Present and Future of Russian Space Device Engineering

Alexey Romanov
Deputy General Director for Research & Development

SkolTech, 9 February, 2016
1. RSS Historical Heritage

2. GLONASS/GPS Technologies Applications in the Russian Economy

3. RSS Program on Development of Small Satellites for Different Applications

4. Conclusions
The enterprise has been founded in 1946. Now it is one of the six enterprises participating in establishment of domestic rocketry

The first council of the chief designers of missiles and space systems

Korolyov Sergey Pavlovich
Chairman

Barmin Vladimir Pavlovich
Chief designer of refueling and start equipment

Glushko Valentin Petrovich
Chief designer of missile engines

Pilugin Nikolay Alekseevich
Chief designer of autonomous control systems

Ryazansky Michail Sergeevich
Chief designer of radio systems for control the missiles, ranges, space radiotechnical means and space systems

Kuznezov Victor Ivanovich
Chief designer of gyroscope systems
HISTORICAL HERITAGE

Systems for radio control of long-range missiles

Automated complexes for control of the satellites in near, middle and deep space

Search & rescue space system COSPAS-SARSAT

Satellite communications and relay systems S/C control systems and scientific equipment for space exploration («Moon», «Venus», «Mars»)


Radio systems for global positioning «Sphera» and «Tsyklon»

Radio technical complex for Global Navigation Satellite System GLONASS

Radio telemetry complexes for all Earth remote sensing Satellites («Resurs», «Meteor», «Ocean»)

Ship-based TT&C systems
PRINCIPAL ACTIVITY DIRECTIONS OF THE JSC RSS AS A HEAD ORGANIZATION IN THE BRANCH

- National segment of the space search & rescue system (92%)
- System for monitoring of resources, critically important objects and dangerous cargoes (80%)
- Information-telemetry systems (70%)
- System of Earth remote sensing, data receiving stations (70%)
- Range measurement complexes (50%)
- Electronic Component bases (80%)
- On-board system of command, control and communication (70%)
- Satellite navigation and geodetic systems, user equipment (70%)
- On-board transponders (70%)
GLONASS/GPS TECHNOLOGIES APPLICATION

- GLONASS system status and future prospects
- Advantages of combined use of GLONASS and GPS signals
- Examples of specific monitoring projects based on GNSS data in Russia
CURRENT GLONASS CONSTELLATION STATUS

The total number of satellites as of February 09, 2016 - 29

Block 54 (Launched on March 2014)
- «Glonass-M» № 36
- «Glonass-M» № 37
- «Glonass-M» № 38

Block 55 (End of 2014)
- «Glonass-M» № 39
- «Glonass-M» № 40
- «Glonass-M» № 41

Test launch (Dec 2010)
- «Glonass-M» № 21
- «Glonass-M» № 18
- «Glonass-M» № 19
- «Glonass-M» № 20
- «Glonass-M» № 22
- «Glonass-M» № 23
- «Glonass-M» № 24
- «Glonass-M» № 25
- «Glonass-M» № 26
- «Glonass-M» № 27
- «Glonass-M» № 28
- «Glonass-M» № 29

CDMA signal (L3 band)
- «Glonass-K» № 1
Objectives:
- All types of high accuracy service
- Integrity for critical safety applications

DATA PROCESSING FACILITY
- Master Center
- Back-Up Center

INTERNET

GNSS CONSTELLATION

BROADCASTING FACILITY
- L1/L3 GLONASS
- L1/L5 SBAS
- NTRIP
GLONASS SYSTEM USAGE

Transport
- Traffic and transportation control

Agriculture
- High-accuracy tillage, Fertilization optimization, yield control

Power Production
- Power networks synchronization

Telecommunications and Data Transfer
- Data flows synchronization, capacity growth

Construction
- High-rise buildings, bridges, roads construction

ERA-GLONASS and public safety
- Road accident emergency response system

Oil and Gas Transportation
- Flowrate control

Geodesy, Cartography and Land Regulation
- Land surveying, cadastral works, land mapping

