A Design Study in Nickel Aluminum Bronze Castings

Operator Pedal System for School Buses

Design Study Outline

Start the Design Study !

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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.

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Pedal System - Application

The adjustable operator pedal system is manufactured by Teleflex Morse for use in school buses. The system provides a range of positions for the brake and accelerator pedals to accommodate different drivers.

The adjustable system is required because the driver seat is locked in a predetermined position to fix the distance between the driver and the safety air bags.

This fixed distance insures that the air bags will deploy properly and protect the driver in an accident.

The pedal system uses electric motors to adjust the pedal positions to the driver's comfort.

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Pedal System -- Function

The pedal system is comprised of two subsystems:

- **the BRAKE SUBSYSTEM with the brake pedal and the upper brake component**
- **the ACCELERATOR SUBSYSTEM with a lower accelerator component and an upper accelerator component**

The pedal system provides the driver with safety-critical control of the vehicle brakes and engine acceleration.

The system must function reliably for the full life of the vehicle across a broad range of stress loads, temperatures, and corrosion conditions.

Brake Pedal Components

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Brake Pedal System -- Description

The lower brake pedal is 10" long, 4" wide, and 3" high with a weight of 29 ounces. It consists of an upper cylinder, a curved I-beam section, and a flat brake pedal.

The upper brake component is in the form of two perpendicular cylinders with a fitted steel tube and a mounting flange. It is 6" wide, 4" deep, and 3" tall with a weight of 50 ounces.

- **Both components have numerous cut-outs, flanges, holes, and rib stiffeners.**

Brake Components

The minimum wall thickness in the four castings is 0.21".

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Accelerator System -- Description

The upper accelerator casting consists of two perpendicular cylinders with two attached flat flanges. The casting is 1 1/2" x 4" x 3" with a weight of 14 ounces.

The lower accelerator casting is rectangular frame with a cylinder feature. It has dimensions of 2" x 5 1/2" x 3" and a weight of 26 ounces.

Both components have numerous cut-outs, holes, flanges, and rib stiffeners

The four castings require machining only at critical mate-up surfaces.

Components are supplied to the system manufacturer in a machined and black powder coated condition.

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Pedal System Requirements

- **Because the components are safety-critical, they have to meet rigorous strength (torque loading) and cyclic fatigue requirements.**
- **The components have stringent dimensional tolerances on the machined bores and slots for fit and assembly.**
- **The lower components must also resist corrosion and abrasion from slush, snow, deicing agents, and gravel on the operator's shoes.**

Upper Brake Casting

Lower Accelerator Casting

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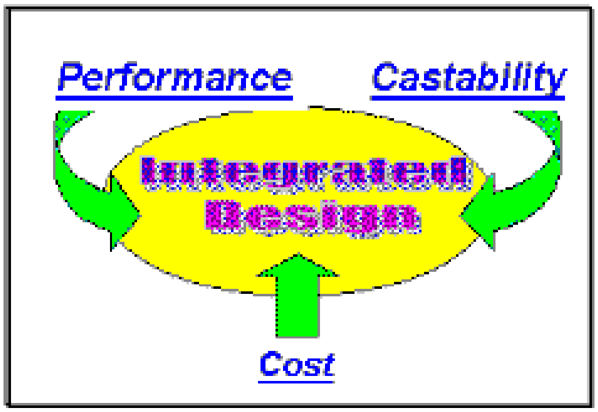
The Casting Design Issues



The Casting Design Approach -- The casting design engineers at Piad Precision Casting in Greensburg, PA 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 an alloy that meets performance requirements.**
- **Design critical features for stress reduction**
- **Make a coring versus machining decision that meets precision and cost targets.**
- **Choose a system design approach that optimizes overall production costs.**

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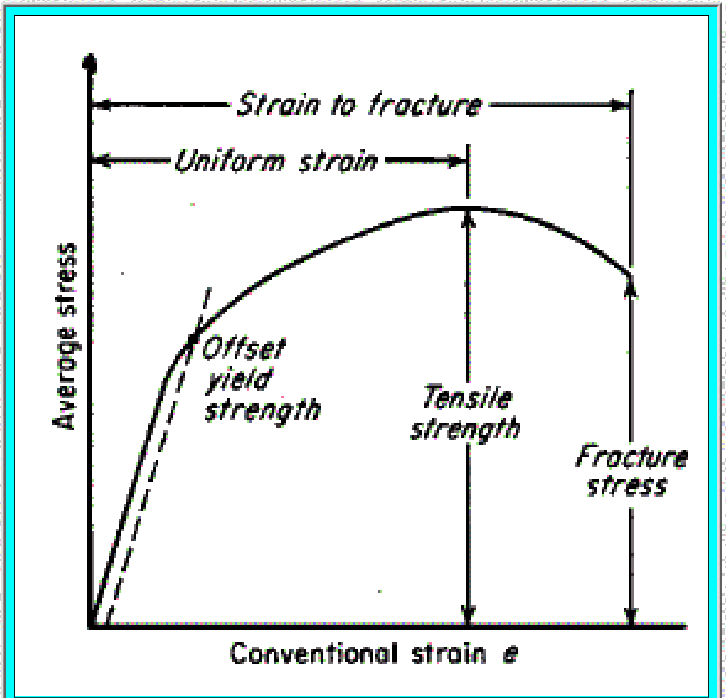
Alloy Selection

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

For the pedal components, the mechanical requirements in the critical areas are:

-- 90 ksi ultimate tensile strength,
-- 50 ksi yield strength,
-- 5% ductility.

These strength requirements have to be met while providing high corrosion resistance, modulus of elasticity, and hardness, while avoiding excessive weight and production cost.



