Experiments and prospects for development of science and educational “AIST” micro-satellites

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Sputnik-1 - the first Earth’s artificial satellite

Satellite classification based on mass characteristics:
- femto — up to 100 g;
- pico — up to 1 kg;
- nano — 1–10 kg;
- micro — 10–100 kg;
- mini — 100–500 kg;
- small — 500–1000 kg;
- large — more than 1000 kg.
Main technical characteristics:
- initial orbit parameters: near-circular $H = 575$ km; inclination $i = 64.9^\circ$;
- mass – 38 kg (53 kg with adapter);
- dimensions: $400 \times 500 \times 600$ mm;
- lifespan – up to 3 years;
- the spacecraft performs non-oriented flight;
- radio circuit: 2 receivers 145MHz, 2 transmitters 435MHz.
The “AIST” small satellite was designed to solve the following tasks:

• development of a unified compact space platform with weight up to 100kg for long-term (up to 3 years) research, technological experimentation and implementation of modern educational programs;
• creation of an information link in the amateur frequency bands for communication of educational and scientific nature from the universities of Samara region to another Russian and foreign universities;
• monitoring the Earth's magnetic field and study of the problems of microgravity, the implementation of long-term compensation modes of the low-frequency acceleration component on board the spacecraft to a minimum value that does not exceed the range of values from $10^{-5} \ g_0$ to $10^{-7} \ g_0$ (“MAGCOM” scientific equipment);
• study of the behavior of high-speed mechanical particles of natural and artificial origin, interacting with the surface of the ionization sensor and the estimation of their parameters - mass and velocity; periodic measurement of the spatial position of the sun relative to the body axis coordinates of the spacecraft, followed by evaluation of the possible charged particle flows on its surface (“METEOR” scientific equipment);
• study of the level of electrification of the spacecraft and the dynamics of change in the surface charge;
• experimental space testing of new types of future photovoltaic arrays of gallium arsenide (GaAs), created using nanotechnology;
• development of the technology of associated launch of a small satellite into a working orbit with a heavy research spacecraft-carrier;
• development of production technologies for small non-hermetic spacecraft with highly integrated onboard equipment.
A technological prototype was manufactured in order to comply with the industry standard of ground satellite testing (“AIST” testing prototype).

Development iterations of the project during design stage

Testing and flight “AIST” satellites during radio hardware testing

Design space onboard of «Bion-M» №1 satellite

Satellite panel

Separation device
Ground testing

Vibration strength testing

Ground testing of the separation device

Development testing

Thermal-vacuum test
Methods of orbital injection

Small satellite “AIST” RS43 as a part of spacecraft “BION-M” № 1 (associated launch)

Small satellite “AIST” RS41 at on "Volga" upper stage on rocket “Soyuz 2-1.V”

Adapter

“SKRL” satellites (2 pieces)

“Volga” upper stage
Launches

Launch from Baikonur cosmodrome 19.04.2013 г.

“AIST” satellites trajectories based on the NORAD data


**Initial parameters of the operational orbit**

<table>
<thead>
<tr>
<th>“AIST” RS43as</th>
<th>“AIST” RS41at</th>
</tr>
</thead>
<tbody>
<tr>
<td>– Orbit altitude 575 km</td>
<td>– Orbit altitude 625 km</td>
</tr>
<tr>
<td>– Inclination 64,9°</td>
<td>– Inclination 82,4°</td>
</tr>
</tbody>
</table>
Main scientific results of the project

The method of "floating limit" in the scheme of solving design tasks

\[
\begin{align*}
\mathcal{P}_i = \{ p_i : p_i \in P_{\text{out}} \subseteq \mathbb{R}^n \}, & \quad i = (1, N), \\
\mathcal{P}_{10} = (P_{101}, P_{102}, P_{103}, P_{104}, P_{105}) ^T, &
\end{align*}
\]

Diagram of average daily temperature values of satellite’s onboard systems

Parameters of the angular orientation of small satellite

Development of fundamental and applied science

Earth's magnetic field researches

Formation of spatial maps of micrometeorites situation

Broad implementation of the results in the educational process

Development of multi-agent technology of work with satellites

Distributed space laboratory was created with orbital and ground segments
The telemetry data obtained from the “AIST” satellite constellation is deeply integrated into the educational process of Samara University, and are implemented into laboratory, practical and diploma work for bachelor, specialist and master students.

