A Design Study in Aluminum Casting

Uplock Support for a Boeing 767

Design Study Outline

Introduction

Design for Performance/ Castability/Manufacturability

- *Aluminum Alloy Selection*
- *Feature Design*
- *Microstructure Control*
- *Machining Allowances*
- *"No Weld" Requirements*

Quality Assurance

Lessons Learned and Summary

Boeing 767

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 Logistics Agency, Attn: DLSC-T, Ft. Belvoir, VA, 22060-6221

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Uplock Support - Application

The uplock support box is a major structural component in the landing gear system for the Boeing 767 long range aircraft.

767 Landing Gear and Engine

Uplock Support

- **An uplock support box is positioned in the wheel well in each wing. The landing gear doors hook and latch into the support boxes when the landing gear is up and the doors are closed for flight.**
- **The support box carries the weight of the closed landing gear door during flight.**

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Uplock Support

Function and Design

Installed Uplock Support

In addition to supporting the closed gear door, the uplock also has two emergency functions--

- **The box has to be strong enough to support the weight of the landing gear, if the gear control system should loose hydraulic pressure and the landing gear releases in the closed wheel well.**
- **If there is a tire burst in the wheel well, the support box has to be robust enough to resist damage and to retain function after side, bending, and bursting loads.**

The mechanical requirements in the high stress areas of the support are:
-- 50 ksi ultimate tensile strength, 40 ksi yield strength, and 5% elongation

In other areas the mechanical requirements are:
-- 45 ksi ultimate tensile strength, 36 ksi yield strength, and 3% elongation.

These strength requirements have to be met while minimizing weight.

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Uplock Support -- Description

The uplock support is designed as a box structure with a right triangular shape.

- **The dimensions are 35" x 26" x 12".**
- **Minimum wall thickness is 0.120".**
- **The box is cast in aluminum with a machined weight of 33.5 pounds.**

The box has numerous holes, flanges, internal and external ribs, lugs, clevises, bosses, and stand-offs for structural, assembly and system routing purposes.

Uplock Support

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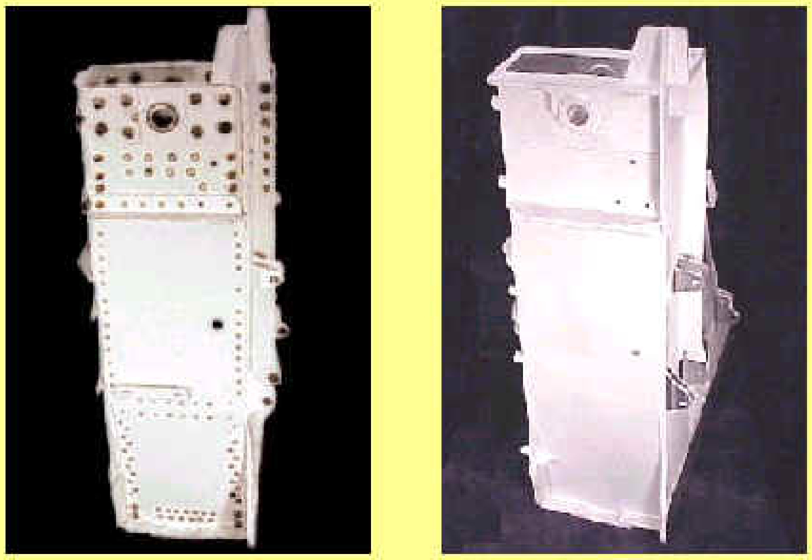
Uplock Support - Conversion



Uplock Fabrication and Uplock Casting

The uplock box was redesigned as a casting after considerable production problems (tolerance stack up and assembly variations) were experienced with the original design -- a bolt/rivet assembly consisting of metal sheet sections and machined forged components.

Hitchcock Industries, Minneapolis, MN was given the design lead for the uplock support, developing a configuration that would maximize structural performance and producibility, while minimizing total manufacturing cost.

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Uplock Support -- Conversion Benefits

The finished casting design for the uplock support had cost and performance benefits for both the aircraft manufacturer and the airline operator.

Uplock Support

Benefits for the Aircraft Manufacturer

50% cost savings based on --

- Part count reduction (35 parts in original fabrication)
- Elimination of 25 shims, 2 assembly jigs, and 29 technical drawings.
- Assembly cost savings with reduced tooling, simplified assembly process, shortened build time, tighter tolerances, fewer assembly errors, and easier fit-up/installation.

Benefits for the Airline Operation

- Reduced acquisition and replacement cost.
- Improved reliability and serviceability with no rivet holes, greater corrosion resistance, easier inspection and maintenance, and simplified repair.

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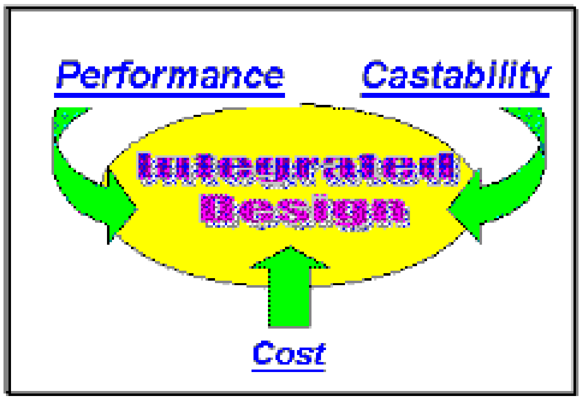
The Casting Design Issues



The Casting Design Approach -- The casting design engineers at Hitchcock Industries chose gravity casting with "no-bake" sand molds and cores. The engineers had three imperatives for an integrated casting design.

