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Work-in-Progress: A Complementary Training Program in Control and Automation Engineering and its Role in Undergraduate / Master's Program Integration

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Abstract

Federal grants have been supporting many Brazilian engineering master's students. The availability of these grants is dwindling, so universities on one hand and master's candidates on the other have been looking for alternatives to obtain master's degrees with less grant dependence/support. On the technical university side, this led to the emergence of options to start a master's program in the last semesters of the typical 10-semester undergraduate program. From the university's side and from the student's side it is interesting that such integrated effort is time and resource-efficient. To support this, at Instituto Tecnológico de Aeronáutica (ITA), a new Complementary Training Program (CTP) in Control and Automation Engineering was started in August 2021, serving mainly Mechanical, Electrical, Aeronautical, and Computer Engineering students. The standard goal of CTPs in Brazil is to extend the major undergraduate training in a similar way as a US minor does. Thus, the baseline purpose of the new program is to provide undergraduate students with a complementary education, transversal to engineering courses, which enables them to work as Control and Automation engineers, without the need for training supplementation after graduation. However, by offering a well-designed course choice, this program will also allow for: (a) extending the scope of undergraduate studies, and (b) deepening specific topics that are already part of the undergraduate curriculum. In the scope of the Institute's undergraduate and master's degree integration initiative, this second particularity (item b) may yield anticipated credits for a master's program. Specific features of the program may further benefit students aiming at a master's degree. This paper details the structure of the CTP and the gains expected in terms of incentives for the Institute's Mechanical-Aeronautical Engineering as well as the Electronics and Computer Engineering Master's Programs.

1 Introduction

This contribution is concerned with the implementation, the advantages, and the benefits expected from a Complementary Training Program (CTP) in Control and Automation Engineering in the context of undergraduate engineering education and the undergraduate / master's program integration at one of Brazil's major engineering schools, Instituto Tecnológico de Aeronáutica (ITA), located in São José dos Campos.

The creation of this CTP comes in line with the institution's recognized involvement in the advancement of industrial development through the fostering of engineering education in general and Control and Automation Engineering education in particular, which has been reported in publications on various aspects of the history of Brazilian engineering, e.g. [1].

Industrial development in Brazil became more relevant after World War II and one of the important events of this development was the creation of the ITA. It was one of the first higher educational Brazilian institutions inspired by American educational institutions, particularly the Massachusetts Institute of Technology (MIT). The Institute, i.e. ITA, started in 1950 as an Aeronautical and Electronics Engineering School, with few students. It became the seed for great and highly important educational transformations in Brazil since then, in undergraduate as well as graduate education. Graduate education in Brazil, inspired by the American Graduate Education Paradigm, started at ITA in 1961, and from then on completely changed the university education paradigm in the country, most visibly in the areas of Engineering. In 1953, Edward Wilson Kimbark (1902-1982) [2], the first Dean of ITA's Division of Electronics Engineering, taught the first course on automatic control in a Brazilian engineering school. His successor was Otto Joseph Mitchell Smith

(1917-2009) [3], who spent a few years teaching automatic control courses at the institution. In 1957, Luiz Valente Boffi (1917-2009) [4] came to ITA after earning a Ph.D. degree at MIT. He became the first national leader of control education in Brazil. He organized a group for education and research in automatic control at ITA; this was the first such group in the country. Several members of this group, as well as several graduates from the institution, took leading roles in key developments in Brazilian engineering education and the introduction and advancement of research and education in Control and Automation Engineering (for details see [1]).

In the mainstream international literature, one reference was found on the implementation of a CTP in the Brazilian context and the scope of the applicable legislation [5]. It reports the establishment of a CTP in Electrical and Computer Engineering in partnership with a large company (industry) from the Manaus Free Trade Zone, in the Brazilian Amazon. The goal there was "to meet the demand for trained human resources according to the (current) market interests and company needs."

The motivation and goals of the CTP addressed herein, which is not focused on one specific stakeholder from the industry, will be discussed in the next section. Section 3 of the paper describes the structure of the CTP. The resources available to the CTP are the subject of Section 4. Gains expected and conclusions are addressed in Sections 5 and 6 respectively.

