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EVOLUTION OF (AERO)SPACE ENGINEERING STUDIES IN ITALY IN THE PAST 20 YEARS

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Abstract

The paper presents the evolution and trends in the Master's-level studies in aerospace engineering in Italy, looking at the past 20 years. In the year 2000, a major reform of the higher education in engineering took place in Italy, with the introduction of the so-called 'Bologna system' and the clear separation of Bachelor's and Master's degree studies. With this reform, a relatively high flexibility was given to universities to define their programme structures. The ministerial rules defined only broad subject areas within which courses and credits should be allocated. This reform allowed the diversification of the educational profile within each university and, even more relevant, allowed the creation of mobility across the country between Bachelor's and Master's study programmes. The paper will show the basic facts and figures in the six Italian universities participating in the Partnership of a European Group of Aeronautics and Space UniversitieS (PEGASUS) network (*Politecnico di Milano, Politecnico di Torino, Università di Pisa, Università degli Studi di Napoli 'Federico II', Sapienza Università di Roma* and *Alma Mater Studiorum – Università di Bologna*), elaborating on the impact of the potential workforce for the sector. Data have been collected from the official open data repository of the Italian Ministry of University, supplemented by information provided by the six universities under analysis. The comparative analysis shows two major results: the positive impact of the reform on the overall Italian higher education and, specifically, a greater appreciation of the aerospace curricula proposed in accordance with the new system.

Keywords: aerospace engineering education; aerospace master; space engineering
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1. INTRODUCTION

Aerospace engineering, one of the most advanced technological industrial sectors, requires a specific professional figure capable of adapting to the continuous and rapid evolution of the state of the art of aerospace sciences and technologies. In this context, graduates must be trained with a solid background in the basic disciplines, in the primary disciplines of industrial engineering and in those characterising the aerospace sector, allowing them to carry out design, verification and management of complex systems that operate within (aeronautical) or outside (space) the atmosphere. This vision and approach to the education of aerospace engineers is common in the Italian universities providing Master's-level education in aerospace engineering, in particular in the six universities that are members of the Partnership of a European Group of Aeronautics and Space UniversitieS (PEGASUS) network of excellence in the field of aerospace engineering. These are *Politecnico di Milano, Politecnico di Torino, Università di Pisa, Università degli Studi di Napoli 'Federico II', Sapienza Università di Roma* and *Alma Mater Studiorum Università di Bologna*. In the past 2 decades, stimulated by the growth of the space activities and owing to the possibilities offered by a major reform in the Italian university study courses, the six universities developed specific curricula for the domain of space engineering, gradually creating specific competences for the sector and differentiating them from a generic aerospace curriculum. This new approach to aerospace education has, for sure, caught the attention of students, with a remarkable increase in their number, and will hopefully better serve the needs of the corresponding job market.

The objective of this paper is to provide some details of how the curricula have been developed for the sector in the six universities, showing commonalities and differences and providing reference figures on the attractiveness for students.

The analysis conducted in this paper has been made possible as a result of data collected from the official open data repository of the Italian Ministry of University and supplemented by information provided by the six universities under analysis. In particular, data on the student population are collected yearly by the Italian Ministry and include academic and gender information. The six universities under analysis have instead provided detailed information on the available curricula and on the student distribution among curricula. Additional data on geographical distribution, financial status and high school background have not been collected, even if available, since this level of detail is beyond the scope of the present analysis.

2. EVOLUTION OF THE NATIONAL SYSTEM

With specific legislative actions in years 1999, 2008 and 2010 (*Legge* 240/2010), the university study courses in Italy were reformed, with the introduction of the so-called 32 graduation system, i.e. the creation of the 3-year degree (first-level degree or *Laurea*) and the successive 2-year degree (second-level degree, subsequently called *Laurea Magistrale*). Hence, in Italy, the replacement of the traditional 5-year graduation tracks has been early (it started in 2000), leading to a strict 32 scheme based of the sequence of the *Laurea* (L) and *Laurea Magistrale* (LM) degrees. In general, the third year of the *Laurea* course is offered in two different versions to the students: a job-oriented one for those who consider the possibility of an immediate employment and a different one for those who aim to continue their studies inside the *Laurea Magistrale* courses. Graduates from the first path, however, can also be admitted to the second level provided they comply with specific admission requirements.

