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# A Study on CAD Modelling and File Generation Issues in Rapid Prototyping

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**Abstract:** *With the evolution of the RP industry and the advent of RE tools and techniques there is an increased interest in the development of computer aided design (CAD) tools and techniques to decrease the lead time when creating prototypes. This study was performed with the intention of contrasting two methods of input to the rapid prototyping (RP) process, viz., manual modeling (MM) and reverse engineering (RE) techniques. An object was selected to generate CAD models via MM and RE techniques and STL (STereoLithography) files were generated. The plots of file size versus deviation tolerance; and file size versus angular tolerance were developed in order to provide practitioners an opportunity to assess the capabilities of MM and RE approaches in acquiring a better CAD file. From the study results, several observations were made by evaluating the obtained STL file sizes; time taken to create the CAD models, the surface quality of the models, and computer resources required.*

***Keywords:*** *Rapid Prototyping, Reverse Engineering, Manual Modeling, Deviation Tolerance and Angular Tolerance*

## 1. Introduction

The rapid prototyping (RP) process has revolutionised the manufacturing industry with research is being undertaken worldwide to find ways of improving the process. For RP to be regarded as a mainstream process, parts created by the RP process have to consistently accomplish critical tolerance specifications for various features of the part (Paul and Anand, 2011). The input to the process, namely the CAD model, is a very important step in examining and improving the accuracy and efficiency of the process. It requires accurate CAD models from which suitable STL files can be attained (Page et al., 2005; Bagci, 2009; Chowdary et al., 2010; Ali and Chowdary, 2011; Chowdary and Sahatoo, 2011). There are two major ways of obtaining the CAD model for use in the RP process. One of the methods is by manual modelling (MM). Page et al. (2005) describe it as modeling through engineering drawings. With this method, a human being sits in front of the computer screen and by using appropriate pointing devices and CAD software, creates the STL model to be used in RP process. The whole approach is often seen as tediouos and time consuming which has prompted the evolution of new and faster ways of obtainig the CAD model.

The second approach is reverse engineering (RE): this involves using appropriate equipment to obtain points or images of an object in 3D space and then reconstructing the object with this data using suitable RE software. RE is of particular importance in cases where an object needs to be modified, but the CAD model is not available (Page et al., 2005; Ali and Chowdary, 2011; Chowdary et al., 2011). RE equipment can be classified into two major categories, namely contact and non-contact. As mentioned in Page et al. (2005) and Bagci (2009), coordinate measuring machine (CMM) falls under contact type RE system and it basically consists of a probe at the end of an arm which is used to record several points from the surface of the test sample. This data in turn can be used to create the CAD model. On the other hand, 3D laser scanners can be grouped under non-contact type equipment. They are used to digitise images of an object and then reconstruct these images on a computer system to obtain the CAD model (Chowdary et al., 2011; Ali et al., 2013).

The current study aims at comparison of MM and RE approaches in creation of CAD models in order to provide insights to practitioners on the ways and means to obtain an accurate CAD model which can be provided as input file to a RP machine. The ShapeGrabber AI310 laser scanner was employed to digitise the selected object. Then the adapted RE process was compared with the MM alternative. In addition the study focuses on establishing the relationships between the file size and angular and deviational tolerances. In addition, results with respect to model surface quality, time and resource usage with the selected modeling approaches, are reported.

## 2. Literature Review

This section reviews the literature on CAD modeling issues in the context of RP environment.

Onuh (2001) dealt with the integration of RE and rapid tooling (RT) for rapid manufacturing (RM) of objects, while Page et al. (2003) explored the technical challenges of generating CAD models for vehicular parts using laser range imaging methods. Hieu et al. (2003) covered design methods for medical RP of personalised cranioplasty implants. Hieu et al. (2005) have also been investigated medical RP methods based on RE and medical imaging data. Page et al. (2005) have studied a wide range of RE issues and emphasised the need for development of ways to create CAD models. They defined the RE process and enumerate a scheme of RE techniques. Noorani (2006) outlined the various RE techniques including recent applications and trends. Ferreira et al. (2006) emphasised the role of RP and virtual prototyping models for evaluation of industrial objects, and provide an RE approach for inspection and quality control of parts made from RT and RM technologies.

