Additive Manufacturing Research activities contributing to Cleansky2 flagship demonstrators

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EASA FAA AM Event 2021

www.cleansky.eu

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- Advanced Research on Additive Manufacturing in CS2
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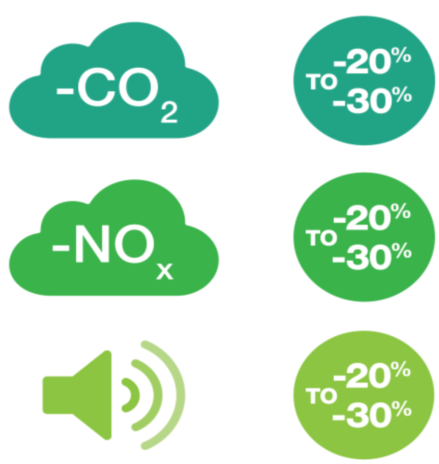
- Summary and way forwards

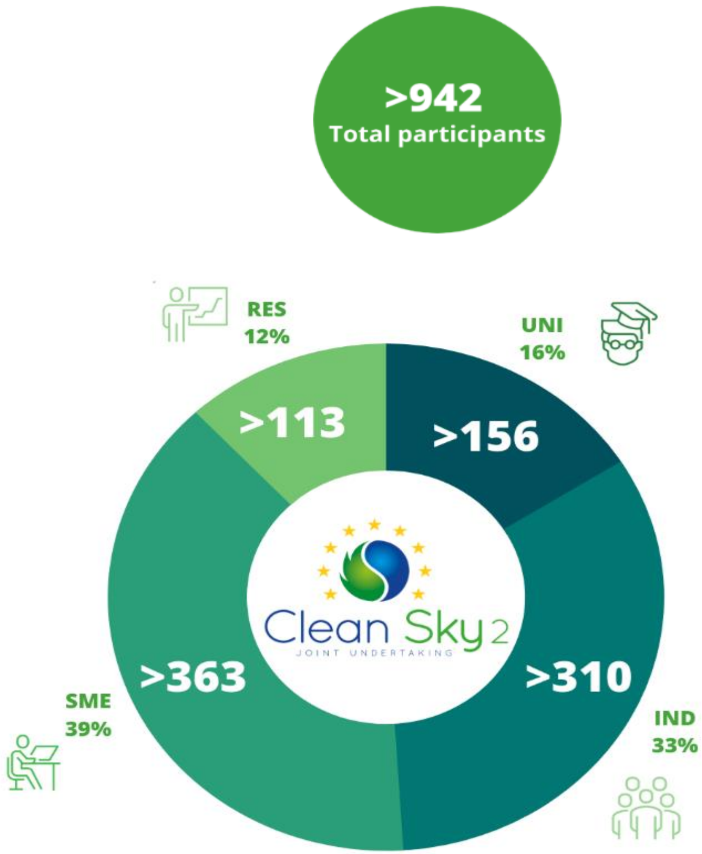
CleanSky2 at Glance

Clean Sky2 is the largest European research programme developing innovative, cutting-edge technology aimed at reducing CO_2, gas emissions and noise levels produced by aircraft. Funded by the EU's Horizon 2020 programme, Clean Sky contributes to strengthening European aero-industry collaboration, global leadership and competitiveness.

Environmental Objectives*



** vs 2014 best aircraft*



CleanSky2 at Glance

Delivering on its commitments

CleanSky2 at Glance

- 75% of programme effort reached early 2021
- 160 projects (out of 543) already closed
- 30% of demonstrators to be completed by end 2021(*)
- 2000+ Dissemination activities over 2014-2021 period, of which half of them are technical papers or scientific publications
- 271 patents applications

(1) LR+ CO2 reduction (-13%) is made versus the A350-900 as reference aircraft, EIS 2015, a very highly optimized platform.

(2) SMR++ (-8% NOx) as CROR core engine model does not yet include low NOx combustor technology, unlike SMR+ model (-39%).

