Integration of HF and SPF technology in an efficient industrial production flow for high rates aeronautical parts

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Abstract. The presentation will illustrate the creation and production ramp-up of the Titanium Hot Forming and Superplastic Forming Technology in a French aeronautical supplier from Industrialization to A320NEO full-rate production. With deformation and elongations well beyond classical « cold » sheet metal forming capabilities (especially with high-strength titanium alloys such as Ti64 and refractory Ti6242), Hot Forming and Superplastic Forming were key assets to be complementary to other standard manufacturing methods already used in the factories of the LAUAK group. Several aspects of the project will be presented, including the installation of HF/SPF workshop and presses, the industrialization steps of Airbus A320NEO pylon parts from tooling design to the qualification, and then integration of the HF & SPF in the full logistics flow of the factory production lines (from the material, blanks, forming, 5-axis laser trimming and machining, control and finally assembly). Some of the industrial challenges faced and overcame will be highlighted and illustrated.

Introduction

Mostly driven by cost and performance improvement objectives, Titanium was introduced in the aeronautical industry and is now used more and more widely. Applications of Titanium alloys increased in the last forty years and can now represent up to 15% of the total weight of a modern airplane.

Uprising in environmental awareness in conjunction with energy prices boosted the need for lighter higher performance materials, especially to accommodate higher temperatures for engines and exhausts. High-temperature resistant titanium alloys such as Ti-6-2-4-2 could be considered as an interesting option to substitute for much heavier nickel-based alloys (i.e. Typ. Inconel) for application of semi-high temperature where Ti-6Al-4V would give up.

Industrialization of parts with such materials could be a real challenge, especially in the context of higher volume productions of bestselling aircraft programs like the A320NEO (Fig.1). This publication will present the development and production activities of LAUAK of refractory Titanium alloy formed parts on engine pylon (Fig 2).

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Fig 1:Airbus A320 NEO (2 engine versions available)

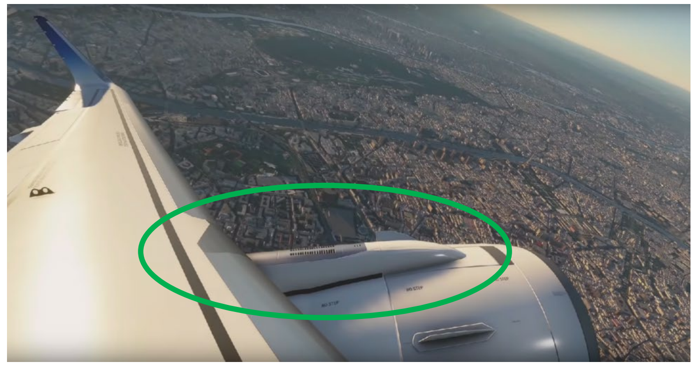

Fig 2:A320NEO Pylon with SPF and refractory Titanium applications

LAUAK GROUP

LAUAK Group is highly active in the aeronautical industry, with operation in 10 production sites in 5 Countries with more than 1600 employees.

Specialized in elementary parts and sub-assemblies for major aircraft manufacturers and tier 1 suppliers, the major division (LAUAK AEROSTRUCTURES) is experienced with various activities like machining, sheet metal forming, welding and assembling, both on light alloys and hard metals (Fig3).

Fig 3:LAUAK AEROSTRUCTURES main activities and partners

Titanium Hot Forming (HF) and SuperPlastic Forming (SPF) Workshop

The development of the Titanium applications in the pylons of the Airbus new program A320 NEO (New Engine Option) pushed the need for new production processes and machines in the LAUAK Hasparren Plan (Pays Basque – FRANCE).

A dedicated workshop (Fig 4.) was created in 2018 in order to accommodate two new Hot forming and Superplastic Forming Presses with platen dimensions up to 1.8m x 1.5m and temperatures up to 940°C.

