Strategies and Techniques for Rapid Parameterization of Vehicle Surface Mesh

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ABSTRACT – Designed experiments and optimization studies require the rapid generation of multiple base model variants and rapid analysis techniques. Recent advances in mesh generation and simulation speed have significantly reduced the time requirement for computational analysis of vehicle exterior airflow. Time associated with CAD construction & CAD modification is now becoming the dominant factor in defining total throughput time for vehicle aerodynamic analyses. This paper describes the strategies and techniques used for rapid morphing of vehicle models used to support early theme analysis.

TECHNICAL PAPER -

1. INTRODUCTION

1.1   Background

Computational fluid dynamic (CFD) analysis of vehicle exterior airflow has historically been a time consuming process. In the early 1990's CFD model construction, including CAD cleanup, could take up to a month to complete. Simulation time alone could take as much as one week to complete depending on the level of compute hardware available. Many of these limitations have been overcome in recent years. Major OEMs now have access to compute clusters containing thousands of cups.   It is no longer unusual for a single simulation to run on 128 or 258 cups. Model construction techniques have also steadily improved and are becoming increasingly automated. Automated routines now routinely include surface mesh wrapping, prism layer generation, and well defined volume mesh refinement strategies.

CFD has undergone a significant evolution since its early deployment in industry. The initial goal of many early CFD practitioners was to demonstrate that simulation could accurately duplicate the results observed in a given wind tunnel. Much effort was devoted to this level of analysis and the results were generally good but never perfect. Over time, more and more people began to realize that the true strength of CFD was not its ability to duplicate the results of an existing tool but to provide insights and understanding of the flow field around a vehicle that could not be easily obtained experimentally. CFD became a tool for ranking the effect of specific shape changes and providing an understanding of the flow physics behind those changes.

Like all good analytical tools, CFD continues to evolve. Most recently, there has been an increased interest in using CFD to support designed experiments (DOEs) and optimization studies. The use of DOEs and Optimization studies represents a critical advancement in the application of CFD for simulating vehicle external flow. DOEs and Optimization can replace the typical "single configuration" analysis with a response surface defining a broad design space and the engineering insight associated with it. This interest has been sparked by technological advances in three areas. The first two areas include the significant decreases in model creation and simulation time already mentioned. The third key advance is the

ability to rapidly morph a base model into the multiple configurations required to support either a DOE or an optimization study. ANSA is embedded into our process to provide that morphing capability.

1.2   Key Process Enablers

The traditional CFD modelling process begins with CAD data provided from the design studios. In this process, ANSA is used for both CAD cleanup and vehicle surface mesh generation. The surface mesh generated in ANSA is then used to provide the geometry definition for our CFD solvers.

Construction of an efficient process for performing DOEs and Optimization studies requires an automated tool for performing rapid configuration changes to the base model under evaluation. One approach would be to modify an existing surface and then create a surface mesh representative of that new surface. An alternative approach would be to utilize a tool capable of making rapid modifications directly to the surface mesh of the base model. Our process follows the second approach and utilizes the ANSA morphing module to directly morph the surface mesh of the original base model.

A second requirement for an effective DOE/Optimization process is the ability to drive the base model configuration changes in an automated fashion. The process described here accomplishes this task by using ANSA in batch mode and driving the model variants using the "design variable" ASCII file interface.
The ability to automate construction of model variations from a single initial base model without additional input from the user is critical to the success of this process.

