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COMPETITIONS, GAMES AND PRIZES - MEANS FOR ADVANCED SPACE RESEARCH?

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Abstract

The traditional main mechanisms to advance science and technology in the space sector have recently been complemented by the use of competitions, prizes and games. Historically competitions and ex-ante prizes have played an important role among the tools of governments to stimulate innovation and advance science and technologies. Triggered by the success of the Ansari X-Prize in late 1990s / early 2000, these mechanisms have steadily gained grounds and supporters, also among governments. Scholarly literature on the effectiveness, advantages and disadvantages of these methods is emerging but still scarce. Most of the available scholarly literature assesses their impact based on US case studies and examples. The present paper provides a first analysis of these mechanisms and tools within the European Space Agency (ESA), based on three different areas: scientific research within its Advanced Concepts Team, business and innovation oriented competitions and prizes within the technology transfer programme and system level studies within the General Studies Programme.

The ESA Advanced Concepts Team has experimented and used new ways of engaging with the larger scientific community via the use of scientific competitions, online games and scientific crowdsourcing experiments. The Technology Transfer programme uses challenges and prizes to engage with students, for businesses and entrepreneurs and to showcase successes and opportunities. Within the General Studies Programme, challenges and competitions are used to trigger early assessments of innovative systems and compare system-level solutions.

The present papers presents an overview and analysis of these different methods, including results obtained by using these tools during the past 8 years.

Keywords: Competitions, prizes, games, crowdsourcing, research, innovation

1. INTRODUCTION

The present paper presents an overview of the use of prizes, competitions and games by the European Space Agency and in particular by three distinct activity areas: advanced concepts, technology transfer and general studies. It first outlines the main properties of these tools, together with a short overview of their use and a brief analysis of the scholarly literature on the subject. Sections 2, 2.4 and 3.5 describe and assess how these tools are used in the frame of its Advanced Concepts Team, its Technology Transfer Office and the General Studies Programme respectively.

1.1. Competition and Prizes

With the turn of the century, two relatively new phenomena regarding prizes have emerged in the scientific and technical field: high-velue science prizes and inducement prizes/technical grand challenges.

On the one hand, a number of new, high-value science prizes have joined the traditional high-prestige reward prizes such as the Nobel Prize, the Fields medals, the Abel prize and the Lasker awards: the most valuable ones are the Fundamental Physics Prize (introduced in 2012) and the Breakthrough Prize in Life Sciences (introduced in 2013), both awarding $3M, followed by the 2013 introduced asian Tang Prize and the Queen Elizabeth Prize for Engineering. Most of these have been initiated and sponsored by wealthy individuals. The relatively large sums involved and the motivations for these prizes have already started changing the scientific reward prize landscape and raised a number of questions on their impact and effectiveness.[1] One of the criticism relates to the post-achievement nature of such award prizes, raising the question whether such high prizes would not be more effective if they were used to drive research directly.

This point is addressed by the second recent phenomenon regarding prizes: the renaissance of incentive or inducement prizes. These have played only minor roles during the second half of the 20th century but got strong attraction since the turn of the century, following the highly publicised success of the Ansari X-Prize. The present paper deals with the opportunities of such inducement prizes and their use within the context of the European Space Agency.

Research grants, the traditional mean of governments to fund research during the second half of the 20th century, have also

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added an almost prize-like form at their upper extremes in Europe. As an example, the European Commission has initiated a "Future and Emerging Technologies 'flagship' competition", for which the winners were announced in January 2013. The winning teams were competing for an unusually large research grant fund for proposed research work. Each of the two winning proposals received €500M, which according to the European Commission will "help to improve the lives, health and prosperity of millions of Europeans".[2] These are reported as being among the biggest awards ever made for research. The two winning proposals are the *Human Brain Project*, a supercomputer simulation of the human brain and the *Graphene* project, aiming to "take graphene and related layered materials from academic laboratories to society, revolutionise multiple industries and create economic growth and new jobs in Europe."[3]

1.1.1. Terms

The scholarly literature tends to differentiate between different types of prizes. Davis and Davis distinguishes between on the one hand *ex ante* R&D prizes and related incentive systems like patent buy-outs and secondly, and rewards based on *ex post* data.[4] They then differentiate between three types of *ex ante* prize systems: 1) intra-firm incentives, 2) pre-bidding signalling devices in procurement and other contracting systems, and 3) *ex ante* "grand prizes" to stimulate R&D.

The third category is by far the least studied. In such grand prizes, "the sponsor of the prize defines a problem to be solved, a reward for solving it, and the terms of the contest. The sponsor evaluates the different entries and determines the winner. The reward is often a large cash payment, but it may also consist of credible commitments by future buyers to purchase a given quantity of a product that satisfies specified criteria."[4] Authors refer to such *ex ante* grand prizes also as "inducement prizes" or "grand challenges".

1.1.2. History of competitions and prizes in spurring scientific and technical innovation

Prizes and the associated competitions for them have been one of the main mechanisms to trigger the advancement of technological progress until the 18th century.[5] They were used to trigger research on important challenges of the time. It is reported that more than twice as many 18th-century scientific societies paid for results using prizes or medals than paid for effort with grants.[1].

Records for some of these prizes date back to the 16th century though most reported inducement prizes are from the 18th and 19th centuries. These span practically all disciplines, from agriculture and food, to construction, architecture, medicine, flight, mathematics and navigation to arts, social improvements and governance related topics.[7]

One of the best know historic examples of *ex ante* grand prizes is the £20,000 Longitude Prize sponsored by the British Government for anyone who could devise a way for a ship's navigator to determine its longitude and therefore its position at sea.[8] The most important prize winner was John Harrison, in 1773, revolutionising maritime navigation and thus trade. The british longitude prize was preceded by two unclaimed spanish and dutch longitude prizes two centuries earlier. Similar prizes were used also by other European governments. The French government under Napoleon offered an award of 12,000 French francs via the Society for the Encouragement of Industry for an effective method of preserving large amounts of food, which was won in 1809 by Nicolas Franois Appert. His method to sterilise and preserve food by heat and subsequent air-tight sealing (originally in Champaign bottles) directly led to food cans.

