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# Solid State Welding and Application in Aeronautical Industry

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**Abstract**

*In this study solid state welding andapplication in aeronautic industryhave been researched. The solid state welding technicisused in the industrial production fields such as aircraft, nucleer, space industry, aeronautic industry, ect., actually solid state welding is a process by which similar and dissmilar metals can be bonded together. Hence a material can be created as not heavy but strong strength. Beside, advantages and disasvantages of solid state welding have been discussed. Also the diffusion welding and friction welding which belong to the solid state welding is obsevered in aeronautic industry.*

**Keywords:** solid state welding, aeronautic industry,diffusion welding, dissimilar materials

## 1 Introduction

Welding is a metal joining process which produces coalescence of metals by heating them to suitable temperatures with or without the application of pressure or by the application of pressure alone, and with or without the use of filler material. Basically, welding is used for making permanent joints. It is used in the manufacture of automobile bodies, aircraft frames, railway wagons, machine frames, structural works, tanks, furniture, boilers, general repair work and ship building.

*Advantages of Solid State Welding:*

- Strong and tight joining,
- Cost effectiveness,
- Simplicity of welded structures design,
- Welding processes may be mechanized and automated.

*Disadvantages of Solid State Welding:*

- Internal stresses, distortions and changes of micro-structure in the weld region,
- Harmful effects: light, ultra violate radiation, fumes, high temperature,

Also there are many kinds of welding processes;

- Arc welding;
  - Carbon arc welding,
  - Shieled metal arc welding (SMAW),
  - Submerged arc welding (SAW),
  - Metal inert gas welding (MIG,GTAW),
  - Tungsten inert gas welding (TIG, GTAW),
  - Electroslag welding (ESW),
  - Plasma arc welding (PAW),
- Resistance Welding (RW);
  - Spot welding (RSW),
  - Flash Welding (FW),
  - Resistance butt welding (UW),
  - Seam welding (RSEW),

- Gas Welding (GW);
    - Oxyacetylene welding (OAW),
    - Oxyhydrogen welding (OHW),
    - Pressure gas welding (PGW),
- Solid state welding (SSW);
    - Forge welding (FOW),
    - Cold roll welding (CRW),
    - Friction welding (FRW),
    - Explosive welding (EXW),
    - Diffusion welding (DFW),
    - Ultrasonic welding,
- Thermit welding (TW),
- Electron beam welding (EBW),
- Laser welding (LW),

Solid-state welding describes a group of joining techniques which produces coalescence at temperatures below the melting point of the parent materials without the addition of third material. External pressure and relative movement may or may not be used to enhance the joining process.

This group of joining techniques includes e.g. friction (stir) welding, cold pressure welding,diffusion welding, explosion welding,electromagnetic pulse welding, , and ultrasonicwelding. In all of these joining methods, propercontrol of the process parameters (time, temperature, and pressure individually or in combination) results in the coalescence of the parent materials without melting or only negligible melting at the interface. Technically, solid-state welding methods are not welding processes in the traditional sense since the materials do not reach their melting point, but can be rather compared with the traditional forging techniques [1].

Solid-state welding offers specific advantages since the base metal do not (or only marginally) melt and re-solidify [1].The parent metals essentially retain their original properties; heat-affected zone problems - which generally develop when there is base metal melting - are significantly diminished. Also the formation of intermetallic phases at the interface which can be brittle and may yield corrosion concerns is largely eliminated or minimized. Furthermore, when dissimilar metals are joined, their thermal expansion and conductivity characteristics have much less influence on the resulting joint performance than with fusion welding processes.

Solid state welding in the aeronautics industry is experiencing exciting developments. The widespread application of computers and the improved knowledge and design of new materials are shaping the way welding is implemented and process and product are being designed.

This article focuses on the application of solid state welding in aeronautical industry, and on the trends in the industry that can be expected from progress at a fundamental level. It describes the following processes: friction welding and diffusion welding.