A third key enabler for an effective DOE/Optimization process is the ability to integrate multiple supporting functions into a single process. ModeFrontier is used as our process integration tool and supports DOE and Optimization studies. Process integration templates have been developed which enable the engineer to select alternatively between DOE and optimization studies.   ModeFrontier uses the ASCII interface file to communicate the factor levels associated with each model configuration to ANSA.   A typical ModeFrontier process chart is shown below. The process is designed in a consistent format making it appear to be "solver-independent" to the user.
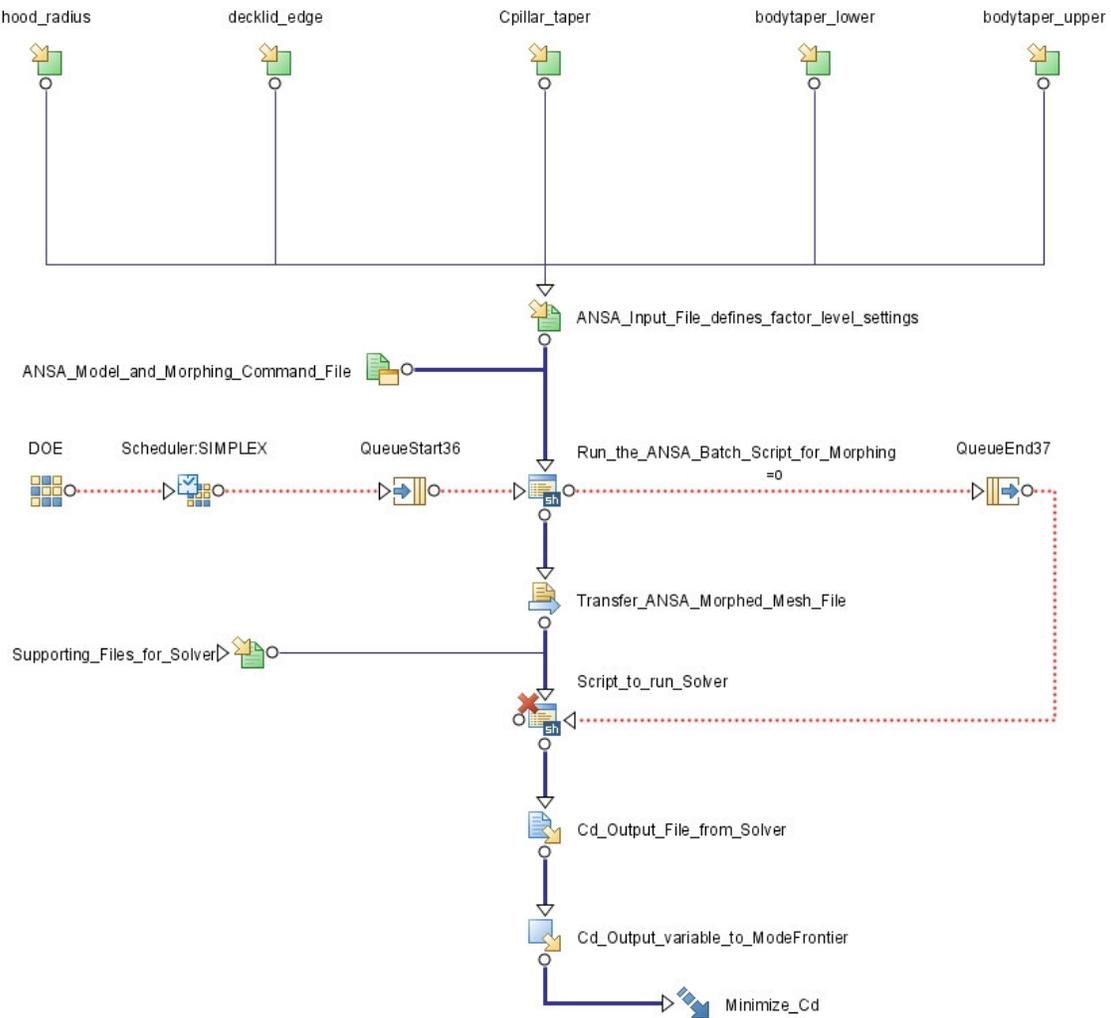
2. APPLICATION STRATEGIES

2.1 Morphing Preparation

Surfaces provided by the design studios are not typically created parametrically. Some level of parameterization is required in order to achieve clear factor definition and avoid confounding the results of the DOE or Optimization study. This is accomplished via a "pseudo-parameterization" of the base model surface mesh.   This process begins by using ANSA to identify the key feature lines of the base model surface mesh.

