From Brazil to the World: The Journey of a Fluid Dynamics Experimentalist

Tamara Guimarães

When planning and designing a fluid dynamics experiment, we usually try to find the most efficient way to reproduce a process or to operate a machine. The less energy you use to achieve an end goal, the more efficient you are. This concept can also be applied to our everyday lives. But a lot of times in life, unlike in fluid dynamics experiments, the most straightforward and efficient path may not be the way to go.

Looking back at my journey and where life has taken me—see Fig. 1—since I first heard about this profession called "Engineering" in high school, it may seem that I did not take the most efficient way to get to my career goals. And that is absolutely correct. Just like in an experimental investigation in fluid dynamics, there were several moments in my life in which I faced questions, frustrations, failed hypotheses, and misleading conclusions, and I had to take a step back and reassess my strategies. In addition to that, I also faced some of the many challenges of being a woman in a male-dominated field such as engineering: sexism, imposter syndrome, and self-doubt.

In the next pages, I will talk about my journey as a woman and an immigrant in engineering all the way until preparing to start working as an Assistant Professor at Penn State University, and how each step of the way was influenced by the very few women I could look up to and the few men who were willing to offer me support. With this, I hope to be able to help future generations of female engineers and scientists to not feel so alone, and understand that they can and should go after the career they want, because we should all be pursuing our dreams, and the path can be much easier and more enjoyable when we feel seen, heard, and represented.

T. Guimarães (✉)
Department of Mechanical Engineering, Pennsylvania State University, State College, PA, USA
e-mail: guimaraes@psu.edu

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Fig. 1 Places that have been part of my (very much not straightforward) journey

From Journalism to Engineering

I was born in São Bernardo do Campo, a city in the metropolitan area of São Paulo known for being the heart of the automotive industry in Brazil. My grandfather worked for General Motors and Volkswagen before I was born. Both my parents worked long hours, so I was raised mostly by my grandmother, who would help me and my brother with our homework, even though she herself had only finished elementary school. She was also the cook, the manager of the household, my right-hand (wo)man, and definitely the first example of a strong female leader that I had in my life.

When I was around 4 years old, she gave me a cheap little toy car that she bought at the farmers market. The 50-cent toy soon became my favorite, even though I had many dolls with which I did not even once play. My parents and teachers could have then noticed that I was more interested in "boy" toys, such as cars, puzzles, and Lego blocks, and that I had the potential to be an engineer, and then could have helped me find the easiest way to get there. But traditional gender roles were (and still are) really hard to overcome in Brazil. So for the longest time, I did not even think engineering was an option for a woman. I thought I wanted to be a journalist.

I have always been very communicative. I was that kid at restaurants who would run around striking up conversations with complete strangers. So, in elementary school whenever my teachers asked what I wanted to be when I grew up, "a journalist" was my go-to answer. To that, my math teacher would always reply: "What a waste!" That reaction outraged me. I didn't understand what that meant. It always sounded very offensive to me. What did it mean for it to be a waste? What was it that she saw in me that made it such a waste for me to choose a career in journalism?

In Brazil, everyone who wants to pursue a higher education degree must take an entrance exam which is offered only once a year. I picked a high school that would prepare me for that exam. In my first year, I had a Physics teacher who was

phenomenal. His classes were fun, engaging, exciting, but right off the bat he made a clear statement that girls did not do well in his class, because "*girls are not cut out for sciences*"[1]. That statement bothered me so much that one day I raised my hand in class and told him I would ace his exam. He told me that if I did that, he would dress up as a woman for the next class. Well, I did ace his exam, and while wearing a white top and a pink skirt, he asked me what I wanted to be when I grew up. I defaulted to my usual answer: journalist. And he finally finished that statement for me: "What a waste, you should be an engineer!" That was the first time someone said that to me. But that didn't go much further. What does an engineer do? Why should I be an engineer? What kind of engineer? How do I prepare for that?

