NASA/TM—2000–210558

Application of Rapid Prototyping and Wire Arc Spray to the Fabrication of Injection Mold Tools

(MSFC Center Director's Discretionary Fund Final Report, Project No. 99–05)

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August 2000

Acknowledgments

The author would like to thank the following people for participation and support in this project:

Ricky Johnson, Boeing/MSFC
Heather Miller, Boeing/MSFC
Jim Bond, Boeing/MSFC
Joe Paxton, UAH Research Institute
Pat Salvail, Illinois Institute of Technology Research Institute/MSFC
Ron Lee, MSFC
Danny Jordan, MSFC

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NASA Center for AeroSpace Information
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LIST OF ACRONYMS

CAD	computer-aided design
MSFC	Marshall Space Flight Center
PEC	Productivity Enhancement Complex
RP	rapid prototyping
UAH	University of Alabama in Huntsville
WAS	wire arc spray

TECHNICAL MEMORANDUM

APPLICATION OF RAPID PROTOTYPING AND WIRE ARC SPRAY TO THE FABRICATION OF INJECTION MOLD TOOLS (MSFC Center Director's Discretionary Fund Final Report, Project No. 99–05)

1. BACKGROUND

Rapid prototyping (RP) is a layer-by-layer-based additive manufacturing process for constructing three-dimensional representations of a computer design from a wax, plastic, or similar material. Wire arc spray (WAS) is a metal spray forming technique that deposits thin layers of metal onto a substrate or pattern. Marshall Space Flight Center (MSFC) currently has both capabilities in-house, and this project proposed merging the two processes into an innovative manufacturing technique.

The concept of spray metal forming onto RP patterns has been demonstrated at MSFC using a low-temperature metal alloy and wood- or plastic-based patterns. Unfortunately, the pattern can then be difficult to remove from the metal shell, especially on parts with complex features. This project used a water-soluble, starch-based material, which is currently the build material used in the Z402 three-dimensional printing process located on site, as well as a low-temperature, wax-polymer material used in the on-site thermojet machine.

1.1 Z402 Three-Dimensional Printing Process

The Z402 three-dimensional printing process is an ink jet-based RP technology that builds starch patterns directly from computer-aided design (CAD) data. The process builds the part from the bottom upward by adding thin layers of powder, then printing a binder solution in the shape of the current cross section of the part. The resulting object is a soft, water-soluble material that typically would be infiltrated with cyanoacrylate or paraffin wax to be used as a concept model or casting pattern. The Z402 three-dimensional printer is shown in figure 1.

1.2 Thermojet Process

The thermojet process is also based on ink jet technology; however, instead of powders and binder, this process simply prints layers of hot wax. Each layer is printed to match a cross section of the part, from the bottom upward, until a solid wax pattern is created. These parts are typically used for concept models or investment casting patterns. The thermojet is shown in figure 2.

This proposal was for a 1-yr application study, in which intermediate injection tools would be fabricated with RP and WAS metal forming. It provides an indepth development effort between NASA, Boeing, and the University of Alabama in Huntsville (UAH), utilizing multiple materials to provide optimum performance for an injection tool.

