

# A Sustainable Method for Quantifying the Benefits of NASA Technology Transfer

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Since NASA's creation, technologies developed to advance NASA missions have found secondary applications, leading to products, services, and processes that create jobs, generate profits, improve efficiencies, and even save and improve lives. Despite a general consensus that these "spinoff" benefits are prevalent, no consistent methodology, analytic framework, or sustainable system has been established to quantify their benefits using standardized measurements. Over the years many efforts have attempted to quantify benefits. Each, however, has had limitations including scope, data integrity, and sustainability. NASA has historically recorded its benefits anecdotally in its annual *Spinoff* report with qualitative discussions and ad hoc quantification, but has not developed a systematic method for capturing quantifiable benefits. This paper describes a new approach that NASA is developing to systematically and routinely capture quantitative benefits from its *Spinoff* stories each year, using a framework that is sustainable over time. Surveying approximately 200 commercialized technologies recently featured in *Spinoff*, NASA has developed a suite of standard categories that can be used to quantify benefits. By surveying firms represented by those stories in *Spinoff*, NASA was able to collect additional quantitative data retrospectively. NASA will use these new categories to collect and standardize reporting data each year, as the stories are collected and developed. While not comprehensive of all benefits generated by the Nation's investment in space research and technology, this new analytic framework provides a sustainable and consistent source of data from the top technology transfer successes published in *Spinoff* each year, with the data coming directly from the firms that are commercializing NASA technologies. The new quantification categories include: jobs created; revenue generated; productivity and efficiency improvements; lives saved/not lost; and lives improved.

## I. Background

One of NASA's primary objectives as outlined in the recent 2011 NASA Strategic Plan is to "drive advances in science, technology, and exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of Earth."<sup>1</sup> This mandate traces all the way back to NASA's founding, when the U.S. Congress first signed into law the Aeronautics and Space act of 1958 that created the space agency, in which the newly-formed agency was charged not only with exploring the universe and advancing aeronautics but also with transferring its technologies "for the benefit of all mankind."<sup>2</sup>

The primary purpose of the research and development (R&D) performed by NASA is to enable technology development to achieve capabilities needed for current and future NASA missions. In addition to enabling missions, however, there are many ancillary benefits of NASA R&D to the government, economy, and general public. These

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benefits are visible in our everyday lives in a wide array of applications ranging from the grocery store to the hospital.

Since 1976, NASA has generated anecdotal evidence of benefits using its annual *Spinoff* publication to document examples of private sector companies developing products and services derived in part or in full from NASA technologies and other resources.

The *Spinoff* publication accomplishes several goals. It serves as a tool to educate the media and the general public by informing them about the benefits of NASA's research. This fulfills a reporting requirement outlined in the National Aeronautics and Space Act of 1958 that requires NASA to find secondary uses for its technologies and to inform the public of both these secondary applications and opportunities for additional technology transfer. As an added benefit of this reporting, the positive results of technology transfer activities resonate with the public, demonstrating tangible benefits from the Nation's investment in space and aeronautics.

Recently, to illustrate these terrestrial benefits, NASA created a web feature called *NASA Home and City* designed to help the public understand how ubiquitous the benefits of space technology can be.<sup>3</sup> Additionally, all 1,750 examples of NASA spinoff technologies have been documented in the agency's annual *Spinoff* publication are now searchable in an online database.<sup>4</sup>

## A. Prior Studies of NASA's Economic Benefit

Many attempts have been made to examine the economic benefits of NASA's technologies while each study independently has value; there is no consistent coherent, standardized analytic framework by which benefits are characterized. As a result, these benefits are difficult to measure, and quantify, both collectively and longitudinally. Identifying a source of consistent data for measuring the benefits is challenging. As a result, benefits are often characterized anecdotally.

A wide variety of systems, equations, algorithms, theories, and methodologies of measurement and quantification of these secondary benefits have been proposed and developed through numerous studies and surveys, the most comprehensive of which are summarized in Table 1. However, none has been able to generate a defensible and generalized mechanism that has been sustainable. Many analytic models used in past studies use economic multipliers based on input/output models that are based on generalized data not traceable to specific examples. To address this weakness, it would be appropriate for data to come from the companies who are actually commercializing the technology; as is often the case, however, companies are reluctant to share the data due to concerns related to its proprietary nature and or the time required to collect the data. There are many potential quantitative measures of benefits in addition to those that are dollar-based, such as revenues or profits. These measures could range from *jobs created* to *efficiency improvements* and *environmental remediation*.

As noted above, the quantification, and particularly the aggregation, of data can be difficult if there is no standardized set of measures of quantification. Even in the case where the companies themselves provide the data, if there is no internal consistency in the measures being used, data cannot be reliably combined to enable aggregate quantification of overall benefits.

The reliability of studies of economic benefits could be improved by having traceable data with identifiable and specific sources rather than data or ratios based strictly on economic models. A generalized method could be established by identifying standard categories of measurement that are used consistently and which are easily understood by those providing the data. For data collection to be consistent and coherent over time, and thus sustainable, a common set of analytic categories must be developed, and reporting must be standardized. In addition, data collection protocols must be incorporated into routine processes and activities, instead of collecting data intermittently and outside of standard processes.

While limited in utility or scope, many of the past studies are still useful today to illustrate particular aspects of the economic benefit of space research and technology development. As noted earlier, often these studies (summarized in Table 1) have resulted in an economic or productivity impact model or the development of a numeric ratio expressing the effect of economic benefit from investments in NASA. Studies have indicated discounted rates of return from 33% to 43%, and include ratios from around 7 up to a 23.4<sup>iv</sup> multiplier effect depending on the study, its criteria, and its methodology. Another ratio often calculated in past studies is the number of jobs created as a result of investment in NASA.<sup>5</sup> The multiplier for jobs created as a result of every \$1 million (2009 dollars) invested in NASA ranges from 7.8<sup>6</sup> to 19.4<sup>7</sup> over several studies conducted on this subject.<sup>v</sup>

<sup>iv</sup> Mathematica calculated the high measure in a study based on the benefits of a technology transfer program that infused little funding into the effort. It is therefore not an accurate measure of national cost/benefit effect of NASA R&D funding. It is, nonetheless, often used as such.

<sup>v</sup> It should be noted that these ratios were developed on a regional basis, around NASA Field Centers and are not representative of national impact.

In summary, in spite of the lack of a consistent analytic framework, and an almost exclusive reliance on the capture of *economic* benefits, many of these studies have weathered years of criticism and analysis and still provide a useful foundation and context for future studies. A few of the most comprehensive of these studies are summarized below.

**Table 1.** Over the past several decades, there have been many efforts to quantify the benefits of NASA’s technology transfer efforts. This table summarizes several of the most significant, their methodologies, and their limitations.

