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The Teaching of Gas Dynamics in the National University of Cordoba - UNC

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ABSTRACT: This paper presents the teaching and research activities carried out at the National University of Cordoba (UNC) on issues directly related to Gas Dynamics. Currently, this University offers three courses on this subject: Gas Dynamics I, Gas Dynamics II and Advanced Gas Dynamics. The first two correspond to undergraduate studies, while the third to graduate studies. Gas Dynamics I is a required subject for all Aeronautical Engineering students at UNC, and represents the most advanced degree course within the area of Fluid Mechanics taught at the Department of Aeronautics. While Gas Dynamics II is an elective course that is only taken by students who are interested in deepening concepts in compressible flows. On the other hand, Advanced Gas Dynamics is a valid course for the Aerospace Master's Degree and the Doctorate in Engineering Sciences. In addition, the growth in activity at the UNC in recent years stands out, both in the number of professors trained in the area, as well as in the number of Undergraduate, Master and Doctoral Theses and in the number of research projects.

KEYWORDS: Gas-dynamics, Aeronautical Engineering, Engineer Education.

I. HISTORICAL REVIEW

The word *gas* was proposed by the Dutch physician Jan Baptist Van Helmont (1579-1644) in the 17th century. Before him, the words *vapors* and/or *spirits* were used. Van Helmont considered that gases were made up of invisible particles that move in all directions and that they were the image of chaos, as opposed to order. From the Latin word *chaos*, he derived the name *gas* [1].Galileo (1564-1642) was the first to establish that a denser fluid generates greater resistance to the movement of an object immersed in it. Descartes (1596-1650), Huygens (1629-1695), Carnot (1796-1835), and others developed this idea and expanded it by specifying that the same fluid can generate different resistance to the advance of the same body immersed in it. However, the idea remained for a long time without a full understanding. Then, Augustin Louis Cauchy (1789-1857) and Pierre-Simon de Laplace (1749-1827) worked on the problem and emphasized that their equations were valid only for incompressible media, probably indicating that they inferred the concept of compressibility in Fluid Mechanics [2].Leonhard Euler (1707-1783) and mainly Joseph Louis de Lagrange (1736-1813) worked, with relative success, to establish relationships between pressure and density. Euler extended the concepts of Newton's Second Law to Fluid Mechanics, giving rise to Eulerian acceleration, to the equations for non-viscous fluids (currently Euler's equations). However, it was Lagrange who realized the need to use the equations of continuity and state to allow the integration of the equations of motion proposed by Euler. Lagrange was the first to realize that Euler's equations can be solved in two situations: i) potential flow (irrotational); ii) non-potential steady flow (rotational). Furthermore, the well-known Bernoulli Equation was first obtained by Lagrange as an integral form of the Euler equation of motion. On the other hand, Lagrange introduced the derivative that bears his name that allows to follow the evolution of an elemental volume (particle) of fluid. It could be said that Euler and Lagrange are the founders of Fluid Mechanics as a physical-mathematical science.

Pierre-Henry Hugoniot (1851-1887) was the one who fulfilled the role of integrator of the foundational knowledge for compressible fluids flow. He was also able to establish a correct description of the speed of sound considering isentropic flow. Laplace proposed the equation $a = dp/d\rho$ for the speed of sound, while Sir Isaac Newton (1642-1727) tried to express the speed of sound considering an isothermal relationship, p/ρ = constant, but found that $a \approx 280$ m/s. Hugoniot established mathematically that the speed of sound can be derived from the Laplace expression considering isentropic conditions for its propagation [3].The Austrian physicist Ernest Mach (1838-1916) was the first to establish that the compressibility effects in a gas depend on the relation between speed and speed of sound v/a, and not on the speed directly. He also introduced the Schlieren technique for the study of shock waves. The Schlieren technique was developed by the German physicist August Joseph Ignaz Töpler (1836-1912) for research in acoustics. However, the

Swiss aeronautical engineer Jakob Ackeret (1898-1981) was the one who discovered that the *v*/*a* ratio is an important dimensionless quantity in gas flows and called it Mach number in honor of the Austrian physicist and philosopher [2]. Through the creation of the Military Aircraft Factory in 1927 [4] and the National Space Research Commission (Commission National de Investigations Specials - CNIE) in 1960 [5], the activities of design, development and production directly related to the aeronautical and space engineering in Argentina initiated. This gave rise to the need for the training of aeronautical engineers in the country and the development of the teaching of Fluid Mechanics.In this article we want to analyze some experiences and advances in the teaching of gas dynamics at the National University of Córdoba in recent years.

