A Design Study in Ductile Cast Iron

The Axle Housing for a Skid-Steer Loader

Design Study Outline

- ***Introduction***
- ***Designing for Cost and Performance***
  - **The Cylinder**
  - **The Stiffening Ribs**
- ***Designing for Manufacturability***
  - **Core Design**
  - **Controlled Solidification**
- ***Controlling Pattern Costs***
- ***Finished Design and Casting***
- ***Lessons Learned and Summary***

Start the Design Study

Acknowledgement --
The metalcasting design examples are a joint effort of the
American Foundrymen's Society and the Steel Founders' Society of America.
Project funding was provided by the American Metal Casting Consortium Project, which is sponsored by the
Defense Logistics Agency, Attn: DLSC-T, Ft. Belvoir, VA 22060-6221

Axle Housing for a Skid-Steer Loader

The Application -- The axle housing is a key structural component in the drive train of the Mustang skid-steer loader, used for lifting and moving earth and heavy items at construction sites. The axle housings serve as mounting points for the front and rear axles and contain the bearing assemblies that support the axles.

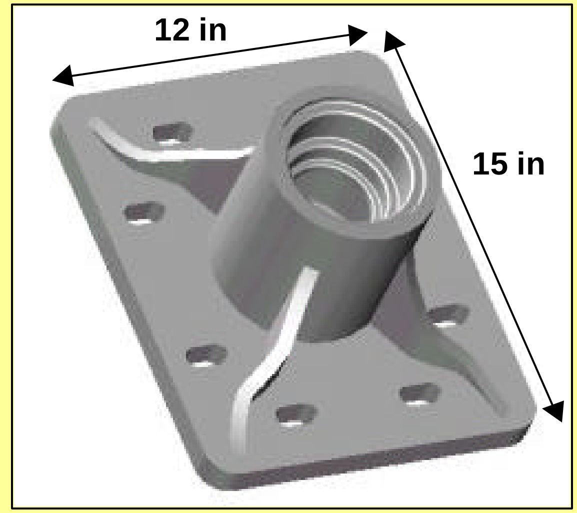
Component Description -- The axle housing is designed as a cylinder on a rectangular base plate with a total weight of 65 pounds. The housing is 9" high and the base plate is 12" x 15". The cylinder is reinforced with four rib stiffeners and the base plate has eight mounting holes for bolting the housing to the frame. The mounting holes are slot-shaped for use on two differently sized loader models.

- The critical performance issues for the housing are high stiffness, resistance to load and impact stresses and alignment for the eight bolt holes.
- There are four axle housings on each loader and the annual production is 8,000 housings.
- The specified alloy is ductile cast iron Grade 80-55-06.

Ductile Iron Castings to Reduce Cost and Improve Performance

<u>The Challenges</u> -- Originally designed as a welded assembly of 6 steel pieces, the housing assembly --

- – Had significant fabrication costs in the fixturing and welding of the assembly.
- – Required extensive machining for eight bolt slots, 3 internal bearing pockets, and 4 rib stiffeners.
- – Was not optimized for strength and weight savings

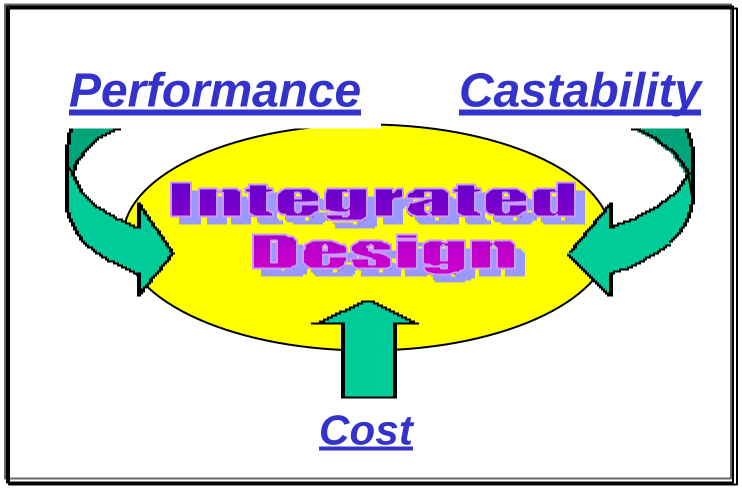


<u>Benefits of Using a Ductile Iron Casting</u> --

- The casting design study showed that the housing cost could be reduced by 15% (compared to the original assembly design) by using ductile iron casting in sand molds. This cost reduction was achieved by:
  - – Improved near-net shape which eliminated cutting, assembly, and welding steps and reduced machining operations.
- Conversion to a casting optimized the weight and strength of the component with more robust cross-sections in stressed sections and reduced weight in unstressed volumes.
- redesign of the reinforcement ribs provided for easier tool access during bolting of the housing to the frame.

The Casting Design Issues

- **<u>The Casting Design Approach</u>** --
  The casting design engineers at the Dotson Company of Mankato, MN had three imperatives for an integrated casting design:
  - ***Design for Performance***
  - ***Design for Castability/Manufacturability***
  - ***Design for Cost***

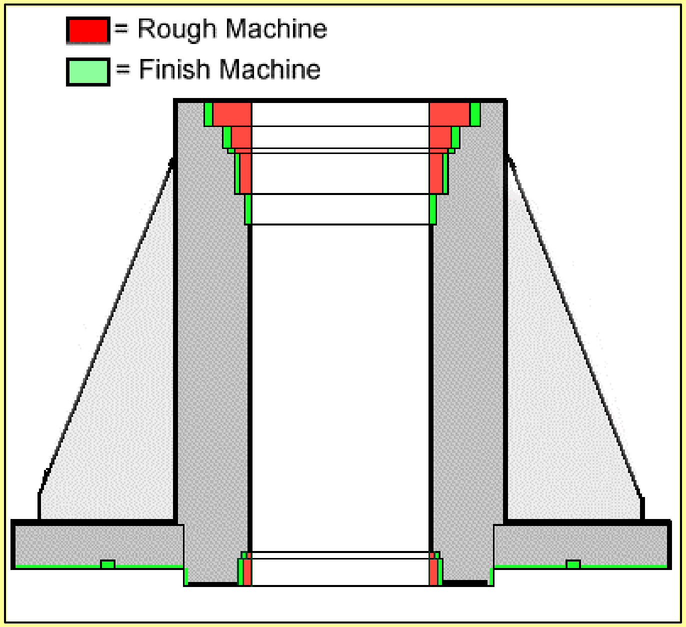


<u>Critical Casting Design Issues</u> --The requirements for performance, manufacturability/castability, and cost are closely interconnected. Four casting design issues played a major role in meeting the three design imperatives:

- ✓ Review the ***<u>component design (cylinder and stiffening ribs)</u>*** to eliminate machining steps, reduce weight, and reduce stresses.
- ✓ Design the ***<u>core</u>*** to maintain precise tolerances and alignment for the eight bolt slots.
- ✓ Develop the ***<u>mold design</u>*** to control solidification and produce the desired microstructure and material properties.
- ✓ Select a ***<u>tool production method</u>*** to minimize tool cost over the extended production run.

