A Design Study in Rapid Prototyping for Castings

Internal Interface Frame for LCD Digital Projector

Design Study Outline

- Introduction
- Design for Performance and Production
  - *Material and Process Selection*
  - *Rapid Prototyping Process & Benefits*
  - *Thin Wall Considerations*
  - *Gating Design*
- Final Mold Design
- Lessons Learned and Summary

LCD Digital Business Projector LP130 from InFocus

Start the Design Study ! Next

Acknowledgment --
The metalcasting design studies are a joint effort of the American Foundry Society and the Steel Founders' Society of America.
Project funding was provided by the American Metalcasting Consortium Project, which is sponsored by the Defense Supply Center Philadelphia and the Defense Logistics Agency, Ft. Belvoir, VA.

Return to AFS Home Page

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Interface Frame - Application

The LP130 LCD Digital Business Projector is a cutting edge portable LCD projector from the InFocus Corporation, Wilsonville, OR.

LP 130 Projector

- **The LP130 projector weights only 3 pounds with a 6.7 x 8.6 inch footprint.**
- **The design of the projector was driven by the requirement for low weight and size with high performance (XGA-1024 x 768, 1100 lumens, 400:1 contrast ration)**

A critical factor in meeting the performance goals was to design internal structural components that minimize weight and maximize stiffness and strength

Back Next

Return to AFS Home Page

Page 1

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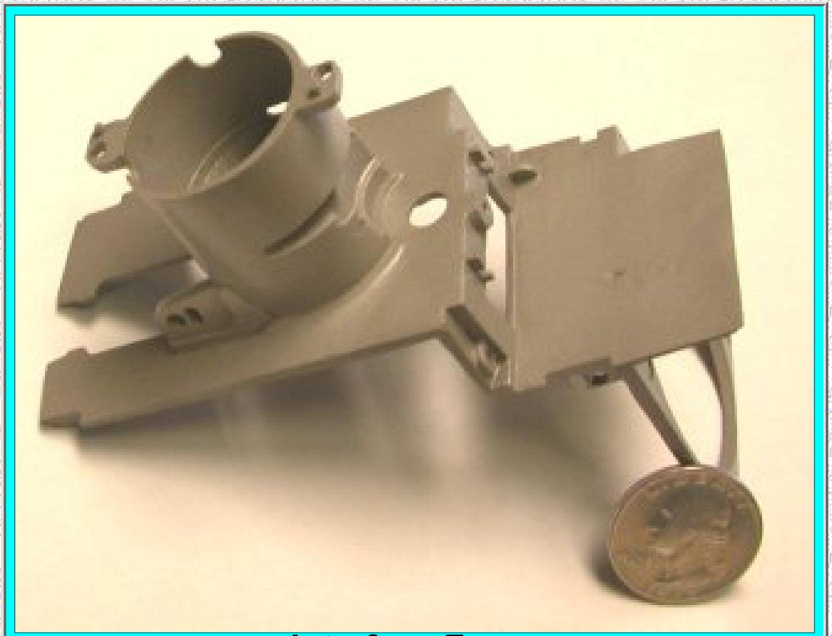
Interface Frame -- Function

- **One of the critical structural components in the projector is the internal interface frame.**
- **The frame couples and aligns the lamp assembly to the optical engine. The frame also fixtures two fans and several circuit boards.**



Interface Frame

Back Next

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Return to AFS Home Page

Page 1

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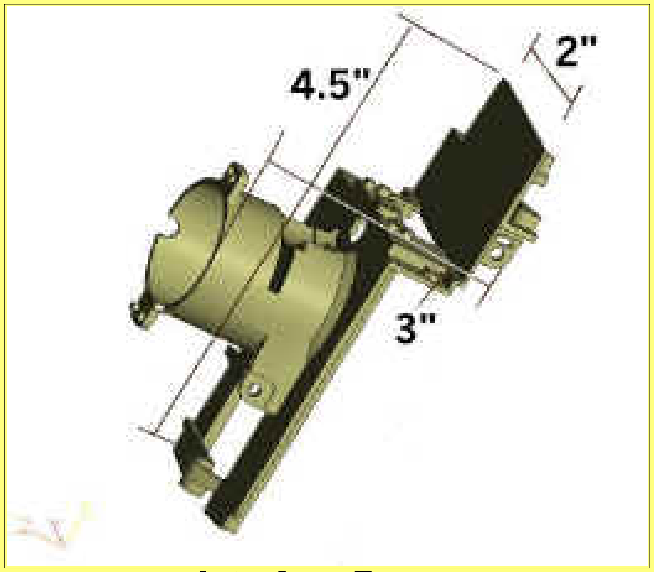
Interface Frame -- Description

The interface frame is a thinwall structural component, consisting of a two step flat bracket with a complex tube on the front face of the bracket.

- **There are numerous mounting ears, alignment pins, cut-outs, and attachment points on the frame.**



Interface Frame

The overall dimensions are 4.5" x 3" x 2" with a nominal finished weight of 22 grams. The wall thicknesses are on the order of 0.05 in (1.2 mm)

Back Next

Return to AFS Home Page

Page 1

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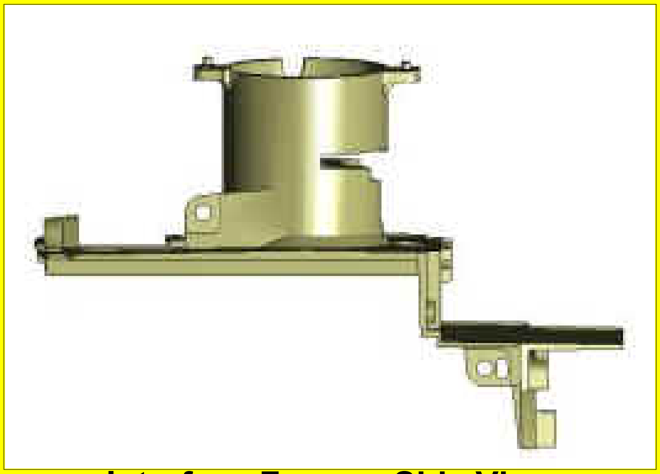
A Design Study in Rapid Prototyping for Castings

