

Esteban Terradas and Spanish technoscientific modernity*

Science, technology and technoscience

We live in an age in which science and technology play such important roles in the lives of individuals and nations that they figure among the most important affairs of any nation. And although many persist in seeing science and technology as separate disciplines –as island-universes separated by the deepest oceans–, they are increasingly interrelated and interdependent. Technology relies on science, but so also does science rely on technology. Naturally, it may still make sense to refer to ‘basic science’, to science which becomes technology when ‘applied’. However, this is not always the case: without the stimulus of technology, without its skills and instruments, and without the problems posed by technology, basic science would likely become a banal and futile exercise. Nineteenth century electromagnetism is a prime example of this encounter between science and technology, an encounter that heralded the technoscience of today. The great Michael Faraday –one of the fathers of modern electromagnetic theory, as also of the industry based on this theory– demonstrated this permeability of the frontiers between science and technology, and the theory of electromagnetism developed during the second half of the nineteenth century was to a large extent the result of the cross-fertilisation between technology and science. Indeed, that electromagnetic technoscientific world gave rise to developments so decisive for the history of twentieth century as, on the “technology side”, the telegraph, radio, telephone, as well as innumerable electronic devices. And on the “scientific side”, we have that the study of electromagnetic phenomena led to the discovery of cathode rays; the study of cathode rays led to the discovery of the first elementary particle, the electron; the analysis of cathode rays led to the discovery of X-rays; and the study of X-rays led to the discovery of radioactivity, a phenomenon which cannot be explained outside quantum physics, a

branch of physics that brought about a profound change in the world. In this chain of events we see the fecundity of the technoscientific culture of the nineteenth century researchers who constructed the electromagnetic universe. In fact, we are now fully cognisant of the fact that the world in which we live has long been one in which science and technology are closely linked. Take, as one example, the discipline of molecular biology, which daily reveals untold secrets: can we really draw a clear distinction between developments in genetic *engineering*, *biotechnology* and molecular biology? To me, the answer to that question is no, or at least, not always.

Nonetheless, few are the individuals who can or who have moved between the two worlds of science and of technology with equal ease, knowledge and sensitivity. This statement is possibly even more valid in the case of Spain, a country which has historically been scientifically and technologically underdeveloped. Nonetheless, in the person of Esteve Terradas i Illa** we have an example of a Spaniard who distinguished himself in both areas of knowledge.

Any attempt to fully reconstruct the personal and professional undertakings and activities of Esteban Terradas is undoubtedly an arduous task (perhaps even impossible) for a normal human, even for someone who may have achieved a certain distinction in, and familiarity with, one or two specific areas of knowledge. As pointed out by Julio Rey Pastor, the Spanish mathematician and Terradas' friend and colleague, in his response to Terradas' inaugural address to the Madrid Royal Academy of Sciences, an analysis of “his proteiform and multifaceted work... would require the collaboration between mathematicians, physicists and engineers from a range of disciplines” [1]. It is this multifaceted dimension of his personality –his skill and interest in learning and in combining knowledge usually classified as either scientific or technological– which distinguishes Terradas from any other Spanish scientist or engineer of his day. Despite the fact that he has to his credit a number of notable scientific publications (for example, on the movement of a string [2], stability theory, radiation theory, electricity and applied mathematics), it was not in the purely scientific field that he distinguished himself but in the technoscientific world. Terradas was, in fact, a man ahead of his time in regard to technoscience, and even more so in the Spanish context (with not even the great Leonardo Torres Quevedo bearing comparison with him in this area). So advanced was he that we could say of him what was said of Monsieur Jourdain, from Molière's *Le bourgeois gentilhomme*, who spoke in prose without being aware of it. Terradas' whole professional life

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** Esteve Terradas is known internationally as Esteban Terradas. This latter designation of his first name in Spanish will be used along the present text.

was dedicated to technoscience, even before the concept was defined. Nowadays 'technoscience' features in numerous academic book or articles titles, and it is defined in the *Oxford English Dictionary Online* (2003) as: "Technology and science viewed as two mutually interacting disciplines, or as two components of a single discipline; reliance on science for solving technical problems; the application of technological knowledge to solve scientific problems".

Terradas moved in the technoscientific environment like a fish in water, equipped as he was with the kind of skills required to explore and discover new worlds. However, he was –to use another metaphor– navigating difficult terrain: he was an engineer with the heart of a scientist, but equally a scientist with the heart of an engineer. Erudite, and scientifically and technologically adept as he was, his intelligence was not that of an Einstein, or –going down the scale of excellence and creative capacity– an Erwin Schrödinger or an Arnold Sommerfeld. He had, rather, more of an inclination –even a capacity– for changing the world than for constructing the theoretical instruments for understanding fundamentals (although naturally, he also was deeply interested in the latter). *Rara avis* in the academic universe, his singularity lay in the depth and extent of both his technical knowledge and his knowledge of physics and mathematics, but above all for the realism of his approach to any problem. An interesting comment in this respect is one he made in an article on railways, published in the journal of the Association of Industrial Engineers of Barcelona, *Técnica*: [3] "All engineering problems are questions of proportion; if ingenuity is required in electro-mechanics, it is no less necessary in economics and banking. One should never be led to the logical demonstration of a theorem on the basis of agreed principles. No axioms, no rigid logic or emphatic and categorical affirmations; opportunity generated by the occasion, the probability of success based on previous experiences, the interest generated, vainglory and politics, the position of the bank, etc., these are the primordial and determining elements. It is only on the basis of such premises that selection criteria can be established... technology is like a Cinderella [sic] with whom one can always reach an agreement."

The present article is dedicated to the memory of Terradas and his work [4]. He died just over fifty years ago –not so long ago even from the standpoint of contemporary history. But so much has happened since then that there is the danger that his memory will fade, been unknown for increasingly larger numbers of people, something which, of course, is but the consequence of the passing of the years, a necessary consequence of the generational handover, of the new life that accompanies death.

Biographical details

Esteban Terradas (1883–1950) distinguished himself in a range of knowledge domains and professions. He was an engineer, mathematician and physician who explored territories as diverse as electrodynamics and electrical engineering,

relativity, quantum physics, hydrodynamics, statistics, geodesics, pure and applied mathematics, aeronautics, telephony, nuclear physics and energy, as well as railway project design and management (including that of the Metropolitan Transversal Railway of his city of birth, Barcelona). He lived through a number of political regimes –the Mancomunitat de Catalunya, the monarchy of Alfonso XIII, the dictatorships of General Primo de Rivera and General Francisco Franco, and the Second Republic–, and collaborated with several, and quite different, educational and cultural institutions –the Consejo de Investigaciones Pedagógicas (Pedagogical Research Board), the Institut d'Estudis Catalans (Institute of Catalan Studies), of which its sciences division he a founding member, the Industrial School of Barcelona, the Universities of Barcelona, Zaragoza, Madrid and Buenos Aires, the National University of La Plata, the Junta para Ampliación de Estudios e Investigaciones Científicas (Board for the Extension of Studies and Scientific Research; JAE), and in particular with its Laboratorio y Seminario Matemático (Mathematics Seminar Laboratory), the Escuela Superior Aerotécnica (Advanced Aeronautics School), the Institución Cultural Española (Spanish Cultural Institute) of Buenos Aires, and the Consejo Superior de Investigaciones Científicas (Higher Council of Scientific Research; CSIC). Moreover, he participated in the founding of the Instituto Nacional de Técnica Aeronáutica (National Aeronautical Technology Institute; INTA), presiding



Figure 1. Esteve Terradas i Illa (Esteban Terradas).

its “Patronato” (Board). To honour his memory, after his death the center was renamed in 1950 “Instituto Nacional de Técnica Aeronáutica Esteban Terradas”. Also, and although he did not see (he had died by then) the formal creation of the Junta de Energía Nuclear (Nuclear Energy Board), he participated in the works that led to its funding [5].