Cost & Weight Savings and Strength Improvement

- In the **original welded design**, the cylinder had a uniform wall thickness of 1.575”, which provided the required machining stock for the bearing pocket and the axle shaft hole. In addition the base plate has two machining operations.
  - The machining stock is shown in red-(rough machining) and green-(finished machining.)



Original Welded Design

Casting technology provides near-net shape fabricability, which can be used to improve the design with --

- *Casting to near-net shape, reducing machining requirements*
- *Weight reduction in unstressed areas*
- *Smoother geometric transitions to reduce stress concentrations*

Cylinder Design for Cost/Weight Savings and Strength Improvement

With casting design flexibility, there are opportunities to reduce machining stock and excess weight and to reduce stresses through optimized geometry and generous rounding.

The drawing to the right shows five potential areas for near-net shaping and stress reduction.

Feature #1 - Radius at Top Outer Edge

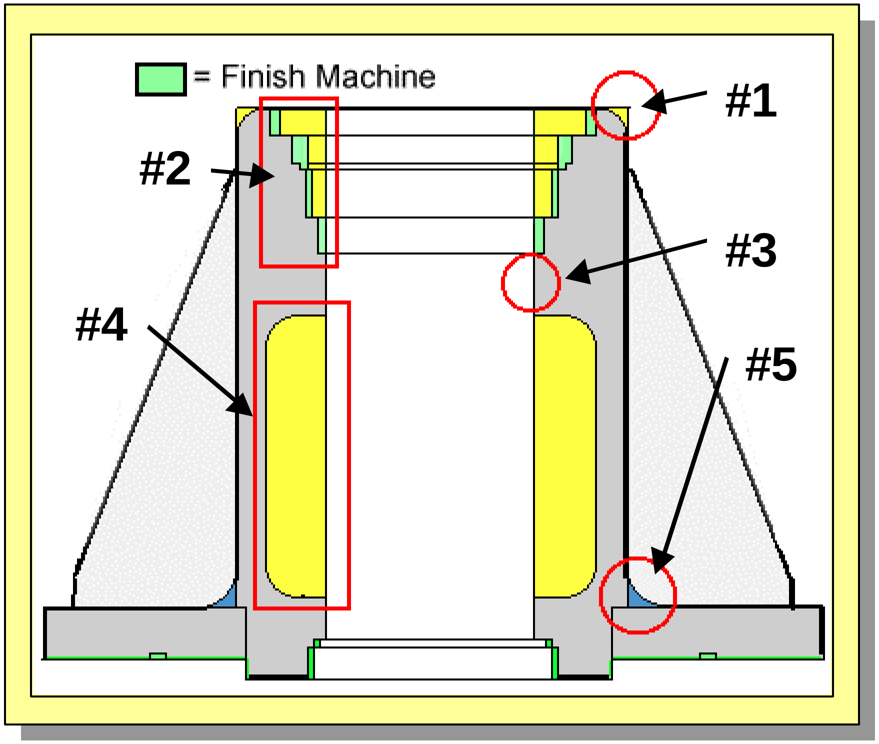
Feature #2 - Top Bearing Pockets

Feature #3 - Axle Shaft Hole

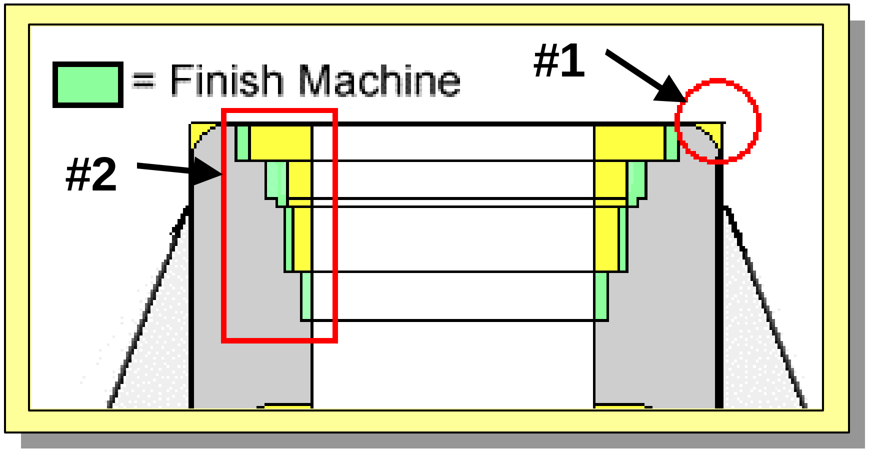
Feature #4 - Internal Wall Thickness

Feature #5 - Fillet at Cylinder Base

•Choose three features that have the greatest benefit for reducing machining costs and weight and improving strength.



Features #1 & #2 -- Top Cylinder



Feature #1 -- The outer edges at the top of the cylinder are not stressed sections. A rounded edge is <u>not</u> a critical design feature for stress reduction.

– A slightly rounded edge is desirable for appearance (0.25” radius)

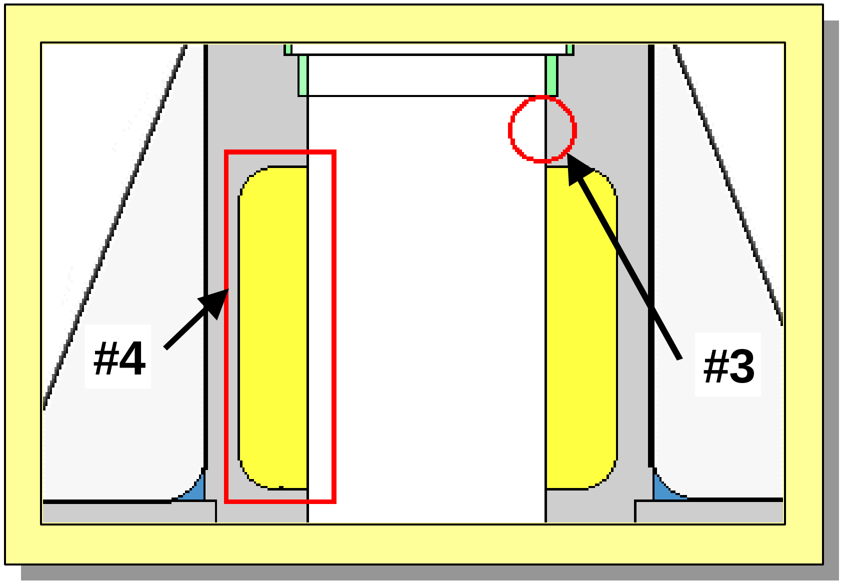
Feature #2 -- The bearing pockets on the top and bottom sections of the cylinder are good candidates for reduced machining stock.

