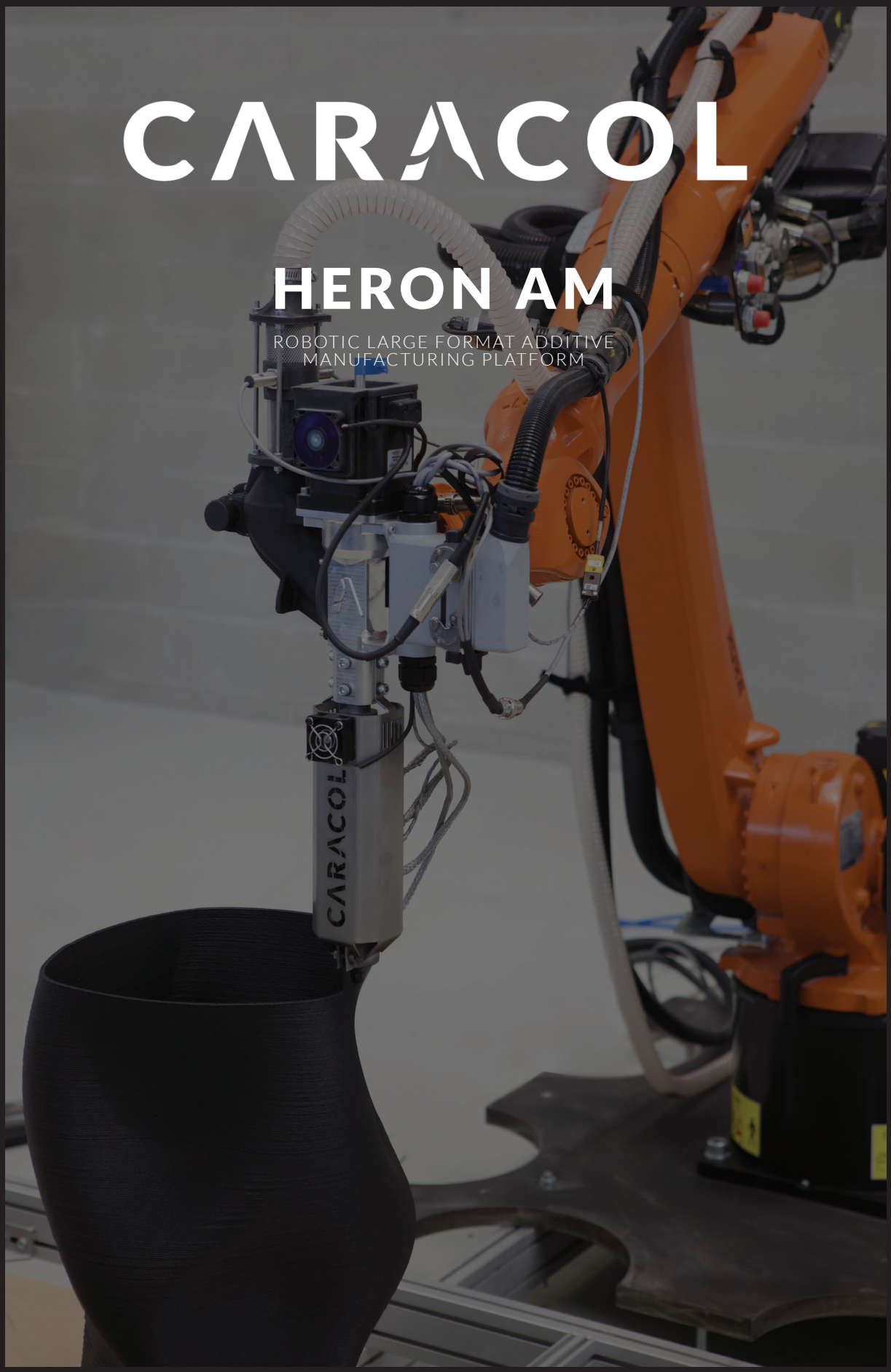
CARACOL

HERON AM

ROBOTIC LARGE FORMAT ADDITIVE MANUFACTURING PLATFORM



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This document's conformity has been verified with regards to the described hardware and software
Minimal differences and variations on the technology cannot be excluded with the utmost certainty.
All information in this document has been checked, any edits or technical improvements and variations
to the described technology will be published in following versions.

