Проблемы

Нелинейного

Анализа в

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Системах

Методы Подходы Гипотезы Решения

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Феномен буферности: механизмы возникновения и проявление в математических моделях

Экспериментально-теоретическое уточнение методов расчета подкрепленных оболочек на устойчивость

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• to inform the specialists of appropriate fields about recent state in theory and applications; about
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• to promote close working contacts between scientists of various Universities and Schools;
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• to mathematize the methods for solving the problems generated by engineering practice;
• to unite the efforts, to synthesize the methods in different areas of science and education.

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engineering systems are published (including new results, methods, approaches, hypothesises,...).
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V.V. Chekanin. Experimental and theoretical improvement of methods of buckling analysis of stiffened shells.

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E. Escultura. Problems of modelling in geology and oceanography.

P. Santoli. In memory of Dr. Salvatore Santoli.
From Editorial Board

International Journal “Problems of Nonlinear Analysis in Engineering Systems” is an interdisciplinary bilingual scientific periodical Edition, which represents the research of nonlinear problems in general, in the whole diversity of fundamental and applied sciences, including the disciplines of natural science and the Humanities.

Our World is one (uniform) complex system in which studying we are guided important gnosiological principles:

“Unity in Diversity”, – V.Lakshmikantham, Founder of International Federation of Nonlinear Analysts;

“...I always believed that the objective character of Self Organization and Irreversibility should be based on some qualitative properties of Dynamics; ...Universe is a construction in progress, in which we participate”, – I.R.Prigogine, Nobel Laureate, Honorary Editor of Journal;

“...We specialize not on Sciences, but on Problems. The Problems these do not pack in frames single, determined, established Science...;

... It is empirical generalizations, which are the acknowledging fact, not having for it the explanation...”, – V.I.Vernadskiy, RAS Academician (we celebrate 150 years), Founder of novel theory about “Noosphere”.

Note, close interdisciplinary relation between the fundamental and applied fields of science, between different disciplines has vital importance for the development of our Knowledge in whole. Fundamental s cience “MECHANICS” and its sections play an important role from this point. Prominent 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:

“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 branches. 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 Committee on theoretical and applied mechanics, 2011).

- The Mechanics is «the main foundation» to development of all adjacent disciplines, in which studied objects are the interdisciplinary systems requiring knowledge from various scientific areas. Exactly on boundary between different disciplines the new hypotheses are generated, that providing deep knowledge of World around, with understanding of occurring phenomenas.

- Without Mechanics, without close interdisciplinary relations between theoretical and applied areas, between different disciplines of the Science, the deepening our Knowledge in whole is impossible.

Moreover exactly Mechanics is promoting the development of “mathematical constructions of exclusive beauty”: the dynamic systems theory, A.M.Lyapunov stability theory ..., and it plays in all this the major role:

“... 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,...”, - V.M.Matrosov, Academician of Russian Academy of Science (President of Academy of nonlinear sciences, 2001).
Problems of Nonlinear Analysis in Engineering Systems

International Journal Kazan

Exactly Mechanics, with uniting efforts of theorists and engineers, provides the development and synthesis of methods for the solving problems in interdisciplinary spheres of a science, education and engineering practice, in the research of nonlinear problems in general, in the whole diversity of fundamental and applied sciences including the disciplines of natural science and the Humanities (mathematics, mechanics, physics, chemistry; engineering, biological, medical, social, political sciences; ecology, cosmology; economics and financial mathematics; nanoscience and nanotechnology, stability and sustaining development, problems of risk and information security, operation research; geology, oceanography,…).

In this direction it is very important the A.M.Lyapunov-N.G.Chetayev methodology, developed for problems of modelling and analysis in engineering practice and for extending our Knowledge in whole. The A.M.Lyapunov stability theory is giving for us the constructive mathematical tool, and it is confirming:

“mathematics is an effective “transport” which is able to provide significant breakthrough in understanding of the essence of Environment, with deep penetration of its approaches into all the spheres including the unconventional ones”.

The current issue of Journal “Problems of Nonlinear Analysis in Engineering Systems” (№2 (40), t.19, 2013) carries articles, analytical researchers and authors results, scientific and information papers that reflect the views of specialists and highlight some topical interdisciplinary problems of present and future.

Among them it is presented the papers and reviews of interdisciplinary subjects, scientific research and interdisciplinary spheres generated by the needs of fundamental science and engineering applications. These articles are prepared in the development of the research results discussed at the International scientific forums and conferences, including International Conference on Operational Researches (EURO-2013), within invited scientific Session “Problems and methods of modelling and analysis in Complex multidisciplinary Systems Dynamics”, devoted to methods of “Stability theory of A.M.Lyapunov” and to Memory of great, brilliant Scientists – N.G.Chetayev I.R.Prigogine, NOBEL LAUREATE V.M.Matrosov; XXIII International Scientific Workshop (2013) on problems of modelling and dynamics of complex multidisciplinary systems.

The subjects represented in these works: buffer phenomenon in mathematical models; methods of buckling analysis of stiffened shells; modelling for dynamic deforming problems in constructions with composite foldcore; analysis methods of composite constructions; method on encapsulated polymeric material formation with required features; ultrahigh resolution on basis of phenomenon of one-electronic tunneling; modelling and statistical analysis for volcanic eruptions; models and methods in geology and oceanography, in atmosphere investigations.

The submitted articles will undoubtedly promote the cooperation of specialists in theory and applications, support the synthesis of approaches to the solution of problems in interdisciplinary spheres of science, education and engineering practice.

The issue is prepared with support of our Partners: International Federation of Nonlinear Analysts, Academy of Nonlinear Sciences, International Nano-biotechnology Center (INT), Kazan Federal University (KFU), N.E.Bauman Moscow State Technical University, Moscow Aviation Institute (National Research University), V.F.Trapeznikov Institute of control problems of RAS, A.A.Dorodnitsyn Computing Centre of RAS; Concern CSRI Elektropribor, JSC; TsNIImash; OAO “Russian Space Systems”.
Buffer phenomenon: mechanisms of onset and realization in mathematical models

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An efficient tool for studying various specific objects and phenomena of the world around us is theoretical and numerical research of their mathematical models. Meanwhile it was a thorough analysis of such models that often led to setting purely mathematical problems and induced the development of new mathematical methods. The so-called buffer phenomenon is an important example of such mutually enriching interaction of theoretical research of a mathematical model for a real event and deep penetration into the essence of this event. Its comprehensive and complex study has started only recently. However, detailed investigation of such a phenomenon allowed introduction of new elements into the interpretation of “nonlinear world” notion and clearer understanding of possible mechanisms of sophisticated order-chaos relations in nature.

The special role of various oscillatory processes in mechanics, physics, engineering, chemistry, biology, economics, etc. is well-known. An important aspect of their research is theoretical analysis of mathematical models of specific oscillatory systems.

When oscillatory objects with lumped parameters (or lumped oscillatory systems) described by autonomous systems of ordinary differential equations are studied, the notion of a stable limit cycle of such system is a key one. It was introduced by A.Poincare in 1880s. But only in 1920s an outstanding Soviet physicist A.A.Andronov established that a stable limit cycle is an adequate mathematical description of a real steady oscillatory process (stationary periodic regime) in the systems with lumped parameters.

It is absolutely clear that depending on the particular nature of applied problem, in one case it is essential that such cycle is unique, in another case there can be several or even “many” of them. As a system of ordinary differential equations, being an adequate mathematical model of some real object or event, always contains parameters (describing specific characteristics of an object or event under consideration) different values of these parameters generally yield different number of stable limit cycles (or the absence of latter). It is easy to give examples of systems of ordinary differential equations, in which proper choice of these parameters’ values can provide existence of any finite a priori set number of stable limit cycles.

Oscillatory objects with distributed parameters (or distributed oscillatory systems) are often found in different fields of science, new hardware and modern technologies. Their state depends on time and space variables: an object’s state at each spatial point changes periodically with time. In other words, self-oscillations or autowave processes (term submitted by R.V.Khokhlov) are typical of these objects. Dynamics of such objects is usually simulated by systems of partial differential equations supplemented with boundary conditions. Stable cycle (or simply: cycle) corresponding to a self-oscillatory regime is a steady in space and periodic in time solution of a system of partial differential equations which meets boundary conditions.

Such a boundary-value problem surely contains also the parameters that characterize properties of a real object or phenomena. If the parameters are fixed, then the boundary-value problem can admit one or several cycles (or lack them). It is essential to determine their number, as in practice it means to establish the number of coexisting self-oscillatory process. It is natural that in general terms the number of such cycles is different for different values of parameters. Hence, a purely mathematical problem of studying the dependence of a number of stable cycles on parameters in a boundary-value problem for a system of partial differential equations (or equations) arises.

1.

Buffer phenomenon in a mathematical model of a distributed oscillatory system is observed when the considered boundary-value problem for the given system of partial differential equations under proper choice of the values of involved parameters can contain any finite preliminarily fixed number of different stable cycles. In other words, buffer means that for any natural \( N \) it is theoretically possible to find such characteristics of an object that \( N \) different autowave regimes are implemented in the object.

In general case, buffer phenomenon of a parameter-dependent dynamic system is the following property: any a priori chosen finite number of single-type attractors (stable equilibrium states, stable time-periodic solutions, tori, etc.) exist in the system’s phase space when the parameters are chosen properly.

Obviously, the problem of research of time-periodic regimes in oscillatory objects with distributed parameters was stated for the first time by Soviet physicist A.A.Vitt [1]. The name and works of this remarkable scientist are unfortunately little-known except, probably, his...
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paper [2]. Meanwhile, Alexander Adolfovich Vitt – collaborator and colleague of A.A. Andronov – was one of the brilliant representatives of Soviet School of oscillation theory, who performed a number of original and promising researches and was a coauthor of “Theory of oscillations” monograph. A.A. Vitt was repressed (and died in 1937), his works were rarely cited, his name was deleted from the list of authors of [3] and readmitted many years later. A.A. Vitt submitted a hypothesis that the so-called “self-excited oscillator with a section of long two-wire line in a feedback circuit” can have several stable cycles at once. Later physicists established the fact of growing number of self-oscillating regimes when changing the parameter of a real self-excited oscillator [5]. Mathematical study of the buffer phenomenon was initiated by Yu.S. Kolesov, who studied it first numerically in parabolic systems of reaction-diffusion type [6], and then theoretically – in hyperbolic equations [7]. He also introduced “buffer” term.

2.
Detailed statement of strict mathematical theory of buffer phenomenon can be found in papers and monographs [8-12]. The considered mathematical models are nonlinear boundary-value problems for the systems of partial differential equations of hyperbolic or parabolic type; a scenario of growing number of e.g. their time-periodic solutions (cycles) usually takes place when some parameter determining the system’s energy is increasing. (Gain coefficient is often taken as such parameter in radiophysical applications). It is essential that buffer phenomenon itself is specific to bifurcation process, in the course of which unlimited increase of the number of coexisting stable attractors takes place.

The conducted research showed that buffer phenomenon is “typical” of rather broad class of mathematical models that adequately describe many nonlinear oscillatory processes in natural science (radio physics [13, 14], mechanics [15], optics [16], combustion theory [17], ecology [18], neurodynamics [19]). Besides, relation of buffer phenomenon to such nontrivial phenomena as turbulence and dynamic chaos has been traced [20-22].

The proof of corresponding mathematical statements is associated with significant analytic difficulties. Main mathematical tool for buffer phenomenon analysis is a method of infinite-dimensional normalization, which is a special version of Krylov-Bogolyubov-Mitropolsky-Samoilenko asymptotic method aligned algorithmically with Kolesov method of quasinormal forms [23].

As it has been already mentioned, buffer is a universal nonlinear phenomenon that emerges in mathematical models of different fields of natural science. Hence the study of typical scenarios of accumulation of attractors in different dynamic systems is quite topical. Four scenarios of this kind have been discovered so far: Vitt scenario (which is the most widespread), Turing, Hamilton, and homoclinic mechanisms of accumulation of attractors.

3.

The situation in which Vitt mechanism (named in memory of A.A. Vitt) is implemented is typical of a large class of physical processes described by hyperbolic equations (e.g. for self-oscillatory processes in distributed electric and mechanical systems). It consists in the following:

Assume that in the problem of stability of equilibrium zero-state of some hyperbolic system there is a critical case of denumerable number of eigenvalues, and when parameters of the system change, a part of spectrum points is successively displaced to the right complex half-plane. Then in case of no certain resonant correlations between the system’s eigenfrequencies, an elementary version of buffer phenomenon is observed in such a system: unlimited accumulation of quasiharmonic stable cycles (i.e. cycles that are close to harmonic in time),
and each cycle originates from zero-state of equilibrium as an unstable one, and then it acquires stability, rising its amplitude [9, 11, 13, 14].

4.

Turing mechanism differs from Vitt mechanism only in the following: when control parameters change, each individual cycle (or equilibrium state) first gains stability and then loses it once again. Thus, though the total number of attractors grows, their set is constantly renovated. As [12] show, such situation is implemented mainly in reaction-diffusion-type systems under proportional decrease of diffusion coefficients, but it can also show up in the systems with delay under unlimited increase of delay time. In particular, we face such situation when considering a well-known model of “brusselator”, which was studied by A.Turing (the mechanism was therefore named after him).

5.

The described scenarios of accumulation of attractors are typical only of the systems with infinite-dimensional phase space. As to finite-dimensional systems, the most elementary mechanism of buffer onset is, obviously, Hamiltonian scenario illustrated in [24, 25] by a number of 2D mappings from mechanics and systems of ordinary differential equations that are close to 2D Hamiltonian ones. The main point of the scenario is as follows. Consider at first some Hamiltonian or conservative system of ordinary differential equations (physicists often call them reversible, as time reversal does not make these systems change) with one and a half or more degrees of freedom. According to the modern understanding of general dynamics of such systems, chaotic movement in them coexists with a denumerable number of so-called stability island adjacent to elliptic state of equilibrium and cycles. It means that outer chaotic trajectories cannot get into the mentioned islands and vice versa any trajectory from the island (which in the simplest case is periodic or quasiperiodic) remains there for all $t \in \mathbb{R}$.

Assume that our system is disturbed by small additional components that provide its stability. Then some of the equilibrium states and cycles mentioned above can become asymptotically stable, attractors emerge at the stability islands, and the most important is the fact that the number of attractors can grow without limit when disturbances tend to zero. This means that buffer phenomenon is observed in the considered system, and it is appropriate to call its mechanism a Hamiltonian one.

It should be noted that Hamiltonian mechanism despite its simplicity has been the less studied one, though it is illustrated by many examples like pendulum-type equations with time-periodic small additional components [26] (in physical literature such equations are usually called the systems with one and a half degrees of freedom).

6.

In the case of systems of ordinary differential equations there are other, much more complex, mechanisms of accumulation of stable cycles that result from so-called homoclinic contacts existing in such systems; such mechanisms can also be conventionally called homoclinic. Among many results obtained for the systems with homoclinic structures, let us comment on three of them that are the closest to our subject.

The first result can be formulated for $C^r$-smooth ($r \geq 4$) system of ordinary differential equations in $\mathbb{R}^3$ assuming that it has an isolated equilibrium state $O$ with characteristic roots
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\[ \lambda_{1,2} = -\gamma \pm i \omega, \quad \gamma > 0, \quad \omega \neq 0, \quad \lambda_3 > 0. \]

Assume now that there is a trajectory \( \Gamma \) homoclinic to \( O \). Then, as it has been established by I.M.Ovsyannikov and L.P.Shilnikov, for

\[ \sigma_1 = \text{Re} \lambda_1 + \lambda_3 > 0, \quad \sigma_2 = 2 \text{Re} \lambda_1 + \lambda_3 < 0. \]

in the class of such systems the systems with denumerable set of stable periodic movements are dense.

The second result, which is similar to the latter, belongs to Newhouse. Let \( p \) be a hyperbolic saddle fixed point \( f \) of \( C' \)-diffeomorphism in \( \mathbb{R}^2 \), for which \( \det f'(p) < 1 \) holds, and assume that stable and unstable manifolds of \( p \) point are tangent to each other at some point \( p_0 \). Then in an indefinitely small \( C' \) vicinity of \( f \) there exists a diffeomorphism \( f' \), which has infinitely many stable periodic orbits.

The third result obtained by N.K.Gavrilov and L.P.Shilnikov consists in the following. Emergence and disappearance of the point of homoclinic tangency are preceded by cascades of saddle-node-type bifurcations. Such bifurcations cause cycle pairs (stable and unstable), and the number of stable periodic movements due to suitable choice of bifurcation parameters can be made arbitrarily large. Specific examples showing the implementation of this scenario of buffer onset are well-known (Duffing equation with insignificant dissipation and slight periodic external influence, equation of pendulum low-attenuation swing with vibrating suspension center).

7. Note that buffer phenomenon in self-excited oscillators with a section of long two-wire line in a feedback circuit has been experimentally shown to be feasible [8, 14].

References


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Experimental and Theoretical Improvement of Methods of Buckling Analysis of Stiffened Shells

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Introduction

The quality of optimal engineering of orthogonally stiffened shells under compressing strains significantly depends on methods of the analysis, as each design option of the shell should meet the requirement of holding the shape under specified loads. This condition is a starting point for synthesis of the shell structure. All subsequent modifications of the design option with minimization of the objective function of the shell mass and meeting some limiting requirements are performed with obligatory adherence to the specified condition. Besides, the shell mass corresponding to the extreme value of the objective function significantly depends on accuracy of methods of the analysis. The more accurate is the computational dependence, the lower can be assigned the safety coefficient increasing the operational load up to the designed one, and the lower is the shell mass. Therefore, there are many finite solutions of a linear orthotropic theory of shells, which improve accuracy of methods of the analysis. Paper [1] describes a comparative accuracy analysis of different methods according to values of corresponding coefficients of variation of the sample random variable expressed in a ratio of experimentally and theoretically obtained critical loads. In this case it was obtained that the highest accuracy by a criterion for minimum coefficient of variation of the random variable was provided with a more complex method of analysis [2] accounting for more stiffness characteristics of the stiffened shell sections and their interaction. However, complication of methods of the analysis results in increasing time for synthesis of design shell options and difficulties in analyzing the effect of design parameters on the objective function. A simple equation [3] comprising of expressions for membrane and flexural stiffness of the stiffened shell section is widely used in practice. This equation provides a dynamic synthesis of design options of the stiffened shell and behavior analysis of the objective mass function. However, in such a case this brings up a problem of degraded accuracy and, therefore, a necessity for verification of each chosen design option to confirm the required design compressive load. Paper [4] proposes a method to improve finite formulae of a linear orthotropic theory of the stiffened shells with correcting functions, which allows increasing significantly accuracy of the equations. Each correcting function includes design parameters to the powers defined with the step-by-step minimization of the coefficient of variation of the random variable from a corresponding representative sample of experimental data obtained in analyzing stability of the stiffened shells.

1. Determination of Empirical Dependences of Stability Coefficients on Load Parameters and Correcting Functions for Methods of Buckling Analysis of Stiffened Shells Under Axial Compression

The method of the analysis is described in [3]:

\[ \rho_T^T = k_s \delta_r^2 \omega, \]

where \( \rho_T^T \) is the theoretical value of the normalized parameter of critical axial force; \( T^T = \frac{T^k}{E_s r^2} \) is the theoretical value of the normalized parameter of critical axial force; \( T^k = k_d T^o \) – design value of axial force; \( T^o \) – operational value of axial force; \( k_d \) – safety coefficient.
coefficient; $E$ – elasticity modulus of shell material; $r$ – shell radius; $k_y$ – numerical coefficient; 
$\delta_y = \frac{\delta}{r}$; $\delta$ – skin thickness between ribs; $\omega = 1+ \varphi \beta (\psi-1)^2$;
$\beta = \frac{0.4}{\varphi 0.333} + \frac{1.3}{\psi 0.5} - 0.54$; $\varphi = (\varphi_1 \varphi_2)^{0.5}$; $\varphi_i = \frac{2\pi c_i}{l_i}$; $\psi = \frac{\delta_{\text{inc}}}{\delta}$; $\delta_{\text{inc}} = h_i + \delta$ – initial thickness of the shell wall, which is equal to the sum of the rib height $h_i$ and skin thickness between ribs $\delta$; $c_i$ – rib width; $l_i$ – distance between ribs; 1 – axial direction, 2 – circumferential direction.

The appendix includes the following: $\beta_0 = \frac{b_0}{\delta} = \psi - 1$; $\lambda_i = \frac{\varphi_i (\psi - 1)}{2\pi}$; $\rho_T^O = \frac{T^O}{E \gamma^2}$ – experimental value of the normalized parameter of critical axial force, $T^O$ – experimental value of critical axial force.

The numerical coefficient $k_y$ provides a single center of distribution of the random variable $\varepsilon = \frac{\rho_T^O}{\rho_T}$.

The coefficient defined from a statistical analysis of the representative sample of 134 experimental data (Appendix hereto) with eliminated three random variables at $3\sigma$ is 1.691. The coefficient of variation $k_w$ in this sample is 6.99%.

For the dependence obtained from a characteristic equation for combined action of axial compression and external pressure [2],

$$\rho_T^p = k_y \delta^2 \left( \frac{b_1}{b_2} \right) \left( d_1 + d_2^{0.5} \right)$$  \hspace{1cm} (2)

where: $b_1 = 1.1 + \lambda_i$; $d_1 = 0.33 \lambda_2 h_1$; $d_2 = d_1^2 + 0.33 \beta_2 \left[ (1 + \lambda_2 b_0^2) h_2 + 3 \lambda_2 h_1^2 h_3 \right]$;

$h_1 = \beta_0 + 1$; $h_2 = b_1 b_2 - 0.11$; $h_3 = h_2 - \lambda_2 b_1$

similar results with eliminated three random variables going outside $3\sigma$ amount to $k_y = 1.766$ and $k_w = 5.98\%$, respectively. Fig. 1 and 2 present smoothing of the experimental curve with the theoretical ones (1 and 2).
In the figures \( s = \rho_o \) is the theoretical value of critical axial force estimated from dependences (1 and 2), \( \rho_o^{p} \) – experimental or theoretical design value of critical axial force: \( \rho_o = \rho_o^{O} \); \( \rho_o^{p} = \frac{1}{s^2} \).

As can be seen in fig.2, the experimental data are placed more densely relative to the theoretical curve than in fig. 1. This is a graphic representation of lower coefficient of variation of the random variable for method (2).

The sample given in Appendix was divided into four groups of experimental data with close in magnitude critical loads: 1–24, 25–75, 76–114, 115–121. Moreover, the forth group of experimental data was formed with seven shells buckled, when an axial compression and a torque were applied simultaneously. The statistical analysis of experimental data resulted in a dependence of random variable on the critical load value. It is most demonstrated in method (1). In this case for experimental data 1–24 all random variables are below 1 \((\varepsilon < 1)\), for experimental data 76–114 practically all random variables are above 1 \((\varepsilon > 1)\), and for experimental data 115–121 the random variables are above 1 \((\varepsilon \gg 1)\) so much that three of them are eliminated at 3\(\sigma\).

So, the coefficient of stability should be clearly specified by a variable depending on the load parameter. For methods (1 and 2) the corresponding empirical dependences for coefficients of stability were estimated as:

\[
k_y = 3.737 \left( \frac{\rho_o^{p}}{1 - 9800 \rho_o^{p}} \right)^{0.092} ; \quad k_y = 2.208 \left( \frac{\rho_o^{p}}{1 - 10140 \rho_o^{p}} \right)^{0.026}.
\]
When using these dependences in method (1) a coefficient of variation reduces to 4.93% with eliminated two random variables at 3σ, and in method (2) a coefficient of variation (5.99%) does not reduce, but at the same time just one random variable is eliminated at 3σ. Moreover, in this case all random variables corresponding to experimental data 115–121 for methods (1, 2) are within the interval limited by 3σ.

The curves plotting relations between coefficients of stability and axial compression load $\rho_T$ are given in fig. 3.

As it can be seen from the figure, the coefficient of stability for method (2) varies not so much from its constant value of 1.766 over the whole interval of the parameter $\rho_T$ due to a lower power than a similar variation of the coefficient of stability for method (1) from the value of 1.691. Nevertheless, when the load parameter exceeds $8 \times 10^{-5}$, curve 2 deviates significantly relative to the constant value. Therefore, it can be concluded that both methods of the analysis with constant coefficients of stability overestimate critical axial force at low load parameters and underestimate it at high values. Lower power in the empirical formula of the coefficient of stability for method (2) indicates a higher accuracy of the critical axial force.

Additional drop of the coefficient of variation of the random variable from a sample for the method of the analysis is provided by a correcting function, as mentioned above. The coefficient of variation of the equation formed in the improvement of method (1) and determination of the empirical dependence for $k_y$

$$\rho_T = k_y \frac{1}{\delta_r^{0.25} \phi_1^{0.01} \omega^{0.07} \delta_r^2 \omega} = k_y \delta_r^{1.75} \frac{\omega^{0.92}}{\phi_1^{0.07} \beta_\delta^{0.01}}, \quad (3)$$

where $k_y = 1.144 \left( \frac{\rho_T}{1 - 9600 \rho_T^2} \right)^{0.108}$; $\beta = 0.39 \frac{\rho_T}{\phi_2^{0.16}} + 1.3 \frac{\rho_T}{\psi^{0.50}} - 0.54 \frac{\rho_T}{\phi_1^{0.08}}$.

with eliminated one random variable at 3σ reduces to 4.36%. It should be noted that in method (3) the correcting function along with design parameters raised to the powers includes...
a complex parameter $\omega$ raised to the power. The complex parameter $\omega$ comprises an expression for the parameter $\beta$ with corrected powers of the parameters and their composition. When improving the method of the analysis a possibility of modifying expressions entering indirectly into its composition identifies a major advantage of the applied method of correction as compared to the least-square method, which does not permit to make such modifications.

