

Prize Competitions and NASA's Centennial Challenges Program

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Abstract. This paper provides a programmatic overview of the Centennial Challenges program including a description of the origins of the program. Some prizes that have been used throughout history are listed and some lessons learned from prize history are given. Centennial Challenges that have been announced and are active as of the time of this conference (mid-September 2005) are described and their current status is given.

INTRODUCTION TO PRIZE COMPETITIONS

Prize competitions have been used throughout history to accelerate the development of many different technologies. The desires for new or better technologies have often come from unmet needs in various sectors of society, including commerce, industry, military, public safety, public health, and adventure/tourism.

The history of successful prize competitions has shown the potential for break-through developments at best and the accomplishment of "impossible" feats at the very least. The detrimental effects from a competition when the prize is not won are negligible since there was little cost and no resulting purse payment.

Although the U.S. government has a long history of awarding medals to individuals of merit (a.k.a. 'recognition prizes') to a great extent, they have only recently begun experimenting with inducement prizes to spur technology developments in selected areas. Centennial Challenges is a program recently initiated at the National Aeronautics and Space Administration (NASA) to fully implement the prize philosophy as applied to NASA's aeronautics, space science, and exploration goals.

In order to benefit from the lessons of past experience, prize competitions of the past can be reviewed to identify some best practices and common pitfalls.

History

Prizes dating back to the 18th century have stimulated technological advances, and enhanced various sectors of society, including commerce, industry, military, public safety, public health, and adventure/tourism. Prizes of the 18th and 19th centuries include:

- The British Longitude Prize – A cash purse of 10,000 to 20,000 British pounds (depending on accuracy of the solution) was offered in 1714 for the determination of longitude at sea. After receiving incremental financial support from the Board of Longitude to develop and improve increasingly accurate timepieces of decreasing sizes, the prize was finally won by John Harrison for his invention of H4 (a marine chronometer) in 1761. The first half of the prize purse (10,000 pounds) was made to Harrison in 1765, but ultimate public recognition as having solved the longitude problem and the remainder of the prize purse (8,750 pounds) was not made until 1773. At that time, Harrison successfully convinced King George III of his accomplishment and Parliament finally ordered the balance of the purse payment despite the continuing objections of the Board of Longitude.
- The Alkali Prize – A purse of £2,400 was offered in 1783 (and raised to £12,000 in 1789) by the Académie des Sciences of France to promote the foundation of a domestic soda industry. (Soda was the basis of the paper, glass, and soap product industries.) Nicolas Leblanc patented technology to win the prize in 1791, but the prize was abolished in 1793 and Leblanc's patent was put in the public domain. Others monopolized on his process, and Leblanc killed himself in 1806 after a failed attempt to become successful in the industry his discovery created. Leblanc's achievements were recognized in 1855, however, when Napoleon III bestowed a payment on his heirs and erected a statue of him in Paris.
- The Food Preservation Prize – Due to the inability to satisfactorily feed his troops during long military campaigns, Emperor Napoleon Bonaparte offered 12,000FFF in 1795 for a reliable method of food preservation. In 1804, a Parisian chef named Nicolas Appert built upon the process of pasteurization to develop the modern canning process. He also invented the necessary containers (glass bottles closed with cork and wire) used in the process,

still called “Appertisation,” and won the prize in 1810. (The technique of sealing food in tin-coated metal cans was developed shortly afterwards in Britain.)

There were numerous airship and aeronautical prizes offered in the early days of the 20th century, but only a few are described here.

