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Making deep space more accessible for all through inclusive involvement in a volunteer-based research lab

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Abstract

Currently, entering the space industry is challenging, as the space sector is mainly targeted at a workforce with specific educational backgrounds. Early hands-on experience in a professional organization, accessible for both students and those wanting to change industry is severely limited, closing the doors to talents from non-traditional backgrounds. Moreover, formal education does not adequately provide the multidisciplinary skills needed for a successful career in space, including soft skills and experience in integrating individual methods into a successful space project. With the space industry estimated to triple in the coming decade, providing accessible learning opportunities for the next generation of researchers and engineers is critical.

In this paper, we discuss an educational concept of hands-on education through volunteer-based space technology development. We use the case study of Team Tumbleweed, an international, online-enabled volunteer research lab building a novel wind-driven Mars rover to reach Mars in 2030. The organization was initially founded out of an unmet need for a way to get involved in the industry without prior experience or expertise. Currently, the team has around 60 part-time members, aged 18-62, with 25+ nationalities from 5 continents situated in Delft and Vienna, as well as remotely from across the globe.

We show that an international, volunteer-based team setup that is diverse with respect to age, culture, and background, and is guided by a strong culture focusing on iterative, hands-on learning, plays an important role in space education and workforce development. This setup has been successful in attracting and educating people from a wide variety of backgrounds, curricula, and nations, coming together as an effective team, and making real strides in the space industry. We find that the option of remote work is crucial to making hands-on learning in the deep space industry more accessible. It also allows people outside the standard career path to get involved and equips fresh university graduates to face the challenges of space innovation. However, this setup is prone to several limitations, such as reduced technical progress of the team and lack of compensation, which are further explored in the paper.

In this study, we discuss how a digitally-enabled, hybrid remote and global volunteer organization united by a strong vision can tackle innovation in the space industry in an integrated manner, and serve as an impactful learning experience to its members.

Keywords: Team Tumbleweed, Tumbleweed Mission, Space Education, Learning Experience, Team Accessibility

1 Introduction

The space industry, with its endless opportunities and frontiers, has historically been limited to a select group with specialized educational backgrounds and resources. For those without a traditional entry point, the path to space has often seemed daunting and impassable. However, with the space sector projected to expand dramatically in the coming decade, it has become increasingly vital to diversify and democratize participation in this field.

The space industry has historically required specific educational backgrounds, creating a barrier for entry that excludes individuals from non-traditional backgrounds or those looking to transition into the field. Access to early hands-on experience has been limited, and formal education often lacks multidisciplinary skills, including essential soft skills and experience in integrating diverse methodologies into successful space projects. As the space industry undergoes exponential growth, providing accessible learning opportunities for the next generation of researchers and engineers becomes imperative.

There is a lack of research on the topic of making space education more accessible to people from not traditional educational, professional or socioeconomic background. This paper proposes and explores the innovative educational concept of hands-on learning through volunteer-based space technology development, using the exemplary case of Team Tumbleweed. This international, online-enabled volunteer research lab is not only building a pioneering wind-driven Mars rover set to reach the Red Planet in 2030 but will also be capitalizing on the data acquired from these missions by selling it to companies on Earth. Team Tumbleweed was created out of a pressing need to provide an entry point for individuals without prior experience or expertise in the space industry. Comprising approximately 60 part-time members ranging in age from 18 to 62, hailing from over 25 different nationalities across five continents, and working both locally in Delft and Vienna, as well as remotely from around the world, the startup embodies diversity in every sense. At the heart of Team Tumbleweed's success is its international, volunteer-based team setup, which thrives on diversity. This diversity extends beyond mere demographics; it encompasses a wide range of backgrounds, cultures, and skill sets. The startup is driven by a robust culture of iterative, hands-on learning, where every member is encouraged to participate actively and learn through direct experience. This approach not only fosters the development of hard technical skills but also cultivates essential soft skills like teamwork, communication, and problem-solving—crucial for a successful career in the space industry. It has been shown that entrepreneurial activity during studies has a positive influence as these programs offer invaluable non-tangible benefits, enhancing participants' self-confidence, motivation, and entrepreneurial abilities [1]. Another study suggests that the entrepreneurial skills need to be practiced as part of the "incubation" stage of the educational process [2].

There are several other space companies and initiatives that contribute to the democratization of space exploration and education, aiming to break down barriers, inspire inclusivity, and make space more accessible to individuals of diverse backgrounds and ages. For example, the Space Generation Advisory Council (SGAC) connects young space enthusiasts worldwide, offering educational programs and fostering diversity. Students for the Exploration and Development of Space (SEDS) empowers students through projects and educational outreach, promoting diversity across its global chapters. The Planetary Society advocates for space exploration and science, providing educational resources and embracing a diverse membership. Asgardia, a unique space nation project, emphasizes peace and accessibility, encouraging education and representing a diverse global community in space-related endeavors. While all of these organizations play vital roles in advancing space education in today's society, there is an educational gap for space technology development through practice [3, 4].