Terradas studied physics and mathematics at the University of Barcelona, graduating with a *Premio Extraordinario* in 1904. He obtained two doctorates at the early age of 22 –in mathematics and in physics– from the Central University of Madrid (at that time the only Spanish university entitled to award doctoral degrees) [6]. He also graduated, in 1909, as *ingeniero de Caminos* (civil engineering), at that time possibly the most demanding, and prestigious, profession in Spain, taking all twenty subjects of the degree in a single examination period. Terradas had an extraordinary love of knowledge and erudition, and anecdotes abound of his learning, even while he lived. For example, referring to Terradas’ civil engineering examination, the architect Joan Bergós (a colleague of Terradas in both the Institute of Applied Electricity & Mechanics and in the Mancomunitat de Catalunya Railways Department) related that his friend, who was very knowledgeable about architecture, confided in him that he had “not dared to study it formally for fear that in the Advanced School he would lose his passion for this [architecture], the first of the arts.” [7] Bergós added that in the architecture examination for the Civil Engineering School, when questioned in regard to ‘Byzantine decadence mouldings’, Terradas was able to draw these without hesitation, to the total stupefaction of the Examining Board.

Terradas was also a consummate linguist: as well as his native Catalan and Spanish, he could speak perfect German –as a consequence of having lived in Charlottenburg (near Berlin), from age two to thirteen [8]– as also English, French and Italian. As to posts held by Terradas, he was Professor of Rational Mechanics at the University of Zaragoza (1906), of Acoustics and Optics at the University of Barcelona (1907),

of Differential Equations (1928) and later of Mathematical Physics (1941) at the University of Madrid. He was the first President of the Astronomical Society of Barcelona (1910), and a teacher of automobile technologies at the Escuela de Artes y Oficios (School of Arts and Crafts) of the Diputación Provincial (Provincial Council) of Barcelona (1914). From 1930 he taught very different courses (Resistance of Materials, Rational Mechanics, Mathematical Theory of Elasticity, and Architecture) at the already mentioned Escuela Superior Aerotécnica, founded in 1928 by the military engineer Emilio Herrera and located next to the military aerodrome of Cuatro Vientos (Madrid). When, during the Franco regime, that aeronautical training centre was replaced by the Academia Militar de Ingenieros Aeronáuticos (Military Academy of Aeronautical Engineers), Terradas taught there Quantum Mechanics and Hydrodynamics [9]. He was responsible for the construction of the Metropolitan Transversal Railway of Barcelona (1923–1926), and was Director of the Telephony Division (1916–1924) and of the Secondary Railroads Departments (1918–1924) of the Mancomunitat de Catalunya. Between 1929 and 1931, he was Director-General of the National Telephone Company of Spain. He was also President of a number of institutions, such as: the Junta de Investigaciones Atómicas (Atomic Research Board), which laid the groundwork for the eventual creation of the Nuclear Energy Board; the Consejo Nacional de Física (National Physics Board); the Board of INTA; the Board of Administration of the power station (1944–1948) to be constructed by the National Electricity Company (subsidiary of the Instituto Nacional de Industria [National Industry Institute]) in Ponferrada (Leon). Besides, he was also, for a brief period in 1948, Director of the National Electronics Institute and a member of the “Juan de la Cierva Board” –both departments of the CSIC, which for political reasons replaced the JAE in 1939. Terradas also represented Spain in the Provisional International Civil Aviation Organisation. During his lifetime, moreover, he was admitted to three Royal Academies: the Royal Academy of the Sciences and Arts of Barcelona (his inaugural lecture, delivered in 1909, was entitled *Sobre la emisión de radiaciones por cuerpos fijos en movimiento*); the Royal Academy of Exact, Physical and Natural Sciences (he took possession of his medal in 1933 with a discourse entitled *Programa de un curso de ecuaciones diferenciales*); and the prestigious Royal Spanish Academy, to which he was appointed in 1946, taking possession of his seat, which corresponded to the the “g” chair, with an impressive speech on technical vocabulary and terminology (*Neologismos, arcaísmos y sinónimos en plática de ingenieros*) [10].

He was active in many areas, whether attending conferences, writing books and articles, or as editor of collections of scientific books. One of his most notable work was for the *Enciclopedia Universal Ilustrada Europeo-Americana* (Espasa). Although it is difficult to be absolutely certain (most of the Espasa archives have been lost), is estimated that Terradas contributed to the *Enciclopedia* with about 181 entries. In alphabetical order (not necessarily coinciding with the publication of the different volumes), his entries com-

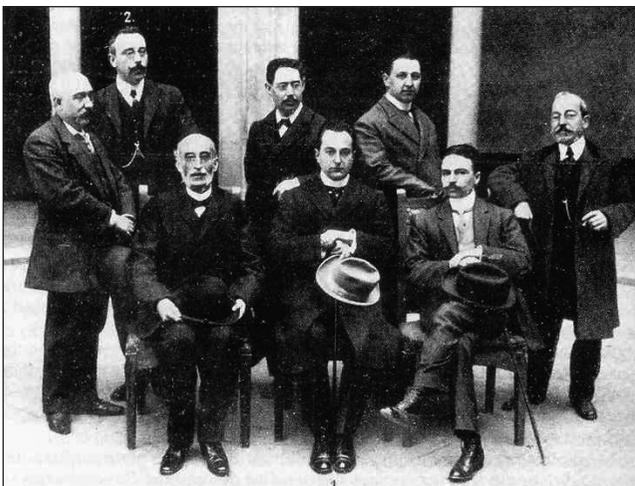


Figure 2. Terradas with other members of the first board of the Sociedad Astronómica de Barcelona. From left to right: L. Canalda, E. Terradas and F. Tallada (first row; seated); J. Subiranas, S. Raurich, E. Fontserè, E. Calvet and M. Font Torné (second row). (*Nuevo Mundo*, March 10, 1910).



Figure 3. Albert Einstein at the Escuela Industrial de Barcelona (1923) (Arxiu Fotogràfic Institut Municipal d'Història, Barcelona).

menced with *aberración* (Volume 1, 1909) and terminated with *vibraciones* (Volume 68, 1929). Some of his articles - for example, *Mecánica estadística* (Appendix Volume 7, 1933), *Cálculo de probabilidades* (Supplement, 1934), and *Hidrodinámica* (Supplement, 1935), each one of about some 25 pages in length— were authentic treatises.

Terradas and the *Cursos Monogràfics d'Alts Estudis i d'Intercanvi*

Another aspect of Terradas' life and work that deserves to be commented is his cosmopolitan personality and international relations and activities.

Science and technology are shared, international endeavours which require an intensive and free exchange of ideas. The proper domain for science and technology is a world free of frontiers. Naturally, both scientific and technological advances are made within nation-states, whose borders and interests profoundly affect the development and exchange of scientific and technological knowledge. Indeed, it is underdeveloped countries who can least afford to ignore this global perspective on science and technology; rather, they must eagerly monitor developments occurring beyond their frontiers. During the nineteenth century and, more recent in our memories and lives, in the early years of the twentieth century, Spain was one of these underdeveloped countries [11]. However, few were the actions taken to try improving the situ-

ation by sending Spanish students abroad or by inviting foreigners to give talks in Spain [12]. In terms of invitations to scientists and engineers from other countries, Terradas was ahead of his time, as evidenced by his activities in relation to the *Cursos Monogràfics d'Alts Estudis i d'Intercanvi* (Monographic Courses for Advanced Studies and Exchange).

These courses—an initiative of Terradas' primarily— began in the spring of 1915. They were organised by the Pedagogical Research Board of the Mancomunitat de Catalunya, to which Terradas had been appointed in 1913. Focusing solely on foreign scientists invited to Spain (and excluding the period of the World War I when travel was near impossible): between 1920 and 1923 courses were given by luminaries as: the Italian mathematician Tullio Levi-Civita, who spoke on the subject of classical and relativist mechanics in January 1921; the French mathematician Jacques Hadamard, who lectured on Poincaré and the theory of differential equations in April 1921; the mathematician and theoretical physicist Hermann Weyl, who dealt with the mathematical analysis of space in March 1922; Albert Einstein, who explained his theories of relativity in February 1923; and the Hungarian mathematician Szerkeszti Bèla Kérékjártó, who chose topology as his subject in May-June 1923 [13].