## 2 Solid State Welding (SSW)

Solid State Welding is a welding process, in which two work pieces are joined under a pressure providing an intimate contact between them and at a temperature essentially below the melting point of the parent material. Bonding of the materials is a result of diffusion of their interface atoms [2].

*Advantages of Solid State Welding:*

- Weld (bonding) is free from microstructure defects (pores, non-metallic inclusions, segregation of alloying elements),
- Mechanical properties of the weld are similar to those of the parent metals,
- No consumable materials (filler material, fluxes, shielding gases) are required,
- Dissimilar metals may be joined (steel - aluminum alloy steel - copper alloy).

*Disadvantages of Solid State Welding:*

- Thorough surface preparation is required (degreasing, oxides removal, brushing/sanding),
- Expensive equipment.

### 2.1 Forge Welding (FOW)

Forge Welding is a Solid State Welding process, in which the components are heated to about 1800°F (1000°C) and then forged (hammered). Prior to Forge Welding, the parts are scarfed in order to prevent entrapment of oxides in the joint. Forge Welding is used in general blacksmith shops and for manufacturing metal art pieces and welded tubes [2, 3].

*Advantages of Forge Welding:*

- Good quality weld may be obtained,
- Parts of intricate shape may be welded,
- No filler material is required.

*Disadvantages of Forge Welding:*

- Only low carbon steel may be welded,
- High level of the operators skill is required,
- Slow welding process,
- Weld may be contaminated by the coke used in heating furnace.

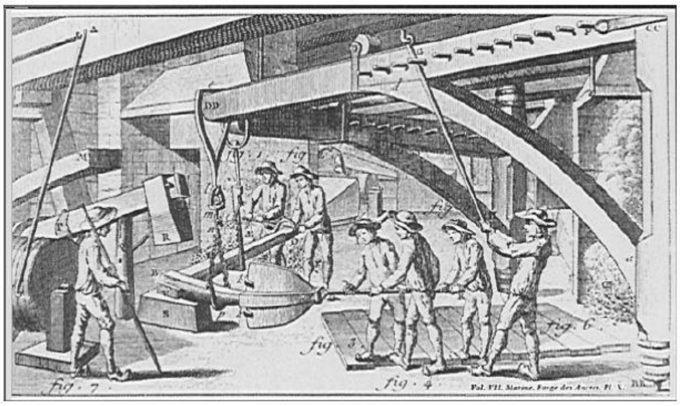

Figure 1: Woodcut showing a large ship's anchor being forged in 18th century France. The arm and the shaft of the anchor are being forge-welded together in this view.

## 2.2 Cold Roll Welding (CRW)

Cold Welding is a Solid State Welding process, in which two work pieces are joined together at room temperature and under a pressure, causing a substantial deformation of the welded parts and providing an intimate contact between the welded surfaces [3].

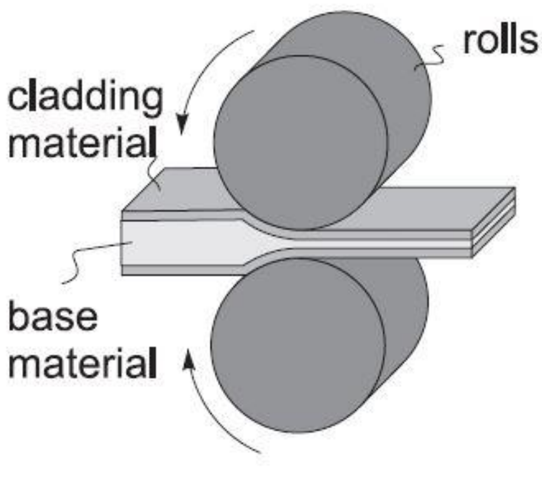


Figure 2: Cold welding (also cladding) process

As a result of the deformation, the oxide film covering the welded parts breaks up, and clean metal surfaces reveal. Intimate contact between these pure surfaces provides a strong and defectless bonding.Aluminum alloys, Copper alloys, low carbon steels, Nickel alloys, and other ductile metals may be welded by Cold Welding.