-- *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. Five casting design issues played a major role in meeting the three design imperatives

- **Select the *aluminum alloy* to meet the mechanical strength and processing requirements.**
- **Insure that *strength requirements* are met in the critical features.**
- **Plan for *microstructure control* in high stress regions during casting.**
- **Design for *machining stock and tolerances* .**
- **Understand and manage requirements for *"no-weld" regions.***

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Aluminum Alloy Selection

The primary performance requirements for the uplock support to meet the minimum mechanical strength targets in the primary and secondary regions

- **Primary -- 50 ksi ultimate tensile strength, 40 ksi yield strength, and 5% elongation ductility.**
- **Secondary -- 45 ksi ultimate tensile strength, 36 ksi yield strength, and 3% elongation ductility.**

In addition, the aluminum alloy should be have good casting properties and be machinable, weldable, and corrosion resistant.

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Aluminum Alloys

Three aluminum casting alloys were considered for the uplock support --

- **A201 Aluminum alloy** -- ***4.6% copper, 0.7% silver, 0.35% manganese, 0.35% magnesium, and 0.25% titanium***
- **A206 Aluminum alloy** -- ***4.5% copper, 0.30% manganese, 0.25% magnesium, and 0.22% titanium***
- **D357 Aluminum alloy** -- ***7% silicon and 0.6% magnesium.***

Aluminum Alloy		201 T7	206 T7	357 T6
	Requirement			
Ultimate Tensile Strength (ksI)	50 or greater	67	49	50
Tensile Yield Strength (ksI)	40 or greater	60	44	40
Minimum Elongation (%)	5% or greater	4.5%	11%	5%
Castability/Fluidity (1= Excellent, 5 = Poor)	2 or less	4	3	1
Corrosion Resistance (1= Excellent, 5 = Poor)	2 or less	4	4	2
Machinability (1= Excellent, 5 = Poor)	3 or less	4	4	3
Weldability (1= Excellent, 5 = Poor)	1	5	5	1

Which aluminum alloy (201, 206, or 357) best meets the requirements for strength, ductility,castability, corrosion resistance, machinability, and weldability?

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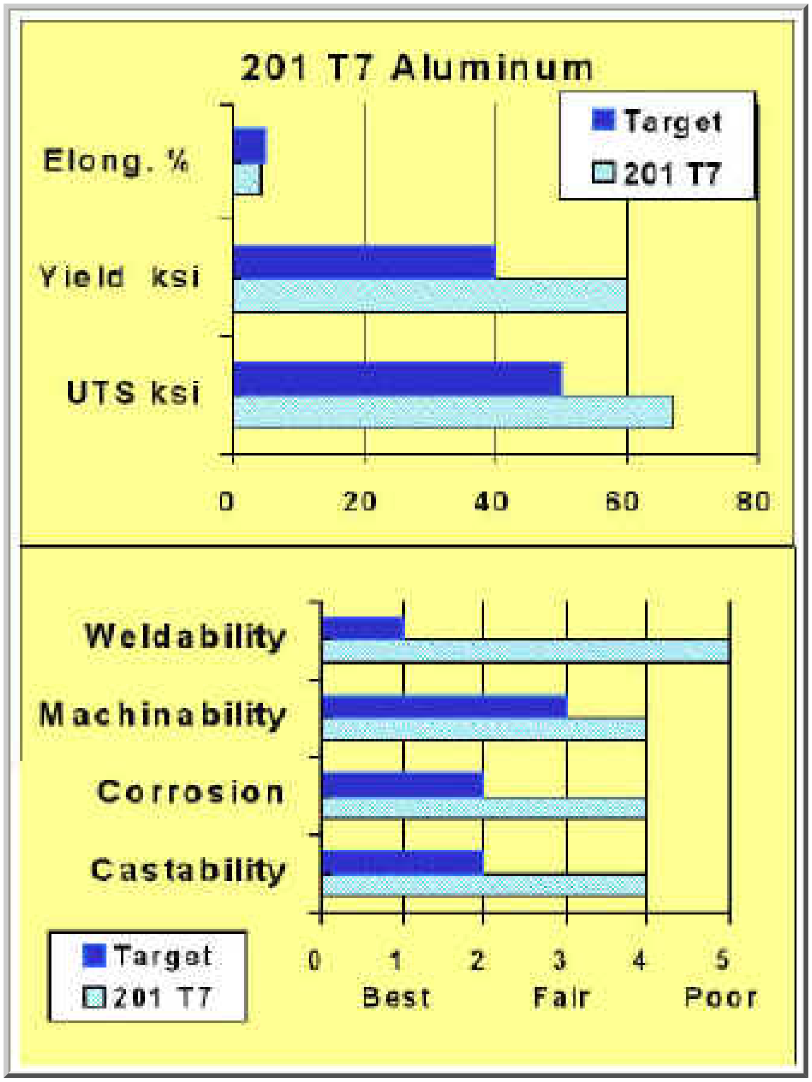

Aluminum Alloy 201

- The aluminum 201 alloy with the T7 temper meets the requirements for ultimate strength (67 vs 50 ksi) and yield strength (60 vs 40ksi), but fails to provide the required elongation (4.5% vs 5%).
- In addition, the alloy has poorer than desirable weldability, machinability, corrosion resistance, and castability.