Five years later, a third machine is now installed and more than 10 000 parts are produced per year with either Hot forming or Superplastic Forming technology.

Fig 4:LAUAK HF SPF Workshop with 800T PRESS

Production organization was a key factor to create a functional production unit with high-performance “Means and Tools”, but also skilled and trained operators supported by a strong technical team and process experts.

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The full integration of the Titanium hot forming workshop (Fig5) in the global production flow of the whole factory is a major element for the best industrial performance achievement.

Good interaction with all "support services" are also a major contributing factor of the global performance: Method, Logistics, Quality, Purchase, IT, Laboratory, Maintenance,… all with daily interaction, especially in the context of recurring high production rates.

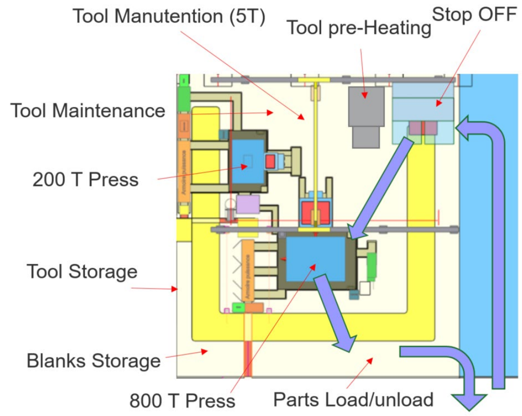

Fig 5:HF/SPF Workshop Flow and environment

Industrialization process

After being awarded new productions and selecting the manufacturing methods, the industrialization process starts with "definition analysis" to design the tools needed for parts production in the most efficient way regarding the global company's main objectives of performance: *Quality, Cost and Delay*.

In Titanium sheet metal applications, Ti6-4 can only be "cold-formed" to 10% elongation. Related to typical part geometry and complexity, Hot Forming is then usually a good option if you need to reach up to 60% elongation. In case of much more complex shapes with higher deformations and elongations (up to 300%), SPF would be the alternative but would require a higher forming temperature and longer processing time.

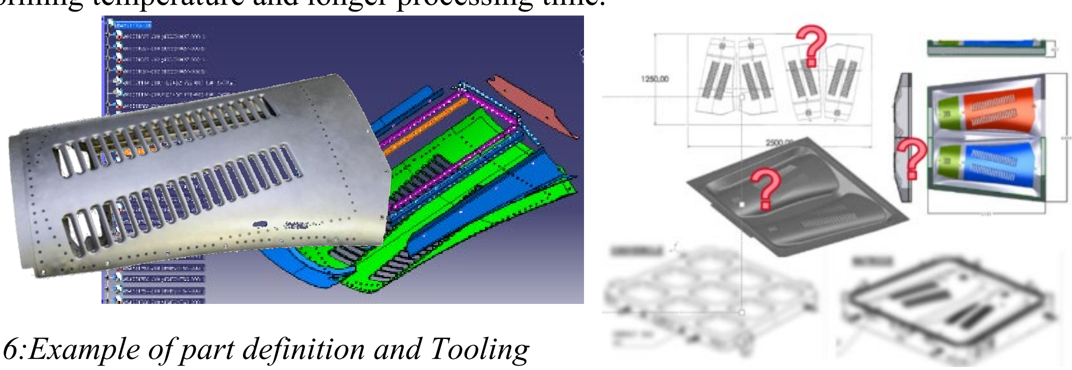

Fig 6:Example of part definition and Tooling configuration analysis

The "manufacturing cost" analysis (Fig 6) is a critical step and is the occasion of many practical choices where you ABSOLUTELY do not want to take wrong decisions or make mistakes, especially for high-rate production situations. Typical choices are related to part-forming technology and configurations, tooling types and materials, calculation of future forming parameters and machine selection.

Mistakes in the definition of hot forming dies worth 100 to 300 k€ could be a nightmare both from an economical and a planning point of view. Leading hypothesis and tool definitions have to be secured and optimized as much as possible during all the industrialization design phase.