Geosciences
- Earth modelling, geodynamics research, earthquakes registration

Personal Navigation
- Positioning, routing

MULTI-GNSS USER EQUIPMENT IS USED (GENERALLY GLONASS/GPS)
EXAMPLES OF SPECIFIC GNSS PROJECTS IN RUSSIA

- Global vessel monitoring system based on satellite AIS technology
- Space vessel monitoring system for fisheries
- Projects in vehicle tracking
- ERA GLONASS project: saving lives
GLOBAL VESSEL MONITORING SYSTEM BASED ON SATELLITE AIS TECHNOLOGY

Space search and rescue system for personal buoys consumers

COSPAS – SARSAT MEO satellites (GLONASS-K, GPS, GALILEO)

Space based AIS

GLONASS
GPS
Nanosatellite

Out of coverage coastal AIS

AIS data

30 miles

Costal AIS coverage zone

AIS land based station

406 MHz

Accident, radiobeacons activation

MEOLUT – MEO local user terminal
MCC – mission control center
SAR - Search and rescue services
SPACE VESSEL MONITORING SYSTEM FOR FISHERIES

GLONASS/GPS satellites

Communication systems
- Inmarsat
- Iridium
- Meteor-M / Kurs
- Gonets

Regional monitoring centers
(Murmansk, Petropavlovsk-Kamchatsky)
MAJOR PROJECTS ON GLONASS/GPS VEHICLE TRACKING

- Police cars management system
- Buses MUE «Sochiavtotrans»; MUE «Lazarevskoe»
- JSC «GMK «Norilsky nikel»
- GLONASS/GPS in-car navigation
ERA GLONASS PROJECT: SAVING LIVES

**Functions of ERA GLONASS:**
- Communication of accident location coordinates with control center
- Vehicle movement parameters control
- Theft prevention
- Navigation
- Loudspeaker communication
GLONASS/GPS technology applications are actively implemented in Russia.

Combined use of signals from multiple GNSS is important

GLONASS performance is improving

- Introduction of CDMA signals on a new GLONASS-K spacecraft
- Further development of SDCM network
- 100% of global availability will be guaranteed by the end of 2010

Several monitoring projects based on satellite GNSS and AIS technologies are currently under development
1. The 10\textsuperscript{th} anniversary of TNS–0 launch: lessons learned
2. TNS–0 #2: status of «Radiomet» project and ISS experiment
3. Ionoshperic Radiotomography Nanosats cluster
4. «CosmoAIS»: space qualification of payload onboard «Resours-P» #2 satellite
5. Conclusions
The first Satellite in the world was Russian microsatellite «Sputnik» launched on October 4, 1957 with a total mass of 83.6 kg.
BASIC PRECONDITIONS FOR PROGRAM DEVELOPMENT

- Enhance of research and commercial activity
- Acceleration of onboard equipment miniaturization
- Using of perspective technologies of small satellites control and data transfer
- Integration to the world community of future space systems designers
- Teaching graduated and post graduated students inside RSS corporation
| General concepts of satellite development | - refusal from “service platform and payload are separate” and application of “satellite as flying device” concept;  
- net and interactive methods of super-small satellite development |
| --- | --- |
| Attitude control systems | - application of passive/active geomagnetic attitude control systems  
- MEMS usage in electromechanical attitude control systems |
| Command & Telemetry Systems | - united transponders for command and telemetry data  
- high-rate telemetry through ERS-data downlinks  
- satellite communication systems and Internet technologies application for flight control |
| Observation data downlink | - progress in data packing  
- application of L- and S- range downlinks |
| Electronic & optoelectronic instruments | - application of COTS-components (photo- & video cameras, controllers, sensors, etc.) |
| Thruster units for orbit correction | - application of high-effective, low energy microthrusters (plasma electro-reactive, cold-gas thrusters, etc.)  
- new concepts of orbit correction (solar sail, etc.) |
The main goal was space validation of:

- Satellite control via *Globalstar communication satellites, mobile phone and Internet*
- Satellite tracking with the help of *COSPAS-SARSAT trasmitters*
- Onboard integrated information system *IBIS-0*
- Passive magnetic *attitude control*
- Experimental sensors of *SUN and horizon*
- New type of Li battery
- Using of concept *Satellite as flying device*
- Nanosatellite *Launch from ISS*
SATELLITE DEVELOPMENT LIMITATIONS AS DRIVERS FOR TNS-0 #1 MASS AND COST MINIMIZATION

