# Superplastic Forming – Cost Effective?

Bill Swale, Aeromet International plc, Watchmead, Welwyn Garden City Hertfordshire. UK. Bill.Swale@aeromet.co.uk

Mauro Pizzingrilli, Aeromet International plc, Watchmead, Welwyn Garden City Hertfordshire. UK. Mauro.Pizzingrilli@aeromet.co.uk

Eddie McCullagh, Aeromet International plc, Watchmead, Welwyn Garden City Hertfordshire. UK. Eddie.McCullagh@aeromet.co.uk

**Keywords**: Superplastic Forming, Titanium, Hot Forming, Cost Effective.

**Abstract**. When Superplastic Forming (SPF) was offered as a production process in the mid 70's it became the panacea of all processes for sheet metal products designed to be made from Titanium and Aluminium materials. The claims were (1) Reduced part count (2) Reduced assembly time (3) Weight reduction (4) Monolithic parts and (5) Stronger structures.

Following Pearson's work in the mid 30's with Lead-Tin and Bismuth-Tin alloys [1], showing higher than 1000% elongation without failure, the Aluminium industry developed SPF alloys and launched into numerous commercial applications. Other research facilities focused on the potential of achieving superplasticity in Titanium alloys. This was demonstrated in the late 60's using the now well established Ti 6 Aluminium 4 Vanadium alloy. Considerable funding was allocated, both in the USA & UK specifically for the development of the process. The USA focused on the Military Programmes and the UK on the Civil Aircraft (Concorde) and some Military Aircraft. Success in these programmes and the claims made, resulted with a production process. Companies invested in suitable plant and equipment and designers grasped the process potential and applied SPF to their sheet metal designs expecting to reap the claimed benefits.

The claims are valid if applied to correctly chosen components. All too often the SPF manufacturing choice did not deliver its claims. In many cases cost of material, need to chemical mill and higher energy costs were either not envisaged or taken into account.

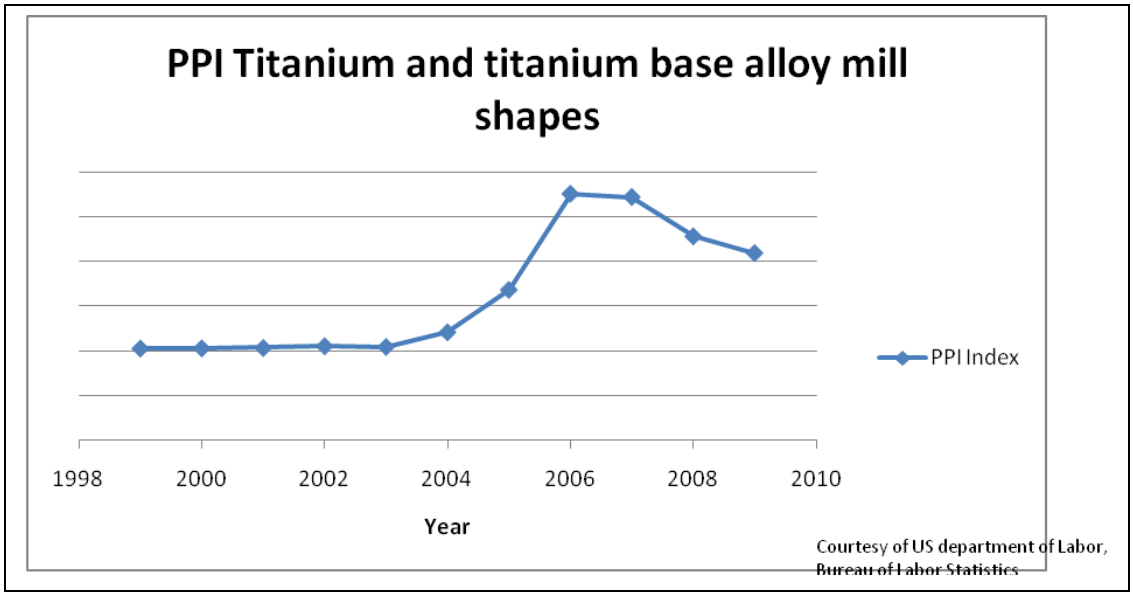
Today all processes, material cost and alternative material types have to be assessed before the manufacturing method is chosen. The aerospace industry is attacking the Buy-Fly ratio. Energy and labour cost are at a premium and these have caused the SPF and Hot Forming community to examine ways of producing products (a) from less material (b) by Hot Forming (eliminating the need to apply chemical milling to remove the Alpha Case) (c) questioning the material choice (CP instead of Ti6/4) and (d) by applying modern fabrication methods.

The paper will illustrate this change in philosophy; shows today's choices and demonstrate how the SPF process can be cost effective and in fact still does have a major role to play in producing Airframe and Engine Structures.

## Introduction

Aeromet has been producing Superplastically Formed (SPF) Titanium components since 1978. It now utilises 70 – 80 tons of titanium sheet metal on an annualised basis to produce a wide range of aerospace products delivered to a global customer base. It has fifteen Hot Platen Presses in a range of sizes up to 157" long by 78" wide, ten of which are geared for the SPF process. Typical SPF press price is ~$1.5m. To complement the SPF process, Aeromet has Chemical Milling tanks to remove the alpha case (a brittle oxygen rice layer). This level of equipment has grown over the last 20 year period, to match the market demand for titanium aerospace products, whilst at the same time meeting the constant customer challenge to reduce product costs whilst at the same time achieving the Aeromet operating profit margin.

The major portion of the product cost is the price of the raw sheet material. Whilst the SPF process, trimming and finishing operations can be optimised, little can be done to reduce the material prices. The following PPI chart (Producer Price Index) illustrates the marked increase in material price from what was a stable period in the pre 2003 period.




In view of this, Aeromet began the process of developing alternative methods to convert parts formed by the SPF process to being formed by the Hot Forming process, a lower cost alternative.

## The Superplastic Forming Process

**SPF Process principles:** The SPF process is reliant upon a stable, duplex, fine grain material, which can be elongated to strain levels up to and above 300% without localised necking. The titanium alloy Ti 6Al 4V material exhibits this property at or around 1650°F and along with its other attributes of high strength and corrosion resistance makes it an ideal alloy for Aerospace use. The typical, well-known, arrangement for SPF is shown in Fig. 1 for reference purposes.

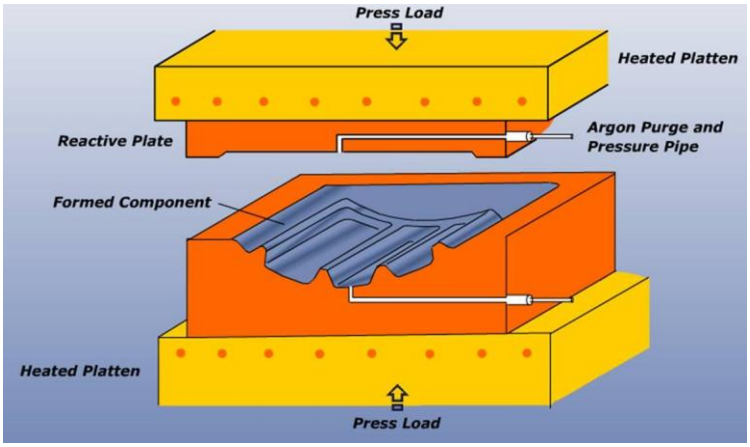



Fig. 1 Superplastic Forming Arrangement

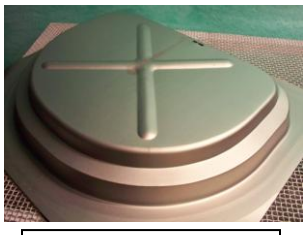
To form a shape, the blank is placed between the forming tool and reactive plate, with time allowed to achieve the forming temperature. The press is then fully closed and an adequate reactive load is applied to form a gas tight seal around the tool's periphery. Injecting argon gas, between the component blank and the reactive plate, as dictated by a calculated strain rate sensitive pressure/time cycle, forms the component. At the end of the cycle the gas is released and the component removed and allowed to cool.

During the process, despite forming with Argon gas to minimise oxidation, an oxide layer forms on the material surface, commonly called 'Alpha Case'. To remove this layer and render the material 'fit for purpose', grit blasting followed by Chemical milling is used to remove ~0.003" per surface. Care must be taken not to induce any hydrogen absorption during the Chemical Milling operation.

