International Astronautical Federation
International Programme / Project Management Committee

IAF-IPMC
Young Professionals
Workshop 2019

Workshop Results Report

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Group Photo of the 2019 International Project Management Committee Young Professionals Workshop delegates on 20 October 2019 at Washington Convention Center, USA

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1. Executive Summary

The International Programme/Project Management Committee Young Professional Workshop sought to gather ideas and recommendations from early career employees in the international space community and provide the IPMC and IAF member organizations with greater knowledge, insights, and perspectives that can help better develop and empower the next generation of space program employees. The IPMC was supported in this effort by a group of young professionals who participated in previous workshops and served as the Workshop Organizing Committee (WOC) to manage the overall process and finalize preparation of a workshop report.

The workshop itself represented the culmination of an initiative that began in the second quarter of 2019 with the nomination and selection of workshop participants who were assigned to working groups focusing on five discussion topics. Over the ensuing period these groups discussed and investigated the topics and reached preliminary conclusions. The groups then met face-to-face at the workshop, finalized their recommendations, and presented the outcome to the IPMC members, workshop delegates and guests at the IAC.
Following the workshop, the WOC prepared a final report with a summary of the results and recommendations.

Topic 1: Earned Value Management (EVM) in Project Management of Large Space Projects

Earned Value Management is a project management technique that allows integrating time and cost aspects into the planning, the execution reporting and the control of the project development. EVM provides early signals of cost and schedule deviations that ease the implementation of corrective actions. EVM has been used since 1960, and is often a contractual requirement. However, a significant number of large space agencies and contractors do not implement EVM. This is either because of the project funding approach and selected contract implementation or due to the expected implementation effort of EVM.

The group has performed extensive research and in-depth discussion of the following areas:
- How the most common project management methodologies and types of contracts can benefit from EVM.
- Which are the key benefits and shortcomings of using EVM, making reference to specific large space projects chosen as relevant Case Studies.
- How EVM can be improved to alleviate its shortcomings and allow its implementation also in those projects where it is currently discouraged: a number of suggestions have been given for a tailoring of the method.

- How EVM can help improve the cost effectiveness in the long term of large space development projects: elaborating upon the results of available initiatives in ESA and UK MoD.

Topic 2: Fostering Project Management in the world of Diversity

The process of putting together and orchestrating minds that think differently, have different experiences as well as interdisciplinary and intercultural backgrounds is a crucial aspect of future innovation. Many organizations have realized that the extent to which the workforce diversification of the 21st century is effectively and efficiently managed will affect organizational functioning and competitiveness.

However, most organizations end up with a "diversity in a box" strategy, where diversity is forced top-down through the hierarchy. Therefore, there must be a fundamental culture change of how diversity and inclusion is understood, managed and translated into actions in order to complement the aforementioned top-down approach.

The group has initially researched the following elements:

- The core of diversity, including macro- and micro-diversity.
- The return that can be obtained by fostering diversity.
- The current status of mitigation actions in the space sector, including examples from DLR, JAXA and Airbus Group.
- Methods which are used in adjacent sectors and could be adopted in the space industry.

Finally, the group proposes a tool to measure micro-diversity by gathering self-assessments of team members, and postulates that this tool could help project managers probe inclusion needs and create more effective teams.

Topic 3: Challenges faced by teams working on space projects between emerging and legacy space economies

Driven by aspirations to increase geopolitical influence, regional autonomy and the desire to reap growing socio-economic and technological innovation benefits, governments all over the world are formulating new or more ambitious space programme objectives. Increasingly, governments are also relying on the private sector to provide space infrastructure and services.

Many countries and companies, however, lack the required experience that is necessary in the implementation of technologically and programmatically challenging space projects. One promising mechanism to overcome this issue is for new or less experienced project teams to team up with a more senior space administration or agency elsewhere, benefiting from their skills and experience.

The group initially researched the categorization of diverse economic space actors, including differences in their project management experience and skills. Then they focused on two case studies, NASA COTS (US) and PTS Mission to the Moon (EU), as actual examples of partnership projects between emerging and legacy space actors.

Topic 4:   Knowledge Management practices

Knowledge management, or KM, means ensuring that knowledge and information is created, shared, transferred, used, stored, and managed within an organization. More specifically, knowledge is an understanding gained through experience, study, training, or sharing, which establishes a basis for judgment and the potential for action.

Maintaining good KM practices is a challenge for organizations in any field, but there are two specific circumstances in the space industry that highlight why this is a more complicated challenge for this sector: 1) A low ratio between senior experts and newcomers, and 2) The wide range and large amounts of prior knowledge required.

The group based their research on results from the 2018 edition of the IPMC YP WS, and explored in depth the social aspects of knowledge management, in particular the implementation of communication and human interactions in KM processes in academia and start-ups. They did so by analysing these elements:
- Practices and difficulties in transferring knowledge to newcomers, and the extent to which there is a willingness to do so.
- The different weights of implicit and explicit knowledge in different organizations.
- Examples of new initiatives (found in academia, start-ups and non-space players) that could benefit legacy space organizations.

Topic 5:   Project Management practices for encouraging rapid prototyping and short fused product life cycle for space projects

Rapid prototyping is a group of manufacturing technologies that manufactures products on an additive or layered-basis, and thus far have been used to support Rapid Product Development (RPD), a manufacturing methodology that accelerates the development of new products, from the initial design stage to mass production.

The quick turnaround and ability to perform inexpensive changes makes rapid prototyping attractive to many, as does the option to validate a product before full-scale manufacturing. In the aerospace industry specifically, these methodologies allow the crafting of complex structures at a reduced cost and time scale. However, this advanced method for product development requires a new way of project management.

The group has focused their attention on the following points:
- Advantages of rapid prototyping, with an eye on the relevance for the aerospace sector.
- Different management approaches and their applicability to different phases of the product life cycle.
- Link between rapid prototyping, technology readiness level and risk management.

Throughout the following report, the various topics will discuss in detail their methodology and findings which ultimately resulted in recommendations to be implemented.

2. Introduction

On October 20th, 2019 a group of 22 international young professionals – working in space agencies, companies and professional organizations – met to participate in an annual workshop organized by the International Programme/Project Management Committee (IPMC) of the International Astronautical Federation (IAF). The workshop was planned and organized by a team of international young professionals working in collaboration with the IPMC. It was held at the Walter E. Washington Convention Center in conjunction with the 70th International Astronautical Congress (IAC).

The IPMC Young Professional (YP) Workshop is an annual initiative of the International Project Management Committee (IPMC) of the International Astronautical Federation (IAF). The IPMC – which brings together representatives from more than twenty IAF member space agencies, companies and professional organizations – meets semi-annually to exchange experiences, best practices and to collaborate on projects that nurture the global space workforce.
The YP Workshop is held just prior to the IAF's International Astronautical Congress (IAC). The IPMC selects a small group of young professionals who previously participated in a YP Workshop to serve as the Workshop Organizing Committee and help the IPMC organize and manage the event. The 2019 Workshop Organizing Committee (WOC) members were:

Birgit Hartman	Project Manager
Marie Botha	Operations Manager
Peter Batenburg	Mentors Manager
Jennifer Sizemore	Delegates Manager
Elizabeth Barrios	Logistics Manager
Kavya Manyapu	Assistant WOC

Stacha Petrovic	WOC Representative
Eleonora Zeminiani	WOC Representative
Lionel Metrailler	WOC Representative
Andreas Pedersen	WOC Representative
Mark Fittock	WOC Representative

The Workshop Organizing Committee members were also asked to closely follow the development of the discussion topics, guide the discussion group deliberations, and prepare this final report. The 2019 IPMC Young Professionals Workshop attracted twenty-two early career employees from government, industry, research and professional organizations throughout the

world. Each of the participants was nominated by an IAF member organization to attend the workshop in response to a call for nominations.

The workshop participants selected one of five discussion topics to continue in smaller discussion groups that met virtually during the period prior to the actual workshop session. (Please see Chapter 3: Pre-Workshop Activities and Virtual Session Collaboration, below.) The results of these investigations and deliberations and associated observations and recommendations are presented in this report. The ideas and views expressed herein are those of the participants as individuals and do not necessarily reflect the views or positions of the IPMC, the IAF or its member organizations.

3. Pre-Workshop Activities and Virtual Session Collaboration

In late Spring 2019, the Workshop Organizing Committee (WOC) published the SOW and Call for Delegates and then collected candidatures and applications.

After the selection of the delegates, the Organizing Committee administered a questionnaire to obtain information including individual delegate profiles for the workshop handbook, along with their preferred social networking tools and professional capabilities and personal hobbies. This information helped establish a basis for assigning the delegates into the various topic groups. Each participating Young Professionals expressed particular interest in one of the proposed topics. In addition to their topic interest the participants could express their desire to function as either a team leader or a rapporteur.

Since the Young Professionals Workshop is a one-day event, the WOC felt it was necessary to establish relationships among the delegates in advance of the event. With a globally distributed and diverse group, the WOC elected to encourage use of online virtual, social and collaborative tools, such as Skype, Google Hangouts, Slack and Google Docs and the scheduling tool Doodle. The goal was twofold: on one hand to facilitate "breaking the ice", and on the other hand to initiate group conversations around the chosen discussion topics.

The WOC then organized a first meeting via Hangouts for each group, to introduce the Statement of Work (SOW) and explain in detail the expectations, goals, timelines and deliverables. This was also a good time for the delegates to ask any questions, and to share their initial thoughts and ideas. Each group selected a topic leader and a rapporteur. The topic leaders were responsible for producing requested deliverables and for managing other related discussion group tasks. The topic leaders were also the main point of contact for the WOC. The rapporteurs were asked to document the discussions and the progress made. These documents were helpful to ensure all of the team members understood the status of the deliberations.

The virtual session process began in June 2019. Until the October Workshop, the delegates were asked to work on their individual topics. Discussion group meetings were facilitated via Skype or Google Hangouts and scheduled mostly through Doodle, which allowed delegates to self-organize times in line with their availability. Documents, such as mid-term reports and project execution plans were submitted as deliverables and shared under folders in Google Docs. This proved to be a very helpful and reliable tool and was easily accessible by delegates around the world. The teams then conducted in depth investigations, held various interviews, and shared their own day-to-day experiences working in the space industry as young professionals. As a tool for collaboration among the participants from diverse locations globally, the virtual sessions worked well as a means to bring the delegates together and facilitate the research prior to the face-to-face Workshop.

Mentors have been key contributors to the success of the initiative. Mentors are senior professionals, with specialist insight with respect to the topics being investigated.

Mentors have been selected by the WOC in late Spring 2019, by collecting volunteer applications and by scouting suitable profiles and connections. A dedicated orientation session (once more, an

online virtual meeting) has been held between the WOC and Mentors, to introduce the purpose and inner workings of the workshop and to better explain to the Mentors what was expected from them. One mentor has then been assigned to each topic group, with the objective to offer advice and steering, evaluation of ongoing research, critical assessment of results and recommendations. Mentors have also been the "critical voice" which helped the Delegates measure their work against the typical key drivers of project management (cost, schedule, quality) and build the case for their proposals by discovering weaknesses and clearly identifying the possible "return on investment". Mentors were in contact with their assigned topic group (though the topic leader) and each team agreed on a preferred pattern of attendance. Some teams worked more closely and more often with their Mentor, involving them in every teleconference and every discussion, while others established recurring checkpoints spaced out by periods of autonomous research.

In any case, Young Professionals and Mentors were able to form fruitful alliances to improve the value of workshop outcomes and to collectively grow the space community. They met face to face at the final presentation where they had a chance to discuss in person the results of their own and other teams' research.

4. IPMC YP Workshop reaching YPs worldwide

In the 8 editions of the workshop since 2012 the workshop has had 253 participants from 12 different countries on average.

Based on the location of the IAC, the WOC can observe the following;
- The nationality of the participants shows a direct link, i.e. more Asian Nationalities at IAC Beijing, a majority of Europeans at IAC Bremen, etc.
- The cost of accommodation and travel is an important decision factor for young professionals to attend.
- Visa requirements can prevent young professionals to attend.

5. Group Topic Results

During the 2019 IPMC Young Professionals Workshop the five discussion groups met face-to-face for the first time, finalized the results of their discussions and presented their findings to the other groups along with several IPMC representatives. The topic reports prepared by the five groups, along with each group's concluding observations and recommendations, are presented below. Due to the amount of information gathered, this report is a concise compilation of the results.

5.1 Earned Value Management (EVM) in Project Management of Large Space Projects

5.1.1 Introduction and methodology

Earned Value Management is a project management technique that allows integrating time and cost aspects into the planning, the execution reporting approach and in the control of the project development. EVM provides early signals of cost and schedule deviations that ease the implementation of corrective actions.

EVM has been used since 1960, and is often a contractual requirement for NASA, U.S. Department of Defense (DoD) and the UK Ministry of Defense (MoD), among others. It has now become an international industry-applied management technique that is standardized by ISO 21508. Despite the implementation cost, if applied thoroughly, it has been effective in helping maintaining cost and schedule under control.

However, a significant number of large space agencies and contractors do not implement EVM. This is either because of the project funding approach and selected contract implementation or due to the expected implementation effort of EVM.

The objective of this report is to identify how EVM can contribute to the success of large space projects and assist project managers to make informed decisions for future planning.

The research revealed that cost and schedule control is key in the success of large space projects. This statement is true regardless of the type of project, whether it is development or production, the contractual framework (e.g. firm fixed price (FFP), fixed price plus variation (FPV), cost reimbursement) or the specific project management approach.

Earned Value Management is one technique to control cost and schedule. This methodology has been used for many years for select NASA and DOD projects and has defined de facto, a cost control standard for their suppliers. However, it is found to be applicable mainly for cost reimbursement contracts following the predictive project management approach.

However, EVM will not ensure the quality of the final product and relies on other control techniques to guarantee that the scope is fully respected. Furthermore, the implementation of EVM generally introduces additional overhead effort to the management activities in the contract chain. This overhead is first related to the additional manpower required to manage the EVM accounts, but also in the definition and implementation of the accounting systems throughout the customer

chain so that the information is exhaustive and coherent. Therefore, the added value of implementing EVM will vary depending on the cost and schedule risks as well as their relevance versus scope and quality.

Having a unified methodology for cost control would allow monitoring effectively large contracts and provide useful performance information across different suppliers.
Therefore, this report provides a number of recommendations to expand the validity of EVM to FFP, lean manufacturing and adaptive contracts as well as to control the change of scope of development project.
These recommendations are the following:
1) For FFP contracts, define EVM as a requisite to access the management reserve
2) Adjust EVM for iterative PM approaches
3) Adjust EVM to monitor scope changes
4) Introduce quality measures to align with the EVM methodology to track the validation of requirements

The team first performed an extensive literature review to understand how Earned Value Management (EVM) is defined and used within project management. Numerous case studies were identified and summarized that span U.S., Europe, government and commercial examples.
The team then focused on answering the following questions:
- Define EVM, through a literature study
- Identify PM approaches that could benefit from EVM
- Identify benefits of utilizing EVM in project management
- Identify shortcomings of EVM in project management
- Investigate the benefits to contractors of utilizing EVM
- Define the potential long-term gains for an organization by utilizing EVM

5.1.2 Earned Value Management definition

Earned Value Management is a tool for project management for measuring financial and project performance (Ernst, 2006 & PMI, 2011). It is used to objectively measure project performance and progress by comparing the cost and duration of the work done and planned. It is also identified as an excellent tool for contractors to control internal costs and inform the customer about cost impacts. Key Performance Indicators (KPI) allow EVM to serve as a warning tool to help identify problems before they become critical. EVM was introduced by the U.S. Air Force in 1967 and is now applied to many fields, such as engineering, research and development, and contract administration.

