3D Printed Control Surface for UAVs

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Abstract

3D printing, more known as Additive Manufacturing (AM) in the Aerospace industry, supposes a disrupting technology to design new components. Polymeric materials processed with SLS technology have been identified as a mature combination for non-structural parts. This paper collects the application of this technology for an integrated structural component, in this case an AM prototype for an UAV control surface. The new AM concept development process is presented, starting from the material characterization, followed by the redesign, and finalizing with the inspections and structural tests performed to demonstrate that the new design complies with the flight loads.

1. Introduction to Additive Manufacturing

3D Printing (or Additive Manufacturing, as is commonly known in almost every industrial sector) is defined as the process which allows, starting from CAD 3D models, objects to be built layer by layer. This process is clearly opposed to subtractive manufacturing technologies, such as traditional machining. According to ASTM International this definition includes a large number of different technologies that had been grouped as follows:

- **1. VAT Photopolymerisation:** This process uses a vat of liquid photopolymer resin. The resin is cured layer by layer over a mobile platform using ultraviolet (UV) light.
- 2. **Powder Bed Fusion:** These methods use a laser or an electron beam to melt and fuse powder. Powder from the supply chamber is spread over the build chamber, which is consolidated layer by layer by the action of the laser or the electron beam.
- **3.** Material Extrusion: These processes deposit the material by an extrusion head on the build platform where required, building the part depositing each layer over the previous one.
- 4. Directed Energy Deposition: These methods use a 4 or 5-axis robotic arm fitted with a powder nozzle or a wire feeder and a laser, an electron beam or a plasma ark. This arm moves around the substrate of the machine consolidating the part layer by layer, melting the powder or the wire.
- 5. Binder Jetting: These methods use two built materials: the base material (powder) and the binder (liquid), which acts as an adhesive. Powder from the supply chamber is spread over the build chamber which is consolidated by the binder, deposited over the powder using a print head.
- 6. Sheet Lamination: The different layers that compose the part are cut to their required shape and then joined together. For metals, the layers are frequently cut using a laser beam and then joined together by ultrasonic welding (Ultrasonic Additive Manufacturing, UAM).

- 7. Material Jetting: These technologies jet material from a nozzle that moves horizontally across the build platform. The material can solidify in a natural (ambient temperature) or in a forced way (UV light, photo-curing resins).
- 8. Hybrid Methods: These methods combine pure additive manufacturing techniques with traditional manufacturing techniques.

In the aerospace sector, where the majority of the parts are relevant from a structural point of view (loaded parts), the main advantages that additive manufacturing techniques have over traditional methods are, among others:

- **1. Increased design freedom:** These technologies allow manufacturing geometries that are impossible using traditional techniques.
- 2. Lightweight structures: Weight optimization of structures is especially important in the aerospace sector, and these technologies may help to obtain weight-optimized parts through the following mechanisms:
 - **a. Optimized structures:** Additive manufacturing techniques may allow manufacturing parts where material is only placed where it is needed. Specific software is being developed to help the engineers to create this kind of structures.

Moreover, the design constraints introduced by the manufacturing technique are fewer. Technological minimums reduction might be also considered as a way to optimize the structure. As a general rule, traditional techniques technological minimums are higher than those achievable by additive techniques.