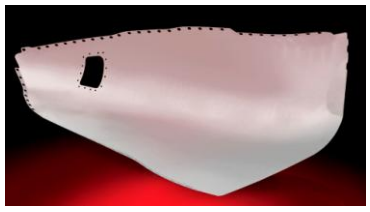
**Advantages of the SPF Process:** Complex monolithic structures can be produced as single or multi items in one tool at one forming cycle. This reduces component part count, spreads press set up costs, removes the need for assembly rivets and hence reduces weight and cost. The following pictures, in Fig. 2, show examples of ideal cost effective, medium sized SPF products.

Fig. 2


36" x 30" x 0.060" thick


38" x 32" x 0.040" thick


26" dia x 0.060" thick


50" x 36" x 0.048" thick


20" dia x 0.080" thick


30" x 20" x 0.80" thick

**Disadvantages of the SPF Process:** Whilst products are repeatable, product thickness is not consistent, deeper regions of the pressing and sharp features will be thinner than surrounding areas. All products require the removal of the 'Alpha Case' which necessitates a chemical milling plant and strict environmental controls. Excess material (circa 2" wide boundary around the component) is required to provide an adequate seal bead region. Tools are normally produced from low creep, oxidation resistant NiCr Steel, cast, machined and polished and can cost up to $200,000 each. High energy use typically 250 – 450kva per press.

## The Hot Forming Process

**Hot Forming Process principles:** The Hot Forming process can be applied to almost any grade of titanium, the most common, in use for the Aerospace Industry, are Ti6% Al 4%V and the various grades of Commercially Pure titanium. The titanium blanks are normally formed between matching press tools, see Fig. 3, and depending on the grades, at temperatures between 1200°F to 1380°F at which point the material is slowly creep formed by bringing the tooling together in a single or multi action pressing operation.

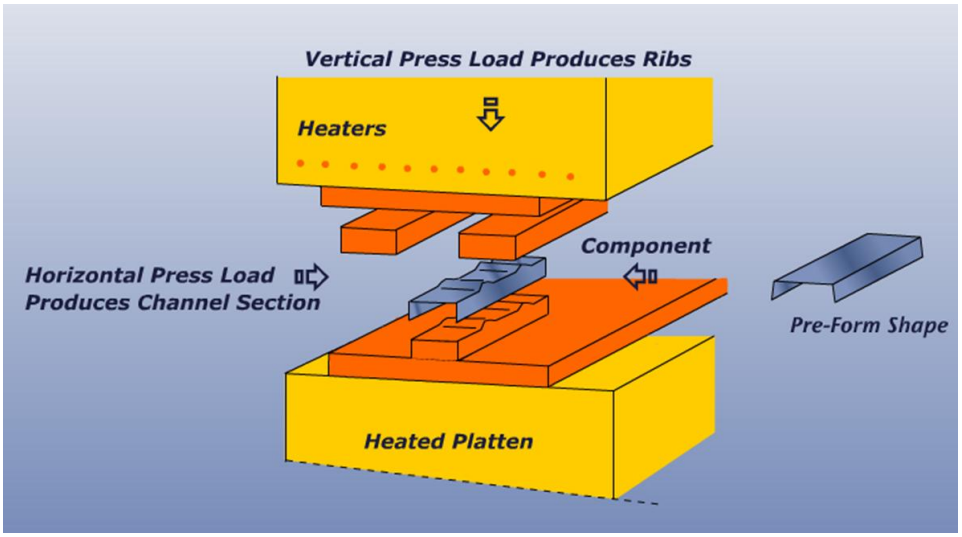



Fig. 3

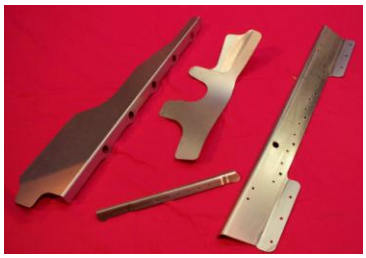
Hot Forming Arrangement.

Inert lubricants are used to prevent galling and scratching. At these low temperatures little or no alpha case is produced and following forming, standard descale and pickle operations are employed to removing less than 0.001" per surface, rendering the material 'fit for purpose'.

**Advantages of the Hot Forming Process:** Low temperature forming, hence reduced energy costs. Basically zero 'Alpha Case' therefore no requirement for a Chemical milling plant. Material blank sizes can be net size to plus 0.25" of the finished edge position and there is no requirement for a seal bead band. Uniform thickness control over the whole surface can be achieved and because there is no requirement for 'Alpha Case' removal a thinner starting stock can be employed than for the SPF process. The following pictures show some of the Hot Forming capability Fig. 4.

Fig. 4

Skin 36” x 40” Ring 20” dia



Struts up to 96” long

Skin 38” long, Strut 48”long, Ring 12”

Bets 21S Skin 36” long 0.080” thick

Various shapes 24” long

Angular struts 24 – 48” long

**Disadvantages of the Hot Forming Process:** Limited complexity, limited depth of draw and may have to perform a performing operation. Tooling prices are similar to the SPF tool prices.

**Process Selection**

It is clear that the SPF process can produce very complex structures but the temptation to apply it to every conceived structure should be questioned and evaluated. Comparisons of the SPF and Hot Forming operation sequences illustrate where process savings are made Fig. 5.

| Comparison of Operations | | |
|---|---|---|
| **Superplastic Forming at 1650 F** | **Hot Forming at 1400 F** | Net Size Hot Forming at 1400 F |
| Cut Blank | Cut Blank | Cut Blank |
| Superplastic Form | Hot Forming | Hot Forming |
| Grit Blast | Descale & Pickle | Descale & Pickle |
| Chemical Milling | | |
| Alpha Case Test | Tests one in ten | Tests one in ten |
| Tensile Test | | |
| Bend Test | | |
| Laser Trim | Laser Trim | |
| Finals | Finals | Finals |

Fig. 5

With the emphasis on costs, economic use of material (to obtain optimum 'Fly to Buy' ratio) and environmental obligations, an analysis must be made to ensure the process selection meets the need. All too often in the past the SPF process has been applied, believing it to be the only way to make the product and partly because it was considered to be a novel process. The following section will illustrate complex products which were previously SPF formed that have now been successfully converted to Hot Forming, Fig. 6a, 6b, 6c. In making the change significant cost reductions have been achieved through material and process savings.

**Examples of products converted to Hot Forming plus percentage savings achieved through reductions in process time and material volume employed.**

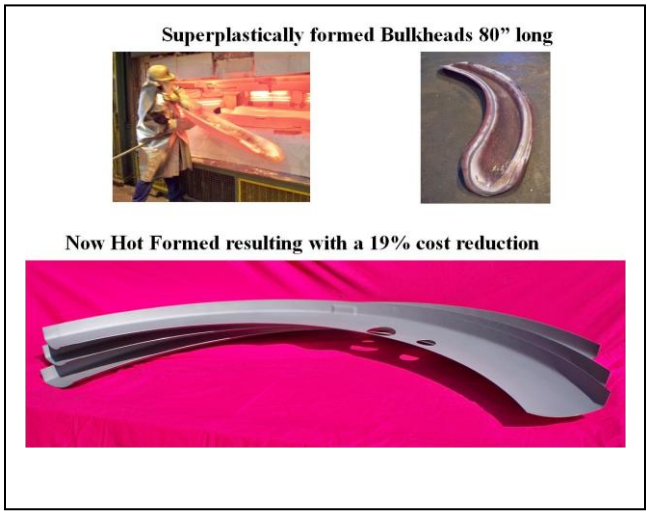



Fig 6a


Fig 6b

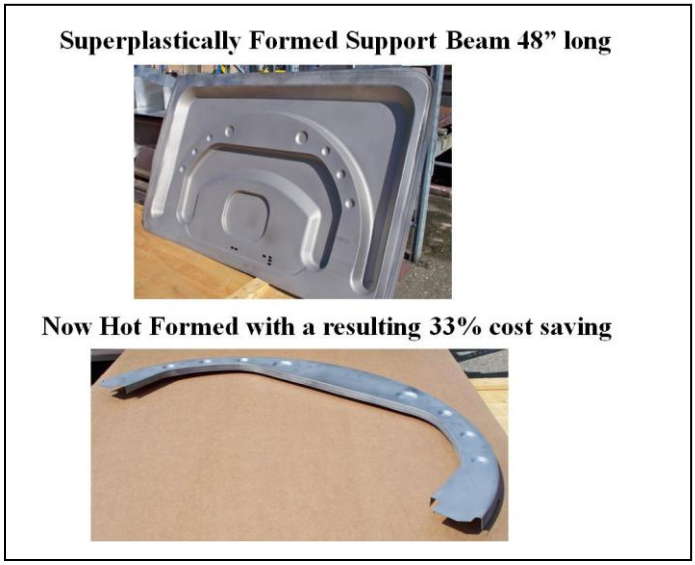



Fig 6c

Example of a product currently Superplastically Formed, which if converted to a Fabrication would show savings of 24%. See Fig 7