- COST OF DESIGN AND LAUNCH MUST BE MINIMAL
- PROJECT DURATION: 1-2 YARS

CONSEQUENCES

- S/C MASS – NOT MORE THAN 10 Kg
- OPERATIONAL FUNCTIONALITY IS MINIMAL
- TIGHT SCHEDULE OF DEVELOPMENT

- Maximum usage of COTS components;
- Wide usage of global telecommunication networks and TT&C standards for S/C control and data transfer links;
- New nontraditional structures and materials for S/C construction;
- Development of simple S/C attitude control systems based on geomagnetic field orientation;
- Multifunction integration and onboard data processing of commands and telemetry information.
The TNS-0 #1 was manually launched by the Russian astronaut S. Sharipov at 11:30:15 UWT on March 28, 2005 from ISS during outdoor activity in open space.
FIRST GENERATION NANOSATELLITES

TNS - 0 #2
S/C control via global telecommunication networks

TNS - 0 #3
Space qualification of AIS payload

TNS - 0 #4
Atmospheric parameters study above anomaly light storm areas.
Research of structure of ionospheric currents systems

Satellite for educational purposes GRESat
Comparable analysis of different types of small S/C control. Testing of
active magnetic system for 3-axes attitude control

TNS - 2 #1
Testing of nanosat’s micro engines

TNS - 2 #2
Radio occultation monitoring of atmospheric and ionospheric
parameters
<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attitude control system</td>
<td>passive, magnetic</td>
</tr>
<tr>
<td>Power supply</td>
<td>solar batteries, 9 W</td>
</tr>
<tr>
<td>Power consumption</td>
<td>3-5 W (average), up to 18 W (peak)</td>
</tr>
<tr>
<td>Basic command and telemetry data link</td>
<td>via «Globalstar» modem «Qualcomm 1620», 1,6/2,5 GHz, 7400 bps</td>
</tr>
<tr>
<td>Reserve command &amp; telemetry data link</td>
<td>via UHF-modem «ROGER KD 9600», 435 MHz, 2400 bps</td>
</tr>
<tr>
<td>Lifetime in orbit</td>
<td>2 – 3 years</td>
</tr>
<tr>
<td>Temperature control system</td>
<td>passive</td>
</tr>
<tr>
<td>Total mass</td>
<td>5,1 kg</td>
</tr>
<tr>
<td>Mass of additional payload</td>
<td>up to 2 kg</td>
</tr>
</tbody>
</table>

TECHNOLOGICAL NANOSATELLITE TNS-0 #2 – NEXT GENERATION OF SATELLITE CONTROL TECHNOLOGY DEMONSTRATORS
The emitting device (G) is located onboard GPS or GLONASS satellite. A receiver is installed onboard a low-orbit satellite L of radio occultation space constellation. The altitude h of the investigated area is determined by geographical location of point T – perigee of radio ray GTL, where the distance TD from the Earth’s surface is minimal.

The coordinates of the investigated area are determined by latitude \( \varphi \) and longitude \( \lambda \) of point D on the Earth’s surface. Longitude \( \lambda \) is measured from Greenwich meridian \( Mg \). Designations F, E, A correspond to ionosphere layers F, E and atmosphere A. \( R1 \) and \( R2 \) – are the orbital radii of GPS satellite G and low-orbit satellite L of radio-occultation monitoring space system.
In addition to traditional meteosatellites, space systems of radio occultation monitoring can implement the following objectives everyday and globally:

- monitoring of high-resolution vertical gradients of temperature and geopotential for improving weather forecast and investigation of climate changes;

- monitoring of vertical gradients of humidity in atmosphere for investigation of water circulation global processes and climatology;

- investigation of internal stratosphere waves and their role in energy exchange;

- monitoring of electron density for investigation the influence on ionosphere status from Solar activity, technogenic impact and other factors, etc.
Space system «Radiomet» for GLONASS/GPS navigation signal radio occultation monitoring of lower atmosphere and ionosphere based on super-small satellites

Navigation satellites
GPS & GLONASS (48 total)

International GPS/GLONASS Services

Mission control center of «Radiomet»

«Radiomet» T&C datalink

Improved data of atmosphere/ionosphere models

Final data - physical parameters of lower atmosphere and ionosphere

Final users – meteorological, geophysical and other services
BASIC FEATURES

- Multy-system receivers. Low-orbit «Radiomet» satellites to be equipped with multi-system receivers in order to register signals from both GPS and GLONASS (also from Galileo – in future). That should increase up to 2...3 times the number of everyday observations of atmosphere and ionosphere.