Figure 4. Terradas delivering his inaugural discourse at the Real Academia Española (October 13, 1946) (Terradas Archive, Institut d'Estudis Catalans).

Terradas and the introduction of the new physics to Spain

Terradas himself participated as a lecturer in the *Cursos Monogràfics*. Thus, in 1915 he lectured on discrete elements in matter and radiation; that is, he chose as his topic aspects of the new quantum physics revolution that was being carried out since Max Planck introduced the law $E=h\nu$ in 1900. The Spanish scientist and engineer also dealt with aspects of atomic theory (among them, the experiments of Millikan on measuring electrical charge). In connection with the theory of monatomic gases, he broached various issues in relation to statistical physics, including Boltzmann's entropy which, as is widely known, was used by Planck to deduce his blackbody radiation law and the $E=h\nu$ equation that related radiation energy and frequency. Planck's radiation theory was the subject of another Terradas talk, another being on Peter Debye's theory of the monatomic solid body [14].

As a matter of fact, Terradas was revisiting these subjects that he had previously covered in what were probably the first public talks given in Spain on the subject of quantum physics (with the exception of some brief comments by the German chemist Werner Mecklenburg published in the *Anales de la Sociedad Española de Física y Química* in 1907, in a section devoted to German contributions to physics). These public talks, two in total, had been given by Terradas at the First Congress of the *Asociación Española para el Progreso de las Ciencias* (Spanish Association for the Advancement of Sciences), held in Zaragoza in October 1908, one (delivered in a session of the Exact Science section) on the subject of statistical mechanics, and the other on light emission theories (Chemistry & Physics section). On taking possession of his chair at the Royal Academy of the Sciences and Arts in Barcelona in 1909, Terradas spoke again about quantum physics and the special theory of relativity [15].

As regard Albert Einstein's 1905 relativity theory, it is appropriate at this point to indicate that it seems that Terradas was not aware of the real meaning, and significance, of that contribution of the twentieth century genius of physics. In his inaugural Academy speech, when he dealt with was really the special theory of relativity (which he, like others at that time, denominated "relativity principle"), Terradas only mentioned Einstein on two occasions. Indeed, in his text he referred (whether in error or ignorance) to 'Eisenstein', and subordinated Einstein to Lorentz in a reference to 'the Lorentz-Eisenstein relativity principle' [16]. Furthermore, in his treatment of Planck's quanta, he failed to mention Einstein's groundbreaking work of 1905 entitled "On a Heuristic Point of View Concerning the Production and Transformation of Light," [17] in which the Bern Patents Office employee went further than Planck, proposing that light should be considered, at least in part, as consisting of independent quanta of energy (later denominated 'photons'), and exploring possible applications of such "heuristic idea," among others to the photoelectric effect. Likewise, it comes as something of a surprise that, in his 1915 lecture on Peter Debye's theory of the monatomic solid body, Terradas also failed to mention Einstein. The surprise is even greater if one consults one of Debye's articles on the theory of specific heat [18] cited by Terradas on a footnote of page 66, where the following can be read: "Recent observations in Nernst's laboratory in regard to the dependence of specific heat on temperature have convincingly demonstrated that the theorem of equipartition of energy is also incorrect when we deal with matter. As is well known, Einstein was the first scientist to call attention to this fact and to devise a formula, using the theory that Planck had developed for radiation, for giving specific heat as a function of temperature". Besides, on mentioning Einstein, Debye added as another reference the article, published by the former in 1907, on Planck's theory of radiation and the theory of specific heat, [19] in which the creator of the theories of relativity applied the ideas on the quantisation of radiation that Planck and Einstein had developed (in 1900 and 1905, respectively) to matter, and specifically to the the-

ory of specific heat, whose formulation on the basis of classical physics gave results that in some cases did not coincide with experimental results. Details such as these indicate that Terradas' pioneering contributions to the introduction of quantum theories to Spain were in some respects limited. Nevertheless, as would be expected in a man with his thirst for learning, his knowledge of quantum theories would improve substantially with time. Evidence of this is provided by the classes (to which I have already alluded) he gave, from 1941 at the Military Academy of Aeronautical Engineers, on solid matter physics (subsequently published between 1943 and 1945 in three parts), in which he covered various aspects of solid-state quantum, mechanics and statistics. It should be pointed out, nonetheless, that he concerned himself mostly with the most elementary and mathematical aspects of quantum mechanics [20]. More advanced quantum themes will be taken up during the late 1940s and the 1950 decade by some of his students at Madrid University, such as María Aranzazu Vigón, Ramón Ortiz Fornaguera and Carlos Sánchez del Río, who eventually would join the Nuclear Energy Board. In terms of the introduction of quantum ideas and theories to Spain, there is no doubt that Blas Cabrera (1878-1945), the Canary Islands physicist and Professor of Electricity and Magnetism at Madrid University, played a far more important role than Terradas, both as a researcher or in terms of conferences and books, not to mention the reviews he published (mostly) in the *Anales de la Sociedad Española de Física y Química* [21].



Figure 5. Terradas at the Romanesque cloister of Santa Maria de l'Estany (Terradas family).

Exile in Argentina and return to Spain

The most important posts held by Terradas in Spain throughout his life have been mentioned already, but his life was not lived solely in Spain.

Branded a conservative—with all the corresponding implications in the Republican Barcelona of autumn 1936—, he left Spain at the end of October 1936 to start a new life in Argentina, where he remained until 1941, by all accounts particularly happy with his existence there [22]. In a letter to the engi-



Figure 6. Julio Rey Pastor, with Terradas behind him, in Buenos Aires, circa 1937-1941 (Terradas Archive, Institut d'Estudis Catalans).

near Julio Zuker in May 1943 [23], Terradas said that he considered himself “as Argentinean as any one of you,” adding that he had never felt himself to be a foreigner in Argentina and that he would never be able to repay his debt, referring to himself as a “shipwrecked survivor of the civil war” who had been received with courtesy and showered with honours. “His metaphor is graphic; like many other compatriots, he was indeed a ‘shipwrecked survivor of the civil war’.

Terradas was very active in his years in Argentina. At the University of Buenos Aires he gave courses on mathematics and engineering; at the National University of La Plata, he was associated with the Astronomical Observatory and participated in the measurement of a meridian arc extending from the extreme north of Argentina to the south, directing the hydrographical part of the project (specifically, the determination of the mean height of the sea along the Atlantic coastline) [24]. His activities also included aeronautics. At the University of Buenos Aires, in 1940, he gave a course on theoretical aeronautics; at the National University of La Plata, he set up a group to study problems of aviation engineering, and gave courses and seminars on elasticity theory, aerodynamics and technical aviation problems (among them the construction of landing strips). Indeed, one of the few articles that he published in Argentina was on aeronautics. This work, on aircraft propellers, originated in a conference given at the National University of La Plata on the 24th June 1937, and eventually came to form part of his course on aeronautics [25]. Terradas does not appear to have been exaggerating, therefore, when at the end of 1942 or early 1943, he wrote to his friend, the Spanish mathematician Julio Rey Pastor (who had settled in Argentine before him) claiming credit for “the initiative –at least– in terms of the idea and organisation of the means for teaching aerodynamics at the National University of La Plata” [26]. Nonetheless, his most important activity in the area of aeronautics was not educational but his participation in a project for the construction of an airport-seaport for Buenos Aires and La Plata, to be located to the south on Demarchi Island and close by the river. In this project Terradas demonstrated, as in few others, his aeronautical engineering skills.

