 km, and the Pirani instruments will be exposed to the atmosphere. Because of the shock front that is created due to the high speed of the sounding rocket (∼1000 m/s), the density measured by the Pirani gauges will be higher than the density of the ambient atmosphere. As mentioned in the previous section, for an axially symmetrical geometry of the flow, i.e. for the instrument placed in the symmetry axis of the payload, we can precisely derive the ram correction factors for our density measurements.

The measurements with the sensor mounted in the symmetry axis of the payload are aimed to establish the new cost effective technique for the density and, therefore, temperature measurements using (possibly small, i.e. meteorological) sounding rockets.

For the two side-mounted sensors (Fig. 4), however, the aerodynamical calculations become much more complicated and require an experimental verification. This leads to the second objective of the MONDARO project, to derive the empirical ram correction factors for the density measurements with the side-mounted Pirani sensors. This can be done by comparing the density measurements from the gauge placed at the symmetry axis of the payload that has a relatively simple aerodynamics with measurements obtained by the two sensors mounted symmetrically off the symmetry axis (Fig. 4). This, in turn, will allow to validate several other measurements done using similar payload configuration, i.e. during the ECOMA sounding rocket program [see, e.g. RSS+09].

5. SUMMARY

The REXUS/BEXUS programme is an excellent opportunity for students to gain experience in organization of their own projects, conducting scientific research, and international collaborative work. Apart of that, the MONDARO project also aims to yield an important scientific results. The Pirani instrument should yield a cost-effective high resolution temperature measurements in the height range between ∼60 and 100 km.

ACKNOWLEDGMENTS

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EuroLaunch, the cooperation between the Esrange Space Center of the Swedish Space Corporation (SSC) and the Mobile Rocket Base (MORABA) of DLR, is responsible for the campaign management and operations of the launch vehicles. Experts from ESA, SSC and DLR provide technical support to the student teams throughout the project.

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