Richard F. Aubin
United Technologies/Pratt & Whitney
400 Main Street MS 118-38
East Hartford, CT 06108
Phone 203-565-9073

A CASE STUDY IN RAPID PROTOTYPING

INTRODUCTION:

Since the first quarter of 1988, Pratt & Whitney (P&W), a Division of United Technologies Corporation (UTC), has been involved in the development for the use of rapid prototyping technologies that use a "layer-by-layer" building approach. Based on over 4 1/2 years experience with Stereolithography, this paper will address three aspects of our experience including: Implementation, Current Operations, and Future Plans.

BACKGROUND:

Component parts for gas turbine engines are required to function in environments that are unlike any other industry, with combustor temperatures reaching 2,500 degrees F., and pull loads on our 1st blades reaching 50,000 g's. However, manufacturing these parts is accomplished using conventional methods that are similar to other industries.

Conventional methods for prototype fabrication, small batch production and manufacturing process development have relied on drawings, hard tooling, numerical control programming, complex machining and/or extensive hand work. These approaches are typically characterized by long lead-time, high cost and multiple iterations to achieve desired results.

There are many organizations today, that continue to employ these methods, but before they can make the transition into the new era of rapid prototyping, they must recognize that they are out of step with the current environment. Without feeling the need to change, the "*Boiled Frog Phenomenon*" is likely to occur.

The Boiled Frog:

This phenomenon is based on a classical experiment in biology. A frog which is placed in a pan of cold water but which still has the freedom to jump out can be boiled if the temperature change is gradual, for it is not aware of the barely detectable changing heat threshold. In contrast, a frog dropped in a pot of boiling water will immediately jump out: it has felt the need to survive. In a similar vein, organizations and managers that are insensitive to gradually changing environments, are likely to become "boiled frogs"; they act in ignorant bliss of environmental triggers and eventually are doomed to failure.

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IMPLEMENTATION:

Up until 1988, P&W was deeply involved in conventional prototyping methods. We had an extensive investment in CAD/CAM equipment and trained personnel, but still had to "iterate" at the expense of extended lead times and increased costs. However, unlike the frog, we felt the water getting warm before it was too late.

Along came an opportunity to "beta test" a new technology called Stereolithography (SLA) from 3D Systems Inc., of Valencia, California. Although faced with many unknowns and associated risks, we decided to get involved, and acquired 2 "beta machines" in January - February 1988. One SLA machine with a 9-inch part building capacity was located at our facility in West Palm Beach, Florida, while the second one was located at our manufacturing facility in East Hartford, Connecticut.

We were fortunate to have extensive resources in computer modeling hardware and software, and experienced people proficient in its use. Initially, we used floppy disks to transport the computer models from the CAD systems to SLA, but learned quickly that complex computer models were very large in size. By using our shop computer network system (ethernet), we are now able to download computer models directly to the SLA machine.

To increase the exposure of this new technology and to demystify its operation, we gave walking tours and presentations to:

- Managers - So they understood its potential "fit" for their requirements,
- Engineers - So they understood the computer modeling requirements, e.g., bases & supports,
- Mfg. Shop - So they could understand its capabilities and how to get access.

We soon felt that we were a "tours-r-us" operation, but it paid off. Shortly, we were building a large variety of prototype objects and identified many tangible and intangible benefits.

One of the most significant tangible benefits was the identification of design errors early in the design process. Because SLA was so fast and relatively inexpensive to produce a prototype as compared to traditional methods, engineers were given more latitude to improve their designs, so design quality was enhanced prior to reaching manufacturing. In the past, too many design flaws were uncovered after the manufacturing departments made the tooling and the parts, investing time and resources only to find out they did the "wrong part right." By working out these errors before involving manufacturing, we can better align our shop resources to doing the "right part right."

Joel Mokyr, Professor of Economics and History at Northwestern University and author of

his recently published book titled, The Lever Of Riches, states: "*Technological progress has been one of the most potent forces in history in that it has provided society with what* *economists call a 'free lunch,' that is, an increase in output that is not commensurate with the increase in effort and cost necessary to bring it about.*" There have been several occasions where, as a result of rapid prototyping, we have had a taste of this "*free lunch.*"

Another tangible benefit was the improvement in communications among design engineers, and between engineering and manufacturing personnel because they now had a physical object to use instead of a sketch or drawing that was subject to interpretation.

On the intangible benefits side, the SLA process provided an incentive and reward mechanism to our engineers to learn and use computer solid modeling that for more than just "pretty pictures". By generating computer models of their design ideas, they would be rewarded with the satisfaction of possessing a physical prototype in return.

Although considered intangible, our engineers were thus enabled to "think-out-loud", meaning that they were now able to generate physical objects directly from their computer models quickly and inexpensively. A new degree of enthusiasm resulted in the engineering community as a result of this new capability that essentially kept them "fresh" instead of growing "stale" while waiting for the hardware to arrive.