2 Motivation for the Complementary Training Program (CTP)

Federal grants have been supporting many (if not most) Brazilian engineering master's students. The availability of these grants is dwindling, so universities on one hand and master's candidates on the other have been looking for alternatives to obtain master's degrees with less grant dependence/support.

On the technical university side, this led to the emergence of options to start a master's program in the last semesters of the (typical) 10-semester undergraduate program. From the university's side and from the student's side it is interesting that such integrated effort is time and resource-efficient. To accomplish this, at ITA, a new Complementary Training Program (CTP) in Control and Automation Engineering was started in August 2021, serving (mainly) Mechanical, Electrical, Aeronautical, and Computer Engineering students.

Nevertheless, the standard goal of CTPs in Brazil is to extend the major undergraduate training in a similar way as a US minor does. Thus, the baseline purpose of the new program is to provide undergraduate students with a complementary education, transversal to engineering courses, which enables them to work as Control and Automation engineers, without the need for supplementary training after graduation.

The implementation and fostering of CTPs at ITA result from recommendations by ITA's Strategic Planning Commission in its 2011 and 2021 editions. This Commission deliberates once a decade and has in its membership high ranking personnel from industry, academy, and science & technology agencies, as well as student representatives. About half of the members are external to the Institute. So far, CTPs in Physics Engineering (2020[1]), Innovation (2020[1]), Bioengineering (2021[1]), Control and Automation Engineering (implemented in the second half of 2021), and Data Science (not yet implemented) were created.

In the case of the CTP in Control and Automation Engineering, by offering a well-designed course choice, this program, currently in its second semester of existence, will actually allow for: (a)

1 Year of implementation with inclusion in the Institute's Catalog.

extending the scope of undergraduate studies, and (b) deepening of specific topics that are already part of the undergraduate curriculum. In the scope of the Institute's undergraduate and master's degree integration initiative, this second particularity (item b) may yield anticipated credits for a master's program.

In a more general context, which was part of the Strategic Planning Commission considerations, CTP creation initiatives at ITA conform to the recommendations of "more flexibility" and "increased research participation" in engineering programs [6]. As explained above, it will streamline interested undergraduate students into master's programs with a solid practice base. As a result, these will provide master's degrees as entry degrees into the engineering profession, thus also conforming to proposals outlined in [7].

3 Structure of the CTP

The program involves three main curricular components, namely:

a) Classroom activities (classes) – students are required to complete at least 144 credits, with each credit[2] being equivalent to a 50-minutes lecture or supervised laboratory experiment. In the Institute's Catalog [8], every year the CTP publishes a list of the eligible courses offered. As of 2022, 41 courses are listed, out of which:
   i. two are offered as optional undergraduate classes, one by the Electronics Engineering and the other by the Mechanical Engineering Undergraduate Program;
   ii. 39 are offered as graduate courses, out of which 19 are from the Electronics and Computer Engineering Graduate Program, 19 from the Mechanical-Aeronautical Engineering Graduate Program, and one from the Physics Graduate Program;

b) Complementary activities – a total of 40 hours of certified complementary activities is required. Complementary activities are formally defined in a document published by the Institute [9], and include research internships at laboratories, participation at scientific meetings, publication of papers, internships at engineering companies, work on engineering challenges and campaigns (e.g. Rocket Design, SAE Aerodesign, RoboCup, Formula SAE), among others. However, it is important to emphasize that each activity must be validated by the CTP Council as pertaining to the scope of Control and Automation.

c) Monograph – a research project encompassing 80 hours supervised by a professor on a topic related to Control and Automation Engineering. The student is also required to deliver a technical report and give a presentation of the work to the supervisor and another expert not linked to the project.

Complementary activities and research carried out in the laboratories briefly described in the next section will provide for industry orientation, as activities are part of industry projects being developed in those laboratories.

The classroom activities were selected and grouped from available (i.e. already existing) options by an interdisciplinary team with representatives from the Departments of Systems and Control, Flight Mechanics, Mechatronics, and Computing Methodologies.

