



**HAL**  
open science

## Geometric Models and Standards for Additive Manufacturing: A Preliminary Survey

Jinhua Xiao, Benoît Eynard, Nabil Anwer, Julien Le-Duigou, Alexandre  
Durupt

► **To cite this version:**

Jinhua Xiao, Benoît Eynard, Nabil Anwer, Julien Le-Duigou, Alexandre Durupt. Geometric Models and Standards for Additive Manufacturing: A Preliminary Survey. Virtual Concept 2016 major trends in product design, 2016, Bordeaux, France. hal-01364825v1

**HAL Id: hal-01364825**

**<https://hal.science/hal-01364825v1>**

Submitted on 12 Sep 2016 (v1), last revised 3 Jul 2017 (v2)

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

---

# Geometric Models and Standards for Additive Manufacturing: A Preliminary Survey

Jinhua XIAO <sup>1</sup>, Benoît EYNARD <sup>1</sup>, Nabil ANWER <sup>2</sup>, Julien LE-DUIGOU <sup>1</sup>, Alexandre PURUPT <sup>1</sup>

(1) : UMR 7337 Roberval, Université de Technologie de Compiègne, Sorbonne Universités  
60203 Compiègne Cedex, France  
Phone/Fax: +33 (0) 3 44 23 44 23  
E-mail : [first.lastname@utc.fr](mailto:first.lastname@utc.fr)

(2) : LURPA, ENS Cachan, Univ. Paris-Sud,  
Université Paris-Saclay  
94235 Cachan, France  
Phone/Fax: +33 (0) 1 47 40 24 13  
E-mail : [anwer@lurpa.ens-cachan.fr](mailto:anwer@lurpa.ens-cachan.fr)

**Short abstract:** The implementation of Additive Manufacturing (AM) digital flow and product data management system rely more on data formats and standards that nowadays convey Geometric Dimensioning and Tolerancing (GD&T) information directly in the 3D model. The consideration of geometric deviations and variations is an important issue for tolerancing and geometric quality assessment in AM through product and manufacturing information (PMI). This paper reviews current challenges of geometric models and standard formats for AM technologies, which largely impede its advancement. Two criteria to enhance AM geometric models and standards are presented in this paper: tolerancing and compatibility of PMI. The analysis presented in this paper highlights that STEP standard can be a good basis for future research to integrate geometric models and standards for AM.

**Key words:** Additive Manufacturing, Geometric Models, Tolerancing, Product & Manufacturing Information, Standards.

## 1- Introduction

Additive manufacturing (AM) technologies have been applied to the automotive, aerospace and medical industries for many years [1-2]. However, it is a difficult technology for AM that geometric models describe precision and accuracy of product shape, dimensioning and tolerancing.

Geometric models have become ubiquitous and offered essential and different tools for the digital product development [3]. In the 1960s Herbert Voelker considered the possibilities of using computer-aided machine to operate machine through CAD geometry. In the 1970s mathematical tools for describing 3D solid modelling had been invented in the early algorithms [4]. At present, geometric deviation has become a major issue on the tolerancing research [5]. Skin model concept has been applied to describe tolerancing representation and analysis [6]. Standards play an important role in the adoption of many technologies. Some of standardized formats include Stereo Lithography (STL), Additive Manufacturing File (AMF) and

Standard for Exchange Product (STEP) [7-8].

The theoretical geometrical model has been developed to consider geometric deviations [9]. And the developing and using standards (i.e. ASTM AMF, 3MF, ISO 10303 STEP) and tolerances (ASME Y14) [10-11] have integrated information related to AM process [12]. In order to realise this AM process: design, simulation, build plan, monitoring and control and verification, standard organizations have begun to establish AM file format for data exchange[4]. The design and manufacturing of high performance product may lead to an inevitable need for geometric deviations and tolerancing management [13-14]. The geometric tolerancing models have been proposed [15-18]. Tolerancing analysis has been used in predicting inevitable geometric deviations on the function and quality of product [19]. Skin model shapes can extract valuable information for geometric deviation [20]. Product manufacturing information (PMI) includes the geometric dimensioning and tolerancing (GD&T) [21]. These PMI standards, such as ISO TC213, ASME Y14.5, can define tolerancing [22].