- The Deutsch Prize - Alberto Santos-Dumont was a Brazilian who went to Paris in 1887 to study the problems of flight. By 1900, he had built a series of airships and had demonstrated some success and gained a bit of fame. That same year, the 100,000 French franc Deutsch Prize was offered for the first airship to fly from the French Aero Club's field, around the Eiffel Tower (a distance of 11 kilometers, or almost 7 miles), and back again to the starting point in under 30 minutes. After a number of test flights, including one crash landing, he finally succeeded in rounding the tower and returning to the airfield on October 19, 1901. Although his trip took 30 minutes and 40 seconds, he was awarded the prize purse and the Brazilian Government matched the purse as an unexpected bonus. Later in 1906, Santos-Dumont won a small purse of 3,000 francs for a 60 meter flight in a heavier-than-air ship (aeroplane) and, later, a 1,500 franc purse for the first flight of 100 meters.
- The Daily Mail English Channel Crossing Prize - Louis Blériot designed aeroplanes between 1900 and 1909 using his personal fortune earned from his automobile headlight manufacturing business. His Blériot XI design was the aircraft he used to win a prize worth 1,000 British pounds offered by the Daily Mail for the first flight across the English Channel. Blériot took off from Calais, France on July 25, 1909 with a badly burnt foot, an engine that had suffered a fire only days before, and no compass for navigation. His flight took 37 minutes and ended with a crash landing in Dover, England. He received a hero's welcome in London and the French Government augmented his winnings with a payment of 50,000 French francs.
- The Milan Committee Prize - Gorges Chavez was a Peruvian citizen living in Paris and an accomplished pilot in the early days of aviation history. In 1910, he took up the Milan Committee challenge of flying from Switzerland to Italy over the Alps through the Simplon Pass for a purse of 160,000 Italian lire. Two weeks earlier, Chavez set a new altitude record of 2,652 meters (8,840 feet, or more than 1.5 miles) in the Blériot XI aeroplane and he would need to climb to at least 2,000 meters to cross the Alps. After several unsuccessful attempts by himself and others, Chavez made his last attempt on September 23, 1910. His flight was cold and turbulent, but after 41 minutes, Chavez appeared on the Italian side of the Alps. He stopped his engine and was gliding to a landing when he crashed from an altitude of only 10 meters (30 feet). Chavez was fatally injured and it is thought the plane suffered structural damage or he was so cold that he let the plane slow down too much and it simply fell out of the sky. Chavez won the prize, but died four days later.
- The Daily Mail Trans-Atlantic Prize – In 1913, a purse of 10,000 British pounds was offered by the Daily Mail newspaper for the first trans-Atlantic flight within 72 continuous hours. The start of World War I put the competition on hold between 1914 and 1918, but the seemingly impossible feat was accomplished in 1919 by British airmen John Alcock and Arthur Whitten Brown in a modified World War I aircraft, the Vickers Vimy bomber aeroplane. The 2,000 mile flight started from Newfoundland and was very foggy most of the way. The pilots could only navigate for the brief periods using the stars and Moon when there was a break in the clouds. When they reached Ireland, they aimed for a field which turned out to be a bog. Their flight ended in a crash, but both Alcock and Brown walked away unharmed.
- The Hearst Prize – In October 1910, American newspaper man William Randolph Hearst offered an aviation prize of 50,000 U.S. dollars to the first person to fly across the United States in under 30 days. The competition deadline of November 1911 came and went with no winner able to claim the purse, although Calbraith Perry Rodgers made a valiant effort, starting only weeks before the contest expired, but finally arrived cross-country after 49 days full of crash landings, repairs, and taking to the air once again.
- The Orteig Prize – 25,000 U.S. dollars was offered by Raymond Orteig in 1919 for the first non-stop flight between Paris and New York. There was fierce competition to win this prize and Charles Lindbergh was an unknown air mail pilot at the time. Lindbergh was very familiar with planes and convinced a group of St. Louis businessmen to back his idea to modify a Ryan M-2 airplane, the "Spirit of St. Louis," to make the trip. Lindbergh took off from New York on May 20, 1927. Thirty-three hours and 3,600 miles later, he landed at Le Bourget airfield near Paris and was greeted by 100,000 excited aviation fans.
- The Kremer Prizes – A number of competitions were offered by Mr. Henry Kremer in 1959 for human-powered flight. 50,000 British pounds was awarded to designer Paul MacCready in 1977 when his Gossamer Condor flew a mile-long, figure-eight course. 100,000 British pounds was awarded in 1979, again to MacCready, for his

Gossamer Albatross, a bigger and improved version of the Condor. The Albatross was the first human-powered vehicle to fly across the English Channel. There are still three unclaimed Kremer Prizes for human-powered flight: one for a flight around a specified twenty-six mile marathon distance course in a time of under one hour; one for a human-powered sporting aircraft; and one for a human-powered take-off from water followed by a figure-eight flight.

