A.M.Lyapunov methodology in modelling and dynamics analysis of stabilization and orientation systems

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This work is devoted to the specific problems of avia-, aerospace systems, with reference to problems of the mathematical modelling, analysis and synthesis for the systems of stabilization and orientation with gyroscopic controlling elements (with using two-degrees gyroscopes) [1-26]. The research is developing the reduction principle, solving the decomposition problem for such systems by elaborated approach, that is based on A.M.Lyapunov methodology, with the *deep strong roots from Mechanics*…(see Sections 1,2).

PRELIMINARY WORD ABOUT «MECHANICS»

The past year (2011) was declared a Year of Astronautics in Russia and the whole World in commemoration of the first space flight of a Man.
On 12 April 1961, for the first time ever, Yuri Alexeevich Gagarin, the First astronaut of the Earth, pilot in command of Vostok-1 spacecraft, got off the launch pad at 09:07 a.m. and performed a single orbit pass, which opened the next step in Space exploration with manned space flights. *The new stage of the Space Era for Mankind has begun.*
Congratulating again all our colleagues on this outstanding event, we (representatives of Kazan Chetayev School of Mechanics and Stability) should emphasize that this success was provided, first of all, by the development of the science of *Mechanics*, which is a basis for the entire Building of theoretical considerations and engineering achievements, including the ones in Astronautics.
The great Russian scientist **Konstantin Eduardovich Tsiolkovsky** was the Founder of the Epoch of Space exploration, with profound development of all the areas of basic and applied astronautics. This Epoch is associated with distinguishing achievements in Space exploration, implemented on the basis of fundamental science of Mechanics and thought-out engineering practice:
from the *first* Earth satellite (Soviet "Sputnik", 4 October 1957) – to the *first* Man on space orbit (Yu.A.Gagarin, 12 April 1961), to the satellite constellations and International space stations, to the space flights and lunar landing, to the interplanetary missions. It was generating the next *qualitative jump* in evolution of our Civilization in whole.
Scientific theories and approaches of *Mechanics* that are a basis for the space theoretical and applied researches, including complex engineering problems of space flights, are associated with the names of outstanding *mathematicians and specialists in Mechanics*, with *Russian* scientific and design Schools, which have been recognized all over the World.
They are the Academicians: **Leonard Euler**; **Alexander Mikhailovich Lyapunov**, Founder (**1892**) of the motion stability theory; **Nikolay Guryevich Chetayev**, who extended A.M.Lyapunov's concepts and theory to the whole scientific and engineering World, who founded Kazan Chetayev's School of Mechanics and Stability and organized (**1932**) Kazan Aviation Institute (KAI – A.N.Tupolev KSTU – NRU); **Sergey Pavlovich Korolev**, Chief Designer of rocket-space technique; **Mstislav Vsevolodovich Keldysh**, scientific Head of the USSR Space Program, Theorist in Astronautics – a brilliant specialist in *mechanics and mathematics*…
Close *interdisciplinary* relation between the fundamental and applied fields of science, between different disciplines has vital importance for the development of the elaborate rocketry and for successful solution of Space exploration problems. *Fundamental science*

“MECHANICS” and its sections play also an important role from this point.Important role of Mechanics as a fundamental basic scientific discipline for all another disciplines and for our Knowledge in whole is unquestionable.

Science “Mechanics” is investigating the motion and interactions of objects; and “Mechanics” supplies us with models and methods that are covering all areas of theory and engineering.

From Newton and Euler times, Mechanics has been the main tool for the research of celestial bodies and all the processes in near-Earth and outer Space.

At present “Mechanics” provides powerful tools for description of processes at micro level; also – for description of complex processes inside the Earth, in geodynamics; in the study of volcanic eruption processes, hurricane dynamics; in arctic exploration, …

Methods and models of Mechanics are giving very effective approaches for **multidisciplinary engineering applications,** including various domains: medicine, robot-technique, biomechatronics, mechanics of materials, nano-biotechnology; **complex problems of designing in aviation and space technique,** …

*“**Newtonian mechanics** is an unequalled achievement of physics (natural philosophy), the whole history of human civilization. **It is everlasting**. Its powerful tree is sprouting more and more bran-ches. Among them there are the branches that have grown from scions grafted on this tree and cultivated in other natural sciences”.*

G.G.Chyorny, Academician of Russian Academy of Science (Chairman of Russian National Commi-ttee on theoretical and applied mechanics, 2011).

*“… the stability theory and dynamic properties analysis of nonlinear systems – it is magnificent tree, possessing the classical stem, the **deep strong roots from Mechanics**, …, from important engine-ering problems, and the unfolded branches of mathematical constructions of exclusive beauty”.*

V.M.Matrosov, Academician of Russian Academy of Science (President of Academy of nonlinear sciences, 2001).