Research is conducted in the following areas:
- Analysis of the navigational data of the "AIST" satellites acquired from the NORAD system in order to assess the evolution of orbits and to predict the position of the satellites in orbit at a given time.
- Determination of the zone of satellite visibility for different ground receiving stations at a given time.
- Analysis of the temperature values on the satellite’s surface (including temperature sensors on solar panels, payload, battery, command and control navigation system - 30 channels in total), depending on the light and shadow conditions in orbit and operating modes of equipment.
- Modeling of the Earth's magnetic field parameters according to the data of the "MAGKOM" system in various orbits of "AIST" satellites; Study of the processes of orientation and stabilization of a satellite using magnetometers.
- Modeling the operation of the power supply system of the satellite, taking into account telemetry data on the charge-discharge level of the battery and the system’s voltage level.

More than 50 diploma projects have been defended on the topic of creation of scientific and educational small satellites during the last 5 years, more than 20 graduate works of bachelors have been prepared, 9 master's and 7 candidate's dissertations have been defended.
Ground control station in Samara University

Antenna complex of the Ground control station of Samara University

Operator’s workstation

Ground station software

Ground station center
Primary processing of telemetric information

Secondary processing of telemetric information

Ground control center scheme of Samara University
Analysis of the influence of the light-shadow environment on the payload performance

Minimum daily battery capacity, taking into account the light-shadow situation (satellite “AIST” RS41at)

Influence of the light-shadow environment on the parameters of the power supply system

Minimum daily battery capacity, taking into account the light-shadow environment (satellite “AIST” RS43as)
Failure rate of the “AIST” satellites onboard equipment

Failure rate of the “AIST” RS43as

Early failures

Period of normal operation

Wear-out failures

Failure rate of the “AIST” RS41at
Combined failure rate

Satellite failure distribution by type

- Failures due to the battery degradation
- Failures due to the payload malfunction
- Failures due to the local radiation exposure
- Failures of unknown origin

Combined failure rate:
- AIST RS41at failures
- AIST RS43as failures

Satellite failure distribution by type:
- 44% unknown
- 39% payload malfunction
- 13% radiation exposure
- 4% battery degradation

01.04.2013, 01.06.2013, 01.08.2013, 01.10.2013, 01.12.2013, 01.02.2014, 01.04.2014, 01.06.2014, 01.08.2014, 01.10.2014, 01.12.2014, 01.02.2015, 01.04.2015, 01.06.2015, 01.08.2015, 01.10.2015, 01.12.2015, 01.02.2016, 01.04.2016, 01.06.2016, 01.08.2016, 01.10.2016, 01.12.2016
The average daily temperature of the outer side of the faces of the "AIST" small satellite RS-43as lies in the range from +10 to +50 °C, except for the panel +X.

The average daily temperature of the outer side of the faces of the "AIST" small satellite RS-41at lies in the range from +10 to +50 °C, except for the panel +X.
The average daily measured temperatures of the "AIST" small satellite RS-43as lies in the range from 0 to +60 °C, except for the panel + X.

The average daily measured temperatures of the "AIST" small satellite RS-41at lies in the range from 0 to +60 °C, except for the panel + X.
The average daily measured temperatures of the "AIST" small satellite RS-43as lies in the range from +10 to +60 °C, except for the panel + X

The average daily measured temperatures of the "AIST" small satellite RS-41at lies in the range from +10 to +60 °C, except for the panel + X
"AIST-2D" technological small spacecraft has developed in cooperation with SRC "Progress" in the framework of the complex project on creation of hi-tech production in accordance with the decree of the Government of the Russian Federation of 09.04.2010, №218.

"AIST-2D" was launched on 28 April 2016 from the new Vostochny cosmodrome by space rocket "Soyuz-2" phase 1A with upper stage "Volga".
## Overview of the “AIST-2D” small satellite

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operational orbit</td>
<td></td>
</tr>
<tr>
<td>- orbit type</td>
<td>SSO</td>
</tr>
<tr>
<td>- near-circular, average height, km</td>
<td>490</td>
</tr>
<tr>
<td>Resolution, $H=490$ km, $m$</td>
<td>1.48/1.9-2.1</td>
</tr>
<tr>
<td>- In panchromatic mode (from 0.58 to 0.80 mkm)</td>
<td>4.44</td>
</tr>
<tr>
<td>- in multispectral mode</td>
<td>122</td>
</tr>
<tr>
<td>(RGB from 0.45 to 0.52 mkm; from 0.52 to 0.60; from 0.63 to 0.69 mkm)</td>
<td></td>
</tr>
<tr>
<td>- In infrared (from 8 to 14 mkm)</td>
<td>122</td>
</tr>
<tr>
<td>The capture band for the visible range equipment, km</td>
<td>39.6</td>
</tr>
<tr>
<td>The capture band for the equipment of the infrared range, km</td>
<td>47</td>
</tr>
<tr>
<td>The duration of the survey route, s</td>
<td>3...300</td>
</tr>
<tr>
<td>The speed of transmission of target information to the ground receiving point, Mb / s</td>
<td>150</td>
</tr>
<tr>
<td>Average daily payload power consumption, W</td>
<td>300</td>
</tr>
<tr>
<td>Active life, years</td>
<td>3</td>
</tr>
<tr>
<td>Mass, kg</td>
<td>530</td>
</tr>
<tr>
<td>Payload mass, kg</td>
<td>150</td>
</tr>
</tbody>
</table>