With the advent of the 21st century, the popularity of prize competitions increased. The following are some examples of recent prize competitions.

- The Cheap Access to Space (CATS) Prize – A 250,000 U.S. dollar cash purse was offered by the Space Frontier Foundation in November 1997 for the launch of a 2 kilogram payload to an altitude of 200 kilometers. A smaller prize of 50,000 dollars was offered for the first team to launch to an altitude of 120 kilometers. The prize expired in the year 2000 without being won.
- The ANSARI X PRIZE - Ten million U.S. dollars was offered by the X PRIZE Foundation in 1996 for the first, privately funded, reusable suborbital vehicle capable of carrying three people to 100 kilometers twice in two weeks. This competition spurred the creation of many companies and different spacecraft designs from around the world. The prize was finally won by Burt Rutan of Scaled Composites with SpaceShipOne flights on 29 September and 4 October 2004. Rutan employed innovative ideas to solve the problems of suborbital spaceflight, including carrying SpaceShipOne to an altitude of 50,000 feet underneath the White Knight aircraft before igniting the rocket engines. Another innovation was the "feathering" of SpaceShipOne's wings to allow "carefree" reentry of the vehicle during descent.
- DARPA Grand Challenge - One million U.S. dollars was offered by the Defense Advance Research Project Agency (DARPA) for a competition in March 2004. The winner would be any autonomous ground vehicle that most quickly navigates a designated route over desert terrain within 10 hours. No team won the original competition and a second race will be held in October 2005.
- The Feynman Prize - The Foresight Institute is offering a 250,000 U.S. dollar prize for the first nano-scale robotic arm and the first nano-scale computing device that demonstrates the feasibility of building a nanotechnology computer. These prizes are currently unclaimed.
- The Methuselah Mouse Prize – This competition is organized by the Methuselah Foundation to accelerate the discovery of methods to slow or stop the aging process. The cash purse is based on the amount of private donations and the amount of life extension achieved. The prize has not yet been claimed.

There are many other prize competitions not explored here, including the Soviet Incentive Awards for Innovation, the Rockefeller Foundation Prize, the Atomic Energy Patent Compensation Awards, and the Super-Efficient Refrigerator Program.

Lessons Learned

Taken as a whole, the collection of historic accounts provides insights into the value and limitations of prize competitions. Some of the more dominant themes as they relate to NASA are described below.

- The Simpler, the Better – Challenges that are objective, transparent, simple, and unbiased are preferred over those that require complex rules, expensive testing and verification, and/or qualitative judging.
- Relevance to NASA Programs – Challenges that develop and demonstrate capabilities that have strong relevance to NASA programs provide greater leverage to NASA programs and are preferred.
- The Right Level of Difficulty – Many technical problems have multiple solution pathways. While it can be difficult to decide a priori which pathway is the best, a prize competition can be more effective than a standard contract or grant. Also, technical challenges that are too easy or too hard to achieve are not desirable.
- Follow-On Opportunities – Historically, the most successful prize competitions are those that are aligned with some near-term economic opportunity for the competitors. All other things being equal, challenges that will produce a capability that can be applied to a future NASA program, another aerospace market, or that have synergy with Earth-based applications are more desirable.
- Competitor and Sponsor Interest – Interest from potential competitors and/or sponsors of the competing teams is a strong indicator that a particular prize competition may be a good candidate. Interest from potential co-sponsors of

the prize purse itself (i.e., other organizations in the government, industry, and academia with R&D interests coincident with NASA's) is another strong indicator.

- Public Excitement – The most successful competitions produce excitement among the public, media, and educators. This excitement, in turn, encourages the participation of competitors and sponsors to earn their share of the fame associated with winning the prize. All other things being equal, challenges with greater potential to generate public excitement are more desirable.

PROGRAMMATIC OVERVIEW

Bolstered by the success stories of past prize competitions and knowing how prizes fit into technology development, the Centennial Challenges program plan was developed to maximize the advantages of prizes.

Origins of Centennial Challenges

1999 National Academy of Engineering Report

In 1999, a panel was assembled by the National Academy of Engineering to provide guidance to the U.S. government on the use of inducement prizes to stimulate technological advances. The report issued from this panel emphasized the historical importance and use of prizes in technology development and urged their implementation by federal government research agencies. Specifically, they recommended that “Congress encourage federal agencies to experiment more extensively with inducement prize contests in science and technology.”