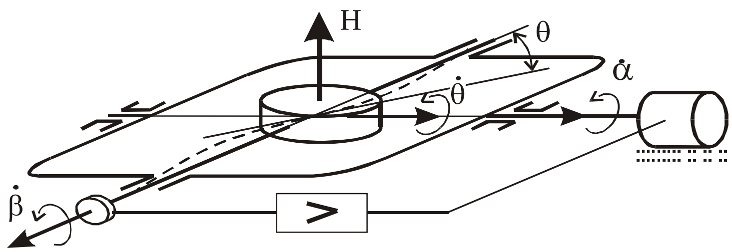
So, Mechanics is “main tree” for all disciplines. *Without Mechanics*, without close interdisciplinary links between the basic and applied spheres, between different disciplines of Science it is *impossible the Space exploration* and the development of our Knowledge in whole… Just MECHANICS plays the *most important role*, with its domains based on dynamic systems theory, on A.M.Lyapunov theory (120-th Anniversary of that we celebrate in this year) that has the *deep strong roots from Mechanics*…

After this Song about “Mechanics “ we come back to our research topic…

SECTION 1

Initial statement

The work is formed on the accepted basic assumption about global methodological connection between modelling problems and methods of A.M.Lyapunov stability theory [1,14,15]. Such approach ascends to a stability postulate (N.G.Chetayev) and to property of stability with parametrical perturbations (P.A.Kuzmin). The developed method establishes the uniform approach based on a singularity postulate (L.K.Kuzmina), with interpretation of examined objects as singular class systems, with combining of methods of the stability theory and perturbations theory. The dynamics of initial object is described by mathematical model with singular perturbations. Two basic principles (stability postulate and singular postulate) are accepted here as main axioms. From these points the systems of gyroscopic stabilization-orientation are treated as singular systems; working models for them are shortened models of *less order*. In practice these models are introduced on intuition, without the strict mathematical analysis of influence of the rejected members on dynamic properties. The problems of a correctness and qualitative equivalence are not discussed. The experiment is accepted as criterion of legality of these models "of an intuitive level". But the general theory is necessary [16-22]. For illustration some examples of a concrete physical-technical matter are considered. Let consider the system of one-axis gyroscopic stabilization, OGS;
let full initial model, IM (equations in the Lagrange form), is (1); here IM has 3 freedom degrees (k = 3).



IM
$$
\begin{aligned}
A\ddot{\beta} - H\dot{\theta} - H\dot{\alpha} &= -b_1\dot{\beta} + \dots \\
J\ddot{\alpha} + B\ddot{\theta} + H\dot{\beta} &= -b_2\dot{\alpha} - e\beta + \dots \\
B(\ddot{\theta} + \ddot{\alpha}) + H\dot{\beta} &= -b_3\dot{\theta} - c\,\theta + \dots
\end{aligned} \tag{1}
$$

In engineering practice the various shortened models (SM) for (1) are used as working models, in the assumption about fast gyroscope (*H* is big parameter): (2) or (3);
these models are introduced an intuitive level.

SM
$$
\begin{aligned}
- H\dot{\theta} - H\dot{\alpha} &= -b_1\dot{\beta} + \dots \\
H\dot{\beta} &= -b_2\dot{\alpha} - e\beta + \dots \\
H\dot{\beta} &= -b_3\dot{\theta} - c\theta + \dots
\end{aligned} \tag{2}
$$

SM
$$
\begin{aligned}
- H\dot{\theta} - H\dot{\alpha} &= -b_1\dot{\beta} + \dots \\
\tilde{J}\ddot{\alpha} + H\dot{\beta} &= -b_2\dot{\alpha} - e\beta + \dots \\
H\dot{\beta} &= -b_3\dot{\theta} - c\theta + \dots
\end{aligned} \tag{3}
$$

Model (2) is shortened model with 1,5 degrees of freedom (k_S = 1,5); (2) is precessional model, known in the applied theory of fast gyroscopes. But (2) is the *only formalized mathematical construction* with $k_S < k$, k_S is non-integer number. It is necessary to get a strict substantiation for acceptability, with estimations of required values of *H* for legality of this shortened model (here the gyroscopic matrix is generated one!).
Model (3) is other shortened model, with k_S = 2. This model has not the members corresponding to mass and the moments of inertia for gyroscope and mount; only the members appropriate to the inertia moments of stabilized object (platform) are kept. Shortened model (3) is also formal mathematical formalization ($k_S < k$). In engineering practice this model also is named precessional model; the researchers assume, that the acceptability of (3) can be based on same assumption about fast rotating gyroscope (big parameter *H*). The detailed analysis shows, that it is *non-correct assumption*. The acceptability of (3) should be based on the other physical property, it is corresponding to *big mass of stabilized object*.
The main questions in reference to the analysis of systems of gyroscopic stabilization-orientation (SGS): - building of this shortened model by a strict analytical way; - condition of a correctness of the shortened model; - physical interpretation of these shortened models.
The similar problems take place and in generally, for systems of gyroscopic stabilization-orientation, modelled as electromechanical (interdisciplinary) system, when the transient processes in following systems are taken into consideration; initial mathematical model is the Lagrange-Maxwell (Gaponov) equations (4). The standard designations [19] here are used.