The 201 alloy is not the best choice.
Go back and select another alloy

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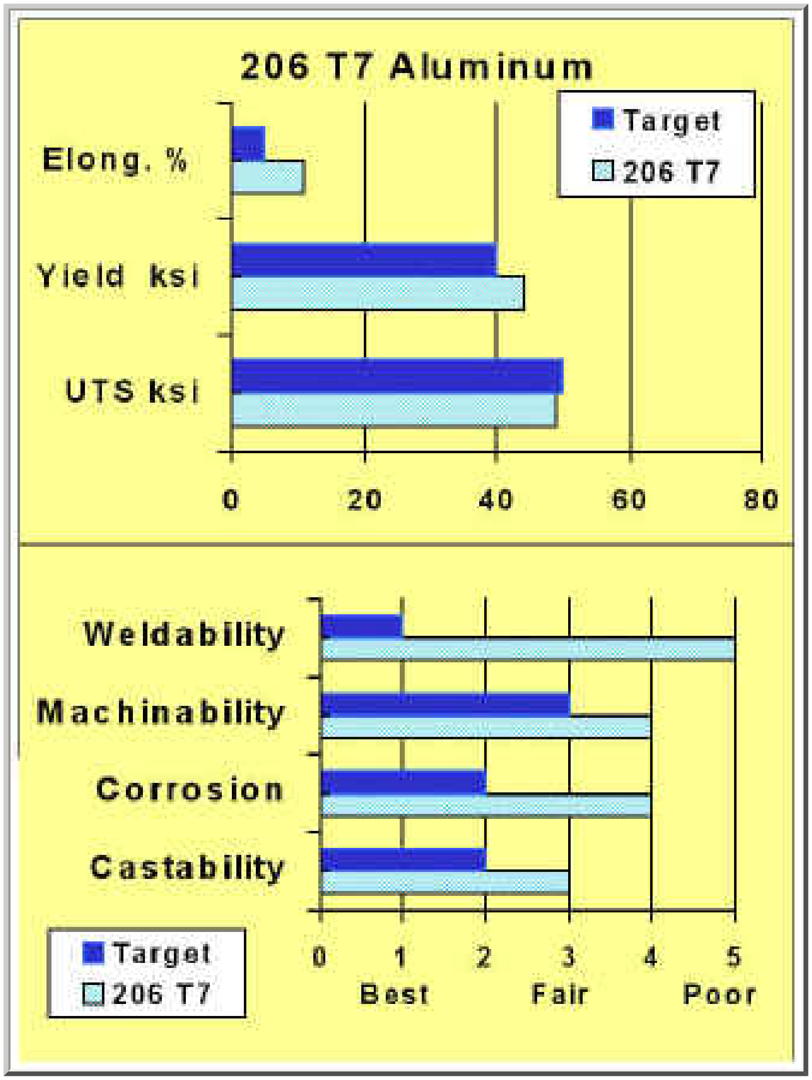

Aluminum Alloy 206

- The aluminum 206 alloy with the T7 temper meets the requirements for yield strength (44 vs 40 ksi) and required elongation (11% vs 5%) , but fails to provide the ultimate tensile strength (49 vs 50 ksi).
- In addition, the alloy has poorer than desirable weldability, machinability, corrosion resistance, and castability.

The 206 alloy is not the best choice.
Go back and select another alloy

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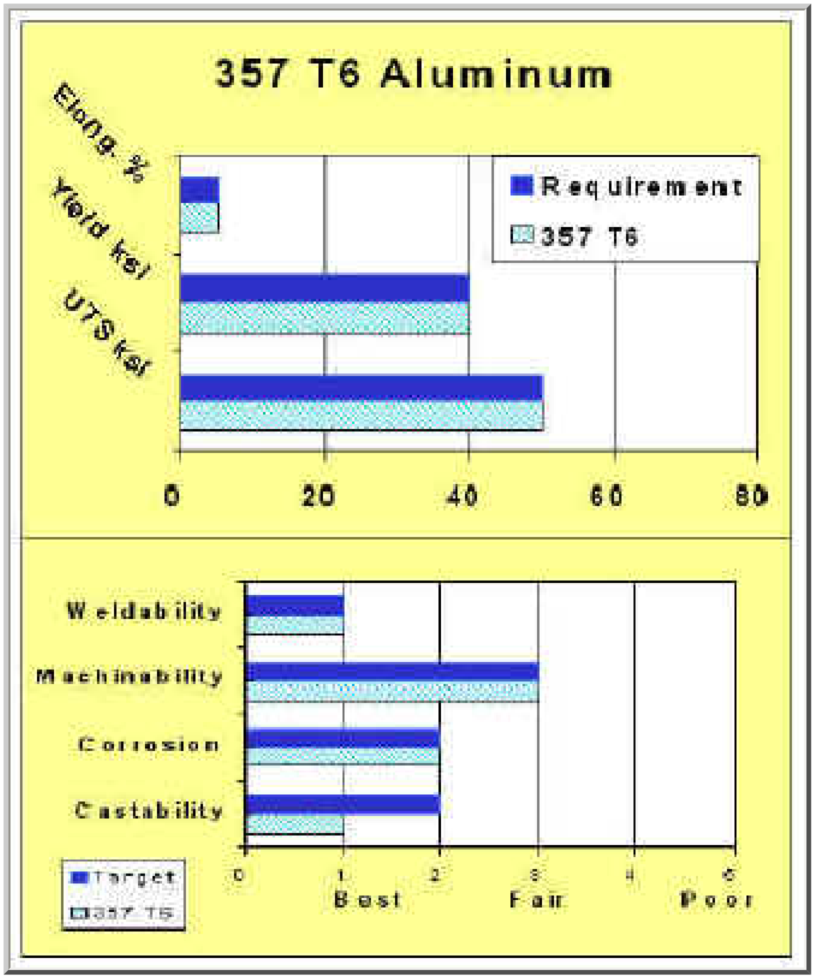