2.2 Capturing Vehicle Feature Lines

Creating geometrical curves for the features serves two purposes. First, these curves represent the original shape and the location of the feature and second, it can be used to fit the edges of the morphing boxes close to the model for precisely controlled modification of the feature. ANSA's FL2CURV function in the MESH>PERIMETERs menu is used to create the curves.
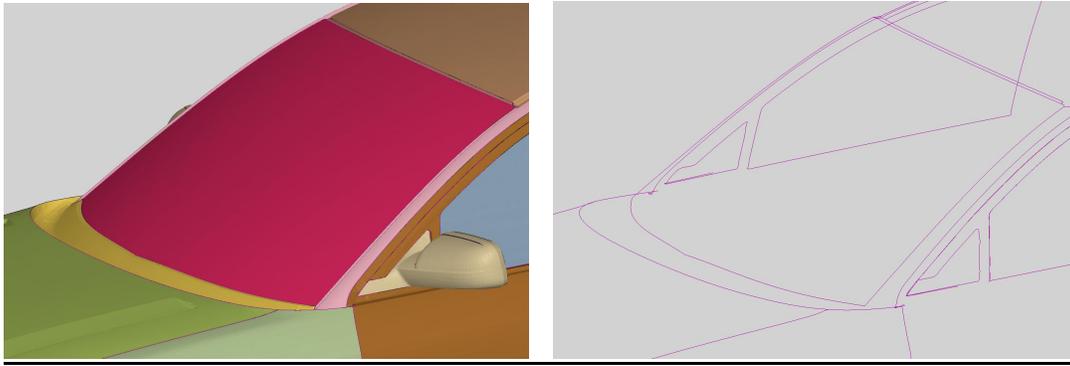
2.3   Modularization of the Vehicle

The concept of optimizing the exterior surfaces of an entire vehicle is technically exciting. To be viable, the process developed to perform the task must be constructed with an understanding of the constraints/limitations within the particular organization. Typical constraints include computer queue wait times, computer hardware (cpu) limitations, model size limitations, etc. The first step in designing this system was to define the factors of interest at a full vehicle level. An image from an early scoping exercise is shown below: Review of the number of factors and existing hardware limitations required that we develop an approach to minimize the number of factors analyzed in a single study. The was accomplished by subdividing the entire vehicle into a series of four modules;

1. Overall Vehicle Proportions
2. Front end surfaces
3. Back end surfaces
4. Greenhouse

This approach of vehicle modularization provided additional advantages:
• Reduced throughput time requirements.
• Minimized potential for undesired interactions (surface mesh distortions) during surface mesh morphing.

It was noted that the more complex the morphing strategy became, the more likely it would be to generate undesired/unforeseen changes to the surface mesh. A manual check of the surface mesh variations is performed prior to any study to confirm that no anomalies are created. This evaluation is performed with each factor set at its maximum and/or minimum level. When surface mesh anomalies are identified, factor level ranges are reduced until the anomalies no longer are generated.

2.4   The ANSA Morphing Interface

For this optimization study a base model with all the morphing boxes set up to parametrically modify the shape of the vehicle exterior was created. To run the shape optimization in batch mode, the inbuilt Optimization Task template from the libraries of ANSA Task Manager was used. This template was expanded to add more design variables to fit to this study. A Design Variable file was created as a child item in the task, which acts as an adapter file between ANSA and the Optimizer. The "Current Value" field in the design variable file, which provides the input value for the design variables, was updated for each iteration. The input provided through the design variable file drove the shape change parameters of the base model.

Various types of tightly and loosely fitted morphing boxes were created to accomplish desired shape change. These morphing boxes were parameterized using different types of inbuilt ANSA parameters such as Length, Angle, Translate, Offset, Slide, etc. These morphing parameters were linked to the "Morph Parameters" items for each "Design Variable" item of the Optimization Task.

