FFF at Ford Motor Company

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Introduction. Ford's effort in Free Form Fabrication (FFF) began in 1987 with the formation of an internal consortium, composed of a dozen different activities, whose purpose was to evaluate and apply, where possible, this emerging technology. Each of the consortium members agreed to contribute some money and, more importantly, one or more people to work on this project. By the following year (1988) the first machine, an SLA-1, had been installed at the Alpha Manufacturing Development Center and formed the cornerstone of the FFF Lab.

An Early Success. By the end of the year a number of successful parts had been built. One of the most dramatic was a rocker arm for the 1992 5L engine. The story of this arm has been told several times in articles and presentations but, nonetheless, bears repeating. A young engineer had designed this arm and had sent the design out to suppliers for quotes. (This particular part is purchased from outside.) Normal practice at that time was to use a 2-D detailed drawing to describe the part to be quoted. The initial round of quotes had already been completed based on the information contained in the drawing. Four suppliers had been contacted and asked to quote. Three of the four had responded with per-unit prices and the fourth had come back with a "No-Bid". The engineer was assigned to the FFF lab, built a 3-D Solid model of the part and then used the model to build a stereolithography prototype. It was only upon inspection of the prototype that he discovered a problem with the design. He corrected the design and built a second prototype to verify that the problem had been solved. Since the design had changed, a second round of quoting was initiated. This time, however, plastic stereolithography prototypes were sent to the suppliers in place of revised drawings. Each of the suppliers came back with a lower quote than on the first round and the supplier who had "no-bid" first time around, came in at a price roughly 50 cents lower than any one else. This reduction amounted to several million dollars of savings per year.

Fundamental Value of FFF. The rocker arm story illustrates the basic value of FFF technology. The ability to take a computer model and build an accurate prototype of it in a few hours or days provides a new, high-bandwidth medium of communication for information about parts. Consider the process by which 2-D drawings are produced today: the engineer conceptualizes the part in his head; makes a few rough 2-D sketches and passes these along to a designer or detailer who must first get an accurate concept of the part, then, conceptually pass planes through the conceptualized part at various angles and then accurately conceptualize how these cross-sections would look; then he begins drawing these conceptualized cross-sections. This is a very complex and error-prone process. Once the drawings are complete, they are sent to a manufacturer who must then reverse the process conceptually and reconstruct the original design intent from the drawn cross-sectional information - an even more complex and error-prone process. All of this conceptual gyrating is completely short-circuited by FFF. The FFF prototype becomes the primary method of communicating all of the geometric intricacies of the part. In a sense, representations of the part are replaced by the part itself. It is never easy to quantify the benefits of improved communications, but the millions in savings spawned by the plastic rocker arm certainly indicate that "..there's gold in them thar hills!!!..."

FFF and Prototyping. Prototypes have been in the mainstream of invention, engineering and product development since Alley Oop first laid chisel to stone in search of the wheel. In the past, the role of prototyping has been severely limited by our inability to produce prototypes rapidly and cost-effectively. FFF holds out the prospect of being able to provide prototypes at virtually every stage of product development. Let me emphasize that this ability is not here today, but is coming. Prototypes seem to fall into three main categories, related to the stage of development of the product: "touch - feel" prototypes, "form, fit, limited function" prototypes and fully functional prototypes.

"Touch-Feel" Prototypes: Like the rocker arm cited above, these prototypes are used in the early stages of design for a number of purposes - concept verification, communication of design intent, even for verifying the CAD representation of the part. We have seen numerous examples where the FFF prototype showed up a flaw in the CAD model that was not detectable on the screen. This is the area where FFF currently has its greatest impact.