II. INTRODUCTION

At the National University of Cordoba there are currently three courses directly related to the subject of gas dynamics. These are Gas Dynamics I (GDI), Gas Dynamics II (GDII) and Advanced Gas Dynamics (AGD). The first two correspond to undergraduate courses, while AGD is a graduate one which is valid for the Master of Engineering Sciences - Aerospace Mention and for the Doctorate in Engineering Sciences.GDI is a required course of the Aeronautical Engineering curriculum and should be taken at the 7th semester of this degree. On the other hand, GDII is an elective course of the 10th semester. It is highlighted that the 10th semester is the last one in which subjects could be taken for the Aeronautical Engineering degree. After that, the students have other activities such as Supervised Professional Practices and the Degree Thesis.GDII and AGD are courses with similar contents, but with different evaluations according to the degree it corresponds to. In this way, the subject collaborates for an orderly transition between undergraduate and graduate studies.

III. GAS DYNAMICS I

The Gas Dynamics I course is part of the applied technologies block of the Aeronautical Engineering degree. This one is the last of the required subjects related to the study of Fluid Mechanics. To enroll, the student must have previously approved the Fluid Mechanics course, and it is also recommended to have taken Mathematical Analysis III. The course is composed of two parts. The first presents the physical foundations for the flow of stationary one-dimensional compressible gases, that is, the resulting equations depend only on one independent variable. The effects of area variation in the length of ducts, friction, and heat injection or extraction are considered at this stage. In the second part, the concepts for more complex compressible flows such as unsteady one-dimensional flow and steady two-dimensional flow are developed. In these flows, the equations have two independent variables.Both parts of this course present applications to characteristic cases such as gas flows in ducts, wind tunnels, nozzles, diffusers, and wing profiles. A laboratory activity is also carried out in the supersonic wind tunnel (the only one currently functional in the country), which allows reinforcing the theoretical concepts learned. Also, the curse has student group presentations about scientific and technological applications of compressive flows.

Objectives and activities: The objective of this course is to present the basic physical concepts, the mathematical theoretical structure, and the analytical methods necessary to describe the behavior of gases in internal and external compressible flow applications. The aim is to train students to solve practical problems in which the compressibility of the gas is decisive in finding the solution. On the other hand, it is desired to provide the student with a training level that facilitates his incorporation into work groups dedicated to research and industrial application in specialty areas such as the design of nozzles, diffusers, supersonic wing profiles, flow in ducts, etc.To achieve this objective, the teaching methodology is proposed within the framework of exposition classes and the realization of a laboratory activity that takes place at the end of the course. Classes are not formally divided into theoretical and practical but, as each topic is treated, there is an interaction in the format of a dialogued interchange of experiences where the teacher guides the students to carry out deductive analyzes and thus be able to find solutions to problems raised by applying the theoretical concepts previously developed. The classes have mainly an expository nature, where the teacher presents the definitions, concepts and mathematical formulations using the projection of slides, videos, blackboard, books, and manuals. During these sessions, it is sought to give prominence to the deductive method (from the general to the particular). It is also about ensuring that the classes, due to their content and type of dictation, stimulate the active participation of students. To develop the ability to model and solve problems, students have a set of standard problems that are solved in class under the teacher's supervision.

Performance indicators: To meet the proposed objective, the performance indicators detailed below were defined:

1. Understand the basic physical and mathematical concepts that are necessary to describe the movement of gases. For this it is crucial to describe the fundamental physical characteristics for compressible flows. It is also necessary to know and interpret the valid equations, identifying the limitations imposed by the simplifying hypotheses applied in each case.
2. Train the student to solve problems in which the compressibility of the gas is a determining factor in the solution. This implies raising the valid hypotheses with the physics of the problem to be solved by correctly applying the appropriate equations.
3. Acquire a training level that facilitates incorporation into work groups dedicated to research and industrial application in specialty areas. This is achieved by working as a group in the preparation and presentation of an exhibition on aerospace engineering topics directly related to the course subjects. This seeks to develop critical analysis and analytical criteria on the approach and solution of problems related to the flow of compressible gases.

Evaluation: The evaluation system is designed in such a way that the student demonstrates that he has acquired the necessary basic knowledge on all the fundamental topics of the subject. This system consists of two theoretical-practical written exams throughout the semester, an oral presentation on an application of a topic of interest related to compressive flows in aerospace engineering and a final oral colloquium. The theoretical-practical written evaluations must be solved individually. Each of them includes at least three practical exercises and a set of conceptual questions. To carry out the evaluation of the practical part, students can have books, manuals, notes, and the didactic material of the subject. Only one of these evaluations can be taken again as a substitute exam. The oral presentation on a topic of interest in aerospace engineering is a group activity. Each work group, made up of a maximum of three students, must present a research on a topic of their choice.At the end of the semester, an integrative colloquium is held on the general content of the course for those students who did not perform satisfactorily during the two written evaluations and oral presentation.

Competences to which the subject contributes: The current trend in higher education is to provide students with skills that allow them to develop the application of the knowledge acquired. The study of gas dynamics enables the student to calculate, design, project and analyze the performance and operation in different conditions of aircraft and space vehicles as well as jet propulsion plants, combustion chambers, compressors, internal combustion engines, and gas turbines, and propellers in general.

