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Advantages and Disadvantages of Prizes in a Portfolio of Financial Incentives for Space Activities

Testimony prepared for presentation to:
U.S. Congress
House of Representatives
Committee on Science
"NASA Prizes"
July 15, 2004

by Molly K. Macauley, Senior Fellow
Resources for the Future

Dr. Macauley testified on a panel with:

Rear Admiral Craig E. Steidle (Ret.), NASA Associate Administrator for Exploration Systems, who oversees the Centennial Challenges program, NASA's program of prize contests.

The Honorable Robert Walker, Chairman of Wexler & Wexler Public Policy Associates and former Chairman of the House Science Committee and former member of the Aldridge Commission.

Dr. Peter Diamandis, Chairman of the X Prize Foundation, a non-profit organization dedicated to promoting the formation of a space-tourism industry through a $10 million prize.

Dr. Douglas Holtz-Eakin, Director of the Congressional Budget Office.

1616 P St., NW, Washington, DC 20036-1400
Tel 202-328-500 • www.rff.org

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ADVANTAGES AND DISADVANTAGES OF PRIZES IN A PORTFOLIO OF FINANCIAL INCENTIVES FOR SPACE ACTIVITIES

Molly K. Macauley[1]
Senior Fellow
Resources for the Future
Washington, DC 20036

macauley@rff.org

Mr. Chairman and distinguished members of the Committee, thank you for inviting me to meet with you today. My name is Molly K. Macauley and I am a senior fellow at Resources for the Future, a nonpartisan research organization established in 1952 upon the recommendation of the presidentially appointed Paley Commission. Researchers at RFF conduct independent analyses of issues concerned with natural resources and the environment. I emphasize that the views I present today are mine alone. Resources for the Future takes no institutional position on legislative, regulatory, judicial, or other public policy matters.

My research interests are space policy issues with a focus on economics. My areas of study include: space transportation and space transportation vouchers; economic incentive-based approaches, including auctions, for the allocation of the geostationary orbit and the electromagnetic spectrum; management of space debris; the public and private value of remote sensing information; the roles of government and the private sector in commercial remote sensing; and the economic viability of satellite solar power for both terrestrial power generation and as a power plug in space for space-based activities. This research has taken the form of books, lectures, and published articles. My research on these topics is funded by grants from the National Aeronautics and Space Administration, the Federal Aviation Administration, and Resources for the Future. My comments on today's discussion of space prizes are funded solely by my discretionary budget at Resources for the Future.

Before offering my comments I'd like to make two introductory points.

The first is that for years, we have searched for the "magic bullet" that would propel our nation back into space by way of the shuttle and space station for the multiple pursuits of scientific exploration on one hand and a vibrant commercial space industry on the other. There is no lack of ingenuity in ideas for both of these goals. But critics of NASA's plans – regardless of the specific details involved -- assert that they take too much time and money away from more pressing societal needs. And, critics of commercial space activities assert that such projects carry unique risks, take too much time to develop, and take too much time before they earn any money.

Obviously, priority determines the allocation of budgets in both the private and government sectors of the economy. Risk, long lead times, and long payback periods cannot be blamed as a death knell of space because significant investment takes place in other high risk, highly uncertain industries including pharmaceutical development, information technology-related hardware and software, and hybrid autos.

[1] I thank Maria Schriver for excellent research assistance, particularly in collecting and organizing information about the history of aviation prizes. Responsibility for opinions and errors in this testimony rests exclusively with the author.

A second introductory comment summarizes my conclusions. Prizes, although not a silver bullet for invigorating enthusiasm for space or elevating its priority in spending decisions, could nonetheless complement government's existing approaches to inducing innovation -- procurement contracts and peer-reviewed grants. Even if an offered prize is never awarded because competitors fail all attempts to win, the outcome can shed light on the state of technology maturation. In particular, an unawarded prize can signal that even the best technological efforts aren't quite ripe at the proffered level of monetary reward. Such a result is important information for government when pursuing new technology subject to a limited budget.