- **b. Parts integration:** Additive techniques allow integrating parts reducing the number of joints, the number of standard parts used, etc. This mechanism may also have relevant impact on product cost and lead-time (less standard parts used, less assembly operations, etc.).
- **c.** Multifunctional parts: Integrating several functions in the same component might reduce the number of parts and therefore optimize the weight of the structure.
- **3.** Net shape manufacturing: Additive techniques allow manufacturing of net or near-net-shape parts. This might have the following advantages over traditional manufacturing techniques:
 - **a.** Less raw material consumption: Additive technologies put material only where needed, generating small amounts of scrap. Compared to subtractive techniques such as machining, the raw material consumption could be up to 25 times less, depending on part size, dimensions, etc.
 - **b.** Helps creating complex integrated parts: As previously mentioned, these technologies allow reducing assemblies, welding or brazing operations, etc. obtaining one-shot final parts.
- **4. Tooling reduction:** The amount of molds, clamps, metal forming tooling, removal tools, jigs, etc. is significantly reduced, as many of the parts are manufactured net shape or near-net-shape.
- 5. Cost and lead-time reduction: Cost and lead-time reduction in relation with classic manufacturing technique are especially relevant for complex parts or for short series. Even though being in one of these two scenarios, it is recommended to perform an exhaustive trade-off to ensure that the right manufacturing technique is chosen.

Not every manufacturing technique is suitable for any application as the materials available, the mechanical properties, the part finishing, etc. may vary from technique to technique. Taking into account all advantages and disadvantages of the methods and materials available, Selective Laser Sintering (SLS, one of the variants of the Powder Bed Fusion methods) and polyamide material were chosen to manufacture a control surface for a UAV.

Selective Laser Sintering (SLS) for polyamide works as follows:

- 1. A layer of raw material powder from the powder supply chamber is spread over the build platform.
- 2. The laser fuses the powder, creating the first cross-section of the part.
- 3. The supply chamber moves up and the build chamber moves down exactly the thickness of one layer.
- 4. The leveling roller spreads another layer of powder and the process is repeated.



Figure 1: SLS Process (schematic).

This manufacturing method for polymers allows producing parts with hollow structures and overhangs without support structures. This is one of the main differences of powder bed fusion techniques applied to polymers and metals, as metals, in general, do need support structures for overhang surfaces below 45° with respect to the build direction.

Moreover, it is important to define at the design stage the sizes and positions for the holes which will allow the removal of the un-sintered powder. This is an important consideration to take into account for the ruddervator design, since it might be partially hollow.

2. UAV Tail and Control surfaces: V-Tail and Ruddervators

V-tail (or butterfly tail) is an uncommon arrangement of the tail stabilizing surfaces with two aerodynamic surfaces positioned in a V-shaped configuration, viewed from centerline of the aircraft. Each aerodynamic surface consists of a fix part (fin) and one or several moving parts (ruddervators) to control the pitch and the yaw of the aircraft. Although there are exceptions, the V-tail is symmetrical to the aircraft centerline. A classic example of an aircraft with this configuration is the Beechcraft Bonanza Model 35 (first flight, 1945). Compared to the same aircraft but with conventional tail (Beechcraft Debonair Model 33, later renamed Bonanza Model 35 with conventional tail) the version with the V-tail was 5 knots faster (less aerodynamic drag).

This concept was developed in the 1930 and although having some advantages over the conventional cruciform or T-shape arrangements (minimization of the fuselage-tail interference aerodynamic drag, rudder blanketing at high angles of attack, less wetted surface compared to the conventional tail configuration and enhanced stealth characteristics for military aircrafts), nowadays it is mostly used to avoid placing the vertical tail in the exhaust of the engine in civil aircrafts with small turbofan engines mounted outside of the fuselage (Cirrus Vision SF50 or Eclipse ECJ/400) or to avoid damaging the tail when landing on unpaved runways (mainly for gliders).

Enhancing stealth characteristics might have influenced the V-tail arrangement in some military aircrafts as the Lockheed F-117 Nighthawk, the General Atomics MQ-9 Reaper or the Northrop-Grumman RQ-4 Global Hawk, as inclined surfaces help to reflect the radar signal in different directions. Moreover, the V-tail arrangement in the MQ-9 Reaper and in the RQ-4 Global Hawk allows the engine to be mounted above the fuselage between the tails. This configuration may also help to reduce the infrared signature of the engine installed below the fuselage.



Figure 2: Beechcraft Bonanza 3 Views.