In this study, we discuss how a digitally-enabled, hybrid remote and global volunteer organization united by a strong vision can tackle innovation in the space industry in an integrated manner, and serve as an impactful learning experience to its members. The paper also serves as a reflection on various learnings by the leadership team over the years of founding, expanding, and professionalizing the team.

2 Team Tumbleweed

In this chapter, we briefly present Team Tumbleweed, the subject of the study.

2.1 Vision and Objectives

Team Tumbleweed aims to make deep space more accessible to everyone by revolutionizing the current approach of space exploration, with the Team Tumbleweed as their beacon project. Current Mars surface exploration is characterized by large, infrequent, risky, and relatively high-cost space missions that gather in-depth data on a small area. To reach the ambitious Mars exploration objectives set for the coming decades, significant reductions in cost, risk, and schedule are needed. As a result, Team Tumbleweed is proposing a mission architecture based on a swarm of wind-driven rovers that can provide novel observations while reducing high mission costs and risk for Martian exploration [5]. The rover itself promises a rapid, swarm-based exploration of the red planet analogous to

the bionic tumbleweed concept. The organization's innovative, lightweight solutions with low mechanical complexity, developed by students, cut manufacturing costs significantly and enable broader access to deep space. By offering simplified payload slots and data-as-a-service to research and industry, Mars is set to become commercially available for the first time in history.

2.2 Team History & Present Day

Team Tumbleweed dates back to 2016, when three high school students participated in an international competition - the Odysseus Contest - for innovative space-related ideas. Their idea of using wind-driven rovers to provide cost-effective and rapid exploration of the Martian surface was the winning entry of the contest that year. After that, the team participated in a Mars analogous mission in Oman (AMADEE-18[1]), where their second prototype was tested, followed by the third prototype tested in the Negev desert in 2021 (AMADEE-20[2]), both organized by the Austrian Space Forum (ÖWF)[3].

From 2020 to 2022, the team was a part of ESA BIC Austria. During this time, the team expanded globally, going from around five members to roughly 80 volunteers, at its largest. There are two large hubs in Vienna and Delft, but many team members are dispersed throughout Europe, with some in the Americas, Africa, and Asia. The organization has tight connections with educational institutions such as ESA, TU Delft, and other industrial partners.

In 2021, Team Tumbleweed underwent its first large technical review with the help of industry professionals and academics, which resulted in significant adaptations and improvements to the technology and strategy. In 2022, the research lab published its first 3 papers at the International Astronautical Congress, followed by another paper at Lunar & Planetary Science Conference in 2023, proving that the research conducted by the team has merit. Next to that, first two Master of Science theses were written about Team Tumbleweed in 2023. Currently, the organization counts 60+ part-time members and is part of the Aerospace Innovation Hub in Delft. The technical teams are actively developing an Earth Demonstrator and Deployment Demonstrator Missions, which are set to demonstrate important technologies for the mission while aiming to acquire funding through grants and strategic partnerships with industry.

In the near future, Team Tumbleweed intends to become a full-time research-based organization, eventually growing into a commercial organization, diversifying its activities to include other space-based applications and technologies, with the ultimate goal of launching a Tumbleweed Mission to Mars (in 2034) and thereby broadening access to the red planet.

Despite the future plans, the current team setup has proven to successful in achieving considerable technical progress, and the reflections on the achievements of the team motivated creation of this study.

3 Methodology

Our methodological approach comprises three steps: designing the team setup, conducting an internal survey (of both current and former members) to measure accessibility and learning, and evaluating the technical progress.

3.1 Team Setup

Team Tumbleweed's approach involves a hybrid setup that combines remote collaboration with a global volunteer workforce. As mentioned previously, the team is composed of approximately 60 part-time members from over 25 nationalities across 5 continents. The team enables a strong feedback culture and focuses on hands-on learning, which creates an environment conducive to multidisciplinary skill development, fostering innovation and teamwork.

The aforementioned qualities of the organizational culture manifest through the following team values, that all members are committed to uphold:

- Be respectful. The basis of all of our interactions is mutual respect. Be considerate to everyone on the team, listen to what they have to say, give feedback constructively, and treat others as you wish to be treated. Show respect to your teammates by coming to meetings and completing your work on time, by being kind, inclusive and supportive.

