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**RAPID PROTOTYPE FABRICATION PROCESSES
FOR HIGH-PERFORMANCE THRUST CELLS****N95-70862**

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ABSTRACT

The Thrust Cell Technologies Program (Air Force Phillips Laboratory Contract No. F04611-92-C-0050) is currently being performed by Rocketdyne to demonstrate advanced materials and fabrication technologies which can be utilized to produce low-cost, high-performance thrust cells for launch and space transportation rocket engines. Under Phase 2 of the Thrust Cell Technologies Program (TCTP), rapid prototyping and investment casting techniques are being employed to fabricate a 12,000-lbf thrust class combustion chamber for delivery and hot-fire testing at Phillips Lab. The integrated process of investment casting directly from rapid prototype patterns dramatically reduces design-to-delivery cycle time, and greatly enhances design flexibility over conventionally processed cast or machined parts.

I. INTRODUCTION

The present focus on advanced modular rocket engines dictates the need for development of high-performance thrust cells, which embody operational versatility, low cost, high producibility, shortened cycle times from design to hardware, and enhanced reliability and durability.

The objectives of the Air Force Phillips Lab (AFPL) Thrust Cell Technologies Program (TCTP) are to develop the fundamental materials and fabrication process technologies needed to produce reliable, high-performance thrust cells for launch and space transportation rocket engines. A thrust cell design requirements study was performed under Phase 1 of the program, in which candidate mission applications were reviewed to establish the baseline thrust cell requirements upon which subsequent hardware design and fabrication efforts would be focused. As a result of this study, a baseline thrust cell configuration supporting an integrated modular engine (IME) application was established, - specifying O₂/H₂ propellants, 1860 psia chamber pressure, 6.0 mixture ratio, and 11,500 lbf vacuum thrust.

II. THRUST CELL DESIGN

The objective of the TCTP Phase 2 effort is to integrate rapid prototyping techniques with conventional investment casting processes to produce near-net shape components for fabricating a

baseline thrust cell combustion chamber . Phase 2 will culminate with the delivery of a combustion chamber to Phillips Lab for hot-fire validation tests.

The Phase 2 thrust cell chamber design layout is presented in Figure 1. The chamber design features cast stainless steel coolant manifolds which are liquid interface diffusion bonded (LIDB'd) to a cast NARloy-Z coolant liner. The coolant liner structural closeout is formed by a layer of electro-deposited nickel-cobalt (EDNiCo).

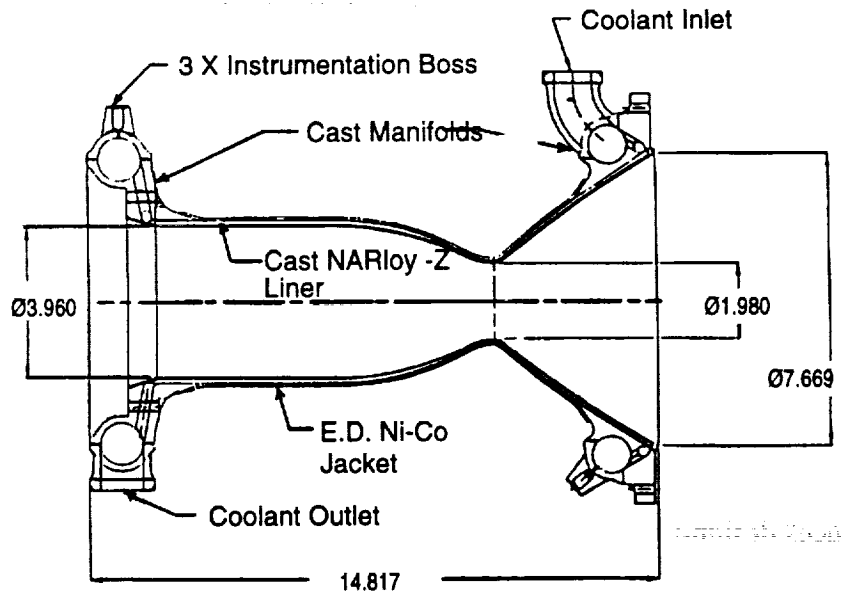


Figure 1. TCTP Phase 2 Thrust Cell Combustion Chamber Design Layout

The integrated process employed to produce the cast manifold and liner components consists of defining the geometric details of the components via 3-D computer-aided design (CAD) modeling, formatting the CAD database files such that a solid freeform replica of the component can be generated using a selective laser sintering (SLS) process, and providing the resulting SLS patterns to casting suppliers for direct mold preparation and investment. The use of directly fabricated ("rapid prototyped") casting patterns greatly reduces casting development lead times, small production quantity fabrication schedules, and development cost by eliminating the need for high-cost, labor-intensive wax injection tooling.

