Using Surface tools in CAD to create CFD geometry

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Abstract

This report attempts to guide users through the complex range of surface modeling tools offered by most modern CAD packages, with a view to the eventual use of generated models in downstream applications such as CFD. Addressed here are the advantages that make surface modelling such a powerful freeform design tool, but also an assessment of the limitations of these techniques in generating mathematically sound models. The report concludes by detailing techniques that avoid these pitfalls and allow surface models to be used successfully in downstream applications

0.1 Introduction

In recent years many advances have been made in the field of CAD programing. This has seen it surpass it's beginings as a simple drawing tool and allowed for the generation of models with great analytical potential in a number of engineering applications including CFD, FEA and Rapid Manufacture. One of the foremost advances here has been the development of a number of surface modelling tools. Much less restricitve than their solid modelling counterparts, these tools allow for the freeform modelling of many complex and irregular geometries, making them a powerful tool in the arsenal of the designer. These tools are a significant improvement in increasing the potential of CAD models but they are still not without their problems. They often allow for the creation of geometry that cannot be correctly read by downstream applications in their native form. Whilst this does not make these surface models completely redundant when creating models for CFD, it does mean that some degree of surface post-processing is required in order that they be accepted downstream. This report then, attempts to analyse the benefits and drawbacks of using surface tools in the creation of models for CFD and assesses the effectiveness of a number of methods used to enhance them to an acceptable state.

0.2 Use of Surface Models

Traditionally CAD programs have used sketches consisting of individual lines, circles, splines and other variations to define the geometrical boundaries of components. These sketches can then be used to create entities of virtual material, again using a number of methods such as extrusions, sweeps, lofts etc. This can either be done by creating solid bodies of this virtual material, with geometry in all 3 directions, or by creating 2-dimensional surface models that are infinitely thin.

Using Dassault Systems' *Solidworks* package it was possilbe to assess a full range of the current surface modelling tools currently available. For the benefit of the inexperienced these are summarised below:

Planar surface One of the two simplest type of surface tool, the planar surface as the name suggests is a simple flat surface created on a 2D plane. They are often defined by single basic sketches as the basis of many surface models. They can also be created using the internal bounds of pre-existing surfaces, providing of course that they are all on the same plane.

Extruded surface The other simplistic surface, the Extruded surface tool can be used to extrude a single line, curve or spline in the direction normal to the plane on which they are drawn. They are very useful for creating geometry that is complex in 2 dimensions and also for creating planes that can be used to trim other surfaces.

Revolved surface The revolved surface tool allows for the extrusion of a surface profile in a circular direction at a defined radial distance from a central axis. This is a good tool for creating parts with rotational symetry but with complex profile geometry. Examples could be complicated venturii throttle bodies or cast parts.

Swept surface Similar to the revolved surface tool, this tool allows the extrusion of a single profile along a path. This tool is very suitable for creating extruded shapes such as complex pipework, structural frames or any other construction that has a constant cross section but traverses a number of different directions.

Boundary surfaces Boundary surfaces allows for the creation of a surface between four boundaries. What makes this tool special is that it is able to retain the tangential or normal curvature of the bounding curves over the surface, allowing for great control over the curvature of the surface as a whole.

Filled surface One of the most freeform surface options, this tool literally allows for the plugging of holes that exist between any number of surfaces in a surface body. Whilst very hard to control, the flexibility of this tool is often very useful when it comes to repairing imported models that contain faults. It is also a good tool to use when a particularly complex but small section of geometry such as corners cannot be modelled using conventional methods.

Lofted surface Probably the most freeform and designer friendly surface tools, the loft tool allows the user to create geometry from a set of different profiles, connected by a set of guide curves. Given that all of these can be completely irregular spline sketches, and also completely geometricaly independent of each other, lofts can be used to model virtually any geometry from the most simple to the most complex.

Not all of these surface tools will be discussed here but an attempt has been made to address a comprehensive enough range of these so as to provide a thorough overview of the benefits and drawbacks associated with surface modelling.

0.3 Benefits of surface modelling

In order to understand why one would use surface models over solid models it is important to understand the differences between the two. With this in mind the following definitions have been provided:

"freeform surfacing is used in CAD and other computer graphics software to describe the skin of a 3D geometric element."

"solid modelling is a consistent set of principles for mathematical and computer modelling of three-dimensional solids. Solid modelling is distinguished by its emphasis on physical fidelity."