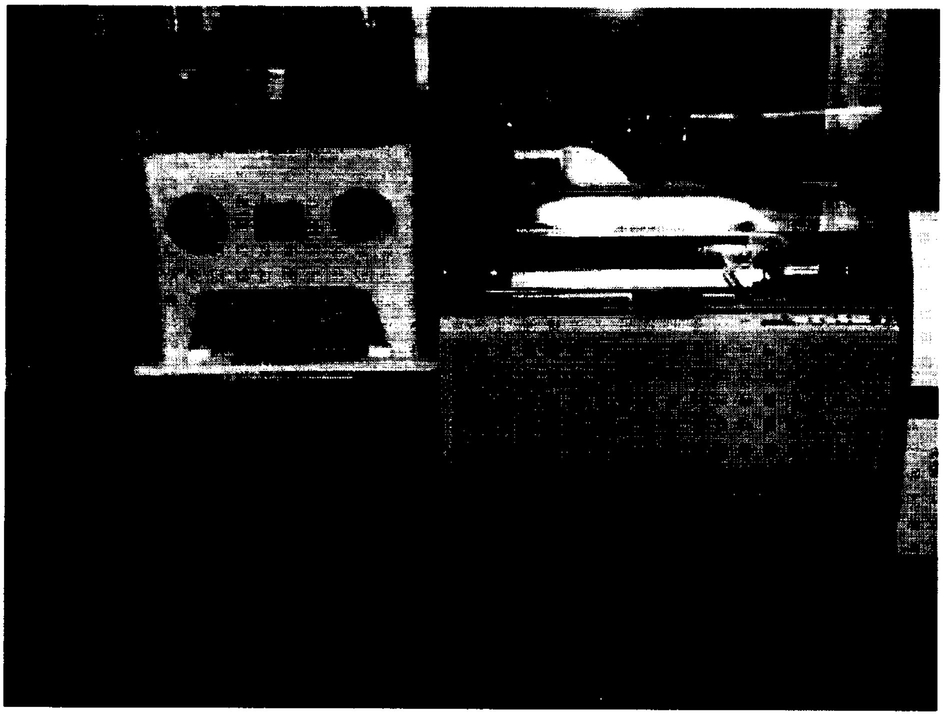

Figure 1. Z402 three-dimensional printer.

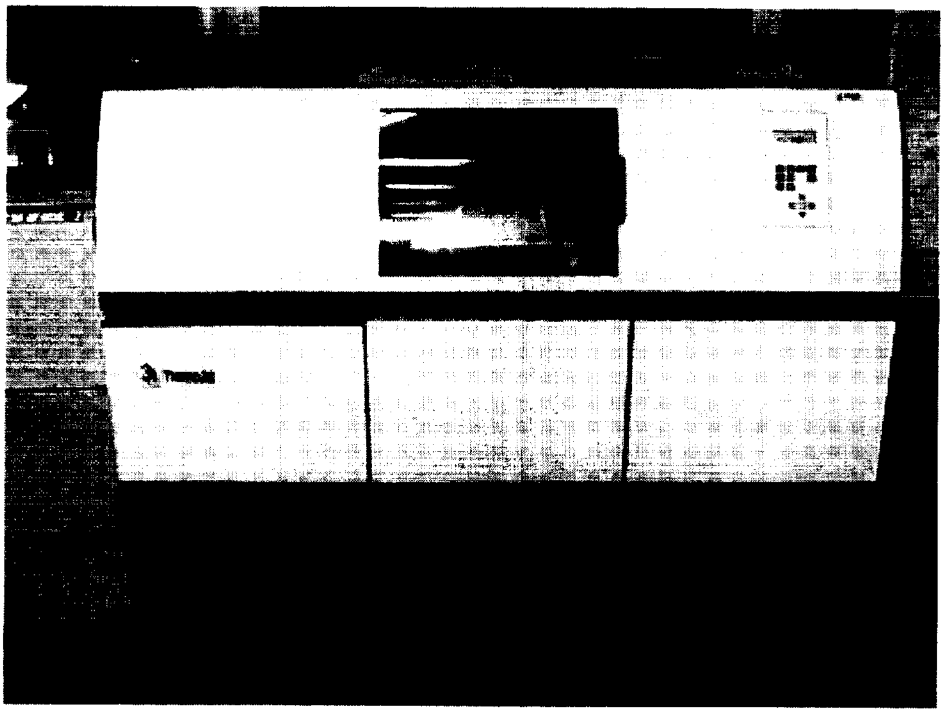

Figure 2. Thermojet RP machine.