The design variables used to morph tightly fitted local shape changes were handled first, followed by loosely fitted local shape change and finally the global shape change design variables. The problem of this scale required to load the model to the morphing boxes at every design variable stage. The dynamic loading of elements of the model were handled by organizing the FE-Model, tightly fitted local shape change morphing boxes, loosely fitted local shape morphing boxes and global shape change morphing boxes in the ANSA parts manager. The FE-Model was loaded into these different sets of morphing boxes as required, through the custom developed script.
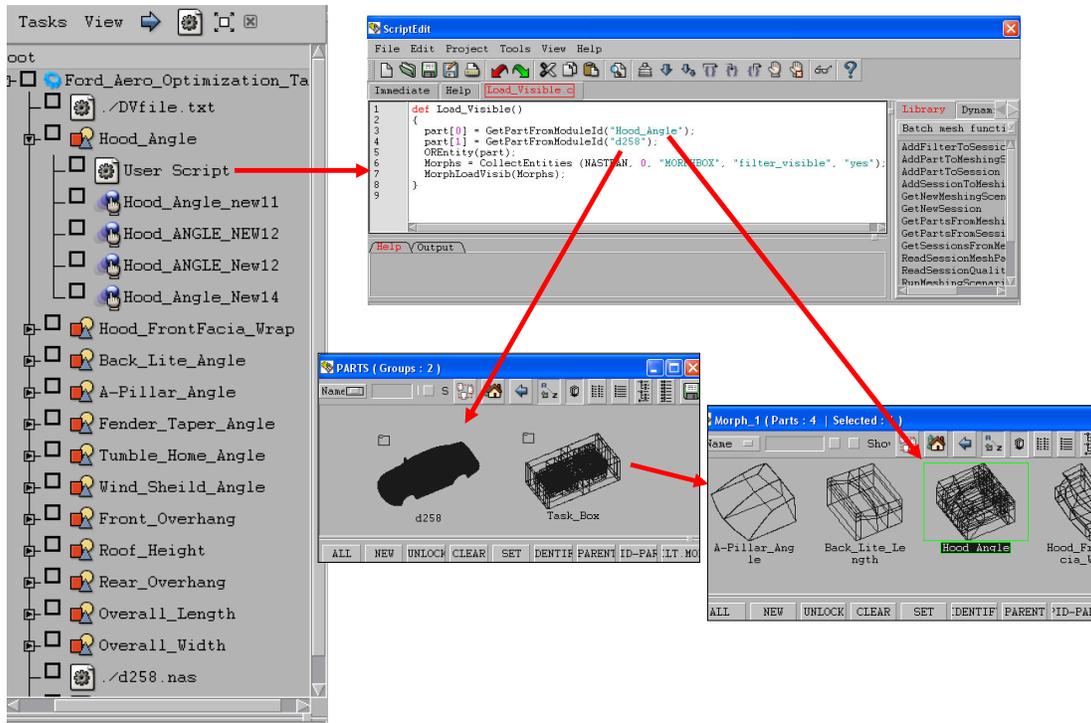
The final Optimization Task was driven by the optimizer by a no-gui batch mode functionality of the ANSA, with no user interaction.

3. MORPHING BOX STRATEGIES

The following approaches were used to set the morphing boxes to accomplish the desired shape change.

### 3.1   Feature Line Translation
To modify detailed features such as Front Facia Wrap and Hood Wrap, TRASLATE parameter is used.
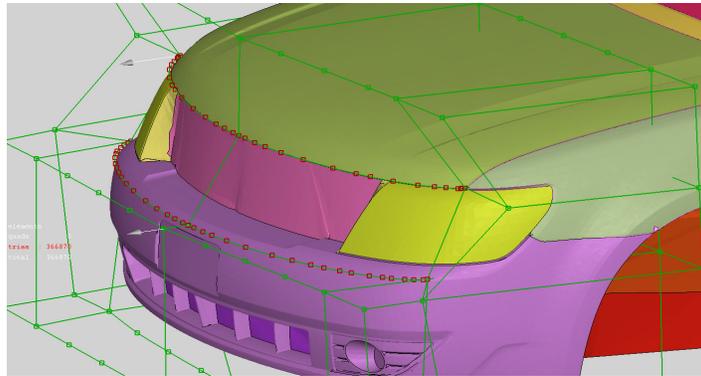
The TRANSLATE parameter is used to select control points on the morph box edges and to translate then in a specific direction based on global or user selected coordinate system.

