TAXONOMIES for CORPORATE INTELLIGENCE in the AERONAUTICAL and SPACE SECTORS

Vicente GÓMEZ-MOLINERO – PAE (Spanish Aerospace Technology Platform)
c/ Profesor Waksman, 14 bis-1ª planta 28036 - Madrid - SPAIN
vicente.gomez@plataforma-aeroespacial.es

Héctor GUERRERO-PADRÓN – IMDEA Nanoscience
c/ Faraday, 9 28049 - Madrid – SPAIN
hector.guerrero@imdea.org

Abstract

Spanish Aerospace Technology Platform (PAE) is a forum of different organizations related with aerospace research and innovation activities in Spain. In order to manage the information related to the aerospace sector under the same framework, PAE decided to develop a 'common language' open to all members. Two taxonomies (a taxonomy is understood as classes with definitions in a hierarchical structure) were developed, one for aeronautics and other for space. The developed taxonomies have offered novel results from the auto-classification of PAE entities (industries, universities and research centres) and demonstrated as a powerful tool for corporate intelligence at sector level.

1. Introduction

When the new phase of the Spanish Aerospace Technology Platform (PAE) started in 2017, we decided that a common language to allow us the management of the information related with research and innovation in aerospace sector could be very useful. After some initial discussions it was decided to develop two frameworks, one for aeronautics and one for space, in the form of two taxonomies understood as a set of classes hierarchically structured.
This paper summarizes the process of creation and foreseen enhancements for both taxonomies, their first complete applications to the self-classification of the PAE members and the different types of analyses - using a novel type of graphs known as classgrams [2] - that can be performed in a systematic way using a common metrics allowing to better know the research capacities of the sector in Spain.
Some another foreseen uses of taxonomies will be related with the SRIA (Strategic Research and Innovation Agenda) that PAE is developing, allowing the comparison between the self-classified capacities and the recommended technology development areas and the elaboration of a catalogue of Spanish research capacities and infrastructures applicable to aerospace field.
In conclusion, the aeronautical and space taxonomies developed by PAE have offered novel results from the self-classification of PAE entities (industries, universities and research centres) and they have been demonstrated as powerful tools for corporate intelligence at sector level.

2. Spanish Aerospace Technology Platform (PAE)

The Spanish Aerospace Technology Platform (PAE) is a forum that gathers different organizations related with aerospace research and innovation activities in Spain. In June 2019, the list of members includes 53 Industrial firms (big companies and SMEs), 17 Universities and 16 Research and Innovation Centres.

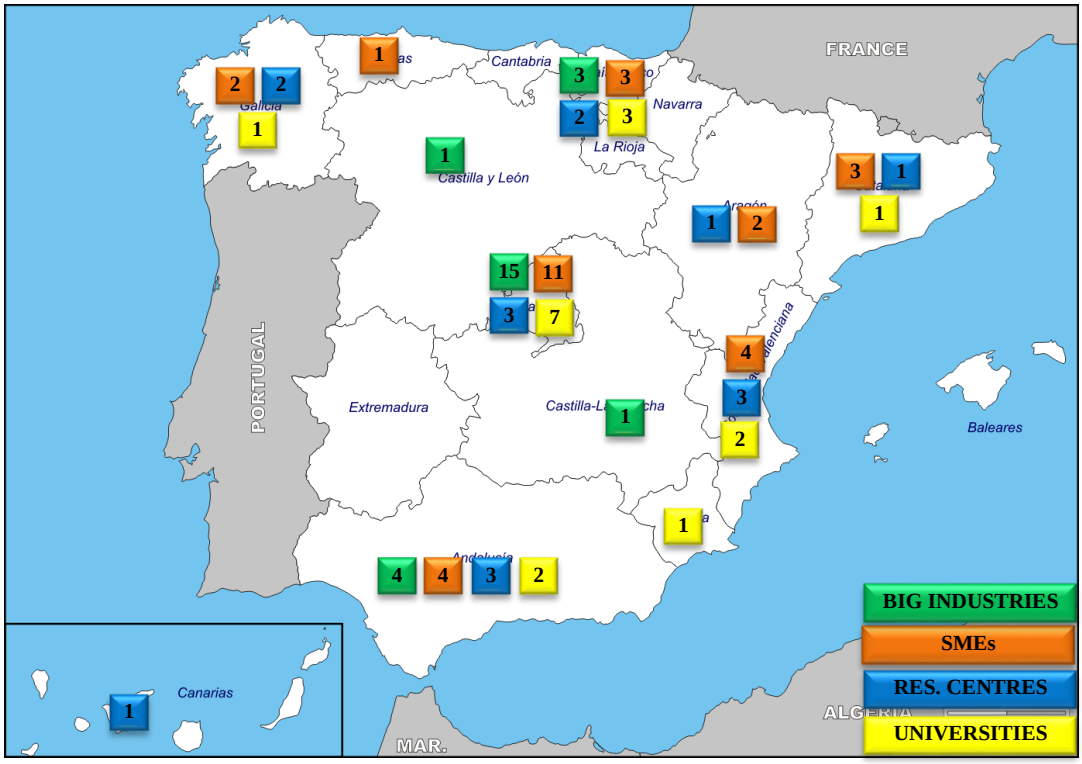

Figure 1: Geographical distribution of PAE's entities

European Technology Platforms (ETPs) were proposed by European Commission in 2003 with the main aim of: bringing together technological know-how, industry, regulators and financial institutions to develop a strategic agenda for leading technologies. European Commission defined the main functions of ETPs as follows:

- Develop strategies and provide a coherent business-focused analysis of research and innovation bottlenecks and opportunities related to societal challenges and industrial leadership actions: **strategy function**.
- Mobilize industry and other stakeholders within the EU to work in partnership and deliver on agreed priorities: **mobilizing function**.
- Share information and enable knowledge transfer to a wide range of stakeholders across the EU: **dissemination function**.

Currently PAE is organised in the following working groups:

- Strategy Working Group, the most general one, dealing with the recruitment of new entities, relationship with national and international technology platforms and similar organisations and communication and outreach. Specific sub-groups are in charge of:
    - Developing a Strategic Research and Innovation Agenda for Aeronautics, inspired in the SRIA developed by ACARE at European level.
    - Developing a Strategic Research and Innovation Agenda for Space.
    - Performing a study of future skills and competences for inter-disciplinary engineers in the framework of industry digitisation.
- Aeronautical Technology Working Group in charge of any study or activity related with typically aeronautical technologies.
- Space Technology Working Group in charge of typically space technologies studies and activities.
- Common Technology Working Group developing the activities related with more horizontal technologies common to aeronautics and space like aerospace materials or manufacturing processes. This Working Group is also in charge of further development of PAE's taxonomies and their future applications.