Version: **HERON AM - 230413**

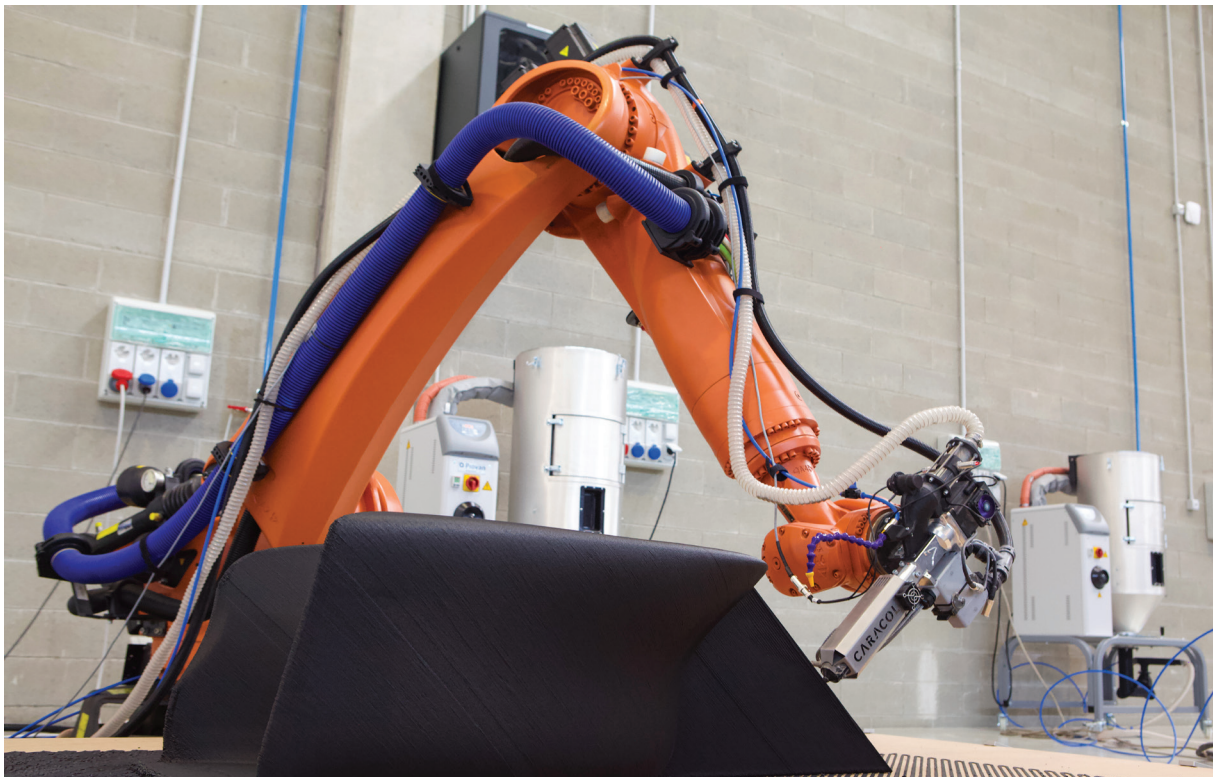
INTRODUCING HERON AM

Caracol was born from the idea of pushing the limits of AM, beyond what was possible.

That idea was brought to life by evolving the possibilities of Additive Manufacturing on scale, shape, and materials with **HERON AM**.

HERON AM is Caracol's Large-Format Additive Manufacturing system: a robotized extrusion head, with direct and continuous feeding of composites and polymers, a dedicated software platform for the most complex tool paths, and many more features to fully integrate all that is needed to manufacture advanced industrial parts.

The solution is one of the leading LFAM systems in the world, and the only one that is offered as a turnkey solution to maximize flexibility, process control, and performance for clients who want to manufacture parts on-demand and in-situ.



The system can produce components with a wide range of thermoplastics and composites (both from virgin and recycled origins) in the form of pellets and shreds. This makes the system ideal for the production of several medium to large-scale parts, such as: structural elements, tooling (e.g., jigs for positioning, drilling, and cutting, molds, assembly rigs, beams), prototypes, metal replacement, temporary or permanent substitution of parts, and an array of applications and components that continue to be discovered every day.

The system was developed as an integrated hardware and software solution that can be customized for different applications and manufacturing requirements so every element can be adapted to different end-user's needs.

This is possible thanks to the modular approach adopted in the development stages of the system, and thanks to the "application-first" focus

HERON AM was created by Caracol first of all as end-users, looking to manufacture parts that would not have been possible before. After several years of research, over 30000+ hours of printing, and hundreds of projects for clients in sectors like Aerospace, Automotive, Energy, Marine, Architecture and Design, HERON AM was perfected.

Today the company's cutting-edge technology is helping clients achieve their productivity, efficiency, and sustainability goals.

AN INTEGRATED TURNKEY SOLUTION WITH A SET OF CORE ELEMENTS

Heron AM can be flexibly integrated in clients' shop floors with different customizable options. The Engineering team works hand-in-hand with clients' teams to understand manufacturing needs and the types of applications that one intends to manufacture with their system to define the exact layout, additional features, and define the ideal configuration.

Having developed the platform as a modular integrated hardware and software solution there are a set of key elements which complete the structure. Moreover, the portfolio of Heron AM platforms includes a range of alternative models (e.g., extruders, robotic arms, ...), and it is also possible to include optional features to achieve specific requirements

KEY ELEMENTS

1 **EXTRUDER**
range of patented extrusion heads for thermoplastics and composites

2 **PERIMETRAL PROTECTIONS**
set up of perimetral barriers or insulated cell for full environmental control

3 **EIDOS Manufacturing™**
software interface for part design, optimization and slicing

4 **EXTRUDER CONTROL PANEL**
integrated panel for movement, extrusion, and temperature control

