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SUPERPLASTIC FORMING APPLICATIONS ON AERO ENGINES. A REVIEW OF ITP MANUFACTURING PROCESSES

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Abstract

This paper reports a brief review of materials, manufacturing technologies and non destructive inspections of different superplastically formed parts for aero engines. Example of a manufacturing process of a SPF + DB part in ITP is presented.

Keywords :

Superplastic forming, aero engine, titanium, applications, inspection.

1 INTRODUCTION

Since the early 1970's, superplastic forming of titanium alloys became a feasible manufacturing technology for military aircraft in USA and also for the Concorde supersonic civil aircraft in Europe. In the next decade, new superplastic titanium and aluminium alloys were developed for different structural applications for military airframes and engines, but the first really implementation of SPF/DB was Boeing F15 Eagle, and Eurofighter afterwards.

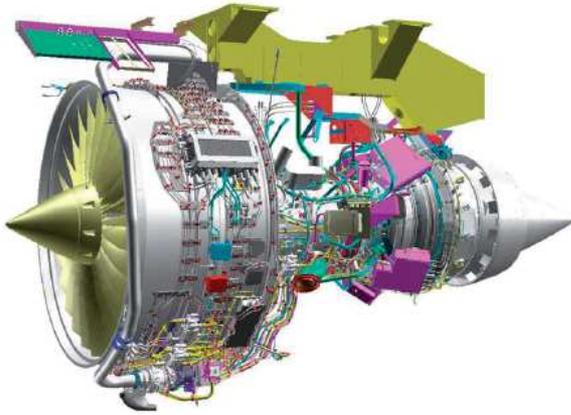
Jet engines appeared in World War II, but superplastically formed parts were not introduced in civil aero engines until 1980's, after important efforts on the study of metallurgical properties of different advanced materials. Because of severe working conditions, other metals such as nickel based alloys have also been studied and tried on different applications in engine components. Today, SPF/DB parts are used not only for simple static fabrications but for complex rotating parts in most of the new military and commercial engines.

In this paper, a brief review of SPF/DB parts of different materials for aero engines is described along with an example of an Eurojet EJ-200 Fairing flap manufacturing process.

2 AEROENGINES

2.1 ENGINE BASICS

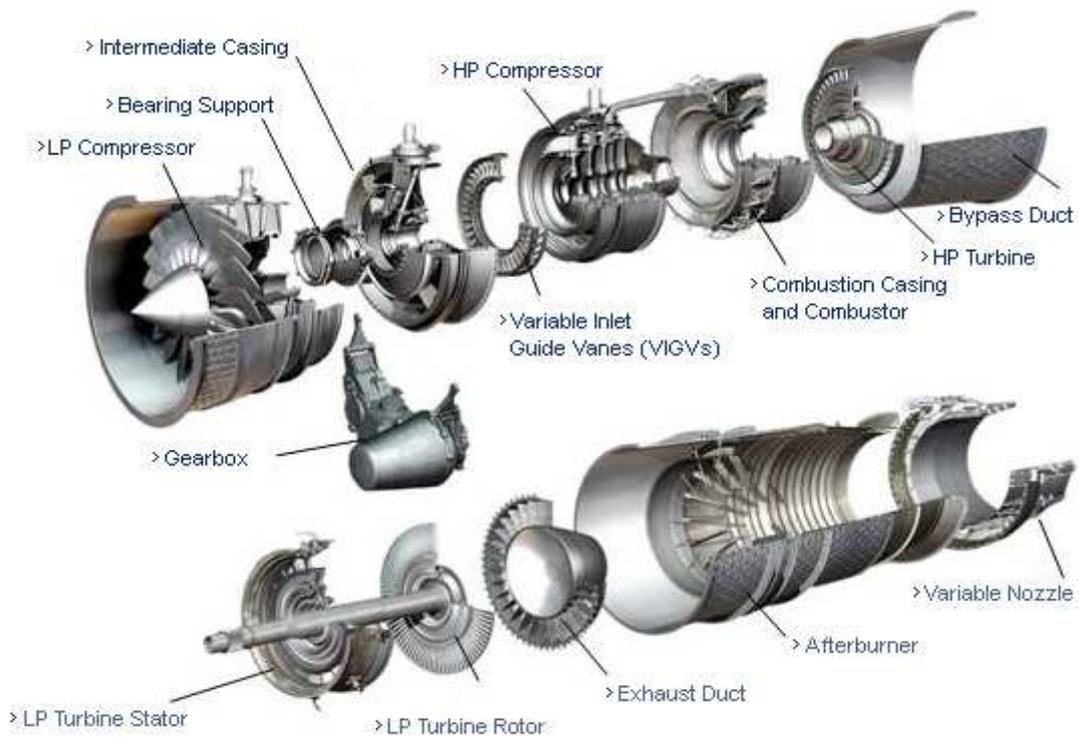
A state of the art civil and military turbofan engines are shown in Figs.1-3.