- Optimization of orbits. Periodicity of observations to be increased for any area of the Earth (including near-equatorial and polar zones) due to optimization of the constellation orbit parameters (polar-orbit satellites to be added).

- Real-time on-board data processing. Delay of data delivery to final users to be crucially minimized (up to real-time). GPS/GLONASS signals will be thematically processed on board of «Radiomet» satellites. New radio holographic methods of navigation signal processing (developed by IRE RAS) will be applied. Final data of vertical gradients of the electron density, humidity, pressure, temperature etc. can be transmitted from satellites to users’ local stations.

- Miniaturization of satellites. «Radiomet» system incorporates super-small (less than 20 kg by mass) satellites based of nano- and microtechnologies. That would ensure significant cost savings of the satellite development and launch.
Artificial impact of shortwave RF radiation on the Earth ionosphere is a source of local heating of the ionosphere at different heights, which tends to the local areas of increase total electron concentration affecting onto proper operation of navigation and telecommunication satellite systems.
**Basic equations**

**Problem statement**

\[
\varphi = I = \lambda r_e \int N(h, \tau) dh
\]

\[
I(\beta, \tau_i) = \int_0^{h_2} \frac{F(h, \tau)(R + h)}{\sqrt{R^2 \sin^2 \beta + 2Rh + h^2}} dh
\]

**Inverse problem solution**

**Linear system formation**

\[
A_{JM} F_M = D_J, \quad D_J = \frac{\Delta I_J}{\Delta \beta}, \quad A_{JM} = \frac{\Delta L_M}{\Delta \beta}
\]

**ART algorithm for system solving**

\[
f^{k+1} = f^k + d_i - \frac{\langle a^i, f^k \rangle}{\langle a^i, a^i \rangle} a^i
\]
LITHOSPHERE-ATMOSPHERE-IONOSPHERE COUPLING MODEL (PULINETZ AND OUZUNOV (2010))

- LITHOSPHERE
- ATMOSPHERE
- IONOSPHERE

OLR anomalies

Air temperature growth

Latent heat release

Relative humidity drop

Jet streams

Temperature and pressure anomalies

Linear cloud structures formation

Ions thermal convection, charge separation, drift in electric field

Ions hydration—formation of aerosol size particles

Air ionization by $\alpha$-particles – product of radon decay

Deformations – pre-seismic radon emanations

VLF noises, high energy electrons precipitation

Longitudinal electron concentration variations

Anomaly atmospheric electric field effects

Atmospheric electric field growth

Boundary level conductivity changing
The first strong earthquake happened on 09.03.2011 at 2:45 am
M 7.2, N 38.424, E 142.836

Strongest earthquake happened on 11.03.2011 at 5:46 am
M 8.9, N 38.322, E 142.369
Relative STEC data from Yuzhno-Sakhalinsk ionosphere receiver
IONOSPHERE ELECTRON CONCENTRATION FIELDS VARIATIONS on 6th, 8th and 10th of MARCH, 2011
It was planned to deploy about 50 tomography stations in Russia till 2015
GLOBAL IONOSPHERE MONITORING VIA CLUSTER OF NANOSATELLITES

Perspective ionosphere monitoring system on the basis of nanosatellites cluster

Traditional ionosphere tomography scheme with ground stations provides only local monitoring

Signal receiving segment transfer into space makes it possible to realize the global ionosphere monitoring and to almost completely refuse from ground radiotomography receiving stations
1. «CosmoAIS» project description
2. Onboard and ground equipment
3. First results of AIS receiver testing onboard «Resource-P» #2 satellite
4. Satellite AIS data validation
5. Some future plans
6. Conclusions
THE WORLD OCEAN AS AN ILLEGAL ACTIVITY AREA

- Piracy
- Transnational crime
- Terrorism
- Illegal weapon transportation
- Drug trafficking
- Undocumented immigration
BASIC ELEMENTS OF SHIP MONITORING SYSTEM BASED ON SPACE AIS DATA