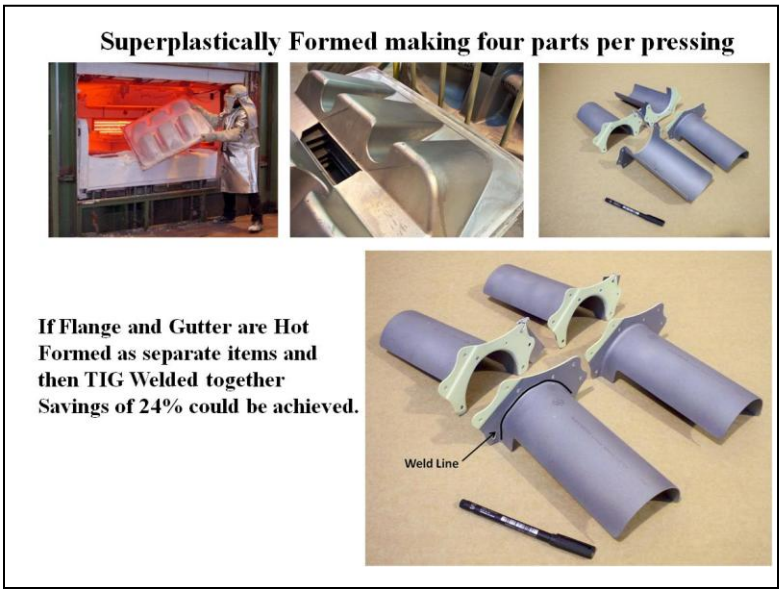



Fig 7

## Conclusion

1) The SPF process is still a key process for the Aerospace industry and there are many products that benefit from its use and without which the products could not be made.

2) Deep pressings, Monolithic parts, where were it not for SPF, several individual brackets, frames, angles and plain sheets would be required to create the same product plus assembly time. Figure 8 shows examples of unique SPF parts

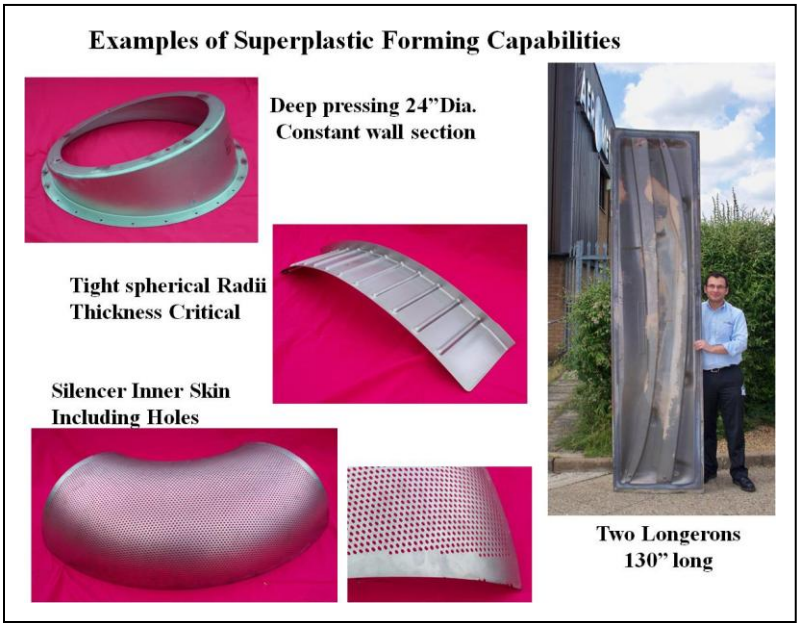



Fig 8

3) Selection of the process is the key and in some cases a change in material can be made where an SPF capable alloy is not required for the products duty.

4) Hot Forming can show remarkable cost reductions but propriety process know-how is essential to make the changes.

5) The key to 'cost effective' and 'fit for purpose' product manufacture is close collaboration between the design engineer and product producer where both can share their requirements and collectively achieve the best solution.

**References**

[1] C.E. Pearson, "The Viscous Properties of Extruded Eutectic Alloys of Lead-Tin and Bismuth-Tin", J. Inst. Metals, 54, 1934, 111-124.

[2] PPI information, U.S. Department of Labor, Bureau of Labor Statistics, Series Id: PCU3314913314913 www.bls.gov

# Ti 2009

# Aeromet International plc

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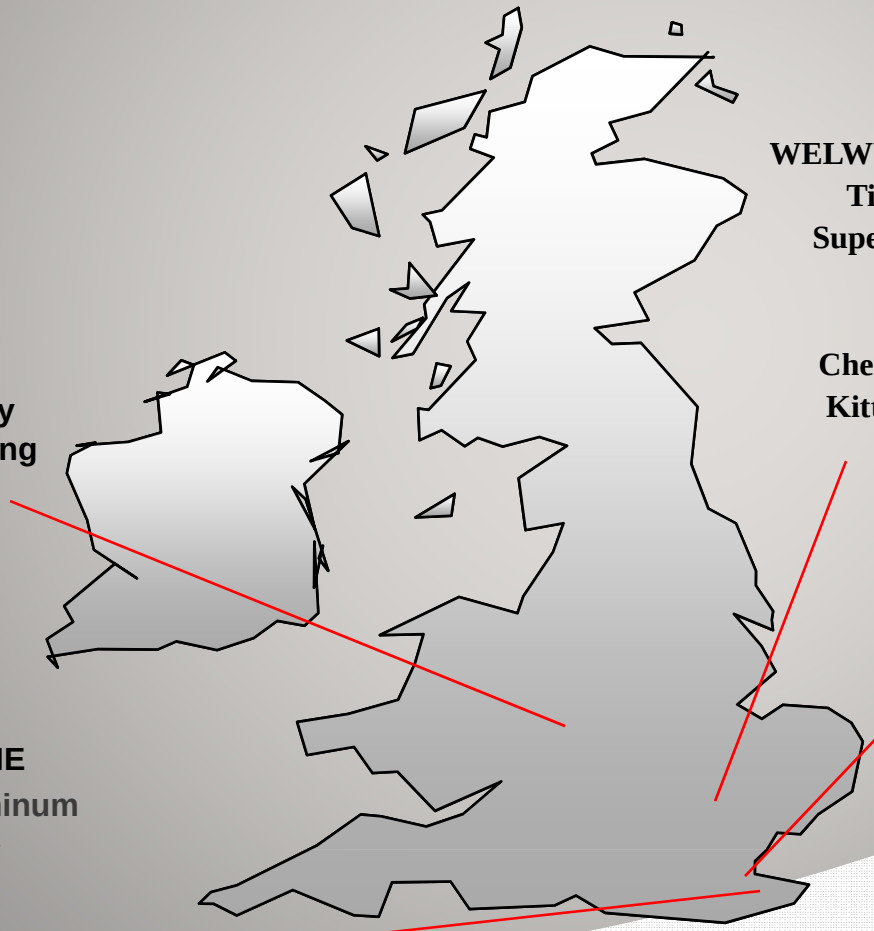
Bill Swale
Ed McCullagh
Mauro Pizzingrilli