3. Taxonomies to manage the information at sector level

The word "taxonomy" is usually related with the animals and plants classification proposed by the Swedish physician and botanist Carolus Linnaeus in his "Systema Naturae" published in 1735, although some authors consider the Greek philosopher Aristotle like "the father of science" and the first precursor of taxonomy with his "History of Animals" ("Historia Animalium" in Latin) [7].
The AERO and SPACE taxonomies of PAE are conceptually different from those examples from biological sciences: they are conceived as a set of classes hierarchically organised in a tree structure and designed to classify the aerospace related information from different points of view. Their main power comes from the possibility of multiple cataloguing of the information relating it with the different classes under the various branches of the taxonomy.
When you are developing a taxonomy this must be conceived for a particular application. In our case, the main aims of our taxonomies are as follows:

- Establishing a common language applicable to our SRIA in Aeronautics and Space, highlighting the fields where our sector must develop itself.
- Providing a commonly shared framework for a better classification of our research capacities and infrastructures in the form of web based catalogues.
- Offering a common way to organise the technical, commercial, organisational information for each of the entities of PAE and providing them a common reference frame to measure their activities/capacities in comparison with their counterparts and the overall sector in Spain.
- Creating information repositories of our sector organised following the taxonomies, using common metrics and facilitating the decision making.
- Allowing an overview of the Spanish aerospace sector, its main key indicators and better ways to communicate with the Public Administrations and society.

3.1 Structure of PAE's taxonomies

The two taxonomies of PAE have been designed as a Cartesian 3 axes space where each of the axes correspond to one of the three main branches of each taxonomy: any information element will correspond with a set of points in that 3D space and the whole information of each sector would be included into a 3D volume (figure 2).

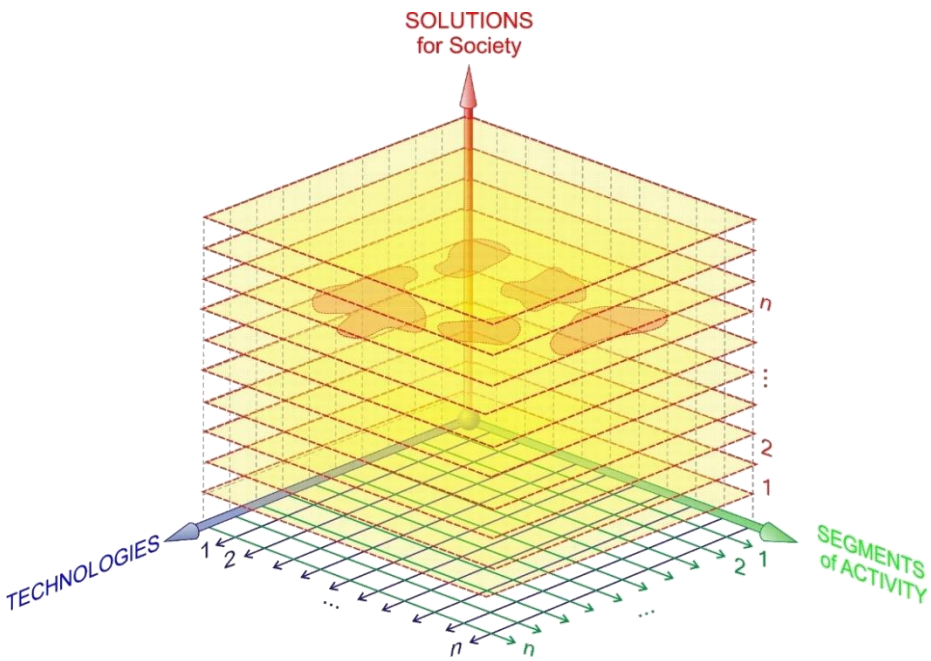

Figure 2: Structure of a taxonomy for a sector

Those three main branches try to answer the following three basic questions:

1. **How do we make the things?** = Research and Technology
2. **What the people are working for?** = Segments of Activity
3. **What the sector activity is applied for?** = Solutions for Society

To classify the information of the sector related with other relevant sectors, we have defined a fourth branch trying to answer **"How the relationship with other sectors is?"** A graphical representation of the classification of any item in those taxonomies is shown in the figure 3:

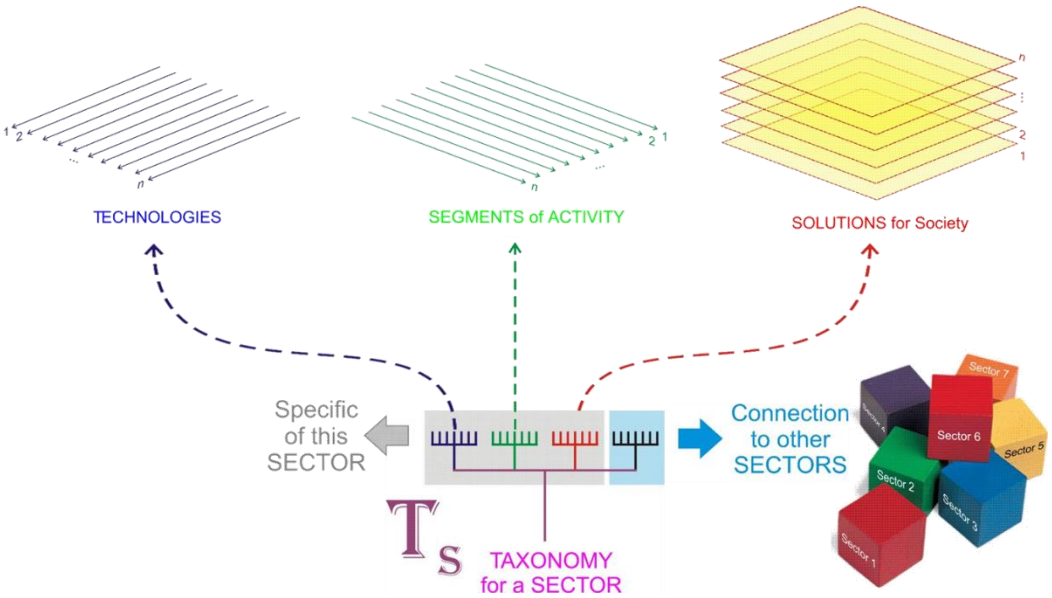

Figure 3: Classification of information into the taxonomies

The structure and content of AERO and SPACE taxonomies of PAE have been detailed to a maximum of three levels (mainly in the first Research & Technology branch): the idea is that each level of the taxonomy is thought to be easily understood by different types of persons: the first level (four main branches) would be clearly understood by the general public and politicians, the second one (classification of each of those main branches) by the general managers of the sector and the third one (sub-classification of each of the classes of the three main branches if any) by the specialised technical people.

3.2 AERO taxonomy

The AERO taxonomy of PAE bases its technology branch in the one defined by ACARE (Advisory Council for Aviation Research and Innovation in Europe) in 2003 [3], complemented for "Digital Industry" class with the technology roadmap of the Eureka SMART project [6]. The other three branches have been developed by PAE. The summary and detailed description of AERO taxonomy may be downloaded from PAE web page [8] and [9].

