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a numbers game

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Towards a new future in engineering education, new scenarios that European alliances of tech universities open up

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THE FUTURE OF WOMEN AEROSPACE ENGINEERS IN ACADEMIA – A NUMBERS GAME

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ABSTRACT

The gender divide for women in the engineering domain in academia is still very large today, even though most institutions are committed to changing this. Although there are slow improvements in the number of women working in academic positions in Engineering, the Netherlands, in particular, is still lagging badly behind the rest of Europe with women making up only 17.6% of all full professors in the engineering domain and for 25.7% in the entire academic domain. This is despite many efforts across the board to improve this situation.

The situation is even worse in the field of Aerospace Engineering and within this field, the lack of progress is not unique to the Netherlands with similar issues being reported in the United States of America and wider afield.

This paper reports on research on the capacity building among women required within the aerospace engineering domain to reach the commonly defined critical mass percentage of 30% of women full professors using metrics on career progress and on as well as labour market data on the career development of Aerospace graduates to show where potential new interventions can be made.

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1 INTRODUCTION

Women Aerospace Engineers to date are still few and far in between, despite the many campaigns worldwide by both industry and governments to change this. This is especially true for women aerospace engineers in academia, which should be seen as a major concern as research has shown that there is a strong correlation in engineering between student diversity and faculty [1].

Although the Faculty of Aerospace Engineering at Delft University of Technology (TU Delft) in the Netherlands is the largest aerospace engineering school in Western Europe with over 2800 BSc and MSc students enrolled in 2021/22, only 14% of its students are women, a number that has only slowly increased over the last decades. Of the 19 full professors in aerospace engineering at TU Delft, only 2 (10.5%) are women, ranking at the lower end of TU Delft's representation of women full professors (17.9% over the whole of TU Delft). TU Delft ranks last in the list of Dutch universities when it comes to the number of women professors in the Netherlands [2], which averages at 25.7%, making the Netherlands one of the worst-performing countries in the EU in this respect. The Dutch Network of Women Professors has therefore set itself a target of reaching a "critical mass" with 30% women professors by 2024 [2].

The critical mass percentage of 30% is widely attributed to the political scientist Dallerup as the threshold when women's participation is no longer tokenism. After reaching this critical mass a qualitative shift will take place in an organization. As she states, however, this idea of a specific absolute turning point of 30% has been found not to exist but the notion that a certain mass of representation has to be build-up to achieve a qualitative shift in an organisation remains [3].

With the number of women in aerospace in academia in the Netherlands still being so low, this paper reports on research into the required capacity building to reach the suggested target of 30%. Is this an achievable number within the next 10 years given TU Delft's capacity for training aerospace engineers also compared with other countries?

2 HISTORIC CONTEXT

To provide some explanation as to why the current numbers are still so low, it is important to take into account the historical context of the academic field of aerospace engineering and the socio-economic context of the Netherlands over the past 100 years.

2.1 Development of the Field of Aerospace Engineering

Aerospace or Aeronautical Engineering as a recognised academic field of study is itself not that old. Initial degrees were named Aeronautical Engineering and from 1958 onwards the term Aerospace Engineering was often adopted to also reflect the Space content of the programmes. Although the discussion still rages on who exactly is the first to start teaching courses in aerospace, the first courses are taught in Europe from 1907-1910 onwards[4] in London and Paris with today's 'ISAE

SUPAERO' now in Toulouse, France the first to establish a formal degree programme. In the USA, the University of Michigan follows suit in 1916 and M.I.T founds its aeronautical engineering programme in 1926. At TU Delft the degree programme in aeronautical engineering was founded in 1940, days before the outbreak of World War II in the Netherlands. Today, aerospace engineering schools are spread all over the world covering every continent apart from Antarctica, and the demand for aerospace engineers in the job market remains high and is expected to continue to increase [5].

