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NEW CHALLENGES FOR AEROSPACE EDUCATION PROGRAMS IN AMERICAN AND RUSSIAN UNIVERSITIES

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Abstract

Education programs in American and Russian universities have been analyzed to find positive factors which will be helpful in mutually beneficial cooperation between the universities and aerospace companies, working together to realize international projects. The pre-college activities, curricula and existent ways of collaboration between industry and universities in the United States and Russia have been comparatively analyzed. Some new ideas (such as *Advanced Distance Learning System for High-School Students, Experimental Learning Approach in Fundamental Sciences, Computer Learning, Industry-based Special Courses, Research & Design Projects for Sophomores, Juniors, and Alumni Industrial Teaching Activities*) have been discussed.

Introduction

Last decade can be characterized by the end of the "Cold War" and by major shifts in the political, military, and economic conditions in the world. The international cooperation in these areas has become a dominating tendency. The exploration of space and conversion of aerospace technologies should be beneficial for all nations.

According to a review of the aerospace industry published in *Aerospace America* in 1995, "one problem industry faces is that newly graduated engineers are often ill-equipped to do the jobs available".[1] As a result, their prospects for finding a good job in aerospace remain grim. The number of aerospace scientists and engineers had dropped by 30% since 1989 when the employment peak has been reached.[2] There are several other new features of the industry, namely: new international programs (i.e., *International Space Station, Mars Exploration, Sea Launch International Space Program, etc.*) have been announced, product design and manufacturing has increasingly become a multi-company, multi-national enterprise. All mentioned factors are extremely important and should be accurately considered during reconsideration of the education strategy in American Universities. Better understanding of foreign partners, their background and cultural traditions, will be helpful for educators, students, engineers and managers.

In the present paper, the analysis of education programs successfully realized in Russia has been discussed. Special topics of the program (*recruitment of the future students, education curriculum and content, CO-OP/Industrial Experimental Learning,* etc.) have been analyzed on the basis of the author's teaching experience at Moscow Institute of Physics and Technology, Moscow Aviation Institute, Worcester Polytechnic Institute (Massachusetts, USA), and University of New Hampshire (USA), as well as on his 15-year research conducted at the Central Aero-Hydrodynamic Institute (Moscow region, Russia) and consulting for American and Russian companies in aerospace and technology transfer.

International Programs in Aerospace

The International Space Station (ISS) program[3] combines the resources and scientific and technological expertise of 13 cooperating nations, including the United States, Russia, Japan, Canada and nine nations of the European Space Agency. The Station is planned to be a permanent laboratory for human-monitored long term research in life sciences and materials sciences under the unique conditions of the nearest space environment. It is based on a combination of U.S. modules, Russian Mir components, and the modules of other partners. The experience of Russian engineers is widely used.[4]

The second phase of the ISS project began with the orbiting of the Russian Zarya (Dawn) module on November 20, 1988. Thirteen days later, Space Shuttle Endeavor launched the U.S. Unity module, and the STS-88 team assembled these two ISS elements.[4]

The Mars exploration program is the other example of international collaboration in space studies. Unfortunately, during past decades, some launches of the Martian probes were unsuccessful. The Mars Observer spacecraft fell silent just three days prior to entering orbit around Mars, and further

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communications have not been restored.[5]

The Mars-96 spacecraft designed by Russian engineers in collaboration with researchers from the United States and 20 European countries crashed into the eastern Pacific Ocean in November 1996.[6] This project has been planned to be the main Russian research program of Solar System studies for next 10-15 years. After the crash, the reviewing of international collaborative opportunities is provided under the umbrella of the Martian Exploration programs of the U.S. (Mars Pathfinder[7] and Mars Global Surveyor[8]).

One of the causes of the latest crash of the Mars Climate Orbiter[40] (September 1999) is directly related to the mishandling of measurement units in software design. According to the NASA's report[9], one engineering team used metric units while another used English units for a key spacecraft operation. "The problem here was not the error, it was the failure of NASA's systems engineering, and the checks and balances in our processes to detect the error. That's why we lost the spacecraft," said Edward Weiler, NASA's Associate Administrator for Space Science.[9]

In 1993, NASA and the Russian State Committee for the Defense Branches of Industry signed a memorandum of understanding to cooperate in the following areas in aeronautics[10]: transition and turbulence, composite structures and materials, chemically reacting flow, thermal protection system materials, environmental concerns in aviation, hypersonic technologies, experimental test facilities, and advanced aerospace materials. Since July 1992, significant progress was made in carrying out a wide range of projects[11], including expansion of cooperation in life sciences and global change research, the exchange of American and Russian astronauts, and a Space Shuttle rendezvous and docking with the Russian Mir Space Station. As a result of this cooperation, first modules of the International Space Station were successfully assembled on the orbit.