Cold Welding is widely used for manufacturing bi-metal steel - aluminum alloy strips, for cladding of aluminum alloy strips by other aluminum alloys or pure aluminum (Corrosion protection coatings). Bi-metal strips are produced by Rolling technology. Presses are also used for Cold Welding. Cold Welding may be easily automated [3, 4].

## 2.3 Diffusion Welding (DFW)

Diffusion Welding is a Solid State Welding process, in which pressure applied to two work pieces with carefully cleaned surfaces and at an elevated temperature below the melting point of the metals. Bonding of the materials is a result of mutual diffusion of their interface atoms [5, 6].

In order to keep the bonded surfaces clean from oxides and other air contaminations, the process is often conducted in vacuum. No appreciable deformation of the work pieces occurs in Diffusion Welding.Diffusion Welding is often referred more commonly as Solid State Welding (SSW). Diffusion Welding is able to bond dissimilar metals, which are difficult to weld by other welding processes:

- Steel to tungsten,
- Steel to niobium,
- Stainless steel to titanium,
- Gold to copper alloys.

Diffusion Welding is used in aerospace androcketry industries, electronics, nuclearapplications, manufacturing composite materials.

*Advantages of Diffusion Welding:*
- Dissimilar materials may be welded (Metals, Ceramics, Graphite, glass),
- Welds of high quality are obtained (no pores, inclusions, chemical segregation, distortions),
- No limitation in the work pieces thickness.

*Disadvantages of Diffusion Welding:*
- Time consuming process with low productivity,
- Very thorough surface preparation is required prior to welding process,
- The mating surfaces must be precisely fitted to each other,
- Relatively high initial investments in equipment.

### 2.4 Explosion Welding (EXW)

Explosive Welding is a Solid State Welding process, in which welded parts (plates) are metallurgically bonded as a result of oblique impact pressure exerted on them by a controlled detonation of an explosive charge.

One of the welded parts (base plate) is rested on an anvil, the second part (flyer plate) is located above the base plate with an angled or constant interface clearance.Explosive charge is placed on the flyer plate. Detonation starts at an edge of the plate and propagates at high velocity along the plate.The maximum detonation velocity is about 120% of the material sonic velocity.The slags (oxides, nitrides and other contaminants) are expelled by the jet created just ahead of the bonding front.Most of the commercial metals and alloys may be bonded (welded) by Explosive Welding.Dissimilar metals may be joined by Explosive Welding:

- Copper to steel,
- Nickel to steel,
- Aluminum to steel,
- Tungsten to steel,
- Titanium to steel,
- Copper to aluminum.

*Advantages of Explosive Welding*

- Large surfaces may be welded,
- High quality bonding: high strength, no distortions, no porosity, no change of the metal microstructure,
- Low cost and simple process,
- Surface preparation is not required.

*Disadvantages of Explosive Welding:*

- Brittle materials (low ductility and low impact toughness) cannot be processed,
- Only simple shape parts may be bonded: plates, cylinders,
- Thickness of flyer plate is limited - less than 2.5” (63 mm),
- Safety and security aspects of storage and using explosives.

Explosive Welding is used for manufacturing clad tubes and pipes, pressure vessels, aerospace structures, heat exchangers, bi-metal sliding bearings, ship structures, weld transitions, corrosion resistant chemical process tanks [5].