– In the original welded design, extra stock was required for the two machining operations (rough and the finish) for each bearing pocket. With casting to near-net shape, the rough machining steps can be eliminated and only finish machining is required for the bearing pockets.

Go Back to the Cylinder Design Page

Or Go on to the next Design Issue

Interior Cylinder Features #3 & #4



Feature #3 -- The axle shaft holes do not require a machining operation; so casting does not provide a near-net shape advantage here.

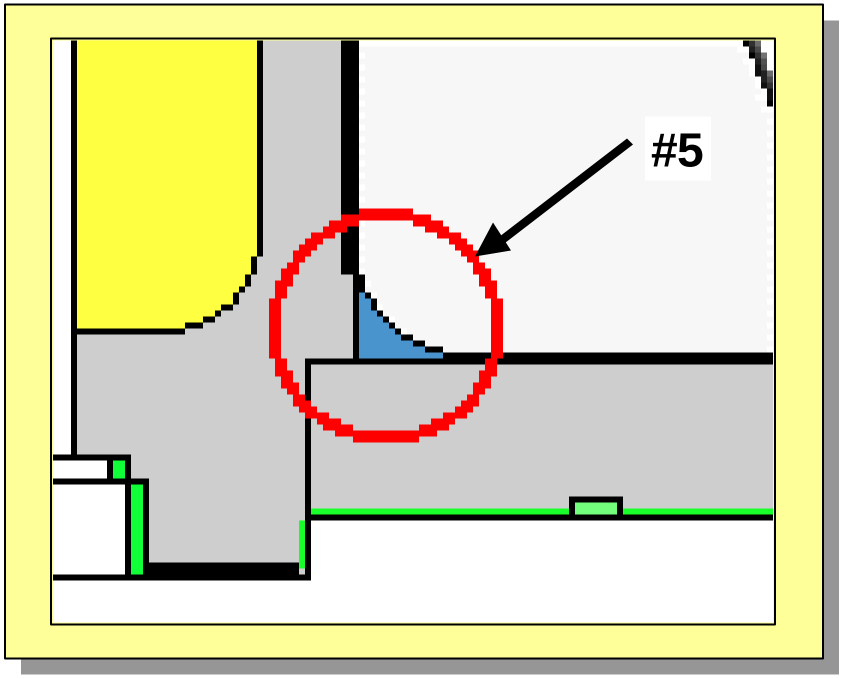
Feature #4 -- With a casting, the wall thickness of the lower cylinder section can be contoured, saving weight and metal costs.

- The inner diameter geometry is produced by using a sand core in the mold to form the interior cavity of the cylinder.

Go Back to the Cylinder Design Page

Or Go on to the next Design Issue

Fillet Feature #5



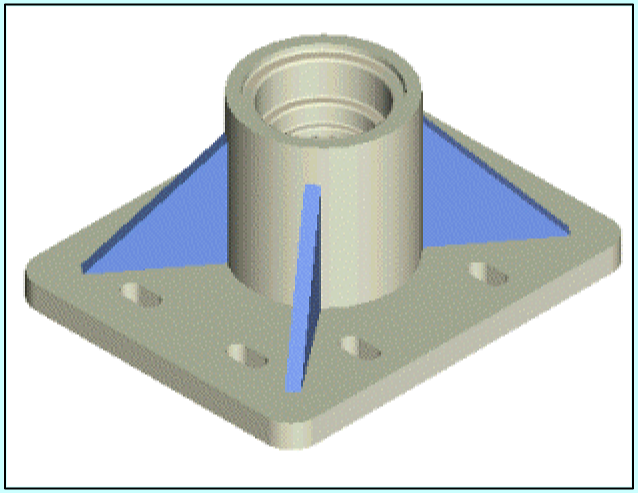
Feature #5 -- The junction of the cylinder to the support base is a highly stressed region and should be rounded (0.5” radius)

- A generous fillet between the cylinder and the base will markedly reduce the stress concentration at this critical juncture.

Go Back to the Cylinder Design Page
Or Go on to the next Design Issue

Rib Design for Cost Savings and Strength Improvement

- **The stiffening ribs on the axle housing serve a major structural function, bracing and supporting the main cylinder against bending stresses.**
  - As originally designed, the ribs were triangular, straight and relatively thin. The rib thickness was limited by the need for washer and wrench clearance for the mounting bolts, as shown..
- **With the design flexibility in casting, the designer can reshape the stiffening ribs to accommodate complex geometries and improve the strength and stiffness.**