To realize these projects many American and Russian aerospace companies have established mutually beneficial partnerships. For example, Lockheed Corporation and Russia's Khrunichev Enterprise established in 1992 Lockheed-Khrunichev International to serve as the entity for worldwide sale ($1B) of Proton Space launch vehicles.[1] To gain a foothold in the Russian aerospace industry, the Boeing Commercial Airplane Group established the Boeing Technical Research Center in Moscow in 1993.[12] According to the Annual Review of Aerospace Sciences, published by *Aerospace America* in 1993, "Boeing conducted two exploratory tests in the T-128 Transonic Wind Tunnel at the Central Aero-Hydrodynamics Institute in Zhukovsky, Russia. The results confirmed the T-128's potential to be one of the world's premier test facilities."[13] At the same time, France, Germany, and the U.K., in developing new hypersonic technology for future space transportation systems[14] successfully used the scientific and engineering capabilities of this famous Russian aerospace center.

In September 1999, an international consortium (Boeing Co., RSC Energia of Russia and KB Yuzhnoye of Ukraine) carried out the first commercial launch of a rocket into space from a floating platform.[15] The remote launch site would avoid risks associated with populated areas and takes advantage of the Earth's high rotational speed at the equator, which allows for heavier payloads.

The new cooperative ventures represent an advantageous blend of American and Russian capabilities. And, as Mr. Daniel S. Goldin, the Administrator of NASA, mentioned in his statement associated with the Cooperative Agreement between the United States and Russia on Space, Aeronautics and Science, "... in a large sense, a truly international space program could signal a new era of peace and cooperation among nations."[16] These long-term perspectives can only be realized under the conditions of good-will and the understanding of cultural differences in aerospace education systems of the countries.

Aerospace Education Programs in American and Russian Universities

In 1992, NASA announced a new strategic plan[17] for the period from 1993 through 1998. The Program Objectives cover the following statements: program are designed to increase teacher and faculty knowledge, research, and teaching skills, and hence to enhance teaching effectiveness; instructional materials should be based on NASA's unique mission and resources in the areas of science, engineering, and mathematics leading to increase student interest and achievement; NASA and other institutions and companies provide research and enrichment experiences for students as well as financial support in order to increase and maintain student interest and achievement in science, engineering, and mathematics, fostering careers in those fields; NASA will support Education Advanced Technology Research and Development including internet services, CD-ROM databases, video, computer software, multimedia systems, etc.

Some of these projects are successfully realizing nowadays. NASA's Central Operation of Resources for Educators (CORE) became an international distribution center for NASA's audiovisual educational materials. These materials are designed to increase awareness and understanding of NASA's scientific research and technology, life science, physics, astronomy, earth resources, mathematics and career education.[18] These educational materials are disseminated for teachers and students of all grade levels through the NASA Centers, the Teacher Resource Center Network (TRCN)[19], NASA Television, and NASA Spacelink.

In Spring 1996, students in grades K-12, working together with America's foremost astronomers, provided real science observations using NASA's Hubble Space Telescope.[20] Mars "virtual" teacher training conference in July 1996 connected teachers, students and scientists across the country with the NASA Discovery Program's Mars Pathfinder and Mars Global Surveyor missions. Four live telecasts, hand-on curriculum materials, and online resources were provided from November 1996 through November 1997. Unfortunately, Russian students were not planned to participate in these training conferences.

In August 1996, NASA and FAA announced their traditional sponsoring of a General Aviation Design Competition[21] for the 1996-1997 academic year that is open to undergraduate and graduate students at U.S. aeronautical and engineering universities. The competition would become international.

In April 1999, the American Electronics Association issued the report[22], which found that high-tech degrees (including engineering, math, physics and computer science) declined 5 percent between 1990 and 1996. Preliminary findings from 1997 and 1998 indicate the trend is continuing. A significant portion of the degrees awarded went to foreign nationals, i.e., 45 percent of high-tech degrees at the doctorate level were granted to non-U.S. citizens. [22]

Since 1993, three new university research centers (Syracuse University, NY, the University of Maryland, College Park, and the University of Texas at Arlington) had been funded by NASA to foster the next generation of researchers and engineers in hypersonic aeronautics.[23] The university research centers also work in aerodynamics, hypersonic propulsion, materials and structures, stability and control, test methods and systems integration. The schools work closely with NASA research centers under realization of the National Aero-Space Plane (NASP) program.