III. SLS PATTERN DEVELOPMENT

Rapid prototyping capability was obtained by Rocketdyne in January 1993 with the purchase of a Sinterstation 2000 SLS machine manufactured by the DTM Corporation. The SLS process is one of many emerging solid freeform fabrication technologies that electronically format a CAD database into thin cross-sections from which a desired shape can be constructed. In the SLS process, the parts are constructed by laser-sintering successive layers of heat-fusible powder. The operating principles of the process are illustrated in Figure 2. The DTM Sinterstation is equipped with a 50-watt CO₂ laser capable of sintering investment casting wax, polycarbonate, and nylon powder materials. It also has the capability of directly sintering metals and ceramics. For producing thrust cell casting patterns, the use of polycarbonate material has been adopted because (1) wax patterns are weaker (less durable) and

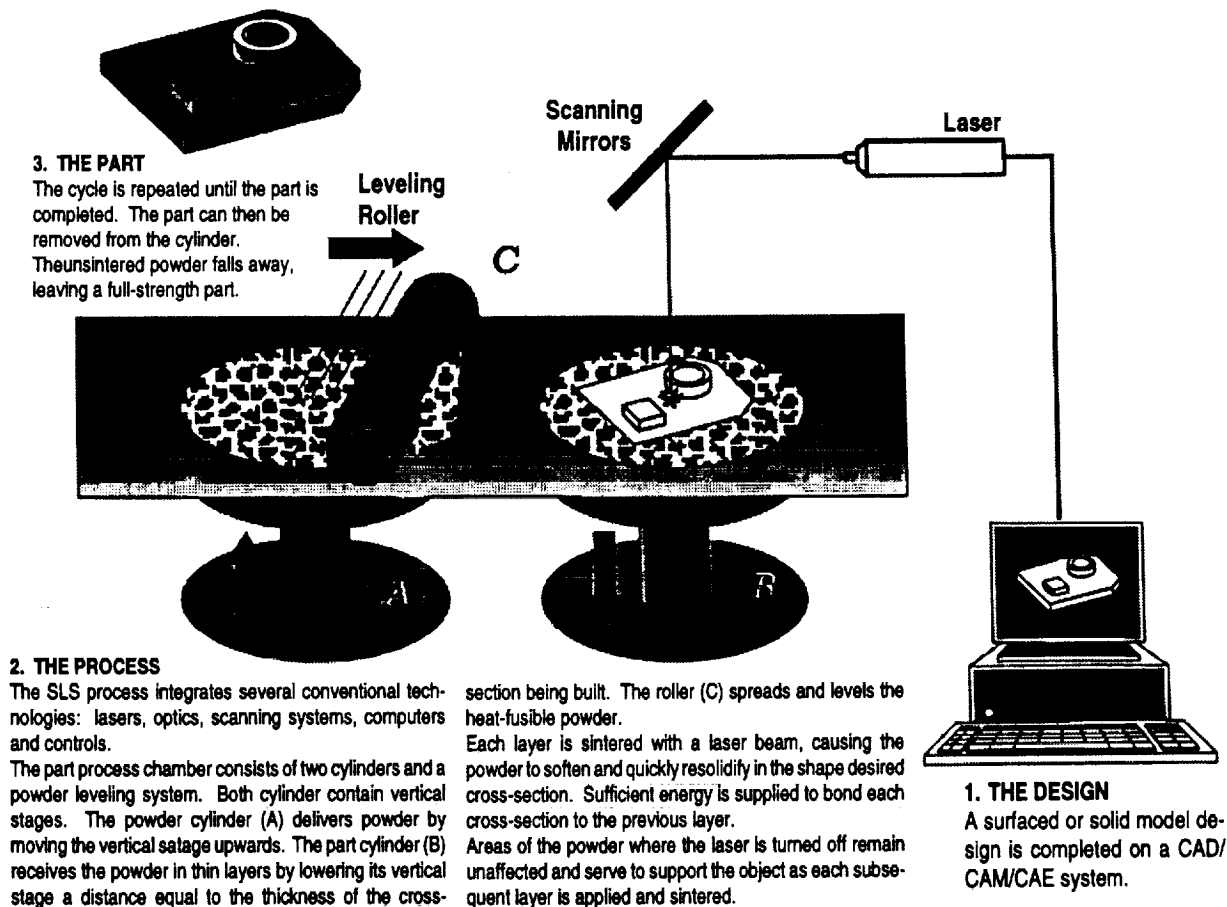


Figure 2. Selective Laser Sintering (SLS) Process Schematic

exhibit rougher surface finishes, and (2) the thermal expansion characteristics of nylon parts result in mold cracking during pattern burnout cycles.