- Communicate a lot and often. Through open and active communication, our organization thrives. Engage in discussions actively, do not be afraid to express your opinion, and stay updated with the team's progress. Be responsive on Slack, active on Discord, come to all meetings, be on top of your notifications and stay connected to the team the best way you can. Disappearing without prior announcement hinders others' work.

- Be accountable. Building a Mars rover requires a high level of responsibility and ownership. Be trustworthy for completing your tasks, do not be afraid to own your mistakes, seek help when needed, and

[1] More info: https://oewf.org/en/portfolio/amadee-18/
[2] More info: https://oewf.org/en/amadee-20/
[3] https://oewf.org/en/

be transparent about your progress. Most importantly, be open to growth - reach out for various resources, ask for feedback and make sure to follow up on it.

- Be committed. Without a strong commitment, Team Tumbleweed would not be able to exist. So be committed to the cause and have the best interest of the organization at heart. Constantly remind yourself of our vision and mission. Be proactive and engaged - take on new responsibilities within the team and strive to make the whole team better. Maintain strong relationships with your team members.

- Be professional. Produce high-quality work in a timely manner. Make sure to reach your deadlines, and when you cannot - communicate properly, improve your planning for the next project, and keep in mind that a delay in your work will delay someone else's work.

While this setup was primarily created out of necessity to maintain the operations of the team at a low cost while making the required technical progress to meet the initial deadlines, it has proven to achieve the set-out objectives, motivating further improvement of the team. Thus, as the team expanded in size and geographically, the organizational side of the team was iterated upon and improved, taking into consideration team's feedback and external advice of mentors and advisors, in order to maximize the value provided.

3.2 Survey Design

To measure the effectiveness of the learning experience and the accessibility of the research lab setup, a survey[4] was conducted across current and former members of Team Tumbleweed. The survey consisted of three sections, collecting data on team demographics, learning experience, and team accessibility across different subgroups of people. In the first section, survey participants were asked to give basic information about their profile, such as their nationality, gender, or their previous industry experience. The respondents were then asked to rate their educational experience from 1 (strongly disagree) to 7 (strongly agree) by answering questions about their skill development, learning opportunities, hands-on experience, among others. The questions and results are further explained and elaborated on in the following section (4). Finally, the participants had to give their opinion through open questions about the accessibility of the team, such as reasons to join or leave the team, feeling of inclusion, and others. Next to that, the impact that being part of the team had on their professional and academic lives was reflected on. The format of open questions was chosen purposely as to not influence the potential answers of current or previous team members. Naturally, the survey was conducted anonymously, to make sure that respondents feel comfortable to give their honest opinion.

3.3 Technical Progress Review

For the final step, a technical progress evaluation took place considering various internal technical and externally published documents, such as ESA Report (in line with participation at ESA BIC) and IAC publications, as well as internal documentation for tracking progress on objectives. Additionally, several informal learning experiences by the leadership team (such as outcomes of technical mentoring meetings) were taken into consideration in the review.

4 Results

4.1 Team Demographic

57 current and former members of Team Tumbleweed completed the survey. Out of these, 25 are no longer members, hereafter also referred to as "alumni". Together, the two groups give an overview over impressions of the team over a time period since late 2018. Over two thirds of the current members who participated in the survey have joined since 2021. Most of the alumni (11) joined in 2019, 9 in total in 2020 and 2021. They remained for an average of almost two years.

The median age of respondents was 23 years, the mode 22 years. These values were similar both for current and former members. The youngest member stated their age as 18, the oldest as 62. Approximately 12% of respondents specified their gender as "female", the remaining as "male". While the group included 30 different countries of nationality (multiple responses possible), around two thirds were European countries. 46% lived in the Netherlands, another 25% in Austria. Over 75% of the respondents indicated their marital status as "unmarried" or "single", 4 responded "married".

26 or 46% of the people questioned were currently studying in a Master's program, followed by 13 in a Bachelor's program. 16% of alumni each worked full-time or part-time, whereas 25% and 19% of current members worked full- or part-time, respectively, some alongside their studies. Almost half of all respondents indicated their highest level of completed educational degree as "Bachelor's degree".

86% of respondents stated having no experience in the space industry prior to joining Team Tumbleweed. However, almost one third stated their education discipline as "Aerospace Engineering". In broader terms, almost half

[4]The full survey questions and results are available upon request.

of current and former members were in the field of engineering and another 32% in computer science/engineering, mathematics or physics/astronomy.

While there was a large variety of first languages, with German being the most common at 22 responses, a self-evaluation by respondents showed that all rated their English listening and reading skills as "advanced" or "fluent/native". Aside from one to two exceptions, the results for speaking and writing were similar.