In the 20th century, prizes plaid an important role in spurring innovation and progress in the nascent aviation sector. Well known prizes include the 1900 Deutsch de la Meurthe prize of 100,000 French francs to the first machine capable of flying a round trip from the Parc Saint Cloud to the Eiffel Tower in Paris and back in less than thirty minutes, the £1000 prize from the British Daily Mail newspaper for the first flight across the English Channel (won by Louis Bleriot in July 1909) following by a number of similar prizes leading to the first transatlantic flight in 1919 and the first solo flight from England to Australia in 1930. The best known aviation prize however was the $25,000 Orteig Prize for the first nonstop flight between New York and Paris offered in 1919 and won May 1927 by Charles Lindbergh.

Following the second world war, advances in science and technology were mainly made via regular mainly governmental science funding and research grants. Murray et al. list some potential explanations for this shift, including rising costs of innovation (it would be too difficult to raise the required research funds in advance of a potential later awards) and the "*difficulty in designing prizes which credibly commit to rewarding qualified winners however unexpected the design or the innovator*".

The most famous recent innovation prize is most likely the 1996 $10M Ansari X-Prize, promoting private space flight. The prize was won in 2004, after the two successful flights of SpaceShipOne.

The subsequent renaissance in the use of prizes has been further promoted in 2010 by the US government, which uses challenges and prizes to promote open government.[10]

The rapid increase of the use of prizes by governments, organisations and corporations seems to have been based mainly on the recognition of reported successes, results and lessons learned while the scholarly literature has been rather sparse on the topic until recently. The most thorough recent analysis reported was in form of a 2011 PhD thesis defended by Luciano Ray on "How do prizes induce innovation? Learning from the Google Lunar X Prize" and related follow-up publications such as his 2013 book on the same topic.[11]

The sections of this paper relevant to competitions, challenges and prizes draw from the analysis of Kay. Murray et al. have published in 2012 the first scholarly work dedicated to the systematic examination of the use of what they call a "Grand Innovation Prize" to address the lack of economic theory on the properties of innovation prizes, or how prizes operate in comparison to other incentive mechanisms. By analysing in detail from various angles a specific X-Prize challenge, Murray et al.

[1] Robin Hanson, an economist at George Mason University, cited in [6]

attempt to address the lack of empirical studies of contemporary grand innovation prizes.[9]

1.1.3. Motivation for competition organisers and sponsors

Scholars have reported a number of reasons for the use of prizes by organisations to induce research and development effort from individuals or organisations. These include

- to encourage basic research; [5, 6]
- to spur the initial development of an industry;[9]
- to focus innovative efforts on problems for which solutions otherwise do not seem to be forthcoming; [4]
- to open and increase the traditional communities dealing with certain challenges; [11]
- to provide a transparent, equal and fair comparison different solutions; [11]
- to reduce the risk of public research investments by paying only in case of successful results; [9, 11]
- to increase the effectiveness of research funds by counting on multiple times the prize money made as investments by competitors; [9]
- to obtain intellectual property rights; [9]
- to identify brightest researchers and problem solvers in certain areas;
- to reduce the administrative effort and bureaucratic burden; [11]
- to take advantage of governmental budget spending rules, since prize money is reserved for several years and does not need to be re-approved every year in some countries;
- to raise public attention; [11]
- to identify problems requiring solutions that go beyond the need of the organising organisation and thus promise having other customers for resulting products, which could increase the reliability of future supply situations;

1.1.4. Competitions and open innovation

Given the importance of innovation for economic growth, governments no longer only stimulate research and development to solve specific problems and address challenges. The impact on economic growth has become an increasingly important driver for governmental R&D spending. The associated governmental tools to encouraging innovation and protecting innovators are centred around patents and intellectual property in general. Inventors are granted via a patent a time-limited monopoly. This is specifically true for innovations with a potential commercial application. Basic research is funded mainly by grants, with peer-reviewed publications serving both as intellectual property tool and quality measurement.

Harford speculates that prizes could eventually replace patents as main tool for governments to stimulate innovation. Governments could offer prizes for innovations, thus immediate monetary rewards to these and at the same time free the innovation to be used by everybody, thus increasing the speed of innovation diffusion and the associated benefits. The difficulty of fixing appropriate prize levels *ex ante* as reported by Harford seems only problematic when compared with the current patent system, which links the value of a patent solely to its market success in exploiting its monopoly use. The determination of the amount of *ex ante* prizes however would also take into account the effort in achieving the innovation and its potential societal benefits.

1.1.5. Space sector agencies pioneering use of prizes in the US context

Possibly due to the closeness to the aeronautic sector and inspired by the role of prizes in the early development of airplanes, the space sector has been among first and the most active adopter of prizes since the late 1990s. These prizes started essentially in 1995 wit the "Ansari X-Prize", the 1997 "Budweiser Cup", the 1997 "Cheap Access to Space Prize", the 2004 "America's Space Prize" and in the same year the launch of the NASA "Centennial Challenges". These included challenges such as a "Regolith Excavation Challenge", a "Green-Flight challenge", a "strong tether challenge", a "power beaming challenge", a "lunar lander challenge", an a"stronaut glove challenge", a "sample return robot challenge", a "robot night challenge" and the "UAS Airspace Operations Challenge". In addition to the government, private entities issued also high-profile challenges such as the "Google Lunar X-Prize".

While NASA is among the most prolific US agencies using inducement prizes and challenges, DARPA is organising some of the biggest science and technology challenges in the US. The DARPA challenges show that in principle, relatively large amounts of money could be granted via prizes (up to \$50M), though most prizes are well below the \$10M limit.

Europe, and especially ESA has been using inducement prizes in a similar manner. These have not yet been reported and described systematically. The scholarly literature has therefore also not taken these and their results into account.