The CTP intersects the master's programs of the Institute in two of the above-mentioned curricular components: the classes and the monograph. For completion of the master's programs, about 290 credits and a master's dissertation are required. Moreover, the majority of the courses eligible for

2 The term "credit" herein is used informally for explanatory purposes. The rather elaborate credit definition in the Institute's catalog results being equivalent to about 16 "credits" mentioned here.

consideration in the CTP are also eligible for the master's program (39 out of 41 as described above). Furthermore, the monograph is similar to a master's dissertation with respect to the required formalism of the written report, the presentation to experts, and the evaluation procedure, although much less depth is required.

Classes offered only at the undergraduate level, which are mainly aimed at providing the students with a more hands-on engineering experience in Control and Automation, mark a difference regarding the conception of the CTP, as it is aimed at providing professional education in Control and Automation Engineering. A less subtle difference lies in the complementary activities. These are nowhere present in any master's program, yet they are a relevant component of the CTP curriculum. Since a plethora of different practical and research-related activities in engineering are considered, students have the freedom to decide upon the profile they want to strengthen: (a) advance towards a possible master's program, or (b) acquire more field experience.

As a rule, minors in North America also require additional credits in the subject of study, ranging from four to eight classes. However, there is no requirement regarding a monograph and complementary activities. These differences are a cornerstone of the philosophy behind the CTP at the Institute. Although the curriculum recognizes that taking classes is a relevant way to deepen the knowledge of a subject, it also emphasizes the importance of research, writing, and (guided) field experience.

Still in comparison to North America, both minors and our CTP are recorded in the student's transcript, which serves as an accreditation of competence in the respective subjects. However, in the Brazilian context, there are also legal issues involved. The Federal Board of Engineers (CONFEA) [10] regulates who may legally perform tasks in several engineering subjects. For that purpose, upon graduation, engineers have to join their regional State Engineering Association, which evaluates their transcripts to specify the extent of their licenses. As opposed to other professionals, such as lawyers, no professional exam must be taken (nor is it offered), and the evaluation considers solely the transcript. Usually, graduation in any established program results in automatic licensing for the engineer to work in the related fields. However, there are sub-specialties that may or may not be included in a license. For instance, at our Institute, there is no Control and Automation Engineering Program, but the students graduating in Electronics Engineering and in Mechanical Engineering are granted a license to also perform tasks that are typical of Control and Automation Engineers. This happens because the Board considers sufficient the specific core curriculum of these programs, which would be equivalent to a major in North America. On the other hand, Aeronautical Engineers are not licensed to perform the tasks in question. What we foresee with the CTP in Control and Automation, as formatted including a monograph and complementary activities, is that these students will be in a position to apply for a broadened license upon presentation of their transcripts.

Table 1 – Summarized comparison of the CTP in Control and Automation at ITA and typical minors in North American institutions

Characteristic	CTP at ITA	Minors in North America
Classwork	144 credits (~ 3 classes)	Four to eight classes
Complementary activities	40 hours	Not required
Monograph	80 hours, final paper	Not required
Record in the transcript	Yes	Yes
Impact on the professional license	Possible	No

Table 1 presents a summary of the comparison between the CTP at ITA and the minors in North America. The side-by-side comparison shows that the concept of the CTP is not in general

equivalent to a minor. In fact, the relation of the CTP in Control and Automation at ITA to the master's program is much more direct than with a minor. As highlighted in the text above, the CTP and the master's program intersect in terms of required classwork and the monograph, with the CTP demanding about half the credits of a master's and a monograph of reduced complexity as compared to a master's thesis. On the other hand, the relationship of the CTP with practical training is present in the required complementary activities and yields the possibility to apply for an extended license to work as Control and Automation engineer.

4 Highlight of special resources available to the program

Besides providing a multidisciplinary perspective, our CTP promotes the optimized and domain-oriented usage of institutional resources and laboratory infrastructure to support students along with their training, being jointly implemented by the Divisions of Mechanical-Aeronautical Engineering, Aeronautical Engineering, Electronics Engineering, and Computer Science. Thus, laboratory classes and students' research projects and monographs are hosted by several labs of the cited Divisions, such as:

- LRA: Aerial Robotics Lab, http://www.lra.ita.br/
- LABSCA: Autonomous Computational Systems Lab, http://www.comp.ita.br/labsca/
- CCM: Competence Center in Manufacturing, https://www.ccm.ita.br/
- The IEE lab cluster: a lab cluster of the Division of Electronics Engineering (IEE, ITA), dedicated to automation, control, and intelligent systems, as well as robotics.