Space Exploration Policy

In January 2004, a policy report entitled “A Renewed Spirit of Discovery – The President’s Vision for U.S. Space Exploration” was issued from the Office of the President of the United States. This report gave NASA a clear objective and goal emphasizing the role of private industry in exploration by saying that NASA should “promote... commercial participation in exploration to further U.S. scientific, security, and economic interests.” A presidential commission was also established at this time, and chaired by the Honorable E.C. "Pete" Aldridge, Jr., to make recommendations for the implementation of this policy.

Vision for Space Exploration

One month after the White House’s space policy was issued and the President verbalized the policy at a public event held at the NASA Headquarters building in Washington, D.C., NASA released “The Vision for Space Exploration,” a report giving specific programmatic responses to the exploration directives. NASA’s document established Centennial Challenges as a technology inducement prize program. Justification for its formation was that “NASA will need to leverage the ideas and expertise resident in the Nation’s universities and industry... [by] establishing prizes for specific accomplishments that advance solar system exploration...”

Aldridge Commission

In June of 2004, the Aldridge Commission issued a report that included findings and recommendations for the implementation of the exploration effort. Recommendation 5-2 from the report specifically states “The Commission recommends that Congress increase the potential for commercial opportunities related to the national space exploration vision by providing incentives for entrepreneurial investment in space, by creating significant monetary prizes for the accomplishment of space missions and/or technology developments and by assuring appropriate property rights for those who seek to develop space resources and infrastructure.”

2003 Space Architect Study

In preparation for the establishment of the Centennial Challenges program, NASA performed an internal study to identify and prioritize possible competition ideas. X PRIZE Foundation President Dr. Peter Diamandis and Executive Director Gregg Maryniak conducted interviews with NASA field center personnel from the field centers compiled and then analyzed the results. Their report was issued in November 2003 and identified 129 technology development challenge ideas. Each idea was rated on criteria (e.g., alignment of technology development to NASA’s mission) to produce a prioritized list. The top 20 ideas were then recommended for further consideration.

2004 Centennial Challenges Workshop

The 2004 Centennial Challenges workshop was held on Tuesday and Wednesday, 15 and 16 June 2004 at the Hilton Washington hotel. In attendance were representatives from big and small industry, aerospace and non-aerospace, universities, government, and interested individuals.

Over two hundred attendees and 30 session moderators discussed generated ideas for future challenges in the areas of aeronautics, exploration systems, planetary systems, earth observation, bioastronautics, and astrophysics. Attendees and moderators also discussed potential rules and other details for over 30 competition ideas. The specific competitions were selected from the 2003 Space Architect Study results as well as ideas generated by workshop attendees in previous sessions.

Three guest speakers, including Senator Sam Brownback (Chair of the Commerce Subcommittee on Science, Technology, and Space), Dr. John Marburger (Director of the White House's Office of Space and Technology Policy), and Mr. Elon Musk (Founder and CEO of Space Exploration Technologies Corp.), discussed the importance of prize competitions in fulfilling the Vision for Space Exploration and NASA's ongoing missions. They also provided unique perspectives on the role of government and private industry in space technology development.

Three discussion panels were also conducted to provide workshop attendees with multiple viewpoints of the subject areas pertinent to technology development. The Launch Vehicle panel featured leaders of the nascent reusable launch vehicle industry. The Past, Present, and Future of Prize Competitions panel included brief presentations by prominent personalities who had direct experience with conducting or winning prize competitions. The Fund Raising panel featured descriptions of the sponsorship, venture capital, angel, and state subsidy communities.

Programmatic Description

NASA Centennial Challenges was established to conduct prize competitions in support of the Vision for Space Exploration and ongoing NASA programs. Centennial Challenges is modeled on past and ongoing prize competitions, including the 18th century British Longitude Prize; early 20th century aviation competitions, such as the Orteig Prize won by Charles Lindbergh; the ongoing Defense Advanced Research Projects Agency (DARPA) Grand Challenge; and the recently won, privately funded, Ansari X PRIZE. By making awards based on actual achievements instead of proposals, Centennial Challenges seeks novel and lower-cost solutions to engineering obstacles in civil space and aeronautics from new sources of innovation in industry, academia, and the public.