Date	Study	Methodology	Quantitative Findings	Limitations
1971	Economic Impact of Stimulated Technological Activity,” Final Report, Midwest Research Institute, Contract NASW-2030	<ul style="list-style-type: none"> <li>• Macroeconomic projections</li> </ul>	<ul style="list-style-type: none"> <li>• Average 7:1 rate of economic return on each dollar invested in NASA</li> <li>• Discounted rate of return on NASA investments of approximately 33%</li> </ul>	<ul style="list-style-type: none"> <li>• Limited to ratios of R&amp;D expenses to national economic gains</li> </ul>
1976	“Quantifying the Benefits of the National Economy from Secondary Applications of NASA Technology,” Mathematica	<ul style="list-style-type: none"> <li>• Case studies of four major NASA technology categories (cryogenics, gas turbines, integrated circuits, and NASTRAN computer system)</li> </ul>	<ul style="list-style-type: none"> <li>• \$1B estimated benefit of NASA contribution to cryogenics</li> <li>• \$5B estimated benefit of NASA contribution to integrated circuits</li> <li>• \$111M estimated benefits of NASA contribution to gas turbines</li> <li>• \$701M estimated benefit of NASTRAN</li> </ul>	<ul style="list-style-type: none"> <li>• Small data set, lacking comprehensive overview of full NASA technology transfer portfolio</li> <li>• Not sustainable</li> <li>• Dated</li> <li>• Restricted only to revenue generation</li> <li>• Forward-looking projections of future benefit</li> </ul>
1976	Michael K. Evans, “The Economic Impact of NASA R&D Spending,” Chase Econometric Associates, Inc., Bala Cynwyd, Pennsylvania, Contract NASW-2741	<ul style="list-style-type: none"> <li>• Simulations and modeling</li> </ul>	<ul style="list-style-type: none"> <li>• Average 7:1 rate of economic return on each dollar invested in NASA</li> <li>• Historical rate of return from NASA R&amp;D spending of 43%</li> </ul>	<ul style="list-style-type: none"> <li>• Focused solely on economic forecasting and projections using theoretical increases and decreases in NASA funding</li> </ul>
1988	“Economic Impact and Technological Progress of NASA Research and Development Expenditures,” Executive Summary, Midwest Research Institute, Kansas City, Missouri, for the National Academy of Public Administration	<ul style="list-style-type: none"> <li>• Macroeconomic projections</li> </ul>	<ul style="list-style-type: none"> <li>• Average 9:1 rate of economic return on each dollar invested in NASA</li> <li>• Discounted rate of return on NASA investments ranging between 19 and 35%</li> </ul>	<ul style="list-style-type: none"> <li>• Limited to ratios of R&amp;D expenses to national economic gains</li> </ul>
1989	“An Exploration of Benefits from NASA ‘Spinoff,’” Richard L. Chapman, Loretta C. Lohman, and Marilyn J. Chapman	<ul style="list-style-type: none"> <li>• Examination of 259 published <i>Spinoff</i> stories</li> <li>• Telephone interviews and inquiries</li> </ul>	<ul style="list-style-type: none"> <li>• \$21.3B NASA contributions to sales</li> <li>• \$315.7M NASA contributions to cost savings</li> <li>• 325,000 jobs created/saved</li> <li>• \$365M in tax receipts</li> </ul>	<ul style="list-style-type: none"> <li>• Data set restricted to NASA <i>Spinoff</i> companies</li> <li>• Restricted to revenue from sales and cost savings</li> </ul>
1993	“The Nature and Extent of Benefits Reported in NASA ‘Spinoff,’” Richard L. Chapman, Marilyn J. Chapman, Mary F. Chapman, and Jody Briles	<ul style="list-style-type: none"> <li>• Examination of 353 published <i>Spinoff</i> stories</li> <li>• Telephone interviews and inquiries</li> <li>• Continuation of 1989 Chapman Report</li> </ul>	<ul style="list-style-type: none"> <li>• \$32B NASA contribution to sales</li> <li>• \$1B NASA contributions to cost savings</li> </ul>	<ul style="list-style-type: none"> <li>• Data set restricted to NASA <i>Spinoff</i> companies</li> <li>• Not repeated</li> <li>• Restricted to revenue generated and savings</li> </ul>
1994	“The Economic Impact of the Space Program: A Macro and Industrial Perspective,” prepared for Rockwell International by The WEFA Group, Bala Cynwyd, Pennsylvania	<ul style="list-style-type: none"> <li>• Economic modeling</li> </ul>	<ul style="list-style-type: none"> <li>• Estimated 380,000 NASA-generated jobs by 1997</li> <li>• \$153.5B in GDP generated by NASA-related activity by 2000</li> </ul>	<ul style="list-style-type: none"> <li>• Restricted to job growth</li> <li>• Restricted to human spaceflight and ISS</li> </ul>
1997	“Space as an Investment in Economic Growth,” Henry R. Herzfeld	<ul style="list-style-type: none"> <li>• Surveys</li> <li>• Telephone interviews and inquiries</li> <li>• Literature review</li> <li>• Case studies</li> </ul>	<ul style="list-style-type: none"> <li>• Over \$1.5B in value added to 15 NASA life sciences partner firms</li> </ul>	<ul style="list-style-type: none"> <li>• Small dataset, restricted to 15 program-specific technologies</li> <li>• Difficulty collecting data, survey responses</li> <li>• Not repeated</li> </ul>

1. “*Quantifying the Benefits of the National Economy from Secondary Applications of NASA Technology*” *Mathematica*, 1976.

One of the early major studies of NASA’s economic influence was conducted by Mathematica Inc. in 1976, “Quantifying the Benefits of the National Economy from Secondary Applications of NASA Technology,” and laid the foundation upon which many subsequent studies of these benefits have been based. According to the researchers:

The purpose of this study was to develop preliminary estimates of the economic benefits to the U.S. economy from secondary applications of ‘NASA technology.’ If technology is defined as the body of knowledge concerning how society’s resources can be combined to yield economic goods and services, then NASA technology represents NASA’s contribution to this body of technical knowledge. Secondary applications refer to uses of NASA generated knowledge for purposes other than those primary mission-oriented ones for which the original R&D was done. These applications occur whenever a non-NASA entity, with or without encouragement from NASA, uses this knowledge in some economic activity.<sup>8</sup>

In this study, Mathematica examined four major technology categories: cryogenics, gas turbines, integrated circuits, and the NASA Structural Analysis (NASTRAN) computer system. Mathematica based its analysis of these four categories on microeconomic consumer surplus theory. The goal of this approach was to form “an understanding of how technological change generates economic benefits and a determination of the role that NASA can play in the process of technological change.” In order to capture data from these technology categories, Mathematica conducted case studies of exemplary partnerships between non-government entities and NASA, selecting these based upon the availability of existing data and the estimated superiority of their success in generating benefits.

In the category of cryogenic multilayer insulation materials, “the ‘best guess’ or ‘probable’ estimate of benefits [due to cost savings via implementation and use of NASA technology] was \$1,054 million.” In the category of integrated circuits, “based on a simultaneous equation estimation of the demand for integrated circuits [a NASA-pioneered technology], the ‘probable’ estimate [of benefits] was \$5,080 million.” In the category of gas turbines for electric power generation, the “‘probable’ estimate of the total fuel cost savings [using NASA-pioneered gas turbines instead of other available power sources] of \$111 million was determined.” In the final category of the NASTRAN software package, “the ‘probable’ benefits accruing to the population of NASTRAN users were estimated at \$701 million.” This “indicates that the total benefits due to NASA for the four cases studied are probably on the order of \$7 billion.”

Mathematica concluded the study by stating that a few “general observations could be safely made: operational methods can be developed for estimating the secondary benefits of mission oriented R&D, secondary benefits attributable to NASA’s R&D programs may be impressively large (for example, the \$7 billion total for the four cases studied is more than twice NASA’s present [(1976)] yearly budget), and because secondary benefits may indeed be significant, public decisions concerning the allocation of resources to research and development programs should, where possible, consider such benefits.”

While this study set the stage for future work in this field, it had several key limitations. It lacked a comprehensive overview of the full NASA technology transfer portfolio; rather than providing an all-inclusive portrait of NASA’s work, limited its scope to four known successes and NASA’s role in speeding up the process by which new technologies were developed. Another limitation is that it focused only on revenue generation as a result of technology transfer. While revenue generation is a compelling unit of analysis, this figure is really *only one* of the potential quantifiable datasets that could have been uncovered. In addition, Mathematica also used projections of anticipated revenue. While a common and accepted economic modeling practice, this does introduce a degree of uncertainty.

1. *Chapman Report, 1989*

In 1989, Chapman Research Group Inc. conducted a study “to explore those applications of NASA technology (or NASA-assisted technology transfer) that have been reported in the annual report, *Spinoff*.”<sup>9</sup> NASA’s *Spinoff* publication was used as the source of data for this study based upon its abundance of well-documented cases of successful technology transfer and partnership between NASA and non-government entities. “The primary focus of the study [was] the nature and extent of benefits from the application of NASA developed or NASA provided technology.”

While the Mathematica study focused on four well-established technologies, the Chapman report took a broader approach, looking at a large sampling of recent successes.

Chapman developed a list of contacts by cross-referencing the information in *Spinoff* articles and files with former Denver Research Institute case files and other available company directories. An interview guide was then developed and used consistently in eight months of telephone interviews. Chapman used a spreadsheet system to keep records of the interviews.