IM
$$
\begin{aligned}
&\frac{d}{dt} a\dot{q}_M + (b+g)\dot{q}_M = Q'_M + Q_{ME} + Q''_M \\
&\frac{d}{dt} L\dot{q}_E + R\dot{q}_E = Q'_E + Q_{EM} + Q''_E; \quad \frac{dq_M}{dt} = \dot{q}_M \\
&Q_{ME} = A_M\dot{q}_E; \; Q_{EM} = B_E\dot{q}_M; \; Q'_E = -\omega\, q_1 - \Omega\, \dot{q}_E
\end{aligned} \tag{4}
$$

In engineering practice, *idealizing* IM of ($2n+u$) order, the authors use for (4) the various shortened models, SM of less order, as working models: SM of the ($n+u$) order, SM of the (n) order, SM of the ($2n$-l + u) order, … [9,10]. These SM of the less order are used in the solving of the analysis and synthesis problems for initial model, though without strict substantiation for such transition. These SM are obtained at an intuitive level, but ones are *only formalized mathematical abstractions*, which are not generally qualitatively equivalent to initial model.
The main purposes of research: (a) - the optimal shortened mechanical-mathematical models; strict manners of idealization; (b) - legality of the short models in dynamics; conditions of qualitative equivalence for gyrostabilization-orientation systems; …

General principles

Consider IM in the form (4). Main tasks: (a) modelling problem (constructing of SM by a strict mathematical way); (b) acceptability problem (the conditions of models equivalence); (c) estimations problem (finding of allowable values areas of parameters); (d) problem of constructing of the *minimal model* (in N.N.Moiseev sense). The powerful tool here is methods of A.M.Lyapunov theory with expansion of property of parametrical stability on an irregular case (N.G.Chetayev, P.A.Kuzmin). The main hypothesis: all examined objects are ones of singular perturbed class (L.K.Kuzmina), and always there exists such transformation of variables $(q,\dot{q})\rightarrow y$, with which the initial mathematical model can be presented in the standard form of system with irregular perturbations in form (5), initial system (IS).

IS $$M(\mu)\, dy/dt = Y(t, \mu, y) \qquad (5)$$

Here μ is small positive dimensionless parameter; $M(\mu)=\|M_{ij}(\mu)\|$; $M_{ii}(\mu) =\mu^{\alpha_i} I$, $0 \leq\alpha_i\leq r$, I is identity matrices; y is N-vector of new variables; $Y(t, \mu, y)$ is nonlinear N-vector-function with the appropriate properties.
The system (5), named here initial system (IS), has the N order ($N = 2n + u$). Let here shortened system (SS) for (5) is introduced as simplified system (6) (comparison one for (5)).

SS $$M_S(\mu)\, dy/dt = Y_S(t, \mu, y) \qquad (6)$$

The system (6) has N_S order ($N_S < N$). (6) is obtained from (5) as system of s-approximation on μ parameter. We shall name it shortened system of a s-level (s-system, SS_S); (5), (6) are singularly perturbed systems (SPS). Coming back in (6) to old variables (q, $\dot{q}$), we shall get shortened model of s-level (s-model, SM_S). SM_S has k_S of degrees of freedom ($k_S = N_S/2$). From the view point of the mechanics SM is *idealized model* (idealization on the chosen physical properties, corresponding to small parameter μ). By such approach all family of possible models for considered SGS is constructed. It gives regular algorithm for building of the shortened mathematical models (working ones) of object (IO) by strict mathematical way:

$$IO \rightarrow \underset{(q,\,\dot{q})}{IM} \rightarrow \underset{(y)}{IS} \rightarrow \underset{(y)}{SS} \rightarrow \underset{(q,\,\dot{q})}{SM} \qquad (7)$$

The decomposition of initial model on a submodels is automatically carried out, the initial state variables are divided on *different-frequency groups*; the initial parameters are divided on essential and non-essential, the main degrees of freedom are automatically revealed by this method.
General results here are given for full solving on a problem (a). The following stages are (b), (c) … Not discussing all details and obtained theorems, we shall result here only some results within the framework of the used approach. On a task (b) (task of an acceptability): it is known, dynamic properties (stability, optimality, speed, …) do not possess the decomposition. The special conditions [20,21] should be executed. For the solving of these questions the developed method is used. The results for a stability problem (“s-stability"), proximity problem ("s- proximity"), problem of s-speed, s-optimality are obtained.
The application to dynamics of systems of gyrostabilization and orientation were considered.

In reference to examined objects the developed approach has appeared rather fruitful.
Let initial model is accepted in the form (4).

(a). Modelling problem for SGS.