Tensile Stress-Strain Curve

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Alloy Options

Three metal alloys were candidates for the pedal system components --

- *Structural Aluminum A201 with a T7 Heat Treat*
- *Structural Nickel Aluminum Bronze Alloy - A020 from Piad Precision*
- *Structural Ductile Cast Iron - ASTM A536 100-70-03*

	Requirement	Aluminum Alloy A201 T7	Nickel Aluminum Bronze - A020	Ductile Cast Iron A 536 100-70-03
Ultimate Tensile Strength (ksl)	>90	67	95-108	100
Yield Strength (ksi)	>50	60	58-68	70
Elongation in 2"	5%	5%	10%-6%	3%
Elastic Modulus (MSI)	--	10.3	17.5	24
Density (g/cc)	--	2.8	7.3	7.1
Brinell Hardness (10mm/500kg)	--	130	190-210	250
Corrosion Resistance	Fair	Fair	Excellent	Fair

Which material (aluminum, nickel aluminum bronze or ductile cast iron) best meets the requirements for tensile and yield strengths and ductility with acceptable corrosion resistance, weight, and elastic modulus?

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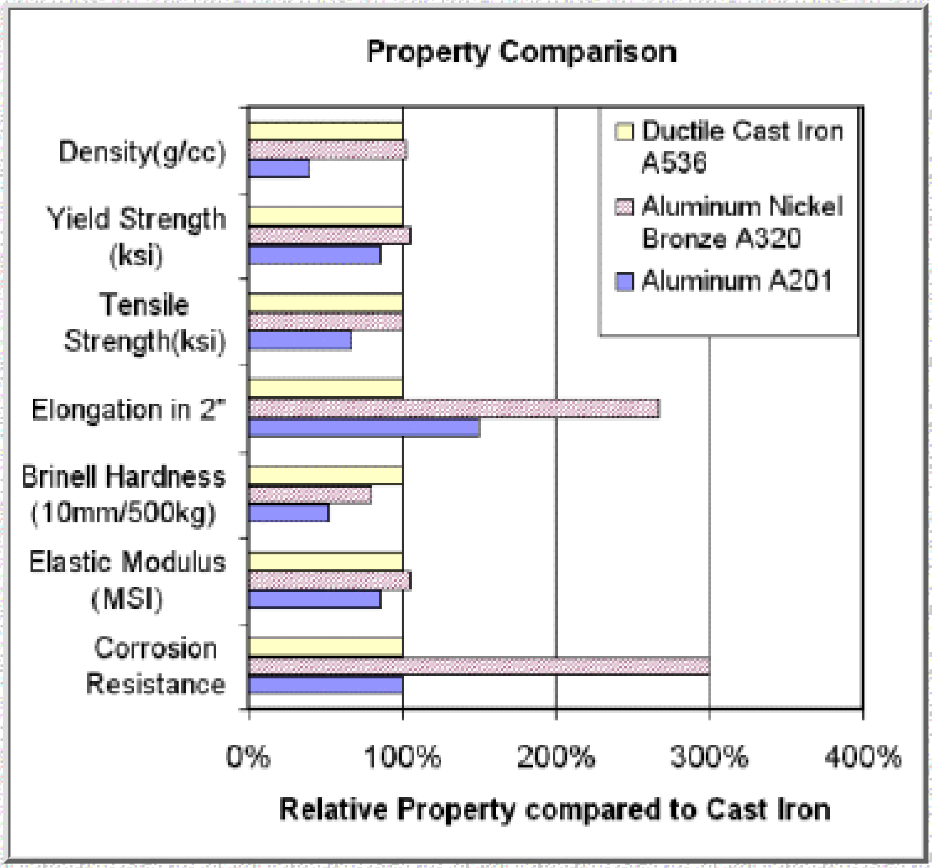
Aluminum A201 - T7



- **The aluminum A201 alloy with the T7 heat treat has the lowest density, but it cannot meet the tensile strength requirement specified in the design.**
- **In addition, the aluminum has the lowest values for modulus of elasticity and hardness and the corrosion resistance is rated as fair**

The A201 aluminum is not the material of choice
Go back and select another material.

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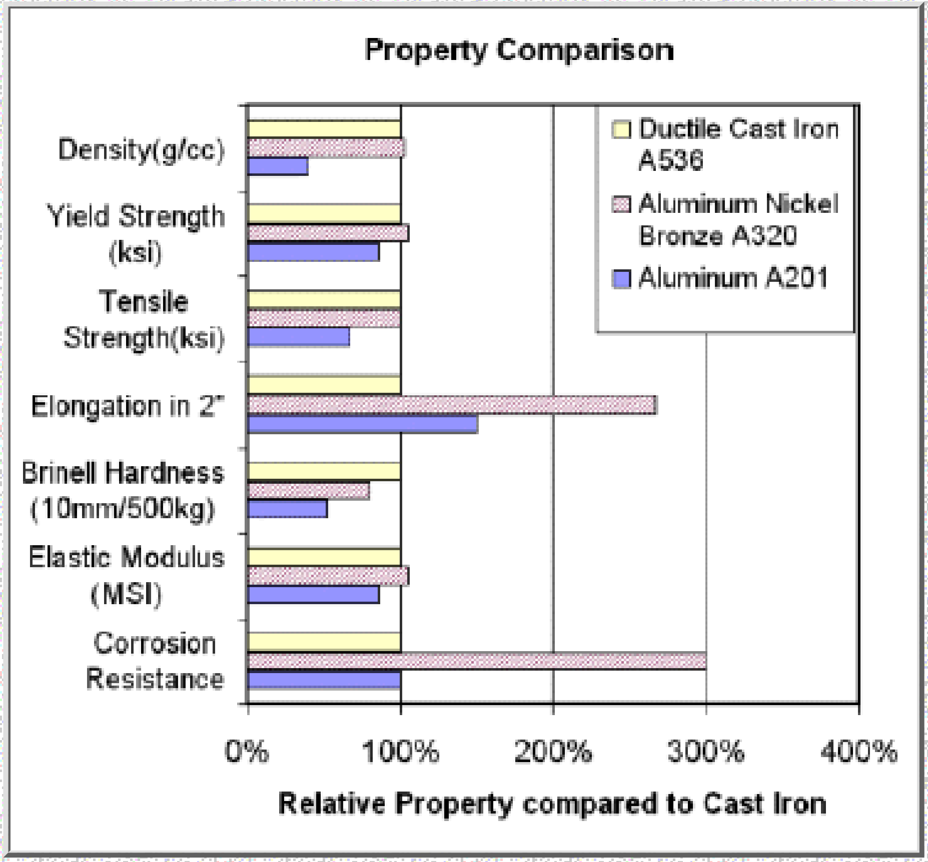
Nickel Aluminum Bronze - A020