1.1.6. Key aspects of successful competitions

Given the increasing interest in competition and prizes as tools for innovation, the scholarly literature has reported a number of key characteristics for competitions to be successful. For a more thorough review of these and how they apply to the different types of competitions, the reader is referred to the dedicated scientific literature on the topic such as

For the purpose of the present analysis, these can be summarised to these general characteristics

- suitable incentives
- clear rules (for determining winners in an non-ambiguous way)
- suitable topics and problem framing

Table 1: Summary comparison of prizes and grants/monopolies as tools for innovation

Prizes	**Grants and Patents**
Advantages	Advantages
reach a wider community of problem solvers	more steady innovation financing
attract new actors & unconventional approaches	better control over the process and progress
stimulate decision-making and entrepreneurship	better suitable for large research communities
low administrative overhead	directly linked to market value
also for goods/goals not suitable for markets	prospect of monopolies generates large resources for R&D
faster sharing and distribution of innovation	opportunities for innovations indep. of governments
Disadvantages	Disadvantages
difficult to pre-specify useful outcomes from research	weaker link to simply formulated (societal) needs
non-sustainable support of S&T advancements	closer community
less suitable for gradual technology maturation	innovation stifling by monopolies

- clear timeframes / deadlines
- publicity

Suitable incentives can be not just a cash prizes, but also publicity, prestige or contract opportunities. Deadline tend to help attracting informally organised teams, to help assembling resources and motivate people. The choice of the topic is probably the most difficult one.

1.2. Criteria for competition subjects and topics

The scholarly debate on the type of problems and topics that are suitable for competitions and prizes is still open. Similarly, there are no clear cut criteria to decide when a traditional grant scheme is preferable to competitions and prizes as tools for achieving certain goals. Additionally, while the use of grants and patents is well established as a tool for industrial policy, the opportunities and drawbacks of competitions and prizes for industrial policy are poorly understood.

Some reported general criteria for topics for what is sometimes called "grand challenges" include:

- open to many possible solutions
- uncertainty on best option / solution
- room for lateral thinking
- accessibility to a larger community of potential problem solvers
- followup commercial interest

For the purpose of this paper, space missions can be described as large, complex problems, which are subdivided into many layers of sub and sub-subsystems and thus sub-problems. These are individually developed, often with substantial uncertainties on the actual path to follow at beginning of a mission. Especially for science and exploration missions, the development of these subsystems tends to include significant research and development activities. The interdependencies of these subsystems are dealt with via interface requirement documents.

The approach to research and development for each of the subsystems needs to be success oriented and thus by consequence tends to follow a conservative approach that is most likely to succeed, innovating only where necessary for mission success. The natural way to increase the level of innovation in such missions is to make them more ambitious, thus forcing engineers to consider novel approaches. This however also naturally increases overall mission risk levels, and tends to contribute to budget and schedule overruns. Could prizes provide an alternative option to include novel solutions into regular spacecraft designs without jeopardising overall risk levels, schedules and budgets? Could space projects describe subsystem problems for which a solution is planned for via R&D in a manner that would include the interface requirements, the required time schedule, the subsystem objectives and an associated prize, and attract a larger, typically engineering/science community to put forward novel solutions?

A pathway to implement such an approach would be via a platform to call for solution to space problems. Such "problems" could come from within ESA or from industry, in which case the prize for the solution might be born by industry or co-funded by ESA (e.g. if related to specific technical R&D problems faced by industrial companies/research centres/universities in the execution of ESA contracts). ESA could use existing commercial platforms or create, together with space industry a dedicated space platform. Initially, such problems would be those that are not on a critical path, solutions that would be "nice to have", problems for which no known solution exists and which are therefore not addressed via regular technology development programmes and problems for which solutions exist but where there is a potential for improvement.

1.2.1. Organisation of competitions

Different organisations have adopted different organisational approaches to competitions. Most competitions have no intermediate decision points at which contestants are down-selected.

For some of the more complex and demanding competitions, such an approach has been tried. It substantially adds overhead costs but by organising a two stage selection process, in which the most promising competitors are selected in the first round and then given some additional funding in order to compete in the second round, the process becomes more structured and higher success-oriented. The US DARPA has organised some of its challenges in this way. (e.g. the Urban and Robotics Challenges.)

1.3. Games

Contrary to the use of competitions, challenges and prizes in the pursuit of innovation and advancing scientific research, which has recently received some attention in the scholarly literature especially following the work of Kay, only very few scholarly articles explore the use of games for advancing scientific research.[11]

Good and Su proposed in 2011 an analysis of "games with a purpose".[12] Scientific games tend to be associated with the concept of scientific crowdsourcing. Scientific crowdsourcing has been enabled by the widespread use of connected computing devices. It taps into the cognitive labour of a large number of individuals, usually considered as interested lay-persons in the respective field. In most cases, large complex problems are divided into relatively small, possibly easy but time-consuming tasks, which can be performed with little or almost no training. These are then distributed to a large number of volunteers.[12]

Examples range from folding proteins to classifying astronomical images and annotating genome sequences. Harness the voluntary contributions of many volunteers usually outside of the traditional scientific communities.

The most critical challenge for many of these scientific crowdsourcing efforts is to attract the required large number of individual volunteers.