"Form, Fit, Limited Function" Prototypes: Components designed by different activities must often be assembled to form an integrated system. The ability to build each component quickly and accurately is of tremendous value in assembly studies, in finding interferences and in discovering problems early enough that they are easily handled. Again FFF prototypes are having a tremendous impact in this arena. Fig. 1. shows a partial engine block, made in an SLA 500. This block was sent to the plant which was to manufacture it. The plastic block was used to check out tooling, fixturing, material handling equipment and dunnage. A number of potentially costly problems were discovered and corrected before the final specification for the plant equipment. Fig. 2. shows an experimental intake manifold made on a Cubital solider. This manifold was attached to an engine and run through several power cycles to determine the effect of the design on engine performance. We have made many such manifolds on Cubital and SLA machines. The ability to actually test a new design within a few days is a capability that our engineers have never had before. This is an example of a "limited functionality" prototype. Several of our divisions now make this type of prototype where the functionality is primarily due to the geometry. Manifolds, throttle bodies, pump housings, alternator housings and AC housings are all examples of this kind of application.

"Full Functionality" Prototypes: For the most part, FFF-generated parts do not have the material properties required for full functionality. In this case, the FFF part is used as a model or pattern in a more traditional type of manufacturing process. Fig. 3a shows a stereolithography transmission case and Fig. 3b shows the aluminum casting that was made in our experimental foundry. Figs. 4a and 4b show a stereolithography crankshaft and the iron on made from it. In both instances, our engineers have gotten functional prototypes in a fraction of the time it would have taken using conventional methods. Sand, plaster and investment casting of metals and molding of some plastics (e.g. silicone rubber molding of polyurethane) are all sped up dramatically by the use of FFF models as patterns. Significant time reductions (at least 50%) in the prototyping process are almost universal.

FFF and Tooling. A recent study has estimated that there are 1200 PARTS THAT MUST BE DESIGNED AND MANUFACTURED FOR EACH PART THAT GOES INTO THE AVERAGE FORD VEHICLE. Tooling, fixtures, material handling and dunnage all fall into this category. A similar study by GM came up with an estimate of about 1800 such parts. Since work on these parts can't seriously begin until the product design is reasonably stable, it seems evident that the application of FFF to this arena will be essential to reduce time to market. We are currently carrying out work to develop ways of making tools (molds and dies) directly from FFF parts. Fig. 5 shows an FFF part in the right foreground. It is actually a sand core which will be assembled into a sand mold to make an aluminum engine block. This particular core will be an internal oil drain passage. To the left of the part is a stereolithography prototype of the part sitting in a mold half. This was produced by designing the mold half on a CAD station with the part embedded. In the background are two epoxy mold halves which were formed as follows: the right mold half was formed directly from the stereolithography piece. The left half was then formed from the right half with the part inserted.

FFF Limits. These few examples illustrate the variety of parts and applications that we have completed. Where applicable FFF gives a tremendous advantage in terms of time savings and cost savings. However, not all of the parts the Ford Motor Company makes can be successfully prototyped today using FFF. The most obvious limit is the size of a part that can be built in one piece. Many of our parts must be built in two or more pieces and then joined. In many cases this is a perfectly satisfactory process, producing acceptable prototypes. However, this approach doesn't work, for example, in the area of large sheet metal parts. No machine available today can build a durable hood or fender out of any material. Along with size, the layering process appears to be an impediment in very thin but extended parts. Compared to more traditional processes for making prototypes, FFF is nothing short of a miracle. After a while however, speaking of limits, one begins to become impatient with the build speed of today's FFF machines. (An example of the infinite perversity of homo sapiens? - They're NEVER satisfied.)

Given the rapid (and seemingly accelerating) pace of development in the FFF arena and the fact that the industry is still in its infancy, we can expect to see many of today's limits overcome in very short order.