SPS with fast gyroscopes. In this case in (4) it is introduced big parameter H ($g = g^*H$, $H = 1/\mu$, μ is small parameter). Here the required transformation of variables is constructed, IM is presented in the form of SPS (5), the state variables are divided into three groups: $\dot{q}_M$ - *high-frequency* variables; $\dot{q}_E$ is *middle-frequency* variables; q_M is *low-frequency* variables. Two types as of shortened models $(SM_1, SM_0)_\mu$ are constructed: (8), (9).

$$(b+g)\dot{q}_M = Q'_M + Q_{ME} + \overline{Q}''_M, \quad \frac{dq_M}{dt} = \dot{q}_M \tag{8}$$

$$\frac{d}{dt} L\dot{q}_E + R\dot{q}_E = Q'_E + Q_{EM} + Q''_E$$

$$g\dot{q}_M = Q'_M + Q_{ME} + \tilde{Q}''_M \tag{9}$$

$$R\dot{q}_E = Q'_E + \tilde{Q}''_E; \qquad \frac{dq_M}{dt} = \dot{q}_M$$

Here (8) is SM_1 of the $(n + u)$ order on μ; (9) is SM_0 of the n-order. (9) is limit on μ model (new model). SM_1 is precessional model for controlled SGS.

SGS with high-speed following systems. In this case (4) is system with small inertia electrical circuits. Here small parameter μ_1 corresponds to small time constant of electrical circuits. For this case required transformation of variables also is constructed; IM is presented as SPS; the state variables are divided into three *other groups*: $\dot{q}_M$ is middle-frequency variables; $\dot{q}_E$ is high-frequency variables; q_M is low-frequency variables. The shortened models $(SM_1)_{\mu 1}$ of the $2n$ order are constructed (we shall designate it by (10), not writing out), $(SM_0)_{\mu 1}$ of the n order (it is limit on μ_1 model) - (11).

$$(b+g)\dot{q}_M = Q'_M + Q_{ME} + \overline{Q''_M} \tag{11}$$

$$R\dot{q}_E = Q'_E + \tilde{Q}''_E, \quad \frac{dq}{dt} = \dot{q}_M$$

All shortened models are obtained by a regular mathematical way, on our uniform algorithm; $(SM_1)_\mu$ and $(SM_1)_{\mu 1}$ are known models; but $(SM_0)_\mu$ and $(SM_0)_{\mu 1}$ are new (limit) models.

SGS with big stabilized platforms. Initial model is (4). In applied researches [10] for this case the shortened model is introduced as the simplified mathematical model of the $(2n$-l $+ u)$ order (it is SM, such as model (3), named "precessional model", with the references on its substantiation on "precessional theory of gyroscopic systems with fast gyroscopes"). But such references are *not correct* for this case of big stabilized object (D.R.Merkin, A.Yu.Ishlinsky). In this case masses and inertia moments of gyroscopes and mounts are small (in comparison with the mass characteristics of stabilized platforms). Correspondingly other small parameter, μ_2, should be introduced in this statement: $a_M=\|a_1, a_2\|^T$; $a_1 = a_1(q_M, \mu_2) = = a_1^*\mu_2$; $a_2 = a_2(q_M, \mu_2)$, $a_2(q_M, 0) = \bar{a}_2 \neq 0$. On the same algorithm (7) shortened model SM_0 (on μ_2) of $(2n$-l $+ u)$ order is constructed. It is new shortened model SGS with big stabilized objects; it is non-precessional model. It is new result with *new working* SM, with new conditions of acceptability, that is different from known ones [10].

(b). Acceptability problem for SGS.

According to the developed approach the concrete types of SGS were considered from this view point. The acceptability problem is divided on separate subproblems; the problem of model acceptability in general statement is not correct; *the concept of an model acceptability is relative one*, concept "of acceptability in general" is meaningless. It should be examined within the framework of the concrete purposes of designed model (L.Ljung, L.K.Kuzmina). Here within the framework of the accepted statement the theorems of decomposition for stability property (asymptotic and non-asymptotic), about proximity between the solutions of

IM and SM (with estimations of N.G.Chetayev type), about decomposition of speed property, about property of the maximal degree of stability, about optimal parameters are obtained. The results were received both for the general perturbations theory, and for the SGS theory.

Not showing all details and proofs, the theorem for reduction-decomposition problem (4)→(11) is formulated. Here (11) is corresponding to the idealized model with inertialess elements of mechanical and electrical subsystems (small parameter μ_1 corresponds to small time constant of electrical circuits).

Theorem. If equations $d_1=|L\alpha+R^0+\Omega^0| = 0$; $d_2=| a^0 \beta+b^0+g^0| = 0$;

$$d_3 = \begin{vmatrix} b^0_1+g^0_1 & 0 & \\ (b^0_2+g^0_2)\lambda & -A^0 & \\ \omega^0 & 0 & R^0+\Omega^0 \end{vmatrix} = 0$$

will satisfy Hurwitz conditions, then: - under small μ_1 values the stability property (asymptotic or non-asymptotic) of system (11) trivial solution is entailing the corresponding stability property for system (4) trivial solution;

- for given in advance numbers $\varepsilon>0$, $\delta>0$, $\gamma>0$ (here ε, γ are taken as much small) there is such μ_1^* value, that in perturbed motion for all $\mu_1<\mu_1^*$, $t \geq t_0+ \gamma$ it will be valid

$$\left\|\dot{q}_M - \dot{q}_M^*\right\| < \varepsilon, \left\|q_M - q_M^*\right\| < \varepsilon, \left\|\dot{q}_E - \dot{q}_E^*\right\| < \varepsilon, \text{ if for } t_0 \;\; q_{M0} = q_{M0}^*, \left\|\dot{q}_{M0} - \dot{q}_{M0}^*\right\| < \delta, \left\|\dot{q}_{E0} - \dot{q}_{E0}^*\right\| < \delta .$$

Here the system (11) solution is marked by index“*”; the system (7) solution is without index “*”. The theorem gives conditions of an acceptability for new SM (11), more simple, than known (10).