Further, engineers were now receptive to change by incorporating suggested improvements from peers and from manufacturing personnel.

Needless to say, these benefits provided significant time and cost savings.

By the end of the first year of using SLA, we recognized the value of working together with other "beta test companies". Collectively, we worked and shared ideas to improve accuracy and surface finish. We also identified errors in the SLA process, and provided suggestions for improvement by submitting enhancement proposals to 3D Systems. Eventually, these enhancements were manifested in later revisions of the software, so mutual benefit was realized as a result of team-playing.

With a few "free lunches" under our belt, we finished the first year with some valuable lessons learned, and unlike the "boiled frog," we found ourselves rewarded by being sensitive to our changing environment.

After beta testing the early version of the SLA device, we were given another opportunity. This time, 3D Systems was offering their larger SLA machine for beta test, that had a 20-inch part building capacity. This gave P&W the capability to build larger prototype objects; we proceeded without hesitation.

Having recognized the benefits of working with other companies throughout the beta testing programs, P&W and the other beta test companies took the initiative to establish the SLA users group. This group was comprised of all users of SLA for the purpose of providing a forum for technical information exchange among the SLA users community. Through this forum, companies share lessons learned, and identify strategies to improve their output. P&W provided leadership to this group by chairing this organization from its inception through its first year.

Internally, P&W decided to expand its rapid prototyping capabilities, and share its lessons learned with our sister divisions of UTC by establishing what we called an "Express Prototype Consortium." This consortium served as a vehicle for technology transfer with: Carrier, Hamilton Standard, Otis Elevator, Pratt & Whitney Canada, Sikorsky Aircraft, and United Technologies Automotive.

CURRENT OPERATIONS:

Currently, our operation in East Hartford has grown to include a total of 4 SLA machines and through the benefits of economies of scale, we are able to be responsive to the prototyping demands of our entire corporation. Last year, 1990, over 1,600 prototypes were processed at our East Hartford facility.

We see this activity in several basic areas:

- Design Verification

  As previously mentioned, there is great value in identifying design errors prior to manufacturing involvement. Improving designs by "iterating in plastic" is much more effective in time and cost than by conventional manufacturing techniques which iterate in "hard tooling."

- Manufacturing Producibility Studies

  Rapid prototyping is one of the key facilitators of integrated product development or concurrent engineering. Our manufacturing shops can get an earlier startup on process development by having a replica of a part to use to prove out tooling and fixturing while the actual real parts are being produced. For example, while investment castings are being processed, plastic replicas can be used in the manufacturing environment to ensure proper fixturing and tooling for final machining. When the actual parts arrive, the machining process is already up and ready.

- Prototype Parts For Test And Conversion To Other Materials

  Occasionally, the plastic object can serve directly as a prototype in a test where the physical properties of the plastic can suffice. Techniques to convert the plastic object to other plastic materials having improved physical properties are also commonly available in industry through injection molding processes. And lastly, investment castings can be generated in a fraction of the time through the use of temporary tooling.

- Research and Development Efforts

  To date our biggest limitation with the photo-curable resins has been accuracy and surface finish. Our focus therefore has been to improve the process steps which affect them. We have learned that all variables in the total process must be considered, including: computer modeling preparation, hardware and software development, materials, and post-processing.

Additional activities we have pursued include development relationships with resin suppliers to improve the basic resins themselves for less shrinkage, distortion, and better surface finish.

Because of the benefits we realized from beta testing Stereolithography, we are currently involved in the beta testing of new emerging technologies:

- Selective Laser Sintering (SLS), from DTM Corporation of Austin, Texas. This is a process that uses the heat of a CO_2 laser to sinter powdered materials in a layer-by-layer technique. The materials offered include wax and poly carbonate plastic.

- Fused Deposition Modeling (FDM) from Stratasys Inc., of Minneapolis, Minnesota. This is a process that uses a heated extruder mechanism to deposit thin layers of wax or nylon-like plastic materials.

Both technologies build prototype objects directly from computer models, and each has its advantages; however, because of beta testing and non disclosure agreements, further information is prohibited at this time and is best derived directly from the companies developing the technologies.

Finally, we are actively involved in several rapid prototyping consortia with academia including MIT, and the University of Texas.

FUTURE PLANS:

As you have seen, we have been very active players in the Stereolithography field. We look forward to improvements in that field as it improves and in other technologies that we are hearing about in this conference. We feel strongly that continued development is essential to improve the accuracy and surface finish for prototype objects and to come closer to the "real" physical properties of "production-like parts."

As leaders in the application of rapid prototyping, we can't wait for these developments to mature. Although much can be done unilaterally and internally, more can be accomplished by pro-actively working with the manufacturers of rapid prototyping technologies, other users, and academia to drive development in the direction for maximum benefit to industry.

The next "free lunch" just may evolve through dedicated continuous improvement.