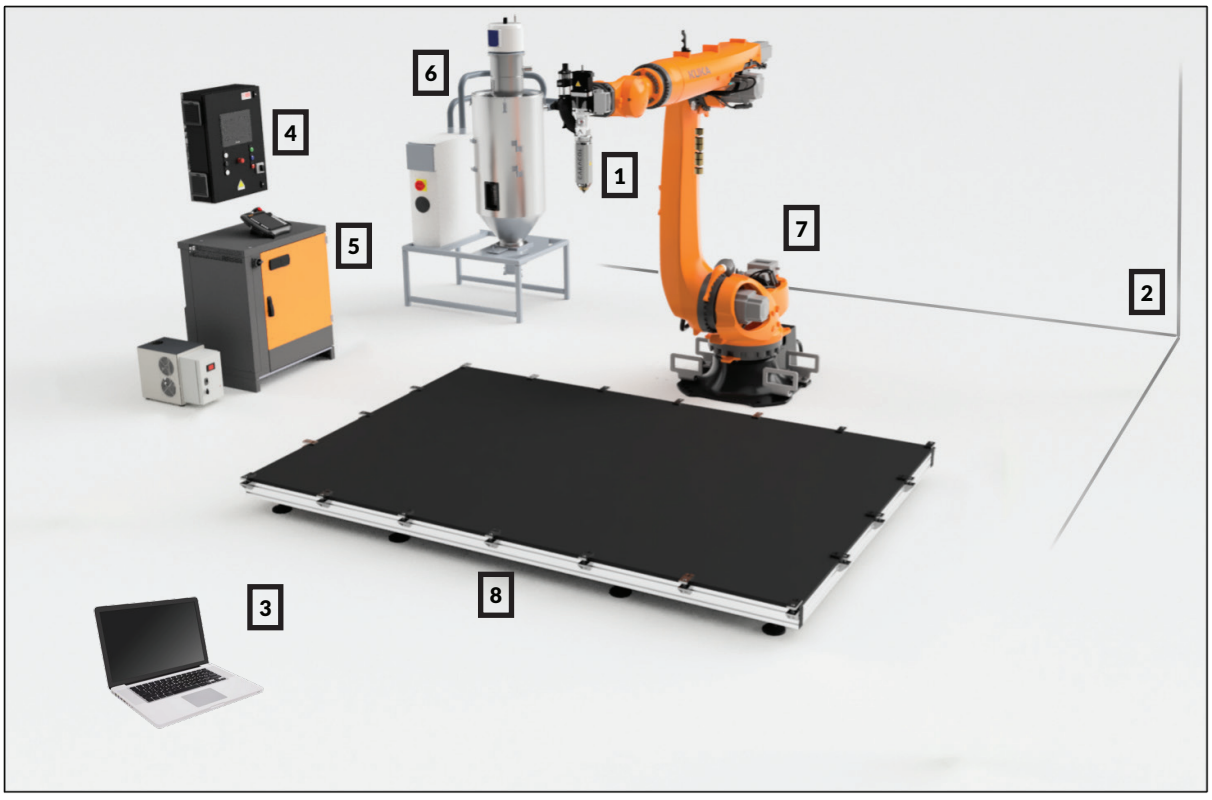
5 **ROBOT CONTROL PANEL**
unit for robot, PLC, motion, and safety control

6 **FEEDING SYSTEM**
automated system for quality and control of material feeding

7 **ROBOTIC ARM**
range of sizes for 6-axis manipulator for extrusion head support and movement

8 **PRINTING BED**
range of print beds with different features to satisfy production needs

All components can be customized according to specific manufacturing needs



EXTRUDERS

Caracol has developed a set of extruders to cover a range of possible needs:

HIGH ACCURACY (HA)

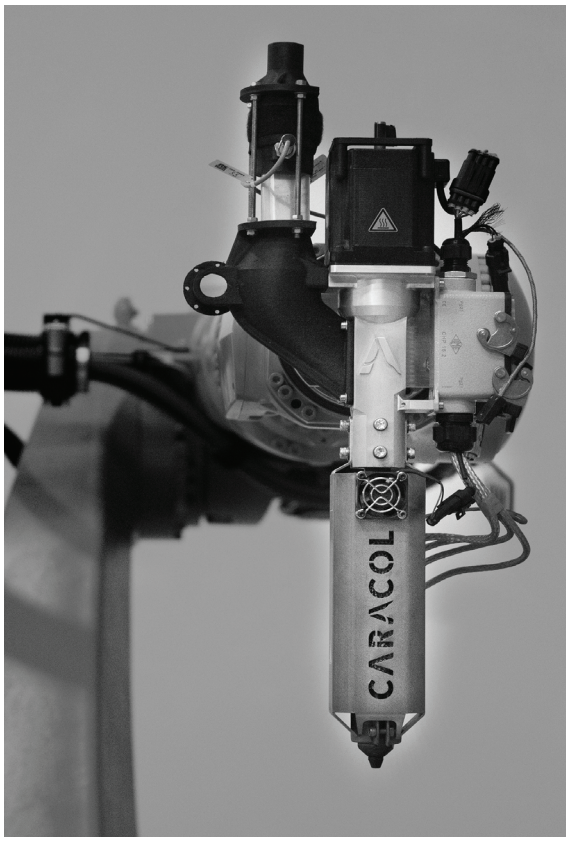
The High Accuracy extruder was developed with the aim of providing an extremely lightweight and compact solution.

The small size ensures the system's **greater agility** during the printing phase by limiting risks of collision with printed parts while maintaining a high . ow rate.

These characteristics make the machine great for **printing at high speed** while ensuring the highest quality in material processing.

