Hybrid Surface Reconstruction Technique for Automotive Applications

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***Abstract*— Reverse engineering has become a viable technique to create a 3D virtual model of an existing physical object. It enables the reconstruction of body surfaces to create a suitable CAD model required prior to its manufacturing or improvement via simulations such as Computational Fluid Dynamics or Finite Element Analysis. Two main tools can be used in reverse engineering to recreate external surfaces from complex 3D shapes: Rapid Surfacing (RS) and Classical Surfacing (CS). RS is a fast-modelling method contrary to CS which is time-consuming but produces far higher quality surfaces. This paper describes the construction of a suitable triangulated mesh of a reverse engineered car from which body surface reconstruction can take place. RS and CS are used independently to create two distinct models which are then compared with a suggested hybrid CAD model that takes advantages of both techniques. Results show that the hybrid method reaches a balance between the two methods: it enables the construction of a suitable model with quality surfaces in a satisfactory time. Finally, CFD is used to numerically compute the drag of the reverse engineered vehicle.**

***Keywords*— CAD procedure, hybrid method, reverse engineering, surface reconstruction, CFD.**

I. Introduction

Performed through various stages, reverse engineering is the process of creating a 3D virtual model of an existing component. There are several application areas that often use a part for which there is no initial CAD data such as in virtual simulations, in medicine and in industry where re-manufacturing of certain parts is required for further improvement [1,2].

The reverse engineering process starts with point cloud data being extracted from the physical object by scanning the model followed by mesh generation and fitting of the surfaces to the model to create the exterior skin of the 3D geometric element [3]. Numerous factors need to be taken into account when generating surfaces over the polygonal model such as the level of accuracy and quality desired for the final CAD model. In the automotive industry and other similar industries, a perfect visual surface finish with very smooth lines and contours is to be expected and high quality surfacing of the body part is a requirement. The creation of surfaces on the model is thus a crucial step in reverse engineering.

Software packages that deal with surfacing 3D objects have evolved rapidly in terms of accuracy and speed of algorithms to the point where it is possible to produce a CAD model within hours. Two different types of procedures are available: rapid surfacing techniques [4] where the surfaces are produced from intersecting curves forming a three or four-sided patch and classical CAD techniques based on free-form modelling [5].

This paper describes the 3D digitisation of a whole car and the creation of its subsequent polygonal model through reverse engineering from which surface reconstruction can take place. The creation of two distinct CAD models via RS and CS are then analysed and compared with a CAD model produced via a suggested hybrid procedure. Finally, the aerodynamic performance of the hand-made sports car is numerically assessed

II. Case Study

The reverse engineering process is applied to a complex hand-made sports car (TVR Cerbera) as seen on figure 1. This is used as an illustration case and the application described here can be extended to any other similarly intricate industrial component. This part is chosen because of its complex shape encompassing varied details such as grooves, lights and air holes. For the purpose of this 3D object it is necessary for the final surfaces to reach a high quality standard. Only one half of the car is studied here, the other half being created by symmetry.

III. Reverse Engineering Procedure

A. Material and digitization from components

A seven-axis articulated measuring arm (Cimcore 2.8 m) equipped with a laser scanner (Perceptron V4) which generates a line of points at the rate of 23,000 points per second was used to scan the external surface and create a precise image. This car is a fairly large object and thus, to produce a suitable polygonal model, the arm was positioned in a dozen of different arrangements in order to collect all the data desired and scan the component in various directions. A total of about 3000 scans were taken. It took three days to scan half of the car. The time required to scan the car could have been reduced by using other scanner technologies.

Manuscript received October 31, 2007.