With a review of several hundred technologies featured in the *Spinoff* publication and interviews with the featured companies, Chapman determined that:

There are six principal means by which NASA technology is spun off to other uses: direct use, making a market, facilitating commercialization, indirect NASA assistance, employee spinoff, spinoff to public agencies, and spinoff resulting from regular NASA activity. Each of these means has its own or shared characteristics and considerably broadens the opportunities for successful application and use.

After using these means to categorize the spinoff benefits, Chapman attempted to express these benefits in dollar figures, either as sales or saving, or as a percentage of business. The figures for this broad study were relatively modest compared to the results of the Mathematica study:

Of the 259 cases [examined in this study] in which the respondents were able to identify sales or savings, it was possible to identify contributions toward sales of \$21.3 billion. Contributions toward savings were \$315.7 million. Total contributions toward sales and savings were \$22 billion. This figure excludes nearly \$12 billion in sales that included NASA-furnished technology, but which were given as total sales figures for a company, including all products.

Chapman's data collection revealed something else, too. Of the 259 companies interviewed, there were 67 instances in which a product, process, or even an entire company would not have come into existence had it not been for the NASA-furnished technology. These represented 18% of all cases involving sales/savings and amounted to \$5.1 billion in sales/savings.<sup>10</sup>

Chapman also noted that there was room to postulate other benefits of economic value, specifically the jobs created or saved that could be associated with the revenue of the companies in the *Spinoff* cases. "Using standard economic projection procedures, [Chapman asserted that] it is estimated the Federal Government received corporate income tax receipts of nearly \$356 million as a result of these spinoffs and that over 352,000 jobs were created or saved. And these jobs were in relatively high skilled categories."

In addition to economic benefits, Chapman realized after conducting the case studies that many other benefits outside of the obvious and quantifiable economic benefits existed, and that these benefits, although essentially non-quantifiable, were of significant value. "It was possible to classify [these benefits] into five general categories: provided knowledge/technology of a critical/valuable nature; opened new opportunities; helped meet 'competition;' promoted safety, facilitated meeting regulatory requirements, improved working conditions, or improved the quality of life; and, avoided R&D 'dead ends.'"

This study suggests "the need for early and systematic attention to means for identifying and tracking potential spinoff applications—if only to more fully understand this phenomenon and its contributions to the nation. This study cannot answer the question: 'What proportion of the total technology transfer benefits from NASA does this [data] represent?' In order to approach an answer to this question, the next logical step [according to Chapman] is to attempt the characterization of NASA's technology transfer efforts—both formal and informal; then to determine an acceptable means to explore that universe."

The report also laments that, despite the possibility of measuring some economic returns on the technology transfer successes, any attempt to limit the discussion to this focus neglects the other non-quantifiable benefits of NASA's technology transfer results.

Recognizing the limitations of a one-time study to tell a comprehensive story of an evolving and program, the researchers also recommended that NASA conduct this type of study regularly in order to best capture data related to its technology transfer results.

As a result of the numerous and successful findings of this study, Chapman Research Group Inc. conducted a follow-on study again in 1993.

### 3. Chapman Report 1993

According to the 1993 report, "Several years after the completion of the 1989 study, NASA commissioned the Research Triangle Institute to develop a 'user friendly' database, using information from the Chapman study. Once

this was in place, the need to provide more up-to-date information was considered necessary, and plans were made for an update of the 1989 study, covering those articles that appeared in the annual *Spinoff* publication for the years 1987 through 1991.”<sup>11</sup>

In order to maintain some level of continuity and comparability of data, the researchers approached the data collection in the same way, contacting companies that had been featured in *Spinoff* and asking similar questions.

This study demonstrated that time necessarily plays an important role in the calculation of NASA’s economic impact. The research:

showed additions to already determined sales (from the 1989 study) of \$10,492,092,000—an increase of 48 percent over the old total of \$21,331,190,000. This provides a grand total of contributions toward sales of \$32,139,031,000. On the savings side this updated added \$734,385,700, an increase of 232 percent over the figures collected in the 1989 study. This brought the grand total of contributions of savings to \$1,050,135,000. Thus, it is fair to say, that based on 353 completed cases where users were willing to give estimates on contributions to sales or savings by NASA developed, furnished, or assisted technology, that there was a grand total of contributions to sales or savings of over \$33 billion resulting from these examples from the annual *Spinoff* publication.<sup>12</sup>

The 1993 study also reaffirmed the existence and value of the other, non-quantifiable benefits detailed in the 1989 study and the importance of recording these benefits.

The conclusions drawn from this follow-up study were the same as those of the 1989 study: that the economic and “other” benefits of NASA spinoff technologies need to be acknowledged, studied, and systematically tracked and quantified. This research also showed the importance of continued tracking of technologies in order to get a more accurate impression of their impact.

#### 4. Hertzfeld, 1997

In 1997, Dr. Henry Hertzfeld, Research Professor of Space Policy and International Affairs at the George Washington University, examined the various methods that have been used to assess NASA’s economic benefit. While admitting that economists are not in agreement about the methods and approaches, he concluded that multiple units of analysis would yield a more effective measure of the benefit of investing in space research and technology. Hertzfeld summarized and detailed the majority of existing studies attempting to measure the benefits of NASA R&D and found limitations in each of the major economic models employed. After reviewing much of the work done previously on this subject, Hertzfeld concluded that:

The process of calculating and equating a rate of return to NASA (or any other government) expenditures with a rate of return to an equivalent private investment in a venture with high levels of risk is not accurate. Although there may well be robust returns to NASA R&D, using the type of methodology and statistics available when these studies were performed was much more of an exercise in doing research and experimentation on economic methodology than it was in measure the benefits to NASA’s programs.<sup>13</sup>

Hertzfeld conducted a pilot study intentionally limited to a subset of economic benefits from a subset of NASA’s research portfolio, the Life Sciences Program. The study used a methodology designed to create an aggregate measure of economic impact taken from the cumulative benefits provided by several different technologies. The goal was not, however, to find the elusive dollar investment to return ratios, but rather to illustrate that, regardless of the multiplier, the public realizes significant and substantial benefit from NASA technology transfer.

The study focuses on 40 companies (15 of which responded) that had previously acknowledged successful sales of NASA-enabled products and then developed an orderly and consistent method for surveying the companies. It focused on several specific areas of benefit: sales, commercial benefits of association with space brand, commercial benefits of ventures brokered by NASA, application of space program management models to commercial ventures, and the role of the highly-skilled space sector employee in the success of a commercial venture. When Hertzfeld applied various types of data measurement, most could be summarized as a function of productivity.

Like the Chapman reports, Hertzfeld’s study began with surveys of companies featured in NASA’s *Spinoff* publication but also interviewed NASA personnel for additional suggestions. Most of the data, however, came from management at the partner companies who provided the detail specific to this study.

The benefits examined were divided into four major categories: technological effects, commercial effects, organization and methods effects, and work-factor effects. Product sales were then attributed to each category using

information gathered from the interviews. This figure was then modified by the percentage that could be attributed to the core R&D funding.

A summary of the findings of this study includes the following data and propositions:

Over \$1.5 billion in value added can be attributed to the investment in life sciences from NASA in [the] fifteen firms [which provided useful data for this study] alone; the benefits are purposely understated by not quantifying social benefits (even when they have been identified); other firms are known to have claimed successful commercial applications from NASA Life Sciences R&D; there are many documented examples of social benefits from space life sciences research that are not associated with commercial products; and, NASA's life sciences total expenditures over the past 40 years [(to 1998)] has amounted to approximately \$3.7 billion (which includes many mission related projects that have made it possible for NASA to engage in manned space flight and for which there have been with no expected commercial benefits).

One of the conclusions Hertzfeld was able to draw from his data was that, even with the relatively small sampling of companies, "NASA Life Sciences investments have more than 'paid for themselves.'"<sup>14</sup> Hertzfeld also arrives at a list of recommendations based upon the conclusions reached in this study. First, NASA should continue a regular program of monitoring not only spinoff successes but also their impact. Second, NASA should continue to foster relationships with companies that have commercialized NASA's technologies, as these relationships could be beneficial to both parties. The establishment of a new NASA program office to implement these suggestions would be, he suggested, unnecessary. The existing technology transfer offices could supplement their regular activities with more routine follow-up of partner companies; and the tracking of benefits could become an ancillary portion of that routine function. Additionally, he recommended NASA establish an "ombudsman" type position to help these companies test and use their technologies with other government agencies, given that many of them expressed the frustration with overcoming the stage between R&D and a true commercial product. Another recommendation was that the NASA R&D money also acted as a stimulus for the company itself to invest more into their R&D, both to perfect the technology and to develop the market for it.