The motivations for individuals to voluntarily contribute to crowdsourcing initiatives have been widely debated, but they range from altruism, to ego, to a shared sense of purpose. One emerging trend expands that list of motivations to include the pursuit of fun and enjoyment through games. Khatib et al. have described several success stories behind Foldit, a game for protein folding.[13] Among these successes, the most recent and perhaps the most groundbreaking was the development of a novel algorithm for protein folding by game players.[13]

While scholarly work on the topic is still lacking, it seems clear from the reported evidence that purposefully designed games can help advance scientific progress.[12, 13]

2. COMPETITIONS AND GAMES USED FOR ADVANCED RESEARCH

The Advanced Concepts Team (ACT) of the European Space Agency (ESA) was created in 2002 with the mission to "*monitor, perform and foster research on advanced space systems, innovative concepts and working methods*". [14–16] As part of its task, the team delivers to ESA rigorous and rapid assessments of advanced concepts not necessarily yet linked to space. It furthermore performs research on, explores and experiments with new working methods. These include also competitions, prizes and games. The ACT operates at an average annual funding of about €1M, provided entirely by the ESA General Studies Programme. [17] This figure includes its internal costs plus overheads (e.g. in form of salaries for its researchers) as well as external research grants. [15]

Its main contractual mechanism for collaborative research with universities is the *Ariadna* scheme, a mechanism for collaborative research between ACT and university researchers, with three distinct funding levels from small €15k exploratory studies to €35k extended studies. Beside this scheme, other means for collaborative research have emerged and gained importance over time.

2.1. TheSpaceGame - Intuitive design of optimal trajectories

"The Space Game" is a browser based game and a crowdsourcing experiment developed by the Advanced Concepts Team with the goal to improve the methods for designing interplanetary trajectories.[18] During the 2011 "Space Week" it was the most visited listed 'event'. In one only week more than 3000 users created their account, played the game and submitted at least one valid solution. All solutions are visualised in real time on the website and explained with additional information.

In the game, the player is confronted with the task of finding optimal planetary phasing allowing low ΔV transfers between solar system planets as computed using a multiple gravity assist model.[19] While such a trajectory model is rather simple and, in fact, only suitable for preliminary mission design (early phase 1) it contains many of the basic building blocks of more complex trajectories: a fly-by propagator, a multi revolution Lambert solver and a complex planetary encounter sequence. It is interesting to see how the best trajectory returned during the space week (visualised in Figure 1) exploits multiple revolutions in the Lambert's problem to achieve its very low ΔV. The collected data allows to extract information on the process players adopt to find good trajectories, a process based essentially on intuition.

The game was also later selected as one of the Google Chromium Experiments, a showcase of emerging and innovative uses of the html5 technology for browser based applications. Along the same lines and inspired by the 6th edition of the Global Trajectory Competition, a new game called "Space Hopper" is being developed aiming at demonstrating that humans can, without any prior knowledge of astrodynamics, plan their own optimal tour of the Jupiter moons performing better than established tree search algorithms.[20]

2.2. Global Trajectory Optimisation Competition

The Global Trajectory Optimisation Competition is an event taking place every one to two years over roughly one month during which the best aerospace engineers and mathematicians world wide challenge themselves to solve a "nearly-impossible" problem of interplanetary trajectory design. The problem and the rules for determining the winner and ranking of solutions of the subsequent competition are determined by the winning team of the previous edition.

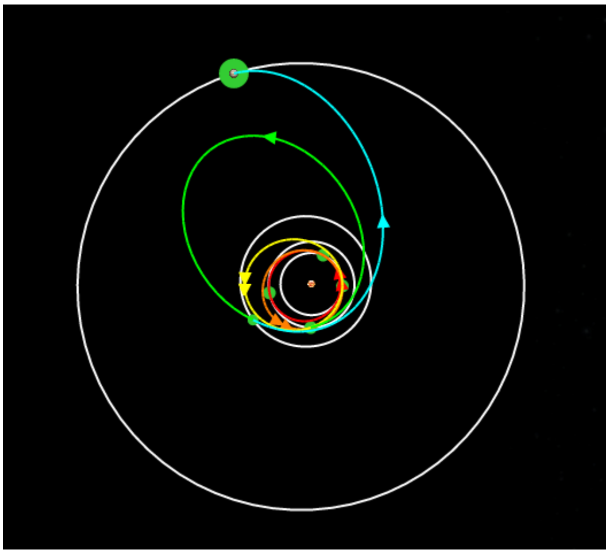

Figure 1: Best trajectory returned during the Space Week by the user Giovanni Ruggeri as visualised by the game web interface. Note the double arrows in two of the trajectory legs indicating the use of multiple revolutions.

The problem needs to be related to interplanetary trajectory design, its complexity needs to be high enough to have no obvious and fast solution and the rules for ranking and winning need to be mathematically clear and unambiguous (typically an objective function to be optimised). Over the years, the various problem statements and solutions, collected in several websites and publications, are building a formidable database of experiences, solutions and challenges for the scientific community.

The competition, as reported in its dedicated web portal, attracted, in its first six editions, teams from roughly one hundred different international institutions including space agencies (NASA, ESA, JAXA, DLR, CNES), academic institution in Europe, China and the US and advanced research teams located in the aerospace industry.[21] Participants tend to be driven by the opportunity to compare own approaches and solutions to others in a structured way, by the open, objective "peer-evaluation" of solutions, by scientific pride, by the need for peer-recognition and the simple joy of competing in solving very difficult problems.

More than 30 publications describe the approaches of various team to the design problems posed over the years.[21] They can be classified as local or global, automated or human-based, direct or indirect. The scientific discussion over what approach works best is far reaching and has been at the heart of the workshop organised after each edition. Overall the competition is now also recognised as an occasion for a team-building, for improving the in-house tools and knowledge in a concentrated one-month period.

The 7th GTOC will be organised by a joint team from University Sapienza of Rome and Turin Polytechnic (the winners of the 6th edition) during one month in early 2014.[21]

2.3. AstroDrone - A scientific robotic crowdsourcing app

The AstroDrone game is the first scientific crowd sourcing project of the ACT that also involves actual robots. Its main scientific goal is to teach robots to use visual cues from still images for fast distance estimations. The second goal of the experiment is to discover relationships between the feature descriptors and their sizes / distances via various machine learning techniques.