The limited weight of the extruder makes it extremely flexible to different sized robots, from the smaller sizes in the Heron AM range to the largest - the HA extruder easily adapts to all needs.

NOZZLE RANGE	From 1 to 5 mm
TEMPERATURE	up to 350°c



HIGH FLOW (HF)

The High Flow extruder was built to provide a high throughput, temperature, and robust structure to process an extensive range of technical polymers and composites.

It was designed with the aim of **drastically reducing printing times** to optimize the production **of very large components**. It can be installed on higher-payload robots, which also provide a **greater build volume**.

The fusion chamber with various thermal control sections allows for highly refined process monitoring, ensures the extruder is suitable for printing the most critical materials while maintaining their properties and print quality.

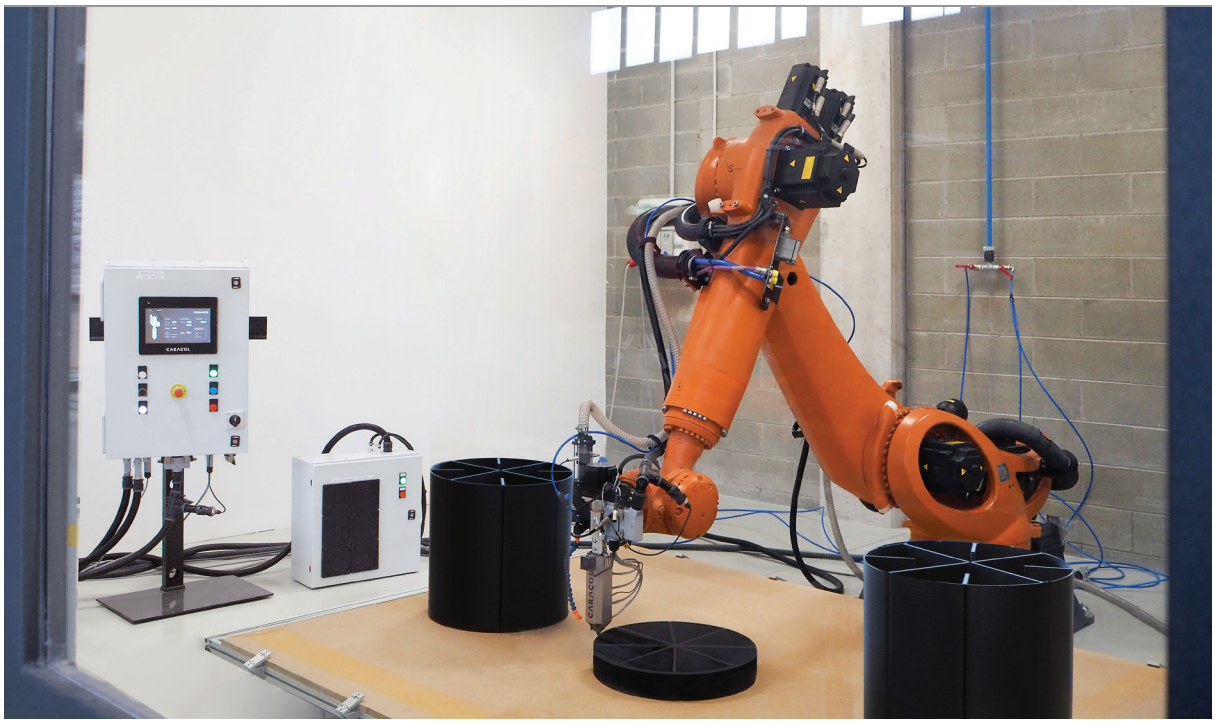
NOZZLE RANGE	From 2 to 15 mm
TEMPERATURE	up to 450°c

PERIMETRAL PROTECTION

A key element that can be customized according to available space or manufacturing requirements is the perimetral protection.

To manufacture advanced applications and print high performance composites and polymers, the recommendation is to enclose the system into acclimatized cells that allow to control several environmental parameters throughout the production process, such as temperature and humidity.

Controlling these environmental elements allows us to track several production indicators and guarantee process repeatability, quality, and safety requirements for clients, in accordance with AS/EN 9100 standards.



There are different options for system configuration:

- **Structural Insulated Cells**: these are completely enclosed environments, built with structural walls, and fully climatized systems. This solution is ideal when clients can integrate the system in their permanent factory layouts. It is also especially recommended for high temperature, high-performance composites, and for the manufacturing of advanced components, such as aerospace applications.

- **Mobile Container for LFAM systems**: this solution is ideal for in-situ manufacturing in remote locations, where automatized manufacturing can help reduce risks for operators. For example, when production is needed on construction sites, offshore sites, or camps set up in response to emergencies.

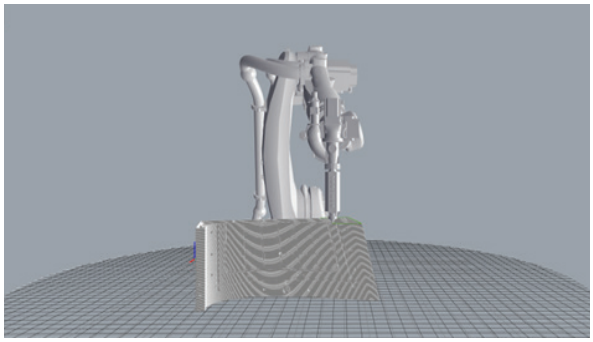
- **Open Air System**: this solution is ideal when constructing permanent barriers isn't possible and when clients need to work with low-temperature polymers and composites, which can be handled at room temperature.