The remainder of my testimony addresses these topics: previous experiences of using prizes to encourage innovation, including prizes in aviation, automobiles, and rocketry; use of prizes in the current era of heavy government involvement in R&D (most experience with prizes pre-dated "big government"); and advantages and disadvantages of prizes compared with procurement contracts and peer-reviewed research grants. The concluding sections draw from these observations to offer comments about NASA prizes.

I. Observations about the history of using prizes to encourage innovation

Prizes have a long history of encouraging innovation, and a look back at these contests can offer insights into what might be expected from NASA prizes. The following examples highlight use of prizes in basic and applied research in chemistry, autos, and aviation. Another example, rocketry, is a case in which prizes were scarcely used.

Soda alkali. One of the earliest documented uses of prizes took place in the 1780s when the French Academy offered 100,000 francs to whomever could produce a soda alkali from sea salt. The competition successfully led to a process that became the basis of the modern chemical industry.[2]

Autos. Prizes also figured prominently in the development of the automobile, with dozens of popular, well-publicized auto races beginning in the 1890s, mostly in Europe. One of the notable contests in the United States – the "Great Chicago Auto Race " -- is credited with giving birth to the American auto industry. In 1895, H.H. Kohlstaat, publisher of the *Chicago Times- Herald*, sponsored this competition to test the overall utility, cost, speed, economy of operation, and general appearance of cars.[3]

Kohlstaat was surprised at the number of letters and telegrams he received expressing interest in participating in the contest. The auto business had seemed centered in Europe, yet he found that there were widespread efforts underway in the U.S. Most of the inventors were simply unaware of the work of the others. Unlike previous road races, the contest placed only secondary emphasis on the outcome of the race itself– rather, the awards were for evaluating performance of characteristics of the cars. Entrants included individual inventors as well as the R.H. Macy Company and the De La Vergne Refrigerating Company. Macy's had been importing German-built Benz cars and hoped to sell them in Chicago after publicity from the race.

Only six cars ultimately participated -- many competitors were discouraged by a large snowstorm the night before the race. Two cars finished the race, but four entries won cash awards: the first place finisher, inventor Frank Duryea, earned $2000 (about $50,000 in 2004 dollars) for his auto's speed, power, compactness, and overall race performance; the other finisher won $1,500 for performance and overall economy. The Macy entry, which did not finish the race, and another entrant won $500 each for general performance. A fifth entrant got a special gold medal for safety; the absence of noise, vibration, heat or odor; and general excellence of design and workmanship. Duryea later went on to become the biggest

[2] See Joel Mokyr, *The Lever of Riches* (New York: Oxford University Press), 1990.
[3] See Paul A. Hughes, "A History of Early Electric Cars," at http://www.Geocities.com/Athens/Crete/6111/electcar.htm (accessed July 2004) and Richard Wright, "A Brief History of the Automobile Industry in the United States," at http://www.theautochannel.com/content/mania/industry/history/chap10.html (accessed July 2004).

producer of autos in the U.S., building 13 cars in 1896 (the cars were hand-built; mass production of autos was years away).

Aviation[4]***.*** Another notable and frequent use of prizes – and much of the inspiration for the X-prize -- was in the early history of aviation. Between roughly 1908 and 1915, the heyday of privately sponsored competitions for distance, elevation, and speed jumpstarted the aviation industry. Three dozen or so individual prizes during this period – at roughly the rate of four or more annually – fostered innovations that decidedly gave birth to the industry. Some general observations about aviation prizes include:

1. Prizes were usually offered for incremental improvements. For example, the first couple of prizes were for flights of 25 meters and 100 meters, then for over 1000 feet in elevation. Subsequent prizes were for longer distances, higher elevation, and faster time.
2. Prizes were almost without exception offered by private individuals and companies, not by governments. Sponsors were mostly wealthy entrepreneurs such as Raymond Orteig, a New York hotel owner; Jacques Schneider, a wealthy French industrialist; Ralph Pulitzer, the son of newspaper publisher Joseph Pulitzer; James D. Dole, a Hawaiian planter; Eduoard and Andre Michelin, executives of what was to become the Michelin Tire Company; and James Gordon Bennett, the publisher of the *New York Herald*. Prizes were also offered by the French Aero Club, which undertook private fundraising to obtain the prize money; the French champagne industry; the Harvard Aeronautical Society; the Daniel Guggenheim Fund; the *Daily Mail* of London; and the *New York World*. Governments funded military planes to race in competitions after World War I but didn't supply the prize money.
3. Big air meets were popular during 1909 – 1911 but then they either continued without much publicity or became less profitable. Many meets continued as annual races into the 1930s – the meets were not competitions for "be the first to…" but were for speed and demonstrations of skill.
4. There were prizes that were never awarded or that were awarded only after a long extension of the competition deadline. For example, the Orteig prize, awarded to Charles Lindbergh in 1927, was originally offered in 1919 for a period of up to five years, but the deadline was extended.
5. Prizes were offered for generally specified objectives like distance, speed, or minimum number of refueling and maintenance stops. Prize guidelines typically did not include stipulations about the technological approach or other engineering characteristics.
6. In at least one documented instance, a company underwrote a competitor in exchange for advertising the company's product (consumer soft drinks) on his plane.
7. Prize amounts varied widely – in 2004 dollars, the amounts ranged from about $200,000 to over $1 million. The typical amount was around $300,000. Later prizes were almost always for more difficult achievements, but prize monies didn't increase accordingly. The amounts do not seem correlated with the difficulty of the achievement required to win – but this observation may be biased by the paucity of detailed information about the prizes.
8. Accidents and fatalities were common – but did not lead to standdowns in holding competitions.
9. Whether contestants sought commercial gain from their innovation is not clear from the available records about the prizes. Some winners – but by far the minority -- became founding fathers of a product line of aircraft – such as Louis Bleriot, Glenn Curtiss, Henri Farman, and Igor Sigorsky.

Rocketry. The success of prizes in fueling innovation in autos and aviation sharply contrasts with the history of rocketry and space travel.[5] With one exception, the earliest efforts in rocket development never attracted prize money. Research grants rather than prizes typically financed studies of rockets – although even research grants were rare in the early decades. Konstantin Tsiolkovsky, Robert Goddard, and Hermann Oberth – the fathers of space travel – worked independently in self-financed home-based or

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[4] The history of prizes in this section is drawn from M. Josephy Jr., editor in charge (1962), The American Heritage History of Flight (American Heritage Publishing Company); "The History Buff," at http://www.ehistorybuff.com/wwrightals.html (accessed July 2004); and Gregg Maryniak (2001), "When Will We See a Golden Age of Spaceflight?" Pre-publication draft at http://www.xprize.org/papers/XP-CATO-Maryniak.5Mar01.doc (accessed July 2004).

[5] See Wernher von Braun and Frederick I. Ordway III (1975), *History of Rocketry and Space Travel* (New York: Thomas Y. Crowell Company)

academic laboratories. Tsiolkovsky received a grant of 899 rubles in 1899 from the Russian Academy of Science. Goddard, after making multiple requests (with the urging of Lindbergh), was given grants of $5000 and later, $3,500, from the Smithsonian Institution during 1917-1920.

In 1927, some forty years after the first serious, scholarly articles on rocketry had been published, Robert Esnault-Pelterie, a well-known airplane inventor, and his friend, banker Andre Louis-Hirsch, established a 5000-franc prize. The prize was to be awarded annually to the author of the most outstanding work on astronautics.