- CRPD – Center for Receiving, Processing and Disseminating Data
- GS – Ground Station for Receiving and Processing Data
<table>
<thead>
<tr>
<th><strong>Structure of the «CosmoAIS» nanosatellite</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mass</strong></td>
</tr>
<tr>
<td><strong>Dimensions</strong></td>
</tr>
<tr>
<td>- With undeployed antennas</td>
</tr>
<tr>
<td>- With deployed antennas</td>
</tr>
<tr>
<td><strong>Lifespan</strong></td>
</tr>
<tr>
<td><strong>Orbit</strong></td>
</tr>
<tr>
<td><strong>Attitude determination and control system</strong></td>
</tr>
<tr>
<td>Attitude along the Earth’s magnetic axis</td>
</tr>
<tr>
<td><strong>Stabilization accuracy</strong></td>
</tr>
<tr>
<td><strong>Power supply (max.)</strong></td>
</tr>
<tr>
<td><strong>Payload</strong></td>
</tr>
<tr>
<td>AIS onboard receiver gets AIS signals in frequency range from 156,775 to 162,025 MHz, with transmitted power from 1 to 12.5 W, with GMSK modulation at a transmission speed of 9600 bps</td>
</tr>
<tr>
<td><strong>Data transmission rate</strong></td>
</tr>
<tr>
<td>- Ground-space command transmission in UHF range, modulation</td>
</tr>
<tr>
<td>- Space-ground data transmission in VHF range, modulation</td>
</tr>
<tr>
<td><strong>Working frequency</strong></td>
</tr>
<tr>
<td>- Ground-space command transmission in UHF range</td>
</tr>
<tr>
<td>- Space-ground data transmission in VHF range</td>
</tr>
</tbody>
</table>
DESCRIPTION

The Center for Receiving, Processing and Disseminating data (CRPD AIS) is a complex of both telecommunications and server equipment.

CRPD is the central node of the ground infrastructure, its main functional core, which solves the issues of consolidation and integrated analytical processing of AIS data, received from regional GS, as well as presentation of the post-processing results to authorized end-users.

CHARACTERISTICS

1. CRPD AIS availability factor – no less than 0.9999.
2. Lifespan – no less than 50 000 h.
3. Provides connection of more than 30 thousand users simultaneously (possible to scale up to 100 000).
4. Power voltage – 220 V.
5. Power consumption – no more than 10 kW.
LOCATION OF REGIONAL DATA RECEPTION CENTERS AND AIS SPACE SEGMENT’S RADIO COVERAGE ZONES

GS AIS locations # 1-6 and coverage zones for LEO satellites (angle > 10°)
FIRST DECODED AIS MESSAGE FROM AIS RECEIVER, BASED ON BOARD OF «RESURS-P» #2 SATELLITE

17.01.2015 22:06:22
(76 E.L. 33 S.L.)

!AVDM.1.1..A.1815>5001R5LcTUe33:4I CLn06HH.0*
### VESSEL DATA COMPARISON RECEIVED BY AIS RECEIVER AND marinetraffic.com SERVICE ON 03.02.2015

<table>
<thead>
<tr>
<th></th>
<th>Time, UTC</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Direction</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marinetraffic</td>
<td>22:06</td>
<td>21.1088</td>
<td>-157.5537</td>
<td>291</td>
<td>7.0</td>
</tr>
</tbody>
</table>
DATA FLOW FOR THE DEMONSTRATION PROJECT OF SPACE AIS DATA USAGE FOR THE DEPARTMENT OF TRANSPORTATION

GS «Resurs-P» #2
- Telemetry, AIS data

AIS data
- CRPD
- GS «Resurs-P» #2, Moscow

GS AIS # 1-6
- Telemetry, AIS data

AIS data customer
- Department of Transportation («MoRe» system), Department of fishery (Special ship monitoring system)

CRPD – Center for Receiving, Processing and Disseminating Data
GS – Ground Station for Receiving and Processing Data
RESULTS OF AIS RECEIVER WORKING SESSIONS DURING 01.03.2015 – 30.07.2015

Total number of AIS receiver working sessions during flight tests from 01.03.2015 to 30.07.2015: 377
Total number of decoded messages: 33052
Number of detected ships: 4451