[Fig.1] Rolls Royce - Trent 900



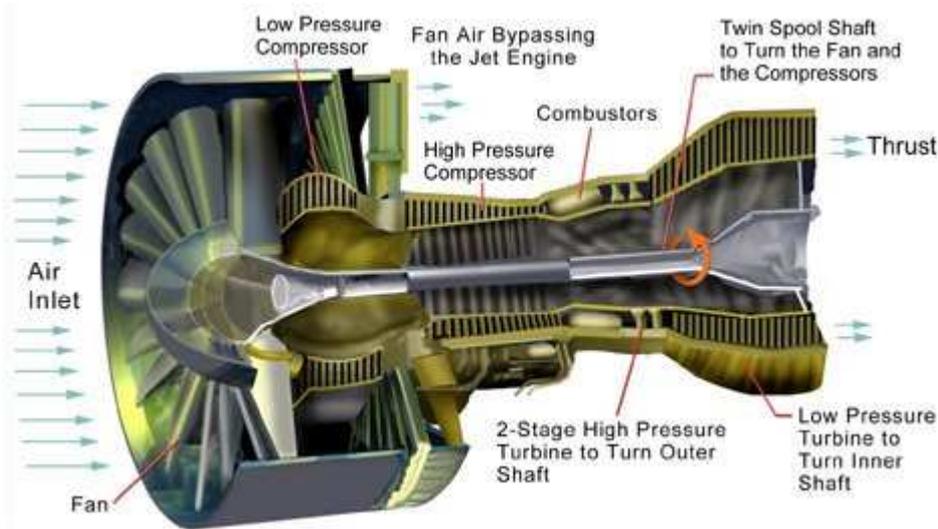
[Fig.2] IAE – V2500



[Fig.3] Eurojet - EJ 200 Modular construction

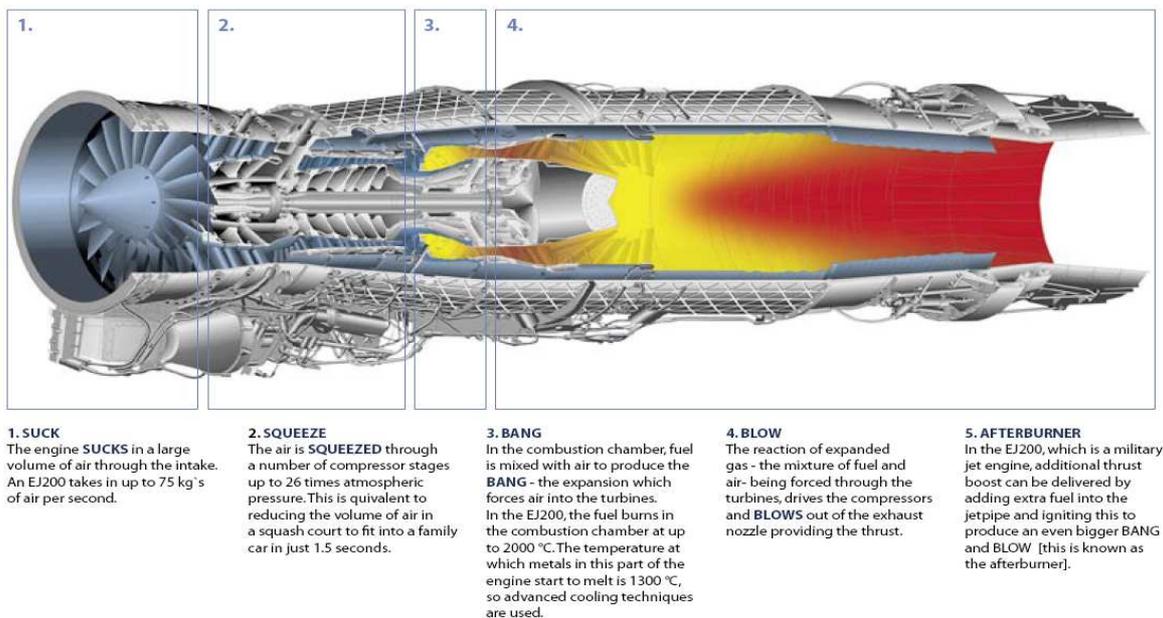
Almost all of the jet engines used in currently manufactured commercial jet aircraft are turbofans. They are used commercially mainly because they are highly efficient and relatively quiet in operation. Turbofans are also used in many military jet aircraft while Turboprops are used in small or slow subsonic aircrafts where combination of take-off and landing performance, cruise fuel efficiency and tactical mission performance is required.