2. THE STUDY

2.1 Design and Rapid Prototyping

The MSFC Rapid Prototyping facility in the Productivity Enhancement Complex (PEC) created six sets of tooling patterns with the water-soluble and wax pattern materials. This required software manipulation of the CAD models to convert them into tooling form, as well as the actual rapid fabrication of the components on the Z402 three-dimensional printer and thermojet machine. The geometry chosen was a standard injection mold tool used as a baseline in the RP industry for new tool fabrication techniques. The part combines thin walls and complex fin arrangements suggestive of typical injection-molded components. Figure 3 demonstrates the chosen model for this project.

One modification was made to the design for the injection port available on the mold press at UAH. Due to the high clamping pressure (8 tons), it was recommended to have the mold halves join parallel to the press, or horizontally. In order to achieve this, the injection port was arranged to enter the top of the part, perpendicular to the original configuration.

The time required to build a two-piece mold on the Z402 machine was found to be ≈2 hr. These patterns had a rough surface finish and were also very soft in the as-processed form. The surface quality of the molds was not acceptable for an injection molding application.

The thermojet wax patterns were built in ≈3 hr, with an additional cooling and postprocessing time. The surface finish of these patterns was very smooth and of high quality. Because of this, the remainder of the study focused solely on the thermojet patterns as opposed to the Z402 parts. In addition, the thermojet patterns were much more rigid than the Z402 soft patterns; hence, less careful handling was required for a successful run.

Slight preparation for the injection port was required on all tool halves. A small metal tube was inserted upright into the wax pattern by heating it slightly and holding it in place with a pin. This would allow for metal to be sprayed around it; hence, upon removal of the pin, a ready-made injection port was created. A set of the final wax mold is shown in figure 4.

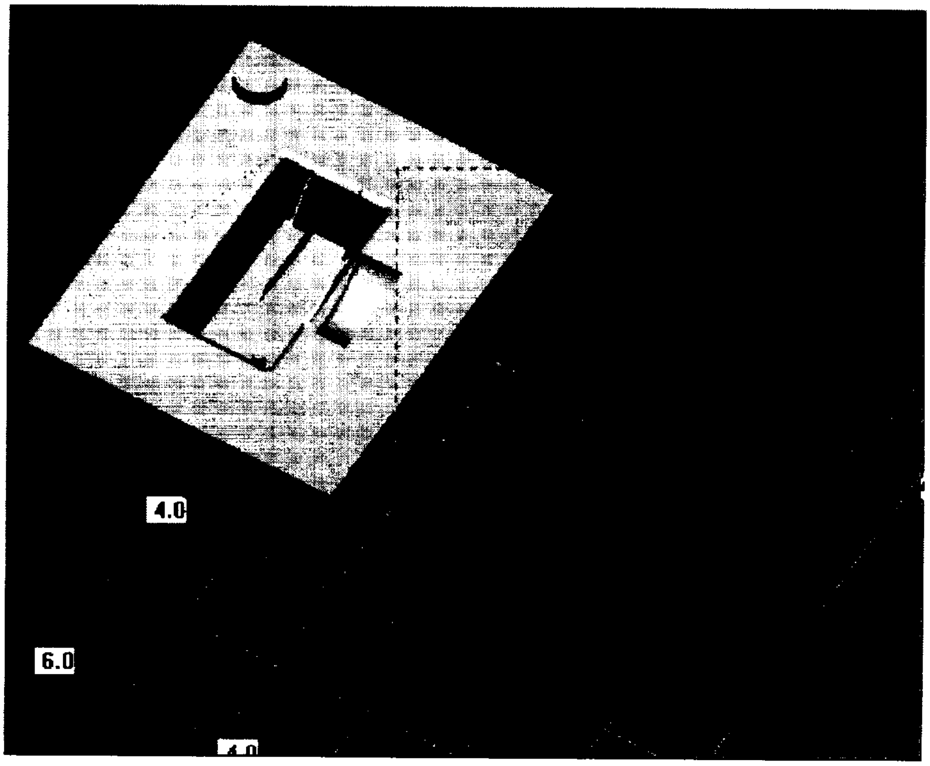

Figure 3. Baseline injection tool design.