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(Advance online publication: 19 February 2008)

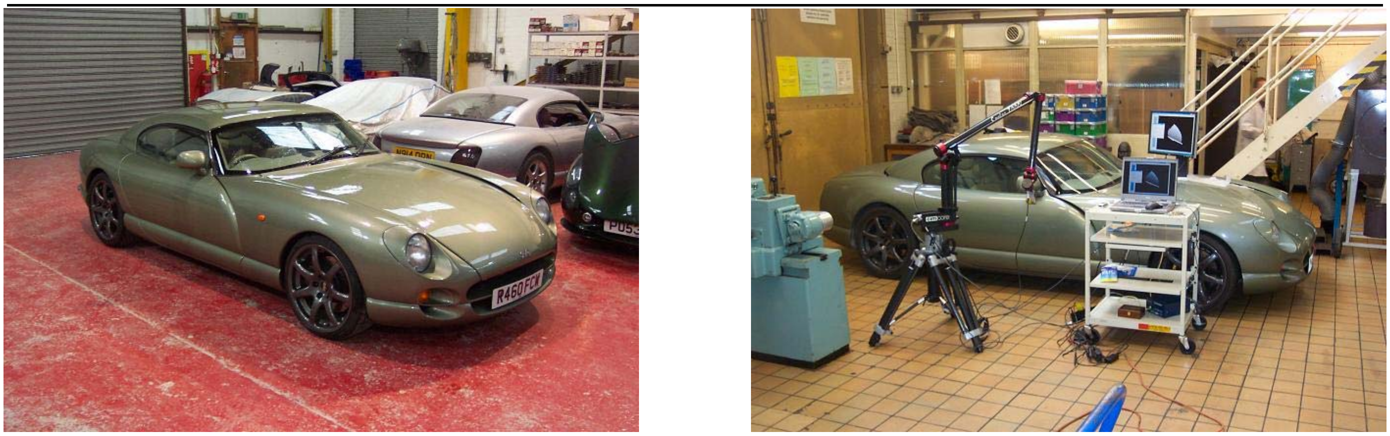


Figure 1: TVR sports car with scanning equipment.

The reverse engineering software used for pre-processing the data is PolyWorks V9. It is a proprietary software package that deals with cloud points, mesh repair, surface generation and inspection. However, the successive stages described here could be carried out in a similar fashion using any other reverse engineering package.

As the body is scanned, images must meet two criteria. Firstly, each group of scans has to share adjacent data with other groups. Secondly, each image overlap should contain shape variations as the algorithms do a shape-based alignment to bring all scans in the same coordinate system.

B. Preprocessing of the point clouds

The scans are imported into a module where they are treated to remove irrelevant points. When all of the scans are ready the alignment can commence [6].

The first portion of the car is locked with its corresponding scans fixed and all the subsequent scans for other parts will be aligned relatively to them (see figure 2). This rough and automatic alignment is carried out semi-automatically by picking common points from the adjacent pieces. This initial alignment will be improved by an iterative best-fit alignment for an optimal and accurate alignment. These scans can now be positioned and the process is repeated until the point cloud is shaped. When all the scans seem aligned, the last action consists of optimising the pre-alignment. Again, a best-fit alignment is used to generate the final cloud points. The point clouds data are now ready for meshing.

C. Generation of the initial mesh

Once the point cloud is edited, the triangulated mesh can be produced. A high-resolution and accurate polygonal model is generated from sets of aligned scans. However, at this stage the merged model is not complete and further improvement is required to deal with some imperfections. About three hours were necessary to merge data and produce an initial mesh.

D. Optimisation of the mesh

The triangulated model obtained from the meshing stage has various imperfections such as holes and gaps and needs to be refurbished and optimised [7].

Abnormal triangles such as residuals over the whole model are first deleted. Small holes are quickly filled in automatically but a manual operation has to be performed to surface over large holes and gaps in a proper and accurate way. Bezier surfaces are used to repair these areas by fitting them to triangles surrounding the holes. The geometry is then repaired and remeshed locally.

Once the geometry is repaired the mesh is optimised and subdivided in order to create a suitable stereolithography (STL) file as illustrated in figure 3. The polygonal model obtained is the starting point for the generation of the CAD surfaces. When fitting surfaces, the smoother the mesh the higher quality the produced surfaces will be.

