Faster-Better-Cheaper Projects: Too Much Risk or Overreaction to Perceived Failure?

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***Abstract*—From 1992 until 1999, NASA adopted a Faster-Better-Cheaper (FBC) paradigm—i.e., smaller low-cost spacecraft—for its unmanned missions. When many early missions met their objectives at much lower cost than traditional flagship missions, the FBC approach seemed successful. However, after the failures of two Mars spacecraft in 1999, the FBC paradigm was viewed as a failed experiment. We reflect on the legacy of FBC. In particular, we focus on the organizational learning literature to explore whether FBC, a stretch goal, was a good step for NASA. Previous examinations of FBC have focused on failure rates rather than on cost effectiveness. We revisit the question of FBC by examining all unmanned NASA missions launched between 1974 and 2007. We find that FBC missions resulted in more scientific publications per dollar of mission cost than other types of missions. From our analysis, we perceive lasting benefits to current projects from the adoption of the stretch goals, and perceive that NASA suffers from a bias against learning from the FBC experiment because of the stigma of the high-profile failed projects. We conclude with the recommendation that NASA should challenge itself with stretch goals, but with science goals rather than human exploration goals.**

***Index Terms*—Faster-better-cheaper, risk, stretch goals, space mission.**

I. Introduction

NASA, in 2013–2015, is again facing flat funding levels as it did in the 1990s, but additionally, today there is little in NASA's current budget that many in the public would find of "great significance" [1, p. 222]. Given the current NASA climate to rely on commercial entities for transit to the space station, the lack of specific goals and schedules for deep space human exploration missions, and no flagship robotic missions to outer planets under development, we revisit the legacy of an equally challenging NASA era, the Faster-Better-Cheaper (FBC) mission paradigm of the 1990s.

When Daniel Goldin was named NASA Administrator in 1992, he came to the position with a mandate to cut NASA's expenditures without significantly scaling back its mission. This directive was necessary as NASA's budget was reduced more than 20% in real terms during Goldin's administration [2]. Goldin sought to carry out this charge in several ways, including the privatization of many functions related to the Space Shuttle program [3]. Another approach introduced by Goldin to reduce the cost of carrying out NASA programs was the adoption of the FBC mission paradigm for unmanned science spacecraft. The FBC paradigm called for the creation and launch of a large number of relatively small, low-cost spacecraft with limited capabilities (compared to past "flagship" missions). The premise was that many FBC missions could make up for in number what each lacked in size and flexibility. A NASA task force charged with studying the FBC approach defined FBC as "simply attempting to improve performance by being more efficient and innovative," combined with the willingness to take risks as embodied in the FBC slogan, "It's OK to fail" [4]. Reflecting FBC's emphasis on taking calculated risks, Daniel Goldin stated that if NASA could carry out enough missions at a low enough cost then it "could afford to lose a few" [4].

After several of the early FBC missions met their science objectives at much lower cost than traditional missions, the FBC approach appeared to be a success. However, following two Mars mission failures in 1999—the Mars Climate Orbiter, which failed on September 23, 1999, and the Mars Polar Lander, which failed on December 3, 1999—public outcry demonstrated that from the public's perspective, NASA could not "afford to lose a few." An investigation into the failure of the Mars Climate Orbiter argued that: "The success of 'Faster, Better, Cheaper' is tempered by the fact that some projects and programs have put too much emphasis on cost and schedule reduction (the 'Faster' and 'Cheaper' elements of the paradigm). At the same time, they have failed to instill sufficient rigor in risk management throughout the mission lifecycle. These actions have increased risk to an unacceptable level on these projects" [5, p. 6].

Broader analyses of the FBC approach conducted following these two failures called into question the viability of the entire FBC approach. For example, a NASA investigation of FBC, although optimistic about the possibility that FBC could make strong future contributions, concluded that, "The current mission failure rate is too high and must be reduced" [6]. Similarly, a study of the viability of FBC conducted by the Aerospace Corporation concluded, "Recent failed or impaired small planetary science satellites have brought into question NASA's FBC approach to missions in both the planetary and earth-orbiting applications. While recent missions have resulted in lower costs and shorter development times these benefits have, in some cases, been achieved at the expense of increasing performance risk" [7].

Following the two Mars mission failures and the criticism they invited from both inside and outside of NASA, the FBC paradigm was discontinued, and NASA's unmanned mission paradigm shifted to "Mission Success First" [6]. By the end of the 1990s, the FBC paradigm was generally considered to be a failed experiment.

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However, reviews of failed FBC missions and these evaluations of the FBC paradigm have implicitly assumed that the most appropriate metrics for evaluating the effectiveness of FBC are success and failure rates. Such performance metrics, however, are inherently biased against the FBC approach, which consciously accepts a higher likelihood of the failure of any individual mission in exchange for reduced mission costs that permit the development of additional missions. A more reasonable measure of the success of the FBC paradigm should incorporate both mission outcomes and costs and should consider the benefits to NASA in terms of learning that even failures can provide. For example, Ward [8, p. 50] provocatively points out that, for unmanned science missions where failure does not jeopardize human life, "success-per-dollar is a more meaningful measurement of achievement than success-per-attempt because there is no limit to the number of attempts we can make. The only real constraint on our activity is the amount of time and money we can spend. In other words, the important thing is not how much success we get out of 100 tries, but rather, how much success we get out of 100 dollars."

