PRELIMINARY RESULTS FROM HEDGEHOG REXUS PROJECT – SOUNDING ROCKET EXPERIMENT ON ACCELERATIONS, VIBRATIONS AND HEAT FLOW

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Abstract— This paper presents preliminary results from HEDGEHOG REXUS Project - an experiment on a sounding rocket performed with cooperation of European Space Agency. Temperatures in specific locations of launcher were measured in order to determine heat flux density on rocket skin. Additionally, accelerations of the rocket were measured.

I. INTRODUCTION

As access to space conditions becomes more available, both technically and economically, scientists' interest in launching finer and more sophisticated experiments grows. This applies now more than ever to fragile by nature biological and chemical experiments [1].
To be qualified for launch, such experiments need to be carefully tested prior to the event. The tests should represent actual launch conditions as closely and in as detailed manner as possible. For this reason, comprehensive measurements of launch conditions are required. Most important acceptance tests required for module acceptance are vibration tests and thermal tests. This experiment focuses on measuring acceleration and vibrations (especially eigenfrequencies) conditions and heat transfer inside a sounding rocket as a reference for future ground acceptance tests [2].
The experiment's scientific challenge is to obtain precise information on acceleration and vibration environment that payload is subject to during whole course of sounding rocket flight. Although an envelope of environmental conditions is known and publicly available, including spectral data their application is usually limited to serving as general guideline due to their lack of details. In case of vibrations, this is usually low frequency range of measurements, as high frequency vibrations tend to be less important for sturdy REXUSexperiments [3].

The second scientific objective is to measure temperature in various locations of the section of the sounding rocket. With such data, it would be possible to create the model of heat flux transfer [4] inside the launch vehicle. Obtained results will allow for precise verification of future payload. Previous REXUS experiments typically included single point temperature measurements, focusing on local effects rather than heat transfer phenomena [5].

II. EXPERIMENT GOALS

The second part of the experiment focuses on heat transfer phenomena. We plan to construct a cylinder of aluminium covered with thick layer of insulation (styrofoam, MLI, to be determined). The design with necking (see figure \ref{fig:thermal}) forces homogenous heat flow, creating a simple 1D flow situation, easy for model fitting. At each end of the "neck", a thermocouple will be placed in such a way as to interfere the heat flow as least as possible. The bigger inner part will act as a heat tank that will hold a specific amount of thermal energy.

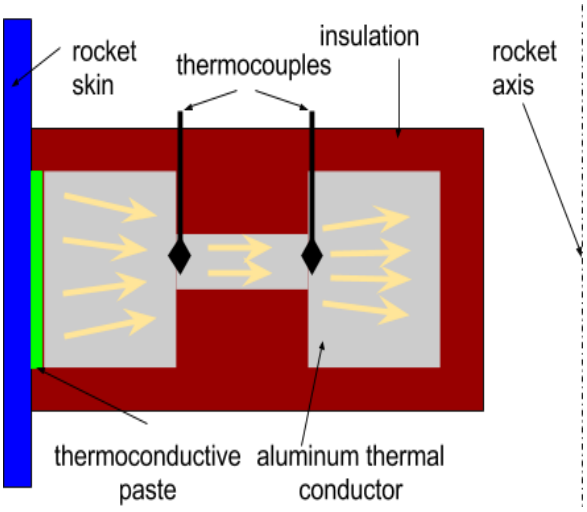


Fig. 1. Heat flux measurement device (patent pending).n.

The heat transferred Q [J] can be calculated using Fourier's Law [4]:

$$Q = \frac{k \cdot A \cdot (T_1 - T_2)}{L} \quad (1)$$

where k is thermal conductivity of material [W/(mK)], A is the cross section [m^2], T_1, T_2 are temperatures in thermocouples [K] and L is length of

the necking [*m*]. By measuring temperatures with thermocouples, temperature difference can be calculated, while other values are constants.This would allow for calculating external heat flux on rocket skin.

To allow for dimensioning, initial guess for heat flow on the rocket surface was required. This has proved to be difficult, as not only no other REXUS experiment has measured heat flux through rocket skin during flight. A heat flux on rocket skin was measured by DLR [6], but they focused on heat flux from the propulsion engine rather than on this from aerodynamic friction. Most of REXUS teams focused on local temperature changes.

We decided to use SMARD, REXUS-18 experiment [4] data (temperature vs. time, see figure \ref{fig:fig_smard}) with precise location and geometry of their experiment to solve \textit{inverse heat transfer problem (IHTP)}, i.e. find the heat flux given temperature. As their setup was not designed for it, the results can only be used as a first educated guess.

