Overview
Investment casting, also called lost wax casting, is a process in which a master pattern traditionally made of wax, is covered with a ceramic slurry. The wax pattern is normally produced with injection molding. The wax is melted out of the ceramic shell, which is pre-heated before molten metal is poured into the pattern. After the metal cools, the ceramic is vibrated and blasted from the metal casting. Investment casting generally provides higher accuracy and better surface finish than other casting processes. It is generally used in applications with moderate production quantities that require the accuracy and surface finish benefits provided by the process.

Application Outline
Investment casting wax patterns are typically produced using an injection molding process. Tooling cost ranges from $5,000 to $25,000 and lead time is approximately two months. A big problem for many investment casting foundries is that they are unable to produce prototype castings until the injection mold is completed. At this time, problems are often discovered, such as interference with other components in an assembly. Additional time and money must be invested to fix the injection mold. In a worst-case scenario, it may be necessary to scrap the original tool and start over, which is a big setback in cost and time. Another problem with wax patterns is that the complexity is limited by what is feasible from an injection mold design.

Additive Manufacturing (AM), both FDM® (Fused Deposition Modeling) and PolyJet™ (PJ), provide an alternative method for producing investment casting patterns that provide dramatic time and cost savings. Both of these technologies build plastic parts layer by layer using data from CAD files. With FDM, an added benefit is that the pattern can also serve as a prototype for form and fit evaluation. In one day, the foundry can provide the customer with a prototype that’s a perfect match to the casting. The strength of the materials used in the FDM process also makes performance testing possible. If any problems are discovered, a new pattern can be produced in about 24 hours.

BENEFITS OF AM
- No tooling delay; 70% - 98% lead time reduction
- No tooling expense; 60% - 95% cost reduction
- Part consolidation; assemblies become one piece
- No restrictions on design changes
- Niche market products become practical
- Full, functional testing before any tooling investment

AM IS A BEST FIT
- Short project lead time (less than 2 months)
- Complex, intricate designs
- Low production quantities (1 to 1,000’s)
  - Prototype and process refinement
- Design iterations anticipated
- Fine, but not delicate, features
- Blast furnace available for high-temperature burnout
PJ masters are best suited for dimensional and visual inspection prior to casting since the pattern tends to be more fragile than FDM patterns. As soon as the customer approves the prototype, the foundry can move into production by using the AM parts as patterns for investment casting. Since both FDM and PJ are additive processes, the patterns can incorporate more complex design features without any impact on cost. This is not true for injection molding, where increasing pattern complexity requires a more complex and more expensive tool. AM patterns are also more durable than wax and allow for greater accuracy by avoiding the dimensional compensation needed for the creation of the wax parts during molding. The durability is important because it prevents damage that often occurs in the transportation and handling of patterns made of wax or other fragile materials.

Process Overview
Both FDM and PJ patterns are direct replacements for traditional patterns that are injection molded with foundry wax. One significant difference is that both FDM and PJ materials do not melt like wax. These materials burn, which leaves a small amount of ash in the shell cavity, typically between 0.01 – 0.26%, depending on the process and material. The ash is later removed in a shell-washing operation.

Venting should be added to the ceramic shells to speed the burnout of the pattern and ease the shell-washing step. Investment casting patterns need to be produced to close tolerances and with an excellent surface finish because any defects are reproduced in the finished part. PJ parts have a very fine finish directly out of the printer and FDM parts can easily be post-processed to get the desired surface finish. Using the Stratasys Finishing Touch Smoothing Station, a semi-automated process to improve the surface finish of FDM parts, near-injection molded quality can be achieved without the labor or cost associated with traditional finishing. Advancements in finishing technology have improved FDM parts to the point that hand finishing is no longer needed, making FDM a much stronger competitor in the investment casting market.

Customer Story
RLM Industries (RLM) is a leading supplier of investment castings to the military, construction, automotive, and food processing and handling industries. One of RLM's customers, a major manufacturer of components and assemblies for the military, found itself in danger of missing critical delivery deadlines when its foundry couldn't produce investment castings that met specifications. The original foundry used injection molding to make wax patterns. RLM's customer needed a faster and less-expensive solution to the problem and asked for help.

RLM began the project by modifying the customer's CAD model. The revisions were completed and an AM prototype was created in one day and provided to the customer for assembly review. After some modifications, another prototype was produced and approved by the customer.
RLM then moved immediately into production of the first prototype castings using the AM prototypes as patterns. The prototype castings matched the patterns perfectly and the customer approved them. The production of the first prototypes were also used to refine the casting process, primarily for evaluating the gate location.

“Using Stratasys equipment and technology, we were able to build patterns in less than a day,” said Rick Meachum, vice president of sales for RLM. “The patterns were then expedited through our process and in seven days we produced perfectly matching gear set castings that met drawing requirements and specifications and were functional as part of the assembly. The castings were used for a test launch, and we now have time to build hard tooling with all parties confident in the knowledge that the part design and dimensional attributes are correct for a large quantity production order.”

### How Did Stratasys Compare to Traditional Tooling Methods for RLM?

<table>
<thead>
<tr>
<th>METHOD</th>
<th>COST</th>
<th>PRODUCTION TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection Molding</td>
<td>$5,000 to $20,000</td>
<td>2 months</td>
</tr>
<tr>
<td>FDM</td>
<td>$16*</td>
<td>1 week</td>
</tr>
<tr>
<td>PJ</td>
<td>$45*</td>
<td>1 week</td>
</tr>
<tr>
<td>Savings</td>
<td>$4,955 to $19,984 (99.1% to 99.9%)</td>
<td>7 weeks (88%)</td>
</tr>
</tbody>
</table>

*Machine time pricing includes the following assumptions:
- Qty of 1 each male and female model priced
- Machine cost amortized over 5 year period, with 67% up time
- Material priced at retail pricing
- PJ: Objet 30 Prime™ machine package price of $50K
- FDM: F370™ machine package price of $55K
- No other factors are included in this price (post-processing, overhead, electricity, etc.)