Aluminum Alloy 357

- **The aluminum 357 alloy with the T6 temper meets all the requirements for ultimate strength (50 vs 50 ksi), yield strength (40 vs 40 ksi) and elongation (5% vs 5%).**
- **In addition, the alloy meets the castability, corrosion resistance, machinability, and weldability requirements.**

The 357 alloy is the best choice.
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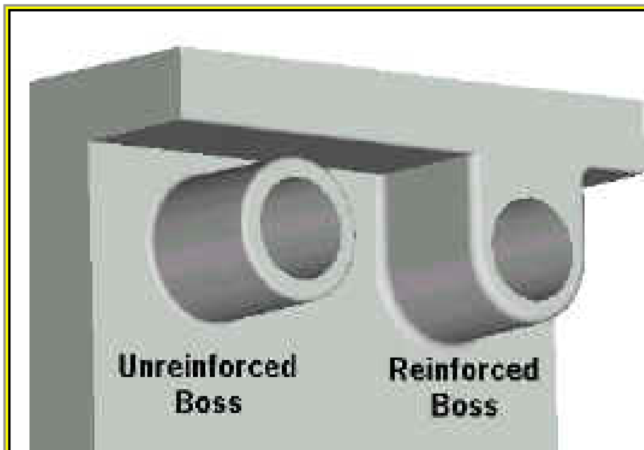
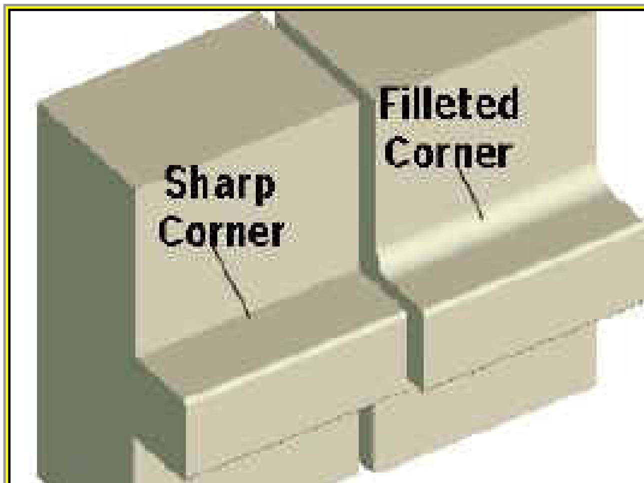
Feature Design for Strength and Stiffness

- The highest stresses in the support box occur at the joining and attachment points, where loads and moments are transferred into and out of the component.
  - The uplock support has numerous flanges, ribs, lugs, bosses, grommets, and stand-offs for strength and assembly purposes.
- One of the benefits of casting is the design flexibility to reinforce section thickness at high stress areas where improved strength and stiffness are desired.
- In addition, the generous fillets designed into and produced in castings reduce/eliminate the stress concentrations found at joints between sections.



Example of Reinforced Boss



Example of Fillet

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Feature Design

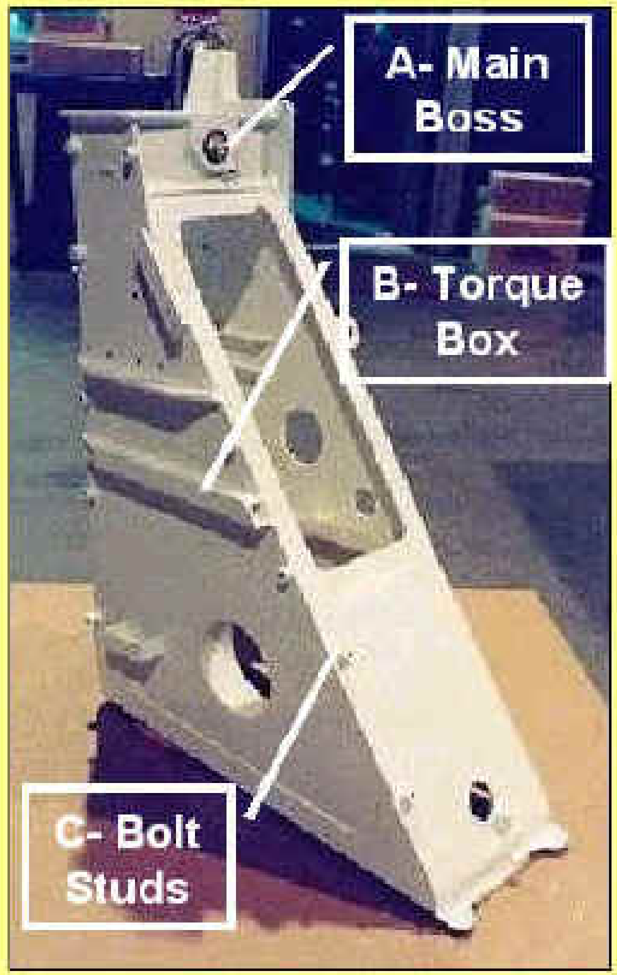
The drawing to the right highlights three features on the uplock which were considered for reinforcement.

Feature A -- Main Boss and Hole for the locking rod bearing.

Feature B -- Horizontal torque box for stiffening the side wall.

Feature C -- Bolt studs on the access wall.

The casting engineer should consider which features are subject to high stresses and do a stress analysis to determine if the feature should be reinforced and filleted to meet the load safety factors.



Choose the Features (A, B, and/or C) which are subject to high loads and should be considered for reinforcement and/or filleting.