Students of the program can take part in any of the undergraduate and optional graduate-level courses held by the professors of these laboratories. Some of the special characteristics and resources of the labs are presented in the following.

4.1 Resources and research lines at LRA

LRA (see Figure 1 for views of this lab) has its research and development focus on modeling, identification, attitude control, path planning, mapping, and navigation of micro aerial vehicles (MAV).

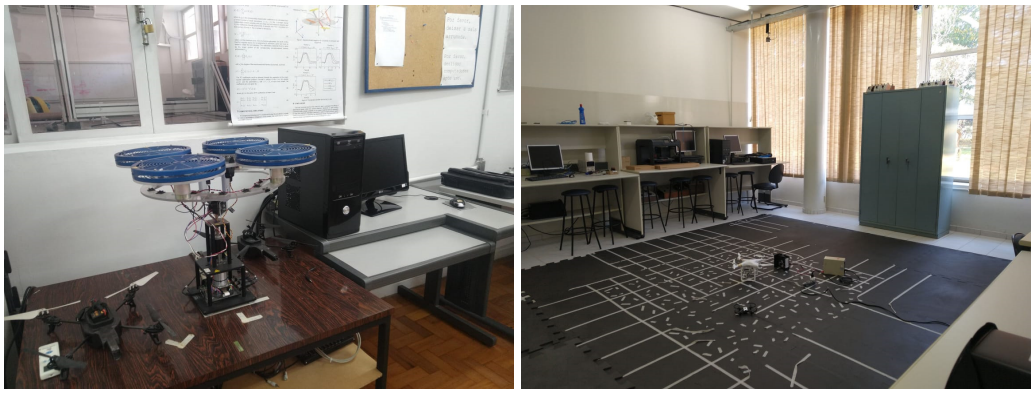

Figure 1 – LRA resources. Source: http://www.lra.ita.br/index.php

Several resources are available for research in this lab, such as an indoor flight test arena with a motion tracking system; Quanser ® 3D Hover Educational Kit for attitude control classes and experiments; and high-fidelity 3D Unity®-based computational models for simulation and training purposes. The research knowledge and resources of the lab support developments and industrial applications in energy, defense, agribusiness, logistics, and maintenance. Four graduate courses have been issued in this lab, e.g. *Dynamic Modeling and Control of Multicopters* and *Optimal*

Filtering with Aerospace Applications, both of them available of up to 10 students per year.

Figure 2 shows a simulation scenery of a R&D project conducted in the lab, the CTEDS (Cooperative Drone Engagement for Critical Applications) project. In this project, graduate-level researchers perform tutor work with undergraduate level CTP students, preparing them with basic concepts of control, navigation, optimal filtering, and virtual reality, paving also the way for those who want to obtain a master's degree.

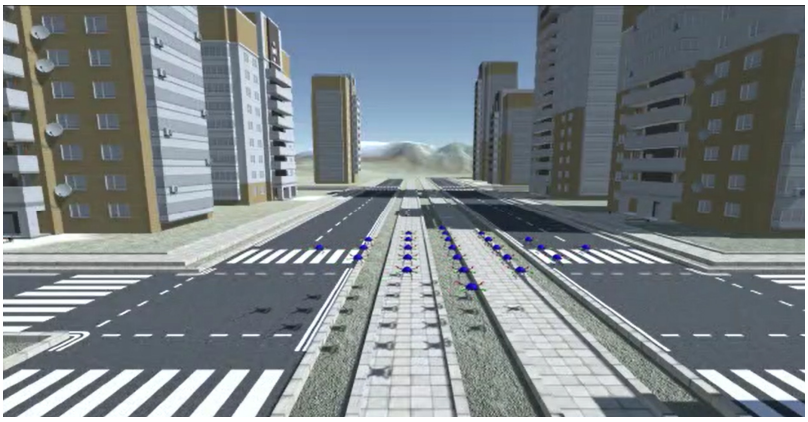

Figure 2 – Simulation scenery of an R&D project at LRA. Source: http://www.lra.ita.br/index.php

4.2 Resources and research lines at LABSCA

LABSCA (see Figure 3 for views of this lab) has its research and development focus on machine learning, autonomous systems, robotics, computational vision and multi-agent systems.