2.2 The History of Women in Aerospace Engineering

With the field of aerospace engineering itself still being so young, it will not come as a total surprise that it was not until 1929 that Canadian woman Elsie McGill was the first woman to graduate with a Master's degree in aeronautical engineering from the University of Michigan. This did not mean there were no female aircraft designers before this: Lilian E. Bland (Ireland, 1909) and E Lillian Todd (USA, 1910) designed and build their own aircraft, both of which flew. Like many other early aviators, they schooled themselves in aircraft design. In Europe, not all countries had established degree programmes in aeronautics yet, but this does not mean that women are not interested in studying aeronautics. In Germany, Ilse Essers (nee Kober) in 1926 and Melitta von Stauffenberg (nee Schiller) in 1927 also obtain Master's degrees with aeronautical-related theses in Mechanical Engineering at what is now RWTH Aachen and Applied Physics at what is now TU München, respectively. The first European woman with a master's degree in aeronautics is likely British woman Hilda Lyon, who obtained a Master's in aeronautical engineering at MIT in 1932. However, it was not until 1965 before the first woman graduated in aeronautical engineering from TU Delft, Indonesian national Koo Siu Ling, with the first Dutch woman Hedwig Ritzen graduating in 1969. It would not be until 1996 that the first PhD degree in Aerospace Engineering was awarded to a woman at TU Delft and it took until 2006 before Hester Bijl (now rector at Leiden University) was appointed as the first woman professor in Aerospace Engineering at TU Delft.

2.3 Socio-Economic Development of Women in the Netherlands

To understand why it took so long for the first women to graduate in aeronautical engineering at TU Delft, it is important to understand the socio-economic context in the Netherlands at the time. Until the end of the 19th century, secondary education in the Netherlands was only open to the privileged few. A change in the Dutch education system in 1876 allowed anyone with the national advanced secondary education diplomas *Gymnasium* and *HBS* to gain entry to university, although not all universities were equally happy to admit women.

Admittance policies differed per university but the first woman to graduate from TU Delft was Maria Elizabeth Bes, a chemical engineer, in 1904. This did not mean that women were flocking en mass to universities. Although women were given the right to vote in 1919, married women were deemed legally incapacitated and a marriage ban was in place at all government institutions, often mirrored by industry, under pressure from unions and Christian political parties. They favoured the breadwinner economic model and successfully argued that allowing women to work would take away jobs from men with families and lead to lower wages. Even after the abolishment of these laws in 1957, the lack of childcare facilities or the ability for children to eat lunch at school instead of going home for lunch until well into the 1980s made having a professional career as a woman an uphill battle. In addition, until 1988, a person was not deemed to be of age until they reached the age of 21, meaning that young people needed parental permission to enrol at university. Only from 1990 onwards, the breadwinner model was abandoned and men and women were expected to each be able to earn their own income regardless of their marital status and women were actively encouraged to gain professional qualifications. As a result, the percentage of financially independent women rose from 25% in 1990 to 64% in 2020 - compared to 80% of all men)[6].

3 METHODOLOGY

3.1 Data sources

All data reported and used as input in this paper is publically accessible data from various government sources and international organisations. When comparing different countries the same base year for all countries was used, being 2018 as that was the year the most complete data set could be determined. Relevant international data was found for the United States of America [7], the United Kingdom, and Spain. Next to that, the European Union's *She Figures* report [8] was also consulted. All data for the Netherlands as a whole came from the Universities of the Netherlands, all TU Delft data came from the TU Delft data tableaus.

3.2 Netherlands Academic Career Model

Different countries will have different academic career progression models. In the Netherlands, to enter a PhD programme at a Dutch university a Master's degree is mandatory and as a general rule, a PhD is the minimum requirement for an Assistant Professor position. Although PhDs have been awarded at TU Delft since 1906, only since 1982 have formal PhD programmes been in place at Dutch Universities. The Dutch academic system until recently has largely been a hierarchical system, meaning that full professors were only hired when a vacancy occurred or when a new research group was started. More recently, qualifying associate professors can also be promoted to full professor, but this is not an automatic system and the qualifying conditions can vary greatly.

3.3 Capacity Modelling

The Royal Society [9] reported in 2010 that in the United Kingdom 0.45% of all PhD graduates will become full professors and 3.5% will become permanent research staff. How this number is determined differs from country to country based on methods, different academic career models and definitions of academic positions. It is however important to realize that, especially in the field of engineering, the university system is an open system. It means that people leave academia for other employment, but also that people come back to academia. Research by the Rathenau institute shows that overall the in- and outflux are almost in balance [10]. In the capacity model proposed in this paper, it is therefore assumed that the in- and outflux are in balance.