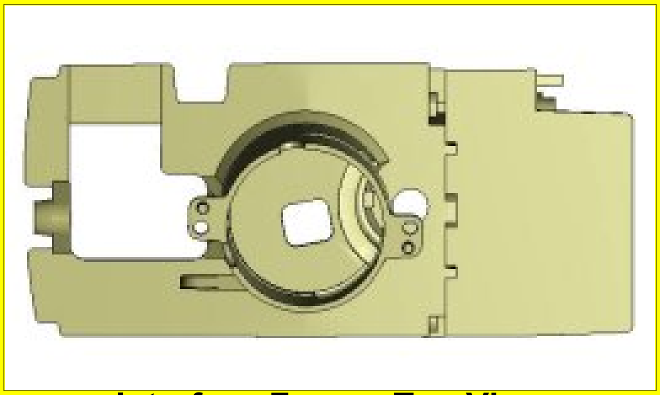
Interface Frame Requirements

Critical manufacturing & performance requirements for the frame are --

- ***Low weight***
- ***High structural stiffness and low thermal expansion to maintain component alignment***
- ***High thermal conductivity and high heat tolerance (Local temperatures as high as 250C.)***
- ***Ability to achieve complex thin wall shape and precision features with typical post-machine tolerances of +/-0.1 mm.***
- ***Near-net shape forming to minimize machining operations and cost.***



Interface Frame - Side View



Interface Frame -Top View

Back Next

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Return to AFS Home Page

Page 1

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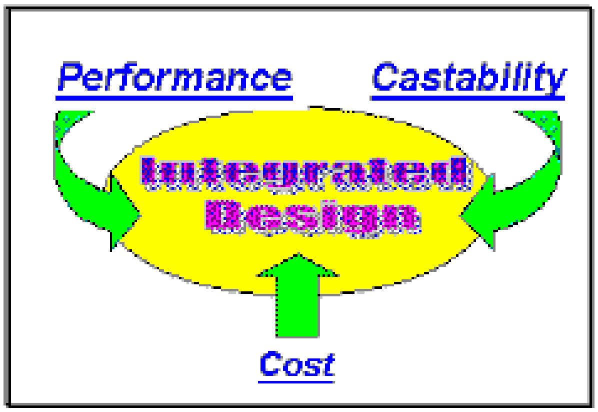
The Casting Design Issues



The Casting Design Approach -- The casting design engineers at InFocus teamed with the casting design team at Prototype Casting and focused on three design imperatives --

-- *Design for Performance*
-- *Design for Castability/Manufacturability*
-- *Design for Cost*

Critical Casting Design Issues

--The requirements for performance, castability/manufacturability , and cost are closely interconnected. Four casting design issues played a major role in meeting the three design imperatives

- **Select a *material* to meet the performance requirements.**
- **Choose a *production method* that meets precision and cost targets.**
- **Use a rapid, efficient *design/prototype* methodology to reduce lead time.**
- **Design *critical features* for high yield production.**

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Material Selection

A fundamental design decision is the selection of a specific material that best meets the desired performance and production requirements.

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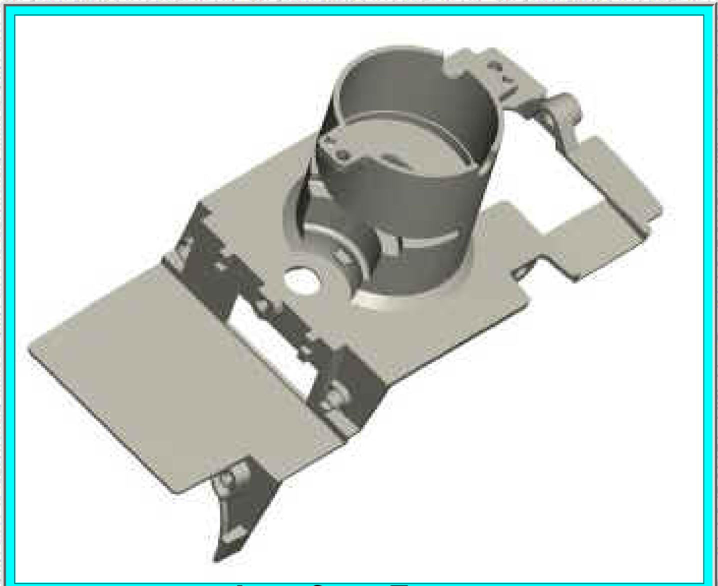
For the interface frame, the ideal material should have --

- ***Minimum weight***
- ***High structural stiffness and low thermal expansion***
- ***High thermal conductivity and high heat tolerance***
- ***Ability to achieve complex thin wall shape and precision features.***
- ***Near-net shape, low cost, high volume production.***



Interface Frame

Back Next

Return to AFS Home Page

Page 1

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A Design Study in Rapid Prototyping for Castings

Material Options

Three low density materials were considered for the interface frame:

- **High Performance, High Temperature Polymer -- Polyimide**
- **Structural Magnesium Alloy - AZ91D**
- **Structural Aluminum Alloy - A356**

	Polyimide	Magnesium	Aluminum
Density (g/cc)	1.43	1.81	2.68
Elastic Modulus (MSI)	0.45	6.5	10.5
Thermal Conductivity (W/mK)	0.25	72	150
Thermal Expansion (10^-6/K)	57	26	22
Deflection/Solidus Temperature (C)	360 (D)	470 (S)	555 (S)
Ultimate Tensile Strength (ksi)	12.5	33	38

Which material (polyimide, magnesium, or aluminum) best meets the requirements for low density, high modulus, high thermal conductivity, low thermal expansion, high temperature stability, and high tensile strength?