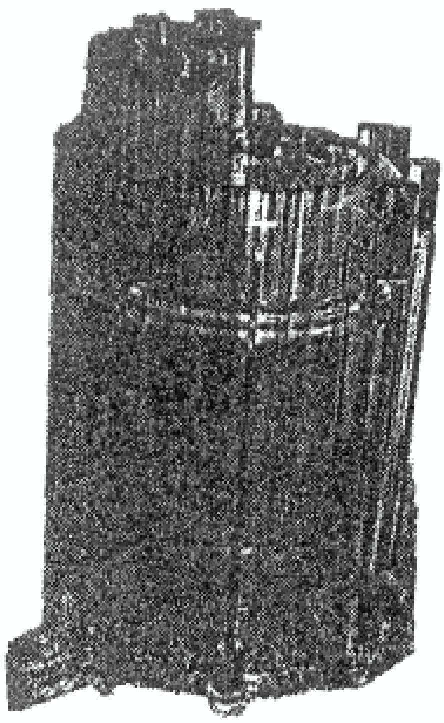

Figure 3a.
Stereolithography
Transmission Case

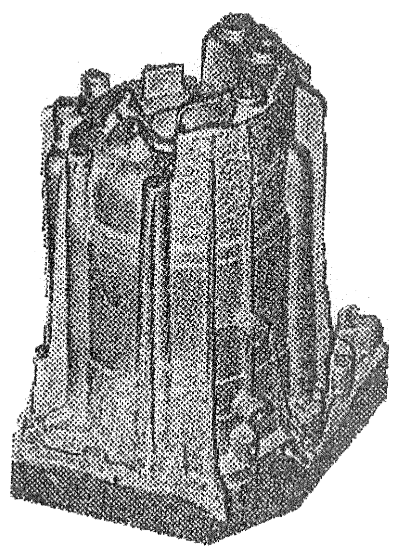

Figure 3b.
Cast Aluminum
Transmission Case

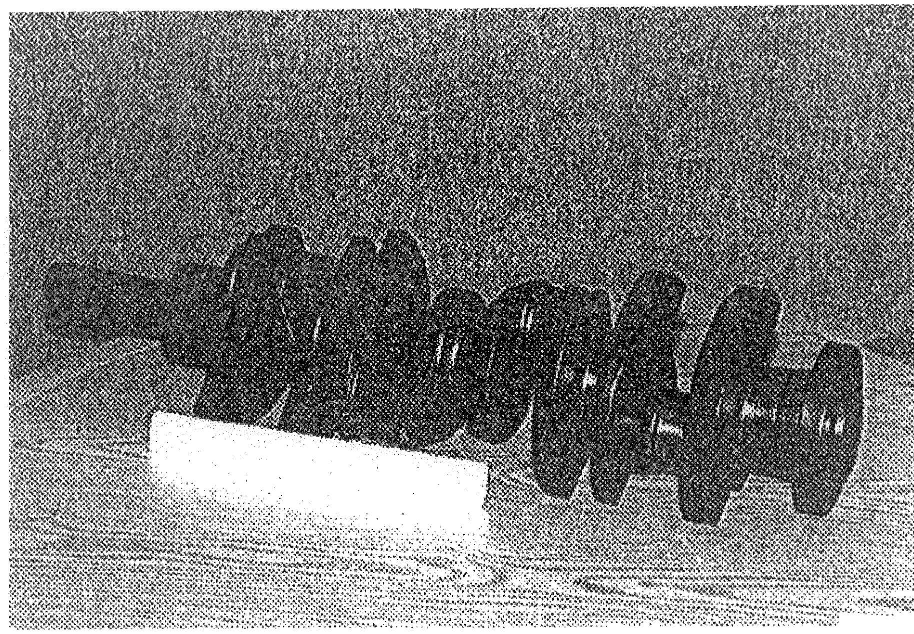

Figure 4a.
Stereolithography
Crankshaft (Coated)

