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A DIFFICULT CASE: BRINGING PRODUCT DESIGN METHODS TO NASA ENGINEERS

C. L. Gill, B. W. Lilly and R. C. Forsgren

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1. Introduction

As manufacturing firms seek competitive advantage in today's global marketplace, product design grows ever more important. The relentless pace of innovation demands that firms must be able to meet stringent requirements for high quality and reduced time to market if they are to survive. Increasingly, a key factor that determines a product's success or failure is the blending of form, function, and appearance that is collectively known as "product design". The growing emphasis on design as a key product differentiator has led many firms to create design teams composed of specialists from fields as diverse as anthropology, mechanical engineering, and behavioral psychology [Kelley, 2005]. Assembling diverse design teams is no great feat in and of itself: the challenge lies in forging coherent, highly functional teams that can exploit the individual team members' expertise, temperament, and design experience to consistently deliver truly innovative products on time and under budget.

The runaway success of products such as the Apple iPod has led to a heightened level of interest in the procedures and practices that result in such innovative designs. Breakthrough products such as the iPod and the original Palm Pilot, both of which created very lucrative market segments seemingly out of thin air, have increased the visibility of product design in the global business community. This in turn has led to greater interest in the tools, methods, and design techniques that lead to innovative products. In general, one can say that the focus of these practices has been to provide a systematic approach to product development that is grounded in domains such as anthropology, linguistics, and psychology – disciplines that traditionally have not been seen as integral to product design. What these methods have in common is a focus on the total experience of the user, and as such they are often based on techniques that discover, exploit, and develop mass-market opportunities that address the lifestyles and values of the intended consumers. (See, for example, [Cagan, 2002], [Norman, 2003], [Fulton–Suri, 2005], [Vogel, 2005]).

Product design firms such as IDEO have been quite successful at promoting their consumer–centered approach to the design process. While this focus on the consumer experience clearly has met with success in the marketplace, it doesn't address an entire class of design situations in which innovative solutions are clearly called for, but where the role traditionally played by the user goes unfilled. Many enterprises fit a model characterized by tight constraints, demanding requirements, and highly technological applications, but in which there is no obvious "user" at the center of the design, and where the traditional concepts of the profit–centered market also do not apply. It is important to be clear about what we are claiming here: there is always a "customer", in some sense, for every designed and fabricated artifact, whether that customer is an individual consumer, a business enterprise, or a government agency. Our contention is that there is a large class of design problems, typically encountered in highly engineering–centric organizations, to which the usual methods that guide product design practice are not easily transferable.

In this context, an interesting question is: do the methods, tools, and techniques of contemporary, consumer–oriented product design apply? For the past three years we have sought to answer this question by introducing some of these techniques into very "engineering centric" organizations. Previously we have discussed our efforts in both academic and professional domains [Lilly, 2004], [Gill, 2005]. This paper offers a critical look at our efforts to introduce some of these tools and methods into an organization that is very much "task–centered" rather than "user–centered" – the U.S. National Aeronautics and Space Administration. Here we describe our work in developing a successful course in ideation methods for the Agency.

2. A product design course for NASA

Because of budgetary and program cuts after the successful moon landings and particularly due to general government cutbacks in civil service employment in the 1980s, NASA now finds itself with an aging workforce, most of whom were trained in the traditional engineering design techniques of the past. As of 2004 nearly 40% of the 18,146 people at NASA are age 50 and over and 22% of them are age 55 and older. NASA employees over age 60 outnumber those under age 30 by a ratio of three to one. A scant four percent of NASA's workforce is under age thirty. NASA's leadership sees a fundamental problem in keeping its very capable workforce up to date in a world where both technology and methodology change constantly [NASA, 2004].

NASA is a difficult environment in which to introduce product design methodologies. Unlike almost all industrial firms, NASA does not produce products in large quantities: in fact, NASA very often is engaged in "one of a kind" production, which typically requires the fabrication of the actual flight hardware in addition to a few prototypes for testing and simulation. While the phrase "lot size one" has become familiar to manufacturing firms attempting to master lean production techniques, at NASA "lot size one" *is* the norm. This fact has a direct bearing on production methods (CNC machining is by far the preferred production technique) and hence the types of designs that are considered feasible. Mass production methods, such as polymer injection molding, die casting, and sheet metal forming are essentially unknown in the Agency.