MISSION LEVEL ASSESSMENT

CONCEPT MODEL	$-CO_2$	$-NO_x$	NOISE
Long Range	-13% (1)	-38%	< -20%
Short-Medium Range	-17% to -26%	-8% to -39% (2)	-20% to -30%
Regional	-20% to -34%	-56% to -67%	-20% to -68%
Commuter and Business Jet	-21% to -31%	-27% to -28%	-20% to -50%

(*) after recovery of the COVID-19 pandemic impact

Concept definition

Based on selection of technologies > TRL3 in 2018

Concept EIS

- a few concepts EIS 2025+
- next earliest EIS is 2030 (Adv.)
- 2035+ for Ultra-Adv. concepts.

Additive Manufacturing for Integrated Technology Demonstrators

CleanSky1 contributed to the development of AM processes towards to Aviation standards. Nowadays, new generation aircrafts are incorporating hundreds of printed parts (mainly for interiors, thermoplastics) .

A/C seat covers

Interiors

A/C piping

AM is widely used in the development of manufacturing and assembly tooling

Tooling for Morphing Winglet and Multifunctional Outer Flaps

Tooling for Tail Assembly

https://www.cleansky.eu/CS2/the-racer-gets-its-rotorless-tail-in-gear
https://cordis.europa.eu/project/id/737889

Additive Manufacturing Main Research Areas in CS2

- About 40 projects(GA) in CS2 contribute to develop and validate AM technologies for applications in A/C

MAIN Research Areas

Chemical and (Micro)mechanical studies for manufacturing process optimization

Modelling and simulations methods for AM

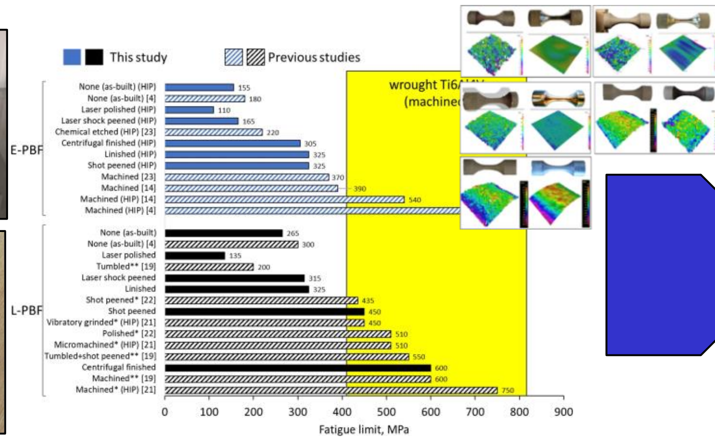
Manufacturing Process optimization

Validation of AM manufacturing processes at high TRL

Clean Sky JOINT UNDERTAKING

Advanced Research on AM - Powders and mechanical properties

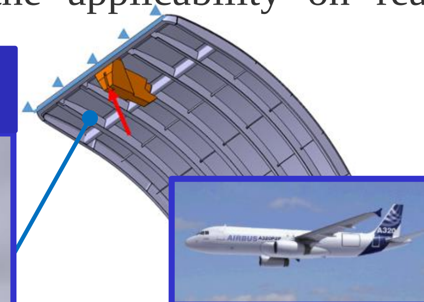
Addman - To test and characterize Electron Beam Melting and Selective Laser Melting manufactured parts to determine the effect of geometry, microstructure, surface roughness and residual stresses on material behavior to enable optimization of fatigue performance; Demonstration of the applicability on real components.



doi.org/10.1016/j.ijfatigue.2020.105497

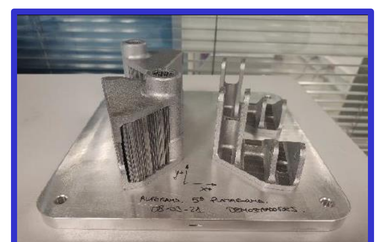
Load lift fitting of the cargo aircraft door.