Equation (1) is proposed to calculate the number of PhD graduates needed to appoint 1 full professor. Divide 100 by the multiplication of the percentage of people progressing from 1 academic rank to the next:

$$N_{PhD\ per\ full\ prof} = \frac{100}{\%(PhD \rightarrow PostDoc) \cdot \%(Postdoc \rightarrow Asst.) \cdot \%(Asst. \rightarrow Assoc.) \cdot \%(Assoc. \rightarrow Full)} \tag{1}$$

Using the reported data by the Rathenau institute over the 2003-2013 period this comes to 333 PhD graduates per full professor appointment or 0.3% of all PhD graduates become full professors. This is slightly lower than the reported 0.45% by the Royal Society for the United Kingdom [9] but is likely more accurate as Dutch universities require a Master's degree before entering a PhD programme whereas in the UK a Bachelor's degree suffices.

It is proposed that Equation (1) can be expanded to calculate the number of graduates with a Master's degree that are needed to appoint one full professor:

$$N_{Mdegree\ per\ full\ prof} = \frac{100 \cdot N_{PhD\ per\ full\ prof}}{\%(Mdegree \rightarrow PhD)} \tag{2}$$

The earlier mentioned *She Figures* report [8] by the EU indicates that 0 - 20% of all women with a Master's degree enter a PhD programme and 0 - 30% of all men. For the Engineering, Manufacturing and Construction domain, this is 10% for women and 13% for men in the Netherlands [8]. To see if this data was representative for TU Delft a further step was taken: To estimate the percentage of Master's graduates that obtain a PhD degree the 5-year average of the number of awarded PhD degrees at TU Delft over the 2017-2021 period, 387, was divided by the number of awarded MSc diplomas over the same period, which averaged at 3496, which comes to 11%.

3.4 Glass Ceiling Index

The Glass Ceiling Index (GCI) is used by both the EU and the Dutch government as a measure of career progression for women. Each has a slightly different definition. The EU definition of GCI is [8]:

$$GCI_{EU} = \frac{\%\ all\ woman\ full, associate\ and\ assistant\ professors}{\%\ all\ women\ full\ professors} \tag{3}$$

The Dutch government defines GCI per academic rank [2]:

$$GCI_{NL} = \frac{\%\ women\ in\ highest\ rank - 1}{\%\ women\ in\ highest\ rank}$$

(4)

In both cases a GCI of 1 means there is no difference between men and women being promoted, a GCI > 1 means there is a Glass Ceiling effect with the higher the value, the more women are underrepresented in higher academic positions, whereas a GCI <1 means women are overrepresented in a higher academic position.

4 RESULTS

4.1 Capacity Building

From a capacity-building point-of-view, it is interesting to see how many woman PhD graduates in AE are needed to reach the "*magic*" number of 30%, which in the case of AE is 6 full professors and compare those numbers to the actual number of women PhD graduates. A similar calculation can then also be made with respect to the number of woman MSc graduates needed to reach 30% full professors.

As was mentioned before, 333 people must have gained a PhD in Aerospace to appoint 1 full professor which means 1,998 women must gain a PhD in Aerospace from TU Delft and subsequently using Eq. 2 and the percentage MSc - PhD of 11% results in a requirement of 3,003 people with an MSc degree in Aerospace in order to appoint 1 full professor. Therefore to reach the number of 6 woman professors at TU Delft without using capacity from outside, some 18,000 women must gain a Master's degree in Aerospace Engineering from TU Delft.

This naturally leads to the following question: How many women have obtained a PhD or MSc degree in AE at TU Delft so far? Based on aggregated TU Delft data, by 31 August 2021, 7,140 MSc diplomas have been awarded in total since 1943 when the first diploma was awarded, of which 576 were awarded to women. The total number of PhD -degrees in AE from TU Delft that have been awarded since the first one in 1947 is 605 of which 75 were women. It is worthwhile noting that only recently, in March 2022, TU Delft awarded its 10,000th PhD degree.

It is safe to say, that based on these numbers AE at TU Delft is not educating sufficient Aerospace Engineers at Master's and PhD levels to even sustain its current total of 19 full professors, let alone women. This probably also goes a long way to explaining why of the current 19 full professors in aerospace engineering only 6 hold a PhD in Aerospace Engineering from TU Delft of which only 1 is a woman and of whom only half hold any aerospace PhD or MSc degree.

