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

AerospaceEurope Conference2021
WARSAW, POLAND | 23 -26 NOVEMBER 2021
CEAS Council of European Aerospace Societies

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Abstract

The paper presents the evolution and trends in the Master studies in aerospace engineering in Italy, looking at the last 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 and Master studies. With this reform, a relatively high flexibility was given to universities to define their program structures. The ministerial rules defined only broad subject areas within which courses and credits should be allocated. This reform allowed to diversify the educational profile within each University and, even more relevant, allowed to create mobility across the country between Bachelor and Master study programs. The paper will show the basic facts and figures in the 6 Italian Universities participating in the PEGASUS network (Politecnico di Milano, Politecnico di Torino, Università di Pisa, Università degli Studi di Napoli "Federico II", Sapienza Università di Roma, Alma Mater Studiorum - Università di Bologna), elaborating on the impact of the potential workforce for the sector.

Keywords: aerospace engineering education, aerospace master, space engineering.

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 characterizing the aerospace sector, allowing them to carry out design, verification and management of complex systems that operate internally (aeronautical) or externally (space) to the atmosphere. This vision and approach to the education of aerospace engineers is common in the Italian Universities providing Master-level education in aerospace engineering, in particular in the 6 Universities that are members of the 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 last two decades, stimulated by the growth of the space activities and thanks to the possibilities offered by a major reform in the Italian university study courses, the 6 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 5 Universities, showing commonalities and differences and providing reference figures on the attractiveness for students.

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 3+2 graduation system, i.e. the creation of the three-year degree (first level degree or Laurea) and the successive two-year degree (second level degree, subsequently called Laurea Magistrale). Hence, also in Italy the replacement of traditional 5 years graduation tracks has been early (it started in 2000) leading to a strict 3+2 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 ECTS: European Credit Transfer System). 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 stages, to write homework papers, ... 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, to acquire a first level degree it will take 180 credits and to reach a further second level degree, additional 120 credits.

Another novelty of the reform is the introduction of the so-called classes (Classi di Laurea). The classes constitute containers of 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 enroll at university must know that the choice of the degree class towards which to address 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 thanks to the student's freedom to identify the courses most consistent with their interests and employment prospects (optional courses) [1].

The reform has also included some guidelines for the implementation, in terms of maximum number of credits that can be offered (mandatory + electives) as a function of the student population, as well as reference number of students for a single course (maximum should be 120 students for Master-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 mandatory modules in 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 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 fulfill 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 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 6 Italian Universities members of the PEGASUS network [2] have implemented their Master 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 degrees are structured in terms of mandatory credits, elective credits and credits assigned for the Master thesis. It appears that Universities with a smaller number of students are offering less elective credits, which is consistent with a constraint imposed by the Italian Ministry that links the number of overall credits (courses) offered to the student population [4, 5, 6, 7, 8, 9].