EBM-Ti6Al4V



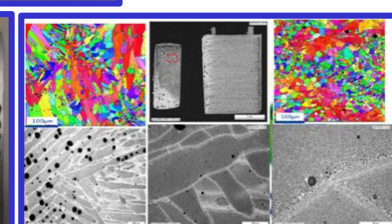
- 45% Material waste reduced
- Buy-to-Fly ratio close to 1
- Weight reduced 23% -29%
- Manufacturing lead time reduced
- Static and fatigue performance below defined limits.

AlForAMA – Development of an innovative High Strength Al alloy, feasible for powder metallurgy and SLM (selective laser melting); Assessment of samples manufactured for static, fatigue and corrosion tests



~30% improved mechanical behavior compared to standard AL powder.

PASSPORT – To test and characterize Selective Laser Melting manufactured parts made in AlSi10Mg and define optimized process parameters to ensure homogeneous mechanical properties.

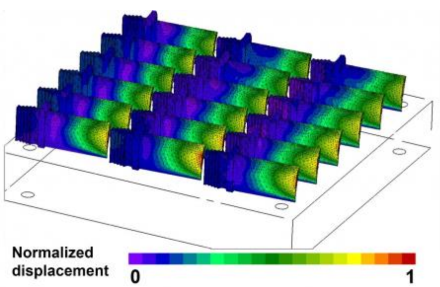


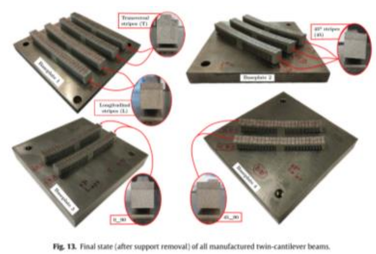
https://www.cleansky.eu/addman-yields-lightweight-airframe-components-using-additive-manufacturing-techniques
https://cordis.europa.eu/project/id/738002 - AddMan GA n.738002
https://www.alforama.eu/dissemination-activities/
https://cordis.europa.eu/project/id/785562 PASSPORT GA n785562

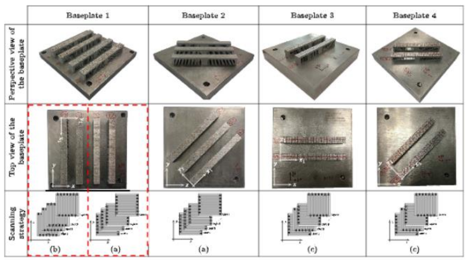
Advanced Research on AM - Modelling and simulations methods for AM

- One of the most investigated processes variants in metal additive manufacturing (AM) are the Selective Laser Melting (SLM) and the Laser Beam Melting (LBM).
- Component distortion is a critical issue during Additive Manufacturing (AM) of metallic parts.

Ascent AM - Development of a simulation-based process chain enabling a prediction of distortions with high accuracy – focus on LBM. (IN718)







https://zenodo.org/record/2637851#.YXLRuhpBxPY

DISTRACTION – To develop rapid distortion prediction numerical methodologies applicable to machining and additive layer manufacturing of metallic parts – Focus on SLM(Al7075 and Ti6Al4V)

PADICTON – to develop distortion prediction models for Additive Manufacturing of polymeric and composite parts - Efforts will focus on Fused Filament Fabrication (FFF), with or without fiber reinforcement, and the Selective Laser Sintering (SLS) process.

https://cordis.europa.eu/project/id/686808 - DISTRACTION GA n 686808
https://cordis.europa.eu/project/id/714246 - Ascent AM GA n. 714246
https://www.cleansky.eu/CS2/added-value-max-design-min-waste-for-clean-skys-ascent-am

Advanced Research on AM - Manufacturing prototypes

- Fused Filament Fabrication (FFF) has been largely limited to polymers with fairly low melting points. This has limited application in Aviation, where high-performance polymers such as ULTEM (poly etherimide) and PEEK are considered more suitable in order to provide thermal and mechanical performance.