Messages Type | Quantity
--- | ---
Messages Type 1 | 27,547
Messages Type 2 | 67
Messages Type 3 | 3,514
Messages Type 5 | 470
Messages Type 18 (class B) | 30
Total number of messages | 33,052
Total number of ships | 4,451
Number of working sessions | 377
In the preliminary variant of the federal space program for 2016-2025 years, AIS receivers are planning to be placed on board of 11 satellites.
I. PROJECT MANAGEMENT:
Joining in the frame of a united project all necessary research and development works and additional funding, which tend to solving common tasks

II. CREATION AND FLIGHT TESTING OF NEW KEY TECHNOLOGIES, DEVICES AND SYSTEMS INSIDE PARTICULAR DESIGN:
Make an initiation of new design on space complexes development only if new key technologies, devices and systems clarified their realization and effectiveness

III. NEW SERVICES:
Scientific and technological support for all phases of space equipment design life cycle, program management, deployment and execution of public orders, quality monitoring during space systems building, development analytical support of FSP-2025

IV. PLANNING SCHEDULE OF PROJECT REALIZATION REDUCED TO 5-7 YEARS
LIFE TIME REDUCTION OF INNOVATION PRODUCTS

Average time to new product appearance, years

<table>
<thead>
<tr>
<th>Industry</th>
<th>1990s</th>
<th>2000s</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automobile industry*</td>
<td>1.5 - 2</td>
<td>2 - 3</td>
<td>6</td>
</tr>
<tr>
<td>IT</td>
<td>0.5 - 1</td>
<td>2 - 4</td>
<td></td>
</tr>
<tr>
<td>Electronics*</td>
<td>1 - 1.5</td>
<td>2 - 3</td>
<td>10-15</td>
</tr>
<tr>
<td>Space industry</td>
<td>5 - 7</td>
<td>7 - 10</td>
<td></td>
</tr>
</tbody>
</table>

Stuff education stages, years

<table>
<thead>
<tr>
<th>Stage</th>
<th>1990s</th>
<th>2000s</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational standards renovation</td>
<td></td>
<td></td>
<td>5-10</td>
</tr>
<tr>
<td>Basic university programs</td>
<td></td>
<td></td>
<td>4-6</td>
</tr>
<tr>
<td>Post university education</td>
<td></td>
<td></td>
<td>1-3</td>
</tr>
</tbody>
</table>

Global leaders decisions
Cisco Systems, HP, Alcatel-Lucent, IBM, Huawei, Microsoft, Oracle and others

During educational standards reformation industrial technologies changes several times.

The dynamics of life cycle of innovation product do not agree with current duration of educational process. It demands seeking of new educational approaches, including the usage of «continuous education» concept.

*- IDC analytical reports – 2011
Space information systems: Communications, Navigation and Remote sensing (150)

Systems of information processing, control and security (200)

Computation systems and complexes, including software preparation (200)

Machine building and production technologies in radio electronics (100)

Radio electronics systems and complexes (500)

Radio physics and remote sensing. Thematic information processing (250)

Information and measurements technique and telemetry (100)

Enterprises of the «Russian corporation of rocket and space device engineering and information systems» (JSC «Russian Space Systems»)
1. In conclusion, it is necessary to point out that, as a result of the «CosmoAIS» project, a sea vessel monitoring technology based on registering AIS signals was created.

2. Several key elements of the proposed technology were developed: the on-board AIS signal receiver; the «CosmoAIS» nanosatellite; ground stations; a Center for Receiving, Processing and Disseminating data; and special AIS decoding software.

3. At the moment flight tests are taking place on board the satellite «Resurs-P» #2; they should lead to further improvement of AIS data decoding algorithms. It is supposed that, with the help of the experience gained during testing, AIS data adaptive processing algorithms capable of working effectively on board a satellite will be developed.

4. In the near future the technologies developed within the framework of the «CosmoAIS» project are expected to be used for designing a specialized satellite for registering AIS/AIS-SART/ADS-B and COSPAS-SARSAT signals.
Thank you for your attention!

Alexey Romanov, Deputy General Director, Doctor of Technical Science, professor
Tel: +7 (495) 673-99-20; Fax:+7 (495) 509-12-00
E-mail: romanov@spacecorp.ru