# Aeromet International Plc UK sites



**WELWYN GARDEN CITY**
Titanium Hot &
Superplastic Forming
CATIA
Tool Design
Chemical Machining
Kitting & Assembly

**WORCESTER**
Aluminum
Investment Foundry
Solidification Modeling
CATIA
Tool Design
Sophia Process
Heat Treatment

**ROCHESTER**
Aluminum
Investment Foundry
Solidification Modeling
X-Ray
Heat Treatment
Machining, Kitting

**SITTINGBOURNE**
Magnesium & Aluminum
Sand Foundry
X-Ray
Heat Treatment
Machining

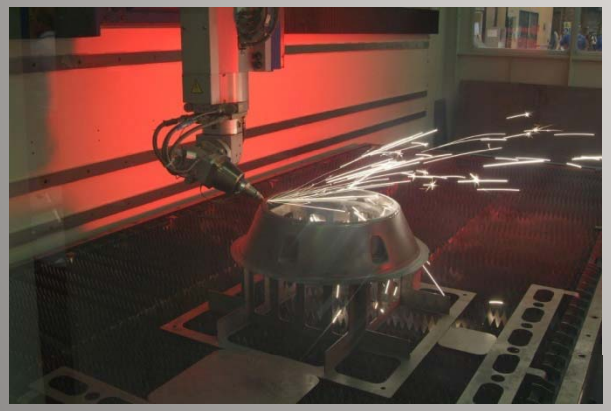
# Aeromet overview

| | | |
|---|---|---|
| ANNUAL SALES US $ | - | $50 million. |
| NUMBER OF EMPLOYEES | - | 425 |
| EMPLOYEE BREAKDOWN | - | 347 Direct, |
| | - | 11 Management |
| | - | 44 Engineering |
| | - | 30 Quality |
| | - | 18 production Control. |
| TOTAL SITE SIZE | - | 268,000 Sq. Ft. Factory Floor 244,000 Sq. Ft. |
| PERFORMANCE | - | On Time Delivery 95% Acceptance 99% |
| Titanium | - | 70-80 Tonnes per year sheet, plate, 70,000 parts |

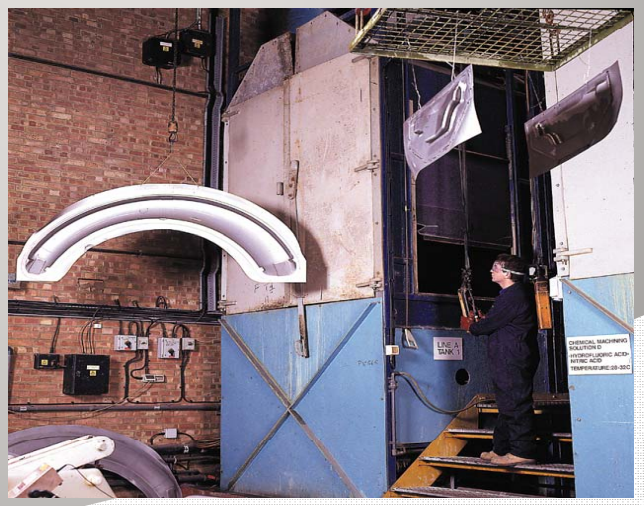
# Forming Division


**Aeromet Forming Division, established in 1985 produces Airframe and Engine Components from Titanium Sheet and Plate by Superplastic Forming, Hot Forming, Chemical Milling and & Laser Trimming**

**Superplastic Forming Press**



**5 Axis Laser Trimming**



**Chemical Milling Plant**

# Forming Division

## Core Processes

- Superplastic Forming
- Hot Forming
- Diffusion Bonding
- 5 Axis Laser Cutting
- Chemical milling.
- Stretch Forming & detail fabrication.
- Machining.
- Assembly and testing.
- Logistic and kitting supply.
- CATIA.
- Concurrent Engineering

# Titanium Materials Formed & Fabricated

- Ti 6Al 4V
- Ti CP1
- Ti CP3
- Beta 21S
- Ti 6242
- Ti 6Al 4V Fine Grain
- Ti 15-3-3-3
- Ti 3Al 2.5V
- SP 700
- Ti5553

# Approvals

**Certified to ISO 9001:2000, AS9100 RevA:2001**

**NADCAP - NDT, Materials Testing, Chemical Milling, Heat Treatment and Welding.**

**Environmental controls. ISO 14000-1**

**Customer Approvals include:-**

- **Airbus**
- **Aermacchi**
- **Alenia**
- **BAE SYSTEMS**
- **Boeing**
- **Bombardier**
- **GKN**
- **Korean Air**
- **Rolls Royce**
- **Spirit AeroSystems**

# Plant & Equipment - SPF Presses

| Make | Tonnage (tons) | Capacity (Inches) | Max Temp (ºF) |
|---|---|---|---|
| • BAILEY | 1500 | 90 x 83 x 51 | 1680 |
| • FIELDING | 1000 | 96 x 75 x 45 | 1680 |
| • REDMAN PRESS | 550 | 157 x 37 x 41 | 1680 |
| • ELDAIR | 623 | 95 x 55 x 27 | 1680 |
| • BERRY | 500 | 60 x 63 x 25 | 1680 |
| • WELDALL | 600 | 87 x 48 x 31 | 1680 |
| • MILLS | 100 | 41 x 31 x 24 | 1680 |
| • BERRY | 150 | 35 x 43 x 33 | 1680 |
| • BIPEL | 100 | 39 x 35 x 24 | 1680 |
| • No2 Fielding | 500 | 48 x 79 x 29 | 1680 |

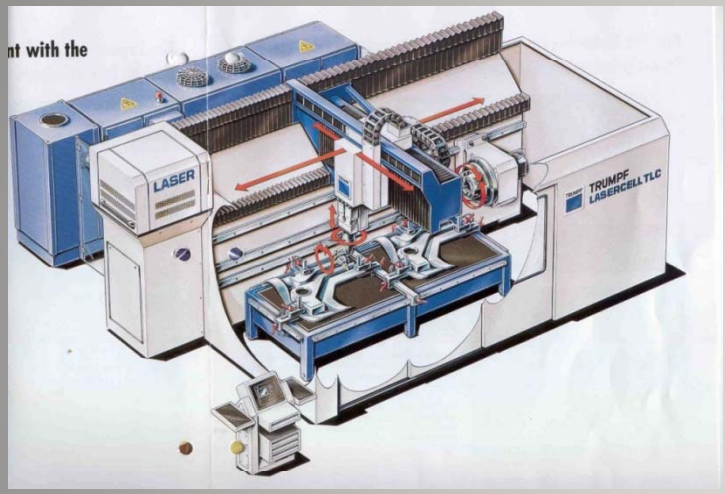
# Forming Division

## Chemical Milling Equipment

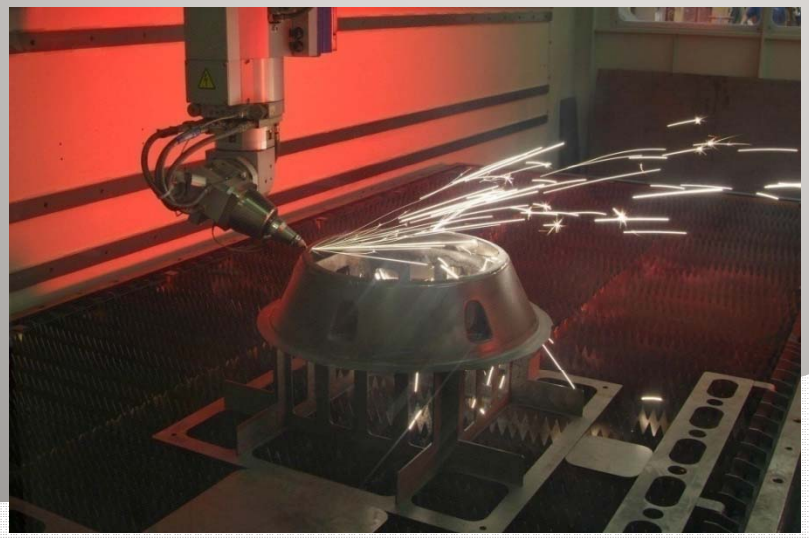
| | |
|---|---|
| • DOUBLE-ENDED ETCH LINE | 3 OFF TANKS 120” x 60” x 60” DEEP |
| • DOUBLE-ENDED ETCH LINE | 2 OFF TANKS 80” x 67” x 80” DEEP |
| • DOUBLE-ENDED ETCH LINE | 2 OFF TANKS 80” x 80” x 70” DEEP |
| • ETCH TANK | 1 OFF TANK 157” x 20 x 24” DEEP |