The purpose of this paper is to reexamine the FBC paradigm, incorporating the approach of examining mission success relative to mission cost while considering the potential for organizational learning, and to use these lessons to derive organizational insights. In addressing this topic, we first revisit the legacy of FBC in terms of the potential for organizational learning from this resource-constrained paradigm. Organizational learning theory examines actions that can make organizations search outside their current routines and processes for long-term learning and change [9]. Sitkin *et al.* [10] identify one method for this sort of exploration that pushes new ways of thinking and acting, i.e., setting "stretch goals." Stretch goals, or extreme goals, are meant to intentionally generate internal crises to spark energy and to spur change [10]–[12]. FBC in 1992 was a stretch goal for NASA. FBC involved a familiar task (developing new spacecraft) but the target (primarily in terms of cost and schedule) was dramatically beyond the then-current performance capabilities of NASA as well as the range of industry practices [10, p. 547]. So, was FBC an appropriate goal for NASA to undertake in the 1990s and did sufficient organizational learning occur to compensate for the failures? Following the initial FBC successes and before the 1999 failures, several studies identified changes to past practices that were largely touted as successful learning from FBC [13], [14]. We examine these studies for the potential and perception of organizational learning from this new paradigm.

We then examine the question of whether the FBC paradigm was a success or a failure from a learning perspective by examining all unmanned NASA missions launched between 1974 and 2007. In this analysis, we define mission success in terms of the science output per dollar of mission development cost. Thus, by comparing science output per dollar of the missions across various time periods, we can understand how successful FBC actually was compared to previous and subsequent unmanned mission paradigms. The results of the analysis show that FBC missions were significantly more likely to fail than non-FBC missions. But even so, FBC missions resulted in more publications (and citation-weighted publications) per dollar of mission development cost than did missions developed under other paradigms. Thus, the results show that although the FBC program may have been a public relations failure, it was an operational success, at least when success is measured in terms of organizational learning, from both science and operational perspectives.

Finally, we consider challenges facing NASA in the current environment and recommend NASA as an organization focus on stretch goals related to scientific discovery rather than human exploration.

II. Learning from a Stretch Goal, The FBC Paradigm

Stretch goals or extreme goals need to be carefully considered and managed in organizations. Under the right circumstances, stretch goals can "impose a crisis" [10, p. 550] that stimulates organizations to undertake experimentation and learning. Research on organizational learning finds that members of organizations become increasingly innovative and risk tolerant as the difficulty of the goals they are working toward increases and the likelihood of failure to achieve goals becomes more salient [11], [12]. The implementation of stretch goals can induce such fear of failure that drives risk taking and innovation. But in the wrong circumstances, primarily when the stretch goals represent "a bridge too far" [10, p. 551], rather than learning, an organization's response becomes disorganized, impulsive, and less systematic in the management of projects.

Sitkin *et al.* [10] identify two criteria for characterizing organizational readiness to implement stretch goals: recent performance (prior to introducing the stretch goals) and slack resources (during the implementation process). Organizations are most likely to adopt stretch goals after recent poor performance and this is true with the institutionalization of FBC following the loss of Mars Observer, an $800 million mission that was lost while entering orbit around Mars in 1993. McCurdy [2, p. 18] describes that the "loss of the Mars Observer helped build support for the 'faster-better-cheaper' initiative." However, to achieve stretch goals, organizations need to have slack resources that allow for radical process experimentation, and by definition, FBC removes the slack from the process. Without any slack resources, Sitkin *et al.* [10] predict that FBC would not reliably lead to organizational performance increases, or said another way, consistent with reality, FBC would not be sustainable. But prior to the losses of the Mars missions in 1999, several studies were documenting and describing new successful management features learned from FBC [13], [14].

In 1997 and 1998, Paté-Cornell and Dillon examined the successful attributes and potential weaknesses of the FBC paradigm by preparing four case studies for NASA's Jet Propulsion Laboratory. The four missions examined were one flagship mission already being developed at the time (Cassini) and three FBC missions (Mars Pathfinder, Mars Global Surveyor, and Deep Space 1). Based on these cases studies, they identified a number of management features that seem to have contributed to the success of the early FBC projects [14]. Table I lists the 14 success factors they identified with brief descriptions of each.