As an important part of LAUAK production capabilities "Cold forming" manufacturing alternatives are often evaluated to check parts formability limits in order to get the best understanding of the Hot forming eligibility and industrialization.

Detailed CAD studies are often tested with FEM simulation in order to secure critical hypotheses and decisions regarding tooling designs and choices (Fig 7).

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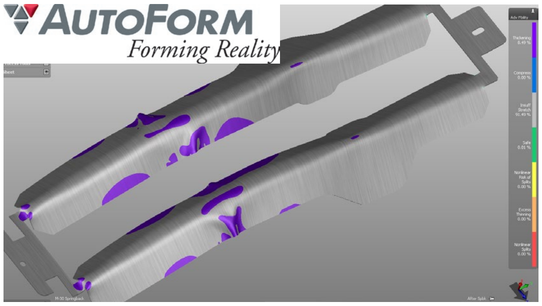


Fig 7: LAUAK studies with AUTOFORM to predict and localize critical zones (left) compared to real part trials (above).

Many specific questions related to HF/SPF tooling studies and detailed design need to be nailed just right in the first attempt in order to carry the project to success (Fig 8).

As an example amongst critical details: thermal differential dilatation of Ni-based (tooling material) and Titanium (part) have to be COMBINED to precisely define a tool machining modifier coefficient (0.9###) in order to target accurate final part dimensions. One of the many challenges to overcome…

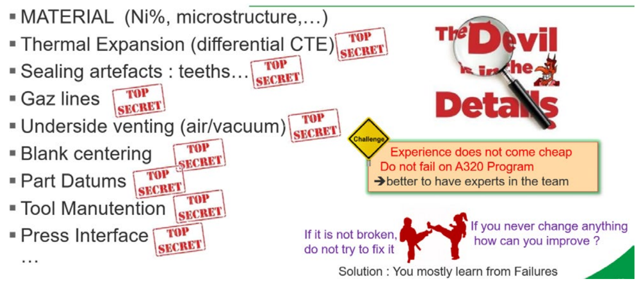


Fig 8:Example of SPF tooling design "hot" topics

Production / Hot Forming & SPF: in the heat and fire thou shall be formed

As an example of Titanium's important components of A320NEO, two main applications of hot forming and superplastic forming in pylons are presented (Fig 9).

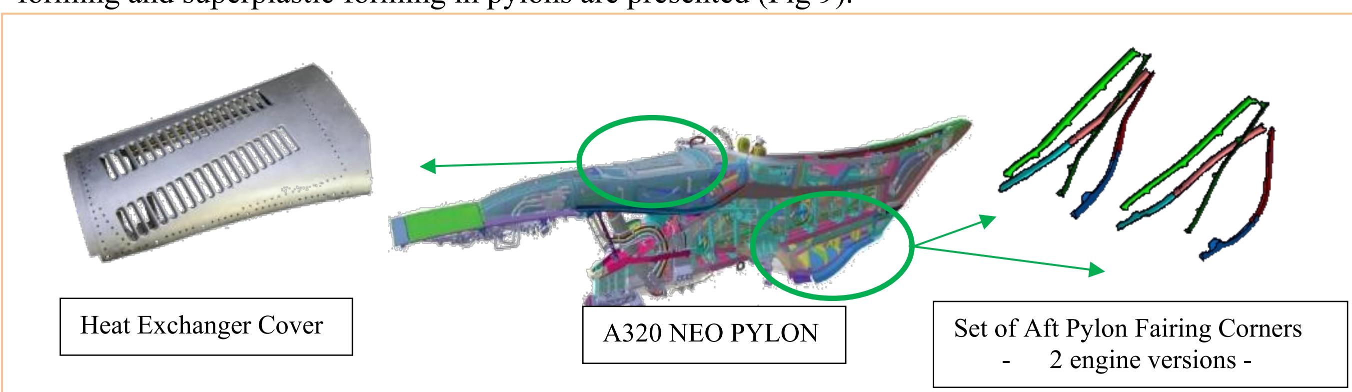


Fig 9 : Examples of applications For LAUAK Titanium SPF and Hot Forming for High Volume A320NEO Productions

The "Heat exchanger cover", with an aerodynamic 3D shape and louvered discharg[illegible]s, is produced by superplastic forming of Ti6-4 sheet.