V-tail configurations have also disadvantages: They require a much more complex control system (mixer) so the pilot notices no difference regarding the control of the aircraft compared to a conventional tail arrangement. They are structurally more robust (penalty weight) than the conventional tail arrangements due to the increased aerodynamic loads involved, which are translated into higher control forces to operate the control surfaces.

3. AIRBUS ATLANTE Ruddervator

In the following sections a brief description of the AIRBUS ATLANTE unmanned aerial platform will be described.

3.1 ATLANTE General Description

ATLANTE, an acronym which stands for *Avión Táctico de Largo Alcance No Tripulado Español* (Spanish Tactical Unmanned Aerial System), is an unmanned aerial system defined to meet the requirements of Spanish Army for an Unmanned Aerial Vehicle (UAV) with ISTAR capabilities (Intelligence, Surveillance, Target Acquisition and Reconnaissance) 24 hours a day in adverse climatologic conditions.

Moreover, it shall be able to carry out missions oriented to fighting terrorism and piracy, immigration control, drug trafficking, managing natural disasters, coordinating fire fighting activities, supervising critical infrastructures, railways, airports and highways besides searching and identifying people in danger or missing.

First flight was on the 25th of September 2014.



Figure 3: AIRBUS ATLANTE Aerial Platform.

Length	5470mm	
Span	8000mm	
Height	1847mm	
Maximum Take-Off Weight (MTOW)	570kg	
Payload	60kg (Baseline), 100kg (maximum)	
Range	150-200 Km	
Endurance	10 hr	
Cruise Ceiling	15000 feet	

Table 1: AIRBUS ATLANTE General Characteristics and Performance	es
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Figure 4: AIRBUS ATLANTE 3 Views.

3.2 ATLANTE Ruddervator

The aircraft presents 4 ruddervators (2 per side). The dimensions of each ruddervator are shown in Table 2:

Dimension (mm)	INBD	OUTBD	
Length	475	745	
Maximum chord	200	160	
Minimum chord	160	105	
Maximum Profile Height	42	35	
Minimum Profile Height	35	25	

Table 2: ATLANTE Ruddervators approximate dimensions

The structural arrangement of each ruddervator is exactly the same, only the dimensions change. For this project the INBD Ruddervator was chosen, as dimensions are critical to guarantee the manufacturability of the part, compared to the selected printer build chamber.

Current ruddervator presents a complex architecture consisting of a Rohacell core covered by a carbon Fibre Reinforced Plastic (CFRP) skin. The extremities of the core (where the ribs are attached) are covered by a Glass Fibre plies in order to avoid the component from water ingestion and to prevent corrosion between the composite and aluminium parts. The outer surface of the ruddervator is covered by a copper mesh ply in order to fulfil the lightning strike requirements applicable in this zone of the aircraft.



Figure 5: AIRBUS ATLANTE Ruddervator.

A pair of metallic ribs (Al7050 T7451) is installed in the extremities of the ruddervator. These ribs are riveted to the skins and include the hinge points of the control surface (with bushings installed). The inner rib also integrates the actuation point.

A pair of supports is installed in each rib to install the corresponding bonding jumpers.

4. Ruddervator AM Redesign

4.1 Material

Within the different polyamide materials available in the market and suitable for SLS technology, polyamide 12 is one of the most widely polymeric materials used for AM aerospace applications due to its flame retardant capability and powder recyclability which leads to cost reductions. This material is currently being qualified within Airbus to allow the different programs to deploy it but with clear restrictions.

As a first step the material will be only used for non-loaded applications (for instance: loom brackets, covers, furnishing...) within the fuselage of the aircraft and not submitted to high temperatures. This project, framed in a R&T activity, attempts to demonstrate the possibility to use type of material for the development of an AM control Surface to be installed in an UAV, in this case the previously presented AIRBUS UAV ATLANTE.