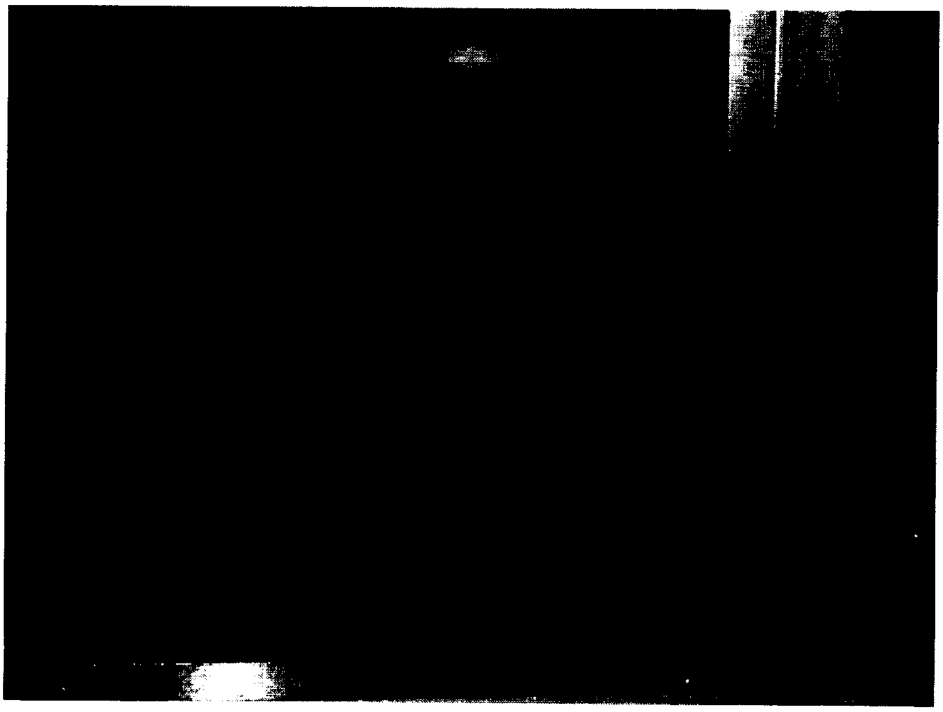

Figure 4. Wax thermojet patterns.

2.2 Metal Spraying of Tool Halves

The MSFC/Boeing WAS facility, also located in the PEC, metal sprayed five tool sets using rapid prototyped patterns. The metal was deposited by the WAS process using a hand-held spray nozzle.

In wire arc spraying, two filaments of material are oppositely charged, then fed together into a plasma spray path. The result is a low-temperature metal "painting" process that can rapidly deposit metal coatings of significant thickness.

The initial layer of metal consisted of a low-temperature tin-zinc alloy (maximum 400 °F), sprayed ≈0.1 in. thick onto the pattern. This "tooling" material is typically used as a primer for higher temperature metallic coatings.

Next, a coating of higher temperature tin-zinc (maximum 800 °F) was deposited to a total thickness of 0.25 in. Finally, some patterns were additionally sprayed with an added 0.1 in. of 95-percent nickel/5-percent aluminum for added rigidity. Time required to complete a set of sprayed tools was ≈1 hr. A metal-sprayed tool half is shown in figure 5, immediately after the tooling material was deposited.

