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THE IMPORTANCE OF ADDITIVE TECHNOLOGY AND MANUFACTURING PROCESSES FOR LABORATORY EXPERIMENTS IN AERONAUTICS

La importancia de la tecnología aditiva y los procesos de fabricación para los experimentos de laboratorio en aeronáutica

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Abstract

In recent years, world manufacturers of aviation equipment have made significant progress in the use of high efficiency (in terms of economic and time parameters) Additive Technology and Manufacturing processes. In aeronautics, at the stages of design, production and operation, laboratory tests and trials of various parts of the aircraft are very important and very often this can only be accomplished with the use of scaled-down prototypes. Today, the best way to produce prototypes of various parts of the aircraft is Additive Technology and Manufacturing processes. This article provides the reader with an opportunity to learn more about the use of additive manufacturing technologies for the needs of experimental activities in Aeronautics.

Keywords: aeronautics, additive manufacturing, additive technologies, airfoil, 3D printing.

Resumen

En los últimos años, los fabricantes mundiales de equipos aeronáuticos han realizado importantes avances en el uso de procesos de fabricación y tecnología aditiva de alta eficacia (en términos de parámetros económicos y de tiempo). En aeronáutica, en las fases de diseño, producción y explotación, las pruebas de laboratorio y los ensayos de diversas partes de la aeronave son muy importantes y, muy a menudo, esto sólo puede lograrse con el uso de prototipos a escala reducida. Hoy en día, la mejor manera de producir prototipos de diversas partes de la aeronave es la tecnología aditiva y los procesos de fabricación. Este artículo ofrece al lector la oportunidad de aprender más sobre el uso de las tecnologías de fabricación aditiva para las necesidades de las actividades experimentales en aeronáutica.

Palabras clave: aeronáutica, fabricación aditiva, tecnologías aditivas, perfil aerodinámico, impresión 3D.

1. INTRODUCTION

Before the advent of digital processing technologies and the creation of virtual and physical objects, the production of parts, sub-assemblies and machines was carried out entirely by weaning technologies. This primarily applies to the field of mechanical engineering and turning to creating parts, assemblies, mechanisms, and apparatuses. However, the development of computing devices, their evolution and creation of more and more efficient software complexes for data processing and simulation of different physical processes in a virtual environment, led to the emergence of ideas and then to the creation of methods and techniques for obtaining physical objects from digital models. Thus, in the early 80s of the twentieth century, the first technology of manufacturing physical objects by layer-by-layer curing of photopolymer resin was created. Inventor and engineer Charles Hull created a stereolithographic method of printing three-dimensional objects with photopolymer resin that hardens under the influence of ultraviolet light [1-2].

In 1984, the world's first 3D printer was patented, and in 1986 a company was established to promote 3D printing technology, modeling, printer assembly and photopolymer supply [2]. Since then, much has changed - the number of methods of growing objects, the productivity of printers, the variety of materials from which an object can be made, and most importantly, the availability of 3D printing technology. Additive technologies, additive manufacturing are technologies for creating physical objects (having any shape) by adding material.

It should be noted that during the last decades the rate of study of additive technologies has been increasing, so it is possible to find a large number of scientific and popular science papers describing both in detail and generalized principles of creating three-dimensional physical objects. Types of the most commonly used additive technologies for small batch production and prototyping of parts, mechanisms and apparatuses in mechanical engineering, presented in Table 1. The information obtained and presented in table below was based on the analysis of works [2, 3] [4–8] [13, 14].

The technology of three-dimensional printing (3D) is based on design and modeling with the help of digital technologies, as well as extensive computerization. It is possible to make changes in the design quickly, without having to re-manufacture tooling, casting molds or dies, it is enough to change the digital model. With the help of additive technologies, it is possible to produce parts from composites, for example, to create gradient structures from metal powders of different chemical composition or structure for parts whose parts work in different conditions. It is possible to use Additive Technology and Manufacturing processes in the development of repair techniques by filling damaged parts of structures with the material. Particularly important is the ability to make an entire part rather than assembling it from parts.