2020 exceptional situation: In the aforementioned year, the Gas Dynamics I course had to be taught in remote mode. This was due to the sanitary measures adopted by the National University of Córdoba (Rectoral Resolutions n° 334/20 and 447/20) in accordance with the decrees of necessity and urgency issued by the National Executive Power of the Argentine Republic. The measures attended the public emergency in health matters that the national and international community went through due to the COVID-19 pandemic. Although the academic activity of the first semester of 2020 began with in-class teaching as usual, from the third week of march all activities foreseen in the academic calendar were migrated to be taken virtually via distance learning due to the need to comply with preventive and compulsory social isolation. This exceptional situation affected the regulations on instances of studying and evaluating students, so it was necessary to adapt them to the conditions set forth in the current teaching regimes.

It should be noted that this course is taken by all aeronautical engineers graduated from the UNC, therefore, to improve the teaching-learning process, the professors of the chair have written three books that are used as the fundamental bibliography of the course [6, 7, 8].

IV. GAS DYNAMICS II

The Gas Dynamics II course corresponds to the tenth semester of the Aeronautical Engineering degree of the Faculty of Exact, Physical and Natural Sciences. This course is within the basic technologies block and is constituted as the last of the Fluid Mechanics subjects taught in the Aeronautical Engineering degree. Its fundamental purpose is to advance the physical and mathematical concepts of gas dynamics. The course is elective and the students who attend have a special inclination towards fluid and gas mechanics. The course introduces a greater emphasis on the mathematical formulation of Gas Dynamics and introduces physical and mathematical concepts of Magnetogasdynamics. In addition, it is desired to transmit in Gas Dynamics II the work methodology in research and development in compressible aerospace flows. The teaching emphasis is placed on developing the student's ability to analyze and use concepts to apply them properly.

The course contents can be divided into three groups:

1. Review of concepts: vectors, tensors, fluid dynamics, constitutive equations, equations of conservation of mass, momentum, and energy. The following books are used for dictation [9,10].
2. Systems of differential equations in hyperbolic partial derivatives. Analysis of Euler's equations. Riemann gas dynamic problem. Godunov schemes. The fundamental book used is [11], but texts such as [12,13] are also used.
3. Equations of magnetogasdynamics. Magnetogasdynamics Riemann problem. It is used as support texts [14,15].

Objectives:

- Present the physical-mathematical concepts involved in the time-dependent equations of Gas Dynamics (GD) and Magnetogasdynamics (MGD).
- Train the students to find solutions of the GD and MGD equations with high resolution methods.
- Enable the students to acquire a training level that facilitates their incorporation into groups of work dedicated to research and industrial application in specialty areas.

Activities and methodology: The classes have mainly the same structure that those of Gas Dynamics I. The dictation structure of the course consists of a weekly class. In addition, teachers establish a consultation schedule outside of formal class hours, which has an appropriate length depending on the number of students enrolled.The teacher will explain to the students how the content of the topics in this subject is related to the knowledge taught in the other subjects of their study plan in order to articulate the new skills to those already acquired. This seeks to form an aerospace awareness in the professional, giving them the ability to interpret the phenomenology of the activity.

Evaluation: The evaluation system is designed in such a way that the student must show that he has acquired the minimum necessary knowledge of all the fundamental topics of the subject. It consists in the preparation of a portfolio of practical works, a final integrative theoretical-practical exam and two integrative projects that involve computational code programming. The portfolio can be prepared jointly, but the final exam and the two integrating projects must be solved individually. This exam includes practical exercises and theoretical questions. To carry out the evaluation of the practical part, the students can use books, manuals, notes, and didactic material related to the subject.

V. ADVANCED GAS DYNAMICS

This course is within the set of courses corresponding to Fluid Mechanics for graduate studies within the aerospace area. It is taught simultaneously with Gas Dynamics II, therefore the thematic contents, the bibliography used, and the structure of the course is the same. It is highlighted that the simultaneous dictation of both courses has a didactic-pedagogical objective to coordinate activities between undergraduate and graduate activities, facilitating the incorporation of new master's and doctoral students.It is expected that the applied methodology will develop in the student the competences for the following objectives:

- Understand the physical-mathematical concepts involved in the time-dependent equations of Gas Dynamics and Magnetogasdynamics.
- Describe the fundamental mathematical properties of compressible gas dynamic and magnetogasdynamic flows.
- To mathematically describe the fundamental phenomena of the one-dimensional flow of gases and magnetogasdynamics dependent on time.
- Train to solve problems in which the compressibility of the gas is a determining factor in the solution.
- Make valid hypotheses with the physics of the problem that the solution is sought.
- Correctly apply and manipulate the necessary and appropriate equations for problem solving.
- Acquire a training level that facilitates incorporation into work groups dedicated to research and industrial application in specialty areas.
- Develop critical analysis and analytical criteria on posing and solving problems related to the flow of gases.

In addition, it seeks that the graduation student acquires character competencies on one hand attitudinal, such as the fulfillment of responsibilities and obligations and having active participation in practical activities, and on the other aptitude, such as the identification of problems and the organization of time and tasks.

