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Design of additively manufactured wind tunnel models for use with UAVs

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Abstract

In recent years, the potential applications of additive manufacturing have expanded considerably. This paper demonstrates the use of two important additive processes in the manufacturing of wind tunnel models of an unmanned aerial vehicle (UAV) for measurements in the wind tunnel. The UAV parts are manufactured by means of the binder jetting process. The application of different post-processing steps gave rise to models with a high degree of surface quality. Such models were investigated in the wind tunnel under different flow velocities and orientations. In order to carry out measurements, an adjustable measuring stand made of standard profiles was designed and constructed. Thereby, devices and fixtures manufactured with the assistance of the FDM process were used. A force torque sensor was used to record the measured values. For the economic assessment of models manufactured with generative methods, the cost structure and delivery times were analyzed. In addition, external options were obtained, in order to enable the comparability of costs between additive and conventional manufacturing processes

Keywords: Additive manufacturing, binder jetting, fused deposition modeling, wind tunnel model, fixtures

1. Introduction

From the 1980s up to today, Additive Manufacturing (AM) processes have experienced rapid development. In particular, through the possibility of design freedom that was barely possible in recent times (that is, the application of complex forms and geometries), additive processes today represent a powerful alternative to conventional manufacturing methods [1]. While such processes were initially used only for the manufacturing of prototypes (Rapid prototyping, RP) and small series, they are now also able to produce medium-sized quantities (for example, in vehicle and aircraft construction) on a cost-effective basis. Overall, the number of components manufactured with additive processes has increased considerably in recent years [2]. In addition to the manufacturing of prototypes and components, tools (e.g. molds for the thermoforming of plastic films and sheets) and devices (for example, assembly aids and gripper arms for robots) are also manufactured with additive processes (Rapid Tooling, RT) [3].

A common factor with all additive processes is that the components are built up layer-by-layer. Moreover, manufacturing takes place directly; that is, there is no requirement for programming or sophisticated tools or devices. Thus, on the one hand, it is possible to produce complex shapes, such as arc-shaped cooling channels, in forming plants. [4]. An additional advantage - from the point of view of sustainability - is that hardly any material is wasted in additive manufacturing [5]. While, for example, a large portion of slug volume is converted into shavings in the case of conventional machining, in additive manufacturing, only the support material is regarded as waste.

Today, the market features a multitude of processes that use varying materials and layer construction methods. The materials range from plaster, paper and photopolymers to plastics and metals. Laser-based methods in particular are suitable for the manufacturing of components for vehicle and aircraft construction, since, in doing so, components with complex geometries can be manufactured from metal powders that offer sufficient strength for the application.

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New processing centers, in which additive and subtractive manufacturing processes are combined (hybrid AM), have recently been developed [6]. In this manner, complex shapes can be produced by means of laser sintering, and a high degree of surface quality can then be achieved by means of final machining.

2. Literature review

The options of additive processes with regard to freedom of design and the rapid implementation of ideas and virtual models into physical models has already produced interest in the manufacturing of models for use in wind tunnels. In the late 1990s, a comprehensive study, in which a large number of processes were investigated for this application, was carried out. As the sample part, only a single wing was manufactured with additive processes as a model. It has already been shown that the manufacturing of a model for visualization is quite possible. However, at higher loads, the models (given their low strength) were only able to be used with the help of reinforcements [7].

Based on the rapid development of additive processes, the first complete models for the wind tunnel could be manufactured and investigated with the use of stereo lithography (SLA) in the 2000s [8, 9]. It was found that such processes were better suited to the requirements than Fused Deposition Modeling (FDM), since more precise structures could be produced. However, reinforcements made of metal were also used, such that the model was a hybrid model made of plastic and metal.

At present, additive processes for the manufacturing of wind tunnel models are primarily used to realize complex geometries. Thus, with conventional manufacturing, it is often necessary to divide the models into many individual parts, in order to manufacture undercuts (for example). This complex process step can be omitted with AM [10]. Metal reinforcements can also be used to develop models for use in sound-tight areas, which are particularly light [11]. In addition, it can be demonstrated in tests that models manufactured with SLA have sufficient strength. It has been shown that such hybrid models also achieve a precision similar to that of models made of metal, and at the same time are significantly lighter and more cost-effective [12].

The use of structural elements manufactured with additive processes with the assistance of FDM technology in combination with reinforcements made of carbon fiber CF is already known from the manufacturing of UAVs with the assistance of 3D printing [13]. At present, the use of FDM for the manufacturing of wind tunnel models is also under investigation. In this case pipes made of CF instead of metal parts are used as reinforcement [14]. However, a failure of the models caused by creep can be detected, in particular with large loads and with thin-walled component areas.

3. Development process from virtual to physical models

This contribution presents, in addition to the development of a wind tunnel model, the development of a device for a force torque sensor (FTS). This device serves to position the wind tunnel model and to receive the sensor. The Fused Deposition Modeling process is used for the additive manufacturing of the device. The wind tunnel model is realized by means of Binder Jetting (BJ).

The development of the model or device begins with the clarification of the tasks and the specification of the requirements (see Fig. 1). Subsequently, the design of the model, which usually consists of several parts, is carried out with the assistance of a CAD system. The CAD data are transferred to data processing and, after slicing layers are passed on to the actual generative manufacturing process. After the completion of the AM process, post processing is carried out. In the case of a multi-part model, it is still necessary to assemble the model and to connect the sensors for the force measurement, before it can be used in the wind tunnel.

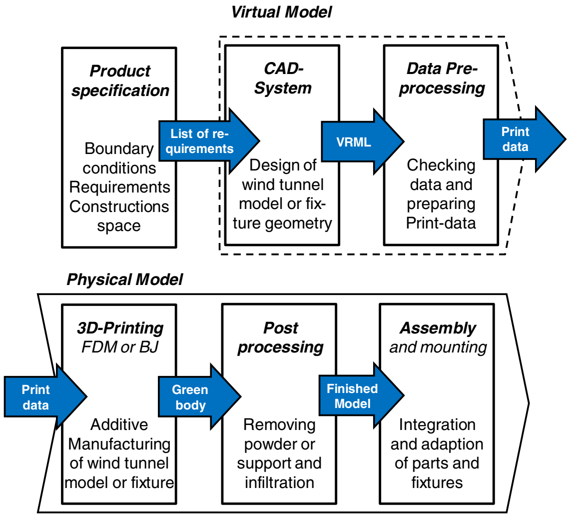

Fig. 1: Process from a virtual to a physical model

4. Development and manufacturing of a measuring stand with additively manufactured fixtures

Since, at the beginning of this paper, a suitable measuring stand for the UAV model was not available, a concept was developed especially for this purpose. In order to meet the needs, it was first necessary to determine the requirements of the measuring stand. Essentially, these could be subdivided into the following items:

- The FTS should be able to be pivoted around two axes in order to adjust different pitch and yaw angles.
- The FTS should be able to be moved along all axes, in order to be approach different positions within the measuring range.
- The device should be sufficiently stable to withstand the loads in the wind tunnel and during the measurements, and not to distort the measurement results.
- The travel paths of the Prandtl tube must not be blocked.
- The costs of the device must be compatible with the project budget.

The considerations for a suitable measuring concept resulted in two sub-tasks. These include the construction of a flexible