Analysis of the use of additive technologies, according to Wohlers Associates [2], shows that in 2012 the global market of additive manufacturing amounted to $2.2 billion, in 2013 it grew to $3.2 billion, with an average growth rate of 20-30%. The global additive manufacturing market was valued at $11.2 billion in 2020 and is forecast to reach $30.6 billion by 2028 (CAGR of 26.4%), [8]. Today, the most promising sectors of industry for the introduction of additive technologies account for about $9 trillion. Additive technologies can be used in production by 20-40% already within the next 5-10 years. Thus, about $2-3 trillion of the total volume of global industry may soon be associated with additive technologies [8].

It is expected that by the end of this decade, the traditional application of additive manufacturing will change from prototyping and hypothesis validation to full-fledged integration into mass production chains. There is a trend to increase the scale of implementation of additive technologies in various industries: already now 2/3 of leading industrial companies use additive manufacturing in production processes, by 2030. 2/3 of all manufactured products in the world will be produced with printed components, and by 2030-2050, 3D printing will make it possible to print fully finished products in several manufacturing sectors.

Table 1. Types of the most used additive technologies.

Method	Technology	Valor
Extrusion	Fused deposition modeling (FDM–Fused Deposition Method)	Thermoplastics: most commonly poly lactic acid (PLA), acrylonitrile butadiene styrene (ABS) and others.
Powder	DMLS–direct metal laser sintering	Any metal alloys
	EBM–electron beam melting	Titanium alloys, cobalt-chromium alloys, stainless steel, aluminum
	SLM–Selective laser melting	Ti alloys, Cr-Mo alloys, stainless steel, Al alloys.
	SHS–Selective heat sintering	Powder thermoplastics
	SLS–Selective Laser Sintering	Thermoplastics, metal powders, ceramic powders
Jet	3DP–Three-Dimension Print	Gypsum, plastics, metal powders, sand mixtures
Laminations	LOM–Laminated Object Manufacturing	Sheet material (paper, metal foil, plastic film)
Polymerizations	SLA–Stereolithography DLP–Digital Laser Processing	Photopolymers

Technological advances in hardware and the development of digital modeling are making additive manufacturing cheaper and more accessible, including through a paradigm shift in terms of printers - instead of selling equipment, leasing or 3D printing as a service is offered. SmarTech experts estimate the polymer 3D printing market for equipment and related materials at $11.7 billion in 2020. The main manufacturers of polymer materials for 3D printing are DSM (Netherlands), SABIC (Saudi Arabia), BASF (Germany), Arkema (France), Solvay (Belgium), and Carbon (USA) [9].

According to AMPOWER, the global metal additive manufacturing market was valued at $2.44 billion in 2019, including equipment, materials, and service. This value is forecast to reach $7.1 billion by 2024. The key players are GKN Plc (UK), Rio Tinto (UK), Hitachi Chemical (Japan), ATI Powder Metals (US), and Sandvik (Sweden) [10].

The analysis of patent and publication activity in the field of additive manufacturing and technologies shows a growing interest in both the technology itself and its application areas. The leading countries in terms of publication and patent activity in this area over the past five years are the USA, China, Germany, and the UK. United Technologies has the largest number of patents in the field of additive technologies among global companies, Figure 1 [10].

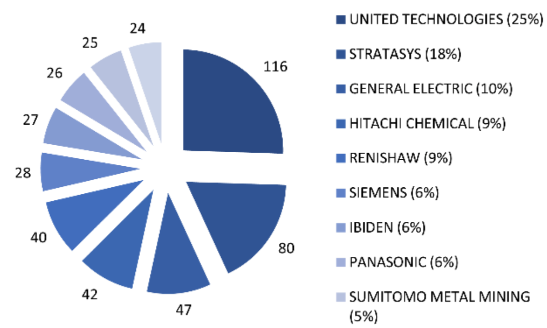

Figure 1. The leading global companies, holding the largest number of patents in the field of additive technologies [10].

The additive technology industry will continue to grow at a high rate over the next 10 years, with annual growth rates ranging from 18% to 36% for various market segments [10]. Automotive will remain the largest market (over $7 million), followed by consumer products, aerospace, commercial and industrial equipment, and prototyping [10]. Market participants have high hopes for the aerospace and aeronautics industries, which are expected to become one of the top three industries.

NASA, the J. Marshall Space Flight Center (Huntsville) and Directed Manufacturing conducted a firing test of an injector developed as part of the U.S. government's Space Launch System super-heavy manned launch vehicle program [2]. A 3D-printed jet engine component with only two parts was presented, while similar injectors made with traditional technologies included 115 parts. The properties of the injector material (powdered nickel-chromium alloy) were tested under extreme conditions. During the tests, liquid oxygen and gaseous hydrogen were injected into the combustion chamber through the injector, thus increasing the engine thrust by 10 times [2].