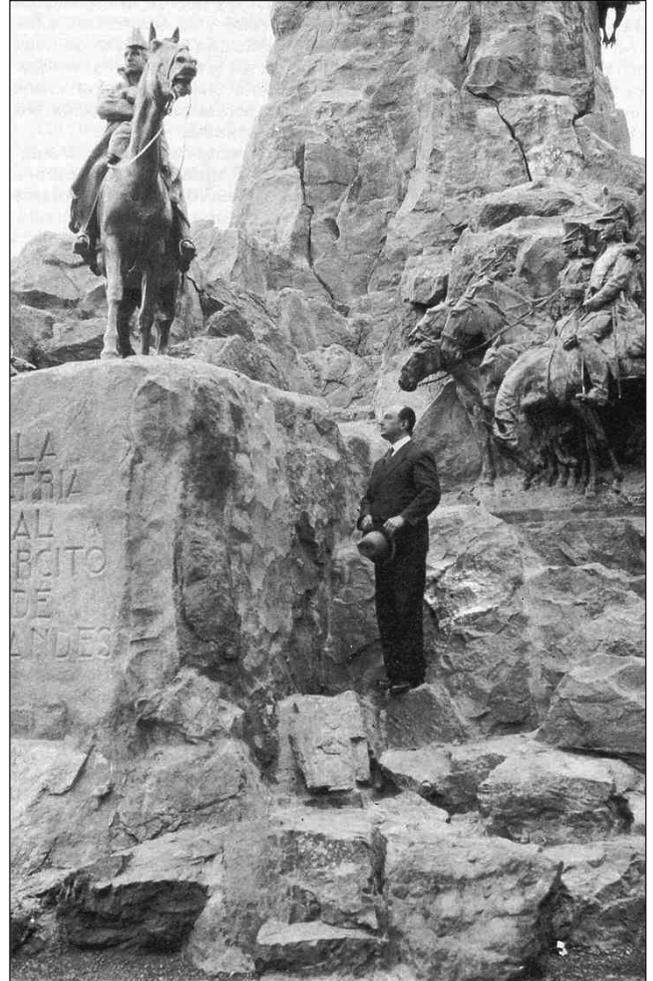


Figure 7. Terradas at the Cerro de la Gloria monument, Argentina, February 23, 1939 (Terradas Archive, Institut d'Estudis Catalans).

Bearing in mind his interests, knowledge and skills, it is hardly surprising that at the end of 1941, the Spanish Civil War over, the Spanish Minister of the Air Force, General Juan Vigón, managed to persuade Terradas to return to Spain, nor that he came to play a very active role in the INTA, as we have already pointed out. The INTA –attached to Vigón’s Ministry– was founded in 1942 (that is, immediately following the return of the versatile engineer and scientist) in order to take charge of all matters related to aeronautical development, research and practice in Spain.

Terradas, foreign ambassador of INTA

As mentioned, Terradas was elected President of the Board (*Patronato*) of the INTA, a post he kept until his death. The first task he set himself on his appointment was to attempt to overcome any obstacle Spanish aeronautical engineers might find for studying at specialist centres abroad (and in particular, in the USA). The approach was one he had used decades previously in Barcelona with physicists and mathematicians: to persuade as many foreign aeronautical experts as possible to come to the INTA headquarters at Torrejón, near Madrid. Terradas’ success was such that he could be

referred to, in a metaphorical sense, as the ‘foreign ambassador’ of INTA [27].

Although the role of the Board was more one of supervision than of management (the INTA Director-General was the military engineer Felipe Lafita), Terradas was true to type and participated actively in the establishment and development of the institute [28]. Here, however, I will focus exclusively on his activities as foreign envoy, which included not only his own travels abroad, but also the establishment of international contacts. One important journey he made was to the United States in 1944–45.

On the 21st of October 1944, Terradas departed from Madrid, in the company of several Director-Generals from the Ministries of the Air Force and Foreign Affairs, in order to attend the International Convention on Air Navigation to be held in Chicago between the 1st of November and the 7th of December. The Spanish government had appointed Terradas as the president of the commission that would participate in talks on the establishment of international airlines. Nonetheless, Terradas also had other plans, among them to study the possibilities for acquiring materials and equipment for the INTA, as well as to try finding US aeronautical centres which would admit INTA staff for widening their knowledge. With these aims in mind, he made contact with a number of centres and individuals in US aeronautics. One such contact was Edward S. Taylor, Professor of Flight Propulsion at the Massachusetts Institute of Technology, to whom he wrote (on the 14th of February 1945 when still in the USA) as follows: [29]

“Dear Sir,

I write to you as the President of the Board of the National Institute of Aeronautical Technology based in Madrid, Spain. This organisation is similar in many aspects to the NACA in the United States.

We are at present building several laboratories for testing materials, structures, aeroplanes, engines and signals. As an example of what we intend to achieve, in the area of engine testing, we plan to construct four U-tunnels for tests of up to 4,000 HP at the station level, as well as a special engine laboratory with air conditioning that simulates atmospheric conditions at 50,000 feet for the same power. The laboratory is similar to that constructed recently by Brown Boveri in Switzerland, and will be adapted to accommodate all kinds of machinery, bombs, ventilators, refrigerators, brakes and measurement instruments. We propose to test not only our own aeroplanes and engines, but also to contribute and cooperate in the area of collective research.

We consider the laboratories of the United States to be the best-equipped laboratories in existence, and consequently expect that your engineers and scientists will provide a strong impetus to research in the area. We believe, therefore, that the most satisfactory method for co-operation in new lines of research would be for three of our staff to work in laboratories here, to later take up their work in the newly constructed laboratories in Spain. As a point of

departure, we would like to place three Spanish engineers trained in theoretical thermodynamics and mechanics (vibration, wave propagation in hot gases, chain reactions, etc.) for a period of two to three years in engine laboratories specialising in research. Our people would like to establish contact with, and apply the knowledge of, the most brilliant and best-trained engineers of the USA, assuming that you agree to co-operation once the war has ended.”



Figure 8. Terradas with some of the founders of INTA. At Terradas' right (seated in the center) his P. Huarte Mendicoa (J. M. Sánchez Ron, *INTA. 50 años de Ciencia y Técnica Aeroespacial*).

Despite all Terradas' efforts, however, these contacts produced little in the way of concrete results (after eight months in the USA, Terradas calculated that he had covered a total of 5,924 kilometres, 14,894 land miles, plus 13,894 nautical miles) [30]. Moreover, the official international situation for Spain did not improve, as demonstrated in May 1947, when Terradas travelled to Montreal to participate in a meeting of the Provisional International Civil Aviation Organization (PICAO), a body dependent on the United Nations (UN). It was at this conference that Spain was formally expelled from the PICAO as a consequence of a ruling of the UN. This decision profoundly affected Terradas, as can be appreciated from these comments, in a letter dated the 4th of August, to Rey Pastor: [31] “I have been to Montreal, where I lived one of the bitterest moments of my life; I tried that my country [Spain] got the most favourable situation as possible given the enormous air of hostility... [However] the country has not shown me the least degree of gratitude nor has any notice been taken of the incident, not has anybody asked me anything. I have sent you my defence of Spain in a separate envelope, although judging from the silence and coldness with which my action has been received, it seems that nobody gives a damn about what has happened. I am more and more convinced each day of my lack of interest in politics, and increasingly disillusioned and amazed at what remains of universal and utopian ideas once they have been flaunted and peddled by social climbers who cling to the opinions of the moment... The only consolation for the saddened heart is the advance of the Physical Sciences.”