The above advantage of the correction method is realized when improving method (2) with an additional change of $d_2$ power

$$\rho_T = k_y \delta_r^{1.54} \left( \frac{b_1}{b_2} \right)^{1.02} \left( d_1 + d_2^{0.25} \right)^{1.04} \frac{1}{\lambda_1^{0.02} \lambda_2^{0.05} \rho_0^{0.05}}$$  \hspace{1cm} (4)

where $k_y = 0.630 \left( \frac{\rho_T}{1-9600\rho_T} \right)^{0.12}$.

In method (4) the coefficient of variation with eliminated one random variable analogous to method (3) at $3\sigma$ reduces to 4.20%. The least coefficient of variation $k_v = 4.00\%$ with eliminated similar random variable at $3\sigma$ is provided with the method of analysis as a correcting function composed of the product of design parameters raised to the corresponding powers and a coefficient of stability given by the empirical dependence:

$$\rho_T = k_y \delta_r^{1.40} \phi_1^{0.15} \phi_2^{0.28} \rho^{0.91}$$  \hspace{1cm} (5)

where $k_y = 0.302 \left( \frac{\rho_T}{1-9300\rho_T} \right)^{0.125}$.

It should be noted that the limit axial compression force determined from the equation for the coefficient of stability increases with improvement of the method accuracy. Thus, for method (2) $\rho_T = 98.62 \cdot 10^{-6}$, for method (5) $\rho_T = 107.52 \cdot 10^{-6}$. Fig. 4 presents smoothing of the experimental data with the theoretical dependence (5).
Therefore, the analytical methods improved with the corresponding correcting functions and empirical dependences for coefficients of stability, which determine their variations against the load parameter $r$, adapt more efficiently theoretical results to experimental data and reduce significantly the coefficients of variation $k_e$ of a random variable of the experimental sample.

2. Analysis of the effect of a preliminary local skin buckling between ribs on overall stability of the shell under axial compression

The fifth group of 122–134 was formed by experimental data on the stiffened shells with preliminary local buckling of the skin between ribs. The experimental data on these shells and random variables $e$ for method (5) are given in Table 1.

<table>
<thead>
<tr>
<th>$r^O_T \cdot 10^4$</th>
<th>50.65</th>
<th>57.30</th>
<th>51.92</th>
<th>56.03</th>
<th>61.28</th>
<th>70.63</th>
<th>51.38</th>
<th>54.14</th>
<th>55.09</th>
<th>48.76</th>
<th>51.04</th>
<th>45.40</th>
<th>37.62</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\rho^O_T / \rho_T$</td>
<td>0.725</td>
<td>0.920</td>
<td>0.988</td>
<td>0.944</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>0.86</td>
<td>0.94</td>
<td>0.95</td>
<td>0.82</td>
<td>0.69</td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>1.083</td>
<td>0.998</td>
<td>0.995</td>
<td>0.951</td>
<td>0.941</td>
<td>0.962</td>
<td>0.941</td>
<td>0.952</td>
<td>0.968</td>
<td>1.039</td>
<td>0.959</td>
<td>1.046</td>
<td>0.816</td>
</tr>
</tbody>
</table>

In Table 1 $\rho^O_T / \rho_T$ is the critical axial force of the local skin buckling.

For the last shells in the Table a distance between ribs is more than the length of boundary disturbance propagation of 2.5 ($\delta_r)^{0.5}$. In the analyses of $\rho^T_T$ of these shells the distance between ribs was taken equal to the length of boundary disturbance propagation. As a result, the random variable $\varepsilon$ was increased, for example, in the last column from 0.728 to 0.816. This is the only random variable indicating a clear effect of preliminary local buckling of the skin on underestimation of critical axial force of the overall shell stability. Moreover, the critical force of the local skin stability equals to 0.69 of the realized critical force of the overall shell stability and 0.69-0.816=0.563 of the theoretical critical force of the overall stability. However, for the ratio of experimental forces, which is close to the previous one, $0.725 \varepsilon=1.083$, for the ratio of 0.82 $\varepsilon=1.046$, for the ratio of 0.86 $\varepsilon=0.968$. Other random variables in Table 1 are also within the range of the sample random variable. The mean random variable in Table 1 without the last value equals to ~ 0.986, which is less than unity only by 1.4%. Accounting for a slight decrease of the mean random variable it can be concluded that at the ratio $\rho^O_T \geq \rho^O_T \geq 0.9 \rho^O_T$ a preliminary buckling of the shell between ribs does not result in the decrease of critical load of the overall stiffened shell stability. However, for reliable exclusion of this effect it is necessary to ensure equal theoretical critical forces of the local skin stability $\rho^O_T$ and overall shell stability $\rho^T_T$, when designing stiffened shells. The shell is designed upon the recommendations of [3] with the increased critical load of the local skin stability by 10-15% of the critical load of the overall shell stability. Therefore, when designing, equal critical loads of local and overall stability allow decreasing the skin thickness and the shell mass.

3. Analysis of the effect of relative increase in height of the reinforcing ribs on overall stability of the shell under axial compression

It is mentioned in [3] that relative increase in height of the reinforcing ribs $h/c_1 > 5$ results in nonuniformity of stresses over the shell section and decrease of $k_y$. Table 2 includes the values...
of $\psi > 9$ for several experimental data from the Appendix, and also the corresponding values of $h/c_1$ and random variable $\varepsilon$ for method (5).

Table 2.

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$h/c_1$</td>
<td>5.529</td>
<td>5.550</td>
<td>5.608</td>
<td>5.823</td>
<td>5.935</td>
<td>5.948</td>
<td>6.743</td>
<td>6.896</td>
<td>7.045</td>
<td>7.059</td>
<td>7.139</td>
<td>7.209</td>
<td></td>
</tr>
<tr>
<td>$\varepsilon$</td>
<td>0.993</td>
<td>1.083</td>
<td>0.990</td>
<td>1.040</td>
<td>1.020</td>
<td>0.981</td>
<td>0.992</td>
<td>1.051</td>
<td>1.048</td>
<td>0.998</td>
<td>1.042</td>
<td>0.991</td>
<td>1.022</td>
</tr>
</tbody>
</table>

As it follows from the Table, the relation of relative increase in height of the reinforcing ribs and decrease in the coefficient $k_\psi$ is not observed. Thus, the random variable $\varepsilon = 1.022$ corresponds to maximum value of $h/c_1 = 7.209$, i.e. the value of $k_\psi$ should be slightly increased to obtain equal theoretical and experimental critical loads. And quite the contrary, for the least value of $h/c_1 = 5.529$, $\varepsilon = 0.993$, and the value of $k_\psi$ should be inessentially decreased. The other values of $h/c_1 > 7$ from Table 2 refer to the random variable variations similar to the values of $h/c_1 < 7$. Therefore, the obstacles are removed for designing of shells with the parameters of $\psi > 8$ and $h/c_1 > 7$, if the critical stresses in rib tops are lower the yield stress. The practical use of these results eliminating the existing restrictions to the values of these parameters is determined by the lower mass of the reinforced shell due to the lower skin thickness under shortening of a distance between ribs and increasing of $\psi$ and $h/c_1$. If labour intensity in the stiffened shell production increases, but not significantly, due to the shell deeper milling under the reduced skin thickness, it cannot be a reason suppressing realization of these design options, accounting for essential reduction in the shell mass. In this case the most critical restriction is a technological one to the skin thickness, which weakens with increase of the shell radius. For example, if minimum mass of the stiffened shell for the desired load corresponds to a relative skin thickness $\delta_r = 1.5 \cdot 10^{-3}$, at the shell radius of 1 m the skin thickness will be less than the accepted technological restriction of 0.0018 m, at the shell radius of $>1.2$ m the skin thickness exceeds the technological restriction, and parameters of the shell with minimum mass can be achieved.

4. Analysis of efficiency of analytical methods improved with empirical dependences for coefficients of stability and correcting functions

The results given in Sections 1.1 and 1.2 herein are useful in validation of a capability to reduce mass of the stiffened shells designed with the improved methods of the analysis. The efficiency of improving the method of the analysis is estimated by the formula given in [5] and relating the safety coefficient, quantile of reliability and coefficient of variation for the coefficient of variation $k_\alpha \leq 0.1$:

$$k_\delta = \frac{1}{1 - \theta k_\delta}$$  \hspace{1cm} (6)

Thus, the quantile of reliability is given by $\theta = \frac{1}{k_\alpha} \left(1 - \frac{1}{k_\delta}\right)$. It is obvious that for the fixed safety coefficient $k_\alpha$ the quantile of reliability increases with decrease of the coefficient of variation. Paper [5] also presents a tabular relationship between the probability of the structure failure $V$ and the quantile of reliability $\theta$. Using these results and relationship between the probability of failure-free operation of the structure and the probability of its failure $Y = 1 - V$, one can calculate $Y$ in accordance with the corresponding value of $k_\alpha$ for each method of the analysis. For example, if a directive safety factor $k_\alpha = 1.3$ is
specified, then for method (1) \( k_\theta = 6.99 \cdot 10^{-2} \), the quantile of reliability \( \theta = 3.301 \), \( V = 8.2 \cdot 10^{-4} \) and \( Y = 0.99918 \), and for method (2) \( k_\theta = 5.98 \cdot 10^{-2} \), \( \theta = 3.859 \), \( V = 8.1 \cdot 10^{-5} \) and \( Y = 0.9999919 \). Therefore, the highest accuracy of method (2) leads to a higher probability that the stiffened shell will hold the shape under design compressive load. Even higher probability of failure-free operation of the stiffened shell structure under axial compression is provided with method (1) improved with the empirical dependence between the coefficient of stability and the load parameter. Given that in this case \( k_\theta = 0.0493 \) with eliminated two random variables at \( 3\sigma \), \( \theta = 4.681 \), \( V = 8.1 \cdot 10^{-7} \), \( Y = 0.99999919 \), i.e. practically a unity. As mentioned above, the improvement of method (2) with the corresponding empirical dependence for the coefficient of stability does not result in decrease of the coefficient of variation.

Further modification of methods (1 and 2) with correcting functions and generation of method (5) improve their agreement with experimental data and, consequently, result in additional decrease of the coefficients of variation in such a way that the probability of the shell failure \( V \) for a specific directive safety factor \( k_\theta = 1.3 \) becomes less than \( 1 \cdot 10^{-8} \), and the probability of failure-free operation of the shell structure \( Y \) is characterized by eight decimal nines.

The results of designing of a stiffened shell for axial compression \( \rho_T = 4.174 \cdot 10^{-5} \) and lateral compression \( \rho_Q = \frac{q_p}{E r^2} = 3.252 \cdot 10^{-5} \) (\( q_p \) – design lateral compression) at their combined action with the internal pressure \( \rho_q = \frac{q_p}{E} = 1.209 \cdot 10^{-5} \) (\( q_p \) – design internal pressure) applied separately to the shell are given in Fig.5 as curves 1, 2, 3, 4, 5. The curves were obtained from the corresponding methods (1, 2) improved with empirical dependences for coefficients of stability and also methods (3, 4, 5) with equal critical loads of the overall and local stability of the shell under relative shortening of a distance between axial ribs. In this case, the skin thickness was calculated on the assumption of its local stability between ribs:

\[
\delta_r = 0.358 \left( \frac{\rho_T}{1 + 0.16 \rho_2 \beta_8} \right)^{0.5} \frac{1}{\tau_1}, \quad \tau_i = \frac{2.5 \sqrt{\delta r}}{l_i}.
\]

Fig.5.
In the figure the vertical axis is the total sectional height $\delta_h=\delta_{\text{isc}}/r$, the horizontal axis is the parameter of mass thickness $\delta_m=\delta_r(1+\lambda_1+\lambda_2+\Delta m)$.

$$\Delta m = 0.172 \left( \frac{r_0}{r} \right)^2 \frac{\tau_1 + \tau_2}{\delta_r^{1.5}} + 0.1376 \left( \frac{r_1}{r} \right)^2 \frac{\tau_2 \tau_1}{\delta_r} \beta_\delta - \frac{\lambda_1 \lambda_2}{\beta_\delta}$$

- increase of the parameter of mass thickness due to technological radii of transition between the ribs and the shell $r_0$ and between the ribs crossed at the mesh corners $r_1$. The specified technological radii are formed from mechanical milling of the reinforcing ribs.

Design values of all loads were calculated with a directive safety coefficient equal to 1.3. When designing, the internal pressure was as the restriction on the effective shell thickness in circumferential direction $\delta_{r}=\delta_r(1+0.16\varphi_2\beta_\delta)=2.116 \times 10^{-3}$. Besides, when designing, a strict condition was imposed to the total sectional height parameter $\delta_h<1.5 \times 10^{-2}$. The extreme design shell options meeting the internal pressure value and restriction to the parameter $\delta_h$ on curves 2, 3, 4, 5 are marked with vertical segments. The decrease in mass of these shell options was estimated with respect to the design option mass in the extreme right point of curve 1, where the recommendations of [3] for the parameters $\psi =7.60$ and $h/c_1=3.79$ were fulfilled. Thus, drop in mass for the extreme design option on curve 2 was 9.69% at $\psi=9.22$, $h/c_1=4.66$, on curve 3 – 5.77% at $\psi=10.19$, $h/c_1=4.51$, on curve 4 – 6.19% at $\psi=9.89$, $h/c_1=4.30$, on curve 5 – 7.28% at $\psi=9.13$, $h/c_1=4.01$. Hence, the stiffened shell mass is effectively decreased in method (2) improved with empirical dependence for the coefficient of stability and method (5). Designing with uniform shortening of distances between axial and circumferential ribs (with a square net of ribs) provides decreasing of the shell mass: with method 2 – by 8.87% at $\psi=9.48$, $h/c_1=5.57$, with method 5 – by 7.18% at $\psi=9.39$, $h/c_1=5.29$. However, if different coefficients of variation of methods (1-5) are taken into account and safety coefficients are determined from dependence (6) at the probability of failure-free operation of the stiffened shell structure equal to 0.999 and the quantile of reliability equal to 3.15, then for methods (1 and 2) improved with a variable of the stability coefficient the safety coefficients are 1.184 and 1.233, for methods (3, 4, 5) they are 1.160, 1.153, 1.145. Fig. 6 gives the results of designing of a stiffened shell with relative shortening of a distance between axial ribs under methods (1, 2, 3, 4, 5) with a design axial force different for each method.

Fig.6.
In this case, as can be seen from the figure, the mass of extreme design options marked on curves 2, 3, 4, 5 with vertical segments additionally decreases with respect to the mass of the same design option in Fig. 5. For the design option on curve 2 the mass decreases by 11.53% at $\psi=9.10$, $h/c_1=5.00$, on curve 3 – by 12.37% at $\psi=9.27$, $h/c_1=5.42$, on curve 4 – by 12.83% at $\psi=9.36$, $h/c_1=5.75$, on curve 5 – by 15.87% at $\psi=9.02$, $h/c_1=7.04$. The mass of the design option corresponding in Fig. 6 to the extreme right point of curve 1 also decreases by 5.79% at $\psi=7.92$, $h/c_1=4.37$. When designing with uniform shortening of distances between axial and circumferential ribs (with a square net of ribs) and applying method 5, the shell mass decreases by 13.92% at $\psi=8.98$, $h/c_1=6.89$. Thus, the less complex method of analysis (5) provides the best design option of the stiffened shell with the least mass and simultaneous decrease of the total sectional height.

**Conclusion**

When comparing theoretical results of the critical axial force of the stiffened shell with experimental data of the representative sample, it was observed that the analytical methods under consideration with constant coefficients of stability overestimated critical load at low normalized parameters of the axial force and underestimated it at high parameters.

The article proposes empirical relations between coefficients of stability and axial compression force, which adapt more efficiently theoretical results to experimental data. Additional reduction in deviation of the sample random variable expressed in a ratio of experimentally and theoretically obtained critical loads ensures application of correcting functions.

The performed analyses of several random variables of the sample and corresponding experimental data show the lack of sensitivity of critical axial force of the stiffened shell to the increase of normalized parameters of the total sectional height and rib height, and to preliminary local buckling of the skin between ribs, if the critical load of the skin local stability is within $\rho^O_T \geq \rho_{T/L}^O \geq 0,9 \rho^O_T$.

Designing of a stiffened shell for different ways of definition of the safety coefficient confirms the efficiency of design shell options generated under the improved methods of the analysis by the criterion of mass minimum.

**References**

Appendix 1. Experimental data (n=134) on critical force of axial compression of orthogonally stiffened cylindrical shells.

<table>
<thead>
<tr>
<th>№</th>
<th>(\delta \cdot 10^{-3})</th>
<th>(\lambda_1)</th>
<th>(\lambda_2)</th>
<th>(\beta_8)</th>
<th>(\rho_{r} \cdot 10^{-6})</th>
</tr>
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<tbody>
<tr>
<td>1.</td>
<td>2.147</td>
<td>0.201</td>
<td>0.166</td>
<td>7.505</td>
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<td>0.181</td>
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<td>0.162</td>
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<td>9.</td>
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Valeriy Vasilyevich Chekanin. Leading Systems Designer (OAO «Academician V.P.Makeyev State Rocket Centre»; Miass, Russia). Sphere of scientific activity: inverse optimization problems of the stiffened shells, numerical methods with their modifications on the basis of experimental data.
Sandwich panels with composite foldcore under dynamic loading

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A method for numerical solution of dynamic deformation of composite plates and foldcores with various types of layers, stacking sequence and geometry under high- and low velocity impact and airblast loading has been created using the finite-element ANSYSLS-DYNA software. Modeling of protective shield with aluminium foam core and composite foldcore has been implemented.

Keywords: Finite-element simulation, foldcores, composite material, impact loading, material failure, airblast, impactor.

Literature review

Composite foldcores have high performance and low weight. This causes higher interest to processes in foldcores under static and dynamic loading [1-7]. Compressing and shear loading are studied sufficiently by many authors. Research review can be found in [1]. At the same time, dynamic loading investigation demands much more resources. Significant number of investigations of lightweight cores under low- and high-velocity loading has been carried out. Special attention should be paid to composite foldcores made at KNRTU-KAI by technology described in [2]. In research [3] considers both static and dynamic loading. There are also a lot of experimental and theoretical investigations of honeycomb core [4-7], aluminium foam core [5,8-9] and lattice pyramidal core [10]. However, a research of composite foldcores has not been carried out, although numerical experiments [1] revealed promising results in energy absorbing problems.

Finite elements and geometrical models

All calculations were carried out using the ANSYSLS-DYNA software. 4-node shell elements (according to Belytchko–Tsay [11]) were chosen as finite elements (FE) of the core model. Each element has 12 degrees of freedom at each node: three components of displacement, speed, and acceleration vectors for x, y, and z axes of the midsurface, and of the vector of rotation around these axes.

The geometry of foldcore cells is assigned by several layout parameters of the initial material, after which a model is constructed in accordance with the degree of folding [1].

Material models and failure criteria

In the LS-DYNA software, an analysis of strength of thin-wall layered composites is carried out by using various failure models of materials, which are combinations of criteria responsible for particular types of failure of filler and matrix of the material. For the calculations, we used material models 54 and 55 (MAT_ENHANCED_COMPOSITE_DAMAGE [11]). Table 1 presents failure criteria for these models. In Table 1: $X_t$ and $Y_t$ are the ultimate tensile strengths along and across fibers (warp and weft threads), respectively; $X_c$ and $Y_c$ are the ultimate compressive strengths along and across fibers; $S_c$ is the ultimate shear strength in the layer; $\sigma_{uu}$, $\sigma_{hb}$, $\sigma_{sh}$ are layer stresses in orthotropy axes; $\beta$ is the contribution of tangential stresses to the failure in tension ($0 \leq \beta \leq 1$); $\tau$ are tangential stresses of high nonlinearity:

\[ \beta = \frac{\sigma_{uu}}{\sigma_{tu}} \]
where $\alpha \geq 0$ is the nonlinearity factor. For model 54, at $\beta = 1$ and $\alpha = 0$, the Hashin criterion for fibers can be obtained.

Table 1.

<table>
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<th>Layer stress</th>
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<th>MAT55</th>
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<td>$\sigma_{aa} \geq 0$</td>
<td>$\left( \frac{\sigma_{aa}}{X_t} \right)^2 + \beta \tau \geq 1$, $E_a = E_b = G_{ab} = v_{ba} = v_{ab} = 0$</td>
<td>$\sigma_{bb}^2 + \left( \frac{\sigma_{ab}}{S_c} \right)^2 + \frac{1}{Y_c - Y_c} \sigma_{bb} \geq 1$, $E_b = v_{ba} = v_{ab} = 0$, $\Rightarrow G_{ab} = 0$</td>
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<td>$\sigma_{aa} &lt; 0$</td>
<td>$\left( \frac{\sigma_{aa}}{X_c} \right)^2 \geq 1$, $E_a = v_{ba} = v_{ab} = 0$</td>
<td>$\left( \frac{\sigma_{ab}}{S_c} \right)^2 + \frac{1}{Y_t - Y_c} \sigma_{bb} \geq 1$, $E_b = v_{ba} = v_{ab} = 0$, $\Rightarrow G_{ab} = 0$</td>
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<td>$\left( \frac{\sigma_{ab}}{S_c} \right)^2 + \frac{1}{Y_t - Y_c} \sigma_{bb} \geq 1$, $E_b = v_{ba} = v_{ab} = 0$, $\Rightarrow G_{ab} = 0$</td>
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<td>$\left( \frac{\sigma_{bb}}{2S_c} \right)^2 + \left( \frac{Y_c}{2S_c} \right)^2 - 1 \left( \frac{\sigma_{bb}}{Y_c} \right)^2 + \tau \geq 1$, $E_b = v_{ba} = v_{ab} = 0$, $\Rightarrow G_{ab} = 0$</td>
<td>$\left( \frac{\sigma_{ab}}{S_c} \right)^2 + \frac{1}{Y_t - Y_c} \sigma_{bb} \geq 1$, $E_b = v_{ba} = v_{ab} = 0$, $\Rightarrow G_{ab} = 0$</td>
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</table>

In the case of failure of an element in all layers according to one of the strength criteria presented in Table 1, the finite element is removed.

Model 54 allows one to "control" the failure by using the maximum strains: DFAILT – tensile along the fibers, DFAILC – compressive along the fibers, DFAILM – tensile and compressive across the fibers, and DFAILS – shear, as well as the effective strain EFS, which is a complex parameter including tensile, compressive, and shear strains.

If the maximum strains are nonzero, the failure in a layer occurs only when strains in this layer reach one of the maximum values; if stresses in the layer reach the limiting surface earlier than the layer fails from maximum strains, the material “flows” until strains in the layer reach one of their maximum values.

If the effective strain EFS is assigned, the destruction occurs when the equivalent strain reaches the value of EFS.

For reducing the ultimate tensile strength of fiber $X_t$ after the destruction of the material in compression across fibers, both models can employ the parameter $FBRT > 0$, which lowers this limit according to the rule $FBRT \times X_t$. Individually, model 54 supports the possibility of decreasing the compressive strength $X_c$ along the fiber after exceeding the compressive strength $Y_c$ across fibers by means of the parameter $YCFAC$ according to the expression $X_c = YCFAC \times Y_c$ (by default, $YCFAC = 2$).

In model 54, the possibility of failure of an element after a certain number of time steps TFAIL is also realized. By assigning this parameter, it is possible to additionally take into account the decreased rigidity of neighboring elements upon destruction of a central one. For
this purpose, a “crashfront” algorithm is used in the LS-DYNA software, which is controlled by the SOFT parameter. For example, if we take that SOFT = 0.4, it is considered that the neighboring elements are damaged by 60%.

Modeling of Z-crimp foldcore under low- and high-velocity impact; model and method verification

Material model, finite-element discretization of core and face sheets are equal to investigation under static loading [1].

Impactor is a steel full sphere with diameter 25.4 mm, material model of rigid body MAT_RIGID and mass equal to 1.56 kg. Geometrical model and finite-element discretization are presented in figure 1.

![Fig.1. Geometrical model and finite-element discretization.](image)

Boundary condition in simulation were following:
- zero displacements $U_x$, $U_y$, and $U_z$ of nodes adjacent to the lower covering of the panel;
- impactor has initial velocity equal to 9 m/s for low velocity impact and 64 m/s for high velocity.

Contact interaction between impactor and sandwich panel has been developed in the model. Method and model verification has been carried out by comparing numerical results with experimental data [3] by internal energy and force. Divergence does not exceed 10%.

Investigation of deflection of aramid and cytec composite plate under impact loading depending on initial velocity of impactor

In this case the following initial velocities of the impactor were considered: 2.5, 5, 9, 15, 30, 60 m/s. Plate material is Cytec [1] with stacking sequence [+45,-45] and layer thickness is equal to 0.25mm.

Maximum deflection was measured in the center of plate- the point of initial contact with the impactor. Simulation results are presented in table 2.
Table 2. Simulation results.

<table>
<thead>
<tr>
<th>Pressure, Pa</th>
<th>Max. stress, Pa</th>
<th>Max. deflection, mm</th>
<th>Initial velocity, m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.31e7</td>
<td>1.10e8</td>
<td>2.5m/s</td>
<td>1.11mm</td>
</tr>
<tr>
<td>7.84e7</td>
<td>1.94e8</td>
<td>5m/s</td>
<td>1.76 mm</td>
</tr>
<tr>
<td>6.54e7</td>
<td>2.12e8</td>
<td>9m/s</td>
<td>2.69 mm</td>
</tr>
<tr>
<td>1.35e8</td>
<td>3.88e8</td>
<td>15m/s</td>
<td>3.97 mm</td>
</tr>
<tr>
<td>1.27e8</td>
<td>5.08e8</td>
<td>30m/s</td>
<td>7.26 mm</td>
</tr>
<tr>
<td>1.52e8</td>
<td>5.25e8</td>
<td>60m/s</td>
<td>13.29 mm</td>
</tr>
</tbody>
</table>

Method of FE simulation of airblast shock action; Kingery-Bulmash blast model

To simulate the blast loading, LS-DYNA built-in Conwep function, based on Kingery-Bulmash method for the air shock wave, was used. A sufficiently realistic approach is implemented there with an exponential decrement of pressure:

\[ P(t(x)) = P_{so} \left[ 1 - \frac{t(x) - T_a}{T_0} \right] \exp \left[ -\frac{A \times (t(x) - T_a)}{T_0} \right] \]

where:
- \( t(x) \) – current time;
- \( P(t) \) – pressure at time \( t \) (KPa);
- \( P_{so} \) – max pressure (KPa);
$T_0$ – positive phase duration (ms);  
$A$ – decrement ratio;  
$T_a$ – moment of wave contact (ms).