The entire project consists of four distinct elements:

1. a hardware platform
2. a smart-phone application (app)
3. a game
4. a background scientific experiment

In order to test the hypothesis and to train algorithms to learn the distances to objects by 'just' looking at their appearance in a still image with a simple camera, it was necessary to get a large number of various, real-live data. These data needs to contain many different types of objects which can be classified and reliable information of the distance between the camera and the object(s) in the field of view. One of the most widely sold flying gadgets, the *Parrot AR* drone, a quadro-copter, allows to access the video images of the on-board cameras and the state information of the quadro-copter including especially acceleration. The processors of modern smart phones allow the running of the algorithms to extract abstract mathematical features from the images.[22, 23]

Putting these three elements together allowed conceiving a method to use the quadro-copter to get the right type of raw data and implement the algorithms in an application directly on the smartphone. The missing element, the generation of large amounts of data is addressed by taking advantage of the attractiveness of games and space missions. Players are presented with a virtual reality challenge to dock to one of the docking ports of the International Space Station which is dynamically shown on the screen of the smartphone while actually flying their real-world quadro-copter towards a marker and getting different points for the time and smoothness of the docking approach. These processed features can neither be interpreted by humans, nor can the original image be reconstructed. However, the features can be used by robots to learn how to navigate in their environment. Players are free to join the experiment by going to the high score table. If players agree, the feature data is transmitted over the internet to a central server.

The actual game part of the project is related to the interaction of a physical drone that is challenged to perform different space missions in an augmented reality setting. The first release contains the training level, in which players learn to dock as well as possible to the International Space Station. New levels will be added incrementally with new releases. An asteroid approach and landing level is currently in the final development phase.

The launch of the app has received a large media echo and resulted in 10 thousand downloads within months and a steady increase of scientific data.

2.4. Analysis of competition uses of the ACT

Compared to the different motivations listed in the scholarly literature on the reasons for organisations using competitions as

Figure 2: AstroDrone scientific robotic crowdsourcing game - users simulating "docking" to the ISS and contributing to robotic vision algorithm research.

listed in section 1.1.3, the ACT competitions would fall under these categories:

- to focus innovative efforts on problems for which solutions otherwise do not seem to be forthcoming;
- to open and increase the traditional communities dealing with certain challenges;
- to provide a transparent, equal and fair comparison different solutions;
- to identify brightest researchers and problem solvers in certain areas;
- to raise public attention.

3. COMPETITIONS, PRIZES AND GAMES IN THE SERVICE OF INNOVATION AND TECHNOLOGY TRANSFER (TTP)

The mission of ESA Technology Transfer Programme (TTP) Office is to inspire and facilitate the use of space technology, systems and know-how for non-space applications. With the goal of creating a full innovation support package, the TTPO team and its network of partners offers a variety of schemes for companies at any maturity stage throughout the innovation chain. At first, a network of technology brokers throughout ESA MS was established to act as a gateway for space companies to non-space sectors. As a second stage, a network of incubators was set up to host and provide assistance to entrepreneurs wishing to create a space spin-off.

Yet, over the years, the team has realised the need to reinforce its awareness activity through the promotion of success stories but also by fostering the birth of new ideas. Competitions are a suitable tool for this. This year will mark the tenth year anniversary since its first competition. Seven yearly competitions are now taking place, some of which have become of international standard.

3.1. Main goal of TTP competitions

The main goal of those competitions is to stimulate the use of space technology in every day life, as well as raising awareness to ESA and its activities, space technologies and space systems and know-how. Thinking outside the box, re-examining applications for patents, as well as challenging fresh young minds to critically think about space technology, are just part of the challenges posed throughout the competitions. While the developers of a technology have a unique understanding of the technology, it might be a challenge to come up with new applications outside their field of expertise.

Promoting entrepreneurship spirit and skills are at the core of these activities, and by supporting these, ESA invests in the future entrepreneurs, as well as increasing the European competitiveness.

Three competitions, all centred around best business plans, are specifically geared to students:

1. The Entrepreneurial Teams Seminars
2. The CEMS Seminar, and
3. The S2UN Challenge.

Three other events are challenging entrepreneurs around the world

1. The ESA App Developer Camp
2. European Satellite Navigation Competition, and
3. the Copernicus Masters.

Additionally, the "Space Spin-Off Award" prize is given to companies for the successful transfer of technology from the space sector to ground applications.

3.2. Student competitions

3.2.1. Entrepreneurial Teams Seminars

Every year, a one-day intensive Entrepreneurial Teams seminar is arranged together with TU Delft and Rotterdam School of Management. The students are being challenged to come up with a business case for a real space technology in only one day. Typically, technical students have very little time to team up with students coming from a completely different field: business and management. Forming mixed teams encourages the exchange of views and expertise, which results in innovative and collaborative results.

3.2.2. CEMS Seminar

This year, ESA hosted the ninth edition to the one-week CEMS seminar, which gives business students the chance to work with space technology and to discover its exploitation potential. CEMS is organised by ESA TTPO in cooperation with ESA Human Spaceflights Erasmus Centre as well as the Rotterdam School of Management Erasmus University (RSM), and the Community of European Management Schools (CEMS). The participating students are divided into competing teams, each working on the same space technology patent. They have to complete a feasible business plan and pitch their business at the end of the week to a jury. During the week, the students are given lectures on entrepreneurship, technology transfer, intellectual property and new venture creation.

The challenging aspect is that the teams are composed only of business students who have to face a lot of technical jargon, which most of the time they cannot make sense at first. They have to overcome their first apprehension and ask the relevant questions to the technical staff which is there to support them. In a week time, the teams are challenged to call potential customers to test their interest.

3.2.3. S2UN Challenge

The Space Solutions University Challenge is an initiative devised to give European students the opportunity to work with ESA in the pursuit for non-space applications based on the ESAs intellectual property portfolio. Aside of the similarity with the CEMS Seminar and the Entrepreneurial Days, the S2UN Challenge has a unique context and the time frame, in which the students are developing their business plans. The entrepreneurship class students have to develop a business plan, and, instead of working on a fictive case, TTPO offers the students a real space technology to use. The group that develops the most complete idea in each university is invited to travel to ESTEC in the Netherlands to present their work in front of a jury.[24]

3.3. Competitions For Entrepreneurs

The objective in the competitions for entrepreneurs is to stimulate new business creation in order to encourage European innovation and improve European competitiveness. The three competitions (The ESA App Developer Camp, the ESNC and the Copernicus Masters) have the clear objective to spread the awareness and use of satellite data in our everyday life and foster creation of start-up companies.