### 5. Additional Relevant Study Data

The following studies attempted to calculate the impact of NASA's technology transfer activities using different economic models. While interesting representations of NASA's economic impact, without the granularity of survey data, they provide only an argumentative framework for the proposition that NASA technologies create public benefit and are therefore as useful in the effort to quantify NASA's technology transfer benefits as the collected anecdotal evidence NASA can already provide through its *Spinoff* publication.

#### a. *Economic Impact of Stimulated Technological Activity," Final Report, Midwest Research Institute, Contract NASW-2030, October 15, 1971.*

This study measured the effect of investment in technology and R&D during a period between 1949 and 1968 and found that, on average, each dollar spent on R&D returns slightly over seven dollars in technologically induced economic gains over an 18-year period following the expenditure. According to this report, \$25 billion, in 1958 dollars, spent on civilian space R&D in the time between 1959 and 1969 returned \$52 billion through 1970 and will continue to produce payoff through 1987, at which time the total payoff will have been \$181 billion. The discounted rate of return for this investment will have been 33 percent.<sup>15</sup>

#### b. *Michael K. Evans, "The Economic Impact of NASA R&D Spending," Chase Econometric Associates, Inc., Bala Cynwyd, Pennsylvania, Contract NASW-2741, April 1976.*

Like the Midwest Research Institute report, this study showed an overall seven-to-one return on NASA expenditures but arrived at this figure using different methodology.

Additionally, the study suggests that a sustained increase in NASA spending of \$1 billion for the 1975-1984 period would increase the gross national product (GNP) by \$23 billion by 1984; reduce the rate of increase in the Consumer Price Index by 1984 such that it would be a full 2 percent lower than indicated in the baseline projection; reduce the unemployment rate by 0.4 percent by 1984, and increase the size of the labor force so that the total number of jobs would increase by an additional 0.8 million; and by 1984 increase productivity in the private non-farm sector by 2 percent more than the baseline projection.<sup>16</sup>

c. “*Economic Impact and Technological Progress of NASA Research and Development Expenditures,*” Executive Summary, Midwest Research Institute, Kansas City, Missouri, for the National Academy of Public Administration, September 20, 1988.

Another Midwest Research Institute study, this one replicated the methodology of the group’s 1971 analysis but this time calculated a nine-to-one return.<sup>17</sup> The MRI studies analyzed specific technologies and the economic impact of those technologies. Many were in aeronautics. All of them were detailed in a companion volume to the one that focused on overall aggregate values.

d. “*The Economic Impact of the Space Program: A Macro and Industrial Perspective,*” prepared for Rockwell International by The WFA Group, Bala Cynwyd, Pennsylvania, May 1994.

This report suggested that by 1997, NASA-related activity would have created 380,000 jobs, and an estimated \$23.49 billion economic output in the U.S. economy would be tied to activities at NASA. It goes on to project that in the years between 1995 and 2000, the space program will contribute a cumulative addition of \$130 billion to real GDP.

This report also focused on human space flight, estimating that in 1997 there would be 179,000 jobs in the U.S. economy created by the human space flight activities, with an estimated \$8.37 billion of real GDP in the U.S. economy. The report goes on to explain that additional and valuable spinoff technologies would be lost if the human space flight program were eliminated.<sup>18</sup>

## B. Observations

As the above summaries and discussions illustrate, a variety of researchers have taken multiple approaches to quantify NASA’s technology transfer benefits, and many have found different results. Some of the challenges and limitations revolve around the size of the data set, the scope of the benefits being recognized, and even the reliability of the projections and modeling being done without solid data. The common conclusion, however, is that NASA’s R&D yields tangible and economic benefit in addition to the meeting mission needs. Another common conclusion noted in many of the studies is that NASA should develop a sustainable approach to gathering this information.

## II. Establishing Standardized Quantification Categories

A critical first step for a systematic approach to capturing quantitative benefits is defining standard categories of quantification.

Many previous attempts to document quantitative benefits pulled from the *Spinoff* publication, where articles are classified into the following categories, depending on where the benefits are seen: health and medicine, transportation, public safety, consumer goods, energy and the environment, information technology, and industrial productivity. A systematic approach—one that reaches across all of those benefits categories—would be most useful in capturing a fuller story of NASA’s benefit.

As with many of the previous studies, this effort focuses on those stories that have been published in *Spinoff*, but an attempt has been made to find broader, quantifiable classification of the benefits.<sup>vi</sup>

### A. Assessment Process

While the anecdotal evidence provides a collective overview of the character of NASA’s technology transfer activities, a structured and measurable quantification of the benefits of these commercialized technologies is lacking. NASA generates many technology transfer success, and 40-50 of the most compelling of the known successes each year are published in *Spinoff*. Just as the stories within the publication have been categorized into subject categories (health and medicine, transportation, etc.), across these categories, there should be standard classification of the actual benefits in quantifiable terms.

In order to develop an architecture of standard classification, 187 *Spinoff* stories featured over the years 2010, 2009, 2008, and 2007 were examined in detail with the intent of assessing and validating a set of quantifiable measures of benefit due in part or in full to NASA’s influence on the company’s product or service.

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<sup>vi</sup> While the collection of *Spinoff* stories does not exhaustively capture all of NASA’s technology transfer successes, it is still the most complete record and therefore a reliable starting point.



### 1. Quantification Categories

The previous studies attempting to quantify the benefits of NASA technology have identified numerous categories in which to group the benefits, some of which are summarized in Table 2 below:

**Table 2.** Many different categories have been used to classify NASA’s public benefit.

Provided knowledge of a critical nature	Provided technology of a critical nature	Opened new opportunities	Helped meet “competition”	Promoted safety	Commercial effects
Workforce effects	Improved working conditions	Improved quality of life	Avoided R&D “dead ends”	Sales	Organizational Effects
Commercial benefits of association with space brand	Commercial benefits of ventures brokered by NASA	Application of space program management models	The role of highly skilled space sector employees in the commercial venture	Technological effects	Facilitated meeting regulatory requirements

This range of potential benefit categories provides insights into the nature of benefits, but may not be easily understood by many, and some may be difficult to quantify. An objective of this analysis is to develop a suite of standardized, easy-to-understand quantitative benefit measures that can be used consistently across most *Spinoff* stories. While all *Spinoff* stories may not include all of the benefits, the goal is to have most stories covered by at least one or more of the quantitative measures in the standardized group of categories. To initiate this assessment, five categories of benefit were initially identified.

A range of candidate categories was discussed internal to NASA, and there were brainstorming sessions using the collective experience of several members of NASA’s technology transfer team. The result was five draft categories to use in the initial assessment. The draft categories were:

- Jobs created, measured in number of jobs
- Revenue generated, measured in dollars
- Productivity and Efficiency Improvements, measured in dollars
- Lives Saved/Not Lost, measured in number of individuals
- Lives Improved, measured in number of individuals

A sixth category designed to capture environmental-related benefits was also desired. An easy to understand and comprehensive standard measure of environmental benefit was not evident as the analysis began, although possibilities such as tons of carbon reduced were considered.

Four key objectives drove the assessment of recently published *Spinoff* stories. First was a qualitative assessment, based on the content of the story, of whether there was likely a benefit in one of the identified categories that would have resulted from the spinoff. Second was to identify whether there was a quantitative benefit included in the story and if so, to capture that benefit in one of the draft categories. Third was to identify where there may have been a quantitative benefit described by the story that was not captured by one of the draft categories, and identify what that benefit was. The final goal was to develop an effective standard category to measure environmental benefit.

#### a. Jobs Created

This category measures the number of people a company has hired since it started to use or produce a NASA-derived product or service. If the company was created to produce or offer this NASA-derived product or service, then all employment at that company could be considered to result from this technology transfer.