- **The A020 from Piad Precision Casting is a nickel aluminum bronze with a copper, aluminum, iron, and nickel composition.**
- **The alloy meets and exceeds the design requirements for tensile strength, yield strength, and ductility.**
- **The nickel aluminum bronze alloy has excellent corrosion resistance, with high values of hardness and elastic modulus.**

The A020 nickel aluminum bronze is the best choice

Go the next design issue!

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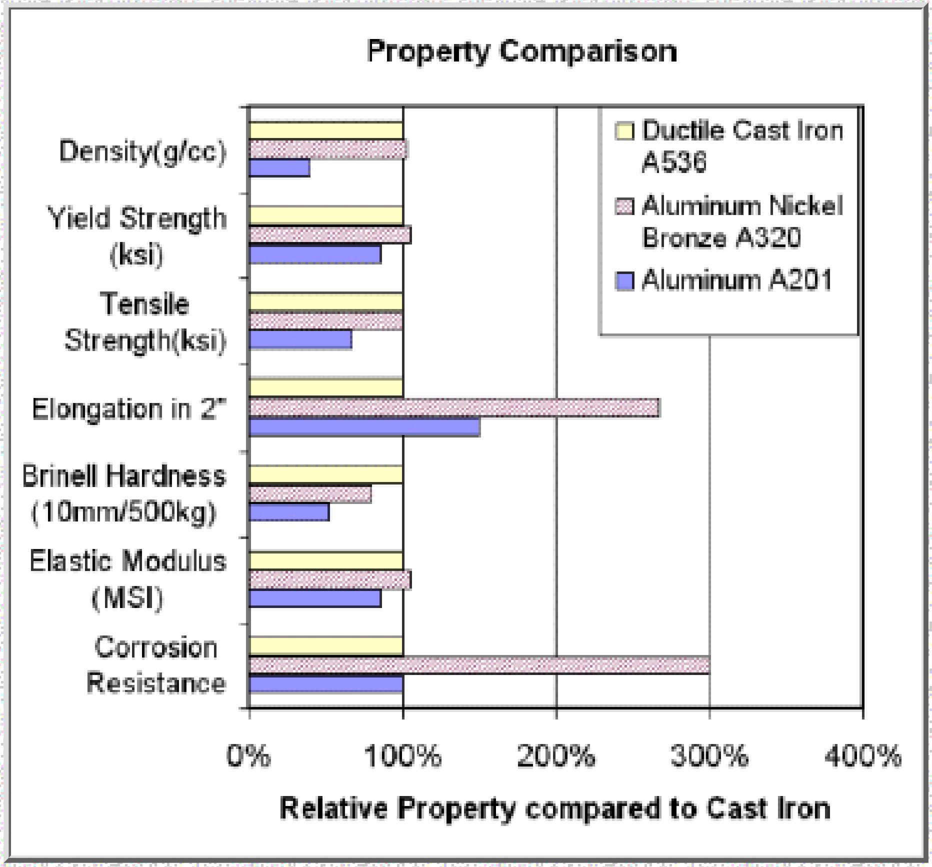
Ductile Cast Iron A536 - 100-70-03



- **The ductile cast iron A536- 100-70-03 meets the requirements for tensile and yield strength, but cannot meet the ductility requirement specified in the design.**
- **In addition, the corrosion resistance of the ductile cast iron is rated as fair**

The *A536 ductile cast iron* is not the material of choice
Go back and select another material.

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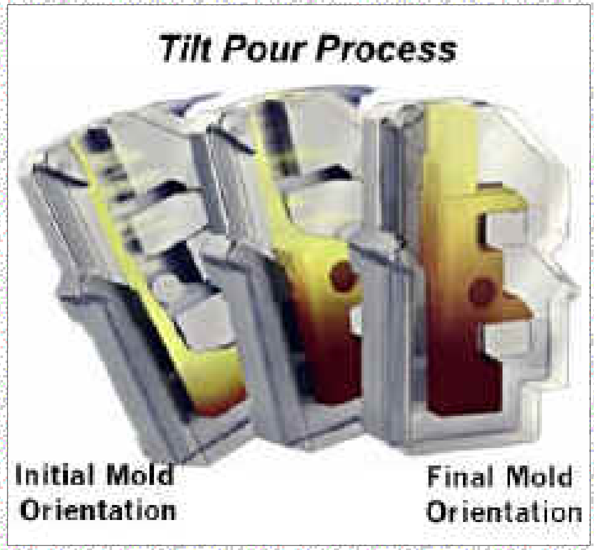
The Chill Casting Approach

The PIAD process employs chill-casting techniques and a specialty-metal permanent mold to produce precision castings in copper and copper-base alloys.