Thus, solid models are generally used to generate models for mechanical analysis. The rigid parameterization of their mathematical structure gives them a very good basis for downstream analysis, but renders them rather stiff when it comes to aesthetic design. As a result, surface modelling is still widely used in the fields of automotive, aeronautical and naval design amongst others.

Surface models are essentially connections of NURBS (Non Uniform Rational B-Spline) curves which are defined by a series of control points along their length. These control points can be added or deleted as required and manipulated in all 3 dimensions. It is this mathematical freedom of definition that makes surface modelling so attractive to those designing non-conventional geometry. They can have mathematical definitions added to them to make them more sound but do not require them to exist.

Whilst great progress has been made recently in terms of developing the flexibility of solid modelling, it is still far from being able to effectively represent the complex geometry found in many modern engineering structures and as such surface modelling continues to be a very powerful tool for designers. With this comes interest from engineers who are interested in analysing and manufacturing these designs, and it is at this point that the use of surface models begins to diminish.

0.4 Drawbacks in using surface models for downstream applications

Whilst conducting the research that has lead to this report a number of deficiencies were found when it came to importing these models into CFD packages. For the purposes of this study two different CFD packages were used; *ANSYS Workbench*, a commercial closed source CFD code with a direct plug-in to *Solidworks*, and *OpenFOAM*, an open source code accepting non-native file types such as `.stl` and using a cartesian cut-cell mesher: `snappyHexMesh`.

Firstly, discussing the direct import into *ANSYS* it was hoped that this would be very accepting of surface models given its direct connection to the geometry. Many CAD/CFD interfacing problems are caused by converting the files into multiple formats along the way and so removing this step was expected to eliminate many of these problems.

This was sadly not found to be the case. It was found that pure surface models, as simple as a cube, could not be analysed correctly. Whilst a mesh of the geometry could be generated for most cases, this mesh would not correctly transfer to the solver; *Fluent* and as such resulted in the flow simply being calculated for empty domains (examples of this will be given later).

Given the failure at this stage to mesh any of the geometry that was supplied to a transferrable standard, next attempts were made to convert the surface files into `.stl` files in order to transfer them to *OpenFOAM* for analysis. It was hoped in this case that, given that the `.stl` conversion was to be done in *Solidworks* itself, that this process would be less dependent upon the CFD program itself and therefore possibly more reliable. Sadly, once again, it was impossible to create `.stl` files of pure surface models, with *Solidworks* claiming that they were of the wrong filetype for that opperation.

0.5 Experimental results on correct drawing of surface models for CFD

Looking at the previous sections, it would appear that surface modelling has no place in the toolbox of those creating models for CFD. Actually this is not the case, but it is obvious that surface models cannot simply be generated on their own as solid models can to be simply passed on from program to program. There are a number of methods which need to be used, and indeed practices to be observed to make surface models suitable for downstream applications. The remained of this report focus's on these, with the hope of saving future designers who may be slightly inexperienced with CAD, many hours of wasted labour in completing a CAD/CFD analysis!

In order to vaguely understand why surface models on their own are so problematic we must remind ourselves that the mathematical freedom they enjoy, is also their downfall. It often results in the geometry of surfaces being poorly defined and/or insufficiently mathematically defined to be made use of by the triangulations algorithms associated with meshing tools. Whilst it is impossible to gain access to the algorithms within the CAD package itself to see how surfaces are being defined, it is possible to use some of the tools of the CAD package to provide some mathematical integrity to collections of surfaces. These process are (usually!) enough to render all but the most complex models suitable for downstream analysis.

0.5.1 Surface knitting

Surface knitting is the action of unifying two or more surfaces with adjacent edges. This goes some way to eliminate the gaps that occur between ajacent surfaces as shown in the following example:

Quarter-disc case

In this example, a quarter of a disc has been drawn by drawing half a right angled arch and then a symmetrical, leaf-shaped surface. Both are planar surfaces with the resulting profile then being extruded, and finishing with both original planar surfaces being mirrored about the centre of the part in order to create the far side. Even in *Solidworks* if we zoom in we can see that there are evident gaps between the two surfaces, despite the fact that they share the same sketch spline.