Back

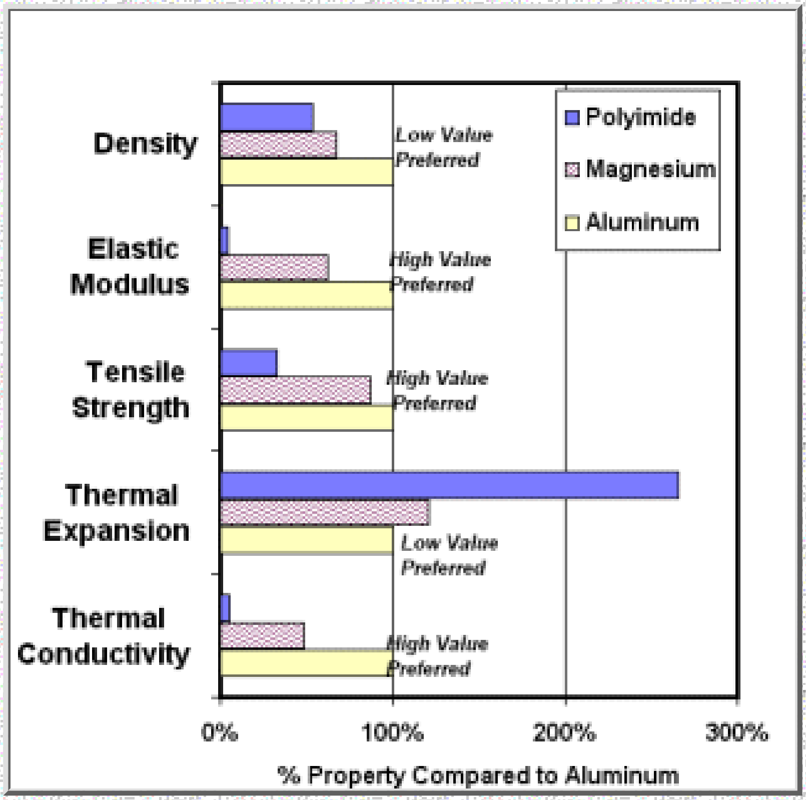
Address comments to: jss@afsinc.org
Last Modified:September, 2002 by STG

Return to AFS Home Page

Page 1

In cooperation with prototype casting, Inc

A Design Study in Rapid Prototyping for Castings



Polyimide

- The polyimide resin has the lowest density (1.43 g/cc) compared to the two metals.
- But it does not match the stiffness/ modulus, thermal conductivity, temperature capability, or strength of either magnesium or aluminum.
- In addition, the polyimide has significantly higher thermal expansion, compared to the metals.

The polyimide is not the material of choice
Go back and select another material.

Back

Return to AFS Home Page

Address comments to: jss@afsinc.org
Last Modified:September, 2002 by STG

Page 1

In cooperation with
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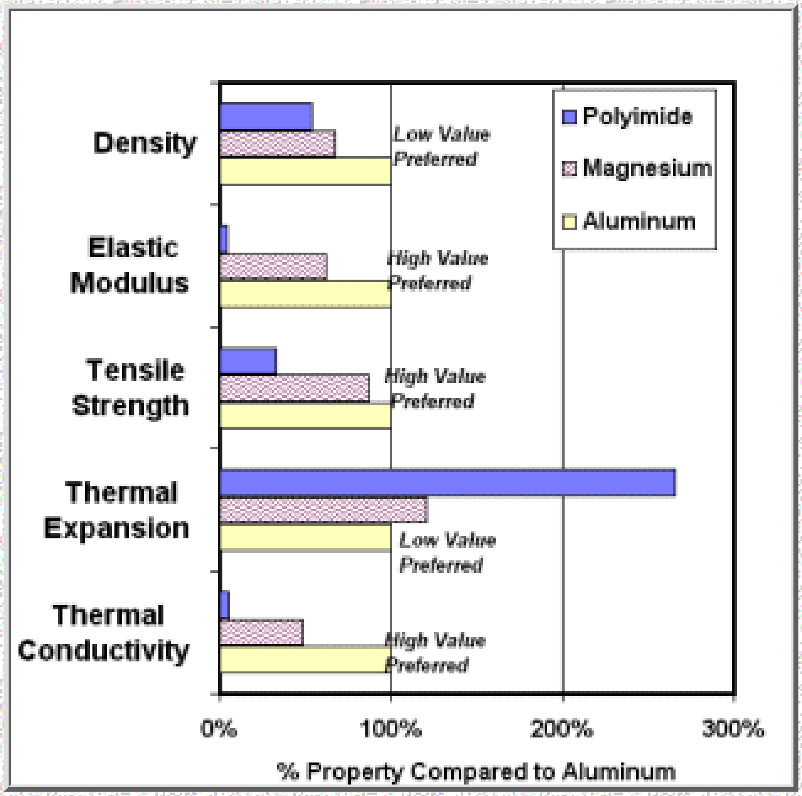
A Design Study in Rapid Prototyping for Castings



Magnesium

- The magnesium alloy has much higher values for modulus, thermal conductivity, tensile strength, and thermal stability, as compared to the polyimide polymer.
- In addition, the magnesium has a 33% weight savings over the aluminum, even though the aluminum has a moderate benefit in mechanical and thermal properties.
- Given the imperative to save weight, the magnesium is the material of choice

The magnesium is the best choice

Go the next design issue!