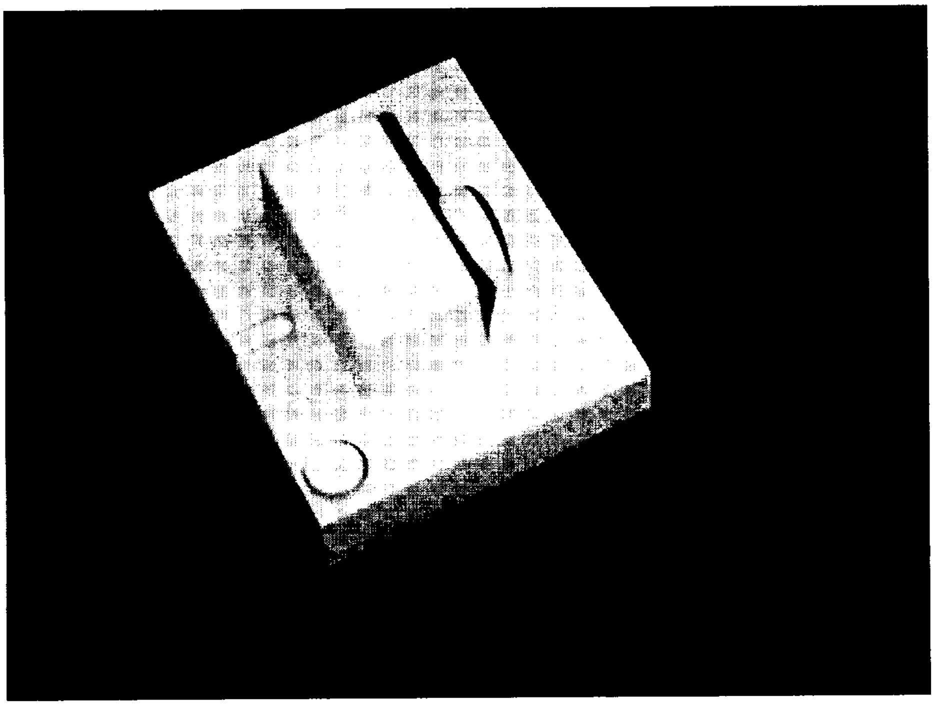

Figure 5. Metal-sprayed wax pattern.

2.3 Pattern Removal and Backfilling

The MSFC RP team executed the removal and backfill as well as final molding prep work for the tooling halves. First, the tools were suspended in an oven at 225 °F until the wax softened and fell out of the metal shell (≈30 min).

The molds were removed from the oven and the final traces of wax were removed using a hot air gun, similar to a common portable hair dryer. Within 5–10 min, the remainder of wax was sufficiently removed from the shell. Figure 6 shows a metal tool shell after wax removal. Notice the flashing metal remaining from the WAS process, which was removed simply by breaking each wall off with a set of pliers.