The chill casting approach consists of two steps --
1 -- Tilt Pour ***2 -- Mold Chill***

- **In the tilt pour step, the liquid metal enters the mold via gravity or low pressure.**
- **Pouring of the metal and movement of the mold are coordinated to avoid turbulence when the metal enters and fills the mold.**



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The Mold Chilling Step

In the chill step, the mold is water quenched after the casting is removed. This cools the empty mold and produces a repeatable, controlled mold temperature for the next casting cycle.

- ***The controlled temperature difference between the mold and the molten metal produces a fine, dense grain structure and high strength in each bronze casting.***

Fine Bronze Grain Structure

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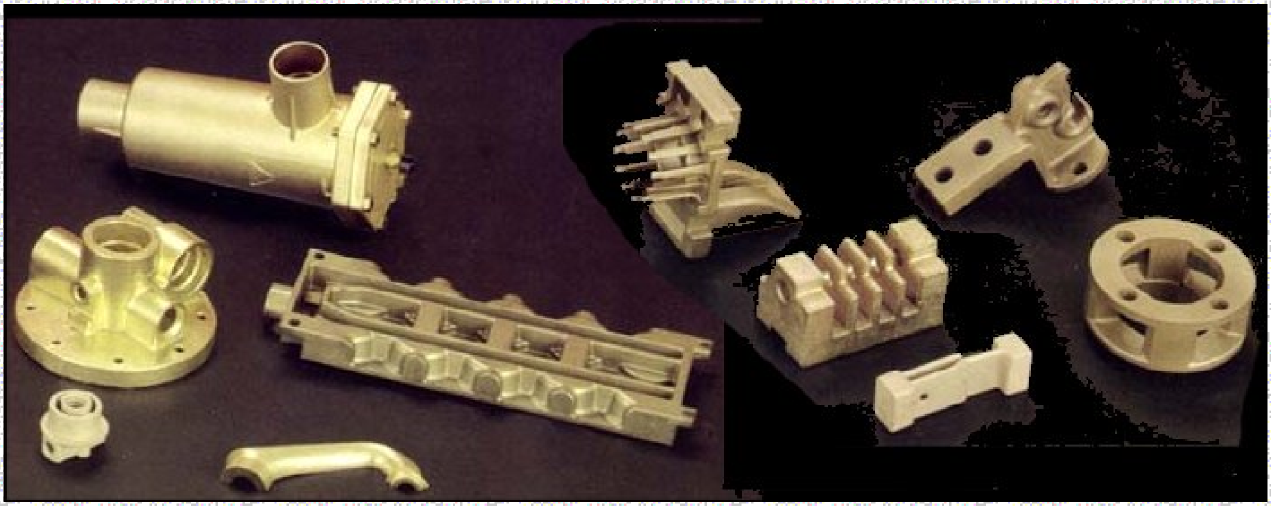
Chill Casting -- The Benefits

The high-quality castings that result from the PIAD chill casting process offer designers, engineers, and manufacturers many advantages:

- **Engineered components with near-net-shape**
- **Improved mechanical properties**
- **Close tolerances with dimensional accuracy, uniformity, and repeatability**
- **Pressure tightness**
- **Bright, smooth metallic surfaces**



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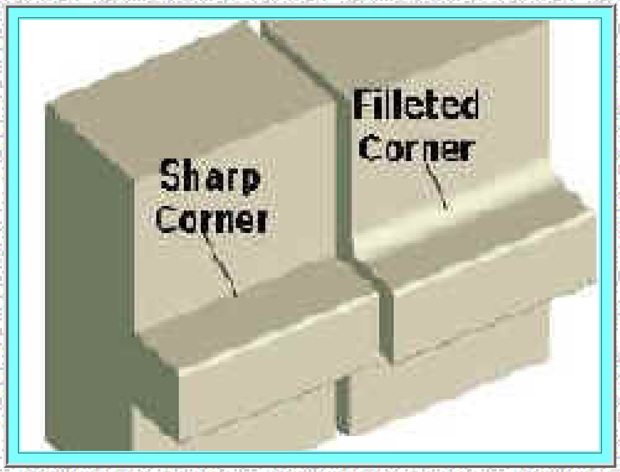
Design Issues -- Stress Reduction

The highest stresses in the pedal system components occur at the joining and attachment points, where loads and moments are transferred into the different sections.

- **Generous fillets and radii designed into castings minimize the stress concentrations found at joints between sections.**
- **One of the benefits of casting is the design flexibility to reinforce section thickness at high stress areas or to remove section thickness to save weight where stresses are low.**



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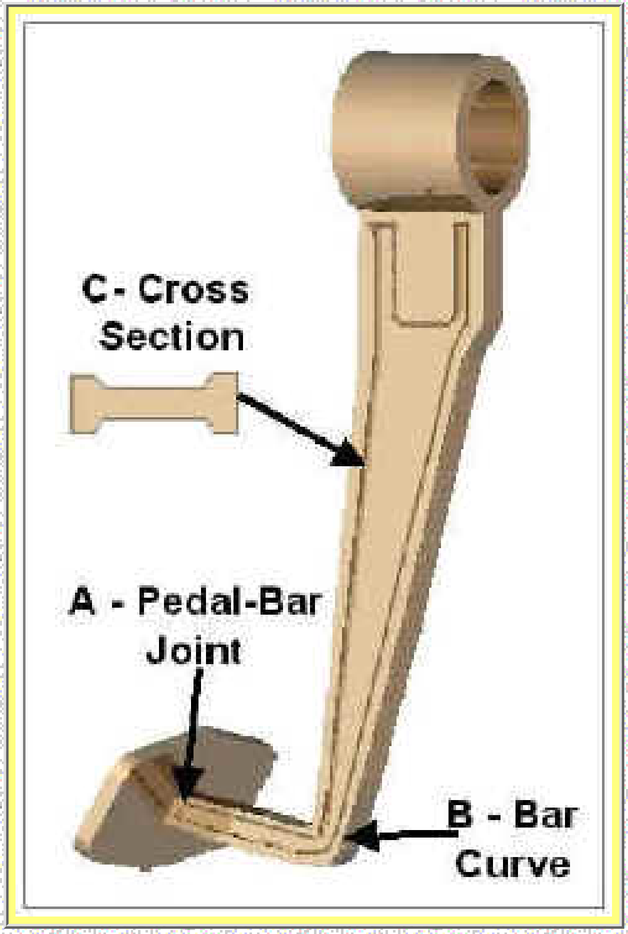
Stress Reduction in the Brake Pedal