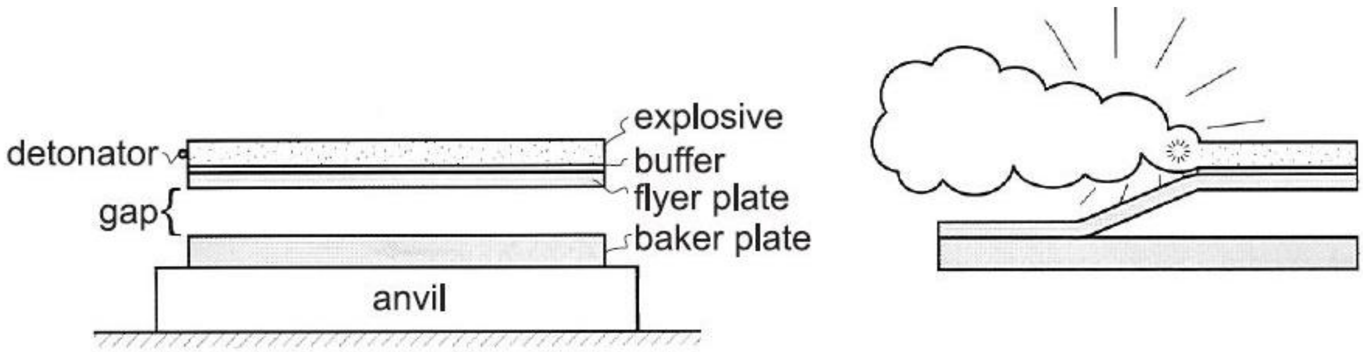


Figure 3: Explosive welding showing the initial setup and the process of explosive welding with the propagating shock wave.

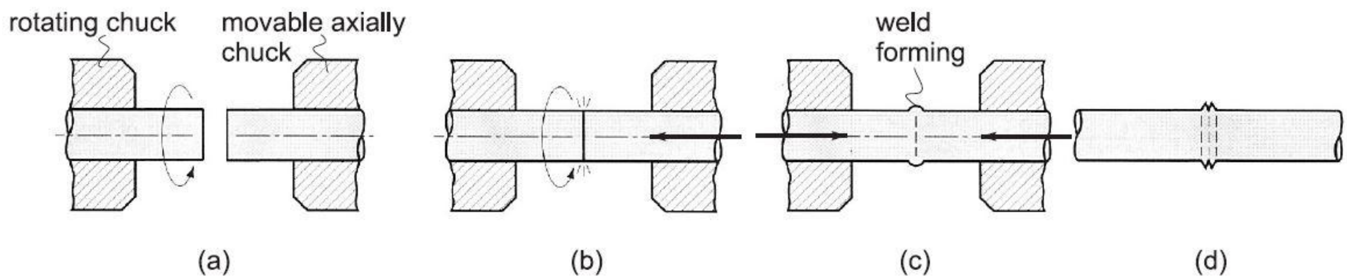


Figure 4: Friction welding: (a) no contact, (b) parts brought into contact to generate friction heat, (c) rotation stops and axial pressure applied, (d) final product showing the flash.

### 2.5 Friction Welding (FRW)

Friction welding is a solid-state welding process in which coalescence is achieved by frictional heat combined with pressure. The heat is generated by the friction between the two components surfaces, usually by rotation of one part relative to the other. Then the parts are driven toward each other with sufficient force to form a metallurgical bond. The sequence is portrayed in the figure for the typical application of this operation, welding of two cylindrical parts.

The axial compression force upsets the parts, and the material displaced produces a flash. The flash must be subsequently trimmed to provide a smooth surface in the weld region. No filler metal, flux, or shielding gases are required.

Machines used for friction welding have the appearance of an engine lathe. They require a powered spindle to turn one part at high speed and a means of applying an axial force between the rotating part and the non-rotating part.

With its short cycle times, the process is suitable for mass production. It is applied in the welding of various shafts and tubular parts of similar or dissimilar metals. One typical application of friction welding is to coalesce medium-carbon steel shanks to carbide tips in producing twist drills.

### 2.6 Ultrasonic Welding (USW)

Ultrasonic Welding is a Solid State Welding process, in which two work pieces are bonded as a result of a pressure exerted to the welded parts combined with application of high frequency acoustic vibration (ultrasonic).