One of the novelties of the reform is the introduction of credits (CFU: *Credito Formativo Universitario*, also equivalent to the European Credit Transfer System [ECTS]). It is a unit of assessment of the work required by a student to learn what is required by the specific course. In practice, the system assigns for each course a score established based on the commitment necessary to pass the corresponding written and oral exams, to carry out work in different stages, to write homework papers, and so on. Each credit

corresponds to the hours that the student is deemed to spend at the university and individually at home to pass the exam ('1' credit usually equals 10 hours of frontal lectures or 25 hours of individual work). The average amount of work done by a student in an academic year is conventionally set at 60 credits. Therefore, acquiring a first-level degree will take 180 credits, and to reach a further second-level degree, an additional 120 credits are required.

Another novelty of the reform is the introduction of the so-called classes (*Classi di Laurea*). The classes constitute guidelines for university courses (for first- and second-level degrees) and outline precise information on the qualifying educational objectives, on the indispensable training/teaching activities and on the number of credits to be assigned to each of them. The student about to enrol at the university must know that the choice of the degree class towards which he/she is oriented is not the only one that he/she must choose within the same degree course. In fact, it is possible to follow different study paths owing to the student's freedom to identify the courses most consistent with their interests and employment prospects (optional courses) [1].

The reform also includes some guidelines for the implementation, in terms of the maximum number of credits that can be offered (mandatory electives) as a function of the student population, as well as the reference number of students for a single course (maximum should be 120 students for Master's-level courses). In practice, degrees with high number of students are entitled to offer a wide variety of elective modules and, in principle, should split the mandatory modules into several sub-courses, while degrees with a low number of students will have some limitation in the activation of elective courses.

The reform had, among others, the objective to make all Italian degrees more flexible and better structured, thus improving the attractiveness for students and increasing the number of graduates.

3. THE NEW (AERO)SPACE CURRICULA IN ITALY

Curricula falling into the aerospace engineering class need to fulfil the following conditions: at least 45 credits within the qualifying aerospace disciplines (these include Flight Mechanics, Aerospace Structures, Aerospace Systems, Fluid Mechanics, Aerospace Propulsion and Design Methods in Industrial Engineering), at least 12 credits in complementary disciplines (all other disciplines except those qualifying) and, in total, the number of teaching modules for each curriculum should not exceed 12 plus the final Master's thesis. Within these constraints, each university can design its own curriculum and structure it into a single track (with mandatory and elective courses), multiple tracks (with a mix of overall mandatory courses, mandatory courses per track and electives) or even multiple degrees (such as separate Aeronautical Engineering and Space Engineering, each with eventual tracks). The six Italian universities, which are members of the PEGASUS network [2], have implemented their Master's degrees with different structures, albeit adhering to the quality standards recommended within the network and proposed within a former H2020 project [3].

Figure 1 shows how the Master's degrees are structured in terms of mandatory credits, elective credits and credits assigned for the Master's thesis. It appears that universities with a smaller number of students offer fewer elective credits, which is consistent with a constraint imposed by the Italian Ministry, which links the number of overall credits (courses) offered to the student population[1,2,3,4,5,6].

[1] https://www.polimi.it/en/programmes/details/?anno=2021&campus=&corso=470
[2] https://didattica.polito.it/pls/portal30/sviluppo.offerta_formativa.corsi?p_sdu_cds=32:26&p_lang=EN
[3] http://aerospace.ing.unipi.it/magistrale/laurea-magistrale/
[4] http://aerospaziale.dii.unina.it/index.php/lm
[5] https://corsidilaurea.uniroma1.it/en/corso/2021/29396/home
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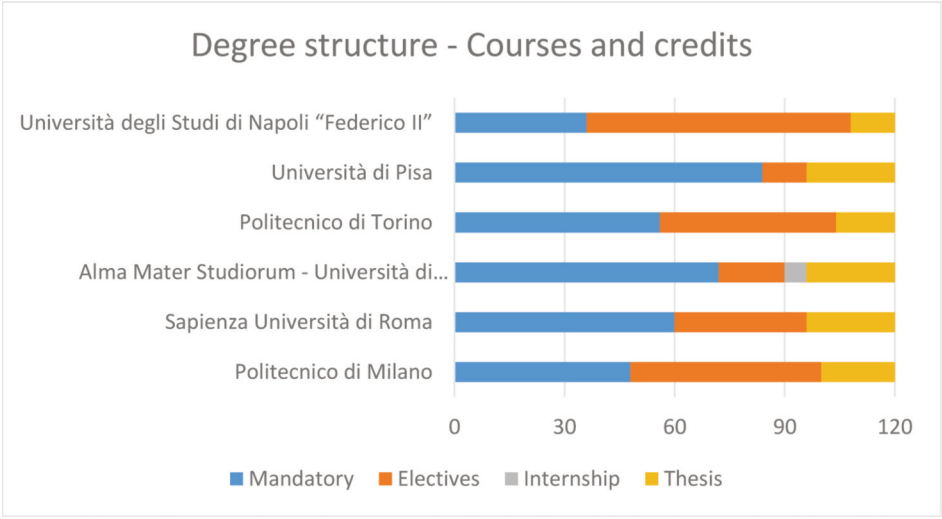