3.2   Using Translation to Morph the Decklid Edge
To precisely morph the Decklid edge the morph box edges are closely fitted to the model. First the box is split to get an edge close the decklid edge and then that edge is fitted to the model using the curves extracted using FL2CURV function. The translate parameter is used to provide user defined direction for the translation.
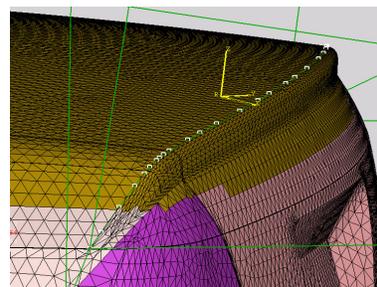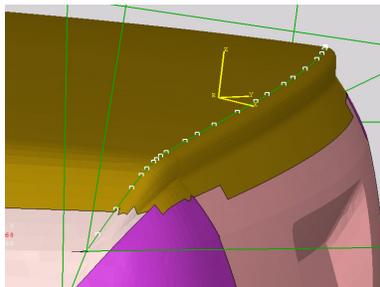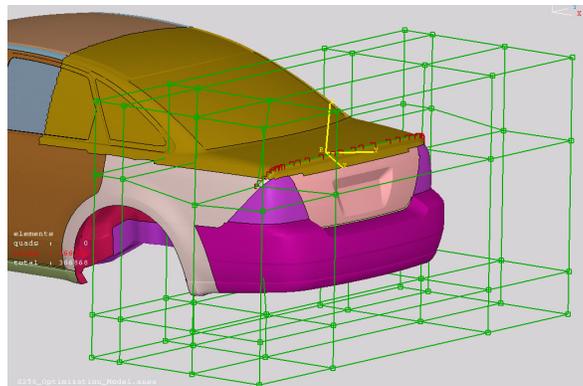
3.3 Single Angle Transformations

For controlled modification of features like Hood Angle, the angle parameter is used.
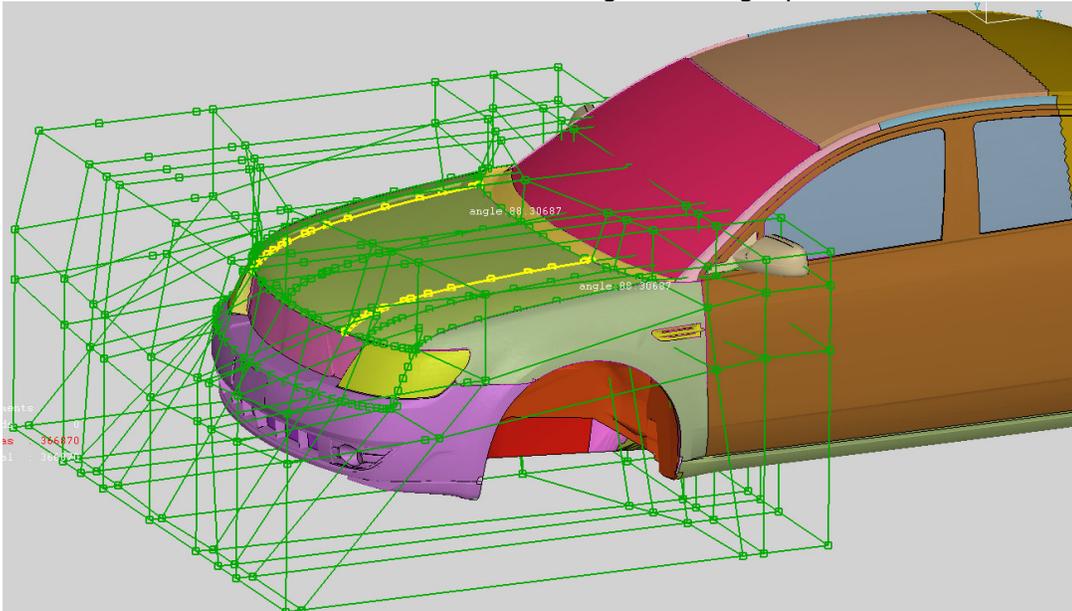
The morph box is split and modified to accommodate the hood entirely with the buffer boxes around. Then the edges of the morph box are fitted close to the hood using the EDGEFIT function. The angle parameter is defined with one fixed edge and one moving edge. The parameter when morphed keeps one edge fixed and morphs the other according to the input value for the angle in degrees.