Back Next

Return to AFS Home Page

Address comments to: jss@afsinc.org
Last Modified:September, 2002 by STG

Page 1

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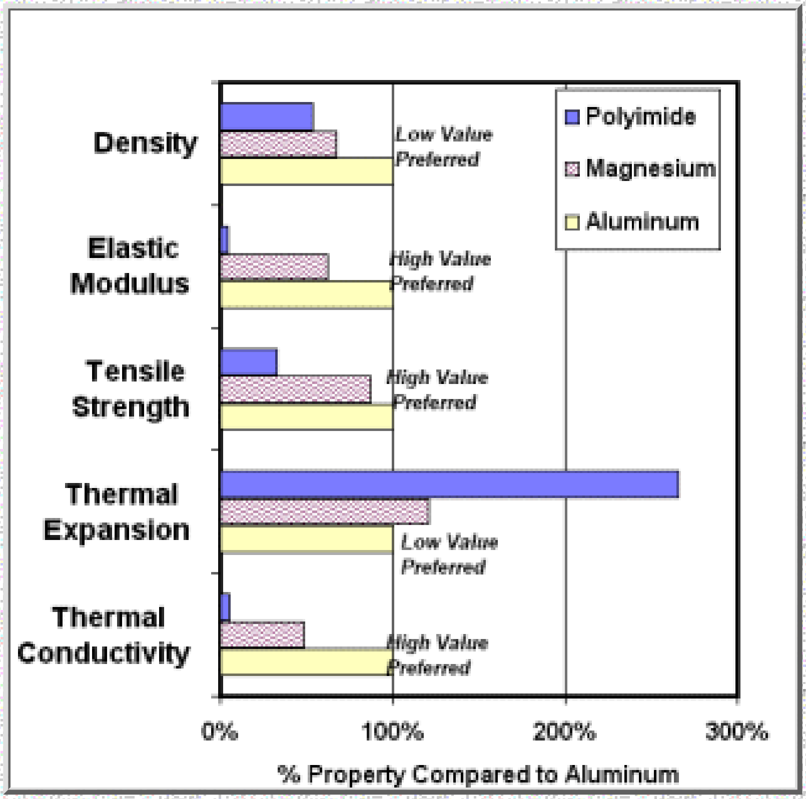
A Design Study in Rapid Prototyping for Castings



Aluminum

- The aluminum, like the magnesium, has a much higher modulus, thermal conductivity7, tensile strength, and thermal stability, as compared to the polyimide polymer.
- But the aluminum has a much higher density than the magnesium, without a comparable benefit in strength of thermal expansion.
- Given the imperative to save weight, the aluminum is not the material of choice.

The aluminum is not the material of choice
Go back and select another material.

Back

Address comments to: jss@afsinc.org
Last Modified:September, 2002 by STG

Return to AFS Home Page

Page 1

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A Design Study in Rapid Prototyping for Castings

Interface Frame - Production Options

- **The production requirement for the projector is 60,000 to 80,000 units per year.**
- **The design engineers at InFocus had three options for manufacturing the interface frame in magnesium --**

Production Method	**Characteristics**
Machining from Metal Stock	**Too expensive and time consuming for high volume production**
Multi-part sheet metal assembly	**Tolerance/alignment limitations and high assembly costs**
Metal Casting	**Tight tolerance capability and low cost, high volume production**

It was obvious that a one piece precision casting would provide the best performance at a market acceptable cost for this high volume precision component

Back Next

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Return to AFS Home Page

Page 1

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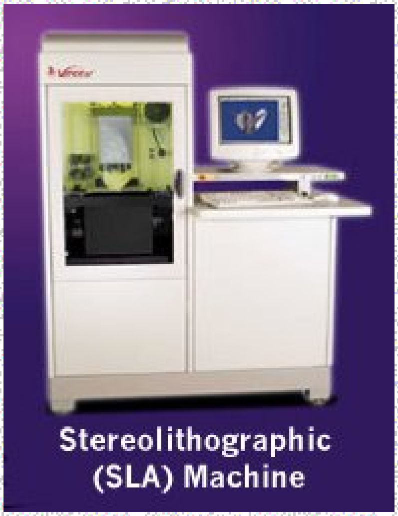
A Design Study in Rapid Prototyping for Castings

The Design Approach - Rapid Prototyping



The upfront challenge for the design engineers was how to rapidly and cost-effectively design and verify an optimized component configuration.

- **In the past, the design effort would have required iterative diecasting prototypes based on machined dies, requiring long lead times and high cost.**

- Design engineers don't have the luxury of long lead times in today's competitive, short cycle time market. They need a verified casting design ASAP.

- InFocus went to the design team of Prototype Casting, Denver, CO to work with their rapid prototyping capability to develop and test a cost-effective design for cast components.

Back Next

Address comments to: jss@afsinc.org
Last Modified:September, 2002 by STG

Return to AFS Home Page

Page 1

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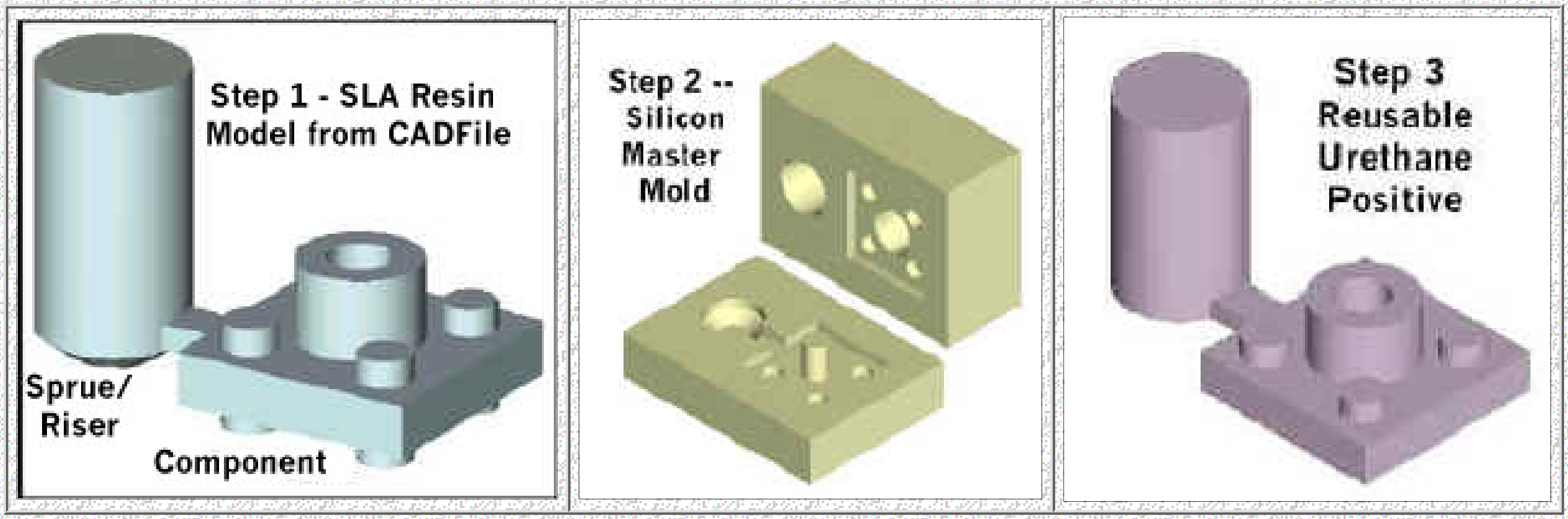
Rapid Prototyping -- The Process

Prototype Casting uses a 5-step process to produce high quality magnesium, aluminum and zinc prototypes with a 5-10 day turn-around time.