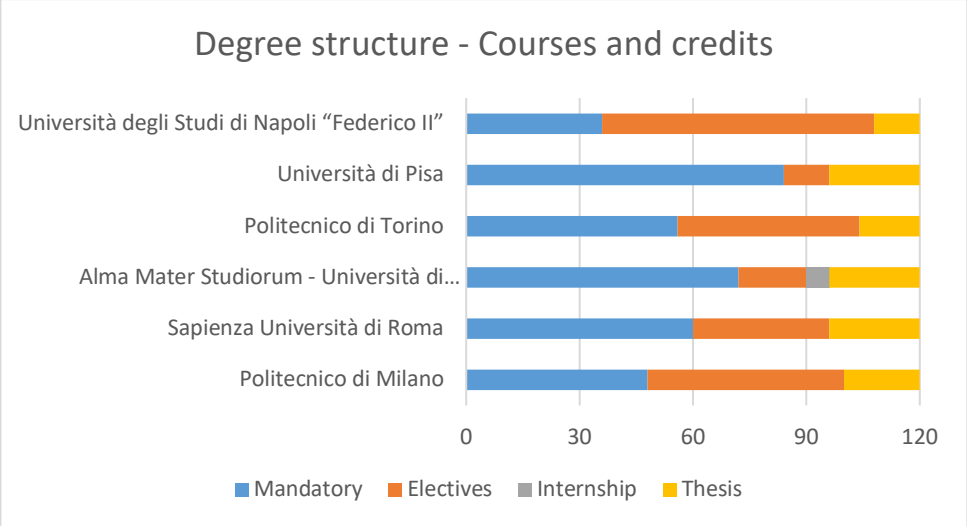

Figure 1 – Structure of Master degrees in the Italian Universities of the PEGASUS network

3.1 Politecnico di Milano

The educational offer in the aerospace field at the Politecnico di Milano foresees three cycles, Bachelor of Science in Aerospace Engineering, Master of Science in Aeronautical or Space Engineering and PhD in Aerospace Engineering.

Limiting the analysis to the Master of Science courses, mandatory courses common to all students are offered all in the first year of the Programme (the whole semester 1 and part of semester 2, for a total of 48 credits for Space Engineering and 40 credits for Aeronautical Engineering). The completion of semester 2, the whole semester 3 and part of semester 4 are characterized 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 interests and attitudes. Elective courses total 54 credits, chosen among 30 available modules (13 in the core aerospace subjects and 17 distributed in other disciplines). The choice represents a motivating dimension for the students who therefore acquire an active role in addressing their professionalization, 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 thesis, for which 20 credits are awarded [4].

To facilitate the students' choice in the context of the Study Program offer, coherent and well-

characterized educational pathways are defined having specific training objectives. In the Space Engineering degree 3 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 on semester 2 of the Master. Students can select among 37 different Universities and mobility ranging from one semester up to 4 semesters for some double-degree programs.

3.2 Politecnico di Torino

The MSc study program 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 property to associate an attitude to the applications to the classical approach of the scientific research), Specialist in construction and aerospace structures, Specialist in aerospace propulsion, Specialist in flight mechanics and aircraft systems and Specialist in Astronautics.

Master-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, sensitivity to safety and security issues) that can readily be applied in a range of jobs outside the aerospace sector where 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 MSs program is divided into several thematic blocks:

- Scientific and methodological complements: mainly focused on applied mathematics and numerical methods;
- General aerospace engineering: it provides the knowledge base common to all Master-level aerospace engineers (advanced flight mechanics, aerospace construction and structures, aerospace equipment and systems, aero-gasdynamics and aerospace propulsion);
- Contextual knowledge/final exam: 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 program there are also many opportunities for periods abroad ranging from six to eighteen months. Moreover, the MSc program in Aerospace Engineering offers to a selected number of students the possibility to obtain also the foreign equivalent degree (double degree agreements and mobility programs) [5].

3.3 Università di Pisa

The Master Degree program in Aerospace Engineering is intended to train specialized professionals capable of operating effectively in the design and management of aeronautical and space systems. First established in the late 1970's as Aeronautical Engineering, the master degree course has evolved during the following decades through the introduction of various electives, later consolidated in curricula. In the early 2000's, the educational offer was finally structured in two curricula, namely aeronautical and space. The course is a 2-year graduate program 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 train specialized 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 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, 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 Electric Propulsion and to 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 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 [6].

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 degree with several pathways from theoretical to simulation and industrial applications. Quite soon it became evident that bachelor students need to be guided on the basic principles of the aerospace disciplines to help them developing knowledge for selecting specific field of their mature choice. The bachelor degree has been reformulated fixing most of the basic topics for all the aerospace disciplines and limiting to the minimum number of credits for the bachelor thesis, also taking into account the almost total continuation to the consecutive master 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 student the selection, in a broad range of opportunities, of the other courses for fulfilling the required syllabus. At the master level the thesis gained an important number of credits allowing the possibility to use a sufficient period to enter deeply in some specific topic. This organization of both bachelor and master courses revealed its efficiency for long time, allowing the students to smoothly gain the knowledge of the aerospace disciplines being able to operate convinced and mature choices for their professional life. Many students also take the opportunity for studying abroad, based on the Erasmus program and double degree agreements, reporting the positive feedback across Europe and USA. Recently we introduced a little modification of the course organization, only at master level, to open toward 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 applies for a PhD position offered both by the University or external institutions like research centres, private companies, European programs or foreign universities [7].