The drawing of the lower brake pedal to the right shows three features which are candidates for reinforcement, rounding, or section thickness adjustment

- **Feature A -- Pedal-Bar Joint**
- **Feature B -- Bar Curve**
- **Feature C -- Bar Cross Section**



Choose the Feature
(Feature A , B, or C)
which should be considered for redesign for stress reduction.

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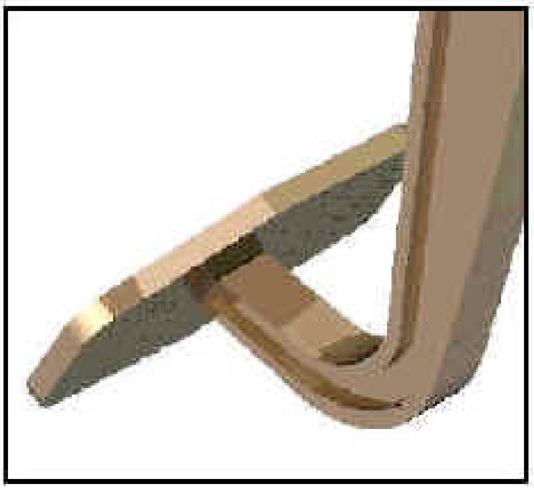
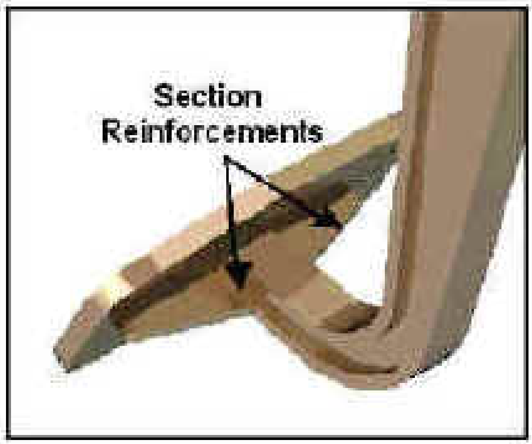


Original Design



Joint with Section Reinforcements

Feature A - Pedal Bar Joint

In Feature A, the joint between the foot pedal and the brake bar is subject to a significant torque and force.

The joint should be reinforced with two triangular sections to stiffen up the joint and reduce the bending stresses.

The pedal bar joint does need to be reinforced.

Go to the next design topic or Go back and choose another feature

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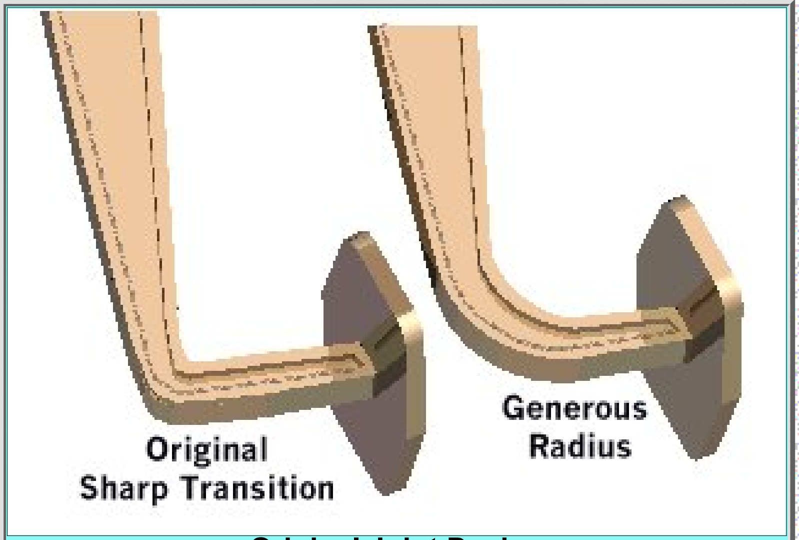

Original Joint Design
Joint with Reinforcements

Feature B - Bar Curve

- In Feature B, the angular transition of the brake bar is too abrupt and sudden. The sharp transition is an obvious stress concentration.
- The transition of the brake bar can be smoothed and evenly rounded to significantly reduce the stress concentration and improve the strength of the bar.

