SOME ASPECTS OF USING STL FILE FORMAT IN CAE SYSTEMS

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Introduction

The format called "STL", relates to "stereolithography" which is the method of layered manufacturing invented by 3D Systems™. Process of product design development is mainly performed using the computers and computer-aided-design (CAD). Computers are used to create 3D models of object's geometry. Also, various physical, technological and other properties can be noted as an information part of the model. The progression from CAD to physical design requires building physical prototypes based on the computer model for validation of form, fit, and function. STL is file format of rapid prototyping method that allows translating the CAD model data into a file format that could be interpreted by rapid prototyping machinery, and thus physical prototype can be created.

Notes to creating STL file output

Most of solid and surface CAD software devices enable automated export of their models to STL file format. In most of these CAD systems, the settings of STL export depend on following parameters:

?? **Chordal Tolerance:** Chordal tolerance numerically describes the maximum distance between the actual part surface and the tessellated surface of the STL file, as it is shown in Figure1.

?? **Angle Control:** Setting the angle control influences the tessellation of curves with relatively small radii in comparison to the overall size of the CAD model.

?? **Type of exported STL file:** In most systems, two types of exported STL files are allowed, binary and ASCII. The binary format is compressed and allows smaller file size, (6:1 ratio) whereas the ASCII format can be read and visually checked.

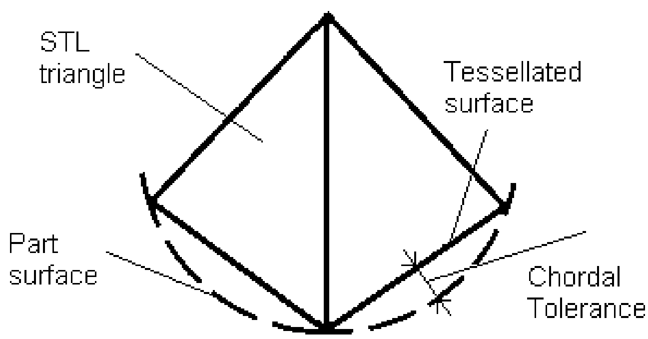
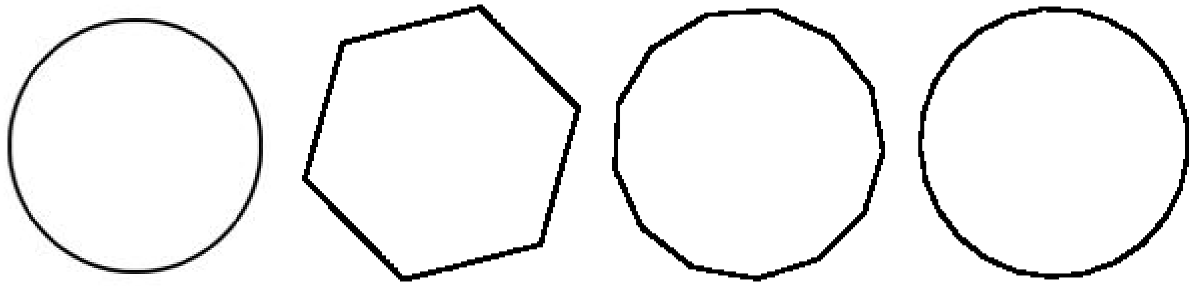


Figure 1 STL triangle

As the number of triangle increase and the relative triangle size decreases, the shape begins to be more accurate what is defined as facet resolution. Parts constructed by rapid prototyping may require additional finishing or may not measure to accurate dimensions if the facet resolution is too low. The user has to balance the accuracy issue with the file size. Often, the users over-tessellate exported design, but rapid prototyping technologies have limited feature spot sizes, so one spot size may include facets with useless information.