**Protective shield with Al foam core under blast loading**

Geometry model of protective shield with Al foam core (FE discretization is presented in fig. 2) corresponds to investigation [2]. The body of BTR-80 was replaced by corresponding boundary conditions- zero displacements $U_x$, $U_y$, and $U_z$ of nodes adjacent to the lower facesheet.

**Table 3.**

<table>
<thead>
<tr>
<th>Steel facesheet</th>
<th>Al foam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Property</td>
<td>Value</td>
</tr>
<tr>
<td>$E$</td>
<td>200 GPa</td>
</tr>
<tr>
<td>$\nu$</td>
<td>0.27</td>
</tr>
<tr>
<td>$\sigma_T$</td>
<td>310 kPa</td>
</tr>
<tr>
<td>$E_T$</td>
<td>763 kPa</td>
</tr>
<tr>
<td>$\rho$</td>
<td>7860 kg/m$^3$</td>
</tr>
</tbody>
</table>

Boundary conditions:

- panel has anchorage at whole perimeter;  
- core and facesheets are moving jointly in contact areas;  
- explosive is placed at the center of panel offset 0.45m from upper facesheet.

**Protective shield with composite foldcore under blast loading**

FE model of protective shield with V-crimp composite foldcore is presented in fig 3. The model consists of 267000 SHELL163 finite elements.

Following material models were used:

For foldcores- *MAT_ENHANCED_COMPOSITE_DAMAGE  
Steel facesheets- *MAT_PLASTIC_KINEMATIC.  
Boundary conditions match the case with Al foam foldcore shown above.
Velocities and accelerations of nodes have significant dependence on timestep and shutting down of elements while material failure. It is almost impossible to estimate behavior of protective shield by these data. Indirect estimation of panel response could be obtained by node velocity of lower facesheet. Maximum velocities of nodes along Z-axes are given in table 4.

Comparison of modeling results for Al foam and V-crimp made of aramid and carbon with various stacking sequence is presented in table 5. Geometrical dimensions of core (Width×Depth) is 1100×1100 mm, thickness of steel facesheets is equal to 3.5mm. Hereby, according to simulation results, protective shield with Al foam core is equal to V-crimp made of 4 plies of aramid in terms of maximum deflection. Besides, sandwich panel with Al foam core is much worse in mass and thickness.

### Table 4. Maximum velocities of lower facesheet

<table>
<thead>
<tr>
<th>Core</th>
<th>Max. velocity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al foam</td>
<td>32.52 m/s</td>
</tr>
<tr>
<td>Z-crimp</td>
<td>32.47 m/s</td>
</tr>
<tr>
<td>V-crimp</td>
<td>43.96 m/s</td>
</tr>
</tbody>
</table>

### Table 5. Al foam and V-crimp

<table>
<thead>
<tr>
<th>Panel thickness</th>
<th>Al foam</th>
<th>V-crimp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel thickness</td>
<td>50 mm</td>
<td>28 mm</td>
</tr>
<tr>
<td>Panel mass</td>
<td>98 kg</td>
<td>14.5 kg</td>
</tr>
<tr>
<td>Max. deflection</td>
<td>35.32 mm</td>
<td>41.34 mm</td>
</tr>
</tbody>
</table>

### Conclusions

In the present study, a procedure for FE simulation of sandwich panel behavior under dynamic loading has been created. Simulation results have revealed perspectives of using composite Z-, V-crimp foldcores, made of aramid material, as energy absorbing multilayer sandwich panels. V-crimp core demonstrates ability of resistance to airblast wave loading equal to panel with Al core, with significant benefits in terms of weight (-70% of Al core mass) and thickness (-42%).
References


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The calculation of composite constructions in the designing setting

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Extensive use of composite materials in aircrafts both in power and in extra loaded units leads to the need of the development of techniques of the stress-strain state assessment of construction at the design phase. An algorithm for design calculation of a structure made of composite materials allowing for the constrained warping of sections with the opportunity to vary the solution accuracy is described. This results in complication of calculations. The technique is used for structural analysis of a caisson and a shell of open section type. It is shown that the solution allows taking into account such phenomena as constrained bend and constrained torsion of the open-loop structure.

Technical progress of the 20th century led to the creation of new construction materials with the high strength and stiffness on the plastic, metal and ceramic substrates. In mid 1960’s, elaboration of a new class of materials started in the aircraft industry – reinforced composite materials (CM) or composites. At the beginning of 1970’s, their implementation led to wide application of composites in aircraft production [1]. The application of CM with high specific characteristics in non-power elements has been actually mastered and the main trend is now the implementation of CM in power units, which will certainly allow reduction of aircraft weight. Thus, for example, the Experimental Design Bureau of JSC Kazan Helicopter Plant develops ANSAT helicopter, in which most elements are designed using multilayer materials (main rotor and tail rotor, rotor head, vertical tail, cockpit canopy, nose cone, cone of the tail boom, hoods of gear compartment). Besides, modernization and optimization of existing aircrafts does not stop. For example, a stabilizer construction completely made of CM was designed and proposed for MI-8 helicopter. It allowed weight reduction by 30 \% comparing with its metal analogue.

Thus, the issue of calculation of composite structures is becoming increasingly important. It is not always reasonable to use the existing calculation software based on finite element method because of relatively high price, labor intensity and difficulties in learning how to use it. At the design stage, when structural layout of a product is formed, it is more reasonable to use approximate (engineering) calculation methods.

One of the main methods of structural strength analysis is a girder theory. This approach is easy to implement, which makes it easy to obtain approximate results for structure’s stress-strain state. But the accepted assumptions limit the application field of the theory.

We have already proposed [2] an algorithm for the calculation of CM construction using the beam theory without finding the principal central axis of sections which are different for each section. The proposed algorithm takes into account the effect of heating on structure stresses. To implement the above algorithm, a computer program has been written that enables to obtain the result quickly. The paper [2] presents a sample calculation of a three-longeron caisson section. Relations of the finite element method are used for calculation, enabling to link the solutions for multiple sections.

Substantial variation of multilayered materials’ parameters with temperature complicates the CM product design. The temperature coefficients of linear expansion of the monolayer in the direction of “natural” axes can be significant and can differ both in magnitude and in sign. Temperature coefficients for a layer package depend also on its structure. Changing the temperature of a package in general leads to thermal stresses that in some way affect the bearing capacity of the structure.

The values of thermal stresses depend on the multilayer package’s thermal coefficients. Here are the calculation procedure and working formulas for the coefficients of thermal expansion and thermal stresses of a multilayer package. The need to calculate them often occurs before
The calculation of composite constructions in the designing setting

the actual calculation for a package under contour forces acting on it. We assume that the technical constant values of thermal elasticity of monolayers are known. We perform calculations in the following order.

1. Compute the coefficients of thermal stresses \( \beta^k_{ij} \) for “natural” axes of monolayers of the package:

\[
\beta^k_1 = \left( \alpha^k_1 + \mu^k_1 \alpha^k_2 \right) E^k_1 / (1 - \mu^k_1 \mu^k_2) \\
\beta^k_2 = \left( \alpha^k_2 + \mu^k_1 \alpha^k_1 \right) E^k_2 / (1 - \mu^k_1 \mu^k_2)
\]

2. Find the coefficients of thermal expansion \( \bar{\alpha}^k_{ij} \) and stresses \( \bar{\beta}^k_{ij} \) of monolayers package for arbitrary axes \((x, y)\):

\[
\bar{\alpha}^k_x = \alpha^k_1 \cos^2 \theta_x + \alpha^k_2 \sin^2 \theta_x; \quad \bar{\alpha}^k_y = \alpha^k_1 \sin^2 \theta_x + \alpha^k_2 \cos^2 \theta_x; \quad \bar{\alpha}^k_{xy} = 2(\alpha^k_1 - \alpha^k_2) \sin \theta_x \cos \theta_x
\]

\[
\bar{\beta}^k_x = \beta^k_1 \cos^2 \theta_x + \beta^k_2 \sin^2 \theta_x; \quad \bar{\beta}^k_y = \beta^k_1 \sin^2 \theta_x + \beta^k_2 \cos^2 \theta_x; \quad \bar{\beta}^k_{xy} = (\beta^k_1 - \beta^k_2) \sin \theta_x \cos \theta_x
\]

3. Determine the coefficients of thermal stresses \( \beta_{ij} \) for the axes \((x, y)\) of the package:

\[
\beta_x = \sum_{k=1}^{n} \bar{\beta}^k_x \bar{h}_k; \quad \beta_y = \sum_{k=1}^{n} \bar{\beta}^k_y \bar{h}_k; \quad \beta_{xy} = \sum_{k=1}^{n} \bar{\beta}^k_{xy} \bar{h}_k
\]

The coefficients of thermal expansion of the package are generally defined by the formula \( \{ \alpha_{xy} \} = \{ S \} \{ \beta_{ij} \} \), where the compliance matrix \( \{ S \} \) is found by inversion of the stiffness matrix. For the package of symmetrical structure

\[
\alpha_x = (g_{22} \beta_x - g_{12} \beta_y) / (g_{11} g_{11} - g_{12}^2) = (\beta_x - \mu_{xy} \beta_y) / E_x
\]

\[
\alpha_y = (g_{11} \beta_x - g_{12} \beta_y) / (g_{11} g_{11} - g_{12}^2) = (\beta_y - \mu_{xy} \beta_x) / E_y
\]

Knowing the coefficients of thermal expansion of the package, it is possible to determine values of thermal stresses: \( \varepsilon_{Tz} = \alpha_z t, \varepsilon_{Ts} = \alpha_s t \) - temperature deformation of multilayer package along \( z \) and \( s \) axes. With the help of the obtained temperature deformation the thermal stresses are determined, using methodology for the calculation of the stress-strain state of the structure.

Table 1

<table>
<thead>
<tr>
<th>Case</th>
<th>( \theta_k )</th>
<th>( n_c )</th>
<th>( E_{xx} ) daN/mm²</th>
<th>( E_{yy} ) daN/mm²</th>
<th>( G_{xy} ) daN/mm²</th>
<th>( \alpha_x \times 10^6 ), K⁻¹</th>
<th>( \alpha_y \times 10^6 ), K⁻¹</th>
<th>( \sigma_f ) daN/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( \pm 45^o )</td>
<td>2</td>
<td>880</td>
<td>880</td>
<td>1765</td>
<td>0.926</td>
<td>0.926</td>
<td>\pm 0.48</td>
</tr>
<tr>
<td>2</td>
<td>( \pm 30^o )</td>
<td>2</td>
<td>2360</td>
<td>532</td>
<td>1386</td>
<td>-14.21</td>
<td>37.77</td>
<td>\pm 1.59</td>
</tr>
<tr>
<td>3</td>
<td>( \pm 60^o )</td>
<td>2</td>
<td>532</td>
<td>2360</td>
<td>1386</td>
<td>37.77</td>
<td>-14.21</td>
<td>\pm 2.12</td>
</tr>
<tr>
<td>4</td>
<td>( \pm 44.55^o )</td>
<td>2</td>
<td>901</td>
<td>860</td>
<td>1764</td>
<td>0</td>
<td>1.88</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>0°; 90°</td>
<td>2</td>
<td>3707</td>
<td>3707</td>
<td>248</td>
<td>0.926</td>
<td>0.926</td>
<td>\pm 1.47</td>
</tr>
<tr>
<td>6</td>
<td>( \pm 45^o ); 0°</td>
<td>3</td>
<td>2905</td>
<td>1240</td>
<td>1259</td>
<td>-5.03</td>
<td>11.48</td>
<td>\pm 0.03</td>
</tr>
<tr>
<td>7</td>
<td>( \pm 45^o ); 90°</td>
<td>3</td>
<td>1240</td>
<td>2905</td>
<td>1259</td>
<td>11.48</td>
<td>-5.03</td>
<td>\pm 1.75</td>
</tr>
<tr>
<td>8</td>
<td>( \pm 30^o ); 0°</td>
<td>3</td>
<td>3993</td>
<td>611</td>
<td>1007</td>
<td>-10.05</td>
<td>39.48</td>
<td>\pm 1.23</td>
</tr>
<tr>
<td>9</td>
<td>( \pm 60^o ); 0°</td>
<td>3</td>
<td>2656</td>
<td>2656</td>
<td>1006</td>
<td>0.926</td>
<td>0.926</td>
<td>\pm 1.17</td>
</tr>
<tr>
<td>2a</td>
<td>( \pm 30^o )</td>
<td>2</td>
<td>2360</td>
<td>532</td>
<td>1386</td>
<td>-14.21</td>
<td>37.77</td>
<td>\pm 6.39</td>
</tr>
</tbody>
</table>
Thus, the effect of fiber orientation and structure of the package on the level of thermal stress through the example of organoplastic Kevlar 49 was studied in paper [3]. The temperature stresses encountered in the flat panel consisting of two ribs bound by a layered CM package of symmetrical structure are determined under uniform heating at 100°C. The panel width was $B = 150$ mm, length $L = 200$ mm. In longitudinal CM ribs the fibers are mainly oriented along their axis. Sheathing panel between the ribs is divided into three equal-area sections, and dummy ribs taking into account the capability of the sheathing to sustain normal stress are located in their centers of gravity.

Table 1 gives the numerical values of the above moduli and thermal coefficients for a number of structures of the package. The last column shows the values of thermal stresses in the sheathing and panel ribs found using the beam theory. Since the total cross-sectional area of ribs and sheathing is the same, the stresses in ribs and sheathing differ only in sign. Case 2a differs from case 2 only in metal panel ribs which replace the metal ones made of aluminum alloy. In the case 2a, thermal stresses appeared to be the most significant. In the case 6, thermal stresses are negligible. This is because the thermal expansion coefficients along the sheathing panels and ribs are almost equal.

In the course of design it is necessary not only to determine the stress-strain state of the structure, but also to evaluate the acting stresses. The design algorithm of the minimum mass structure is based on the selected criteria of strength. So, today, there are many phenomenological strength criteria which help, in general, to get a limit surface, the internal volume of which is a number of allowable stress ratios. From an existing set of criteria it is necessary to determine the most appropriate one for each design, which will obviously ensure the structure reliability. For metal structures there are most preferred criteria for durability. For composite materials there are no definitive guidelines for the recommended strength criterion.

To assess the strength of intact monolayer composite material one of the phenomenological criteria may be used, for example:

Hill’s criterion:

$$\frac{\sigma_1^2}{S_1} - \frac{\sigma_1 \sigma_2}{S_1^2} + \frac{\sigma_2^2}{S_2} + \frac{\tau_{12}^2}{S^2} = 1$$

where $S$ is a limiting tangential stress; $S_1$ and $S_2$ - limiting normal stresses along and across the grain, respectively:

$$S_1 = \begin{cases} \sigma_{a1} & \text{for } \sigma_1 \geq 0; \\ \sigma_{-a1} & \text{for } \sigma_1 < 0; \end{cases} \quad S_2 = \begin{cases} \sigma_{a2} & \text{for } \sigma_2 \geq 0; \\ \sigma_{-a2} & \text{for } \sigma_2 < 0 \end{cases}$$

Where $\sigma_{a1}$, $\sigma_{-a1}$ are the ultimate strength of monolayer in tension and compression parallel to grain, respectively, $\sigma_{a2}$, $\sigma_{-a2}$ - across the grain.

Tsai’s criterion:

$$\frac{\sigma_1^2}{S_1} - \frac{\sigma_1 \sigma_2}{S_1 S_2} + \frac{\sigma_2^2}{S_2^2} + \frac{\tau_{12}^2}{S^2} = 1$$

Hoffman’s criterion:

$$\frac{\sigma_1^2}{\sigma_{a1} \sigma_{-a1}} - \frac{\sigma_1 \sigma_2}{\sigma_{a1} \sigma_{-a1}} + \frac{\sigma_2^2}{\sigma_{a2} \sigma_{-a2}} + \frac{\tau_{12}^2}{S^2} + \frac{\sigma_{-a1} - \sigma_{a1}}{\sigma_{a1} \sigma_{-a1}} \sigma_1 + \frac{\sigma_{-a2} - \sigma_{a2}}{\sigma_{a2} \sigma_{-a2}} \sigma_2 = 1$$

D’Alil’s criterion:
Fisher’s criterion:

\[
\frac{\sigma_1}{\sigma_{-e_1}} - K \frac{\sigma_1 \sigma_2}{\sigma_{-e_1} \sigma_{-e_1}} + \frac{\sigma_2^2}{\sigma_{-e_1} \sigma_{-e_1}} + 3 \frac{\tau_{12}}{S^2} + \left(1 - \frac{\sigma_{-e_1}}{\sigma_{-e_1}} \right)(\frac{\sigma_1 + \sigma_2}{\sigma_{-e_1}}) = 1
\]

where the coefficient \(K\) is determined by the deformation properties of the monolayer:

\[
K = \frac{E_1(1+\mu_{21}) + E_2(1+\mu_{22})}{2\sqrt{E_1E_2(1+\mu_{21})(1+\mu_{22})}}
\]

Based on the selected strength criterion, a combination of medium stresses is defined, at which the layer is destroyed. Since the unidirectional layer has a strong anisotropy of strength properties (high strength in stacking direction of fibers and relatively low in transverse direction and under shear), then, depending on the state of stress, the matrix can be initially destroyed because of transverse and shear stress, while along the fibers the layer can still sustain further load increase. When the fibers are destroyed, it can be assumed that the layer is completely destroyed. Hence two limiting conditions for composite constructions are possible [4]:

- primary, when the binder is destroyed in one or in several layers;
- exhaustion of bearing capacity, when a multilayer package is not able to sustain further increase of load.

We assume that if the fiber is destroyed, the bearing capacity of the package is exhausted at least in one of its monolayers. We call the average stresses corresponding to the primary limit state the admissible ones, and the stress corresponding to the exhaustion of carrying capacity the limit one. Thus, there are two surfaces for the selected strength criterion: admissible and limit.

It is obvious that in the design of aircraft structures made of multi-layer composite it should be required that the operation load does not lead to material disintegration, and the exhaustion of bearing ability occurs at the loads not lower than the design ones. Thus, the criterion of durability of CM structures can be written down this way:

\[
\sigma^3 \leq \sigma_{\text{don}} \quad \sigma^p \leq \sigma_{\text{np}}
\]

where \(\sigma^3\) and \(\sigma^p\) are operational and design stresses, respectively; \(\sigma_{\text{don}}\) and \(\sigma_{\text{np}}\) – admissible and limit stresses, respectively.

Paper [1] compares strength criteria for the four-layer composite package from KMU-7T. From the analysis of results based on various strength criteria, it follows that:

- under primary fracture there is a significant discrepancy in the results, the results especially differ with respect to D’Alema’s criterion;
- secondary fracture results obtained over all criteria are almost identical;
- results based on Hill and Tsai criteria are lower and upper bounds, respectively, and they should be used in practical applications.

It should be noted that the connection between the primary and secondary destruction is not proportional to the external loading.

Hill-Mises criterion provides an a priori sturdy construction. Influence of construction temperature change on the phenomenological criterion consists in the onset of additional
stresses and change of stiffness characteristics of the material and failure stress. Thus, the
Hill-Mises criterion allowing for temperature stresses is the following:

\[ \frac{(\sigma_1 + \sigma_{1t})^2}{S_{1t}^2} - \frac{(\sigma_1 + \sigma_{1t})(\sigma_2 + \sigma_{2t})}{S_{1t}^2} + \frac{(\sigma_2 + \sigma_{2t})^2}{S_{2t}^2} + \frac{\tau_{12}^2}{S_t^2} = 1 \]

where \( \sigma_{1t}, \sigma_{2t} \) are thermal stresses for the axes of layer orthotropy; \( S_{1t}, S_{2t}, S_t \) – values of failure stresses at temperature \( t \).

Algorithm of "cold" structure design with minimum mass is shown in the paper [5]. Using the
Hill-Mises criterion allowing for temperature stresses in the algorithm of the “cold” minimum
mass construction design enables to design a full-stress construction located in non-uniform
temperature field. The difficulty that arises in the design of heated structures is the need to
know the failure stresses at the estimated temperature.

For example, paper [5] describes an algorithm to optimize the design of CM structure through
the example of three-longeron caisson of rectangular cross-section. Dimensions of the cross
section along the midline sheathing: width \( B = 40 \) cm, height \( H = 10 \) cm, length of the caisson
\( L = 60 \) cm. Caisson is loaded by vertical uniform load per unit length, which is applied along
the axis of the first longeron. Stresses that are acting in the structure elements are defined
using the beam theory described in [2]. The fiber model, which does not take into account any
binder’s work (i.e. all the load is sustained by reinforcing fibers) was used for optimization of
the construction.

Due to the significant limitation of the beam theory, there is a necessity of rejecting the
hypothesis of plane strain distribution in the cross sections. Taking into account the
constrained warping sections, the solution was obtained using a discrete-continuum model of
structural analysis.

Consider a slightly conical construction located in the non-uniform temperature field and
loaded by transverse loads and a system of axial forces applied to the longitudinal stringers.
Suppose the sheathing contour is rigid, which is provided by a set of transverse diaphragms
(ribs, frames) or a light filler. Wherein assume that the normal stress \( \sigma \) on the contour is zero.
Discretization of the sheathing is performed along the cross-sectional contour. As a result, the
calculated model will consist only of longitudinal stringers, which sustain only axial forces,
and multilayer sheathing panels between these stringers, which work only in shear.

Axis \( z \) of the main orthogonal system of coordinates is oriented along the length of
construction, axes \( x, y \) are in cross section plane. The longitudinal stringers are enumerated in
clockwise direction of the contour. Let us assign the numbers of the subsequent stringer to
each of the sheathing panels. Axis \( s \) is tangential to the cross section contour.

According to the accepted assumptions, longitudinal forces in the ribs \( P_i \) and line forces in the
panels \( q_k \) are related to axial offset of ribs \( v_i \) by the equations:

\[ P_i = E_i F_i (v_i' - \varepsilon_{ri}), \quad q_k = \frac{G_i \delta \varepsilon_{k}}{S_k} (v_k - v_{k-1} + \sum_{j=1}^{3} \theta_{jk} \varphi') \]  \( (1) \)

Here \( E_i, F_i, \varepsilon_{ri} \) are reduced modulus of a material, cross sectional area and reduced
temperature deformation of \( i^{th} \) stringer, respectively.

\[ \theta_{1k} = x_k - x_{k-1}, \quad \theta_{2k} = y_k - y_{k-1}, \quad \theta_{3k} = 2w_k \]

The equations of the problem can be solved by applying the principle of virtual displacements
to the rod element \( dz \). The work of internal and external forces over the possible
displacements of stringers with a weak construction’s conicity can be written as:
The calculation of composite constructions in the designing setting

\[
\sum_{k=1}^{m} S_k q_k \delta y_k dz - \sum_{i=1}^{n} \left( \frac{dP}{dz} + p_i \right) \delta v_i dz = 0
\]

(2)

Where \(n, m\) are the number of longitudinal stringers and sheathing panels (walls), respectively.

From the equation (2), taking into account ratios (1) and considering randomness of \(\delta v_i\) variation, we obtain the differential equations of balance of longitudinal stringers. Having excluded functions \(\varphi_j\) in it by means of three equations of balance of tangent forces in the rod's cross sections

\[
\sum_{k=1}^{m} \theta_{jk} q_k + \sum_{i=1}^{n} \alpha_{ji} P_i = R_j \quad (j = 1, 2, 3)
\]

(3)

(here \(R_1 = Q_x, R_2 = Q_y, R_3 = M_z; \alpha_{1i}, \alpha_{2i}, \alpha_{3i}\) - directing cosines of \(i^{th}\) stringer with axes \(x, y; \alpha_{3i} = \alpha_{3i}, x_i - \alpha_{3i}, y_i))\), we obtain the solution, which coincides with Yu.G.Odinokov solution [6] for metal designs.

To find the solution, allowing variation of the required labor and calculation accuracy depending on objectives of the research, we represent the axial shifts of stringers as a finite sum:

\[
v_i = \sum_{\eta} \psi_{\eta} r_{\eta i}
\]

(4)

\(\psi_\eta\) are the unknown functions \(z; r_{\eta i}\) – the set forms of cross sections’ deplanation; \(N \leq n\), where \(n\) is a number of longitudinal stringers.

Then

\[
\delta v_i = \sum_{\eta} r_{\eta i} \delta \psi_\eta \quad \delta y_k = \frac{1}{S_k} \sum_{\eta} \Delta r_{\eta k} \delta \psi_\eta \quad q_k = b_k \left( \sum_{\eta} \Delta r_{\eta k} \psi_\eta + \sum_{\xi} \theta_{\xi k} \varphi_\xi \right)
\]

(5)

where \(b_k = G_k \delta_k / S_k\), \(\Delta r_{\eta k} = r_{\eta k} - r_{\eta, k-1}\).

From the equation (2), taking into account ratios (5) and considering randomness of variations, we find \(N\) differential equations which express the conditions of longitudinal stringers’ balance:

\[
\left( \sum_{\eta} b_{\eta i} \psi_\eta - N_{TV} \right) \psi_\eta = \sum_{\eta} a_{\eta i} \psi_\eta + \sum_{\xi} c_{\xi i} \varphi_\xi - P_v^* \quad v = 1, 2, ..., N
\]

(6)

where \(b_{\eta i} = \sum_{i} E_i F_i k_{\eta i} r_{\eta i}, a_{\eta i} = \sum_{k} b_k \Delta r_{\eta k} \Delta r_{\eta k}, c_{\xi i} = \sum_{k} b_k \Delta r_{\eta k} \theta_{\xi k}, P_v^* = \sum_{i} k_{\eta i} P_i, N_{TV} = \sum_{i} k_{\eta i} P_{Ti}, P_{Ti} = E_i F_i e_{Ti}\).