I asked my mom for advice. She has a degree in electronics technology and was leading her own company as a newly divorced mother of two. She has always been the one woman among all the men, having dealt with sexism, being shut down and diminished by her coworkers and mentors her whole life, and knows how hard it can be to succeed as a woman in a technical field. She was not really supportive at first and asked me what happened to my passion for journalism – she even suggested a Law degree because I was so good at arguing with her all the time. We ended up finding a good compromise: I enrolled in a Technical Drawing class to see if I would be interested in (and if I could handle) something very technical that would be a necessary skill if I really wanted to be an engineer.

So there I was, at 16 years old, for the first time being one of the few women among all the men. The class was aimed at machine operators who worked for the automotive industry, so there were only three women – myself included – and over fifty guys in the class. The environment was so sexist and so uncomfortable that the (obviously male) teacher would only call the guys to the board to solve problems so that the women wouldn't be on the spot and subject to harassment. I was learning so much and was so excited to show that I could do everything that they could do that I found it really upsetting to never be called to the board. I wondered if that would be my whole life as an engineer. Would I never be invited to be in the spotlight? Would there never be a chance for me to prove that I could be as good as them? However, regardless of the uninviting environment, that experience was the push I needed: I was going to be an engineer.

A Woman Among the Men

The decision to study engineering turned out to be the easiest part of the process. With a lot of study hours —and the privilege to be able to focus on only studying for a whole year—I got into a public university that had just been founded near my hometown: *Universidade Federal do ABC* (UFABC). They offered an innovative

[1] This type of statement is now widely understood to be a stereotype threat that discourages female students from choosing STEM fields.

approach for higher education in STEM in Brazil: Students would first get a Bachelor's degree in Science and Technology, and then choose a specific STEM-related major and get a second Bachelor's degree.

UFABC was also the first university in Brazil in which all professors had a PhD [1], the main goal being to promote academic research. Since I was in the top 3% of the incoming students, I was offered a scholarship named *Researching Since the First Day*, which offered financial support for research activities. As Physics had been my favorite subject in high school, I started doing research with Professor Eduardo Gregores, who is an international reference in Particle Physics, having been one of the authors of the paper that describes the Higgs Boson at CERN in Switzerland [2]. Particle Physics isn't exactly an easy subject, so I struggled for a year, and ended up giving up on that research once I failed a class directly related to my research topic for the first time in my life.

I had never gotten a bad grade before, let alone failed a class. On top of that, I was one of the few women in my classes and had to deal with professors who would make jokes during the lectures, or constantly ask us the tricky questions, putting us on the spot and hoping for us to answer incorrectly. A Heat Transfer professor once added a picture of a kitchen oven to a slide "*so that the girls would see something they were familiar with*." I had a supervisor at my first internship in my junior year who would not invite me to any of the meetings with our international customers, even though I had taught English at a language school for 5 years, but would invite the male interns who could barely speak a full sentence in English. Those were some of the moments when I really considered giving up. What if my high school teacher and these professors were right and women were not cut out for sciences? What if my mom was right and I should have studied journalism? I decided to push harder and focus on my engineering classes, which I figured would give me more insight on whether I could be an engineer or not.

Energy Engineering was my chosen major after taking some introductory classes during my third year. The course offered an interesting mix of classes in the thermal and electrical sciences, so I built a solid foundational knowledge of Fluid Mechanics, Thermodynamics, and Heat Transfer, while also learning in depth about Electrical Circuits, Power Systems, and Sensors and Instrumentation. The most fascinating part of it for me was bringing all that knowledge together into the more interdisciplinary classes, which focused on Energy Efficiency, Management, and Planning. That was also when I got closer to the other women in my class, who are still today some of my best friends. At this point, there were three to five women in each class, and about twenty-five men. But it was only then that I realized something: The women were usually in the top 5% of the class.

That was mind blowing! Even though the sample size was pretty small, that was a pattern I had not noticed before. It showed me that women are not only cut out for sciences, but we can THRIVE. So I should stop questioning myself every time I struggled, after all, I would rarely see men questioning themselves. Struggling is normal and it is part of being an undergraduate student, and it was ok for me to not do so well in an exam or in a project, but yes, I could still be an engineer. My best friends from that time at UFABC now all have remarkable careers: Maria Brasil

works at an international bank in São Paulo; Juliana Pin is getting her PhD in Operations Research at North Carolina State University; and Dr. Laura Novoa got her PhD in Mechanical Engineering at University of California Irvine in 2019 and has since been working as an engineer at Tesla.