As well as assessing current status, EVM can be used to forecast project progress. In order to implement EVM, a baseline plan where scope, budget and schedule are defined is necessary. The five high level stages of general project management are described below (Kwak et al., 2010):
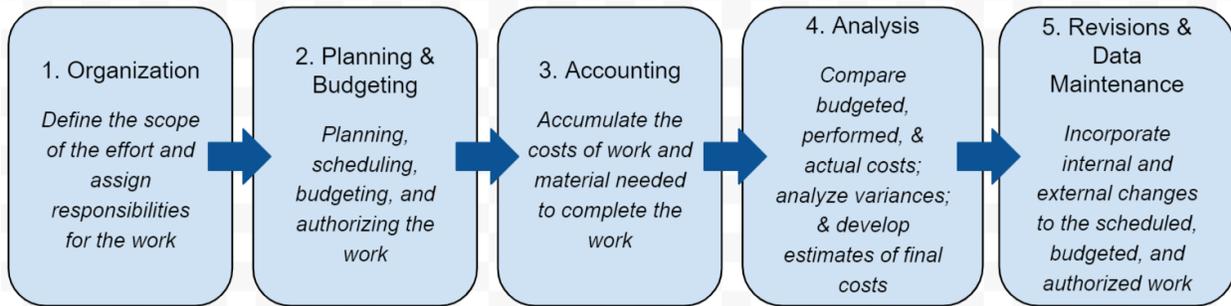
Figure 1 - Five stages of general Project Management (Kwak et al., 2010)

EVM is used to monitor progress. For this to work at the start of a project, the performance baseline needs to be defined and a Work Breakdown Structure (WBS) created. In order to use EVM, the project must be split up into elements for which the planned budget is known, as well as the time by which it needs to be completed. Additionally, the work should be sufficiently granular in order to identify any potential overruns or challenges in a timely manner.

With the WBS, the following approach should be adopted:
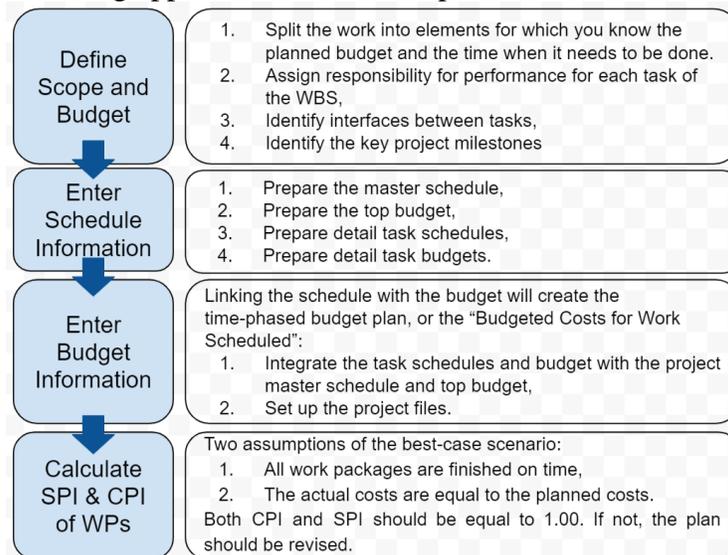
Figure 2 - EVM approach with a WBS

5.1.3 PM approaches that could benefit from EVM

In today's space business environment, almost every project is planned and executed following a standardized project management approach. These are often imposed by internal guidelines or specified as part of the statement of work. These practices are important to ensure a coherence between the different products of a project and to allow higher management to monitor and control the development of the different activities ensuring the success of the project.

Earned Value Management System is one of the management techniques that can be incorporated into most of the existing standardized project management methods in its planning, monitoring and control phase.

Which project management approach are more suitable to EVM?
A solid baseline with a dedicated WBS with clearly defined budgets and durations are required when implementing EVM. This system is more suitable for traditional predictive project management methodologies than to adaptive ones, as the latter are not planned in full detail and thus lack a baseline to compare the progress. Nonetheless, it can still be a very useful performance indicator when following a hybrid approach with overall traditional planning, used to allocate budget and resources to a specific development, and relying on EVM techniques to monitor the progress of agile developments after each iteration.
There are situations in which EVM is not required by NASA or DOD (Blythe, 2014 & Ernst, 2006). For Firm Fixed Price (FFP) contracts, the cost risks are theoretically shifted to the prime contractor and as such an EVM as defined in (Blythe et al.,2014) cannot be applied at the customer side.

Principles similar to those of EVM, such as coordinating cost and schedule aspects, can still be applied at the customer side, especially if a full EVM approach is followed at the prime level. EVM can be a fundamental tool at the supplier side to maintain cost and schedule under control. Even if not required by the customer, EVM metrics can be fundamental to justify technical, financial or schedule relaxations in order to prevent cost overruns.

As an example, as part of an FFP contract, a similar level of control could be achieved with the following approach:

1) A dedicated milestone payment plan linked to specific achievements at prime and subcontractor level is defined and agreed upon up front.
2) Milestones payments are monitored throughout the project, providing schedule performance.
3) The required contract change costs not driven by updates on the customer requirements. This provides cost variance.

Given that the milestone payment is controlled at the customer level, the reliability of the data is ensured.
It is still recommendable to introduce EVM at the supplier level in order to control the internal costs and support potential unforeseen additional effort claims. In addition, EVM is of utmost importance at the supplier side as the final price is fixed and cost overruns affect the final project revenue.

Level of Effort and Lean manufacturing
Two specific types of developments cannot be managed with the defined EVM approach, and they will be described in more detail hereinafter.

First, there are activities that do not lead to specific outputs and therefore a clear WBS with specific budget and schedule cannot be defined. This is generally the case for Level of Effort (LOE) activities. In these cases, EVM cannot directly be applied and alternative performance indicators will be required.

Also, EVM can be particularly helpful in critical chain methodologies and lean management methodologies. Critical chain methodologies identify the tasks and resources that drive the critical

paths and the interconnection between them. The critical paths and the related constraints in terms of resources will be a very important project descriptor, to be closely monitored and controlled.

Lean management proposes the principles of Lean manufacturing to produce high quality competitive products by minimizing waste and allowing for a continuous improvement. This approach, together with a strong supplier relationship, allows for improved performance. For this management approach, EVM can be an effective tool to measure development performance and identify areas where improvement is possible.

On lean principle developments, and especially in a production environment, EVM can help identify sources of potential improvement. In this specific case, EVM will not be defined for the complete project, but the earned value will be defined per product and will be divided among the different suppliers acting on it.

The flowchart below, derived from (Moujib, 2007), shows the relationship between a traditional project management life cycle (PMLC) and the lean management philosophy, identifying how EVM can be used to improve the value in ongoing developments.
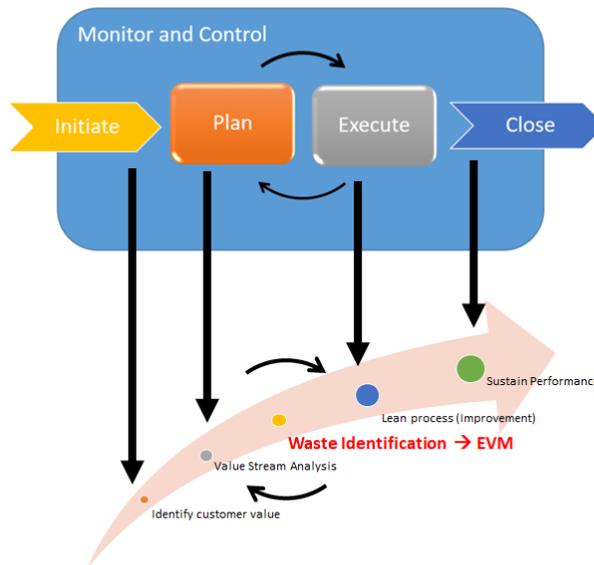
Figure 3 - Lean Management and EVM

5.1.4 Benefits of EVM in Project Management

At the beginning of the project, the work breakdown structure (WBS) should integrate work, costs and schedule (Van Wyk, 2015). This process helps companies to have a product-oriented WBS and be more efficient in organizing the contributions of all the stakeholders. It also ensures that all relevant data are collected and centralized on a single system which helps having faster and more trustworthy reports.

Earned Value Management analyses the costs needed to do the amount of work required, as well as assessing costs, schedule and work progress in isolation. EVM key performance indicators

(KPI), such as Cost/Schedule Variance or the Cost/Schedule Performance Index, increase transparency and ensure anyone can easily determine project performance.

EVM allows project managers to take proactive actions early if the project is not on track. After ~20% of completion of any tasks, variance in cost and schedule can be detected and mitigation measures taken in a timely fashion. Recording the status of the project throughout its timeline can help to identify reasons for success or failure, which can be studied to gain insight for future projects.

In innovative development projects, some schedule and cost overruns are caused by technical issues. For these, EVM will serve as a performance indicator but will not provide means to resolve the problems. Also, an important number of cost and schedule overruns are caused by customer/supplier relationships, insufficiently defined interface requirements and late changes to requirements. These problems will often reveal themselves at an earlier stage with EVM, allowing higher management to intervene before the situation becomes critical.

Beyond quantifying progress and performance, EVM can also prove valuable by capturing useful statistics for future projects. Assuming that clear analyses of cost and schedule variances are provided, EVM can document the most likely costs, schedule durations, and risks associated with certain types of tasks.

Key Takeaways
In general, EVM can serve as a useful long-term tool for organisations to monitor their cost and schedule progress over the project lifecycle and further identify areas of opportunity, as demonstrated by the case studies. In general, EVM can prove beneficial to project managers by allowing them to:
- Closely monitor cost and schedule progress
- Collect progress metrics on a centralized, single system
- Increase transparency between contractors and project teams
- Improve customer/supplier relationships
- Respond proactively with corrective actions and mitigation steps
- Identify and take advantage of cost underruns
- Accurately predict completion end dates and project critical paths

EVM can particularly be beneficial in monitoring and controlling cost growth in complex, cutting-edge missions, as experienced within the NASA Science Mission Directorate (SMD). A program management study conducted in 2008 found that SMD projects using EVM as a management tool showed lower average growth in development costs (19% growth) compared to projects that did not utilize EVM (31% growth) (Perry & Bruno, 2008).

EVM can be most beneficial to large-scale, long period of performance projects. For example, NASA and the DoD require EVM to be performed on projects that are at least $20M in value and have a period of performance of at least 18 months (Brueker, 2017). First and foremost, the U.S. government utilizes EVM as a tool to ensure that taxpayers' dollars are being used efficiently and

effectively. Furthermore, on such large-scale and complex projects, managers can find EVM particularly helpful in monitoring performance between reporting milestones that may be very spread out over time.

5.1.5 Shortcomings of EVM in Project Management

Although EVM can be a useful tool, it requires project managers to correctly execute and follow specific guidelines. However, even when EVM is executed correctly, there are fundamental limitations with the technique, which are highlighted below.

Highlighted Shortcomings of EVM
- Lacks ability to measure quality, technical maturity and scope of project or products:
- EVM tracks budget, schedule and the quantity of the work performed. However, the quality and technical content should be monitored by other processes. Also, it does not control risks of a project.
- Requires complete, reliable, and timely data as inputs; relies upon clear variance explanations to provide context to project management on the causes of cost and schedule variances:
- Data needs to be collected in context and effective communication between teams is critical to ensure that data can be interpreted correctly. The process of collecting the data required for EVM can be time consuming, as can the supervision required by management to ensure compliance.
- Requires objective assessment and measurement to a realistic baseline:
- Using EVM implies a significant increase in costs, but measuring the wrong metric or not measuring a metric in the right way could be even more expensive.
- Not an effective tool for level-of-effort (LOE) activities:
- For non-schedule-based contracts (i.e., contracts composed primarily of LOE), EVM may not be effectively implemented because of a lack of measurement on work efforts that cannot be segmented.

In order to address the highlighted shortcomings and implement improved EVM systems, the team recommends:
- Contractually require EVM reporting in the formulation of contracts
  - Specify clear requirements on the 1) frequency of reporting, 2) quality of data and 3) baselines to be measured to
- Develop key "quality earned" metrics linked to the level of quality of products or processes for contractors to report on (see Recommendation 4).
- Modify the EVM methodology to monitor tasks that are not based on WBS structures (See Recommendation 2).

These recommendations will be further expanded upon in Section 5.1.7.

5.1.6 Potential long-term gains from utilizing EVM

The European Space Agency (ESA) studied reasons for costs and schedule overruns and EVM could solve some of these issues: this study case is described in the first example. Also, the UK MoD developed a contractual agreement which applies to suppliers and obliges them to regularly report on costs and schedule: the second example could give helpful suggestions on how to contractually implement EVM. The following relevant case studies are more thoroughly analyzed in the full topic report, see chapter 10:

- European Space Agency
- UK MoD

Example of the European Space Agency:
In 2008, recommendations were made to the ESA DG, and summarised in (van Beekhuizen, 2019), on the basis of a review related to the causes for the cost overruns / schedule delays on some ESA programs. Indeed, an analysis showed that a number of ESA missions had significant schedule and cost overruns. Causes such as poor industrial performance or programmatic impositions have been identified and mitigations measures on four different areas have been studied.

- "**Reinforcement of Gate reviews:**" Projects are divided into phases/subphases. The completion of a phase is directly linked to the calculation of the Earned Value.
- "**Systematic tracking of schedule and cost evolution:**" Cost and schedule evolution are inputs for EVM. Therefore, a precise tracking is required.
- "**Ensure sufficient funding is allocated to technology in due time**", and
- "**Enhance predictability of Launch Service Price**".

On all four potential areas, cost variances can be detected during the early phases and mitigation measures can be taken. Therefore, the cost evolution can be predicted in advance.

Example of the UK MoD:
In 2011, the SSPF (Single Source Procurement Framework) was developed to act as a regulatory framework for single source procurement for the UK MoD thanks to the independent office SSRO (Single Source Regulations Office), as presented in (Chorley, 2019). In order to get the contract, the supplier must prove that the company is compliant to the SSPF. The goal is to have greater visibility on the supplier's costs through contract reports. This transparency is achieved by means of 7 reports that are required at different steps of the project, and has several benefits such as:

- Improving the UK MoD **understanding of typical costs** on single source contracts,
- Identifying areas where **costs are higher or lower than expected**,
- Fostering adoption of **good contract management** and reporting.

This framework and EVM point in the same direction and this example could be used as a model for a contractual implementation of EVM.

5.1.7 Conclusions and recommendations

Recommendation 1: Define EVM as a requisite to access the management reserve

FFP contracts can be monitored at the defined payment milestones. By monitoring the milestone achievement at a prime and subcontractor level, it is possible to monitor cost and schedule performance. On the other hand, this approach does not provide advance notice for the problems which, when they occur, lead to contract change claims and management reserve requests without possibilities to act on the root of the problems.

Given the nature of FFP contracts and the financial accountability of the suppliers, it is not recommended to impose EVM to the subcontractors. However, it can be defined as a prerequisite to use the management reserve to cover for unforeseen additional effort not linked to changes of scope. This approach would provide sufficient independence to the suppliers to evaluate the risk of a given activity and decide accordingly if EVM needs to be applied and reported to the customer, effectively increasing the share of cost risk, or kept only internal thus minimizing the EVM reporting effort.

Recommendation 2: Adjust EVM to allow flexible WBS

Adaptive PM methodologies do not have an initial finalized plan as this evolves during the development of the project. It is therefore not possible to apply EVM as described in Section 5.1.2. For adaptive projects, such as those following Agile PM approach:

1) The number of iterations is initially unknown
2) Although each iteration is initially considered a fixed cost, the development process might lead to unforeseen costs.

The group believed it still can be useful to implement cost and schedule control mechanisms in a coordinated way. Proposed is to modify the EVM methodology as follows:

1) Estimate, at the initiation of the project, a cost per iteration and an estimate of the necessary number of iterations. For each iteration, estimate the number of functionalities, requirements or trades to be performed as performance metric.
2) Monitor at the end of each iteration the actual cost, scope and duration.
3) Based on 1) and 2), derive the relevant KPIs.

Recommendation 3: Adjust EVM to monitor scope changes

EVM does not address scope changes (as noted in Section 5.1.5: Shortcomings). The group recommends a modified EVM that keeps 'current baseline,' 'reference baseline' and 'actual'—to address drift of scope. Earned Value Management is based on monitoring scope and schedule versus a previously defined baseline. While this is effective in recurrent development projects where the tasks can be quantified in terms of cost and schedule a priori based on heritage, it is proved to be difficult for highly innovative large space projects.

There are several mechanisms to track the changes of scope either because the requirements are changed (for example through Contract Change Notices), or because the supplier understands in

the course of the development, that the initially planned activities need to be revisited (typically with Engineering Change Proposals).

Our recommendation is **to introduce an additional baseline updated with every change**.