4.2 Team Accessibility and Learning

All respondents were asked to rate the following statements regarding their experience at Team Tumbleweed on a scale from 1 (strongly disagree) to 7 (strongly agree):

- Experience in Team Tumbleweed helped me develop hard skills, specific to my education.
- Experience in Team Tumbleweed helped me develop hard skills, unrelated to my education.
- Experience in Team Tumbleweed helped me develop soft skills, e.g. leadership and teamwork.
- Without Team Tumbleweed, hands-on learning would have been more difficult to access, e.g. at university.
- After having spent some time in Team Tumbleweed, I feel more confident in my space industry knowledge./Experience in Team Tumbleweed made me more confident in my space industry knowledge.
- I feel/felt included in Team Tumbleweed, regardless of my background.
- In Team Tumbleweed, there are/were sufficient opportunities to learn and grow in my responsibilities.
- Team Tumbleweed has (had) an overall positive impact on my professional and/or academic life.

The responses regarding the development of hard skills both related and unrelated to the respondents' fields of education showed 72% and 77%, respectively, as 5 or higher. However, upon comparison with the fields of education, the distribution varied slightly for those in- versus outside the area of engineering. As shown in figures 1 and 2, agreement to development of hard skills specific to education was slightly higher than to skills unrelated to education for those in the field of engineering. For those outside the field of engineering, however, there was a stronger tendency to agree with the statement regarding the development of hard skills unrelated to their field of education. In comparison, the development of soft skills showed a steady increase in votes from 2 (1 vote) to 7 (26 votes).

Notably, the statement concerning the possibility of hands-on experience without Team Tumbleweed was the only one where less than 50% of members chose an option of agreement (i.e. between 5 and 7).

Only one respondent rated the statement regarding an increased confidence in space industry knowledge below 4, with most answers ranging between 5 (17 votes) and 7 (15 votes).

Inclusion in Team Tumbleweed regardless of background achieved the highest rate of agreement, with 98% of respondents indicating 5 or higher.

While generally there seemed to be no major deviations between the ratings by current members and alumni, both the statement regarding sufficient opportunities to learn and grow in responsibilities as well as that concerning an overall positive impact on the respondent's professional and/or academic life peaked at 7 for current members and at 6 for past members.

In addition to those above, alumni and current members were presented with some differing statements. Current members were asked to rate the statements "I feel positive about the team culture at Team Tumbleweed" and "Team Tumbleweed's feedback culture and iterative approach have had a positive impact on my learning experience". These statements received a 90% and 78% rate of agreement, respectively. The first statement peaked at 6 (16 votes), the second one at 5 (13 votes). Alumni were asked to rate "After leaving the team, experience in Team Tumbleweed specifically helped me find a job or continue my education" on the same scale, with slightly more than half choosing an option of agreement. 24% each chose 3 and 5.

The respondents were also presented with several open questions:

- What aspects of the team encouraged you to join Team Tumbleweed?
- What aspects of the team made Team Tumbleweed accessible to you?
- What impact has Team Tumbleweed had on your professional and academic life?
- What impact has Team Tumbleweed had on your personal life? (optional)
- Further elaborations, any other positive or negative aspects. (optional)

In asking what aspects encouraged people to join the team, more than half of respondents mentioned the vision/idea/concept of Team Tumbleweed and its mission, making it the most important factor. Over 40% referenced the values of the team or its members ("driven and

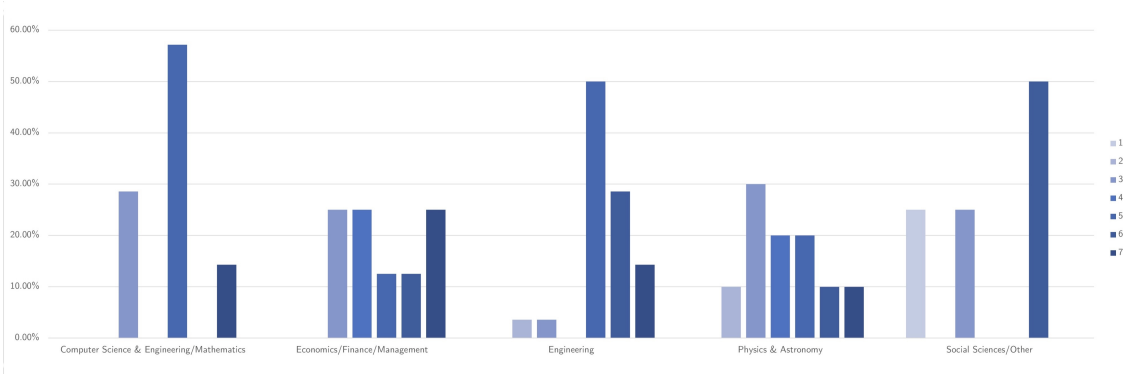

Figure 1: Answers to the statement ”Experience in Team Tumbleweed helped me develop hard skills, specific to my education.” by educational background, where 1 corresponds to ”strongly disagree” and 7 to ”strongly agree”.