Other cases and singular problems were considered; the appropriate theorems are obtained [23-25].

Some remarks

In conclusion of this Chapter (Section 1) we would like to note.

The developed methodology based on A.M.Lyapunov theory, perturbations theory, postulates of stability and singularity (LPSS-approach), allows:

- to consider all initial objects from uniform view of SPS;
- to approach to a problem of modelling in the mechanics through understanding of it as SPP;

In reference to problems of multi-channel, multi-axis stabilization systems with gyroscopic controlling elements, this approach allows to get the conditions of decomposition of initial nonlinear models with the possibility of division on channels of control and stabilization (see Appendix), in problems of synthesis and analysis; to construct the full family of shortened models, with separation of cases both for small satellites, and for big stabilized objects (space stations). As illustration we give here few results for multi-channel gyrostabilization system.

Appendix

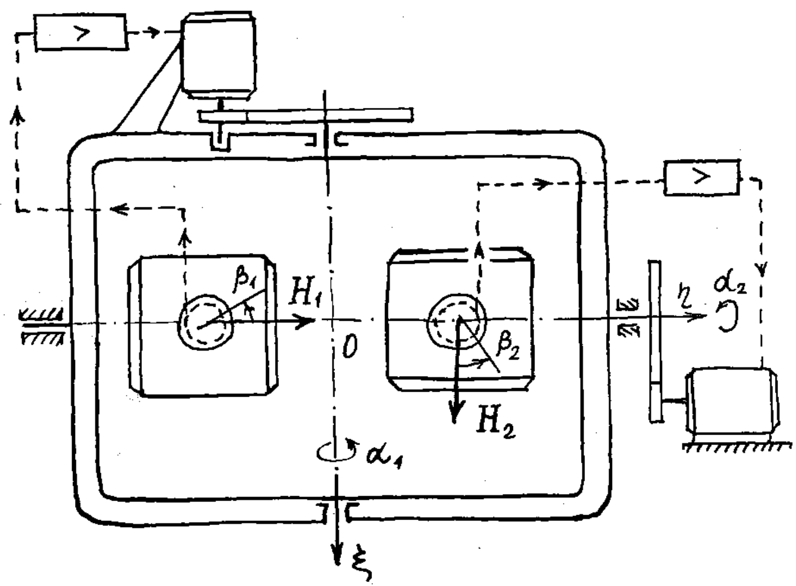
Application for system of two-axes gyrostabilization (two-axes gyrostabilizer, TGS)

Problem of modelling

TGS is modeled as electromechanical system with two channels of stabilization.
FM, $N=2n+u=14$; $q=(q_M, q_E)$, $n=4$, $u=6$,

$q_M=(\beta_1, \beta_2, \alpha_1, \alpha_2)$, $\dot{q}_E=(i_{11}, i_{21}, i_{31}, i_{12}, i_{22}, i_{32})$,

here second indexes mark the number a stabilization channel.



Let we consider TGS with small stabilized object (small satellite); and here we consider TGS with fast gyroscopes. Using developed here regular algorithm (see (5), (6), (7)), with introducing small parameter $\mu=1/H$ (H is big parameter corresponding big eigen kinetic moment of gyroscope), for this case we constructed the family of reduced models (shortened models, SM) for TGS. Here

SM (SS I); *precessional model*; $N_{\mathrm{SI}}=10$*;*

SM (SS II); *limit model*; $N_{\mathrm{SII}}=4$; *the stabilization channels are divided in nonlinear statement.*

For considered here case of fast gyroscopes the shortened model (SM, limit model) is minimal model (in sense of N.N.Moiseev [12]) of 4-th order; *with divided stabilization channels.*

The transition from full model (FM, $N=14$) to this shortened model (SM, $N_S=4$) will be acceptable on infinity time interval under corresponding conditions. The acceptability conditions we obtain using of Lyapunov methods as in Section (b) (here we do not show these conditions). Here for TGS: FM has form (4); SM (limit model) has form (9), where the stabilized channels are *separated in nonlinear statement*.

Author is grateful to Russian Foundation of Fundamental Investigations for support of research.

Section II

Main remarks

- The developed approach, based on A.M.Lyapunov theory methodology, is very effective one in dynamics analysis of complex multidisciplinary systems of aviation and aerospace technology; and with this developed method:

  – the motions in original model are separated on different-frequency groups;

  – the reduced working model, that is acceptable in considered here sense, is constructed.