Figure 1. Structure of the Master's degrees in the Italian universities of the PEGASUS network. PEGASUS, Partnership of a European Group of Aeronautics and Space UniversitieS.

3.1. *Politecnico di Milano*

The educational offer in the aerospace field at the *Politecnico di Milano* foresees three cycles: Bachelor of Science (BSc) in Aerospace Engineering, Master of Science (MSc) in Aeronautical or Space Engineering and Doctor of Philosophy (PhD) in Aerospace Engineering.

Limiting the analysis to the MSc courses, mandatory courses common to all students are offered in the first year of the programme (the whole of Semester 1 and part of Semester 2, for a total of 48 credits for Space Engineering; and 40 credits for Aeronautical Engineering). The remainder of Semester 2, the whole of Semester 3 and part of Semester 4 are characterised by a wide and diversified educational offer, within which the student can identify, through the choice of courses, the educational path that best enhances his/her interests and attitudes. Elective courses total 54 credits, chosen among 30 available modules (13 in the core aerospace subjects and 17 distributed among other disciplines). The choice represents a motivating dimension for the students, who therefore acquire an active role in addressing their professionalisation, favouring the core aerospace disciplinary aspects or the multidisciplinary aspects, optimally reconciling their interests/attitudes. Some courses aimed at the acquisition and improvement of personal writing skills and technical presentation and introductory knowledge and skills in research are also proposed. The course ends with the defence of a Master's thesis, for which 20 credits are awarded[1].

To facilitate the students' choice in the context of the study programme offer, coherent and well-characterised educational pathways having specific training objectives are defined. In the Space Engineering degree, three paths are suggested, allowing students to focus more on space mission design, payload design and operation, or launchers. Study-abroad periods are encouraged and possible starting in Semester 2 of the Master's course. Students can select among 37 different universities and mobility ranging from one semester up to four semesters for some double-degree programmes.

3.2. *Politecnico di Torino*

The MSc study programme at *Politecnico di Torino* qualifies the following professional profile/s: Chief Engineer (this is the industry engineer profile, as emerging from the classical curricula in industrial engineering), System Engineer (the requested professional profile is an engineer who knows all elements

of the aircraft system and is able to fix the requisites to the providers of components), Research Engineer (this profile, particularly appreciated in an international context, has the characteristic to associate an attitude to the applications of the classical approach of scientific research), Specialist in construction and aerospace structures, Specialist in aerospace propulsion, Specialist in flight mechanics and aircraft systems and Specialist in Astronautics.

Master's-level graduates possess multidisciplinary awareness and specific competences (fluid dynamics and aerodynamics, lightweight structures, weight and material savings in design, familiarity with advanced materials and technologies, ability to envision whole systems, as well as sensitivity to safety and security issues) that can readily be applied in a range of jobs outside the aerospace sector, in which product and process innovation play a dominant role. European-level data show that about 50% of aerospace engineers are offered employment outside the aerospace industry, even in regions where aerospace activities are more strongly represented and offer the greatest employment opportunities.

The MSc programme is divided into several thematic blocks:

- Scientific and methodological complements: mainly focussed on applied mathematics and numerical methods;
- General aerospace engineering: it provides the knowledge base common to all Master's-level aerospace engineers (advanced flight mechanics, aerospace construction and structures, aerospace equipment and systems, aero- and gas dynamics and aerospace propulsion);
- Contextual knowledge/final examination: the former may be acquired during preparation of the thesis, especially if undertaken within an industry or abroad, or selective from optional courses offered by the university.