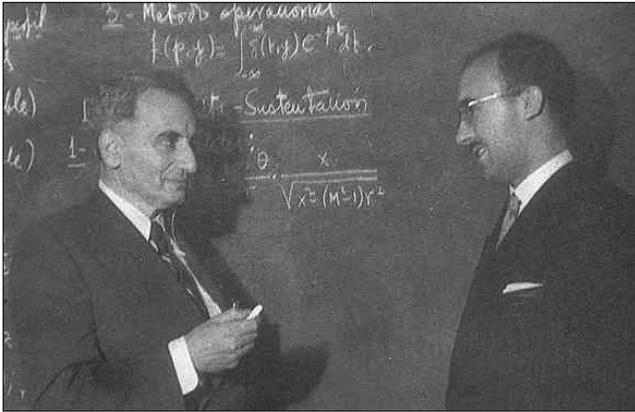


Figure 9. Theodore von Kármán with Gregorio Millán, during one of his first lectures at INTA (1948) (J. M. Sánchez Ron, *INTA. 50 años de Ciencia y Técnica Aeroespacial*).

Impervious to discouragement, however, Terradas resorted to his other stratagem: the invitation of foreign experts to Spain. He put forward his ideas in a plenary meeting of the INTA Board on the 8th of October 1946, as evidenced by the corresponding minutes. As one of the points on the agenda Terradas proposed “*Corresponsales en el extranjero*” [Foreign contacts], in relation to which he had the following to say: [32] “They can further the work of obtaining technical information and can greatly help us in the task of sending our staff on placements to industrial establishments or similar institutions abroad. As in other countries, regular invitations can be extended [to these contacts] so as to develop personal links and organise, whether by or through them, series of conferences involving important figures from the world of aeronautics.” In this plenary session in particular, Terradas proposed extending the first invitation to Frank Stanton, a former President of the Civil Aeronautics Authority who continued to wield considerable influence in the US aeronautics field. “This gentleman,” said Terradas “has not only demonstrated a positive attitude to our country, but has also defended us on a number of occasions at international meetings.” His proposal was approved and Stanton was accordingly invited.

From 1948 on, in particular, the INTA was the object of frequent visits by foreign scientists. Thanks to the invitations of this Spanish aeronautics centre –generally extended through Terradas– it was possible to hear a number of important figures from the world of aeronautics speak in public in Spain. One of these figures was Luigi Broglio, Professor of Aeronautical Construction at the University of Rome, researcher in the Guidonia aeronautics laboratories, and author of notable contributions to the theory of structures applied to aeroplanes; during the two months that Broglio spent in Madrid in early 1948 he gave a series of talks on structure calculations and also provided the INTA with plans for a six-component balance that he had designed and that would be installed in one of the INTA wind tunnels [33]. Other visitors included Louis Milne-Thomson, Professor at the Royal Naval College of Greenwich; W. J. Duncan, Professor of Aerodynamics at the Cranfield College of Aeronautics (UK); the mathematician Gaston Julia, President of the French

Academy of the Sciences; and Maurice Roy, Director of the French National Office for Aeronautical Studies and Research.

The list so far is impressive, particularly if we remember that autarkic Spain was isolated internationally in the post-war period as a consequence of having sided with Germany during World War II (even though it had maintained the status of a non-belligerent country). However, one name remains to be added to the list, the most important of them all, that of the single individual who contributed most to the development of Spanish aeronautics: Théodore von Kármán (1881–1963).

Born in Hungary, von Kármán’s genius led him in 1913 to head the Aeronautical Institute at the University of Aachen; in 1930 –at the instigation of the physicist Robert Millikan– he was appointed Director of the Daniel Guggenheim Aeronautics School of the California Institute of Technology. He soon became the maximum authority in the United States in the field of the aeronautical sciences. Given the importance acquired by aviation in the course of the World War II, it is hardly surprising that von Kármán would soon become an influential individual with important connections in the North American political and military world. This fact did not escape Terradas, who contacted him in the summer of 1947. On the 11th of June the following year, he wrote again to von Kármán inviting him to give a series of talks on subjects “with which you are familiar and on which you have left the mark of your genius”, although Terradas subsequently qualified this statement by indicating that he would particularly appreciate it if von Kármán chose “subjects related to aerodynamics.” The invitation was accepted and von Kármán visited Madrid in October 1948, where he gave four talks on high-speed aerodynamics and turbulence in the Main Hall of the Physics Institute of the CSIC.

Naturally, in order to fully comprehend the significance of the visit of this important figure in North American science and technology we also have to take into account other factors over and above the initiatives taken by Terradas.

In the immediate post-war period there were no diplomatic relations between Spain and the USA; von Kármán’s early visits, however, coincided with the commencement of the Cold War (1947), and the Truman government’s attitude to Spain gradually began to change. So it was that at the end of 1948 a US military delegation visited the INTA. In fact, von Kármán’s visit to Spain coincided with the beginnings of the end of Spanish isolation. The celebrated Caltech professor greatly facilitating the re-establishment of relations with the USA, a development that would have seemed very unlikely just a few years previously.

From 1948 onwards, von Kármán proved to be an assiduous visitor to Spain. The history of the INTA and of Spanish aeronautics and related branches of knowledge (theoretical and applied mechanics, fluid physics, combustion theory, etc.) would have been rather different were it not for his help. Moreover, without the links established by Terradas between von Kármán and Spain, illustrious names in the Spanish aeronautics and technology fields –such as Gregorio Mi-

Ilán Barbany or Amable Liñán (1993 Prince of Asturias Award for Scientific Research)– would undoubtedly have seen their careers develop very differently.

Terradas, child and victim of his times: an overall assessment

Each of us is, to some extent, a product of the past, whether of our own, of our family, or of the society in which we live. We are also enslaved to a present over which we have little control. A magnificent example in this respect is Esteban Terradas who could be said to be the perfect mirror of the history of Spain in the first half of the twentieth century. Born into the world of science and technology in a country that hovered very much on the margins of these universes, Terradas was fifteen years old when, in 1898, Spain suffered the traumatic loss of its last overseas dominions when defeated by the USA in Cuba. In regard to Spain's capacity for creating knowledge, few better descriptions of the period can be found than that contained in Ricardo Macías Picavea's book *El problema nacional (The National Problem)* published in 1899: "Verbosity continues to be the hallmark of the learned; original investigators, conscientious experimentalists, promoters of positive knowledge in literature, history, philology, physics, chemistry, biology, law... where are these to be found? Amounting to a mere handful of individuals and academic or scientific institutions, they survive, we can be sure, in stark and precarious conditions as a consequence of the asphyxiating vacuum in which they live." And he subsequently concluded:

"Our culture is a mere second-hand culture, superficial, copied, non-national, filtered almost exclusively through French channels.

Independent spirits and original investigators –those who create and lay foundations in Spain– barely number the half dozen...

How many scientists are there who are genuinely capable of making advanced physical experiments?

How many are capable of operating a laboratory of depth and precision in the generous and marvellous field of chemistry?

How many can handle a microscope or perform biological experiments in any one of many astonishing applications?"

Although it is indeed true that the histologist Santiago Ramón y Cajal and the engineer Leonardo Torres Quevedo had by this stage given clear indications of their genius, in general there was a great deal of truth in the statements of the *regeneracionista* Macías Picavea.

This notion of *regeneracionismo* –the idea, or, better, the cultural movement that claimed that Spain should renew herself and attain the position she deserved (and had had on the past) in the civilized world, through work and study– was an important feature of many, political as well as cultural,

discussions that were held in Spain during the closing years of the nineteenth century and the early years of the twentieth century. Even if he did indeed resent the situation in which his country found itself, Terradas was not a *regeneracionista* of the type of Costa, Maeztu, Baroja or Unamuno, all literary men. Nor did he raise his voice in the same manner as other scientists (not very many, to say the truth) had done. An examination of his writings does not reveal, for example, any statement in relation to the 1898 defeat as vociferous as that of Cajal, who had wrote: [34] "We fell before the United States because we were ignorant and weak; we even denied its science and its strength. We need... to regenerate through work and study." Or like the declaration made in 1909 by José Rodríguez Carracido, Professor of Biological Chemistry at the University of Madrid, that the "question of a scientific education in Spain is seen as an immediate and pressing need following the loss of our remaining colonies. In retreat behind its frontiers the nation underwent an examination of conscience and saw, in all clarity, that Spain's defeat was the direct consequence of an ignorance of the kind of knowledge that infuses social organisations with positive mental vigour. As was succinctly pointed out in reference to the subjects taught at secondary level, Spain's defeat was inevitable in view of the fact that whereas in the USA pupils studied physics and chemistry, in Spain pupils studied rhetoric and poetry." [35] Cajal and Carracido made their statements whether through newspaper articles or at solemn and well publicised acts. Besides, the tone of their manifestations was rather dramatic and grandiose.