There are some things that cannot be done in the conventional Manufacturing way. For example, from the point of view of gas dynamic efficiency, the blade outlet edges (blade tips of compressors and turbines) must be very thin. The use of Additive Technologies (AT) makes it possible to obtain edges with a thickness of about 0.15 mm. This is impossible to achieve by casting, and thin edges result in higher efficiency.

Table 2. Comparison of jet engine injector fabrication methods.

Parameters	SLM 3D printing	Traditional processing methods
Time spent	3 weeks, 40 hours for production	24 weeks
Number of part components	1	4
Number of welded joints	0	5
Part cost	$5000	$10000

This is the new quality that unleashes the hands of designers [1]. To maximize the benefits of AT, part design can go beyond the designer's experience and established design approach. For example, for aircraft engine parts, one of the objectives is to minimize the mass of the structure while satisfying strength constraints under given operating conditions, but the strength properties of a "printed" blade will be different from those of a part produced by traditional methods. So before you can "print" a part and put it on an engine, you have to do a lot of extra research. Aircraft engine companies all over the world are now studying the properties of such products first on samples, then in real parts, the strength characteristics of which depend not only on the chemical composition of the material, but also on the type of semi-finished product, as well as on heat treatment modes. In the case of AT, there are many more parameters affecting strength.

In powder materials, it is not only the chemical composition, but also the size of the granules, size variation, their geometry, inclusions, manufacturing method, etc., which demonstrates the multivariable of additive technology. In laser processes it is the power of the beam, the direction of its tracks, the size of the spot, and the exposure time. The structure of the part is obtained inhomogeneous, and the mechanical characteristics are anisotropic in the growing direction and the characteristics are generally different in the transverse direction.

Thus, simultaneously with the part, in fact, its production technology is developed, so in the case of AT we are no longer talking about design engineering, but about the search for a design and technological solution, since physical and mechanical properties, strength and other characteristics of the part are established in the process of its manufacture.

The market for additive technologies is changing rapidly, mergers and acquisitions of machine manufacturing companies are taking place, new service centers are emerging, these centers are joining the European and now global network. The main use case for 3D printing now is primarily meeting the rapidly changing needs in research and laboratory experiments.

The use of additive technologies for manufacturing computer-optimized geometries of physical objects and their experimental study will lead to the strengthening of interaction between professional communities engaged in experimental and model-design work. Additive manufacturing represents a new path in terms of energy efficiency, cost effectiveness and time savings when producing objects [13–15].

Furthermore, it makes it possible to produce shapes and geometry that might not be possible through any other process. Possibilities include parts that have highly complex internal channels, parts that require voids, or honeycomb-like structures for weight savings. Additionally, additive manufacturing can eliminate assembly work because a part made up of small components can be built as a single piece [16–18].

A wide variety of parts can be created using AT, including engine components and other parts for the real aircraft, and its prototype for the laboratory experiments. In this report we are sharing our experience of designing and manufacturing half wing prototypes of aircraft with and without winglets.

2. MATERIALS AND METHODS

Artillery Sidewinder SW-X2 3D Printer was used to produce half wings prototypes parts. Three types of material were evaluated for the manufacture of the half wings which were: PLA, ABS and PET. After evaluating the properties and availability of each material, it was decided to work with PLA because it is more resistant and has better thermal properties. Two rolls of 3mm diameter PLA filament from eSun brand were used for our project.

3. RESULTS AND DISCUSSION

3.1. Design of 3d models of half wings with and without winglet and cad files

The first design of the half wing was made with the selected wing profile. In the first instance, two half wings with and without winglet were designed with the space corresponding to the sensor (approximate measurements). Figures 2 show the first two designs with approximate measurements. As it is a symmetric wing profile, the position of the sensor was placed in the center of each half wing, so that the same geometric design could be used for each one.

This design was made in Solidworks. Subsequently, the file was saved to carry out the additive manufacturing tests and check that the sensor could be placed inside the half wings. But design, presented on figures 2 [A] and [B] was not feasible since, after the first additive manufacturing test, it was seen that its dimensions were not optimal and that it was not possible to place the vibration sensor in the space intended for it, therefore what proceeded to make the modifications and changes to the design.