The employees accounted for in this category must be in some way related or essential to the invention, production, sale, and/or implementation of this product or service. The jobs created may therefore be attributable in part or in full to NASA, as the employees may not have been employed had the company not commercialized the NASA-derived technology.

It can be expected that most *Spinoff* companies should be able to provide some number of jobs created as a result of NASA technology transfer, because each company will require employees to produce the NASA-derived product or service.

*b. Revenue Generated*

This category measures the revenue in dollars generated by a company producing or offering a product or service that is a direct application or spinoff of NASA technology. These revenues must fully or partially have depended on the company's commercialization of the NASA technology and resulting product or service.

It can be expected that all *Spinoff* companies should be able to report some revenue as a result of NASA technology transfer because to qualify as a spinoff it must have demonstrated sales of its NASA-derived product or service.

*c. Productivity and Efficiency Improvements*

This measures, in dollars, the costs that have been saved or avoided due to use of a product or service that is a direct application or spinoff of NASA technology. This could include costs saved directly by a company or their customers as a result of improvements in efficiency in operations or production, including reduced fuel or energy consumption. Dollars is a good standard unit of measure for this category, as most processes could be in some way related to dollars. For example, energy efficiency could be translated into dollars by costs avoided by reducing fuel or power costs. Process improvements could be translated into dollars by reduced capital expenditure required for equipment or lower costs associated with waste or rework.

*d. Lives Saved/Not Lost*

This measures the number of people whose lives were not lost as a result of a product or service that is a direct application or spinoff of NASA technology. The persons in this category must have been faced with a situation in which they would likely not have survived had the NASA-derived product or service not been present to prevent their death. Whether secondary or primary, this technology must have played a role in the rescue, revival, or healing of these persons which prevented them from perishing.

*e. Lives Improved*

This measures the number of people whose lives have been extended, enhanced, and/or improved by a product or service that is a direct application or spinoff of NASA technology. Simply using a product or service is not sufficient to be included in this measure. To be included, the technology must have materially contributed to the betterment of the health, quality of life, environmental conditions, and/or safety of these persons. For example, consuming a NASA-derived electrolyte drink to replenish fluids after exercise is not sufficient, but a premature baby using a NASA-derived baby formula with a unique algae-based nutritional supplement essential for early brain development is. Wearing sunglasses developed with NASA technology is not sufficient, but being able to go outside due to NASA technology when previously confined indoors due to risk of UV exposure is sufficient.

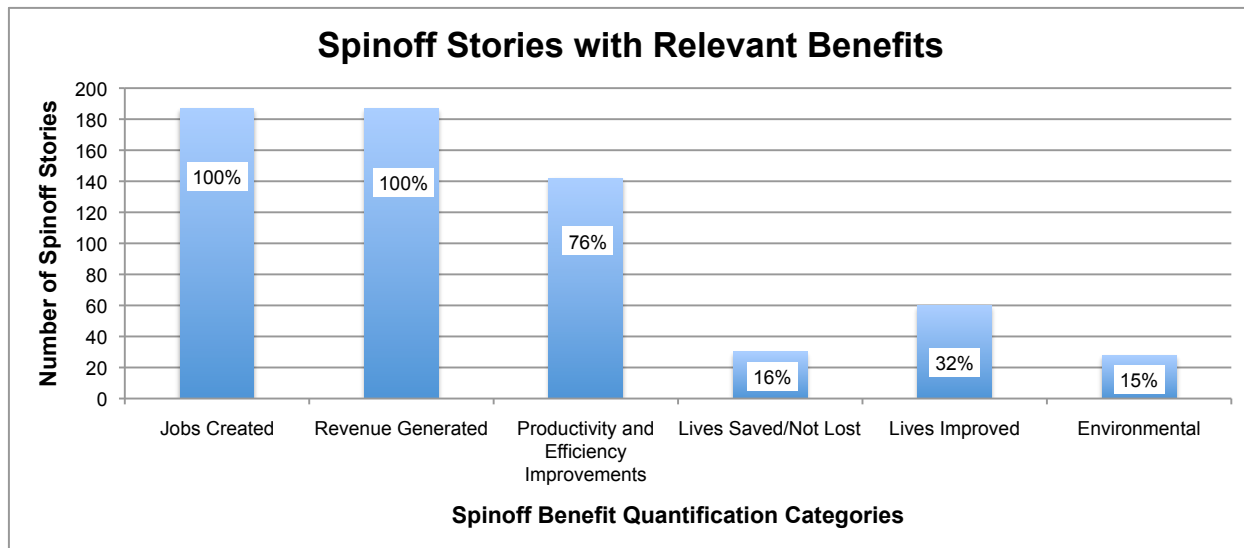
### III. Spinoff Analysis Results

To assess the efficacy of the draft quantification categories, a thorough examination of the 187 examples from the 2007–2010 issues of *Spinoff* was conducted. As summarized previously, the objectives of the analysis were fourfold:

1. A qualitative assessment, based on the content of the story, of whether there was likely a benefit in one of the identified categories that would have resulted from the spinoff.
2. Identify whether there was a quantitative benefit included in the story and if so, to capture that benefit in one of the draft categories.
3. Identify where there may have been a quantitative benefit described by the story that was not captured by one of the draft categories, and identify what that benefit was.
4. Develop an effective standard category to measure environmental benefit.

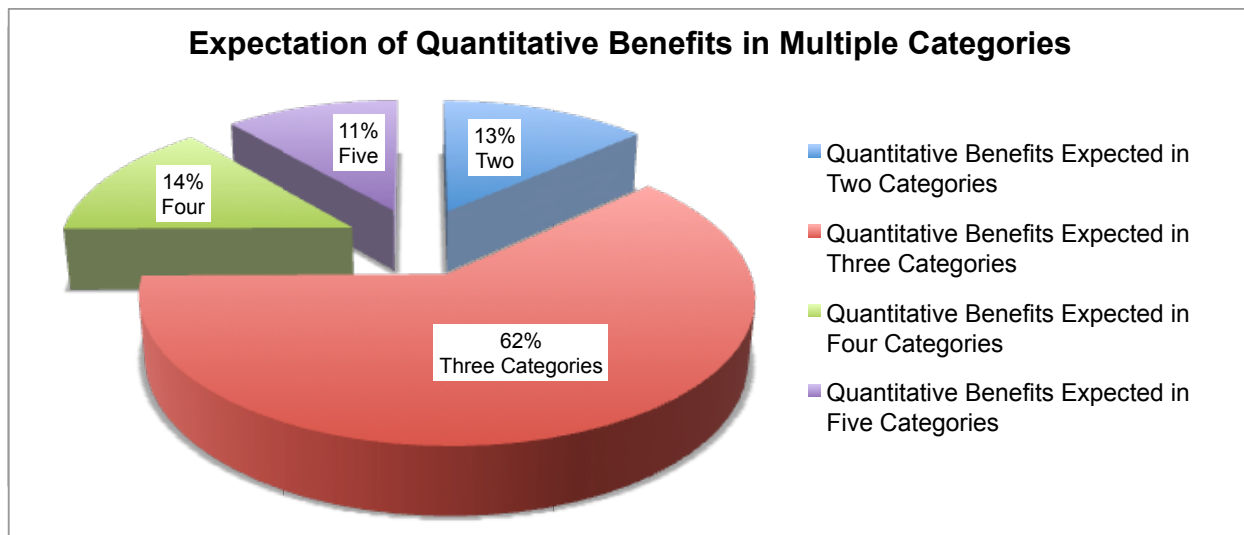
Figure 1 below provides the results of the first objective, indicating the number of the assessed *Spinoff* stories where benefits in each of the categories *could be expected to be found* based on the *qualitative* description of benefits in the stories. All stories were expected to be able to provide some quantitative value for the number of jobs created and revenue generated. Of the 187 stories assessed, 142 (76%) were expected to be able to show some sort of productivity or efficiency improvements, 30 (16%) were expected to be able to demonstrate that they resulted in

lives saved or not lost, 60 (32%) were expected to show that they could demonstrate quality of life improvement, and 28 (15%) were expected to show some quantitative benefit relevant to environmental cleanup or remediation.



**Figure 1.** 187 Spinoff stories from 2007-2010 were analyzed to identify the percentage that would be expected to have quantitative benefits in each of several different candidate quantification categories.

