IAA-AAS-CU-17-10-03
AAS 17-988

PROJECT OF THE TECHNOLOGY TESTING OF THE FORMATION FLIGHT OF LOW-ORBIT NANOSATELLITES

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Space Research Department of Samara University is currently working on the design of the nanosatellite SamSat-M containing propulsion system. Nanosatellite is aimed to test the maneuvering technology on orbit and to test the technology of small space debris inspection. It is supposed that the formation will contain only two nanosatellites. The first one (SamSat-M with the propulsion system) will test inspectoral movement and the technology of keeping of the certain distance to the second one and de-orbiting. The second nanosatellite will be a target for the first one and, at the same time, it will have its own scientific experiment. It is supposed that these nanosatellites will be launched at low orbit of 300-400 km. It is also planned to use existing low-orbit communication satellite systems like Iridium and Globalstar to provide the intersatellite link.

INTRODUCTION

The main problem of usage of low orbits is a short orbital lifetime of a satellite. Despite this, nanosatellites of CubeSat format, which is popular today, are used at these orbits. It prevents the growth of the amount of space debris, as nanosatellites do not have its own means for de-orbiting after finishing of the active part of the mission. At this type of orbits nanosatellites can perform various tasks of monitoring of the Earth atmosphere, testing of new materials and technologies, providing new services based on new information and communication technologies. Even very low orbits (altitude about 200-300 km), despite small orbital lifetime (from one week to several months), may be used for short-time missions like studying of entering to the atmosphere or investigation of lower atmosphere.

Space Research Department of Samara University is currently working on the design of the nanosatellite SamSat-M of CubeSat standard. Nanosatellite is designed to test the maneuvering technology on orbit and space debris inspection. It is proposed to equip the nanosatellite with a propulsion system to achieve these goals. The propulsion system is also being developed at the Space Research Department of the Samara University.

THE PROPULSION SYSTEM FOR THE NANOSATELLITE

The propulsion system, which is being developed for the nanosatellite SamSat-M mission, will be the main payload. The propulsion system is electrothermal and it will use a liquid working

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mass. The working mass is stored in a tank, which allows it to have mass of fuel about 450 g. The electric heater evaporates the working mass before entering the Laval nozzle, and then the resulting gas (steam) is superheated to the required temperature by the same heater.[1]

The working mass of SamSat-M is a water-alcohol mixture. It contents 40% of an ethyl alcohol by weight. Water, because of its low molecular weight, allows high steam expiration rates, is not toxic, has good environmental characteristics, but freezes with possible orbits temperatures in near-Earth. The choice of water-alcohol mixture is approved by the fact that it prevents the freezing of the working mass at –25°C with a relatively small loss of specific impulse. This mixture remains practically safe and does not cause any environmental damage.

The overall dimensions of the propulsion system do not exceed the internal volume of 1.5U. The maximum mass of the propulsion system (fully charged) is 1.55 kg. Expected total impulse of velocity is not less than 80 m/s. The magnitude of the output of a single impulse of velocity is 0.1 m/s with an error not more than 10%. The duration of each velocity impulse is 3 s. The model of the propulsion system is shown in the figure 1.

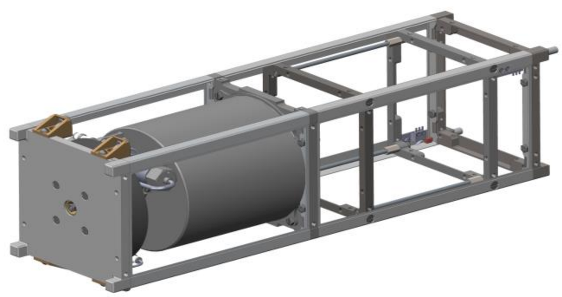

Figure 1. The propulsion system.

The electrothermal propulsion system consists of a tank with a liquid working mass, a distributor with a check valve, a set of heaters and actuators - Laval nozzles (one is for braking and four are for acceleration). Accelerating nozzles are mounted on the nose frame at an angle to the longitudinal axis. Such a setting of the accelerating nozzles will prevent the loss of thrust in the inelastic collision of the working mass molecules in a deep vacuum with the side walls of the nanosatellite during the orbital flight. The braking nozzle is mounted on a fiberglass plate attached to the end of the nanosatellite, along the longitudinal axis.