Fig.4 is a drawing of the main parts of a turbofan commercial engine.



[Fig.4] Pratt & Whitney turbofan engine

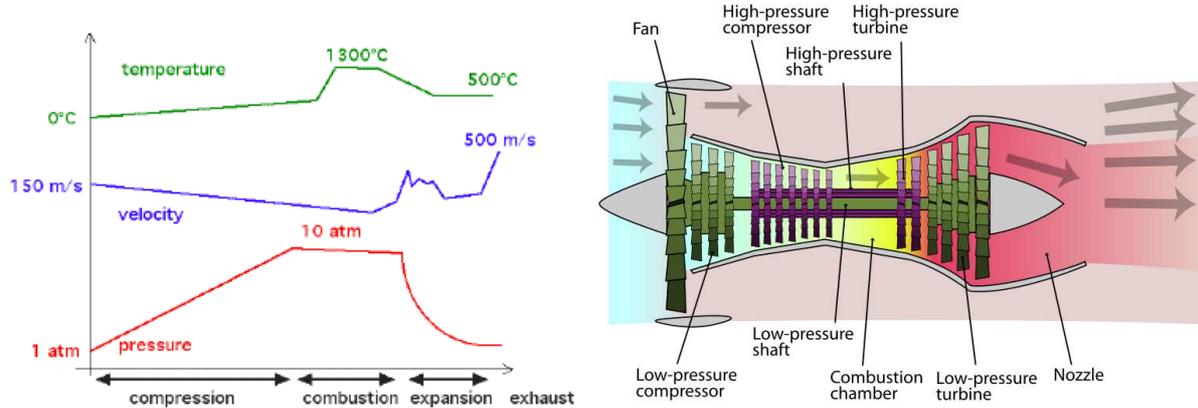
Fig.5 shows a basic explanation of how a turbofan military engine works.



[Fig.5] How EJ 200 works

2.2 WORKING CONDITIONS

In normal operation conditions, air is sucked at atmospheric conditions and squeezed up to 10 (40) atm. through the different compressor stages before reaching 1300-1500°C in the combustion chamber. Then, the resulting gas is expanded through the turbine and finally blown out of the exhaust nozzle at 500°C and recovering the initial pressure.