- **Solar panel**
- **DC-1**
- **Infrared payload**
- **Ground orientation system**
- **Optical payload**
- **Transmitting antenna**
- **Receiving antenna**
- **Meteor-M**
- **DMS-1**
Images obtained with the “AIST-2D” satellite
On-board laboratory for experimental study of the influence of space environment factors on samples of optical elements, coatings and electronic components.

First scientific results, obtained in the first 4 months of operation:

1. Weight loss of polyimide coating
2. The change in the coefficient of glass transmittance
“KMU-1” scientific payload

Angle of declination

Variation of micro-acceleration modulus

Angle of declination

Electric magnets

KMU-1 control block

Solar sensor

Illumination sensors
“ METEOR-M ” is designed for recording the parameters of high-speed microparticles (micrometeoroids and debris particles) in the near-Earth space.

First obtained results:
- The temperature of the unit is within the permissible value range from 0 to 9°C.
- Analysis of “METEOR-M” telemetry data has shown that the equipment is operating in the normal mode.
- Telemetry packages are generated without errors.
- The collision of high-speed microparticles with the target of the sensor has not yet been recorded.
Purpose:
- Study of changes in the parameters of experimental lithium batteries in the charge-discharge cycle;
- The study of the change in the parameters of the elements of experimental solar batteries (VAC);
- An experimental study of a fiber-optic displacement sensor.
Production and testing facility for high-tech manufacturing of small spacecraft

On the basis of Samara University established the production and testing facility for high-tech manufacturing small spacecraft for scientific and application purposes with various types of target equipment (remote sensing: electro-optical, hyperspectral, radar, infrared). The complex includes an assembly hall, cleanrooms (cleanliness class ISO 8,5), coordinate measuring machine ZEISS MMZ G 20/30/20, servo-hydraulic testing machine SHIMADZU EHF-EV100kN, vibration test system, Data Physics, LE-2016/DSA10-200K, thermal complex, climatic chambers and other high-tech equipment.
The development of the “AIST” project

The range of small technological spacecraft of “AIST” series

“AIST” - 39 kg

“AIST-3” - 170 kg

“AIST-2D” – 530 kg
Objectives of the project:
- development of target equipment of SPE "OPTEKS", ground controls, receiving and processing information and methods of processing remote sensing data with high resolution;
- development of monitoring system of radiation environment in outer space;
- check for new technological solutions, used in the manufacture of small satellites;
- development of program and technical means of the unified small space platform;
- development of new automatic identification system which serves to identify ships and providing relevant data about their size, date and other indicators.

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<tr>
<td>- orbit type</td>
<td>SSO</td>
</tr>
<tr>
<td>- near-circular, average height, km</td>
<td>400-700</td>
</tr>
<tr>
<td>The motion control system of a small satellite provides:</td>
<td></td>
</tr>
<tr>
<td>- quieting a small satellite after separation from the launch vehicles;</td>
<td></td>
</tr>
<tr>
<td>- uniaxial orientation of a small satellite by magnetic induction;</td>
<td></td>
</tr>
<tr>
<td>- uniaxial orientation to the Sun;</td>
<td></td>
</tr>
<tr>
<td>- the reorientation of a small satellite.</td>
<td></td>
</tr>
<tr>
<td>The capture band on orbit of 490 km, km</td>
<td>11</td>
</tr>
<tr>
<td>Resolution on orbit of 490 km, m</td>
<td>1,375</td>
</tr>
<tr>
<td>The speed of transmission of target information to the ground receiving point, Mb / s</td>
<td>130</td>
</tr>
<tr>
<td>Active life, years</td>
<td>3</td>
</tr>
<tr>
<td>Mass, kg</td>
<td>till 170</td>
</tr>
<tr>
<td>Mass of payload, kg</td>
<td>till 20</td>
</tr>
</tbody>
</table>
Thank you for attention!

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