The second level of the four AERO taxonomy branches is developed following a logic:

- For the Research & Technology branch (how do we make the things?), the logic is as follows: to fly the basic requirement is the knowledge of Flight Physics (1A): this is the starting point. When you think in a flying vehicle you need an aerostructure (1B) together with power and propulsion systems (1-C) and avionics and control systems (1D). For a right flight in the atmosphere the Fights Mechanics (1E) is crucial. And to develop an operational air vehicle the Integrated Design and Validation Methods (1F) must be implemented. Once flying the Air Traffic must be safely managed (1G) as well as the infrastructures to allow all the ground based operations: Airports (1H). Human factors (1I) including man-machine interfaces and training are an essential part of aviation. The future evolution of aerial systems (1J) and the particular technologies for unmanned aerial systems (1K) must also be included. Finally, as well as other industries, the digitalisation or Industry 4.0 technologies (1L) are critical for the future competitiveness.

  From 1A to 1J, the definitions of reference [3] have been maintained with some minor updates. In 1K four sub-classes have been defined and in 1L, following reference [6], five sub-classes have been introduced.

Aeronautics Taxonomy

1 - Research & Technology Domain

1A - Flight Physics
1B - Aerostructures
1C - Propulsion & Power
1D - Aircraft Avionics, Systems & Equipments
1E - Flight Mechanics
1F - Integrated Design & Validation (methods & tools)
1G - Air Traffic Management
1H - Airports
1I - Human Factors
1J - Innovative Concepts & Scenarios
1K - Unmanned Aerial Systems Technologies
1L - Digital Industry - Industry 4.0

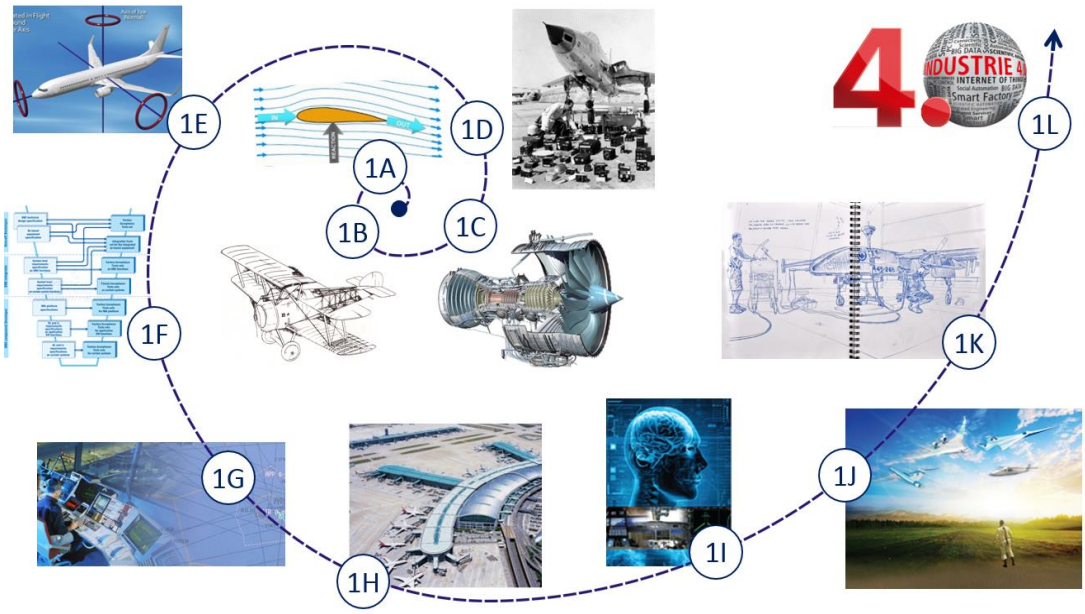

Figure 4: AERO taxonomy Research & Technology classes

- The Segments of Activity branch (what the people is working for?) is divided into 13 categories shown here below:

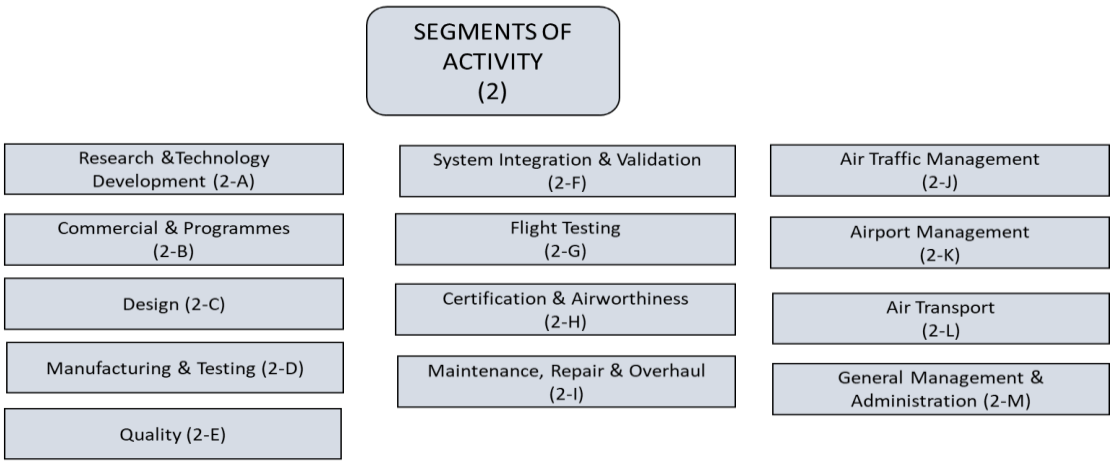

Figure 5: AERO taxonomy Segments of Activity classes

- For the Solutions for Society branch (what the aeronautical activity is applied for?) the classes are: Scheduled Air Passenger Transport (3A), General Aviation (3B), Air Freight (3C), Defence (3D), Security (3E), Civil Surveillance (3F), Environmental (3G) and Future Applications (3H).
- The fourth branch Aeronautics & Society (how the relationship with other sectors is?) includes relations with: Other Industries (4A), Economy (4B), Policy & Regulations (4C), International Co-operation (4D), Education (4E), Outreach (4F) and Humanities (4G).

As a matter of example, the level 3 classification for the first Research & Technology class is shown into the figure 6:

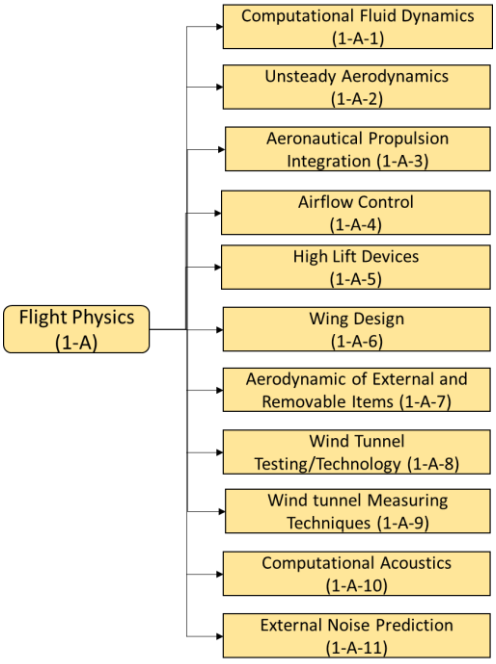

Figure 6: AERO taxonomy Flight Physics sub-classes

3.2 SPACE taxonomy

The SPACE taxonomy of PAE has been more complex to develop because we have not found any previous complete taxonomy already published similar to the one from ACARE in the aeronautical case. So, we have decided to base our SPACE taxonomy in the ESA's Technology Tree [4] complemented with NASA Technology Roadmaps [5] and with some adaptations made by PAE for the technology branch. The "New Space Paradigms" class is also partially based on the technology roadmap of the Eureka SMART project [6]. The other three branches have been developed by PAE. The summary and detailed description of SPACE taxonomy may be downloaded from PAE web page [10] and [11].