Using the maximum efficiency of our SPF 800T/ 1.8mx1.5m capacity press, each blank is capable of forming several parts per cycle, with more than 10 cycles per day, making the process efficient and capable of high production volumes.

The main challenge was the design of an optimized tool being able to sustain the hard forming conditions with Thermo-mechanical cycling at 920°C + stress caused by 500T + 30 bars applied in the SPF process.

Fig 10: High-temperature SPF blank extraction at 920°C

SPF Production with dimensions more than 1.5m needs special care regarding the hot unloading phase (Fig 10) because forces applied to extract the part from the "sticking hot SPF tool" can be a source of important distortions. *Most of the dimensional defects of large SPF-formed parts are generated between extraction and cooling*. Extra care is needed during the "stripping + handling" phase, including finding the best sequence with special manutention tools, and if needed cooling jigs. Quality of shapes needs to be controlled, usually with templates. With the proper optimization of the process (and it might be tricky to find), the need for final shape adjustments can be completely avoided, and this is what you have to aim for, dealing with high volume A320 parts!

Efficient reliable tool sealing and argon lines are also key for production stability. Adequate tooling care and maintenance ensured our tool's good production capacity for more than 2000 cycles.

Thanks to the quality of the initial industrialization and the commitment of the production staff, The HF SPF LAUAK workshop has been able to steadily form and deliver SPF productions (Fig. 11) towards downstream operations during the last four years.

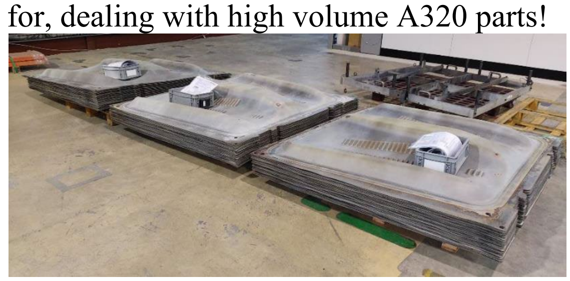
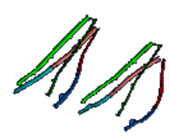


Fig 11 : Example batch of SPF formed blanks ready to be transferred to next operations (i.e. : Laser 3D Trimming)

The "Aft Pylon Fairing (APF) corners", represents even a greater technical challenge with twisted complex and 3d profiles with deep bending and joggles (Fig 12). The need for a more heat-resistant titanium alloy (Ti6242) due to parts positions close to the engine exhaust makes the forming *even more difficult* with unusually important stress caused on the Ni-based hot forming tools.



With kits of more than twelve different individual parts requiring tools for each operation like forming, laser cutting, fitting, machining, control, … Detailed studies were conducted and more than 70 different toolings were required to design and produce for the full manufacturing process of this work package.

Fig 12: Example of complex 3D shapes challenging HF limits

Hot forming tools were the most challenging to design due to part complexity and unusual extreme HF process parameters of the 6242 material.

All three LAUAK Hot Forming machines (Fig 13;14;15) are successfully contributing to the industrialization with more than a dozen of different HF new tools involved in this project.

Fig13:APF Corners forming on 0.9x0.6m press

Fig14 : Ti6242 HF on 1.2x1.2m Press

Fig15:Ti6242 production on 1.8x1.5 Press

In addition to the 3D shape of most of the parts being really complex, the major challenges for this "APF Corners" application were caused by the refractory nature of the Ti Alloy used. The specific chemical composition (6%Al, 4% Zr, 2% Mo and 2% Sn) being source of significant higher mechanical properties at elevated temperatures than the usual 700-750°C used for HF with Ti Alloys like Ti64.