Many successful programs and initiatives nationwide were realized by 52 consortia that participated in the National Space Grant College and Fellowship Program. In 1993, these programs[24] included nearly 1,600 fellowship and scholarship awards for students, 263 programs for the enhancement of research infrastructure, 223 higher education programs, etc. On the whole, the consortia conducted over 1,400 program activities, which reached more than nine million precollege students and teachers, undergraduate and graduate students and faculty.[24] This type of programs is not available nowadays in Russia.

The above examples demonstrate a wide range of education programs supported by NASA. Unfortunately, in some cases, they are too wide, and, as a result, some programs are not challenged and deep. As an example, make a review of NASA TV Educational Programs scheduled in November 1996. You can be a participant of excellent videoconferences: *A Pitch for Microgravity; On the Cutting Edge: International Space Station; Live from the Hubble Space Telescope: Making Your Observations; Live from the Stratosphere: Return to the Stratosphere,* etc. However, the Mathematical Projects are still restricted by topics: *The Theorem of Pythagoras; Sines & Cosines (Parts I-III); Polynomials; The Story of Pi*. Three years later, the October'99 Education Schedule offers again *The Story of Pi; Polynomials*. Is it enough to meet the requirements of the space era exploration in the next century?

A new program in the NASA's October'99 Education Schedule is the *Mathematics of Space*. This program addresses the basic mathematical operations of spacecraft rendezvous in Earth orbit. Middle school students in a mathematics class would solve some problems that permit the Space Shuttle to rendezvous and dock with the Russian Space Station Mir.

In 1994, the Ministry of Science, Higher School and Technological Policy of the Russian Federation initiated the Scientific Program "Universities of Russia."[25] The Program would achieve the following goals: setting up conditions for development of universities as regional centers of fundamental research, developing multi-level educational system in universities; integrating Russian universities into the world communities of university education and scientific research; exploring effective mechanisms allowing universities to survive in the market-economy conditions; developing mechanisms of university innovation activity and setting up university's scientific parks.

Russian universities (in Moscow, St.-Petersburg, Novosibirsk, Rostov, Nizhiy Novgorod, Saratov, Kazan, Vladivostok, Tomsk) and other educational institutions are trying to follow the best traditions in education. Regional and Technical Universities support activities of the Special High School of Physics and Mathematics under the supervision of top Russian scientists (i.e., the Moscow State University High School No. 18 was founded by famous Russian mathematician Andrei N. Kolmogorov[26]; the Distance Learning High School at the Moscow Institute of Physics and Mathematics supports new talents in Physics and Mathematics in generations; the Novosibirsk University High School of Physics and Mathematics has been founded by Academician

Lavrentiev, etc.). Talented students are selected from the high schools around the country to continue studies in the challenging university programs. In 1992, only 17% of students from ordinary high schools had continued education in the universities. All 100% of students from the Special High Schools became the students in regional or technical universities.

The curriculum in the mathematical classes includes introductory courses in calculus, theory of groups, tensor analysis, abstract mathematics, combinatorics, etc. The courses in physics are based on experimental studies in laboratories equipped by modern facilities and devices. In the United States, there are several similar examples, i.e. the Massachusetts Academy of Math & Science at the Worcester Polytechnic Institute.

Russian nationwide competitions in physics, mathematics and chemistry are very popular among pupils.[27,28] These students become the most active students in universities. They seek challenging problems and projects. Without their activities, it will be impossible to carry out research and to develop new technologies in aerospace.

American and Russian Education Centers

One of the best examples of the American education center is supposed to be the Stanford University. The Department of Aeronautics and Astronautics was established in 1959. In 1995-1996 academic year the graduate enrollment in the department was 239 students (less than 10% of the School of Engineering graduate enrollment).[29] The department supports aerospace-technology research, and offers the graduate degrees Master of Science, Engineer, and Doctor of Philosophy. At the undergraduate level, the department also offers a minor in Aeronautics and Astronautics. MS candidates must select five basic courses in Fluids, Structures, Guidance and Control, Propulsion, and Experimentation, and three advanced courses in the same areas. The MS candidates are expected to exhibit competence in applied mathematics. They may take a minimum six units of advanced mathematics offered by the Mathematics department or choose at least six units of technical electives which emphasize these methods. Also, in addition, four technical elective courses should be chosen by a student.