The bar curve does need to be generously rounded

Go to the next design issue or go back and choose another feature

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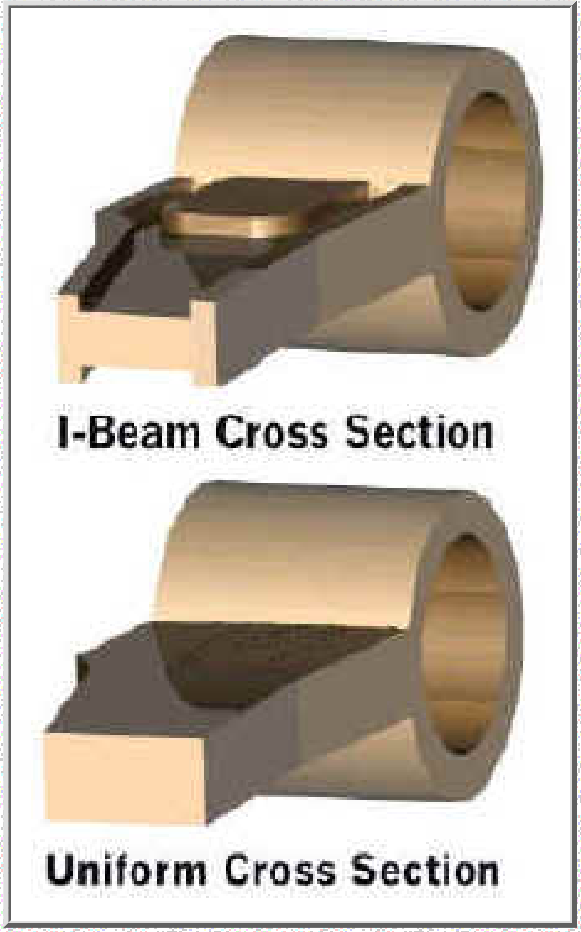

Feature C - Bar Cross Section

- In Feature C, the bar cross section already has an I-beam shape to provide the required stiffness without excessive weight.
- Increasing the cross section to a uniform thickness would not significantly improve the stiffness, but would add weight to the component.

The I-beam cross section is effective as designed.

Go back and choose another feature

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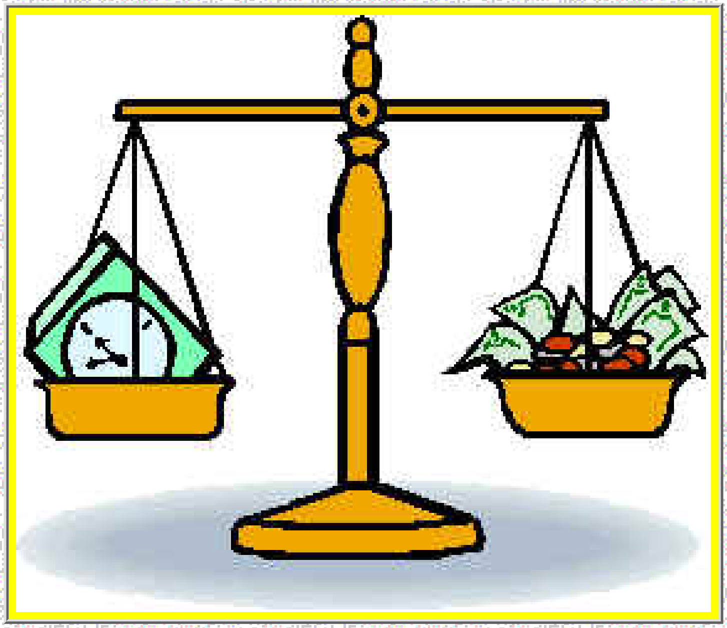
Casting Process Optimization

The foundry engineer always optimizes his casting design, balancing benefits versus costs. A critical design issue is the selection of how complex features should be produced in the component.

In the ideal situation, the casting can be produced in net-shape, with every feature produced in the mold and no rough or finish machining required.

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



In the real world, increased mold complexity and cost have to be compared against the costs of rough and finish machining, considering the entire production process and production volume.

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Slide Cores versus Machining

The casting design engineer chooses the optimal production approach for each feature, meeting tolerance and dimension requirements with acceptable final production costs.

The drawing to the right shows the two intersecting holes in the upper accelerator.

Upper Accelerator Fixture

It can be produced --

- ***by two slide cores in the mold and a finish machine step***
- ***by a two step (rough & finish) machining process***

Which fabrication method (Slide Cores or Machining) should be used for the intersecting holes?

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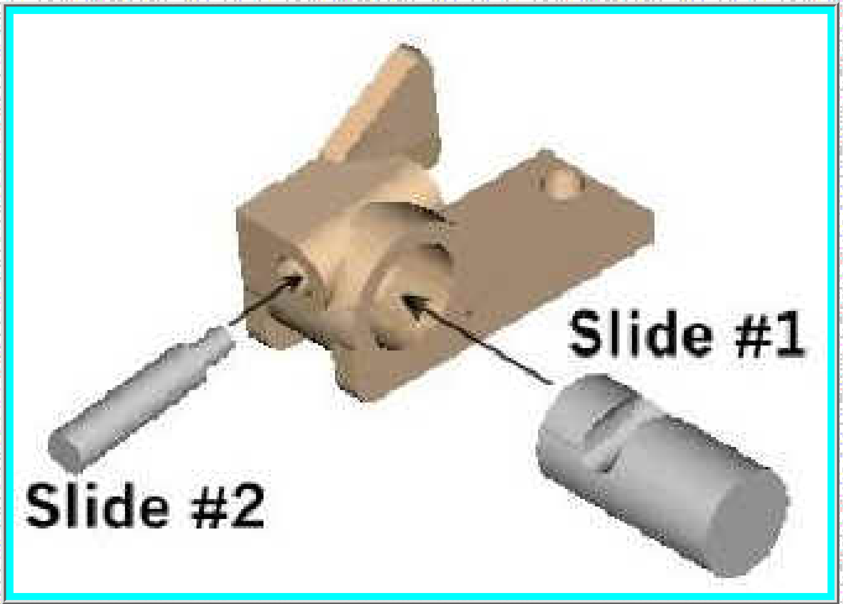

Slide Cores

The upper accelerator casting has two intersecting holes for fitting the actuator and the drive cylinder.

- **The primary cylinder has a 1" ID; the secondary hole has a 3/8" ID. Machined tolerances are +/- 0.003"**.

The best way to form these features is to use TWO intersecting slide cores to form the holes in the casting, followed by finish machining for precise tolerances.

Cores have a distinct cost advantage over the full production run, compared to a two step machining operation for both holes.