To enclose the system there are two alternatives:

- ***Safety Light Curtains*** – these laser sensing devices can be set up and connected to identify when a person moves too close to the technology and interrupt production, guaranteeing safety and avoiding injuries.

- ***Protective Cages*** – these physical barriers can be built with metal or plexiglass structures, providing an enclosure that is more evident to operators and can be compliant with the most demanding safety standards.

SOFTWARE



EIDOS MANUFACTURING™

The expertise developed in Design and Manufacturing for LFAM, slicing strategies, and robotic kinematics, allowed the company to create EIDOS Manufacturing: the integrated software solution that completes and fully integrates the technological platform Heron AM's hardware and process, ensuring full control and flexibility.

The software is characterized by an extremely friendly user interface, that enables the elaboration of complex path planning both planar, non planar, non-orthogonal, to allow maximum control also on the most complex geometries.

EIDOS Manufacturing allows to manage different in ll strategies and to have direct control on all parameters that might influence quality and performance of the printing process.

Another key feature is connected to the possibility of truly simulating the printing process for the part one wants to manufacture, as a way to obtain all needed data regarding production time, material quantity needed, and be able to accurately estimate the full job.

CONTROL PANEL

To fully automate Caracol's turnkey solution and provide seamless management of all technological elements by end-users, the company developed a custom automation control panel that integrates all the inputs coming from the robot, the extruder, the feeding system, and the software into one pad that can activate and manage the full printing process.

Through the control panel, the operator will be able to set up and control all parameters such as on/off signals, movement, speed, temperature, and full cell calibration.

The control is set up on industrial PLC with a software developed 100% by Caracol.

MODULAR CONFIGURATIONS

The flexibility of the system allows it to be set up around specific needs in terms of space, manufacturing requirements, or target applications. Caracol has defined a set of configurations:

BOUNDING BOX	**HERON 200**	**HERON 300 / +**	**HERON 400 / + / R***
	approx. 2m³ (70.6 ft³)	approx. 3m³ (105.9 ft³)	approx. 4m³ (141.3 ft³)*
TECHNICAL FEATURES			
EXTRUDER			
- High Accuracy (HA)	■	■	
- High Flow (HF)		■	■
ROBOTIC ARM			
- Reach	up to 2m (6.56')	up to 3m (9.84')	up to 4m (13.12'), extendable*
- Models	200	300 | 300 **+**	400 | 400 **+** | 400 **R**
PRINTING BED			
- Aluminium Frame with Interchangeable Top	■	■	■
- Automatic Bed for unmanned part clamping and unloading	■	■	
EIDOS Manufacturing Software	■	■	■
FEEDING SYSTEM			
- Automatic dryer, 50-80kg unit	■	■	
- Multiple Dryer & Storage units		■	■
PERIMETRAL PROTECTIONS			
- Structural Insulated Cells	■	■	■
- Mobile Container	■	■	
- Open Air (light curtains, cages)	■	■	■
OPTIONALS			
- 7th Axis Rail		■	■
- CNC dedicated workstation	■	■	■
- Multiple material feeding units	■	■	

LEGEND ■ Available for all Configurations ■ Only for selected models

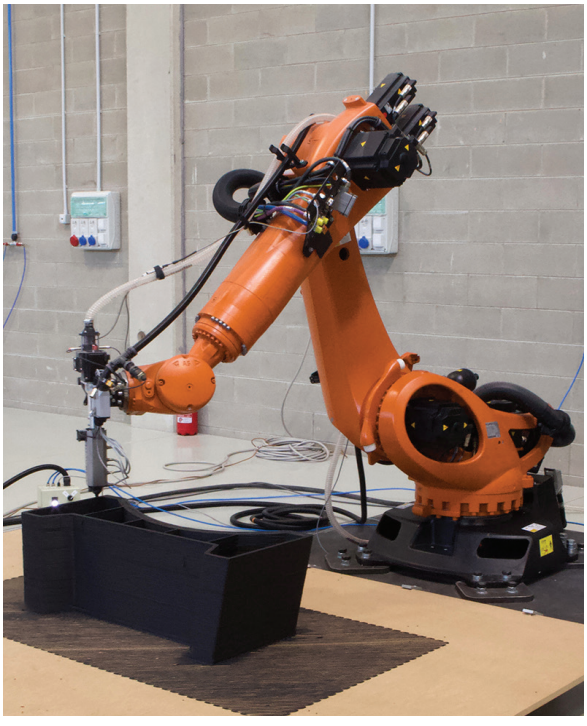
*Heron 400 R (Rail) can be extended along the x-axis by several meters

ROBOTIC ARMS

Caracol has chosen robotic arms as movement supports for LFAM system to leverage their modularity and flexibility (i.e., 6-axis movement). This allows to easily print complex geometries that may require non-planar tool paths, unconventional slicing, for example 45° printing to create hollow structures.

Robotic arms are easy to manage logistics-wise and can be easily transported and set up within existing production spaces without needing to build structural elements.