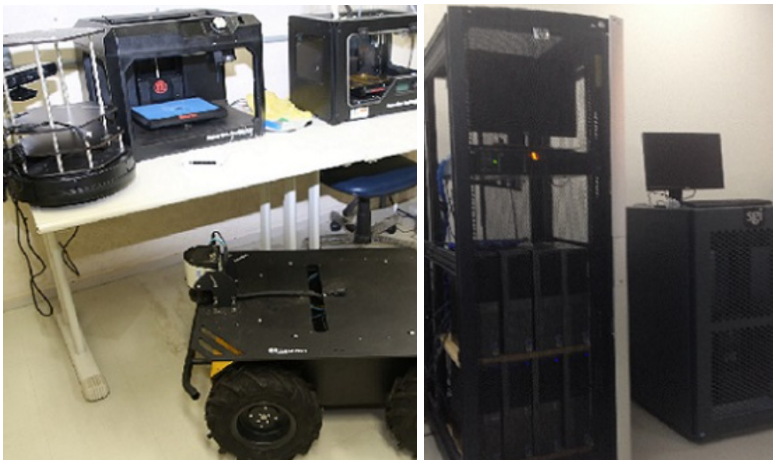

Figure 3 – LABSCA resources. Source: http://www.comp.ita.br/labsca/

This lab hosts several research and academic initiatives that engage students with the interest profile oriented toward the CTP in Control and Automation. For instance, supported by LABSCA is a Robotics team of undergraduate and graduate students, ITAndroids (http://www.itandroids.com.br), which participates in national and international Robotics competitions since 2005.

Due to its nature, the lab's activities are multidisciplinary and involve concepts of Computing, Electronics, and Mechanics. Currently, the lab also offers an undergraduate-level course, named *Design and Manufacturing of Mobile Robots*, which engages up to 20 CTP students per year in hands-on work on mechanisms, electronics, microcontrollers, sensors, and the development of embedded algorithms for navigation and control.

4.3 Resources and research lines at CCM

CCM (see Figure 4 for a view of this lab) focuses on applied research in manufacturing technologies that support Industry 4.0 concepts, such as automation and robotics, digital manufacturing and computational simulations, structural analyses, and metrology.

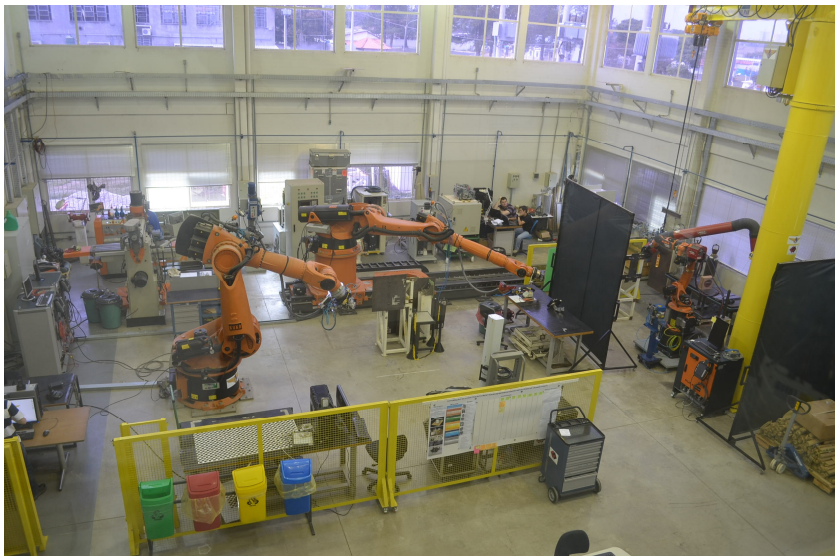

Figure 4 – CCM resources. Source: https://www.ccm.ita.br/

CCM is equipped with several different industrial robots, high-volume metrology systems, automatic machining centers, 3D printers, and a range of experimental test-beds used for research on materials, vibration and structural mechanics, and concepts of automated and computer-integrated manufacturing processes. The lab is strongly focused on industrial research topics, fostering academy-industry-government projects that, besides providing students with field applications, put them in contact with companies from the automotive, aeronautical, energy, and oil & gas sectors. A setup from a sample R&D project hosted by this lab is seen in Figure 5. This project addressed the automation of aircraft structural assembly.