Ultrasonic vibration causes friction between the parts, which results in a closer contact between the two surfaces with simultaneous local heating of the contact area. Interatomic bonds, formed under these conditions, provide strong joint.Ultrasonic cycle takes about 1 sec. The frequency of acoustic vibrations is in the range 20 to 70 KHz. Thickness of the welded parts is limited by the power of the ultrasonic generator.Ultrasonic Welding is used mainly for bonding small work pieces in electronics, for manufacturing communication devices, medical tools, watches, in automotive industry.

*Advantages of Ultrasonic Welding:*

- Dissimilar metals may be joined,
- Very low deformation of the work pieces surfaces,
- High quality weld is obtained,
- The process may be integrated into automated production lines,
- Moderate operator skill level is enough.

*Disadvantages of Ultrasonic Welding:*

- Only small and thin parts may be welded,
- Work pieces and equipment components may fatigue at the reciprocating loads provided by ultrasonic vibration,
- Work pieces may bond to the anvil.

## 3 Solid State Welding Processes for Aeronautics

The nature of welding in the aeronautical industry is characterized by low unit production, high unit cost, extreme reliability, and severe operating conditions [7]. These characteristics point towards the more expensive and more concentrated heat sources such as plasma arc, laser beam and electron beam welding as the processes of choice for welding of critical components. But mostly diffusion welding and friction welding techniques are used in the industry, and it has been growing permanently[8].

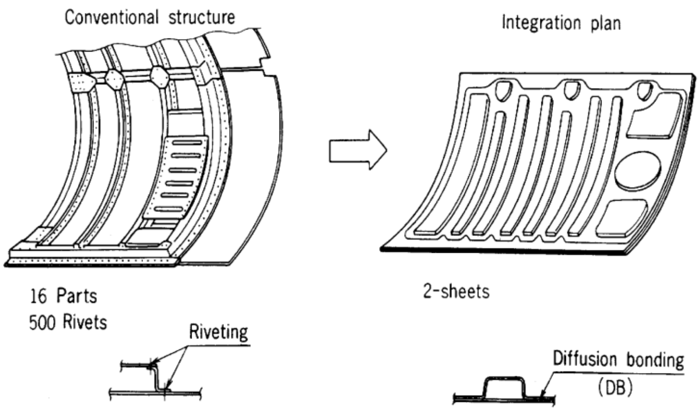


Figure 5: Conventional structure and integrated plan for door panel using SPF/DFW