# Forming Division

## 5 Axis Laser Cutting



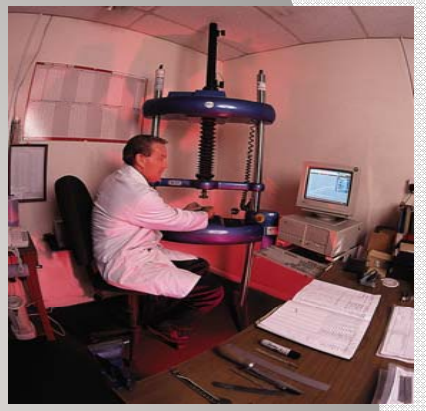




# Quality Control Equipment

Alpha case detection

Hydrogen analysis



Tensile testing

PFD NDT

Faro Arm Inspection

Plus a Chemical analysis laboratory

# Kitting to Customer Assembly Lines

**Examples**

**Firewall Kits**
**750 Details in 10 kit boxes**

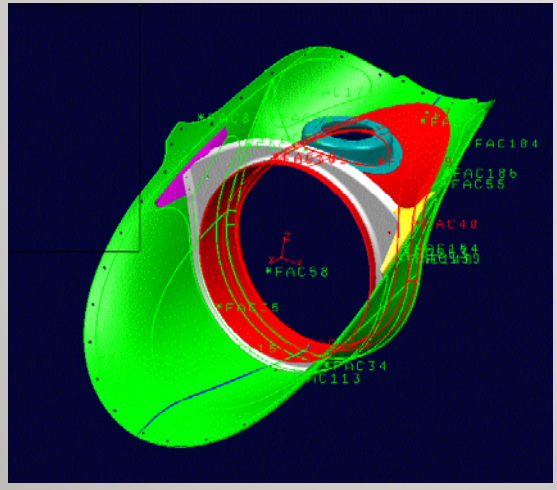
**Nacelle Kits**

**Pylon Details**

# Forming Division

## Concurrent Engineering

**Aeromet working with Customers Design Team Proposed Material Changes to achieve 45% Weight Saving and achieve cost targets.**




# Forming Division

## Sample Products


Door Surround 48”

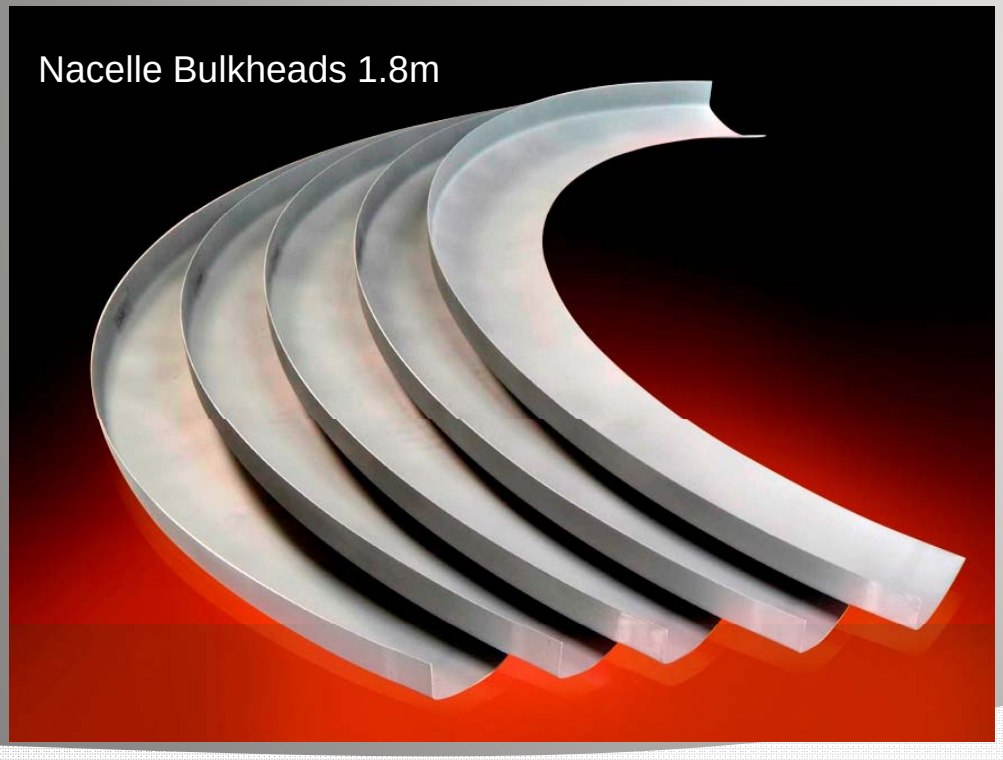

Finger Seals 24”

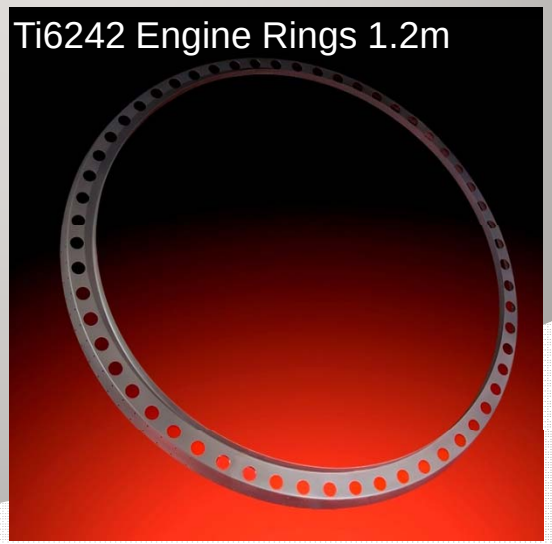

Erosion Shields 157”


Side Struts 27”