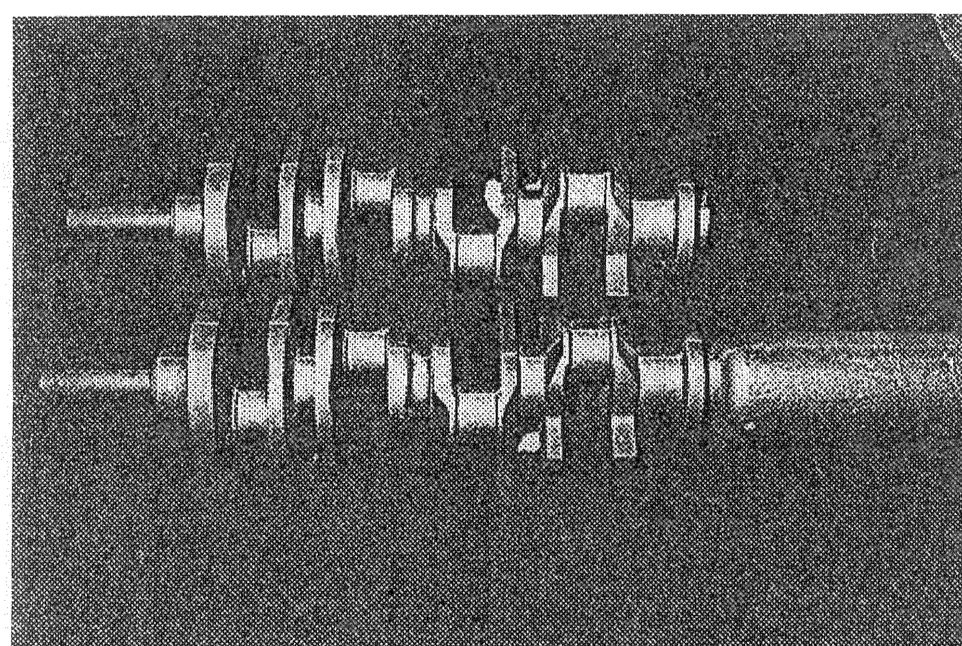

Figure 4b.
Iron Crankshafts cast
using SLA part as pattern.