TABLE I
SUCCESS FACTORS OF FBC IDENTIFIED BY PATÉ-CORNELL AND DILLON [13]

1. Strict constraints of schedules and budgets	Engineers/project leaders are presented with a fixed-cost target and must adapt the system design and its costs to these constraints.
2. Co-location of people	Co-location tends to turn traditional engineers into more general problem solvers, often promotes a greater team focus, and makes communications easier.
3. Flat management chart	Project with fewer levels in the decision making hierarchy can save both time and money.
4. Concurrent engineering especially with a system testbed	Concurrent engineering allows the parallel processing of different tasks, resulting in shorter schedules. Incorporating a system testbed allows items to be tested in the most realistic situations as early as possible, thus reducing the development time and costs.
5. Use of industrial contractors and an incentive system based on shared risks	Contract arrangements where vendors design, develop, and deliver the completed spacecraft with contract incentives based on project's performance in flight.
6. Streamlined proposal processes	A streamlined process that brings participants on-board quickly.
7. Commercial off-the-shelf (COTS) components	As commercial parts (especially the electronics) continue to improve rapidly, custom-designed parts are less necessary than in the past so less expensive COTS parts are used more frequently.
8. Inheritance from previous missions	Inheritance has greatly benefited projects in which the reuse of a large amount of technology and spare parts saved both time and money.
9. Design of system interfaces for contingency	Saves time and money when switching units late in development if the interfaces are ready.
10. Adequate reserves and front-loaded funding profile	Technology development missions need to receive the majority of their funds up-front in order to "jump-start" the project.
11. Simplified review process for early detection (and fixing) of potential problems	While maintaining some formal reviews, use more frequent, informal, focused, and less expensive peer reviews.
12. Single-string design and/or minimum redundancy	Use a limited number of redundancies, thus reducing costs, weight and complexity.
13. Extensive testing	Use extensive testing to offset the lack of spacecraft redundancy
14. Proactive public relations	Missions can have broader value beyond the data captured for the scientific community. Choosing missions that balance scientific value and public appeal will help inspire future engineers and scientists.

TABLE II
LESSONS LEARNED FROM FBC IDENTIFIED BY COCKRELL [11]

1. Use cohesive technical teams with authority to do the job.	5. Use experienced personnel.
2. Maintain visibility through reviews.	6. Establish good communication.
3. Use a design-to-cost philosophy.	7. Conduct better up-front planning.
4. Apply risk management techniques.	8. Have clear requirements definition.
	9. Use technology with an appropriate readiness level.

In a similar time frame, Charles Cockrell of NASA's Office of Safety and Mission Assurance comprised his own list of lessons learned from FBC programs [13]. Table II describes the nine lessons he captured from the early successes. Looking at the 14 factors identified by Paté-Cornell and Dillon [14] and the 9 factors identified by Cockrell [13], we see two categories of factors that provide different benefits in terms of contributing to success: 1) factors that generate focus and support among the team for the stretch goal, but do not provide slack; and 2) factors that generate slack in the development process.

A. Factors that Generate Focus and Support for the Stretch Goal

Factors such as setting strict constraints of schedule and budget, having clear requirements definitions, and establishing proactive public relations focus the team on the stretch goal and help make the goals clear for the organization and the individual project teams. The literature from organizational behavior and psychology has demonstrated the importance of setting goals for motivating individuals and organizations. These aspiration levels are critical variables that affect the future behavior of individuals encouraging them to try to meet these goals [15], [16]. Heath *et al.* [15] summarizes this literature with two key results: 1) studies that have manipulated goal difficulty have found that performance increases as the difficulty of the goal increases, even when goals are extremely high, and 2) studies that have compared different instructions ("to set a specific, challenging goal" versus "to do your best") found that performance is superior for specific challenging goals. These results have been documented using both cognitive tasks (such as solving anagrams) to physical tasks (such as cutting logs and pedaling a bicycle). Paté-Cornell and Dillon's factor 1—"strict constraints of schedules and budgets"—falls into this category, as do Cockrell's lessons 7 and 8—"conduct better up-front planning" and "have clear requirements definitions."

B. Factors that Generate Slack in the Development Process

While a few of the success factors identified fit into the first category for generating support for the goal, the majority of the factors identified in these analysis of FBC projects are ways to generate slack in the development process. These factors are critical for stretch goals which by definition have little slack. Any steps that can be taken to generate slack help increase the chances of the organization meeting the stretch goal. For example, the recommendation to have adequate reserves is by definition a recommendation to establish some slack in the development process. Other factors identified in [14] focus on saving time and money or both such as co-location of people (i.e., faster communications), flat management chart (i.e., cheaper development costs and faster communications), concurrent engineering (i.e., faster development), streamlined proposal process (i.e., faster development), use of industrial contractors (i.e., faster time to get resources often for a fixed price), use of off-the-shelf components (i.e., less development time and costs), use of components inherited from previous missions (i.e., less development time and costs), single-string design (i.e., less development time and costs), and simplified reviews (i.e., less development time and costs). The two recommendations that seem to be more