- The new regular algorithm of engineering level, developed in research, is giving the simple schemes, that allows:

  – to analyze the complicated multidisciplinary systems by analytical (computer-analytical) methods,

  – to solve the problems of designing, analysis and synthesis with separation on control channels in dynamics (for robotic systems; for stabilization and orientation systems,…).

- Moreover:

  – The big significance has the revealing of interdisciplinary relations between theoretical and applied areas, between different disciplines of Science; that is very important for engineering practice, and - it is impossible without Mechanics.

  – Such close interdisciplinary link between the basic and applied spheres of Science, between its separate disciplines is of vital importance for successful development of the whole aviation and rocket-and-space engineering, for Space exploration.

And this was established as a basis for the entire scientific, educational, engineering and design work aimed at the training of specialists in Kazan on N.G.Chetaev's initiative and according to the innovative ideas of the "fathers of Russian aviation" N.E.Zhukovsky, S.A.Chaplygin , aiming at extension of traditions of advanced scientific and educational National School (P.L.Chebyshev – A.M.Lyapunov– N.G.Chetaev);
that are continued in Kazan Chetayev School of Mechanics and Stability (P.A.Kuzmin – V.M.Matrosov – …), with highly effective results for multidisciplinary complex objects of different nature, including in first – complex aerospace systems analysis and synthesis.
From this point Academician V.M.Matrosov, formed under powerful influence of well-known scientific School of Mechanics is brilliant Representative of Kazan Chetayev School of Mechanics and Stability; he is -

"Planet in Universe of multidisciplinary Science in whole" [26] …

Planet in Universe

To the 80-th Anniversary of

Vladimir Mefodyevich Matrosov

(08.05.1932-17.04.2011)

Vladimir Mefodyevich Matrosov, Academician of RAS, Honorary Professor of A.N.Tupolev Kazan State Technical University (KAI), USSR State Prize Laureate, Founder-President of the Academy of Nonlinear Sciences.

This International Association "Academy of Nonlinear Sciences" consolidates over 220 Russian and foreign Doctors of sciences, representing the leading scientific schools of the world in the theory of stability, nonlinear dynamic analysis and control theory, with departments deployed in six countries and seven regions of Russia from 1995, in close relations and joint activity with International Federation of Nonlinear Analysts (Founder/President – Prof. V.Lakshmikantham).

Academician V.M.Matrosov was an initiator and editor of the International scientific *bilingual* Edition established in 1994 on the basis of Kazan Chetaev School of Stability under the aegis of the International Federation of Nonlinear Analysts and the Academy of Nonlinear Sciences, which has been issued since 1995 in the format of two international Journals:

"Problems of Nonlinear Analysis in Engineering Systems", ISSN 1727-687X;

"Actual Problems of Aviation and Aerospace Systems", ISSN 1727-6853.

V.M.Matrosov graduated from KAI, he is a disciple of Pavel Alexeevich Kuzmin and was raised under the influence of deeply rooted traditions of Kazan Chetaev School of mechanics and stability (Prof. P.A.Kuzmin is direct disciple of Academician N.G.Chetayev).

V.M.Matrosov was an outstanding scientist of worldwide reputation, who contributed much to the development of the theory of stability and control. He submitted a fundamental comparison principle, which became a powerful tool in the general theory of systems and enriched the **gold fund** of modern Science (Matrosov-Bellman comparison principle). His method of Lyapunov vector functions (LVF method) is developing the ideas of S.A.Chaplygin. ,T.Vazhevskiy and the concepts of A.M.Lyapunov – N.G.Chetayev. This LVF method, developed for the theory of stability and control ,was appreciated by the world scientific society and it is published as main one in educational literature. The scientific areas set up by V.M.Matrosov give new opportunities in basic research of artificial intelligence, mathematical theory of systems, theory of differential and functional equations, stability theory, including their applications in the complex research of engineering systems , of global and regional stability of development with establishment of a computer system for analysis of strategic stability in a multipolar world; also – very important applications in aerospace systems with intelligence contol systems...

V.M.Matrosov published significant scientific works, monographs, and articles that assure the priority of national Soviet-Russian Science in basic research and worthily carry on the traditions of Kazan Chetaev School of mechanics and stability with their extension to other spheres of Knowledge.

V.M.Matrosov's huge scientific contribution to the development of A.M.Lyapunov stability theory enabled to raise the research of complex nonlinear systems to a qualitatively new level and ensured a significant progress in the study of their dynamical properties with applications to complex multidisciplinary objects.
A distinguished scientist, talented organizer in science and higher education, brilliant representative of famous scientific Kazan Chetaev School – this is Vladimir Mefodyevich Matrosov.

Vladimir Mefodyevich Matrosov (born on 8 May 1932, in Altai, Barnaul)in 1950 entered Kazan Aviation Institute and graduated cum laude in 1956.
During 1956-1975 (Kazan period) Vladimir Matrosov worked at Kazan Aviation Institute. He successively was a postgraduate student (supervised by Professor Pavel Alexeevich Kuzmin), an assistant lecturer, an associate professor of Theoretical Mechanics Department, and a Head of the Higher Mathematics Department. He established a Cybernetics Department in 1972 and managed it till 1975.

