Executive summary

In the aircraft, there are high costs and long lead times associated to the production of sheet metal parts made of titanium and other difficult-to-deform materials such as after pylon fairings, fan blades, exhaust ducts or air collectors because the forming technologies used today (cold/hot stamping, SPF) are based on dedicated tooling.

The INMA project aimed to decrease production costs and to gain flexibility when manufacturing sheet metal parts made of titanium and other difficult-to-deform materials by introducing the asymmetric incremental sheet forming technology (AISF) into the production chain.

The AISF technology shows the potential to produce complex sheet metal parts without dedicated tooling. Thus, the development costs can be reduced and agility and flexibility be gained during the design phase for prototyping or the production of spare parts and low volume series.

The project contents were oriented to the deployment of an AISF technology for titanium and other difficult-to-deform materials and considered: generation of experimental process data, acquisition of process numerical simulation capabilities, characterization through material testing and analysis of the deformed material properties, development of a knowledge-based (KB) tool path correction utility to compensate the part geometric deviation and implementation of hot forming for materials of interest, namely Ti 6Al-4V. Relevant foreground was generated in all these fields and allowed fabricating an Inconel 718 strut half and two generic shapes made of Ti 6Al-4V showing typical design features of pylon fairings.

The assessment of these parts reported promising results about the attainable quality of parts, even in terms of the geometric accuracy, representing a significant step forward towards the future industrialization of technology.

The integration of the AISF technology in the aeronautic production will not only bring cost reduction and increased flexibility through specific tooling avoidance but also other benefits such as a decreased consumption of lubricants and energy or new job opportunities for researchers. Relevant industrial participation in the project makes very likely the rapid orientation of the generated results towards its acceptance, approval and final exploitation.

Project context and objectives

Sheet components made of titanium and its alloys mostly concentrate in aircraft areas where high strength-to-weight ratio combined with excellent corrosion resistance and strength at elevated temperatures requests must be met. The pylons, the nacelles or the engine itself are sub-assemblies where many of these components are found. Examples include after pylon fairings, fan blades, exhaust ducts or air collectors. Additionally, growing use of composite structure is making the content of titanium sheet components increase in the airframe

"AISF is a technology which features the potential to produce complex sheet metal parts without dedicated tooling"

due to titanium galvanic compatibility with the carbon fibres which is not fully guaranteed by corrosion protective coating of aluminium. Moreover, titanium can also be found in areas where specific requests make it the best choice. Such is the case, for instance, of the cabin area where the crown panel must show high impact resistance to withstand the damage incurred during bird strikes. Thus, titanium made sheet components seem likely to progressively increase in order to contribute to the weight reduction requested to decrease fuel consumption and consequent CO_2, NO_x and noise emissions which penalize the environmental impact of aviation.

However, forming technologies being used today by the aircraft industry to shape titanium (e.g. cold/hot stamping, SPF, hydroforming) make use of specific tooling which feature high costs and long lead times. Modifications in the tooling due to iteration between the design and industrialization phases and more and more frequent design evolutions also penalize costs and lead times.

The INMA project aimed to lead to cost reduction and increased flexibility when shaping titanium, and other other difficult-to-deform materials, by introducing the asymmetric the incremental sheet forming technology (AISF) into the production chain.

AISF is a technology which features the potential to produce complex sheet metal parts without dedicated tooling. Thus, the development costs are reduced and agility and flexibility are gained during the design phase for prototyping or the production of spare parts and very low volume series.

Asymmetric incremental forming robotic cell

In order to make use of the AISF technology to shape titanium, as well as other difficult to deform materials (e.g. Ni-base alloys) the following objectives were defined:

- Generate process data from experimental forming trials for the alloys of interest
- Implement and validate FE models that provide process simulation capabilities
- Perform material testing and analysis to generate a data base of the deformed material conditions
- Make use of knowledge-based (KB) techniques to generate systematic correction of the part geometric deviations
- Implement hot forming means and methods to deform relevant alloys (i.e. ti 6Al-4V)

Main S&T results and foreground

"significant improvement in the geometric accuracy of parts was observed compared to state-of-the-art practices"

Research activity oriented to fulfil the S&T objectives led to the following results:

- Process data were generated for grades Ti-40 and Ti 15-3-3-3. Process data included process parameters, tool paths and experimental practises.
- Process data were generated to hot form alloys of interest (i.e. Ti 6Al-4V).
- Cold Spinnability data were generated for grades Ti-40, Ti 15-3-3-3 and Ti 6Al-4V.
- Specific rolling tools were designed, fabricated and tested for both cold and hot forming operations.
- FE process models were implemented and validated to simulate cold forming of Ti-40 and hot forming of Ti 6Al-4V.
- Numerical computation techniques were tested to upscale the FE process models to real conditions (large scale parts, long tool paths).
- A specific material formability test was designed and formability data were obtained for Ti-40 and Ti 15-3-3-3.
- Post-forming material properties were tested and analysed for all cold and hot formed grades/alloys including metallographic analysis, static tensile testing and microhardness measurements.
- A classifier algorithm that predicts the geometric deviation of parts due to material springback was programmed and trained.
- An intelligent process model that using the classifier algorithm prediction provides a corrected tool path was implemented and validated.
- Heating means to heat up locally or globally Ti 6Al-4V along a hot forming operation were implemented and compared against each other.