3.3.1. The ESA App Developer Camp

In its second year, the App Camp saw 20 developers from 16 countries convened at ESAs ESRIN centre in Frascati, Italy. The goal of this one-week event is to develop mobile applications (apps) using Earth-monitoring data on smartphones, building on the possibilities offered by Europe's Global Monitoring for Environment and Security (GMES) programme.

Divided into groups of four, each team has a week to create an app under the following categories: Crowd-sourcing in support of GMES, Games and Leisure, Land-monitoring using GIO Land, and Observe and Learn. The teams presented their apps to a panel of ESA judges who rank the projects based on innovation, relevance for GMES, attractiveness for intended users, stage of development and overall presentation.

In 2013, developers of the Thermal Guidance System app won the challenge. The group of aviation enthusiasts proposed the use of satellite data to detect areas of high thermal updraft, rising air currents that are responsible for keeping the planes and gliders aloft. The app provides maps of these areas and a 3D view to assist pilots of gliders and small motorised planes, as well as for flying unmanned aerial vehicles. Members of the winning team were each presented with an iPad3.

App Camp participants are encouraged to submit their apps to the Copernicus Masters' ESA App Challenge for the chance to win a €10,000 cash prize, and to have the idea further developed in one of the seven ESA Business Incubation Centres, valued at €60,000.

3.3.2. Copernicus Masters competition

The Copernicus Masters competition (previously known as the GMES Masters) rewards the best ideas for services, business cases and applications based on satellite Earth observation data. The competition was originally initiated by ESA, the Bavarian Ministry of Economic Affairs, the German Aerospace Centre (DLR), and T-Systems in 2011 with endorsement of the European Commission.

With a prize pool of €350k in cash prizes, technical support, data packages and business incubation, the competition aims to foster product development and entrepreneurship in Europe.

Participants in the Copernicus Masters can choose from a total of nine Challenges covering topics such as environmental monitoring, cloud computing, and mobile services, as well as the innovative use of radar and very high-resolution satellite imagery. Applicants have to submit a high-level business plan which a jury of experts will assess.

3.3.3. European Space Navigation Competition (ESNC)

Now celebrating its 10th year anniversary, the European Satellite Navigation Competition (ESNC) is looking for services, products, and business innovations that use satellite navigation in everyday life. Prizes worth around €1 M will be awarded - including special prizes from some of the most relevant institutional stakeholders, such as ESA, the European GNSS Agency (GSA), The German Aerospace Centre (DLR), and the European Patent Office (EPO). In addition, 25 partner regions worldwide are hosting regional challenges.

Participants are expected to propose a high-level business plan like for the Copernicus challenge.

3.4. Showcasing successful space spin-off

Finally, ESA's Space Spin-Off Award is given to individuals or an organisation that have carried out a space technology transfer of extraordinary success with significant economic impact and remarkable results in a non-space sector - and maybe also beneficial to the Earth environment or improving quality of life on Earth.

The main objective of these competitions is to raise awareness and to stimulate the generation of ideas. Therefore additional tools and means are provided to support competition winners, ready to continue the innovation after the competition stage.

3.5. Analysis of the use of competitions by the TTP

Compared to the different motivations listed in the scholarly literature on the reasons for organisations using competitions as listed in section 1.1.3, the competitions conducted by the TTP fall under these categories:

- to spur the initial development of an industry;
- to focus innovative efforts on problems for which solutions otherwise do not seem to be forthcoming;
- to open and increase the traditional communities dealing with certain challenges;
- to raise public attention.

4. COMPETITIONS AND PRIZES FOR ADVANCING SYSTEM STUDIES

4.1. Lunar Robotics Challenge

The ESA Lunar Robotics Challenge (LRC) was a competition funded by ESA General Studies Programme and implemented by an interdisciplinary team involving experts in robotics, space mechanisms, Lunar exploration, communication and education activities, among other.[25, 26]

The LRC was held at the Minas de San Jos in the National Park of Teide on the island of Tenerife, Spain. The location was chosen early in 2008 by a joint ESA project team. The challenge proposed to the eight participating teams consisted in performing pre-defined tasks in Lunar-like volcanic terrain of the site. These tasks included descending the rim of a geological structure similar to a crater, the collection of soil samples and the return of the vehicle with the samples to the base station outside the crater. The tests were performed at night and with extreme temperatures, making the challenge similar to conditions a Lunar mission might face.

The competition did not have a cash prize, but the recognition of the achievement of the winning university team as part of a wide communication campaign on the event.

One of the main purposes of the competition was to provide a levelled playing field to be able to compare rover mobility solutions that can be effective in navigating a terrain that is as challenging as the one close to the Lunar South Pole, a region of interest for future Moon missions. This comparison would have been almost impossible on the basis of paper descriptions or CAD models and simulations.

The competition also allowed comparing control stations and the interaction of the student teams with their rovers. This might in some ways be similar to terminals that will allow astronauts to interact with their robot assistants in human exploration missions assisted by robots. While ESA has already prototyped a number of these stations, the evaluation of imaginative and cost-effective solutions implemented by the student teams contributed additional insights.

Technically, the competition was a complete success. Built within strict size, weight and power constraints, CESAR, the winning rover successfully descended down the steep 40 degree slopes of the 15 metre deep crater, collected 0.1kg of specifically selected soil then it carried it back out of the crater to the top base station all while in darkness. From the communication point of view, the competition was also a complete success; the event had extensive coverage in both national and international media.