STL file represents surfaces of CAD model, as a mesh of triangles. The quantity and size of the triangles determines how accurately the surface mesh represents the product, as shown in Figure2.



a) Desired Shape *b) Low Quality Mesh* *c) Medium Quality Mesh* *d) High Quality Mesh*

Figure 2 STL - quality of meshing

Accuracy issues, making the export of model created in CAD to STL is obviously performed for two possible reasons, direct use of STL file for rapid prototyping method and use of STL file as exchange format required by some CAE software. For both exploitation areas, it is necessary to take into account that exporting the models to STL file formats can be influenced by several types of errors:

?? **Tessellation generation error:** In some of the generated triangles of the model, the distance between origin surface and tessellated surface is more that chordal tolerance. This type of error is shown in Figure 3a.

?? **Convex boundary error:** In this case, the tessellation results in a smaller object where the two left segments are removed and the third segment results in added material. This type of error is shown in Figure 3b.

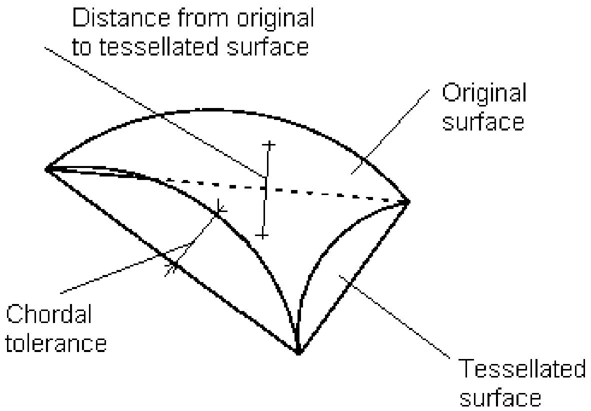
?? **Flipped normal:** The points that form a triangle are not listed in the correct order, that typically follows some convention (right hand rule) which results in the cross product of the two vectors formed by the three points. Occasionally, the computed normal is in the opposite direction or is non-existent or plains wrong, and must be corrected. This error is typically easy to correct.

?? **More than two triangles per edge (mid-line nodes):** The basic rule used to check the validity of the STL file to ensure that each edge of a triangle is shared by only two triangles is not kept. This type of error is shown in Figure 3c.

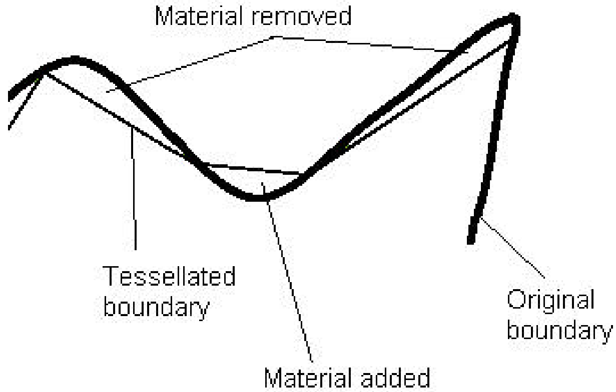
?? **Closure (holes):** The tessellation is performed with round-off errors and this causes one point to be at multiple locations at the same time. Thus, triangles are formed, and a thin hole is present in the finished model. This type of error if often generated if user selects a very small chordal tolerance and it is shown in Figure 3d.

?? **Truncation errors:** These are the errors added by the computers that preprocess the files. Each of these machines has only certain accuracy, and errors can result from reading and writing the files on different platforms. These errors are usually negligible.

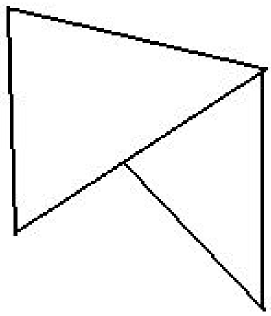
?? **Other errors:** These errors are obviously caused as a result of pure CAD to STL converter and can have various forms.