In Figure 2, for the sake of clarity, the main components of the propulsion system are marked. Tank with pressure-fed system 1. The working mass is fed from it in the controllable distributor 3 by stepper motor 2. The stepper motor rotates the distributor shaft from the neutral (closed) position by 45° counter-clockwise for the braking impulse, or by 45° clockwise for accelerating impulse. It returns to the neutral position after each impulse. The time while the distributor shaft in the open position determines the amount of the working mass. This time is determined by experiment.

For the acceleration impulse a portion of the working mass goes to the accelerating channel of the heater block 5. Then, the superheated steam flows through the collector 4 to the accelerating nozzles 6.

For the braking impulse a portion of the working mass goes to the braking heater located closer to the frame, after which the superheated steam of the working mass enters the braking nozzle.

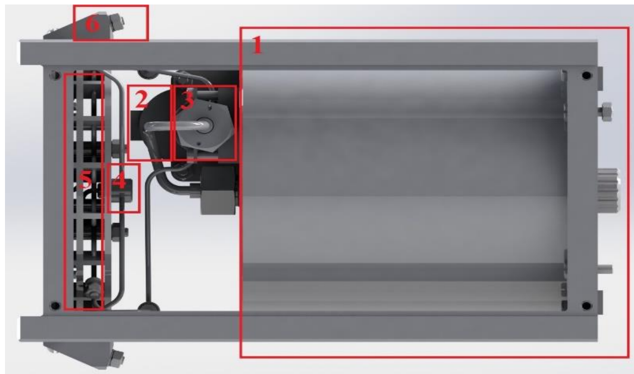

Figure 2. The main components of the propulsion system.

To power the heaters of the propulsion system requires a large amount of energy. In this regard, the onboard power supply system of the nanosatellite will be supplemented by supercapacitors of Maxwell company to ensure the delivery of the required high power to the heater. This will be first applied to spacecraft of this class.

CURRENT STATUS OF THE PROJECT

At present, the project of the first modification of the nanosatellite SamSat-M that includes the developed propulsion system has been developed. The propulsion system will be a payload. The nanosatellite will test the performance of the propulsion system and will keep the altitude of an orbit and test de-orbiting.

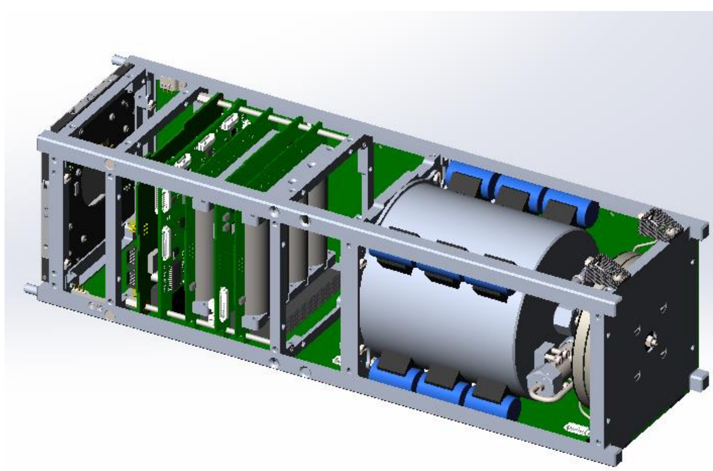

Figure 3. The nanosatellite SamSat-M for propulsion system test.

It is assumed that the propulsion system is located in front of the nanosatellite SamSat-M mass center along the velocity vector. Since the propulsion system is more massive than other structural elements, this arrangement allows to provide a sufficient static stability with the use of passive aerodynamic attitude control of the nanosatellite.

Figure 3 shows the model of the SamSat-M nanosatellite being developed for testing the propulsion system. This modification of the nanosatellite has static stability 31 mm.