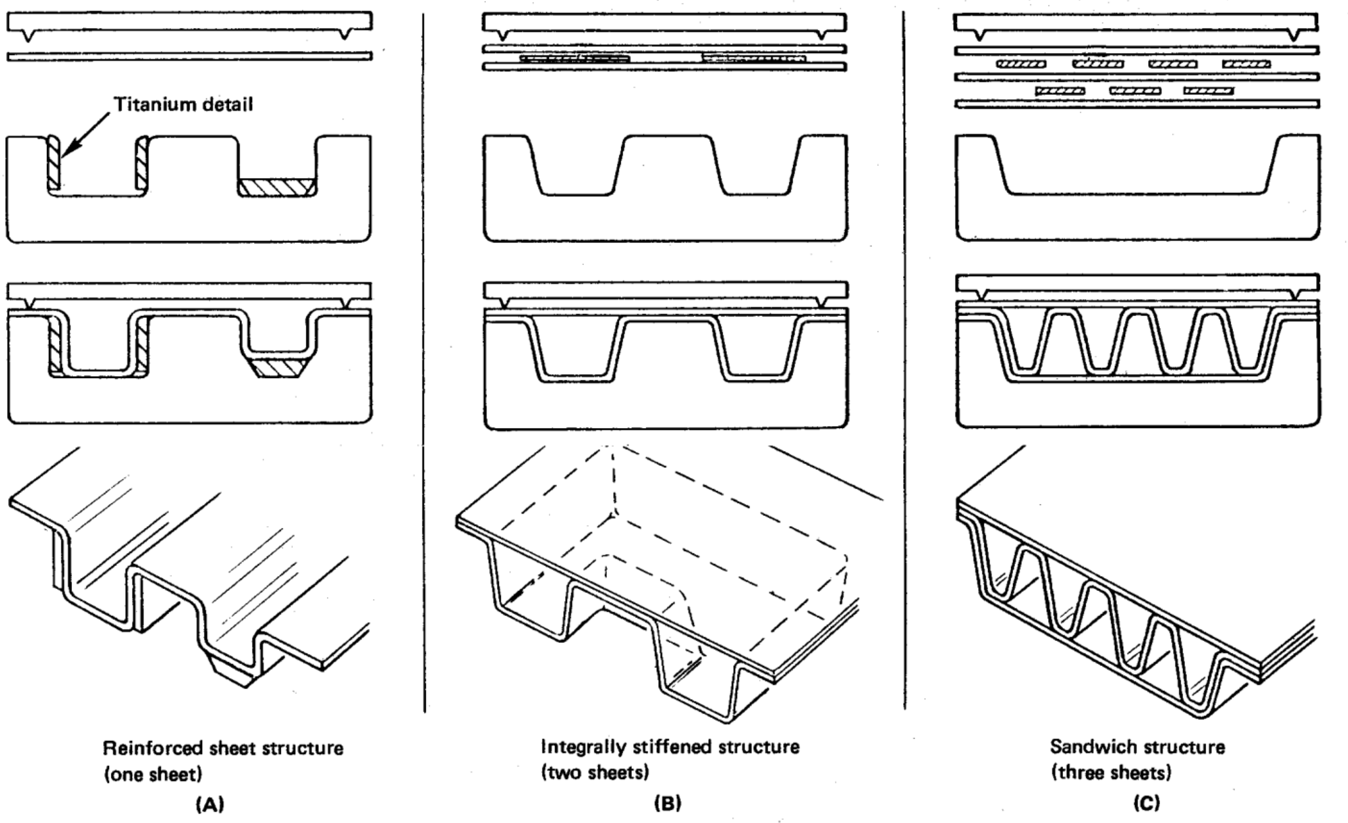


Figure 6: Manufacturing of reinforced structures in titanium by a combination of SPF and DFW32

### 3.1 Diffusion welding in Aeronautics Industry

It is a solid-state welding process that produces a weld by the application of pressure at elevated temperature with no macroscopic deformation or relative motion of the pieces [9]. The aeronautic industry is the major user of DFW25. This process has proven particularly useful when combined with the superplastic forming (SPF) of titanium alloys. In this case, complicated geometries can be obtained in just one manufacturing step as shown in Figure 6. The quality and low cost of the joint enables in some cases the substitution of riveted aluminum components with SPF/DFW titanium replacements. Figure 5 shows a possible improvement for the door panel of an aircraft fuselage [10, 11]. The conventional fabrication consisted of 16 parts held together by 500 fasteners. It was proposed to replace that design by a 2-sheet assembly, integrally stiffened produced by SPF/DFW. Figure 8 shows an exit hatch for the British Aerospace Bae 125/800. The application of SPF/DFW reduces the original riveted aluminum design from 76 detail parts and 1000 fasteners to a titanium version with only 14 details and 90 fasteners with a total cost savings of 30%. Figure 7 shows a wing access panel for the Airbus A310 and A320 in which switching from riveted aluminum to SPF/DFW titanium achieved a weight saving in excess of 40%. The success of SPF/DFW with titanium stimulated much research with the goal of accomplishing a similar process with aluminum[11, 12, 13].

The fundamental difference between DFW of titanium and aluminum is that titanium can dissolve its oxides, and aluminum cannot [13]. Therefore, the residual oxide at the interface of aluminum joint dramatically reduces the strength of the diffusion weld. This problem has prevented the SPF/DFW of aluminum from being generally adopted [14, 15].