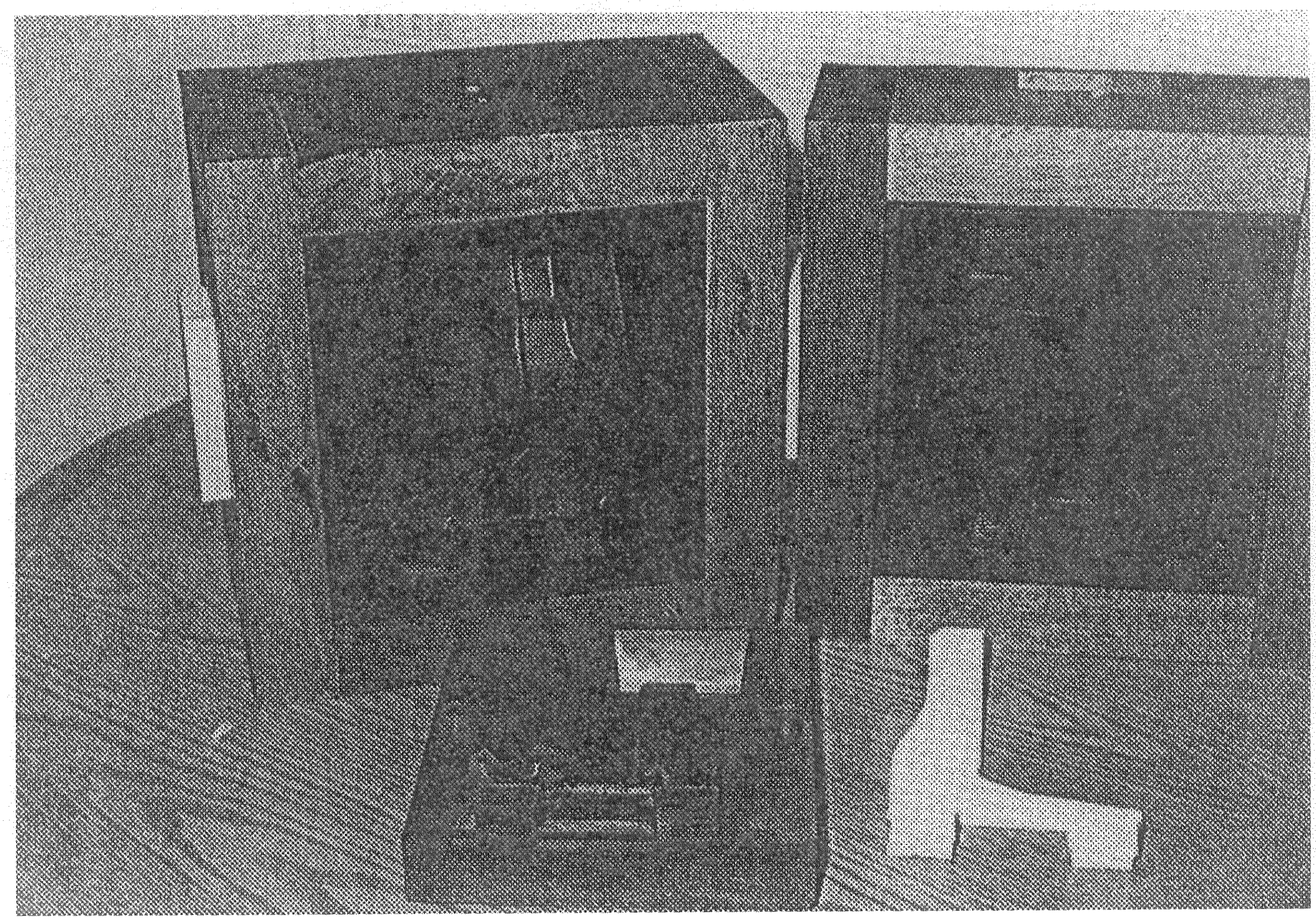

Figure 5.
Right foreground: FFF model of oil drain sand core.
Center foreground: SLA model of core embedded in mold half.
Background: Epoxy mold made directly from SLA model.