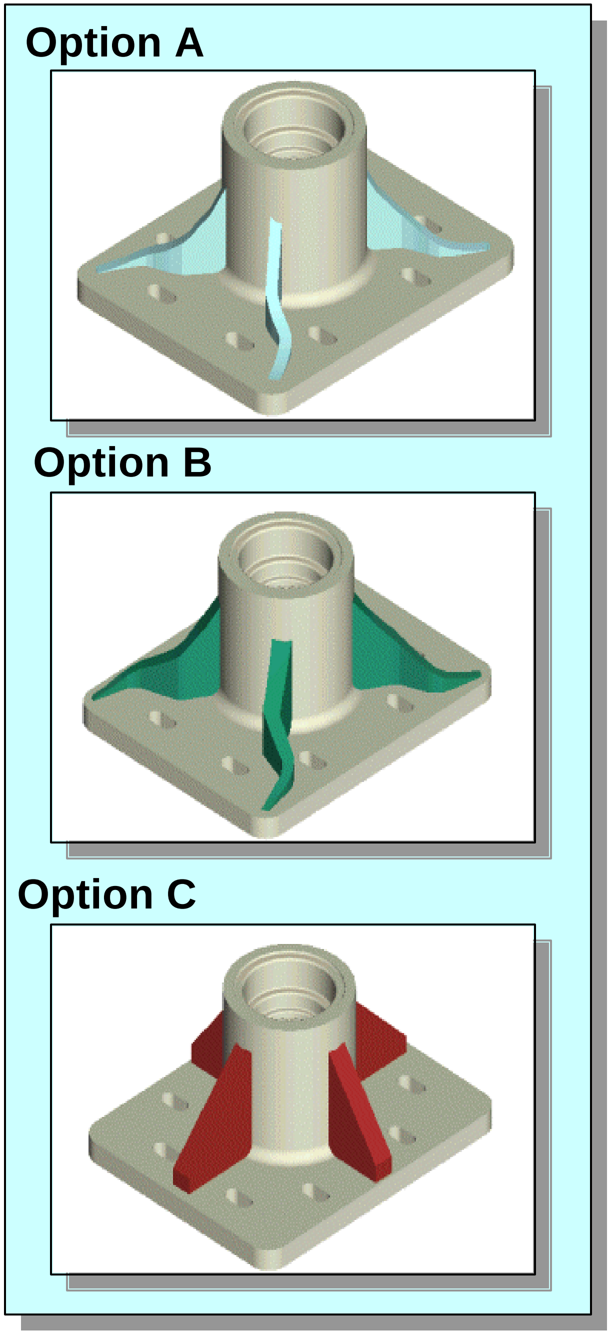


Original Design

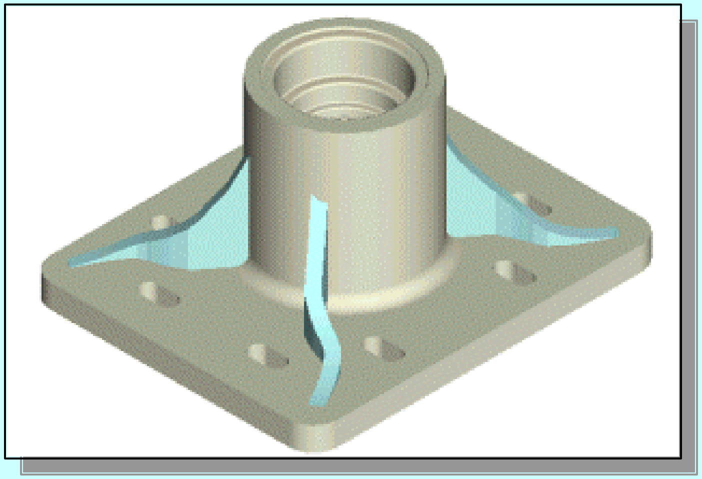
Rib Design for Cost Savings and Strength Improvement

- **The casting designer has three options in redesigning the stiffening ribs --**
  - ***Option A*** -- Angle the ribs around the bolt slots to provide the needed clearance for the bolt washers.
  - ***Option B*** -- Angle the ribs around the bolt slots and increase the thickness of the ribs to add strength and stiffness
  - ***Option C*** -- Thicken the ribs and shift them to the 0º, 90º, 180º, and 270º to provide clearance for the bolt holes.

Which option would you choose (Option A, B, or C)?



Option A -- Angled Ribs



Option A

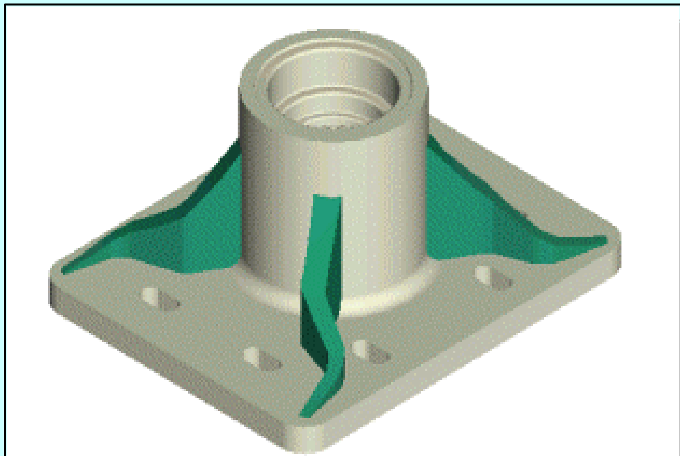
In Option A, the ribs are reshaped to angle around the bolt slots.

- This provides clearance for the washers on the bolts, as well as easy wrench access during assembly.
- Reducing the height of the ribs provides more clearance and reduces interference with the inner diameter of the wheel hub.
- But the ribs are same thickness as the original design; an increase in thickness would provide additional strength and stiffness.

Option A is a good design improvement, but does not address the opportunity for strength and stiffness improvement.

Go back to the Rib Design Options page

Option B -- Angled Ribs with Tailored Thickness



Option B

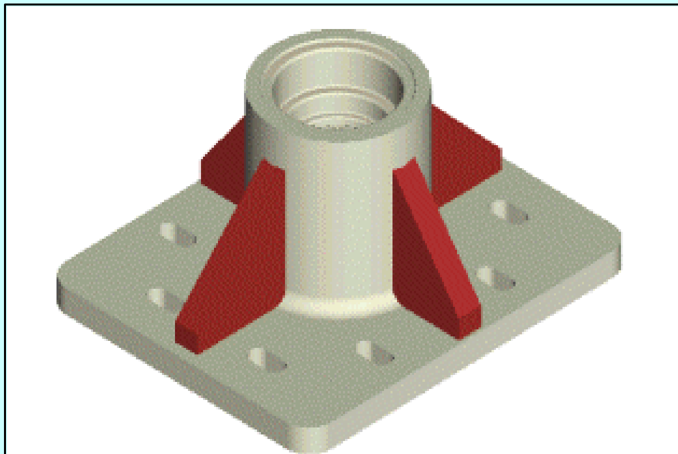
In Option B, the ribs are reshaped with two design changes provide the tool clearance and improve the strength and stiffness.

- The angling of the ribs around the bolt holes provides the needed tool clearance.
- Thickening the ribs provides an increase in strength and stiffness with a resulting improvement in durability.
- Reducing the height of the ribs provides more clearance and reduces interference with the inner diameter of the wheel hub.

Option B is the best combination of design improvements.

Go on to the next Design Issue

Option C -- Shifted Ribs with Tailored Thickness



Option C

In Option C, the ribs are thickened and then shifted to provide tool clearance at the bolt holes.