Steps 4 and 5 on the next page

Back Next

Address comments to: jss@afsinc.org
Last Modified:September, 2002 by STG

Return to AFS Home Page

Page 1

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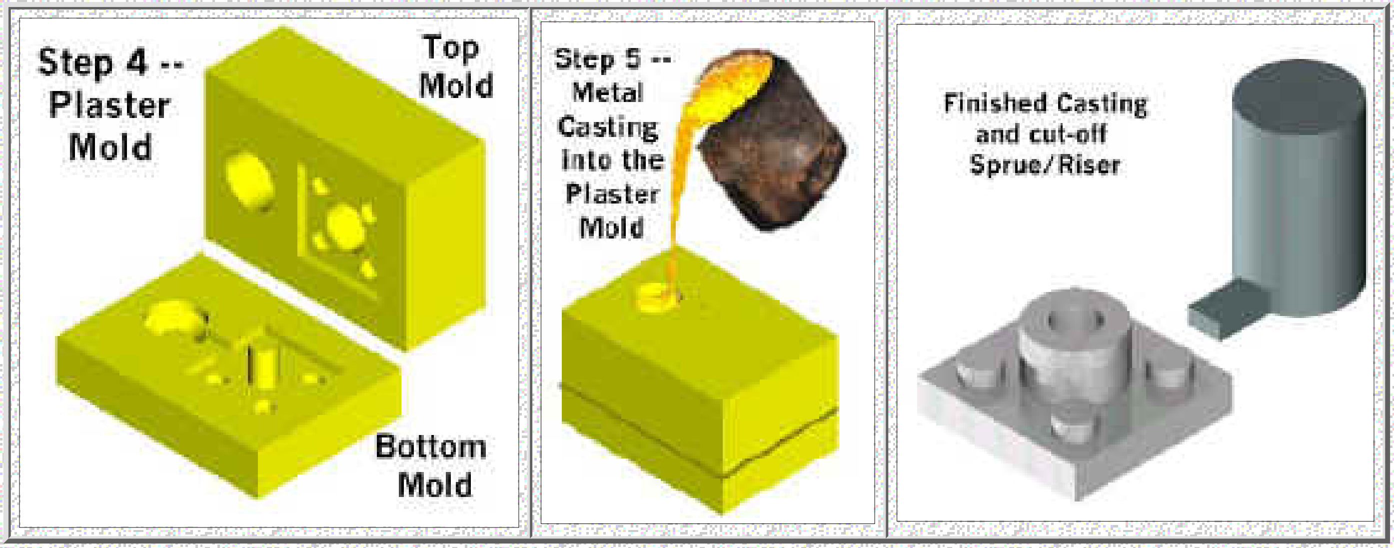
A Design Study in Rapid Prototyping for Castings

Rapid Prototyping -- The Process

The metal casting is produced by pouring the molten metal into the disposable plaster mold to get a near-net-shape casting.



Back Next

Address comments to: jss@afsinc.org
Last Modified:September, 2002 by STG

Return to AFS Home Page

Page 1

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A Design Study in Rapid Prototyping for Castings

Rapid Prototyping -- Benefits & Capabilities

Prototype Casting uses rapid prototyping and casting technology to turn complex CAD designs into metal castings.

- **The customer receives a finished metal casting, suitable for form, fit, and function tests.**
- **Design iterations can be done in a 5-7 day cycle time.**
- **Performance and manufacturing design issues can be quickly identified and optimized, based on the metal prototypes.**
- **Casting capabilities include thin walls, intricate geometry with multiple slides or cores, zero draft and complex parting lines.**

-- Wall thicknesses of 0.050" are common; 0.025" is possible depending on feature geometry.
-- Tolerances of +/- 0.005" for the 1st inch; +/- 0.002" for each inch thereafter

Back Next

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Return to AFS Home Page

Page 1

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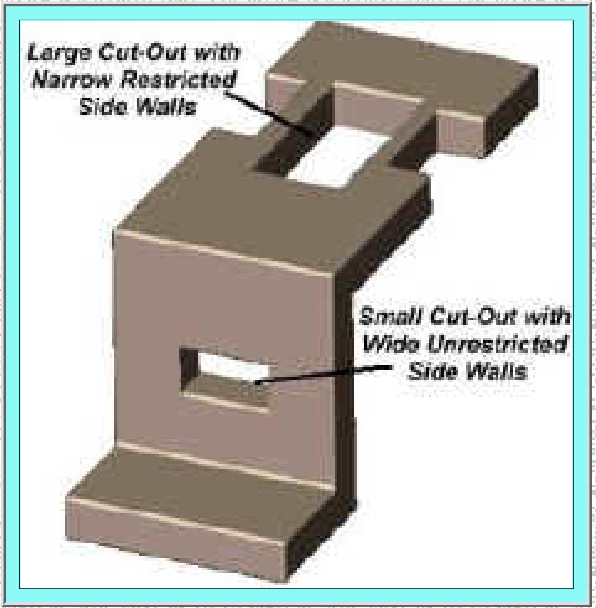
A Design Study in Rapid Prototyping for Castings

Design Issues -- Thin Wall Considerations

- **The casting design engineer has to ensure that the molten metal will flow smoothly and rapidly into all sections of the die to produce a flaw free component.**

  -- Molten magnesium cools quickly and can solidify prematurely in thin, very narrow side wall sections, blocking metal flow into the mold.