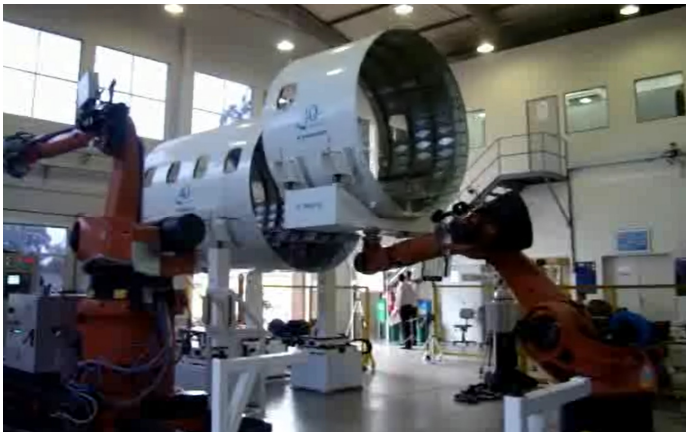

Figure 5 – Setup from a sample R&D project in CCM. Source: https://www.ccm.ita.br/

In this project, students of graduate and undergraduate levels worked together with core concepts of automation, robotics, industrial networks, systems integration, and other core subjects of the expected CTP profile.

Currently, among the graduate-level courses that have been issued by professors from this lab, up to

10 CTP students per year could take the following electives courses: *Industrial Robotics* and *Integrated Product Development*. Furthermore, an undergraduate-level course, *Mechatronics Devices, and Systems* has part of the classes taught in this lab. In this course, CTP students are introduced to concepts of instrumentation, sensors and actuators, and programmable logic controllers (PLCs).

4.4 Resources and research lines at the IEE lab cluster

The IEE lab cluster includes the following facilities:

- A laboratory of control and avionics. Both undergraduate and graduate supervised lab activities are conducted in this lab, featuring several servomechanisms, inverted pendula, gyroscope, and magnetic levitation systems. Although mainly aimed at supervised coursework, research activity is also in the scope of this lab.
- A laboratory for computer control systems. The focus of this lab is research on robust and predictive control of computer-controlled systems. The techniques developed are experimentally tested on several platforms, including helicopters with three and two degrees of freedom, a quadrotor fixed to a base for attitude control only, a magnetic levitation system, servomechanisms, inverted pendula, a servo coupled with a flexible rod, an active vibration damping system, and thermal processes.
- A laboratory for intelligent systems and robotics. This research lab is dedicated to building and testing terrestrial, aquatic, and aerial mobile robots, with a particular focus on localization and mapping using sensor fusion and navigation with the aid of artificial intelligence paradigms. The lab has several mobile robots and infrastructure for testing them, such as cameras.
- An industrial pilot plant (Figure 6). This plant was custom built for ITA and serves teaching and research efforts in process control. It offers resources to program control loops in Programmable Logic Controllers (PLCs), uses industry-standard actuators, run supervisory algorithms and perform automation and supervision tasks typically supported by industrial networks.

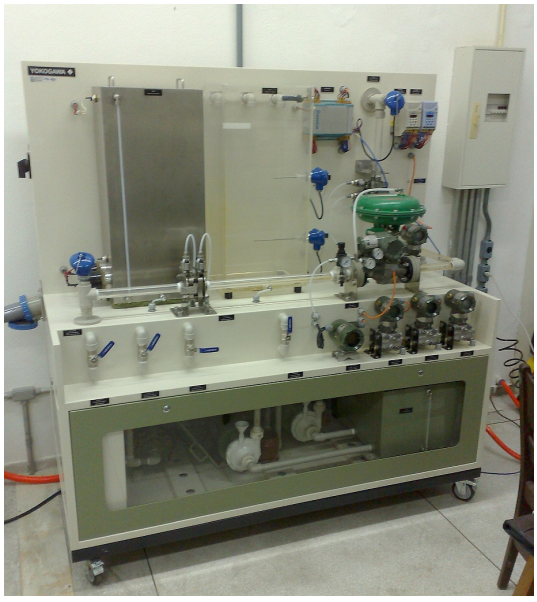

Figure 6 – The industrial pilot plant at the IEE lab cluster. Source: Division of Electronics Engineering, ITA