SPECTRAL - To develop enabling technologies for affordable industrial-grade PEEK FFF printers and validate the overall process at component level.

FFF- PEEK, PEKK, PEI, PEEK carbon

ADDAPTTA SEALS - To develop new concept seals for wing aerodynamic surface, with better performance than currently used and further advantages in terms of cost, time to market and maintainability of the aircraft.

FLOWCAASH - To design and manufacture reliable and safe flow control actuators for aircraft by SLM. Pulsed Jet Actuators (PJA) and Steady Blowing Actuators (SBA) have been designed, manufactured and tested.

PJA actuator

Selective Laser Manufacturing TI6AL-4V

https://cordis.europa.eu/project/id/737845 - SPECTRAL GA 737845
https://cordis.europa.eu/project/id/821040 - ADDAPTTA SEALS GA 821040
https://cordis.europa.eu/project/id/785408 - FLOWCAASH GA 785408

Integration of AM in Aircraft – Small A/C

- Technology affordable for low volume production
- Low Cost Manufacturing technology
- Complex geometries joint-less.

A full scale ground cabin demonstrator for more affordable small aircraft integrating additive manufacturing components (aka 3D printing)

Tomographic Analyses

Static tests

Front landing gear fitting lug

Front landing gear fitting lug

NLG Support fitting

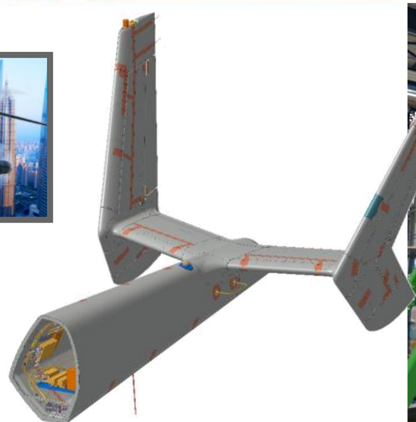
Electron beam manufacturing - TI-6AL-4V

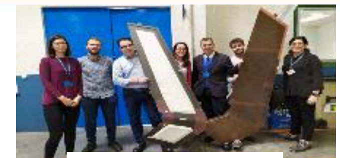
LESSON LEARNED/BEST PRACTICES

- Suitable for making very complex shapes
- Short production time of prototype parts in AM technology
- Significant material savings, final part weight reduction of 71% was achieved.
- The tensile tests have shown high mechanical performance of Ti6Al4V EBM-processed,
- The fatigue performance of **Ti6Al4V processed by EBM are generally lower than Ti6Al4V standard (in annealed condition)**.
- Special attention should be paid to the drop (hammer) test required for the PtF, according to Certification Specification (CS) and selected load cases.

https://www.cleansky.eu/the-small-print-3d-printing-and-innovative-aero-tech-could-boost-europes-sat-manufacturing
https://www.cleansky.eu/news/eco-friendly-cabin-ground-demo-for-small-aircraft-built
https://www.youtube.com/watch?v=NtZ241C0vaw

Integration of AM in Aircraft – Fast Rotorcraft





Vertical fins Skins

Cambered Tail Boom Skins

HS Torsion Box RTM

AH-E Design Concept: Fail Safe

Process: PBF-SLM / Material: Ti-A6L-4V

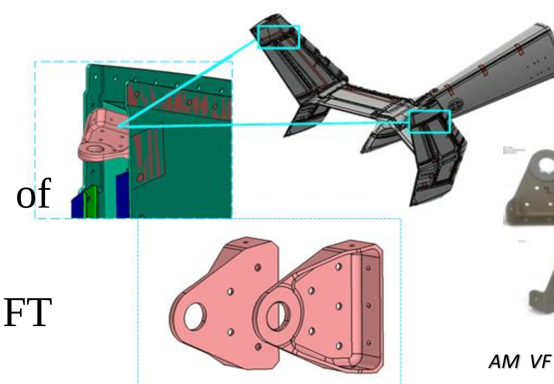
Design logic focus on PtF : 2 VF Tab Trimming Fittings:

1 Machined/1 AM (Ti) with Back to Back Design.

VF Trimming Tab Fitting 1st STRUCTURAL PART in LPBF ever flight in AIRBUS

Benefits:

1) Progress in the AM Related parts implementation in Platforms.
2) Safe and Reliable Design based on a Fail Safe Concept.
3) Explore the PtF logic and criteria to be applied to this kind of elements.
4) Traceability between Machined and AM parts – Thanks to FT campaign

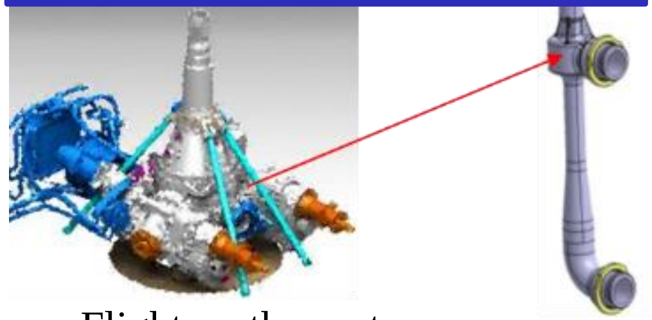


AM VF Trimming Tab Fittings

https://www.cleansky.eu/CS2/the-racer-gets-its-rotorless-tail-in-gear

Integration of AM in Aircraft – Fast Rotorcraft

Gearbox Jet Pump in Additive Manufacturing

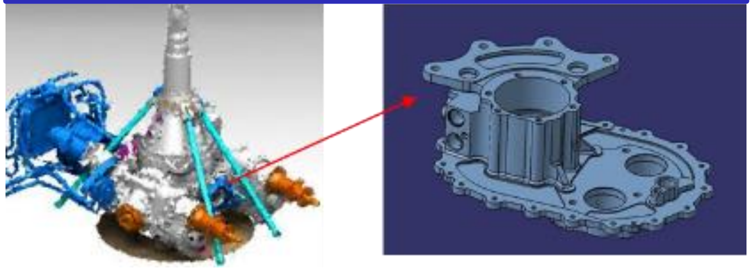


Challenges

To obtain the permit to fly and validate process: additional tests required to convince our Design Organization and Authority (at material level, at component level, at system level, Tests in flight)

- Flightworthy parts
- Innovative Passive draining system: A step toward dry oil sump
- Important weight reduction: -77%
- Single part: no assembly
- No need of 2D drawings
- Never done for a major gear box function

Gearbox Rear Cover in Additive Manufacturing



- Flightworthy parts
- Significant Lead time and weigh reduction.
- Single part: no assembly
- Propose disruptive design

Challenges

- To propose design compatible certification requirement and functioning specification
- To validate feasibility of manufacturing

Criticalities

Minor parts require the same order of substantiation than a critical part (due to uncertainty in the process)

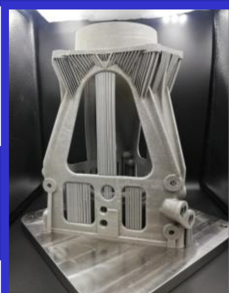
This additional effort significantly reduce the benefit to use such technology for industrial application.

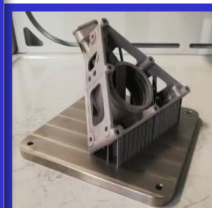
Integration of AM in Aircraft – Fast Rotorcraft