The active attitude control system will be installed on the SamSat-M in addition to the passive aerodynamic attitude control system. It is designed and manufactured in Samara University and it is universal for nanosatellites of the CubeSat format. This system is designed to reorient and stabilize the nanosatellite due to the use of the Earth's magnetic field and consists of flat magnetic coils, which are boards and they are installed under the solar battery panels. It is planned to place the boards in three mutually perpendicular planes.

Nanosatellite SamSat-M has a passive damping system consisting of a set of hysteresis rods to dissipate the energy of the attitude motion of it.

Described attitude control system, consisting of both active and passive elements, before each actuation of the propulsion system provides the necessary orientation of the nanosatellite along the orbital velocity vector: angular velocity < 0,1°/c, angle of attack < 10°.

At the moment, the orbit of the SamSat-M nanosatellite has not been finally determined. This is the reason why an analysis of the propulsion system efficiency was made when it operated in the modes: 1) keeping the orbit, 2) de-orbiting. Analysis was mad for a range of altitudes from 300 to 500 km. The analysis was carried out by simulation of the nanosatellite motion along the orbit in the noncentral gravitational field of the Earth and taking into account the atmospheric drag. The density of the atmosphere in the orbit was assumed to be equal to the values at an average level of solar activity.

Figure 4 shows the dependence of the number of impulses that the developed propulsion system has to make in one turn to keep the orbit. Figure 5 shows the dependence of the nanosatellite SamSat-M descent time from the selected initial altitude to 200 km with a certain number of impulses per one turn.

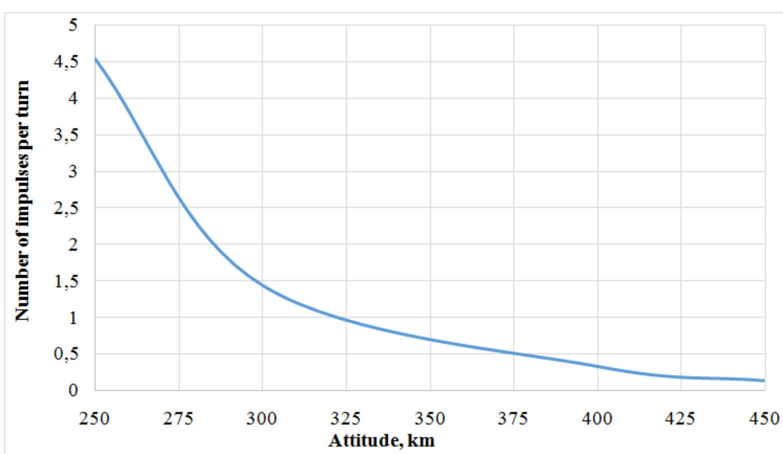

Figure 4. Keeping orbit with propulsion system.

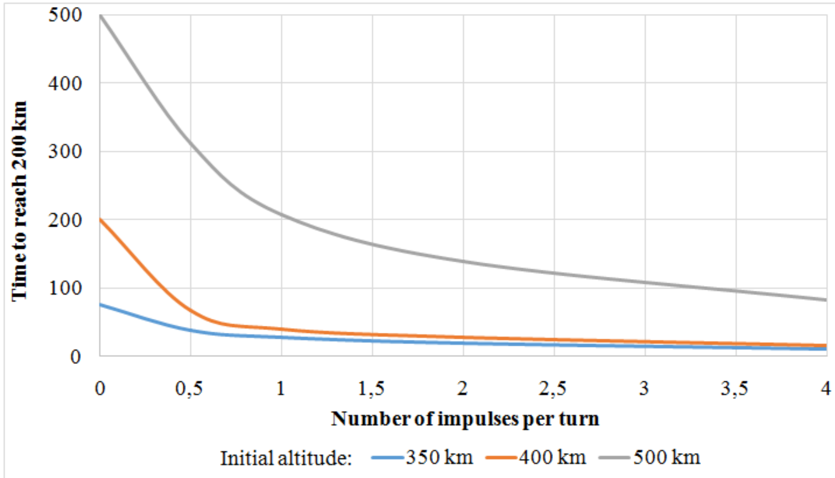

Figure 5. De-orbiting with propulsion system.