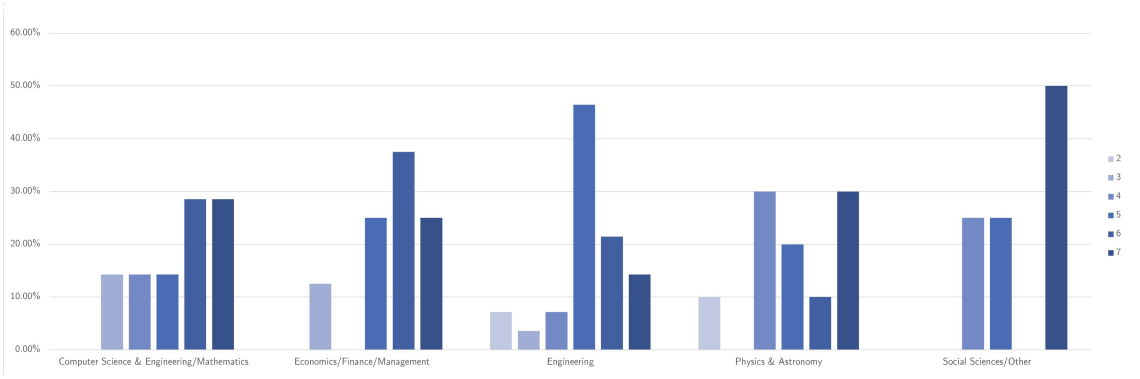

Figure 2: Answers to the statement ”Experience in Team Tumbleweed helped me develop hard skills, unrelated to my education.” by educational background, where 1 corresponds to ”strongly disagree” and 7 to ”strongly agree”.

dedicated people”, “Working with nice people passionate about similar things”). Other reasons included gaining experience or skills and career-related motivation (15 mentions), interest in the engineering/scientific aspects (10 mentions), and the team’s international composition (8 mentions).

The culture and attitude of team members was also mentioned by around one third of respondents in answering what aspects made Team Tumbleweed accessible to them. Over 10% specified knowing a member prior to joining. The inclusiveness of the team, acceptance of various backgrounds and low entrance barrier was deemed a deciding factor by 13 respondents (“There are interesting things to do for everyone and with every educational background”, “opportunities offered at the very beginning of my career path”). While another 13 mentioned the team being close to their location and in-person meet-ups as being important, a slightly larger number highlighted the online/remote or hybrid work environment as making the team accessible. Several respondents (9) also mentioned the work’s flexibility and it being part-time.

The question concerning the team’s impact on the respondents’ professional and academic lives showed a large proportion benefiting from professional experience, hard skills or career opportunities (over one third) as well as networking and connections (over 15%). One person stated: “Team Tumbleweed made me developed [sic] skills I never would have received from normal lectures. Moreover, it for sure helped me find the PhD position I am currently holding”. However, soft skills were mentioned by more than a third of respondents. Some even specified positive effects on their personal development: “It has taught me a lot in terms of technical knowledge and also teamwork. And overall it has boosted my confidence”, “Practical experience and opportunity to grow, resulting broadening [sic] my view on the world”.

Current and former members could optionally specify the impact on their personal lives. More than 35% mentioned making friendships and personal connections with other members in the team. Further, around 10% indicated a positive impact on their personal development (“[...] made me feel part of something very special”, “Made me more excited and content about my life”). A similar number of people each mentioned a growth in skills or knowl-

edge, as well as some negative effects on personal lives to reduced time available for other endeavors or leisure.

For comments that had not previously been made, respondents could indicate further positive or negative aspects of working Team Tumbleweed. Some (3) mentioned issues with communication in the team or in organizational aspects. 4 respondents highlighted the limitations of the current set-up, with one person specifying:

> Super friendly work environment, but often times difficult to work with due to academic and personal limitations between all team members. These issues do make it difficult to work for the team and find motivation sometimes, but that has to be expected due to the way the team is currently built up.

Further mentions included that of time investment toward Team Tumbleweed reducing members' ability to pursue paid employment.

Furthermore, the former members were asked to share their reasons for leaving Team Tumbleweed, with multiple mentions possible. 12 people indicated a lack of time or high outside workload as a reason, 11 people mentioned other opportunities or a shift in focus (e.g. uni or work). Further reasons included issues with the work or team (7 mentions) and feeling burned out or a lack of motivation (4 mentions).