Some problems were faced and tooling design optimizations were needed to improve deformations trajectories regarding tooling contact causing scratches (Fig.16) and unacceptable tool surface degradation, especially considering this program needed to be conducted for several years with high production volumes.

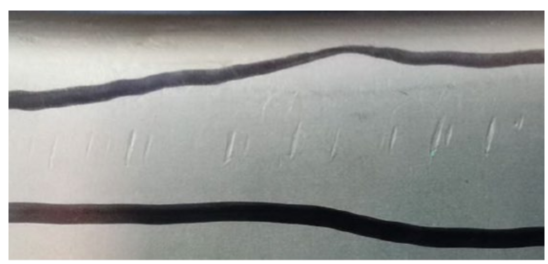


Fig 16: Example of scratches with Ti6242 HF

Optimum forming parameters were explored in order to find the best balance between "*Higher temperature for reducing spring-back and metal toughness*" and "*not too high to maintain minimum part toughness for handling and preserving tool life"*

Serial production started in 2022 in the frame of a careful quality control (Fig17) and process monitoring of the production (Fig 18) to secure the HF/SPF performance and part production flow.

Fig 17: Example of Dim control jigs

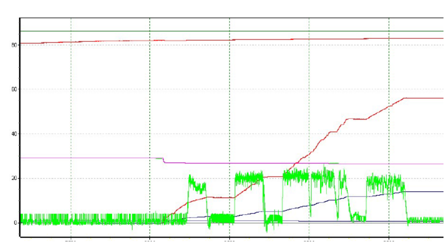


Fig18: Example of process control monitoring

Other contributing factors such as lubrication and tooling maintenance were also identified as key to maintain the best quality of formed production month after month.

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There are more things in life than Hot forming: Other Productions steps and Logistics

Of course, the Production of these parts does not start and stop at the hot forming sequence.

From the starting material supply (Titanium alloys sheets) to the finished part controlled, packed and ready to be delivered, many critical steps (Fig 19) need to be conducted in almost every LAUAK workshop, preferably under the management of the Logistics teams to optimize "On Time Delivery" (OTD).

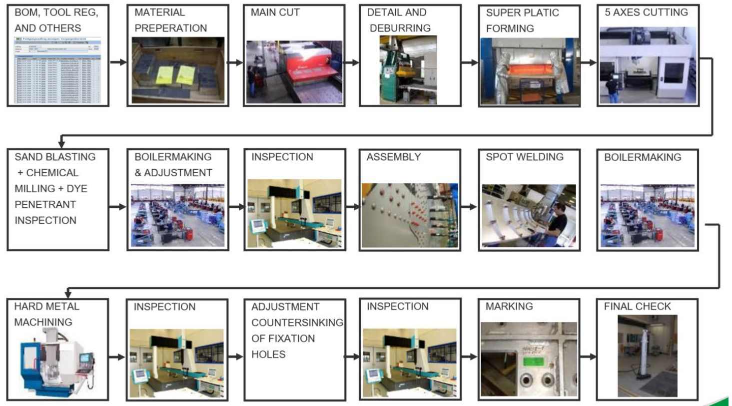

Fig 19 : Full production workflow of Heat Exchanger Cover

<u>Prior hot forming</u>, early operations include Material supply (sometime to be ordered 12 to 18 months in advance for Titanium Material) and laser 2D blank cutting (Fig 20).
Efforts are being made on a daily basis to optimize blank placement on sheets to reduce material loss.

