

A REVIEW ON BLISK TECHNOLOGY

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Abstract: Blisk is one of the most original components in modern aero-engines. A **blisk** is a single engine component consisting of a rotor disk and blades, which may be either integrally cast, machined from a solid piece of material, or made by welding individual blades to the rotor disk. The term is used mainly in aerospace engine design. *Blisks* may also be known as integrally bladed rotors (IBR).

Keywords : BLISK, Blade, Linear Friction Welding (LFW), aero-engine.

I. INTRODUCTION

Aircraft engines are high-technology products, the manufacture of which involves innovative techniques. Also, aero-engines face up to the need of a continuous improving of its technical capabilities in terms of achieving higher efficiencies with regard to lower fuel consumption, enhanced reliability and safety, while simultaneously meet the restrictive environmental legislations (External Advisory Group for Aeronautics of the European Commission, 2000). Technological viability and manufacturing costs are the key factors in the successful development of new engines. Therefore, the feasibility of enhanced aero-engines depends on the achievements of R&D activities, mainly those concerning the improvement of materials and structures.

Advanced compressor designs are critical to attain the purposes of engine manufacturers. Aircraft engines and industrial gas turbines traditionally use bladed compressor disks with individual airfoils anchored by nuts and bolts in a slotted central retainer. Nevertheless, an improvement of the component disk plus blades is the BLISK, a design where disk and blades are fabricated in a single piece. The term "BLISK" is an acronym composed of the words "blade" and "disk" (from BLaded DISK). BLISKS are also called integrated bladed rotors (IBR), meaning that blade roots and blade locating slots are no longer required. Both designs are illustrated in Figure 1.

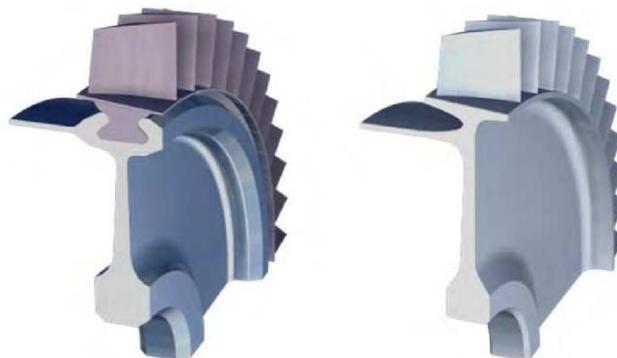


Fig. 1. Mechanical attachment blade-disk (left side) and of a BLISK (right side)

BLISKS can be produced by machining from a single forged part or by welding individual blades to a disk structure. This paper covers the welding process and its application to manufacture BLISKS of titanium alloys.

II. BLISK PRODUCTION

BLISK is one of the most original components in modern aero-engines. First used in small engines for helicopters, BLISK was introduced in the year 1980's for military airplanes engines, and it is rapidly introduced in commercial turbofan and turboprop engines. This is due to its advantages, such as:

- weight saving (usually as much as 20-30%): resulting from the elimination of blade roots and disk lugs
- high aerodynamic efficiency: because BLISK diminishes leakage flows
- Eradication of the blade/disk attachment, whose deterioration by fretting fatigue is very often the life limiting feature.

Of course, BLISK has disadvantages too. The main one is the laborious, and then expensive, manufacturing and repairing processes. Also, an exhaustive quality control is required to ensure reliable performance. Development efforts are currently trying to mitigate these drawbacks.

BLISKs can be produced by machining from a single forging or by bonding single blades to a disk-like structure. Depending on the material and also on the design, factors that in turn depend on its location in the engine, each BLISK has its particularities that determine the selection of the manufacturing process. A complete description of the optimization process for BLISK design and manufacture is given by Bu mann et al. (2005).

In the case of BLISKs produced by machining, there are also two possible paths: milling the entire airfoil or using electrochemical material removal processes. The first technique, illustrated in Figure 2, is used for medium and small size blades.

In the case of low pressure compressor stages, where the length of the blades is a significant proportion of the diameter of the total component (disk + blades), machining the BLISK from a single forged raw part is a costly and inefficient way.



Fig. 2. BLISK machining by high-speed milling (courtesy of MTU Aero-Engines).