- **For thin wall castings, it is important to decide what features (cut-outs, holes, slots) would severely restrict fluid flow in the mold.**
- **Those features should be machined, rather than formed by cores in the mold.**

Back Next

Page 1

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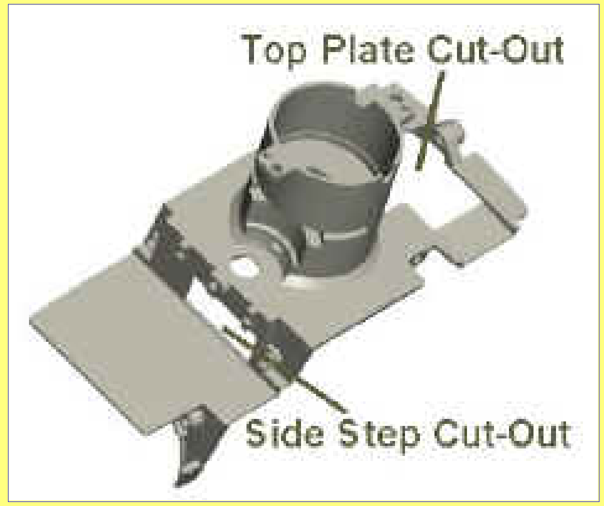
A Design Study in Rapid Prototyping for Castings

Thin Wall Considerations

The drawing of the finished frame to the right shows two features which may restrict metal flow if they are produced in the casting, rather than by rough machining.



Feature A -- Top Plate Cut-Out

Feature B -- Side Step Cut-Out

Choose the Feature
(A-Top Plate Cut-Out or B- Side Step Cut-0ut)
which should be considered for rough machining, rather than net-shape casting with cores.

Back

Address comments to: jss@afsinc.org
Last Modified:September, 2002 by STG

Return to AFS Home Page

Page 1

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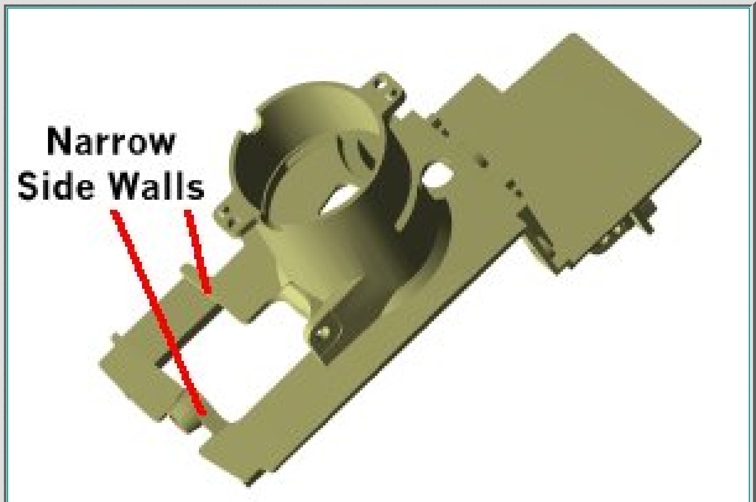
A Design Study in Rapid Prototyping for Castings

Feature A - Top-Plate Cut-Out



Top Plate Cut-Out Showing Restricted Metal Flow

- In Feature A, the top plate cut-out is relatively large and long, compared to the section size.
- If the cut-out is produced in the casting, metal flow in the side and far edges of the top plate could be restricted, limiting flow into the far edge.

Feature A **does** need to be rough machined in after casting.

Go on to the next design issue

Back Next

Address comments to: jss@afsinc.org
Last Modified:September, 2002 by STG

Return to AFS Home Page

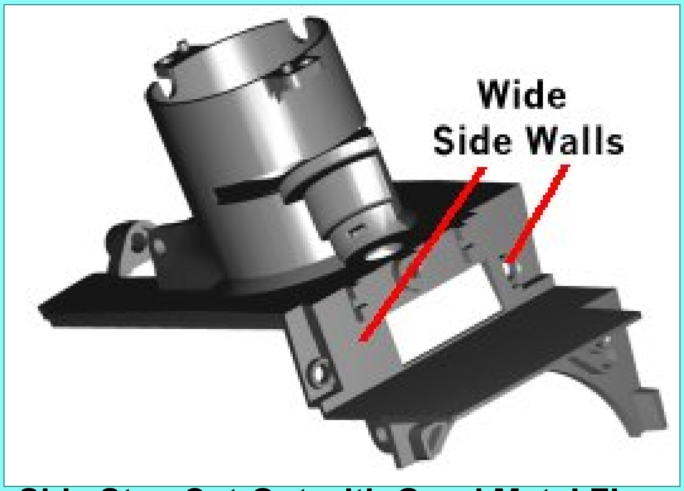
Page 1

In cooperation with

prototype casting, Inc

A Design Study in Rapid Prototyping for Castings

Feature B - Side Step Cut-Out



Side Step Cut-Out with Good Metal Flow

- **In Feature B, the side-step cut-out is a small enough feature that metal flow in the side walls will be smooth and unrestricted into the lower step.**
- **The cut out can also be easily produced with a feature on the bottom mold, without using an extra core, which would increase cost and mold complexity.**

Feature B **is best** produced in the casting, rather than by machining.
Go back and choose another feature.

Back

Address comments to: jss@afsinc.org
Last Modified:September, 2002 by STG
Return to AFS Home Page

Page 1

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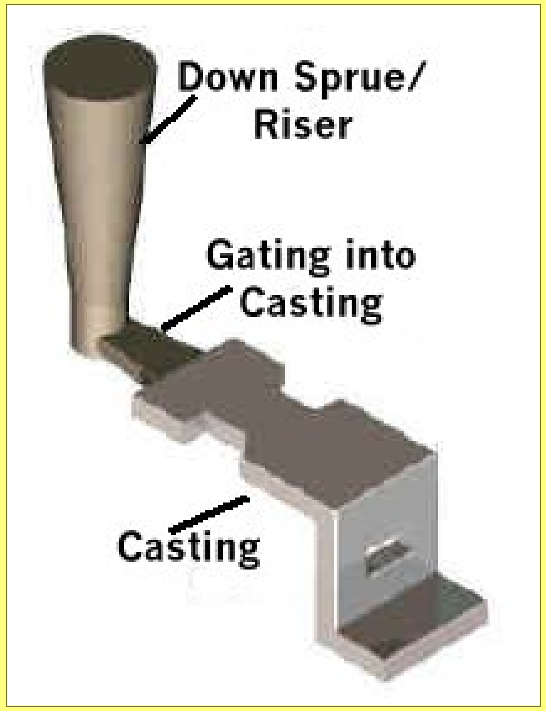
A Design Study in Rapid Prototyping for Castings

Gating System Design

The gating system serves as the flow path for molten metal from the down sprue into the mold cavity.