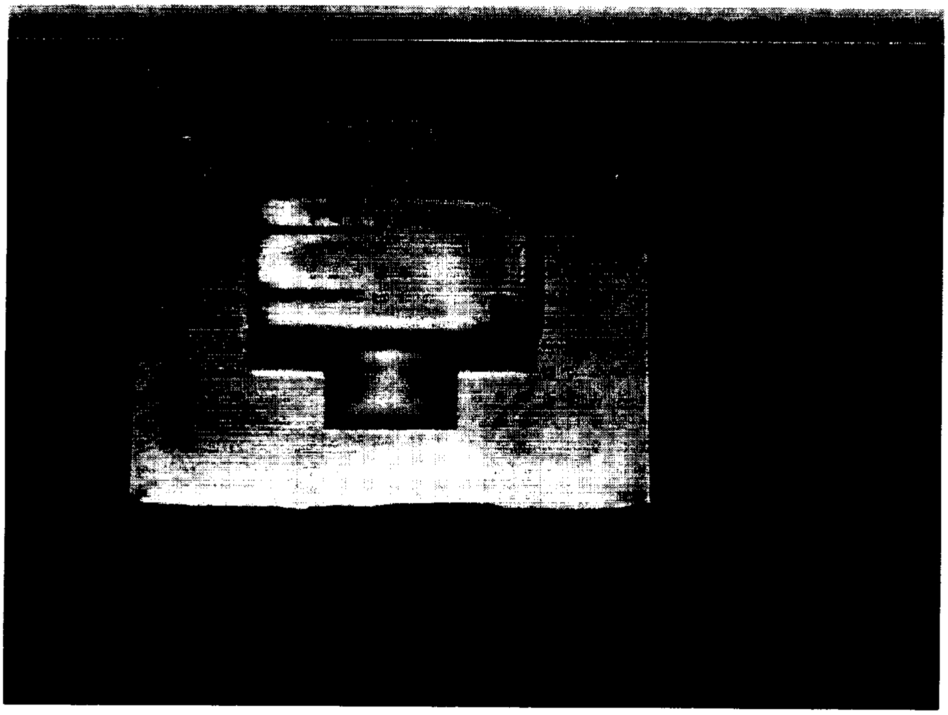

Figure 6. Metal tool shell after wax removal.

While the wax patterns were in the process of being metal sprayed, a set of hollow wax frames was fabricated on the thermojet for use in the backfilling process. These frames took ≈1 hr to make, and hence were completed by the time the patterns were metal sprayed and the wax removal was finished. After the wax removal was completed, the metal shell was placed into the wax frame face down so that an empty "box" was formed around the rough side of the tool. This box was then filled with a two-part, 1-min-cure polyurethane molding mixture. After the quick cure, the exothermic reaction softened the wax frame enough to simply slip the part out; the result being a tool half made of polyurethane with a smooth metallic face, as shown in figure 7. The metal sprayed onto the surface therefore mimicked the smooth surface finish of the wax pattern.

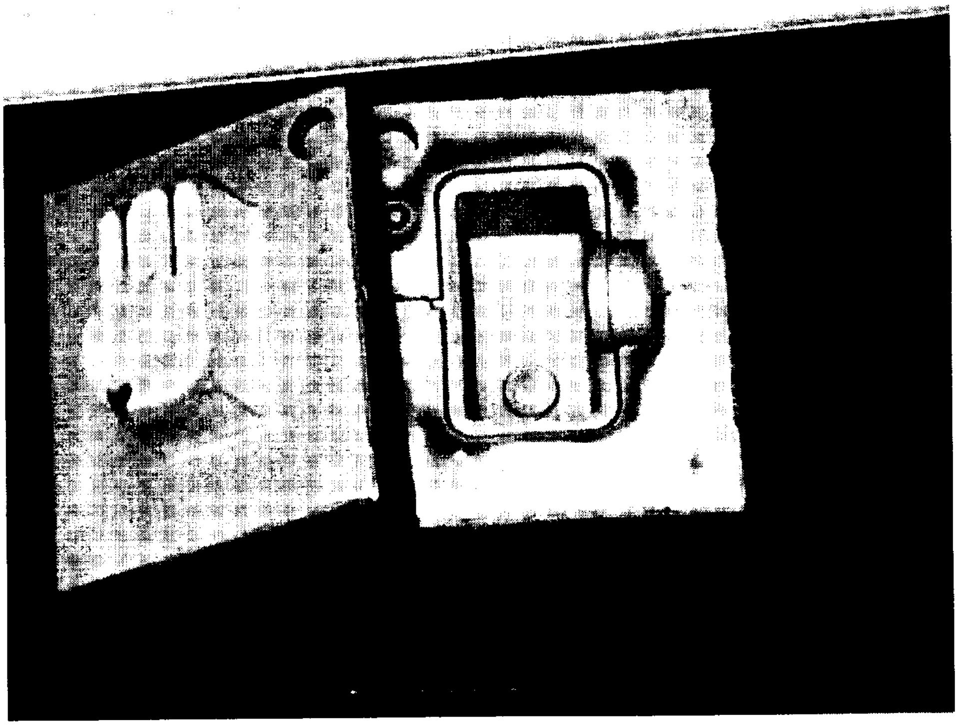

Figure 7. Finished metal-faced tool halves.