The doctoral study program is a specialized continuation of that for the MS degree.[29] A total of 90 units of credit is required beyond the Master's program, including a minimum of 36 units of formal course work (including 12 units of mathematical courses), and other units may be in the form of either Ph.D. dissertation units or free electives. Each Ph.D. candidate is required to take the University oral examination.[29]

The similar requirements are applied to the MS and Ph.D. students in the best Russian technical universities, such as, for example, Moscow Institute of Physics and Technology (MPhTI). But there are some significant differences. There are two departments at MPhTI, related to aerospace sciences: the Department of Aerodynamics and Cosmic Research, and the Department of Aeromechanics and Aircraft Design. The first department is closely connected with the research institutions and companies of the space industry, and the second one cooperates with the aviation companies. The departments enroll about 1,000 students in the six-year MS program and 120 post graduate (Ph.D.) Students. Space communications related work is also performed in the departments of Radio Technical Cybernetics, Physics and Quantum Electronics and Applied Mathematics.[30]

The Moscow Institute of Physics and Technology was founded by a group of top Russian scientists (the Nobel Prize winners Peter Kapitsa, Lev Landau, Academicians Lavrentiev, Christianovich, and others) 53 years ago, right after the WWII. Originally it was a department at the Moscow State University. The "system of Phys-Tech" is based on the following principles: the selected talented students should receive fundamental knowledge in physics and mathematics; under the supervision of scientists and practical engineers, they would develop their skills in the areas of engineering specialization, and carry out their research projects in the best research laboratories of the country; their start in these areas should be as early as possible. During the first two years, students study the major fundamental topics of modern mathematics, physics, and chemistry, including experimental courses. For the second two years, they continue studies in applied mathematics and theoretical physics, as well as take eight basic courses in the basic areas of Aeronautics and Astronautics, and, in addition, six advanced courses in these areas. During the forth and fifth academic years, the students take 6-8 elective courses, which are usually taught by the scientists from the research institutions. Starting from the second academic year, students visit the research institutions and have to be increasingly involved from year to year into research under the supervision of scientists. In the last (sixth) academic year, they carry out final research projects (MS theses), which can be continued later for three or four years to receive the Ph.D. degree.

Each department also has experimental laboratories and research programs. For example, the Chair of Physics at the Department of Aeromechanics and Aircraft Design carries out research in dynamics of unstable non-linear systems[31]. The laminar-turbulent transition in hypersonic boundary layers was studied in collaboration with the Rockwell International Science Center. The similarity methods have been successfully used to indicate a new procedure for preliminary design of hypersonic vehicles and fast tradeoff studies.[32]

The last example indicates a new tendency in collaborative research of Russian and American scientists from universities and industry. Researchers from Rutgers University, Pennsylvania State University and Institute of Theoretical and Applied Mechanics (Novosibirsk, Russia) studied asymmetric crossing-shock-wave/ turbulent-boundary-layer interaction on the flat plate, using unique experimental and theoretical techniques.[33] Scientists from the Worcester Polytechnic Institute and the Central Aero-Hydrodynamics Institute (TsAGI, Zhukovsky, Russia) provided collaborative study of application of new exponential finite-difference schemes[34] in hypersonic aerodynamics and supersonic hydrogen-combustion research.[35] The experimental data of nonequilibrium high-temperature processes in gases of the Martian, Venusian and Earth atmospheres have been studied by researches from the Institute of Mechanics at Moscow State University and the North Carolina State University under Research Grant No. 93-0987-01.[36]

The excellent educational background in fundamental sciences became a key-factor for students in developing new technologies and professional areas, as well as in changing directions of their engineering practice. Many researchers were involved in painful process of Soviet Defense conversion. Several success stories of the conversion have been studied by researchers from the Center for International Security and Arms Control at the Stanford University.[37]

Unfortunately, there is extremely painful time for Russian scientists, Aerospace industry and universities. Russian engineers appeared to agree that poor government financing was ultimately to blame. People of the plant that built the Mars'96 probe had not been paid in three months.[38] In July 1995, a group of Russian scientists stood in a cage next to an orangutan in Moscow Zoo, where they spent a day to draw attention to plight of scientists in Russia.[39] Academician G. Arbatov, the director of the Russian Academy of Sciences' Institute of the United States and Canada, wrote that many Russian specialists work in foreign universities and companies, and "... it is depressing that the nation is bleeding itself dry by depriving itself of an intellectual élite. Science, especially basic research, culture, and public education have become the first victims of reforms."[40]

Industry-University Collaboration

American Universities have a good practice of collaboration with the aerospace industry. For example, "Lockheed has identified universities that emphasize systems integration studies for their high-technology graduates and tends to recruit at those schools."[1] The Center for Turbulence Research[29] operated by Stanford University and NASA Ames Research Center is a research consortium for fundamental study of turbulent flows. The three university's hypersonic research centers[23] supported by NASA have tight bonds with NASA research centers and aerospace companies.

