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CHALLENGE IN THE AEROSPACE UNIVERSITY CLASSROOM

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Abstract

Challenging problems and research have been considered as vital components of Aerospace Engineering curricula. Some Engineering, Computer Science, and Math Courses in American colleges have been analyzed to find positive factors that would be helpful in mutually beneficial cooperation between colleges and industry. The analysis of traditional and modern applications of the course concepts [design of a hypersonic vehicle, nonequilibrium thermodynamics, anisotropic media and liquid crystals, properties of Martian atmospheric gases, non-monotone aerodynamic coefficients of simple-shape bodies, etc.] and ways of collaboration between industry and universities have been discussed. Students' "mistakes" have been reviewed allowing to generate new research ideas and numerical algorithms, as well as to discover new physical phenomena. Challenge in the classroom allows motivating students in the analysis of modern engineering concepts, developing strong background and research skills, finding unique solutions of new problems, and preparing students for success and surviving in industrial environment.

Introduction

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] At the same time, the enrollment of freshmen and graduate students with aerospace majors dropped around the country.[3]

The next generation of researchers and engineers are challenged to solve complex problems in hypersonic aeronautics[4], Mars's exploration[5,6], developing International Space Station[7,8] and Space Telecommunication Systems.[9] Many talented young people should be supported in their endeavor to meet this challenge.

In present study, challenging problems, study cases and research have been considered as vital components of Aerospace Engineering curricula. Several traditional and new engineering, computer science, and mathematical courses have been reviewed to develop a new strategy in motivating students in the analysis of modern engineering concepts, developing strong background and research skills.

"Old" ideas have been newly applied in studies of anisotropic media, properties of Martian atmospheric gases, the Magnus effect on rotating bodies in non-continuum flow, the drag reduction, and the absence of the Reynolds analogy between heat flux and skin friction. Sometimes student's jokes and mistakes could generate fruitful discussions of new numerical algorithms, physical results, and applications. Some of these "discoveries" have been studied, i.e. "bagel"-torus aerodynamics, plate-cylinder interference in hypersonic rarefied gas flows, projectile aerothermodynamics, and a fuzzy logic approach in formulating optimum criteria. Abstract group analysis has been applied to find common features in algebra, continuum theory and "classical" artificial intelligence.

Experiments and Physical Concepts of Media

Usually we started aeronautics classes at the University of New Hampshire (UNH) and Worcester Polytechnic Institute (WPI) with a demonstration of excellent films developed by the National Committee for Fluid Mechanics Films (NCFMF). Detailed summaries of the films are contained in Refs. 10-11. Among others, *Eulerian and Lagrangian Descriptions in Fluid Mechanics*, *Deformation of Continuous Media, Flow Visualization, Low-Reynolds-Number Flows, Rarefied Gas Dynamics, Fundamentals of Boundary Layers, Vorticity, Cavitation, Flow Instabilities, Turbulence*[10], and *The Fluid Dynamics of Drag*[11] give a good review of the flow types, and experimental and theoretical approaches.

Students like discussions of different flow types (laminar and turbulent flows, compressible flows, jets, external and internal flows, vorticity and circulation, flow around a wing and blade cascades, cavitation, and

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non-Newtonian fluid flows), which are described in the excellent album of fluid motion by Van Dyke[12], the book of Lugt[13], and in the text of the Japan Society of Mechanical Engineers.[14]After this warming-up students are ready to discuss mathematical models of media.

Mathematical Models for Media

Only few books published more then 25 years ago discuss in detail the mathematical theory of gases, liquids, and plasma (i.e., see Refs. 15-18). Usually these books are recommended for additional reading, but not as major textbooks for the course. Even the texts of Anderson[19-20], Davies[21], Fung[22], and Oosthizen and Carscallen[23] do not consider in detail the kinetic aspects of the media. The authors use a phenomenological approach, which is a traditionally applied in study of Fluid and Gas Dynamics. The approach does not allow describing properly transfer coefficients and some physical phenomena (i.e., multicomponent mass- and thermodiffusion, thermophoresis, etc.).