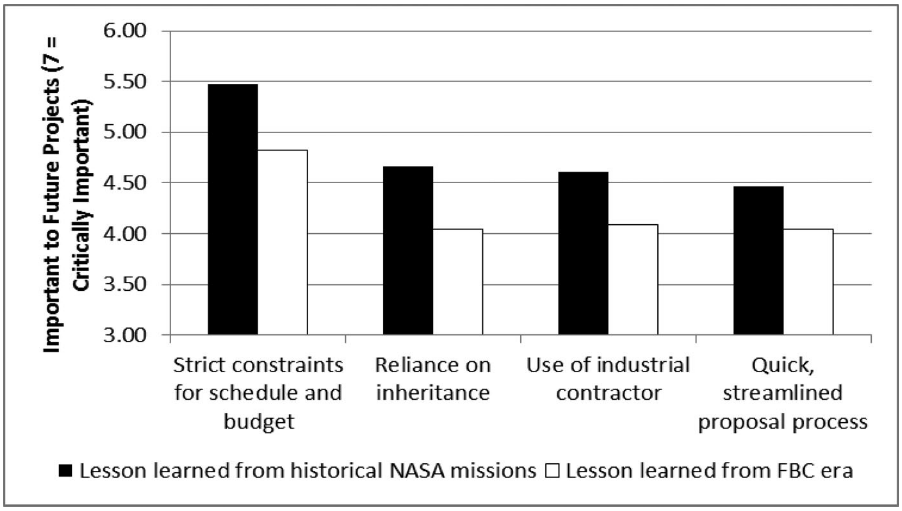

Fig. 1. Evaluation of best practices.

time intensive and more costly—extensive testing and apply risk management techniques—attempt to appropriately balance the goals of faster and cheaper with better. Extensive testing and risk management techniques if done well should provide the project with slack in meeting the "better" goal.

III. Legacy of FBC Lessons Learned

The lessons learned from the early successful FBC projects are not "rocket science." While these practices may have been paradigm shifts for NASA from how they developed space missions in the 1980s, many can be described simply as good engineering and project management practices. To better understand people's perception of these practices, we surveyed 101 randomly selected attendees at the 2013 IEEE Aerospace Conference in Big Sky, Montana. The respondents' average age was 40.2 years (s.d. = 11.4). On average, the respondents have been in a management position for 8.35 years (s.d. = 7.9) and supervise 51.3 people (s.d. = 127.6). Respondents were in one of two conditions. Those in the FBC condition were told that from 1992 until 1999, NASA adopted the mission paradigm of FBC—i.e., a large number of relatively small, low-cost spacecraft—for its unmanned space missions. Despite some challenges with failed missions that attracted critical media attention, several important best practices have emerged including the following.

1) Strict constraints of schedules and budgets: Project managers need to ensure that mission scope is correctly designed for the constraints of the schedule and the budget. This means not planning the scope without concurrently considering the schedule and budget, but it also means not overpromising the scope when schedules and budgets are severely constrained.
2) Relying on inheritance: Projects can save both time and money when they reuse large amounts of technology and spare parts from previous missions.
3) Using industrial contractors with shared risks: A successful project development strategy is to enter into contract arrangements where vendors design, develop, and deliver the completed spacecraft with contract incentives based on project's performance in flight.
4) Streamlined proposal processes: Missions need a streamlined process that brings participants on-board quickly.

Then participants were asked: *To what extent is each of these four best practices that emerged from FBC projects important to future successful spacecraft development projects?*

In the control condition, participants were provided the same lessons learned but the first sentence and last sentence were changed to not mention FBC. The first sentence in the control condition was: *From decades of experience with past unmanned NASA missions, several important best practices have emerged including*... [the same four descriptions as described earlier]. And the last sentence was: *To what extent is each of these four best practices that emerged from decades of experience with unmanned missions important to future successful spacecraft development projects?*

In both conditions, participants were asked to score the four best practices (strict constraints of schedules and budgets, relying on inheritance, using industrial contractors with shared risks, and streamlined proposal processes) on a 1–7 scale, where 1 = not so important for future projects and 7 = critically important for future projects. Using a 2 (message condition) × 4 (best practice) mixed-model analysis of variance (ANOVA) statistical test, the results of an analysis of responses show main effects for both the different practices and the different messages but there is no interaction. The means for the four best practices are: $M_{\text{strict constraints}} = 5.15$ (standard deviation (s.d.) = 1.6), $M_{\text{inheritance}} = 4.35$ (s.d. = 1.7), $M_{\text{contractor}} = 4.35$ (s.d. = 1.3), $M_{\text{proposal process}} = 4.26$ (s.d. = 1.6), $F(3,97) = 7.3$, $p < .001$) (see Fig. 1). Contrasts showed that the perception of strict constraints was greater than the other three practices. The means for two message conditions are: $M_{\text{historical missions}} = 4.8$ (s.d. = .8), $M_{\text{FBC missions}} = 4.2$ (s.d. = 1.1), $F(1,99) = 8.76$, and $p < .001$.