Within the RE environment, Chowdary et al.'s (2010) study investigated how the file size, the number of triangular facets, the number of errors and the surface finish vary with tolerance. In this regard, the study provides evidence that the ASCII file size is considered to be six times that of the binary equivalent. In addition, the study proved that there is a significant decrease in the size of both ASCII and binary files with an increase in tolerance. Moreover, in the recent past, Chowdary and Sahatoo (2011) used a structured experimental approach to show the effect of slicing on the surface finish, layering error and build time of a prototype. In particular, the study used a screen shot evaluation approach to show the slicing effect on layering error and proved that the slice thickness has a great impact on the selected factors. The screenshot approach has been proven effective in the past research studies (Choi and Kwok, 2002; Holzer and Fadel, 2002).

From the above brief review of literature it can be seen that several RE issues are dealt with from different perspectives: the different techniques examined and integration of RE with RP was also discussed. However, there is no single study found that contrasts MM and RE techniques with regard to identifying various issues such as model creation time, model quality and usage of computer resources. In addition, very few studies looked at the generation issues of STL files within the RE environment (Fadel and Kirschman, 1996; Chowdary et al., 2010; Chowdary and Sahatoo, 2011).

## 3. Motivation of the Study

In the RP industry, the time taken to create a prototype can have a huge impact on customer satisfaction and the profit made by the company. This has lead to many studies to explore ways of reducing manufacturing lead time, and maintaining CAD model accuracy by simultaneously focusing on STL file generation methods. Manufacturing lead time is also of grave importance especially where RP is used for medical purposes (Gopakumar, 2004; Hieu et al., 2005; Armillotta, 2006; Gibson et al., 2006; Dhakshyani et al., 2012).

Based on the literature review, no comparisons have been made of MM to RE approaches for the creation of CAD models. Thus, the current study compares MM with RE approaches to creating CAD models with tolerance along with file size as the main focus of the research. The selection of tolerance and file size as study parameters is based on pioneers' research works (Zhang et al., 2003; Noorani, 2006; Sahatoo et al., 2008; Chowdary et al.,2010; Chowdary and Sahatoo, 2011; Sreedhar et al.,2012). A brief explanation in this regard is provided in the following paragraphs.

In the process of tessellating the CAD model to generate STL file, there are a number of issues involved which influence the choice of various tolerances such as deviation tolerance and angular tolerance. For instance, deviation tolerance is the maximum perpendicular distance allowed between a curved surface and the plane used to represent it when tessellation is performed on a CAD model (Sreedhar et al., 2012). Further, angular tolerance represents the maximum angle allowed where the curved surface and plane meet. Thus, these two types of tolerances are critical and thus selected as parameters of the current study. In addition, the two tolerances produce STL files of different qualities and hence require individual comparisons.

After an object is created on a CAD system it is tessellated and stored as a STL file. However, the storage space required for this precision file format which is compatible to a RP machine is generally very high (Niekerk and Ehlers, 2000). Moreover, tolerance is an influential factor in STL file generation and can determine the smoothness of the surface (Noorani, 2006; Solidworks, 2012). This is conquered with Chowdary et al. (2010)'s study which reveals that in tessellating the CAD model to its STL file equivalent, there is a need for more storage space due to the increase in file size. Moreover, the study concluded that with the change in tolerance there will be variation in roughness of the tessellated surfaces.

Motivated by the above, the current study focuses on the comparison of MM and RE techniques that can be applied in CAD model acquisition and STL file generation. At the end, observations and recommendations are made based on the generated CAD models of the selected object.

## 4. Research Methodology

For the investigation, an object (Alblock) was chosen and modeled using MM and RE techniques. The generated CAD models are shown in Figure 1 and Figure 2 respectively. From the created CAD models, STL files were generated and graphs plotted in terms of the angular and deviational tolerances with the STL file size. Then the two selected modeling approaches were compared to evaluate the effect of tolerances on the file size.

For the MM approach, the object dimensions were assessed and modeling was done using the SolidWorks package and a typical computer workstation with keyboard and mouse as pointing devices. With the created CAD model, STL files were generated by varying the tolerance values. Whereas for the RE, a 3D laser scanner (ShapeGrabber AI310 System) was used. The selected object was first coated with D-NF Developer to remove any surface shine which may reflect the laser. The laser scanner was then calibrated. The selected object was oriented in several ways such that the laser passed over and captured three of its sides (in the x, y and z directions). Several scans were made which were all manually merged together using GeoMagic Studio. The merged CAD model was edited to clean the unwanted data captured in the process of the digitisation. The final CAD model was then exported using the IGES file format.