Near the end of my undergraduate studies, the Brazilian government – led at the time by the country's first female President, Dilma Rousseff – launched a study abroad program called *Science Without Borders*. They had the bold goal to send thousands of Brazilian students abroad to improve their language skills, experience different cultures, and promote international academic exchange with other countries. I had always wanted to study abroad, so I applied for that scholarship and ended up as an exchange student in Engineering at University of California Davis, which completely changed my life.

What Is an Experimental Research Lab?

Studying abroad is an experience like no other: Being away from friends and family and taking classes in a language that is not your own is not easy, no matter how comfortable you are with the language. With many other Brazilian students in the same program, a support community was quickly built, which helped us navigate the challenges. The percentage of women in the engineering classes was not much higher than in Brazil, but it felt to me that being a woman in engineering in the US was *normal* and not a joke-worthy matter, which fostered a more inclusive and less hostile environment than what I had experienced before.

The *Science without Borders* program offered a scholarship for students to take classes during the academic year and also encouraged them to find a summer internship. Since I was close to finishing my degree in Brazil, I was able to take graduate-level classes, which I picked because they were taught by professors who ran energy-focused centers on campus. I wanted to have the chance to learn from professors who were references in their research fields, but also to get to know them during office hours and potentially find an internship. The Director of the Western Cooling Efficiency Center at UC Davis (WCEC), Professor Mark Modera, taught a class called Building Energy Performance offered by the Department of Civil Engineering. His lab had just moved to a new building and they were looking for students to help them with setting up and building new experimental rigs, so I reached out to him and got my internship for the summer.

My time at the WCEC completely redefined the meaning of academic research to me, especially experimental research. Since the campus of my home university was not completely built (which is way too common for government construction in Brazil), I had very few opportunities for hands-on engineering experience. Being at UC Davis and working at an on-campus research lab was the complete opposite. I was assigned to build an experimental rig that would simulate a hot room being cooled by an HVAC unit equipped with sensors that controlled and monitored the temperature inside the chamber and in the air conditioning lines. This experiment

was aimed at assessing the quality of measurements taken by HVAC technicians in the field by having them come to the lab and use their equipment to measure the parameters in our rig, which then would be compared to the built-in sensors. With this, we could quantify how the efficiency in those home systems would be affected by inaccurate or biased measurements. I worked with three female engineers at the WCEC: Theresa Pistochini and Dr. Kristin Heinemeier, who were my direct supervisors; and Mayra Garcia, a Master's student whose family had immigrated to the US from Mexico, as have many others in California.

Mayra had a similar background to mine. She also came from a different culture and was used to speaking a different language back home. Seeing her working on the next steps after becoming an engineer meant I could do that as well. I could get a graduate degree after finishing my Bachelor's, and I could do experimental research, which could be relevant to the world. Unlike in Brazil, where most research funding comes from a few governmental agencies, the WCEC had funding both from the US government and from industry partners, who had more application-oriented goals. So there was an obvious next step for me after my year abroad at UC Davis: Getting a PhD in the US.

I started looking into graduate programs all over the US when I returned to Brazil. My boyfriend at the time (now my husband) also wanted to get a PhD, so we narrowed it down to a couple of universities that offered programs in both our fields. We received offers of admission to Virginia Tech (VT), Mechanical Engineering for me and Biological Systems Engineering for him. I also received a Teaching Assistantship (TA) for the first year, so I did not have to worry about finding a research group and an advisor right away. Once again, I had to leave the comfort of my family, my friends, and my country to pursue my dream. In August 2014, I packed one suitcase and moved to Blacksburg, Virginia, to start my PhD studies. I was one of the five women in a group of twenty-six TAs for a senior lab class in Mechanical Engineering. I was the only first-year international graduate student. Once again, I felt alone and like I did not belong. So questions started popping back in my mind: How could I balance classes with being a TA and doing research? Did they really offer admission to the right Tamara Guimarães? I really felt like I was going to fail and be kicked out of the program. And I might have, if it hadn't been for the support of the two female professors who led that class and the professor who was teaching my Fluid Dynamics class, Dr. Francine Battaglia. (See "Educating the Next Generation of Mechanical Engineers in Fluid-Thermal Sciences" in this volume, by Francine Battaglia, Lu Chen, Mirka Deza, & Bahareh Estejab, to learn more about Dr. Battaglia and her mentees' approaches to engineering education and mentorship.) They assured me that what I was feeling was normal and that I should not be so hard on myself, something I still struggle with constantly, which is an example of imposter syndrome, widely recognized to be a common issue for underrepresented students during graduate studies.[2] An hour of conversation and just showing that they were there whenever I needed made all the difference to me.