Slide cores (with finish machining) are the optimal production method for the intersecting holes.

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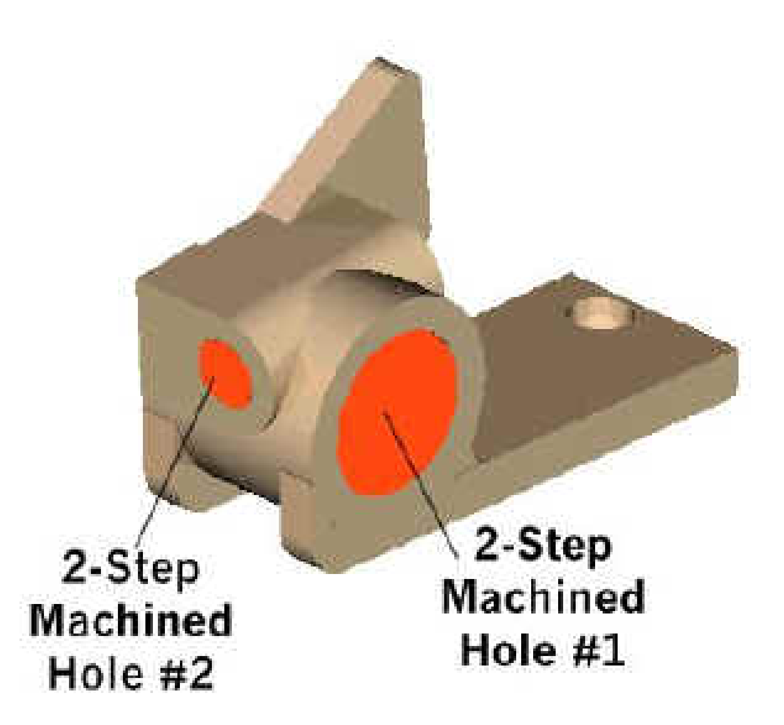

Rough machining is not the optimal production approach for the intersecting holes.

Go back and choose the other method.

Machining

The upper accelerator casting has two intersecting holes for fitting the actuator and the drive cylinder.

- **The primary cylinder has a 1" ID; the secondary hole has a 3/8" ID. Machined tolerances are +/- 0.003".**

A two-step machining process would be required to meet the tolerance and precision requirements.

Rough machining both holes will be cost prohibitive, compared to producing the holes by cores in a net-shape casting.

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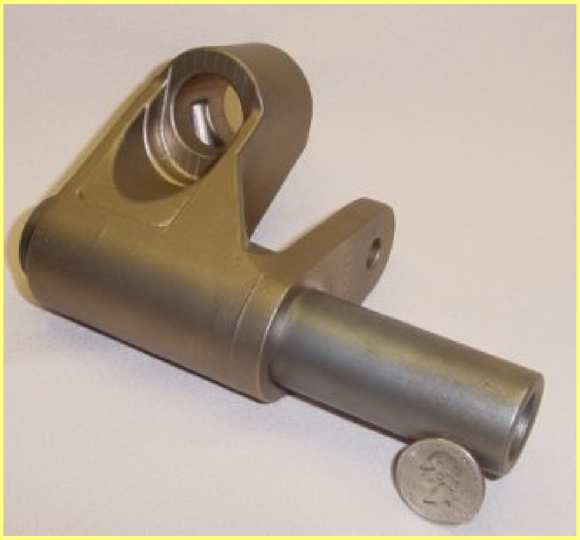
Upper Brake Component

The upper brake component has two functions --

- ***an assembly point for the actuator, the control line and the drive cylinder***
- ***a pivot arm for the pedal action***

The pivot arm uses a hollow steel tube (1.12" OD and 0.75" ID) as a structural feature.

- ***The steel tube must be firmly fixed to the casting to transfer the torque and to prevent slippage.***



Upper Brake Component

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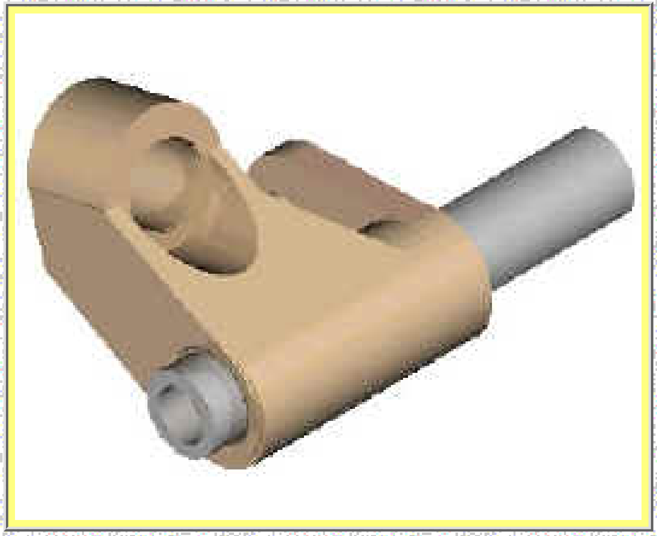
Joining of the Casting and the Steel Tube

Two production methods were considered for joining the steel tube to the casting.



***Approach A* -- Ream the cast hole in the fixture and press-fit the steel tube into the hole in th casting.**

***Approach B* -- Place the tube in the mold and cast the metal directly around the tube for a direct shrink fit.**

Which joining method (Approach A or Approach B) will provide the precision fit and alignment of the steel tube at low cost.