Substituting \(q_i\) in (2), we obtain

\[
\sum_{i} g_{ji} \varphi_\xi = \bar{R}_j - \sum_{\eta} c_{\eta i} \psi_\eta - \sum_{\eta} \chi_{ji} \psi_\eta \quad j = 1, 2, 3
\]

(7)

Here \(g_{ji} = \sum_{k} b_k \theta_{ji} \theta_{\xi k}, \chi_{ji} = \sum_{i} E_i F_i \alpha_{ji} r_{\eta i}, \bar{R}_j = R_j + \sum_{i} \alpha_{ji} P_{Tij}\).
The differential equations (6) and (7) can be written in matrix form as follows:

\[
([b]\{\psi\}' - \{N_T\}') = [a]\{\psi\} + [c]\{\varphi\}' + \{p^*\},
\]

(8)

\[
[g]\{\varphi\}' = \{\vec{R}\} - [c]^T\{\psi\} - [\chi]\{\psi\}'
\]

Equations (8) contain \( N + 3 \) unknown functions. The solution can be simplified by eliminating three functions from the system \( \Phi_j \).

From the second equation, we have:

\[
\{\varphi\}' = [g]^{-1}\{\vec{R}\} - [c]^T\{\psi\} - [\chi]\{\psi\}'
\]

(9)

Substituting \( \{\varphi\}' \) in the first matrix equation of the system (8), we find:

\[
([b]\{\psi\}' - \{N_T\}') = [a^*]\{\psi\} + [e]\{\psi\}' + \{d\}
\]

(10)

where

\[
[a^*] = [a] - [c][g]^{-1}[c]^T, \quad [e] = - [c][g]^{-1}[\chi], \quad \{d\} = [c][g]^{-1}\{\vec{R}\} - \{p^*\}.
\]

For integration of the differential equations (10) the following force and geometrical boundary conditions have to be satisfied:

\[
\left( \sum_{\eta=1}^{N} \int_{z=0}^{L} b_{\eta} \psi_{\eta}' \right) - N_{T\psi} = \sum_{i} P_i(L)\kappa_{i}, \quad (\psi_{\psi})_{z=0} = \psi_{\psi}(0) \quad (\nu = 1, 2, \ldots, N).
\]

Functions \( \varphi_{\xi} \) can be found by simple quadratures from equations (9) under boundary conditions in the section of rod attachment: \( (\varphi_{\xi})_{z=0} = \varphi_{\xi}(0), \quad \xi = 1, 2, 3 \).

Differential equations (10) together with boundary conditions enable to completely define the stress-strain state of the construction. However, in general it is possible to solve the system (10) only numerically. For this purpose we use the integrating matrices of M. Vakhitov [5].

Having integrated (10) from \( z \) to \( L \) once and considering that \( \psi_{\psi} = \int_{z=0}^{L} \psi_{\eta}' dz + \psi_{\psi}(0) \),

we obtain the system of integral equations with respect to \( \psi_{\eta}' \) functions:

\[
\sum_{\eta=1}^{N} \int_{z=0}^{L} a_{\eta}^* \psi_{\eta}' dz + \sum_{\eta=1}^{N} e_{\eta} \psi_{\eta}' dz = \Pi_{\nu} \quad (\nu = 1, 2, \ldots, N),
\]

(11)

where \( \Pi_{\nu} = \sum_{i} P_i(L)\kappa_{i} + N_{T\psi} - \int_{z=0}^{L} \omega_{\psi} dz, \quad \omega_{\psi} = d_{\psi} + \sum_{\eta=1}^{N} a_{\eta}^* \psi_{\eta}(0) \).

Specifying integrals via discrete values of the functions in \( r \) calculated cross-sections along the length of the construction, we obtain:

\[
H_{\psi} = \Pi
\]
\[ \Psi' = \{ \Psi'_1, \Psi'_2, \ldots, \Psi'_n, \ldots, \Psi'_1, \ldots, \Psi'_r \} \]; where additional subscripts from 1 to \( r \) indicate the number of design cross section along the length of the structure; \( \Pi \) – the same column of \( \Pi_\psi \) values.

There is a calculation of rectangular three-longeron caisson (fig. 1) loaded at its free end by a vertical force of \( Q = 1000 \) daN, applied to a wall of front longeron. In cross-sections along the length of the caisson, this force gives a shear force \( Q_y = -1000 \) daN and a torque \( M_z = 300 \) kgf·m (\( z \)-axis is directed along the wall of the middle longeron).

Three-layer sheathing of the caisson consists of two base layers and a lightweight filler. The layers are made of organoplastic SVM with the following rigidity characteristics of monolayers: \( E_1 = 2549 \) daN/mm\(^2\), \( E_2 = 2451 \) daN/mm\(^2\), \( G_{12} = 226 \) daN/mm\(^2\), \( \mu_{12} = 0.14 \). The sheathing package consists of layers with reinforcing angles \( \pm 45^\circ \), \( 0^\circ \) and \( 90^\circ \), monolayer thickness – 0.14 mm. The total thickness of the bearing layers – 1.12 mm. Calculated values of the reduced sheathing moduli – \( E_z = 1818 \) daN/mm\(^2\), \( G_{zs} = 662 \) daN/mm\(^2\).

Longerons are made of fiberglass T-10-80 with the rigidity characteristics of monolayers: \( E_1 = 2765 \) daN/mm\(^2\), \( E_2 = 1784 \) daN/mm\(^2\), \( G_{12} = 291 \) daN/mm\(^2\), \( \mu_{12} = 0.144 \). Unidirectional fibers laying at an angle \( 0^\circ \) dominate in the longeron zones. The area of cross-sectional zone is 4 cm\(^2\). The design of longeron wall is similar to sheathing design. It consists of monolayers with fibers oriented at \( 45^\circ \) and \( 0^\circ \). Monolayer thickness is 0.25 mm, the total wall thickness of the supporting layers is 2.5 mm. The calculated reduced values of wall moduli are \( E_z = 1249 \) daN/mm\(^2\), \( G_{zs} = 876 \) daN/mm\(^2\).

The caisson can be calculated by variation method using different versions of discretization and setting of deplanation forms.

**Version 1.** Sheathing panel between adjacent longeron zones is a single dummy stringer situated in the middle (at the center of gravity) of the panel. As a result of such discretization the cross section of caisson computational model will have 10 longitudinal stringers. To obtain an exact (within the accepted hypotheses) solution in the general case, it is necessary to use 10 forms of deplanation. Knowing the construction symmetry and the load, it is possible to reduce the number of deplanation forms (down to five forms in our case). Below there are the results of the exact solution to the computation model.
Fig. 2 shows the distribution of normal stress in the longeron zones and sheathing along the caisson length. It is a typical case for the constrained torsion of metal constructions: approaching the attachment region the front longeron is loaded completely, and the rear one is unloaded. The specificity of the composite structure is manifested in the fact that the stresses in the sheathing are significantly less than in the zones. It is explained by the fact that reduced modulus $E_z$ of the sheathing is less than the modulus $E_1$ of the zones.

Table 2 shows the values of line tangential forces in caisson panels in five sections along the construction length. The origin of the coordinate system is placed at the attachment section. $q_1$, $q_6$, $q_{11}$ are line tangential forces in the walls of front, rear and middle longerons, respectively; $q_2$, $q_3$, $q_4$, $q_5$ – line tangential forces in sheathing panels.

<table>
<thead>
<tr>
<th>Coordinate $z$, cm</th>
<th>$z = 0$</th>
<th>$z = 25$</th>
<th>$z = 50$</th>
<th>$z = 75$</th>
<th>$z = 100$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$q_1$, daN/cm</td>
<td>89.9</td>
<td>76.0</td>
<td>69.6</td>
<td>66.8</td>
<td>66.0</td>
</tr>
<tr>
<td>$q_2$, daN/cm</td>
<td>2.68</td>
<td>2.26</td>
<td>29.7</td>
<td>32.5</td>
<td>33.1</td>
</tr>
<tr>
<td>$q_3$, daN/cm</td>
<td>2.68</td>
<td>8.4</td>
<td>13.1</td>
<td>15.7</td>
<td>16.5</td>
</tr>
<tr>
<td>$q_4$, daN/cm</td>
<td>2.68</td>
<td>18.6</td>
<td>26.1</td>
<td>29.5</td>
<td>30.5</td>
</tr>
<tr>
<td>$q_5$, daN/cm</td>
<td>2.68</td>
<td>11.6</td>
<td>15.6</td>
<td>17.4</td>
<td>17.9</td>
</tr>
<tr>
<td>$q_6$, daN/cm</td>
<td>15.8</td>
<td>4.46</td>
<td>-0.76</td>
<td>-3.2</td>
<td>-3.88</td>
</tr>
<tr>
<td>$q_{11}$, daN/cm</td>
<td>37.0</td>
<td>39.5</td>
<td>40.8</td>
<td>41.1</td>
<td>41.2</td>
</tr>
</tbody>
</table>

**Version 2.** Let us reduce the labor required for the implementation of the computational model of the first version by selecting specific deplanation forms. We use linear local forms of deplanation, considering the longeron caps as nodal stringers (fig.1). As a result, the number of deplanation forms reduces to six.

Fig. 3 shows the distribution of the normal stress along the construction length when there are six forms of sections deplanation. It can be seen that in the second version the values of normal stresses in the longeron zones became smaller, and the values in the sheathing increased.

**Version 3.** Let us distribute the sheathing to longeron zones with the corresponding reduction factor. As a result, we get six-stringer computational model, which requires 6 forms of
deplanation for the exact solution. Fig. 4 shows the obtained distribution of the normal stress along the caisson length in longeron zones.

**Version 4.** When the computational model 3 is implemented, the number of approximating functions reduces from 6 to 4. We introduce three types of deplanation, corresponding to the hypothesis of planar sections, and one form that takes the constrained torsion into account. We assume the last one as follows: \( r_{41}=1, r_{42}=0, r_{43}=-1, r_{44}=1, r_{45}=0, r_{46}=-1 \)
Fig. 5 shows the calculated distribution of normal stresses in the longeron zones along the caisson length.

The summary in Table 2 shows the normal stresses in longeron zones in the cross section of attachment for the considered versions of the solution. A comparison of versions 3 and 4 shows that they are slightly different. A proper choice of deplanation forms can significantly reduce the labor input of the solutions.

Table 3

<table>
<thead>
<tr>
<th>Option</th>
<th>$\sigma_{n1}$, daN/cm²</th>
<th>$\sigma_{n2}$, daN/cm²</th>
<th>$\sigma_{n3}$, daN/cm²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1150.4</td>
<td>723.1</td>
<td>316.6</td>
</tr>
<tr>
<td>2</td>
<td>1086.3</td>
<td>660.7</td>
<td>286.7</td>
</tr>
<tr>
<td>3</td>
<td>1061.1</td>
<td>663.2</td>
<td>308.6</td>
</tr>
<tr>
<td>4</td>
<td>1053.1</td>
<td>676.7</td>
<td>300.3</td>
</tr>
</tbody>
</table>

In Table 3 $\sigma_{n1}$, $\sigma_{n2}$, $\sigma_{n3}$ are the normal stresses in the zones of the first, second and third longerons, respectively.

Calculation of the section of attachment should be considered separately. In the paper [7] there is an algorithm for the calculation of the attachment of CM construction taking into account the constrained deplanations of the sections. It is shown that the problem of determining the tangential stresses in the attachment section can be solved relatively simply and without integration of the system of differential equations. Degree of sheathing discretization has an insignificant effect on the labor input when finding the solution, and the areas of longitudinal stringers are not involved in the calculation at all.

The distribution of tangential stresses in the attachment depends on panels’ shear stiffness and geometric parameters of the section contour.

The provided solution is based on the hypothesis of resistance to deformation of the contour cross-sections and it is similar to the solution obtained by Yu.G.Odinokov [6] for metal structures.
The calculation of composite constructions in the designing setting

References


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Experimental check of method of encapsulated polymeric material formation in gas phase

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The paper presents the results of experimental studies of the method of formation of the encapsulated polymer materials in the gas phase. The experiments were performed to confirm the physical assumptions underlying the process of encapsulation. For this reason the particles of polystyrene were “grown” on the surface of talc using experimental apparatus. The presence of polymer particles on the surface of talc was confirmed by JEOL Auger microprobe.

One of the priority themes of scientific and technological research is producing new nano-modified and nano-structured materials with specific properties. At the present stage the new technologies of producing of polymer materials with desired and reproducible properties are intensively developing. Composite materials including thermoplastic materials (polyethylene, polypropylene, polyvinyl chloride, etc.) represent a great interest for research. These materials have a number of mechanical properties, without which it is difficult to imagine the manufacture of modern high-tech products. Production technology of nano-modified polymer materials for different industries should meet the following general requirements:

− reproducibility of parameters and characteristics of nano-modified polymeric material;
− production versatility: the ability of manufacturing equipment to produce several types of polymeric materials with various types of filler (nanoparticles process equipment);
− providing the required percentage nanoparticle concentration in the final material for modified plastics;
− providing homogeneous distribution of the nanoparticles in the final modified polymeric material;
− automation of production: a minimum of maintenance personnel;
− economic efficiency technology of polymeric materials with desired and reproducible properties;
− safety.

The currently used technology for the new composite materials with improved polymeric macroscopic properties with nanoparticles inserted into the polymer matrix can not sufficiently achieve a uniform distribution of the nanoparticles and the desired orientation in the polymeric matrix and ensure reproducibility of the properties and characteristics of the polymer material at all stages of the main process. Modernization of existing production lines can not fully provide all the requirements for the new technology of polymeric materials.

The introduced method is a fundamentally new approach to the formation of filled polymer material. It is the establishment of an encapsulated polymer material consisting of condensation center (filler) and the polymer film. Formation of polymer takes place in a gas stream. A detailed explanation of this method is shown in the diagram Figure 1.

A method for producing the material can be divided into several stages:

Stage 1 - the organization of two-phase flow of charged particles.
Step 2 - charge and dispersing of a monomer and nanoparticles.
Step 3 - the mixing of charged nanoparticles and monomers.
Step 4 - condensation of the dispersed particles in the monomer charged nanoparticles.
Step 5 - polymerization.
Step 6 - allocation of polymer powder modified by nanoparticles.

Deposition of monomer particles on the surface of condensation center is carried out by mixing of two two-phase flows of charged particles. Nanoparticles could also be used as centers of condensation. For the production of polymeric material by the above method, it is required to provide mixing of two-phase flows of charged particles with sufficient homogeneity. Mixing must meet certain requirements imposed on the nanomodified process for preparing polymeric material.

In this work criteria for evaluation of mixing chambers are formulated. On the basis of comparative analysis of flow mixing organization methods we selected the most appropriate design of the mixing chamber.

The main criteria for evaluating the effectiveness of the mixing of two multiphase flows of oppositely charged particles are:

- providing a high homogeneity of mixing of two multiphase flows of oppositely charged particles of monomer and filler particles;
- the characteristic time of mixing of multiphase flows of charged particles should be less than the characteristic lifetime of the excited particles (free radicals);
- no backflow of particles from the mixing chamber into the channels;
- the absence of collisions of excited particles with elements of the design: the high probability of collisions of particles deactivation.

Considering previously mentioned criteria, mixing of two-phase flows can be provided by creating turbulence in the mixing chamber. The efficiency of mixing of two multiphase gas flows of oppositely charged particles was evaluated by the degree of turbulence. The degree of turbulence \( \varepsilon \) is the ratio of the root mean square fluctuating velocity to the average velocity \( \bar{u} \) of translational movement of the gas flow.
Thus, a comparative analysis of ways to organize the mixing of two multiphase flows of oppositely charged particles showed that the most suitable design is a mixing chamber in which the mixed flows are directed at an angle to each other, and the side wall of the mixing chamber provides additional input of gas streams.

![Fig.1. Mixing chamber for encapsulated polymer material.](image)

An experimental setup was developed, in which the flow turbulence was studied using PIV method. Experimental studies have confirmed theoretical calculations, i.e. for the encapsulated polymer material the optimal scheme is the one shown in fig. 2, namely a scheme in which streams are directed at an angle to each other, and the additional turbulence is generated by supplying the gas from the mixing chamber wall.

**References**

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Diagnostics and microscopy of ultrahigh resolution on the basis of phenomenon of one-electronic tunneling

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The technology of modern semiconductor manufacturing is based on complex processes of precision materials processing, such as photo- and electron beam lithography, oxidation, ion-plasma sputtering, ion implantation, diffusion, etc. The materials used in the manufacture of devices and circuits impose high requirements to purity and perfection of the structure. The optical, ion-beam, thermal equipment with unique characteristics is used for the majority of manufacturing operations. Processes are carried out in special dust-free rooms with certain humidity and temperature.

New devices of integrated circuits cannot be made using the same techniques and the same equipment that was used for the production of simple IC. In order to create a new VLSI, it is necessary to develop new materials, processing methods; technology and quality control measurements of the characteristics at different stages of their production also play an important role.

Many of the latest achievements of science and technology are associated with the development of nanotechnology, which is now regarded as one of the promising areas of science. The work in this field requires special research facilities and qualified specialists capable of working with high technology. Program of infrastructure nanotechnology development in Russia involves the establishment of specialized laboratories designed for the research in this area. Within this program in 2007 Scientific Research Institute of Nanotechnology and Nanomaterials (NTM) has been established at A.N.Tupolev Kazan National Research Technical University (KNRTU-KAI). Head of this Institute, NTM, is Professor I.K.Nasyrov. The idea about such Institute was generated from 2005 within Partner Treaty about collaboration with Prof. S.Santoli (Italy). He prepared also the plane (with full structure) about International Center for Nanoscale Science and Technology (ICNST) in Kazan.

KNRTU-KAI is a national research university, whose task is not only to prepare qualified engineers, but to develop items of commercial potential. From this point of view, the creation of the Institute enables KNRTU to gain a foothold in its main educational and scientific activities and make full use of all available resources.

To equip the NTM Institute with advanced scientific, research, technological and educational facilities under the Federal Program "Development of infrastructure of nanotechnology in Russia in 2008-2011", budget funding of 125.4 million rubles has been allocated. KNRTU budgeted significant funds to purchase equipment for NTM Institute in the framework of funding the research. This allowed the purchase of new equipment intended for the research dealing with production of carbon, organic and hybrid nanomaterials, polymers and elastomers, composites and ceramic materials, new materials and technologies for nanoelectronics, optoelectronics and spintronics, etc.

Intensive introduction of nano-structured materials requires the development of methods and equipment for diagnosis and testing of both the nano-materials and products on their basis. The need for determining the parameters associated with the nanostructures is related to the fact that they are often the important certification parameters of the final product or are used for prediction of the product’s consumer properties.
The most extensive and informative method in the field is undoubtedly the transmission electron microscopy and high-resolution scanning electron microscopy in conjunction with local microprobe and diffraction analysis, allowing visualization of the nanostructure of the object, identification of nanoscale phase and determination of the structural parameters of the individual nanoparticles. Atomic force microscopy allows obtaining pictures of the objects’ surface with high resolution of details.

X-ray analysis method applied to nano-structured materials not only can determine the structural parameters of the nanoparticles and their content in the bulk of the matrix, but is the most effective method of determining their size. Thermographic analysis in conjunction with electron microscopy and X-ray analysis provides a measure of the temperature ranges of stability of nanostructured elements.

Fig.1. The result of ion cutting of a section using multi GPU (magnification 15.000x and 50.000x)
The complex spectroscopic methods such as atomic absorption spectroscopy, optical spectroscopy, X-ray fluorescence analysis and gas chromatography provide information on the elemental and molecular composition of objects, as well as the nature of the interaction of nanoparticles with a core matrix.

Using a universal workstation Auriga CrossBeam, which works as a scanning electron microscope of ultra-high resolution (1 nm) and as a technological station (FIB column), we performed a cross etching of a portion of transistor by a focused ion beam. Due to the unique technology of Gemini electronic column, a highly sensitive phase contrast (Low Loss BSE) was conducted on InLens detector of back-scattered electrons. This is an advanced technique developed by one of the leading members of Carl Zeiss, which enables us to distinguish even weakly doped regions on a section of the transistor.

This technique combined with the technological capabilities of cutting (etching) and deposition allows us to expand our analytical capabilities, and even to perform 3D reconstruction by means of layer-by-layer cutting of a sample.

Wave properties are manifested in the phenomenon of electron-electron tunneling. This phenomenon is one of the progressive ways to create new types of electronic devices in which the motion of a certain amount of electrons is controlled. Since the time of tunneling is small, the theoretical limit of response time of single-electron devices is very high; meanwhile the energy consumption of single-electron circuits must be extremely low. As a result they are of considerable interest as one of the most progressive ways to create new electronic devices.

A transistor was developed on the basis of high dispersion silicon-on-insulator technology (SOI). The advantages of SOI single-electron transistor as compared to previously demonstrated devices are as follows: simple production technology, mechanical strength, resistance to electrical overload, the ability to increase the operating temperature at the same resolution of lithography, possibility to make the suspended structures.

Fig. 2. The implementation of the final phase of obtaining a single-electron transistor
Experimental structures were fabricated from SOI wafers created by UniBond technology, in which the thickness of the oxide layer SiO$_2$ was about 160 nm, and the thickness of the top layer - 60 nm. Full cycle of silicon-on-insulator structures consisted of the following main steps:
- SOI recrystallization by thermal annealing at 950 °C;
- electron lithography of transistor geometry;
- formation of a metal mask by spraying a thin film of gold - palladium;
- formation of the transistor structure using reactive ion etching through the silicon metal mask.
All structures were obtained on Auriga CrossBeam workstation with ionic FIB Cobra column, which allows working with platinum, tungsten, carbon, and so on. Kleindiek Nanotecnik manipulators enable to measure the input and output characteristics of a single-electron transistor.
Diagnostics and microscopy of ultrahigh resolution on the basis of phenomenon of one-electronic tunneling

The use of electron microscopy can be illustrated by the quality control thin film resistors, which are widely used in electronic equipment. An important feature of film microwave resistors is their ability to consistently and reliably work when a high-power microwave pulse is fed to the resistor. The presence of a high-capacity microwave can lead to breakdown of the resistive layer and appearance of corona discharges on the elements of dissipative structures. For example, at a microwave power of 30 kW the resistive load of 50 Ohm acquires a potential of 1200V. The high potential irregularities in the resistive layer lead to the destruction of film elements. The nature of these defects can be effectively investigated with the use of a probe microscope and a scanning electron microscope (SEM).

![Fig. 5. Breakdown of microwave resistor obtained by Auriga CrossBeam scanning electron microscope.](image-url)

Figure 5 shows a typical breakdown of the film resistor resulted from the impact of the microwave pulse power, fixed by Auriga CrossBeam SEM. It should be noted that unlike the typical burning at a constant current, when the entire film is completely destroyed, the pulse impact makes the breakdown affect only the intergranular space, forming a tree structure. Figure 6 shows one of breakdown branches pictured by Innova Bruker probe microscope. Resistive film defects and the nature of breakdown are clearly seen in the picture. Pictures of probe microscope can be used to control the quality of the resistive layer, since it is possible to visualize the crystallites of the film at the micro and nano levels.

Promising direction of electron microscopy is quality control of multilayer metal coatings in engineering, which are widely used to protect against corrosion and increase the life of the bearings.
Figure 7 shows the pictures of the section of the multilayer coating of a diesel-powered car’s friction bearing. Multilayer coating consists of the following layers: steel, bronze, aluminum and a layer of nichrome with tin microparticles. Such multilayer coatings are widely used to increase the service life of automotive engines. Pictures taken by Auriga CrossBeam SEM.
enable not only to measure the thickness of the coating, but also to see the quality of the layers, to perform qualitative and quantitative analysis of the section of interest with nanometer resolution. Electron microscopy enables to achieve the desired quality of multilayer coatings, to make quick changes in the production process and significantly reduces the time of development of technology process for multilayer micro and nano metallic coatings manufacture.

NTM Institute has been included in the National Nanotechnology Network. It is the leading institution of the Volga Federal District in monitoring activities in the field of nanotechnology. It works under the guidance of Kurchatov Institute. NTM Research Institute incorporates the leading laboratories of the university: Center of Composite Technology, Strength Testing Laboratory, Regional Center of metrology and certification. Center for Diagnostics and Certification of Nanomaterials of NTM Research Institute actively cooperates with the All-Russian Research Institute of Metrological Service (Moscow) and D.I.Mendeleev All-Russian Scientific Research Institute of Metrology (St. Petersburg) in the field of measurement assurance and conformity assessment of products of nanotechnology and nanoindustry.

The results of complex scientific and technical support activity are widely used in the development of nano-modified materials using carbon nanotubes for aviation and engineering. Joint projects are being implemented with Joint Stock Company “Kazan Aviation Production Association named after S.P.Gorbunov”, "Kazan Helicopter Plant", Sokol Experimental Design Bureau, Tupolev Design Bureau, KazanOrgSyntez plant, KAMAZ.

The specialty of "Nanotechnology in Electronics" was licensed at Tupolev Kazan State Technical University in 2007. Students have been being educated and engineers of industrial companies have been being retrained according to this specialty. Two-stage education (Bachelor/Master of Electronics and Nanoelectronics) was introduced in KNRTU-KAI in 2011.

Tupolev KNRTU was shortlisted by the Ministry of Education as one of 16 leading universities, on the basis of which a system of additional professional education in nanotechnology is to be established. Feature of the system is a network information-analytical system for organizing and tracking the route of training in professional development on the basis of scientific and educational structures.