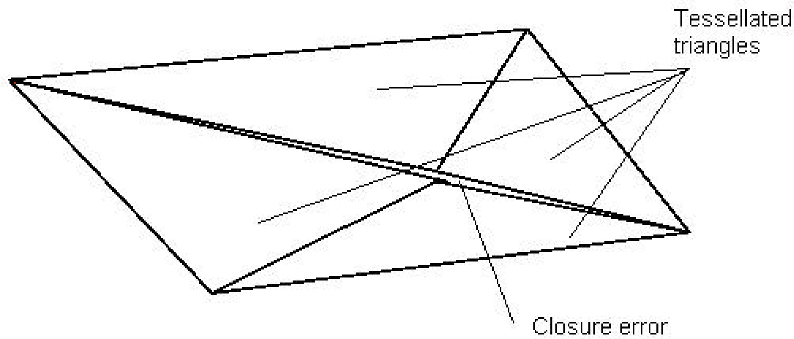
a) tessellation generation error



b) convex boundary error



c) mid-line nodes error



d) closure error

Figure 3 STL software export errors

The above-described errors are the errors caused by software export modules. If using some of the rapid prototyping machine, it is necessary to consider other types of errors, such as:

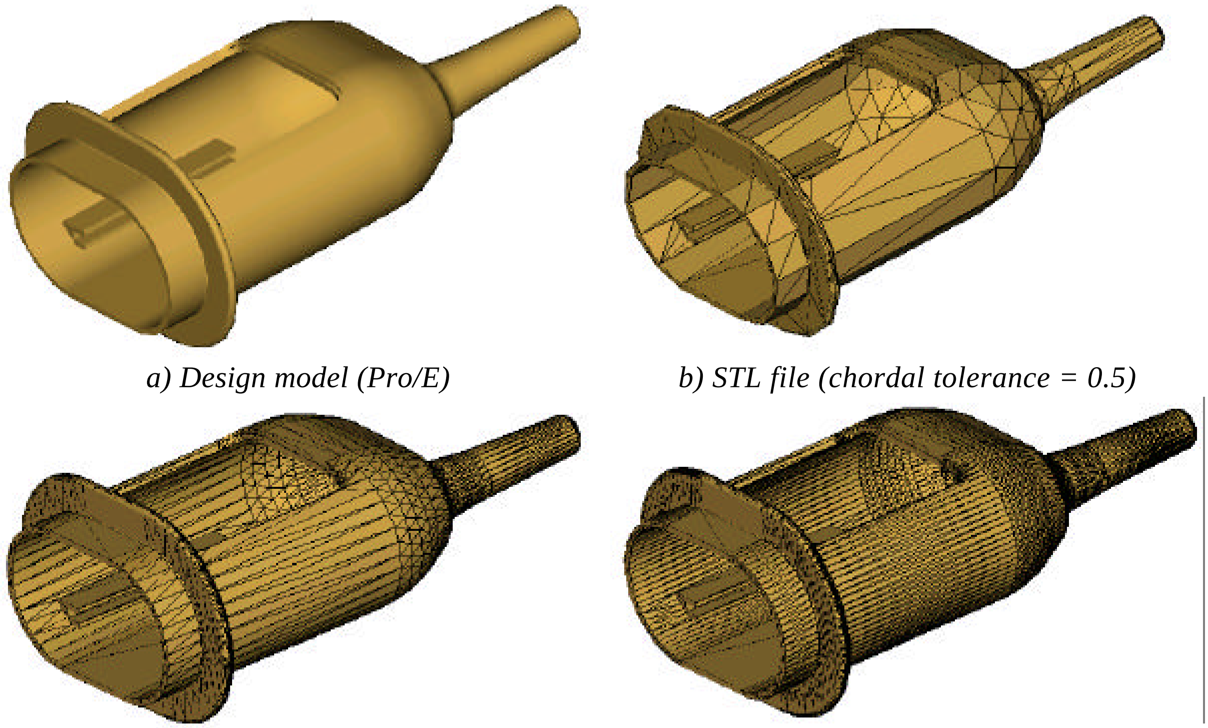
- **Improper vectorization:** Vectorization is the transformation of curves into series of vectors. In most current rapid prototyping processes, the tessellation converts non-planar surfaces into a mesh of triangles. The intersection of these triangles with parallel planes at z height increment results in the vectors that drive the laser or build head controllers. Improper method of vectorization can result in problems with transferring the file to rapid prototyping machine.
- **Laser beam or jet thickness error:** Most processes, whether laser based or printer head-based have to compensate the thickness of the delivery system. Laser beams thickness used in the SLA is typically 0.25 mm in diameter.
- **Z effect:** The error is caused if the slicing is performed by constant layer thickness and the curvature of the surface is complicated. Slicing process at constant z height increments may lead to missing planes or missing edges on top surfaces of parts. This is solved by adaptive layering process, with slice height changing in accordance to curvature of design. Using adaptive slicing, surface finish quality increases significantly.