The figure below shows a graphical example where the EVM approach, if traditionally implemented with respect to an initial baseline, would identify a significant delay and cost overrun. However, the modified approach shows that actually the cost overrun is driven by the changes in scope and only a portion of the delay is induced by the extension of the activities.
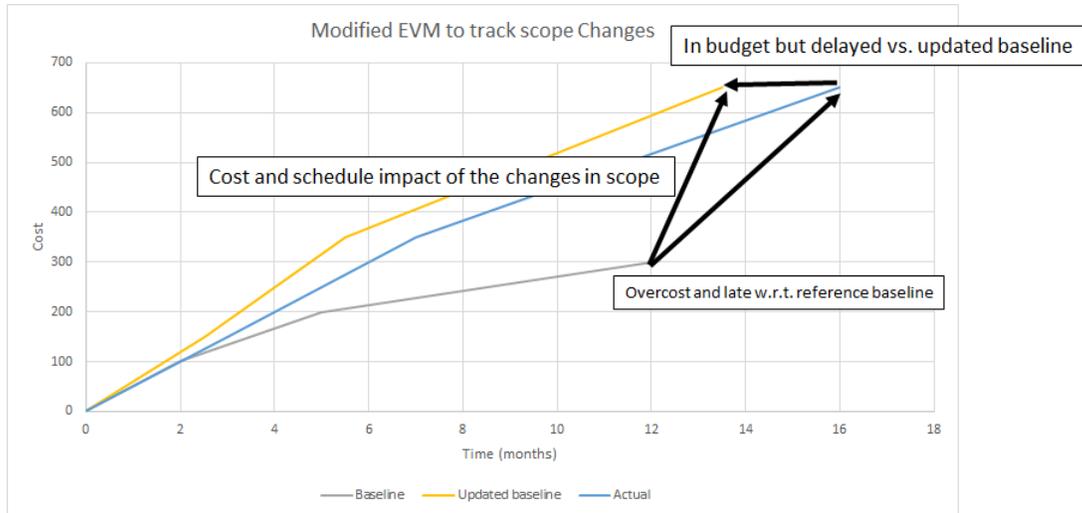
Figure 4 - Modified EVM: new baseline including scope changes

While change control mechanisms already incorporate cost and schedule impacts, the systematic integration of this information in EVM reporting can allow identifying with greater granularity the sources for cost and schedule overruns.

Recommendation 4: Addressing Quality Through EVM
As previously stated, EVM does not measure the quality of a project or product. Therefore, through the existing EVM framework, it is possible that a project is completed under budget, ahead of schedule, and fully executed in scope but still fails to meet the stakeholders' quality requirements of the deliverables. As a result, the following recommendation can be shared:
  1) Integrate project quality requirements into the performance measurement baseline
  2) Specify performance towards satisfying project quality requirements as a base measure of earned value
        a) Quality requirements are quantifiable units defined by the project's stakeholder

At the definition of the project, the PM should identify product metrics and their expected values which will affect the quality of the product and provide information of the progress. Then, during reviews, results are compared to the requirements to determine the level of technical and quality satisfaction and variations from the requirements. (Solomon, 2005)

Technical performance, scope and quality are also three issues tackled by Performance-Based Earned Value (PBEV), which is an intensification of EVM to address the shortcomings in the classic EVM method (Solomon, 2005). It is for example used at *Northrop Grumman Integrated Systems*. It specifies the most effective ways of measuring costs, schedule and quality performance. It has principles that differentiate this method from EVM:

- It integrates product scope and product quality into the performance measurement baseline: the product which is delivered should meet the customer quality requirements within cost and schedule objectives (as described in Recommendation 3),
- Performance is specified through satisfying product quality requirements: the customer should define a list of characteristics of the product that have to be met to satisfy customer needs (as described in Recommendation 4). This list should be integrated in the baseline, as well as cost, schedule and scope objectives.
- Risk management is also integrated into EVM.

Therefore, PBEV could be used as a version of EVM integrating quality requirements and technical performance.

These performance metrics can be fundamental for some level of effort activities, like management or product assurance tasks, which cannot be directly related to a WBS. In those situations, the Earned Value should not be linked to cost but to quality metrics. In the specific example of product assurance, quality indicators could be defined as the median time to close NCRs.

5.2 Fostering Project Management in the World of Diversity

A new qualitative tool to analyze team makeup and dynamics to foster post disciplinary teamwork.

5.2.1 Introduction and methodology

Diversity means all the ways we differ (Jordan, 2011). It can therefore be defined as "any dimension that can be used to differentiate groups and people from one another" (Giovannini, 2004, p. 22). Apart from this rather uncertain definition, it is common to distinguish between two major dimensions of diversity: (1) Macro-diversity comprises the aspects that are difficult to or cannot be changed, such as age, race, ethnicity, gender, physical qualities and sexual orientation; and (2) Micro-diversity refers to qualities below the surface, which include income, education, religious beliefs, military experience, location, parental and marital status. (Loden & Rosener, 1991) called these two groups *primary* and *secondary* dimensions of diversity.

Understanding the need for diversity, current approaches often focus on the makeup of the population or demographics, while inclusion encompasses involvement, engagement, and "the integration of diversity into organizational processes" (Roberson, 2006, p. 228; Turnbull et al., 2009). Many organizations have realized that the extent to which the workforce diversification of the 21st century is effectively and efficiently managed will affect organizational functioning and competitiveness (Roberson, 2006).

However, even though researchers are actively searching for ways to *integrate* diverse individuals in organizations (Thomas & Ely, 1996), most organizations end up with a *diversity in a box* strategy (Miller & Katz, 2002). In this case, diversity is seen as something that an organization is forced to do even though it doesn't want to, or as an issue to be managed, shaping it and getting it *fit* into existing structures.

Observations outlined on a company level also apply on a project management and team level. As pointed out in (Norman et al., 2019; Kleinberg & Raghu, 2018), numerous studies have demonstrated that diverse groups (in both cognition and identity) outperform groups that are more homogeneous, even when the homogeneous group is comprised of all "high achieving experts." Proposing a rather theoretical framework for modeling functionally diverse problem-solving agents, Hong and Page (2004) found that when selecting a problem-solving team from a diverse population of intelligent agents, a team of randomly selected agents outperforms a team comprised of the best-performing agents.

In (Yeager & Nafukho, 2011) it could be demonstrated that recognizing the underlying individual differences, mental models and assumptions that team members bring to the organization can help build teams that are able to overcome dysfunctional barriers and ensure performance improvement of the individuals, teams and organizations. Motivated by this, the group proposed a bottom-up approach starting by individual self-reflection with respect to their own profile, as well as their role within a team or project consortium.

Based on first-hand experiences from delegates, colleagues and the team members themselves, it is believed there is an obvious need for a fundamental change in how diversity and inclusion is understood, managed and translated into actions in space and other sectors. This is further underpinned by a literature review covering the past IPMC workshop reports, related scientific works, best practices documents and reports provided by companies in this work.

According to this, putting inclusion measures into action is known to be a huge barrier and often results in a *diversity in a box* strategy, which is implemented within existing structures and focuses on standard macro-diversity dimensions, such as gender and age. By also taking into account more hidden dimensions, such as personal experiences, this topic group aims to adaptively take into account those dimensions that matter for each project or team individually. A top-down approach starting with the commitment of managers is a good first step. But what about the smallest company entities—the individuals who are organized in small teams and the team culture? Inclusion measures should be guided by the requirements of those who are an active part of a workforce, since they have their own opinions about which components are missing to reach the defined goals. In order to complement the top-down approach, the team proposes a team dynamics survey tool to initiate a bottom-up walkthrough of the hierarchies. This qualitative approach starts with self-reflection and therefore helps with building up awareness and analyzing the current team makeup.

The tool not only contains questions to answer with text, its main components are interactive elements, such as sliders and shapes that have to be arranged and can have multiple meanings. After the first internal design iteration, the tool was implemented as a web page and deployed as a website available at **"http://teamdynamics.space."**

5.2.2 What is the core of diversity?

Diversity management is a complex topic with increasing resonance for organizations across different industries, including aerospace. To stay competitive, businesses should always continue to innovate.
Research clearly and extensively suggests that one of the best ways for businesses to boost their capacity to transform themselves and their products may involve hiring more women and culturally diverse team members.

Because there is a critical difference between merely having diversity in an organization's workforce and developing the organizational capacity to leverage diversity as a resource, this research provides a newer and fresher view on how diversity may be facilitated or supported in organizations.

In order to profit from workforce diversity, an appropriate atmosphere of inclusion needs to be established. In (Sherbin, 2017) diversity means the mere presence or representation of different groups, whereas inclusion is the act of implementing and incorporating diversity into the organizational structure. It requires, among other factors, eliminating discrimination and guaranteeing that the groups belong in the organization and play an active role, with equal

opportunities for development. "Diversity is being invited to the party, inclusion is being asked to dance." (Sherbin, 2017).

5.2.3 Why diversity matters and what is the return?

Disruptive innovation comes from non-domain specific direction, when a challenge is tackled in a new, different way than the current expert practice. Iconic examples of Kodak and analogue cameras disrupted by digital photography or Encyclopedia Britannica by Wikipedia demonstrate that it is necessary for companies and industries to look outside of their expertise (Diamandis & Kotler, 2015).

Research clearly shows that diversity brings many advantages to an organization: increased profitability and creativity, stronger governance and better problem-solving abilities. Employees with diverse backgrounds bring their own perspectives, ideas and experiences, helping to create organizations that are resilient and effective, and which outperform organisations that do not invest in diversity.

In recent years a body of research has revealed another, more nuanced benefit of workplace diversity: non-homogeneous teams are simply smarter. Working with people who are different from you may challenge your brain to overcome its stale ways of thinking and sharpen its performance.

A 2015 McKinsey report on 366 public companies found that those in the top quartile for ethnic and racial diversity in management were 35% more likely to have financial returns above their industry mean, and those in the top quartile for gender diversity were 15% more likely to have returns above the industry mean.
In a global analysis of 2,400 companies conducted by Credit Suisse, organizations with at least one female board member yielded higher return on equity and higher net income growth than those that did not have any women on the board.

Only 2.2% of venture capital funds are going to female-founded businesses, and yet, companies led by women perform 63% better than all-male teams (Forbes, 2019b). The results of other studies reveal that businesses run by culturally diverse leadership teams are more likely to develop new products than those with homogenous leadership.
Also a Boston Consulting Group study highlights that companies with more diverse management teams have 19% higher revenues because of innovation.

This finding is particularly significant for tech companies, start-ups and industries where innovation is the key to growth (Waveforum, 2019).

5.2.4 The reality check: 'un-boxing' diversity

In order to 'unbox' diversity, let's look at the box first.

Diversity in the business environment includes gender, race and ethnicity, as well as diverse religious and political beliefs, education, socioeconomic backgrounds, sexual orientations, cultures and disabilities.

Supporting and promoting a diverse and inclusive workplace is for most companies an important factor to demonstrate.
Organizations have adopted different approaches to diversity management. Common perspectives on managing diversity focus on targeted recruitment initiatives, education and training, career development and mentoring programs to increase and retain workforce heterogeneity in organizations (Cox, 1993; Morrison, 1992). Furthermore, organizations rely on programs and initiatives including employee participation, communication strategies, and community relations (Wentling & Palma-Rivas, 2000), which emphasize the removal of barriers that block employees from using the full range of their skills and competencies in organizations (Harvey, 1999). As such, some organizations espouse a focus on inclusion in the management of diversity (Mehta, 2000).

5.2.5 The state of affairs

Companies are aware and sensitive to diversity and inclusion. However, several limitations exist that limit the real application of measures for encouraging diversity in the workplace. Some of the reasons are listed in the following.
Together with these, the last two items instead represent possible approaches which pave the way to the policy of diversity inclusion.
- External: Legal restrictions to include experts that do not satisfy certain pre-established requirements
- Internal cultural restrictions: Biases (conscious and unconscious) limiting the opening of individuals or companies to groups of people different from the usual ones
- Space Sector: Suffering from stereotypical figures involved in this field; It is first of all a matter of the covered disciplines but also of the larger interest for men rather than for women as well as for the relative low interest from the younger generations to the space sector.

Possible approaches which may pave the way to the policy of diversity inclusion:
- Concurrent engineering: Systematic approach to integrated product development that emphasises the response to customer expectations. It embodies team values of cooperation, trust and sharing in such a manner that the decision-making is by consensus, involving all perspectives in parallel, from the beginning of the product life-cycle.
- With the increase of the Space Economy, more disciplines will have to be included to facilitate innovation. New private actors have emerged challenging the traditional space economy.

5.2.6 An overview of current mitigation approaches in the space sector

From the research, it has been understood that the companies already recognize the importance of diversity and inclusion. However, they are still just scratching the surface of how to create diversity culture within project teams. Below, the key positive actions are analyzed to improve diversity scores that companies are currently undertaking.

DLR approach to diversity and inclusion

The German Aerospace Center (DLR), as Germany's largest engineering science research institution, employs approximately 8,000 people from around 90 countries. According to (DLR, 2019) DLR's staff among others includes scientific and technical personnel, trainees, doctoral candidates, colleagues with and without physical impairments, parents and employees with dependent family members, i.e., "a truly diverse workforce."

DLR signed the Diversity Charter ("Charta der Vielfalt") in 2014 and therefore committed to create a prejudice-free working environment based on mutual respect and appreciation. German Federal Chancellor Angela Merkel is the patron of this corporate initiative to promote diversity in companies and institutions in Germany. Since 2016, DLR participates in the annual German Diversity Day.

According to an internal resolution of DLR's executive board in 2013, the dimensions of gender, internationality, interculturality and generational diversity are focused.

Diversity Management has been included in the DLR Strategy 2030. New measures will be developed in the strategic services department (part of executive board) and implemented after consultation with the relevant interface departments as well as the official GO from the executive board.

JAXA approach to diversity and inclusion

The Japan Aerospace Agency (JAXA) is the core performance agency to support the Japanese government's overall aerospace development and utilization.

When it comes to gender balance, JAXA started to focus on diversity beginning in 2007. At that time, the rate of women was less than 14% and the rate of women employed at management level was 0.3%. To address that, the organization created recruitment programs for female students to enter JAXA after graduation, which resulted in the increase of the rate of women to 27.4% and the rate of management level to 9% in 2019, with numbers still increasing. (JAXA, 2019)

Another important goal for JAXA is to encourage professional diversity and nationality (Tyson, M.F., 2016). The job rotation system gives the opportunity to employees to change fields of work, for example from initial employment in rocket engineering to satellite engineering.

International collaboration is an important strategy for the agency. The inclusion of foreign nationals varies — numbers are lower in satellite missions and higher in human spaceflight as well as in carrying cargo to the ISS, as the agency is a part of the ISS program.

Airbus Group

Airbus is a global leader in aerospace, defense and related services, with approximately 140,000 employees worldwide. The success of the group is enhanced by the diversity of its workforce. The group cultivates an inclusive workplace where all employees are respected and valued for their abilities, is developing the full potential of the employees and provides equal opportunities to all.

The Airbus Diversity and Inclusion (D&I) team works with UK stakeholders to share best practices across the divisions and ensure that the Group can advance in its journey to become a truly diverse and inclusive employer.

The Diversity and Inclusion vision of the Airbus Group is "To develop and leverage a diverse and inclusive workforce at all levels of the organisation that leads to greater engagement, performance and innovation."
The company formalized in 2016 a "Diversity and Inclusion agreement" in the UK with the aim of providing a statement of intent for Diversity and Inclusion (D&I) strategy and activities across the Airbus Group in the UK (Airbus, 2016).

Below is a non-exhaustive list of examples of some of the actions/interventions taken from the Airbus group to drive progress in each strategic area (Airbus, 2016).

BEHAVIOURAL CHANGE	REMOVE BARRIERS	INTERNAL & EXTERNAL BENCHMARK	SELF-INITIATIVE
• INCLUDE Training • Disability E-learning • Bespoke Equip & Guide • OCTAVE Intergenerational programme • A UK D&I Steering Group • Dignity at Work training available for managers and employees	• Review of reasonable adjustments in workplace • Review HR processes to ensure inclusion • Equal Pay review • Ensure engagement and recognition events are fully accessible	• Sponsorship of external events to promote diversity and equality • Signatory on WISE 10 Steps • BDF Disability Standard • Understand best practice on LGBT inclusion	• BalanceforBusiness • The netWork • Outreach activities • D&I Survey • Mentoring - Alta • Disability work placements

Examples and inspiration from other non-space industries

Academia
From the regulatory angle, academic institutions of higher education operate within the legal framework of equity, reinforced with Higher Education Code of Practice, which aims to eliminate discrimination, foster equality of opportunity and develop an inclusive environment.