5 Gains expected

The CTP is expected to bring several gains to the Institute's undergraduate students and its graduate

programs, especially those related to Aeronautical, Mechanical, and Electronics and Computer Engineering. By encouraging the completion of graduate courses and the writing of a monograph, the undergraduate student will become more familiar with the advanced use of methods of science and technology in a research and development environment and will be encouraged to complete a master's degree in a reduced time. Thanks to these incentives, an increase is expected in the rate of undergraduates who continue their academic studies through master's and doctoral programs. Complementary training should also open up new employability options for engineers trained at the Institute.

From the point of view of the Institute's graduate programs, the training directly involves professors and researchers from different departments, who up to now had limited interaction with each other. The CTP, which is jointly coordinated, brings research groups together and encourages new internal collaborations, either through projects, monographs made in co-supervision, or the preparation of courses/seminars in partnership.

Finally, the increase in the number of undergraduate students pursuing a master's degree is expected to provide gains in research productivity to the graduate programs, thanks to the potential of increasing the number of students with excellent academic backgrounds and records.

6 Conclusions

In this Work-In-Progress contribution, a Complementary Training Program (CTP) in Control and Automation Engineering initiated in the second half of 2021 was described, starting with its motivation, curricular structures, and the available facilities for its implementation. A historical glimpse of the institution's involvement in the advance of Control and Automation was also provided to portray the general institutional context of the new CTP. Furthermore, its relation to North-American-style minors was briefly addressed.

Expected gains for students as well for the Institute were described. These gains are entailed by the enhanced opportunities of undergraduate training, but mostly by the envisioned Undergraduate/master's program integration this CTP will yield.

References

[1] BOTTURA, C.P.; PEREIRA, C.E. Points in the History of the Brazilian Society of Automatics ("Sociedade Brasileira de Automática" – SBA). *Controle & Automação*[3], v. 22, n. 1, p. 1-8, 2011.
[2] KIMBARK. E.W. *Power Systems Stability*, 3 volumes, Wiley, 1950. (Also in the IEEE Selected Reprint Series)
[3] SMITH, O.J.M. *Feedback Control Systems*. McGraw-Hill, 1958.
[4] BOFFI, L.V. *Electrodynamics of moving media*. Ph.D. Diss., Massachusetts Institute of Technology, 1957.
[5] MONTEIRO, F.R. et al. "Complementary training programme for electrical and computer engineering students through an industrial-academic collaboration." *2016 IEEE Frontiers in Education Conference (FIE),* 2016.
[6] GRINDEL, T. (Ed.) *Final Report of the Global Engineering Excellence Initiative: Educating the Next Generation of Engineers for the Global Workplace.* Continental AG, Hannover, 2006.
[7] DUDERSTADT, J.J. "Engineering for a changing world." *Holistic Engineering Education*. Springer, New York, 2010. 17-35.
[8] INSTITUTO TECNOLÓGICO DE AERONÁUTICA. *Cursos de graduação em engenharia: catálogo*. Instituto Tecnológico de Aeronáutica, São José dos Campos, 2022. (Available at

3 In 2014, *Controle e Automação* became the *Journal of Control, Automation and Electrical Systems*.

http://www.ita.br/sites/default/files/pages/collection/ITA-CG-2022.pdf)
[9] INSTITUTO TECNOLÓGICO DE AERONÁUTICA. *Normas reguladoras para os cursos de graduação do Instituto Tecnológico de Aeronáutica.* ICA 37-332, 2017. (Available at http://www.ita.br/sites/default/files/pages/collection/NOREG-GRAD_ICA_37-332_2017.pdf)
[10] CONFEA, *O Conselho*. https://www.confea.org.br/confea/o-conselho/, 28 Jan 2022.