In this case, the model is compressed from 6,000,000 triangles to 300,000 triangles. About four hours were required to complete these editing operations and create a suitable polygonal model necessary to generate the body surfaces.

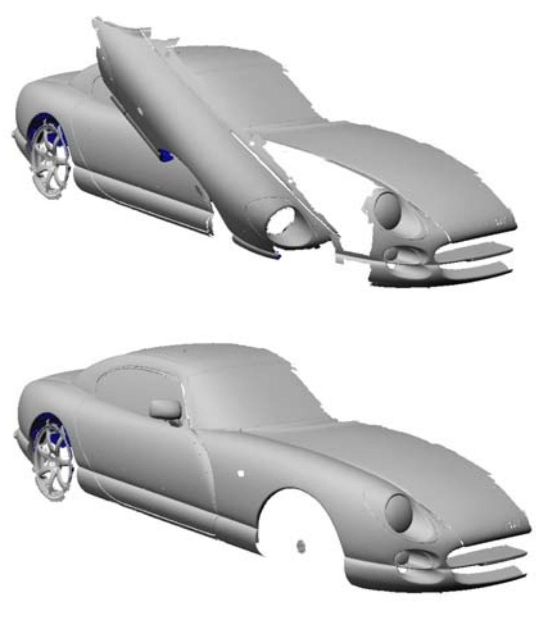


Figure 2: Scan alignment of the cloud points.

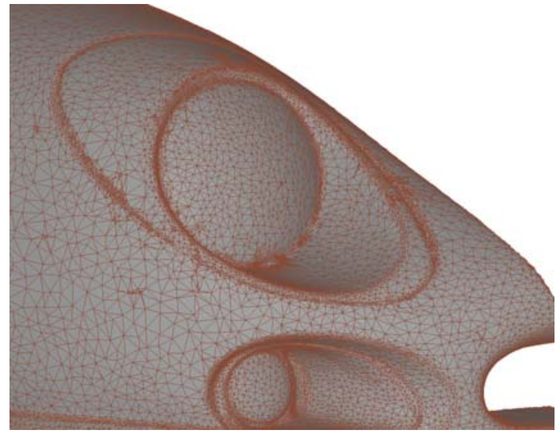


Figure 3: Optimised mesh as an STL file.

IV. SURFACE CREATION

A. Rapid Surfacing (RS)

Surfaces produced using this fast-modelling procedure follow accurately the mesh but are not perceived as a high quality standard.

In this method, boundary curves and feature curves are first extracted either automatically or manually for meticulous shapes. Feature shape is a representation of shape aspects that are mappable to a generic shape [5]. For example, chamfer and rounding are geometric features and therefore curves can be extracted by tracking lines of curvature. Many other curves are then created manually to generate further various quadrilateral patches. A curve network is thus built from a set of magnetized curves. Two magnetized curves have a common control point at their intersection in the Hermite representation. The basic curve element for constructing complex composite curves is the parametric cubic curve.

Patches tends to have four boundaries in order to respect continuity with other adjacent patches but in some cases a three-sided patch can be created. To get rid of any wrinkles and waves on surfaces, T-junctions are located in flat areas. Colouring the polygonal model by curvature enables the operator to differentiate precisely flat areas from the blend shapes. In the case where a patch has more than 5 boundaries, this will result in a hole on the surface of the final model.

Finally, generation of NURBS surfaces is performed automatically within minutes. To obtain a suitable CAD model which fallows accurately the mesh, the number of control points per boundary is set to 6. A greater number of control points are not necessary because of the heaviness of the model that could be obtained [7].