3.5 Sapienza Università di Roma

The educational offer in the aerospace field at Sapienza Università di Roma is structured in Bachelor of Science in Aerospace Engineering, Master of Science in Aeronautical or Space and Astronautical Engineering and PhD in Aeronautical and Space Engineering. Moreover, second degree professional Masters in satellites, in Space Transportation Systems and in Civil Aviation Management are also included in the offer.

Focusing on the Masters of Science courses, both of them are organized in a first year (semester 1 and 2) based on mandatory courses and a second year characterized by a wide educational offer corresponding to 2 curricula for Aeronautical Engineering and 5 curricula for Space and Astronautical Engineering, including 1 international curriculum. Each curriculum delivers a coherent and well-characterized educational pathway with specific objectives and makes the student’s choice of the path that best enhances his/her own attitudes easier.

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 which allow the students to build their personal professional core and allow them to improve personal soft skills like writing technical presentation team working.

The courses end with the defence of a Master thesis, for which 23 credits are awarded.

Study-abroad periods are encouraged starting on semester 2 of the Master. Students can select among different Universities and mobility ranging from one semester up to 2 semesters for some double-degree programs [8].

3.6 Alma Mater Studiorum - Università di Bologna

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

Focusing on the Master of Science degree, with the activation of the Aeronautics and Space distinct curricula, the main goal and expected learning outcomes do not vary, but the aeronautical and astronautical engineer professional figures are more defined. They both have solid background, 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 2nd cycle degree programme by some specific course units, 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 2 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 (5 exams) which are specific to each distinct curriculum and 3 additional exams (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) [9].

4. Attractiveness and student population

The reorganization of the Master 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 analyze 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 [10].

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 Figure 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 (+51% in the period 2015-2020, see Figure 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 reorganized 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.

It should be also remarked that the number of graduates in aerospace engineering has increased with the same overall trend but slightly less than the increase in overall student population (+44% in the period 2015-2020, see Figures 4 and 5). Also, it can be noticed that the number of graduates is far less than half the student population, even considering a two-year lag between the two numbers. This is a clear indication that the nominal duration of the Master, 2 years, is still much lower than the average time-to-graduation for students, that is in fact on average in the order of 3 years. Also, it must be considered that the overall student population reported in Figure 3 includes full-time as well as part-time students.

As evident from Figure 6, the distribution of students among the different Universities offering aerospace engineering Master courses 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, that 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.

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

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 last 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.

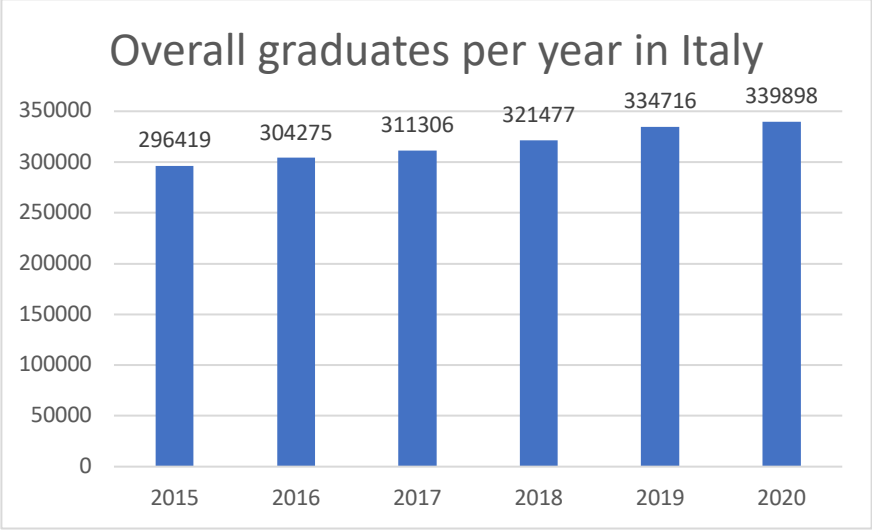

Figure 2 – Number of graduates from Italian Universities.