[2] If you are struggling with imposter syndrome during a graduate program, considering seeking campus resources for help.

A month or so after starting at Virginia Tech, I had my first meeting with Professor Todd Lowe, who was looking for a PhD student for his group to work with experimental fluid dynamics. Todd was, and still is, one of my greatest cheerleaders. Both he and Dr. Walter O'Brien, my unofficial co-advisor, have led established research groups and centers at VT with funding from government agencies and from the industry. My PhD research was funded by NASA Langley and NASA Glenn and focused on experimental fluid dynamics using laser-based diagnostics, mainly particle image velocimetry (PIV).

My research was part of the NASA Environmentally Responsible Aviation (ERA) Project, a 6-year program created by NASA in 2009 to explore ways in which aviation could reduce its impact on the environment through the development of more efficient aircraft designs, reducing fuel consumption, noise levels, and nitric oxide (NOX) emissions [3]. There is extensive research in the aviation and turbomachinery community on how to improve the efficiency of gas turbines (both for flight and for ground applications, such as power generation), and even very small percentages of efficiency improvement mean millions of gallons of fuel and millions of dollars saved every year [4]. To meet the very bold goals of the project, NASA developed a novel aircraft concept named Hybrid Wing Body, which, unlike traditional aircraft configurations that consist of a tube-shaped body and wings, has a different design (see Fig. 2). There are numerous steps in the research and development of a new aircraft, involving hundreds or even thousands of people in different research groups around the world. The Turbomachinery and Propulsion Laboratory at Virginia Tech (TurboLab) was tasked with developing a 3D-printed device called StreamVane™ that would assist in the ground testing phase of assessing the impacts that such a novel aircraft concept would have in engine performance. The device can be seen in Fig. 3 installed in a research engine inlet.

My work focused on analyzing in depth how distortions to the airflow caused by that aircraft design would behave in the inlet of the engines. I performed experiments in different wind tunnels and at the full-scale engine test rig at the TurboLab using a laser-based diagnostics technique to measure the flow called particle image velocimetry (PIV), in which micron-sized particles are added to the airflow and a

Fig. 2 Hybrid Wing Body aircraft concept. Credit: NASA

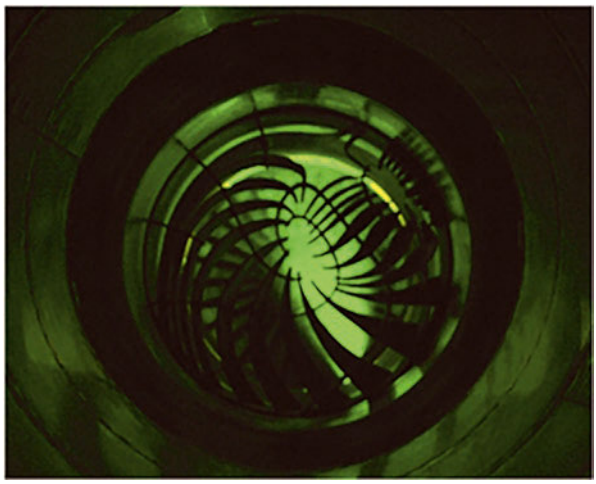

Fig. 3 Laser sheet during PIV experiment in the inlet of a full-scale research engine at the Virginia Tech Turbomachinery and Propulsion Laboratory. Credit: personal archives

laser sheet is used to illuminate those particles (see Fig. 3). Using two cameras placed at an angle from the laser sheet, two consecutive pictures are taken with a predetermined time delay. By knowing that time delay and using a post-processing software to track the displacement of the particles between the frames, it is possible to calculate the three-component velocity vector field in the flow, describing the flow behavior. The main impacts of my research were applying this measurement technique to a full-scale engine experiment, which had not been done before, and describing the similarity in the flow distortion across the different scales of the experiments, showing that the StreamVane is a powerful tool that can be used for reducing costs during the development of novel aircraft concepts [5, 6].