Then, a 3D model was made again based on approximate measurements of the sensor. The second additive manufacturing test was carried out to check that the sensor could be placed in the space intended for it. Finally, after the manufacturing tests of the first two designs, a 3D model was designed using the specifications of the vibration sensor data sheet, so that its correct assembly was possible. In addition, the shaft bore and space for the ferromagnetic rod were added that would help to hold the sensor inside the half wings.

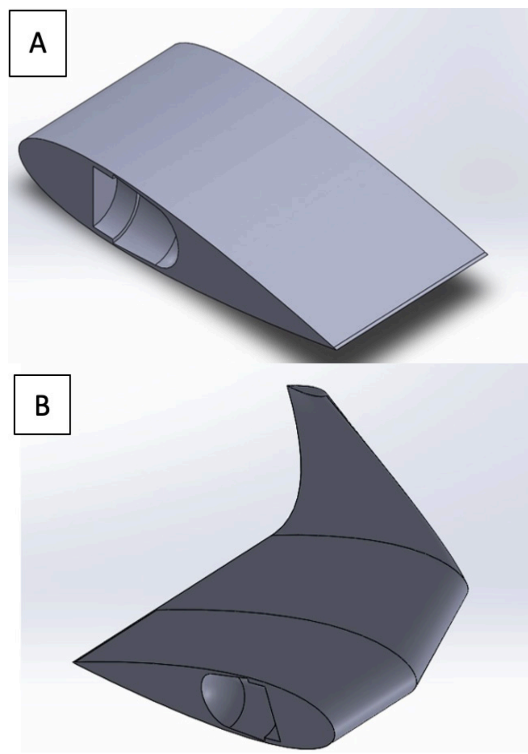

Figure 2. First design without [A] and [B] design with winglet.

Additionally, it was decided to cut the models of the semi wings and add elements that would facilitate their assembly. Figures 3 show the final design of the half wing without winglet, while in figures 4 the final design of the half wing with winglet. Figures 5 show the assemblies of the parts of each half wing: the assembly of the half wing without winglet in figure [A] and the assembly of the half wing with winglet in figure [B].

In the design of both half wings, the same wing profile was used throughout its entire surface, even in the winglet design. Likewise, it was decided to design a winglet with an angle of inclination of 90º.

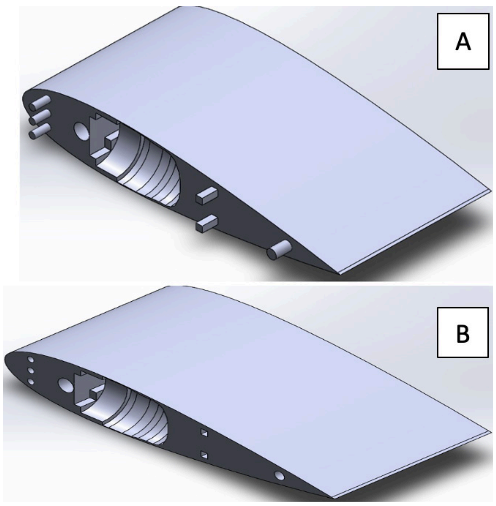

Figure 3. Final design half wing without winglet "Part 1" [A], and "Part 2" [B].

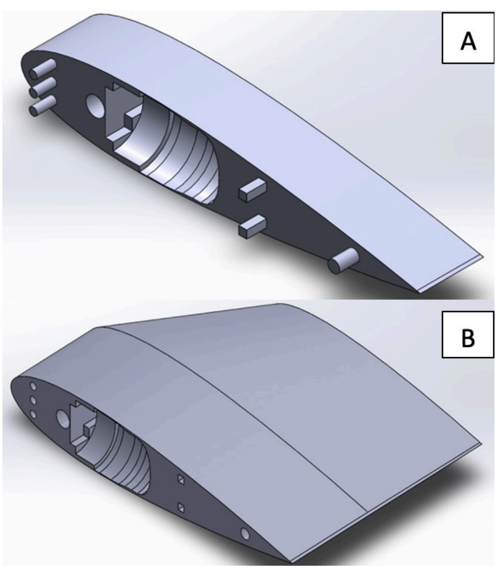

Figure 4. Final design half wing with winglet "Part 1"[A], and "Part 2" [B].