Is there perhaps additional capacity for aerospace engineers elsewhere? To find out several international databases and publications on aerospace engineering graduates were consulted, notably in Spain (Educa database), The United Kingdom (HEPA), and the USA [7]. The data shown in table 1 lists the number of MSc and PhD graduates of the 2018/2019 academic year in each country and the total population of the country with the exception of the USA which shows the data for the 2017/2018 academic year.

Table 1. Number of MSc and PhD degrees in Aerospace Engineering awarded in 2018/19 (USA in 2017/2018) in the Netherlands, Spain, the United Kingdom and the United States of America in absolute and normalized by million of population.

	NL		Spain		UK		USA	
Population (mlln)	17		47		67		332	
Number	**Abs**	**Norm**	**Abs**	**Norm**	**Abs**	**Norm**	**Abs**	**Norm**
MSc (total)	296	17.4	419	3.9	935	14.0	1,587	4.8
MSc (women)	39	2.3	92	2.0	161	2.4	233	0.7
PhD (total)	37	2.2	N/A	N/A	180	2.7	412	1.2
PhD (women)	7	0.4	N/A	N/A	22	0.3	54	0.2

It is clear from the small selection of countries that capacity is also limited in other countries. If the numbers are normalised per million inhabitants, the Netherlands outperforms all countries when it comes to the number of MSc degrees awarded per year and forms the top 2 with the United Kingdom when it comes to the number of PhD degrees awarded per year per million inhabitants. It also shows the even direr situation in the USA.

*Table 2. Share of Women in Academic staff at TU Delft AE, TU Delft as a whole, the Engineering Domain of the Dutch Research Universities, and All Dutch Research Universities (excluding Healthcare), based on data for Dec 2020. *excludes external PhDs and bursary students. (Sources: WPO Data Universiteiten van Nederland and TU Delft)*

	AE			TU Delft			Eng NL			Uni NL		
Rank	**All**	**W**	**%W**	**All**	**W**	**%W**	**All**	**W**	**%W**	**All**	**W**	**%W**
Full	19	2	10.5	274	49	17.9	545	96	17.6	3,555	889	25
Assoc.	25	4	16	302	66	21.9	543	10	18.8	2,827	886	31.3
Assist.	56	16	28.6	543	171	31.5	1,068	326	30.5	6,383	3,820	44.1
PhD	288	74	25.7	2,911	887	30.4	3,112*	942	30.3	9,721*	4,366	44.9

Table 3. GCI Indexes at TU Delft Aerospace Engineering, TU Delft as a whole, the Engineering Domain of the Dutch Research Universities, and All Dutch Research Universities (excluding Healthcare) based on data for Dec 2020. (Sources: WPO Data Universiteiten van Nederland and TU Delft)

GCI	AE	TU Delft	Eng Domain NL	UNI NL
Assoc.→Full	1.5	1.2	1.1	1.2
Assist.→Assoc.	1.8	1.4	1.6	1.4
PhD→Assis.	0.9	1.0	1.0	1.0
EU	2.1	1.4	1.4	1.4

4.2 Glass Ceiling Index

Using the public data files of the Universities of the Netherlands and the data available from TU Delft data tableaux, the GCI_{NL} indexes were calculated for the Aerospace Engineering (AE), TU Delft, the entire Dutch Research Universities Engineering Domain and all Dutch Research Universities (excluding healthcare). Healthcare is not reported as this domain is reported separately. Also, Dutch universities of applied sciences are not included in this data as they have a different academic structure. The share of women in academia is shown in Table 2. The GCI indexes are presented in Table 3.

It is clear from the GCI_{EU} index that Aerospace has a solid glass ceiling when it comes to women advancing in their academic careers. *T*he GCI of TU Delft, the Dutch Engineering domain, and the Netherlands as a whole *are* all at 1.4 which in itself is also still far away from parity. There may be a slimmer of hope in that GCI for transitioning from PhD to Assistant Professor is smaller than 1, indicative of a better possibility of transitioning for women who have just finished their PhDs.