# Forming Division

## Sample Products

# Forming Division

## Sample Products



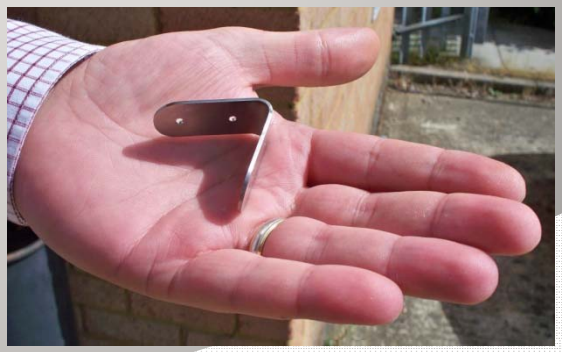
# Forming Division

No part too

Big

or too

Small

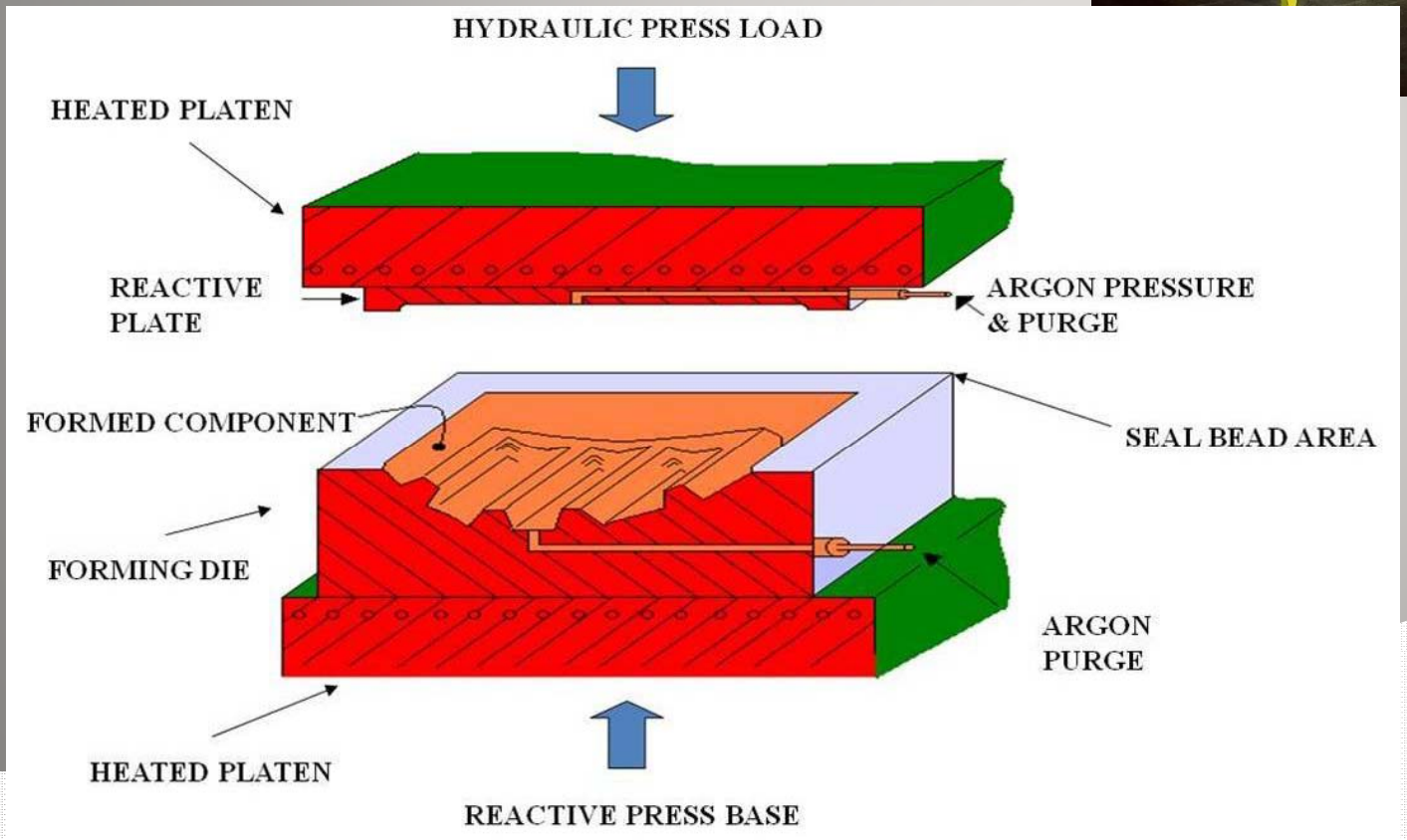


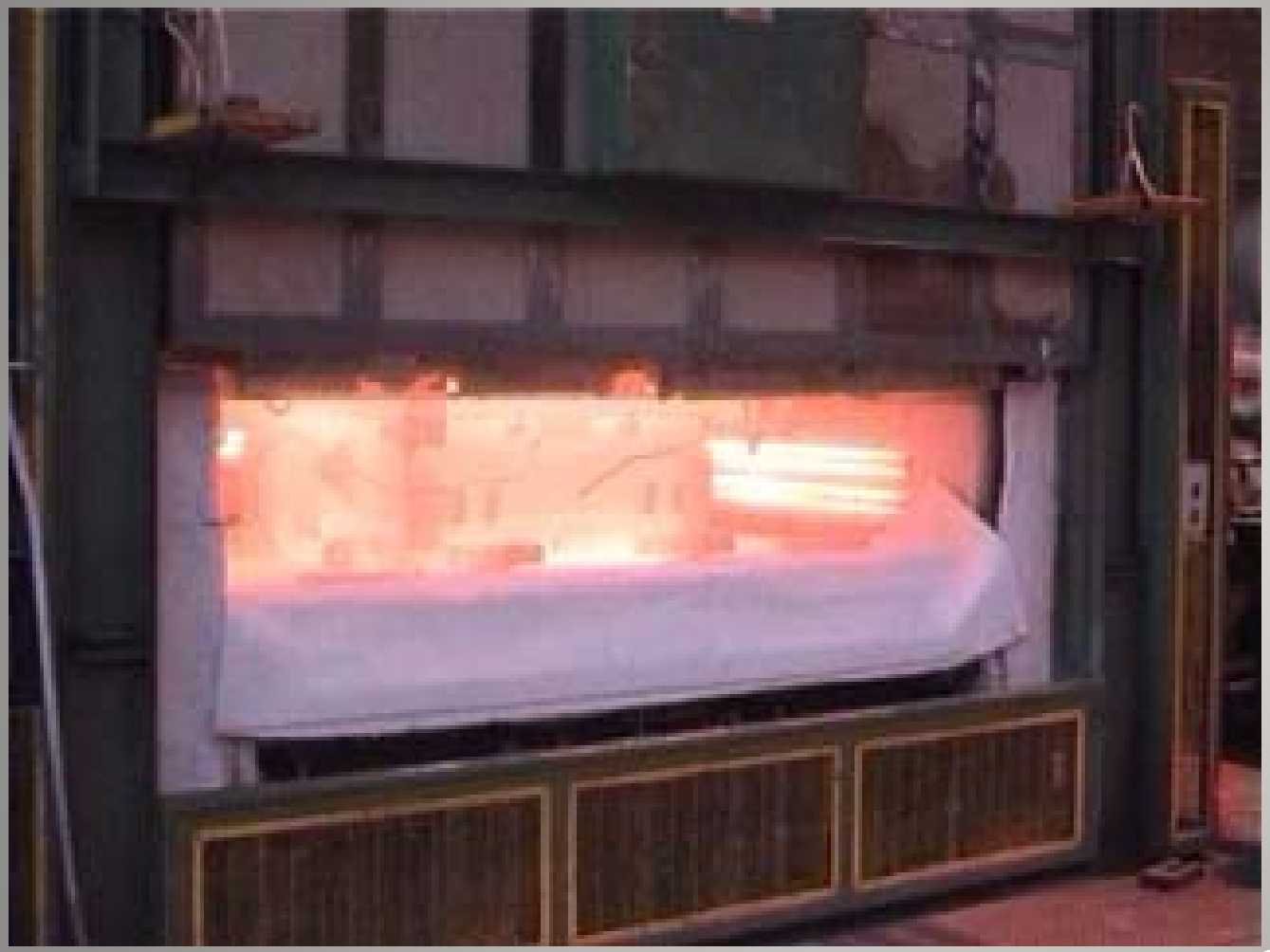
# Superplastic forming, Cost effective? (titanium)

# Why Superplastic

- Advantages
  - Complex shapes can be formed
  - Reduced part number count
  - Single or multi part forming
  - Reduced assembly time, weight and cost
- Disadvantages
  - Non uniform thickness
  - High temperature forming
  - Removal of alpha case

# Superplastic Forming
# Classical arrangement





# SPF examples

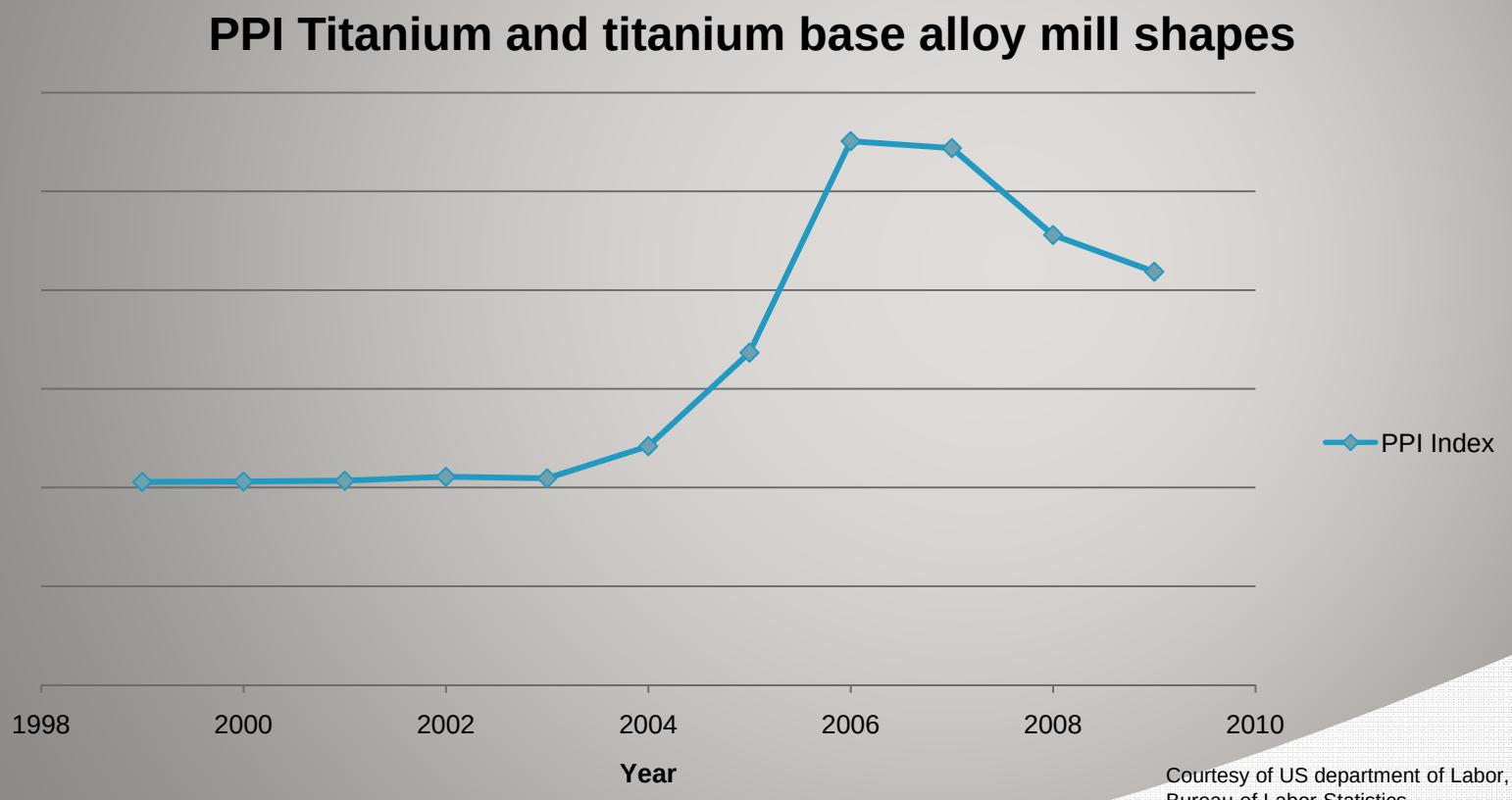
Firewall 48”