Another important issue to assess is the degree to which the candidate quantification categories effectively represented the benefits to be expected from the *Spinoff* stories. The results of this analysis are shown in Figure 2. As noted in Figure 1 above, all stories were expected to show benefits in terms of jobs created and revenue generated, but most stories also were expected to show benefits in other categories as well. Only 13% of the stories had only jobs and revenue benefits whereas the majority (62%) were expected to have quantitative benefits in one of the other categories. 14% showed benefits in four categories and 11% in five categories.



**Figure 2.** The percentage of all spinoff stories expected to show quantitative benefits in multiple categories.

The second objective of the analysis was to determine the number of stories that had already published quantitative benefits in each of the candidate quantification categories. The results of this analysis are summarized in

Table 3. It is clear from these results that a small proportion of *Spinoff* stories that were expected to have quantifiable benefits in each of the categories actually documented the benefits in those categories. While all stories were expected to have quantifiable benefits from jobs and revenue, only 8 (4%) had jobs data and 9 (5%) had revenue data documented in the *Spinoff* publication. Similarly for the other categories, only 4 (2%) of stories included quantitative productivity and efficiency improvements or lives improved benefits and only 2 (1%) included quantitative numbers on lives saved or not lost.

**Table 3.** This table depicts the categories where we found measurable benefits and were then able to harvest existing information.

	Jobs Created	Increased Revenue	Productivity and Efficiency Improvements	Lives Saved/Not Lost	Lives Improved
	1,665	\$532M	\$4.13B	695	30M
Percentage of Companies	4%	5%	2%	1%	2%

While the availability of published data in these quantification categories is low, the aggregate benefit numbers they represent are impressive. The available data from stories already published in *Spinoff*, while representing only a small fraction of the total number of stories, shows over 1,600 jobs created, over \$500 million in revenue, more than \$4 billion in productivity and efficiency improvements, nearly 700 lives saved or not lost, and over 30 million people benefiting from quality of life improvements.

What follows is a discussion of the analysis results, a sample of the type of data that was gathered, and a discussion of the issues that emerged while analyzing the data and issues anticipated when collecting the data from companies. Also included is a review of the environmental benefits category that ultimately proved too broad for consolidated data gathering as well as a discussion of other potential benefit categories that were considered.

## A. Jobs Created

### 1. Employment Analysis Results

Of the 187 *Spinoff* stories reviewed, 8 provided tangible data for the number of jobs created due to their technology transfer with NASA. The sum of the jobs created in these 8 stories was 1,665 jobs.

One example of the types of data collected involved a Space Act Agreement with Goddard Space Flight Center and West Virginia University that enabled Aurora Flight Sciences Corporation, of Manassas, Virginia, to develop cost-effective composite manufacturing capabilities and open a facility in West Virginia. The company now employs 160 workers at the plant, tasked with crafting airframe components for the Global Hawk unmanned aerial vehicle (UAV) program. While one-third of the company's workforce focuses on Global Hawk production, the rest of the company develops advanced UAV technologies that are redefining traditional approaches to unmanned aviation. Since the company's founding, Aurora's cutting-edge work has been supported with funding from NASA's Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs. Aurora now has 350 employees and has facilities in Mississippi and Massachusetts, in addition to its West Virginia and Virginia operations.

### 2. Issues Gathering Employment Data

There are many problems that arise when attempting to measure the number of jobs that were created in a company as a result of their application of NASA technology. It is a somewhat subjective process to attempt to determine whether or not an employee's job would have existed in the event that the company did not produce a NASA spinoff product or service. In order to attempt this measurement, a company could first isolate all jobs that were created (employees hired) after the instance of technology transfer with NASA. The company could then intrinsically examine each of those positions to determine whether or not that employee would have been hired to perform said job had the technology transfer not occurred. Some of these jobs will be quite obvious to select, as certain manufacturers and engineers in companies producing a physical product will be dependent on their unique skills to help produce that product and would not be otherwise necessary to the company for employment. The majority of employees hired after the technology transfer will perform a variety of tasks that could be considered dependent upon the NASA-derived product or service and many that could seem unrelated to its production, sale,

and/or use. The number of jobs created will have to be a determination made by each individual company based upon their own unique analysis, and will most likely lack precision. NASA can do a reasonableness assessment based on the information that the companies provides, but will likely not have resources available to do a rigorous validation of the companies self-assessment. Therefore, the best and most appropriate source of this data is the companies themselves.

## **B. Revenue Generated**

### *1. Revenue Generation Analysis Results*

Of the 187 *Spinoff* stories reviewed, 9 included tangible data for the number of dollars generated in revenue due to technology transfer from NASA. The sum of the revenues generated by these 9 companies was \$532 million. Most of these revenue numbers were for a single year of sales, although some included multiple years.

One example of a technology culled from the issues of *Spinoff* that provided data regarding revenue generated included a company called Picometrix, a wholly owned subsidiary of Advanced Photonix Inc. (API), of Ann Arbor, Michigan, invented the world's first commercial terahertz system. The company improved the portability and capabilities of their systems through Small Business Innovation Research (SBIR) agreements with Langley Research Center to provide terahertz imaging capabilities for inspecting the space shuttle external tanks and orbiters. Now API's systems make use of the unique imaging capacity of terahertz radiation on manufacturing floors, for thickness measurements of coatings, pharmaceutical tablet production, and even art conservation. It is estimated that there are over \$200 million in opportunities for the terahertz systems over the next 7 years.

### *2. Issues Gathering Revenue Data*

If the company is based solely on the NASA-derived technology, then the revenue determination is easy--just total company revenues. However, if the company was already established, they likely generated revenue from other sources. Separating revenues from different product or service sales should not be too difficult for most companies, but it may require some unique analysis to support the collection of data for this particular benefit quantification exercise. One of the challenges in collecting and aggregating data is ensuring consistency in the data collected. Showing only a single year's revenue could understate the total revenue generated for the life of the product/service, and if companies are providing estimates of future revenues it could overstate the revenue metric.

## **C. Productivity and Efficiency Improvements**

### *1. Productivity and Efficiency Improvements Analysis Results*

Based on the qualitative description of benefits in the *Spinoff* stories, roughly 76% of them should have some sort of productivity or efficiency improvement that would yield cost avoidance benefits. Of the 187 spinoff stories, only 4 included tangible data for the number dollars in productivity and efficiency improvements due to NASA technology transfer. The sum of the costs avoided in these companies was \$4.13B.

A prime example of cost savings comes from NASA's work on blended winglets. The upturned ends now featured on many airplane wings are saving airlines billions of dollars in fuel costs. Called winglets, the drag-reducing technology was advanced through the research of Langley Research Center engineer Richard Whitcomb and through flight tests conducted at Dryden Flight Research Center. Seattle-based Aviation Partners Boeing—a partnership between Aviation Partners Inc., of Seattle, and The Boeing Company, of Chicago—manufactures Blended Winglets, a unique design featured on Boeing aircraft around the world. These winglets have saved more than 2 billion gallons of jet fuel through 2010, representing a cost-savings of more than \$4 billion (at \$2 a gallon) and a reduction of almost 21.5 million tons in carbon dioxide emissions.

### *2. Issues with Calculating Productivity and efficiency improvements*

The problems in capturing productivity and efficiency improvements can be separated into two categories: company and customer. In many of the 187 cases examined in this study, companies experienced internal improvements in efficiency and resulting reductions in cost from implementation or production of NASA-derived technology. Placing a dollar amount on the amount of time and money saved by using or producing this technology can be a difficult task. Most companies use process control metrics to analyze the efficiency of their operations, and

are able to monitor changes in those efficiencies over time. If they determine that efficiencies are a result of applying a NASA-derived technology, it should be a fairly straightforward estimate for them to determine productivity and efficiency improvements resulting from the spinoff. An example could be improvements in how hospitals schedule use of expensive imaging machines. If they demonstrate an increase in efficiency and higher utilization of existing machines, they could have avoided the cost of acquiring additional capital equipment in extra imaging machines. There is no standard approach for calculating productivity and efficiency improvements benefits, and each company must apply their judgment and analysis to develop an appropriate estimate. While many process improvements would go unreported, additionally, the estimates provided by companies in this category would lack precision and should be viewed as “reasonable estimates” as there can be no unified system by which all NASA *Spinoff* companies could calculate this dollar amount. NASA should conduct reasonableness assessments of the information the companies provide.