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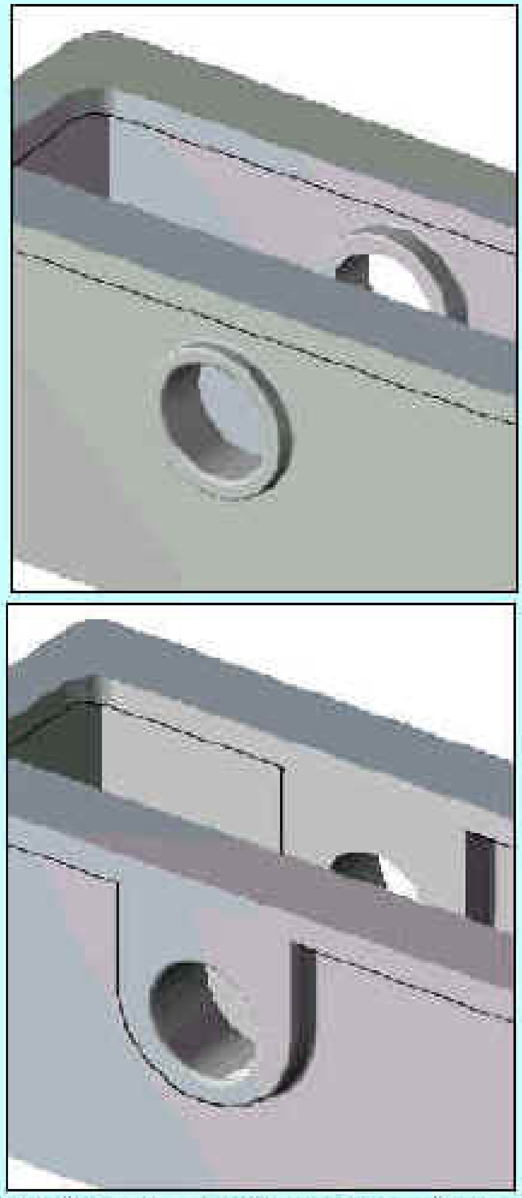

Initial and Final Design of Main Boss and Hole

Feature A - Main Boss and Hole

In Feature A, the main bosses hold the bearings which support the locking rod.

- **The hook on the landing gear door latches onto the locking rod to secure the doors in flight.**
- **The locking rod carries the full load of the doors and the bosses have to be heavy enough to transfer the load into the uplock support.**

The bosses are strengthened with additional material in the depth and width on both sides of the main wall to carry the full load. In the final design the bosses are 1.3 inches in depth with a diameter of 2.0 inches to accommodate the 1.187" diameter bushing hole.

Feature A does need to be changed.

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

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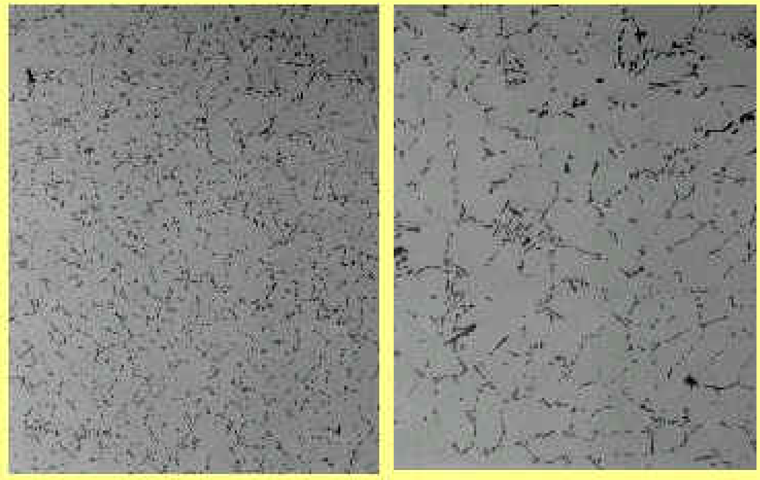
Microstructure Control

The mechanical properties of aluminum are affected by the microstructure (the size, phase,and distribution of the grains) of the alloy.

- **Smaller grain structure produces higher strength than coarse grain structure**
- **Rapid cooling produces small grain structure; slow cooling produces coarser grain structure**



Fine Grain and Coarse Grain Aluminum Microstructures

Chill Block on a Thick Section

The foundry engineer uses chills to produce sound castings by controlling thermal gradients and the initiation, location, and direction of solidification in the casting.

-- A chill is a block of material (sand or metal) which has a high heat capacity and/or thermal conductivity, which accelerates the rate of heat extraction in a critical area.

-- Chills are placed against features that need to cool rapidly for microstructure control, but would tend to stay hot because of their heavier cross section and higher thermal mass.

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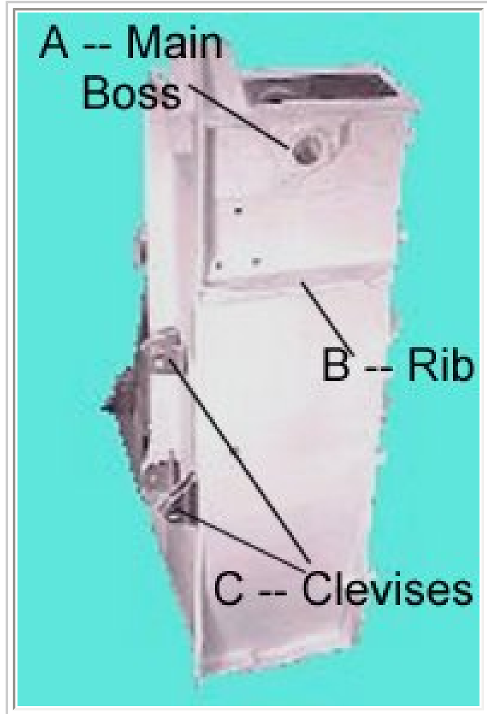
Microstructure Control



The drawing to the right highlights three features on the uplock which have a structural function

- **Feature A -- The main boss and hole for the lock rod.**
- **Feature B -- The horizontal stiffening rib.**
- **Feature C -- The clevises on the side wall.**

The casting engineer should consider which of these features are isolated and have heavier cross-sections where chills should be used in the mold to control solidification.