B. Classical Surfacing (CS)

In this method, surfaces are produced manually. Curves are first fitted to cross-sections extracted from the mesh using a lower to higher degree process in order not to overbuild the final model. A quadrilateral patch is then produced using surface creation tools. This surface has a simple mathematical representation and is further modified by moving manually the control points to reach a balance between a nice arrangement for a high quality standard and a close fit to the scan. Once non-adjacent patches are produced using this technique, degree-five or higher transition surfaces are then built to ensure a continuity of the curvature and thus a high-quality set of patches. Finally, trim functions and automatic tools such as fillets are used to complete the preliminary CAD model.

This procedure turns out to be time-consuming and tedious even for a skilled operator. Numerous manual operations such as the creation of curves and surfaces which both need a manual modification of their control points required prolonged time period. However, this technique produces far higher quality surfaces compared to those obtained from the rapid surfacing method. Such smooth surfaces are habitually classified as “class A” due to their high quality [8].

C. Hybrid Surfacing (HS)

This suggested method is implemented to take advantage of both techniques above. It allows a quicker surface reconstruction than Classical Surfacing and a higher quality than Rapid Surfacing.

Feature curves and square-like patches are first created using RS techniques. These subsequent patches cover a large piece of the mesh where the curvature does not change suddenly. When the curve network is established, surfaces are accurately and automatically fitted to the mesh where they may be constrained on a specific area such as the symmetry when necessary.

This rapid stage is then followed by a classical CAD procedure; the obtained patches are quickly rebuilt using both automatic tools and manual operations to generate a nicer control point distribution and constrain adjacent patches with curvature continuity when required. Finally, the rest of the surfaces are built using manual surfacing as seen previously.

V. CREATION OF THE DIFFERENT CAD MODELS

A. Rapid surfacing:

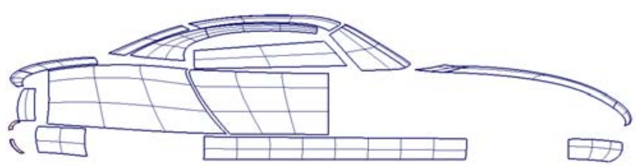
The model is quickly built from a curve network which defines boundaries of each patch. Surfaces are then fitted to the mesh within minutes. The CAD model obtained is not complete and requires the addition of a few details. A lack of data may appear such as in grooves where the mesh is impaired because of the difficulty of scanning narrow areas. A manual operation is then required to add these subsequent parts.

B. Classical surfacing:

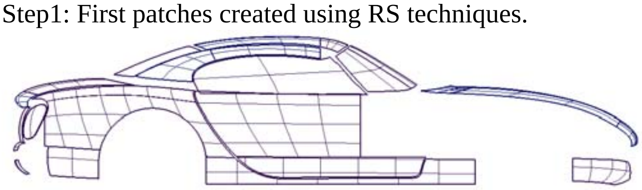
A significant investment in time is required to achieve a balance between smooth surfaces and a close fit to the scan. The parameters used for the construction of adjacent surfaces are 0.001 mm for a maximum gap, 0.1 degree for tangency and 0.1 mm-1 for curvature continuity. In CAD modelling, the connection between patches is classified as G0 for the gap, G1 for tangency and G2 for continuity.

C. Hybrid method:

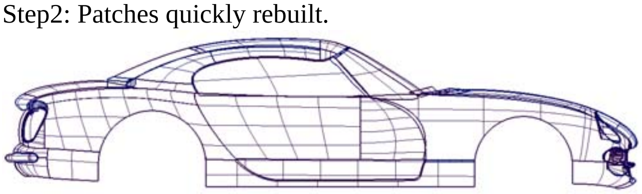
Square-like patches are produced using RS procedure as seen on figure 4. These subsequent patches are then extended and the CV distribution is improved to achieve a higher quality and a closer fit to the scan. Some surfaces are then trimmed to shape the car. Finally, the rest of the missing body surfaces such as the front wing are created via classical surfacing. The final CAD models are illustrated on figure 5.



Step1: First patches created using RS techniques.