Gear-box Housing

Proof of Concept

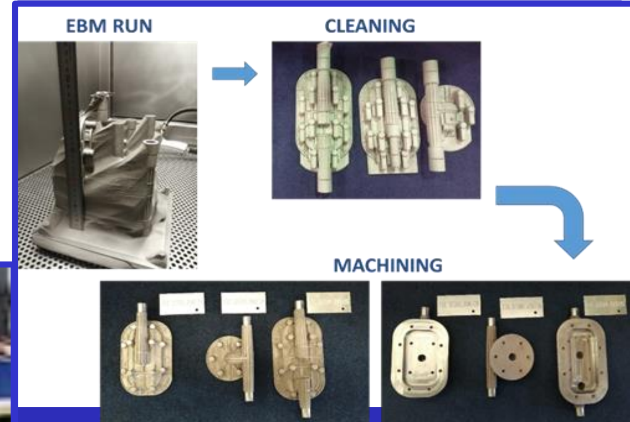
Electron Beam Melting
Material: Ti-6Al-4V





Selective Laser Melting
Material: Ti-6Al-4V

ALM flanges for NGCTR-TD fuel tanks



Electron Beam Melting (EBM), Material: Ti-6Al-4V (Titanium alloy)

PROS:

- Reduced number of machining steps
- Higher degrees of freedom during design phase (integration of dedicated features)
- Reduced weight
- Minimised number of parts.

CONS:

- Geometry needs to be optimised and varied from original to realise it in Electron Beam Melting (EBM) or in Selective Laser Melting (SLM)
- Specialised heat treatments and post-processing is required to improve the mechanical properties of the material

https://www.cleansky.eu/thinking-out-of-the-box-with-clean-skys-amatho
https://cordis.europa.eu/project/id/717194

PROS

- Higher integration with respect to CNC technology → fewer parts, Joint-less → higher vehicle fuel capacity
- Environmental impact reduced (recycled powders)
- Higher integration, ALM tailored design → lower weight
- Lower production costs

CONS

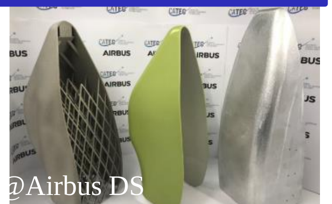
- Safety of flight justification for NGCTR-TD based on a different route with respect to CNC:
  - Set up of acceptable internal defects dimensions with respect permeability to fuel and vibration levels.
  - Acceptance of flight parts based on 100% tomography demonstration all the internal defects are lower than the maximum one

Belardo et. Al. "Safety Of Flight Approach For Fuel Tanks Alm Flanges For Tiltrotor Application", ERF2021

Integration of AM in Aircraft – Regional A/C

- FTB#2 flight test - tab fairings and Wing and Control Surface seals

TAB fairings



Laser Beam Powder Bed Fusion: TOYAL Scalmalloy®

Wing and Control Surface seals

Fused Deposition Modeling: TPE-V 40D/E

FTB#2 Demonstrator Modification

- **EWIRA(MT&Aciturri):** Wing Hinge fittings (Ti-6Al-4V) with EBM (electron-beam melting) technology for the FTB#2 demonstrator

Benefits: reductions of up to 40% in weight and 90% in raw material).
Criticalities: Challenges to comply airworthiness requirement #25.605 (stable and repetitive process) not fully demonstrated by the given time constrains. Also mechanical properties showed unexpected low deformation before failure.

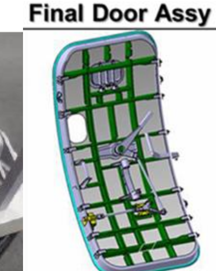
- Not included in A/C.
- Maturation plan of the technology-defined.

hinge fitting

electron-beam melting-Ti-6Al-4V

- **TOD** – To develop full-scale thermoplastic composite door for regional aircraft fuselage barrel. Using L-PBF (Laser powder-bed-fusion), LFW (Linear Friction Welding) and a combination of the two technics to manufacture doors surround components.