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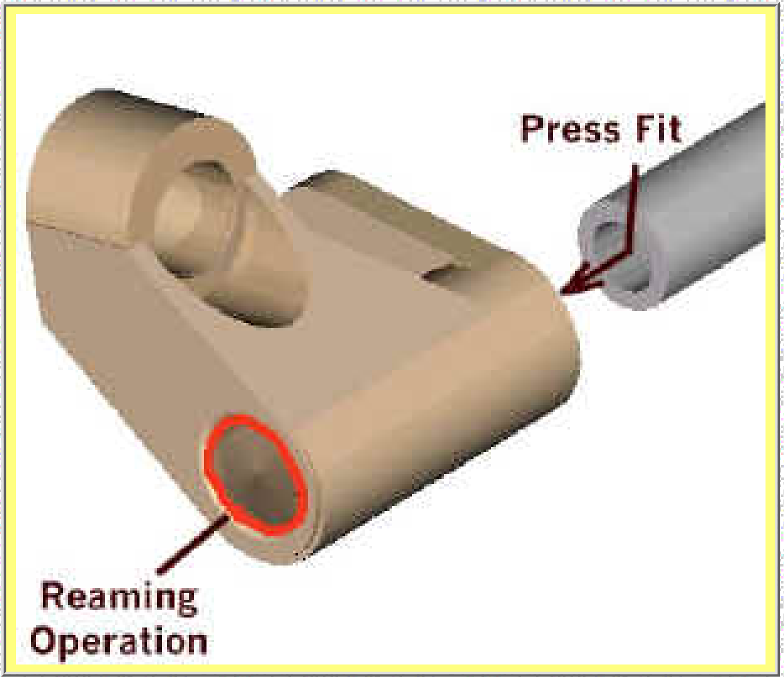
Approach A - Ream and Press Fit



The "ream and press fit" is not a good joining approach.

Go back and choose another design approach

In this approach, both the steel tube and the reamed hole have to be precisely machined for perfect fit.

- Too large a hole and the steel tube will not be secure.
- Too small a hole and the steel tube will not fit in the hole and additional machining will be required.

Dimensional variability, insertion problems, and loose fit are too much of a risk for this joining approach.

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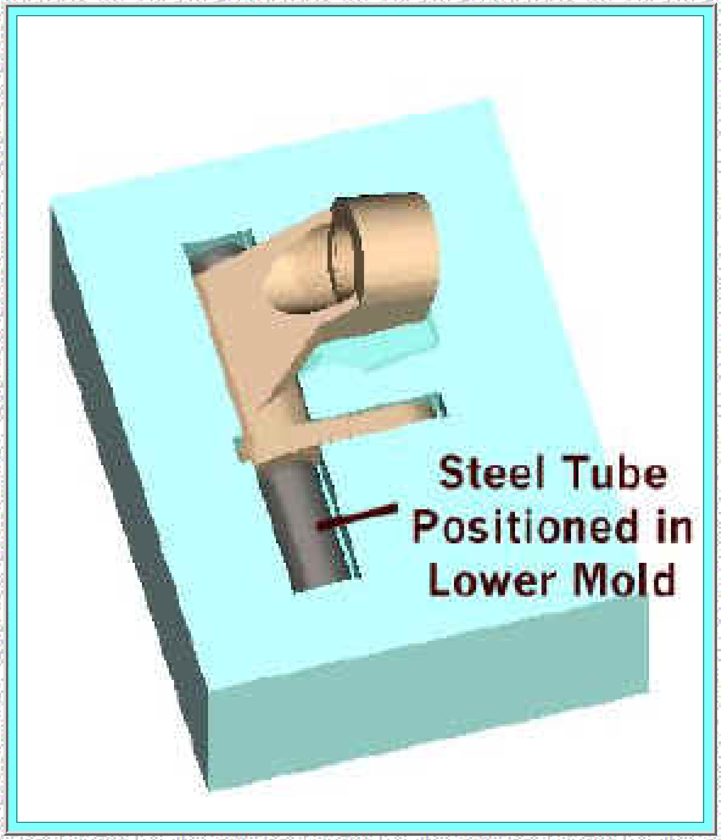
Approach B - "Cast-In" Steel Tube



In this approach, the steel tube is positioned in the mold and the component is cast directly around the tube.

- **The steel tube is carefully cleaned prior to casting.**
- **The tube is precisely positioned in the mold**
- **The solidification shrinkage of the casting provides a strong clamping force between the tube and the casting**

The "Cast-In" approach gives a strong, precise, reliable shrink/mechanical fit between the tube and the casting with no machining or fitting costs.

The "Cast-In" steel tube is a good joining approach.
Go on to the next design issue.

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Quality Assurance

The foundry applies well-defined techniques at each stage of the casting design and production process to assure quality.

- Detailed quality assurance on prototypes, using cyclic impact and wear testing to verify the design.
- Precise casting process control of the alloy chemistry, melt temperature, pouring method, and mold temperature, based on ISO 9000 procedures.
- A comprehensive inspection plan in production, checking critical dimensions and surface finish/ appearance.

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Lessons Learned

Piad Foundry engineers worked in close collaboration with the Teleflex Morse system engineers to develop a component design which met the performance and quality standards and could be cast in a cost-effective, high-yield process.

Key "Lessons Learned" were

- The "chill casting permanent mold" process is a critical technology in producing bronze castings with fine grain structure and high strength.
- The cast-in steel tube produced a finished casting with reduced assembly costs and strong mechanical linkage between the casting and the tube.

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Summary

Operator Pedal System

- Chill mold casting was chosen as the production method for the pedal components, because of near net-shape fabrication, minimal machining, high strength and corrosion resistant alloys, and cost-effectiveness.

Piad Precision Casting worked closely with Teleflex Morse system engineers to develop casting designs that maximize performance, producibility, and cost savings.

For further information on chill mold casting for copper alloys, contact -- Larry Harnish at Piad Precision Castings, Phone-- 800-441-9858 x 314 E-mail -- larryh@piad.com, *Web Site =* *http://www.piad.com*

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