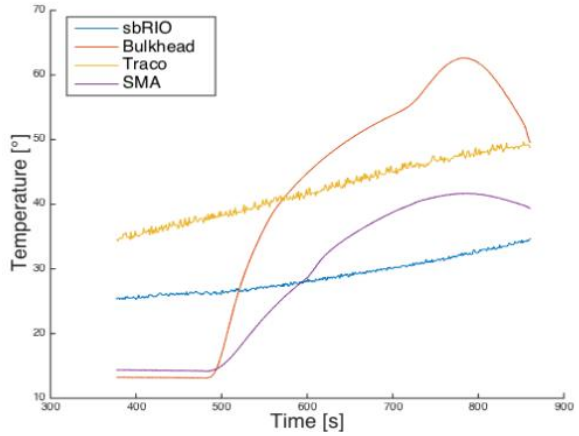


Fig. 2. Temperature curves of SMARD (REXUS-18) experiment.

The procedure was based on [7]:

1. Initial guess for heat flux density on walls [W/m^2].
2. Forward heat transfer problem in ANSYS using SMARD CAD model (Fig. 3).
3. Comparison of results with SMARD data.
4. If the results are not satisfactory, change heat flux and go to 2.

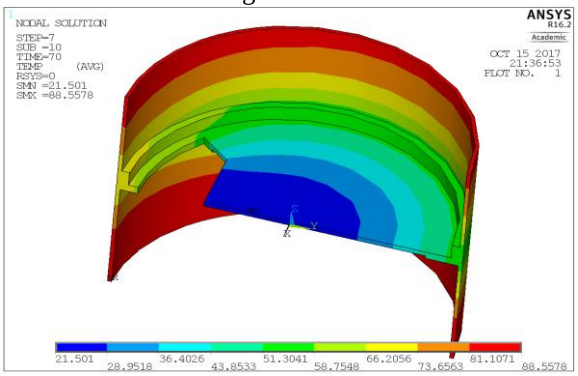


Fig. 3. Heat flux of SMARD (REXUS-18) experiment.

This allowed for dimensioning of our experiment. Initial heat transfer simulation with previously obtained heat flux was performed (see figure *Fig. 3.*), thus suggesting that our experiment can precisely fulfill its goal. We would like to further verify this idea in REXUS programme.

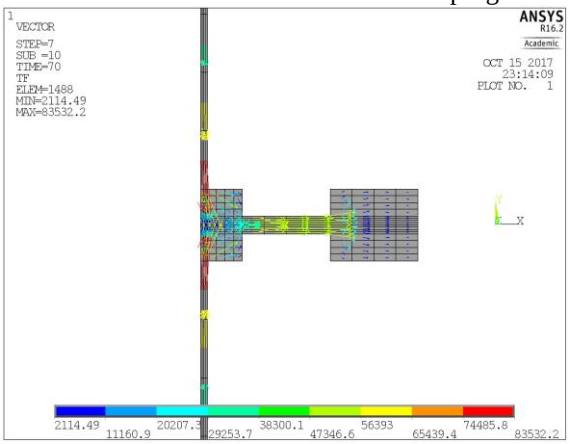


Fig. 4. ANSYS simulation of our heat transfer experiment. Vectors show heat flux. Note 1D flux in the necking.

Method for measuring heat flux on rocket skin is pending patent in Polish Patent Office.

EXPERIMENT SETUP

The mechanical system consists of a cylindrical rocket module. Lower part is a thermal cylindrical structure. It is covered by layer of insulation.

Electronics in the project include:

1. MCU based on STM32 microcontroller,
2. external memory based on flash memory,
3. 8 thermocouples, type T with multi channel amplifiers to thermal experiment,
4. 3 RTDs (resistance thermometer, resistance temperature detector) temperature sensor,
5. digital pressure sensor,
6. step-down voltage converter for MCU and sensors,
7. current sensor, to detect if the system is working properly.

Every analogue sensor will include a passive RC low pass filter. RC filters will be used to cut off the noise that are results of Foucault currents in the connections, conductors and paths on the PCB board.

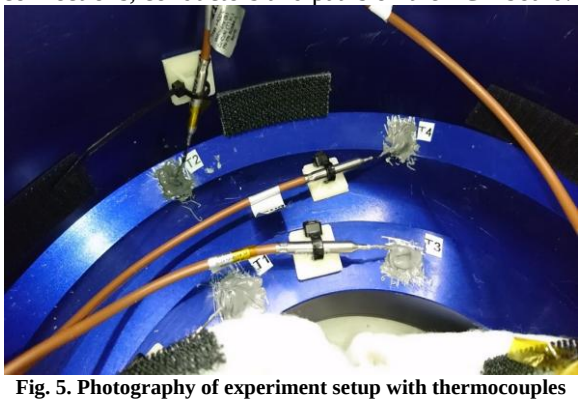


Fig. 5. Photography of experiment setup with thermocouples mounted in the module.