Today Caracol works with a several leading robotics brands (i.e., KUKA, FANUC, ABB) to integrate its additive solution on their arms. The robotic arm's reach determines the "bounding box" and the feasible size of parts; nonetheless, a 7th axis can be installed to extend it x-axis by several meters.



PRINTING BED

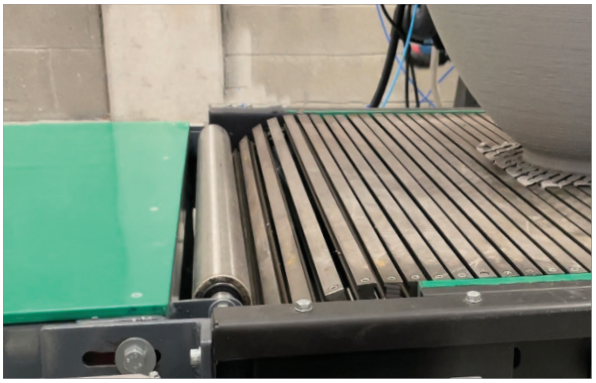
The printing bed is available in two models that can be both customized according to need:

ALUMINUM FRAME WITH INTERCHANGEABLE TOP

This model includes an aluminum frame structure that is easily set up, with interchangeable top panels that allow to solidly secure the first layer, raft or toes to the bed to reduce warping or other issues. The solution that can be customized based on sizing needed by the client, easily modularized by adding panels one next to the other.

AUTOMATIC BED FOR UNMANNED PART CLAMPING & UNLOADING

The automatic print bed was designed and patented to introduce two main features: best mechanical grip for the first layer and automated production. Its structure, made of aluminum slats, ensures the first layer perfectly adheres to the surface of the bed, guaranteeing a great stability of the part during the full job. With its rotating structure the bed allows to potentially print continuously and uninterrupted, with the automatic release of the part at the end of the job, leaving the bed ready for the next print to start. This print bed is also equipped with a heating system to easily work with materials that require a higher thermal control.



FEEDING SYSTEM

The automated material feeding system connects the material drying unit to the extruder to input pellets directly and continuously during the whole job. The system was developed to avoid manual operations such as stopping the process or intervening to add material to the unit.

Moreover, the pellets and shreds are stored at the right humidity and temperature and dried for best performance and quality.

The standard unit holds around 50-80kg (110-176 lb) and can be directly connected to a bigger storage (e.g., big-bag, octabin, etc…) or to multiple units, to potential allow for unlimited hours of uninterrupted printing.

SOME OF THE PROCESSED MATERIALS

Caracol's extruders have been engineered and optimized to process a wide range of high-performing polymers and composites. They've been designed for the direct and continus printing of materials in pellet form.

1 PP GF

Polypropylene with 30% Glass Fiber

Good mechanical properties, lightweight, ideal for glass fiber and aluminum replacement. It has been qualified by Caracol for the production of Marine structural parts and Aerospace molds and tools. It can go up to a 80°C working temperature.

2 ABS CF/ GF

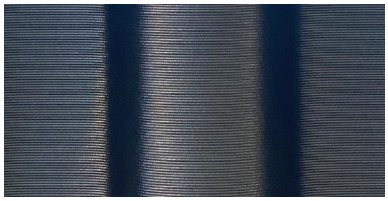
ABS with 20% Carbon / Glass Fiber

Cost effective material for low temperature applications (up to 80°C), it is ideal for applications like: rapid prototyping, vacuum tight molds and tools for trimming and gripping, as well as for finished parts that aren't subject to high mechanical pressure.

3 PC CF

Policarbonate with 20% Carbon Fiber

This composite offers great thermal and mechanical properties. It has been qualified for mid-temperature autoclave processes, as can go up to 130° C and 3-6 bars in terms of working temperature and pressure.



4 TPE FLEX

TPE high strength and flex elastomer

This TPE-based high-strength and flexibility elastomer, is ideal for large-scale rubber-like parts. It is ideal for topologically optimized pliable structures, such as cushions and seating. It goes up to 90 Shore A and 80° C as a working temperature.

5 PET-G

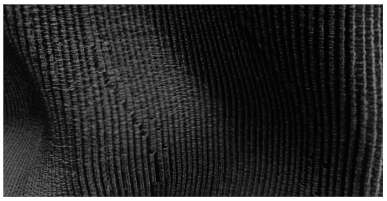
Polyethylene terephthalate glycol

This polyester based polymer, can be found in recycled, transparent, or carbon fiber reinforced versions. It is high impact, chemical and UV resistant, and ideal for PVC-like, exterior structures and prototyping applications. It goes up to 80°C working temperature.

6 BIO or RECYCLED

e.g., PLA, PP or PP GF, PET-G

Thanks to the direct-printing pellet extruders, Caracol's LFAM system works with a wide variety of recycled materials obtained from grinding waste or end-of-life parts, collecting client's waste, or by purchasing material from up-cycled sources.



These are just a few examples of materials that can be processed with Heron AM - nonetheless, the range of available high temperature polymers and composites is much wider. Caracol works every day to identify the most suitable solutions to satisfy specific application requirements, as well as to create customized blends to achieve the most demanding performance requirements clients might have.

SEE HERON AM IN ACTION

Tooling Jigs for Aircraft Manufacturing

AEROSPACE

Caracol produces tools, jigs, and fixtures for advanced manufacturing processes, from vacuum-tight tools for drilling and trimming, to molds for composite curing.