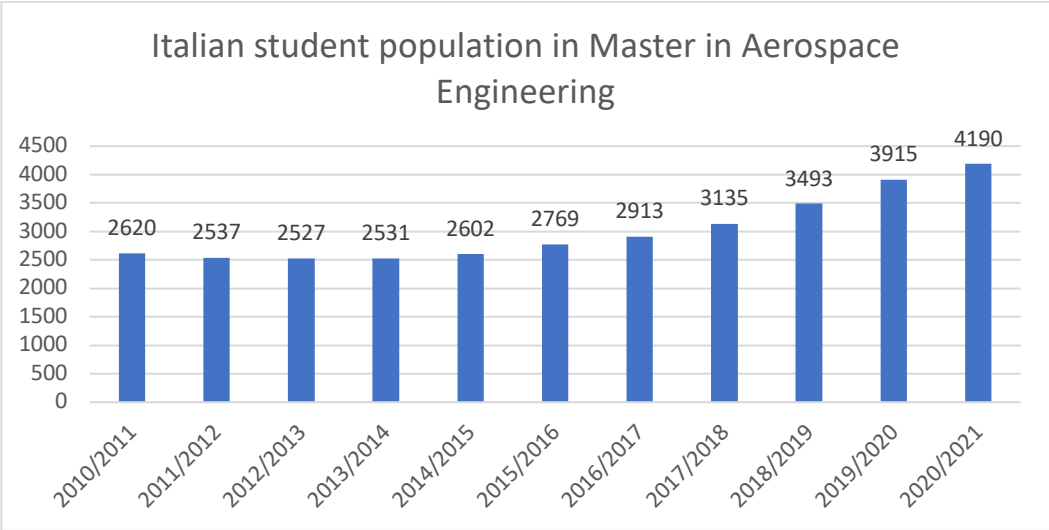

Figure 3 – Italian student population in aerospace engineering Master.

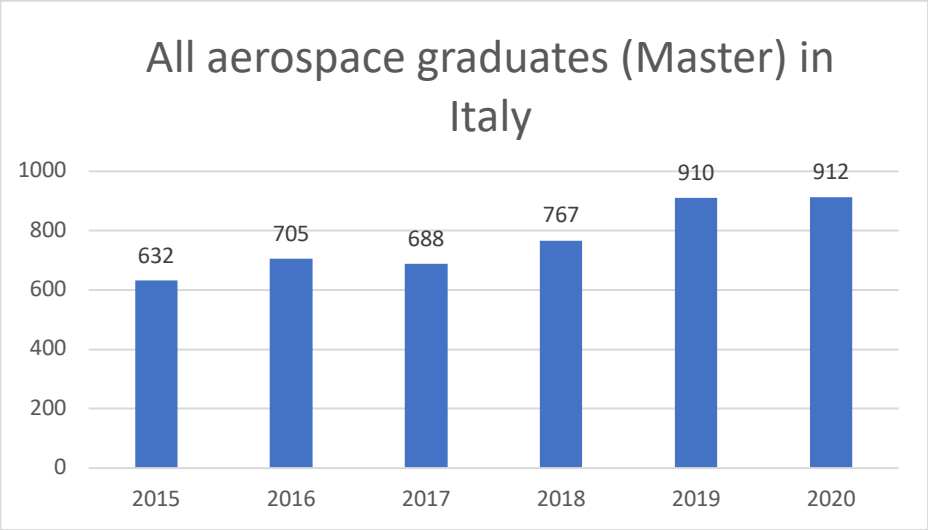

Figure 4 – Aerospace engineering graduates in Italy.