Eligibility to participate in Centennial Challenges competitions is open to participants who are not employees of the U.S. federal government or U.S. government organizations (including federally funded research and development centers such as the NASA Joint Propulsion Laboratory). Participation of non-U.S. individuals or organizations as team members in a Centennial Challenges competition is allowed, but the team leader must be a U.S. citizen or organization.

Competition Structure

NASA plans four categories of prize competitions under Centennial Challenges: Flagship Challenges, Keystone Challenges, Alliance Challenges, and Quest Challenges.

Individual Challenges will take one of two forms: "first-to-demonstrate competitions," like the Longitude Prize, Orteig Prize, and X PRIZE; and "repeatable contests," like the DARPA Grand Challenge.

- Flagship Challenges – To encourage major, private space missions.
- Keystone Challenges – To address key technology priorities at the subsystem level.
- Alliance Challenges – To leverage partnerships to conduct smaller-scale Keystone Challenges.
- Quest Challenges – To promote outreach and education in science, technology, engineering, and mathematics.

Flagship Challenges

Flagship Challenges are intended to encourage external teams to independently design, develop, launch, and operate space missions and thereby generate innovative and/or low-cost approaches to various civil space goals that would not otherwise be pursued. It is envisioned that all Flagship Challenges will be "first-to-demonstrate" competitions with cash purses ranging from millions to tens of millions of dollars. Contributing to the overall purse may be co-sponsors with parallel capability or technology interests being pursued by the specific competition.

Flagship Challenges will be open to competitors from private sector companies, non-profit research institutions, university researchers, student teams, hobbyists, and any combination thereof. Examples of Flagship-type prize competitions include the Orteig Prize and the X PRIZE. Candidate Flagship Challenges under consideration by NASA include prize competitions for:

- A station-keeping solar sail,
- A soft robotic lunar landing,
- A micro reentry vehicle,
- Advances in suborbital vehicle performance, and
- Low-cost robotic or human space missions.

Keystone Challenges

Keystone Challenges are intended to encourage the development and demonstration of advanced technologies and/or innovative capabilities that support NASA's mission areas, and, where possible, have strong synergy with other applications. Keystone Challenges may be component-, subsystem-, or system-level demonstrations, and may involve robotic contests, drop tests, and/or atmospheric flight tests.

Depending on the technical goal, Keystone Challenges may take the form of “first-to-demonstrate competitions” or “repeatable contests” with cash purses ranging from hundreds of thousands to millions of dollars. As in the case of Flagship Challenges, co-sponsors with parallel technology interests being pursued by the specific competition may contribute to the overall purse.

Keystone Challenges will also be open to private sector companies, non-profit research institutions, university researchers, student teams, hobbyists, and any combination thereof. The Longitude Prize and the DARPA Grand Challenge are two examples of Keystone-type prize competitions.

Candidate “first-to-demonstrate” Keystone Challenges under consideration by NASA include:

- A mobile power storage breakthrough,
- An autonomous drill,
- In-space cryogenic propellant management and distribution,
- Improved and new physical and chemical lunar resource processing techniques,
- A human/robotic triathlon, including a sample return mission analog,
- A human, lunar all terrain vehicle, and
- A low-cost, lightweight, flexible pressure suit.

Candidate “repeatable” Keystone Challenges under consideration by NASA include:

- A precision landing system,
- An unmanned aerial vehicle (UAV) for planetary science purposes,
- Advances in materials, especially nanotube tethers,
- Advances in lightweight power transmission, especially beamed power, and
- Advances in general aviation technologies, especially those applicable to other modes of air transport.

Alliance Challenges

An Alliance Challenge is identical to a Keystone Challenge, except that the prize is administered by an organization at no cost to NASA in exchange for the opportunity to be associated with the prize competition. Alliance Challenges are designed to leverage the capabilities of various non-profit organizations with domain expertise and/or members in the organization to administer a Challenge competition at no cost to NASA. Candidate Alliance Challenges for which NASA is seeking partners include any and all of the Keystone Challenges described above.