Mathematical models of gas dynamics are studied in depth primarily in European research literature[24-29] and textbooks[30-33] for students, which are not “popular” among academia in the United States, and are not included into the courses. As a result, only few analytical studies are published by American researchers[34-37] in contrast to the European[38-48] and Japanese[49] schools. A new tendency is a collaboration of American and foreign scientists in this field.[50-52]

Analytical tools include perturbation methods[37] (with applications to studying separated flows,[44,46-48] instability[51], and vortex breakdown[45]), topology studies,[34,38,52] group analyses,[30,32,40-42] attractors,[49] and wavelets.[35-36] These topics only “occasionally” are included into the aerospace university curricula.

Mathematical aspects of engineering fluid mechanics, boundary layers, compressible flow, free surfaces, waves, hydrology, and heat transfer are studied in the book edited by G. A. O. Davies[21]. The book is directed at practitioners who use mathematics to solve problems and explain phenomena in fluid dynamics. This excellent handbook describes the engineering formulation of the problem and mathematical techniques, which would be helpful to solve the problem.

The similar book for future researchers in fluid dynamics is not written yet. The book of Ockendon[30] is addressed to third-year mathematics undergraduates with some of the basic facts about the modeling and analysis of viscous flows (boundary layers, slow viscous flow, thin films, and spatial and temporal complexity). Appendices include a brief introduction to asymptotics and uses of group theory. The book of Ovsyannikov[32] is not yet translated.

Anisotropy and Tensor Analysis

Teaching the Continuum Mechanics course at the University of New Hampshire, I have found that “modern” textbooks (i.e., see Ref. 22) do not cover in depth a tensor analysis approach in studies of anisotropy and global relations (i.e., Newtonian and non-Newtonian stress-strain relationship[25,53-56]). As a result, many fundamental issues would be missed such as isomorphism of transformations,[57-60] multi-component viscosity[58] in liquid crystals,[61] gravitational anisotropy,[62-63] etc. The analytical skills allow students to explore the universal links in depth.

The group properties and isomorphism of transformations are helpful in formulating fundamental equations, in discovery the most significant relations in the medium, as well as in comparison media models. Some applications of these issues have been discussed in the classroom.

Searching for Common Features

Group properties of different mathematical objects would play essential role in searching fundamental laws, similarity principles, criteria, and regularities. The group approach[30,32,40-42] has been successfully used in studies of vortex gas flows,[32,40-41] boundary layers,[64] liquid crystals,[61] and anisotropic continuum media.[40-41]

Pavlov[42] found the correspondences between the basic types of two-dimensional potential flows and groups of continuous transformations that retain the velocity potential and streamline function to be invariant. It was shown that a fully determinate subgroup from the general Lie group corresponds to each class of the potential flows, and the Cauchy-Riemann constraints would be represented by elements of the groups. Some properties of the group of transformations[32,57] are similar to the properties of the algebraic groups.

The fuzzy logic is a successful tool in formulating optimum criteria for aerodynamic performance.[65] Unfortunately, the group properties of the fuzzy logic are not studied yet.

Gas Dynamics and Viscous Fluid Dynamics Courses

The textbook of Oosthuizen and Carscallen[23] was used in my Gas Dynamics course in the University of New Hampshire. Although the topics coverage is not deep in some cases (i.e., Prandtl-Meyer expansion waves, method of characteristics, deflagration), the text is accompanied by free software programs available via the McGraw-Hill Website. A good supplementary material to the course can be found in the books of Anderson[19-20], Liepmann and Roshko[66], Shapiro[67], Hodge and Koenig[68], Thompson[69], and Schlichting[70]. A group of researchers (Parker[71], Korobeinikov[72], Oppenheim and Soloukhin[73], Hayes[74], Zeldovich and Raizer[75], Holt[76], Griffith[77], and Ovsyannikov[32]) considered the physics of explosions, detonation and deflagration waves in detail. This material significantly enriches the topic discussions and students projects.