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Radio-meteor observations of neutral atmosphere
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Abstract
Radio-meteor observations of the neutral atmosphere within the altitude interval of the upper mesosphere - lower thermosphere have been being carried out at the Kazan Federal University for the last 50 years [1-22]. Wind velocity radio-meteor measurements began in 1964-1965, first continuous semi-annual radio-meteor measurements of the wind velocity with altimeter were carried out in 1969. Regular radio-meteor measurements began in 1978 and are still performed with the support of the special and international programs. The investigation progress depends on technical level of the radio devices, implementation of the new technology, increasing the statistical reliability of the spatial and time measurement interval, continuous monitoring a coordinated measuring of the international station network. Fulfillment of these conditions allows expanding the range of the dynamic processes from scales of acoustic-gravity, tidal and planetary waves to long-period variations, caused by solar cycle and climate. The Meteor radar has been upgraded recently, which improved noise immunity and increased statistical reliability of the wind measurement [2, 3, 4]. The database and regional model of the prevailing, tidal, turbulence movement and parameters of the annual, semi-annual variations were created and based on measurements results [1]. Regional model of the prevailing tidal movements has been included in international model [5, 6]. The most significant results of these observations are given in the article.

1. Altitudinal structure of the wind velocity
Stable altitudinal structure of the wind velocity within the altitude interval 0-100 km in Kazan region is shown in Fig. 1. Velocities of the wind were obtained by the radio meteor measurements within the altitude interval 80-100 km. BADC UKMO and archive reanalyzed data were used for obtaining wind velocities within the altitude interval 0-57 km. Velocities within the altitude interval 60-80 km were obtained by interpolation [1, 22].

![Fig.1. Local height-seasonal prevailing zonal and meridional wind's structure for the period 1999-2002.](image)

2. Climatic spectral model in the lower and middle atmosphere
Climatic spectral model of the wave activity with time scales of the planetary waves (2-30 days) for the Kazan region for four seasons was developed using integral wavelet spectra [7, 8], based on Morlet wavelet. The averaging interval – 16 years, from 1986 to 2002.
Wave disturbances with periods close to Rossby wave’s periods were found within the altitude interval of the mesosphere – lower thermosphere. Among the entire set of wave processes, there is a notable 5-day wave, which is indicative for winter and spring in the zonal wind field and for winter, spring and autumn in the meridional wind field. Two and four daily variations showed significant intensity in summer months predominantly, although some wave activity with periods close to 4-days was noticed in other months. Certain wave activity was observed with periods close to 10, 16 and 20-30 days. Thus, intensity depends on height.

Comparison of the intensity of wave disturbance in the zonal and meridional wind field according to time scales shows prevalence of wave intensity in the field of zonal circulation during all months except summer. Thus, in summer the wave processes in the field of meridional wind are most significant for two- and four-day periods. Despite the weak intensity, wave processes with periods above 5 days prevail in the field of zonal circulation.

Phase estimation of the annual cycle maximum within different altitude intervals (tropopause ~ 10 km, stratosphere ~ 29 km, stratopause ~ 55 km, mesosphere – lower thermosphere 84 km, 90 km, 94 km and 98 km) for zonal and meridional wind are shown in the Fig.3a and Fig.3b. Analysis of the phase of the annual cycle maximum for the zonal wind at the heights
Radio-meteor observations of neutral atmosphere

of the mesosphere – lower thermosphere indicates an abrupt change from the spring and summer months with 2-4-day periods to 5-30-day period winter months (December, January). The maximum of the annual cycle of the wave disturbance intensity within the altitude interval of troposphere and stratosphere was revealed in November and December for the whole range of the time scale variations from 2 to 30 days.

Phase of the annual cycle maximum in the field of the meridional circulation reveals no significant abrupt changes and within altitude interval of the mesosphere – lower thermosphere smoothly passes from summer months (July-August) for 2-day wave to winter months (December-January) for a period of 10 days and more. Maximum intensity was revealed in winter for all scales from 2 to 30 days within the altitude interval 0-55 km.

Calculation of the sample variance mean seasonal (winter 1998-1999, summer 1999) altitude profiles of the meridional and zonal wind was carried out to investigate the height structure of wave processes within the altitude interval 0-100 km and time scales of 2-30 days. Computation of these parameters was made for three stations: using radio echo technique in Kazan (Russia, 56N, 49E) within the altitude interval 80-100 km, using LF D1 technique for the altitude about 94 km [9] at Saskatoon (Canada, 52E, 107W) and using MF-radar within the altitude interval 70-97 km [10, 11].

Maximum of the intensity of wave disturbance in zonal and meridional wind is observed at stratopause (~55 km) in winter, while maximum values of $\sigma_U^2$ in summer were obtained within altitude interval of tropopause. Weak wave activity was obtained in summer in stratosphere. As to altitude interval of the mesosphere – lower thermosphere, the height profiles of $\sigma_U^2$ and $\sigma_V^2$ for Kazan and Saskatoon are close to each other below 90 km, whereas intensity is larger in Kazan above 90 km. In winter there are significant differences in measurement results at stations as a consequence of the significant disturbance of the circulation in winter and more pronounced longitudinal differences.

![Fig.3. Phase of an annual cycle maximum of the wave processes intensity within the period interval 1-27 days in the field of the zonal (a) and meridional (b) circulation (1996-2004).](image-url)
Thus, developed spectral climate model shows the time scales of wave disturbance according to season and height: winter – 5 days, 16 days and 27 days (80-90) km, spring – 5 days (90-100)km, and 16 days (80–90)km, summer – 2 and 4 days, autumn – 5 and 10 days.

Stable height-seasonal structure of wave disturbance intensity for time scales of the planetary wave within the altitude interval 0-55 km for regions of Kazan, Collm and Saskatoon for winter and summer in the field of zonal and meridional wind has been established. Longitudinal differences of wave activity are: in winter there is an excess of the wave disturbance intensity in Kazan compared with regions of Collm and Saskatoon, while in summer wave disturbance intensities are approximately equal.

3. Inter-annual, intra-annual and diurnal variations of the dynamic parameters

Method of spectral analysis of non-stationary time series based on modified continuous wavelet transform with Morlet wavelet, adapted for time series with irregular time period and containing gaps, was developed and implemented.

Established altitude structure features of the mean annual values of the parameters of the wave flow's dynamic performance in the field of the zonal and meridional circulation within the altitude interval 0-100 km and amplitudes and phases of its annual and semi-annual oscillations correspond to the altitudes of the zonal circulation regime changes.

It was established that the annual fluctuation amplitudes of the zonal wind exceed the semi-annual ones for mid-latitude atmosphere within the altitude interval 0-55 km and 80-87 km caused by prevalence of the radiative energy sources of atmospheric circulation. At the same time, the amplitudes of semi-annual fluctuations of the zonal wind exceed the annual ones within the altitude interval 87-110 km, because of the vortex processes, which play significant role in this altitude interval and are caused by wave disturbance interactions both among themselves and with background flow.
It was obtained that dynamical efficiency of wave disturbances with scales of internal gravity waves and tidal waves within the altitude interval of 80-110 km is about 20 times higher than dynamical efficiency of wave movements with scales of planetary waves. Prevailing movements are energetically close to wave disturbances with scales of 1-24 hours and dissipation of the internal gravity waves leads to inhibition of the prevailing zonal wind. Experimental confirmation of this was established by using comparison of the height dependence of annual and semi-annual oscillation amplitudes of background circulation and intensity of wave disturbances with time scales of internal gravity waves and tides. Spectral analysis with long-term measurement series (1980-2003) for Kazan region (56N, 49E) showed the pronounced 11-year periodicity in time series of mean annual values and amplitudes of annual oscillations of the zonal wind, averaged within the altitude interval 80-110 km. 11-year oscillations of mean annual zonal wind values were observed in anti-phase with variations of F10.7 parameter. The amplitudes of the 11-year annual oscillations are in anti-phase with 11-year F10.7 oscillation (Fig.5).

![Fig.5](image1)  
**Fig.5.** Time series of F10.7 variation, mean values (A0), annual (A1), semi-annual (A2) amplitude oscillations averaged within the altitude interval 80-110 km of the zonal wind velocities in Kazan region (56N, 49E) (a) and Collm (53N, 15E) (b) (1980-2003).

Calculated power spectral density (PSD) of the A0, A1 and A2 variations for Kazan region with periodicities close to 11 years are shown in Fig.6.

![Fig.6](image2)  
**Fig.6.** Power spectral densities of time series of the mean annual values, annual amplitudes, and semi-annual oscillations of the zonal wind velocities averaged within the altitude interval 80-110 km for Kazan region (56N, 49E) (1980-2002).
The calculation results of the 11-year periodicity of inter-annual variations (a), annual variations (b) and semi-annual (c) variations of zonal wind amplitude within the altitude interval 80-110 km (1986-2002) and within the altitude interval 0-55 km (1992-2003) are shown in Fig. 7. Variability of 11-year periodicities within the altitude interval 0-100 km is clearly seen in Fig. 7 as well as mean annual values, annual and semi-annual wind oscillation amplitude. The growth trend of the annual and semi-annual oscillation amplitudes at altitudes of about 100 km was observed. For the mean annual values the maxima occur at 55 km and 90 km altitudes. Mechanism of wave interaction of different layers of lower and middle atmosphere, dynamic efficiency of wave disturbances with scales of internal gravity waves, tides and planetary waves were established [12-16].

4. Wave interaction with zonal flux

In addition to the wave disturbances, the investigation of wave interaction with zonal flow was carried out using Elliasson-Palm flux conception [17]. Our previous investigations based on MetOffice Stratospheric Assimilated Data for the period 1994-2006 within the altitude interval 0-55 km revealed the presence of three areas of divergence of Elliasson-Palm flux in the stratosphere of extratropical latitudes (Fig. 8). It indicates the existence of stratospheric planetary wave source [18]. Positive divergence local focuses are situated at the altitude about 30 km, 40 km and 48 km while the top focus (most intensive) is situated on a top border of the observed area. In this regard, a further study of the zonal flux vortex forcing was carried out in 2006 using MetOffice Stratospheric Assimilated Data for 2003-2006 within the altitude interval 0-63 km. It was found for three winter seasons that the area of intensive positive forcing of a zonal flux in upper stratosphere of extratropical latitudes has been replaced by negative forcing in lower mesosphere below 60 km. To explain the observed altitude-latitudinal structure it was a hypothesized that there is an altitudinal variability of the non-linear interaction of planetary waves within the altitude interval of stratosphere for latitudes, which are characterized by vertical planetary wave distribution from tropospheric levels. The highlights of hypothesis are in the following.
linear interaction of wave disturbances with time scales of planetary waves and oscillations with periods of 30-90 days was found on the basis of bi-spectral analysis of long time series (6 months of cold period). Nonlinear interaction leads to exceeding of the planetary waves intensity and interaction between the waves and with background flow. In the end, processes of non-linear interactions play the role of possible sources of planetary waves energy that comes from large-scale movements. In general, the lower, middle, and upper atmosphere is a single complex thermodynamic system with a wave mechanism of different altitude layers interaction.

Fig. 8. Ellason-Palm vector and its divergence (m·s$^{-1}$·day$^{-1}$) for January (1994-2006).

5. Influence of Geo-Solar factors on dynamics of the upper mesosphere – lower thermosphere considering phase of solar activity

The influence of the Earth passage through the Interplanetary Magnetic Field boundary of sectors on the dynamics of the upper mesosphere – lower thermosphere’s (80-100 km) prevailing wind was investigated. The results of the observation of the prevailing zonal and meridional wind were obtained using the data of the Radio Meteor Radar of the Kazan Federal University during 1986-1990, 1993-1995, 1998-2002 (56N, 49E) [19]

To exclude the effect of annual and semi-annual variation on the neutral wind velocity, the analysis was conducted for each season. To eliminate the effects of the diurnal harmonic, wind data were averaged over three days before the event and after the event of the IMF polarity change.

Events were separated considering the phase of solar activity and for each type of polarity of the IMF (from "+" to "−" and from "−" to "+") to detect the subtle effects of the Earth passage through the boundary of sectors of the IMF (Fig. 9).

It was established that the most pronounced effect of the polarity change appears in the zonal wind behavior. There is a weakening of the zonal wind velocity in all seasons during the change of the polarity from "−" to "+" in the maximum and ascending branches of the solar cycle in the whole range of altitudes. In winter during IMF polarity change from "−" to "+" the value of the zonal wind component velocity was observed in all solar activity phase branches.

The influence of the polarity change of the IMF on the meridional neutral wind velocity is less pronounced and does not show a steady altitude, seasonal and solar cycle dependences.
The positive correlation between F10.7 values and values of mesoscale turbulence was obtained during the analysis of possible influence of solar activity on mesoscale turbulence in November 1999, 2000 and 2007. In the year of maximum and minimum solar activity the mesoscale turbulence takes the maximum and minimum values respectively (see Table 1).

A joint review of solar and geomagnetic activity variation influence on dynamic parameters [20] of neutral atmosphere and Es layers was obtained to estimate the effect of variation of solar and geomagnetic activity on the neutral wind parameters.

It was shown that negative correlation of the possibility of occurrence of intensive Es layers with solar cycle is a result of indirect effects of solar activity through the parameters of the neutral wind [21].

Table 1. Mesoscale turbulence values in the period of Leonids flow according to solar cycle

<table>
<thead>
<tr>
<th>Year</th>
<th>F10.7</th>
<th>Mesoscale turbulence, m²/s²</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999, ascending branch of solar activity</td>
<td>1537</td>
<td>855</td>
</tr>
<tr>
<td>2000, maximum of solar activity</td>
<td>1787</td>
<td>993</td>
</tr>
<tr>
<td>2007, minimum of solar activity</td>
<td>731</td>
<td>323</td>
</tr>
</tbody>
</table>

![Diagram](image.png)

Fig.9. Prevailing neutral zonal wind mean seasonal height structure during Earth passage through IMF sector boundary in the maximum branch of solar cycle for winter (a) (IMF changes from negative to positive) and summer (b) (IMF changes from positive to negative).

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Problems of modelling and statistical analysis of tephra fallout for volcano Cerro Negro

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In this study, the bi-variate probability distributions of volcanic explosivity index as well as the tephra fallout as measured at Cerro Negro are considered and the skewness of the distribution is considered empirically and the non-skewed bi-variate Gaussian probability distribution is compared to the skewed Gaussian distribution.

Keywords: Bivariate Probability Distribution.

1. Introduction

In the present study the dispersion of ash fall from a volcanic event is considered in two parts. First, we consider the empirical probability of a given Volcanic Explosivity Index (VEI); that is, the associated proportion of the volcanic eruptions at Cerro Negro which correspond to the given VEI: 1, 2 or 3, Connor, Hill, Winfrey, Franklin, and La Femina [3]. Second, we perform parametric inferential analysis of the mass of tephra measured at 80 sites around the ash fall location as it was presented by Connor and Hill (1995), Vogel [15]. If there were no external forces other than gravity and all particles were perfect in shape (round), we would expect the dispersion to be bi-variate Gaussian (normal) probability distribution to characterize the key variable, but with the rotation of the earth and the resulting wind shear, the distribution is skewed, Genton, Editor, 2004 [10]. Therefore, four variations of the standard bi-variate normal distribution are considered in the present study. The fit of these probability distributions is compared using $\chi^2$ and $R^2$ to determine the best-fit probability distribution and percent of empirical distribution explained by the statistical model which best characterizes the behavior of the subject phenomenon.

Establishing the probability distribution of the subject variable (mass in cubic meters) enables us to estimate the amount of mass that is likely to land in a given location. This is extremely important in urban development as well as for strategic planning and risk analysis.

In our present study we will address the following questions:

1. Identify the volcano addressed and substantiate the choice.
2. What is the probable VEI of a volcanic event?
3. What is the probability distribution of tephra, combined and by grain size?
4. What is the best-fit bivariate probability distribution?

2. Cerro Negro, Nicaragua

The volcano of interest in this study is Cerro Negro, Nicaragua. Located at 12.5N and 86.7W, this volcano has an elevation of 2214 feet (675 meters) and a summit of 2388 feet (728 meters). Since its birth in 1850, there have been approximately 24 eruptions; the last eruption was in 1999. At 155 years, this is the youngest of Central America’s volcanoes in the Maribios Volcanic range.

There are many uncertain data from the dates of eruptions to the magnitude of the eruptions. Searching Cerro Negro, Nicaragua, there are many sites, which offer information on volcanoes. The Global Volcanism Program, maintained by the Smithsonian Institution, has posted information on the duration of eruptions, the volcano explosivity index (VEI), column height, the tephra fallout, the lava volume and the source area, see Table 1. Additional information can be gleaned from other sources such as Estimation of Volcanic Photo by William Melson, Cerro Negro 1968, Smithsonian Institution
Hazards from Tephra Fallout, Connor, Hill, Winfrey, Franklin and La Femina [5].

Table 1 gives the eruptions data for Cerro Negro including the year the volcanic event occurred, the approximate duration of the event, the cumulative volume (cubic meters), the approximate fall volume for the given event (cubic meters), the tephra (cubic meters), lava volume (cubic meters), column height (meters) and area affected.

<table>
<thead>
<tr>
<th>Year</th>
<th>Duration</th>
<th>VEI</th>
<th>Cum. (T) Volume, m$^3$</th>
<th>Fall Volume, m$^3$</th>
<th>Tephra Volume, m$^3$</th>
<th>Lava Volume, m$^3$</th>
<th>Column Height, m</th>
<th>Area</th>
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</thead>
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<td>6.0E+06</td>
<td>4.3E+05</td>
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<td>48</td>
<td>2 to 3</td>
<td>1.2E+08</td>
<td>9.7E+06</td>
<td>2.7E+07</td>
<td>6.9E+06</td>
<td>2.0E+03</td>
<td>Summit S F</td>
</tr>
<tr>
<td>1969</td>
<td>10</td>
<td>0 to 1</td>
<td>1.2E+08</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td>10.6 to 11</td>
<td>3</td>
<td>1.4E+08</td>
<td>3.0E+07</td>
<td>5.8E+07</td>
<td>5.0E+03</td>
<td>Summit E F</td>
<td></td>
</tr>
<tr>
<td>1992</td>
<td>3.6 to 5</td>
<td>3</td>
<td>1.5E+08</td>
<td>2.3E+07</td>
<td>2.6E+07</td>
<td>5.0E+03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>79 to 191</td>
<td>1 to 2</td>
<td>1.5E+08</td>
<td>5.8E+06</td>
<td>3.7E+06</td>
<td>2.3E+03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1995</td>
<td>13 to 15</td>
<td>2</td>
<td>1.6E+08</td>
<td>2.8E+06</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1999</td>
<td>2 to 3</td>
<td>1 to 2</td>
<td>1.6E+08</td>
<td>8.4E+05</td>
<td>1.0E+06</td>
<td>6.0E+05</td>
<td>1.0E+03</td>
<td>S. Flank</td>
</tr>
</tbody>
</table>

3. Analysis of Volcanic Explosivity Index of Cerro Negro, Nigeria

Consider the VEI for the volcanic eruptions at Cerro Negro, Nicaragua. There are several capricious data sources, see figure 1 and figure 2. Figure 1 shows VEI of 0, 1, or 2 (Smithsonian) whereas the figure 2 shows VEI of 0, 1, 2, 2.5, 3, Connor and Hill [3].

One source has a VEI of zero when there is little appreciable tephra fallout, no column height and no or little lava flow, while other sources have VEI of 1, for the same eruption. E.g. for the eruption in 1995, one source states there was an eruption which lasted 79 days, but shows
Problems of modelling and statistical analysis of tephra fallout for volcano Cerro Negro

...ve VA of 0, and for that same year an eruption which lasted only 13 days expelled a significant amount of volume with a VEI of 1. Whereas, according to the Smithsonian and historical data the eruption that occurred in 1995 showed a VEI of 2.

The two sources, (Smithsonian) and (Connor, Hill, Winfrey, Franklin and La Femina, 2001), are different; however, they are highly correlated with an estimate of the correlation coefficient, \( R^2 = 71.8\% \). Compare the VEI from the two sources, Table 2. The second source has several zeros whereas the first source only has record of one or higher. That is, the first source states all eruptions have index at least one. If we consider the proportions associated with the various levels of VEI, we see that the second source indicates that 35\% of all eruptions are insignificant with a VEI of 0, and a VEI of 1 or 2 is equally likely at 26\%, but that a VEI of 3 is likely to occur 13\% of the time. More realistically, the first source indicates that a VEI of two is most likely at 61\% of the eruptions. Whereas a VEI of three is the second most likely magnitude of eruption at 30\% and a VEI of one occurs the remaining 9\% of the time. Note, both sources indicate that there has never been an eruption with VEI of four or five; such a powerful eruption has not occurred at Cerro Negro, yet.

Under the assumption that the first source is more realistic, we will proceed with the analysis of the remaining variables; namely, the direction of the deposit, and the thickness of the deposit.

4. Trend Analysis

Consider the cumulative volumes in cubic meters of volcanic fallout. Throughout time, volcanic eruptions of magnitude 3 are commonly followed by eruptions of magnitude two or one. Let \( x_i(t) = n(\text{VEI}_i(t)) \) be the cumulative frequencies for each of the three main magnitudes; \( i = 1, 2, 3 \), shown in figure 3, are the overall cumulative frequencies defined by \( n(t) = \sum_{i=1}^{3} x_i(t) \). Then the probability of an eruption of a given magnitude is \( p_i(t) = \frac{x_i(t)}{n(t)} \) for \( i = 1, 2, 3 \) as illustrated in figure 3.

Figure 4 shows the convergence of the percentage of given VEI over time; that is, approximately 9\% of volcanic eruptions at Cerro Negro have VEI of 1, 61\% of volcanic eruptions at Cerro Negro have VEI of 2, and approximately 30\% of volcanic eruptions at Cerro Negro have VEI of 3.

We see that there are two large gaps in the line graphs given by figure 4 and figure 5, the first gap appeared between 1867 and 1899 (32 years) and the second one between 1971 and 1992 (21 years); but on the average, there is an eruption every 6.2 years. In addition, the first few eruptions after this twenty-plus year lull were: one of magnitude 3 and then two eruptions of magnitude 2 over a seven year period. In fact, over half of the differences indicate an eruption every 3 years. However, there was time when this volcano lay dormant for three decades. This study will not address the probability that there is an event in a given year, but the conditional hazard that relates to the
probabilities that a given event has a specified magnitude and the probability that the tephra will fall in a specified direction relative to the main vent of the volcano.

5. Direction of Deposition: Conic Sections

Data collected at Cerro Negro by the University of South Florida’s Geology department comprises the information on the mass of tephra by grain size that can be used to analyze the probability distribution of tephra fallout. With the main vent of the volcano set as the origin, consider eight sections (45° each) enumerated counter-clockwise off true east. These eight conical regions are defined finding the angle off due east and then dividing into equal sectors

\[ s = \text{int} \left( \frac{\theta}{45^\circ} + 1 \right) \]

The majority of the tephra fallout is in the sixth sector as shown in figure 6. As given in Table, 63% of the mass falls to the south-southwest of the volcano. Also, all mass falls south of the main vent and very little (11%) falls southeast. The differences between the locations where the data is collected and where tephra falls should be minimal; that is, the data is assumed to be gathered at random (systematically) selected locations to represent all locations where tephra falls. Figure 6 illustrates that the probability distribution of the given data is not best characterized by the symmetric bi-variate normal probability distribution.

Table 3. Data by direction (eight sectors).

<table>
<thead>
<tr>
<th>Sector</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>0</td>
<td>2</td>
<td>5</td>
<td>14</td>
<td>49</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Probability</td>
<td>0%</td>
<td>3%</td>
<td>6%</td>
<td>18%</td>
<td>63%</td>
<td>3%</td>
<td>5%</td>
<td>3%</td>
</tr>
</tbody>
</table>
Let us refine this directional partition into twenty-four conical sectors shown by Figure 7 where the cones are defined finding the angle off due east and then dividing into equal sectors, \( s = \int \left( \frac{\theta}{15^\circ} + 1 \right) \). This refined partition shows that while 3.8% of the samples are taken near the main vent of the volcano, 20.7% of the mass fall in this direction. The more refined the sectors, the more normal the distribution appears as shown in Table 4.

![Fig. 7: Scatter plot of Tephra Fallout by conical section](image)

**Table 4. Data by direction (twenty-four sectors)**

<table>
<thead>
<tr>
<th>Sector</th>
<th>Count</th>
<th>Probability Cone</th>
<th>Mean Mass</th>
<th>Probability Mass in Cone</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>1</td>
<td>1.282</td>
<td>850.883</td>
<td>12%</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1.282</td>
<td>753.294</td>
<td>11%</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1.282</td>
<td>373.504</td>
<td>5%</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>2.564</td>
<td>267.685</td>
<td>4%</td>
</tr>
<tr>
<td>9</td>
<td>2</td>
<td>2.564</td>
<td>601.575</td>
<td>9%</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>3.846</td>
<td>568.754</td>
<td>8%</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>1.282</td>
<td>441.885</td>
<td>6%</td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>12.821</td>
<td>362.741</td>
<td>5%</td>
</tr>
<tr>
<td>13</td>
<td>18</td>
<td>23.077</td>
<td>303.451</td>
<td>4%</td>
</tr>
<tr>
<td>14</td>
<td>21</td>
<td>26.923</td>
<td>394.468</td>
<td>6%</td>
</tr>
<tr>
<td>15</td>
<td>10</td>
<td>12.821</td>
<td>354.771</td>
<td>5%</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>1.282</td>
<td>215.712</td>
<td>3%</td>
</tr>
<tr>
<td>17</td>
<td>1</td>
<td>1.282</td>
<td>246.921</td>
<td>3%</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>1.282</td>
<td>343.031</td>
<td>5%</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>2.564</td>
<td>604.44</td>
<td>9%</td>
</tr>
<tr>
<td>21</td>
<td>1</td>
<td>1.282</td>
<td>97.82</td>
<td>1%</td>
</tr>
<tr>
<td>23</td>
<td>2</td>
<td>2.564</td>
<td>294.861</td>
<td>4%</td>
</tr>
</tbody>
</table>

This analysis shows that the data are not Gaussian; the dispersion of the tephra is not symmetrical with respect to the center of the main vent. This analysis also shows that even if the standard (non-correlated) bi-variate normal distribution is assumed, then either the data should be rotated to a primary and secondary axis or the general (correlated) bi-variate normal distribution should be used.
6. Radial analysis

Let the location of the main vent be the center of our volcanic eruption. Assuming the converted latitude and longitude to be denoted in meters (northing and easting, Universal in a Transverse Mercator coordinate), we can compute the distance from this center marker as well as the angle. That is, the distance

\[ d_i = \sqrt{(x_i - x_c)^2 + (y_i - y_c)^2} \]

between \((x_i, y_i)\) (the location of the \(i\)th sample) and \((x_c, y_c)\) (the location of the main vent or center), and the angle \(\theta_i = \tan^{-1}\left(\frac{y_i - y_c}{x_i - x_c}\right)\) is off due east. Then we can best analyze the distance and angle independently.