Terradas behave differently. He was, above all, a professional, and, moreover, had grown, if only because he was younger, in a world different from that of Cajal or Carracido. He was worried about his country, but the lost of Spanish colonies was not so important for him. His tactics was help improving the scientific and technological situation of Spain not only by way of his example (as Cajal did), but also taking part in the often more obscure world of organisation and planning, in academy as well as in industry. I have been able to find a number of statements by Terradas that demonstrate his conviction that a better future required the incorporation of the best scientific knowledge from abroad into Spain's cultural and educational systems. In 1913, for example, in his formal response to Paulino Castells' inaugural speech before the Royal Academy of the Sciences and Arts of Barcelona, he declared: [36] "We are today convinced that our principal mission is not teaching in the archaic sense; rather, our fundamental duty is study and the advance of science. We represent the culture of the homeland, and decorum and duty make it imperative that study becomes our central occupation; the time is long gone when didactic quality was measured in terms of the meticulousness with which a teacher of mathematics made a transformation or progressed from one formula to another. Today... the quality of teaching is measured according to the ideas of the teachers and how these reflect thinking in the great cultural centres, as also by the nature of the problems that an intelligent student is capable of resolving."

Throughout his life Esteban Terradas took great pains to better and modernise his homeland. Naturally he had to deal with politicians and even, on occasion, play at politics himself; moreover, he was required to do this in dictatorial regimes (such as Franco's) in which democratic freedoms were practically non-existent. This role did not always come easy to him, as is evident in his letter to Rey Pastor following his Montreal debacle (already cited): "I am more and more convinced each day of my lack of interest in politics, and increasingly disillusioned and amazed at what remains of universal and utopian ideas once they have been flaunted and peddled by social climbers who cling to the opinions of the moment... The only consolation for the saddened heart is the advance of the Physical Sciences."

Disillusioned and uninspired by politics he may have been, nevertheless it is patently clear that his presence in Spain, his prestige, knowledge, contacts and tireless activity represented an important pillar of support for the Franco regime. Dare we criticise him today from our vantage point of the comfort of a democratic system with all its human liberties? My own opinion, which hopefully is not unduly influenced by having invested many hours in the reconstruction of his life and work, is that such criticism would be unjust; after all, he has not escaped unpunished from the penetrating gaze and intractable judgement of history. Terradas was a professional who endeavoured, with dignity and resolve, to give the best of himself to his community, largely remaining unaware of or choosing to ignore the political events of his time –whether these occurred in the streets or *failed* to take place in government (I am referring especially to the defence and implementation of freedom rights). On the other hand, we cannot overlook his own unhappy experiences during the period of the Republic, including the loss of the Chair of Differential Equations at the University of Madrid in punishment for being a Director-General of the National Telephone Company during General Primo de Rivera's dictatorship and a member of the National Assembly (a consultative body created by Primo in order to improve the image of the regime). He felt, moreover, obliged to leave Spain in the period when it was under Republican control.

Life circumstances, society, the entanglement of many contradictory desires, ambitions and projects make the notion of the ideal man or woman impossible. There are not pure individuals, only, perhaps, pure causes, in which the noblest aspirations of a community and its history are deposited. Some would refer to this perspective as rather cynical, others as utopian, yet utopias do sometimes become reality.

But despite the imperfections of individuals such as Esteban Terradas, ideas and feelings are evident in some spirits that render them genuinely and sincerely human. Never much inclined to reveal his most intimate self, Terradas did, on certain occasions, permit a glimpse of some of his noblest sentiments. One of these occasions was a speech on the subject of Fourier-Stieltjes integrals to inaugurate the 1930–31 academic year at the University of Madrid. The opening lines of his speech allow a rare glimpse into the feelings that Terradas harboured deep in his heart: [37]

"Within me are misgivings and desires that represent a spirited and fervid protest, deep-seated and profoundly felt in my consciousness; yet were this protest to find expression it would meet with opposition and antagonism, maybe even passion and rage. I have a great love for high ideals and aspire to triumph and dominion; but aware of my value, I succumb powerless before regulations and routine, I am cowed by convenience, statute, law and, oh pain!, am I capable even of a diluted expression of the kind of perfection which I cannot hope to attain?"

Spirit of academia, grant me light and illuminate my way in shadow and in darkness, dispel the gloom that surrounds me; my thirst for learning knows no bounds, and only you can preserve me from banality and vanity. Winner of excellence, touchstone of merit, abode of scientific reason. Spirit who breathes genius into life, the noblest of thoughts find in your halls their ultimate expression. The academic spirit, heart and sanctuary of learning, kernel of civilisation."

History records many cases of great individuals, inventors and creators who received no recognition in their lifetime, for example, Evariste Galois in mathematics, van Gogh in art and Kafka in literature. Terradas, fortunately, was not one of these. His genius was widely recognised within Spain, even though it was contested on occasions for political motives. Moreover, he also received the acclamation of key figures in the international scientific community. Responding to Terradas' entrance speech to the Royal Academy of Sciences of Madrid, the mathematician Julio Rey Pastor recalled an incident in Buenos Aires: [38] "Arriving in Buenos Aires on the same day as the eminent physicist [Einstein] –having finished a series of conferences in Argentina– was embarking for Europe, we only had time to exchange a few words, given the multitude of people who had come to the quay to bid him farewell; on asking him about his impressions of a recent visit to Spain he said, and I quote as follows: 'I met an extraordinary man: Terradas.' This single mention represented a condensation of his strongest impressions of Spain." And Rey Pastor added: "Noteworthy as this particular opinion may be, it is not the only opinion voiced by authoritative figures. In the frontispiece of his work on the problem of space, Weyl makes a highly eloquent dedication the like of which I have never seen addressed to any learned individual; Severi and Broglio, among many others, marvel at the fact that one who manages to keep abreast of so many varied disciplines could know of the latest works in mathematics; and Pólya, in his usual expressive manner, wonders if 'they are mad, these Spaniards,' when he hears that we oblige those who have demonstrated their superiority over their colleagues over the period of a quarter of a century to undergo a public examination; at the Bologna Conference he was appointed Vice-President on Pincherle's initiative; and at the recent Zurich Conference he was elected member of the Committee of dignitaries charged with reorganising the defunct International Mathematical Union."

The reference to Weyl's dedication is particularly signifi-



Figure 10. Hermann Weyl.

cant. As I write the closing lines of this article, I have to hand my own copy of *Das Kontinuum und andere monographien* (Chelsea, New York, n.d.) which includes, together with texts by Edmund Landau and Bernhard Riemann (the latter's seminal presentation on the fundamentals of geometry), two articles by Hermann Weyl – *Das Kontinuum* and *Mathematische Analyse des Raumproblems* –, the second one being the result of the course he gave in Barcelona in 1923 as part of the *Cursos Monográfics d'alts Estudis i d'Intercanvi* programme. I cannot help but feel deeply moved when I open the page containing Weyl's dedication of this work to Terradas, full as it is of such deeply felt sentiments and profoundly reverent words. Terradas, I am sure, felt enormously rewarded by the dedication, as it was undoubtedly one of the highest honours he received in his lifetime [39].