The second level of the four SPACE taxonomy branches is developed following also a logic:

- For the Research & Technology branch the logic is as follows: the space development starts with the System Design & Verification (1A). The basic blocks of an overall space system are: Materials, Structures and Mechanisms (1B), Energy and Power (1C), Avionics including OBDH (1D), Thermal matters (1E), Propulsion (1F), Guidance, Navigation and Control (1G) and Communications(1H). In some cases, we have on-board Scientific Instruments (1I). Some space missions may be covered by Automation, Tele-presence and Robotics (1J) but some other ones require Manned Spaceflight (1K). To complete the SPACE Research & Technology domains, we consider Mission Operations & Ground Segments (1L), SSA& Clean Space (1M), Data Technologies (1N) and the New Space Paradigms (1O).

  There is a table where a correspondence is established between each of the sub-classes of the Research & Technology branch and ESA's Technology Tree and/or NASA's Technology Roadmaps.

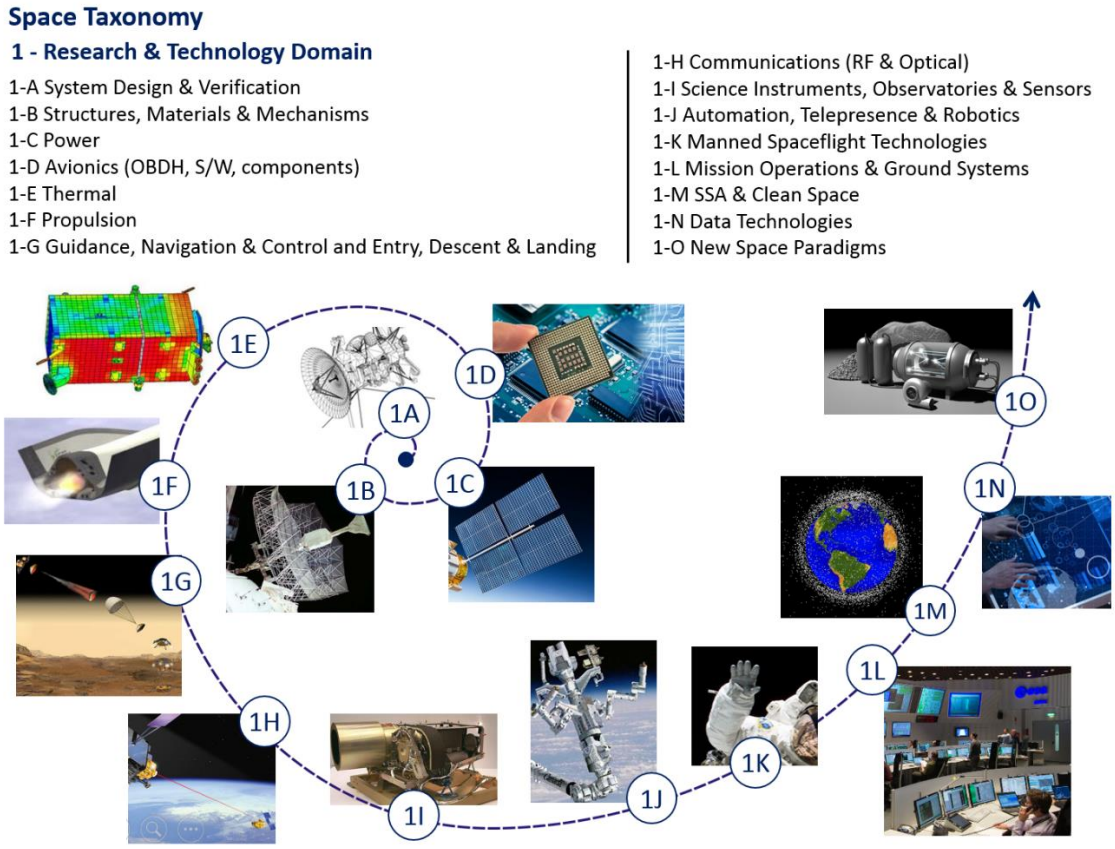

Figure 7: SPACE taxonomy Research & Technology classes

- In the Segments of Activity branch we have identified 14 categories shown here below:

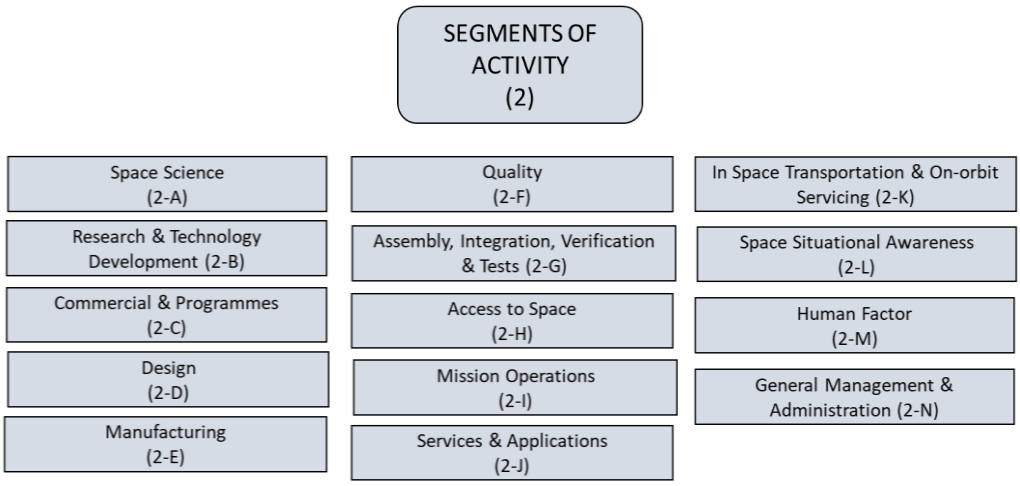

Figure 8: SPACE taxonomy Segment of activity classes

- For the Solutions for Society branch the classes for SPACE are: Earth Observation (3A), Navigation (3B), Communications (3C), Security (3D), Defence (3E), Science (3F), Robotics Exploration (3G), Manned Spaceflight (3H) and Future Domains (3I).
- The fourth branch Space & Society includes relations with: Other Industries (4A), Economy (4B), Policy (4C), Law (4D), International Co-operation (4E), Education (4F), Outreach (4G) and Humanities (4H).