Evaluation: The evaluation system is designed in such a way that the graduation students must show that they have acquired the minimum necessary knowledge of all the fundamental topics of the subject. It consists of the preparation of a portfolio of practical works, a final integrative theoretical-practical exam and two integrative projects that involve software developments for solving Riemann problems and Godunov schemes. The portfolio can be prepared jointly, but the final exam and the two integrating projects must be solved individually. This exam includes practical exercises and theoretical questions. To carry out the evaluation of the practical part, the students can use books, manuals, notes and didactic material related to the subject.

VI. PROFESSORS AND STAFF MEMBERS

The Gas Dynamics Chair in the FCEFyN Aeronautical Department in the last ten years were composed by the following professors and staff members:

- Dr. José Tamagno is an Aeronautical Engineer graduated from the National University of Córdoba and PhD in Aeronautics and Astronautics from the New York Polytechnic Institute. He used to be the Head of Fluid Mechanics II, Aerodynamics, Gas Dynamics I, and Gas Dynamics II Chairs at UNC. Dr. Tamagno was one of the founders and the first Director of the Master of Science in Engineering - Aerospace Mention (UNC), was also Director of the Flight Physics Department of the Military Aircraft Factory in Córdoba and Principal Scientist at the General Applied Science Lab. Inc. Company in New York. He is currently Professor Emeritus and advisor of the aforementioned Master of Science in Engineering - Aerospace Mention Board of Directors.
- Dr. Sergio Elaskar is an Aeronautical Mechanical Engineer and Doctor in Engineering Sciences from the National University of Cordoba, who has been the Head of Gas Dynamics I, II and Advanced Gas Dynamics Chairs since 2005. He has also obtained the title of Doctor in Aerospace Engineering at the Polytechnic University of Madrid (UPM, Spain). Dr. Elaskar has accomplished post-doctoral studies at the UNC, at the Aeronautical University Institute (IUA, Argentina) and at the UPM. He is currently Full Professor at the UNC, Principal Investigator at CONICET (Argentina) and Category I Investigator of the Incentive National Program (Argentina). Dr. Elaskar is the Director of the Institute for Advanced Studies in Engineering and Technology (CONICET and UNC) and Director of the Doctorate in Engineering Sciences at UNC. He has published around 300 scientific-technical papers both in journals and in conferences, is the author of 5 books and has given numerous lectures at international congresses and foreign universities. He has received awards nationally and abroad. Dr. Elaskar is currently collaborating with researchers from the UPM in Spain, the University of Pau et des Pays de l'Adour and the CNRS in France.
- Dr. Walkiria Schulz is an Astronomer from the Federal University of Rio de Janeiro (UFRJ, Brazil), Master and Doctor in Space Engineering and Technology from the National Institute of Space Research (INPE, Brazil). She has a Specialization in Theory and Practice of Scientific Disclosure from the University of São Paulo (USP, Brazil). Dr. Schulz is currently an Associate Professor at UNC and has taken part in the Gas Dynamics I Chair since 2006. She is the Director of the Master of Science in Engineering - Aerospace Mention (UNC). Her research interests are in orbital dynamics of satellites: trajectories, orbits, and maneuvers, specially maneuvers inside the atmosphere. Dr. Schulz has been a pioneer in Argentina in the study of the dynamics of space debris. In her professional career she has worked in the satellite control group at the Brazilian Telecommunications Company (Empresa Brasileira de Telecomunicações - EMBRATEL), the Institute of Aeronautics and Space (Instituto de Aeronáutica e Espaço - IAE, Brazil), the German Center for Aerospace Research (Deutschen Zentrum für Luft und Raumfahrt - DLR, Germany), the National Commission for Space Activities (CONAE, Argentina), and the Department of Aerospace Engineering Sciences of the University of Colorado at Boulder (CU, USA). In 2006 she was awarded the Wagner Session Award in Orbital Dynamics and Control modality conferred by the Judging Commission of the XIII Colóquio Brasileiro de Dinâmica Orbital in recognition for her notorious scientific-technological contributions as a young scientist.
- Prof. Guillermo Cid is a Mechanical and Aeronautical Engineer from the National University of Cordoba. Adjunct Professor of the Gas Dynamics I Chair at UNC since 1992 and Head of Aircraft Maintenance Chair since 2009. He has been the Director of the Aeronautical Department since 2019. Prof. Cid has a Specialization in Airport in the Transport System from the Polytechnic University of Madrid (UPM, Spain), and Aircraft and Aeronautical Products Certification from National Administration of Civil Aviation of Argentina (ANAC). In his professional career, Prof. Cid was Aircraft Maintenance Manager at Lockheed Martin S.A. for more than twenty years. He has worked also in the CBA 123 19 pax aircraft project at Embraer (Brazil) and in the IA 63 advanced training jet project at the Military Aircraft Factory in Cordoba as aerodynamic specialist.