Consider the histogram of the distances sampled as shown by Figure 8 along with the basic statistics that describe the data. More samples were taken closer to the main vent, and fewer were taken more than 10,000 meters from the main vent, but all in all the number of samples is uniform. Percentages for distance (with thirty contours) are given in Table 5, but what is more interesting is the mass measured at these various distances illustrated by Figure 9. Also in the table that follows, in addition to the distance contour, it shows the count, represented by distance, sample mean of the mass present and the percent of mass at each distance. The basic descriptive statistics are also given by the accompanying table (it is shown above the histogram, “Distance”).

<table>
<thead>
<tr>
<th>Distance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>5025.15223</td>
</tr>
<tr>
<td>Standard Error</td>
<td>328.1838868</td>
</tr>
<tr>
<td>Median</td>
<td>4666.926183</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>2916.962207</td>
</tr>
<tr>
<td>Sample Variance</td>
<td>8508668.516</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>-1.18184051</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.165165537</td>
</tr>
<tr>
<td>Range</td>
<td>10936.26742</td>
</tr>
<tr>
<td>Minimum</td>
<td>0</td>
</tr>
<tr>
<td>Maximum</td>
<td>10936.26742</td>
</tr>
<tr>
<td>Sum</td>
<td>396987.0262</td>
</tr>
<tr>
<td>Count</td>
<td>79</td>
</tr>
</tbody>
</table>
### Table 5. Mass by distance

<table>
<thead>
<tr>
<th>Distance Contour</th>
<th>Frequency</th>
<th>Relative Frequency</th>
<th>Total Mass</th>
<th>Percent of Mass by Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1.266</td>
<td>1.87239</td>
<td>6%</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1.266</td>
<td>6.20231</td>
<td>2%</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>5.063</td>
<td>3214.428</td>
<td>10%</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>2.532</td>
<td>1098.318</td>
<td>4%</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>10.127</td>
<td>4914.92</td>
<td>16%</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>5.063</td>
<td>1838.584</td>
<td>6%</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td>2.532</td>
<td>1755.53</td>
<td>6%</td>
</tr>
<tr>
<td>8</td>
<td>2</td>
<td>2.532</td>
<td>953.39</td>
<td>3%</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>5.063</td>
<td>1654.296</td>
<td>5%</td>
</tr>
<tr>
<td>10</td>
<td>3</td>
<td>3.797</td>
<td>1598.424</td>
<td>5%</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>1.266</td>
<td>329.566</td>
<td>1%</td>
</tr>
<tr>
<td>12</td>
<td>5</td>
<td>6.329</td>
<td>2241.005</td>
<td>7%</td>
</tr>
<tr>
<td>13</td>
<td>4</td>
<td>5.063</td>
<td>1307.428</td>
<td>4%</td>
</tr>
</tbody>
</table>

### Fig. 9. Scatter plot of mass kg/m² and distance from the center (main vent).

### Fig. 10. Histogram of the estimated angles off the horizon including descriptive statistics

<table>
<thead>
<tr>
<th>Angle</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>194.5335</td>
</tr>
<tr>
<td>Standard Error</td>
<td>5.334949</td>
</tr>
<tr>
<td>Median</td>
<td>194.7438</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>47.117</td>
</tr>
<tr>
<td>Sample Variance</td>
<td>2220.011</td>
</tr>
<tr>
<td>Kurtosis</td>
<td>3.006374</td>
</tr>
<tr>
<td>Skewness</td>
<td>0.349632</td>
</tr>
<tr>
<td>Range</td>
<td>292.9317</td>
</tr>
<tr>
<td>Minimum</td>
<td>49.47243</td>
</tr>
<tr>
<td>Maximum</td>
<td>342.4041</td>
</tr>
<tr>
<td>Sum</td>
<td>15173.61</td>
</tr>
<tr>
<td>Count</td>
<td>78</td>
</tr>
</tbody>
</table>
Furthermore, considering the distribution of the angle $\theta$, samples appear to be normally distributed, as illustrated by Figure 10, with a mean of 194.5° off due east with a standard deviation of 47.1°; however, this is simply the sampling distribution. However, as Figure 9 illustrates the distribution of mass is also centered about this angle as well. The basic descriptive statistics are also given in the accompanying table.

Further analysis of the mass by angle indicates that the angle of fallout is not normally distributed. The normal plot and box plot given by Figure 12 and Figure 13, respectively, indicate that the data are more uniformly distributed near the central angle determined by the rotation of the earth and the direction of the wind near the main vent. All other directions are outliers as illustrated in the box plot given by Figure 13, where an outlier is any point which falls further than three sample standard deviations from the mean. These angles of trajectory would be uniformly distributed over all 360°; this is due to the fact that without the external forces (and assuming perfectly spherical and uniform particle size) the dispersion of the ash fall would be bivariate normal (Gaussian).
7. Particle size probability distribution

These eruptions produced an ash-rich column extending 2 kilometers. Here we see the smallest particles of ash falling away from the mushrooming column as well as vibrator dust whereas the majority of the particles form a more liquidous buoyant state.

In general, strombolian eruptions are characterized by the sporadic explosion or spewing forth basaltic lava from a single vent or crater. Each event is caused by the release of volcanic gases, and they typically occur periodically - sometimes with appearance patterns and others more randomly. The lava fragments generally consist of partially molten volcanic bombs that become rounded as they fly through the air.

These particles were gathered and sifted into sixteen different particle sizes $\phi = -\log_2 d$ where $d$ is the particle diameter measured in millimeters. The ranges of diameters are listed in Table 6.

<table>
<thead>
<tr>
<th>Diameter $d$, mm</th>
<th>Size $\phi = -\log_2 d$</th>
<th>Mass kg/km$^2$</th>
<th>Diameter $d$, mm</th>
<th>Size $\phi = -\log_2 d$</th>
<th>Mass kg/km$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>16.00</td>
<td>-4</td>
<td>325.4</td>
<td>1.00</td>
<td>0</td>
<td>4792.37</td>
</tr>
<tr>
<td>11.31</td>
<td>-3.5</td>
<td>264.48</td>
<td>0.71</td>
<td>0.5</td>
<td>4370.21</td>
</tr>
<tr>
<td>8.00</td>
<td>-3</td>
<td>572.21</td>
<td>0.50</td>
<td>1</td>
<td>2621.48</td>
</tr>
<tr>
<td>5.66</td>
<td>-2.5</td>
<td>1079.65</td>
<td>0.35</td>
<td>1.5</td>
<td>1463.36</td>
</tr>
<tr>
<td>4.00</td>
<td>-2</td>
<td>1662.49</td>
<td>0.25</td>
<td>2</td>
<td>777.45</td>
</tr>
<tr>
<td>2.83</td>
<td>-1.5</td>
<td>2955.97</td>
<td>0.18</td>
<td>2.5</td>
<td>428.41</td>
</tr>
<tr>
<td>2.00</td>
<td>-1</td>
<td>3921</td>
<td>0.13</td>
<td>3</td>
<td>276.76</td>
</tr>
<tr>
<td>1.41</td>
<td>-0.5</td>
<td>4905.6</td>
<td>&lt;0.09</td>
<td>&gt;3</td>
<td>872.66</td>
</tr>
</tbody>
</table>

Consider when the mass is plotted first versus diameter as shown by Figure 14 and then versus phi shown by Figure 15. Furthermore, consider the probability distribution of the diameter and phi using mass as the frequency.

Fig. 14. Scatter plot of mass kg/m$^2$ by diameter $d$. 

---

Problems of modelling and statistical analysis of tephra fallout for volcano Cerro Negro
Phi does demonstrate a more normal probability distribution, but does not compensate for the distributions in the tail. The best-fit probability distribution is the Log-Normal probability distribution, see Table 7 below; however, many volcanologists use the normal probability distribution which gives misleading results.

<table>
<thead>
<tr>
<th>Test: Diameter (Phi)</th>
<th>Normal</th>
<th>Lognormal</th>
<th>Exponential</th>
<th>Weibull</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kolmogorov-Smirnov</td>
<td>&lt;0.010</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.010 (&lt;0.001)</td>
</tr>
<tr>
<td>Cramer Von Mises</td>
<td>&lt;0.005</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.005 (&lt;0.001)</td>
</tr>
<tr>
<td>Anderson Darling</td>
<td>&lt;0.005</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
<td>&lt;0.005 (&lt;0.001)</td>
</tr>
</tbody>
</table>

Here the empirical distribution is computed by the mass of the various particle sizes;

$$P(j = \phi) = \sum_{i \in \Phi} \frac{M(j)}{M(i)}$$

where $\Phi$ is the set of particle sizes defined by $\phi = -\log_2 d$ with $d$ being the diameter size of the particle in millimeters, $d > 0$. Note: there is loss of mass when converting the percentage particle size at each given location back to comparable mass unit. The manipulated data are accurate up to $\pm 2\%$ of the actual recorded percent mass.

The normal (Gaussian) probability distribution of the size phi is given by

$$f_\phi (\phi) = \frac{1}{\sigma_\phi \sqrt{2\pi}} \exp \left( -\frac{(\phi - \mu_\phi)^2}{2\sigma_\phi^2} \right)$$

where $\mu_\phi$ is the expected value (true mean) of the size $\phi$, and $\sigma_\phi$ is the associated standard deviation, where the recorded mass is the frequency. It may be necessary to include a separate
Problems of modelling and statistical analysis of tephra fallout for volcano Cerro Negro

weighing system to break the mass into frequency or count of number of particles of a given size in a given mass. To consider this interpretation – given the number of particles, the probability that a given particle is of a given size – would require estimations on the mass of particles of a given diameter size. Here we have the cumulative probability distribution of \( \Phi \) given by

\[
F_{\Phi} (\Phi) = 1 - \exp \left\{ - \frac{(\Phi - \mu_{\Phi})^2}{2\sigma_{\Phi}^2} \right\}
\]

and that of \( d \) given by

\[
F_{D}(d) = P\{D \leq d\} = P\{\ln D < \ln d\} = P\{\Phi < \ln d\} = F_{\Phi}(\ln d) = 1 - \exp \left\{ - \frac{(\ln d - \mu_{\Phi})^2}{2\sigma_{\Phi}^2} \right\}
\]

We can simplify this cumulative probability distribution if \( d \) is given by

\[
F_{D}(d) = \frac{1}{d\sigma_{\Phi}^2} \exp \left\{ - \frac{(\ln d - \mu_{\Phi})^2}{2\sigma_{\Phi}^2} \right\} \tag{2}
\]

Furthermore, note that we can write

\[
f_{D}(d) = \frac{f_{\Phi}(\ln d)}{d}
\]

which is the probability distribution function of the mass by particle size as measured by the diameter of tephra.

8. Statistical modeling of tephra fallout

Consider the three variables, mass, distance and angle associated with tephra fallout. Let the mass of the tephra at a given location be denoted by \( m \), then we can consider the linear statistical model given by

\[
m = \beta_0 + \beta_1 d + \beta_2 \theta + \epsilon,
\]

where the \( \beta_i \)'s are the weights that drive the estimate of the subject response and \( \epsilon \) is a random error.

Statistically, we find that only the distance away from the main vent is significant as a contributing variable with \( p \)-value <0.0001 explaining 36.5% of the variation in the amount of mass recorded at a given location. The direction in which the mass of tephra is found is dependent on the wind, but does not significantly contribute to the dispersion of the mass. Thus, an acceptable estimate of the statistical model is

\[
\hat{m} = 810.368 - 0.0613542 d
\]

That is, the response variable only depends on the distance from the main vent. Also, turning these roles around, consider the distances of the mass by particle size \( m_{\Phi} \) given by

\[
d = \beta_0 + \sum_{i=1}^{16} \beta_i m_{\Phi} + \epsilon \tag{5}
\]

where the \( \beta_i \)'s are the weights that drive the estimate of the subject response, and \( \epsilon \) is a random error.
The developed statistical model explains 52.7% of the variation in the distance, but none of the particle sizes was found to be significant. This model is important when considering that most of advection equations assume that the location where tephra is expected to fall depends on particle size. However, the present study shows that the location, at least in terms of distance, does not depend on particle size.

**Bi-variate distribution.**
Consider the mass $m$ over the northing distance $y$ and easting distance $x$ shown by fig. 16. We see that the majority of the mass falls near the main vent and depending on the direction of the wind is blown from the volcano. This wind direction can be measured, then the major and minor axes can be rotated off the north and east at the required angle, after which a simple non-correlated bi-variate Normal distribution can be used; however, there are many contributing factors and the wind is not the only determining factor.

Consider the standard correlated bivariate normal probability distribution given by

$$f(x, y \mid \mu_x, \sigma_x, \mu_y, \sigma_y, \rho_{xy}) = K \exp\left\{ \frac{1}{-2(1 + \rho_{xy})^{\frac{1}{2}}} \left( z_x^2 + z_y^2 + 2\rho_{xy} z_x z_y \right) \right\},$$

where

$$z_x = \frac{x - \mu_x}{\sigma_x}, \quad z_y = \frac{y - \mu_y}{\sigma_y}, \quad \rho_{xy} \in (-1, 1)$$

and

$$K = \frac{1}{2\pi \sigma_x \sigma_y \sqrt{1 - \rho_{xy}^2}}, \text{ for } -\infty < x < \infty, -\infty < y < \infty.$$

Notice that the function estimates given by the above probability distribution are of different scale, this is simply due to the fact that the true empirical probability is

$$P(x, y) = \frac{\gamma m(x, y)}{\sum_{\Omega} m(x, y)},$$

where $\gamma$ is the percent of the mass collected; that is, if the total fallout mass expelled by the volcano is $m$ and

$$\gamma = \frac{\sum_{\Omega} m(x, y)}{m}$$

is the percent of the total mass measured in a sample.
However, even with different scales, we see as shown by Figure 17(a), the distribution of the data collected is skewed toward the volcano’s main vent; whereas, as shown by Figure 17(b) and 17(c), the non-correlated and the correlated bivariate Gaussian are symmetrical.

When comparing the empirical probability distribution with the general non-correlated bivariate Gaussian probability distribution and the correlated bivariate Gaussian probability distributions, one can see that neither accounts for the skewness of the data distribution toward the volcano’s main vent. Compare the contour plots for the non-correlated bivariate Gaussian probability distribution and the correlated bivariate Gaussian probability distribution as shown by Figure 18(a) and 18(b), respectively.

In the non-correlated bivariate, the wind shear effect is not present; that is, the directions are assumed to be independent. Common practice to compensate for this is to use the initially defined advection diffusion equations under the assumption that each layer in the atmosphere moves collectively and falls in normally distributed piles when considered by grain size; that is, the assumption is that the fallout is symmetrical to a center point and not skewed toward the main vent. This “kernel”-like approach does not need not to directly account for the wind shear, but moreover does not account for the skewness of the fallout toward the main vent of the volcano.

Furthermore, while the correlated bivariate Gaussian does address the issue of orientation without any intermediate transformations, it does not address the skewness of the data toward the main vent as illustrated by Figure 19(a). Therefore, either we need to sift (profile) the data according to the particle size in an attempt to justify the general bivariate Gaussian probability distribution function or to test the goodness-of-fit of a skewed probability distribution such as some form continued within the generalized extreme value distribution (GEVD); (the Weibull, the Gumbel, the Frechet or the Pareto) or the skewed Normal distribution.

Furthermore, the categorization of the tephra fallout by particle size defined by \( \phi = -\ln(d) \), where \( d \) is the tephra diameter, is normalized by the scale and homogenized by the variance. For the majority of the particle sizes, the distribution is skewed toward the main vent of the volcano.
volcano, but as the particle size becomes smaller, indicated by the large values of phi, the
distribution loses its center of concentration and becomes more variegated. Therefore, it is
possible for the larger particle sizes to be combined and characterized by the same parametric
distribution, whereas non-parametric techniques may need to be used for the smaller particle
size.

Fig. 19. Tephra fallout by particle size.
The general empirical distributions for the majority of the larger particle sizes are very similar in skewness and dispersion to the distribution of the combined information. The smaller particle size, the more uniform the distribution, yet the dispersion is in the same general region as for the large particle sizes. Hence, the overall correlated bivariate probability distribution can be applied to the total mass and not by particle size to approximate the best probabilistic behavior of the subject phenomenon (location of fallout) using one of the three forms of the bivariate normal distribution: the rotated non-correlated normal probability distribution, the non-rotated correlated normal probability distribution and the rotated (independent) skewed normal probability distribution.

For the data gathered at Cerro Negro, the correlation coefficient between the northing and easting distances is $\hat{\rho}_{xy} = 0.508$ using data location in a listed form and the estimate of the correlation coefficient $\hat{\rho}_{xy} = 0.5378$, using the associated mass as weights.

The sample mean north coordinate is $\hat{\mu}_x = 525944$ ($\mu_x = 527329$) and sample mean east coordinate is $\hat{\mu}_y = 1380440$ ($\mu_y = 1380896$), with sample standard deviations of $\hat{\sigma}_x = 3222$ ($\sigma_x = 27513$) and $\hat{\sigma}_y = 1720$ ($\sigma_y = 14165$). Compare the north-south and the east-west cross-section of the empirical data versus the correlated bivariate normal distribution as shown by Figures 20 thru 23; these figures illustrate that the standard bivariate normal distribution is not the best-fit distribution there. The skewness in the data is not simulated by a symmetric normal bivariate distribution; this appears as a lean in the data as illustrated by fig.20. However, the empirical probability distribution shown in fig.22 is better characterized by the normal probability distribution shown in fig.23.
Furthermore, consider the three-dimensional plot of the empirical probability distribution and the correlated bivariate normal distribution with respect to the map of distance north by distance east shown by Figure 20 and Figure 21, respectively. This further illustrates the contour plots shown by Figure 22 and Figure 23, respectively. In these contour plots, the lines represent $\mu_x$ (true horizontal mean) and $\mu_y$ (true vertical mean) and the main vent is indicated by the dashed line.

Comparison of four forms of the bivariate NORMAL PROBABILITY distribution.

Recall that we defined the distance $d_i = \sqrt{(x_i - x_c)^2 + (y_i - y_c)^2}$ between $(x_i, y_i)$ (the location of the $i^{th}$ sample) and $(x_c, y_c)$ (the location of the main vent or center) and the angle $	heta_i = \tan^{-1}\left(\frac{y_i - y_c}{x_i - x_c}\right)$, off due east. We can therefore transform the northern and eastern directions into a centralized Cartesian plane by considering the transformed data $x_i' = x_i - x_c$ and $y_i' = y_i - y_c$, then in $cis$ notation, we have $r_i = \sqrt{x_i'^2 + y_i'^2} = d_i$ with corresponding radians given by $\theta_i$. To rotate these data to a primary and secondary axes where there is minimum or no correlation, we can rotate the data by a given angle $\alpha$ by defining $x_i'' = r_i \cos(\theta_i + \alpha)$ and $y_i'' = r_i \sin(\theta_i + \alpha)$. We can estimate the necessary value of $\alpha$ by considering the regressed slope between $x'$ and $y'$ set equal to zero. Accurate to the first decimal we have $\hat{\alpha} = 18.8^0$ which shows an associated slope of $m = 0.000357$ and
simple correlation of $r = 0.000801$. Scatter plots of these two coordinate systems are as shown by Figure 28 and Figure 29.

However, even with this rotation the mass is skewed and the majority of the tephra fall more in one direction than in any other, namely the direction in which the wind is blowing.

To compare these statistical models to the empirical distribution, consider the unitized probability distribution. Recall, the sample sets consist of $\Omega = \{ (x_i, y_i) : i = 1,2,\ldots,80 \}$ and the empirical probability at a given location is defined in terms of the mass at that location

$$p_i = P(x_i, y_i) = \frac{M(x_i, y_i)}{\sum_{(x, y) \in \Omega} M(x, y)}.$$  

Then, we can compute the best-fit correlated bivariate normal probability distribution for the transformed data $f(x_i, y_i)$ at the various locations for which we have data and then define the associated probability as

$$\hat{f}(x_i, y_i) = \frac{f(x_i, y_i)}{\sum_{(x, y) \in \Omega} f(x, y)}.$$  

Similarly, we can compute the best-fit non-correlated bivariate normal distribution for the transformed and rotated data $g(x_i', y_i')$ as defined by

$$\hat{g}(x_i', y_i') = \frac{g(x_i', y_i')}{\sum_{(x_i', y_i') \in \Omega} g(x_i', y_i')}.$$  

Then we can determine which distribution yields the best-fit.

Since $x'$ and $y'$ are independent, then $f_{\Omega}(x', y') = f_{X'}(x')f_{Y'}(y')$, where $\Omega' = \{ (x', y') | (x, y) \in \Omega \}$, $X' = \{ x' | x \in X \}$ and $Y' = \{ y' | y \in Y \}$. In this rotated coordinate system, the distribution of the minor axis is normally distributed; that is, $y' \sim N(\mu_y, \sigma_y^2)$. However, the distribution of the major axis is skewed; that is the variable $x'$ is better described by the skewed distribution given by equation 6 where $g(x)$ is the standard normal probability distribution function with parameters $\mu_x$ and $\sigma_x^2$. The skewed probability distribution function is given by

$$f_{X'}(x') = 2g(x')G(\lambda x')$$  

where $G$ is the cumulative normal probability distribution function, $\lambda$ is the skewing factor and $x'$ is the rotated coordinate defined above.
Thus, we have four probability distributions to consider: the transformed non-correlated bivariate normal (TNCN), the transformed correlated bivariate normal (TCN), the transformed rotated non-correlated bivariate distribution (TRNCN) and finally, the (independent) skewed transformed rotated non-correlated bivariate normal distribution (STRNCN).

To determine which of the four probability distributions best-fits the data, we proceed to determine which of the four probability distributions minimize the measure of

\[ \chi^2 = \sum_i \frac{(f(x_i, y_i) - p_i)^2}{p_i} \]

and

\[ \chi^2_{\text{adj}} = \sum_i \frac{(\hat{f}(x_i, y_i) - p_i)^2}{p_i} , \]

we can improve the fit of the distribution by letting \( \hat{\lambda} = 5.23 \), this skewness yields a significant decrease in \( \chi^2 \). According to this statistics, the transformed correlated bivariate normal is the best-fit. Let \( \chi^2_0 \) represent the minimum measured \( \chi^2 \), then the larger of such statistics are given as a multiple of this minimum statistics, see Table 8. Furthermore, with the adjusted statistics, \( \chi^2_{\text{adj}} \), we have that the first two probability distributions (statistical models), TNCN and TCN, are very similar, but STRNCN shows a vast improvement over all the remaining statistical models. Therefore, we can also consider the correlation between \( p_i \) and \( f_i \) for the given probability distribution function, respectively. We compare these probability estimates given by Figures 30 thru 33. This again indicates that STRNCN explains more variation in the empirical probability distribution than the other statistical models with \( R^2 = 39.3\% \); however when we consider the simple correlation between \( p_i \) and \( \hat{f}_i \) for the given probability distribution function, respectively, TRNCN is the most explanatory. Note: all data are considered in its transposed form with graph given by Figure 30 thru 33 in the coordinate system \((x, y)\).

In Figures 30 thru 33, data have different scales; the empirical probability in Figure 30 sums to one, the estimated probability in Figures 34 is based on the bivariate distribution which is only a small portion of the total probability as stated previously.

<table>
<thead>
<tr>
<th>Statistic</th>
<th>TNCN</th>
<th>TCN</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu )</td>
<td>-2964.3</td>
<td>-637.82</td>
</tr>
<tr>
<td>( \sigma^2 )</td>
<td>2751.46</td>
<td>1416.3</td>
</tr>
<tr>
<td>( \rho )</td>
<td>0</td>
<td>0.5378</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>28.90% (52.9%)</td>
<td>35.20% (54.6%)</td>
</tr>
<tr>
<td>( \chi^2 )</td>
<td>1.3( \chi^2_0 )</td>
<td>( \chi^2_0 )</td>
</tr>
<tr>
<td>( \chi^2_{\text{adj}} )</td>
<td>0.413</td>
<td>0.422</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Statistic</th>
<th>TRNCN</th>
<th>STRNCN</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu )</td>
<td>-3196.3</td>
<td>396.23</td>
</tr>
<tr>
<td>( \sigma^2 )</td>
<td>2760.22</td>
<td>1137.5</td>
</tr>
<tr>
<td>( \rho )</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>17% (58.9%)</td>
<td>39.30% (45.1%)</td>
</tr>
<tr>
<td>( \chi^2 )</td>
<td>11.9( \chi^2_0 )</td>
<td>16.2( \chi^2_0 )</td>
</tr>
<tr>
<td>( \chi^2_{\text{adj}} )</td>
<td>0.607</td>
<td>0.265</td>
</tr>
</tbody>
</table>
Usefulness

This type of analysis is extremely important on both a global scale as well as on a local scale. Global impacts are not just the possibility of ash-fall in the area, but also the placement of such things as nuclear power plants and biohazard facilities. On a local scale, there are urban planning for economic growth, and more importantly evacuation planning in case of a volcanic eruption. Unfortunately, this is not an exact science. In 2001, volcanologists stated with 95% confidence that Cerro Negro would erupt again before 2005, but this has not yet come into fruition and it is over a year past this forecast (Connor, Hill, Winfrey, Franklin and La Femina, 2001). Does this mean we are over due, and how does this additional time affect the probable magnitude (VEI) of the next volcanic eruption? Consider the trend over time.
10. Conclusion
The volcano data analyzed in this study were obtained for Cerro Negro, Nicaragua. We have 80 sample sites from which the tephra was measured in terms of mass and sieved down into mass by particle size. The most probable VEI for Cerro Negro is 2.
In terms of the grain size, the probability distributions are the same for larger particle size: the skewed bivariate normal. Whereas the smaller is the particle size the more uniform is the distribution. The majority of the particles, however, are large enough to consider these masses combined.