3.2 Final additive manufacturing process

Once the final design was made, the final impression of each part of both half wings was made, in total 5 pieces were manufactured, those shown in figures 6 [A] and [B] corresponding to the half wing without winglet, and those shown in the Figures 7, 8, and 9 corresponding to the semi wing with winglet.

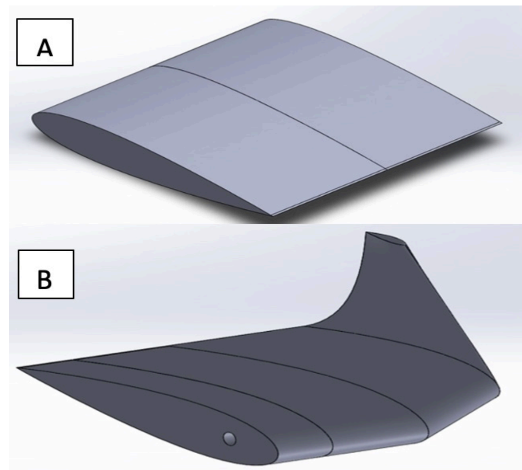

Figure 5. Final wing assembly without winglet **[A],** and with winglet [B].

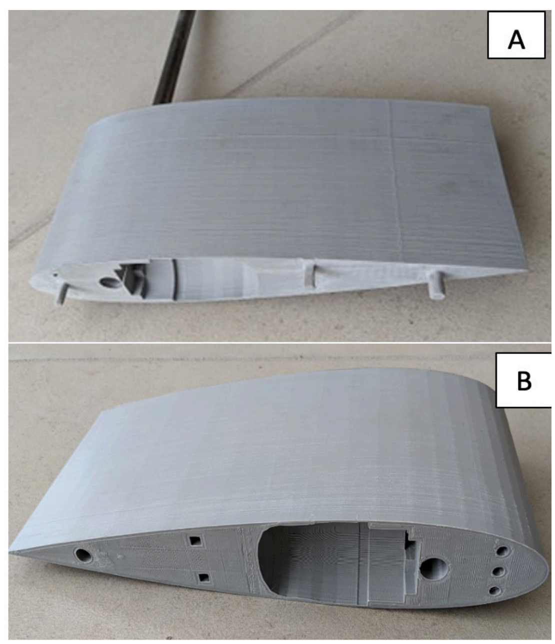

Figure 6. Part 1 [A] and Part 2 [B] of wing without winglet.

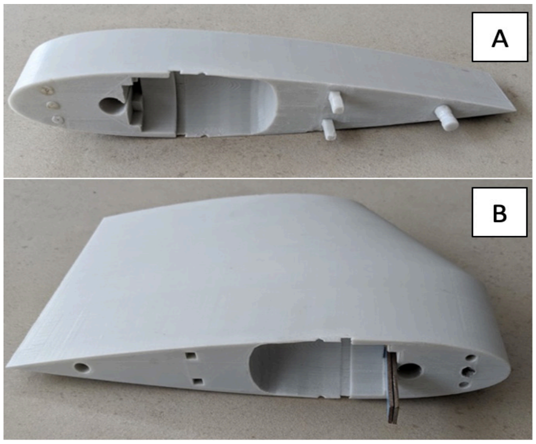

Figure 7. Part 1 [A], and Part 2 [B] of wing with winglet.

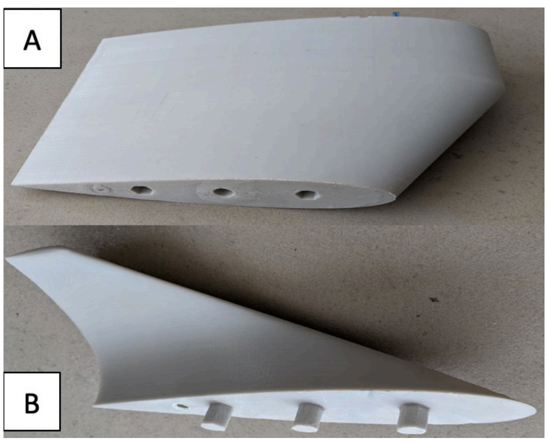

Figure 8. Part 12 [A], and Part 3[B] of wing with winglet.