Alliance Challenges are typically conducted on an annual basis with purses in the tens of thousands to hundreds of thousands of dollars.

Quest Challenges

Quest Challenges are intended to complement other Challenge categories by promoting science, technology, engineering, and math (STEM) awareness, subjects, and careers to youth and other age groups. Quest Challenges, categorized by and targeted to people of all different groups, are designed to be inspirational and enriching. Some Quest Challenges involve individual or group activities, repeatable contests, or submission of entries for judging. Pursues for Quest Challenges are designed to be of interest to the targeted age groups, and include either cash or experiential awards. Examples of Quest Challenges include:

- Relevant student engineering Challenges, such as model rocket or robotic competitions;
- Relevant student science competitions, such as the Intel Science Talent Search;
- Naming and/or logo design contests for individual Flagship, Keystone, or Alliance Challenges;
- Science, Technology, Engineering and Math-related games and tournaments, such as internet-based games, card games, and video games; and
- “Best of Science Fiction” Challenges in literature, art, and/or music.

CURRENT CENTENNIAL CHALLENGES COMPETITIONS

This section gives details for the Centennial Challenges competitions that are active as of the time of this report’s writing.

2005 Tether Challenge

The 2005 Tether Challenge is designed to promote the development of new high strength-to-weight materials that have the potential to dramatically affect engineering solutions in a wide variety of applications, including space exploration.

The 2005 Tether Challenge will be conducted by the Spaceward Foundation in two rounds. In the first round, a single-elimination tournament format will be used where two tethers from two teams will pull against one another until one of them breaks. Teams are eliminated from the first round tournament if their tether breaks.

The winner of the first round will be the team with the strongest tether from among all the entries.

In the second round, the first round winner must compete against a “house tether” supplied by Spaceward that is representative of current commercial, off-the-shelf, state-of-the-art materials.

First, the breaking strength of the “house tether” will be measured using industry standard testing techniques. Next, the breaking strength of the first round-winning tether will be measured the same way.

If the first round-winning tether is at least 50% stronger than the “house tether,” they will win the competition and receive the \$50,000 purse.

Draft Rules

The following are an overview of the rules for the 2005 Tether Competition:

1. The team shall provide a specified number of identical tether samples to Spaceward. A tether sample is a test specimen provided by the team to Spaceward for the competition. A tether sample can be a solid material or comprised of one or more materials constructed in any fashion (e.g., twisted, laid, braided, plaited, etc.).
2. Each tether sample shall:
 - a. Form a closed loop. Splice points are allowed. The team shall determine the location of the tether sample loop splice point, if any, with respect to the testing apparatus interfaces.
 - b. Have an inner circumference of 2.0 meters (+/- 1 cm).
 - c. Have a width at any point along its length no more than 200 millimeters.
 - d. Weigh no more than 2 grams.

- e. Have an elastic modulus of at least 100 gigapascals.
 - f. Have a temperature equal to the testing ambient temperature at all times during the competition. The testing ambient temperature is the uncontrolled ambient temperature of the test site and is expected to be between 10 and 40 degrees Celsius.
3. The tether sample shall compete in the first round of the competition that consists of the tether samples from all teams competing against each other in a last-to-break single elimination tournament. The culmination of the first round is the determination of the first round winner. Depending on the number of teams that register, there may be more than one bracket of competitions during the First Round.
 4. Every time the team's tether sample advances from one bracket to the next in the first round tournament, the team shall have the option to use the same tether sample from the previous bracket for the next, or to use a different tether sample from among the multiple number that the team provided at the outset of the competition.
 5. The first round winner shall advance to the second round of the competition where it will compete against the baseline tether. The second round consists of accurately measuring the breaking force (the force required to completely sever a tether sample) of the winning tether from the first round and the baseline tether. The baseline tether is a tether sample provided by Spaceward that represents commercial, off-the-shelf, state-of-the-art materials.
 6. If the first round winner has a breaking force that exceeds the baseline tether breaking force by at least 50%, the team shall be judged the winner of the competition.

2005 Beam Power Challenge

The 2005 Beam Power Challenge is designed to promote the development of new power distribution technologies that have applications to many aspects of space exploration including surface based or space based, point to point power transmission or delivery for robotic and/or human expeditions to planetary surfaces. This Challenge may also be support for the development of far term space infrastructure concepts, such as space elevators and solar power satellites.