5 Discussion

In the following section, we discuss and interpret the results in context of the organization, across the topics of learning (space education) and team accessibility.

5.1 Learning Experience

Hands-on Learning

The nature of the Tumbleweed Mission comes with a strong focus on engineering in the team. As figures 1 show, this is reflected in engineers' tendency to learn inside their own field, while others learn more outside it - perhaps also in the field of engineering. Especially members in physics and astronomy may be less likely to acquire hard skills related to their field due to the relatively small presence of these topics in Team Tumbleweed's work. Conversely, there are areas of work at Team Tumbleweed that are less prominent in the indicated educational fields, such as HR, media, and law, further allowing members to acquire hard skills unrelated to their education.

However, the results show that soft skills are acquired by members regardless of educational background. Regardless of the area of work at Team Tumbleweed, the often hybrid environment and complex tasks require strong teamworking and organizational abilities from the members. Furthermore, representing the team at events or presenting their research develops additional highly valuable soft skills.

Introduction to the Space Industry

As stated in the previous chapter, the majority of people join Team Tumbleweed without any prior experience in the space industry. However, since over two thirds of current members have joined since 2021 and alumni remained for an average of around 2 years, this amount of time seemed to be sufficient to increase their confidence in their space industry knowledge.

5.2 Accessibility

Hybrid Setup

While the remote set-up should technically allow the participation of members from all across the globe, almost three quarters of members were nonetheless distributed over only two countries. This may be caused by more successful in-person recruiting and personal connections to introduce new members, which may also strengthen the bond between members. Furthermore, larger distances between members may come with differences in time zones, which could lead to difficulties in scheduling work and meetings. Nonetheless, internationality and remote work were frequently mentioned as a factor increasing accessibility to Team Tumbleweed, implying that the option of hybrid work was highly appealing.

Volunteer-Based Team Setup

While volunteer work allows Team Tumbleweed to make technical progress at a time where financial compensation for members is not yet possible, the necessary investment of time may inhibit members from going after paid employment parallel to their studies. However, in comparing the percentage of current members working full- or part-time with that of alumni, it is evident that the number of people pursuing a paid position does not necessarily increase after leaving Team Tumbleweed. Thus, financial compensation does not seem to be a disproportionately contributing factor to exiting the team.

Nonetheless, the initial lack of compensation for work at Team Tumbleweed may already preemptively restrict accessibility to the team, as those who require a paid position due to financial circumstances would not apply to such a team. This reduces the demographic of potential members to people with a stable financial background or external support.

The open questions show that to many, personal connections and friendships are a valuable aspect of working at Team Tumbleweed. This is reflected in the current

members' feeling about the team culture, as well as highly ranking feelings of being included. As a volunteer-based team, this may be a more important factor than in a traditional work environment, as a lack of financial compensation may leave members needing more other sources of motivation and support within the team. A positive, inclusive team culture may help encourage members and increase the joy they experience in completing tasks.

Inclusivity

While many different backgrounds and ages come together in the team, these were not necessarily evenly distributed: a large proportion of engineers, mostly students in their 20s, and largely male members. These factors were further investigated concerning their effects on feeling included in the team.

As figure 3 shows, feelings of inclusion were similar for lower and higher age ranges. The middle age ranges of respondents between 22 and 34 are more distributed across 5, 6, and 7, which is likely due to a larger number of people in these groups. This indicates that Team Tumbleweed succeeds at providing an inclusive environment across several age ranges.

Similarly, the educational background did not seem to greatly influence how included respondents felt, as displayed in figure 4. Economics/finance/management and social sciences/other showed especially high rates of agreement, while they were slightly lower for those with a physics/astronomy background.

Finally, figure 5 shows the effect of gender on feeling included. Female respondents rated the statement slightly lower than male respondents, but positively nonetheless. Thus, no age, educational field or gender showed especially deviating attitudes toward feeling included in the team.

Due to the low percentage of female members, the effects of gender were also inspected on the statement concerning feelings about team culture. As shown in figure 6, female members even showed a slightly higher rate of agreement than male members.

5.3 Technical Progress

Beginning with the initial expansion and acquisition of ESA BIC support of the team in 2019, the primary goal was to build a third iteration of an integrated Tumbleweed demonstrator. The formally stated goals revolved around building said integrated prototype to demonstrate the technology on Earth, and to evaluated and develop critical technologies.

To pursue these goals, the team began to iterate on the existing design of the third-generation prototype - with work having already been started in late 2018 - while at the same time also surveying configuration options for the rover to achieve foldability, which so far had not been demonstrated. Then, the team further split up to pursue the design of the subsystems, with the ultimate focus being on flight hardware, by using iterative improvements, tracking improvements to the team's knowledge and infrastructure.