The high–risk nature of the missions combined with the certainty that failure will be both visible and expensive has naturally led to an extremely risk–averse engineering culture within the Agency. NASA personnel understand that they typically do not get more than one chance at success, and therefore it is essential that every design function perfectly, every time. At the same time, the need for innovative design is just as important now as it was four decades ago during the Apollo Program. Then, Soviet competition motivated innovative solutions to the problem of getting to the moon. Today, the potential for private ventures to successfully compete in space and the mandate to return to the moon with very limited resources has caused NASA to revisit and re–think their standard engineering practices.

2.1 IDEA is launched

For the past three years the authors have taught a course in concept generation and design ideation as part of the NASA Engineering Training (NET) Program. This course, known as Innovative Design for Engineering Applications (IDEA) has been offered at every major NASA Center since 2003. Originally, IDEA was conceived as a two or three day workshop, taught by a single instructor (Lilly), that would be based around a "design for Mars" scenario. The original concept was that engineers from a variety of disciplines and specialties would come together, be given a challenging problem having to do with the manned exploration of Mars, and then have two days in which to design a solution. Several problems with this concept became apparent rather quickly. First, the instructor's experience was in the field of design and manufacturing of consumer products, and thus he had no particular expertise related to spacecraft design or the planet Mars. His exposure to NASA was limited to three years of teaching a course in manufacturing processes through the NET program.

Secondly, it was clear that unless the NASA personnel were introduced to fundamentally new design methods and then forced to apply them immediately to a design problem, what would result would most likely be a fairly typical NASA design, based on previous missions. In this case, the entire rationale for the course would be lost, and little would be gained by the participants. It is entirely reasonable that NASA designers instinctively turn to tried–and–true solutions, given the severe constraints of the environment in which their designs function, and the very high penalties for failure. Our task in teaching IDEA was to convince them to attempt “out of the box” thinking in the very early conceptual stages of their designs, which proved to be a very difficult task.

The problems became apparent during the initial offerings of the course. The course was offered twice during the late summer and fall of 2003, at Goddard Space Flight Center in Greenbelt, Maryland, and at the Johnson Space Center in Houston, Texas, with author Lilly as the sole instructor. While the initial offering at Goddard was somewhat successful, the following session, at Johnson Space Center, was received far less favorably. Several of the attendees were program managers, not engineers, who did not have any particular interest in design and who were quite skeptical of the material presented. This experience resulted in the decision by author Lilly to seek assistance from a design professional, at which point author Gill became involved.

2.2 Rethinking and relaunching

In early summer, 2004, the course was offered at Marshall Space Flight Center, in Huntsville, Alabama. Author Lilly was again the sole instructor, with author Gill in attendance to observe and comment on her impressions. At this time the course consisted of three discrete parts, with each lasting one day. The first day’s objective was to introduce creative thinking processes and conceptualization techniques as they pertain to innovative design as well as product design methodology and practice. The second day’s objective was to introduce the concept of product architecture in the context of system design. The students disassembled one–time–use cameras, looking closely at the top–level system and the individual components in order to better understand the implications of integrated and modular architectures. Following this activity, they developed system level diagrams describing a hypothetical unmanned mission to Mars. This exercise allowed the students to transfer insights gained from the analysis of a consumer product directly into the NASA context. The objective of the third day was to use visualization methods in order to generate and communicate design concepts developed during the group sessions. The visualization methods were to model a specific component and to sketch concepts and diagram the overall mission.

Following this class, which again proved to be only marginally successful, we began to work as a team and revise the entire structure and objectives of the course. Several aspects of the course were not working. The concept generation methods presented on the first day were not applied by the students when generating ideas. While several techniques were introduced in the first day’s lectures, none of them were systematically put into practice during the team design activities. Rather, students reverted to their standard practice of recalling a design that one of the team members had seen or heard of from an earlier mission, and modifying it to meet the demands of the given task. In general, we felt that most of the lecture material of the first day was quickly filed away and not applied to the exercise in any meaningful way.