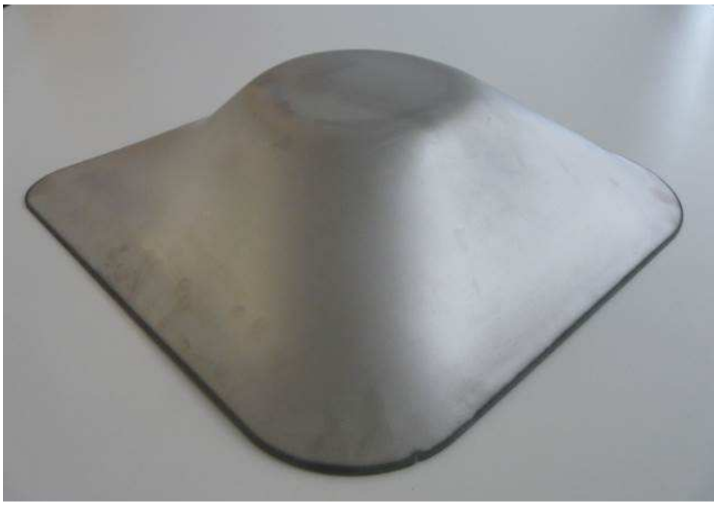
Based on the technology basis implemented demonstrator parts were fabricated and their quality evaluated aiming to assess the potential of the AISF technology for the intended target of fabricating aircraft parts.

A strut half made of Inconel 718 was produced by cold forming to assess the feasibility to fabricate parts made of Ni-base alloys and two generic shapes of Ti 6Al-4V including design features typical of pylon fairings were made using hot dieless in order to assess the geometric accuracy attainable by the process.

The assessment of the demonstrators reported promising results in terms of surface quality and thickness distribution. Even significant improvement in the geometric accuracy of parts was observed compared to state-of-the-art practices.


Engine strut half

Airframe generic shape with features from pylon fairings



	Before	After
Part within ±1mm range (%)	40.00	90.40
Max positive dev (mm)	3.42	1.39
Average positive dev (mm)	1.06	0.36
Max negative dev (mm)	-11.24	-3.40
Average negative dev (mm)	-3.24	-0.60

Geometric accuracy values before (left) and after (right) the hot dieless *approach implemented for Ti 6Al-4V.*

It can be said that though the implemented AISF-based technology requests from further technological developments yet, the generated results point out a significant step forward towards the industrialization of the technology for aircraft applications and, most likely, for applications from other sectors as well.

Potential impact

"avoidance or decreased use of specific tooling will have a strong impact on the component final cost and its associated lead time from the design office to serial production"

Main benefit expected from introducing the technology in the production chain will come from the avoidance or decreased use of specific tooling which will have a strong impact on the component final cost and its associated lead time from the design office to serial production. In particular, by producing prototype parts using the AISF process interaction between the design and industrialization phases does not make use of specific tooling. In the case of the production of spare parts or low volume series the impact is much higher.

There are additional benefits that can also be expected:

- Decreased consumption of expensive (and usually very pollutant) lubricants since roller tools lead to lower friction between the sheet and the tool.
- Higher buy-to-fly ratios compared to SPF resulting from a better control of thickness.
- Decreased energy consumption of hot forming operations compared to SPF since the working temperature is lower.
- Reduced stocks of tooling derived from their avoidance to fabricate prototypes, spare/repair parts and low volume series.

The new technology will also contribute to bring new job opportunities for researchers and to strengthen the leadership position of the European aircraft industry.

Dissemination and exploitation

From numerous dissemination activities where information about the project and its results has been delivered it is worth to mention:

- Display of demonstrators, video and project banner with leaflets distribution at Farnborough International Airshow, Farnborough (UK), 20-14 July 2014
- Display of demonstrator parts at the PSA showcase, Vélizy (France), 30 April 2014
- Display of demonstrator parts and banner with leaflets distribution at TWI's Research for Impact Event (R4i), Cambridge (UK), 31 October 2013
- Oral communication, display of demonstrators and banner with leaflets distribution at the 3rd International EASN Workshop on Aerostructures, Milan (Italy), 9-11 October 2013
- Video display and leaflets distribution at the ILA Berlin Airshow, Berlin (Germany), 11-16 September 2012

An important number of contributions to journals and specialized conferences have also being made with the results generated by the project.

The consortium prepared an exploitation plan based on a list of exploitable results previously identified through a systematic methodology. Relevant industrial participation in the project, including the major European aircraft manufacturer, makes very likely the rapid orientation of the generated results towards its acceptance, approval and final exploitation.

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