Public interest in rocketry was generally cool to lukewarm – in fact, "talk of rockets and space travel was viewed as crackpot by the public and as unscientific by most scientists." [6] Newspaper reporters, seizing upon some of Goddard's writing about how rockets could get to the Moon, sensationalized the statements and referred sarcastically to Goddard as the "moon man." The American Interplanetary Society—a professional organization that was a forerunner of the American Institute of Aeronautics and Astronautics -- changed its name to the American Rocket Society because interplanetary travel was so ridiculed.

For a long time, the early rocket scientists were unaware of each other's work, separated by geography and language. Beginning in the 1920's and 1930's, rocket and interplanetary societies formed in Western Europe and the U.S., researchers began regularly to report results in professional journals, and many experimental studies of rockets began under the auspices of defense agencies abroad (but not in the U.S). At this time, research in rocketry was best organized in Russia, where the Soviets created a government bureau for interplanetary flight, staged an exhibition on rocket technology, and published conference papers and a nine-volume encyclopedia. Research programs in Germany and France were also active in both theoretical studies and experimental testing of rocket components.

In the U.S., the Guggenheim Foundation was funding some of Goddard's research, but as late as 1940 the Army and Navy remained generally uninterested (although the Army was conducting some limited research on rocket propellants). The Air Corps responded to one of Goddard's proposals for support by writing that the Corps "was deeply interested in the research work being carried out … under the auspices of the Guggenheim Foundation (but) does not, at this time, feel justified in obligating further funds for basic jet propulsion research and experimentation."[7] By 1945, the U.S. government rocket program was more fully developed, with large expenditures and production facilities coordinated across the military services by President Roosevelt's National Defense Research Committee.

Some observations. These experiences show the usefulness of prizes in fundamental research (soda alkali) and in advancing technology (autos and aviation). Of course, the counterfactual question of "would innovation have come about in the absence of prizes," and if so how fast and at what cost, is equally important -- but hard to answer. These experiences also took place before the rise of government's heavy hand in R&D (more on this in a later section below).

The absence of prizes in rocketry also raises questions. Several reasons could explain the difference between the role of prizes in spurring aviation and the virtual absence of prizes in the early development of space technology. The industrialists and media who funded aviation prizes appeared to be responding to an enthusiastic public in seeking publicity for derring-do involving human flight, and at least in one case (maybe more, if documentation were more complete), the chance to use a plane as a flying billboard by advertising consumer products on the fuselage. Public perception of rocketry was incredulous, less enthusiastic and as noted, even marked by ridicule.

Rocketry, perhaps more so than aviation, was the "stuff" of science fiction. Visible success– a rocket that successfully launches high and far – was also more difficult to achieve than success in aviation during these formative years. In addition, far fewer individuals were experimenting with rockets – thus, many fewer contestants might have stepped up to rocketry prizes were they to have been offered. Finally, a reason for using prizes in aviation might at first glance be the potential for commercializing the technology, but as

[6] See von Braun and Ordway.
[7] See von Braun and Ordway.

noted earlier, this motive is far from obvious. A commercial profit motive in competing for aviation prizes *per se* (as distinguished from using the plane as a flying billboard for consumer products) is not evident in the written record – most of the competitions were "one-shot" (although, again as noted, some aviation product lines were spawned). More generally, the technological advances encouraged by aviation prizes were each incremental but taken together built a foundation for the evolving commercial aviation industry.

II. What's different now –an era of government-sponsored R&D

The climate for aviation prizes to reward technological advance pre-dated today's complex relationship between the private and government sectors in general and in space-related R&D in particular. The heyday of prizes was about 1900 to 1917 – two decades in which aviation feats made the news for an attentive public interested in the new technology, thrilled by its daredevils, and newly enamored of all modes of transportation as the era of the auto began. The period was undoubtedly one of the most distinctive periods in the history of innovation. The private sector reigned in almost all economic sectors. For instance, almost 100 % of public transit systems – street railroads and trolleys – were privately owned, and individuals or private syndicates held about 85% of electric companies and 50% of water companies.