Next sections will highlight challenges of geometric models and standards for AM technologies. These challenges mainly focus on two issues: geometric deviations and tolerancing management, and refer to two criteria: tolerancing and compatibility with PMI for AM formats. In section 3, skin model is introduced, and PMI standard can define tolerancing in AM systems. In section 4, different AM standards (i.e. STL, AMF, STEP) are compared and we emphasize on STEP in future works. In section 5, a conclusion and outlook are given.

## 2- Impediments of current AM

AM technologies have many problems to be solved on insufficient understanding of geometric shape variations, part accuracy, needs for qualification and functionality, and interoperability of AM standards [23]. Geometric models and standards for AM technologies have become one of main issues for realising precise and accurate 3D part.

### 2.1 – Geometric modelling issues

Geometric models need to provide all the necessary geometric data of an object. It is required to process the information automatically to generate shape, dimensions, and tolerances [24]. In terms of manufacturing tolerancing, there are the two acknowledged axioms for manufacturing process: manufacturing imprecision and measurement uncertainty [25].

Geometric deviations and tolerancing management have seriously restricted the precision and accuracy of AM technologies. Product and manufacturing information (PMI) provided by CAD can describe dimensional tolerances on length and diameter, and geometric tolerances on flatness, perpendicularity, position, surface profile, and circular out. The skin model shapes and PMI have been applied to solve geometric deviations and tolerancing management.

- The skin model shapes which stemmed from the theoretical foundations of geometric product specification and verification has been developed to consider geometric deviations in AM.
- PMI can theoretically realise data management (i.e. tolerancing) through ASME and ISO standards in manufacturing systems.

### 2.2 – Standard issues

The standardized methods are to develop the performance of AM machine. The standard data formats can be used to convert CAD to layers for building parts and reduce the process of manufacturing for component lead time, cost, material waste and energy usage [2].

There exist many issues for AM standards, so it is necessary to come up with many criteria that have key effects on the development of advanced AM technologies. There are two criteria for comparing STL, AMF and STEP standards as follows:

- Tolerancing.
- Compatibility with PMI.

The purpose of standard formats is to develop a high integrated, interoperable and compatible AM standard file.

## 3- Geometric models

Geometric model is used to describe geometric shape, dimensioning and tolerancing in CAD and CAM process. Many models for solving tolerancing have been presented, i.e. vectorial tolerancing [15], technologically and topologically related surface [26], small displacement torsor [27], direct linearization deviation [18], and tolerance maps [28]. However, main drawbacks of these models are the lack of geometric deviation considerations and tolerancing standards [29].

### 3.1 – Skin model

The research of geometric deviations should be dedicated in manufacturing process, which will be helpful to propose functional tolerance specifications [26]. Geometric Product Specification standard builds a comprehensive framework and an unambiguous language to describe geometric deviations. This Standard is modelled by all the concepts and operations based on skin model [30].

Skin model has been developed realistic physical shape

compared to nominal geometry. The discrete skin model can be used to present particular skin mode, to produce a proximate shape and to simulate assemblies in a computer system (Fig.1). And skin model concept describes deviations of manufacturing and assembly process. Discrete geometry representation schemes such as point clouds and surface meshes can be modelled as surface model [31].

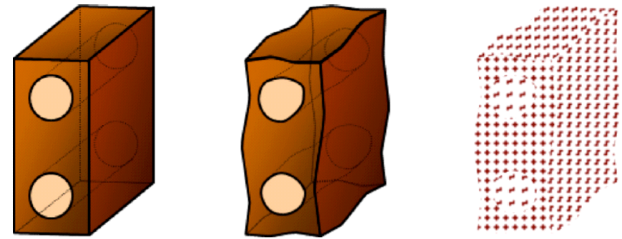


Figure 1: Schemes of nominal model, continuous and discrete skin model [9]

Statistical analysis of shape deviations or Statistical Shape Analysis is commonly used for shape variability considerations [32]. These geometric deviations can be presented as a part of tolerancing, which focus on product data known as product and manufacturing information (PMI).

