Mission Analysis and Design of a CubeSat Network

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1. Motivation & Objectives

In the framework of the QB50 project a network of 50 CubeSats will be launched to perform in-situ measurements of the spatial and temporal variation of atmospheric properties in the lower thermosphere at an altitude of 350 km to 150 km [1]. The project will demonstrate the possibility of using the small satellites as efficient and low-cost technology demonstrators. QB50 will be the first simultaneously launched CubeSat network and helps in gaining a better understanding of such complex missions.

The choice for conducting measurements in the lower thermosphere is influenced by several factors and constraints. The atmospheric properties in this region and their relationship to Earth's climate and space-weather like sun storms are yet not well known. This leads to larger uncertainties in lifetime and trajectory simulations, which the recently uncontrolled re-entries of UARS, Rosat or Phobos-Grunt have shown. Another influence factor is the mitigation of space debri creation and fulfillment of the 25 year lifetime requirement. The performance envelope of the chosen launch vehicle Shtil-1.2, which shall provide sustained and low-cost access to Earth orbit, restricts the reachable maximum altitude and a trade-off between number of satellites and altitude has to be performed.

The PhD main tasks will be the assessment of the atmospheric and aerodynamic input data, the mission design for QB50 with focus on the orbital dynamics of the network of 50 CubeSats and finally analyzing of concepts for deorbiting of satellites.

The first task deals with the aerodynamic characterization of the CubeSats. The flow-field around the satellite will be obtained with DSCM simulations using the software RGDAS. A database with the aerodynamic coefficient for different altitudes, attitudes and configurations will be generated. For the simulations a proper knowledge of the atmospheric conditions is mandatory. Therefore a detailed analysis of different existing atmospheric models will be made to assess the variations in the density distribution and the composition. Since the properties in the lower thermosphere are not well known, the uncertainty quantification is an important factor for the latter mission design.

The mission design of QB50 will be challenging and include several points to be looked at. First the development of an suitable deployment strategy for the 50 CubeSats is mandatory to reduce the collision risk to a minimum. The deployment also effects the spreading and therefore the global distribution of the satellites. This will be analyzed to obtain a suitable strategy and spreading for the distributed measurements in the thermosphere. Simultaneously 6 degree of freedom simulations of the 50 CubeSats will be performed using the software STK[1] or ASTOS[2] to obtain the trajectories and the behavior of the network. The

[1] Satellite Tool Kit, Analytical Graphics, Inc.

[2] AeroSpace Trajectory Optimization Software, Astos Solutions GmbH

network will be analyzed in terms of necessary number of satellites for global measurements. The results from the previous studies of the atmosphere and aerodynamics of the CubeSats will be used to predict the orbital life-time. The communication with the ground stations will be investigated in terms of coverage and communication time. A study of the collision risk with other satellites or debris could be performed.

The third task of the PhD deals with the effect of deorbiting concepts on the trajectory. These concepts like sails, fins or tethers are experiencing increasing popularity. DSMC simulations for different concepts and types mounted on a CubeSat demonstrator should be performed. In addition to that, 6 degree of freedom trajectory calculations will be performed to investigate their efficiency and effects on lifetime.

If the CubeSats will be launched in time during this PhD, the obtained measurements and trajectories will be analyzed and compared with the results from the atmospheric study and the mission design. This will help to further improve the atmospheric models for the lower thermosphere.

2. Challenges & Uncertainties

The challenge in the mission design of QB50 consists of the large number of parameters, the interconnection between them and their associated uncertainties. The proper prediction of the sun's activity for the launch time is difficult and only a crude statement according to the 11 year solar cycle can be made. Strong sun eruptions which are quite common during high activity periods can easily affect the lifetime of the CubeSats. Since the atmospheric models are based on the solar fluxes, the errors and uncertainties coming from the models will be amplified. Comparing different models, even with similar input, lead to discrepancies in terms of density values and global distribution. The inaccuracy for the density is still around 10 % to 15 % [2], even with the models improving over the last few years due to measurements obtained by the GRACE and CHAMP mission [3].

Since each CubeSat will be designed by a different university and the scientific payload will differ in terms of weight, size and external parts like additional sensors and communications links, the ballistic coefficient can not be assumed to be equal. The coefficient is also influenced by the satellite attitude and, most probably not all CubeSats will be perfectly aligned to the free-stream velocity direction. This results in varying atmospheric drag forces which have

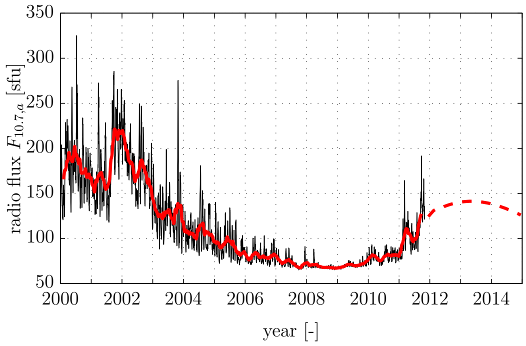

Figure 1: 10.7cm radio flux with prediction

to be considered during the mission planing and especially for the deployment strategy.

3. Comparison of atmospheric models

Currently the two experimental models JB2008 and NRLMSISE00 and the physical model TIEGCM have been analyzed. The launch of QB50 is scheduled for the summer 2014 and the input values have been chosen according to the prediction for this date, e.g. shown in Fig. 1. The deviation of the prediction has been coupled with the $1\,\sigma$ standard deviation of a comparable situation in the past.

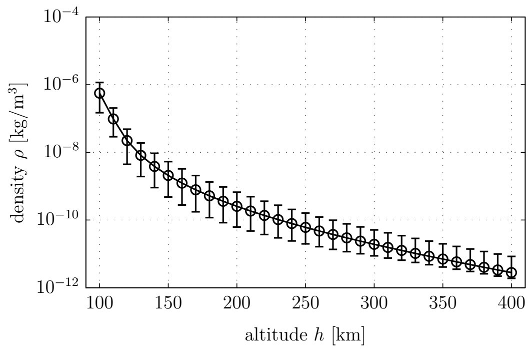

Figure 2: Density from US76 with obtained uncertainty

For the comparison all input parameters have been varied by the obtained deviations to simulate all realistic combinations. A horizontal grid resolution of 5^o and vertical resolution of 5 km have been used. The mean, maximum, minimum and the values of the daylight and night side of the earth have been calculated for each horizontal layer and then afterwards compared to the U.S. Standard Atmosphere US76. Combining the results of all models a possible uncertainty can be obtained for the density, shown in Fig. 2, or other values like neutral temperature.

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References

[1] J. Muylaert, QB50, an international network of 50 double CubeSats for multi-point, in-situ measurements in the lower thermosphere and for re-entry research, 1st QB50 Workshop (2009).

[2] D. A. Vallado, D. Finkleman, A Critical Assessment of Satellite Drag and Atmospheric Density Modeling, Revision to paper AIAA-2008-6442.

[3] B. R. Bowman, W. K. Tobiska, F. A. Marcos, C. Y. Huang, C. S. Lin, W. J. Burke, A New Empirical Thermospheric Density Model JB2008 Using New Solar and Geomagnetic Indices.