Economic growth was also rapid. Per capita income roughly doubled just after the turn of the century due to an economy-wide increase in output. It was the era of modernization in steel mills, the beginning of skyscrapers, and rapid urbanization. It was also the chapter of the great industrialists – Andrew Carnegie in steel, John D. Rockefeller in oil, J.P. Morgan in finance, and railroad magnates like Jay Gould, Edward Harriman, Collis Huntington, and Cornelius Vanderbilt These entrepreneurs and their companies did the bulk of R&D.

Not surprisingly, government began to grow rapidly with the advent of personal and corporate income taxes in 1913 and a corporate excise tax enacted in 1909. Government spending increased from about $500 million in 1902, to about $900 million in 1913, then to $1.8 billion in 1922 (all amounts are adjusted for inflation). Per capita government spending increased 2 ½ times from its level in 1902 to its level in 1922. The Depression and World War II brought further large increases in federal spending. Most expenditures before 1915 were for defense, the postal service, and veterans services; by 1920, expenditures included these activities plus growing interest on debt and financing of air and water transportation.

Increased government expenditure during this time was not, however, directed towards R&D. About the only role of government in innovation – albeit an important role – was protecting invention by way of the very active patent system. The large expansion of government R&D that characterizes today's public sector began after World War II in the form of procurement contracts and peer-reviewed research grants to universities. At the same time, a new, so-called social contract between government and researchers evolved to provide for freely sharing the results of research in exchange for funding.[8]

Government involvement now extends well beyond protecting intellectual property to include direct subsidies and R&D tax credits as well as carrying out research at government laboratories or other facilities, often in partnership with the private and academic sectors. Government's influence is far wider because a host of other policies, although not directed toward R&D, also significantly affect the rate and direction of innovation. These include safety and health regulation, mandatory labor practices, and environmental protection. Analyses evaluating the fruits of government-sponsored R&D reveal a mixed record. The supersonic transport, the Clinch River Breeder reactor, synthetic fuels from coal, and the photovoltaics commercialization programs are among "failures" according to most analysts.[9] In other cases, government investment seems to have paid off. For example, a recent National Research Council study of fossil energy research supported by the U.S. Department of Energy found that a least a handful of R&D

[8] See historical discussion and references in US Congress, Office of Technology Assessment (1991), *Federally Funded Research for a Decade* OTA-SET-490 (Washington, DC: US Government Printing Office).
[9] The edited volume by Linda Cohen and Roger Noll (1991) *The Technology Pork Barrel* (Washington, DC: Brookings Institution) discusses these examples.

initiatives ranging from electronic ballasts in compact fluorescent tubes to atmospheric fluidized-bed coal combustions were "well worth it" in that the estimated net realized economic benefits were positive.[10]

III. The tight coupling of government R&D funding and aerospace

Government stepped in to fund and manage civilian space activity in response to Sputnik and the Cold War – putting a "government in charge" imprimatur on space activities. Government involvement continues -- of all federal R&D money flowing to industry, about a third goes to the aerospace sector, and of that, 98% goes to nine companies. [11] Two-thirds of R&D funding in aerospace is federally financed.[12] Not all space developments have been publicly funded, however. There have been some important exceptions in which large amounts of private money were invested in developing space technology. NASA and the Department of Defense jointly funded a small amount of the development costs of the Hughes Aircraft Company to design the Syncom satellites (the first commercial geostationary communications satellites), but most of the funding came from the Comsat Corporation using money from common carriers and from a public stock offering.[13] Private money also contributed to underwriting the cost and risk of developing the launch vehicle Pegasus and portions of the Sea Launch system. Like any industry, however, for every profitable success there are many more financial failures. There have been unsuccessful attempts to privately finance new space transportation systems, low-earth orbit communications networks, and some commercial earth-observations satellite systems.