Choose the Features (*A, B, and/or* C) where chills should be used to control the solidification and the microstructure.

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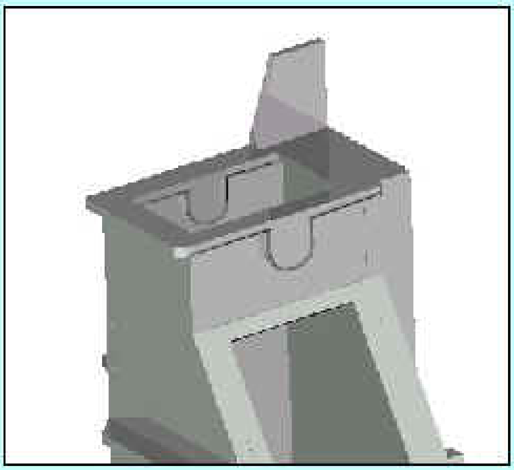
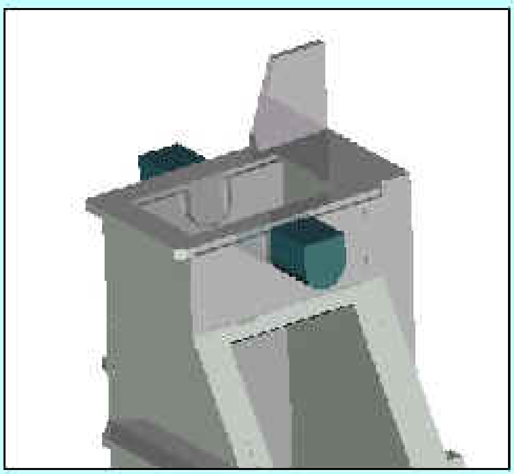
Feature A - Main Bosses and Holes for the Locking Rod



Bosses without Chills



Bosses with Chills

In Feature A, the main bosses hold the bearings which support the locking rod.

This is a section that has a high strength requirement -- 50 ksi ultimate tensile stress and 40 ksi yield stress.

It is important to produce rapid solidification in the boss sections, which are 1.3” inches thick.

Chill blocks are placed in the cores to line up with the main bosses. The chill blocks produce the required rapid heat transfer and controlled solidification and microstructure.

Feature A does need a chill.
Choose another feature or
Go to the next design issue

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Machining Allowances

machined Clevis on Side Wall

Machining Setup for Uplock

- **The uplock support has precise tolerances for form and fit of different features. The machining of the uplock support was extensive --**
  - **Milling of mating and fitting surfaces.**
  - **Boring of holes for bushings.**
  - **Drilling and tapping of screw holes.**
- **One of the key design factors was the addition of machine stock allowances to those surfaces and features which required precision tolerances and final finishing**
- **Tolerance on machine stock should be liberal since it does not affect the finished part. Using +/- 0.060" is a common rule of thumb.**
- **Machined surfaces should have an additional 0.060" allowance for gates and risers.**

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Machining Allowances

The drawing to the right highlights three features on the uplock with different machining and tolerance requirements.

Feature A -- Mating Surface for Cover Plate on Angle Face

Feature B -- Access Hole on Side Wall

Feature C -- Fit-up Surface on Lower Horizontal Edge of Side Wall.

The casting engineer should consider which features need additional machine stock.

Which Feature (A, B, or C) should have added machine stock?

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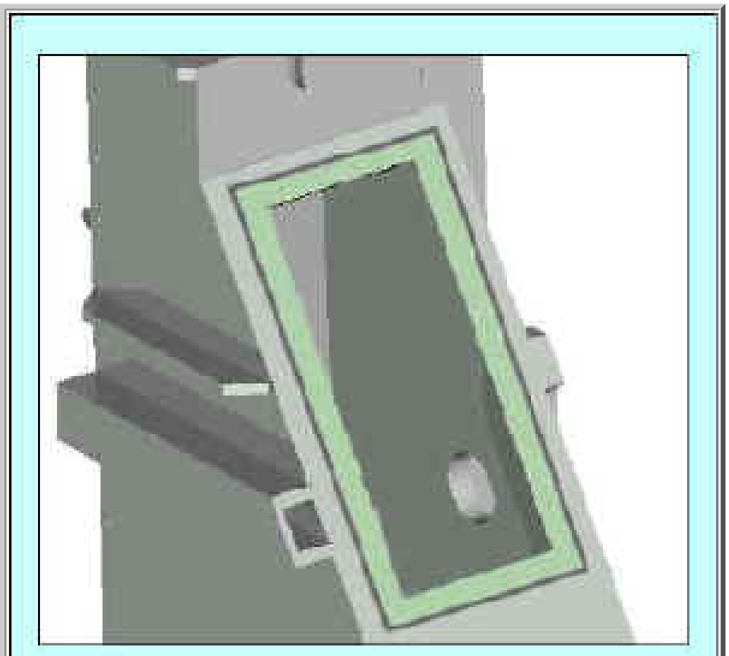
Feature A - Mating Surface for Access Panel



Mating Surface for Access Panel

- In Feature A, the rectangular access hole on the angled face is covered by a flat panel. That cover panel is secured by multiple bolts.

  The mating surface for the cover panel has a flatness requirement of +/- 10 mils.