Access Panels 28”

# Factors affecting SPF cost

- Titanium price
- Forming operation
- Cleaning
- Quality control/testing
- Tooling

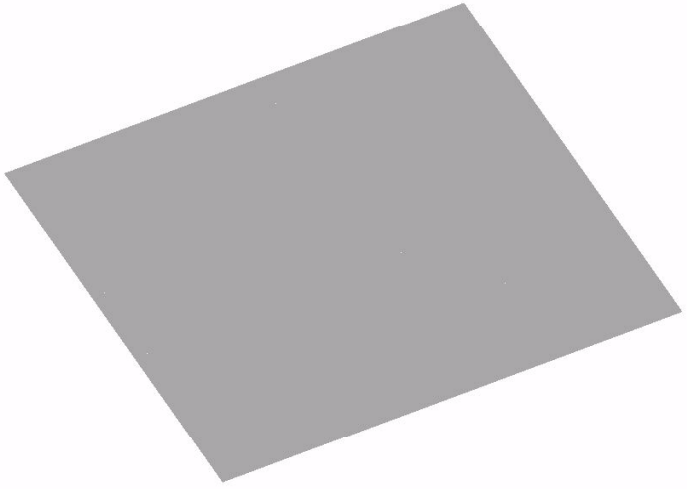
# Titanium

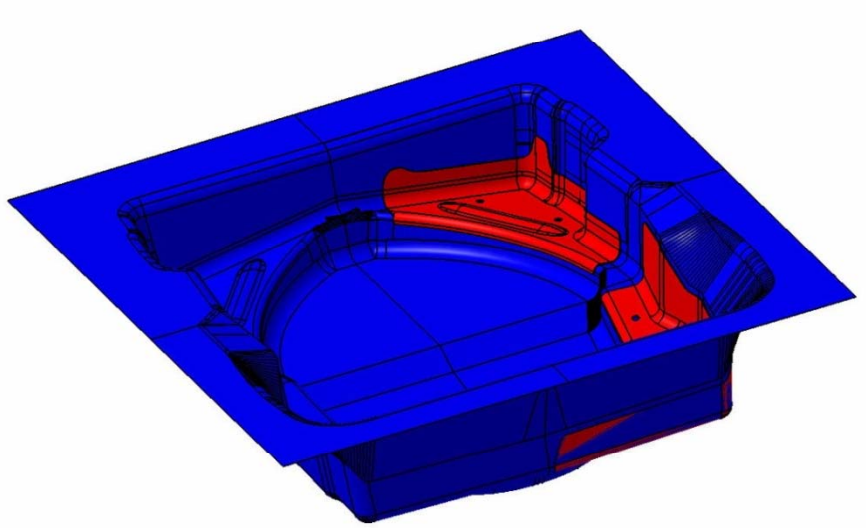



Courtesy of US department of Labor, Bureau of Labor Statistics

# Forming Operation

- Requires Heated Hydraulic Presses ~$1m each
- Temperature, typically 1680 F
- Strain rate sensitive = Pressure v time dependant

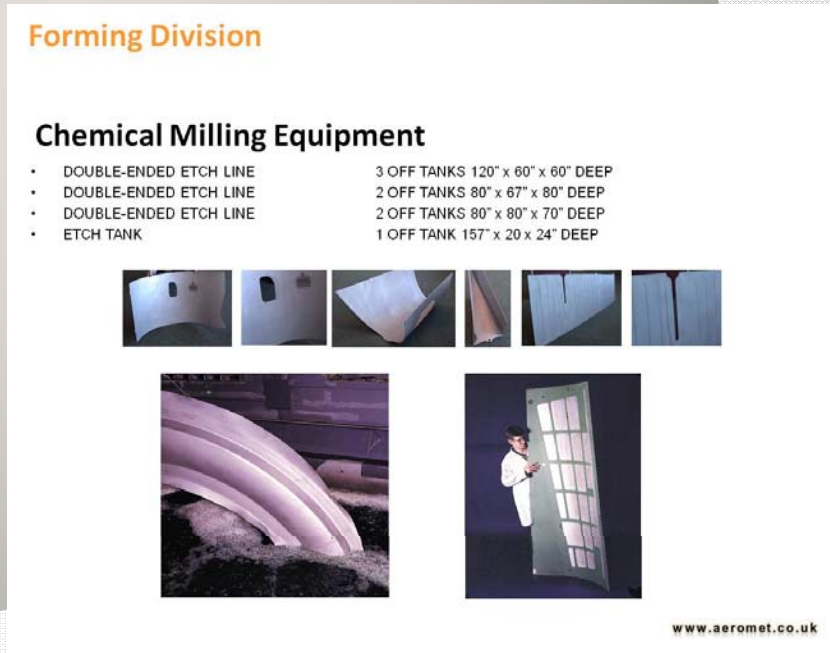




Courtesy of ESI Group

# Cleaning

- To remove alpha case
- Pre clean, abrasive blast
- Hydrofluoric and Nitric Acid
- Environmental compliance
- Monitored & adjusted daily



# QA & Testing

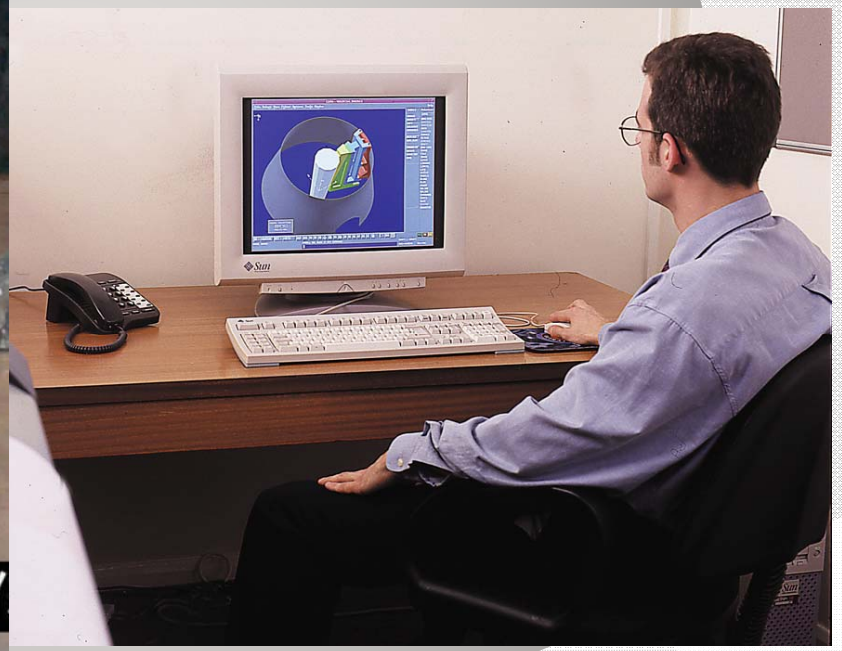
- Tensile testing per part
- Alpha case
- Hydrogen test
- Bend test
- Metallurgical

# Tooling

- Good thermal creep resistance
- High oxidation resistance
- Withstand press clamping loads & forming pressures
- High non-recurring costs (Ni Cr steel)
- Thermal cycle life limited