In spite of the significant lower polyamide 12 mechanical properties respect to the materials used for the original design (CFRP and high strength aluminum alloy) this material is identified as a suitable candidate due to the low level of flight loads to which the ATLANTE ruddervator is subjected to. Original design dimensions are not determined by the loads but by the aerodynamic shape to be respected and by the minimum thickness that can be produced with the manufacturing technologies applied. Even with the minimum thickness allowed by the machined aluminum and CFRP, strength reserve factors are still high indicating component overweight.

Since the material is not fully qualified yet within Airbus, material properties provided by AM printer developers were used for the sizing of the new AM design. However, experience in additive manufacturing shows that real mechanical properties can differ significantly from the ones announced by the printer developers and AM manufacturers. AM mechanical properties, independently of the material, are in general dependent to the printer used to consolidate the powder and the manufacturer experience in the printing process (powder management, printing process parameters...). For this reason a material characterization program was defined to obtain real mechanical properties of the printed material used for this application. Additionally, this data was used for the correlation analyses after structural test execution.

The following tests were carried out within the material characterization test campaign:

- 73 tensile tests on specimens with different position, orientations, test temperatures, ageing/no-ageing condition and surface conditions.
- 32 bearing tests on specimens with different orientations, test temperatures and pin diameters.
- 16 compression tests on specimens with different orientations and test temperatures.

Since the presentation and discussion of previous test campaign might constitute a technical publication itself, only the main conclusions which affect to the new AM design are presented in this publication.

- 1. Tensile tests of non-aged specimens at 23°C and provided mechanical properties below reference commercial values. A Reduction of 20% and 10% in ultimate strength and young modulus respectively was observed.
- 2. Machined tensile samples provided higher values close to commercial reference values. The surface roughness effect must be considered then for the static properties determination when using AM materials in as-built conditions. Two approaches can be followed to consider this effect. First approach consists in obtaining the mechanical properties directly from samples with the same surface conditions that the part to be designed (approach followed in this project). Second approach obtains the mechanical properties in machined conditions and considers during the calculations a section reduction by subtracting the typical roughness present in the design to the nominal section.

Although first approach may result more adequate, in reality, static mechanical properties should not be surface condition dependent. The differences observed between as built and machined surface conditions lay on the impossibility to calculate accurately the area of our sample in as built conditions (due to the surface roughness). In general the measured area would be bigger than the real one, underestimating this way the static mechanical properties of the material due to the use of a non-real reference cross section.

- 3. Tensile samples aligned with the printing direction exhibited slightly lower mechanical properties respect to the ones printed perpendicular to the printing direction. This difference, which was expected, is below 10% reason why the material was considered as isotropic for strength calculations.
- 4. Ageing and high temperatures generated, as expected, a detrimental effect on mechanical properties. As information, tests after ageing showed a reduction of ultimate strength and young modulus around 25% being this reduction, in the case of high temperature (80°C) combined with ageing, around 45% for the ultimate strength and 60% for the young modulus.
- 5. No fatigue samples were produced to have reference fatigue stress values. The new AM control surface was designed with a maximum stress value of 15 MPa to assure an infinite fatigue life. This value was chosen according to [1].

4.2 Optimization driven design process

As explained in chapter 1.0 one of the main advantages of the AM is the higher design freedom allowed by the technology respect to traditional manufacturing technologies. This freedom, if used in a wise way by the structure engineer, may lead to significant weight reductions which bring benefits to the aircraft industry and may result essential in the space sector.

During the last years structure optimization techniques have increased their popularity as consequence of AM development. These techniques, used in the aerospace industry for decades with other manufacturing technologies, represent a perfect ally of AM technology to exploit its full potential. However, the cost reduction obtained is probably the main reason why optimization techniques should be always used for AM, as long as the targeted application allows their use. Unlike traditional subtractive technologies, in the case of AM the less material printed the lower cost for our part due to the shorter printing time and raw material usage.