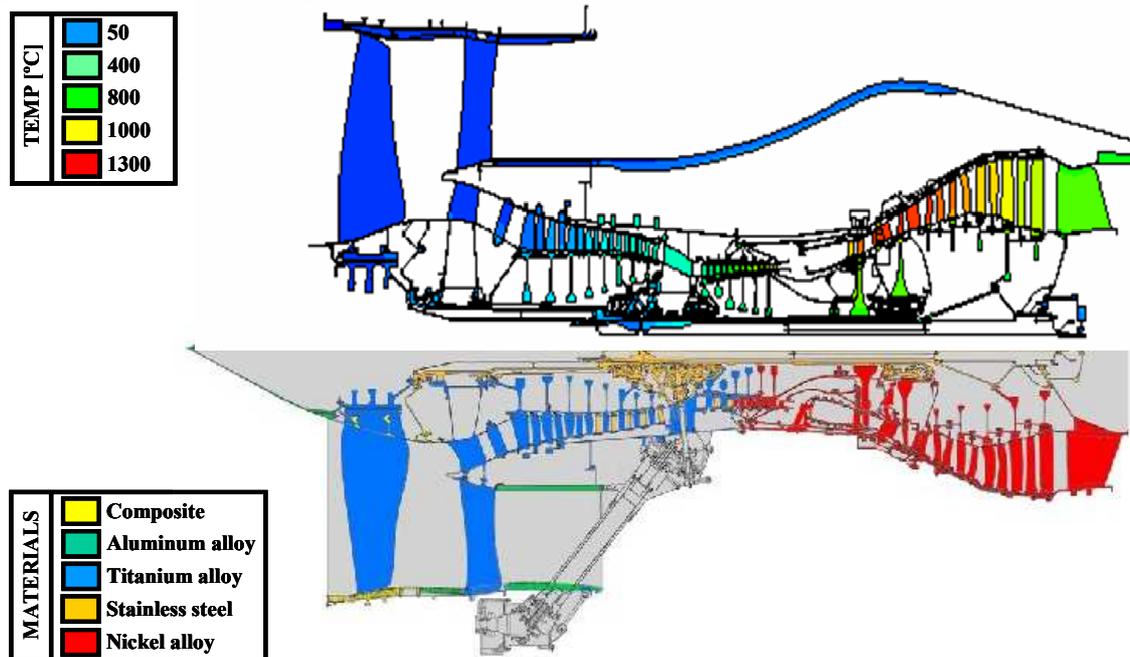


[Fig.6] Temperature, Velocity and Pressure inside a commercial turbofan engine

The most severe conditions are met in the first row of the turbine, where the entry gas temperature is around 1350°C, although temperatures are kept lower at the surface of the blades because of the cooling system and the thermal coat, leading to a metal temperature around 950 °C.

2.3 MATERIALS

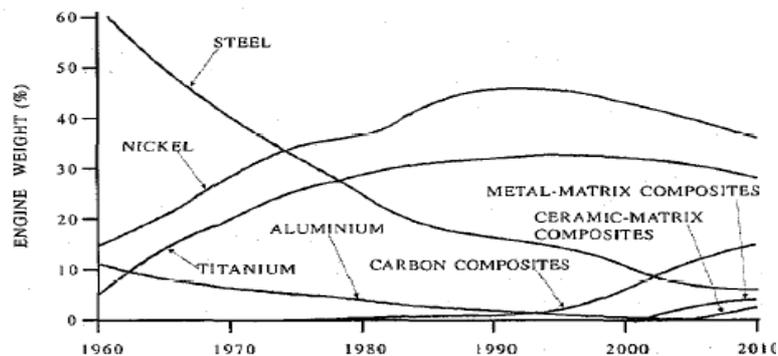
Because of the described extreme working conditions of pressure and temperature, along with corrosion, stress, fatigue and weight concerns, a state of the art turbofan engine is made of the following materials, shown in Fig.7.



[Fig.7] Temperature (1/2 Up) & Materials (1/2 Down) in a Rolls-Royce jet engine

In general terms, titanium alloys are used for their high strength ratio, excellent resistance to heat and corrosion and density properties in fan blades, tanks and low pressure compressor stages, and also in exhaust nozzles. At high temperatures, titanium alloys is replaced by nickel based alloys, like for example in the high pressure compressor, combustion chamber and high and low pressure turbines. Stainless steels like jethete are used in static parts of the compressor and bearings among others. Aluminium alloys can be used in the compressor casing, inlet ring and cone, while composites may be used for the fan casing, fan blades and cowls.

Fig.8 shows the evolution of materials used in aero engines: nickel and titanium alloys represent 70% of the weight of the engine; aluminium and steel have diminished and composites have increased in the last years.