### 3.2 –Product and manufacturing information (PMI)

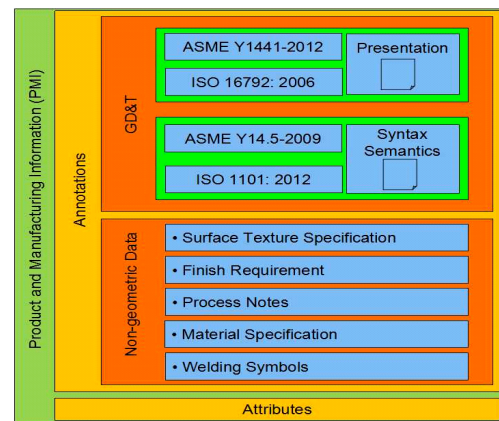


Figure 2: schema of PMI

PMI consists of annotations and attributes associated with CAD model edges and faces in order to define product geometry and product specifications. The industry standards for presentation of geometric dimensioning and tolerancing (GD&T) in views of 3D space are used in CAD systems, i.e. ASME Y14.41-2012 and ISO 16792:2006. These standards are the industry standards for the syntax and semantics of GD&T (Figure 2). It has been developed to address problems related to describing geometric deviations in part and assembly [33].

STEP as a family of standard includes EXPRESS model for PMI that standardizes specifications for dimensional and geometric tolerancing, surface properties, and the related requirements [34]. PMI can be inserted into AM standards that realise all related data management.

## 4- Standard formats for AM

Some of standardized formats include STL, AMF and

STEP. STEP as complementary technologies provides significant standardized content models [8].

STL is used to communicate CAD models to the local rapid prototyping system [35-37]. STL format has many deficiencies, such as redundancy, lack of complete geometric description, not well-defined approximation and technological information. AMF consists of eXtensive Markup Language (XML) and is part of ASTM 2915 standard [22]. AMF has more readability of functions than STL, such as colour specification, texture maps, material specification, etc. STEP is a family of standards defining a methodology for describing product data throughout product life cycle [38-40]. Two STEP application protocols have been implemented in CAD systems: AP203 and AP214 [41]. STEP AP242 is a new STEP specification approved by ISO in 2014 (www.ap242.org).

Table 1 Characteristics of AM standard formats

Criteria	STL	AMF	STEP
Tolerancing	NO	Part	Yes
Compatibility of PMI	NO	NO	Yes

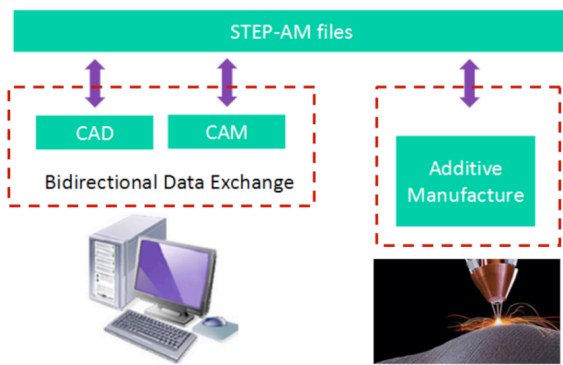


Figure 3: Data exchange schema of STEP-AM files

Table 1 shows these characteristics for AM standard formats. We have compared AM standard formats using two criteria: description of tolerancing and compatibility of PMI, which show advantages of STEP standard for future AM technologies. This result may lead to a combination of STEP standard and other data standards, which we call “STEP-AM” (Figure 3). This schedule describes basic data transmission of STEP-AM files for AM.

**5- Conclusion**

The paper has concluded on technologies of geometric model and standards for additive manufacturing. Skin model has been proposed to solve geometric deviations. Tolerancing can be managed by product and manufacturing information (PMI) that specify geometric dimensioning and tolerancing (GD&T). These PMI standards, such as ISO TC213, ASME Y14.5, can define tolerancing. STEP standard seem to be a good candidate to replace other AM file according to STEP format may realise tolerancing and compatibility of PMI by standardizing manufacturing information.

**6- References**

[1] Ford, S. L. N. Additive Manufacturing Technology: Potential Implications for U. S. Manufacturing. Journal of International Commerce and Economics (USA), (September), 1–35, 2004.