## **D. Lives Saved/Not Lost**

### *1. Analysis Results Related to Lives*

Of the 187 *Spinoff* stories assessed, roughly 16% were expected to be able to show that they resulted in lives saved or not lost. However, only 2 of the stories included tangible data for the number of lives saved due to technology transfer from NASA. The sum of the lives saved from these 2 companies was 659 lives.

An example of NASA technology transfer products saving lives can be found in Apollo-era life rafts still on the market today. To keep life rafts holding astronauts and frogmen from capsizing from the downdraft of rescue helicopters after splashdown landings, engineers at NASA’s Johnson Space Center designed and patented a self-righting life raft capable of resisting tipping in choppy seas and fierce winds. Givens Marine Survival Co. Inc., of Tiverton, Rhode Island, patented this invention and now manufactures and markets the rescue rafts—under the name Givens Buoy Life Raft—in a variety of sizes and models for everything from sailboats to larger ocean-going vessels. To date, Givens has sold several thousand of the ballasted, inflatable life rafts, and this space-age technology is credited with saving the lives of over 450 sailors.

### *2. Issues Related to Crediting NASA with Life Saving*

Saving a life seems to be an easily determined fact on the surface, but in actuality, it is completely qualitative and very difficult to determine using a pre-designed, universal system. The “Rocket-Powered Parachutes Rescue Entire Planes”<sup>19</sup> story in the 2010 edition of NASA *Spinoff*, which was one of the 187 cases examined in this study, illustrates this problem. In this case, BRS Aerospace developed a rocket-powered parachute for the purpose of saving aircraft from crashes. The company acquired Small Business and Innovation Research (SBIR) contracts with NASA Langley Research Center to further develop and refine this technology. BRS claims to have saved 265 lives with this technology as a result of planes saved from crashes after the parachute’s deployment to date. Although a plane crash would most likely result in certain death for all passengers on board, it is very difficult to determine whether or not any of them could have survived the crash had the parachute not deployed, and it is equally as difficult to determine whether or not the pilot could have safely landed the plane without the existence of the parachute as a last-resort safety mechanism. The majority of other cases examined in this study that could reasonably provide a number of lives saved as a result of NASA-derived technology are even trickier to determine than this case, as the conditions of endangerment of the lives saved in those cases are not as definable in terms of whether or not the person saved could have survived the peril without the aid and existence of the NASA-derived product or service. The numbers provided by companies in this category will therefore be based on each company’s individual and unique judgment.

## **E. Lives Extended/Enhanced/Improved**

### *1. Analysis Results Related to Improving Lives*

Of the 187 *Spinoff* stories examined, it was expected that 32% would be able to provide data on the number of lives improved due to technology transfer from NASA; 4 stories included tangible data. The sum of the lives improved in these 4 companies was just over 30 million lives, with the majority coming from unique nutritional supplements used in baby formula and new materials used in surgical implants.

An example of the type of data collected in the category of life improvement can be found in a series of experiments that led to a new medical device and protocols. Johnson Space Center, Henry Ford Hospital in Detroit, and Houston-based Wyle Laboratories collaborated on NASA's Advanced Diagnostic Ultrasound in Microgravity (ADUM) experiment, which developed revolutionary medical ultrasound diagnostic techniques for long-distance use. Mediphan, a Canadian company with U.S. operations in Springfield, New Jersey, drew on NASA expertise to create frame-grabber and data archiving technology that enables ultrasound users with minimal training to send diagnostic-quality ultrasound images and video to medical professionals via the Internet in near real time—allowing patients as varied as professional athletes, Olympians, and mountain climbers to receive medical attention as soon as it is needed. Over 950 ultrasound examinations have been performed on patients so far.

## F. Environmental Impact

Collective units of measure for this category have proven elusive, though in theory, this category would measure the environmental improvement that is a direct or partial result of the implementation and/or use of NASA-derived technology in products and services. The environmental impacts in this category must be reductions in pollution, implementations of “green” practices, improvements in the quality of resources and/or natural habitats, or other measurable benefits to the environment that would not have occurred without the existence and application of NASA-derived technology.

### 1. Environmental Data Analysis Results

Of the 187 *Spinoff* stories examined, it was determined that 28 (15%) would be expected to have demonstrable positive environmental impacts.

As an example, Ames Research Center engineer Leonard Haslim invented an anti-icing technology called an electroexplosive separation system, which uses mechanical force to shatter potentially dangerous ice buildup on an aircraft surface. Temecula, California-based Ice Management Systems (now known as IMS-ESS) licensed the technology from Ames and has discovered a niche market for the lightweight, energy-efficient technology: unmanned aerial vehicles (UAVs). IMS-ESS systems now prevent damaging ice accumulation on military UAVs, allowing the vehicles to carry out crucial missions year round. The system uses around 600-900 watts, whereas typical thermal deicing systems use tens of thousands of watts, requiring a large generator impractical for use on a lightweight UAV.

### 2. Issues Related to Gathering Environmental Data

Environmental improvements can take many different forms, as is very well illustrated by the companies examined in this study that fall into this candidate quantification category. Reductions in use of fossil fuels, reductions in emissions of greenhouse gasses, reductions in carbon footprint, improvements in water quality, improvements of natural habitats and surroundings for different forms of life, and reductions in use of other natural resources can all be considered positive environmental impacts. These benefits are, in most cases, easily visible, and are also considered to be very important in an increasingly “green-oriented” society. The largest problem in the context of this study, though, is in deriving a unified system of measure for all environmental impacts created by NASA *Spinoff* companies. The United States Environmental Protection Agency (EPA) has comprised many methods for quantifying environmental benefits, and these were examined in this analysis. Within the EPA, the most common focus of environmental improvement is the management of pollution and waste. In this area, the EPA uses a series of equations to examine emission factors for various types of material waste, pollution, and waste management scenarios in terms of either metric tons of carbon equivalent (MTCE) or in metric tons of carbon dioxide equivalent (MTCO<sub>2</sub>CE). These emission factors represent the greenhouse gas emissions associated with managing 1 short ton of waste. The formulas and applications of these measurements then become quite complex and ambiguous when applied to a wide range of waste and pollution scenarios. The EPA has also created the Waste Reduction Model (WARM) to help calculate and manage solid waste, but this model is so complex that it must be downloaded from the EPA website in the form of a Microsoft Excel spreadsheet to be used. To calculate the live-cycle greenhouse gas emissions and energy impacts from purchasing and/or manufacturing materials with varying degrees of post-consumer recycled content, the EPA created and uses the Recycled Content (ReCon) tool, which must also be downloaded in Microsoft Excel to be used.<sup>20</sup>

Many other methods exist to calculate various factors of emissions and carbon footprint. Household electricity is calculated using a figure of 1.5 pounds of carbon emissions per kilowatt-hour generated by a coal-fired power station. Natural gas emissions are calculated using a ratio of 0.12 pounds of carbon dioxide per cubic foot. Fuel oil

usage is calculated based on 22.29 pounds of carbon dioxide emissions per gallon. Small car emissions are calculated on 0.59 pounds per passenger per mile. Medium car emissions are calculated using a ratio of 1.1 pounds of carbon dioxide emissions per mile. SUV/4-wheel-drive vehicle emissions are based upon a ratio of 1.57 pounds of carbon dioxide per mile. Air and train travel calculations have no unified system of calculation, are estimated based upon average levels of occupancy, and are then calculated per person. Tree offset calculation is based on a tree planted in the humid tropics absorbing an average of 50 pounds of carbon dioxide annually over 40 years, but this estimate assumes that at least 5 trees must be planted in order for one to live for 40 years or more.<sup>21</sup>

Even if each of these formulas and measurements could be unified into one number of carbon dioxide emissions or other common measureable quantity, this still would not account for environmental impacts such as improvements in water quality and natural habitats/surroundings. In summary, no good representative single quantification measure was found for environmental benefits. NASA will continue to assess options for how best to quantify and aggregate environmental benefits. Nonetheless, spinoffs with environmental benefits may also have measurable benefits in many of the other categories.