In a similar manner, the model–building exercise had unintended consequences. We tasked the students to model various concepts for a sample return container, which had to be designed to ensure that no Martian microbes could survive on the surface of the container when it returned to Earth. Instead, the students used this exercise to model their overall mission design. This segment became an enjoyable team–building exercise, but because it occurred on the last day of the class, it was essentially useless in this role. The original objective, to persuade the students of the value in building models in order to visualize and communicate ideas early in the design process, was entirely lost.

On the positive side, one aspect of the course that was clearly a success was the camera exercise. The objectives were clearly met and the students successfully mapped the flows of energy and information through the system gaining insights into multi–level interactions among components and subsystems. Disassembling the camera has invariably been successful with engineering–oriented students, because it plays so well to their innate interest in mechanical devices [Lilly, 2004]. Another positive aspect was the enthusiasm and interest shown by the students who were clearly interested in alternative methods for innovative design and were intrigued by the product design practices.

From these observations, several changes were put into place immediately following the Marshall experience. We decided to de–emphasize the lectures on conceptualization techniques, by placing greater emphasis on practical product design methods that we felt confident would better fit a technically oriented audience. We introduced the technique of generating group discussions through non–linear diagrams, or “mind maps” early on the first day, as a method of recording and promoting rapid idea generation during brainstorming sessions. We also decided to use scenarios and personas or user archetypes as tools to introduce user–centered design methods. We followed this with a two–hour design exercise in which the students were asked to apply these techniques to a consumer product design problem that was primarily task–oriented and in which the user was at the center of the problem. The main objective of this change was to bring the product design perspective directly to the students and ask them to find relationships between these innovation processes and their own challenges within NASA. We realized from the previous courses that trying to make the connections for them was inappropriate since our experience was far removed from their context.

Figure 1. Mind map for Mars mission

The Mars mission design problem remained essentially the same, but we made a concerted effort to focus the students’ attention on the processes they habitually used when they generated ideas. Once they became aware of their preferred methods, it was easier to convince them to try other approaches. While the NASA engineers were at first resistant to the idea of using mind maps and other visual brainstorming techniques such as storyboarding, by the end of the revised course they began to see their usefulness at different steps in the concept generation process. We encouraged them to explore using visualization techniques when the design constraints are well defined, as for example when brainstorming specific sample container concepts, and also when the constraints are fuzzy and ill–defined, as they were for the mission architecture in the initial definition stages. The students who bought into our approach came to see the mission maps (Figure 1) as cognitive tools which they then referred to later, when creating specific scenarios and designing the actual components (Figure 2).

We also made the decision to increase the amount of time given to the camera disassembly/system architecture segment on the beginning of the second day, expanding it to cover the entire morning session. While continuing to emphasize the importance of mapping flows of mass, information, and energy through the system, we also directly related the system decomposition exercise to the methods outlined in the *NASA Systems Engineering Handbook*, with which many of the students were well acquainted [NASA, 1995]. Our “hidden agenda” in doing this was again to convince the students of the value of using graphical methods to rapidly convey design information. Although engineers constantly use informal sketches, charts, and graphs to communicate with each other, these tools are often overlooked as design aids, in favor of more elaborate, computer–based systems [Ferguson, 1995].