Application of STL file format in CAE systems

STL file format was developed for rapid prototyping technology, but some CAE software devices use this format for import of models and their preprocessing before making the analysis. Figure4 shows plastic cover of voltage tester that was designed in Pro/Engineer system and then analyzed in C-Mold 3D QuickFill software device. Parameters of exports shown in Figure 4b,c,d are noted in Table1.

Table 1: Plastic cover - export to STL

Name	Chord Height	Angle Control	Number of triangles created	Binary file size (kB)
Stl1 (Figure 4b)	0,5	0,5	1492	74,684
Stl2 (Figure 4c)	0,05	0,5	7676	383,884
Stl3 (Figure 4d)	0,01	0,5	25018	1,250,984



a) Design model (Pro/E) *b) STL file (chordal tolerance = 0.5)*

c) STL file (chordal tolerance = 0.05) *d) STL file (chordal tolerance = 0.01)*

Figure 4 Generating STL files in Pro/Engineer system

C-Mold 3D QuickFill allows to study the parameters of cover production such as: melt front advancement, injection pressure required for correct filling, clamp force, pressure trace, temperature of resin during filling, time to cool after filling, air traps, orientation of weld lines and other. Based on this analysis, it is possible to make conclusions about the design properties of plastic cover in relation to its technology. Generating STL file for making the analysis in C-Mold requires:

?? Quality of meshing at level that keeps origin design of the part.

?? Optimal number of triangles created during meshing.

?? Design model is meshed without errors.

As it is clear from Figure4, STL export shown in Figure4b does not meet the criteria for using it for analysis, since the design of origin part is not kept. The selection can be performed from exports shown in Figures 4c,d. In this case both designs were tested in software DeskArtes, that is specialized for work with STL files. It provides many useful options that are commonly not a part of standard CAD systems. DeskArtes enables for example: manual and automatic corrections of STL files, automated check of generated STL files on possible errors and other.

DeskArtes is one of the available software that bridges the CAD to rapid prototyping machines, it is Finnish software that includes file format conversion, correction of STL, slicing, and offsetting. Other similar tools available to bridging between CAD and rapid prototyping are numerous, such as CIDES, Bridgeworks, ADMesh, Shapes, SolidView, Brockware, Majics, Surfacer, STL-Manager and other. Exported STL files shown in Figures4c,d were checked in DeskArtes to make conclusion which of the designs is more suitable for using in C-Mold software. DeskArtes environment is shown in Figure5.