IV. Prizes, procurement contracts, and peer-reviewed research grants in the 21st century

As government grew, prize offerings tailed off not only in aviation but also in other fields. There may be no causal link, or maybe there is one. The answer would shed some light on whether reinstituting prizes now can be successful in inducing innovation. Part of the answer also rests with whether prizes are compatible with or offer significant advantages compared with the ingrained contracting and grant-making relationships between government and the private sector in space R&D. In any case, neither prizes nor, for that matter, other traditional approaches to R&D sponsorship by way of peer-review or procurement contracts guarantee "success" in bringing about innovation.

Much of the preceding discussion has emphasized the historical success of prizes but they have some disadvantages. These include:

- no provision for up-front cash flow to defray expenses;
- duplication of research effort if many individuals or groups compete;
- uncertainty about whether the innovation can succeed; and
- delays in the pace of innovation if a lot of time elapses before it is determined that there are no winners.

In addition, prizes are unlikely to meet other social objectives that government sponsorship in general, or NASA sponsorship in particular, has traditionally pursued. For example, prizes do not necessarily further these goals that NASA has frequently set forth as success measures in its R&D policy:

- increase the number of academic researchers;
- increase the number of scientists and engineers;
- create jobs;

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[10] National Research Council (2001) *Energy Research at DOE: Was it Worth It?* (Washington, DC: National Academy Press).

[11] Federal funding of R&D increased from about $ 50 billion in 1960 to over $80 billion in 1990 (all figures in 2002 dollars), growing rapidly during the "golden years" for research after the launch of Sputnik and the commitment to land on the Moon. Federal R&D funding in recent years has been around $105 billion.

[12] Tables A-9 and A-15, National Science Foundation, *Research and Development in Industry: 2000*, at http://www.nsf.gov (accessed July 2004).

[13] At the time, the public held half of Comsat's stock and communications companies like AT&T, ITT, RCA, and Western Union held the other half. For more on the development of commercial communications satellites see John L. McLucas (1991) *Space Commerce* (Cambridge, MA: Harvard University Press).

- influence political support by way of job creation;
- broaden the participation of traditionally underrepresented groups in science and technology; and
- prop up a particular supplier or group of suppliers to ensure choice (say, to ensure that a range of capacities is available in space transportation by dividing business among companies that offer different classes of vehicle lift)

In addition, there are some disadvantages of *government-sponsored* prizes compared with privately sponsored prizes:

- Government typically cannot commit to funding beyond a fiscal year, thus limiting the timing of the prize competition and cutting short the time that might be required for the technical achievement it awards.

- Any uncertainty about whether the prize will actually be awarded due to government budgets or changes in administration will weaken if not eliminate incentives to compete.

- Intellectual property rights to the achievement may need to reside with the competitor to induce participation, even though the taxpayer, by financing the prize, could fairly claim rights. It is interesting to note that after contentious deliberations, in 1960 the U.S. government awarded the Guggenheim Foundation and Robert Goddard's widow $1 million in settlement for government use of more than 200 of Goddard's patents (Goddard died in 1945).[14]

Some of these disadvantages are also an outcome of traditional grants and procurement contracts. And, grants and contracts offer some advantages over prizes. What follows summarizes some of the differences:

Asymmetry of information: The engineer/entrepreneur may have a better idea of the technical riskiness of the R&D than the government. In this case, offering an award upon completion of rather than in advance of research lessens the cost to the government of pursuing highly risky innovation.

Information and uncertainty. While prizes put the burden of proof on competitors, grants and procurement contracts, by requiring up front information, can more promptly reduce (although not eliminate) uncertainty about whether the innovation is feasible. Prizes may go un-awarded for the duration of the competition, and only then, after this delay, might it be concluded that the technology is not yet feasible (although other reasons may explain the lack of a winner). Using prizes can thus delay a determination that a technology is infeasible and delay pursuit of alternative paths that might have been more quickly pursued under a grant or contract.

Cash flow. Grants and contracts, by providing funding up-front, underwrite early stages of innovation. Prizes, by providing an award only upon completion, could create cash-flow problems for contestants or require them to spend time and resources to find financial support during the competition.