- Dr. Luis Felipe Gutiérrez Marcantoni is an Aeronautical Engineer from Los Libertadores University (UL, Colombia), and has also obtained degrees of Doctor of Engineering Sciences and Master of Engineering Sciences - Aerospace Mention from the National University of Córdoba (UNC). Dr. Gutierrez has done postdoctoral studies, and is currently an Adjunct Professor at the UNC, where he participates in the Fluid Mechanics and Gas Dynamics I Chairs. He is an Adjunct Professor and Head of the Fluid Mechanics Chair at the Catholic University of Cordoba, as well as the Research Director in this University. He has published around 25 articles in international magazines and conferences.
- Dr. Andrea Costa has a degree and a PhD in Physics from the University of Buenos Aires (UBA). She has carried out research stays at the following scientific research institutions: ICTP (Italy), ICN-UNAM (Mexico), IAS-CNRS (France), and University of the Republic (Uruguay). Dr. Costa has been an Associate Professor at the UNC, and an Adjunct Professor at the UBA (Faculty of Exact and Natural Sciences and Faculty of Philosophy and Letters). She is a Principal Investigator (CONICET) and Category I Researcher of the Incentive National Program (Argentina). Dr. Costa was the Director of the Institute of Theoretical and Experimental Astronomy (CONICET) at Cordoba. She has directed a program of the Ministry of Education and Culture of the Nation and has been a consultant for the Curricula Directorate of the Government of the City of Buenos Aires. In her prolific professional activity, she has published about 100 articles in research journals, is the author of 3 books, has given numerous conferences in international congresses, and has been a visiting professor at different universities in the country and abroad to teach courses in Magnetogasdynamics, her specialty. Dr. Costa has retired as Associate Professor of the Gas Dynamics I and II Chairs at UNC in 2018.
- Dr. Denis Lorenzón is an Aeronautical Engineer and Doctor of Engineering Sciences from UNC. He is currently an Adjunct Professor of Gas Dynamics I Chair at the UNC and a Postdoctoral Fellow of the National Council for Scientific and Technical Research (CONICET). Dr. Lorenzón has published around 15 scientific-technical papers in journals and congresses and has participated in a variety of research projects. He has received awards from the UNC for his academic performance.
- Dr. Gustavo Krause is an Aeronautical Engineer graduated from the Faculty of Exact, Physical and Natural Sciences of the National University of Córdoba, where he also obtained a master's degree with Aerospace Mention and a Doctorate in Engineering Sciences. He currently works as Adjunct Professor at that institution and as Assistant Researcher at the National Council for Scientific and Technical Research (CONICET). In his work as a researcher he has published more than 25 articles in specialized journals and conferences.

VII. EXPERIMENTAL FACILITIES

The Laboratory of Aeronautics Eng. Teobaldo Luis Aguirre of the FCEFyN (UNC) provides the following facility to the Gas Dynamics teachers and students: a supersonic tunnel with Schlieren visualization system (Fig. 1). This is a tunnel for educational use that was designed and built with a very low budget by teachers and students of the Department of Aeronautics at UNC [16] - [17]. In this tunnel it is possible to have supersonic flow visualization as it has a 15mm x 45mm x 55mm test chamber and it is obtained Mach 1.9. Figures 2 and 3 are Schlieren views with attached and detached shock waves.

VIII. RESEARCH ACTIVITIES

Research projects developed by the Gas Dynamics staff in the last five years are organized per start year in the following list with the respective publications:

1. Dr. S. Elaskar, Dr. J. Tamagno, "Theoretical and Numerical Studies of Aerospace Fluid Dynamic and Magnetogasdynamic Phenomena," SECyT-UNC, 2010–2012 [18-41].
2. Dr. S. Elaskar, Dr. J. Tamagno, "Theoretical and Numerical Studies of High Enthalpy Dynamic Gas Flows," SECyT-UNC, 2013–2014 [42-51].
3. Dr. S. Elaskar, Dr. J. Tamagno, Dr. L.F. Gutiérrez Marcantoni, "Development and application of theoretical, numerical studies and computational codes in gas dynamics for aerospace engineering," SECyT-UNC, 2014–2015 [52-57].
4. Dr. W. Schulz, Prof. G. Cid, "Evaluation of the risks associated with the impact of hypervelocity particles on nano-satellites," SECyT-UNC, 2014-2015.
5. Dr. A. Costa, Dr. S. Elaskar, "Theoretical-numerical study of compressible astrophysical flows and their comparison with observations," CONICET-PIP, 2014-2017 [58-62].

6. Dr. S. Elaskar, Dr. L. Gutiérrez Marcantoni, Dr. D. Lorenzón, Dr. J. Tamagno, “Development and application of theoretical, numerical tools and computational codes in gas dynamics for aeronautical engineering,” Ministry of Science and Technology, Córdoba Province, 2014–2016 [52-55], [59], [63]-[68].
7. Dr. L. Conde (UPM, Spain), Dr. S. Elaskar, “Development and characterization of a hybrid system of space propulsion by plasma of low electrical consumption,” Ministry of Science and Technology of Spain, 2014-2018.