Final Door Assy

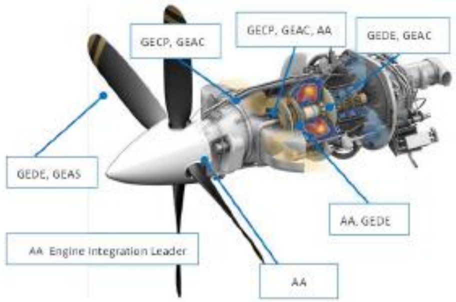


https://www.cleansky.eu/first-prototypes-of-additive-manufacturing-technologies-in-regional-multimission-aircraft-0
https://www.todproject.eu/

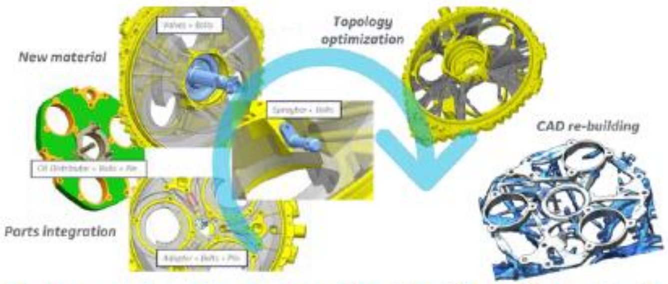
Integration of AM in Aircraft – ENGINES components

Clean Sky 2

MAESTRO



Catalyst engine's first flight powered by Clean Sky 2 MAESTRO Additive Tech's!



Gearbox carrier **design optimization** & **prototyping**

70 ➔ **2** PARTS | **-11%** WEIGHT

Design for **Additive**

Direct Metal Laser Melting

Ultra-compact reverse flow combustor with **Swirlers by AM**
Tested in 2016

All-additive conbustor
to be tested via **CfP Start** by 2021

UNIVERSITÀ DEGLI STUDI FIRENZE

SESTA LAB

Certification requirements

- Continuous dialogue with EASA/FAA
- No specific req.s foreseen w.r.t. components produced with conventional techniques

AM main criticalities

- Material characterization
- Printing process
- NDT controls

5 ➔ **1** PARTS | **-15%** WEIGHT

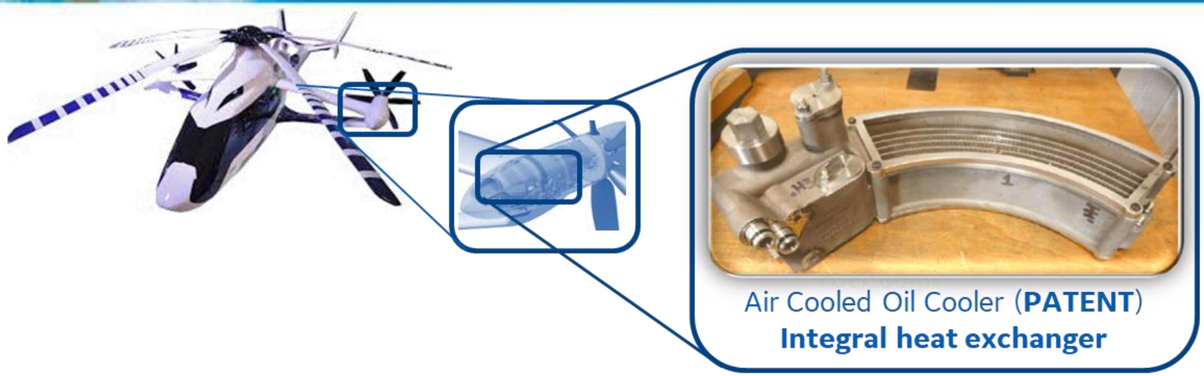
Design for **Additive**

Direct Metal Laser Melting

- NOx reduction w.r.t. conventional combustor: -20%

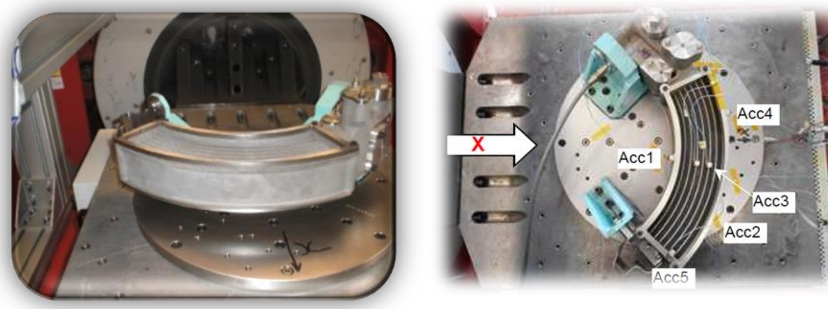
https://www.cleansky.eu/CS2/bravo-maestro-nextgen-sat-engine-gears-up-to-perform