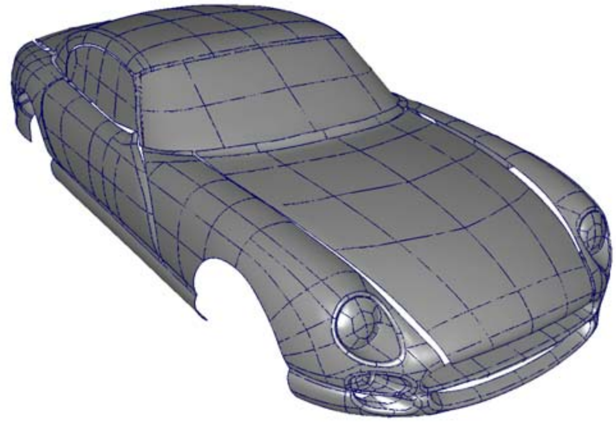


Step2: Patches quickly rebuilt.

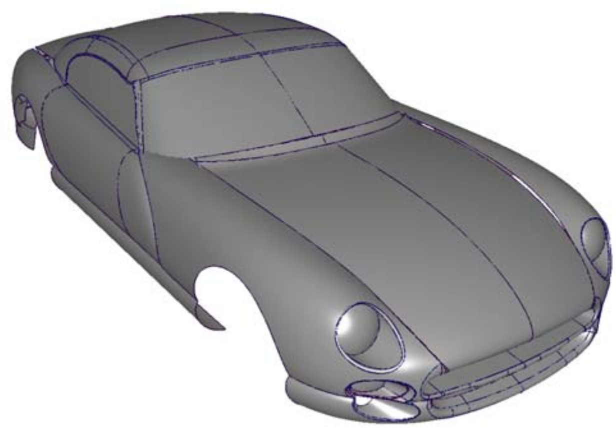


Step3: Addition of patches from CS.

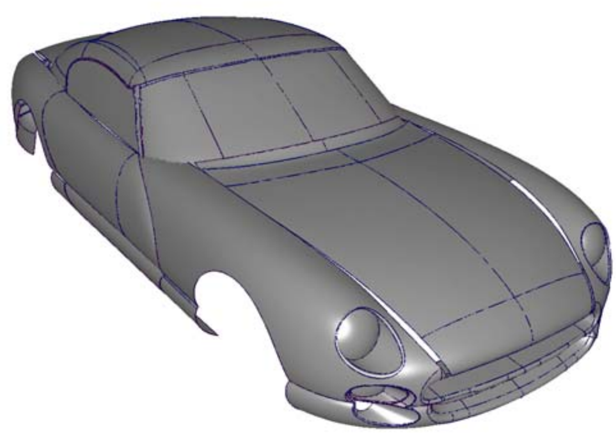
Figure 4: Wireframe of surfaces showing steps leading to the final hybrid CAD model.



Rapid Surfacing



Classical Surfacing



Hybrid Surfacing

Figure 5: Final CAD models of each procedure.

VI. RESULTS AND COMPARISONS

A. Accuracy

Accuracy is quantified by the deviation of the surface from its original mesh. As expected, surfaces from rapid surfacing techniques follow more accurately the mesh as seen on figure 6: approximately 95% of NURBS are within +/- 0.3 mm whereas in the manual method 95% of NURBS are within 1.5 mm. In the manual method, prolonged time period were required to achieve this range of errors but with more time and effort errors could have been slightly reduced.

Our findings suggest that about 90% of NURBS produced using the hybrid method are within +/- 0.5 mm. Errors are therefore minimised and divided by approximately three compared to the manual method.

Although accuracy is a requirement for surface reconstruction, provided that it remains close to its original mesh, surface smoothness and continuity which we refer to as “quality” is a more rigorous test for surface reconstruction when surface smoothness is the prime objective.