Therefore, welding the blades to the disk becomes a more effective approach. Figure 3 shows the three first stages of the low pressure compressor of an EJ200 aero-engine. This engine is fabricated by using the BLISK technology.



Fig. 3. Low pressure compressor of the Eurojet EJ200 turbofan engine fabricated with the BLISK technology.

Full qualification for aero-engine application has been achieved for LFW manufacturing route. Design and manufacturing advantages derived of the fabrication of BLISKS by LFW \square in front of other processing routes are:

- High integrity welding technique
- Low distortion of the welded parts
- Heat affected zone of very fine grain
- Porosity free
- Possible welding of dissimilar alloys for disk and for blades
- Fabrication of large diameter BLISKS without the need for huge forged pancakes
- Tolerances in position and angles of welded blades are very accurate.

III. TITANIUM ALLOYS FOR BLISKS

A modern commercial aircraft is designed to fly over 60,000 hours during its 30-year life, with over 20,000 flights. This amazing capacity is for the most part a result of the high performance materials used in both the airframe and propulsion systems. One of those high performance materials is titanium.

The aerospace industry consumes 50% of the world's annual titanium production that was of almost 218,000 tonnes in 2010. Ti alloys make up 20% of the weight of modern Jumbos. For example, the new generation of huge commercial airplanes, i.e. Airbus A380 and Boeing 787 Dreamliner, include between 130 and 150 tons of titanium components per unit. Military aircraft demand also drives titanium usage. On the other hand, nowadays the range of Ti alloys available is very wide and this is a reflection of its growing use outside the aerospace sector, for example in chemical, marine, biomedical, automotive and other industrial applications.

In the case of the propulsion systems, selection of materials is based on their resistance to a combination of high loads and temperatures, together with extremely high safety levels. Typical engine materials are characterised by high specific strength values, i.e. strength divided by density, together with excellent reproducibility of mechanical properties. In this perspective, the development of modern gas turbine engines is mainly based on nickel-based superalloys, but Ti alloys also figure significantly. Around 33% of the weight for a commercial aircraft engine is due to the use of Ti alloys. For military engines this value approaches 50%. The main properties that justified the success of Ti alloys in aero-engines over the last five decades are their high specific strength, together with good corrosion resistance and weldability. However, titanium has a limited temperature capability, mainly due to oxidation constraints; therefore, Ti alloys are used for parts under moderate temperatures (i.e. fan and compressor) whereas nickel alloys are preferred for the high temperature regions (i.e. last stages of the high pressure compressor and turbines).

Titanium has two allotropic forms: alpha (α) and beta (β). α refers to hexagonal closed packed crystal structure, while β denotes cubic centred body structure. α and β are the basis for the commonly accepted classification of Ti alloys in four types: α , near- α , $\alpha + \beta$ and β . These categories denote the microstructure after processing and heat treatment. In general, α and near- α alloys have better creep and oxidation resistance, $\alpha + \beta$ alloys possess an excellent combination of strength and ductility, whereas β alloys have good formability and may be hardened to reach high strength levels (Donachie, 2000)

For low pressure compressors and the first stage of the high pressure compressor, where maximum operating temperature is 555^oC, principally $\alpha + \beta$ Ti alloys are used. Typical titanium alloys in fan and compressor disks for civil aero-engines are Ti-6Al-4V (Ti-64) for applications up to 300^oC and Ti-6Al-2Sn-4Zr-2Mo-0.15Si (Ti-6242) for service up to 480^oC. The first alloy is the standard alloy and the later one is a near β - alloy. Ti-6Al-2Sn-4Zr-6Mo (Ti-6246) and Ti-5Al-2Sn-2Zr-4Mo-4Cr (Ti-17) are the only approved and certified (very important point in aero-engine business) high strength $\alpha + \beta$ -titanium alloys. They are considered high strength alloys because offer 10-20% higher tensile strength than the typical Ti-64 and Ti-6242, and even higher values can be obtained when used in β - processed conditions. This high tensile resistance is maintained up to 300^oC for Ti-17 and up to 450^oC for Ti-6246.