The diversity report of the Royal College of Art in London monitors ethnicity identifying the proportions of BME in staff and students, gender balance, disability, religion and sexual orientation. In 2017/18, over 18% within full time academic and over 19% in non-academic staff and 42.4% among students, which represented 78 nationalities. The gender balance among staff was 54.9% female – 45.1% male and 10.5% of staff reporting disability. The proportion of reported LGBT community was 5.1% of those who identified as gay and lesbian and 1.5% bisexual. The comparison of the overall median gender pay gap for the RCA is 0%, which compares to over 14% in all higher education, almost 24% of all private sector and over 18% in all national statistics for the UK. (Royal College of Art, Gender Pay Gap Report, 2017)

Within the education models, new post-disciplinary courses are being created that focus on context and addressing challenges through a collaborative mindset in which diversity is essential. The course model is unique both from the structure and team-work focus as well as the student profile intake. This discipline-free approach to innovation in healthcare is based on a context model, rather than 'designing into healthcare' from the perspective of a discipline. This post-disciplinary mindset creates a new opportunity for creating impactful, holistic solutions through design-led innovation. Healthcare sector bears a lot of similarities to the space sector, especially when it comes to quite homogenous discipline diversity and resistance to change of structure. By introducing design thinking approach and design-led innovation model of post disciplinary work, future healthcare sector leaders will propagate the culture of diversity and post disciplinary teamwork. The team believes that this approach could serve as an inspiration to introducing more diversity within teams in the space sector.

IDEO approach

One of the most successful global design companies, IDEO, advocates the power of applying design thinking methods within companies in fostering the culture of diversity within teams. Design thinking serves as a facilitator of successful multidisciplinary collaborations by creating a culture of embracing diverse approaches to create innovative solutions.

It is possible to look at diversity as embracing a variety of different approaches and viewpoints to create impact. Design acts as a facilitator of this kind of *integrative thinking* - 'the ability to exploit opposing ideas and opposing constraints to create new solutions'. (IDEO, 2019)

5.2.7 Measuring diversity and inclusion

Best-practice companies regularly measure the health of the organization with respect to well-articulated success criteria. They live the adage that what gets measured gets done (Thompson, 2017). Diversity and inclusion initiatives are business initiatives that must be managed in the same way that an organization manages any other business initiative (Morris, 2011). While this is clear for researchers and partially for organizations, there are still several barriers to acceptance.

In (Morris, 2011), some best practices on how to keep measurement efforts on track and ensure that they support the organization's work as much as possible, even when other priorities or simple lack of experience stands in the way of a conscientious measurement effort, are mentioned:
- Link Diversity and Inclusion Metrics to Business Outcomes
- Leverage the Power of Engagement
- Insist on Accountability
- Embrace Measurement Basics

Focusing on the question of "What is considered best practice for both defining and measuring 'inclusion' within an organization?", a brief review of tools, metrics and resources is provided in (Thompson, 2017). According to this, diversity and inclusion can be measured in *absolute* and *relative* terms, i.e., measures should not focus just on where organisations are, but how far they have come (Lauring and Ross, 2004).

Metrics mentioned for measuring inclusion are percentage of minorities, employee satisfaction surveys and pay disparities. Further index measurements are diversity, disability equality, global gender gap and the gender empowerment measure (GEM) index. An overview of further quantitative and qualitative measures pointed out in (Fitzpatrick & Sharma, 2017) are outlined in the following.

One finding from the research is that there seems to be room for more directly applicable measuring methods in order to gain plain, scaled, interpretable and comparable scores.

5.2.8 The research toolkit

Based on the experience of the delegates and inspired from some industry examples, the objective has been to go beyond the standard way of approaching diversity and inclusion techniques that are actually difficult to be actuated and to be measured as well.

The team wanted to provide a new approach that could help in enhancing the awareness about the team composition and what is the added values provided by multidisciplinary teams.
With this aim they derived the qualitative tool, designed to help individuals and organizations recognizing the skills necessary to embed an inclusive environment and to identify the skills and gaps that must be addressed in order to ensure a high level of success and competence.

Visualising the shapes and colours of diversity: the qualitative team makeup toolkit

The team's aim is to create a qualitative tool that allows gathering insight-rich information about team composition. It is believed that the true value of this approach will allow the group to develop a novel way of understanding how teamwork is approached across different project teams, how the teams are built and how team interaction looks like through the project progression.

Based on the initial round of qualitative conversations with professionals from different sectors, the team has identified that as soon 'diversity' and 'inclusion' appeared in the conversation, it prompted participants to certain answers, an analogous situation to asking a 'leading question.' In order to eliminate this potential bias the group strived to create a tool, which will allow them to talk about diversity without mentioning it. The team's aim was to create a tool, which without using the word 'diversity,' would aid individual self-reflection on their team make-up and provide a graphical way of describing the team, its interactions and processes throughout the project in a visual way.

The first part of the toolkit focused on understanding the 'profile' of the participant and aimed to facilitate self-reflection. This left-right brain approach mapping tool has been drawn from the research on the design process (Rodgers, 2013). It illustrates visually the preferred approaches adopted by individuals within the project.
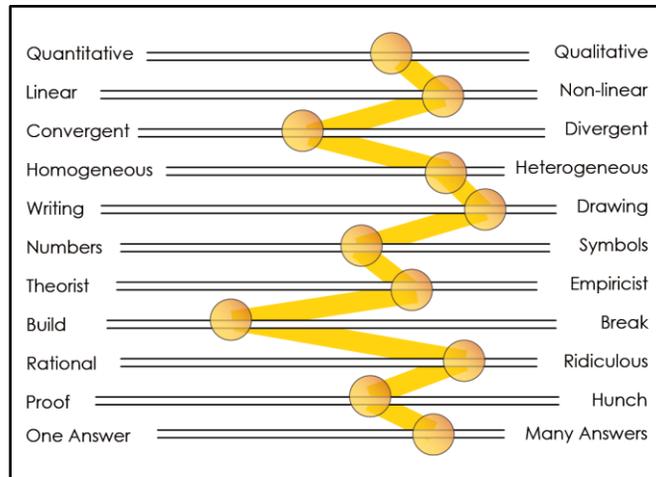
Within the cross-disciplinary teamwork, this tool is currently used in the initial part of the design process to facilitate diverse team building at the multidisciplinary Healthcare and Design Masters Course at the Royal College of Art and Imperial College London (Hall, 2019). Based on the mapped profiles, designers, engineers and medical professionals build project teams to include and mix team members with the most diverse approaches.

The middle part of the tool asks participants to illustrate visually the team make-up. Different shapes and colours represent team members' profiles and the current team structure.

As a next step (4), participants articulate visually the project process within their team.

In the last part, the team aimed to gather insights, reflections and recommendations for improving the team make-up and project process. Those sections ask participants to illustrate visually their 'ideal' team makeup and improved project process. Framing the questions in that way, the tool

indirectly asks participants to provide a constructive critique on the current situation and suggested improvements.

In the final question, participants are asked to share their views and recommendations on what they think would have to happen for their 'ideal' team and project process to be implemented. In line with co-design principles, the group wanted to harvest those insights to allow capitalizing on them.

As the next part of the research, the toolkit has been implemented and hosted on the server: **http://teamdynamics.space.**

5.2.9 Initial results and further developments

Because of time constraints, the toolkit was tested by ten different participants, including the team members. The simple and intuitive way of using shapes rather than text boxes provides much more room for creative answering and indeed has shown to be a good approach to initiate and support in-depth self-reflection. The group furthermore received quite positive responses dealing with diversity while avoiding using this term explicitly. An essential finding revealed from the first results is that the tool is completely free from restricting the survey to specific diversity dimensions. Un-boxing is achieved by the freedom for each participant to decide which factors matter. Furthermore, the tool supports participants to answer in a constructive way, i.e., people like to give recommendations rather than complain about diversity.

However, a downside of the flexibility to answer the questions in a graphical way might be the differences in how the drawings might be interpreted by different people. It is therefore intended to add a question at the beginning related to the available shapes and what specific meanings different attributes (e.g. shape, color, size) individually have. This helps to scale or normalize the results and make them comparable.

The next testing phase will be during the IAC 2019 conference, where the topic group will get in touch with the participants to ask for further constructive feedback. In terms of practicability and valuable outputs, the best approach to use the tool is to give an internal workshop with teams and

to incorporate the tool afterwards. The user feedback is and will be of significant value for further improving the tool.

5.2.10 Conclusions and recommendations

Even though diversity and inclusion are more and more understood as absolutely beneficial requirements, barriers to actively implement inclusion measures still seem to be high. The commitment of an organization's top-level management as well as defining target rates might be a good starting point. As already stated and discussed in last year's workshop, fostering the discussion on diversity and inclusion, as well as the monitoring of the organization might also be helpful. However, the team believes that the usual approach of diversity in a box, (i.e., taking into account a fixed set of chosen dimensions) does not reflect reality in a proper way.

Rather general diversity and inclusion measures don't take into account the single individuals of a company and the makeup of teams and project consortiums. Each project and team are likely to have completely individual goals and reaching these goals in an optimal way usually requires a mixture of people with specific expertise and experience. It is believed that there is a gap in supporting the understanding and self-reflection of the role of each individual within a team. But this information is central for the understanding of required actions from the management side.

The team's proposed tool is a way to express oneself as an employee without offending anyone. Instead of asking people about 'diversity' the group is asking their feedback by means of team makeup to reach a specific goal. Since using the word diversity is known to be a potential obstacle, it is recommended to simply avoid using it. Furthermore, the tool enables individually taking into account those diversity dimensions that matter for specific teams and projects.

The tool will be further developed. By means of a cycle of collection of feedback and corresponding improvements, it is expected to provide a tool that individuals and companies can really exploit multidisciplinary workplaces and teams.
To fully exploit the potential of the tool to further develop team dynamics and research awareness of people, it is recommended running internal companies workshop, focusing on team understanding of 'diversity' and proposing the tool to elaborate multidisciplinary teams, with the aim of shifting the culture and internal awareness.

Further recommendations and potential research directions can be pointed out.

- how to determine a required team makeup in advance? (Kleinberg & Rhagu, 2018)
- transition/correlation from qualitative to quantitative measures that reflect scores
- scores/metrics are essential, especially in non-profit organizations (e.g. DLR) or in already successful organizations, where the question may arise "why should I change something when everything works fine?"

5.3 Challenges Faced by Teams Working on Space Projects Between Emerging and Legacy Space Economies

5.3.1 Introduction

All over the world, a surge in space activities and programs can be observed since the past decade. Driven by aspirations to increase geopolitical influence, regional autonomy and the desire to reap growing socio-economic and technological innovation benefits, governments are formulating new or more ambitious space program objectives (Lahcen, 2015). Typically, governments task an established or new agency, or branch of government, with the technical and programmatic implementation of space projects in order to reach their policy objectives successfully.

Increasingly, governments are also relying on the private sector to provide space infrastructure and services. This is especially occurring in legacy space economies with a critical mass in space activities, and in emerging space economies within developed nations with a solid industrial base and technology. In the latter case, governments seek to spur the development of new lucrative markets that create jobs, innovation and growth (Lahcen and Vaudo, 2016). Considering the rising growth figures and the dawn of the NewSpace economy era, this approach is becoming an ever more pronounced part of industrial and growth strategies in a selected group of countries.

Many countries and companies, however, lack the required experience that is necessary in the implementation of technologically and programmatically challenging space projects. One promising mechanism to overcome this issue is for new or less experienced project teams to team up with a more senior space administration or agency elsewhere, benefiting from their skills and experience. Emerging actors can use this transfer to increase the chances of success in one particular project, current or future, thanks to the accumulation of knowledge and experience gained during the years.

This report aims to shed insight into the specificities, challenges and dynamics of space project cooperation in teams with different levels of experience. It will do so through a theoretical description of the general dynamics, followed by two case studies that look at the specificities of a practical use case, one in the United States and one in Europe.

5.3.2 Project management for diverse economic space actors

First, this report will introduce a framework for differentiating levels of project management capabilities among space actors today. These differences should be taken into account by executive management as well as program and project managers in the implementation of mixed projects between legacy and emerging space actors. More specifically, four categories of space project management skills can be distinguished:

Non-Space Actors
- · Largest group of actors in society
- · No particular space project management knowledge or experience
- · Increasing interest, mostly in space applications and services
- · Demand-pull approach crucial in setting up mixed projects

Emerging Space Actors
- · Rapidly growing group of actors, incl. NewSpace
- · Sufficient knowledge to understand the space sector and operate in it
- · Good disposition for innovation and R&D
- · Financially often reliant upon seed money – not yet self-standing

Maturing Space Actors
- · Growing as a result of growing emerging space actors
- · Typically, actors transition through this phase, rather than staying in it
- · "Best of both": ideally placed to bridge between legacy and emerging actors

Legacy Space Actors
- · Space agencies and large system integrators with experience
- · Small group of main players in the field
- · Extremely high experience in space project management
- · Operate in challenging environment: innovate to push frontiers
- · Can act as mentors for emerging players, but also benefit from more agile emerging player's mentalities and practices on innovation

The model underpinning this distinction, as well as the four categories that result from it, are elaborated extensively in the full topic report, see chapter 10. The Annex A to the full topic report sheds more light on the theoretical dynamics that underpin mixed project management implementation. For stakeholders, this information is highly relevant, as it offers insight into important research questions such as:

- • How differences in Project Management skills and experience can be characterized
- • How space Project Management skills typically develop over time as space actors grow
- • What impact of diverging Project Management skills can have on cooperation projects and innovation outcomes
- • How the ideal cross-fertilisation can take place in mixed project teams in terms of knowledge transfer

However, as this paper focuses on two specific case studies, the elaboration on the above questions is performed outside of the scope of the main body of the paper.

5.3.3 Case studies

Research Questions

The target of the case studies is to evaluate a specific use case, in the light of the subsequent listed research questions.

1. What are ways to promote and encourage new entrants to the space project team?
2. What would be considered a successful project for a new entrant from an emerging space economy to the space project?
3. What unique value proposition could the new entrants from the emerging space economies bring to the legacy space economies team members?
4. How can we help establish a new space economy? Are the emerging economies and companies what is needed for the development of future space programs?
5. Looking at the space program development, what is the demand and are emerging space economies following this demand?
6. The challenges of making collaborations with new entrance business model based (non) space players and space agencies profitable.
7. Revenue of investment: Is the space sector revenue driven and how are emerging and legacy space agencies working towards this goal?
8. Define the challenge or benefit of the changing mind set between "new space" and "established space."
9. What is the risk appetite of new space and how does this affect the aerospace sector?

Case Studies Methodology

This methodology explains the approach of the investigation of the U.S. use case, "Commercial Orbital Transportation Services," and the European use case, "Mission to the Moon." The overall purpose is to determine the impact of the use cases on the problems, described by the aforementioned research questions. It shall be clarified to what extent mechanism, concepts or constructs can claim effectiveness of being a solution. The execution of the case study is guided by the case study core process, described by H. Harrison et al (2017). There, the authors describe common elements of a case study. The subsequent table reveals the connection to the executed use case study, representing a concrete instantiation of the abstract process and its artifacts. This offers guidance and focus for the investigation of the cases studies.

Element/Action	U.S. Case Study	European Case Study
The case	Commercial Orbital Transportation Services	The Mission to the Moon project, including partnerships for that mission
Bounded system (Boundaries/Scope)	U.S. country and market, present and short-term future-oriented	European space industry, global space market, present day-oriented

Element/Action	U.S. Case Study	European Case Study
Contextual variables	Impact on and by politics, socio-economic effects, historical backpack, ...	Impact on and by politics, commercialisation aspects, technological factors, ...
Methods of data collection	Artifact and document review	Artifact and document review, supported by interview where possible
Methods of analysis	Qualitative analysis, focusing research questions	Qualitative analysis
Case study design	Explanatory single case study to answer questions like 'why' and 'how'	Exploratory case study aimed at reviewing methodology employed by the subject

5.3.4 U.S.: Commercial Orbital Transportation Services

The Commercial Orbital Transportation Service (COTS) program, hosted by NASA from 2006, is a direct reaction to the Space Shuttle program and its retirement. The COTS program itself does not target binding contracts, and mainly fosters the development of high-risk commercial technology by the creation of a risk reduced environment for the companies that apply.