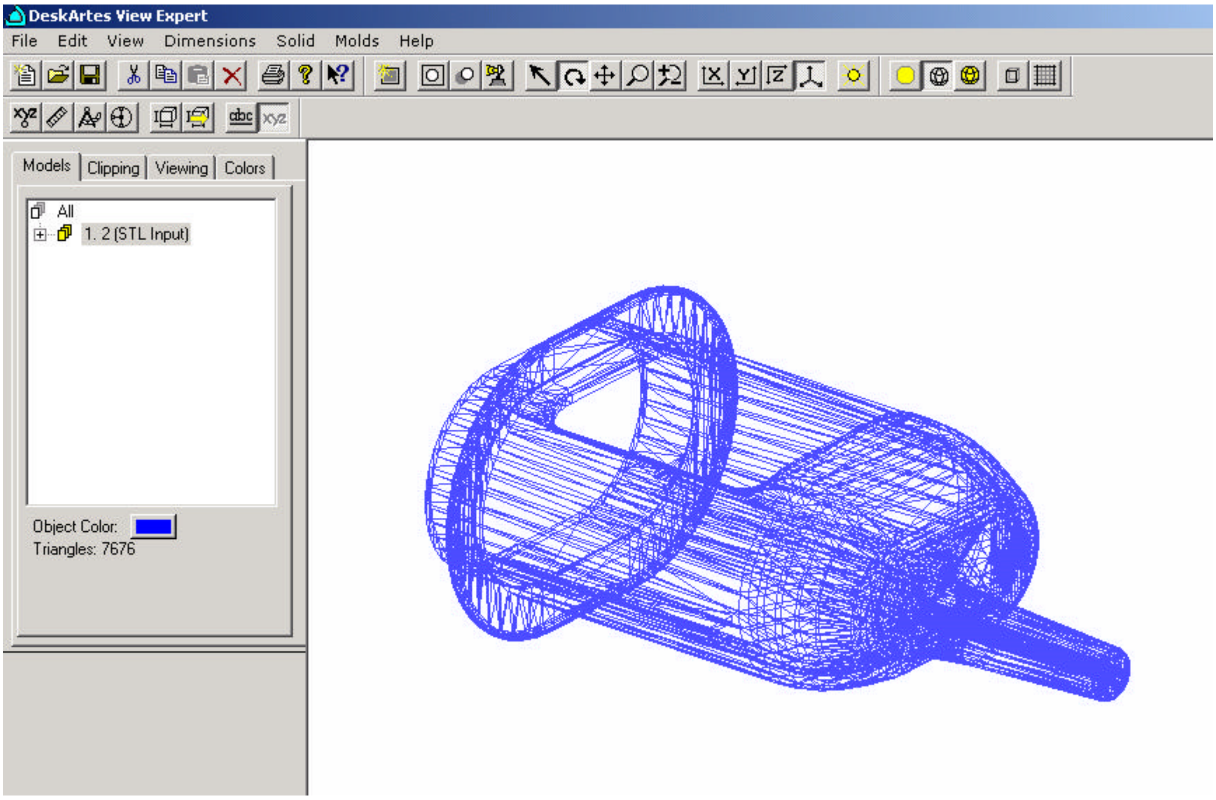
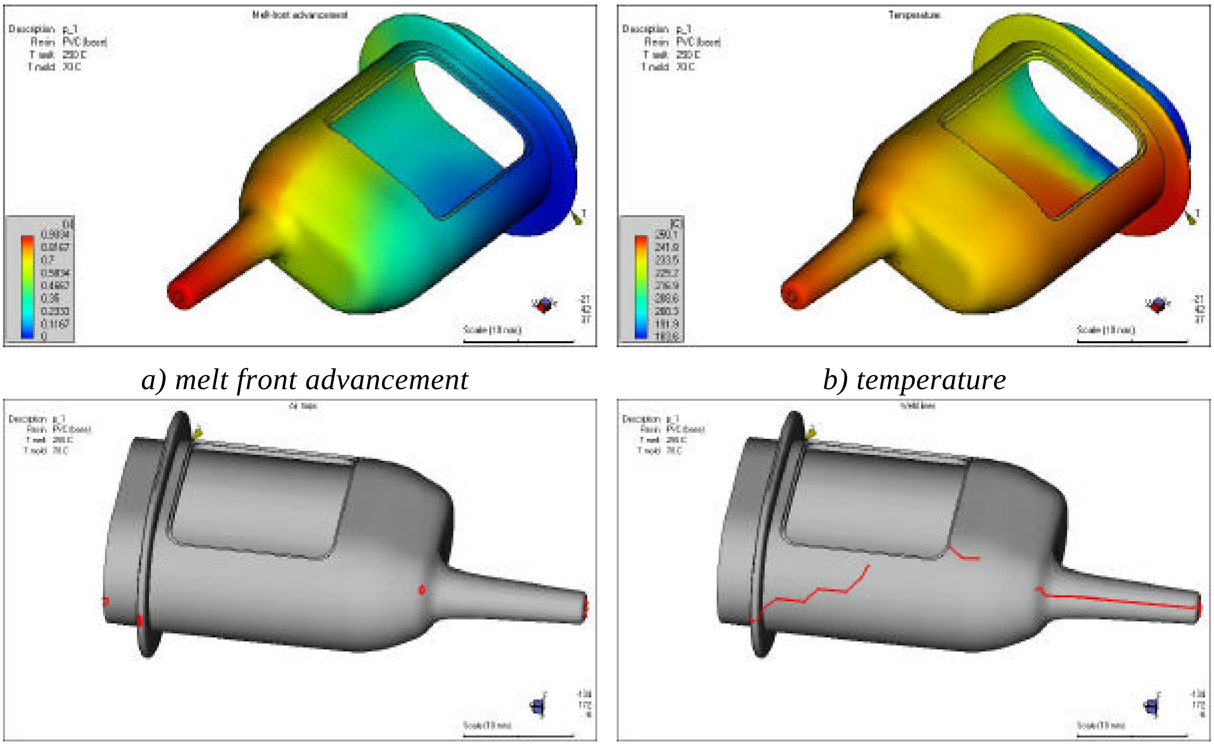