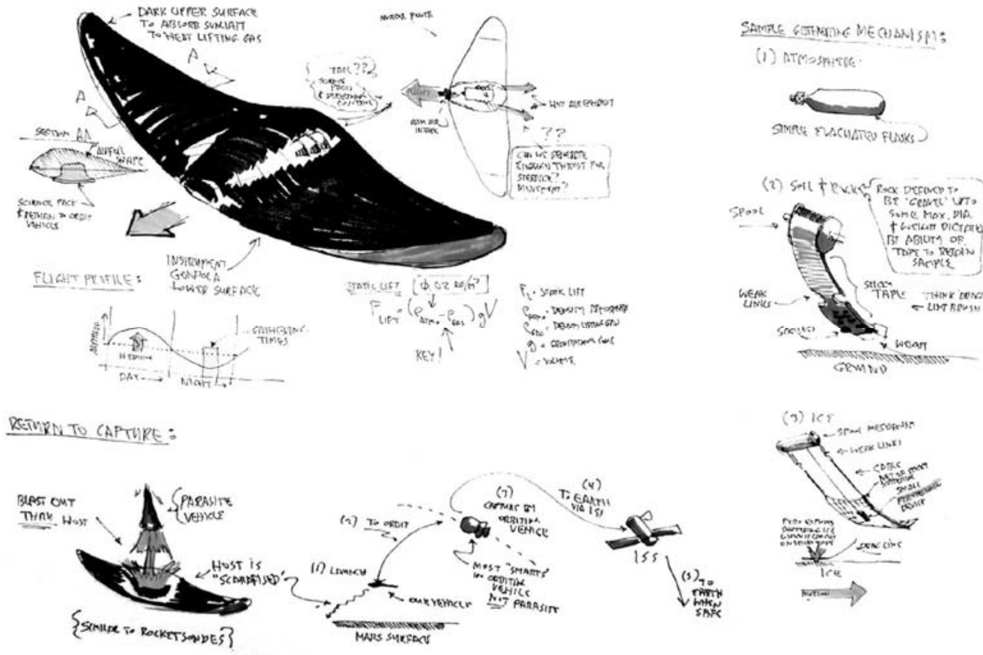

Figure 2. Conceptual sketches for Mars mission

We have taught IDEA a total of five times since the changes to the course were first introduced, and during that period we have continued to refine and test new ideas for bringing current ideation and conceptualization tools into the course. For the past two years IDEA has been taught successfully at several NASA locations, including Kennedy Space Center and the Jet Propulsion Laboratory. The course evaluations have been consistently very high, and students have indicated that they find the experience to be valuable. However, as educators we remain unsatisfied with our efforts to date, and continue to look for better methods of applying some of the insights of contemporary product design methods to highly task–focused application areas.

One area in particular seems to hold potential for bridging the gap between consumer–centered design and task–centered engineering: the use of visualization both for ideation and communication. In IDEA we have begun to place more emphasis on a variety of visual tools, including mind maps, storyboards, scenario modelling, QFD charts, and system diagrams.

3. Conclusions

The success of our course has been primarily a function of the students' open–mindedness and curiosity, and their willingness to leave their own personal comfort zones behind. In teaching IDEA over the past three years, the students we have encountered have run the gamut from recent college graduates to senior scientists with multiple Ph.Ds. We have taught an ex–Apollo astronaut, the payload manager for the International Space Station, and newly hired engineers one year out of college. The common factor among the students who embrace our methods is a willingness to trust us, to take some personal risks, and to have the courage to try new methods that at first glance might seem to be ineffective.

We have also concluded that it is a mistake for us, as outsiders to the Agency, to attempt to "build NASA into the course", as we were earlier advised to do by senior NASA managers. We feel it is much more valuable for us to present ourselves as we are and to bring an outsider's perspective into the organization, rather than pretend to be experts in areas far beyond our ken. We now make it clear that it is the responsibility of the students to translate what we teach them into the NASA context. Our best students have been willing to do that, and we have been gratified by the results of that effort.

Nevertheless, we have also come to realize the limited effectiveness of some of the basic tenets of the course. What seems to work best with a highly technical audience are the exercises in visualization that can be applied immediately. Whether it is a mind mapping exercise or the camera teardown, the activities that consistently rank highest with the students are those in which they can clearly see an application. The students don't respond positively when they cannot translate the material to their own needs. This could be due to the fact that the methods used by product designers are based on markets, consumers, mass production and competitive advantage.

We have concluded that the methods of innovation are not strictly limited to consumer product design. We are searching for ways to extract core qualities from traditional methods that we have found very effective but at the same time restrictive. The fact that these methods come from the consumer environment pose a contradiction that we continue to investigate both at NASA and in the academic world.

In terms of our personal growth as educators, our experience working with NASA has been an extremely rewarding one, at least in part because it has been so challenging and at times frustrating. We learn from each other as we try to teach others, constantly questioning our ideas and methods while giving ourselves the confidence to take risks. Our work for NASA has shown us first–hand how difficult it is to work across disciplines and cultures. By doing so, there is no question that we have developed both professionally and intellectually, and our experience here has led to several other joint projects. In fact, our experience has validated the idea that interdisciplinary work, when it is successful, can be the most satisfying.

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Professor Carolina Gill
Assistant Professor
The Ohio State University, Department of Industrial, Interior, and Visual Communications Design
128 N. Oval Mall, Columbus, OH 43210, USA
Tel.: 614-688-8671
Fax.: 614-292-0217
Email: gill.175@osu.edu