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In general, the optimization driven design process can be divided into two phases, the conceptual phase and the detailed sizing phase. The conceptual phase usually is supported by topology optimization analyses through which the structure engineer is able to find and optimized material distribution for the loads and boundary conditions stablished for the structure. The output from this topology analyses must be understood as a guideline, which must be analyzed and reinterpreted by the engineer using previous experience on the type of structure studied. Once a new design is proposed based on the engineering experience and topology optimization output, the second optimization phase may start. In this case parametric optimization techniques, usually known as size and shape techniques will define the final optimal dimensions of the structure.

In the following figure a scheme of the optimization process used for this AM control surface is presented.



Figure 6: Optimization Driven Design Process of an AM Part

4.3 AM Ruddervator preliminary designs.

Once discussed the AM capabilities to generate new geometries not achievable with traditional manufacturing technologies, the material properties provided by the SLS polyamide 12 and the simulation capabilities to generate optimized designs, the different concepts studied for the ATLANTE Ruddervator are presented. Three concepts were generated following the same principle; generate a new fully integrated and light weight control surface.

Topology optimization was used, as explained in previous chapter, to inspire the new concepts. From the original design it was known that the main sizing structural requirement was the skin buckling. For this reason the topology optimization searched to support the control surface skin with the minimum required mass. In Figure 6 the result of this topology optimization is shown. At a first sight the result might look like rare or difficult to interpret. However, paying attention to this result, valuable information may be extracted for the new AM design:

- 1. A front spar, connecting the hinge lugs is required to withstand the shear load.
- 2. To avoid skins buckling punctual reinforcements might be enough instead of continuous cores typically used for sandwich composite designs. An alignment of these punctual reinforcements with the control surface span is also observed.

Based on previous conclusions, which are supported by the engineering experience, three fully integrated different concepts were proposed. All concepts include holes at extreme ribs to allow powder extraction capsuled within the control surface during the printing process.

1. Lattice design. The most challenging concept for the technology. The intention of this proposal was to check the SLS technology capability to generate this type of structure made of thousands of bars. This design might be considered the closer to the topology output. Front spar made of lattice structure provides a great bending stiffness to the control surface and is enough to withstand the flying loads. Punctual columns, made also by bars, evenly distributed avoid the skin buckling.



Figure 7: Lattice Concept

2. Wavy spar. Following the topology indications regarding the front spar and supports aligned with the control surface span, the two wavy spars concept (to increase buckling strength) is proposed.



Figure 8: Wavy Spars Concept

3. Flat Spars. Same approach than previous concept but reducing the design complexity by flat spars.



Figure 9: Flat Spars Concept

The three concepts were sized against flight loads, printed and inspected to check the SLS technology capability to manufacture them robustly. Wavy and flat spars concepts generated new designs with a 50 % of mass reduction respect to original design. This weight reduction is increased up to a 60 % for the lattice concept. In spite of this major mass reduction the two flat spar concept was selected to be submitted to structural tests. The lower design complexity and easiness to be inspected and cleaned (unfused material removal from voids) makes the two flat spar concept the preferred solution for a possible future implementation in the ATLANTE.

5. Inspections

Previous prototypes were submitted to the following inspections to verify the SLS capability to manufacture these concepts robustly.

- 1. Visual Detail Inspection. Not revealing superficial damage of the prototypes.
- 2. Ultrasonic Inspection to verify skin thicknesses (not measurable by mechanical methods). Measurements revealed that skin thicknesses were produced within the SLS technology typical tolerance, ± 0.2 mm, but with a clear tendency to be lower than the nominal thickness values (none measurement point revealed a thickness value higher than the nominal). This finding should be taking into account for future applications by design engineers, especially for applications which present low thicknesses (close to 1 mm) where the technology tolerance might reduce the effective cross section beyond 20%.
- 3. Radiography. This inspection was performed to evaluate the capability of this NDI technique to identify inner defects or broken bars for the lattice prototype. Radiography results indicated the presence of broken bars but with a low confidence level. For inner defects a similar conclusion is extracted, indications might not be conclusive and therefore this NDI technique should be replaced by an alternative inspection technique like Computed Tomography.
- 4. Borescope. As consequence of the uncertainties offered by previous inspection it was decided to use a borescope to confirm the presence of broken bars within the lattice structure. Figure 10 shows some results of this inspection confirming the presence of broken bars and significant quantity of semi-fused powder covering the inner prototype surfaces.