## Forming Division

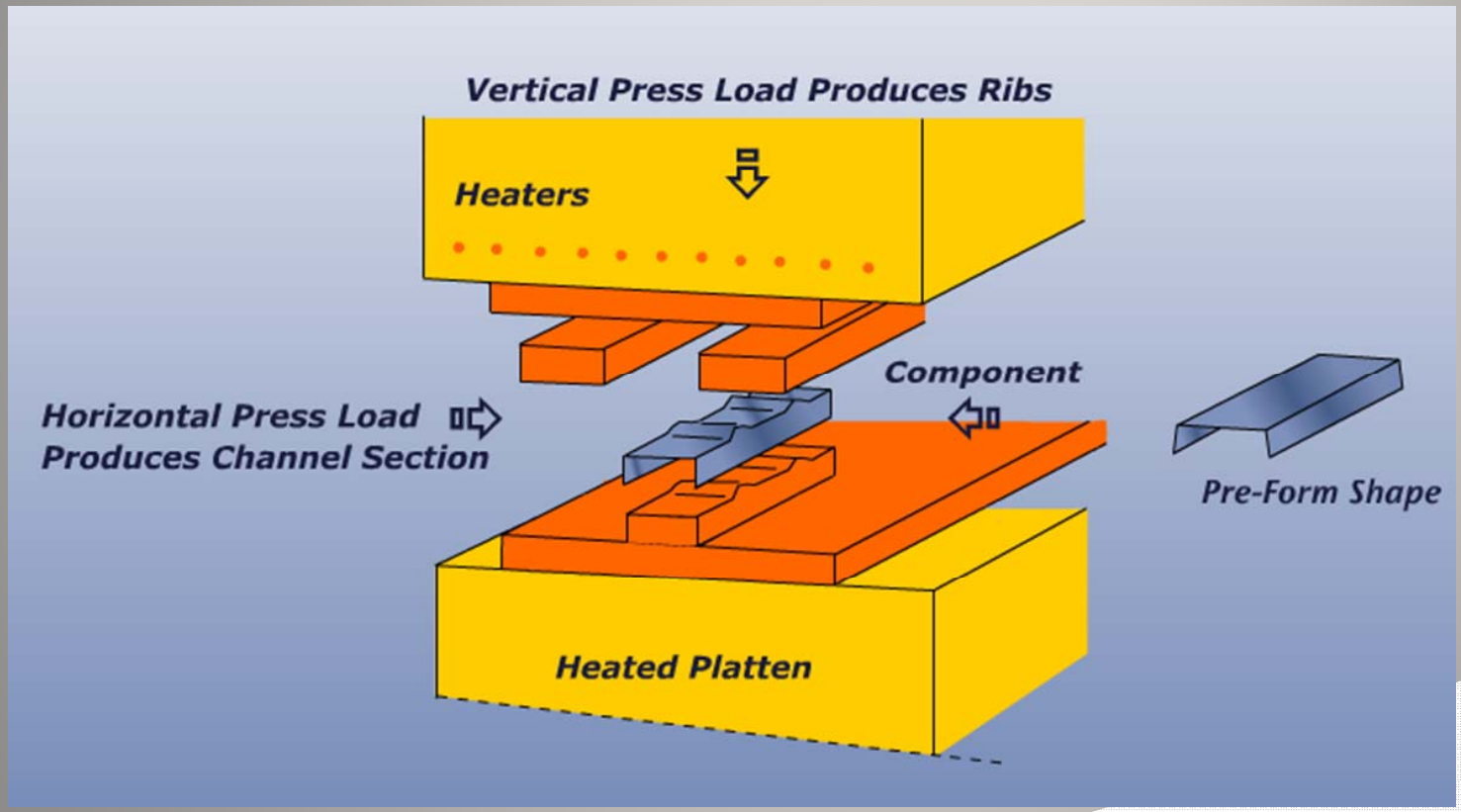
# Tooling Designed with life based upon number of thermal cycles



**Catia 5 rev 19 work station with IGES for surface and solid models**

# What other techniques are available?

# Hot die forming



# Plant & Equipment - Hot Forming

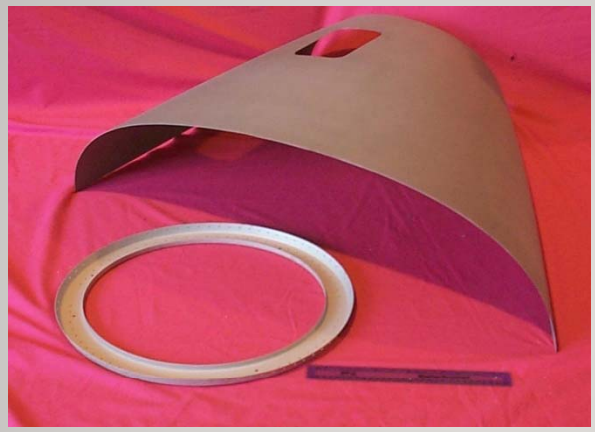
| Make | Tonnage | Capacity (inch) | Max Temp ºF |
|---|---|---|---|
| • NO 1 RIG | 5 TOP, 20 SIDE | 32 x 55 x 12 | 1200 |
| • MURDOCK 1 | 150 TOP, 20 SIDE | 60 x 48 x 24 | 1380 |
| • MURDOCK 2 | 150 TOP, 20 SIDE | 48 x 48 x 24 | 1380 |
| • MURDOCK 3 | 150 TOP, 20 SIDE | 48 x 48 x 24 | 1380 |
| • DIXON | 100 TOP, 5 SIDE | 20 x 18 x 24 | 1290 |
| • HOT BOX | 50 TOP | 20 x 18 x 10 | 1290 |

# Hot forming

- Advantages
  - Applied to all grades of Titanium
  - Lower forming temperature
  - No Alpha Case, descale & pickle
  - Reduced cycle time
  - Uniform thickness
  - Increased tool life
- Disadvantages
  - Limited complexity
  - More parts

# Hot forming examples

Beta 21S skin 0.080”



Skin and ring 0.063”

Bulkhead, Longeron and ring

# Case Studies –

# Case Study 1

# Case Study 1 HF 19% saving

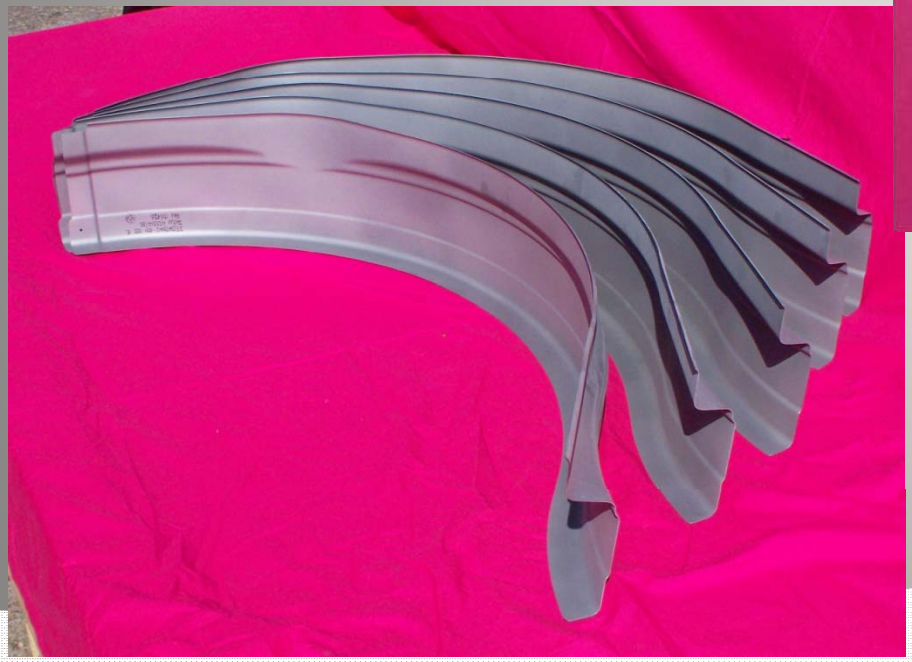
SPF

HF

# Case Study 2 angle support

# Case Study 2 HF Saving 11.5%

SPF



HF

# Case Study 3 Beam Support

# Case Study 3 HF 33% saving

HF

SPF

# SPF v HF

| Comparison of Operations | |
|---|---|
| **Superplastic Forming** | **Hot Forming** |
| Material 0.070” | Material 0.040” |
| Cut Blank | Cut Blank |
| Superplastic Form At 1650°F 90mins | Hot Forming 1300°F 25mins |
| Grit Blast | Descale & Pickle |
| Chemical Milling | |
| Alpha Case Test | Tests one in ten |
| Tensile Test | |
| Bend Test | |
| Laser Trim | Laser Trim |
| Finals | Finals |

# Summary

- Manufacturing selection is key to reducing costs
- Monolithic, deep pressings still requires SPF
- SPF still has a place in aerospace

## SPF examples



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# Thank you for listening