Figure 1. Supersonic tunnel.

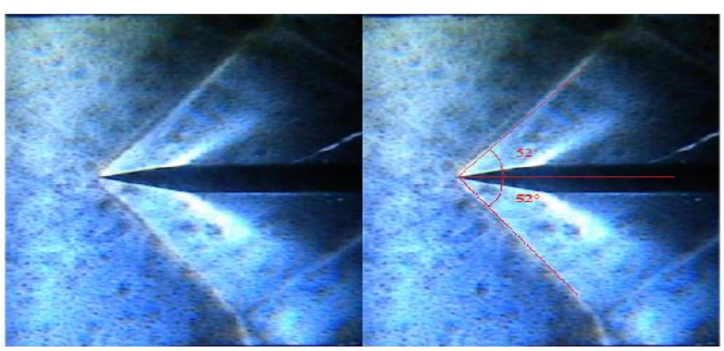

Figure 2. Sharp profile shock wave visualization at M = 1.8.

8. Dr. S. Elaskar, Dr. J. Tamagno, Dr. L.F. Gutiérrez Marcantoni, Dr. D. Lorenzón, "Development and Application of Theoretical, Numerical Studies and Computational Codes in Gas Dynamics and Chaotic Intermittency," SECyT-UNC, 2016–2017 [59], [63-74].
9. Dr. W. Schulz and Prof. G. Cid. "Study of hypervelocity particle impacts on satellites in re-entry situations," SECyT-UNC, 2016-2017 [75-76].

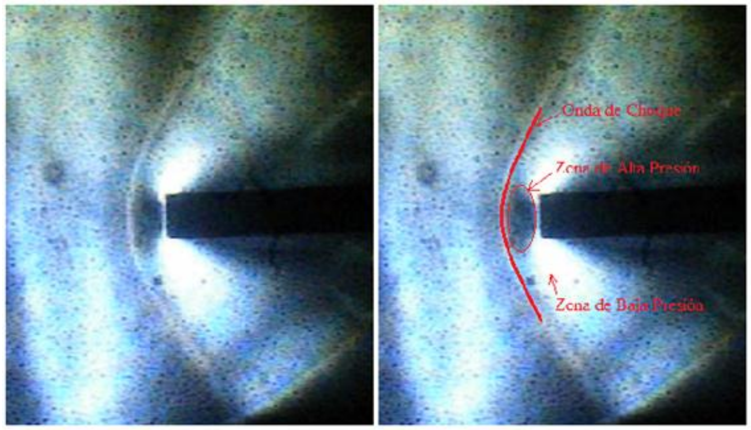

Figure 3. Detached shock wave visualization at $M = 1.8$.

10. Dr. S. Elaskar, Dr. L. Gutiérrez Marcantoni, "Vulnerability of infrastructure and physical environment associated with storage and transport of combustible fluids," CONICET-PUE, 2016–2021 [65-69], [73-74], [77-87].
11. Dr. S. Elaskar, Dr. P. Bruel (CNRS, France), Dr. L. Gutiérrez Marcantoni, "Experimental numerical study of wind flow around liquid fuel storage tanks," ECO Sud (France) and MINCyT (Argentina), 2017-2020 [77-87].
12. Dr. W. Schulz, "Resilience in aerospace missions: development of numerical tools for improvement," SECyT-UNC, 2018-2021 [88].
13. Dr. S. Elaskar, Dr. L.F. Gutiérrez Marcantoni, Dr. J. Tamagno, "Development and application of theoretical, numerical, experimental studies and computational codes in fluid mechanics and chaotic intermittency," SECyT-UNC, 2018–2022 [79-87], [89-100].
14. Dr. S. Elaskar, Dr. L.F. Gutierrez Marcantoni, Dr. J. Tamagno, "Study of the structural vulnerability of fuel storage tanks and pipelines due to wind-generated loads and explosions," MINCyT-PICT-2017, 2018–2022 [80]-[87].
15. Dr. S. Elaskar, Dr. P. Bruel (CNRS, France) "Etude numérique et expérimentale de l'écoulement du vent autour de réservoirs de combustible liquid," ECO Sud (France) and MINCyT (Argentina), 2018-2021 [80]-[87].

IX. THESIS

Undergraduate thesis presented:

1. J. J. Saavedra Laureano, "Computational Models of Subsystems for Orbit and Attitude Determination and Thermal Behavior for a LEO Satellite," 2020. Advisor: Dr. W. Schulz.
2. R. Fernandez Frittelli and M. Jandar Paz, "Space mission pre-design to mitigate asteroid impact threat with the Earth," 2019. Advisor: Dr. W. Schulz.
3. C. Hernandez and A. Albertin, "Alteration proposal for a civil general aviation aircraft. Bases for obtaining CTS," 2019. Advisor: Prof. G. Cid.
4. L. Monaldi, "Analysis of the flow around aerodynamic profiles in subsonic, transonic and supersonic regimes using ANSYS Fluent," 2019. Advisor: Dr. S. Elaskar.
5. L. Gonzalez, "MECA (Cordoba Argentina Space Modeling)," 2019. Advisor: Dr. W. Schulz.
6. M. Dagaro, "Design and construction of a two-dimensional supersonic wind tunnel," 2017. Advisors: Prof. J. García and Dr. D. Lorenzón.
7. F. Nasca and C. Paccioretti, "Visualization of Compressibility Effects of an Air Stream at Supersonic Velocity by the Schlieren Method," 2016. Advisors: Prof. J. García and Dr. L. Gutiérrez Marcantoni.