2.4 Injection Molding Trials

UAH Research Institute was employed for its injection molding capabilities and student/faculty research in the RP field. Patterns finished at MSFC were taken to UAH for plastic injection molding testing for mold degradation, durability, and dexterity.

The first mold set was destroyed on the first attempt at injecting a polyethylene part. Initially, this was believed to be due to an uncured section of backing material near the surface of the metal shell, but other causes were determined during later trials.

Figure 8 shows the first mold after removal from the injection press. Figure 9 reveals the other half of the same mold after separation. These figures also demonstrate the layered materials employed to fabricate the tools throughout the program.

The reason for breakage of the tools was later determined to be that the faces of the tools fabricated were not completely flat. Apparently, the solid wax patterns tended to "sink" in the center while they were cooling just after fabrication on the thermojet machine. The resulting counterpart in the metal shell would then be a slight bow, whereas the tool would be higher in the middle than at the edges, resulting in a fit that was not flush. When the 8-ton injection press was clamped to the tool, the stresses were high enough that even on later tools with stronger materials sprayed, the tool was instantly cracked and would then quickly break.

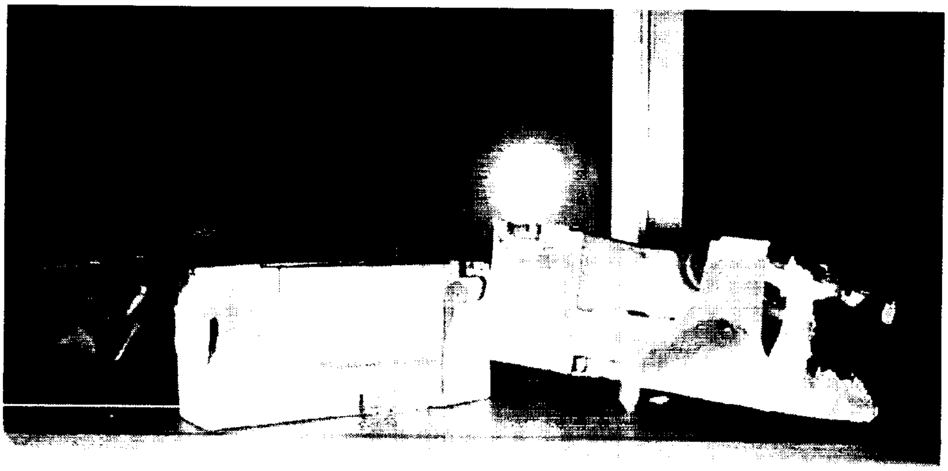

Figure 8. First tool failure after removal.