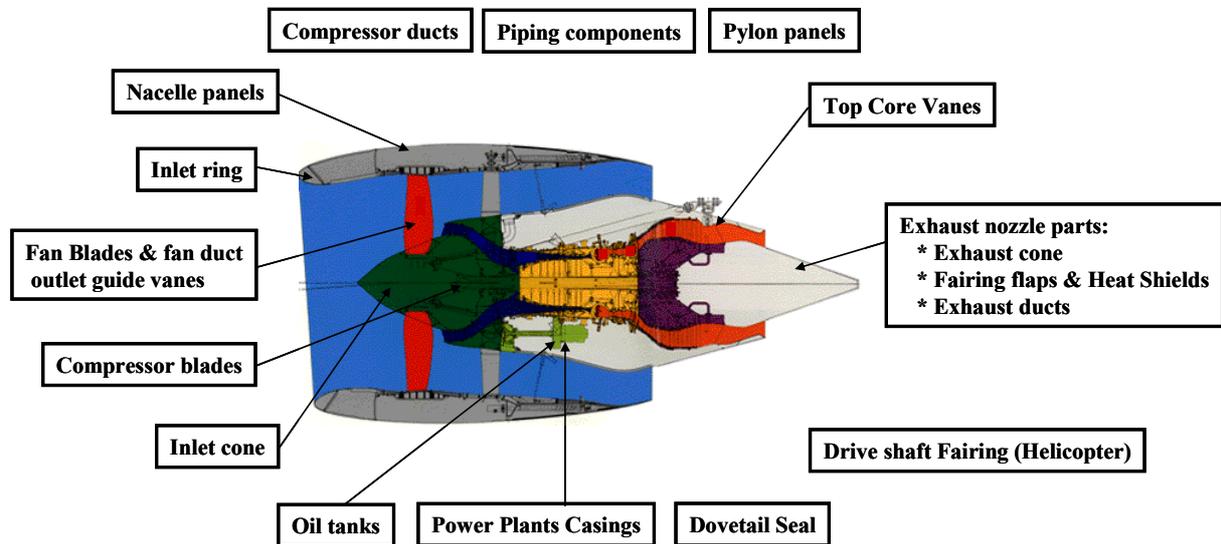
[Fig.8] Evolution of materials used in aero engines

Material election criteria depends not only on the engine performance but also on other matters like to be able to withstand destructive tests. It should be mentioned that critical design parameters in engine components may include bird strike, fatigue, flutter, and blade out.

Therefore, in case superplastic forming and especially if diffusion bonding is used for complex rotating parts, or even for simple static fabrications, it is mandatory to ensure a extremely high process control in order to avoid catastrophic problems. For this purpose, X-ray and ultrasonic inspections along with metallographic and tensile tests of almost 100% of engine components manufactured by means of SPF/DB processes is common practice.

3 SUPERPLASTIC FORMING APPLICATIONS ON AEROENGINES

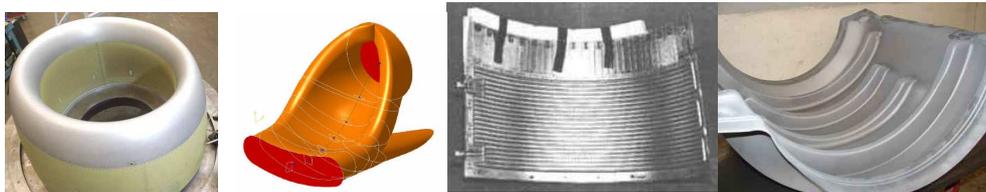
Fig.9 shows different engine parts where superplastic forming and diffusion bonding techniques can be used in aero engines for civil and military aircraft.



[Fig.9] Possible SPF parts in aero engines

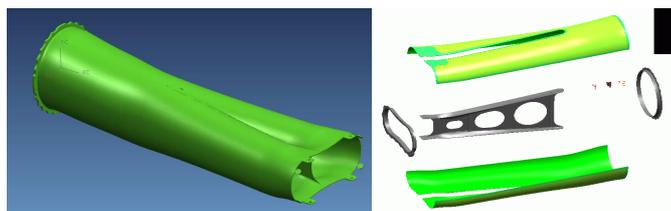
Titanium alloys such as Ti6Al4V and Ti6Al2Sn4Zr2Mo and other Ti alloys are the most employed material in SPF formed parts. It is used mainly for casings and hot parts around engines, ducts handling hot air, exhaust nozzles and engine components in fan, compressor and auxiliary systems.