These gaps will be enough to prevent the tesselation algorithm within the software generating an `.stl` model of the part as it requires the continuous geometry usually associated with a solid model. There is a way of dealing with this however. By knitting the surfaces together it is possible to minimise these gaps to a given tolerance as can be seen in the left of the image below. Whilst purely knitting surfaces is not usually enough to allow `.stl` generation, there is

Figure 1: Quarter disc

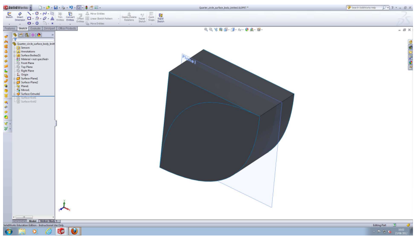
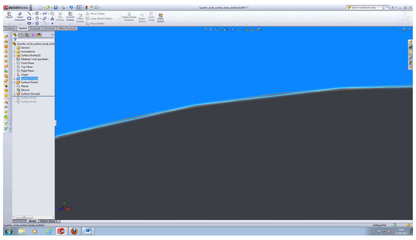
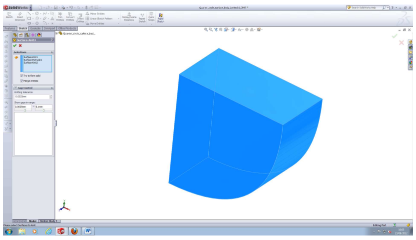


Figure 2: Gaps between surfaces



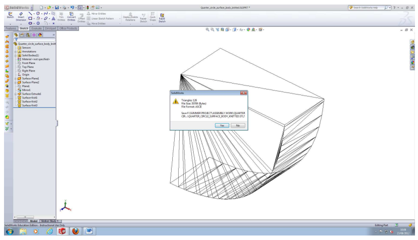
another option available that allows the user to convert the geometry to a solid body.

Figure 3: Knitting options



Once this has been done, the surface body now posseses all the qualities of a solid body and can be successfully exported as a native *Solidworks* file or converted to an `.stl` as seen here. In this case it has been possible to combine the best features of surface and solid modelling using the knitting feature.

Figure 4: Final .stl model



0.5.2 Surface thickening

Whilst knitting can be a very effective solution, it is not fullproof. Often the surface geometry, if sufficiently complex or with too many large gaps, cannot be converted into a solid body simply by knitting all the surfaces and then converting. Occasionally it is possible to knit groups of surfaces and then knit these knits together to acheive solidity, but again this is largely hit and miss. In this case another tactic must be adopted, one reffered to as surface thickening.

As its name suggest, this tool literally allows the user to add thickness to one or both sides of a surface. This effectively turns the surface into a very thin solid body and so inherits all the relavant structural integrity that it needs to undergo downstream analysis. At the same time, it is often infintely quicker when modelling complex geometry to create a surface and then thicken it than it is to trying to sketch profiles for the equivalent solid loft or by trimmming a solid extrusion. It should be noted at this point, however, that thickening is not always an option with significantly complicated or ill-defined surfaces (see section on 'lofts', below).

Torus case

In the last case, the part could quite easily have been modelled as a solid extrusion, thus circumventing all of the associated surface modelling issues. In this case, the freeform nature of surface modelling design begins to come clear as a better solution for drawing complex geometry. This case involves a torus which is designed to transport two fluid seperately in a helical fasion. It has been created by drawing the profile of a semicircle which has then been swept along a circular path for 180 degrees whilst also undergoing a 180 degree twist. The resulting sweep has then been mirrored about the axis that runs diametrically through the circle, with inlet and outlet tubes created as surface extrusions of a circular profile.

Examining the images below we can see that two different meshes, a tetrahedral and a hexahedral mesh, were created in *ANSYS* of the geometry but neither would transmit successfully to *Fluent* in order for an analysis to be completed. The second set of images show the same torus with the exception that all of the surfaces have been thickened by 10mm. Now it has been possible to mesh the geometry and, as can be seen in the last image, the data has been passed successfully to *Fluent* for analysis.