As a matter of example, we show a detailed definition of one of the Research & Technology sub-classes:

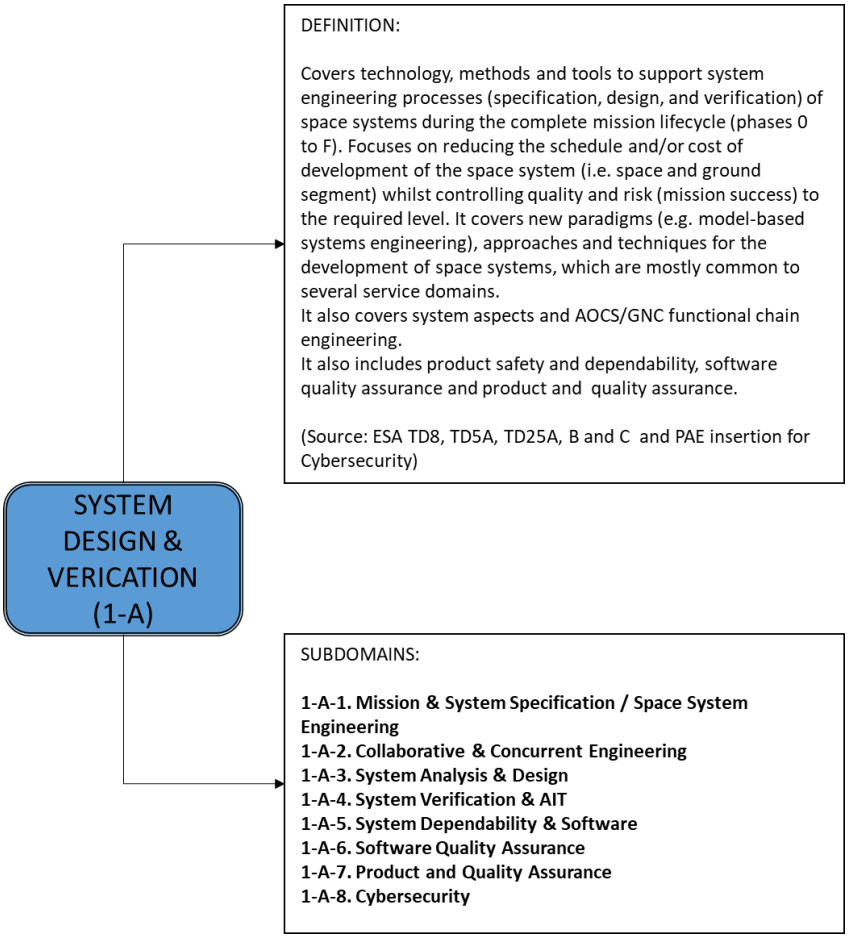

Figure 9: SPACE taxonomy System Design & Verification definition and sub-classes

The two taxonomies defined by PAE have a structure with a number of nodes (classes and sub-classes) summarised in the table 1:

	Number of nodes (each one has an associated definition)		
Taxonomy	**Fist level**	**Second level**	**Third level**
AERO Taxonomy	4	12 + 13 + 8 + 7	139 + 9 + 0 + 19
SPACE Taxonomy	4	15 + 14 + 9 + 8	112 + 0 + 0 + 19

Table 1: Structure of both taxonomies

4. Self-classification of the PAE's entities

The first exercise made with the two defined taxonomies was to request a self-classification of all the entities (industries – big companies and SMEs -, research centres and universities) belonging to the PAE at that time (second half of 2017) in the first three branches of both taxonomies. An Excel file was prepared to allow that classification.

Some of the entities classified themselves in both taxonomies (they have aeronautical and space background) and some other ones only classified themselves in one of the two taxonomies. Approximately 90% of the total entities answered the self-classification exercise.

The criteria used for the classification are defined in the table 2. Each entity classified using that metrics on each of the level 3 nodes of the taxonomies (167 nodes for AERO and 131 for SPACE).

Value	Research & Technology	Segments of Activity	Solutions for Society
NA	We do not work on that domain	In my entity there is nobody working on that activity	Our work is not dedicated to that application domain
1	We have some minor experience on that domain	Less than 5% of my personnel is dedicated to that activity	Sometimes we work for that type of applications
2	We have less than 5 years of experience or a discontinuous one on the domain	More than 5% of my personnel is dedicated to that activity	It is one of our main application domains
3	We have more than 5 years of experience and currently we maintain it		

Table 2: Metrics for taxonomy response measurements

In the case of marking a value 3 in a Research & Technology domain or a value 2 in Solutions for Society, a short comment justifying it was requested (name of main projects, activities or capacities linked with that particular domain).

The figures 10 to 15 are self-explanatory classgrams giving an idea of the possible results that may be obtained using a common metrics. In order to normalise the data in the first branch where we have four possible values, we have defined ponderations of the 1,2,3 values giving a weight of 5 to the value 1, 25 to the value 2 and 100 to the value 3.

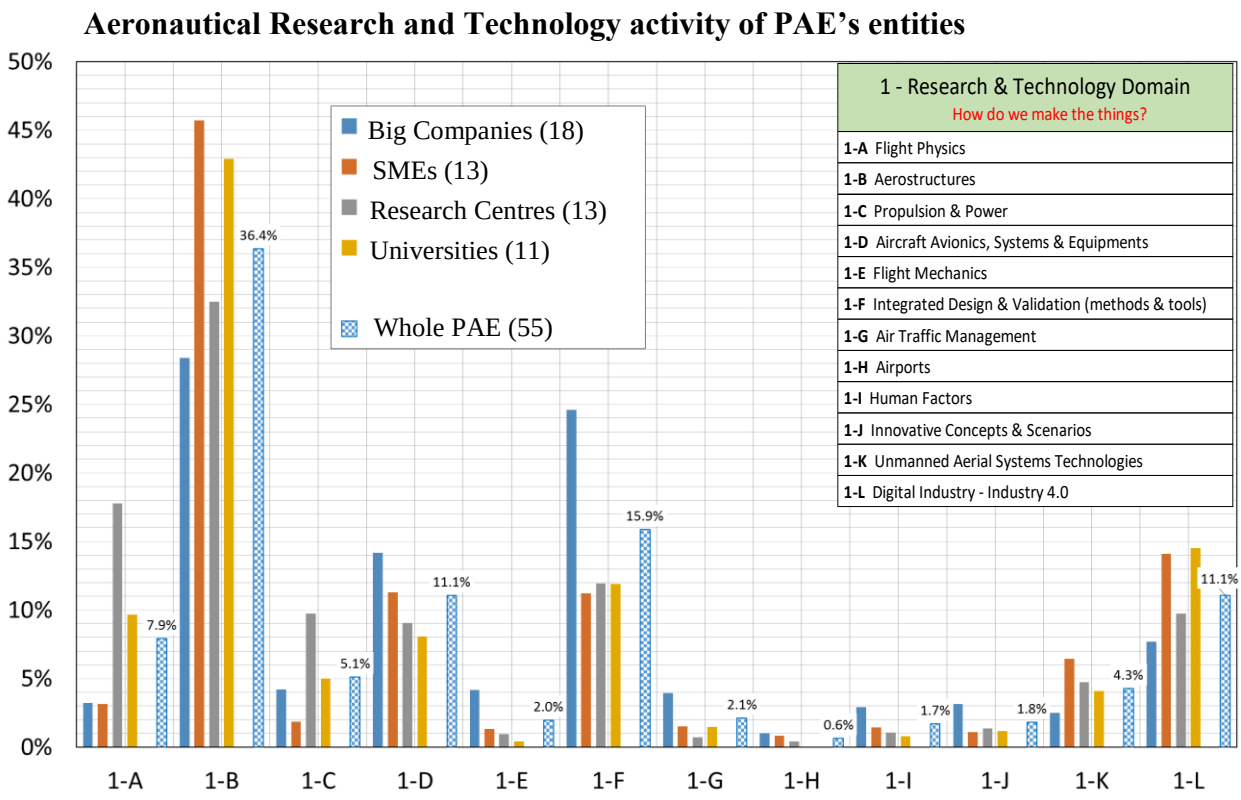

Figure 10: Classgram summarising aeronautical activity of PAE entities

We may see, for instance, that the main expertise of the whole PAE is in Aerostructures, especially for SMEs and universities, but many other visual feed-backs may be obtained.