To produce SLS polycarbonate patterns with the desired surface finish quality and dimensional accuracy for casting the thrust cell components, initial studies were performed to optimize Sinterstation operating parameters. With Sinterstation laser parameters (such as laser power, beam diameter, and raster scan spacing) optimized, dimensional accuracy of SLS pattern features has been consistently demonstrated to be within +/- .003 inches of design dimensions. A typical set of SLS forward manifold polycarbonate patterns produced in support of the thrust cell casting effort is shown in Figure 3.

IV. CASTING DEVELOPMENT

Casting suppliers selected to develop and provide cast parts in support of the Rocketdyne thrust cell concurrent engineering program team are Howmet, Incorporated (chamber liner castings) and Precision Castparts Corporation (PCC) (manifold castings). Liner castings were developed and produced at Howmet's Technology Center in Whitehall, Michigan; manifold castings were developed and produced at the PCC Airfoil Division's prototype foundry in Minerva, Ohio.

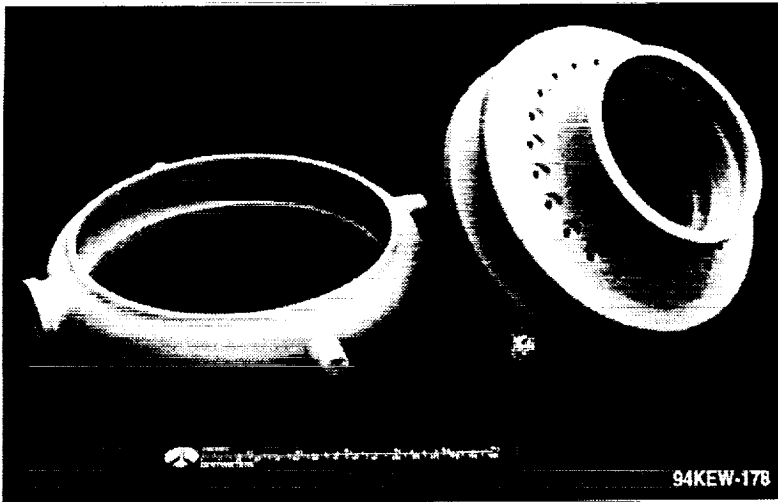


Figure 3. Selectively Laser Sintered (SLS) Polycarbonate Thrust Cell Forward Manifold Details

in Figure 4. All mold gating, shell preparation, and pouring process/parameter development is now considered to be complete by Howmet and Rocketdyne. Evaluation of cast NARloy-Z material samples and parts produced by Howmet indicates that the latest liner castings meet design requirements and inspection criteria. Mechanical properties data obtained to date indicate that cast NARloy-Z strength and ductility are very comparable to wrought material properties, and exceed the assumed design minimum values in the areas of yield strength and elongation. Cast NARloy-Z conductivity data obtained to date indicate that thermal conductivity for the fully processed cast material ranges from approximately 90 to 95% of that for wrought material. The full liner casting shown in Figure 4 is currently being processed through LIDB and EDNiCo processes at Rocketdyne as a manufacturing technology demonstration (MTD) unit, and processing of patterns and castings to support the deliverable chamber fabrication is in work.

Manifold Casting Development

Under the TCTP manifold casting development effort, PCC is contracted to produce a total of 5 sets of manifold castings—three development casting sets and two “final quality” casting sets to support fabrication of a hot-fire deliverable combustion chamber. Each manifold sets consists of four castings: the forward body and shell, plus the aft body and shell. All manifolds are poured using air-melt CF-8C alloy (347CRES equivalent). Gating

Liner Casting Development

Under the TCTP liner casting development effort, Howmet is contracted to produce a total of 13 castings—11 development castings and two “final quality” castings to support fabrication of a hot-fire deliverable combustion chamber. To date, a total of eight liner casting pours have been completed. The first high quality, full liner pour was achieved on only the sixth attempt, and is shown