The best Russian technical universities follow the same strategy. But this process of collaboration between industry and educational institutions has specific features.

Let us review the collaborative practice of the Moscow Bauman State Technical University, which is the oldest and most prestigious engineering university in Russia. Among famous graduates and professors of the University (former Imperial Higher Technical College[41]) are the Nobel Prize winners Professors Lebedev and Vavilov, the founders of fluid mechanics Professors Zhukovsky and Chapligin, the prominent Russian aircraft designers Professors Tupolev, Sukhoi, Lavochkin, Myasichev, Petlyakov, Yuriev, the famous Russian space system designers Professors Korolev, Barmin, Pilugin, Chelomei, Pobedonostsev, and numerous Russian cosmonauts.[41] The engineering educational system of the Moscow Imperial Higher Technical College ("the Russian System") was taken by Professor John D. Runkle, the MIT President in 1870-1878, into foundation of the Massachusetts Institute of Technology.

Presently, there are approximately 18,000 students (including 100 international students from 20 countries) and 1,000 post graduates, working on their Ph.D. theses.[42] The University consists of 13 Departments and offers the bachelor, master and Ph.D. degree programs, as well as internship. According to the 1988 Academic Curriculum[41,42] of the major at the Special Mechanical Engineering Department, during the six academic years "a student goes through 3046 hours of lectures, 1124 hours of practical work, 410 hours of labs, 2064 hours of classes, 4 term-papers, 32 exams, 68 tests, 4 industrial practices and, finally, the diploma project (the MS theses)."[42]

The Special Mechanical Engineering Department consists of 12 chairs established and supervised by famous Russian scientists and spacecraft designers. The following research institutions of the Russian Academy of Sciences are affiliated with the University: Institute of Applied Mathematics and Mechanics, Institute of Mechanical Engineering for Energy Industry, Institute of Mechanical Engineering for Special Industry, Institute of Structural Materials and Technology, and Institute of Informatics.

During the first four years, all students are educated in numerous fundamental disciplines.[42] In the last two years of their studies at the Department of Aerospace Engineering, students are trained in R & D of spacecraft and aircraft vehicles, ground testing of spacecraft, autonomous control systems, and applied mathematics. Starting from the second academic year, students actively participate in research projects using the unique facilities of the Russian space company "NPO Mashinostroenie" under the supervision of highly qualified engineers and scientists. All students are registered as company staff and use all benefits. Typically the department graduates are hired by the company as research engineers or by the research institutions, universities, and companies that investigate, develop and manufacture the advanced space systems. The graduates of the Department of Rocketry and Space Engineering are hired by Russian space companies "NPO Energia", CNIIMASH, "NPO Izmeritelnoi Tekhniki", and "NPO Kompozit".[42]

These examples demonstrate that companies are very active in supporting educational process at all levels, especially the last stage of research projects. The most talented staff of the company participates in teaching, consulting, and recruiting the students.

Russian technical universities and research institutions support the process of growing and developing small research groups of students, graduates, engineers and scholars. As an example, a group of five senior students and young research engineers under the supervision of alumni Dr. Dmitri Chuban from the Central Aero-Hydrodynamics Institute designed a unique computer-based multi-purpose calculating system (MARS)[43] to calculate structural strength parameters by the finite-element method. The system is used for calculating a stress-strained state considering temperature stresses, natural modes, and frequencies of trusses, shells, and stiffened aerospace three-dimensional forms in terms of the theory of linear elasticity. Similar groups are formed and successfully work in many Russian aerospace companies.

Conclusion

Education programs in Russian technical universities are different from the programs of the U.S. universities. The precollege students have better mathematical background than American students do. The topics of modern mathematics and physics (including experimental courses) are offered at the freshman/junior years. The students are involved in research projects since sophomore year, and their research activities progressively increase up to the time of graduation. This process is under supervision and consulting from the engineers and researchers of aerospace companies. Usually, the graduates are hired by these companies. The alumni (the company staff) become faculty and supervisors of incoming students.

Collaboration of American and Russian students and faculty can become mutually beneficial in cultural and professional aspects in the future. Under the NASA Educational Programs, it seems to be possible to improve communication links between the Universities, including the development of Advanced Distance Education System for High-School Students, Special Courses in Fundamental and Computer Sciences, and Industrial Experimental Training in collaborative companies.

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