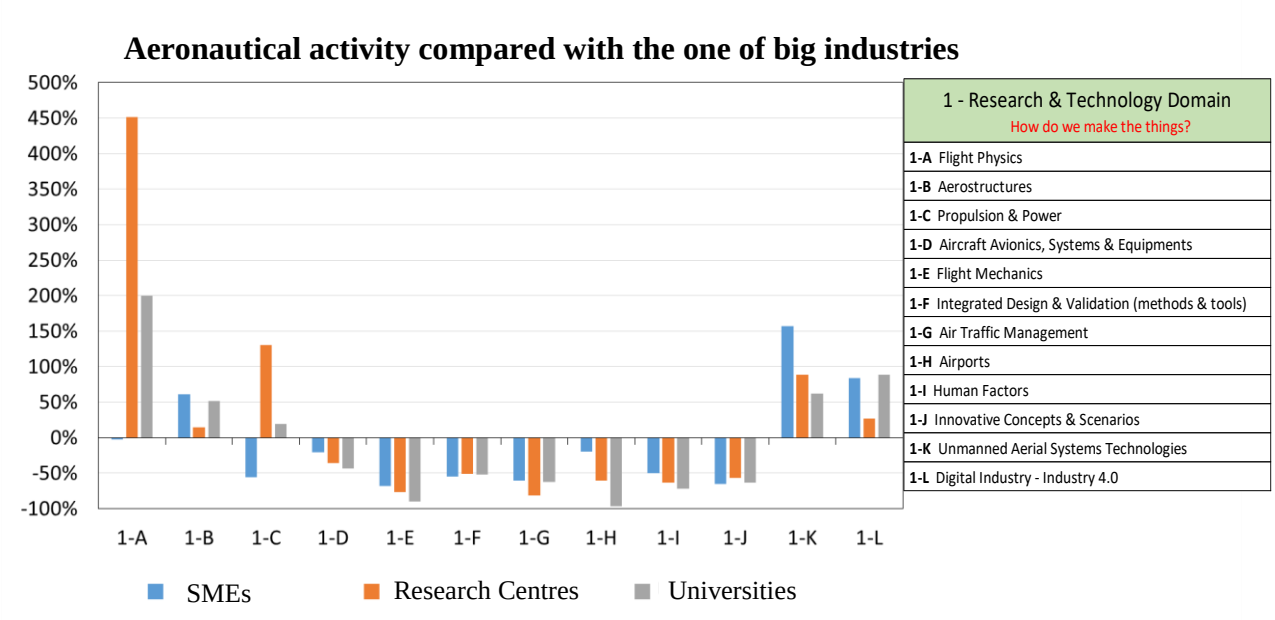

Figure 11: Differential classgram comparing the activity of other entities with the one of big industries

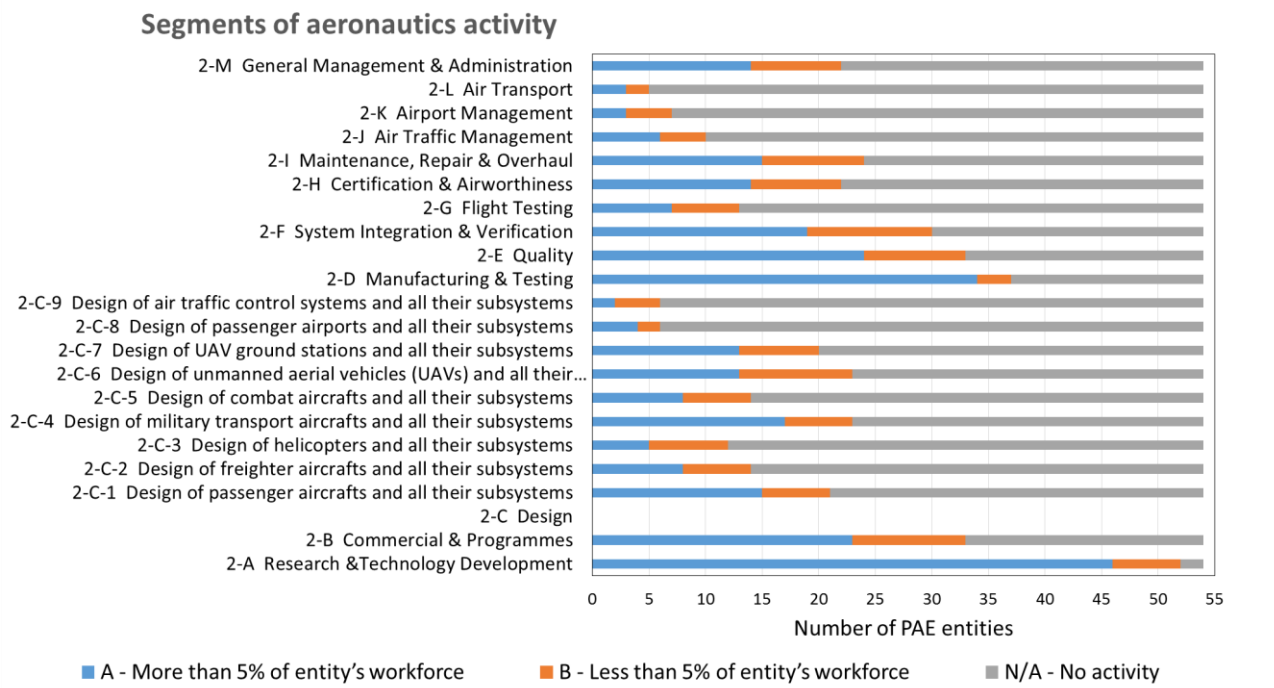

Figure 12: Overview of the distribution of personnel in the different activities

It is interesting to see that, being the PAE a forum about research, most of the entities present into it dedicate an important part of their personnel to research and technology activities. The different types of design activities are also clearly visualised in this figure.