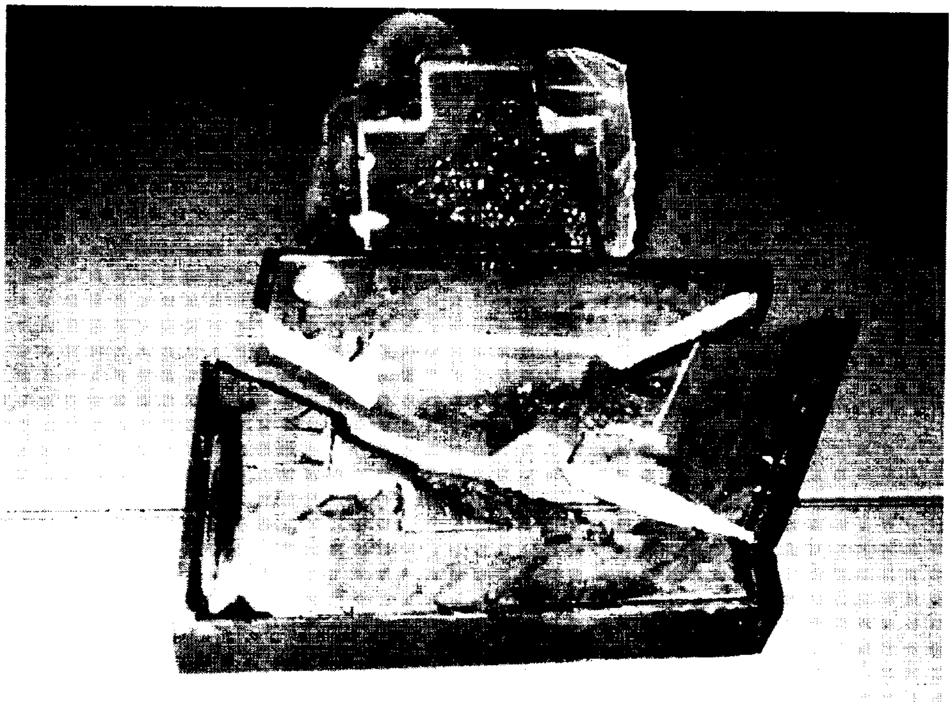

Figure 9. First tool failure (other half).

3. SUMMARY

Although this project ran into some difficulty, some important lessons were learned that still might be applied to injection mold tooling and other applications.

It was determined that tool halves of a surface quality representative of the rapid prototyped pattern could be fabricated quickly and inexpensively via this process. Until the RP techniques can hold a smoother surface finish and tighter tolerance, the metal spray and fill technique may be used on machined wax patterns to achieve the necessary dimensional requirements. This approach would still be more cost effective than machining steel or aluminum tools for only short production runs.

Another application could use the RP/WAS processing tools for less stressful injection molding or pour molding applications; i.e., investment casting wax pattern injection. Further research and testing will continue in these and other related areas at MSFC and other institutions.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	August 2000	Technical Memorandum

4. TITLE AND SUBTITLE

Application of Rapid Prototyping and Wire Arc Spray to the Fabrication of Injection Mold Tools
(MSFC Center Director's Discretionary Fund Final Report, Project No. 99–05)

5. FUNDING NUMBERS

6. AUTHORS

K.G. Cooper

7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(ES)

George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

8. PERFORMING ORGANIZATION REPORT NUMBER

M–993

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

NASA/TM—2000–210558

11. SUPPLEMENTARY NOTES

Prepared by the Materials, Processes, and Manufacturing Department, Engineering Directorate

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Unclassified-Unlimited
Subject Category 37
Nonstandard Distribution

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Rapid prototyping (RP) is a layer-by-layer-based additive manufacturing process for constructing three-dimensional representations of a computer design from a wax, plastic, or similar material. Wire arc spray (WAS) is a metal spray forming technique, which deposits thin layers of metal onto a substrate or pattern. Marshall Space Flight Center currently has both capabilities in-house, and this project proposed merging the two processes into an innovative manufacturing technique, in which intermediate injection molding tool halves were to be fabricated with RP and WAS metal forming.

14. SUBJECT TERMS

manufacturing, injection molding, rapid prototyping, spray metal tooling, wire arc spray

15. NUMBER OF PAGES 20

16. PRICE CODE A03

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

A potential fix for the "sink" problem is to build the wax part hollow so as not to create such a dense mass. The hollow part would then be filled from the back with polyurethane prior to depositing a metal shell on the front. Attempts were made to spray the metal shell onto the hollow wax patterns (with no fill); however, the heat and stresses associated with the WAS were too much for the pattern to stand up to.

Even with the rupture of the tools, a few parts were still molded, with limited success. The layering effect of the RP process along the drafted walls made removal of the injected part difficult, as the ridges would cause the part to stick to the mold.

Some parts did not fill completely while others filled and overflowed as flashing through the mismatched mold face areas. If the mold halves were matched properly, this problem would most likely not occur. Figure 10 shows some of the parts injected with the tools made in this project.

Figure 10. Plastic parts injected into metal-sprayed tooling sets.

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