Integration of AM in Aircraft – ENGINES components



Direct metal laser melting (DMLM) process / F357 material (Al-Si-Mg - lightweight, corrosion resistant alloy with high strength and toughness and excellent thermal conductivity.

From coupons to full scale prototype



Component test campaign (performance, mechanical)

Disruption

- Weight saving (-30%)
- Parts count reduction (20->1)
- Functions integration
- Optimized envelope at nacelle level

Challenges

- Part printability
- Part postprocessing (e.g. cleaning)
- Inspection-ability

Permit to fly for RACER Demo in 2022

Avio Aero
A GE Aviation Business

Clean Sky
JOINT UNDERTAKING

Advanced Research on AM
Assessment of AM towards ECO benefits

eco-design Flagship Demonstrators in the field of Additive Manufacturing

ENG ITD

Heat Exchanger

AMANECO

- ↓ Component weight up to 30%.
- ↑ Efficiency of Heat Exchangers up to 10%.
- ↓ Manufacturing overall costs of heat exchangers by 30%.
- ↓ Material waste and scraps by 15 % per component.
- ↓ CO2 emissions, perceived noise and fuel consumption.
- ↓ Time-to market from several months to one month.

REG IADP

Metallic AM Demonstrator (tbc)

EWIRA

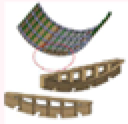
EWIRA Aileron Bracket

Designed and manufactured using EBM

- ↓ Weight reduction
- ↓ Waste reduction
- ↓ Reduced fastener count

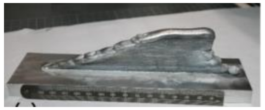
Challenges with surface finishing,

AIR ITD



Metallic Fuselage

IAWAS



WAAM and LBW wires

Implementing new Al filler wires while optimising the process

LCI data is being supplied to carry out LCA

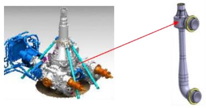
ADDMAN

Load lifting cargo door component

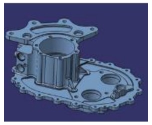
Designed and manufactured with Ti using EBM

- ↓ Weight reduction of 23-29%
- ↓ Buy-to fly ratio is close to 1

FRC ITD



Gearbox Jet pump



Gearbox Rear Cover

AMATHO

Gearbox Housing

Objectives

- LCI data collection on all possible processes from raw material stage to end of life (disposal/recycling).
- LCA / Eco statement at technology level.
- Eco statement at demonstrator level .

https://amaneco.eu/#home-the-project
https://www.cleansky.eu/addman-yields-lightweight-airframe-components-using-additive-manufacturing-techniques
https://www.cleansky.eu/sites/default/files/inline-files/CS2%20Workshop%20on%20Additive%20Manufacturing%20in%20Aviation.pdf

Clean Sky JOINT UNDERTAKING

SUMMARY and WAY FORWARD

- Additive Manufacturing is widely investigated in CS2.
- AM manufacturing Process Optimization for reliable operations and reduced manufacturing costs and complexity .
- Weight and waste reduction in comparison with conventional processes;
- Mechanical performances of AM components (Fatigue, Erosion, shape deviation) for primary structures still remains critical (mainly for Ptf/Qualifications).
- Interactions with Certification authorities is on-going on several applications areas (substantiation for Ptf and qualifications).
- To build best practices and lessons learned for faster development, Integration and validation.

EASA European Aviation Safety Agency

Clean Sky JOINT UNDERTAKING

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