The 2005 Beam Power Challenge will be conducted by Spaceward. Each competing team will build a vehicle, or "climber," that will climb and then descend a 60-meter (almost 200-foot, or 20-story) ribbon (also called a "tether") suspended by an overhead crane.

The only power source available to the climber will be a high-powered search light located at the bottom of the tether.

Each climber will have three chances, or "runs," to demonstrate their ability to climb the tether and carry some amount of payload. Each team will receive a score for each run that rates how efficiently the climber converted the power from the light beam into power available to the climber.

For each run, the climber can be loaded with as much payload as the team wants it to carry to the top of the tether. Of course, the heavier the payload the climber must carry, the slower it will climb. There is a minimum speed of ascent, so the team must be careful not to overload the climber.

The winner of the competition will be the team whose climber got the highest score from among all the climbers on all three runs, and will receive the \$50,000 purse.

Draft Rules

1. Each team will build and operate a climber according to the specifications given in the official 2005 Beam Power Challenge rule book (available from the Spaceward Foundation). In general, the climber will weigh less than 50 kilograms [100 pounds].
2. The primary power source for the climber vehicle will be a 10 kilowatt Xenon search-light with a beam diameter of 80 centimeters and about 25% efficient, which should yield a climber power budget of about 500 watts. More technical specifications are given in the official 2005 Beam Power Challenge rule book.
3. The beam source is a 10 kWatt Xenon search-light (80 cm beam diameter, about 25% efficient), which should yield a climber power budget of about 500 watts.

4. The ribbon is roughly 10 centimeters (4 inches) wide, 2 millimeters thick and about 50 meters (150 feet) long. The tether is tensioned to about 0.5 ton.
5. Each team shall be given three opportunities to climb up a vertical tether 50 meters in length within 60 seconds.
6. Team shall determine how much payload mass their climber shall carry each time they climb the tether.
7. Team shall receive a score each time they climb the tether within 60 seconds. The score is the product of the climber velocity and the payload mass transferred by the climber as it ascends the tether within 60 seconds. If the climber cannot ascend the tether within 60 seconds, the score assigned for that run is zero.
8. The team's highest score will become their team score.
9. The team who receives the single highest team score will be declared the winner of the competition.

MoonROx Challenge

The MoonROx Challenge is designed to promote the development of essential lunar propellant extraction technologies resulting in a monetary award to the winning TEAM. The challenge is to extract 5 kilograms of oxygen in 8 hours from lunar regolith simulant, JSC-1.

The MoonROx Challenge is structured as a "first to demonstrate" competition. Teams will register for the competition, but there will not be a pre-scheduled event where they all come together to compete against each other. Instead, teams will work independently of each other.

When one team has completed their work, they will notify FSRI to schedule a demonstration of their hardware. At the demonstration, FSRI will provide the necessary materials (such as regolith simulant) and infrastructure (such as power) and the team will be given the opportunity to demonstrate their competition entry according to the rules of the competition.

If the team meets or exceeds all of the requirements of the MoonROx competition, they will win the \$250,000 purse. If the team fails to meet the requirements, the competition will remain open until a successful attempt takes place.

If no team wins the purse before June 1, 2008, the contest will expire and no further attempts to win the prize will be considered.

Draft Rules

1. Before the competition attempt, the ISRU hardware must pass a Safety Inspection by FSRI or its designated agent.
2. TEAM is not permitted to use pure oxygen in any form as a reactant in their process.
3. Mass of the ISRU hardware as configured immediately prior to regolith loading and starting the competition attempt (including the empty hopper) shall not exceed 25 kilograms.
4. The ISRU hardware must allow easy connection to the oxygen collection hardware (provided by FSRI) with the provided interface specifications.
5. 3 kilowatts of DC power source will be provided to the ISRU hardware.
6. Before the competition attempt begins, the oxygen storage tank(s) will be weighed to determine the initial oxygen tank weight.
7. TEAM will determine when the competition attempt will start. The competition attempt will end 8 hours later.
8. ISRU hardware shall be fully autonomous for the competition attempt.
9. ISRU hardware cannot employ any processes that would not work in a hard vacuum, lunar gravity environment (e.g., suction). Materials that may not be compatible with a hard vacuum environment are permitted.
10. After the competition attempt has finished, the oxygen storage tank(s) will be weighed to determine the Final Oxygen Tank Weight.
11. The oxygen purity of the extracted gas in the oxygen storage tank(s) will be continuously monitored during the competition attempt. The extracted gas must be of breathable quality (i.e., must contain no toxic compounds) and must contain an oxygen purity of at least 99% by volume.