To give a better idea of how big the problem is, it is important to also compare these numbers to international data. The EU report She figures 2021 [8] reported an EU-average for GCI_{EU} of 1.5 based on 2018 data with the Netherlands also 1.5 which is in line with the EU28 average and based on the 2020 data provided in this data the situation overall in the Netherlands and the engineering domain continues to improve, with AE lagging.

*Table 4. Share of Women in Academic staff in the Engineering Domain of the Dutch Research Universities (Source: WOPI data Dec 2020 – Universiteiten van Nederland), the USA and Canada [7]. * excludes external PhDs and bursary students*

	NL (2020)			USA (2018)			Canada (2018)
Rank	**All**	**W**	**%W**	**All**	**W**	**%W**	**%W**
Full	545	96	17.6	13,808	1,698	12.3	12.5
Assoc.	543	10	18.8	7,081	1,430	20.1	19.3
Assist.	1,068	326	30.5	7,668	1,894	24.7	24.6
PhD	3,112*	942	30.3	12,156	2,869	23.6	23.4

Table 5. GCI Indexes for the Engineering Domain of the Dutch Research Universities, (Source: WOPI data Dec 2020 – Universiteiten van Nederland), the USA and Canada [7].

GCI - ENG	NL (2020)	USA(2018)	Canada (2018)
Assoc.→Full	1.1	1.7	1.5
Assist.→Assoc.	1.6	1.2	1.3
PhD→Assis.	1.0	1.0	1.0
EU	1.4	1.4	1.3

What about the Aerospace domain? An attempt was made to find staff data for the aerospace domain. Sadly, the EU and ASEE do not report at degree level so no comparison within the aerospace domain could be made when it comes to GCI. It is possible to do so on an engineering domain level with the USA and Canada but for the EU the domain definitions are incomparable and the level of data reported in She Figures [8] has insufficient depth to make good comparisons.

From the data in tables 4 and 5, it can be seen that on the more holistic GCI_{EU} level the Dutch engineering domain scores comparable to the USA and Canada but there are differences in the GCIs between the different academic ranks. It is, however, worth noting that the ASEE's Engineering by the Numbers - report [7] does state that aerospace engineering only has 11.8% female academics (compared to 22% at AE TU Delft) and women only made up 13.1% of all doctoral degrees awarded in aerospace in 2018, against 25.7% at AE TU Delft so *again* the situation may be even direr in the USA.

5 DISCUSSION

More women can indeed go some way to solving the capacity problem in aerospace. As this paper shows women are still woefully underrepresented in academia in engineering and thus should be a welcome pool of available additional capacity that is currently underused. University Leadership will often say that there are not enough women out there to increase the number of women in aerospace in academia. The data presented in this paper goes a long way in proving that point when you look at the current available capacity, not just in the Netherlands, but also elsewhere. It is unlikely that the 30% target will be met in the next 10 years. Combine that with the ever-increasing industry demand for aerospace engineers [5] and the capacity problem will not be solved instantly. At the same time, universities themselves are not without blame either. Many universities have limited capacity in terms of the number of students admitted to study aerospace engineering and as the GCI index shows, it is still very difficult for women to rise to the top in aerospace academia. This lack of ability to progress is also what is holding women back in pursuing an academic career in engineering: lack of progression, unconscious bias in recruitment and promotion processes and finally, structural barriers such as work-life balance. One might argue that those who made it are miracle workers as they defied all odds. Better hiring and recruiting practices and, more importantly, better retention practices are needed and are needed fast.

However, it is too easy to just appropriate all the blame on the universities themselves: Governments are restricting education and research funding is also limited which affects the number of available places for students across the tertiary education spectrum. Almost all aerospace degree intakes are capped and the number of PhD positions is highly dependent on external funding. Access to degrees is becoming more expensive year on year and the quality and offering of STEM teaching in secondary schools are declining due to insufficient capacity of STEM teachers thus unnecessarily limiting the pool of (woman) candidates as well. Industry could also step up and take their responsibility: If the (aerospace) industry continues to insist on lower taxes but yet expects an ever-higher yield from (government-funded) universities and other education sectors, they are frankly delusional. If they want to keep their competitive and innovative edge, both in terms of highly trained human capital and in research-based innovation, they must generously invest in the (aerospace) university sector and improve their often not-so-positive image in the eyes of women to make themselves more attractive. It is after all a basic economics question of supply and demand. If you are short in supply, you can choose whom you want to work for.

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