References and notes

- [1] Julio Rey Pastor, "Contestación," in Esteban Terradas, *Programa de un curso sobre ecuaciones diferenciales* (Academia de Ciencias Exactas, Físicas y Naturales, Madrid 1933), pp. 151–162; p. 152.
- [2] The study of strings is a classic topic in the history of mathematics and rational mechanics (dating, at least, to the work of Jacques Bernoulli in the early eighteenth century). It was one of the themes in which Terradas distinguished himself and to which he constantly returned. His doctoral thesis in mathematics (1905) was on this subject, as also a monograph entitled *Estudios sobre los hilos: Equilibrio y movimiento de hilos inelásticos*, which earned him the 1905–1907 Agell Award from the Royal Academy of the Sciences and Arts of Barcelona. The Academy subsequently published Terradas's study (224 pages) in its *Memorias* series (Vol. IX) in 1911. A year later (August 1912), Terradas made a presentation on the same subject at the Fifth International Congress of Mathematics in Cambridge: E. Terradas, "Sur le mouvement d'un fil", *Proceedings of the Fifth International Congress of Mathematicians* (Cambridge University Press, Cambridge 1913), Vol. 2, pp. 250–255, reproduced in *Esteban Terradas*, Antoni Roca Rosell (ed.) (Fundación Banco Exterior, Madrid 1991), pp. 175–190. Emma Sallent del Colombo wrote on Terradas' contributions to the study of string and mathematics in "Aportaciones de Terradas al estudio de los hilos," in Antoni Roca Rosell (coord.), *Esteban Terradas (1883–1950). Ingeniería, arquitectura y ciencia en el siglo XX* (La Salle Ingeniería i Arquitectura/ Universitat Ramon Llull, Barcelona 2004), pp. 47–66; and "Aportaciones de Terradas a las matemáticas," *Quark*, No. 21 (Jan-Mar 2004), pp. 31–40.
- [3] Esteban Terradas, "De ferrocarriles," *Técnica*, Year XLV, No. 47 (November 1922), pp. 221–224; p. 221; reproduced in *Esteban Terradas*, Roca Rosell (ed.), *op. cit.*, pp. 229–232.
- [4] The most exhaustive works on the life and work of Terradas are: Antoni Roca Rosell and José Manuel Sánchez Ron, *Esteban Terradas. Ciencia y técnica en la España contemporánea* (Instituto Nacional de Técnica Aeroespacial/Ediciones del Serbal, Barcelona 1990); Antoni Roca Rosell, "Las maravillosas luces del alba resplandeciente... 'E. Terradas, propagandista de la nueva ciencia,'" in *Esteban Terradas*, Roca Rosell (ed.), *op. cit.*, pp. 3–68; and Roca Rosell (coord.), *Esteban Terradas (1883–1950). Ingeniería, arquitectura y ciencia en el siglo XX*, *op. cit.*
- [5] See José M. Sánchez Ron, *INTA. 50 años de Ciencia y Técnica Aeroespacial* (Ministerio de Defensa/Doce Calles, Madrid 1997), and Ana Romero de Pablos and José M. Sánchez Ron, *Energía nuclear en España. De la JEN al CIEMAT* (CIEMAT, Madrid 2001).
- [6] His doctoral theses were published as: *Algunas propiedades sencillas de la luz absorbida por ciertos cuerpos cristalinos* (Imprenta de la Casa de la Caridad, Barcelona 1905); *Condiciones para que un hilo homogéneo flexible, inextensible e inelástico, deslice según la curva que forma, esto es, para que todos sus puntos tengan por trayectoria la misma curva que realiza* (Imprenta de la Casa de la Caridad, Barcelona 1905).
- [7] Joan Bergós, *Tabicados huecos* (*Cuadernos de Arquitectura*, Colegio Oficial de Arquitectos de Cataluña y Baleares, Barcelona 1965), pp. 17–18; cited in Roca Rosell and Sánchez Ron, *Esteban Terradas. Ciencia y técnica en la España contemporánea*, *op. cit.*, p. 130.

- [8] His guardian (his father had died when Terradas was very young), who was his uncle, the priest Joseph Terradas, took the decision to send the young Terradas to study in Germany.
- [9] Aspects of Terradas' aeronautical activities are described in Antoni Roca Rosell and José M. Sánchez Ron, *Aeronáutica y ciencia* (INTA/Algaída, Madrid 1992).
- [10] Terradas was deeply interested in scientific terminology. While in the INTA he drew up a guide to translators (*Guía de traductores*, 1947), in theory the first of a series that never materialised. In his prologue Terradas wrote: "The following pages are designed to inform, in the strictest sense, translators, and in the wider sense, all those who feel tempted to sprinkle their Spanish with engineering and technology words from foreign languages. The information includes the etymology, semantics and a precise definition of each concept, as also the most appropriate term to represent the concept in our language." Cited in Roca Rosell and Sánchez Ron, *Esteban Terradas. Ciencia y técnica en la España contemporánea*, *op. cit.*, p. 313. See also Jaume Martí, "Terradas y su contribución a la terminología científica," *Quark*, No. 21 (Jan–Mar 2004), pp. 95–103.
- [11] For a general overview of the history of science in Spain, particularly in the nineteenth and twentieth centuries, see José M. Sánchez Ron, *Cinzel, martillo y piedra* (Taurus, Madrid 1999).
- [12] For a discussion of the importance for Spanish physics of international relations, see José M. Sánchez Ron, "International relations in Spanish physics from 1900 to the Cold War," *Historical Studies in the Physical and Biological Sciences* 33, 3–31 (2002).
- [13] Tullio Levi-Civita, *Qüestions de Mecánica clásica i relativista* (Barcelona, 1922); Jacques Hadamard, *Poincaré i la teoria de les equacions diferencials* (Barcelona, 1922), Hermann Weyl, *Mathematische Analyse des Raumproblems* (Berlin, 1923). Terradas' correspondence with Levi-Civita, which provides some useful details concerning the aims of the courses and preparation details, is reproduced in Pietro Nastasi and Rosanna Tazzioli (eds.), *Aspetti scientifici e umani nella corrispondenza di Tullio Levi-Civita (1873–1941)*, Quaderni P.RI.ST.EM, No. 12 (Palermo, 2000), pp. 411–421, and has been commented on by Antoni Roca Rosell and Thomas F. Glick in "Esteve Terradas (1883–1950) i Tullio Levi-Civita (1873–1941): una correspondència," *Dynamis*, 2 (1982), pp. 387–402. See Thomas F. Glick, *Einstein y los españoles* (Alianza Editorial, Madrid 1986), for an account of Einstein's visit to Spain in 1923.
- [14] E. Terradas, *Els elements discrets de la matèria i la radiació* (Publicacions de l'Institut de Ciències, Institut d'Estudis Catalans, Barcelona n.d.).
- [15] Esteban Terradas, "Sobre la mecánica estadística," *Actas I Congreso de la Asociación Española para el Progreso de las Ciencias (Zaragoza 1908)*, Vol. 2 (Imprenta de E. Arias, Madrid 1909), pp. 171–193; "Teorías modernas acerca de la emisión de la luz", *Actas I Congreso de la Asociación Española para el Progreso de las Ciencias (Zaragoza 1908)*, Vol. 3 (Imprenta de E. Arias, Madrid 1909), pp. 291–311; *Sobre la emisión de radiaciones por cuerpos fijos en movimiento*, *Memorias de la Real Academia de Ciencias y Artes de Barcelona* 7 (1909), pp. 419–462, reproduced in *Esteban Terradas*, Roca Rosell (ed.), *op. cit.*, pp. 73–120. For an account of the role of Terradas in introducing quantum physics to Spain, see Antoni Roca Rosell, "L'impacte de la hipòtesis quàntica a Catalunya," in Santiago Garma (ed.), *El científico español ante su historia* (Diputación Provincial de Madrid, Madrid 1980), pp. 383–387, and José M. Sánchez Ron, "La ciencia española se internacionaliza: la introducción de la teoría cuántica en España (1908–1909)", in *Cinquanta anys de ciència i tècnica Catalunya* (Institut d'Estudis Catalans, Barcelona 1987), pp. 71–88.
- [16] Terradas had had the opportunity to attend a talk given by Lorentz during the Fourth International Congress of Mathematics held in Rome in April 1908. The title of Lorentz' talk was "Le partage de l'énergie entre la matière pondérable et l'éther" (reproduced in H. A. Lorentz, *Collected Papers*, Vol. VII [Martinus Nijhoff, La Haya 1934], pp. 317–343)
- [17] Albert Einstein, "Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt," *Annalen der Physik* 17, 132–148 (1905).
- [18] Peter Debye, "Zur Theorie der spezifischen Wärme," *Annalen der Physik* 39, 789–839 (1912); p. 789.
- [19] Albert Einstein, "Die Plancksche Theorie der Strahlung und die Theorie der spezifische Wärme," *Annalen der Physik* 22, 180–190 (1907). For further details on the Einstein of 1907 and Nernst and Debye's contributions, see José M. Sánchez Ron, *Historia de la física cuántica. I. El período fundacional (1860–1926)* (Crítica, Barcelona 2001), pp. 184–190.
- [20] Esteban Terradas, *Lecciones sobre física de materiales sólidos* (Academia Militar de Ingenieros Aeronáuticos, Madrid 1943–1945), an article in three parts. This article has been studied by Carles Gámez Pérez: "Esteban Terradas y los inicios de la docencia de la mecánica cuántica en España: las 'Lecciones sobre física de materiales sólidos' de la Academia Militar de Ingenieros Aeronáuticos", in Roca Rosell (coord.), *Esteban Terradas (1883–1950). Ingeniería, arquitectura y ciencia en el siglo XX*, *op. cit.*, pp. 175–195.
- [21] See, for example, Blas Cabrera, "Paramagnetismo, estructura del átomo y clasificación periódica," *Revista de la Real Academia de Ciencias Exactas, Físicas y Naturales* 23, 177–246 (1926); *El átomo y sus propiedades electromagnéticas* (Editorial Páez, Madrid 1927); and *¿Qué es la materia?* (Escuela Especial de Ingenieros Agrónomos, Madrid 1934;).