Fig.1. The SSO

V.M.Matrosov (PhD Engineering in 1959, Doctoral thesis in 1968) obtained important theoretical and applied results during this period. Outstanding achievements in development of Lyapunov vector functions approach (LVF) published in 1962 made him world-famous. The concept of LVF was taken up in many countries. This enabled to reveal its basic role in the analysis of different dynamic properties of nonlinear systems and profound applications to complex large-scale systems, continuous and discrete, with distributed and lumped parameters.
V.M.Matrosov together with his disciples was awarded (1984) the National Prize of the USSR for his LVF approach.
He developed the fundamentals of dynamics of orbit and stratospheric astronomical observatories. V.M.Matrosov supervised development of control algorithms for certain space systems that were implemented in a number of leading scientific-production centers and central design bureaus of the country.
At this period V.M.Matrosov had been carried in a large contribution on developing the fundamentals on research of the nonlinear dynamics and control for Soviet stratospheric and space astronomical observatories, with applications of VLF method for research and designing the guidance and precise attitude control system for Sun stratospheric observatory (SSO) Saturn, fig.1.
The scientific success in this complicated area of rocket-space systems was provided by scientific, educational, engineering School, that was created in Kazan on initiative of N.G.Chetayev, in developing of novel ideas of "Russian Aviation Fathers" - N.E.Zhukovskiy, S.A.Chaplygin, with deeping of classical traditions of scientific-educational School (P.L.Chebyshev-A.M.Lyapunov-N.G.Chetayev).
Moreover V.M.Matrosov was generated just under influence of this brilliant scientific-engineering School!

During 1975-1991 (Irkutsk period) V.M.Natrosov worked in Irkutsk.
On the invitation of the Chairman of Siberian Branch of the Academy of Sciences of the USSR G.I.Marchuk, V.M.Matrosov and a number of his disciples and colleagues moved to Irkutsk to establish an academic institute – Irkutsk Computing Center. Owing to a huge organizational work performed by Vladimir Matrosov in 1980, IrCC of USSR AS SB was established and housed in a new splendid building. V.M.Matrosov was a Director of Irkutsk Computing Center of USSR AS SB from 1980 till 1991.

V.M.Matrosov's scientific achievements of this period were associated with development of the main concepts of abstract control theory and construction of mathematical models of the systems of processes of different nature. He revealed an abstract comparison principle in control theory and system dynamics useful for derivation of theorems in the theory of dynamic systems, which opened a new scientific area in qualitative analysis of dynamic properties of the systems. The obtained results are of top priority in science and were further developed by his disciples and followers, who established a famous Irkutsk scientific School for the theory of stability and control as next generation of Kazan Chetayev School of mechanics and stability.

He developed a procedure for mathematical simulation, solution of problems in dynamics and control on the basis of software packages. Under Matrosov's scientific supervision, a unique complex of smart software packages oriented towards the methods of nonlinear dynamics and control theory were developed for problems of complex space systems.

Vladimir Mefodyevich was a scientific supervisor of multiple research and designing works carried out by the IrCC of the USSR AS SB by the order of leading companies from the USSR rocket-space industry: Nauchno-Proizvodstvennoye Obyedineniye Prikladnoy Mekhaniki (NPO PM, today "Acad. M.F.Reshetnev Information Satellite Systems" Corporation (Reshetnev ISS), Zheleznogorsk, Krasnoyarsk region), Central Specialized Design Bureau (TsSKB) (nowadays State Research-Production Rocket-Space Center "TsSKB-Progress", Samara), A.S. Lavochkin Association (Khimki, Moscow region), Moscow Institute of Heat Engineering, Central Research Institute for Automatics and Hydraulics (Moscow) etc. Here it is presented two information satellites among a lot of spacecraft created by the NPO PM with participation of Matrosov's team in research and designing their control systems (fig.2).

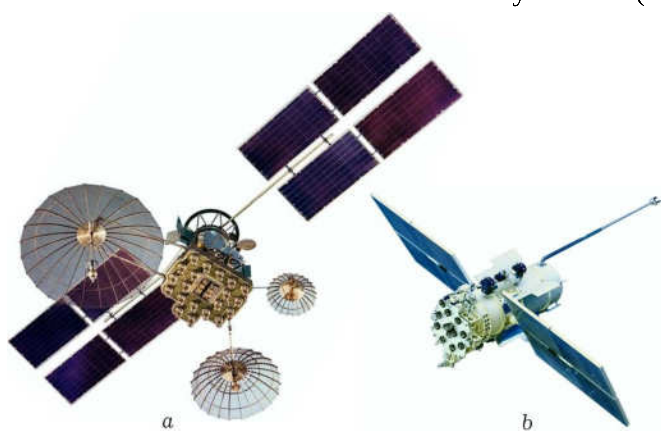


Fig.2. The Soviet satellites: Lutch (a) and Glonass (b)

V.M.Matrosov together with Academician M.F.Reshetnev was a Co-chairman of the session of "Dynamics and control of space objects" at the Scientific Council of USSR AS on motion control and navigation. They edited the collection of papers covering scientific results of this session that was published by Nauka Publishing House (Novosibirsk) in 1992. Also: V.M.Matrosov with his colleagues developed a mathematical model of the regional industry development, which enabled to predict the industry development of Irkutsk region till 1990. The forecast was used by the region authorities.V.M.Matrosov was elected a corresponding member of AS USSR (1976), full member (1987).