- That level of tolerance requires machining stock on the mating surface.
- 100 mils of machine stock thickness is added around the perimeter of the access hole

Feature A requires added machine stock

Go on the next design issue

or Choose another feature

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Aluminum Casting

Hitchcock Industries casts the uplock support in D357 aluminum in precision molds formed in no-bake sand.

- **No-bake sand is used for accurate dimensional control and to achieve the required metallurgical structure and properties.**

The mold system uses over 20 cores to form both the internal and external features of the uplock

Uplock in the As-Cast Condition

Gating, risers, and chills are closely engineered to optimize flow and fill into the thin walls of the casting. This produces a casting free of misruns, shrinkage voids, and porosity.

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In Process Welding

It is the intention of every foundry to produce “defect-free” castings. However, even with the closest control of foundry materials and processes, deficiencies sometimes occur, especially with large and/or complex castings.

- ***These deficiencies include cosmetic defects or processing damage.***

Welding on Aluminum

In order to keep part cost down, in-process welding becomes an economical means of rectifying castings with minor discrepancies.

****

It has been demonstrated that in-process welding does not have significant adverse effect on the structural integrity of aluminum castings, as long as the welds are done correctly, properly heat treated, and inspected after welding.

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"No-Weld" Requirements

- **In-process welding, properly done, is a foundry tool that yields a quality casting and saves cost and time.**

It is important that the designation of ***"no-weld" sections*** on castings be very carefully considered. The casting engineer and design engineer should review the component design to insure that "no-weld" regions are specified only when critically necessary for structural performance.

Historical Note --

- **The original casting design of the uplock support called for "no-weld" regions in critical sections. After 2+ years in production, a subsequent requirements review removed all the "no-weld" sections in the casting design.**
- **The result was a casting that continued to meet performance requirements, but was produced with a lower scrap rate.**

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A Design Study in Aluminum Castings -Uplock Support

Quality Assurance

Finished Uplock Support

Acceptance testing of the Uplock Support is a key factor in providing a quality product to Boeing and is supported by comprehensive process documentation.
The uplock support is inspected and tested against the following requirements--

- ***100% fluorescent penetrant inspection after casting.***
- ***Class B x-ray radiography after casting.***
- ***Dimensional checks before and after machining.***
- ***Periodic tensile testing of test sections from the casting.***

The uplock support is supplied ready for installation --

- **Anodized, primed, and painted**
- **Finish machined with installed bushings.**

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Lessons Learned

Hitchcock Industries has produced more than 100 uplock supports for Boeing Aircraft over the last six years. The successful production of the support illustrates that --

Machined Uplock Support

- **No-bake sand casting is a cost-effective method for producing large, complex structural aluminum castings.**
- **Close collaboration and communication between casting and OEM engineers are essential to develop a casting design which meets performance and quality standards at a reasonable cost.**
- **Vertically integrated in-house manufacturing *(patterns >> molds >> casting >> heat treat >> machining)* offers process control benefits, integrated design and lower total manufacturing cost.**
- **"No-weld" regions need to be designated with due diligence, because unnecessary restrictions raise scrap rates and increase production costs.**

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Summary

Uplock Support for the Boeing 767

The Uplock Support for the Boeing 767 airplane was produced by Hitchcock Industries, Inc. in aluminum by precision sand casting with a 50% savings in total manufacturing cost.

For further information on the design and production of this and other aluminum castings, contact --
Jim Meath at HITCHCOCK INDUSTRIES, INC.,
Phone-- 952-887-7800, FAX -- 952-887-7858
E-mail -- meathj@hitchcockusa.com Web Site = http://www.hitchcock-ind.com/

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 Logistics Agency, Attn: DLSC-T, Ft. Belvoir, VA 22060-6221

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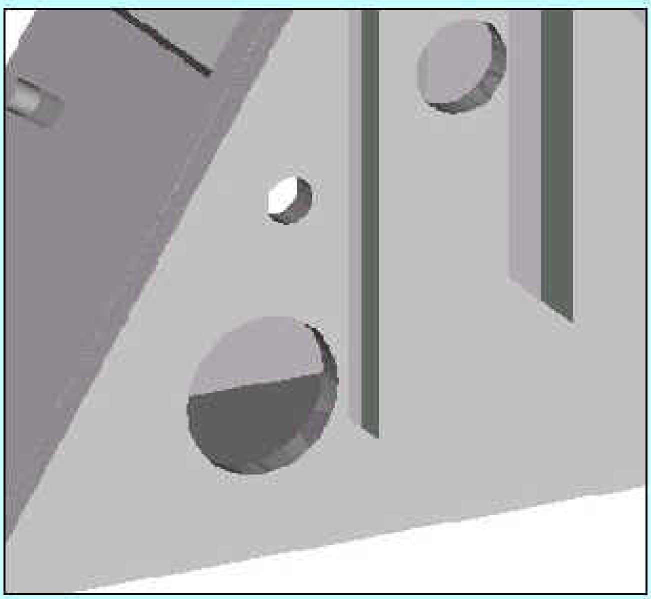
Feature B - Access Hole on the Side Wall



Access Hole on Side Panel

In Feature B, the access hole on the side wall is used for cable routing.

- It is not a precision feature. The location tolerance is +/- 60 mils, which is within the as-cast tolerances.

No additional stock is needed around the hole, because no machining is required.