### 3.4 Multiple Angle Transformations

Tumble Home of the vehicle is morphed using multiple angle parameters.
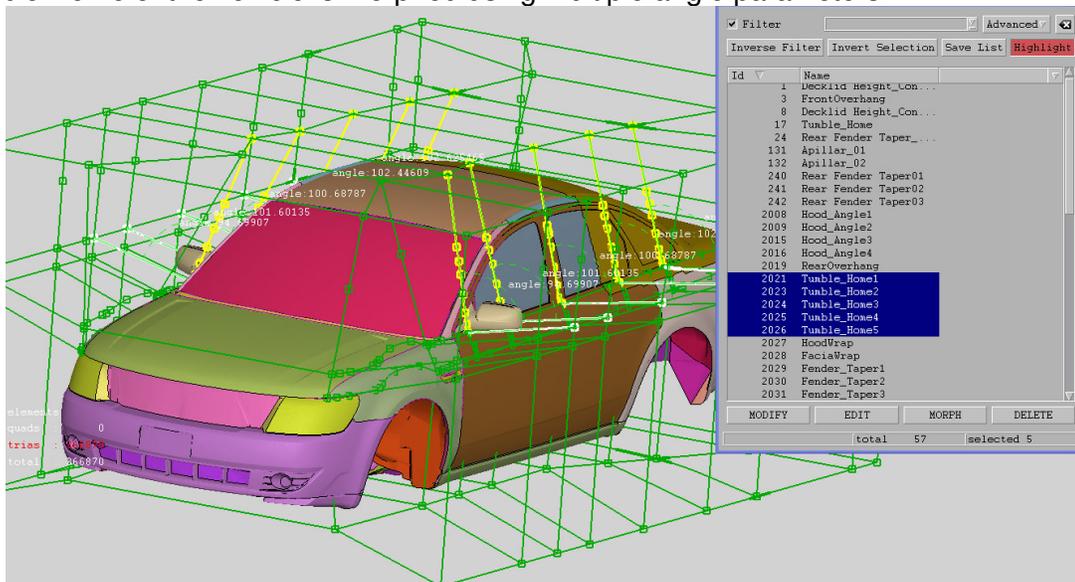
Use of multiple parameters to modify single feature is useful when initial local feature angles differ but the same change of angle is desired.

3.5   Morphing Using Length Parameter

Front Overhang is modified using the length parameter. The length of the box accommodating front overhang controls its length. The box is split horizontally and the middle edges are modified in such a way that the change in the length of the box would change the front overhang without changing the hood angle.
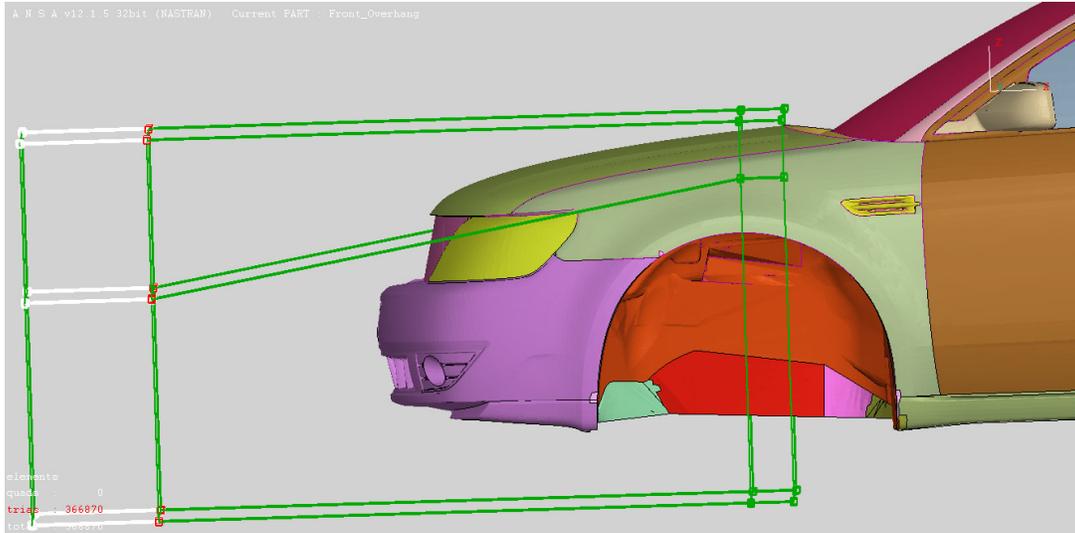
3.6   Morphing of Inter-Dependent Features