- a) Casings and hot parts around engines like nacelle panels, pylon panels, inlet cone, air intake duct (TP400) inlet ring, power plant casings (TP400), cowl doors, drive shaft fairings in helicopters and sensor casings



[Fig.10] Inlet ring, air intake duct (TP400) & nacelle panels

- b) Ducts handling hot air like compressor ducts (Joint Strike Fighter)



[Fig.11] Roll post duct (JSF)

- c) Exhaust nozzle parts such as exhaust cone (Dolsig R&D European programme RR BR715), fairing flaps and heat shields (P&W F100, EJ-200), exhaust ducts and noise attenuators



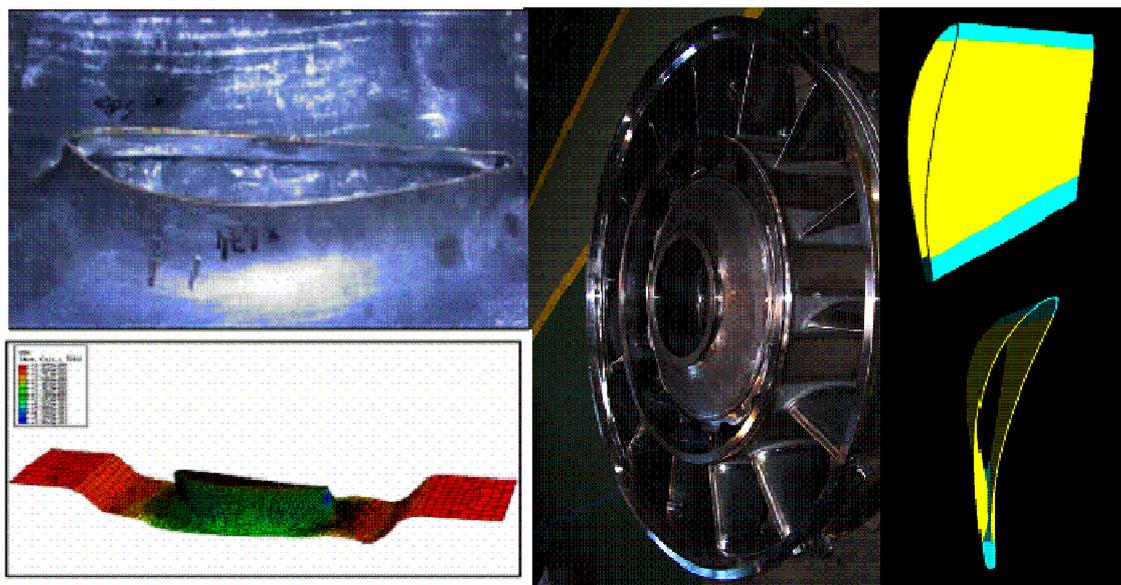
[Fig.12] TiAl exhaust cone (RR BR715) and Fairing flap (EJ-200)

- d) Engine components such as fan blades (RR Trent 900, RR Trent 1000, IAE V2500), fan duct outlet guide vanes, compressor blades, piping components and fuel and oil drain tanks (RR-BR725, EJ-200)



[Fig.13] Fan blade (RR Trent 900) and Piping

Aluminium alloys such as 5083, are only used in small engines for inlet rings. Finally, nickel based alloys like Inconel 718 are being studied in order to implement it on the hotter parts of the engine, especially for structural static parts in the turbine like TBHs and intercoolers.



[Fig.14] Preliminary option for Top Core Vanes in Tail Bearing Housing (RR Trent 900)

4 A REVIEW OF ITP MANUFACTURING PROCESSES.

4.1 FAIRING FLAP EJ-200



[Fig.15] Rear view of the Exhaust nozzle of EJ-200

Each Eurofighter has two EJ-200 engines with 12 Fairing flaps each. These parts are heat shields and stand on the rear side of the exhaust nozzle. They are a three sheet Ti6Al4V diffusion bonded and superplastically formed parts which are “mass produced” in Kits of five parts in each press cycle, in order to achieve a cost effective process.