Who bears financial risk. Financial risk rests largely with the taxpayer under grants and contracts and projects can fail or be terminated before providing any return to the taxpayer. Prizes do not guarantee success but the financial risk rests with competitors and their funders rather than the taxpayer.

Safety risk. The early history of aviation is replete with accidents and fatalities in pursuit of innovation, but efforts continued with scarcely a hiccup. The government's approach to safety risk is wholly different, as illustrated by the lengthy standdown of U.S. human spaceflight activities in the wake of the Apollo 1, Challenger, and Columbia fatalities.

Duplication of effort. A prize rather than a research grant made to one firm may have the advantage that "two (or more) chances are better than one" if there are several independent research

[14] See von Braun and Ordway.

programs. On the other hand, from a broad view of the nation's resources as a whole, there may be wasteful duplication of effort if there are simultaneous research programs all pursuing the same goal.[15]

Awardees' incentives. Most peer-reviewed grants result in publications and sometimes, patents. By and large, grants are not intended for nor do they typically result in commercial products or services. Procurement contracts can satisfy government-unique requirements or lead to commercial feasibility. The motives for competing for prizes are less clear – in the history of aviation prizes, only a few entrants themselves followed up with commercial product lines, but they may have collected patents (the data about the long-term pay-offs to aviation prizes are sparse). Typically an award recipient, whether it is an individual competing for a prize or a corporation winning a procurement contract, capitalizes any expected commercial value of the research or innovation into their decision whether to compete.

Basic research, technology development, and commercialization. All three approaches can underwrite basic research, technology development, or commercialization. For example, a university researcher with access to a laboratory may be as interested in competing for a prize as in competing for a research grant. A private inventor may compete for an award for modest improvements in technology or may be inspired to research more radical innovation, irrespective of commercial potential. Prizes have been awarded for solving mathematical problems (the Wolfskehl Prize for proving Fermat's last theorem[16]) as well as for technology development with commercial potential – the motives for pursuing an award seem varied.

Failure. All three approaches provide an opportunity to learn what "doesn't work." The Defense Advanced Research Projects Agency (DARPA), for example, had no winner in its recent, $11 million Grand Challenge race for robotic navigation of a 142-mile stretch of the Mojave Desert. DARPA admitted that it was pessimistic about a successful finish because the technology is not yet that advanced, but also pointed out that learning from mistakes is a way to advance technology. The agency plans to hold the competition again in 2006. Similarly, a recent government contract for a follow-on earth observation satellite system for the Landsat program was not awarded to any bidder because proposals did not meet all the criteria. In these cases, failing to find a winner signaled that the technology, cost, or both was not yet up to the expected par. The chance to learn more than this -- that is, to learn more about details of engineering design, engineering cost, and so forth – is limited, however, unless competitors are required to share information about their approach rather than keep the information proprietary.

Because of these differences in prizes, grants, and contracts, all three approaches, taken together, can provide a good portfolio of tools to encourage innovation. As an additional note, in all three approaches, ownership of intellectual property needs to be determined and will affect the public and private pay-off to the innovation.

V. NASA prizes

The candidate Centennial Challenges identified by NASA for prize awards range from very low cost spacecraft missions, to breakthrough robotic capability, to revolutionary technology demonstrations.[17] There is precedent in the history of prizes for awards to address all of these types of innovations. However, the specific candidate challenges that NASA has identified do not include prizes for earth science – even though the language accompanying the Challenges preamble embraces earth science. Innovation in earth sciences might be a good prospect for prizes given the rapid pace of new sensor development and the manifested interest of the private sector in earth observations.

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[15] Researchers have investigated the problem of "patent races" and whether simultaneous pursuit of a new technology leads to wasteful duplication. For example, see discussion in Jean Tirole (1988) *The Theory of Industrial Organization* (Cambridge, MA: MIT Press), Chapter 10.
[16] See National Academy of Engineering (1999) *Concerning Federally Sponsored Inducement Prizes in Engineering and Science* (Washington, DC: National Academy Press).
[17] See "Centennial Challenges Program" at http://centennialcallenges.nasa.gov/workshop.htm (accessed July 2004).