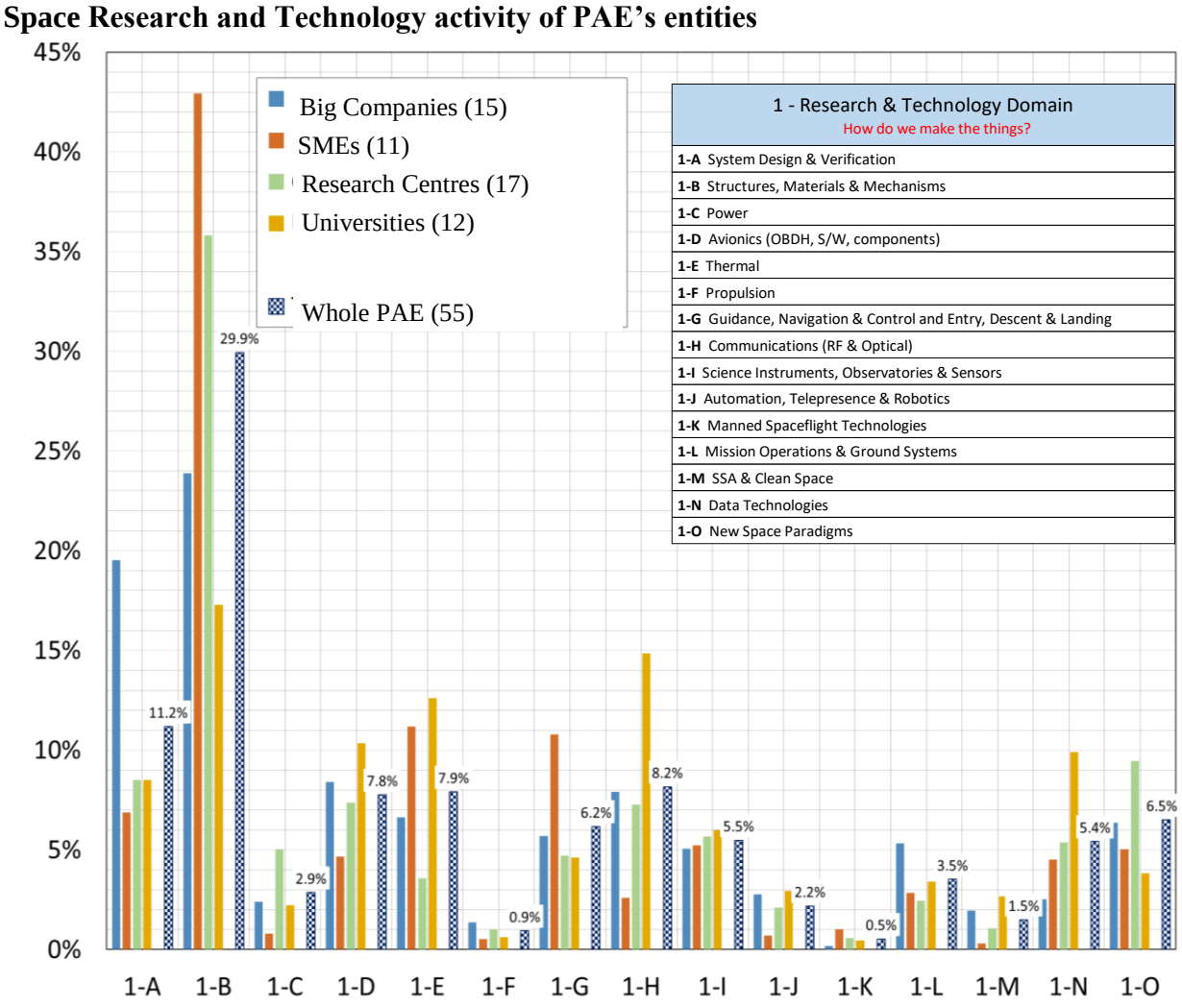

Figure 13: Classgram summarising space activity of PAE entities

We may see, for instance, that the main expertise of the whole PAE is in Structures, Materials and Mechanisms, especially for SMEs and research centres, but we see also that the big companies have more experience in System Design & Verification or there are important experiences in the universities in RF and Optical Communications, Thermal and Data Technologies.

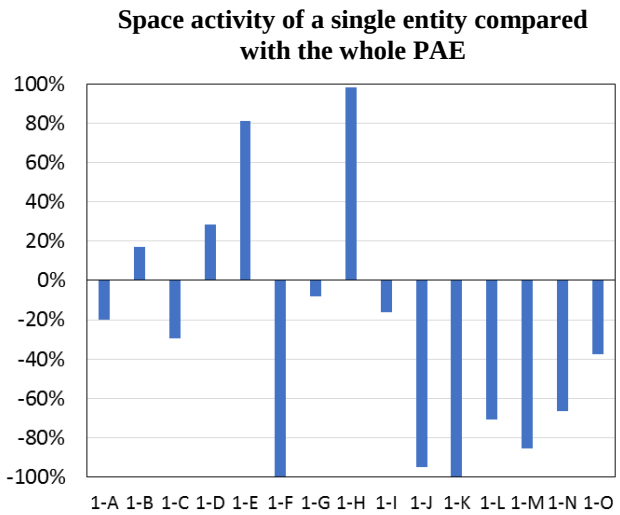

Figure 14: Differential classgram comparing the space activity of a single entity with the whole PAE

Differential classgrams are a very useful tool for each individual entity: they may compare themselves with the rest of the similar or dissimilar ones. For instance, a SME may compare with all the SMEs or with the big companies or a university may compare with big companies and know, in any case, if their self-classification was good enough and what are the areas of improvement for them in comparison with other similar entities or to better follow the experience accumulated by the big companies.

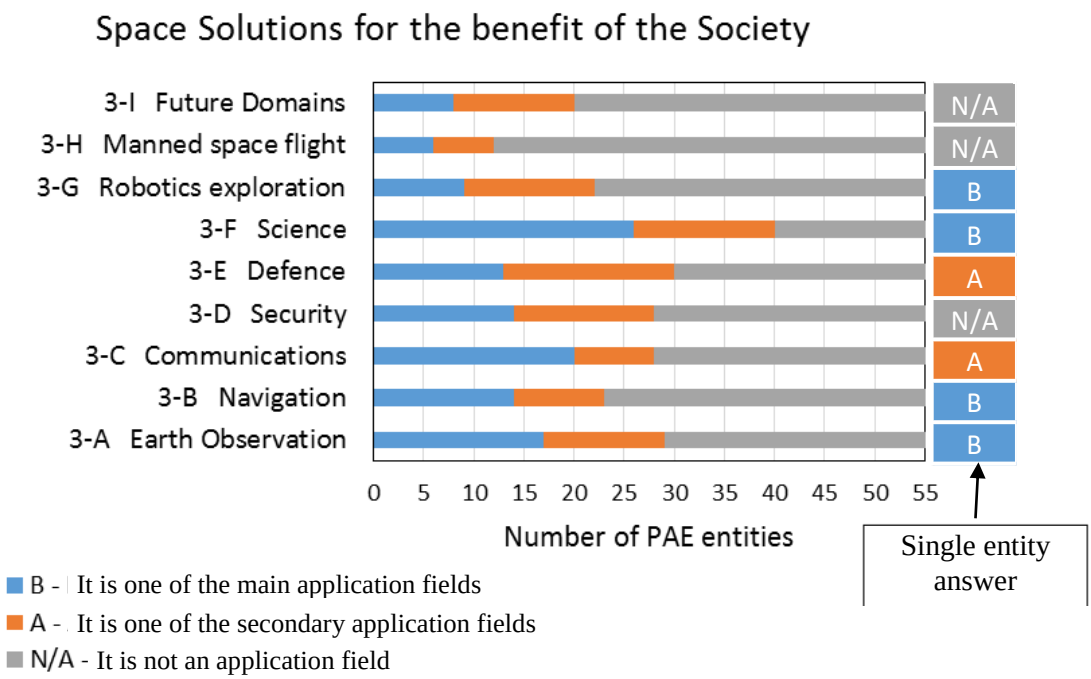

Figure 15: Main application fields of PAE entities compared with a single one

In this classgram we may see that the main application field of all the PAE's entities is Science (in terms of number of them recognising that they have an important activity) followed by Earth Observation, Communications, Security and Defence. And Manned Space Flight is a field with few entities working on it.