Proper design of the gating system is critical to provide for uniform, controlled metal flow.

- **Non-uniform, long path, and/or slow metal flow may produce unfilled sections or solidification shrinkage in the casting.**
- **Excessively rapid metal flow or metal splashing will cause turbulence and produce oxidation of the metal.**
- **In-gates should be --**
  - **large enough for rapid, but smooth, metal flow into the mold.**
  - **shaped to avoid sharp transitions and turbulence at the entry point.**



Back Next

Address comments to: jss@afsinc.org
Last Modified:September, 2002 by STG

Return to AFS Home Page

Page 1

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Gating Design

The interface frame will be gated directly into the center cylinder of the frame.

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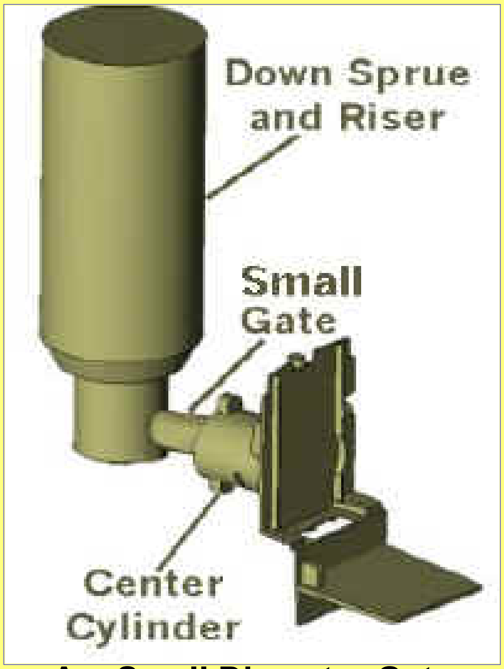
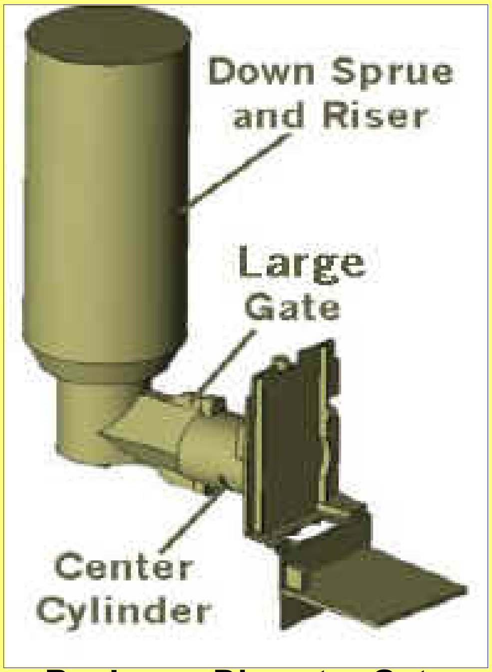
The drawing shows two designs for the in-gate on the frame



A = Small Diameter Gate



B = Large Diameter Gate

Which Gating System Design (Design A or Design B) will provide the more rapid, less turbulent flow into the mold cavity?

Back

Return to AFS Home Page

Page 1

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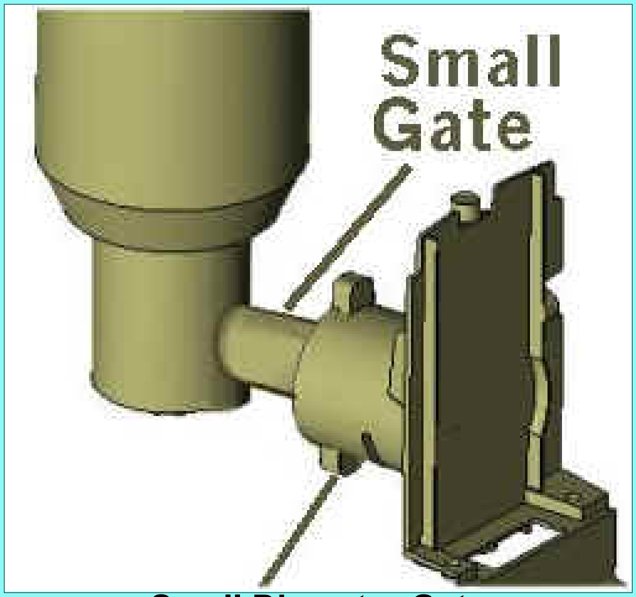
A Design Study in Rapid Prototyping for Castings

Design A - Small Diameter Gate



Small Diameter Gate

- **In this design, the gate into the interface frame is a small diameter tube feeding directly into the large diameter center cylinder.**
- **The small diameter gate will slow down the metal flow and prevent rapid filling of the mold.**
- **In addition, the sharp transition from the small diameter gate to the large diameter bore will produce significant turbulence and splashing.**

The small diameter gate is **NOT** a good design

Go back and choose another design approach

Back

Return to AFS Home Page

Page 1

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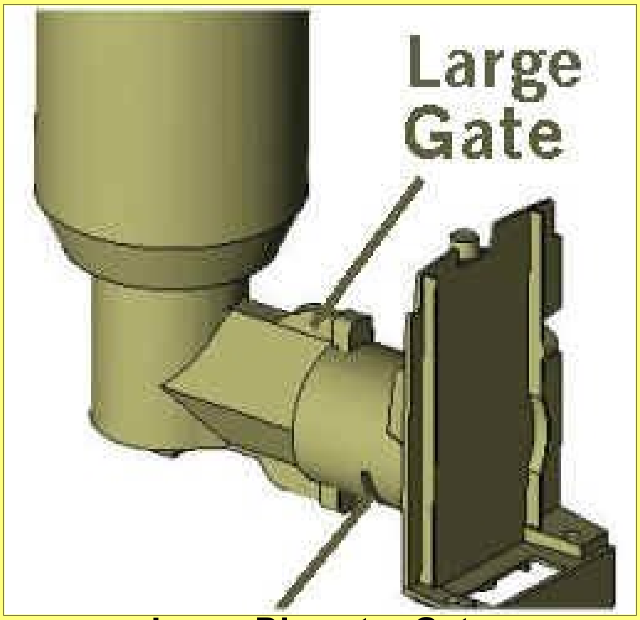
A Design Study in Rapid Prototyping for Castings