Fig.3. The satellite Sesat.

From 1991 V.M.Matrosov with his family moved to Moscow. He was a Head of Moscow Branch of the Institute of Transport Problems of RAS since 1996. He established the Center of stability research and nonlinear dynamics under the A.A.Blagonravov Institute of Machine Science of RAS and was its permanent director.

Matrosov performed a fundamental research of approaches of nonlinear analysis of dynamic properties of complex systems, logical-dynamic systems and systems of variable structure, with developing methodology based on mathematical principles of stability theory of A.M. Lyapunov and N.G. Chetayev in regard to general theory of systems. The obtained results were implemented in development of control systems for complex objects of different nature. Among them: space vehicles of communication, geodesy and navigation (M.F.Reshetnev ISS) and the Earth surface monitoring (TsSKB-Progress), fig.3.

Also these methods are successfully applied to another areas of multidisciplinary objects.

a) The scientific project of RAS-UNESCO and a number of national programs “Bezopasnost” (“Safety”) dealing with *mathematical simulation* of branches and regions of the country allowing for possible man-made and natural disasters and research of safe transition of Russia to sustainable development V.M.Matrosov was one of the authors and an editor of encyclopedia “New Paradigm in Development of Russia in the 21st Century”.

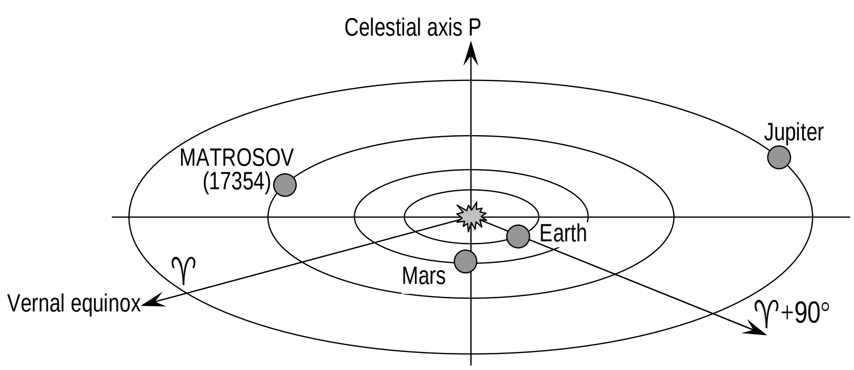
b) Results of research performed by V.M.Matrosov on the recovery from social, economic and environmental crisis and elaboration of trends of long-term development of Russia meeting its national interests and corresponding to the documents adopted by UNO, were refined by a special workgroup established on his initiative under the Committee and Expert Advisory Board. The Committee included academicians, scientists, politicians, professors and representatives of public structures. In 2002 these results were published as an edition of the State Duma “Scientific Foundations of the Strategy of Sustainable Development of the Russian Federation” This edition was translated into English and presented at the World Sustainable Development Forum (Johannesburg, September 2002). The work was awarded the First national environmental Prize established by the Committee of the State Duma of RF FA on Ecology and V.I.Vernadsky Non-governmental Fund.

In conclusion we note: V.M.Matrosov was an Honorary member of K.E.Tsiolkovsky Academy of Cosmonautics since 1996, a member of Russian national Committees on theoretical and applied mechanics (1983) and automatic control. Among V.M.Matrosov’s disciples there are RAS Academician, 19 Doctors, PhD of sciences. He was awarded the Badge of Honor (1981), Order of Friendship (1988), a number of medals and the National Prize of the USSR (1984).

In 2004 he was awarded the Order of Honor of Russia for his outstanding scientific achievements, scientific, organizational, educational and public activities.

Vladimir Mefodyevich is gone. The cherished memory of him is kept; it stays in the hearts of all the people who was acquainted with him…

According to the Decision of the International Astronomical Union, a **minor planet** (object 17354) was named after Academician V.M.Matrosov: «***MATROSOV***».



“… the stability theory and dynamic properties analysis of nonlinear systems – it is magnificent tree, possessing the classical stem, ***the deep strong roots from Mechanics****, …, from important engineering problems, and the unfolded branches of mathematical constructions of exclusive beauty…”,* -

V.M.Matrosov, Academician of Russian Academy of Science (President of Academy of nonlinear sciences, 2001).

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Author is grateful to Russian Foundation of Fundamental Investigations for support of research.