These results show that the overall pattern of responses to the four best practices did not differ for participants in the FBC condition versus the control condition. In both cases, participants thought that the practice of strict constraints of schedules and budgets was the most important practice to the future of spacecraft development projects with the other three practices scored about 1 point less on a 7-point scale. But most interesting to this discussion was that when attributed to learning from the FBC era versus learning from all previous NASA missions, the same practices score about 0.5 points less on a 7-point scale when attributed to FBC. These results imply that residual memories of FBC's well-publicized failures may prejudice observers against lessons learned from the FBC experiment. Sampling only from participants attending a large aerospace conference certainly does not present a diverse sample of opinions, but we were interested in perceptions from those knowledgeable about current space missions and interested in learning that would characterize those who choose to attend such a conference. Thus, we conclude that any learning that occurs from FBC must overcome the stigma associated with FBC because of the well-publicized failed missions. Additionally, managing future missions faster, better, and cheaper will always be a challenge because it will always remain a stretch goal for projects to meet more than two of these three objectives.

IV. Study of FBC Success

To test the performance of the FBC paradigm relative to other paradigms employed in NASA's unmanned science missions, we constructed a sample of all unmanned NASA space missions launched between 1974 and 2007. The year 1974 was selected as the beginning of the sampling frame because our source of data on scientific publications (which we used to construct our measure of mission success), Thompson Reuter's *Web of Science*, is first available in 1974. The year 2007 was selected as the end of the sampling frame in order to leave enough time, post launch, to evaluate the success of a mission (see below for details). The sample contained a total of 83 unmanned missions that were managed by NASA (missions managed by foreign space agencies on which NASA provided instrumentation or other assistance were excluded from the sample).

A. Failure Rates of FBC Missions

To test whether the missions in our sample suggest the same higher likelihood of mission failure for FBC missions than for missions developed under other mission paradigms as has been found in prior studies of FBC, we first tested the effect of FBC on mission failure rates. The dependent variable in this analysis, *Mission Success*, was a binary indicator that took a value of 1 for missions that successfully achieved operational status and a value of 0 for missions that failed prior to attaining operational status.

The independent variable in this analysis, *FBC Mission Indicator*, was a binary indicator variable that took a value of 1 for missions developed under the FBC paradigm and a value of 0 for all other missions. Various authors have developed different lists of missions that qualify as FBC missions. For example, McCurdy [2] identifies only 16 missions that possess all of the characteristics of an FBC mission. However, reviews of the FBC paradigm indicate that it was not merely an approach applied to certain missions, but rather an overriding philosophy that impacted all unmanned missions during the period when it was in use. For example, a NASA review of the FBC approach during its use notes that, "FBC . . . applies to everything and everyone" [5]. For this reason, we define FBC missions as all missions developed after Goldin became NASA administrator and before the failure of the Mars Polar Lander in December 1999. A list of the missions considered to be FBC using these criteria is included in the Appendix.

TABLE III
Logit Regression of the Likelihood a NASA Mission Successfully Reaches Operational Status

	Model 1	Model 2
FBC Mission Indicator		-2.32^{**}
		(0.85)
JPL Managing Mission Indicator	−0.49	−0.77
	(0.73)	(0.83)
Deep Space Mission Indicator	−0.90	−0.65
	(0.74)	(0.81)
# Mission Objectives	0.11	0.10
	(0.16)	(0.20)
N	83	83
Log Likelihood	−30.05	−25.26

Standard errors are in parentheses.
†* $p < 0.10$; * $p < 0.05$; ** $p < 0.01$. Two-tailed tests.

We also included a set of control variables in the analysis of mission success. In selecting these control variables, it was important to select variables that may have impacted mission success, but that were not closely correlated with the FBC paradigm. For example, spacecraft mass and complexity may be related to mission success, but they are both highly negatively correlated with the FBC mission indicator. The control variables selected according to this criteria included *JPL Managing Indicator*, which took a value of 1 for missions managed by NASA's Jet Propulsion Laboratory and a 0 for missions managed by other NASA centers (primarily Goddard), *Deep Space Mission Indicator*, a dichotomous variable that took a value of 1 for missions intended to reach targets beyond earth orbit and a 0 for missions intended to remain in earth orbit, and *Number of Mission Objectives*, the number of formal scientific objectives the mission was designed to achieve.

Since the dependent variable of interest in this analysis, *Mission Success*, was a binary variable, we analyzed the data using Logit regression. The results of this analysis are reported in Table III, above. Model 1 reports coefficients only for the control variables. As can be seen in the table, none of the three control variables exerts a significant impact on the likelihood of mission success. Model 2 introduces the independent variable, FBC Mission Indicator, in addition to the control variables. The FBC Mission Indicator coefficient is negative and statistically significant, indicating that FBC missions were less likely to successfully attain operational status than were missions developed under other paradigms. This finding is consistent with prior work on the performance of the FBC program showing lower success rates for FBC missions than for other NASA missions (e.g., see [11]).