8. M. Fiore, “Simulation of supersonic flows around a diamond airfoil with OpenFOAM,” 2017. Advisor: Dr. L. Gutiérrez Marcantoni.
9. E. Gerez, “Enabling an aeronautical repair workshop,” 2015. Advisor: G. Cid.
10. F. Sahade, “Prediction of Acoustic Loads in the Launch of a Space Vehicle,” 2015. Advisor: Dr. S. Elaskar.
11. M. J. Alvarez, “Analysis of the aircraft maintenance process for the detection of improvement opportunities,” 2015. Avisor: Prof. G. Cid.
12. D. Lorenzón, “Simulation using OpenFOAM of the supersonic flow around conical bodies and vectors,” 2014. Advisor: Dr. S. Elaskar.
13. A. Mel, “Simulation by means of the Lattice Boltzmann method of turbulent incompressible flows,” 2014. Advisor: Dr. S. Elaskar.
14. L. Moreschi, “Simulation of the reentry trajectory of the Delta rocket stage dropped in Corrientes,” 2013. Advisor: Dr. W. Schulz.
15. E. Bauer Espitia, “Dynamics of Space Objects with High Area/Mass Ratio in Earth Eccentric Orbits,” 2013. Advisor: Dr. W. Schulz.
16. J. P. Matar, “Orbital decay of objects in orbits of great eccentricity submitted to drag action caused by a symmetrical, spherical and rotating with constant angular velocity Earth atmosphere,” 2011. Advisor: Dr. W. Schulz.
17. A. Cimino, “Numerical study of the reentry of conical bodies in the atmosphere,” 2010. Advisor: Dr. S. Elaskar.
18. V. Tur, “Pre-design analysis of a Ludwieg type supersonic tunnel,” 2010. Advisors: Dr. J. Tamagno and Dr. S. Elaskar.

Master’s thesis presented:

1. E. Gomez, “Optimization of Teflon ablative pulsing plasma propellants using genetic-type evolutionary algorithms,” 2018. Advisor: Dr. S. Elaskar.
2. D. Antonelli, “Stationary and nonstationary analysis of aerodynamic profiles to ultra-low Reynolds numbers (Re < 10000),” 2015. Advisor: Dr. J. Tamagno.
3. L. F. Gutiérrez Marcantoni, “Simulation of Compressible Flows with OpenFOAM,” 2013. Advisors: Dr. J. Tamagno and Dr. S. Elaskar.
4. C. Fernández, “Theoretical and numerical study of the dynamics and stability of solar magnetic arcs,” 2013. Advisors: Dr. A. Costa and Dr. S. Elaskar.
5. J. Saldía, “Numerical simulation of non-viscous high enthalpy flows considering gas in thermochemical equilibrium,” 2012. Advisors: Dr. S. Elaskar and Dr. J. Tamagno.
6. G. Krause, “Theoretical and numerical study of the DNLS equation,” 2011. Advisor: Dr. S. Elaskar.

Doctoral thesis presented:

1. G. Corrado, “Orbital dynamics, attitude, and control of space vehicles with compound solar sails,” 2020. Advisor: Dr. W. Schulz.
2. D. Lorenzón, “Numerical simulations of plasma kinetics using the Vlasov-Poisson model,” 2020. Advisor: Dr. S. Elaskar.
3. D. Antonelli, “Stationary and stationary analysis of rigid and flexible aerodynamic profiles at ultra-low Reynolds numbers (RE <10000),” 2016. Advisor: Dr. J. Tamagno.
4. L. F. Gutiérrez Marcantoni, “Numerical simulation of reactive processes in gas mixtures with multiple compressible flow components with OpenFOAM,” 2016. Advisors: Dr. J. Tamagno and Dr. S. Elaskar.
5. A. Cimino, “Characteristic based boundary conditions for gasdynamic and magnetohydrodynamic equations. Application to the dynamics of the magnetic arcs of the solar corona,” 2015. Advisors: Dr. A. Costa and Dr. S. Elaskar.
6. C. Francile, “Development of data processing algorithms for analysis and automatic detection of oscillatory phenomena in images of the chromosphere and solar corona. Application to HASTA and MICA telescopes,” 2015. Advisors: Dr. A. Costa and Dr. S. Elaskar.
7. J.Saldía, “Design and development of a high-performance code for the numerical simulation of reactive hypersonic flows,” 2015. Advisor: Dr. S. Elaskar.
8. G. Krause, “Theoretical and Numerical Analysis of Attractors and Intermittency in the DNLS Equation,” 2014. Advisor: Dr. S. Elaskar.