For each model acquired, 50 STL files were generated for demonstration of the issues identified. Five values of deviation tolerance were used, each with five angular tolerance values for both ASCII and binary file types. For instance, 5 deviation tolerance values for an angular tolerance of 10°, binary and ASCII each, making it 10 files. This was also done for the other five angular tolerance values (10 files for each angular tolerance value) and hence 50 (5 x 5 x 2) STL files were created. All these details are presented in Table 1. For each STL model the file size was recorded.

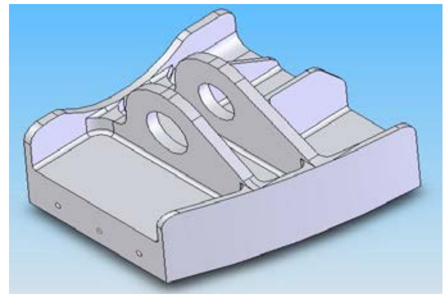

**Figure 1.** Generated CAD model for the selected object using MM approach

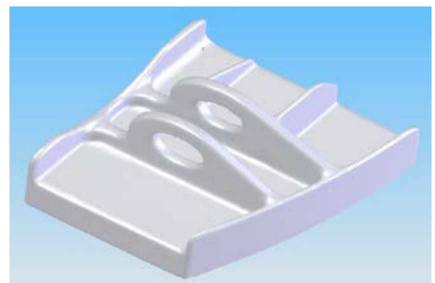

**Figure 2.** Generated CAD model for the selected object using RE approach

**Table 1.** Number of STL files generated

| File Number | Angular Tolerance (degrees) | STL Type | Deviation Tolerance (mm) | File Number | Angular Tolerance (degrees) | STL Type | Deviation Tolerance (mm) |
|---|---|---|---|---|---|---|---|
| 1 | 5 | Binary | 0.05 | 26 | 15 | ASCII | 0.05 |
| 2 | 5 | Binary | 0.07 | 27 | 15 | ASCII | 0.07 |
| 3 | 5 | Binary | 0.09 | 28 | 15 | ASCII | 0.09 |
| 4 | 5 | Binary | 0.10 | 29 | 15 | ASCII | 0.10 |
| 5 | 5 | Binary | 0.20 | 30 | 15 | ASCII | 0.20 |
| 6 | 5 | ASCII | 0.05 | 31 | 20 | Binary | 0.05 |
| 7 | 5 | ASCII | 0.07 | 32 | 20 | Binary | 0.07 |
| 8 | 5 | ASCII | 0.09 | 33 | 20 | Binary | 0.09 |
| 9 | 5 | ASCII | 0.10 | 34 | 20 | Binary | 0.10 |
| 10 | 5 | ASCII | 0.20 | 35 | 20 | Binary | 0.20 |
| 11 | 10 | Binary | 0.05 | 36 | 20 | ASCII | 0.05 |
| 12 | 10 | Binary | 0.07 | 37 | 20 | ASCII | 0.07 |
| 13 | 10 | Binary | 0.09 | 38 | 20 | ASCII | 0.09 |
| 14 | 10 | Binary | 0.10 | 39 | 20 | ASCII | 0.10 |
| 15 | 10 | Binary | 0.20 | 40 | 20 | ASCII | 0.20 |
| 16 | 10 | ASCII | 0.05 | 41 | 25 | Binary | 0.05 |
| 17 | 10 | ASCII | 0.07 | 42 | 25 | Binary | 0.07 |
| 18 | 10 | ASCII | 0.09 | 43 | 25 | Binary | 0.09 |
| 19 | 10 | ASCII | 0.10 | 44 | 25 | Binary | 0.10 |
| 20 | 10 | ASCII | 0.20 | 45 | 25 | Binary | 0.20 |
| 21 | 15 | Binary | 0.05 | 46 | 25 | ASCII | 0.05 |
| 22 | 15 | Binary | 0.07 | 47 | 25 | ASCII | 0.07 |
| 23 | 15 | Binary | 0.09 | 48 | 25 | ASCII | 0.09 |
| 24 | 15 | Binary | 0.10 | 49 | 25 | ASCII | 0.10 |
| 25 | 15 | Binary | 0.20 | 50 | 25 | ASCII | 0.20 |

## 4. Results and Discussion

As per the established number of experiments, data for both MM and RE approaches were collected. Then graphs were plotted to establish the relationships between file size with angular and deviation tolerances. The resultant graphical relationships are shown in Figures 3 and 4.