The PhD in Engineering Experience Beyond the Lab

Getting a PhD in engineering is as much about technical developments and advancements in science as it is about the personal aspects of the academic and research world. Being in the turbomachinery field as a woman and a non-US citizen can be as frustrating as it is exciting. A lot of the funding for this line of research comes from federal agencies, so international students usually cannot work on these projects. As mentioned before, I was extremely lucky to have PhD mentors who kept that in mind and went above and beyond to ensure they were fair to all their students. We had weekly meetings to discuss my progress in the program, and they always asked me how I was feeling and made it very clear that there should be nothing making me uncomfortable. Both my advisors have daughters, which I know has helped them tackle diversity issues with different eyes. Still, I was one of the two women in my lab at the time and the only international student, and I did feel like some of the other students questioned my background and whether I was qualified

to do the research. The support from my advisors and the way they believed in me—even when I didn't—helped me build confidence in my work and in the quality of my research, so I was able to stand up for myself or just ignore some of the comments that could bother me.

Attending conferences is also a great chunk of PhD work. I was lucky to present my PhD work in many, both in the US and internationally, and to network and meet people who I could potentially work with in the future. Regardless of the size of the conference, women usually accounted for about 10% of the participants. Once during a coffee break, an older man walked up to me and thanked me for bringing some color to the conference because I was wearing a pink skirt while everyone around me was wearing dark suits.[3] I *think* he meant that as a compliment, though I can't help but wonder whether he would have offered a similar compliment to a guy wearing a pink suit…

The larger engineering conferences usually promote networking events for women, which are great for meeting people, learning about their stories and struggles, or even just for feeling welcome in a room in which you do not stand out for being a woman. Getting to meet women who have established careers and entered STEM fields in a time in which it was even less common for women to pursue these careers is inspiring but can also get you really (really) angry about the struggles they had to go through. It is not uncommon to hear stories of women who dedicated an entire career to science and had their discoveries and results attributed to men in their groups or departments. Or, even in 2020, hearing from women working in the industry that their male colleagues with exactly the same job earn significantly more than them is not uncommon, even if the men do not have a PhD. One friend saw herself in that exact situation and decided to confront her bosses about it and stand up to what she believes is right, given she worked at a company that had been awarded for having strong female leadership. She was told that her male colleague had been a more aggressive negotiator and that she should not be so emotional when discussing topics such as her salary. Salary negotiations are one of the known causes of the wage gap between men and women, but there is research showing that even if that behavior is changing and women are getting better at asking for raises, men are more likely to actually get them [7].

The Next Generation of Experimentalists

I spent the summer before the last year of my PhD doing research at the *Institut für Strömungsmechanik und Aerodynamik* at the Bundeswehr University in Munich, Germany. I met the head of the institute, Professor Dr. rer. nat. habil. Christian Kähler, at a conference the year before, and contacted him as I was looking for

[3] This type of comment is sadly common for many women in STEM fields. If you experience comments like this it is okay to explain to a male colleague that comments about dress and appearance can make others uncomfortable.

opportunities for summer research. I spent 2.5 months doing experimental research in Acoustofluidics, a field that studies the effects of acoustic waves on microfluidic devices.

What I first saw as an opportunity to learn about a different field of fluid mechanics while living in Europe ended up leading me to another overseas move for a 1-year postdoctoral position once I finished my PhD. Since the field was different from my PhD topic, the research was a lot more challenging. It felt like I was learning everything from scratch, and it took me months to finally start being productive, which is one of the scariest things for women in academia. The levels of frustration I faced during this time, while also struggling with the language and cultural differences made me decide to look for a job in industry at the end of that year.