The main programmatic goal and purpose was to regain/improve access to space after retirement of the Space Shuttle in combination with the trial to seed commercial space applications, mainly targeting LEO. [more background in the full topic report]

Relationship of Space Agencies and Commercial Entities
With the COTS program, NASA changed their paradigm on how to fund and legally handle collaborations with the industry. The program participants are not legally bound to deliver a certain service or artifact, but they have to show a certain predefined progress at a milestone. In case the company can succeed, they get further funding, in case not, the collaboration ends. With this mechanism, NASA tackles cost-overruns and counters the classic costs-plus model (Cypert e.a., 2014). This lowers market entry barriers by enabling a risk-free environment for highly motivated space-domain newbie companies. The model eventually changes with the CRSs flights being contracted and legally binding.
The relationship among NASA, representing the U.S. government, and the companies is an evolving one. It develops from a rather low-risk collaboration to a contractual partnership on eye-level.

Intended Business Cases
The program does not target the development of a distinct business case. It enables companies to develop their own business case, based on the governmental subsidies for their technology.

Without this seed funding, the companies are not able to develop this technology. It can be seen as a technology push by the government, using companies and their technologies as a vehicle. In addition, this technology will lower the market entry barrier for other companies. So far, it is too early to evaluate if this strategy was successful, as the commercialization of LEO had not begun yet. But with eager ventures, like OneWeb from the UK, it should be clear soon.

Legal Aspects
The legal aspects are kept a bit in the background in COTS, for example it does not include legally binding contracts for delivery. To get a formal relationship with the companies, NASA uses Space Act Agreements (SAAs) (NASA, 2014). The legal obligations step into the foreground with CRS contracts. And due to this, the participating companies most pay attention to the various requirements as they moved on to the second step. Things like constant reviews from "Agreement Managers" and other regulating bodies, as well as considerations of intellectual property and cost of insurance. Seed funding and freedom to manage the projects as they choose lowers the barrier to entry, but the second step can become too structured for an emerging company to comply with.[1]

Conclusion
Concluding this small study on the COTS, it gets set into context of the aforementioned research questions. The questions are kept generic, with the answers being adapted to the case study.

Response to RQ 1: Here, public-private partnerships with low risk barrier.

Response to RQ 2: Here, unsuccessful projects are accepted as part of the program. Nevertheless, in the end, the success is determined by whether the entity can sign and implement a CRS contract. So, it is determined if the company can become a space-company and provide a service. Yet, there were "unsuccessful" companies that continue their own technology development and sought out new partners, i.e. Sierra Nevada Corporation and the development of Dream Chaser, they now partner with the UN to give developing countries access to space.

Response to RQ 3: Here, the different services, enabled by the technologies funded in the COTS program, being: external unpressurised and internal pressurized cargo delivery and disposal and internal pressurized cargo delivery, return and recovery.

Response to RQ 4: This program shows that with a different approach/model, market entry barriers can be lowered significantly.

Response to RQ 5: This program lowers entry barriers and funds enabling technologies, which is a step in the right direction when it comes to the desire of commercializing space.

Response to RQ 6: That is covered by the COTS program, by contracting them 'softly' in the beginning. The short-term business case is to get the CRS contract, for the actual business case the companies are on their own.

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[1] This model could be applied in partnerships between established and emerging nations.

Response to RQ 7: The space sector is revenue driven, but dependent on governmental funding, the COTS program is an outstanding example for that. And no agency works towards a revenue-driven space sector (Perhaps with Luxembourg Space Agency as an exception).

5.3.5 Europe: mission to the Moon

Planetary Transportation Systems GmbH (PTS), formerly known as PTScientists (PTS, 2019) , is a start-up founded in 2008 to compete in the Google Lunar XPRIZE and their first mission, Mission to the Moon (please see full topic report Annex B for more details), is scheduled for launch in 2021: this make this company a good candidate to represent the 'Emerging Space Actor,' as introduced in section 5.3.3.

In the first half of 2019, the European Space Agency (ESA), ArianeGroup, Space Application Services and PTS (then PTScientists), signed a contract to study and prepare ESA's planned ISRU (in-Situ Resources Utilization) demonstration mission. The goal of this ISRU mission is to show, by 2025, that water or oxygen production on the Moon is feasible (PTS, 2018). In the frame of the above-mentioned contract, ArianeGroup will provide the Ariane 6 launch vehicle (PTS, 2019), PTS will provide the lunar lander, Space Applications Services will provide the ground segment, communications and related services and specialists from ESA's European Space Operations Centre (ESOC) are providing consultancy on flight dynamics and flight operations as well as preparing for driving two lunar rovers and helping in the preparation of the mission operations concept.

Cooperation with legacy space
Of the various partnerships that attempt to make the Mission to the Moon project possible, this paper will look into the cooperation with one of the legacy space participants to the project. The authors of the paper are grateful to Kim Nergaard, the project lead on ESA (ESOC)'s side, for discussing aspects of this joint effort between ESA (ESOC) and (then) PTScientists (interview in September 2019). Highlights from this exchange illustrate some of the differences that stand out from how ESA more commonly operates.

It must be noted the text refers specifically to the collaboration between ESOC and PTS in the first half of 2019 — the Mission to the Moon project is still on-going to this day, with the intention to launch in 2021 (PTS, 2019).

Project Management
A project management style with a focus on agile processes was applied. This runs counter to the waterfall approach more commonly followed by ESA, although this concept was not fully foregone either because the end result was still subject to a final review. As the cooperation related more to a documentation phase, the difference in application between agile and waterfall approaches was not as pronounced as if, for example, manufacturing and testing of hardware would have been involved. Irrespective of this it was noted that the agile approach called for a different way to collaborate on generating the required documentation — the useful output of the

activity. Documents were shared online, through a dedicated third-party tool, so authors could work together on their assigned sections and discuss topics on the fly. This way, individual sections of the document could mature and iterate through changes, without being impacted significantly by developments in other parts.

The iterative and parallel nature of the effort and process is typical of Agile project management. Short meetings were held (bi-)weekly to ensure adaptability of the schedule and provide for a short turnaround. At the outset it was decided to minimize the effort spent on administration, so team meetings were mostly focused on discussing technical matters. The majority of the interaction occurred on a discipline-level, where content was created through collaboration between those technically responsible for their domain. The vast majority of these meetings and encounters were held by digital means, with only a very limited number of face-to-face instances.
This represents an adaptation to typical Agile project management, to accommodate for geographically dislocated teams.

Relationship of Space Agencies and Commercial Entities
The resulting process was very open and characterized by a results-driven mentality. This mentality was shared among the small sized team(s), its inherent pragmatism also evidenced by the willingness to continuously re-evaluate the followed approach. An example of such is how during the effort, through discussions and information learned, it became obvious a re-scoping of the activity would maximize the return on the effort already spent. The re-scoping was subsequently also applied. This adaptive work method runs counter to the typical predictive planning that ESA most commonly adopts. Flexibility to changing context is one of the paradigms of Agile.

Both PTS and ESA teams were very positive about the partnership. The exchange resulted in comparisons being drawn between the approaches typically followed by either team. Merits for both were appreciated, where on the one hand it was recognized that ESA's planned approach is well substantiated (from experience and due to typical project complexity and risk), but also that PTS' more Agile oriented approach can result in a very efficient and quick development of useful results. Shifting from one approach to the other takes some adaptation, as the Agile process can only be successful if an open mind is kept and changes and iterations are welcomed, while the other requires freezing of planning and features early on. For ESA, a major challenge was perceived in not imposing their way of working, which is a pitfall legacy space economies need to be careful of.

Conclusion
Response to RQ 1: Endeavors such as the one pursued by PTS seem to be an appealing option. The scope of the activity is quite large which means it is best approached through a partnership. In principle, organisations (such as ESA, NASA, DLR, …) can play a role in fostering these types of missions in an attempt to lower the threshold for newer entrants.

Other than a project, a way to encourage new entrants may also be to consider and enable projects that follow a different schedule or approach rather than the one typically followed in the sector. This should reduce exposure to certain risks, and may motivate participation by otherwise uninterested entities, ushering in fresh new perspectives to technical or programmatic challenges.

Response to RQ 2: The definition of success in this context should focus on cooperation and collaboration itself, firstly, then on technological developments secondly. With the proper application of time and resources, developments are most likely to successfully come to fruition. However, in the case of emerging space economies, this process runs an increased risk of unsuccessful conclusion if the proper foundation (the right methods and tools) are not in place from the start. "Right" in this context is considered with a view to enabling the approach that all project members have agreed upon. Potential risks could be: e.g. cash reserves, unfamiliarity with the phased development approach, typical risk mitigation strategies, etc. From that perspective the cooperation between PTS and ESA (ESOC) shows all signs of being successful.

Response to RQ 3: This largely depends on the mission statement of the emerging economy. Organisations entering into the space industry are often established with a specific purpose in mind. The underlying idea on which these organisations are founded may result in the development of a disruptive technology, or may approach an existing challenge from a different perspective. In the case of PTS, the value comes from potentially enabling an end-to-end service, the kind of which is currently only offered by larger space agencies.

Response to RQ 4:
1. Institutions should incentivize new entrants by providing the programmatic frameworks to enable their inception.
2. Participation by newer entrants is bound to increase competition between different space actors. The way for this to result in continued growth is if the sector keeps growing together with these entrants. This means the emerging entities (and the sector as a whole) should only rely on institutions for the conception of the programmatic framework, but that all actors have a shared responsibility to ensure the continued growth thereof.

The role of institutions should be to foster new entrants into the space sector and help reduce their risks, in addition and conversely, institutions should not hinder or impinge on any potential growth.

Response to RQ 5: In general, space programs seem to focus on either delivering or developing an existing product for a lower cost or devising a new product to enable a new (previously unavailable) capability. Within both segments, emerging space economies have proven successful to the point of disruptive. Space projects typically involve many different actors, which makes it possible for new entrants to participate on a variety of levels. It is also in this way that PTS' partnerships are set up.

Response to RQ 6: Financial efficiency is a key target for business model based new entrants. This may drive the entrants to adopt methods uncommon to space agencies. In this context it will be challenging for space agencies not to impose their usual ways of project management and approach on new actors. Similar to this the typical time scales involved with space projects may put a large strain on newer entrants which rely on quicker turnarounds and may be subject to scrutiny by investors. In addition, development costs may be prohibitive — even though the goal

is to achieve a finalized end product the intermediate milestones that space agencies structure their projects around still ensure that some of the development cost may be recovered before completing the product and entry to market.

In the case of PTS the major difficulty faced by ESA (ESOC) was the former, i.e. not to impose their project management and structure style. Enthusiasm on both sides, however, ensured the hurdle was easily conquered.

Response to RQ 7: Institutions are (largely) not revenue driven. Commercial entities will be held more to ensuring revenue, due to shareholder wishes or economic realities otherwise. Because of this a (commercial) new entrant to the space sector faces an increased pressure to secure sufficient revenue to remain afloat in the first years of operations, when exposure to risks is at the highest.

Response to RQ 8: Newer entrants push established entities to continuously evolve and remain up to date on new developments and methods. Oppositely, newer entrants are pushed by established players to maximize the useful output of their activities when competing, due to their higher exposure to risk. Both new and established space stand to gain from a cooperation; established space because it may be able to share the advantages of the newer entrant's (e.g.) technological novelty, and vice versa the newer entrant can benefit economically from the stability established space may provide.

In the case of PTS, the targeted mission and capabilities are currently not readily available (although in development by multiple entities). As such its direct impact on changing the mindset between new and established space is more difficult to assess.

Response to RQ 9: While established space follows more of a "risk mitigation" strategy, new space is more willing to adopt a "risk management" approach. At the same time, the risk new space is willing to take is more on the programmatic and technology side, and less on the end-product side. New space is willing to consider less plausible or less conventional (often perceived as higher risk) concepts or approaches, however this risk is only taken if the potential reward is significant.

The PTS project was run in a more flexible manner, more akin to the agile management style, rather than the typical predictive waterfall approach. This is not necessarily inherently riskier; it is just a different way to handle and resolve potential risks.

5.3.6 Conclusions and recommendations

Project Management skills and capabilities can be considered as a spectrum that develops over time, if the right resources are invested in terms of training and education, building up skills and knowledge-transfer.

This growth process was characterized as a sigmoid function. The first efforts in building up skills yield a high marginal increase, which at a certain level decreases until it flattens out at a level where Project Management skills are very highly developed. Four different types of economic space actors were identified in this paper and mapped onto the spectrum: "non-space," "emerging," "maturing" and "legacy" space actors.

For each group their main characteristics and constituents were briefly described. This description can help Project Managers to identify the nature of their own organization, as well as the one of actors they seek to cooperate with. The dynamics of the envisaged partnerships largely depend on the interplay of these two states, as well is the cross-fertilization largely determined by what type of actors work together.

The group then investigated two examples as use cases: a NASA program with the intention to quicken the commercial space industry and to regain full access to space via the Commercial Orbital Transport Service program and the path of a start-up in Europe, boosted by the Lunar XPRIZE and on its way to the Moon. Both cases inhibit a certain paradigm change, but what are the main takeaways, the recommendations, the "do's" and the "don'ts"?

Bearing in mind Jim Dator's second law of the future, "Any useful idea about the future should appear to be ridiculous," in combination with the possibility that we are on the way to a transformation perspective future, it is acknowledged the fact that the group's recommendations may be wrong. Nevertheless, here they come.

Utilize Geo-economical Change
The growing group of "Emerging" and "Maturing" economic space actors creates a growing pool of potential new entrants to the space economy. This accounts for governmental and non-governmental entities. Together with the trend of using terrestrial technology, namely commercial-off-the-shelf technology, especially in LEO, also non-space high-tech companies have a lower market entry barrier. This is valid for the upstream as well as for the downstream market. It has to be seen as a chance for existing space companies to find further strong partners outside the domain and to enter as an external. Also, more and more venture capitalists see a market.

Create Public Echo
Emerging actors such as the start-up PTS and maturing actors such as SpaceX create a loud media echo, fascinating and motivating the developers and designers of space missions of tomorrow. In this way they are ahead, compared to legacy companies or governmental entities. In addition, the image of space and its missions is surprisingly positive in society, considering sometimes enormous cost overruns and 50% success rate to land on the Moon or Mars. It seems people appreciate the effort and still wallow a bit in nostalgic thoughts about the first man in space or on the moon. Governmental entities have a duty to conduct public outreach, but for commercial entities it is difficult to make a recommendation. There are various contradicting examples in legacy space and in NewSpace (Mantel and Meredith, 2010).

Foster Public-Private Partnership
The COTS program of NASA can be seen as a success, although its full impact cannot yet be determined. It depends on further upcoming and mainly private missions, trying to commercialize space further. The low initial risk and dependencies for the space market entrants enabled their growth and was the key to success. The system allowed also for agile project management and therefore for a fast-moving technology. Nevertheless, when new entrants move from the first stages, the SAAs become more structured and they might find it difficult to adhere to that structure,

as it does not reflect their management. The success of the new entrants impacts also the legacy space actors of the industry, such as large system integrators Boeing, Airbus, etc (Giannopapa e.a., 2012). Therefore, it could be a future model for others, perhaps funding more broadly with initially smaller funds. If governments are to create or encourage a space market, it must allow for agile projects that showcase the proof of concept for the technology. Companies must continue its technology development while taking into consideration the structure of established space players. This can be done by partnering or hiring people from established space entities.

5.4 Knowledge Management Practices

5.4.1 Introduction and methodology

With costs declining, technology improving and public-sector interest increasing, members of the aerospace industry must surely have every reason to feel optimistic about the future of their field. Challenges in engineering are being conquered with unimpeded acceleration and humanity's reservoir of knowledge about space and the universe is expanding with every breakthrough. But with the creation of these new final frontiers, the current and continuous development of the space sector is also guiding us into some uncharted territories – specifically, for the humans that are traversing them. Whilst our technological resources to improve our knowledge of space operations is on a commendable trajectory, there is a concern that this new and complex field needs attention in something that has never had such attention before: namely, how us humans of the space industry operate it back on Earth, and how we can ensure that we maintain a good distribution of the growing pool of knowledge between us.