The Windshield Angle parameter is an example of the parameter which controls the interdependent features. In this case the Windshield Angle and the Cowl Height features are interdependent.
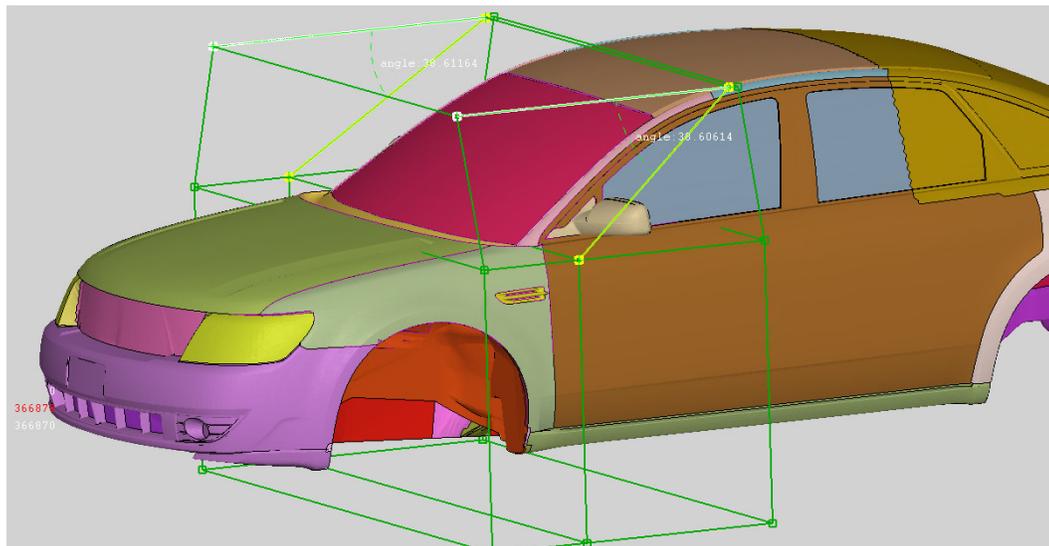
Change in the windshield angle also changes the cowl height.

3.7   Morphing for Overall Change

Wheelbase is an example of the global change parameter. Change in the wheelbase modifies the overall vehicle exterior shape.
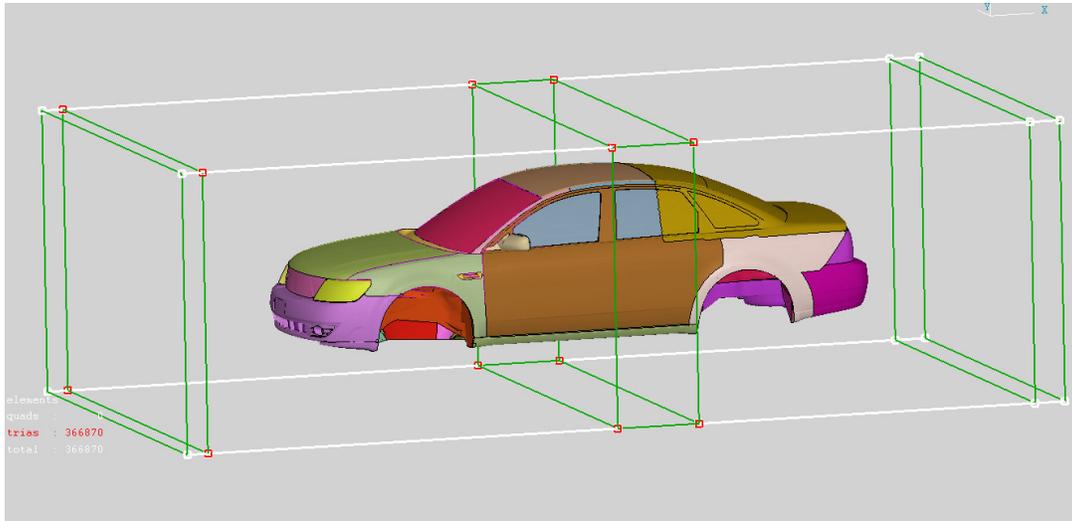
3.8   Mesh Restructuring after Morphing