[2] Kobryn, P. A., Ontko, N. R., Perkins, L. P., and Tiley, J. S. Additive manufacturing of aerospace alloys for aircraft structures. AVT-139 Specialists’ Meeting in Amsterdam, May, 2006.

[3] Song, H., Eynard, B., Roucoules, L., Lafon, P., and Charles, S. Beyond geometric CAD system: implementation of STEP translator for multiple-views product modeller. International Journal of Product Lifecycle Management, 2(1), 1-17. 2007.

[4] Brown, C., Lubell, J., and Lipman, R. Additive manufacturing technical workshop summary report. NIST, Technical Note, (1823), 2013.

[5] Fainguelernt, D., Weill, R., and Bourdet, P. Computer aided tolerancing and dimensioning in process planning. CIRP Annals-Manufacturing Technology, 35(1), 381-386, 1986.

[6] Schleich, B., Anwer, N., Mathieu, L., and Wartzack, S. Skin model shapes: A new paradigm shift for geometric variations modelling in mechanical engineering. Computer-Aided Design, 50, 1-15, 2014.

[7] Scott, J., Gupta, N., Wember, C., Newsom, S., Wohlers, T., and Caffrey, T. Additive manufacturing: status and opportunities, Science and Technology Policy Institute 2012. Retrieved 11th July, 2012.

[8] Peak, R. S., Lubell, J., Srinivasan, V., and Waterbury, S. C. STEP, XML, and UML: complementary technologies. Journal of Computing and Information Science in Engineering, 4(4), 379-390, 2004.

[9] Anwer, N., Ballu, A., and Mathieu, L. The skin model, a comprehensive geometric model for engineering design. CIRP Annals-Manufacturing Technology, 62(1), 143-146, 2013.

[10] Carrier, B., MacKinnon, D. K., and Cournoyer, L. Performance evaluation of 3D imaging systems based on GD&T. Manufacturing Letters, 1(1), 9-12, 2013.

[11] ANSI. and American Society of Mechanical Engineers. ASME Y14. 41-2003: Digital Product Definition Data Practices: An American National Standard. American Society of Mechanical Engineers, 2003.

[12] R. R. Lipman, J. S. Mcfarlane, Exploring Model-Based Engineering Concepts for Additive Manufacturing, Proceedings of the 26th Solid Freeform Fabrication Symposium. Texas, August 2015.

[13] Schleich, B. and Wartzack, S. A discrete geometry approach for tolerance analysis of mechanism. Mechanism and Machine Theory, 77, 148-163, 2014.

[14] Bruyere, J., Dantan, J. Y., Bigot, R. and Martin, P. Statistical tolerance analysis of bevel gear by tooth contact analysis and Monte Carlo simulation. Mechanism and Machine Theory, 42(10), 1326-1351, 2007.

[15] Wirtz, A. Vectorial tolerancing: a basic element for quality control. 3rd CIRP, 1993.

[16] Weill, R., Clément, A., Hocken, R., Farmer, L. E., Gladman, C. A., Wirtz, A. and Trumpold, H. Tolerancing for function. CIRP Annals-Manufacturing Technology, 37(2), 603-610, 1988.

[17] Desrochers, A. and Clément, A. A dimensioning and tolerancing assistance model for CAD/CAM systems. The