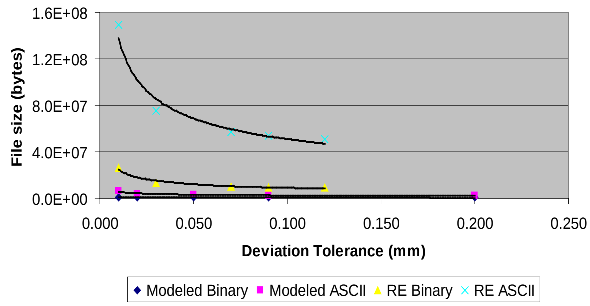


**Figure 3.** File size versus Deviation Tolerance (for a sample angular tolerance of 10°)

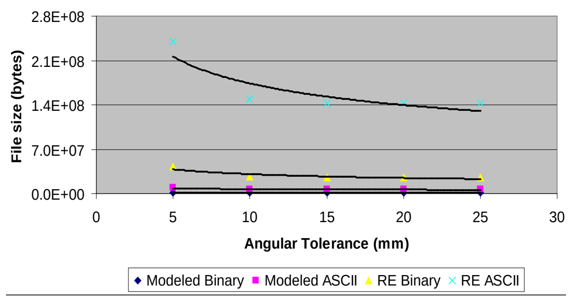


**Figure 4.** File size versus Angular Tolerance (for a sample deviation tolerance of .01mm)

From Figure 3 it is clear that the file size decreases with increasing deviation tolerance. Moreover, a far greater file size is generated by the RE model than for the MM model (ranges from 15-28 times the size). From Figure 4 the file size decreases with increasing angular tolerance, again, the RE model has a larger file size than the MM equivalent. The binary and ASCII versions for each model type (RE and MM) have the ratio 1 to 6 (Binary to ASCII). This was expected and matches previous study results (Chowdary et al., 2010).

However, it took a longer time to produce the CAD model from the RE process than the MM process. The RE process involves several operations such as manual calibration, orientation of the object, manual merging of the digitised multiple views and data cleaning to obtain the desired CAD model. Whereas to apply the MM technique, the user just has to have a good idea of CAD package operations to create the desired CAD model.

Based on the screenshots shown in Figures 1 and 2, the MM approach provides a far better surface finish than the RE method. Further, MM surfaces that have been seen as flat are appeared as bumpy and rough in the RE based CAD model. Also, it is worthy to note that tiny features, such as small holes and fine curves which are less exposed to laser radiation, may not be captured accurately with the RE methodology. Thus, the RE approach generates an incomplete CAD model.

The file size of the model generated using RE was far greater than that obtained by MM. Both IGES and STL files were generated in the RE process, both of which were much larger than the MM equivalent. This is an important factor to be considered as the time taken to process the model at any stage of the manufacturing process would increase due to increase in file size. As expected, products in real world applications are considerably more complex than the object used in this study. Under these circumstances, the file size plays a critical role due to its direct relationship to manufacturing time.

In addition to longer manufacturing time, greater effort is needed to edit the RE model compared with editing the MM model. Also, there is not as much control over the geometry of the object in the RE approach as compared to MM. With the MM approach, the different parts of the objects can be easily altered to any shape or form desired. With RE, it becomes far more difficult, time consuming, cumbersome and may not give the desired results. Furthermore, STLs made from RE took long durations than their MM equivalents. This situation is not desired in the RP industry and thus the RE approach would not be preferred for RM applications.

## 5. Conclusions

From the study it is clear that the MM approach is the preferred method when compared to RE technique, since MM requires less time and less effort to create a CAD model. Moreover, it gives far greater accuracy in surface finish and object feature detail than RE and also requires far less processing time.

In addition, the image detail obtained through MM is better than the RE as can be seen from Figures 1 and 2. The surface of the RE model is rougher than the MM equivalent and it can also be noticed that features such as the small holes of the selected object would not be produced using RE since the laser could not pass through them. Finally, the RE based CAD models as recommended by Chowdary et al. (2011), are however, more appropriate when the physical dimensions and design information of the object are missing due to lack of original design data and the existence of surface contours which are difficult to measure and reproduce manually.

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