Finally, the half wings manufactured by means of additive manufacturing and covered with the black vinyl layer, shown above, were used to complete vibration analysis in subsonic wind tunnel. Figure 11 shows the half wing with winglet mounted on the testing area of wind tunnel. As mentioned above both half wings (wing without and with winglet) were prepared for the vibration analysis in subsonic wind tunnel. This investigation was merely focused on obtaining data and information related to the internal vibrations of the half wings, to make a comparison of the results of the analysis of each half wing. In general, the results of vibration experiments are the subject of another talk and publication, in this paper we have shared only part of the project related to additive technology and processes.

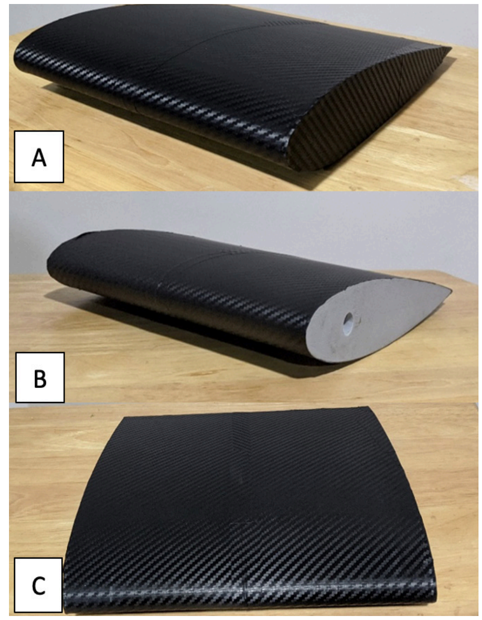

Figure 9. Final wing assembly without winglet [A, B, and C].

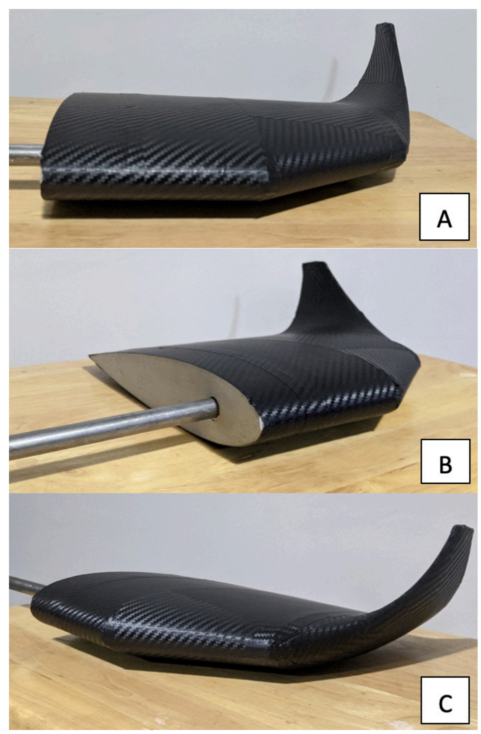

Figure 10. Final wing assembly with winglet [A, B, and C].

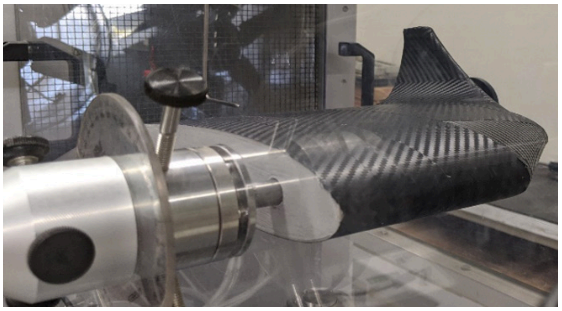

Figure 11. Half-wing with winglet mounted in testing.

CONCLUSIONS

In this publication presented the analysis and importance of Additive Technology and Manufacturing processes in general and particularly for laboratory experiments in Aeronautics.

The conducted analysis of scientific works makes it possible to conclude that the use of additive technologies for manufacturing computer-optimized geometries of physical objects and their experimental study will lead to the strengthening of interaction between professional communities engaged in experimental and model-design work.

If necessary, by interfacing with analytical equipment, analyses can be performed while integrating detection devices into the process system during production. In addition, additive manufacturing facilitates the use of equipment prototyping concepts.

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CONFLICT OF INTEREST

The authors do not have any type of conflict of interest to declare.

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