TABLE IV
ORDINARY LEAST-SQUARE REGRESSION MODELS OF PUBLICATIONS PER DOLLAR OF MISSION DEVELOPMENT COST

	Model 1 Within two years of mission end	Model 2 Within five years of mission end	Model 3 Within five years of mission start	Model 4 Within ten years of mission start
FBC Mission Indicator	0.39*	0.99*	0.32*	1.17**
	(0.15)	(0.38)	(0.15)	(0.37)
JPL Managing Mission Indicator	0.03	−0.22	−0.10	−0.57
	(0.17)	(0.43)	(0.17)	(0.46)
Deep Space Mission Indicator	−0.21	−0.25	−0.05	−0.18
	(0.18)	(0.44)	(0.16)	(0.45)
# Mission Objectives	0.00	0.02	0.01	0.08
	(0.03)	(0.07)	(0.03)	(0.07)
N	57	43	83	55
R^2	0.14	0.19	0.06	0.20

Standard errors are in parentheses.
$\dagger p < 0.10$; $^{*}p < 0.05$; $^{**}p < 0.01$. Two-tailed tests.

B. *Mission Performance Relative to Mission Cost*

This research also explores the effectiveness of the FBC paradigm when mission performance is defined relative to mission cost. Consequently, we constructed a series of cost-sensitive measures of mission success. In doing so, we adopted the perspective that the primary purpose of NASA's unmanned science missions is to generate valuable scientific knowledge. To measure the amount and value of the science produced by a given mission, we adopted bibliometric techniques of publication and citation analysis. Bibliometric refers to the quantitative analysis of academic literature [17]. Although mostly commonly employed in the fields of library and information sciences, bibliometric techniques are the standard method of studying the impact of research programs on knowledge development across a wide range of disciplines [18], including management [19], [20].

Following standard bibliometric practice, we counted the number of articles published in scientific journals that indicate they drew on data or knowledge generated by a given NASA mission. We conducted our journal article counts using Thompson Reuter's Web of Science, which indexes the major journals across both the physical and social sciences. In constructing these article counts, we first searched in the article title and abstract for the name of a particular NASA mission then reviewed the abstracts of the resulting articles to verify that they indeed drew on knowledge generated by that mission (the names or acronyms for some missions, such as DAWN, included common words that made this article verification necessary). Additionally, while Web of Science has been shown to incorrectly represent certain fields, our review corrected errors when articles were incorrectly attributed to a mission, and we assume that other errors would be randomly distributed across missions so would not favor certain types of missions in the regression models.

To render article counts for missions launched in different years comparable, we included only articles that occurred within a given time period relative to the mission. In the analyses reported later, we report results based on counts of articles occurring within two years of the end of a mission, within five years of the end of a mission, within five years of the commencement of the operational phase of a mission, and within ten years of the commencement of mission operations. The selection of these different time periods required tradeoffs; selection of longer time periods enabled us to view the longer term scientific value of each mission, but required the exclusion of more recent missions that had not reached the assigned age by June of 2012 (when we carried out our data collection). Consequently, we report results from four different time windows to provide a more robust picture of our results.

We scaled these counts of journal publications resulting from a given mission by that mission's development cost. We collected development cost data from official NASA mission profiles and reports. Consequently, our final measures of mission success took the form of a journal article count over a particular period of time divided by mission development cost (in millions of constant 2010 dollars). These success metrics became the dependent variables in our analysis of FBC impact. The independent variable in this analysis was the same independent variable employed in the mission success analysis reported earlier, FBC Mission Indicator; and the control variables used in this analysis were the same control variables described previously in connection with the mission success analysis.

All models were analyzed using an ordinary least squares (OLS) regression. The results of this analysis are reported in Table IV. Each model in the table reports results for a different time period over which the article counts were constructed. As mentioned earlier, none of the control variables significantly impacted mission science production per unit of cost. However, across all four variants of the dependent variable, the FBC Mission Indicator coefficient is positive and significant. These findings indicate that FBC missions resulted in more scientific publications per dollar of development cost than did missions developed under other paradigms.

C. *Citation-Weighted Article Counts*

Finally, to test the robustness of these results, we constructed an additional set of measures of mission performance that took into account not only the number of journal articles resulting from a particular mission, but also the scientific impact of those articles. Bibliometric analysis has documented that frequently

TABLE V
ORDINARY LEAST-SQUARES REGRESSION MODELS OF CITATION-WEIGHTED PUBLICATIONS PER DOLLAR OF MISSION DEVELOPMENT COST

	Model 1 Within two years of mission end	Model 2 Within five years of mission end	Model 3 Within five years of mission start	Model 4 Within ten years of mission start
FBC Mission Indicator	3.20*	11.80*	1.21	15.80*
	(1.54)	(4.92)	(1.88)	(6.07)
JPL Managing Mission Indicator	1.05	−3.40	−0.76	−5.59
	(1.71)	(5.68)	(2.04)	(7.52)
Deep Space Mission Indicator	−3.40	−4.58	0.34	−4.28
	(1.77)	(5.72)	(2.00)	(7.37)
# Mission Objectives	0.16	0.37	−0.06	1.09
	(0.28)	(0.91)	(0.38)	(1.20)
N	57	43	83	55
R^2	0.13	0.18	0.01	0.14