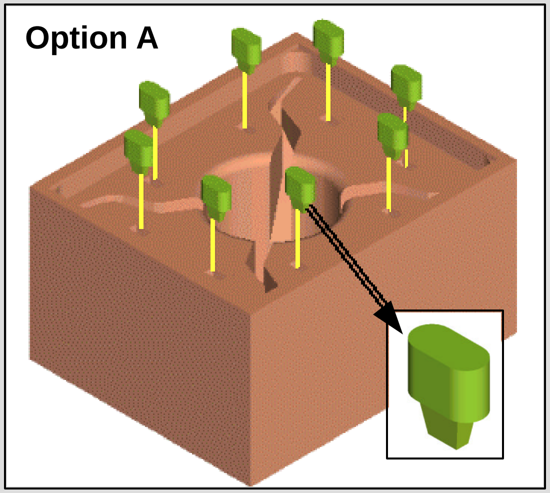
- Thickening the ribs provides an increase in strength and stiffness with a resulting improvement in durability.
- Shifting the ribs to the 0º, 90º, 180º and 270º positions provides the necessary clearance for the bolt holes. But it also shortens the lever arm for the stiffener ribs (compared to the diagonal positions). This will reduce the stiffening effect of the ribs.
- The full height and straight angle of the ribs causes interference with the inner diameter of the wheel hub.

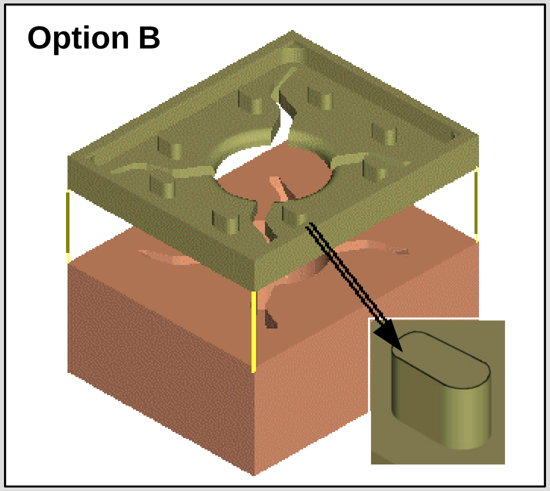
Option C is not the best redesign to provide tool clearance, improve the strength, and provide hub clearance

Go back to the Rib Design Options page

Designing the Mold & Core for Slot Production

- The bolt slots on the original welded design were machined features. One of the primary benefits of a casting is the capability of forming the bolt slots directly and eliminating the machining requirement.
  - The bolt slots are critical features that have to be well aligned to match with the eight bolts on the loader frame.
  - The bolt slots are formed in the casting with cores (an insert made of sand used to form a cavity in the casting) placed in the mold.
- The casting engineer has a choice in the core design for producing the bolt slots. His options are --
  - **Option A --** Fabricating and positioning a single, small core for each slot -- a total of eight cores in the main mold.
  - **Option B --** Fabricating a single core plate that has 8 slot features incorporated and positioning that single core plate in the mold.

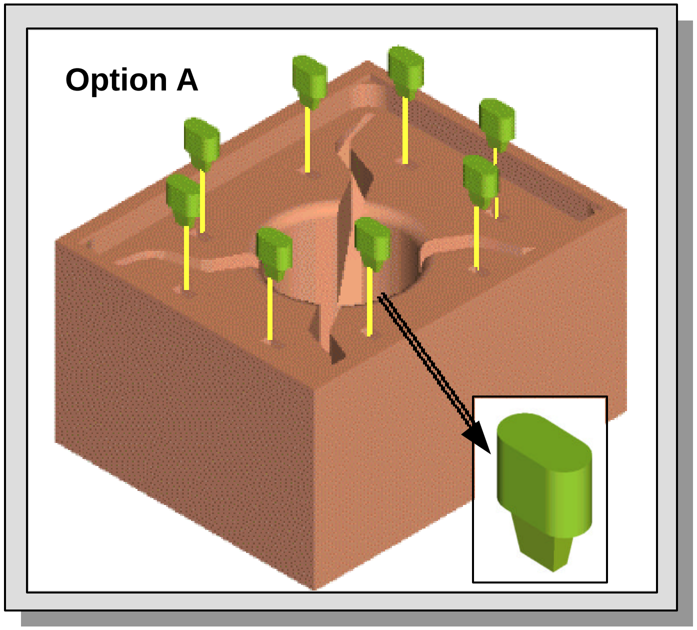




The two core options (Option A and Option B) are shown.

Considering the alignment requirement against the cost of a more complex core, which option would you choose?

Option A -- Multiple Cores

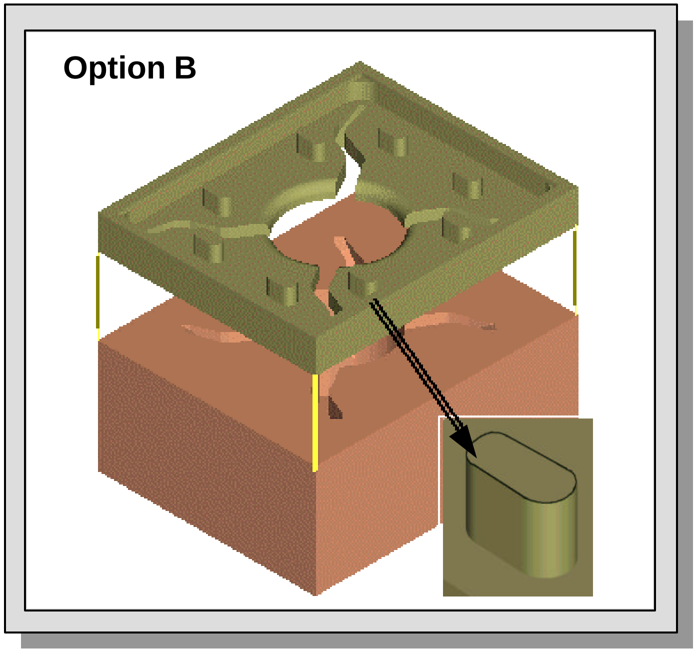


Option A uses eight single cores to produce the bolt slots.