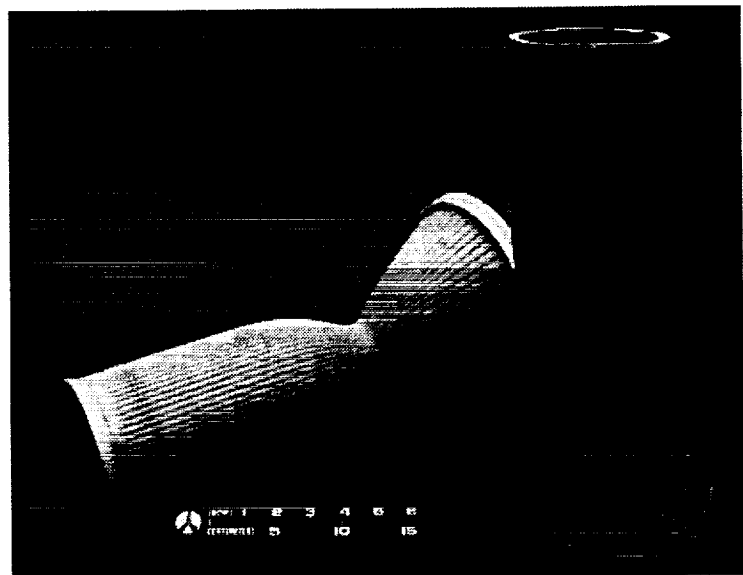


Figure 4. Cast NARloy-Z Chamber Liner (with SLS Polycarbonate Liner Pattern)

development has been completed without major issues. To date, three complete sets of manifold components have been poured, and "final quality" castings have been achieved. Cast forward manifold components are shown in Figure 5. Mechanical properties testing of manifold casting material samples has indicated strength properties which exceed assumed design minimums for cast stainless steel material. The second set of forward and aft manifold parts produced by PCC have been welded and final machined in preparation for LIDB'ing to the full liner (shown in Figure 4) as a thrust cell chamber MTD unit. Processing of SLS patterns and castings in support of the deliverable thrust cell chamber is currently in work.

V. THRUST CELL CHAMBER FABRICATION

Under the current TCTP Phase 2 plan, one LIDB/EDNiCo MTD unit, one deliverable thrust cell chamber, and one chamber spare will be fabricated. Development castings have been machined and prepared for the manifold-to-liner LIDB

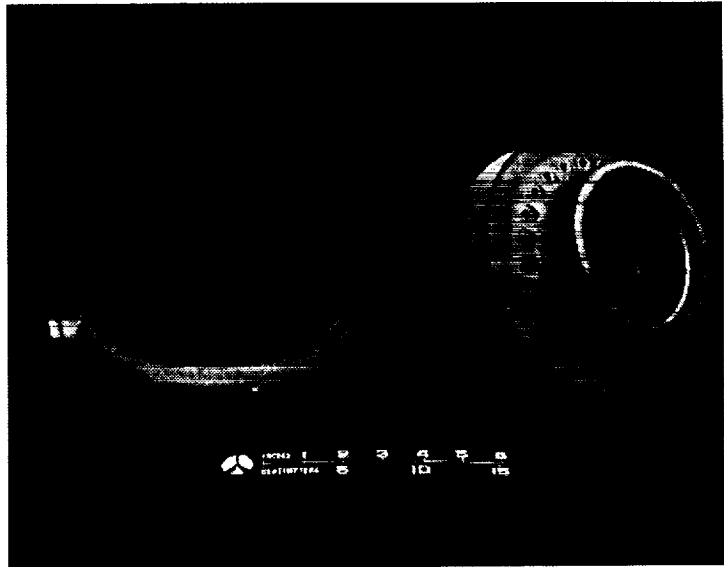


Figure 5. Cast Forward Manifold Components (Body and Closeout Shell)

process. Following LIDB processing and bond joint inspection, the MTD unit will undergo the EDNiCo plating process which forms the structural closeout to the liner coolant channels. Fabrication and delivery of a hot-fire quality thrust cell combustion chamber to AFPL is currently scheduled to be completed in February 1995.

VI. CONCLUSIONS

The effort to integrate the rapid prototype SLS process with traditional investment casting processes has been a highly successful approach for producing high-quality combustion chamber components for thrust cell applications. Cast NARloy-Z and stainless steel materials and components produced to date have demonstrated acceptable characteristics with regard to dimensional conformance, inspection criteria, microstructural quality, and materials properties. Above all, through the development of paperless CAD model-to-cast part processing for thrust cell components, the Rocketdyne concurrent engineering team, including casting suppliers, has demonstrated the capability to shorten design-to-cast part lead times to approximately one month, with the flexibility to implement subsequent design changes without incurring schedule delays to accommodate tooling modification. The integrated rapid prototype casting process holds great promise for supporting the fabrication and testing of limited production components in aerospace and commercial industries.