MARKET CONTEXT

In manufacturing supply chains for advanced parts such as aerostructures, automotive, or space applications, tooling and utensils used for part production involve milling from solid metal.

The produced parts are manually assembled to craft the final tool, with lengthy lead times, high production costs and unsustainable manufacturing processes.

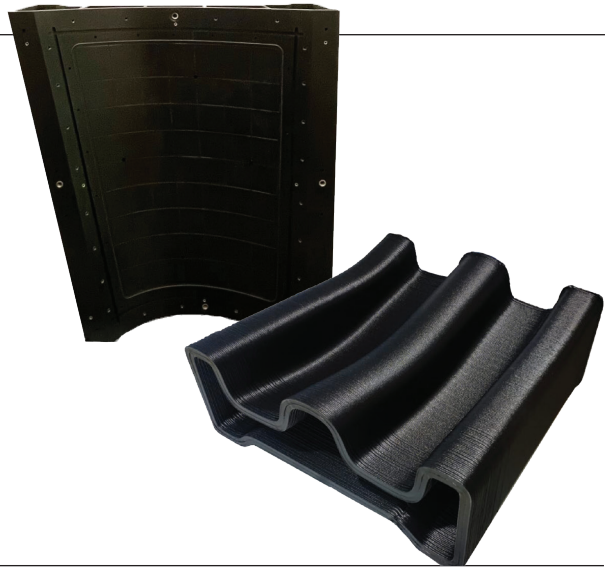
1. Long Production & Assembly Time	Up to 2-4 months for a single tool
2. Failing Supply Chains	Global crisis in raw material sourcing
3. Unsustainable Processes	Waste from metal removed from solids

SOLUTION

To respond to these challenges, Caracol has qualified HERON AM for the production of large scale tools, jigs and fixtures. Integrating Additive Manufacturing with CNC milling of only a small portion of part to achieve the tolerances required.

This provides several advantages to OEMs and Tier 1 manufacturers, including producing parts in a single-piece eliminating assembly needs, metal replacement, drastic reduction of lead time and material waste.

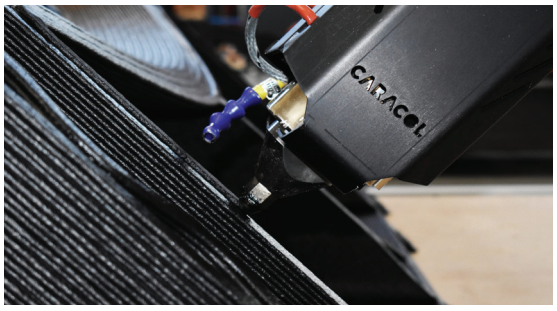
These results were possible combining expertise in tooling production and aerospace applications with the know-how on AM developed by Caracol.



RESULTS - TRIM & DRILL TOOL

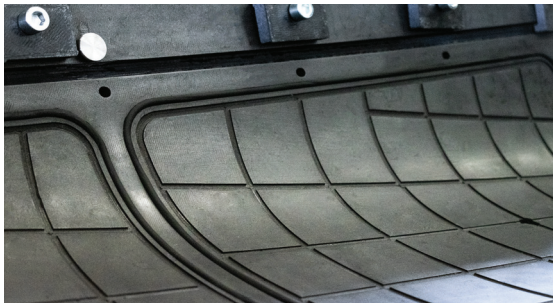
PERFORMANCE REQUIREMENTS

Materials	ABS CF
Weight (kg)	120
Size (mm)	848 l x 1250 w x 327 h
Surface Roughness (µm)	1.6
Dimensional Tolerances (mm)	0.1



SAVINGS Vs. TRADITIONAL PROCESS

Part Integration	From 30+ to 1
Production Time	From 2 months to 2 weeks
Weight Reduction	From 1 ton to 120 kg
Cost saving	35%



MARINE

Air Grids for Yacht Superstructures

Heron AM provides finished parts for the marine sector, working with leading boatbuilders for ships, yachts, and more.

MARKET CONTEXT

Marine architects and designers are looking to produce complex and customized parts to satisfy their customers' desires. This includes several superstructures, finished parts with different aesthetic and practical functions.

SOLUTION

Heron AM can be the solution for yacht and shipbuilding companies, enabling them to manufacture superstructural parts such as yacht grids, for one-of-a-kind or small series productions.

Air grids, for example, are an interesting application for Additive Manufacturing: their designs are complex, not-flat geometrical shapes; and the engineering process in traditional manufacturing still entails hand-made lamination using molds and fiberglass or metal sheet working as laser cutting, bending, machining.

These needs can be satisfied by working with a technology like Heron AM, that leverages its proprietary software and the robotic arm's 6-axes, to extrude at various angles, also printing suspended surfaces and hollow, light, and intricate geometrical forms at 45°.

RESULTS - AIR GRID

PERFORMANCE REQUIREMENTS

Weight (kg)	22
Size (mm)	1720 l x 450 w x 350 h
Material	ABS + 30% Glass Fiber

SAVINGS Vs. TRADITIONAL PROCESS

Production Time	50%
Weight Reduction	25%
Waste Reduction	60%
Cost saving	up to 70%

Micro Wind Turbine Blade & Lamination Tool

Caracol is working to find ways to recycle materials from the energy supply chain and manufacture new parts for the sector - such as the micro wind blade and tool.