Throughout 2020, this work continued, culminating in wind tunnel testing of the prototype, and a variety of reports on initial subsystem level designs. Building on this, the work continued in 2021, with a science team also working on establishing scientific goals for a potential Tumbleweed mission. This work was then reviewed in a big external review, which not only highlighted several issues with the produced technical work (as expected and designed) but also prompted larger-scale organizational changes. For example, the establishment of a centralized systems engineering function was a key outcome.

At the same time, the goals shifted somewhat, focusing more on systems engineering and market research, while improving the standard of work to be more in-line with established industrial and academic standards.

From 2021 to 2022, many of these improvements were implemented, while additional research continued - this resulted in the submission of 3 IAC papers in 2022, as mentioned previously. Then, the work of the team was made even more systematic through the establishment of individual project teams that worked on specific research goals, as opposed to departmental teams.

In 2023, this results in the publishing of 12 IAC papers, a marked increase, while maintaining a constant team size from the previous year. Now, the progress made will be extended further by establishing campaign teams, which integrate disciplines to produce the next generation of demonstration prototypes, marking a renewed focus on producing prototypes.

Impact of volunteer-based organizational setup on technical progress

Being volunteer-based has both had positives and negatives on the technical progress: essentially, it was the only way that, given the initial conditions of the organization (no heritage, almost no funding, limited infrastructure), we could have achieved these technical goals. Especially in the initial stages of technical development, the volunteer setup has proven to be very effective, enabling rapid scaling, while keeping costs low.

While being a definitive enabler, being volunteer-based is now also starting to show drawbacks:

- Being volunteer-based makes long-term retention of team members difficult - only approximately 15-20% of members that join stay for more than 2 years. While the team has always been able to rely on a backbone of experienced team members, this

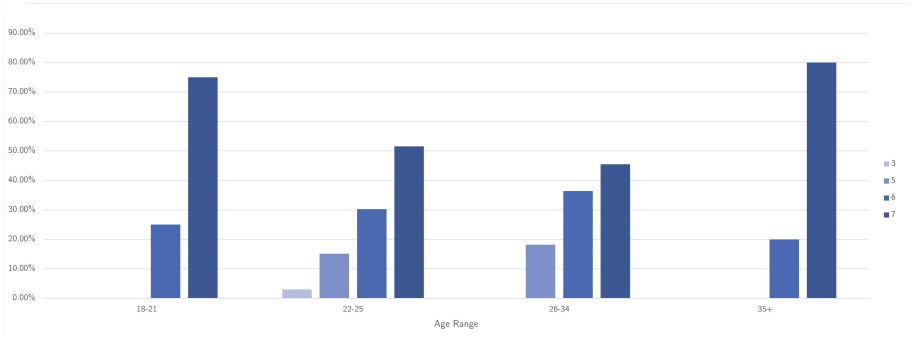

Figure 3: Answers to the statement ”I feel/felt included in Team Tumbleweed, regardless of my background.” by age, where 1 corresponds to ”strongly disagree” and 7 to ”strongly agree”, relative to the number of respondents in each group.

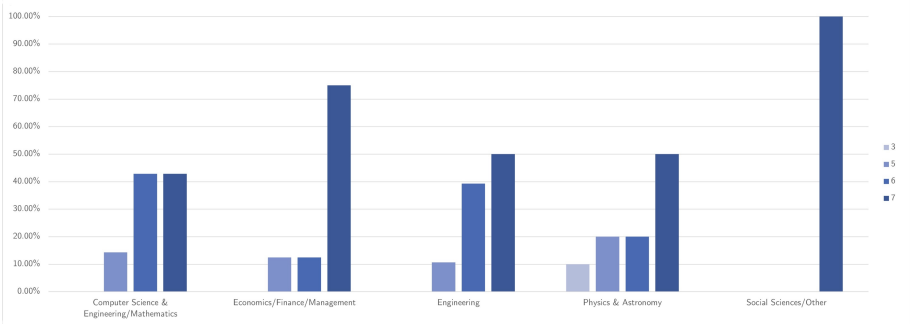

Figure 4: Answers to the statement ”I feel/felt included in Team Tumbleweed, regardless of my background.” by educational background, where 1 corresponds to ”strongly disagree” and 7 to ”strongly agree”, relative to the number of respondents in each group.

nevertheless leads to a lot of time and effort being spent on onboarding. Also, from experience, it takes at least 3 months for a new team member to perform at their optimum in a technical team, owing to the complexity of the subject matter. Consequently, teams struggle to get into and stay in a state of optimal productivity.