On the other hand, the design constrains for disks and blades are different. Whereas high tensile strength and low cycle fatigue resistance are the most relevant properties for disk materials, high cycle fatigue and creep resistance are the main desired characteristics for blades. From this perspective, a possibility for optimisation of compressor performance would be to manufacture stages with a “disk-optimised” material condition for the disk combined with a “blade-optimised” material condition for the blades. Depending on the position in the compressor, a certain combination may be the optimum, whereas at another position another combination would be the right choice. For example, in the temperature regime from 430 to 520°C, an excellent combination would be a β -processed high strength Ti alloy (Ti-6246 or Ti-17) for the disk whitt the typical Ti-64 or Ti-6242 alloys for the blades.

BLISKS produced by machining must comprise one single material, with the same microstructure for disks and blades, the specific condition being mostly optimised for the disks. In opposition, the use of the welding to manufacture BLISK opens this innovative possibility of joining dissimilar alloys, choosing the most convenient alloys and microstructures for each component, i.e. for disks and for blades.

IV DUTIFISK PROJECT

It is expected that BLISKS with optimised material conditions, such as it was described in the section 4 of this chapter, would offer an improved in-service performance. But this will be true only if the mechanical properties of the weld-zone are good enough too. Nevertheless, these properties are difficult to predict because the microstructure produced by joining two different alloys by LFW may be very different of the base materials. Therefore, an ambitious European R&D Program was envisaged with the objective of characterizing the microstructure on the weld-zone and to determine the mechanical response of different combinations of titanium alloys selected to optimise BLISK performance. This research project, called “Dual Material Titanium Alloy Friction Welded BLISK”, acronym DUTIFRISK, was carried out during 54 months, from April 2002 to September 2006. MTU Aero Engines (Germany) was the project coordinator, although another aero-engines producer, SNECMA Moteurs (France), contributed to the project too. Other participants in the project were: Böhler Schmiedetechnik (Austria), as a Ti alloys supplier; TWI (England), as the main LFW expert centre; ENSMA-CNRS (France) and CIEFMA-UPC (Spain), as research centres with large experience on materials science and technology.

V. PRODUCTION AND VALIDATION OF BLISK DEMONSTRATOR

Production of BLISK demonstrators was the last work package of DUTIFRISK project. The objective was assessed and validated the relevant linear friction welding process features on a real part scale. The geometry of the disk and the blades was simplified to reduce the machining cost. In the case of the blades, they were replaced by rectangular blocks, whereas Figures 4 is a photograph of a disk for one of the demonstrators.



Fig. 4 Disk for BLISK demonstrator

Linear friction welded joints of BLISK demonstrators were validated by performing microstructural characterisation and mechanical testing and comparing the results with those obtained from laboratory specimens. Consequently, after welding the blades to the disk, demonstrators were cut in order to extract blocks for machining testing specimens. Figure 5 shows the pre-machined BLISK demonstrator after extraction of blade-blocks. Those blade-blocks were post-weld heat-treated prior to the machining of the specimen blanks. Tensile and HCF tests were carried out and mechanical properties values were similar to those obtained within the normal scatter of materials data.



Fig 5 Pre-machined BLISK demonstrator after extraction of blade blocks

VI. FUTURE RESEARCH WORK

BLISK is a critical part of an aero-engine, for that reason it is obvious that the integrity and reliability of linear friction welds must be totally verified. In order to guarantee in service welds performance, more research is needed in several fields: Optimisation of LFW parameters for each particular combination of alloys; Improving the understanding of the relationship between the very fine microstructure on the weld zone and its mechanical properties, especially concerning fracture toughness; Development of advanced inspection techniques adapted for BLISK inspection, such as computer tomography and ultrasonic inspection, is vital to reveal defects in the welds. On the other hand, the final customers of aero-engines will accept BLISK technology only if suitable and affordable repairing technologies are available. Damages susceptible of being repairable are similar in a BLISK and in “normal” disk + single blades configuration, with the difference that an exchange of a blade in a BLISK is not as simple as for single blades. In DUTIFRISK project, a work-package was dedicated to this topic and the conclusion was that the most convenient repairing technique is the same LFW process (Mateo et al., 2009). However, further investigations should be committed to evaluate the effect on mechanical properties of successive welds in the same area and then to establish repairing procedures.

VII. ACKNOWLEDGEMENT

The author is thankful to the team of DUTIFRISK project team and also grateful to Mr. Antonio M. Mateo Garcia, CIEFMA-University Politecnica de Catalunya – Spain has given the valuable information to the research scholars who want to pursue their research work in this area.

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