Feature B does not require added machine stock

Go on the next design issue or

Go back and choose another feature

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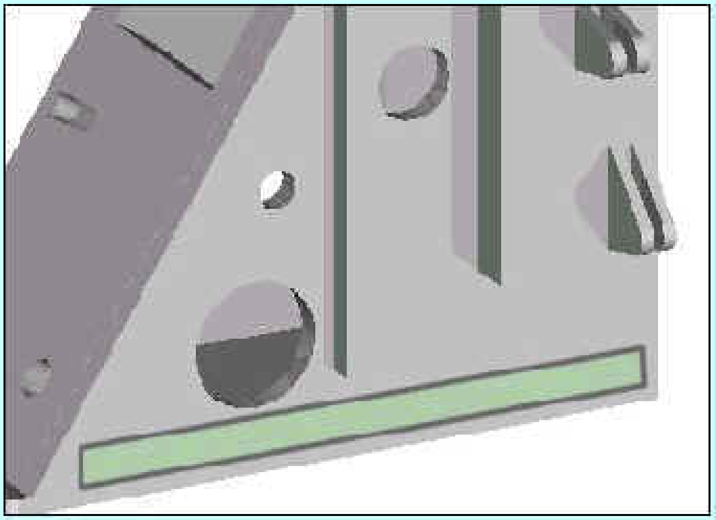
Feature C - Fit-Up Surface on the Side Wall



Fit-Up Surface on Side Wall

- **In Feature C, there is a 2.75" wide flat on the long horizontal edge of the side wall. This edge is a fit-up surface that has a flatness requirement of +/- 10 mils.**
- **The fit-up surface is milled to the desired tolerance and requires machine stock.**
- **100 mils of machine stock are added to the thickness of the fit-up surface**

Feature C requires added machine stock

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Feature B - Horizontal Stiffening Rib

In Feature B, the horizontal stiffening rib increases the section modulus of the wall section, but is not directly loaded.

- **The strength requirement in the wall section is 50 ksi ultimate tensile strength and 36 ksi yield strength.**

The rib cross section 1.5 inches high and 0.25 inches thick. The thermal mass is low enough and the strength requirement of 45 ksi UTS do not require a chill block.

Feature B does not need a chill.
Choose another feature or
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A Design Study in Aluminum Castings -Uplock Support

Feature C - Clevises on the Side Wall

In Feature C, the clevises on the side walls hold the bearings which support attachment rods.

- **The clevises have a high strength requirement -- 60 ksi ultimate tensile stress and 40 ksi yield stress.**

It is important to produce rapid solidification in the clevis sections, which are 0.25 inches thick.

Chill blocks are placed in the cores to line up with the clevises. The chill blocks produce the required rapid heat transfer and controlled solidification and microstructure.

Feature C does need a chill.
Choose another feature or
Go on the next design issue

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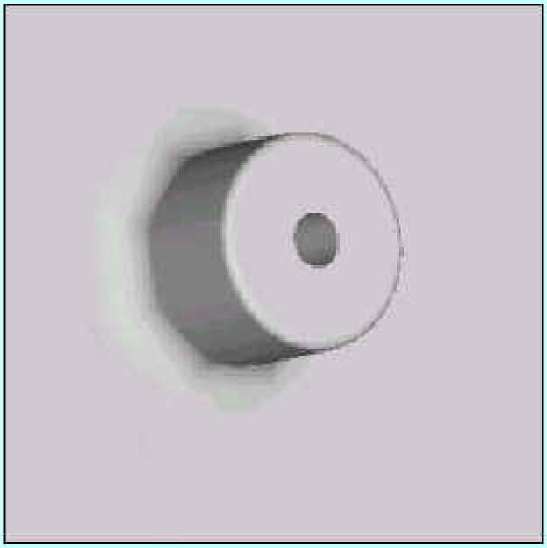
Feature C - Bolt Studs



Initial Stud Design

In Feature C, the bolt studs are attachment points on the diagonal face of the uplock. Bolt holes in the studs are drilled and tapped.

The bolt studs have a diameter of 0.60 inches and a depth of 0.50 inches. They do not carry major loads and are not highly stressed.

The diameter of the bolts studs is sufficient to carry the loads and the design fillet radius of 3/16 inch is appropriate.

Feature C does not need to be changed.

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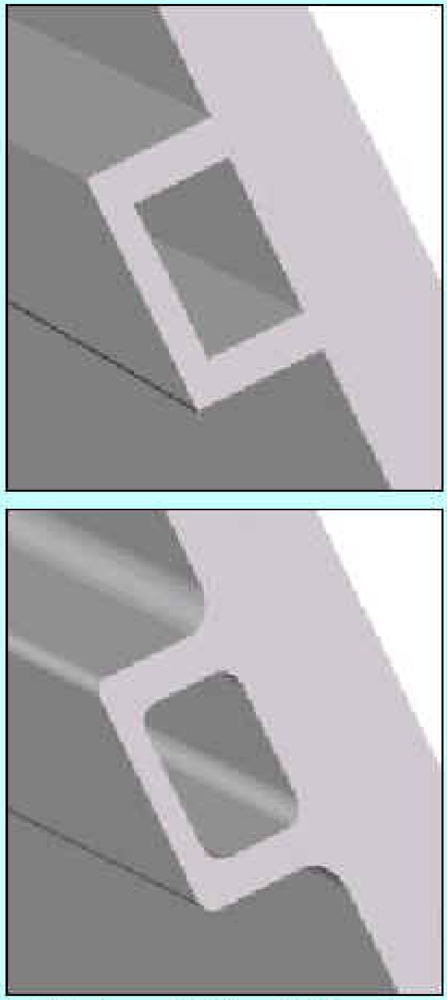

Initial and Final Design of Torque Box

Feature B - Horizontal Torque Box

In Feature B, the horizontal torque box is a stiffener on the sidewall of the uplock support.

- **The box has a wall thickness of 0.120 inches joining into the side wall with a thickness of 0.160 inches.**

Stress concentrations at the joint are reduced by providing a generous fillet on the wall-box joint and the interior corners of the torque box.

Feature B does need to be changed.
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