Design B - Large Diameter Gate



Large Diameter Gate

- **In this design, the gate into the interface frame is a large diameter tube feeding directly into the large diameter center cylinder.**
- **The large diameter gate will produce rapid, controlled filling of the mold.**
- **The diamond shape cross section and the smooth transition into the center cylinder on the frame will give laminar flow into the smaller features on the perimeter of the center cylinder, reducing turbulence.**

The large diameter gate **IS** a good design

Go on to the next design issue.

Back Next

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Return to AFS Home Page

Page 1

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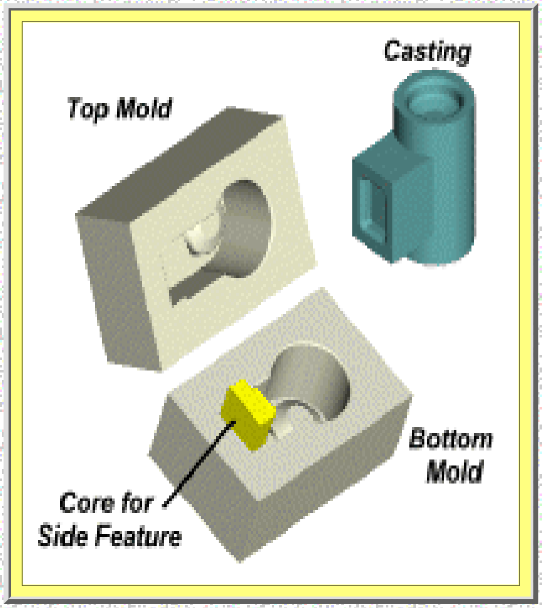
A Design Study in Rapid Prototyping for Castings

Casting Mold Design Optimization

- **The casting design engineer always optimizes his casting design, balancing benefits versus costs and considering how complex features can be produced in the casting.**
- **In the perfect situation, the casting can be produced in net-shape, with every feature produced in the mold and no finish machining required.**
- **In the real world, increased mold complexity and cost have to be compared against the costs of rough and finish machining, considering the required production volume.**



Special features in castings are often produced by additional removable mold components, commonly called "cores."

Back Next

Return to AFS Home Page

Address comments to: jss@afsinc.org
Last Modified:September, 2002 by STG

Page 1

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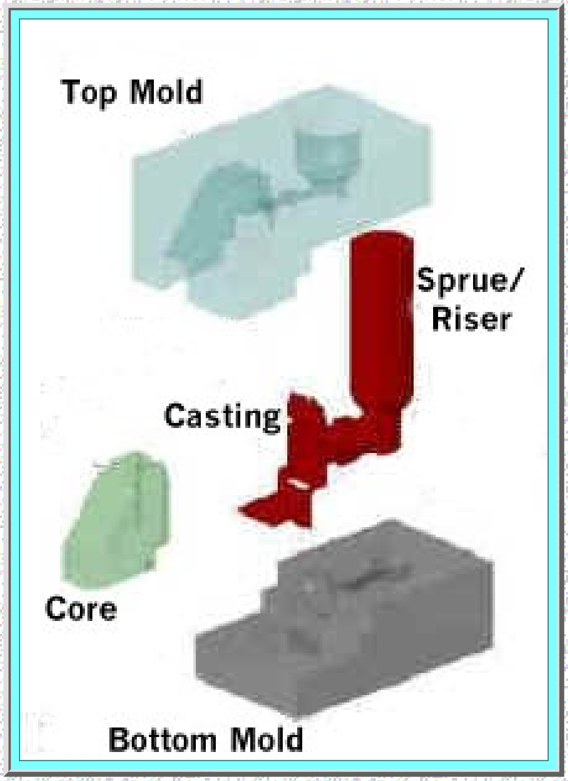
A Design Study in Rapid Prototyping for Castings

Final Mold Design

- Prototype Casting produced the interface frame in magnesium using a three part mold design with a top mold, a bottom mold, and one core.
- Risers and gating are carefully engineered to optimize flow and fill into the thin walls of the casting.
  - **This produces a casting free of misruns, shrinkage voids, porosity and cold tears.**



The optimized and verified mold design was used for producing long life steel dies for full production, precision diecasting.

Back Next

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Last Modified:September, 2002 by STG

Return to AFS Home Page

Page 1

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A Design Study in Rapid Prototyping for Castings

Lessons Learned

Prototype Casting and InFocus engineers worked closely together on engineering this prototype casting.

Machined Casting

The successful production of the prototype illustrates that --

- **Magnesium was the material of choice for weight and stiffness, understanding that magnesium casting requires careful process control**
- **Careful casting design of the thin walls and flow patterns is necessary to produce smooth metal flow and minimize transitions, which produced castings without microcracking or cold tears.**
- **Optimized engineering used a single core mold design in this complex piece, reducing die complexity and cost.**

Back Next

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Last Modified:September, 2002 by STG

Return to AFS Home Page

Page 1

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Summary

Interface Frame for LCD Projector

- **The interface frame for the InFocus LP130 projector was prototyped in magnesium in a cost-effective, fast-cycle process by Prototype Casting.**
- **The development cycle time was three weeks from first CAD file to the final design machined casting**

For further information on the application of rapid prototyping for castings, contact -- Brett Peak at Prototype Casting, Inc.
Phone-- 303-574-0060, E-mail -- brett@protcast.com
Web Site = http://www.protcast.com/

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Back One

The End

Return to AFS Home Page

Page 1

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