Knowledge management, or KM, means ensuring that knowledge and information is created, shared, transferred, used, stored and managed within an organization. More specifically, as defined in the 2018 IPMC Workshop Final Report on Knowledge Management, "knowledge is an understanding gained through experience, study, training, or sharing, which establishes a basis for judgment and the potential for action. Knowledge only happens in the minds of people and it involves both abstract concepts (such as truth, beliefs, judgements, mental models) and practical concepts (such as methods, skills, experience, know-how)."

Maintaining good KM practices is a challenge for organizations in any field, but there are two specific circumstances in the space industry that highlight why this is a more complicated challenge for this sector.

1. A low ratio between senior experts and newcomers. For many industries, higher management and senior employees often have decades of expertise in their field that can be passed down through the 'generations' of an organization. This is not commonly the case for the space industry; many join this sector later in their career and there are more entry positions in space today than there were some decades ago. This results in an uneven ratio between senior and junior employees, with more newcomers than experts. Moreover, large developments in the space industry often require much longer timescales than developments in other industries – oftentimes, projects can range across multiple decades. Consequently, employees of this industry are often only part of a handful of different developments across their career, or only follow a small number of steps for one large development. This all results in a lack of available mentors, which drives a clear need for efficient KM practices in order to avoid losses of knowledge between the different developments.

2. Wide range and large amounts of prior knowledge required. The space industry is particularly demanding because of its complexity, and many positions require knowledge about seemingly unrelated fields in order to perform even basic tasks. For example, lawyers writing space policies on deorbiting regulations must understand at least some orbital mechanics; not exactly a subject matter that is commonly covered by a post-graduate legal education. This, combined with the fact that space industry staff with senior experience is "low-density" compared to many other fields (reducing the possibility of mentorships), means that there is a remarkable incentive for employees of the space sector to have access to knowledge and education regarding their own field in order to propel themselves – and thus, the industry – forward.

Additionally, there is a constant production of new information and knowledge about space science and technology everyday thanks to STEM scientists and researchers across the globe (which is, incidentally, a demographic that is growing). Keeping up with the latest developments in astrophysics, rocket propulsion, imaging, navigation, material science, space policy, social science, and an enormous list of other related topics is daunting at best, if not nearly impossible – especially since such a large amount of new developments require large amounts of specialised, prior knowledge about a certain topic. The road for newcomers to become staff with senior experience is therefore challenging in its depth and variety of new skills and knowledge that must be absorbed first.

These are all conditions that are ongoing against the backdrop of young professionals' own psychology and culture. Research confirms time and time again that young people – especially women – in STEM battle against the large cultural weight of impostor syndrome and other similar fears of inadequacy; and more specifically, perceived inadequacy. "Impostor syndrome" is the name for a common psychological feature where well-qualified individuals may carry an unfounded belief that they are somehow not worthy or qualified for their position in a company, organization, or academic hierarchy due to a preconceived (and often baseless) notion that they are by some means inadequate. Often, this is accompanied by a sensation that they have somehow fraudulently "tricked" or "cheated" their way to their position – and as such, consider themselves an "impostor" in their field. This creates a well-documented fear of exposing any knowledge gaps – perceived or genuine – in front of peers and superiors, which in turn breeds a toxic environment that blocks educational and frank communication about knowledge and KM. The environments of entire organizations are influenced by this combination of employee personality, expectations and cultural understandings.

In theory, it is clear to understand the motivation behind campaigning for increased KM practices, tools and resources for the space industry; the challenge, however, lies in its practical implementation. The positive aspect of the space industry being such an interlinked sector, with staff requiring a large range of skills and education, is that it is highly receptive to interdisciplinary employees. With no shortage of experts, a well-rounded member of the space industry is a welcome addition in many areas. Individuals with an interdisciplinary background, therefore, have great potential to branch off into other areas of space with a three-dimensional career trajectory available to them – but the possibility of making this kind of lateral move is not always well marketed, or encouraged.

Starting from the findings of the 2018 IPMC Workshop Final Report on Knowledge Management, this report focuses on the implementation of communication and human interactions in KM processes in two specific contexts: academia and start-ups. Of course, this does not mean KM practices recommended here are restrained to apply only to these; organizations of any size, shape, or breadth are susceptible to the challenges of KM described above. However, these areas are in focus in this report, partially because of how they exemplify and shape the space industry; these are two early-stage branches that a large percentage of space sector employees move through at some point in their early career. With such a large fraction of employees, present and future, that either will have or have had experiences belonging to one of these types of organization in their early career, investigating KM here can give valuable insight into when and where employees pick up good or bad practices. New additions to the space industry are impressionable by definition with their metaphorically blank professional canvases (even if they may carry experiences from past industries), and these environments are thus where many employees soak up practices that they go on to carry with them throughout their career. As such, many of the good and bad KM practices seen in these areas exist macroscopically in other, larger organizations too.

The first part of the report aims to explain the relevance of human interactions in KM processes and the importance of shifting from impersonal tools to interpersonal ones by analyzing case studies. As pointed out by the 2018 working group survey and interviews, there are some concrete problems to be tackled in order to implement the aspect of human interaction in different organizations. One of these problems is the underrepresentation of human interactions in knowledge sharing, and the lack of a dedicated budget for training. Being that the impersonal tools are often preferred to the interpersonal ones, the working group established that there is an imbalance between tacit/implicit ("knowing-how") and explicit ("knowing-that") knowledge. The survey implemented in 2018 showed that the biggest gaps in KM are related to communication and standardization of documents and tools. With the relevance of communication and human interaction taken into consideration, the academic and entrepreneurial fields are examined in order to better understand the role that KM has in the development of projects and products (and what are the main criticalities). The final aim of this report is to offer concrete solutions to be potentially implemented by actors in the space sector, both in academia and start-ups, as well as being extrapolated to larger organizations.

This group has been organized in weekly meetings. During the first meetings, the team expressed their ideas on how KM practices should be implemented, especially considering personal experiences.

To develop this report, the start-off point came from the idea that this is, in fact, an example of doing knowledge sharing with whoever will be reading this report. This assumption helped the team understand on which specific topic to focus.

A literature review was completed in advance, focusing on the previous IPMC Workshop's report. Considering the size of the group and the timeframe of the activity, the decision was made to opt for direct interviews of two start-ups (Valispace and ArianeWorks) and of two academic entities (educators at the European Space Agency's Education Office and with aerospace engineering

students from the University of Delft). To give the readers an idea of how large companies develop user-friendly tools to support newcomers in their working routines, Goodyear and Ecopetrol have also been interviewed, but as reference points. These interviews offered a more concrete view on the topics to be developed, allowing for a discussion about concrete recommendations.

5.4.2 Case studies -KM Practices in academic environments

The academic environment is an integral greenhouse in which future young professionals arise from, and because old habits die hard, integrating good KM practices and attitudes to learning at an early stage can have a notable positive ripple effect later down a young professional's career. Shortcomings keep educators, as well as the students they work with, from fully capitalizing on, and benefitting from, the knowledge that is generated during the course of an education. And, of course, as humans, we never stop teaching and learning from our peers – so situations in academic environments occur in any and all organizations every single day.

ESA Education Office
The Education Office at the European Space Agency (ESA) is a branch of ESA that works with a multitude of international universities under the program 'Fly Your Satellite!' (FYS). The FYS program is a recurring, hands-on program where students take part in making their own satellites. It is designed and managed by the Education Office in close collaboration with universities from ESA Member States. The objective of this program is to complement academic education and to inspire, engage, and introduce university students to the working methods adopted in professional space programs. In order to help the students, the Education Office relies heavily on transfer practices. Not only for those regarding transfers of knowledge and information related to the running of a space programme, but also to catalyse the students' understanding of the importance of documenting, and how to do it. The practice of documenting is, however, apparently often seen by the students as a bureaucratic and sometimes frustratingly time-consuming task. The interviewee, working as an educator in the FYS program, claims that students seem to simply not fully grasp the sheer importance of meticulous documentation when working on space programs, but rather see the documentation task as a strenuous and unnecessary extra activity. This is seen over time by the "lessons learned" document that the FYS program produces every year, as a monitor of how the students are responding to the program.

According to the interviewee, there has only been limited willingness from the students to do meticulous documenting. The student teams, it was claimed, collectively appeared to not fully appreciate the importance of KM practices to the overall success of the current program, and the potential success of future ones, even though the importance was explained to them. This lack of appreciation could be due to the transfer method not being sufficiently geared towards transferring and conveying the actual message needed for the students to hear.

It was noted that the Education Office places great emphasis on keeping students enthused and motivated throughout their participation of the FYS course program. The interviewee considered it their duty to keep the student teams' enthusiasm and motivation high during the course. Thereto, the interviewee noted that the personal contact with the students is by far the best part of working

in the Education Office as it goes beyond being just work *pro forma;* a statement which further cements the strong emphasis on the human interaction aspect of the Education Office's work. Capitalizing on the human interaction aspect may be seen as key when performing knowledge and information transfers from industry professionals and senior students to newcomers.

University of Delft Students
In order to contrast the perspective of the Education Office, the same interview was conducted with a group of undergraduate students from a technical school, the University of Delft (Netherlands), studying aeronautical engineering and propulsion. As they were asked the same questions as the Education Office interviewee, it became clear that the criticism that had been somewhat projected onto the students by educators – namely, that the students are not putting in sufficient effort in order to maintain good KM practices, and thus being responsible for the potential failure of future generations of students – were being equally projected onto educators by students.

Curiously enough, much of the responses by the educators and students were mirrored, but with ample finger-pointing and *tu quoque* logical fallacies on both sides, with the most obvious criticism arising that both sides accused the other of not putting in enough effort. In the question regarding who should hold the primary responsibility for ensuring KM practices are maintained, the students unequivocally agreed that this role should fall on the organization/institute; but comparably, the Education Office tries with every project to organize a recording and transfer of experiences from past students to new students, and use students as the primary upholder of KM.

Whilst the Education Office describes students as "unwilling" to participate in KM practices like documenting failures, the students underline their preference of "a teacher over a book," because "the teacher can elaborate and try to use a different approach to teach you," highlighting the preference of human interaction over documentation practices (which, since they are only recorded in writing, risks becoming anonymous and uninspiring literature for future students).

5.4.3 Case studies - KM practices in a start-up organization

Even if there is no shared definition of what New Space is, a series of trends (low-cost access to space, democratisation of space data, new business verticals, etc.) characterize the growing presence of start-ups in the space sector. The innovation brought by start-ups in the space sector has a relevant impact on the job market, and a young professional is often more likely to take a gamble on an entry-level job in a start-up than an established professional looking for a senior position. Nonetheless, for both small and medium enterprises, as well as for well-established companies, the importance of sharing good practices with the new employees and senior staff is fundamental.

Valispace
Valispace was founded in 2016 by three engineers from the aerospace industry. Their mission was to present a solution that allowed engineers to collaborate in complex space hardware projects by creating a modern collaboration between software and data storage that is easy to use; that can be

accessed by all team members; and can be accessed from any web browser. By linking all data together in a single platform in this fashion, engineers can be sure that they are always working with the most recent data, and they can quickly learn of new insights and optimize their designs. As emerged during the interview, Valispace does take KM practices into consideration; more specifically, their work is organized so that it allows a collaborative sharing of information and good practices within and across working teams, and the size of the start-up makes it possible to have a collaborative structure. Due to the start-up's relative youth, the information and good practices needed to share is not yet significant in volume. This means most of the knowledge is likely shared implicitly rather than explicitly.

Human interaction has a relevant role in the KM practices, especially when new employees are taken on. According to the interviewee's experience, an online onboarding guide is prepared for the newcomers to support them in the beginning of their work experience at Valispace. Intelligently, the newcomers themselves become responsible for the knowledge sharing from day one, making a natural transition into good KM practice. Optimization is part of the philosophy of most start-ups. For this reason, it is more profitable to rely on practices that favor the interaction of the employees in a fluid way. For example, spontaneous gatherings or dedicated time to favor the interaction between colleagues are quite usual (water cooler culture). Valispace, quite recently, started to organize a team breakfast every Friday morning. Such informal gatherings are the ideal opportunity to share knowledge in a friendly and informal way, as during the breakfast, someone from the team can present a topic related to the ongoing projects in the venture. However, there are challenges in implementing tacit knowledge schemes. The lack of dedicated time and budget makes it difficult to measure the impact on the employees of the knowledge sharing, especially on the newcomers. If a structure is put in place in advance, the possibility of adopting standardized KM practices for senior staff and newcomers would easily help to also measure the KM impact on the core activities of the company.

Having implemented KM practices in a start-up is, according to the interviewee, essential for everyday work because there is a continuous need to learn and improve both the final product and the structure of the organization. Therefore, the benefits are huge, as proven by Valispace's relative success in their short time on the market.

ArianeWorks
ArianeWorks has a mixed composition, gathering people from CNES and ArianeGroup (both well-established organizations with decades of experience). The entity was created at the beginning of 2019 and has approximately 15 staff members. Their objective is to improve and accelerate the development of future launch vehicles. Like many start-ups, they have a horizontal organization with one "leader." Compared to Valispace, ArianeWorks is not a start-up in the traditional sense of the term. It has been created by two major companies/institutions, keeping team members as employees of the parent companies. However, as their working methods are close to start-ups ones, documenting their practices can still be educational for the sake of this study.

ArianeWorks is a young organization and the KM processes used appears to be incremental: a mix between KM processes inherited from the parent companies and new processes. To store data, the

employees have access to the database of their parent companies, which is a major advantage compared to conventional start-ups. However, this solution seems to be possible only due to particular links between ArianeWorks and partner ventures. On the other hand, as a new organization, they do not produce a considerable load of new documents, so their expectations towards KM is mainly focused on how to increase the fluidity and efficiency for sharing information, and is only to a lower extent interested in how to do long-term capitalization.

ArianeWorks has chosen to use collaborative tools. Due to the sensitivity of information they deal with, the team faces some difficulties from a security perspective – a common obstacle in the space industry. Human interaction seems to be very important in the way they have implemented KM practices, as they have a weekly meeting with the whole team involved in order to share information and to ensure everyone is aligned. Moreover, they have started to work with industrial partners, and they plan to develop these partnerships further. In order to manage the knowledge towards partners, there is one team member per partner responsible to share information.

So far, the team has not grown from the beginning except by adding partners. As such, they do not have specific measures to welcome newcomers. They also do not have any staff responsible for KM or a dedicated budget. However, considering the size of the company and their way of working, these incremental methods seems to be efficient enough for now – but challenges risk appearing when the team grows if these vulnerabilities are left unchecked.

The ArianeWorks team appears to have an interest in KM practices, especially to gain fluidity and efficiency. Special attention is paid to human interaction, and they try to use collaborative tools as much as possible. However, this case study reinforces the idea that KM practices for start-ups appear to be experimental and incremental, reflecting the way they carry out their projects. This way of implementing KM practices appears to be efficient because of the particularities of start-ups (small teams, a lot of human interactions, agile methods) but do not necessarily stand the test of time and expansion.

5.4.4 Case studies - KM Practices in large organizations

To make organizations efficient internally, it is fundamental to empower people and support them in their personal and professional development; in their workplace, this includes giving them high chances to succeed. As pointed out during the interview with Goodyear, if the employees are in a stimulating environment and have the tools to learn, employees can boost their creativity and awareness while furthering the development of the company. To do so, Goodyear has created a Learning Journal for newcomers that includes all the relevant information necessary to start their position in the company. Such a tool, currently developed for employees with technical backgrounds but under development for managers, is complemented by topic-oriented courses with learning objectives.

The Learning Journal is an example for every organization: large, medium, or small. Such a tool in the space sector is especially needed in departments where it is important to have continuous training and innovation, specifically where the projects require interaction with different

departments. The Learning Journal can be general, covering general aspects, or focused on specific projects and the development of cross-departmental activities and projects.

From the interview with Ecopetrol, it became clear that KM is a strategic and considered factor for them. They have dedicated KM staff, and an explicit KM policy. In this type of company, with significant operational risks (like many companies related to space missions), good KM practices are essential because an error can cause considerable losses; and these losses could be in infrastructure, or in lives.

5.4.5 Conclusions and recommendations

The concrete recommendations provided below, based on the case studies and interviews, are applicable to a range of organizations, including national and international aerospace agencies and companies. The cultural KM background of employees shapes and dictates the macroscopic KM culture that emerges in larger organizations. This means that larger organizations simply see the facets of smaller organizations on a larger scale. As such, these recommendations translate to entities beyond those of start-ups and academia. Taking them on board is integral for any organization; especially since larger organizations are more likely to have budget and staffing capacities to take the time to implement changes.