MARKET CONTEXT

Technology is not just a matter of performance; it affects environment and society. Many EU projects across sectors are working to foster a green transition to move to climate neutrality by 2025, especially in the Energy industry.

SOLUTION

Caracol took part in a research project to demonstrate how LFAM can be sustainable both in terms of processes and products, a technology that can enable circular economy.

To find new applications for recycled materials from the energy sector, Caracol developed demo cases to show how to reutilize this material into new products, including: a functional lamination tool for micro wind turbines and a prototype of a micro wind turbine.

These projects provided evidence of tangible benefits that can be achieved, including: improved lead time, raw material savings, and waste reduction compared to traditional processes. Furthermore, the tool also maintained the technical requirements, such as dimensional tolerances, surface roughness, and porosity.

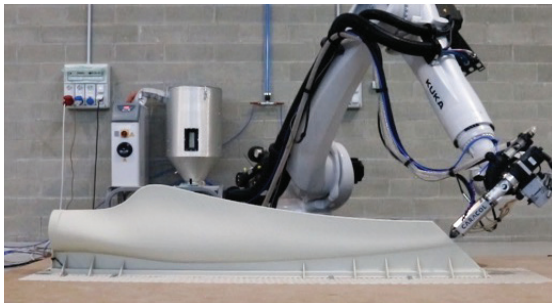
RESULTS - MICRO WIND TURBINE BLADE

PERFORMANCE REQUIREMENTS

Weight (kg)	15
Size (mm)	300 l x 300 w x 2000 h
Material	Recycled Polypropylene (PP) + Recycled Glass Fiber

SAVINGS Vs. TRADITIONAL PROCESS

Production Time	70%
Raw Materials	72%
Waste Reduction	90%
Cost saving	40%



Beluga: World's First 3D Printed Sail Boat

MARINE

Caracol manufactured a sailing boat with a 3D printed hull made with 100% recycled PP GF. The boat was designed, produced, and tested to validate the boat's functionality.

MARKET CONTEXT

Traditional methods to produce sailing boats usually entail manufacturing practices that require molds, produce waste and use materials such as fiberglass - that still struggle to find effecti e ways of being recycled .

SOLUTION

Caracol manufactured Beluga's hull with HERON AM, using only recycled material from MyReplast™. The material recovered through the up-cycling processes of post-industrial waste, is an example of how recycled polymers can be used successfully to produce advanced components with high performance requirements.

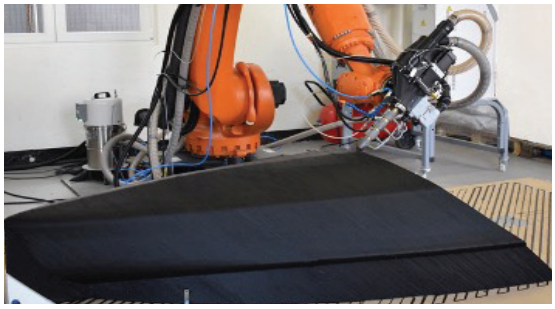
To manufacture this piece, Caracol used 45° slicing, which enables the production of hollow structures, eliminating the need for molds or supports of any kind. The full boat hull was printed in under 40 hours.

The boat was then tested and validated by two competitive athletes in the Open Skiff category (including the 2022 World Champion), who both sailed it in different wind conditions and paces.

RESULTS - HULL PROTOTYPE

PERFORMANCE REQUIREMENTS

Weight (kg)	48
Size (mm)	2800 l x 1290 w x 325 h
Material	MyReplast Recycled Polypropylene (PP) + 30% Glass Fiber



SAVINGS Vs. TRADITIONAL PROCESS

Production Time	40 h
Customization	100%
Waste Reduction	100%
Cost saving	40%

THE COMPANY

Caracol was founded to overcome the limits of 3D printing and traditional manufacturing.

In 2015 the four co-founders started a research project to overcome the limits of existing AM technologies. In 2017, Caracol was born - combining technological innovation with an industrial vision, to provide a new manufacturing paradigm to respond to client's needs for efficiency and sustainability in production.

From the first prototypes built, today HERON AM is one of the best LFAM solutions globally, for the production of advanced components, for high-performing industrial sectors.

Caracol provides its technology and solutions to companies internationally, in sectors that span from aerospace, to automotive, energy, marine, and more. The team the company is building, brings together uniquely talented individuals who share the purpose of disrupting the future of industrial production. They combine expertise in generative design and AM, with an extensive knowledge of industrial goods industries. With the most advanced design and analysis tools, the company works on optimizing geometries and features, to achieve the characteristics and results clients require for their applications.

Caracol accompanies clients throughout their production process, supporting them by facilitating their knowledge and experience with Additive Manufacturing and its opportunities.

The company offers clients a broad range of solutions: from design and concept development, engineering components for AM production, manufacturing prototypes and pre-series with no limit in scale, line production of finished parts, as well as support in internalizing 3D printing technologies, 3D printing training and workshops and more.

Every day, Caracol strives to innovate and evolve production systems, looking for more cost-effective, performing, faster, and environmentally conscious manufacturing solution.

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HERON AM 2023

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