9. L. Maglione, "Studies and Applications in Computational Magnetogasdynamics," 2011. Advisors: Dr. S. Elaskar and Dr. A. Costa.

X. STATISTICS

The statistics of students that attended and approved the courses Gas Dynamics I and II are briefly presented. It should be noted that, as explained above, Gas Dynamics I is required for all Aeronautical Engineering students at the National University of Cordoba, while Gas Dynamics II is optional, and is taken only by students interested in deepening concepts about compressible and supersonic flows. Table 1 shows the statistics corresponding to the course of Gas Dynamics I, covering the years 2013-2019. The first column indicates the students enrolled at the beginning of the course, the second the percentage of students who have approved the subject, the third the percentage of students who have dropped out during the attending, and finally the fourth column the percentage who have not passed despite having carried out all the established evaluations. It is highlighted from Table 1 that the percentage of students who have passed the course from 2013 to 2019 is around 71%, that means approximately 30% of the enrolled students have not finished the course properly. Regarding Gas Dynamics II, from 2014 to 2019, 20 students have enrolled, of which only 9 of them have passed the course that represents 45% of the enrolled students. In addition, it must be taken into consideration that Gas Dynamics II is issued every other year, so from 2014 to 2019 it was issued only three times. Therefore, another parameter that may be of interest is that during these six years, the average enrollment per course is 6.67 students, but if we consider the average per year it is only 3.33 students. The difference in the approval percentage between Gas Dynamics I and II may be due to various causes or origins. The first is that Gas Dynamics I is a more structured course with greater educational follow-up to students. A second factor is that Gas Dynamics II has a greater mathematical depth that makes learning more difficult. A third factor to consider is that since Gas Dynamics II is an elective course, some students enroll, but can choose another course without the obligation to finish the gas one.

	Gas Dynamics I			
	Students	Passed	Incomplete	Failed
2019	31	67%	33%	0%
2018	15	47%	53%	0%
2017	20	70%	17%	13%
2016	20	81%	19%	0%
2015	29	79%	15%	6%
2014	24	74%	13%	13%
2013	27	80%	20%	0%
Total	166	71%	24%	5%

Table 1. Statistics for the Gas Dynamics I course. Years 2013-2019.

XI. CONCLUSIONS

Currently it is difficult to think of the teaching of Gas Dynamics in the same terms as it was a few decades ago. Although the equations that describe the physical phenomena for two-dimensional and unsteady supersonic flows remain the same, both students and teachers currently have new tools that facilitate the assimilation of the abstract concepts implicit in mathematical models for the understanding of the behavior of compressible gases.

Not long ago, teaching was based on the well-known method of lectures where the teacher, chalk in hand, filled out complete blackboards with deductions of the equations that the student had to retain, appealing to his memory most of the time. Today, easy access to computer systems that allow the massive dissemination of knowledge on the subject through classes that can be taught both in real time and by recordings of them and can be reproduced in whole or in part at student convenience represents a clear advance. We must also recognize that the profile of the students is not the same as years ago and that consequently the teacher's task can no longer be limited only to repeating the deduction of the equations of the book, but it is also imperative that he/she be able to capture the audience attention trying to maintain interest in the subject. For this, the dialogue between the teacher and the student must be permanently resorted, asking questions that arouse curiosity and amazement, while relating theoretical knowledge with technical applications that can be easily assimilated. The phenomena for compressible gases occur in everyday life much more frequently than students imagine and it is up to the teacher to demonstrate this reality through examples with practical applications. Fortunately, there are videos that can be accessed easily and for free on the networks that can be used for educational purposes to illustrate the presentations and classes on the various topics covered by this subject. In the same way, it is much easier today to solve the practical exercises both collectively and individually, seeking an interactive method of dialogue where the teacher guides the student to reach the final result.In summary, we can say that there are currently a huge number of tools that are of great value to achieve the objective of imparting knowledge of the subject effectively.

We consider that the teaching of Gas Dynamics is of fundamental importance for the training of Aeronautical Engineers, Masters in Aerospace Engineering and Doctors in Engineering Sciences. The ability to understand the phenomena involved in compressible gas flows, be they subsonic or supersonic, and with that design and/or modify systems or devices is essential for professional development in aeronautical and aerospace engineering. For this reason, there is an active working group on Gas Dynamics in the Aeronautics Department of the National University of Cordoba. It should be noted that in this Department, in 20 years, it has gone from having a single teacher with a doctorate in related subjects to today having eight professors with a PhD who work on issues related to Gas Dynamics. In addition, there are teachers without a doctorate, but with extensive professional experience, who also make up the working group on Gas Dynamics and related topics. This group represents about a third of the professors and about half of the research projects in the Department of Aeronautics of the UNC.

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