Standard errors are in parentheses.
$\dagger p < 0.10$; $^{*}p < 0.05$;$^{**}p < 0.01$. Two-tailed tests.

cited papers have, on average, a greater influence on their fields than do less-cited papers [21], [22]. Thus, to proxy for the ultimate impact of a journal article, we constructed counts of the number of times each article that utilized data from a given NASA mission had been cited in other journal articles (again utilizing Web of Science data). We used these citation data to construct a set of mission performance metrics mirroring those reported earlier but relying on citation-weighted publication counts (where each article increases the publication count by the number of times it has been cited) rather than raw article counts. The results of the analysis using these citation-weighted performance metrics are presented in Table V. As shown in the table, the results of this analysis are very similar to those reported for the performance metrics based on raw article counts reported in Table IV, with the exception that the FBC Mission Indicator coefficient fails to reach significance in Model 3, where the dependent variable includes only citations that occurred within five years of the commencement of a particular mission. This time frame may have been too short to observe the scientific impact of unmanned NASA missions.

D. Discussion

Taken together, the results presented in Tables III–V present a different view of the success of the FBC paradigm than previous evaluations have found. The first analysis summarized in Table III confirmed that FBC missions were more likely to fail than missions from other paradigms. But the analyses summarized in Tables IV and V showed that FBC missions also generated more scientific output per dollar of mission development cost. These findings suggest that the original premise of the FBC paradigm—that by launching a larger number of smaller, less costly missions, NASA could produce space science at lower cost despite the increased risk of mission failure—was valid, in spite of the visible failures that resulted in negative public perception and the abandonment of FBC.

V. FUTURE FBC PROJECTS?

To understand the current public perceptions of NASA in terms of perceptions of failure risks and strategic goals, we surveyed two groups: undergraduate students and the general public. The undergraduate sample included 267 students attending a four-year university in Washington, DC. The average age was 20 years old, and the sample was 48% male and 66% white. The undergraduate students received class participation credits for participating. The general public sample completed the survey at the request of Amazon Mturk and were paid fifty cents for participating. The average age was 37.4 years old, and the sample was 50.3% male and 72.4% white; 89.1% had at least some college education.

Our first observation is that past NASA failures are not readily recallable to our survey participants. We reminded participants that NASA experienced two catastrophic accidents in its human space shuttle program: *One accident occurred on January 28, 1986 during launch and one occurred on February 1, 2003 during re-entry*. Participants were then asked to name the two space shuttles involved in the accidents. Seventy-one percent of the undergraduate students could not name the space shuttle *Challenger*, and 46% of the general public sample could not; 85% of the undergraduate students could not name the space shuttle *Columbia,* and 76% of the general public sample could not. From these data, we conclude that past failures even as high impact as the space shuttles that resulted in loss of human life are not a lasting focus of the public.

Our second observation is that the public is supportive of NASA focusing on science missions. Participants were asked which class of projects NASA should concentrate on (and participants were forced to select only one). In the student sample, 77% chose unmanned spaceflight versus 23% for human spaceflight; in the general public sample, 73% chose unmanned spaceflight versus 27% for human spaceflight. While NASA has always looked to the human exploration mission for inspiring the public starting with President John F. Kennedy's famous Apollo lunar landing challenge [23], from these data, we believe that NASA can inspire the public with science missions. Consistent with the results of our survey data, in his 2014 Earth Day statement, current NASA Administrator and former astronaut Charles Bolden asserted, "Climate change is the challenge of our generation" [24], and he continued to explain "NASA research yields down-to-earth benefits such as improved environmental prediction, preparing for natural hazards, and anticipating the impacts of climate change" [24].

Given the short memory of NASA failures, a strong interest in unmanned, robotic missions, and the challenge for a generation to address climate change, NASA should look to inspire future generations with stretch goals and unmanned/robotic missions. Given the knowledge gained from the unmanned FBC missions in the 1990s, we recommend inspiring the next generation of NASA stakeholders with unmanned missions that focus on saving the Earth from climate change or life-threatening near-Earth objects (NEOs) or otherwise making the everyday lives of humans better or safer, and developing many low-cost missions to produce more science even if it will require convincing the public that NASA "can afford to lose a few" [4].

VI. FBC and Learning from Stretch Goals

The use of challenging, stretch goals in organizations presents contradictions and challenges to organizational members. On the one hand, the difficulty of organizational goals is known to be positively associated with effort, innovation, and performance [10], [11], [15], [16]. But on the other hand, when performance falls short of difficult goals, organizational members show a strong tendency to alter the goal so as to render it more easily achieved in the future [11], [16], [25]. Thus, although stretch goals hold the potential to generate crises in organizations that drive learning, change, and innovation, because crises are inherently uncomfortable for organizational members, most organizations are unable to maintain stretch goals over time [10]. NASA's FBC experiment is an excellent demonstration of these difficulties.