- Being volunteer-based, the organization has little leverage to enforce work being done, and practically speaking, their work at Team Tumbleweed often cannot be members highest priority as they need to also earn money, or complete a degree. This means that team members do not spend as much time as would be optimal on their work - and as keeping updated with the team's progress will inevitably take a lot of time.

This combination of lower time spent per member and lower commitment, together with higher turnover means that the team will likely have to move towards a more conventional set-up from a technical perspective in order to reach its objective to reach Mars by 2030.

5.4 Limitations & Recommendations

The study has several limitations that need to be acknowledged. Overall the survey sample size was relatively small to be able to make general conclusions about the industry, however we consider them to be representative of the team. When it comes to the survey design itself, some aspects of diversity are hard to measure, e.g. socioeconomic status, providing a limited understanding of the real diversity of the team. Additionally, not all members, current and former, were reached or able to respond to the survey due to limited time, unknown contact details (especially relevant for the former members) or other circumstances. The team should aim to increase the number of responses in the next internal study.

Based on the results of this research, we propose the following recommendations. Team Tumbleweed should aim to further increase reach of people with non-traditional backgrounds. Further research should be done on the feasibility of maintaining the current setup in context of making technical progress as an organization.

It is evident that enabling remote work or study opportunities within the industry (ranging from research orga-

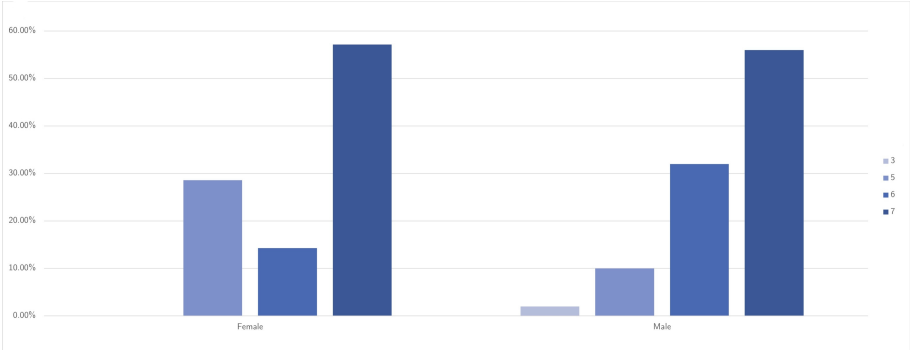

Figure 5: Answers to the statement ”I feel/felt included in Team Tumbleweed, regardless of my background.” by gender, where 1 corresponds to ”strongly disagree” and 7 to ”strongly agree”, relative to the number of respondents in each group.

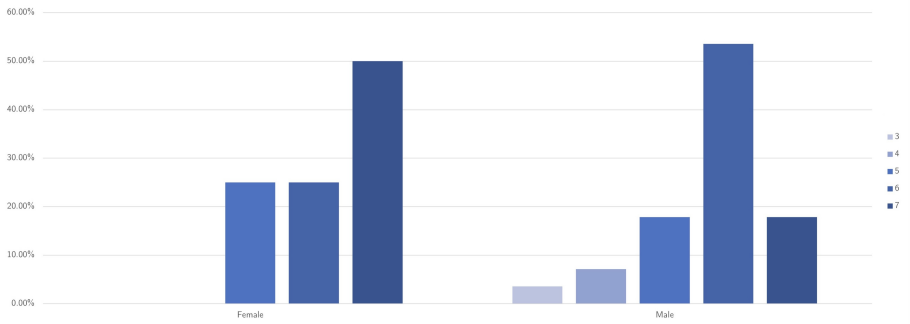

Figure 6: Answers to the statement ”I feel positive about the team culture at Team Tumbleweed.” by gender, where 1 corresponds to ”strongly disagree” and 7 to ”strongly agree”, relative to the number of respondents in each group.

nizations, companies, to agencies and universities) would increase the accessibility to learn skills relevant to the industry.

6 Conclusion

The objectives of the paper were to analyze a case of a remotely accessible, global volunteer research lab, driven by a strong vision and united by team culture, and evaluate the learning experience that such team setup enables its members. We show that Team Tumbleweed is able to make technical progress in achieving its technical goals effectively while being a learning experience for most of its members (many of whom are new to the space industry). As such, we find that Team Tumbleweed's innovative approach to space education and exploration to not only be successful and appreciated by its members, but to also offers a blueprint for democratizing the space industry and making deep space more accessible to everyone.

By embracing diversity, fostering hands-on learning, and making strides in revolutionizing the way we explore space, the team is breaking down the barriers that have historically limited participation in the field. In an era where space exploration is set to undergo exponential growth, Team Tumbleweed's vision not only propels humanity closer to Mars but also opens up a universe of possibilities for a more inclusive and accessible space future.

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