- On a cost basis, the production of eight simple cores for each casting is simple and low cost.
- One negative in using the eight single cores is that it is difficult to insure that all eight cores are accurately positioned in the mold to produce well-aligned bolt slots.
- There are also time costs involved in placing eight cores individually.
- ***Option A (Multiple Cores) is not the best design approach for the bolt slots.***

Go back to the Core Design Options page

Option B -- Single Plate Core



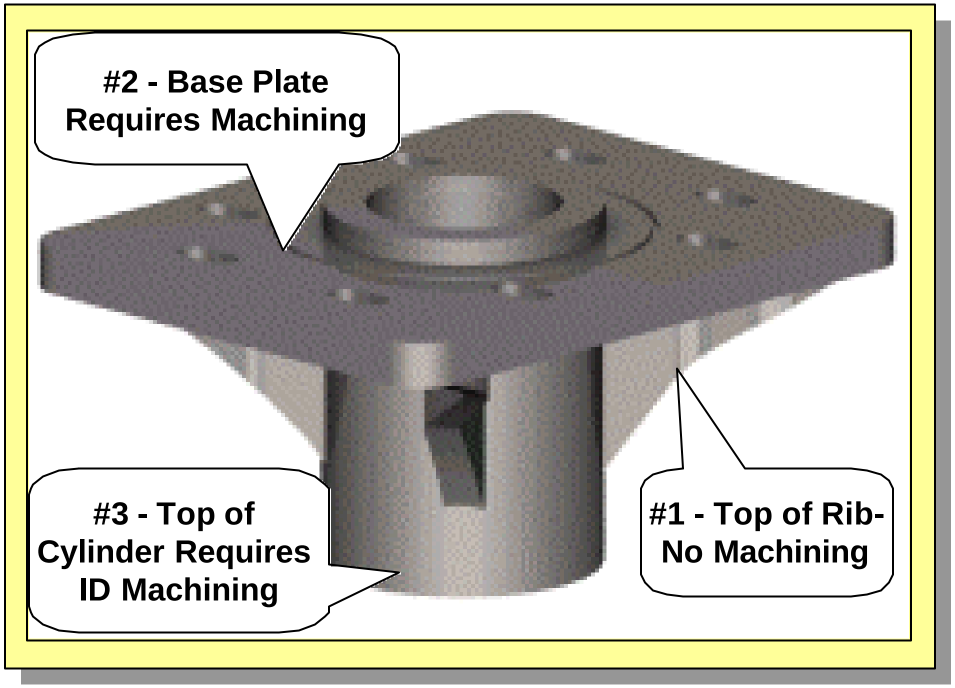
Option B uses a single flat plate core with eight slot features to produce the bolt slots.

- On a cost basis, the production of a single plate core with the bolt slots features is more expensive than individuals cores for the bolt holes
- The major benefit in using the plate core is that the alignment of the bolt slots is more precisely controlled and assured. This improvement in quality justifies the extra cost of a plate core.
- ***Option B (Single Plate Core) is the best design approach for the bolt slots.***

Go on to the next Design Issue

Designing the Mold to Control Cooling Rates and Solidification

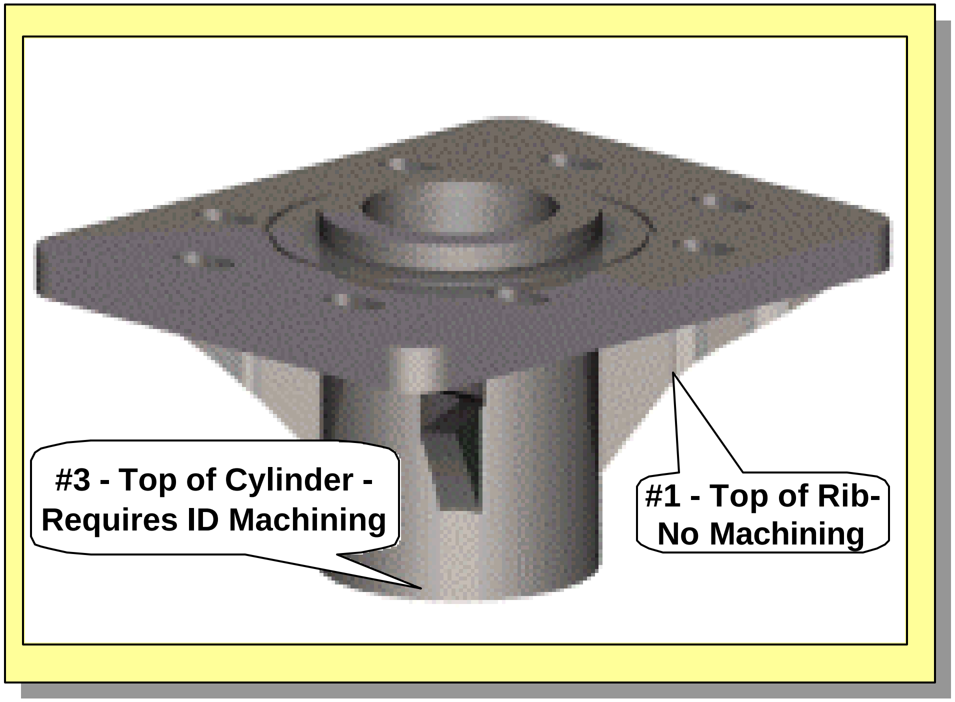
- The mechanical properties (strength, ductility, hardness, machinability) of iron/steel alloys are determined to a significant extent by the microstructure of the alloy formed during fabrication and heat treatment.
  - If sections of a ductile iron casting cool too quickly, the formation of iron carbide can increase the hardness of the casting and reduce the machinability at that section.
- Rapid cooling tends to occur at thin-wall isolated sections. The casting engineer can retain the heat and prevent excessively rapid cooling by the design and positioning of the risers that will act as a source of heat and molten metal feed.



The drawing shows the housing, oriented "base up"for casting in the mold)

Select the section (#1, #2, or #3) which is thin and isolated, where rapid cooling could occur and reduce machinability.