12. Mass consumed by the process will be determined by a method that depends on the specific ISRU hardware.
13. TEAM will receive a score for their competition attempt performance. The score will be calculated by the following formula: The Oxygen Mass (OM) minus the quantity of fifty times the Consumable Mass (CM),
 $\text{score} = \text{OM} - (50 * \text{CM})$.
14. If a team satisfies all rules, the oxygen extracted by the ISRU hardware exceeds the minimum purity requirements, and the score is equal to or greater than 5.0 kilograms, the team will be declared the winner of the MoonROx Challenge.

2006 Astronaut Glove Challenge

The 2006 Astronaut Glove Challenge is designed to promote the development of glove joint technology, resulting in a highly dexterous and flexible glove that can be used by astronauts over long periods of time for space or planetary surface excursions.

The 2006 Astronaut Glove Challenge will be conducted by Volanz in a format that brings all competitors to a single location for a “head to head” competition to determine the winning team. Each team will be required to perform a variety of tasks and will be scored on their performance. The team that earns the highest score will be the winner and be awarded the \$250,000 purse.

Draft Rules

1. Team must provide arm pieces that will incorporate interface hardware to a depressurized glove box and the gloves as given in technical specifications provided by Volanz. There are no other requirements on the arm pieces.
2. Team must provide a left arm piece, a right arm piece, a left glove, and a right glove, all sized to fit the competitor's arms and hands, all with the proper hardware interfaces.
3. Gloves must: have a wrist opening to accommodate 95th percentile male wrist size; have a range of motion of each digit between 45 and 75 degrees; have a length, without the pressure interface, not exceeding 30 centimeters; be able to withstand a maximum operating pressure of at least 5.3 psid; be able to withstand a maximum failure pressure of at least 5.5 psid; be able to withstand a normal operating pressure of 4.3 +/- 0.1 psid; be able to withstand a proof pressure of at least 8.0 psid without experiencing any damage when submitted to this pressure; must pass a structural pressure test; must weigh, without the interface hardware, less than or equal to 400 grams.
4. The gloves will undergo the following tests and receive a score based on the results: the Joint Force Test, where the force required to move each pressurized digit is measured; the Flexibility and Dexterity Test, where the competitor works inside a depressurized glove box for 30 minutes performing a variety of standardized manual tasks; the Burst Test, where the glove is filled with water, capped, and pressurized until it fails.
5. The team whose glove earns the highest score will win the competition.

CONCLUSIONS

Prize competitions throughout history have proven to be cost-effective and efficient means to stimulate technology development in a variety of socially beneficial areas.

Review and study of these prize programs has been adopted by NASA to stimulate technology development for the U.S. government. A 1999 report from the National Academy of Engineering, U.S. space policy, the Vision for Space Exploration, and the Aldridge Commission report all encouraged the participation of private industry in the fulfillment of NASA's missions. These factors, plus the influence of prize activities in the private sector (i.e. the X PRIZE) and the government (i.e., the DARPA Grand Challenge), encouraged NASA to create the Centennial Challenges program.

Centennial Challenges has divided its competitions into four categories: Flagship, Keystone, Alliance, and Quest. Flagship Challenges encompass entire missions or systems with purses in the tens of millions of dollars. Keystone Challenges focus on simple systems or individual technologies with purses in the ones of millions. Alliance Challenges are smaller versions of Keystone Challenges with purse values in the hundreds of thousands. Quest Challenges focus on outreach and education for the general public of all ages.

Within the first year of its creation, Centennial Challenges has announced a number of competitions, including: the Tether Challenge, the Beam Power Challenge, the MoonROx Challenge, and the Astronaut Glove Challenge.

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