Figure 10: Inner Views of Lattice Structure

It is not clear if these broken bars were produced during the printing process or during the unfused powder removal. Although the presence of broken bars may suppose an integrity issue for this concept, the high level of redundancy provided by the lattice structure may assure the component integrity. A certain percentage of broken bars might be allowed as long as this fact is considered by the structure engineers during the component sizing. To control this issue, in case of serial production, the number of broken bars and its distribution should be verified by NDI techniques or testing selected ruddervators along the production.

5. Penetrant Testing. This inspection resulted not conclusive as consequence of material porosity. Liquid is absorbed by the material making difficult its removal to reveal surface indications. Specific liquids should be developed for this material or alternative NDI technique should be used to assure the absence of surface defects in case of structural applications.

6. Structural Tests

Once polyamide 12 material properties were verified by the sample test campaign defined in chapter 4.1, two structural tests were carried out to verify the integrity of the new design against flight loads. As explained in chapter 4.3 the two flat spar concept was selected for this purpose as it was considered the most promising concept for a future implementation in the ATLANTE.

The Two structural tests were performed in the following conditions.

- Test 1. Nominal material conditions.
- Test 2. Aged material condition. One specimen was submitted 1000 hours at 80°C and 95% of relative humidity. The purpose of this test is to demonstrate the component structural integrity after material degradation suffered as a consequence of the harsh environmental conditions.

Airbus structural test facilities, with large experience in big aircraft components testing, faced the mission to define a test rig for this small size control surface. Test rig design must be able to reproduce the critical flight loads and boundary conditions. Moreover the rig must allow the application of loads on the upper and lower skins without moving the specimen to verify up and down bending load cases. These requirements are achieved by the use of bonded pads which reproduce a triangular force distribution along ruddervator chord. Figure 11 shows the rig design, the stress and buckling plots obtained for the flight and test configurations (DFEM predictions) to demonstrate rig capability to reproduce properly the real flight load cases.



Test Rig

Figure 11: Test Rig and Stress/Buckling Plots for Test Rig Validation

Instrumentation was applied to the specimen, previous to test executions, in order to correlate the test results with the DFEM predictions. Linear strain gauges and rosettes were bonded on the skins, actuator arm and the front spar (main load path within the AM ruddervator).

6.1 Test 1 Results.

Test 1 results demonstrated the AM ruddervator capability to withstand both, limit loads and ultimate loads, without detrimental permanent deformation. According to Ref [2] Limit Loads are considered the maximum loads expected in service whereas Ultimate Loads are obtained by applying a safety factor to Limit Loads, in this case this safety factor is 1.5.

Good correlation between instrumentation measurements and test results was obtained. For this correlation the data obtained from the material characterization described in chapter 4.1 was used. Figure 12 shows the correlation for the displacement sensor installed in the maximum foreseen deformation point. Load configuration represented correspond to ultimate loads (upper skin loaded).



Figure 12: Test 1. Displacement Sensor: DFEM Predictions versus Test Measurement

Since the specimen used for Test 1 was able to overcome successfully limit and ultimate loads it was decided to carry the specimen up to the failure. Maximum load applied during this last Test 1 phase correspond to J = 11 (eleven times the limit loads). No specimen failure was produced and test was stopped at this load level due to load cell capacity. After unloading a great recovery capability of the AM design was observed. Maximum measured deformation respect to the nominal geometry was below 1.8 mm. Figure 13 shows the deformations suffered by the specimen at different J values (multiple of limit loads) and the mentioned recovery capability J = 0 after unloading.