Features #1 & #3 -- Isolated Sections

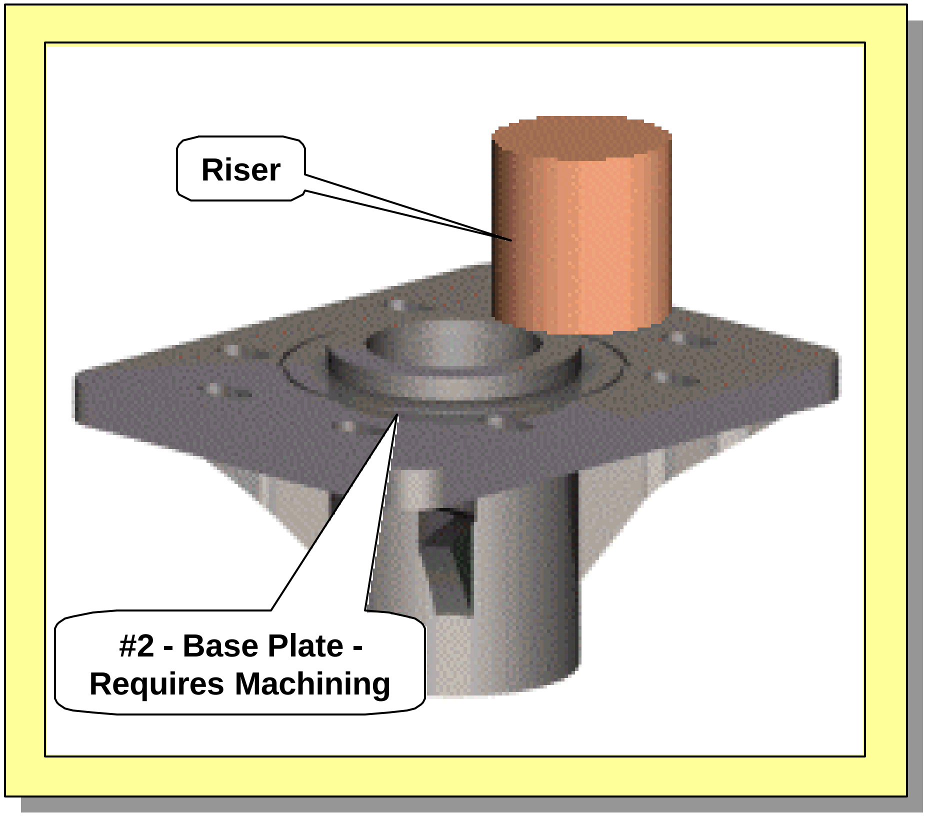


Features #1 & #3

- Feature # 1 --The top of the stiffening rib is an isolated section; however it is an unstressed region where machining is not required. The formation of iron carbide would not have a negative effect and cooling rates are not an issue.
- Feature # 3 --The top of the cylinder with the bearing pocket is an area where machining is required (OD and ID), but the wall thickness immediately adjacent to the pocket is sufficient to retain heat and prevent excessive cooling.
- ***Features #1 and #3 do not require special features to control the heat transfer.***

Go back to the Options page

Feature #2 -- Base Plate



Feature #2

- The bottom of the base plate with its bottom mating flange requires three machining steps-
  - the diameter of the mating flange
  - the overall face of the base plate
  - an O-ring slot
- The base plate is a critical area where rapid cooling could occur and where machinability has to be controlled.
- The cooling rate in the base plate can be controlled by using a large riser in the mold to provide additional heat. The location and size of the riser are shown.

Go on the the next Design Issue

Controlling Pattern Costs

- One of the manufacturing costs in casting is the cost of preparing the pattern.
  - The pattern is used to form the cavity in the sand mold. The cavity is shaped to produce the desired contours and dimensions of the final casting.
  - The pattern is positioned in the the open frame (flask) and sand is packed around the pattern. The pattern/tool is then removed, leaving the casting cavity in the sand mold.

Aluminum is the material of choice for this pattern. The casting engineer has a design choice of how the pattern will be fabricated with a direct impact on the cost of the pattern.

Choose a fabrication method for the aluminum pattern--

Cast or Machined

based on your estimate of best value and a balance of machining costs, pattern life, and tolerance requirements.

Pattern Materials

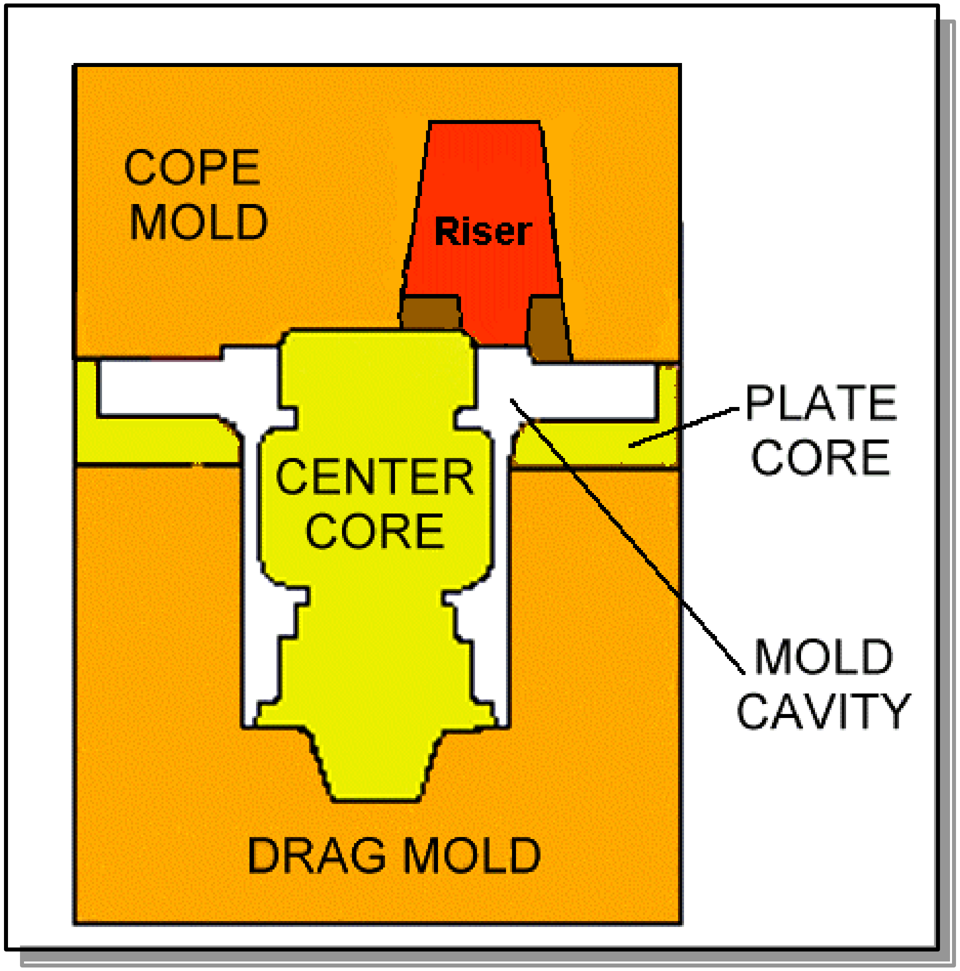
Pattern Fabrication Method	*Relative Pattern Cost*	*Durability and Surface Finish*	*Tooling Tolerance*
Cast Aluminum	1X	Limited life with possible surface flaws appearing with accumulated wear.	+/- 0.030"
Machined Aluminum	3X	Extended life with no surface flaws appearing with accumulated wear.	+/- 0.005"

Machined aluminum is the most cost effective pattern material for this long term (8,000/annum, multi-year) production run.

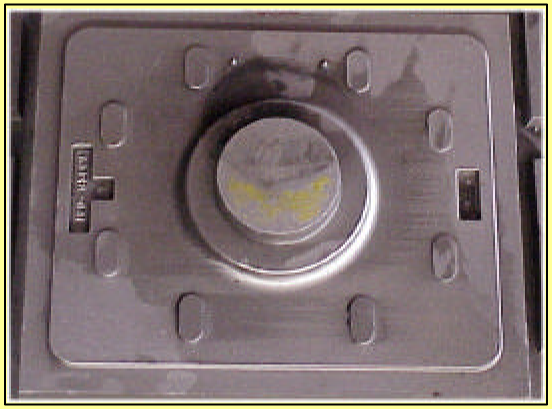
Close Up Photo of Drag Pattern showing detail on the cylinder with the print for placing the cylinder core.