The books of Sherman[78] and White[79] have been used in my Viscous Fluid Flow and Analytical Fluid Dynamics courses with Worcester Polytechnic Institute and the University of New Hampshire. They are much deeper than the book of Shames[80], which is oriented on average undergraduate students.

The dynamics of ideal fluid has been studied using the Landau-Lifshist[31] approach, which covered the formulation of the Euler and Navier-Strokes equations, discussions of entropy and convection instability, vorticity and complex potentials. The theory of complex potentials is used in studies of the Karman's sheets[10,12,13] using the Kibel-Kochin-Rose technique.[33]

The analysis of creeping flows is made using the perturbation theory of Van Dyke[37]. The similar approach is used in course studies of subsonic and supersonic separation flows,[44-48,51,52] underexpanded viscous jets,[81-85] and flows with suction and gas injection.[86-89]

Hypersonic and High-Temperature Gas Dynamics

Planetary exploration programs (i.e., see a review of Gnoffo[90]) set up new requirements[4] to future engineers and researchers in hypersonic and high-temperature gas dynamics and aircraft design. Only few books[19,91,92] are available for students in this area. The text material should be up-to-dated by adding new chapters, i.e., conservation equations,[93-96] boundary conditions,[97-100] and physical models for hypersonic air,[101-104] carbon dioxide[105] in thermal and chemical nonequilibrium.

New topics would be added to the course studies, such as perspectives on hypersonic viscous flow research,[106] similitude in hypersonic aerodynamics and probe design,[107-110] tendencies in aerospace vehicle design,[111-116] supersonic combustion,[117,87,118] transport phenomena at high temperature conditions,[119-122] and rarefied gas-dynamics research.[123-129]

Among new unusual topics related to space exploration and studies of biological environment, we would recommend the reviews of Skalak,[130] Rand,[131] and Canny.[132]

Computer Projects

Computer projects would be considered as important part of "traditional" courses in applied aerodynamics, gas dynamics, fluid mechanics, hypersonic flows, combustion, and aircraft design. Even the best textbooks in these fields (i.e., Andersen[19,20], Bertin,[91,133] etc.) do not included modern software-based tools as supplements for students and professors. The projects allow developing such tools to predict flow parameters behind normal and oblique shock waves, flows in nozzles and inlets, aerodynamic characteristics of wings and simple-shape bodies for different upstream flow conditions. The software would be effectively used not only for perfect air but for monatomic and chemically reacting gases as well. Students love this challenge. The created tools could be used in their future projects, theses, and engineering practice.

The book of Chow[134] describes numerical techniques and thirty computer programs, which can be used as tools for solving physical problems in fluid mechanics, aerodynamics, ballistics, meteorology, magnetohydrodynamics, and convection. It is also a great example of fruitful collaboration of students, professors, aerospace engineers and researchers in improving the manuscript and programming techniques. Only few more texts of this type are available nowadays (i.e., Sherman[78]).

The book of Ninomiya and Onishi[135] describes simple numerical modeling of fluid flows, using the elementary finite element method. BASIC programs are provided on a diskette, which accompanies the text. The programs will run on standard personal computers and engineering workstations. Numerical solutions can be found for potential flows, transient heat conduction, incompressible viscous flow, thermal fluid flows, mass transport, and tidal current.

Usually texts include a detailed description of numerical algorithms, but do not have computer programs for testing and using in applications. Hirsh[136] studies the mathematical models and discretization algorithms for fluid flow simulations, but does not have programs or references to free software.

The excellent text of Bird[123] becomes not only the bestseller for students and researchers in rarefied gas dynamics, but also provide them with valuable tools in programming (see also Ref. 137).