Within the MSc programme, there are also many opportunities for periods abroad ranging from 6 months to 18 months. Moreover, the MSc programme in Aerospace Engineering offers—to a selected number of students—the possibility to obtain also the foreign equivalent degree (double-degree agreements and mobility programmes)[2].

3.3. *Università di Pisa*

The Master's degree programme in Aerospace Engineering is intended to train specialised professionals capable of operating effectively in the design and management of aeronautical and space systems. First established in the late 1970s as Aeronautical Engineering, the Master's degree course has evolved during the following decades through the introduction of various electives, later consolidated in curricula. In the early 2000s, the educational offer was finally structured in two curricula, namely aeronautical and space. The course is a 2-year graduate programme with a mandatory basis of 120 ECTS credits. The aeronautical curriculum aims to train graduates qualified to carry out research, design and experimentation in the fields of structures, fluid dynamics and flight mechanics of aircraft and other aerial vehicles. The space curriculum is specifically intended to prepare specialised professionals able to effectively carry out the design and management of complex space systems, as well as to prepare students for further studies in the space engineering field. These objectives are pursued by providing a thorough education in the fields of propulsion, structures, flight mechanics of space vehicles, design of satellites and space missions, with emphasis on research and the experimental methods.

The aeronautical curriculum has three distinct paths: Flight Mechanics, Structures and Aerodynamics. The space curriculum offers a course of study entirely taught in English to Italian and international students. Within the Space curriculum, students have the choice between two groups of electives related to (i) Electric Propulsion and (ii) Remote Sensing and Telecommunications, respectively, totalling 12 credits each. Seminars by a number of Italian and international experts are offered throughout the academic year.

The Master's degree course is completed by a major individual activity in the second part of the second year, valued at 24 credits, in which the knowledge and methodologies acquired are further developed; students are encouraged to exploit national and international opportunities to carry out their thesis project in a company or in a research establishment[3].

3.4. *Università degli Studi di Napoli 'Federico II'*

The 'Bologna system' was, at its very beginning, interpreted in the Aerospace Engineering course as an opportunity for enlarging the educational offer since the Bachelor's degree came with several pathways from theoretical to simulation and industrial applications. Quite soon, it became evident that Bachelor's-level students need to be guided on the basic principles of the aerospace disciplines to help them in developing knowledge for selecting a specific field of their choice with maturity. The Bachelor's degree has been reformulated fixing most of the basic topics for all the aerospace disciplines and limiting the minimum number of credits for the Bachelor's thesis, also taking into account the almost total continuation to the consecutive Master's course. For this latter, one discipline was selected in each aerospace field (flight mechanics, structures, aerospace systems and fluid dynamics) to be mandatory, leaving to the Master's student the selection of the other courses with a broad range of opportunities for fulfilling the required syllabus. At the Master's level, the thesis gained an important number of credits, allowing the possibility to use a sufficient period to enter deeply into some specific topic. This organisation of both Bachelor's and Master's courses revealed its efficiency for a long time, allowing the students to smoothly gain the knowledge of the aerospace disciplines, being able to arrive at convinced and mature choices for their professional life. Many students also take the opportunity for studying abroad, based on the Erasmus programme and double-degree agreements, reporting positive feedback across Europe and the USA. Recently, we introduced a little modification of the course organisation, only at the Master's level, to become open towards a more multidisciplinary environment with a broader list of elective courses. Most of the aerospace graduates can find an engineering position right after their graduation. A restricted number of students apply for PhD positions offered by both the universities or external institutions, such as research centres, private companies, European programmes or foreign universities[4].

3.5. *Sapienza Università di Roma*

The educational offer in the aerospace field at *Sapienza Università di Roma* is structured as BSc in Aerospace Engineering, MSc in Aeronautical or Space and Astronautical Engineering and PhD in Aeronautical and Space Engineering. Moreover, second-degree professional Master's degrees in Satellites, Space Transportation Systems and Civil Aviation Management are also included in the offer.

Focussing on the MSc courses, both of the courses are organised in the first year (Semesters 1 and 2) based on mandatory courses, and the second year is characterised by a wide educational offer corresponding to two curricula for Aeronautical Engineering and five curricula for Space and Astronautical Engineering, including one international curriculum. Each curriculum delivers a coherent and well-characterised educational pathway with specific objectives and enables the student's easier choice of the path that best enhances his/her own attitudes.