I started working as a Business Development Manager at a startup that manufactures instrumentation devices for aerodynamic measurements in May 2019. Working more closely with customers and visiting wind tunnels, experimental setups, and universities, it did not take me long to realize that I wanted to have a more direct impact on people's lives while also working on research and development. Throughout my academic life and career, I have always tried to be a role model for the younger students I interacted with, especially if they were women or foreigners. But to increase the presence of women in STEM fields, it is also extremely important that there are initiatives to recruit girls focused on elementary and middle school. I wanted to join a program in Munich that would allow me to work with girls to foster their interest in sciences. I couldn't find one that I would fit in, mainly because of the language barrier, so I started my own program, targeted at a very specific group: children of Brazilian or Portuguese parents. I teamed up with the NGO *Casa do Brasil*, and our program named *Science for Kids: Exploring a New World in Portuguese* was created. Once a month, this program would bring together groups of ten to fifteen kids, and was always organized and led by a local Portuguese-speaking scientist who worked directly with research or had research experience from a Master's or PhD. This program did not only benefit the kids, but also the scientists, who often do not have the opportunity to interact with children and present the contents of their research in a simple way, accessible for people outside the scientific community.

Getting back in touch with researchers in academia and being in this learning environment with the kids, I concluded that the next step in my career would be to go back to academia in the US. It wasn't long until I learned from someone at a conference that the Mechanical Engineering Department at Penn State was hiring new faculty members. I was going to visit them the following month for my job, and I had the chance to also meet the Department Head, Dr. Karen Thole—who describes her own journey as a woman in Mechanical Engineering in the Research/Technical section of this volume, with the chapter: "From Watching Planes in the Sky to Making Turbines More Efficient."

Until then, I hadn't been able to find a Mechanical Engineering program that I could see myself in, as most seemed like the same old traditional white male–dominated programs. It was different with Penn State. From my first meeting with Karen, I could see her commitment to diversity and how she had brought her vision to the

Fig. 4 My grandma, my mom, and 9-year-old me

department. I met several assistant professors who had recently joined the department, and about half of them were women. Just like at UC Davis when I first met a female engineer from an immigrant family working on her Master's degree, I could see myself as part of this group of young faculty members. I felt so welcome and comfortable that I even asked about the maternity leave policies of the department during my job interview, which anyone will tell you is one of THE topics to avoid during an interview!

As an Assistant Professor at Penn State, I will be able to work closely with the next generations of engineers through teaching in the classroom, in my research group, and in programs aimed at school kids. My research will focus on sensors and instrumentation for gas turbines and other applications using additive manufacturing. Collaboration between faculty members is highly encouraged at Penn State, so I will team up with professors from Mechanical Engineering as well as from other departments to develop research that will be highly focused on presenting solutions in measurement and control of aerodynamic and fluid dynamic parameters to improve the efficiency of processes and machines.

This is only the next chapter of my career at the moment, but looking back at how I got here and where I have been, there is so much I owe to the women who have been role models for me, from my grandma and my mom back when I was a kid (see us in Fig. 4) all the way to watching history being made by the first female vice president in the US, who is a black woman and daughter of immigrants. We as women still waste so much energy second-guessing ourselves and worrying we might not make the cut. Having someone to look up to and to talk to has made all the difference to me, even if it took me longer to get where I wanted. Seeing someone like me in a position of power or in a next career step made me believe that I too could be there one day. By sharing my story and showing that I, a Brazilian woman who did not know what an engineer was until entering high school, can not only be an engineer, but also teach and advise future engineers as a professor in the US. I hope to be someone that the future generations of girls and women in STEM can also look up to.

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Dr. Tamara Guimarães was born in Brazil and has a Bachelor's degree in Energy Engineering from *Universidade Federal do ABC*. She received her Ph.D. in Mechanical Engineering from Virginia Tech in 2018. Her doctoral research focused on fundamental vortical flow development in the inlet of gas turbine engines. Upon graduation, she moved to Germany for a postdoctoral position at the Institute for Fluid Mechanics and Aerodynamics at the Bundeswehr University Munich, working on Microfluidics. She then worked as a Business Development Manager at a Munich-based start-up that develops flow instrumentation using additive manufacturing. She joined the Department of Mechanical Engineering at Pennsylvania State University as an Assistant Professor in 2021. Her research interests revolve around the improvement of instrumentation, sensor integration, experimental techniques, and measurements for fluid mechanics focused on gas turbine flows.