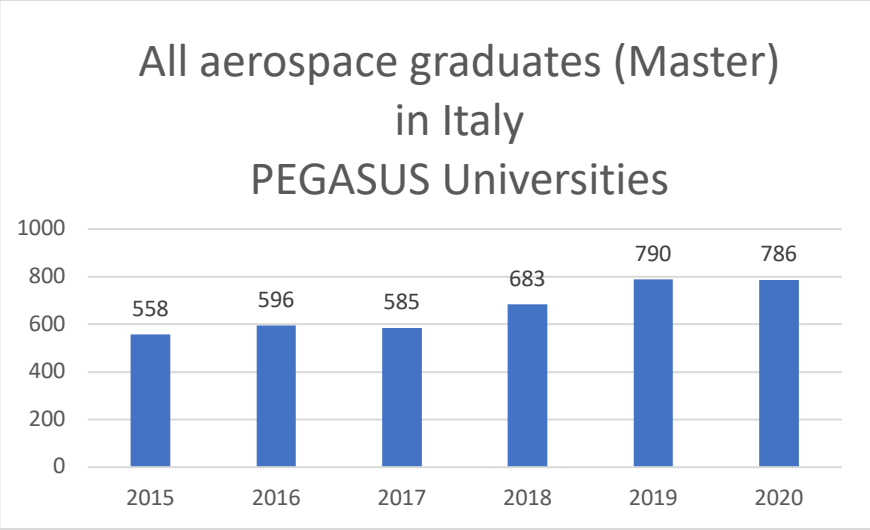

Figure 5 – Aerospace engineering graduates in the 5 Italian PEGASUS Universities.

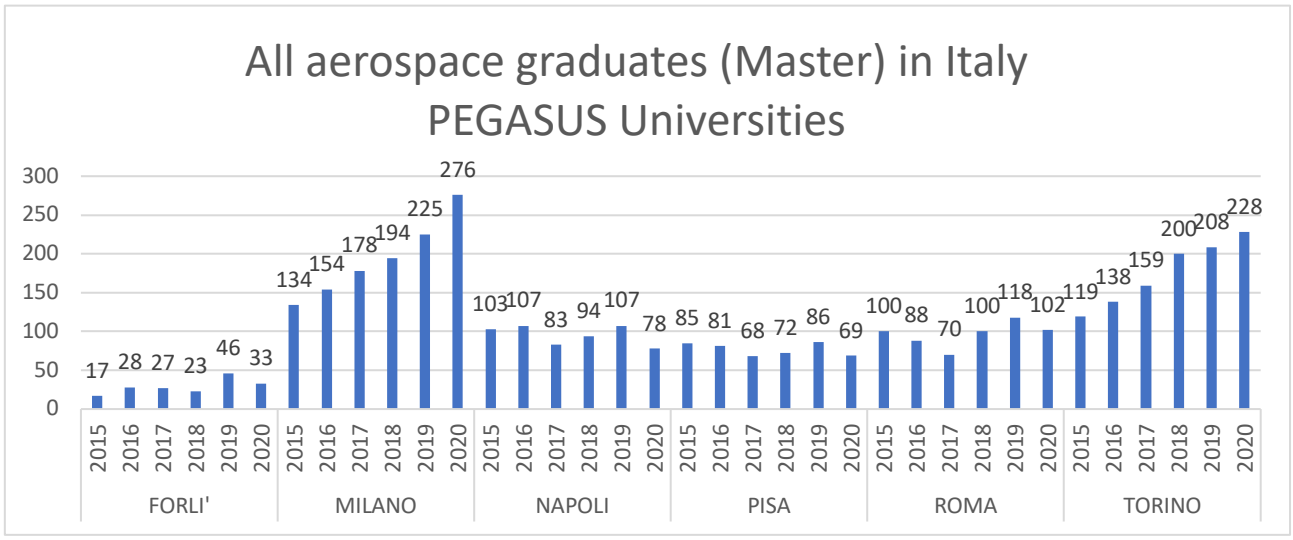

Figure 6 – Aerospace engineering graduates in the 5 Italian PEGASUS Universities.