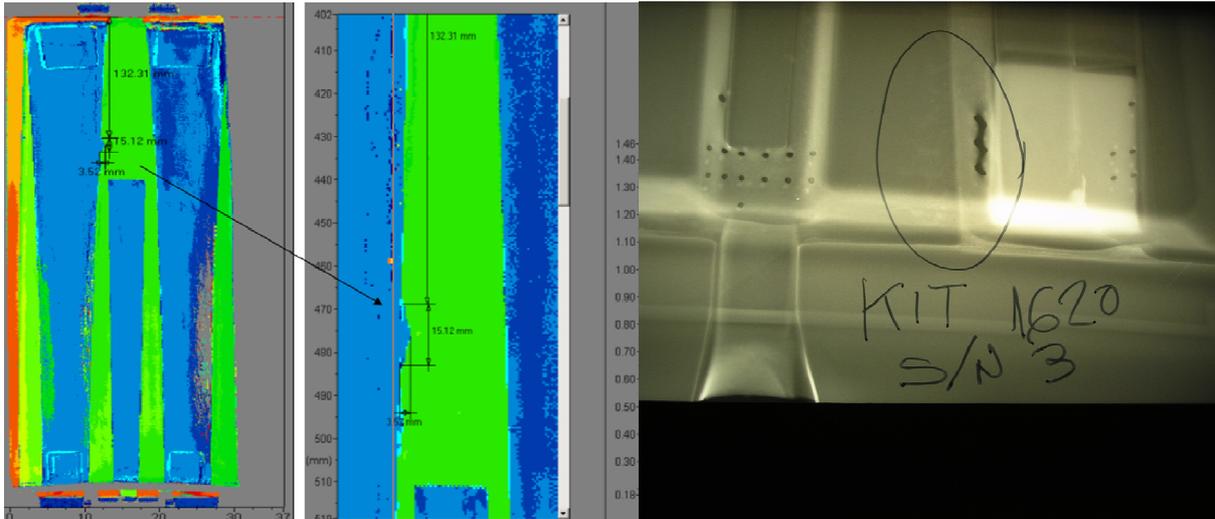
[Fig.16] EJ-200 Fairing flap production

After chemical milling, it is cut to final shape by means of water jet technology. Then front and rear lugs are TIG welded and machined in order to assembly the brackets that will join the component to the Con/Di nozzle.

4.2 DEFECTS DETECTION

In order to make sure that internal ribs remain undamaged after superplastic forming, an X-Ray inspection is carried out in every component.

Ultrasonic inspection on every external surface is carried out for thickness control and detection of not bonded areas because of stop-off failure.



[Fig.17] Not bonded area in ultrasonic inspection & damaged internal rib in X-Ray inspection

Along with metallographic and tensile tests of every kit in order to ensure mechanical properties, every welding is examined with fluorescent penetrating liquids and a final visual inspection of external surfaces is carried out to ensure part quality.

5 CONCLUSIONS & FUTURE TRENDS

- Increasing concerns regarding CO₂ emissions and soaring global demand for oil are driving a big interest in greater efficiency and weight saving in aircrafts. Although there is a move towards composites in airframes, they have few applications on aeroengines because of high manufacturing costs, poor recyclability and limited high temperature properties. Titanium alloys remain the material for choice for most SPF/DB parts in aero engines
- Titanium SPF parts are used not only in military engines but also in almost every state of the art turbo fan commercial engine for fan blades, casings, ducts or exhaust nozzles. Because of expertise and high process controls, diffusion bonded parts have been implemented in rotary complex parts
- Because of nickel price increase, SPF Inconel 718 parts for radial structures like turbine rear frames assembly seem to be a feasible option instead of castings or machined forged parts, where much more material is wasted.
- Although it has been carried out a preliminary assessment to introduce these materials in high performance turbines and defined the implications for future engine components design, Inconel 718 SPF parts are not a real solution yet for radial structures. TiAl alloys, not considered years ago to be a feasible option for SPF applications, are becoming a real solution.

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