Still there were some missing opportunities, for example linked to the identification of a sustainable financing model that could guarantee a regular implementation. The 2008 edition has not been repeated afterwards. One of the aspects that was not fully tapped into was the sponsoring of the event by interested companies. Sponsoring did occur in some cases as private companies supported specific teams, but it was not sought systematically to support the organisation of the event itself. On the other hand, the logistics of the competition were daunting, and not exempt of risks related to hardware and the conditions of the site. As a matter of fact, the organisation of the event was also excessively centralised, relying on ESA to address all such logistic issues, and therefore making it more difficult for the event to be organised without such ESA support (about €250k were spent in terms of logistic support, travel and ESA manpower effort, compared to the €350k that financed the eight university teams work.

In consequence, the LRC demonstrated to be an excellent way *to compare the effectiveness of different technical solutions* and to *draw technical activity and large media attention* on a Lunar exploration project. In spite of this, it fell short of providing a model that could have a more lasting effect in training technical students and evaluating new technologies as they become available to these university groups, to industry and to ESA mission planners. All these issue could, however, be overcome in case a similar technical assessment based on the "competitive prototyping" paradigm as used e.g. in the US JSF programme was adopted.

4.2. SysNova

SysNova is an ESA scheme funded by the General Studies Programme for competitive evaluation of system concepts and technologies which of potential interest for missions beyond current programmes. One of the main purposes of the initiative is to increase the effectiveness of research funds applied to advanced system concepts, by introducing a very demanding competition schedule drawing many resources that might otherwise be unavailable over longer study durations. Limiting the time for the participating teams involved the initiative taps into the often high-quality analysis nominally carried out by the industrial bidders before an ESA contract is placed, which otherwise will mostly serve the purpose of winning the ESA tender, but will not always contribute to the technical study outcome.[27]

In SysNova, technology challenges associated to certain crosscutting subjects e.g. exploration, "Clean Space", future instrument technologies etc. are proposed in an Announcement of Opportunity (AO) for industry to put forward their design solutions. The scheme is based on the definition of high-level requirements (e.g. for a certain mission performance), leaving open to industry the technical solution to address them. This represents a departure with respect to conventional feasibility studies, in which a set of system and mission requirements and a work breakdown is defined by ESA.

The AO proposes challenges in technical areas that are considered of interest for ESA technology strategy, but not yet addressed in a similar way by any planned mission or programme. Examples in the 2012 AO include areas such as in-space propulsion, autonomy, life support and energy systems. These have been identified as enabling technologies in the exploration cross-cutting subject by ESA management, but in all cases, beyond current programmes plans.

The technical solutions identified by study teams composed by experts from both academia and industry is compared with a competition scheme. The study is relatively short in time (about 5 months, including bid evaluation and contract initiation) and the work done during the bidding period (8 weeks) and under ESA contract (also 8 weeks) is all considered part of it, with the tender evaluation board as a kind of Mid-Term Review between the two phases. In this way, ESA matches industry's investment. The total short time from AO definition to response gives ESA a good, fast turn-around, concept assessment tool. This is made possible thanks to a pre-defined schedule and setup, and is made available to all ESA interested users, for them to define scenarios and challenges according to their needs.

The outcome studies and the different solutions proposed by the study teams are compared at the Final Review, and a winning team is nominated. After the Final Review, the consortia are invited to identify -in their proposed roadmaps- technology activities for consideration by ESA's technology programmes.

The first SysNova Announcement of Opportunity focussed on technologies required for the controlled modification of the orbit and attitude of a man-made (i.e. space debris) or natural (i.e. an asteroid) object in space, the guidance problems to small objects (debris, faint asteroids etc) and the systems enabling life support beyond Low Earth Orbit all the way to interplanetary space environment. Four concrete challenges have been proposed, out of which 3 have been addressed by the industrial responses. Five of such responses were selected by ESA and supported by a contract (€ 100k) for study until the final review.

The technical challenges are briefly described below:

SysNova AO 2012 Technology Challenges

- Orbit modification of and Earth-bound artificial object by contact-less means i.e. changing orbital elements by a certain amount for an object of given characteristics.
- Small asteroid orbit modification by contact-less means; as in the previous case, but in interplanetary space and considering a 5-m asteroid as target.
- Double asteroid orbit modification by kinetic impact. The challenge was to find, target and displace a body of given physical characteristics which is part of a binary system.
- A system capable of sustaining animal life in the interplanetary space environment for 1 year for in-situ analysis.

The results are characterised by a very high quality standard and very good level of detail in three aspects of the system concept assessments: physical and technical principles, system solution and technology roadmap. Such thoroughness and accuracy normally corresponds to studies with a budget twice or three times larger, when considering assessment of concepts beyond ESA programmes.

The winning concept of the first *SysNova* edition in 2012, Politecnico Milano, GMV and Thales Alenia Space) addressed the first challenge, and provided design solution for demonstration of the use of chemical propulsion for transfer of momentum to a uncooperative target, for orbit adjustment and remote attitude control.

4.3. Analysis of the use of competitions by the GSP

Compared to the different motivations listed in the scholarly literature on the reasons for organisations using competitions as listed in section 1.1.3, the competitions conducted by the ESA General Studies Programme fall under these categories:

- to spur the initial development of an industry;
- to focus innovative efforts on problems for which solutions otherwise do not seem to be forthcoming;
- to open and increase the traditional communities dealing with certain challenges;
- to provide a transparent, equal and fair comparison different solutions; and
- to raise public attention.

5. CONCLUSIONS

Prizes, competitions and games represent attractive, complementary means for advanced space technology and research, technology transfer and system studies. The successful use of these tools requires novel, unconventional approaches and a thorough preparation. The space sector is particularly suited for such tools given its attractiveness, the high visibility and the benefit of opening up an otherwise rather closed sector.

The recent, renewed interest in competitions and prizes is starting to provide valuable data on the effectiveness of these tools to foster innovation. These data are expected to provide the necessary basis for a thorough scholarly debate on suitable decision parameter for the choice of these tools compared to traditional grant-based mechanisms. We have added another evidence to the still scarce amount of literature on the use of games as an innovation and research tool.