- *Making more resources available:* Academia has existed for generations upon generations, and humanity has spent literal millennia improving teaching and learning methods. Especially with the Internet and technology, there now exists an abundance of teaching tools and learning resources (e.g. StackOverflow, Wikipedia, apps for making flashcards for studying and countless more subject-specific resources). This also appeals to different learning methods, as for example, some people retain information more efficiently by rehearsing it orally as opposed to note-taking. This is often utilized by both students and educators, with students finding what "works" for them and educators recommending and encouraging the use of these resources (as highlighted by the case studies in academia), and it is also encouraged that educators make as much resources available online as possible. For organizations outside academia, this idea can be implemented in their own KM practices by exploring the possibilities of making their own databases and resources available in a range of ways; for example, offering a large spread of available tools complemented by a detailed but precise, and concise, overview allows employees to find and transfer information related both to topics and projects within their sector/department (intra-department) as well as information related to those between two sectors/departments (inter-departments) in a quick and efficient fashion. If users are able to upload their own documents, this also creates a historical, chronological archive. This is compared to the more common practice of having one large system that covers "all" topics (which risks becoming too complex, or too simplified) or indeed not having a system at all.

- *More obvious mentorships:* Academia has a more well-established hierarchy, with professors/teachers clearly above the students. This both means that there can be a higher presence of issues like impostor syndrome or toxic work environments, but it also means that students have a clearer point of contact to use if they need guidance. To 'know your place' in this way can be

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reassuring, and this can be utilized to everyone's advantage. Organizations outside start-ups and academia may consider implementing mentorships with a more socially acceptable and obvious point of contact for new employees if possible. Especially for young professionals, possibly struggling with impostor syndrome or simple intimidation due to inexperience, appointing a referent who is explicitly labelled as the person who they may go to with "stupid questions" without judgement can foster a better working environment and culture for them – and as a result, the office and organization. This is also an excellent long-term investment, especially as these young mentees may mature into well-trained mentors due to their first-hand experience with this kind of friendly rapport.

- *Cultural importance of KM practices*: Optimization of resources in start-ups makes it complicated (and mostly low priority) to have well-defined and established KM practices to be included in the organizational schemes. The main issue is the lack of dedicated budget to implement effective measures, as the main focus is always on the final product. This is true, especially in the first phase of the life of a start-up, as knowledge sharing becomes somewhat more relevant only in a following development phase. This means that KM is too often considered as superfluous or taken for granted as a natural system that doesn't need monitoring or fostering. However, if it were to be considered as an integrated part of the structure of the venture, this would help the start-up to be more efficient internally, and to boost creativity, which is helpful regardless of an organization's size or objective. There is sometimes an attitude of "not my circus, not my monkeys" as said in Poland; meaning, with a high level of silo mentality in an organization's KM culture, there is a risk of reduced cooperation in KM practices. If an organization has a culture where an individual's business is theirs alone, this is a KM liability to both them and their co-workers – if they are reluctant to be proactive in helping their co-workers in an ad-hoc manner, even if that means operating somewhat outside of their immediate realm of responsibilities, their co-workers are unlikely to return the favour even if this attitude would benefit everyone. Organizations of any and all sizes are thus urged to seriously invest in KM practices for themselves, increasing their amount of time, funding, and staffing spent researching and implementing it.

- *Affording human interaction:* Human interaction is often preferred to impersonal tools, such as databases to share information, and was highlighted repeatedly in all case studies. Depending on the size of the organization and their mission, there is quite often a combination of impersonal and interpersonal methods to guarantee knowledge and information sharing. It is therefore of great importance for organizations to ensure that human interaction and implicit knowledge transfer is easily accessible and afforded, making sure that KM is not only confided to impersonal strategies such as databases as both implicit and explicit KM practices need to coexist.

- *Peer-to-peer encouragement*: One strength that often emerges from start-ups and its horizontal hierarchy is that there are oftentimes more direct connections between senior and junior employees, and thus a more even playing field. Especially in light of impostor syndrome, it is integral to not alienate newcomers by their lack of experience (either in the specific organization, or in the aerospace sector) and to ensure that they feel welcome enough that they are comfortable speaking up about anything that concerns them. This is an advantage that all organizations may

bear in mind to encourage a healthy environment and culture amongst peers on similar and different hierarchical levels. This can be achieved by actions such as running occasional workshops aimed at fostering bonds between peers, sharing stories, and by senior staff extending words of encouragement that can reassure and therefore motivate less senior staff to be more direct in their communication and in their KM practices.

- Generations of students: Academic settings have multiple iterations of quickly changing students, meaning that educators can do trial-and-error efforts to see if their teaching material is successful/popular or not (as highlighted by the academic case studies). They can see if their cohort responds well to methods of knowledge transfer each year by comparing average exam grades, etc. and see if a change made from one year or another helps or not. Short cycles of this result in quick feedback, sometimes from one semester to another. For both educators and students, this also means there is more direct accountability and responsibility; if you fail as a student, you are held accountable. If you fail as a professor (e.g. majority of class fails your exam), then you are also held accountable. This is a more direct measure of how well or poorly KM is maintained. Measures to objectively monitor KM in this way could be implemented in any organization. Organizations may consider implementing a similar system by monitoring which "generations" of employees do well or less well in terms of their KM management. Say that an organization takes in a new wave of employees every quarter; if a new KM tool is introduced on January 1, 2020, then by surveying how new employees from 2019 were practicing KM by the end of the year (without the tool) vs. how new employees from 2020 were practicing KM by the end of the year (with the tool), this can allow organizations to appreciate if a tool or practice aids KM or not. Cohorts can be defined depending on how frequently an organization takes in new employees (every 5 years? Or every 5 months?), and by how widely these are spread across an organization (are they all on the same team? Or are they in different departments?) for a fair measure.

In light of these concrete recommendations, there are three fundamental pillars upon which KM practices rest; without them, these recommendations cannot be actualized. These pillars make up the framework on which recommendations may be embedded, and they are the aspects that are most difficult to implement. This is because they are philosophies that are cultivated over time, as a team, as opposed to something that can be implemented by policies. They are built on a foundation of organizational will towards employee empowerment and honing of their skills and expertise; that is, it is in the interest of an organization to have their employees be proficient in their roles, because this ultimately benefits the organization.

Resources

Generations of KM   Mentorships

Peer encouragement

Human Interaction   Cultural Importance

CONCRETE ACTIONS

Mindset   Motivation   Means

ORGANIZATIONAL WILL
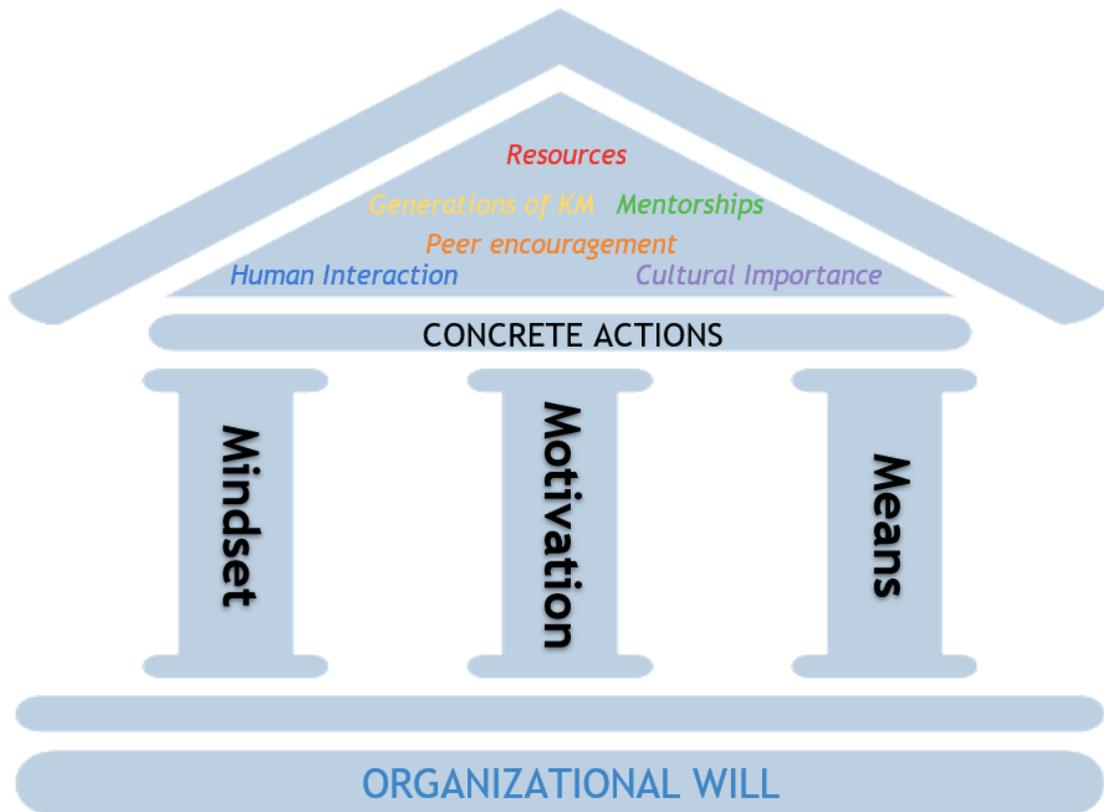
The three "M" pillars on this foundation can be summarized as follows:

- *An open **Mindset**.* All organizations in the aerospace industry – whether in academia, in start-ups, or otherwise – need to address that change can only come when people are willing to change. Any and all organizations need to accept that KM is an active effort that requires real-life training and resolve in order to make progress – effort by the company, by the employees, by the students and by the teachers. And in many organizations, the employees are both students and teachers at the same time, meaning that no one should be left out of the responsibility of fostering healthy practices.

- ***M**otivation and culture.* Related to mindset, these are the biggest threats to an otherwise healthy organization's mindset. It is very easy for an individual – and if that spreads, eventually, an entire organization – to be discouraged from a healthy mindset if the culture is toxic or apathetic. Culture and apathy are, similarly, aspects that need to be actively worked on but can only be worked on if the mindset is there. The two are symbiotic in nature as they can create a positive/negative feedback loop with one another, meaning that (i) toxic behaviour, such as dismissive responses to honest questions, must not be tolerated on any level of an organization's hierarchy, and (ii) apathy must be discouraged wherever it arises, with motivation encouraged in its place. Methods of fighting these threats involves creating workshops and literature highlighting the importance of

healthy KM culture, and establishing a good, definite philosophy that can be promoted as part of newcomers' inductions (and circulated amongst existing employees, such as the Learning Journal from Goodyear or the online onboarding guide from Valispace).

 - ***Means and Resources.*** Even if both the mindset and culture of an organization are nursed to good health, any organization's KM practices can fall by the wayside if there is a lack of resources – both in manpower, in time and in funding. It is up to organizations to take the initiative to delegate resources in these areas, and to ask themselves if they can afford the cost of not committing to this expenditure.

5.5 PM Practices for Encouraging Rapid Prototyping and Short Fused Life Cycle for Space Projects

5.5.1 Introduction and methodology

Rapid prototyping is a group of manufacturing technologies that manufactures products on an additive or layered-basis, and thus far have been used to support Rapid Product Development (RPD) – a manufacturing methodology that accelerates the development of new products, from the initial design stage to mass production. RPD involves new technologies such as Computer Aided Manufacturing and Design Technologies (3D CAD/CAM), Rapid Prototyping and Rapid Tooling, combined with new management philosophies, to address the reduction of time to streamline the manufacturing process. RPD methodologies not only allow companies to put new products into manufacture faster, they concurrently reduce associated development costs. Internationally, companies are finding these methodologies to be extremely beneficial and are adopting them at an ever-increasing rate.

Due to the pressure of international competition and market globalization, there continues to be strong driving forces in the industry to compete effectively by reducing manufacturing times and costs while assuming high quality products and services. However, conventional manufacturing methods are characterized by long lead time and high cost. It cannot meet the demand for rapid product development.
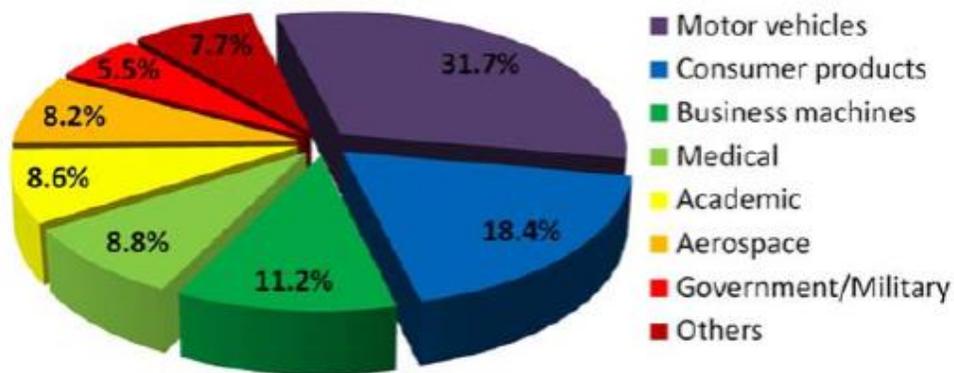

Figure 5 - Usage of Rapid Prototyping in different types of industries

The application of Rapid Prototyping to the product manufacturing process has shown a 60% decrease in lead time over traditional methods. With the various advantages, Rapid Prototyping technology has begun to make its way into the aeronautical industry and is set to have profound implications.

Rapid Prototyping in the aerospace sector is an advanced method for product development that requires a new way of project management. Some project management methodologies are used in various sectors and some of them can be applied also to the aerospace sector.

5.5.2 Project Management methodologies

Common Approach in Aerospace Sector

In the aerospace sector, the systems are large-scale, resources are typically limited and cost/schedule efficiency is required. For an efficient development of large-scale systems with high quality, the Phased Project Planning (PPP) method has been generally applied, which was developed during the Apollo program by NASA and it is a commonly used method in the conventional aerospace sector. The PPP method divides the total development process into several phases and defines the work elements to be performed in each phase. Also, during each project management life cycle, Technical Readiness Level (TRL) standardization is usually used to measure how each component or subsystem is ready for implementation in the flight model.

It is important to conduct rapid prototyping to increase the TRL as quickly as possible.

NASA

PPP & TRL	Formulation			Implementation			
Life Cycle	Pre Phase A	Phase A	Phase B	Phase C	Phase D	Phase E	Phase F
	Concept Studies	Concept & Technology Development	Preliminary Design	Final Design & Fabrication	System Assembly Testing & Launch	Ops & Sustainment	Closeout
TRL	TRL3	TRL4	TRL6	TRL7	TRL8	TRL9	

ESA

Life Cycle	Phase 0	Phase A	Phase B1	Phase B2	Phase C	Phase D	Phase E	Phase F
	Mission Analysis	Feasibility Study	Preliminary Definition		Detailed Definition	Qualification Production	Utilization	Disposal
TRL		TRL4	TRL5	TRL6		TRL8	TRL9	

JAXA

Life Cycle	Pre Phase A	Phase A	Phase B	Phase C	Phase D	Phase E	Phase F
	Concept Study	Concept Design & Project Formulation	Preliminary Design	Final Design	Production & Testing	Launch, Initial & Nominal Ops	Extended Mission Ops & Project Complete
TRL	TRL3	TRL4	TRL6		TRL8	TRL9	

Table 1 - Project Phase/Life Cycle Definition and Corresponding TRL to be achieved

The PM methodologies of Rapid Prototyping Development

Additive manufacturing for rapid prototyping
Additive manufacturing has mainly been used for prototyping in the early phases of product development. Now companies are starting to use metal-based additive manufacturing for more regular production of components. The unit cost for metal-based AM is often very high and the business case has to be carefully chosen to beat the cost of traditional manufacturing methods.

There are four main reasons to use AM:
- customize products for the requirements of individuals;
- improve product functionality with adoption of complex geometries;
- reduce part numbers through consolidation; and
- increase the value to the customer with specific design features

The choice for or against the selection of additive manufacturing can be summarized with the following table that identifies the benefits and the drawbacks of the usage of these methodologies.