Some Applications of Course Ideas

A preliminary design of a hypersonic vehicle has become a real challenge for students in my Aircraft Design Class with the Worcester Polytechnic Institute. The developed software tools have been used in predicting vehicle trajectories,[90,106,108] operational envelopes,[138] probe aerothermodynamics,[111,126] enginefuselage configuration solutions,[110] and trust evaluation for supersonic combustion regimes.[117,87]

The nonequilibrium thermodynamics approach has been considered in detail in the classroom. Students have creatively used these skills in studies of real physical processes at high temperatures,[75,94,139,140] as well as in modeling and simulating flow conditions in nozzles, engines, and underexpended jets.[85]

This "tough" way of learning and studying is beneficial for students allowing them to formulate new physical ideas,[85,140] to develop new numerical algorithms[86,141] and applications.[141,142] At the same time, it is a challenge for a professor as well, to be at the modern edge of science and research.

A team of graduate students and researches was asked to study segmented projectile aerodynamics in hypersonic viscous flow. One of the students did a mistake in a body-shape approximation generating the cylinder-plate configuration. After fruitful discussions of plate aerodynamics in hypersonic flow, we made a decision to continue the study. The drag reduction effect and the absence of the Reynolds analogy between heat flux and skin friction were found in the case of a plate located behind a cylinder.[141]

New Applications of "Old" Ideas

Challenge increases in attempts of funding new applications of "old" techniques and concepts, i.e., in formulating nonequilibrium gas dynamics equations and transfer coefficients in polyatomic gases,[140] liquid crystals,[61] and in simulating nonequilibrium physical processes in gases, plasma, and liquids.[87,88,139]

A group of my students has been assigned to develop a preliminary design of unmanned probes for future exploration of Mars. The kinetic theory of gases has been used to formulate transfer coefficients of Martian atmospheric gases at high-temperature conditions. A unique approximation method has been developed allowing significantly (by a factor of 100) reduce the number and time of calculations.[119]

During this program realization, many mistakes and excellent hypotheses were made. One student offered to consider "bagels" for the Martian mission. He tried unsuccessfully to solve the problem using the continuum approach.[141,142] Continuing his efforts, the student analyzed in depth the box schemes for systems of multi-dimensional equations of gas dynamics using the Yanenko-Shokin technique[143] of the group classification. As an alternative, the direct simulation Monte Carlo technique[123,137] has been used to study flow patterns and aerodynamic characteristics of a torus,[144] which is the best fit for a "bagel".

Unusual types of conical shock-wave interference near a torus motivated a new study of shock interactions and a subsonic high-temperature area located far from the body. A new application of the technique has been found in hypersonic-engine inlet aerodynamics.[145]

The medium structure and properties play fundamental role in predicting different flow parameters and aerodynamic characteristics. Non-monotone characteristics of drag, lift, and pitch moment had been found in many studies.[108,110,146] An opposite sign of the Magnus (lift) force on a rotating cylinder in rarefied gas flow has been discovered after in-class discussions of the Magnus effect found in continuum.[147]

New Resources for Aerospace Education

The Web and Internet have allowed the access to many free resources. The NETLIB[148] can provide students with free software written in C/C++, FORTRAN, ADA for solving CFD problems related to their projects. The two-dimensional Navier-Stokes equations can be numerically solved by the CFD Program NaSt2D free C-code associated to the book of Griebel, Dornseifer, and Neunhoeffer.[149] The DS2G program,[137] which is in public domain, can be successfully used by students and researches in simulating two dimensional flows of rarefied gas. The program is a valuable supplement to the excellent textbook of Bird.[123] Some sort of Aerospace Free Software repository should be created to support the aeronautics education programs and aerospace community. The NASA Centers have promoted some computer programs as well.

The designed Aerospace Education Repository would include the old out-of-print books, which could be put on the CD-ROM as our professional treasure, as well as supplement materials, video films, and free software. After the copyright agreements, this stuff would be used on the Web. These materials would be used not only in the classroom, but in the distance education as well. The free access (or covered by the AIAA membership fee) to this repository would become a significant contribution of authors, researchers, and publishers into the development of the aerospace education and specialists in Aeronautical Sciences. Also this type of activities increase a level of collaboration between universities, companies, NASA Research Centers, and professional public organizations, such as AIAA, ASME, ACM, etc. These new resources would help students, faculty, engineers, and researchers to meet challenges of the aerospace era.

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