The first year totals 54 credits for Aeronautical Engineering and 60 credits for Space and Astronautical Engineering (except the international curriculum, which totals 54 credits). In the second year, the student can identify, through the choice of elective courses, his/her specific path within the pathways identified by the academic council. Elective courses total 42 credits, chosen among 27 available modules for Aeronautical Engineering. For Space and Astronautical Engineering, elective courses total 36 credits, chosen among 31 available modules.

Globally, the courses include modules that allow the students to build their personal professional core and allow them to improve personal soft skills such as writing, technical presentation and teamwork. The courses end with the defence of a Master's thesis, for which 23 credits are awarded.

Study-abroad periods are encouraged starting in Semester 2 of the Master's course. Students can select from among different universities and mobilities ranging from one semester up to two semesters for some double-degree programmes[5].

3.6. *Alma Mater Studiorum – Università di Bologna*

At the University of Bologna, the current teaching scheme for the first and second cycles of the degrees in Aerospace Engineering was finalised in the academic year (a.y.) 2013–2014, with a BSc in Aerospace Engineering (delivered in Italian) and a MSc in Aerospace Engineering (entirely delivered in English). Starting from the a.y. 2020–2021, the MSc in Aerospace Engineering offers two curricula: Aeronautics and Space. Moreover, in the same a.y., a new PhD course in 'Aerospace Science and Technology' was established, thus completing—with the third cycle level—the educational chain dedicated to aerospace.

Focussing on the MSc degree, with the activation of distinct curricula for Aeronautics and Space, the main goal and expected learning outcomes do not vary, but the aeronautical and astronautical engineer professional profiles are more defined. They both have solid backgrounds and apply analytical tools, numerical simulation techniques and experimental laboratory methods. Professionally, graduates will be able to produce physical/mathematical models to analyse aircraft and spacecraft requirements and performance and the physical environment they move in. They may also study advanced methods for air traffic monitoring and control using information processing and telecommunication systems in aerospace environments.

These learning outcomes are achieved through a learning programme, which, based on a solid background in physics and mathematics, is completed in this second cycle of the degree programme through some specific course units, with the acquisition of professional and operative skills in all specific disciplines of Aerospace Engineering, and in particular, aerodynamics, flight mechanics, aerospace structures and materials, propulsion and aerospace systems; through two new proposed distinct curricula, students will be able to complete their preparation in the field of space technologies or in the field of aeronautical technologies. This is achieved through 30 credits (five examinations) that are specific to each distinct curriculum and three additional examinations (18 credits) of elective courses to be selected among 15 available modules. The course ends in the fourth semester with an internship ('6' credits) and a major thesis activity (24 credits)[6].

4. ATTRACTIVENESS AND STUDENT POPULATION

The reorganisation of the Master's degrees in Italy started in the year 2010, and it can be safely stated that the transition to the newest regulations is now complete in all universities. It is therefore possible to analyse the effects on the student population. The analysis considers data openly available and retrieved from the open data archive of the Italian Ministry of University and Research[7].

In terms of output (graduates), it can be noted that the increase in the number of graduates from Italian universities has increased (15% in the period 2015–2020; see Fig. 2), thereby achieving one of the objectives of the reform. It is unfortunately still true that the number of graduates in Italy is still lower than the European average, but the situation is improving. It is also true that the studies in aerospace engineering have experienced a much greater increase in the student population over the same period

[7] http://ustat.miur.it/opendata/

(51% in the period 2015–2020; see Fig. 3). This is most probably due to several factors, among which the fascination for the subject is relevant, but also because aerospace engineering degrees have been reorganised in order to combine in the best possible way the learning objectives and the needs of the job market, thus generating an even higher attractiveness compared to other subjects.