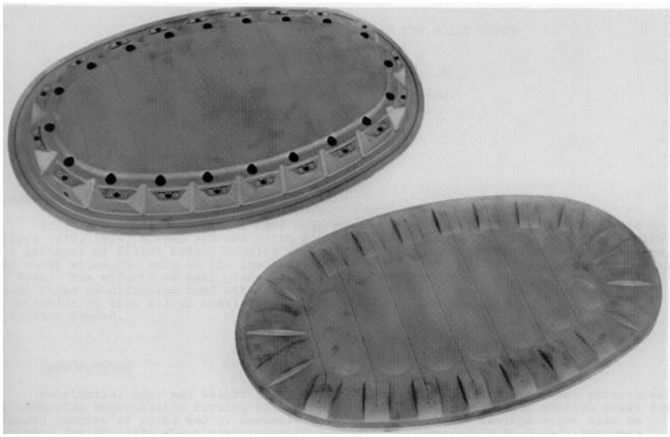

Figure 7: Wing access panel for the airbus A310/A320 made of titanium SPF/DFW33


Figure 8: Exit hatch for the BAe 125/800 made of titanium SPF/DFW33

### 3.2 Friction welding in Aeronautics Industry

In this process, the joining of the metals is achieved through mechanical deformation. Since there is no melting, defects associated with melting-solidification phenomena are not present and unions as strong as the base material can be made [15, 16]. This process can join components with a relatively simple cross section. It is used for the joining of aluminum landing gear components [17]. Linear friction (fretting) welding was considered by General Electric and Pratt & Whitney as an alternative for the manufacture and repair of high temperature alloy blisks for jet engines [18, 19]. Although little was disclosed about these processes, they do not seem to have evolved into commercial applications [20, 21].

## 4 Conclusion

Welding processes and solid state welding processes have been researched, and the application of diffusion welding and friction welding which belong to solid state welding have been investigated, in the aeronautic industry.

Weight reduction and improved damage tolerance characteristics were the prime drivers to develop new family of materials for the aeronautical industry, like Fiber/Metal Laminated (FML) or Metal Matrix Composites (MMC). Those advanced materials cannot be welded by conventional techniques because the high temperatures involved would destroy their properties. For such materials, diffusion welding is an attractive solution because it is a solid state joining technique, which is normally carried out at a temperature much lower than the melting point of the material.

The range of applications for this type of welding on aeronautic industry is vast and includes: structural aircraft sections, blades of aircraft engines, electronic components, helicopters rotor parts, space shuttle fuselage, exhaust components for gas turbines [22].

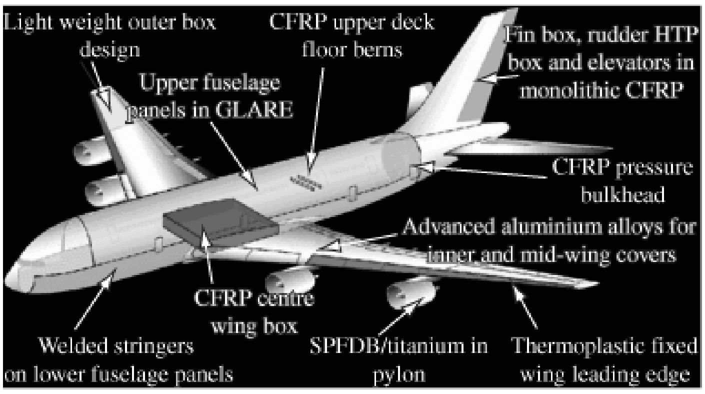


Figure 9: The components of an airplane

In the near future, Airbus planes (A318 and A3XX) will feature fuselage stringers laser welded to the airplane skin. Looking further into the future, it is likely that friction welding will be applied on airplane structural components, since it can reliably join alloys of the series 2xxx and 7xxx [23, 24].

Also, it is reasonable to expect that the amount and criticality of EBW of titanium in future military aircraft will increase. The use of castings in aircraft is increasing; this will surely bring up new challenges that had not been present with wrought alloys. Besides that, diffusion welding is getting more and more useful in aeronautic industry.

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