To determine the bivariate probability distribution which best characterizes the subject response (location of ash fall), four probability distributions are tested for goodness-of-fit: the transformed non-correlated bivariate normal probability distribution (TNCN), the transformed correlated bivariate normal probability (TCN), the transformed rotated non-correlated bivariate normal probability distribution (TRNCN) and finally, the (independent) skewed transformed rotated non-correlated bivariate normal probability distribution (STRNCN). While for both the rotated non-correlated bivariate normal probability distribution and the correlated bivariate normal probability distribution the fit is extremely tight, when measuring the goodness-of-fit using the chi-square statistics, $\chi^2$, it indicates that the correlated bivariate normal probability distribution best characterizes the distribution of tephra. However, $R^2$ indicates that the distribution fits to the data by first rotating the data to a primary axis and then using non-correlated bivariate normal probability distribution. Thus, neither of these probability distributions accounts for the skewness in the data. According to the third way to determine the best-fit, $\chi^2_{adj}$ indicates that the skewed transposed (transformed by center to the main vent of the volcano) rotated (based on removing the correlation between northern and eastern direction) non-corrected (made to be independent) bivariate normal probability distribution best characterizes the behavior of the subject phenomenon. The TCN explains the estimated 35.2% to 54.6% of the variation in the empirical distribution; these values correspond to the correlation coefficient $R^2$, first between $f_i$ and $p_j$, and second between $\hat{f}_i$ and $p_j$. The TRNCN explains the estimated 17% to 58.9% of the variation in the empirical distribution and the STRNCN explains the estimated 39.3% to 45.1% of the variation in the empirical distribution.

Knowing the bivariate probability distribution which best characterizes the behavior of the subject phenomenon (location of ash fall) is extremely important for urban planning, strategic planning and risk analysis.

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References
Problems of modelling in geology and oceanography

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Global geology and oceanography are concerned not only with the dynamics and processes in the Earth’s interior and oceans but also the forces that influence them and the Earth’s cosmological vortex as an eddy in the solar vortex. For instance, why does the Earth’s magnetic field, its gravitational flux, wobble? How do we explain the movement of the plates and its effect on land masses? Why does the ocean plate subduct under the continental plate? Why do asteroids hit Earth rarely despite the Earth’s proximity to the Asteroid Belt in Jupiter’s orbital corridor just beyond Mars and millions of asteroids whizzing by annually? Using a qualitative model of the Earth’s core, i.e., the collected mass around its eye that extends to the atmosphere, the paper not only answers these questions but also explains, for the first time, the breaking of land masses and the movement of their fragments. It also explains the impact of the Moon, as the Earth’s only surviving minor vortex, and solar eclipse on the tidal cycle and occurrence of tectonic earthquakes.

1. Introduction

We recall that qualitative or noncomputational modeling was the crucial factor in the discovery of the basic constituent of matter [1-29] that paved the way for the explanation of gravity and the solution of the gravitational n-body problem in 1997 [4]. The solution required the discovery of 11 natural laws, through qualitative mathematics, in the initial formulation of the grand unified theory (GUT) called the flux theory of gravitation [5]. Since then this methodology that explains nature in terms of its laws has solved the turbulence problem [6], explained natural phenomena and resolved many fundamental questions of physics and the puzzles around the final disastrous final flight of the Columbia Space Shuttle [7]. We again apply this methodology using qualitative mathematics to the formulation of global geology and oceanography and once again explain several long-standing puzzles in these fields such as the movement of land masses and wobbling of the Earth’s magnetic field and reversal of the ocean current in the Indian Ocean. Computational modeling alone that describes nature mathematically cannot explain these phenomena. However, these two methodologies are complementary: qualitative modeling is based on rational thought and analysis, computational modeling on intuition.

As theoretical application of the grand unified theory (GUT) this paper is a sequel to [10]; it provides a qualitative model of the Earth both as minor cosmological vortex of the Sun and as its core, the accumulated mass around its vortex eye that extends to the atmosphere. The Earth’s cosmological vortex that coincides with its gravitational flux carried its minor vortices of the past with the Moon as the only survivor that escaped gobbling by its eye. The entire vortex that coincides with the gravitational flux is called dark halo and the concentration of visible matter along the Earth’s equatorial plane due to centrifugal force of spin and resonance of visible matter’s dark component with the dark halo is called the visible halo. Its shape is discular, thick around the Earth and thin towards the rim that extends far beyond the Moon. This discular configuration of visible halo is uniform for all live cosmological vortices including active galaxies (the Sagittarius cloud of stars is an example of a dead galaxy [17]).

2. Early cosmological history of the Earth

Like any cosmological vortex the Earth started as dark vortex, a term in the nested fractal sequences of vortices that arose from the nested fractal sequences of depression due to the steady shrinking of superstrings, by energy conservation and uneven development [10]. Then the kinetic energy of its spinning dark vortex and the impact of cosmic waves coming from all directions agitated and converted dark matter to its initial visible matter and evolved into nested fractal sequences of cosmological vortices with the initial dark vortex, now populated

Invitation to discussion
by its visible core (collected mass that extends to the atmosphere) and minor cosmological vortices, the early moons.

Just to put the Earth in perspective, in the nested fractal sequences of cosmological vortices that comprise the Milky Way the Earth is a tail sequence of a minor vortex of the Sun with the Sun’s vortex as first term. Therefore, it is a minor vortex of the Milky Way. There is considerable evidence that the Milky Way was formed the usual way and not part of our universe initially but drawn to it, along with the Sun and Earth in the course of our universe’s evolution into a super…super galaxy. It is the oldest galaxy in its neighborhood and there is a good chance it is older than our universe in view of the discovery of a star in it older than the Big Bang [23]. Moreover, we can see our young universe when it was only 3% of its present age. Therefore, the Milky Way was far from the Big Bang when it happened and most likely existed before it. What does this information mean? The Earth could be older than the 4.5 billion estimate of its age. Of course, this is not certain since the Earth could have emerged recently (see [7, 8] on the formation of cosmological vortices including our universes).

3. The Earth’s interior

We distinguish the Earth’s inner and outer core from its core as cosmological vortex and focus on the Earth’s interior, i.e., everything beneath its surface, including the oceans and lakes since it influences atmospheric behavior, particularly, turbulence in the atmosphere and weather change. For example, under-ocean volcanic activity forms el niño or pockets of warm water that, when huge and contiguous, say, as large as the Canadian landscape, may heat up the lower atmosphere and cause hurricane [6] and tropical cyclone. The Earth’s interior, is separated into layers from the inner and outer cores through the mantel crust and oceans. The Earth’s inner core is the hottest layer – 6,000º C [27(a)] – and its most compact solid layer due mainly to the high temperature and kinetic energy that allows only formation of simple prima in polar and equatorial coupling [11] that leaves minimal space between them. Consequently, the inner core has specific gravity of 150, the same specific gravity as that of the deep interior of the Sun. This information about the inner core is based on measurement of passage of seismic waves during earthquake and the fact that speed of passage is proportional to density of the medium.

The inner core wraps the eye and has common boundary with it. The outer layers were pulled and spun by the Earth’s gravitational flux during the early phase of its cosmological history through resonance with their dark component the inner core pulled most effectively and spins with the gravitational flux at staggering speed due its high density, effectiveness of pull being proportional to density. It continues to this day.

By energy conservation and energy conservation equivalence [10] the profile of the inner core viewed from its equatorial plane away from it is a pair of sinusoidal arcs of even power tangent at the ends much like that of a primum [13]. The simple prima form strings of polarly coupled prima end to end and the strings of positive prima are joined equatorially by negative quarks which may also form polarly coupled strings depending on their distribution. The alternate coupled strings of positive and negative quarks wrap around the eye of the Earth in layers and form the inner core. The outer core wraps around the inner core in the same arrangement and profile except for the possible inclusion of coupled prima and light nucleons allowed by its lower temperature of 5,500º C [27(a)].

We do not know what the circular speed of the gravitational flux that pulls the core (we can assume minimal slippage because of its high density and compactness in which case we can assume it is spinning at the same speed as the gravitational flux). We have a clue from its dual in quantum gravity, where the circular speed of the atomic flux induced and powered by the protons’ primal flux around the nucleus is $7 \times 10^{22}$ cm/sec [2]. We do not know if the duality is
faithful. All we can say is that the circular speed of the gravitational flux is huge. It is this great intensity of the Earth’s gravitational flux within the inner and outer cores and effectiveness of pull that determines its magnetic polarity. The increased angular momentum and spin of the cores is enhanced principally by dark-to-visible matter conversion within the hot spinning cores that gains instant mass and momentum upon conversion and augments its angular momentum and spin although the contribution of cosmic dust that falls to the cores is quite significant, e.g., the mass of cosmic dust in the Milky Way is greater than the mass of all its planets combined [1]. The same is true of dark matter sucked by the eye, by flux-low-pressure complementarity [14], that joins the spinning core; it gains instant momentum upon its conversion to visible matter. The Earth’s minor vortices were formed in the same way at smaller scale. At the same time, the increased spin of the Earth broadens its eye due to centrifugal force which, in turn, increases its suction, i.e., gravity. It is known that 65 million years ago the Earth’s gravity was 67% of the present [18]; its mass must have been proportionally less then also. Some scientists conjecture that the demise of the dinosaur was due to the deterioration of its anatomy relative to its increasing weight brought by the increasing gravity of the Earth long before its total disappearance 65 million years ago.

The dark-to-visible matter conversion in the core and mantle expands the Earth’s interior and creates outward pressure from the Earth’s mantle that results in magma oozing out of the crust that builds mountain ranges along both sides of constructive tectonic plate boundaries under the oceans and become part of the crust. Some of them broke out of the ocean surface and formed islands. Constructive plate boundaries along the Pacific rim, called the Pacific Ring of Fire are responsible for much volcanic activity some under the ocean, others find cavities and create volcanoes inland and feed them with lava. The Pacific Ocean seabed is studded with numerous under-ocean volcanoes responsible for much of weather turbulence there including tropical cyclones.

As visible matter accumulates around the inner and outer cores, mainly through dark-to-visible matter agitation and conversion by its intense vibration due to high temperature and generation of seismic waves by the micro component of turbulence there that convert superstrings to visible matter around them, the mantel shields the rest of the outer layers from the hot inner and outer cores allowing formation of more complex atoms and molecules and even biological species close to the Earth’s surface. Ingredients of many biological species have their origin in magma oozing out of the Earth’s crust from the Earth’s interior [27(a)]. This explains why volcanic islands such as the Galapagos west of Ecuador and Hawaii have the most diverse collection of animal species [27(a)]. Here, there are cracks and holes on the plates that form hotspots where magma oozes out and creates volcanoes and feeds them with lava. It appears that most biological species form from magma as it cools to surface temperature. The Galapagos has the most diverse biological species in the world; it was here where Darwin spent the years 1831 – 1836 gathering data for his theory of evolution of biological species [27(a)].

The temperature of the Earth’s interior drops rapidly in proportion to the distance from the outer core because the inner layer of the mantle although hot and in liquid form due to proximity to the hot core shields the outer layers, liquid being good heat insulator. Being the thickest layer, the average temperature of the mantle drops considerably so that complex atoms form but mainly in liquid form. This is verified by the outflow of magma and melting of the crust when it subducts into it at destructive plate boundaries. The crust is made of diverse materials including rocks and minerals cool enough to host biological species near the Earth’s surface. Most species are on the surface and in the oceans but there are metal-based organisms underground, e.g., organisms found two miles
underground in the mines of South Africa [3]. Relative to the rest of the Earth’s interior the crust is quite thin like an eggshell. This is also where most destructive geological occurrences take place, mainly, earthquake and volcanic activity. The density of the Earth’s materials decreases from the core outward due mainly due to the presence of more complex atoms; in the atmosphere the large gas atom take abundant space.

At this time, the Earth is at its ascendancy phase of its cycle as shown by the receding Moon which means that the power of its spin is still growing and the Earth itself is still developing to higher order, e.g., new biological species continue to form the existing ones well on their evolutionary advance [15].

Why should the spin of the Earth continue to rise when there are no longer minor vortices falling on it to enhance its rotational momentum (the impact of meteors and asteroid is negligible)? The main converter of dark to visible matter is the hot spinning core. As soon as visible matter is converted from dark to visible matter it acquires momentum instantly that it adds to the core’s momentum and spin. Moreover, as long as the eye is still there it continues to suck dark matter that gets agitated and converted to visible matter by the hot spinning core and enhances the power of the spin. However, there is a break in that expansion. As the mass of the Earth becomes critically great it provides breaking action on its spin and everything else will begin to decline. Combined with the thinning of its dark halo the expansion of its gravitational flux will decline and come to a halt. Then the Earth will have reached the summit of its power and begins its trek down to its destiny.

4. The trek back home

The eye is a region of calm and depression (low pressure) just like the eye of any cosmological or Earthly vortex, e.g., typhoon and tornado, except that it contains nothing but great concentration of non-agitated superstrings called black hole. Therefore, the eye de-agitates visible matter at its boundary (event horizon) each de-agitated superstring joining the black hole in it, and over a very long period of time, converts them to semi-agitated superstrings first then to non-agitated superstrings that accumulate and join the black hole in the eye.

For comparison, let us look at a star. By energy conservation, over a very long period of time, the kinetic energy of its interior including its angular momentum and molecular bonding weaken. Then its component prima split into separate prima held together only by the suction of the eye. This phase of its life cycle is called neutron star, a misnomer since there is no neutron there. It is a transition phase where the prima eventually collapse to semi-agitated superstrings, by energy conservation, then to non-agitated superstrings that accumulate and join the black hole in the eye. Being dark, the black hole is unaffected by centrifugal force and remains in the eye’s center. When the prima have significantly converted to non-agitated superstrings and joined the black hole then it becomes naked. Naked black holes in the Cosmos are in pockets of “non-activity” their surroundings appearing empty. Many of them have been catalogued by astronomers. Clearly, black hole does not suck; only the eye of the cosmological vortex that nurtures it does. The Earth follows the evolution of a star at much smaller scale.

We conclude from here that every cosmological vortex with minor vortices including our universe follows this evolutionary path to its destiny, a cluster of black holes back in dark matter. For Earth its only moon will have the same destiny, black hole.

5. Volcanic activity

In the interfaces of compressed lava laminas or slabs moving unevenly along the Earth’s crust cavities compression and grinding also occur that generate seismic waves. They convert
superstrings to prima, atoms, molecules and photons that produce earthlights and balls of fire
(earthlights are high up in the mesosphere [20], while balls of fire hover just above ground or
ocean surface). Their physical characteristics shed light on accumulation of lava long before
they reach ground level. They can be used for calculating the power of impending eruption
and predicting its occurrence. Like visible components of shock waves from seismic activity
they are detected as high-frequency waves by seismographs. Movement of huge amount of
lava along large cavities may also trigger motion of huge rocks and crust that may cause slight
tremors and generate seismic waves around cavities. The fractal structure of seismic wave is
reflected in the structure of the lava outflow. Some geologists study it to get underground
information. Technology can be devised to measure and monitor lava accumulation and
movement from tectonic plate boundary through the Earth’s surface and gather information
they reveal. As we have seen ingredients of most living organisms come from volcanic lava.
Ocean species also abound in the boiling waters of the deep around under-ocean volcanoes
[27(b)].

Seismic shock waves (fractal seismic waves from macro to dark frequency) from volcanic
activity are generated in three ways (1) grinding of lava slabs under extreme pressure and
temperature, (2) motion of boulders that give way to lava flow and accumulation that induce
compression, lateral tension and grinding at faults nearby due to motion of boulders and (3)
effect of lava flow as it passes across plate boundaries and cavities. Most lava flow out of
constructive boundary; it induces separation and, therefore, intensifies compression at the
opposite subductive boundary of the plate where earthquake occurs. Thus, there is close link
at different levels between volcanic and seismic activity. Its impact on visible matter is
verified in the Philippines by earthlights and vigorous cloud motion over seemingly dormant
volcanoes. Moreover, the mysterious under-ocean bright lights in the Southern Philippines a
few years ago may have link to the strong tremors that followed (they could have been under-
ocean earthlights).

Areas of intense volcanic activity lie along constructive and subductive plate boundaries.
When subduction occurs lava also oozes out. The Pacific Ring of Fire along the Pacific Rim
consisting of constructive, subductive and conservative plate boundaries generates intense
volcanic activity. They have direct link with el niño (pockets of hot ocean surface) [6] and,
ultimately, cyclones. There is minimal volcanic activity at destructive or subductive
boundary, only when there is subduction. Along constructive plate boundaries massive
outflow of lava heats up the ocean surface to form El niño; it also accumulates along plate
margins that materially affect atmospheric behavior and volcanic activity. The Pacific Ocean
seabed is also studded with volcanoes especially along the Equator from off the Coast of
Ecuador through the Western Pacific just east of the Marianas Trench. They account for
tropical cyclones of the Eastern, Central and Western Pacific [5].

6. Movement of the crust

The Earth’s crust floats on the mainly liquid high density mantel of the Earth. It completes
one rotation with the Earth’s spin every 24 hours or circular speed of 1,609 km/hr (1,000
mph). Energy conservation requires uniform linear speed of the Earth’s gravitational flux
through the layers. However, there is dissipation of energy due to friction since the inner
layers are spinning more rapidly than the outer layers and the layer lag due to ineffectiveness
of pull by the gravitational flux on the Earth’s materials of lesser density. The effectiveness of
pull is proportional to the compactness of the materials and that is roughly inversely
proportional to the distance from the Earth’s inner and outer cores, the most compact layers.
Next in compactness is the basically liquid mantle then the crust being relatively porous is
less dense compared to the mantle although it contains dense solids like minerals which are
Problems of modelling in geology and oceanography

negligible. Next to the crust are the relatively light oceans and the much lighter atmosphere. There is a natural lag that does not entail dissipation of energy and that is the lag in displacement since each element of mass has to travel greater distance the farther it is from the cores. We add this to the layer lag. Moreover, due to lag differential between outer and inner layers, the inner layer travels eastward relative to the outer layer.

If we cut Earth at the Equator and view its profile from the North Pole we will see the iso-circular speed (same circular speed) curves across the layers consisting roughly of smooth family of counterclockwise spirals that covers the entire profile from the rim of the atmosphere towards the core and winds around it. The speed curves do not cut across the core because of the latter’s uniform density and solidity (rigidity); in other words, it spins as a solid rigid core. If we look at each curve there is discontinuity at the interface between the crust and the ocean, between the ocean and the atmosphere and between the crust and atmosphere. Therefore, there is a segment of step function from the crust to the ocean and from the ocean to the atmosphere resulting in a family of piece-wise spiral iso-circular speed curves that covers the entire profile. However, friction rounds off corners in every curve resulting in a smooth family of curves that approximate step functions. We shall use this information later.

The linear speed of the crust decreases from 1,609 km/hr at the Equator to 0 at either Pole, i.e., there is a gradual lag in circular speed towards the Poles which are regions of calm being the extremities of the Earth’s cylindrical eye. We shall refer to it as polar lag. Being extremities of the eye there is much suction at the poles which explains the flattened polar regions. Measurement on the Sun shows that midway between the Equator and either Pole the circular speed of the spinning crust is 30% that at the Equator. Thus, circular speed of rotation decreases away from the core’s center in all directions.

(The edge of the flattened polar region of the Earth is quite evident at the Look Out Restaurant on a cliff overlooking the Pacific Ocean near Sydney).

Energy conservation induces plate movement from region of high kinetic energy which is energy dissipating, such as the region of rapid spin at the Equator, to region of calm at either Pole. Thus, the general movement of the plates in the Northern Hemisphere is northward, in the Southern Hemisphere southward. However, there are particularities that induce slight departure from it. For instance, the huge China Plate and the arrangement of the plates in the region blocks northerly motion; therefore, the Philippine Plate is moving in the north-northeast direction towards the Sea of Japan. The Japanese island of Kyushu southwest of Tokyo, however, which is near and directly south of the mainland has no alternative way of moving north, moves northeastward relative to the mainland which is moving westward as well and is in collision course with it. Such movement and the associated uneven movement of plate boundaries cause earthquakes as rocks that cross geological faults over them snap beyond their thresholds of tension. Of course, the big one will come at collision. The sudden movement of huge chunk of crust in the course of such uneven movement also causes earthquake.

Study of fossils reveals that 200 million years ago the land masses belonged to one continent, Pangaea [27(b)]. Then 20 million years later the continent began to split into two land masses: Laurasia in the north and Gondwanaland in the south [27(b)]. This splitting is the result of these two main movements: the shearing or slicing effect of the polar lag and the movement away from the Equator, by energy conservation. If we look at the land masses and the seabed we will find dramatic verification of this dynamics. While we can explain the break-up of the single continent Pangaea into Laurasia and Gondwanaland we focus on the later splits and movement of land masses that have direct evidence on the seabed and arrangement of the fragments.
(1) The Ancient continent of Gondwanaland split into India and Antarctica 140 million years ago [27(b)]. India moved northward and collided with the Asian mainland forcing the crust upward to form the Himalayan ranges while Antarctica moved southward and settled over the South Pole. The effect on India was the formation of numerous mountains in the North and along the coasts and plateau at the central region which are non-volcanic, i.e., it was due to uneven compression and crust movement as a result of the collision. The Antarctic is the only land mass connected to the oceans of the globe except the Arctic Ocean, the smallest.

(2) Another example of slicing action by both the polar lag and movement away from the Equator is the Australian Island of Tasmania moving south towards Antarctica. The contours of its northern edge clearly match the contours of the Southern coast of Australia where it split from.

(3) A spectacular example of stretching is the North and South American continents cut by the Equator across Ecuador in South America. Clearly, the North American continent moved westward that stretch its link with the South American continent moving eastward that now forms the Central American land bridge. This is an example of a resilient land connection.

(4) Another example of a split where a huge land mass moved westward and a tiny portion stayed put is the land of Sri Lanka that India split from and moved westward. Like Tasmania, the edges of both land masses where the split occurred are still evident.

(5) Still another example of splitting is Madagascar that has been left behind by the movement of the African continent westward, edges where the split occurred still evident.

(6) What looks like broken pieces of a land mass north of Canada is also the result of the slicing effect of the polar lag; so is the group of islands north of Siberia.

(7) A huge land mass does not split; instead it moves as a whole. However, if there is a rift it can split or stretch. Fifty million years from now the eastern portion of Africa will split along the Rift Valley and the rest of the continent will move north and close the Mediterranean [27(a)]. The eastern portion will retain the Horn of Africa that includes Somalia and part of Ethiopia as well as Kenya, Tanzania and part of Mozambique [27(a)].

(8) Just recently (i.e., anywhere since 65 million years ago) Greenland split from Europe. All of the above items are consistent with the combination of the slicing effect on land masses of the polar lag and movement from region of high kinetic energy to relative calm. These two general movements of the crust are mainly responsible for changes in the crust’s landscape including formation of mountains, widening of lakes as well as violent activity such as earthquake and volcanic activity. The latter may even start violent atmospheric turbulence such as hurricane through heating up of ocean surface. In the movement of the Earth’s crust, the two parts of Andreas Fault in California are moving in opposite directions that a mountain near Lake Tahoe, California now used to be in Mexico millions of years ago [27(a)]. One can just imagine the earthquakes such movement must have caused. The Red Sea that separates India from Saudi Arabia has been expanding in the last 25 million years due to a widening ridge in it and its is expected to become wider than the Atlantic Ocean in the future [27(a)]. We can see here that not only land masses change, the oceans change as well. Two hundred million years ago the continent Pangaea was surrounded by the single ocean Panthalassa [27(b)]. Those land masses have spread to their present positions.

7. The Earth’s magnetic field

Like its dual in quantum gravity [10] – the atom – a cosmological vortex is a magnet, its magnetic field or gravitational flux the vortex itself powered by its eye, by flux-low-pressure complementarity. In the atom, the protons in the nucleus provide the vortex flux on which the orbital electron rides [12]. The Earth’s initial dark vortex as an eddy in the solar vortex had autonomy. As the dark and visible halo acquired greater concentration along its equatorial
plane by centrifugal force, flux-low-pressure complementarity and dark halo’s resonance with the visible halo’s dark component, flux compatibility took greater impact on the Earth’s and Sun’s gravitational fluxes. Then energy conservation moved them towards an equilibrium position: when the Earth’s North Pole points towards the Sun or when it points away from the Sun. At present their polar axes are almost parallel with the Earth away by a slight angle of 23.45° with the Sun’s [19]. They have the same gravitational flux spin so that viewed from their respective North Poles their axes point in the same direction (almost but for the tilt) and their fluxes are both counterclockwise. This angle is fixed by the Earth’s great angular momentum as a huge gyroscope. However, it wobbles (oscillates) across the equator by a maximum of about 25° to the North by June 21 and 25° to the South by December 21 every year. They are called the summer and winter Solstices, consequence of the universality of oscillation and uneven development [18]. As the Earth accumulates mass the oscillation angle will tend to zero asymptotically.

Now, the Earth’s magnetic flux reverses its polarity at almost 25,000-year cycles. Why? Let us learn from the swinging of the clock’s pendulum that wobbles about its point of equilibrium. It is understandable since the clock has mass and momentum so that when it is pulled away from the point of equilibrium and released it goes back to the equilibrium position and past it due to angular momentum; then it swings back towards the equilibrium point due to the pull of gravity and goes past the equilibrium point due to angular momentum, etc. This wobbling or vibration is due to synchronized application of opposite forces, in this case, angular momentum and gravity. In the case of the gravitational flux that is weightless and, therefore, has zero momentum why does it wobble? Let us discuss.