References

[1] Z. Merali. Science prizes: The new Nobels. *Nature*, 498(7453):152–154, June 2013. ISSN 0028-0836, 1476-4687. doi: 10.1038/498152a. URL http://www.nature.com/doifinder/10.1038/498152a.

[2] A. Abbott and Q. Schiermeier. Research prize boost for Europe. *Nature*, 493(7434):585–586, January 2013. ISSN 0028-0836, 1476-4687. doi: 10.1038/493585a. URL http://www.nature.com/doifinder/10.1038/493585a.

[3] J. Kinaret. Graphene Flagship website, September 2013. URL http://www.graphene-flagship.eu/GF/index.php. webpage.

[4] L. Davis and J. Davis. How effective are prizes as incentives to innovation? Evidence from three 20th century contests. In *Proceedings, DRUID Summer Conference*, Elsinore, Denmark, June 14-16,, 2004.

[5] L. Brunt, J. Lerner, and T. Nicholas. Inducement Prizes and Innovation: Inducement Prizes and Innovation. *The Journal of Industrial Economics*, 60(4):657–696, December 2012. ISSN 00221821. doi: 10.1111/joie.12002. URL http://doi.wiley.com/10.1111/joie.12002.

[6] T. Harford. Cash for answers. *Financial Times*, (0307-1766), 25 January 2008. URL http://www.ft.com/intl/cms/s/0/a4040a4e-c7bd-11dc-a0b4-0000779fd2ac.html?siteedition=intl.

[7] B. Krohmal, D. Serafino, J. Love, M. Ress, J. Rius, and M. Childs. Selected innovation prizes and reward programs. Technical Report Research Note 2008:1, Knowledge Ecology International, 2008.

[8] D. Sobel. *Longitude : the true story of a lone genius who solved the greatest scientific problem of his time*. Walker, New York, 1995. ISBN 0802713122.

[9] F. Murray, S. Stern, G. Campbell, and A. MacCormack. Grand Innovation Prizes: A theoretical, normative, and empirical evaluation. *Research Policy*, 41(10):1779–1792, December 2012. ISSN 00487333. doi: 10.1016/j.respol.2012.06.013. URL http://linkinghub.elsevier.com/retrieve/pii/S004873331200217X.

[10] J. D. Zients. Memorandum for the heads of executive departments and agencies - Guidance on the Use of Challenges and Prizes to Promote Open Government, March 2010.
[11] L. Kay. *Technology R&D in the context of innovation inducement prizes - Insights from the Google Lunar X Prize*. Edward Elgar Pub, 2012. ISBN 978-1781006474.
[12] B. M. Good and A. I. Su. Games with a scientific purpose. *Genome Biology*, 12(12):135, 2011. ISSN 1465-6906. doi: 10.1186/gb-2011-12-12-135. URL http://genomebiology.com/2011/12/12/135.
[13] F. Khatib, S. Cooper, M. D. Tyka, K. Xu, I. Makedon, Z. Popovic, D. Baker, and F. Players. From the Cover: Algorithm discovery by protein folding game players. *Proceedings of the National Academy of Sciences*, 108(47):18949–18953, November 2011. ISSN 0027-8424, 1091-6490. doi: 10.1073/pnas.1115898108. URL http://www.pnas.org/cgi/doi/10.1073/pnas.1115898108.
[14] European Space Agency - Advanced Concpets Team, 2013. URL http://www.esa.int/act. webpage.
[15] L. Summerer. Evaluating research for disruptive innovation in the space sector. *Acta Astronautica*, 81(2):484–498, December 2012. ISSN 00945765. doi: 10.1016/j.actaastro.2012.08.009. URL http://linkinghub.elsevier.com/retrieve/pii/S0094576512003165.
[16] L. Summerer, D. Izzo, G. Naja, and I. Duvaux-Bechon. ESA's Advanced Concepts Team. *ESA Bulletin*, pages 34–43, 2010.
[17] A. Galvez. ESA - General Studies Programme, August 2012. URL http://www.esa.int/gsp. webpage.
[18] D. Izzo, F. Barnsley, C. Yam, K. de Groote, and F. Biscani. The Space Game, 2010. URL http://sophia.estec.esa.int/thespacegame/. webpage.
[19] D. Izzo. *Global optimization and space pruning for spacecraft trajectory design*, pages 178–200. Cambridge University Press, New York, NY, USA, 2010.
[20] W. Piotrowski, M. Martens, and D. Izzo. Space Hopper: a crowdsourcing approach to designing interplanetary trajectories. In *Proceeding of 2013 Workshop on AI and Space at IJCAI, Beijing*, 2013.
[21] D. Izzo. Global Trajectory Competition Portal, September 2013. URL http://sophia.estec.esa.int/gtoc_portal/. webpage.
[22] Contribute to Science by playing AstroDrone, 2013. URL http://www.esa.int/gsp/ACT/ai/projects/astrodrone_scientific.html. webpage.
[23] space in videos - astrodrone, March 2013. URL http://spaceinvideos.esa.int/Videos/2013/03/AstroDrone. webpage.
[24] N. Eldering. Students turn rocket science into business, September 2013. URL http://www.esa.int/Our_Activities/Technology/TTP2/Students_turn_rocket_science_into_business. webpage.
[25] Lunar Robotics Challenge - A successful cooperation within ESA, 31 October 2008. URL http://www.esa.int/Our_Activities/Human_Spaceflight/Research/Lunar_Robotics_Challenge_A_successful_cooperation_within_ESA. webpage.
[26] Eight teams taking up ESAs Lunar Robotics Challenge, 2008. URL http://www.esa.int/Our_Activities/Preparing_for_the_Future/GSP/Eight_teams_taking_up_ESA_s_Lunar_Robotics_Challenge. webpage.
[27] SysNova - a new initiative to get the most brilliant proposals for the development of new technologies in the space field, 2012. URL http://www.esa.int/Our_Activities/Preparing_for_the_Future/GSP/SysNova. webpage.