5. Further work to be performed

The process of building the final configuration of the Space and Aeronautics taxonomies and the categorization of the PAE entities has taken a year, both to develop and settle the two taxonomies, and to disseminate a new culture of information management in our aerospace community. During this period the taxonomies were 'tested' with a relevant group of experts in the PAE entities and very few modifications were suggested. From now on, the steps to be taken will be simpler and shorter, because the entities of the PAE begin to have assimilated the taxonomies and what they suppose.

After presenting this contribution within the 8th EUCASS framework, with the graphical results of the analysis of the information based on the taxonomies, we are in the position to start a second round with PAE entities to offer them to "rethink" their preliminary self-classification. A view of the global panorama and the 'aggregate positioning' of the set of homologues will invite natural reflection. It also opens a deadline for data to be sent by entities that have not yet participated. That is an important step to take the 2019 photography of the Spanish Aerospace Sector scenario, as perceived by the own Community through the common metrics of the PAE taxonomies.

Sharing a "common language" will contribute to harness the global goals and views for the sector, to advance in the construction of the Strategic Aeronautics and Space Research Agendas. The power of establishing a common metric to classify information will benefit the whole sector. As well the Catalogue of Capacities of Aerospace Infrastructures will be more easily prepared.

The potential of taxonomies must be accompanied by a joint IT capacity. A web portal for the PAE will take into account user requirements to classify and extract information, and facilitate the use of visual analytics techniques. The

proposal of the authors is to join efforts within PAE entities to develop IT tools that facilitate the tasks of self-classification of information, as those based on taxonomy assisted machine learning techniques. The mid-term objective is to create a dynamic repository of classified information according to PAE taxonomies, something that will demonstrate real added value to PAE entities. Each one will be able to observe its own information in contrast to that of the sector, and will help it to improve its vision and to advance in its planning and strategy.

The presented results constitute a first overview of the Aeronautical and Space sectors at the Spanish level and will be a vehicle to design global indicators to create effective and direct messages, intended both for Public Administrations and Society.

The escalation of this model to the European scene has to be addressed in the short term. The first step would be to have an approach to the public information of European projects, with the target of classifying it with PAE taxonomies. The resulting repository will be a competitive advantage to the PAE entities, useful to assimilate the European state of play with respect to public is being financed, and a tool to identify relevant partners, research subjects and future opportunities.

The second step will be to export the PAE model to Europe. That will be done with contacts with the European organizations as CleanSky, GSA and ESA, all of them within the framework of National and EU RTD Programmes. The target is to advocate for the European adoption of both taxonomies as a future standard, after the necessary discussions and evolution. The usefulness of using taxonomies for corporate intelligence in the aeronautical and space sectors will be demonstrated through proof of concepts and pilot cases. In addition, it will be proposed to create the appropriate European forums for the revision, transformation and maintenance of the Aeronautics and Space taxonomies. The implementation of a pan-European system available to the EU sector to catalog the technical, commercial and organizational information, will be much appreciated by the stakeholders and future users. It is expected that they can make a great profit with a global information management system and to advance in the culture of using taxonomies to classify, extract, visualize and analyse information.

6. Conclusions

The construction and first use of PAE Aeronautics and Space taxonomies have been reported. These taxonomies helps to organize information into hierarchical relationships and provide a conceptual framework for discussion, information retrieval and analysis of the information of the Spanish Aerospace Sector.

A first proof-of-concept of how taxonomies are used for the corporate intelligence of PAE has been presented. A common language has been established to define our Strategic Aerospace Research Agenda and the future Catalogue of Capacities and Infrastructures of the sector.

Thanks to the taxonomies we are able to classify both technical, commercial, organizational information of each of the entities of the PAE, as well as the information outside the PAE. Creating a repository of classified information according to taxonomies will allow us to have the same metric to analyze, draw conclusions and facilitate decision making. It will serve us to evaluate if we have the adequate capacities to investigate in the lines that we identify as priority.

The contribution to establish an overall vision of the aeronautical sector and the space sector at the national level has been achieved. This will facilitate the generation of global indicators to create effective and direct messages for both public administrations and society. In the medium term, the use of taxonomies will allow us to put both sectors, in a measured and objective way, in their corresponding European context.

7. Acknowledgements

The development of the PAE's taxonomies was completed by a team of 27 persons from 18 entities (industries, research centres and universities) and the surveys of self-classification were answered by a total number of:

- 23 big industries, 19 SMEs, 18 research centres and 15 universities for the AERO taxonomy
- 22 big industries, 19 SMEs, 18 research centres and 14 universities for the SPACE taxonomy.

The authors want to acknowledge the contribution of all those entities to the work presented into the present paper, as well as to the work performed by a team of people in INTA during the last decade laying the foundations of the use of taxonomies and the associated visual tools applied to corporate intelligence.

References

[1] See definition for example at KPMG, PWC and at INTA webpage
[2] "From information to 'pre-cognitive metadata'. A new gate to Visual Analytics". H. Guerrero, S. Martín-Barbero, F.J. Trueba.
[3] NLR-CR-2002-688 "ACARE Taxonomy: A Common European taxonomy for aeronautical research & technology"
[4] ESA Technology Tree STM-277 Version 3.0 October 2013
[5] NASA Technology Roadmaps, May 2015 Draft
[6] "Technology Roadmap of SMART", the Eureka Advanced Manufacturing Program, draft 2, published in January 13th, 2017
[7] "From Aristotle to Linnaeus: History of Taxonomy" Lois Tilton (2009): https://davesgarden.com/guides/articles/view/2051
[8] Summary of AERO taxonomy: https://plataforma-aeroespacial.es/wp-content/uploads/2017/10/PAE-ATX-REP-01_03.pdf
[9] Detailed description of AERO taxonomy: https://plataforma-aeroespacial.es/wp-content/uploads/2017/10/PAE-ATX-ANX-01_03.pdf
[10] Summary of SPACE taxonomy: https://plataforma-aeroespacial.es/wp-content/uploads/2017/10/PAE-STX-REP-01_03.pdf
[11] Detailed description of SPACE taxonomy: https://plataforma-aeroespacial.es/wp-content/uploads/2017/10/PAE-STX-ANX-01_03.pdf