B. Quality

In this case where the final CAD model must achieve a perfect visual finish, rapid surfacing techniques are likely to reach a sufficient high standard since classical surfacing produces far higher quality surfaces. The curvature comb visibly states the high quality of the final CAD model obtained from CS compared to the jagged curvature comb from RS as illustrated on figure 7.

Patches from hybrid surfacing enable an accurate surface reconstruction with a smooth curvature comb. The quality achieved is not as fine as the one from CS techniques but is far better than surfaces produced using the CS procedure.

C. Time

Rapid surfacing techniques allow the operator to quickly create a CAD model within hours when approximately 6 to 7 days were required to model the car using classical surfacing.

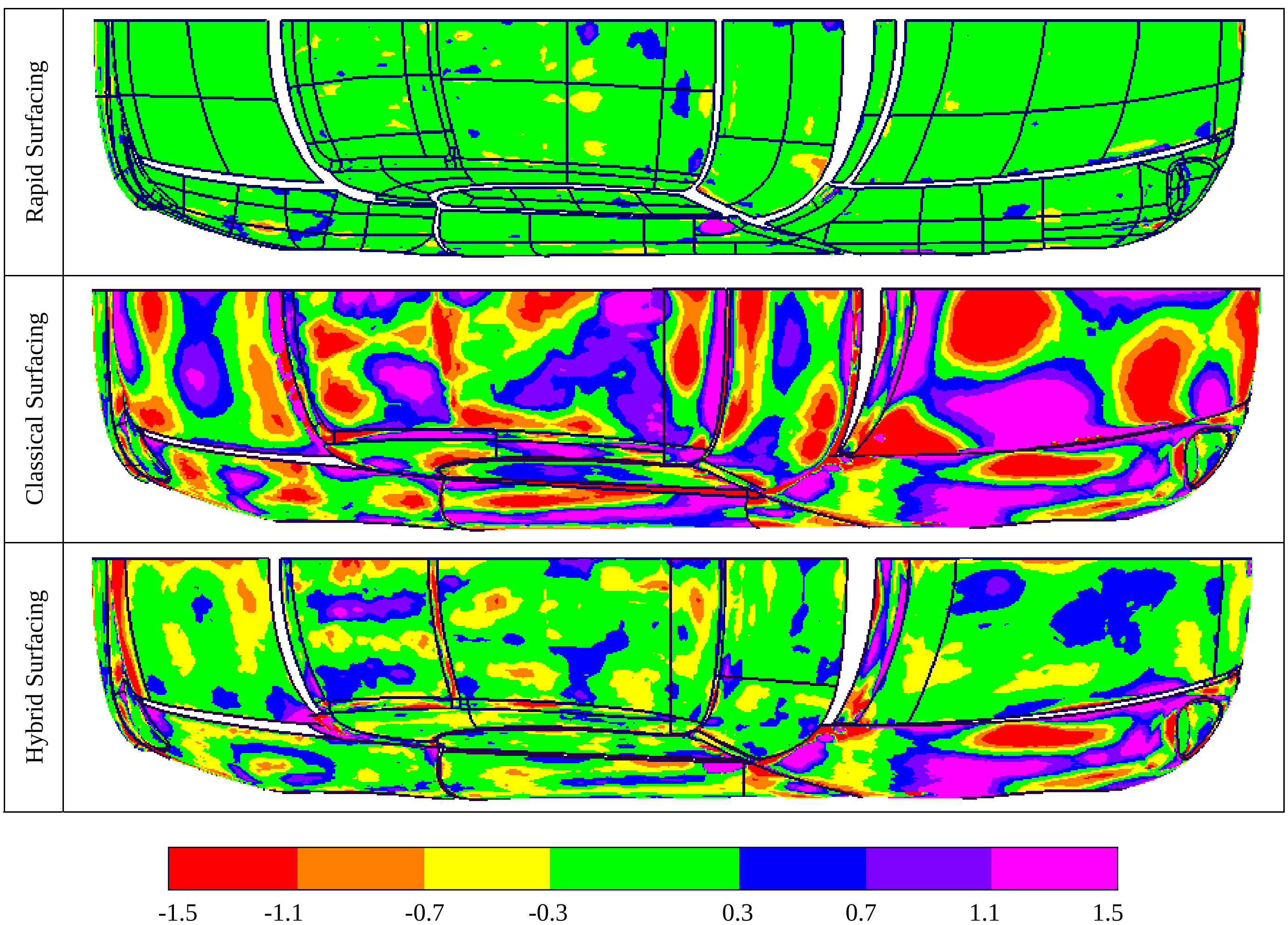


Figure 6: Deviation (in mm) of surfaces from the polygonal mesh.

Using hybrid method, the car is surfaced over within 3 days. The generation of first patches using rapid surfacing procedure and the reconstruction via classical modelling is a quick operation. Only a few hours are required. The longest operation is the addition of the patches using classical surfacing procedure to complete the final hybrid CAD model.

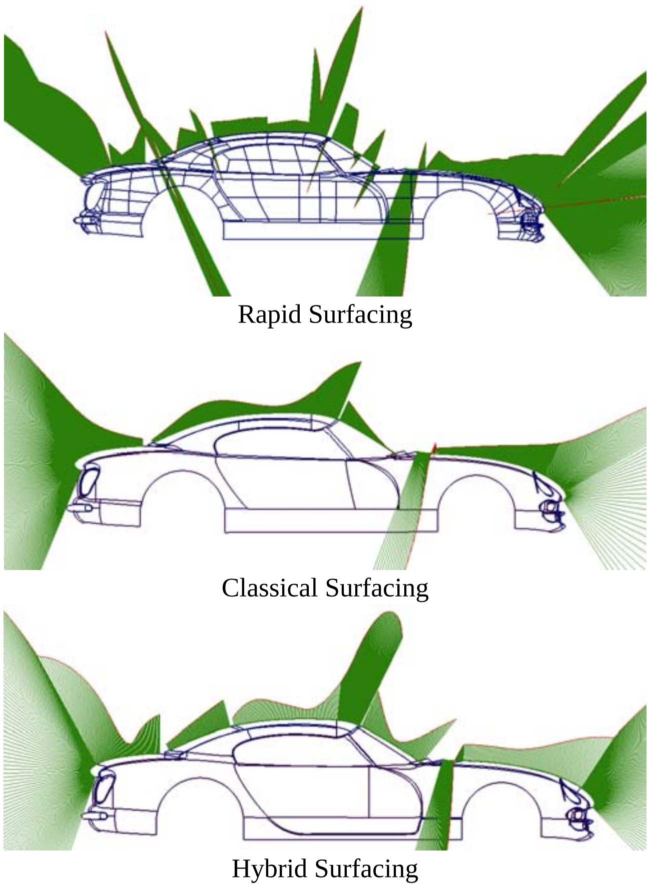


Figure 7: Curvature comb of each final CAD model.

VII. Drag assessment

Using the CS technique previously described, a watertight CAD model of the complex vehicle including meticulous 3D shapes such as wing mirrors, lights and air holes has been produced as illustrated in figure 8.

The CAD model being ready for a CFD analysis, the performance of the sports car can be predicted. The procedure is divided into three steps: the pre-processing, the simulation and the post-processing part.

The pre-processing stage consists in creating a flow domain (or computational domain) where the flow simulation occurred, in bounding the domain with external conditions and in discretising it into an adequate grid. The solution of the flow problem (velocity, pressure etc.) is defined at nodes inside each cell. The accuracy of CFD solution is governed by the number of cells in the grid. In general, the larger the number of cells the better the solution accuracy. Both the accuracy of a solution and its cost in terms of necessary computer hardware and calculation time are dependant on the fineness of the grid. Optimal meshes are often non uniform: finer in areas where large variations occur and coarser in regions with relatively little change. A large amount of time spent in industry on a CFD project is devoted to the definition the domain geometry and grid generation [9].