Final Mold Design for the Axle Housing

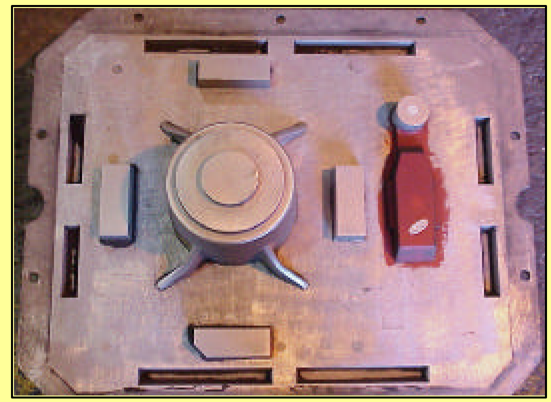
The drawing shows a cross-section of the final mold illustrating the mold cavity, the positioning of the center and plate cores in the drag mold, and the placement of the riser in the cope mold.



Final Design of the Cope and Drag Patterns/Tools



Cope Match Plate Tool

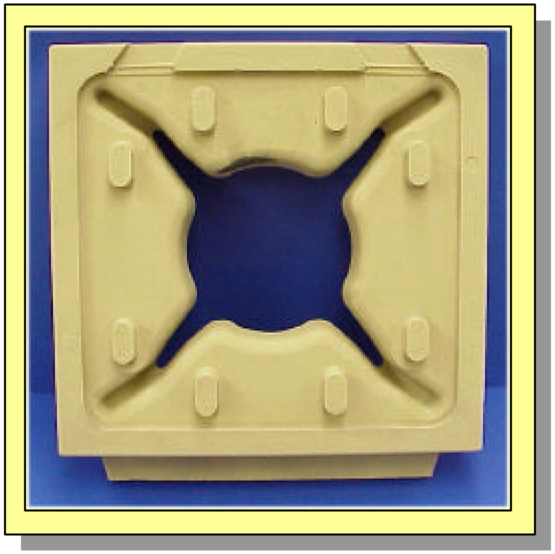


Drag Match Plate Tool

- The photos above show the match plate tools for making the cope and the drag molds.
- The final mold design uses a horizontal parting line, two inches above the support plate. The flat panel core sits in the drag mold and forms the primary parting line in the mold.
- Molten metal feeds down a side sprue, and spreads through runners into the gates on one side of the casting. There is one large riser positioned on in the cope mold, offset from the center point.

Final Design of the Two Cores

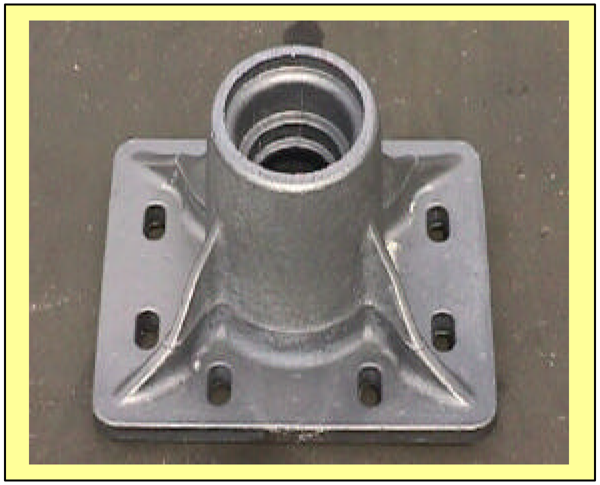
Cylinder Core



Flat Plate Core

- The photos above show the two cores used for the axle housing.
- The cylinder core is positioned in the drag mold to form the inner cavity of the axle housing
- The plate core is positioned in the drag mold to form the top surface of the base plate with the bolt slots.

Photos of the Axle Housing - As Cast and Machined



As Cast

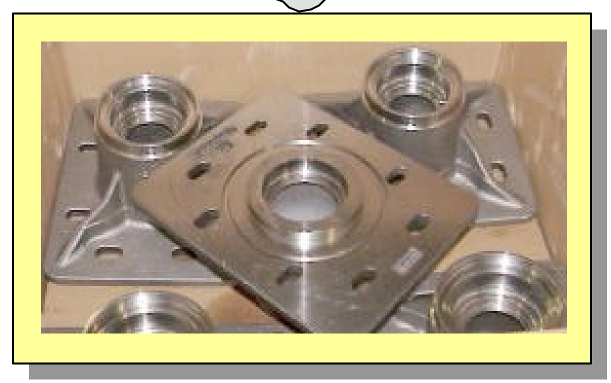
As- Machined

- After shake-out, trimming, and cleaning, the housing casting is checked for dimensional tolerances and prepared for two finishing operations --
  - ***Non-Destructive Evaluation*** - Brinell Hardness testing
  - ***Machining*** -- Mill the bottom of the base plate and turn the cylinder ID's for the bearing pockets.

The Lessons Learned

With the axle housing in the fifth year of production, there were three important lessons learned in this successful redesign and production effort.

- A ductile iron casting replaced the welded steel assembly with equivalent performance and an annual cost savings of $120,000.
- Conversion of the welded assembly to a casting produced a near-net shape piece with reduced machining requirements, weight savings and a final design that simplified final attachment of the housing to the frame.
- Concurrent engineering between the foundry and the buyer was critical for meeting cost, quality, and schedule goals.



Summary -- Casting the Axle Housing in Ductile Iron

- **The axle housing in the skid steer loader was converted to a ductile iron casting with a cost savings of 15%, achieved by --**
  - **Improved near-net shape which reduced machining operations.**
  - **Casting in sand for low cost, high volume, just-in-time production.**

For further information on the design and production of this and other ductile ironcastings, contact **-- Jim Clifford at the Dotson Company,**
Phone -- 507-345-5018, FAX -- 507-345-1270 E-mail - jcliford@dotson.com
Web Site = http://www.dotson.com

Acknowledgement --
The metalcasting design examples are a joint effort of the the American Foundrymen's Society and the Steel Founders' Society of America.
Project funding was provided by the American Metal Casting Consortium Project, which is sponsored by the Defense Logistics Agency, Attn: DLSC-T, Ft. Belvoir, VA 22060-6221