The simulation was performed assuming that each impulse produced by the propulsion system is directed along the velocity vector for the case in Figure 4 and in the direction opposite to the velocity vector for the case in Figure 5.

It is obvious that the frequency of the impulse is directly proportional to the amount of energy spent on heating the working mass. The calculation of the energy balance showed that this modification of the nanosatellite can give a velocity impulse every 40 minutes, which roughly corresponds to two impulses per turn.

FUTURE WORK ON THE PROJECT

After flight verification of the propulsion system, it is planned to create a new modification of the nanosatellite SamSat-M. It will be designed to test the technology of formation flight. It is planned that SamSat-M will be launched together with the base spacecraft, which will be the reference point for SamSat-M. Technology will be developed to keep the distance between satellites in the range from 500 m to 100 km.

In order to provide a formation flight, velocity impulses in a given direction are required with high accuracy. The new modification of the nanosatellite will have an attitude control system based on reaction wheels. This is also because that in formation flight the impulses should be produced not only in the direction of the orbital velocity vector. So the nanosatellite should have more efficient means for reorienting.

For formation flight it is necessary to solve the problem of relative orientation and navigation.[2] To ensure rapid data exchange between two satellites, it is planned to use low-altitude satellite communication systems, for example, Iridium or Globalstar. The Iridium system is more preferable, since it has inter-satellite communication. The data transfer rate through the Globalstar system is higher, but to use it you need to estimate the number and time of possible communication sessions.[3] For example, in Figure 6, estimates of the total duration of possible communication sessions through the Globalstar system during the day are presented.

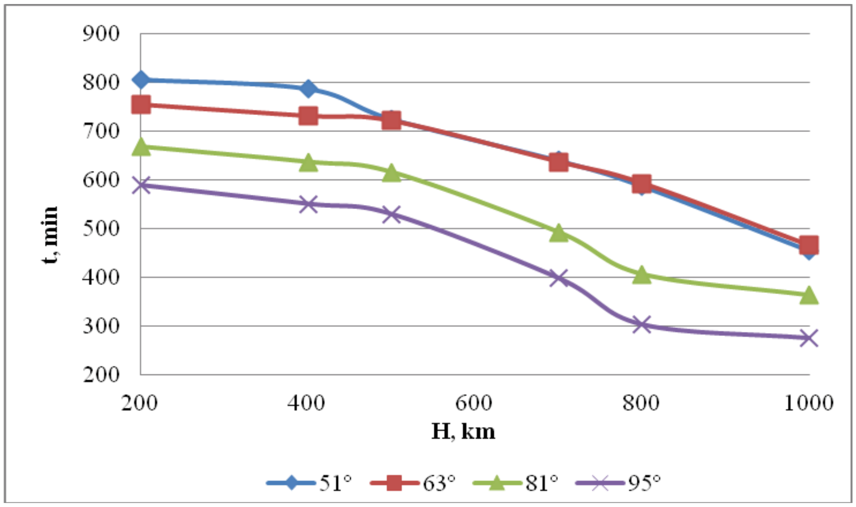

Figure 6. The communication time via Globalstar.

After determining of the platform the satellites will be deployed from, it is necessary to analyze the parameters of their deployment, since it depends on how far they are removed from each other before the onboard systems are switched on[4, 5] and what is the value of the angular velocity and must be reduced to provide the required orientation when the first impulse will be made [6, 7]. This fact plays a significant role, since it determines the amount of energy spent at the initial stage of the flight.

CONCLUSION

Thus, at present, a nanosatellite with a propulsion system is being developed at the University of Samara for the development of formation flight technology. It is planned to create two modifications of this nanosatellite: the first one - for the propulsion system testing in space flight conditions; the second one - to test the maneuvering technology to provide formation flight.

ACKNOWLEDGMENTS

The research was supported by the grant from the Russian Science Foundation (project No. 17-79-20215).

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