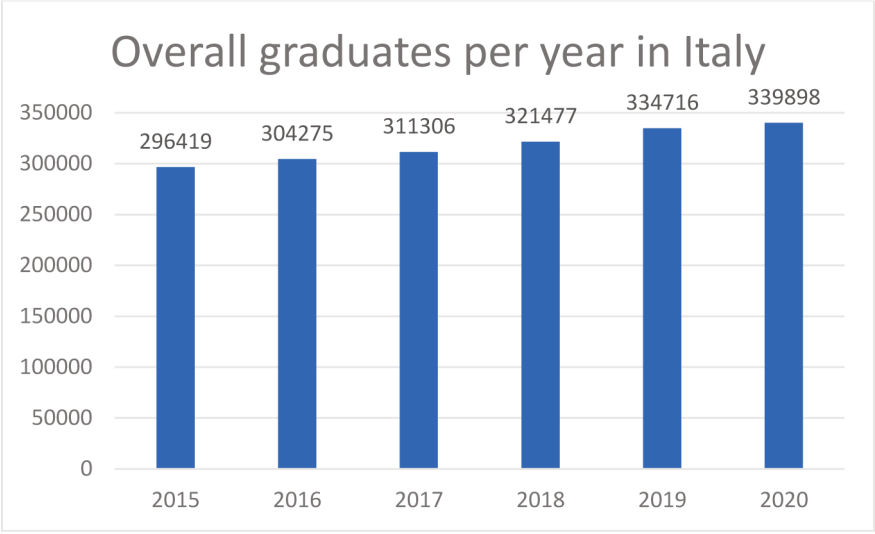

Figure 2. Number of graduates from Italian universities.

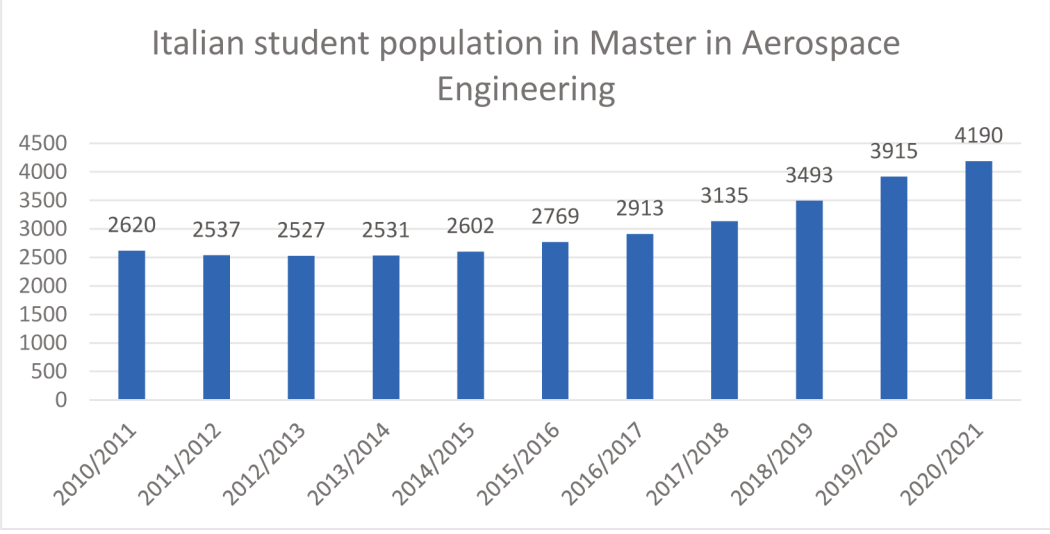

Figure 3. Italian student population in the Master's course in aerospace engineering.

It should be also remarked that the number of graduates in aerospace engineering has increased with the same overall trend, but it is slightly less than the increase in the overall student population (44% in the period 2015–2020; see Figs. 4 and 5). Moreover, it can be noticed that the number of graduates is far less than half the student population, even considering a 2-year lag between the two numbers. This is a clear indication that the nominal duration of the Master's course, 2 years, is still much lower than

the average time-to-graduation for students, which is in fact—on average—in the order of 3 years. Further, it must be considered that the overall student population reported in Fig. 3 includes full-time as well as part-time students.