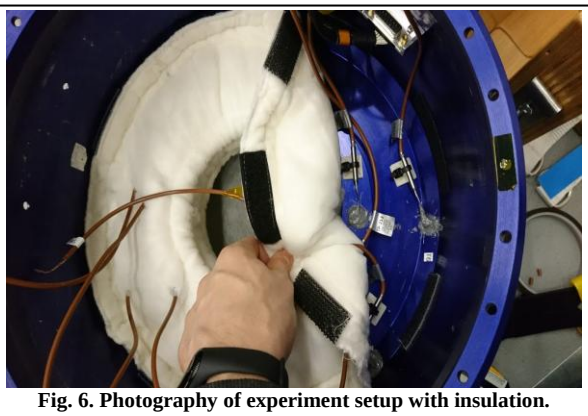


Fig. 6. Photography of experiment setup with insulation.

PRELIMINARY RESULTS

During the course of the experiment, over 50 000 temperature samples were acquired. This allowed for precise determination of heating process in various parts of the rocket. These were presented in Fig. 7.

As expected, temperatures rise highly after lift-off. This is especially visible in graphs of thermocouples close to rocket skin. There is a substantial lag between rise of temperature on skin and inside the module. This is due to substantial thermal capacity of the experiment part.

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REFERENCES

[1] Evans CA, Robinson JA, International Space Station ScienceResearch Accomplishments During the Assembly Years: An Analysis of Results from 2000-2008, NASA/TP–2009–213146, NASA, Houston, TX, 2009

[2] Dąbrowski A., Elwertowska A., Goczkowski J., Pelzner K., Krawczuk S., High-quality Experiment Dedicated to microGravity Exploration, Heat Flow and Oscillation Measurement from Gdańsk, SSEA-2018-60, Proceedings of the 2nd Symposium on Space Educational Activities, Budapest 2018

[3] Gierse A, et al., Experimental in-flight modal-analysis of a sounding rocket structure, Proceedings of 21st ESA Symposium on Rocket and Ballon related Research, Thun, Switzerland, Volume: ESA SP-721, 2013.

[4] T. L. Bergmann, A. S. Lavine F. P. Incropera, D. P. deWitt,, Fundamentals of heat and mass transfer, 120-128, CRC Press, 2007.

[5] M. Grulich et. al., SMARD-REXUS-18: Development and verification of an SMA based CubeSat solar panel deployment mechanism, Proceedings of 22nd ESA Symposium on Rocket and Ballon related Research, Tromsø, Norway, 2015. Trans. Roy. Soc. London, vol. A247, pp. 529-551, April 1955.

[6] Suslov D., Woschnak A., Greuel D., Oschwald M., Measurement techniques for investigation of heat transfer processes at European Research and Technology Test Facility P8, Proceedings of German Aerospace Congress 2005

[7] Balaji C., Reddy B.K., Herwig H., Heat Mass Transfer (2013) 49: 1771. https://doi.org/10.1007/s00231-013-1213-0

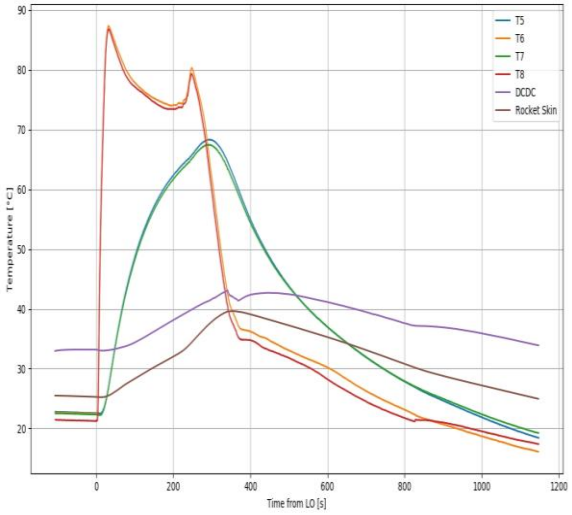


Fig. 7. Temperature profiles from thermocouples.

Further analysis is required to obtain heat flux density on the rocket skin. This will be presented in future papers by authors.

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