- [22] Terradas had already been to Argentina in 1927 as a guest of the Spanish Cultural Institute, which had founded a chair, in 1914, to be occupied during a few months each year by outstanding Spanish scholars and intellectuals. See Roca Rosell and Sánchez Ron, *Esteban Terradas. Ciencia y técnica en la España contemporánea*, *op. cit.*, Ch. IV.
- [23] Cited in Eduardo Ortiz, Antoni Roca Rosell and José M. Sánchez Ron, "Ciencia y técnica en Argentina y España (1941–1949), a través de la correspondencia de Julio Rey Pastor y Esteban Terradas," *Llull* 12, 33–150 (1989); p. 114.
- [24] See Eduardo L. Ortiz, "Terradas y la Comisión Argentina del Arco de Meridiano: oceanografía en el Atlántico Sur", in Roca Rosell (coord.), *Esteban Terradas (1883–1950). Ingeniería, arquitectura y ciencia en el siglo XX*, *op. cit.*, pp. 101–139.
- [25] Esteban Terradas, "Hélices de avión", *Publicaciones de la Universidad: Extensión Universitaria* 21, No. 7 (1938), 40 pages; reproduced in *Esteban Terradas*, Roca Rosell (ed.), *op. cit.*; pp. 281–320.
- [26] Cited in Ortiz, Roca Rosell and Sánchez Ron, "Ciencia y técnica en Argentina y España (1941–1949)," *op. cit.*; p. 106.
- [27] Terradas's relationship with INTA is described in José M. Sánchez Ron, *INTA. 50 años de Ciencia y Técnica Aeroespacial*, *op. cit.* See also José M. Sánchez Ron, "Terradas y la aeronáutica," in Roca Rosell (coord.), *Esteban Terradas (1883–1950). Ingeniería, arquitectura y ciencia en el siglo XX*, *op. cit.*, pp. 153–173.
- [28] "We shall create in Torrejón de Ardoz", he wrote in May 1943 to Rey Pastor, "an aerodynamics and engine-testing laboratory of up to 4,000 horsepower at 18 kms. altitude; there will be several tunnels each with different powers, from twin 500 HP and 75 kms. per hour wind speed, up to 25,000 and 48,000 HP with speeds of 100 and 300 metres per second. The aerodrome will have runways for flight tests." He added that he himself was working on "plans for an aerodynamic tunnel." Cited in Ortiz, Roca Rosell and Sánchez Ron, "Ciencia y técnica en Argentina y España (1941–1949)," *op. cit.*; p. 111. Moreover, on the 19th of September 1944, until a suitable appointee was found, Terradas took on, in addition to his responsibility on the Board, the post of Head of the Engines Department, in whose building he always had his office.
- [29] Copy deposited in the Terradas Archives at the Institut d'Estudis Catalans; cited in Roca Rosell and Sánchez Ron, *Esteban Terradas. Ciencia y técnica en la España contemporánea*, *op. cit.*, p. 282. For a description of the Terradas Archives, see Rosa Soler Mòdena, *Catàleg del fons bibliogràfic Esteve Terradas* (Institut d'Estudis Catalans, Barcelona 1994).
- [30] Statement made by Terradas on July, 23, 1945, at his return to Madrid. Original deposited at the Terradas Archives, Institut d'Estudis Catalans, Barcelona.
- [31] Cited in Ortiz, Roca Rosell and Sánchez Ron, "Ciencia y técnica en Argentina y España (1941–1949)," *op. cit.*; p. 139.
- [32] The minutes referred to are deposited at the INTA campus at Torrejón. These minutes, as well as other documents mentioned elsewhere in this text, are cited extensively by J. M. Sánchez Ron, *INTA. 50 años de Ciencia y Técnica Aeroespacial*, *op. cit.*
- [33] Many of these conferences, including presentations by Terradas, were subsequently published by the INTA.
- [34] Santiago Ramón y Cajal, "La media ciencia causa de ruina," *El Liberal*, 26 October 1898; reproduced in García Durán Muñoz and Julián Sánchez Duarte (comps.), *La psicología de los artistas. Las estatuas en vida y otros ensayos inéditos o desconocidos de Santiago Ramón y Cajal* (Vitoria 1945), pp. 117–122.
- [35] José Rodríguez Carracido, "Contestación" to the inaugural address by Juan Fages Virgili before the Royal Academy of the Sciences of Madrid: *Los químicos de Vergara y sus obras* (Real Academia de Ciencias Exactas, Físicas y Naturales, Madrid 1909), p. 113.
- [36] "Discurso de contestación por el académico numerario Dr. D. Esteban Terradas", in Paulino Castells y Vidal, *Las representaciones mecánicas de los fenómenos eléctricos, Memorias de la Real Academia de Ciencias y Artes de Barcelona X*, 347–373 (1913); p. 372.
- [37] Esteban Terradas, *Integrales de Fourier-Stieltjes (Examen de estudios recientes): Discurso leído en la solemne inauguración del curso académico de 1930 a 1931*. Universidad de Madrid (Imprenta Colonial, Madrid 1930), pp. 7–8; reproduced in *Esteban Terradas*, Roca Rosell (ed.), *op. cit.*, 235–278.
- [38] J. Rey Pastor, "Contestación", *op. cit.*, p. 152.
- [39] The dedication by Weyl to Terradas reads as follows (in English translation): "D. ESTEBAN TERRADAS. To a dear friend! Please accept this book –a fond reminder of a wonderful stay in Barcelona last March that was primarily due to you– as a mark both of my gratitude, great affection and highest regard for you personally, and my admiration for the constructive work performed by you and your colleagues in the service of technology, science and teaching in Catalonia. I do not believe I have ever felt such harmony, finding only good will and enthusiasm, a clear picture of the necessary and the possible, and down-to-earth energy. Your work has had a rich, many-sided, and fruitful impact on the things and people in your environment, contributing among other things to the progressive cultivation of freedom and independence. May the fruits of a rich harvest follow!"