It is hard to outline a formula for determining the size of the prizes– awards set too low may just miss inducing an innovation; awards set too high result in taxpayers paying more than necessary to induce the innovation. Not all competitors will necessarily be pursuing commercialization or an ongoing supplier relationship, if the history of aviation prizes is a guide to motives for participation. For this reason, potential commercial profitability may not figure in competitors' participation decisions or be relevant to government's procedures for determining the size of the prize.

In any case, if a prize is offered but not awarded, the outcome may signal that the technology is simply not yet mature enough at that price – important information for government R&D managers. For "tent pole" technology development – that is, technology that is essential in furthering a goal – the uncertainty of success in a prize competition weakens the usefulness of prizes (although grants and contracts do not necessarily guarantee success either).

Shortcomings of government prize sponsorship, as noted earlier, include commitments to funding across fiscal years, political administrations, and different Congresses. Problems also involve determining an appropriate allocation of rights to intellectual property developed with taxpayer support but possibly of commercial proprietary value. It would be useful for competitors to share results even if their attempt is unsuccessful (learning by doing), but so doing could undermine expected private value and thus come full circle to discourage participation in the competition.

Involving a broad range of expertise, including outside experts, may be an advantage in structuring government-backed prizes. For instance, it may be desirable for a board of directors consisting of experts outside of government to administer and judge contests. Because a prize can "ferret out" new ideas, eligibility to compete should also be broad (the Centennial Challenges prohibit federal employees and employees of federally funded research and development centers (FFRDCs) from competing, but much talent in aerospace is at NASA centers and FFRDCs).

VI. Conclusions

The history of prizes is attractive enough to warrant experimenting with their use in NASA activities. Further review of the structure of previous contests (their guidelines, funding, and results) and in particular, their assignment of property rights would provide helpful "lessons learned" as plans proceed. But prizes cannot fully substitute for peer-reviewed grants and procurement contracts. Even though these funding mechanisms are far from perfect, they balance some of the disadvantages of prizes. Taken together, all of these forms of financial support make up a portfolio of tools for encouraging innovation.

Biography of Molly K. Macauley

Dr. Macauley is a Senior Fellow with Resources for the Future (RFF), a research organization established upon the recommendation of the presidentially appointed Paley Commission in 1952. Dr. Macauley's research at RFF includes the valuation of non-priced space resources, the design of incentive arrangements to improve space resource use, and the appropriate relationship between public and private endeavors in space research, development, and commercial enterprise. Dr. Macauley has been a visiting professor at Johns Hopkins University, Department of Economics, and at the John Hopkins School of Advanced International Studies. She has also been a visiting professor at Princeton University in the Woodrow Wilson School of Public Affairs. Dr. Macauley has testified before Congress on the Commercial Space Act of 1997, the Omnibus Space Commercialization Act of 1996, the Space Business Incentives Act of 1996, and space commercialization. She has served on many national level committees and panels including the congressionally mandated Economic Study of Space Solar Power (chair), the National Research Council's (NRC) Aerospace and Space Engineering Board's steering committee on issues of technology development for human and robotic exploration and development of space, the NRC Space Studies Board steering group on space applications and commercialization, and the NRC Space Studies Board task force on priorities in space research. In 1994, she was selected as one of the National Space Society's "Rising Stars," and in 2001 she was voted into the International Academy of Astronautics. Dr. Macauley has published extensively with more than 70 journal articles, books, and chapters of books. She has served on the Board of Directors of Women in Aerospace and is President of the Thomas Jefferson Public Policy Program, College of William and Mary. Her PhD in economics is from Johns Hopkins University and her undergraduate degree in economics is from The College of William and Mary.