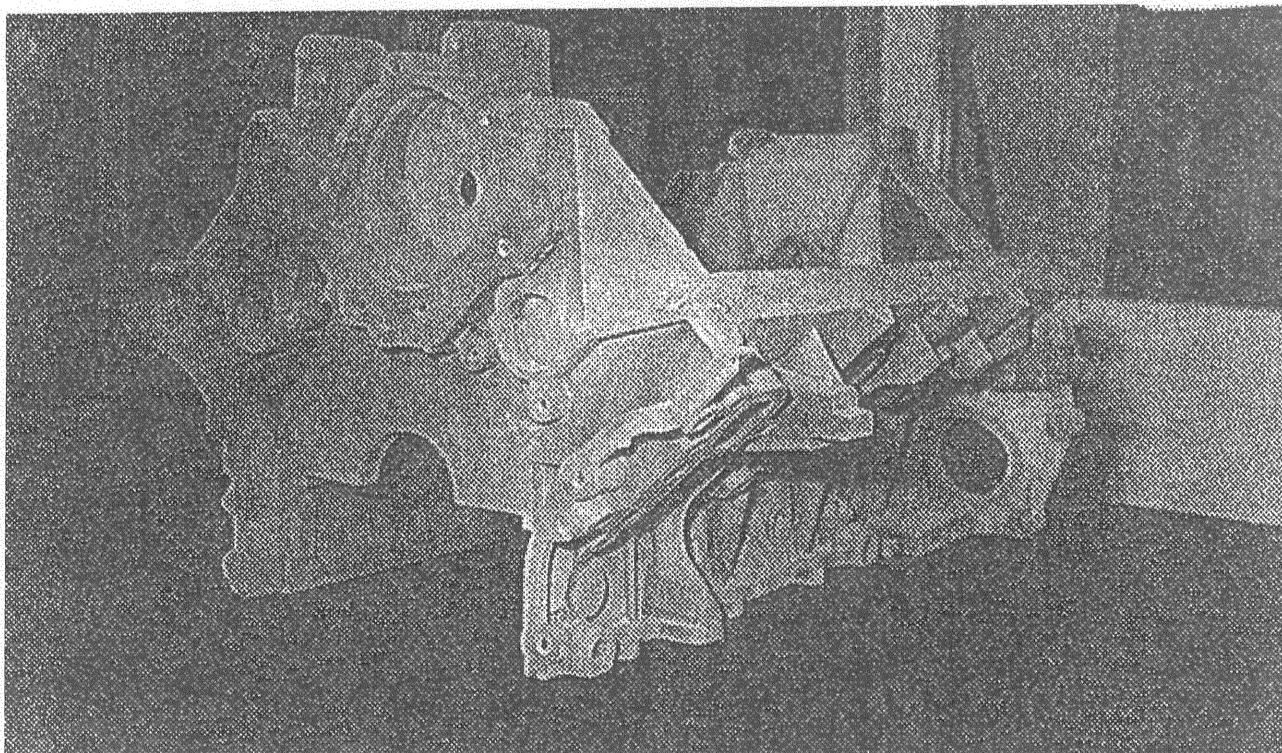

Figure 1.
Partial engine block used to
verify tooling, fixturing & dunnage.

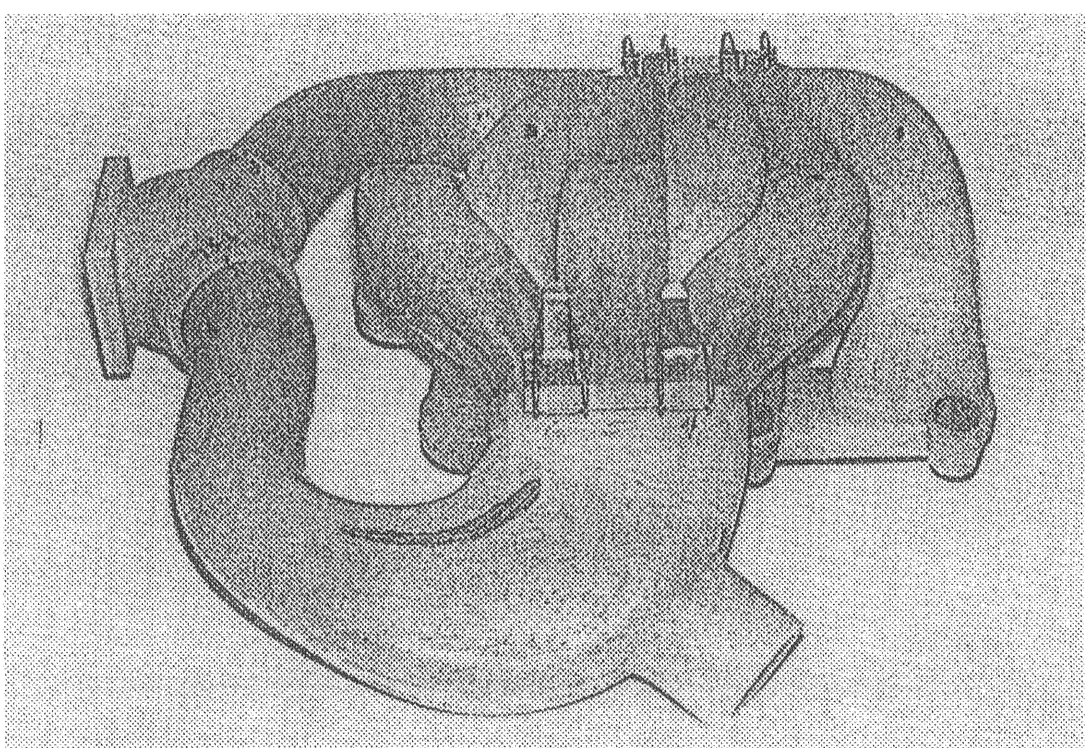

Figure 2.
Intake manifold (Cubital) used
for limited testing.