This outstanding capability to withstand load levels clearly above ultimate loads was expected for two reasons.

- 1. During the sizing phase, a safety factor of 2.0 was applied to ultimate loads to cover material properties uncertainties. A conservative approach was followed for this first structural application using AM polyamide materials.
- 2. With previous loads, a maximum stress of 15 MPa, as explained in chapter 4.1, was imposed to guarantee infinite fatigue life.



Figure 13: Test 1 Pictures during Failure Phase

6.2 Test 2 Results.

Apart from the explained ageing process, the specimen used for this test presented a located damage in the leading edge. A crack, probably generated during instrumentation or installation activities, appeared previous to the test. In these conditions Test 2 results also demonstrated the AM design capability to withstand both, limit loads and ultimate loads, without detrimental permanent deformation.

However, in this case major differences between instrumentation measurements and DFEM predictions are obtained (observed crack was modeled in the DFEM to take into account the stress concentration effect generated). This difference can be explained due to the lack of enough tensile samples data (only 2 samples tested in aged conditions at room temperature) to derive robust material mechanical properties.

During the test continuation after limit and ultimate load phases, failure of the specimen was achieved at a load level J = 9.47. Figure 14 shows the deformations suffered by the specimen at high J values and the final failure.



Figure 13: Test 2 Pictures during Failure Phase

Ruddervator break is originated by the front spar failure at the location of the leading edge crack. Once the front spar failed at this point the damage is rapidly propagated along the upper and lower skins.

7. Conclusions and future investigations

AM ATLANTE ruddervator printed by SLS using polyamide 12 represents one of the first attempts to demonstrate the application AM polyamide materials for high integrated structural components within aircrafts. The work presented shows the structural integrity of the new AM design for the targeted application (low loaded control surfaces of small and medium size UAVs). Currently new thermoplastic materials (PAEK based) using AM, which promise higher mechanical properties than polyamide 12, are being developed within Airbus. This new generation of AM thermoplastic materials will increase range of applications to be tackled in a near future with the SLS technology.

The new design offers clear advantages, 50% of mass and significant cost reductions respect to the original design. Apart from these advantages it must be also highlighted the possibility, once a wide AM supply chain is developed, to print and deliver in a short period of time spare components in case of need when the aircraft is placed in the operation field.

However, there are open points which must be further investigated with the objective to increase the maturity of this technology and material combination. The need to identify proper NDI techniques for structural applications has been highlighted in this work. For a robust aircraft implementation of this type of components, a list of requirements which should be investigated in the future is presented.

- UV resistance
- Fungus Resistance
- Consolidated of Fatigue and Damage Tolerance material values
- Bonding
- Damages produced by Lightning Strike.
- Powder removal for non-accessible areas
- Surface Protection
- NDI techniques

6. References

- [1] Van Hooreweder, B. Kruth, J.P. 2014. High cycle Fatigue Properties of Selective Laser Sintered Parts in Polyamide 12
- [2] European Aviation Safety Agency. 2014. CS25 Certification Specification and Acceptable Means of Compliance for Large Aeroplanes

7. Glossary

AM	_	Additive Manufacturing
ASTM	_	American Society for Testing and Materials
CAD	_	Computer Aided Design
CFRP	_	Carbon Fiber Reinforced Plastic
DFEM	-	Detail Finite Element Model
MPa	_	MegaPascals
INBD	_	Inboard
NDI	_	Non Destructive Inspection
OUTBE) —	Outboard
PAEK	_	Polyaryletherketone
SLS	_	Selective Laser Sintering
UAM	_	Ultrasonic Additive Manufacturing
UAV	_	Unnamed Air Vehicle
UV	_	Ultra Violet