The simulation is then performed through an iterative algorithm until convergence. Finally, all the parameters of interest are extracted from the computed flow field. Visualisation tools such as vector plots, 3D surfaces plots, and particle tracking enable the operator to highlight flow characteristics and high pressure zones.

Since the fidelity of CFD predictions for complex turbulent flows such as flows around a sports car depends highly on the quality of the model, a Realizable k-epsilon model as suggested by Shih et al. was used in this study [10].

The basis of CFD can be found in reference [9, 11]. The drag coefficient (Cd) for the original shape of the car is found to be 0.306. There is no available experimental Cd value for this car but the Cd value for a very similar car (the TVR Tuscan Speed 6) was found experimentally to be 0.32.

Figure 9 shows some pathlines around the CAD model. The high pressure areas such as the front lights, air holes, wing mirrors and the windscreen are easily recognizable.

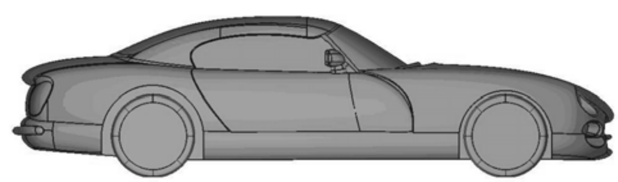


Figure 8: CAD model used for CFD analysis.

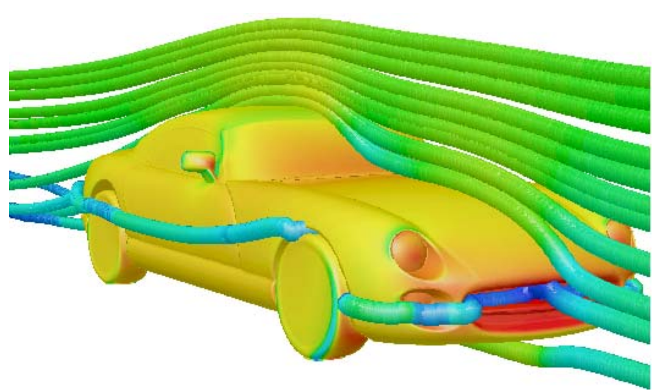


Figure 9: Contour of static pressure and pathlines.

VIII. CONCLUSIONS

This paper describes the successive stages involved in the three dimensional surface reconstruction of a complex industrial model such as a car. Reverse engineering is used to create the polygonal model prior to its surfacing using one of three methods (Rapid Surfacing, Classical Surfacing and Hybrid Surfacing) which are described, analysed and compared.

Rapid Surfacing techniques allow a quick surface reconstruction with a slight deviation from the polygonal mesh. Classical Surfacing techniques produces far higher quality surfaces since all patches are built manually: continuity and quality of such smooth surfaces is taken into account by the operator but a prolonged time period is required to build such a set of quality patches. For the purpose of a complex 3D component such as used in the automotive industry where aesthetic and visual appearance is required, Classical Surfacing is more suitable. Accurate surfaces from the mesh are a requirement but smoothness remains the final objective.

The hybrid CAD model presented in this paper strikes a balance between quality, time and accuracy. Compared with rapid surfacing, deviation is slightly greater but the quality achieved is closer to traditional modelling. Finally, the time required to create this CAD model is reduced since the operator does not perform as many manipulations as the classical procedure.

Finally, The CFD analysis of the flow around the reverse engineered car was carried out.

Further work is currently going on to improve the geometry of the car and reduce drag using an interdisciplinary study involving reverse engineering, Computer Aided Design and Computational Fluid Dynamics. Having a suitable reconstructed CAD surface of the model, the 3D surface can then be distorted and/or stretched to arrive at an appropriate and optimum shape.

ACKNOWLEDGMENT

The authors would like to acknowledge Nick Jarett from the company TVR for supplying the car.

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