Figure5 DeskArtes software device

Based on the analysis performed in DeskArtes software device, it was analyzed that, STL export shown in Figure4d is over-tessellated, both considered exports contain some minor export errors, that are possible to be corrected directly in DeskArtes by AutoCorrect option. Due to this fact, it was decided that, the STL export shown in Figure4c is best of all generated STL export files to be used in C-Mold 3D Quick Fill. The examples of the results performed by analysis in C-Mold are shown in Figure6.

Figure6a shows the results of melt front advancement, which are important for considering the time of form filling. Figure6b shows resin temperature after filling. Figure6c shows possible location of air traps and Figure6d shows possible location of weld lines, what are important kinds of error in final part after mold filling, that have to be considered, before real design of mold components. Based on this analysis, the user can make the decision about usability of tested design model in real conditions.



a) melt front advancement b) temperature

c) air traps d) weld lines

Figure 6 C-Mold analysis

STL file format is often used file format in CAE applications that are determined for analysis of plastics, since the structure of STL meshing is suitable for mathematical description of the mold filling problem analysis. Using this file format has several advantages for plastic designers and mold-makers, since STL as a standard format for rapid prototyping methods can be used for quick making of prototypes in cases, when it is required by design process.

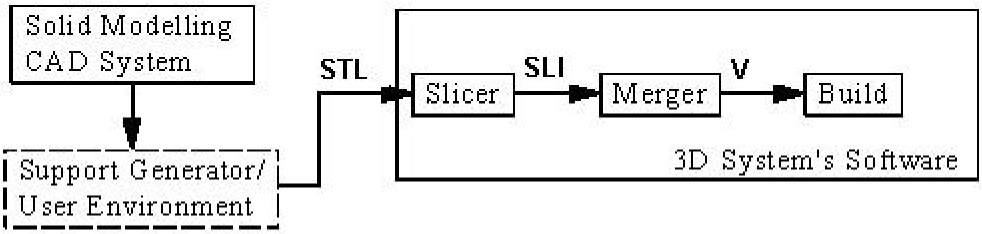


Figure 7 Preprocessing data for rapid prototyping

The work with data before their use in rapid prototyping systems is shown in Figure7. The part is built in the CAD program, and then exported into STL file format. CAD systems often support also work with rapid prototyping equipment, but it is generally more suitable to use specialized software by which is equipped the rapid prototyping machine. STL file is processed through a slicing program that produces a list of filled contours known as an SLI file. Then the support and part SLI are merged to form a V file, which is used with three other process specific files (.r, .l, .prm) to drive the SLA (stereolithography device) and build the prototype.

Conclusions

STL is a standard output format from most CAD software, and the number of triangles used can be user-defined. There is necessary to calibrate between accuracy and file size for most design models. Mapping any curved surface with flat triangles (facets) means that a lot of small facets are needed for a good match to a smooth curve, but on the other hand very large files are difficult to handle by other CAE software or by rapid prototyping machine. Commonly the translation from the modeling format to STL leaves a few flaws, and so the integrity of STL files is usually checked using special software before the files are used in other software or to build a rapid prototyped object. Small errors can be corrected automatically, but big faults have to be repaired manually. Software errors affecting using the STL file format are numerous due to a multiplicity of influencing factors. Many attempts at controlling these errors have been published or are available to the user community, but a good understanding of the various errors and their source is needed in order to maintain control of the process.

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