Regardless of the challenges of stretch goals, with the constrained budget environment facing NASA (i.e., NASA's budget has remained effectively flat from 2010–2015 with *only* a 1% proposed cut in the 2015 FY budget from 2014 [26]), the agency has little choice but to adopt new business practices. This is evident in NASA's support for commercial companies to develop human launch vehicles for low-earth orbit.

Despite abandoning FBC after the 1999 Mars failures, NASA has clearly learned from the FBC experiment and may have opportunities for further learning from it. For example, the scientific knowledge gained from FBC missions was derived more cost effectively, as shown in the regression analyses reported above, than was knowledge from missions developed under other mission paradigms. Additionally, despite the formal end of FBC, NASA continues several programs that focus on smaller, cost-effective missions, including its Discovery Program in Planetary Science and its Pathfinder program in Earth Science.

A recent success story from the Discovery Program is the Gravity Recovery and Interior Laboratory (GRAIL) [27] with many of the lessons learned from FBC implemented on this project. For example, because it was selected as a Discovery Program, the project faced strict constraints on schedule and budget. The proposal process for science was streamlined in that this was a Principal Investigator lead project that after selection never changed the original science requirements. The project relied significantly on inheritance from previous missions, especially the Mars Reconnaissance Orbiter, with "requirements taken as-is from the heritage designs and modified only when absolutely necessary (and then only to the smallest extent possible." [27, p. 6] Additionally, the spacecraft was built by Lockheed Martin under management from NASA's Jet Propulsion Laboratory. Had GRAIL been completed in the 1990s, we believe that GRAIL would have been considered another FBC success story. Possibly if the lessons learned through FBC can be revisited without prejudice, the success of the Discovery Program and other small NASA spacecraft can be further enhanced.

As documented in the research examining FBC before the 1999 failures [12], [14], there are management practices that project leaders can adopt that can generate focus and support for a stretch goal and that can generate slack in the development process. Both steps that are critically important if stretch goals will be met. Additionally, perhaps the greatest lesson that other organizations (and NASA itself) may take from NASA's FBC experience is that working toward stretch goals requires an enhanced tolerance for failure and that such tolerance may be developed by adopting a holistic view of success and failure. When success was defined as the percentage of missions that achieved their objectives, FBC was viewed as a poor philosophy. However, as demonstrated here, a broader definition of success for an unmanned science mission highlighting knowledge creation paints FBC in a different light. Despite the increased likelihood of mission failure, FBC produced knowledge at a lower cost than did other mission paradigms studied. Additionally, it is worth noting that all of the "failed" FBC missions in our sample had nonzero article and citation-weighted article counts—suggesting that even failed missions have science value. Members and stakeholders of other organizations may embrace stretch goals more fully and tolerate the failures that are inherent in pursing challenging goals better if those organizations could utilize broad definitions of performance and recognize the potential value in "failed" missions.

VII. Conclusion

The results presented here suggest that NASA's implementation of a stretch goal (the FBC paradigm) was a success despite the negative perceptions of it that developed inside and outside of NASA. These results indicate that adopting a highly challenging stretch goal may have significant learning benefits for an organization like NASA even long after the goals themselves have been abandoned. This being the case, we suggest that NASA and other engineering organizations should consider adopting stretch goals more frequently and in particular to overcome the current challenging NASA environment, we recommend a return to the FBC stretch goals with a focus on missions that NASA needs to revitalize itself by pursuing missions relevant to ordinary people such as solar energy generation and planetary protection and sustainability.

Appendix

List of FBC-Era Missions Used in the Analyses.

Mission Name	Launch Date
WIND	11/1/1994
Solar and Heliophysic Observatory	12/2/1995
Rossi X-Ray Timing Explorer	12/30/1995
Near Earth Astroid Rendezvous	2/17/1996
Global Geospace Science Polar Satellite	2/24/1996
Fast Auroral SnapshoT Explorer	8/21/1996
High Energy Transient Explorer	11/4/1996
Mars Global Surveyor	11/7/1996
Mars Pathfinder	12/4/1996
Advanced Composition Explorer	8/15/1997
Lewis	8/22/1997
Lunar Prospector	1/6/1998
Student Nitric Oxide Explorer	2/26/1998
Transition Region and Coronal Explorer	4/2/1998
Deep Space 1	10/24/1998
Submillimeter Wave Astronomy Satellite	12/5/1998
Mars Climate Orbiter	12/11/1998
Mars Polar Lander	1/3/1999
Deep Space 2	1/3/1999
Stardust/NeXT	2/7/1999
Wide-field Infrared Explorer	3/4/1999
Landsat 7	4/15/1999
Quik Scatterometer	6/19/1999
Far Ultraviolet Spectroscopic Explorer	6/24/1999
EOS Terra	12/18/1999
Active Cavity Radiometer Irradiance Monitor	12/20/1999
Imager for Magnetopause-to-Aurora Global Exploration	3/25/2000
High Energy Transient Explorer 2	10/9/2000

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