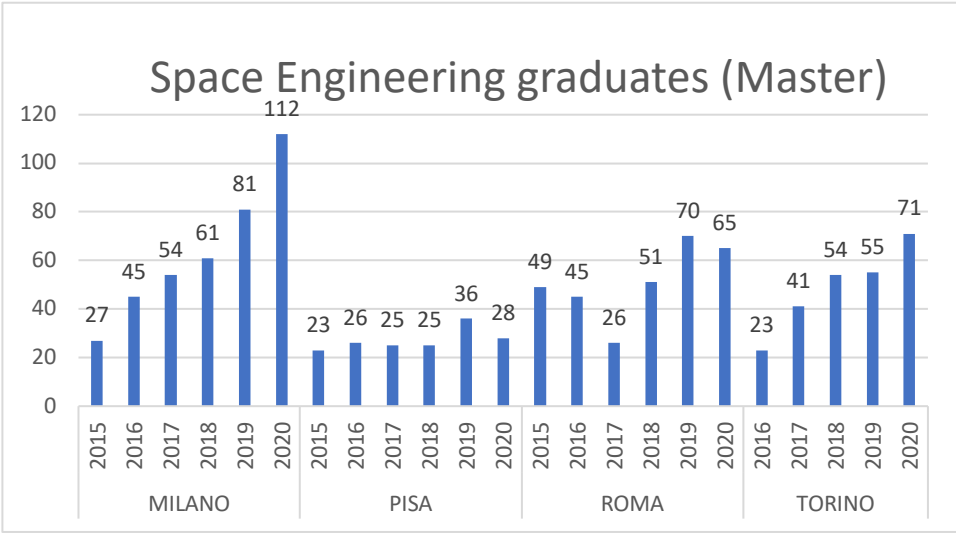

Figure 7 –Space engineering graduates in 4 Italian PEGASUS Universities.

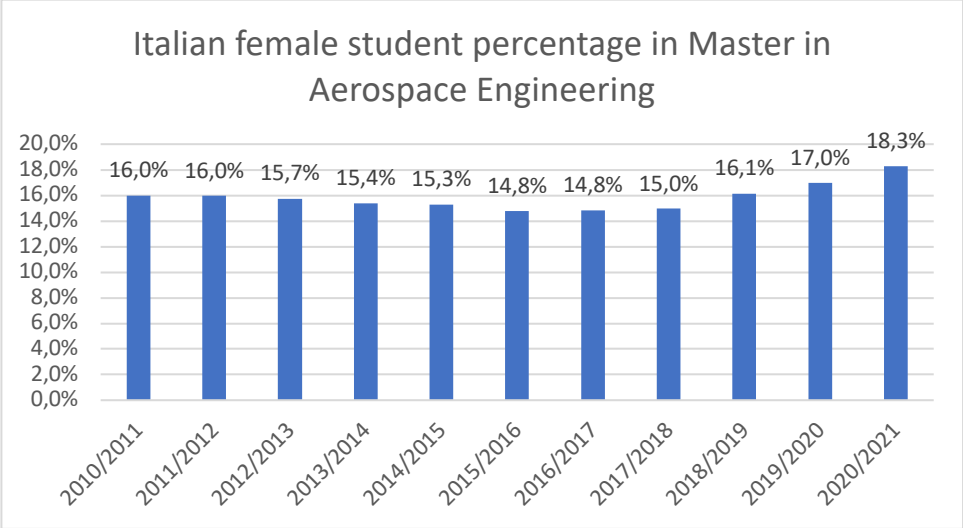

Figure 8 – Female student population in aerospace engineering in Italy.

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. For what concerns aerospace engineering master courses, and more in specific 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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7. Copyright Statement

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