### **G. Other Potential Benefit Categories**

While examining the 187 *Spinoff* cases in this study and determining how best to measure the benefits of NASA technology transfer, many items of data and statistics were observed. The five candidate quantification categories proved very effective at capturing expected benefits from all of the spinoff stories, but much of the specific benefit data did not easily fall into one or more common category.

As *Spinoff* companies continue to be selected and examined for future issues, it is important to continue to collect many forms of data and to classify other possible benefits. Over time, new types of benefits may emerge as common measureable categories that exist in multiple companies as a result of NASA technology transfer. Some of the other possible benefit categories that arose from the 187 spinoff stories include process/manufacturing time improvements (that cannot easily and reliably be equated to dollar amounts in cost avoidance through productivity and efficiency improvements), increases in product lifespan and/or durability, sound exposure reductions, increases in competitiveness (in relation to competitors), improvements in product ease-of-use, intellectual property granted, and other achievements such as world sporting records broken.

## **IV. Conclusions and Recommendations**

NASA will continue to develop sustainable ways to gather and interpret quantifiable benefits data. As the volume of data increases and it becomes apparent which benefit categories most consistently yield data across the technology portfolio, new challenges and opportunities will also be revealed. All of the data gathered will shape the continuing story of the benefit of NASA technology to society.

### **A. Use Appropriate Context When Presenting This Data**

It is important that any use of the findings, data, methodologies, previous studies and data cited, and conclusions in this study be placed in context. The use of these sources should include a disclaimer explaining that this study and all previous and cited studies on this subject were conducted using limited and carefully selected data samples, and that the findings from these samples cannot be extrapolated to encompass, explain, or make predictions concerning the full range and scope of benefits that can be attributed to the U.S. government's investment in, and the general existence and activities of, NASA.

This is not a comprehensive portrayal of NASA's technology transfer activities; rather, it is a series of quantitative benefit estimates based on a specific subset of already-proven successes. The estimates are provided by a variety of sources, each using different methods to gather and report the information.

### **B. Retrospective Data Gathering**

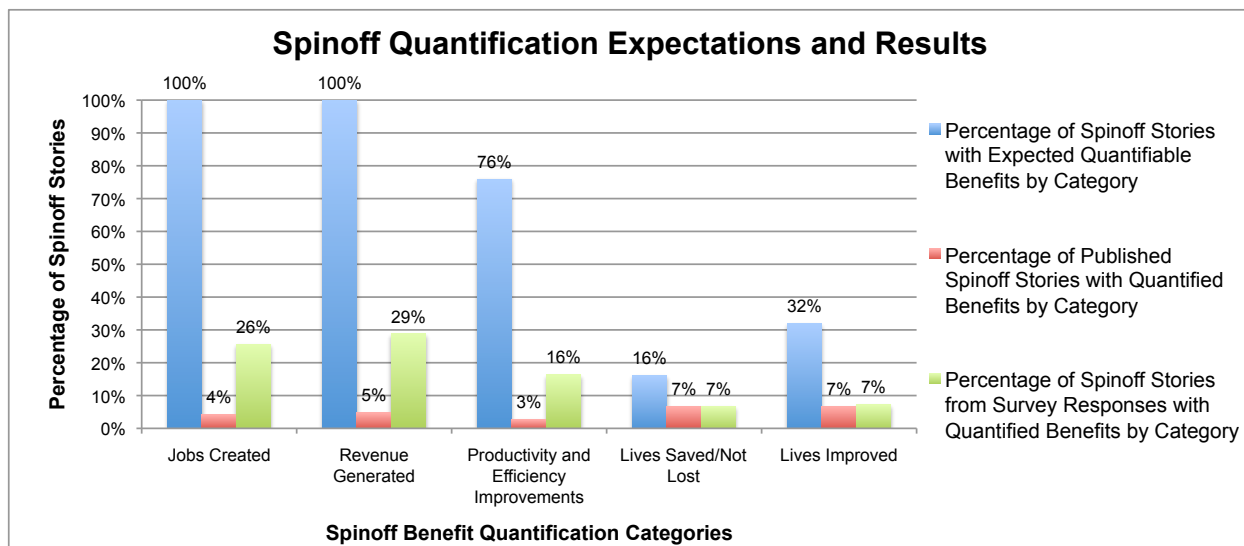
As a result of this study, and because of the paucity of available quantitative data from the last several years of *Spinoff* stories, NASA developed and is in the process of administering a survey based upon the benefit categories identified in the initial review of *Spinoff* stories outlined in this paper. This survey focuses on companies featured in *Spinoff* between 2000 and 2008 and was designed to easily,



consistently, and accurately capture available data that falls into the benefit categories while also gathering other data that could have future use.<sup>vii</sup>

Results are still being gathered, and the data will need to be reviewed and analyzed before it is released, but of the 250 companies (representing 274 different technologies) that have been contacted to date, 85 have responded to date with quantification of benefits in one or more of these categories, representing a response rate of approximately 31%. Figure 3 shows a comparison of the response rate by quantification category that is being achieved by this survey, along with the expected percentage rate of quantifiable benefits that was shown in Figure 1 and the percentage of already-published *Spinoff* stories with quantifiable benefits. It should be noted that some of the companies are no longer in existence and/or no further information is available. This survey is still ongoing, and at its conclusion, the data will be further analyzed and published.

Initial results confirm the effectiveness of the proposed benefit categories, as multiple companies are able to report quantifiable data within these categories. While the percentage of stories for which quantifiable data is available following interviews with the companies is significantly below the expected rate, for several categories it is factor of five above the rate that has already been published in *Spinoff*. Therefore, it is clear that direct contact with companies through the use of surveys, when combined with the use of consistent category models, yields more comprehensive data.



**Figure 2.** Initial survey results show good response rates from contacted firms, and confirm that the selected quantification categories are effectively capturing quantitative data on technology transfer benefits.

### C. Value to be found in Future Data Gathering

It is clear from this analysis that use of consistent categories as well as direct reporting by companies will yield significant improvement in NASA’s ability to understand and communicate the tangible outcome benefits of its technology transfer activities. This approach also addresses the recommendation of many previous studies that NASA develop a routine data-capture method.

<sup>vii</sup> The National Technology Transfer Center (NTTC) based out of The Wheeling Jesuit University in Wheeling, West Virginia is conducting the survey under contract. Attempts were made to contact all of the companies by telephone to introduce the NTTC and its efforts on behalf of NASA. The survey staff then followed up with the survey via email and reminder phone calls.

As NASA continues to gather the stories for the annual *Spinoff* report, the writers will now routinely survey the companies being interviewed and collect quantifiable data within the standard categories. This will provide the agency with an ongoing record of measurable successes in technology transfer. As years pass, and the volume of more accurate data continues to increase, it is possible that broader analyses could be conducted from the aggregate of this information related to the number of jobs and revenue, for example, that secondary uses of NASA technology have provided.

The information gathered in the future will be written into the *Spinoff* articles and will supplement the existing qualitative data, not replace it. While this new data will be a valuable supplement to the traditional anecdotal reporting of spinoff successes, the stories will continue to tell the grainy, interesting, and unexpected personal stories of NASA's contributions to the Nation's well-being.

Validating the information presents another challenge. While staff at the NASA fields centers will have firsthand experience with the companies in question and therefore be able to review the content and provide reasonableness assessments on the information—knowing, for example, whether a small company has actually hired the number of employees reported or has reported revenue that seems out of line with the company's size—NASA does not have the resources to rigorously validate all of this information. The companies are providing the information voluntarily, and it is understood that the data represent their best estimates. Still, as a matter of practice, the technical personnel and technology transfer staff who currently provide approval and consent to publish each of the stories are now also charged with confirming that this new reported information is reasonably accurate to the best of their knowledge. This has been added to the standard vetting checklist signed by center management before a story is published.

Future data gathering could be aided by the inclusion of a requirement in patent licensing documentation or SBIR contracts that requires partner companies to report back on the successes of their activities.

### Acknowledgments

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- <sup>21</sup> Carbon Calculator, Carbonify <http://www.carbonify.com/carbon-calculator.htm>.