Benefits of AM	Drawbacks of AM
• Freedom of design • Ability to combine an assembly/integrate functions of parts into one part • No need for tooling • Lower setup costs • Cost efficient mass customization • Quick response time • Decrease in time to the market • Extra complexity of a part comes at no additional production costs • Reduction of material use and a reduction of the amount of waste • Energy savings (where AM is competitive)	• Lack of standards to ensure quality, repeatability and consistency • High costs of machines • High costs of materials • Low diversity of applicable materials • Post-processing of the final product • Limited dimension of the AM machines • Sensitivity of digital product data (protection of intellectual property)

Table 2 - Benefits and drawbacks of additive manufacturing compared to conventional manufacturing

Project Management for Rapid Prototyping in the Aerospace Sector
Here the team outlines ideas that have already been used in each industry as rapid prototyping management methodologies. Each management philosophy focuses on different priorities, and each methodology can be considered to be integrated into each phase to optimize their resource, cost and schedule.

- **Agile**
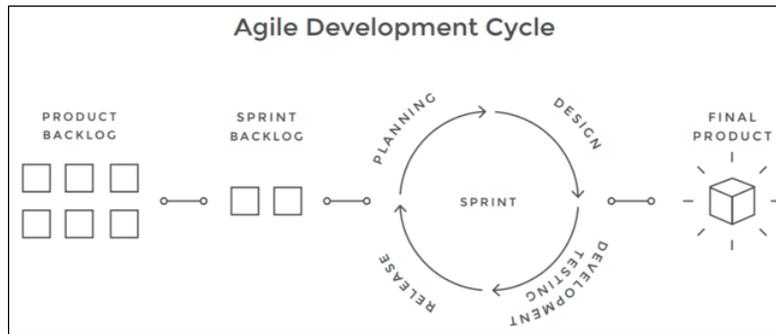
Philosophy: Unlike a straightforward linear waterfall model, agile projects consist of a number of smaller cycles – sprints. Each one of them is a project in miniature: it has a backlog and consists of design, implementation, testing and deployment stages within the pre-defined scope of work. At the end of each sprint, a potentially shippable product increment is delivered. The product backlog is an ordered list of feature items that might be needed in the project's final product. It is the single source of requirements. The product backlog updates as new requirements, fixes, features and details are being changed or added. The sprint backlog is a list of tasks the team must complete to deliver an increment of the product — traditionally functional software — at the end of each sprint.

Proposed lifecycle to implement: Implementation phase is not only the final design and fabrication phase but also the concept phases of a project. Especially for system analysis or flight software development. (Phase0, B to C in aerospace sector)

Example in other sectors: Cloud software service development such as Software as a Service (SaaS).

● **Lean Startup**

Philosophy: The lean startup methodology advocates for entrepreneurs to continually engage in the activity loop – exploring and developing hypotheses that they then test among customers to elicit feedback, something known as validated learning. Entrepreneurs use that customer feedback to re-engineer their products. Its principles ensure that entrepreneurs develop products that customers actually want, rather than attempting to build businesses based upon untested ideas. It describes this mentality as "fail fast, fail cheap" because the lean startup process is designed to limit the time and money invested in product ideas before entrepreneurs have to test and prove their potential value. Additionally, this methodology asks to develop a minimum viable product (or MVP) that they can test.

Proposed Lifecycle to Implement: Mission or service concept validation. (Phase 0 or Pre-Phase A)

Example in other sector: Startup service development like DropBox, Instagram, and so on.

- **DevOps**
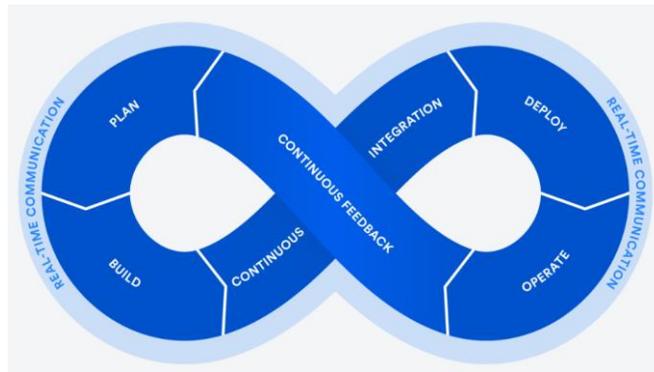
<u>Philosophy</u>: DevOps is about removing the barriers between two traditionally siloed teams, development and operations. In some organizations, there may not even be separate development and operations teams; engineers may do both. With DevOps, the two teams work together to optimize both the productivity of developers and the reliability of operations. One fundamental practice is to perform very frequent but small updates. This is how organizations innovate faster. These updates are usually more incremental in nature than the occasional updates performed under traditional release practices. Frequent but small updates make each deployment less risky. They help teams address bugs faster because teams can identify the last deployment that caused the error.

<u>Proposed lifecycle to implement</u>: Implementation to operation phase (phase C to E).

<u>Example in other sectors</u>: Cloud software service development such as Software as a Service (SaaS).

- **IPM (Integrated Project Management**

<u>Philosophy</u>: Integrated project management is the collection of processes that ensure various elements of projects are properly coordinated.

It establishes and manages the involvement of all relevant stakeholders and resources, according to defined processes devised from your organization's set of standard processes.

Finally, it involves making trade-offs among competing objectives and alternatives to meet or exceed the needs and expectations.

Integrated project management aims to work at an organizational scale. Far too often, project management knowledge remains siloed in individual departments at a business.

Proposed lifecycle to implement: from the early stage of project through preliminary and detailed/final design process (phase A to D in aerospace sector).

5.5.3 Risk and opportunity

In order to assess and prioritize the risks of a project, the common method used in the space industry (NASA, ESA) is the probabilistic risk assessment (P.R.A.) method in which the risk is characterized by two quantities:

1. the magnitude (severity) of the possible adverse consequence(s), and
2. the likelihood (probability) of occurrence of each consequence.

The usage of rapid prototyping (RP) allows to mitigate some very important risk that are always encountered in innovative projects:

- R1: Delivery of a product not corresponding to the real needs
- R2: Overthinking; to design a product that will be impossible to realize
- R3: Wrong estimation of the production/maintenance cost
- R4: Non-detection of critical defects/anomalies/non-conformance until later phases

Risks mitigated by RP		Risk Index in respect to TRL		
		TRL 1 to 4	TRL 5 to 7	TRL 8 to 9
R1	Product not corresponding to the real needs	High	Moderate	Low
R2	Product-realization impossible	High	Moderate	Low
R3	Product cost too high to be sustainable	High	Moderate	Low
R4	Non-detection of critical design defect	High	Moderate	Low

Table 3 - Risks mitigated by RP in respect to TRL

On the contrary, the usage of rapid prototyping also adds risks that have to be evaluated and balanced:
- R5: risk of cost overrun: building the different prototype iterations is not free
- R6: risk of delays: building the different prototype iterations take time
- R7: risk of non-representativity of your prototype in respect to the final product

The level of these three risks vary in respect to the targeted fidelity level of the prototype.

Risks introduced by RP		Risk Index in respect to the fidelity of the prototype		
		Low fidelity (breadboard, demonstrator)	Medium Fidelity (reduced scale prototype)	High Fidelity (full scale prototype, MVP)
R5	Costs	Low	Moderate	High
R6	Delays	Low	Moderate	High
R7	Non representativity of the prototype	High	Moderate	Low

Table 4 - Risks introduced by RP in respect to prototype fidelity level

Iterative methods (agile, lean startup) allow to change the design following the results of prototype testing without restarting the project from scratch and, as such, mitigates the cost and delay risks.

By involving all stakeholders of the company, IPM and DevOps allow radical decisions in order to optimize costs and delays at a company level that would not be possible if the project team worked in isolation.

The focus on production and testing automation (AM, DevOps) allows to reduce costs and delays introduced by the repetition of the production and testing phase of the prototype iterations. It also allows the divergence in respect to the original design and as such limits the risk to obtain a non-representative prototype.

5.5.4 Conclusion and recommendations

The report explains the current status of rapid prototyping in the Aerospace sector and the project management methodologies applied with it. In the following section the group highlights the specific improvements that can be applied in the development of future space project management.

Recommendation 1: Merging of the PM Methodologies during the project

Taking into account the various methodologies, the following table has been determined:

PM Methodologies Considered	Advantages	Disadvantages
Agile	- Flexibility - Freedom - Lower Risk	- No Fixed Plan - Strict Collaboration
Integrated Project Management	- Transparency - Accountability	Extensive Planning
Additive Manufacturing	- Freedom of design - Quick response time - Reduction of material used	- Lack of standards for quality - High cost - Low diversity of product to be produced
Lean	- Waste minimization - Customer relationship - Infrastructure	- Delivery inconsistencies - Equipment failure
DevOps	- Reduce failures - Flexibility - Faster time market	- Software development expertise - Expensive

Table 5 - PM Methodologies for Aerospace Sector: Pro and Cons

The described methodologies can be considered as applicable for the aerospace sector, but taking into account the level of complexity of the aerospace project, a possible way forward for the future could be to merge the various methodologies, depending on the phase of the project:

- At the beginning (phase 0 to phase B) the usage of flexible and versatile approaches is needed: Agile, Scrum
- When the project is mature (Phase C to Phase E) the usage of the IPM (or DevOps) is a great advantage in order to put some standardization into the company and wider use of RP techniques for production

So, in general, the future of space project management doesn't need a real standard method for inducing a reduction of the duty cycle, but merging the management processes can improve the possibility of the reduction of time use and costs and also has the possibility to create a standard for the next projects.

Recommendation 2: Usage of Additive Manufacturing

AM in general has huge potential – it is technically possible to produce components with varying stiffness (by altering the internal structure of the component), build anisotropic components or mix materials in a solid component (for certain AM processes). Also, compared to traditional processes, the manufacturing of a single component can be drastically lower to production time of a variety of parts. This could give the opportunity to create a more explorative iterative design cycle and explore more radical design solutions. AM also introduces challenges, firstly the whole product development process is affected. Design for Additive Manufacturing is a complex approach due to the few design tools and CAD packages that exist for AM. There are few support tools and methods that help the engineers to adopt AM in the design process. Traditional CAD tools are designed for conventional manufacturing methods such as drilling and lathing (features like holes/pockets/ etc.). This forces the engineer into design in a traditional way, instead of encouraging the wider geometrical possibilities that AM brings. A new tool should fit the new possibilities and encourage engineers (especially engineers who are inexperienced with AM) to think and work with an AM focus. In a proposed CAE system the engineer could design in a top-down approach, describing functional requirements (e.g. interfaces, cooling, embedded electronics, structural requirements) and let the system perform topology optimization (similar to existing FE programs for structural topology optimization). There is also little experience of AM within companies, which results in a more cautious approach as opposed to embracing new solutions with low TRL. These uncertainties can both lead to a longer design process and a lower level of innovation within companies and processes.

Recommendation 3: Closer cooperation in early phases of the project

In the early phase, it is very important that the space agencies and the contractor companies will focus on a deeper cooperation in order to determine a more clarity on the requirement that can be considered fundamental for the project. One possibility is to have a common workshop in order to reduce a lot of costs during the design phase because the requirements from the agency and the possibilities of the contractor can be specified right from the beginning.

Recommendation 4: Usage of COTS components

Usage of materials and components not totally space qualified like the COTS (Components Off the Shelf) is an issue that was studied a lot in order to verify the possibility to reduce the cost and time of the product development The certification is the main issue of waste of time of the project, due to the long activity for testing the hardware in extreme situations that never occur. But there

are some projects that now are using COTS material that are not totally certified but are tested directly for use in space. The risk of the project could increase, but if one looks at an example of a set of satellites in a constellation, the failure of the first set of satellites could only create a lesson learned that speeds up the modelization of the next set in favour of a shortened design phase.

Recommendation 5: Testing Time vs. Design Time

Aerospace projects often face issues relating waste of time related mainly to long work on the design strategies and verification, that for the major part of the project are totally modified when the test on the real hardware begins. It is understood that during the testing phase, the design is totally reviewed, so it should be aimed at that the two phases should be synergized more, in order to help avoiding waste of time in the design phase.

A possible applicable solution in order to merge the Testing and Design activities is to work on the Hardware of the various components and instrumentation from the beginning of the project, in order to verify the interface and the connections. In this way it is possible to avoid the development of the design based only on documentation, that increases the risk of failure or modification when the project goes only on the testing phase activities.

The difficulty could be to work with the correct Hardware but can be sufficient to work with something similar, components that have been used in previous projects and can be reused for the development activities.

Disclaimer: Recommendations regarding the merge of different generations in space-related work environments:

Working on this report, the group was frequently faced with questions regarding how to optimize work environments in which different generations of workers must efficiently synergize. While this question was regarded as very important, especially in the context of the emergence of new technologies such as rapid prototyping, the group has decided to exclude this topic from the report, since it recently has been addressed in length by a team in the IPMC workshop in a previous year. Their recommendations are briefly recalled hereinafter, please find the full dissertation in the 2018 IPMC YP Workshop report.

> ### Concluding remarks from previous research on Diversity
> *The space industry tackles some of the most challenging problems on the planet – problems requiring constant innovation, new, gravity-defying ways of working. The literature review of this work summarizes that diversity and inclusion within the space sector is recognized as important. However, the young professionals have experienced that current attempts at inclusion are often related to the standard (easy to measure) dimensions and often feel like an external constraint rather than being related to the actual working goal of the group. They believe that inclusion-related actions could be more efficient and cause more beneficial effects when the individuals and their teams are more focused. Hiring*

individuals who do not look, talk, or think like you can allow you to dodge the costly pitfalls of conformity, which discourages innovative thinking.

Diverse teams are more likely to re-examine facts and remain objective. By breaking up workplace homogeneity, employees are enabled to become more aware of their own potential biases and entrenched ways of thinking that can otherwise blind them to key information and even lead them to make errors in decision-making processes.

Scientists think that diverse teams may outperform homogenous ones in decision making because they process information more carefully. Considering the perspective of an outsider may seem counterintuitive, but the payoff can be huge.

In a nutshell, enriching employee pools with representatives of different genders, races, and nationalities is key for boosting a company's joint intellectual potential. Creating a more diverse workplace will help to keep team members' biases in check and make them question their assumptions. At the same time, we need to make sure the organization has inclusive practices so that everyone feels they can be heard. All of this can make teams smarter and, ultimately, make organizations more successful, independent from the goals.

6. General Concluding Observations

Every year the IPMC YP workshop topics are carefully chosen in close collaboration with the committee members. The topics represent the interest and challenges that the aerospace industry and organisations face on a daily basis.

The young professionals have a clear view of how the space sector is changing and how to navigate in this change. Space sector players are no longer limited to the main Space Agencies and the big consortiums: younger, smaller and non-space companies are playing an important role too. New Countries and new cultures are entering the game. The conservative PM methodologies developed in the past are sometimes no longer sufficient to keep up with, react quickly to and take advantage from the challenging and fast-paced evolutions of the space sector. Some of the core topics of modern society and workplace, such as diversity and knowledge management, take on both peculiar relevance and peculiar obstacles when they are applied to the space field and its human capital. Amidst all of this, Young Professionals bring fresh ideas and new energies, they are technology-savvy and open to change. They will quickly grow into tomorrow's workforce.

We invite the IAF's IPMC committee members and the Young Professionals to further discuss the findings of these topics and find a way to implement the recommendations in their respective organisations. The recommendations are evident, well thought out and based on the examples, experiences and input from today's way of conducting and developing business.

7. List of Workshop Delegates

Name	Surname	Organisation
Mariantoneta	Zonno	DLR
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Jens	Kersten	DLR
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Ashley	Peter	SGAC
Avid	Roman	SGAC
Harriet	Brettle	SGAC
Karina	Perez Molina	SGAC
Ayano	Lida	JAXA
Yuki	Tomita	JAXA
Arne	Lahcen	ESA
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Anna	Wojdecka	

8. Previous Workshop Reports

All previous IAF's IPMC Young Professional Workshop reports are available on the IAF website, please follow this link.

9. Acknowledgements

The IAF's International Program/Project Management Committee greatly appreciates the support of **a.i. solutions**, **KBR** and **Collins Aerospace** who are underwriting the cost of the Young Professional Workshop. The WOC would like to warmly thank the sponsors for their continued support to the Young Professionals Workshop.

The WOC is looking forward to the future with the preparation of the next workshops and the continuation of the implementation of previously presented recommendations. The WOC, in close collaboration with the IPMC, strives to advance on the development and empowerment of the next generation space workforce.

10. Full topic reports
The full reports per topic are presented in the attached link.