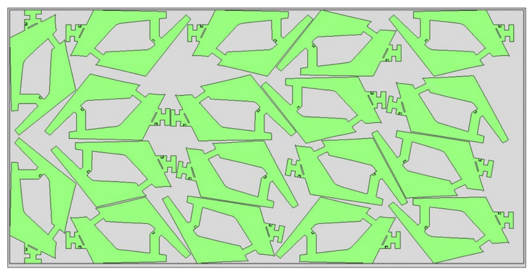

Fig 20: Example of 2D laser cutting blank material optimization

<u>After forming</u>, Main operations are usually 3-axis laser Cutting (Fig 21) and/or machining (Fig 22) (drilling, chamfer, countersink…) to produce the final part contour and interfaces for fasteners ready for assembling (Fig 23).

Fig 21: 5-axis (3D) Laser Cutting

Fig 22: Machining (Contour and Drilling)

Fig 23: Assembling

The efficient use of an "Enterprise Ressource Planer" Software (ERP) is critical not to be lost in the 20 000 "production works orders" (aka job cards, or traveler) currently active at any given time in the plant due to all simultaneous running other productions. Enough anticipation and adhesion to MRP planning are critical for organizing, especially for "high runner" productions.

In addition to our ERP, we launched a project to improve our logistics performance based on geo-localization tags and smart visual planning named "*HORDAGO*" (meaning "*It is there*" – in the Basque language).

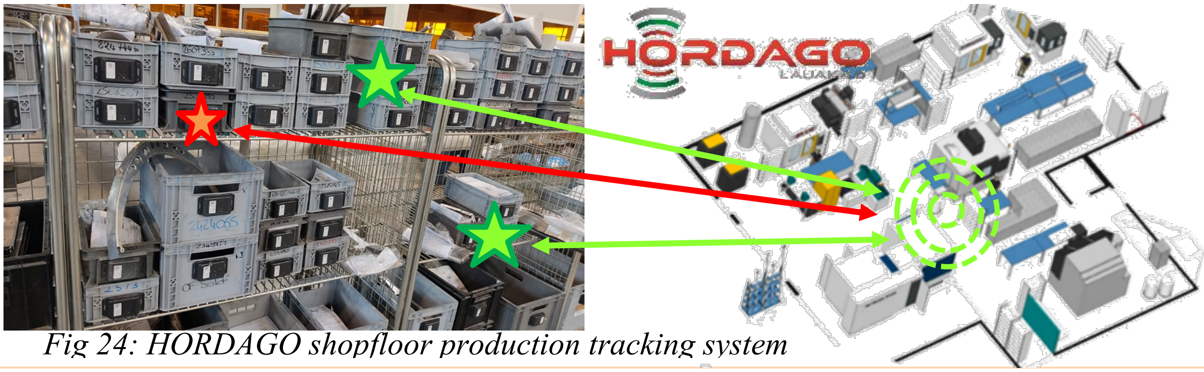

Fig 24: HORDAGO shopfloor production tracking system

Every running production is equipped with wireless tags detected by gates and sensors and can be identified and localized in seconds (Fig 24). Each tag is also linked dynamically to the planification databases and can “call workers for action” via red and green LEDS when needed to help prioritise jobs at the workstation level.

Conclusion

Since 2019, LAUAK has been part of the A320NEO program with several HF and SPF titanium pylon components and demonstrated that these processes can be fully integrated as complementary assets in the global manufacturing frame of a major Tier 1 Aeronautic supplier in addition to all other more classical production activities and technologies such as standard sheet metal forming, welding, machining, assembling,….

Of course, a strong and experienced in-house technical support team is needed to drive all studies and new industrialisation projects taking into account the specifics of Titanium Hot Forming technologies (tooling design, material limits, …)

Finally, to maintain production stability, some specific elements in the Titanium HF and SPF way of life had to be taken into account to steadily sustain the Ramp-UP and the high production volumes associated with the success of the A320. As an example, critical equipment such as SPF Presses need to be kept in the best condition possible by application of consistent Predictive Maintenance to closely monitor machine performance evolutions.