Figure 5: Surface torus

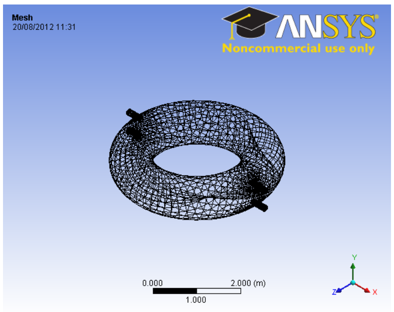
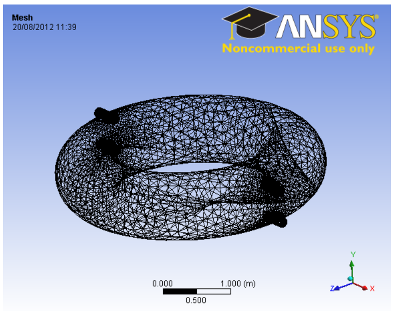


Figure 6: Thickened torus



0.5.3 Lofted surfaces

The discussion of these issues comes to a head within the issue of lofted surfaces. As previously stated, lofted surfaces are the most freeform of surface design tools with the minimum ammount of constraints applied to them. As such this makes them the ultimate design tool, especially for aesthetically pleasing geometry, but also makes them the most mathematically unstable and therefore the most likely to cause meshing algorithms to fail.

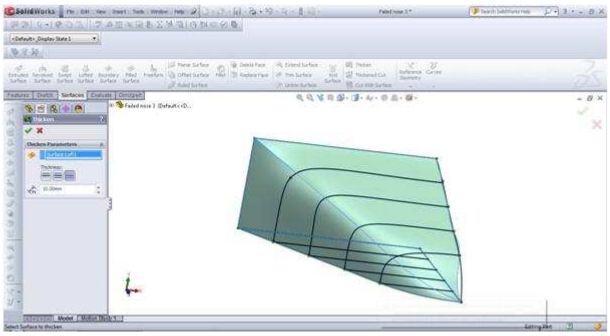
This instability can also render them incapable of cooperating with either knitting or thickening tools, due to their largely undefined relationships to adjoining surface geometry and poorly defined normal directions. As such, drawing lofts that work is often down partially to luck but developing correct and mathematically efficient drawing practices can lead to a much better chance of thickening or knitting a lofted surface.

Car nose case

As an example of this, an industry-relevant case is presented here. This is of half a nose cone for a racing car, similar to those use in Lemans-esque endurance races. The reason that only half of the nose has been drawn is that cars are often only drawn in half down their central line of symetry and then the features mirrored to minimise drawing time (a generally useful tactic for drawing any vehicle or similarly symetrical item).

In the first example here, the designer has attempted to utilise the freeform nature of surface design by drawing the entire cone as a loft consisting of a series of splines. Whilst this has allowed the designer to create quite a fluid form, some issues can immediately be identified with this method.

Figure 7: Unsuccessful nose loft

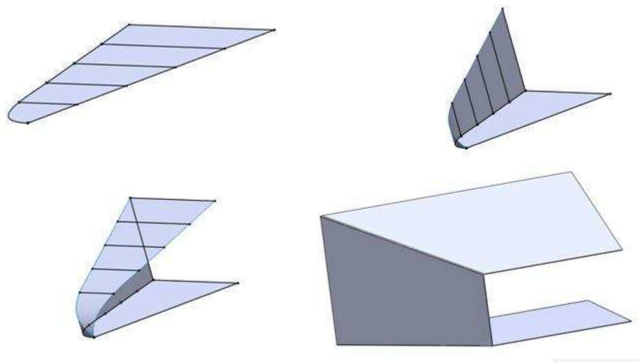


Firstly observation of the area at the end of the cone shows a demonstrable deviation from the guide curve in the actual surface geometry created. By using single splines with many variations and control points or sharp angles, the already vaguely mathematial definition of the surface bounds have been further complicated and so the program is having difficulty fulfilling all the boundary conditions it is being given. This is a common feature of lofts that involve too many, or too complicated splines.

The other problem is clearly shown in the control pannel at the left hand side of the image. The mathematical vagueries which define these surfaces have rendered them incapable of being thickened and so will prevent this part from being transferred downstream as a solid model.

In the second example, the desinger has gone about the task in a more methodical manner. Here the geometry has been created in a piecewise manner, first the base, then the side and finally the top. This means that the lofts have been created as a series of vertical and horizontal lines rather than splines. As a result the model is much more mathematically sound and the surface geometry has been created successfully. The final image presents a section view of the finished part to demonstrate that it has been thickened and also filleted at the edge to include the curvature present in the first example.

Figure 8: Successful nose loft



Thus in this example it has been shown that lofts can be problematic, but with some careful thought into the geometry of the part, do not need to cause potential meshing failure. It is often better to take the time to draw something in a more mathematically sound manner as, whilst it may take longer at the drawing stage initially, it can save much head-scratching and re-drawing down the line.