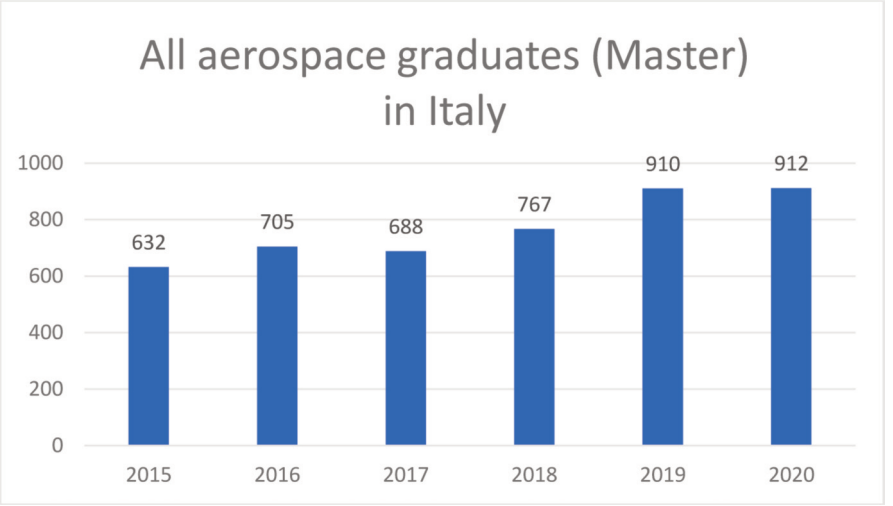

Figure 4. Aerospace engineering graduates in Italy.

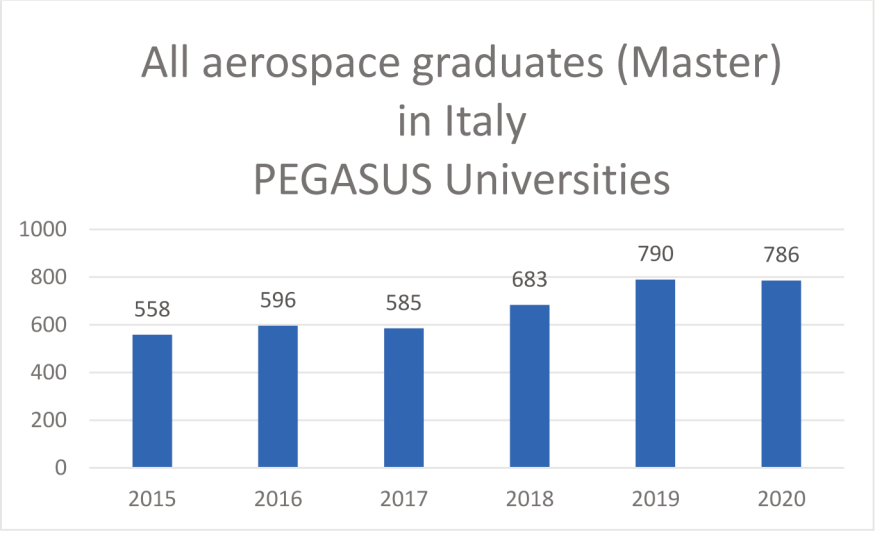

Figure 5. Aerospace engineering graduates in the six Italian PEGASUS universities. PEGASUS, Partnership of a European Group of Aeronautics and Space UniversitieS.

As evident from Figure 6, the distribution of students among the different universities offering Master's courses in aerospace engineering has changed over the years. The greatest increase in student numbers is concentrated in the two purely technical universities, *Politecnico di Milano* and *Politecnico di Torino*, which have seen a growth, respectively, of 105% and 92% in the period 2015–2020. The other universities have registered either a stable or a slight increase in student population.

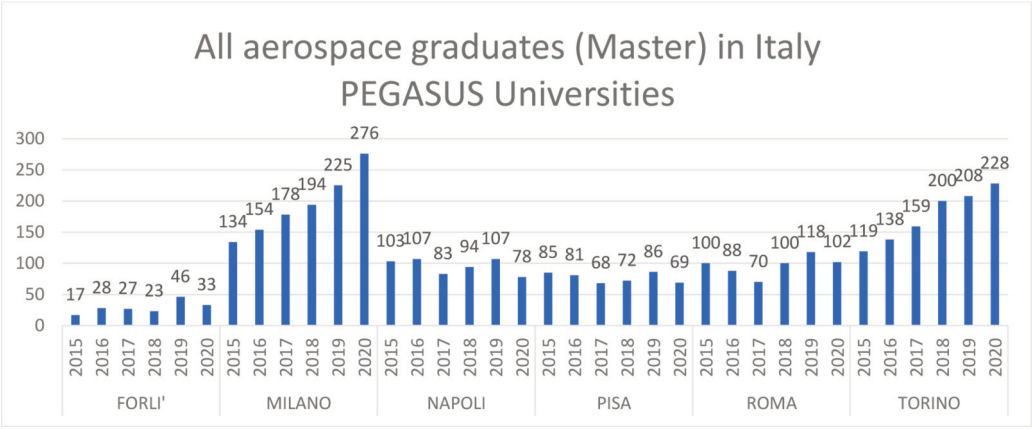

Figure 6. Aerospace engineering graduates in the six Italian PEGASUS universities. PEGASUS, Partnership of a European Group of Aeronautics and Space UniversitieS.