We find some clues from the Earth’s cosmological history. When it was still a dark vortex the gravitational flux was autonomous as an eddy but had fixed orientation. Then as we have already explained it takes an equilibrium position. Let us take one equilibrium position where the Earth’s North Pole points to the Sun so that there is neither repulsion nor attraction on either side of the Earth’s flux since it is normal to the Sun’s. We view the Earth from the Sun’s equatorial plane with the North Pole to our left.

As the hot spinning core converted dark to visible matter and accumulated mass around the eye, the micro component of turbulence produced seismic waves. Seismic wave is nested fractal sequence of basic cosmic waves (graphics in [28]) which also produces macro visible reverse fractal [12] wave envelope. When Earth was still light the macro wave induced its rapid oscillation or wobbling about the equilibrium point. As the Earth’s inner core gained mass the wobbling became slower but wider. Take a phase of the wobble when the Earth’s flux to our right is tilted away from the equilibrium position towards the Sun. Then there is a push by Sun’s gravitational flux there towards the equilibrium position while on the left there is a pull so that they reinforce each other. As the Earth’s flux crosses the equilibrium position each side switches to the opposite by, flux compatibility, and they still reinforce each other but the motion goes on due to angular momentum until it is overcome by flux compatibility and reverses. Due to the effective gravitational pull on the inner core it is carried by this wobble. As its mass grew the angular momentum rose and the wobble became slower and wider, just like a heavy clock pendulum swing, until it reached the present 25,000-year cycle and almost 180-degree of an arc wide wobble. This wobble can increase beyond 180 degrees and become a rapid rotation depending on whether the Earth is still gaining momentum. However, there is a breaking action on the other side when flux crosses the equilibrium position. Most likely only one rotation will occur if it will occur at all. It would be interesting to know if this has happened to some planet in the solar system.

A familiar example of an infinitesimal vibration that progresses to a wide wobble is the Focault pendulum. A heavy weight just above ground is attached to a long narrow wire and
tide to the ceiling on the fifth floor through a hole on the first, second third and fourth floors. Due to the Earth’s rotation the weight vibrates at first in the direction of the Earth’s spin. Then, over time, the vibration increases to a wide steady wobble (if above or below the equator the trace is not a line segment but opens up in the middle due to the polar lag).

The summer and winter Solstices developed independently of the cores’ wobbling since the latter has independent spin due to less pull by the gravitational flux. Being much lighter, it has less momentum and narrower wobble. Its increasing mass has breaking effect because the gravitational flux has more effective pull only at a narrow angle with the equatorial plane. Therefore, the wobble loses energy during the 25,000-year cycle but is replenished somewhat every 25,000 years when the gravitational flux plane is within that narrow angle. This is the situation now.

Both the magnetic field wobble and the summer and winter solstices will come to a halt when the Earth is already a dead planet, i.e., the inner and outer core spin is confined to the immediate vicinity of the eye long before the Earth’s inner core has converted to semi-agitated superstrings in transition towards its destiny – a black hole in the eye back in dark matter.

The magnetic field wobble, radial oscillation that leads to elliptical planetary orbit and summer and winter solstices belong to one category: they all follow from the universality of oscillation and law of uneven development.

8. Debris in the Cosmos

We consider debris in the solar system because it has impact on Earth. A comet is partial debris, a planetoid that just missed falling into the solar core and was catapulted back by the Sun’s gravity into elongated orbit that extends far beyond Pluto but damaged by the intense gravity of the Sun as it whizzed by during its near hit on the solar core. The damaged part of the debris, consisting of fragments, forms the tail of the comet. It is pushed away by solar radiation so its tail is always away from the Sun along its entire orbit. As a comet passes by a massive planet its tail is pulled by the planet’s gravity, some are suspended in neutral region i.e., away from the gravitational influence of any planet but riding on the Sun’s gravitational flux and orbits around the Sun. The comet’s tail consists of asteroids and meteorites and since they have broken vortex flux they do not have gravity and yet they have mass. Therefore, asteroids are counterexamples to Newton’s law of gravity. The huge asteroids cluster in the orbital corridor around Neptune and the smaller ones in the orbital corridor around Jupiter [21,28]. They are called asteroid belts.

At the same time, planetoids concentrate at and are close to the periphery of the solar gravitational flux as they escaped being gobbled up by the core of the solar vortex, the centrifugal force on them surpassing the gravitational suction by the eye. They are really planets, the collected mass around the eye of minor vortices of the Sun that range in size from the smallest planets to the tiny cosmic dust. When a comet passes by, they may be pulled out of their orbits, by flux-low-pressure complementarity, and collide with others adding to the debris of asteroids and meteorites. When a comet returns the debris may be nudged from their orbits and thrown in the direction of inner planets boosted by solar gravity.

There has been recent controversy regarding Pluto; in fact, it has just been expelled from the family of planets due to its small size and elongated orbit [19,25]. Pluto is in all respects a planet; it is accumulated mass at the core of its cosmological vortex, a minor vortex of the Sun; naturally, it has gravity and orbits around the Sun. Its orbit is a bit slender and elongated that part of it lies inside Uranus’ and Neptune’s orbits [18]. It just happens to be smaller than the other planets, its diameter 1,413 miles [19]. But, where should the cut-off be?
The elongated orbit of Pluto reveals that in the past it got near the Sun (as some planetoids near the periphery of the solar gravitational flux did) and was catapulted into elongated orbit. It did not get close enough to the Sun to sustain damage and become a comet.

9. Will asteroid hit Earth this millennium?

While meteorites shower Earth by the millions daily there are only a couple of asteroid hits during the last 65 million years. Why? Consider the present configuration of the Earth and Sun where the equatorial plane of the former forms acute angle with that of the latter. If an asteroid (travels along the solar equatorial plane) approaches, say, on its return trip from the Sun, it is pulled by the Earth’s gravitational flux, by flux-low-pressure complementarity. Viewed from the Earth’s North Pole the asteroid is being deflected to the left by it, by resonance with its dark component (since the Earth’s gravitational flux is counterclockwise). If as it nears Earth it traverses left of a narrow injection angle within which it would crash on Earth, it would miss Earth entirely by its own momentum. Light objects, e.g., meteors are overcome by Earth’s gravity and pulled by it into streamlines of falling minor vortices and debris and crash on Earth. If the asteroid approaches right of the injection angle traveling at a speed of about 25,000 mph, it will be deflected away by the opposite gravitational flux of the Earth, by flux compatibility, and miss Earth.

The chance of asteroid hitting Earth is greatest when its gravitational flux equatorial plane is normal to the Sun’s. That will be at least 6,000 years from now in the course of the Earth’s magnetic flux wobble. For now that chance is almost zero. Therefore, to the question of whether an asteroid will hit Earth this millennium, the answer is: quite unlikely. Consequently, the preparation for blowing up or deflecting an asteroid that approaches Earth is unnecessary.

10. Earthquake

Earthquake occurs (a) when rock across fault line snaps due to uneven motion of the interfacing plates, (b) when big chunk of the Earth’s crust falls, (c) as a result of movement of huge amount of volcanic lava underground and (d) when the oceanic plate pressing against the interfacing continental plate subducts, i.e., its edge goes under the continental plate, causing powerful tremor and allowing lava from the Earth’s interior to ooze out of the interface. Since the plates are 40 km underground, destruction is limited to the epicenter and around it.

A. Earthquake at geological fault and tectonic plate interface

We consider earthquake at geological fault, i.e., upward extension of tectonic plate boundary or crack. It is irregular, usually sinusoidal, so that the relative movement of the interfacing plates causes friction between interfacing crust and tension on huge rock across it. When the friction and tension thresholds are exceeded both the interfacing crust and rock across the fault snap causing tremor. Moreover, the grinding at the interface generates seismic waves that convert dark to visible matter usually in the form of balls of fire that hover along faults. As tension increases at a fault generation of seismic waves intensifies. Compression, grinding and lateral tension at geological fault and tectonic plate boundary involving millions of tons of force cause interpenetration (interfacing plates inducing changes on each other, tension and molecular vibration) and the micro component of turbulence induces collision and energetic vibration of atoms and molecules. Since they occur at the interface of turbulence the dark components of the interfacing turbulence compose or generate and propagate seismic waves [6]. Present seismograph detects only their visible high-frequency wave components and its envelope is visible to the naked eye (e.g., the wave motion of ground surface during earthquake). Seismic wave is actually a nested fractal
sequence of waves from the visible or macro through the micro and then dark component that ends up at the interface, each of the interfacing parts containing its respective fractal sequence of waves. The waves we see on the ground during vertical or lateral earthquake are the visible envelopes of seismic waves. They are actually nested fractal sequences of waves that end up as dark (energetic) cosmic waves at the interface, so energetic they soften or melt metal and crack or pulverize brittle material. They were responsible for the softening of the Columbia Space Shuttle’s chassis and metallic attachments that led to its separation and eventual crash [6].

The micro component of seismic waves irritate the brains of animals causing erratic behavior: horses and water buffalos jumping erratically; dogs howling in distress; ants and termites coming out of their mounds and hives; roaches flying like bees to escape irritation at wall crevices and ceiling; schools of whales and jellyfish leaving the ocean depths for shallow waters; they are signs of impending earthquake. The high intensity seismic waves just before an earthquake convert superstrings to visible matter, e.g., earthlights and volatile gases like radon that shoot off flames from the ground, combined with change in water level at open wells and widening of geological faults; they are danger signs the Chinese are adept at interpreting to predict impending earthquake.

Previously labeled UFO, earthlights of varied colors, intensity and motion have been sighted in California (along Andreas fault), Colorado, South Wales and Mexico. Geologists associate them with earthquakes but have no theory to explain them. Earthlights were sighted over Mexico City two years before the devastating earthquake of 1985. Physical characteristics of earthlights have predictive value. Bluish earthlight being energetic indicates high compression and tension at plate boundaries and faults and reddish one (less energetic) indicates otherwise. Just like guitar string, greater tension on it produces energetic vibration and higher pitch, greater compression at geological faults produce more bluish balls of fire. Then it can be used to gauge the intensity of an impending earthquake.

In both compression and lateral tension there is grinding, interpenetration and energetic vibration of the atoms and molecules that propagate seismic waves. This dynamics cannot be reproduced in man-made laboratory because of the huge forces involved. Verification requires simulation, observation at faults and plate boundaries and gathering and consolidating of data from the literature, US Geological Survey databases and even features by Sky Cable’s Discovery (e.g., Hostallen Project) and National Geographic.

Lateral tension involves compression due to uneven interfaces at faults (usually macro sinusoidal). Therefore, it generates seismic waves which can be monitored and level of compression and tension measured. Opposite infinitesimal lateral movement along faults is verified by macro geological motion and formation. The two parts of the Alpine Fault in New Zealand has now slid past each other by 300 km [27(a)]. The wavy fault interface adds to resistance and, therefore, power buildup; earthquake occurs when these obstacles including huge rocks between sliding parts snap and break, sending powerful shock waves (visible envelope of seismic waves) in all directions on the ground. However, their dark components are thrust in all directions. They convert dark matter to earthlights and balls of fire.

Between earthquakes, compression, grinding and lateral tension generate shock waves converting superstrings to visible matter, e.g., earth lights. They can be analyzed to study fault and plate boundary dynamics that may have important practical applications, especially, for predicting earthquake and assessing its intensity.

Engineers thought shock waves and jolting movement caused by earthquake damage high-rise structures and towers and in the 60s they built rollers and springs at their base to absorb the shocks and jolting action. It did not work. The great devastation in Tokyo and Taiwan caused by earthquakes in the 80s and 90s showed that such precaution has no significant effect.
pictures of the devastation, especially, in Taiwan, the softening of metallic attachment (malleable material) at foundations and cracking and pulverization of concrete (brittle material) were evident. The remedy is non-existent yet: alloy that withstands the softening effect of seismic waves and composite resistant to cracking and pulverization by seismic waves which can be the subject of theoretical and engineering research.

**B. Tidal cycle, solar eclipse and tectonic earthquake**

Since the Moon has the same spin as Earth’s and the Sun’s, its gravitational flux when overhead pushes the Earth’s gravitational flux, by flux compatibility, and the ocean to a low tide and, in turn, pushes the tectonic plate down underneath. The Moon’s gravitational flux has less effect on the porous land mass so that the effect of this action is to misalign the oceanic and continental or land plate with the former going farther down. This is reinforced by the Sun’s gravitational flux when it is on the other side of the globe since it pulls the ocean and the plate underneath towards the Earth’s center, by flux compatibility, and reinforces the Moon’s flux on this face of the Earth. This is the situation at noontime during New Moon and Midnight during Full Moon. The Moon has no effect on the other side of the globe when it is overhead but it is low tide there also but not as much due to the Sun’s push alone. When both the Sun and Moon are overhead their fluxes add up and reinforce each other and push against the Earth’s, by flux compatibility, pushing the ocean down to deep low tide and the ocean plate underneath as well. Even without the Moon the Sun causes low tide on opposite faces of the Earth every 12 hours causing steady misalignment between the ocean and continental plates. The Moon adds to the push in a substantial way when it is overhead with the Sun since it is much nearer Earth and has much greater impact than the Sun. Then the low tide is much deeper. Altogether, the ocean plates are pushed several times every 24-hr period since even when the lunar and solar radii are angled the resultant push still causes low tide. This regular push (greater on ocean plates) creates steady misalignment of tectonic plate interfaces with continental plates at subductive boundaries. Ultimately the ocean plate subducts (goes under the ocean plate) and earthquake occurs.

During solar eclipse, especially, of long duration, the rate of misalignment rises dramatically due to perfect alignment of the Sun and Moon, enhancing earthquake occurrences. The aftermath of the eclipse of long duration in September 1999 saw major earthquakes in Turkey (twice), Taiwan (twice), China, Iran, Indonesia, Mexico, the Philippines and Los Angeles and minor ones in the Philippines (thrice), Indonesia, Japan and Malaysia within the following six months. During the same period several volcanic eruptions occurred stretching from Sicily through El Salvador. They were widely scattered occurrences but since plates are interconnected around the globe, earthquake triggers movement of plate boundaries worldwide that cause lava outflow at the point of subduction and constructive plate boundaries.

It should be clear that when it is low tide in opposite radial directions, there is a bulge or high tide in the opposite radial directions normal to the former. Traditional physics is wrong in this case because it is thought that gravity is only a pull. In fact, it can be a push or a pull, by flux compatibility [8].

**C. Mass suicide by whales?**

Occasionally, whales and dolphins jump off the ocean and other sea creatures of the deep surface; such spectacle is usually followed by major earthquake. On December 12, 1999 there was a blackout over the largest Island of Luzon, Philippines because a major water-cooled power plant that supplies power to the Luzon grid broke down, the coolant water filter clogged by jelly fish from the ocean deep. There was a powerful earthquake the following day.
Water being denser and more elastic than air is more effective medium for seismic waves that irritate sea creatures like whales, dolphins and jelly fish. Even on land the high intensity of seismic waves preceding an earthquake causes erratic behavior of animals.

11. Tsunami

We focus on the devastating tsunami that occurred at the destructive interface of the tectonic plates of Burma and India off the West Coast of the island of Sumatra, Indonesia, December 2004. The plate interface goes from North to South. In this case it was the India plate that did subduct on that fateful day because of the huge Indian west of the interface.

Powerful tsunami is generated only when subduction occurs at just the right depth of anywhere between one to one and a half kilometers below ocean surface. The subduction site extended 300 km along the interface. According to reports when that subduction occurred, the India plate dropped about 50 meters while the Burma plate thrust upward some 20 meters and the whole weight of the column of water above the surface dropped with the India plate and blocked by the elevated Burma plate in the East pushed the ocean water westward. The latter bounced back pushed by the Indian Ocean that, in turn, pushed the column back and, blocked by the elevated Burma plate, thrust upward 50 feet above the ocean surface. Pulled by gravity, it dropped again repeating the previous motion but only after it pushed the ocean water westward and eastward to cause it to travel as a huge wave. The motion occurred three times sending three huge waves (the tsunami) westward and eastward but more energetic westward due to the block by the Burma plate. The westbound waves traveled at speed of 900 km/hr to Sri Lanka, India and beyond the southern tip of India all the way to the Eastern Coast of Africa. The waves slowed down to 450 km/hr as it entered shallow coasts but like the water jet stream through constricted water hose surged powerfully inland one km across the coastline. The waves also traveled with lesser force eastward and flooded the nearby coasts of Sumatra and Thailand by up to 50 meters high due to proximity causing just as much destruction there.

There was no effect of the tsunami northward and southward sparing Mayunmar and Australia from destruction. In the aftermath of the tsunami Australian scientists reported that the earthquake that registered 9 on the Richer scale) vibrated the Earth, dissipated its energy and slowed down its rotation so that it will lose $\frac{1}{4}$ day in the next century (maybe the leap year will vanish then).

12. Global oceanography

We start with the ocean current in the Pacific. The layer lag between the crust and the ocean produces an ocean current along the Equator from East to West. This current is like a river in the ocean that is as wide as 80 km at some points and splits into eddies or local current cycle that narrows it down at other points. Blocked by the Asian land mass, its northern strip curves northward towards the North Pole but blocked by the Chinese coast, it curves again eastward towards Japan and under Siberia, across the Bering Sea and, blocked by North America, curves downward off the Mexican Coast and then curves westward to join the Equatorial current, by flux-low-pressure complementarity, and completes the Northern Pacific Ocean Cycle. The current flows in the clockwise direction.

As the cycle curves it narrows due to its momentum that presses it against the land block aside from the effect of eddies that draws away a strip of the current. Thus, there is a narrowing of the Pacific Ocean Cycle from off the eastern seaboard of the Philippines through east of the coast of Japan through south of Alaska as it bends southward and, again, west of Mexico as it bends westward to complete the cycle. Just like a constricted water hose that
shoots off water jet, when the current narrows its flow rate rises, a consequence of energy conservation. This happens at the bends in the Pacific Ocean. Due to friction with the seabed that pulls the ocean bottom with it towards the East, the lower strip of the west end of the westerly equatorial current off the Philippine Coast bends downwards and curves into a horizontal current towards the East as it is being pulled by friction with the seabed that goes eastward. Then this countercurrent under the northern strip of the westerly equatorial current goes all the way East, bends upward and feeds into the origin of the westerly equatorial current to complete the vertical cycle. Note that formation of the cycles conforms to energy conservation. Current where the head has nowhere to go stops and cannot be sustained. In the case of rivers they empty into the sea and ocean current forms a cycle. The undercurrent in the Northern Hemisphere shifts northward relative to surface current segment due to polar lag.

The Pacific Ocean cycle has a rough mirror image in the Southern Hemisphere that flows in the counterclockwise direction. In both cycles ocean eddies or local cycles serve as ball bearings to minimize viscosity and facilitate ocean flow. In the past the ocean cycles were used by seafarers to facilitate travel and even today village fishermen use the local cycles for the same purpose.

The wind has nothing to do with ocean current; it can only produce waves that appear to travel but, in fact, only ride on the synchronized vibration of water molecules that stay in place. The dynamics is quite analogous to the neon lights that appear to travel due to the synchronized switching that turns on the lights one after another in rapid succession. It would take tremendous amount of force to overcome water viscosity and push a layer of the ocean to form a current. Wind is quite incapable of it.

The situation is similar in the Atlantic but in the Arctic Ocean the ocean current goes around the North Pole clockwise. However, in the Indian Ocean the cycle is quite different. It reverses direction twice during the year: during winter it is counterclockwise and clockwise during summer. Why? During the approach of winter when the Equator tilts northward for the winter Solstice the northern arc of the Indian Ocean Cycle coincides with the westward ocean layer lag. Therefore, it pushes the current westward from India to the South African Coast inducing counterclockwise current along the Indian Ocean Cycle. During the approach of the summer Solstice when the Equator tilts southward, the southern arc coincides with the westward ocean layer lag. Therefore, it induces or forces clockwise current along the cycle. Again, this current reversal has nothing to do with the monsoons but the effect of the winter and summer Solstices.

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In memory of Dr. Salvatore Santoli

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Salvatore Santoli, Ph.D., physical chemist, Fellow of the British Interplanetary Society, has been one of the first scientists to suggest and promote research and development in the emerging fields of Nanotechnology and Nanobiology, meant as the physics of subcellular living structures at the nanometre scale, and of Nonlinear Science, becoming interested in such subjects as early as 1987 and contributing to formulating their first principles and to envisaging their applications, particularly space applications.

In this spirit he co-founded the journal *Nanobiology*, sitting on its Advisory Board, and INT – International Nanobiological Testbed Ltd. in 1997, which is Partner of International Journal “Problems of Nonlinear Analysis in Engineering Systems” within Treaty of collaboration for joint activity. In this International Edition he also published a number of important articles as author and as Guest Editor of special issues. He sat on the Advisory Board of the *Journal of the British Interplanetary Society*, in which he started his active participation, authoring a number of articles and editing special issues, under the management of L.J. Carter. He also sat on the Advisory Board of the journal *Ultra-Scientist of Physical Sciences*; of the *Journal of Aerospace Engineering*; of *Scientific Inquiry - A Journal of the International Institute for General Systems Studies*; of the *International Journal of Computing Anticipatory Systems*, and in the Editorial Board of the *Series on Systems Evaluation, Prediction and Decision Making* (CRC Press).

He applied nanobiological principles to the cosmobiological studies on the origins and evolution of life on the Earth and the Universe, and to the Search for Extra-Terrestrial Intelligence. In this connection he edited a number of special issues of the *Journal of the British Interplanetary Society* on Exobiology, co-authored the book “Self Organization in the Universe and Life” with Dr. V. Maron and Dr. M. Nussinov, formulating and developing the impulse paradigm of self-organization of matter in the Universe by the four fundamental interactions, in order to estimate extra-terrestrial intelligence distribution in space and time.

Dr. Salvatore Santoli
03.08.1934 – 13.03.2013

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and the ultimate evolution of humankind. His paper "Life and Intelligence in the Universe from Nanobiological Principles" was published in the 2000 special SETI issue of Acta Astronautica. In this frame he also authored papers tackling the problem of human/alien communication of semantic information.

He also applied nanobiological principles to the studies on biological intelligence, pioneering the concept of ‘physical information’, as opposed to Shannon’s information, as a necessary means for scientifically describing it, stressing: «standard ‘physics of energy’, with its time as a fundamental coordinate which according to Einstein is “an illusion, persistent though it may be”, shows unable to tackle such problems and to describe in physical terms concepts like ‘intelligence’ as the capability of creating new information, I mean, information not contained in the initial and the boundary conditions, and ‘free will’. Shortly, in increasing the understanding of ourselves». In this connection, he also pioneered the concept of ‘information-driven systems’ for modelling biosystems, as open systems creating new information, by their dissipative nonlinear dynamics, as opposed to the cybernetic model of closed feedback systems which information is fed in by learning and information can only decrease.

He also applied nanobiological views to Nanomedicine and towards bionic developments, in regard of bioinspired information processing and automata for space exploration, envisaging automata endowed with semantic as opposed to merely logical i.e. syntactic information processing. This feature would allow automata to learn and reason about how to behave in response to complex goals in unpredictable environments.

All the activity of Dr. Santoli developed in the aim of a unitary vision of the world and human intellect, in both its cognitive and aesthetical aspects, authoring articles in this connection too, including on aesthetic perception and chaotic information processing.

With his words:

«When a scientist starts working in an utterly new field, where all is to be done from scratch, I mean, when one has to set forth first principles, to devise novel proper experiments and to choose the proper mathematical tools to deepen unexplored ideas, he/she finds him/herself working in a kind of no-man’s land, where the boundaries between Science, Philosophy and the sense of beauty fade out, and intuition plays the major role. The analytical mind, at work when dealing with problems in a well-established field, must give way to the pictorial mind. This position is no different from that of an artist exploiting tools and materials without having a fully clear idea of what the final product will be. In his/her very early creative moment, the scientist’s basic choices will be dictated, maybe in a subliminal way, by his/her ultimate sense of reality: a moment definitely of philosophical nature. In Science, we are always trying to find unity in multiplicity, I mean, a unifying principle in the apparently independent aspects of Nature».

Salvatore Santoli has been an active participant to CASYS International Conference on Computing Anticipatory Systems held by the Université de Liège (Prof. Daniel M. Dubois), Belgium, receiving best paper awards and being vice-president in 2011; to the International Conference on Systems Research, Informatics and Cybernetics held in Baden-Baden, Germany, by the International Institute for Advanced Studies in Systems Research and Cybernetics (Prof. George E. Lasker), from which he was awarded an honorary degree in recognition of his pioneering and innovative work in Nanoscience and Nanotechnology; to
IAA Symposia on *Missions to the Outer Solar Systems and Beyond*, held in Torino and Aosta, Italy by the International Academy of Astronautics and Politecnico di Torino (Prof. Giancarlo Genta), and to BIT Life Sciences’ *NanoMedicine Conference* in China (Dr. Xiaodan Mei). He was also a member of the Association for Computing Machinery.

As a student for graduation he carried out research and development in Nuclear Chemistry within the frame of the Radiochemistry Institute at the University of Rome “La Sapienza”, and had numerous papers published on that subject. In his early years as a physical chemist he also worked as an abstracter of Russian articles for *Chemical Abstracts* (published by The Ohio State University).

Innovation ideas of Dr. S.Santoli were reflected also by perfect plans in 2005 about foundation of International Center for Nanoscale Science and Technology (ICNST) in Kazan. It was actively approved on different levels, including Tatarstan Academy of Sciences, Kazan State Technical University of A.N.Tupolev’s name – KAI, Tatarstan Republic Government.

Kind memory about Dr. S.Santoli will for ever be kept in us.

**Patrizio Santoli**, Dr., General Director (Santoli International Patent and Trademark Law).

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