- International Journal of Advanced Manufacturing Technology, 9(6), 352-361, 1994.
- [18] Gao, J., Chase, K. W. and Magleby, S. P. Generalized 3-D tolerance analysis of mechanical assemblies with small kinematic adjustments. IIE transactions, 30(4), 367-377, 1998.
- [19] Kim, K. J., Sacks, E. and Joskowicz, L. Kinematic analysis of spatial fixed-axis higher pairs using configuration spaces. Computer-Aided Design, 35(3), 279-291, 2003.
- [20] Anwer, N., Schleich, B., Mathieu, L. and Wartzack, S. From solid modelling to skin model shapes: Shifting paradigms in computer-aided tolerancing. CIRP Annals-Manufacturing Technology, 63(1), 137-140, 2014.
- [21] Frechette, S. P., Jones, A. T. and Fischer, B. R. Strategy for testing conformance to geometric dimensioning & tolerancing standards. Procedia CIRP, 10, 211-215, 2013.
- [22] Feeney, A. B., Frechette, S. P. and Srinivasan, V. A portrait of an ISO STEP tolerancing standard as an enabler of smart manufacturing systems. Journal of Computing and Information Science in Engineering, 15(2), 021001, 2015.
- [23] Harris, I. D. and Director, A. M. Development and Implementation of Metals Additive Manufacturing. DOT International, New Orleans, 2011.
- [24] Roy, U., Liu, C. R. and Woo, T. C. Review of dimensioning and tolerancing: representation and processing. Computer-aided design, 23(7), 466-483, 1991.
- [25] Srinivasan, V. Computational metrology for the design and manufacture of product geometry: A classification and synthesis. Journal of computing and information science in engineering, 7(1), 3-9, 2007.
- [26] Shah, J. J., Yan, Y. and Zhang, B. C. Dimension and tolerance modeling and transformations in feature based design and manufacturing. Journal of Intelligent Manufacturing, 9(5), 475-488, 1998.
- [27] Bourdet, P., Mathieu, L., Lartigue, C. and Ballu, A. The concept of the small displacement torsor in metrology. Series on advances in Mathematics for Applied Sciences, 40, 110-122, 1996.
- [28] Davidson, J. K., and Shah, J. J. Using Tolerance-Maps to represent material condition on both a feature and a datum. In The 8th international CIRP seminar on computer aided tolerancing, 2003.
- [29] Bo, C., Yang, Z., Wang, L., and Chen, H. A comparison of tolerance analysis models for assembly. The International Journal of Advanced Manufacturing Technology, 68(1-4), 739-754, 2013.
- [30] Zhang, M., Anwer, N., Stockinger, A., Mathieu, L. and Wartzack, S. Discrete shape modeling for skin model representation. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 227(5), 672-680, 2013.
- [31] Durupt, A., Remy, S., Ducellier, G. and Eynard, B. From a 3D point cloud to an engineering CAD model: a knowledge-product-based approach for reverse engineering. Virtual and Physical Prototyping, 3(2), 51-59, 2008.
- [32] Dryden, I. L. and Mardia, K. V. Statistical shape analysis. Chichester: J. Wiley, 1998.
- [33] Lipman, R. and Lubell, J. Conformance checking of PMI representation in CAD model STEP data exchange files. Computer-Aided Design, 66, 14-23, 2015.
- [34] Lubell, J., Chen, K., Horst, J., Frechette, S. and Huang, P. Model based enterprise/technical data package summit report. NIST Technical Note, 2012.
- [35] Stroud, I., and Xirouchakis, P. C. STL and extensions. Advances in Engineering Software, 31(2), 83-95, 2000.
- [36] Szilvsi-Nagy, M. and Matyasi, G. Y. Analysis of STL files. Mathematical and Computer Modelling, 38(7), 945-960, 2003.
- [37] Cha, J. M., Suh, S. H., Hascoet, J. Y. and Stroud, I. A roadmap for implementing new manufacturing technology based on STEP-NC. Journal of Intelligent Manufacturing, 1-15, 2014.
- [38] Assouroko, I., Eynard, B., Troussier, N., Ducellier, G. and Boutinaud, P. Survey on standards for product data exchange and sharing: application in CAD/CAE interoperability. International Journal of Design and Innovation Research, 5(1), 9-15, 2010.
- [39] Remy, S., Ducellier, G., Charles, S. and Eynard, B. Advanced STEP parameterised and constrained features for reverse engineering. International Journal of Computer Applications in Technology, 32(1), 1-11, 2008.
- [40] Patil, L., Dutta, D., Bhatt, A. D., Jurens, K., Lyons, K., Pratt, M. J. and Sriram, R. D. Representation of heterogeneous objects in ISO 10303 (STEP). In ASME International Mechanical Engineering Congress and Exposition, Orlando, Florida, 2000.
- [41] Pratt, M. J. Introduction to ISO 10303—the STEP standard for product data exchange. Journal of Computing and Information Science in Engineering, 1(1), 102-103, 2001.