For some universities, either due to a specific Master's degree in Space Engineering or a clearly identifiable space track in the Aerospace Engineering Master's course, the interest for space engineering among students is appreciated in Figure 7. At the national level, the increase in the number of graduates in the period 2015–2020 is close to 150%.

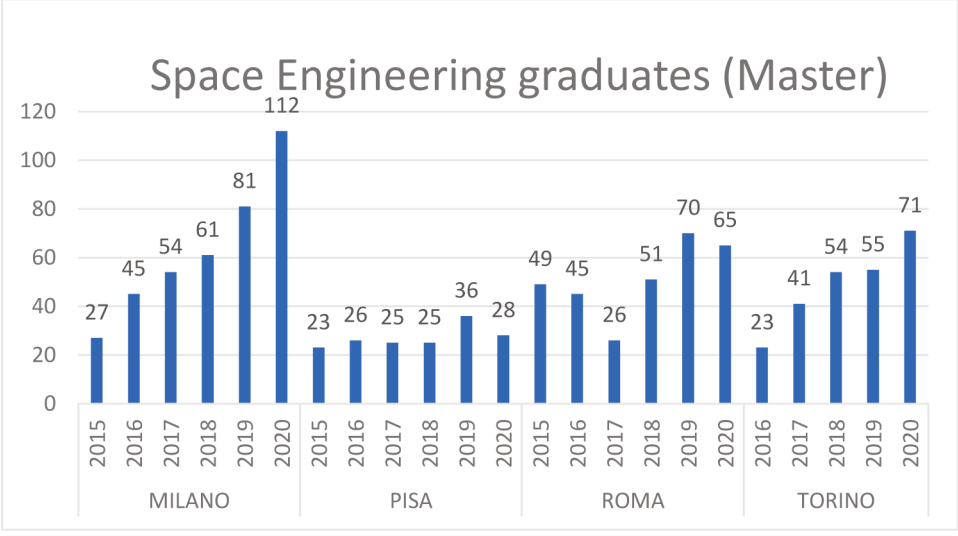

Figure 7. Space engineering graduates in four of the Italian PEGASUS universities. PEGASUS, Partnership of a European Group of Aeronautics and Space UniversitieS.

One last statement can be made concerning the gender balance in the student population, which remains far below the natural potential, as seen from Figure 8. Despite a continuous increase in the past 3 years, the female student population remains on average at 18%, a number that should be increased further and for which most universities are now taking specific actions.

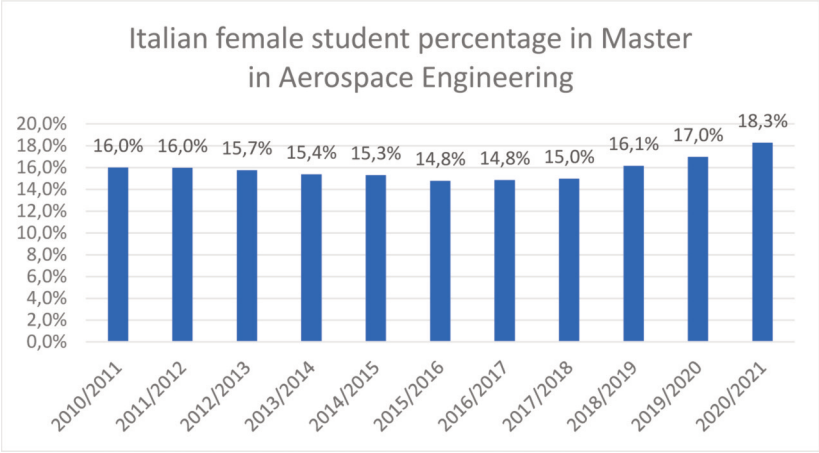

Figure 8. Female student population in aerospace engineering courses in Italy.

5. CONCLUSIONS

The past 20 years have seen an important reform of the university studies in Italy, essentially introducing greater flexibility and allowing individual universities to tailor their educational offer to their specific objectives, student population and job market needs. Regarding the Master's courses in aerospace engineering, and more specifically, the space-oriented tracks, this flexibility has been implemented with success and has attracted a greater student population. The trend towards the increase in the attractiveness is still evident and looks promising in view of the presumed increasing needs of the corresponding job market.

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