When Morphing is applied to large deformations, the resulting mesh may be of poor quality. However this can be easily corrected using the functionality of Reconstruction available within the MORPH menu and can be applied automatically after Morphing if required. For automatically applying reconstruction through the task, a script item can be added to the task which reconstructs the deformed elements during morphing.
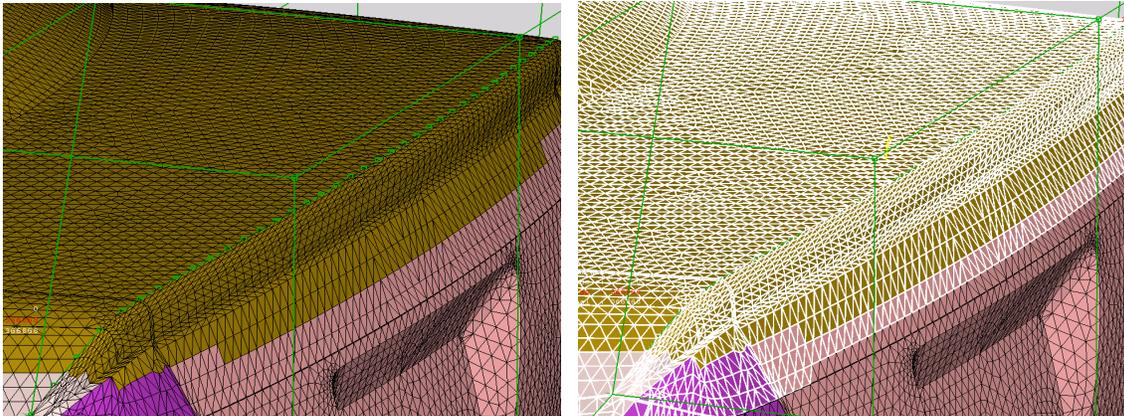
4. ESTABLISHING & CHECKING FACTOR LEVEL RANGES

4.1   Establishing the Morphing Order & Factor Level Ranges

Individual morphing strategies are developed to support each factor being studied. The capability of ANSA Morph to generate quality surface mesh across the user-specified level range is then evaluated prior to beginning any optimization study or designed experiment. This is accomplished by evaluating the mesh quality generated with the factor set at both at both extremes of its specified range. The level range is adjusted if necessary to ensure generation of a quality mesh.

Morphing multiple factors to generate a new model configuration can also produce undesired effects. The model surface mesh can become distorted or warped in unpredictable ways. The capability of ANSA Morph to generate quality surface mesh across the user-specified level ranges for all factors is evaluated. Level ranges are again adjusted as necessary to ensure generation of a quality mesh.

5. PILOT STUDY RESULTS

The vehicle model used in this study included a detailed underbody, closed engine cooling inlets and closed engine bay outlet. The CFD simulations were performed using a transient solver running on 64 cpus. The Simplex optimization algorithm was employed in this study. Initial sampling simulations were run in parallel. Simulations of subsequent configuration changes were performed in series.

Based on the knowledge gained from this pilot study, the time required to establish an initial morphing strategy will typically be in the range of 1-3 days. Subsequent configuration changes to the base model are automated, performed in batch mode, and typically completed in less than 5 minutes.

The pilot study was successful in that it was able to generate a new set of upper body surface within the vehicle program specified limitations which resulted in a reduced drag coefficient.

6. CONCLUSIONS

This paper documents the development and pilot application of an automated, CFD solver-independent, aerodynamic shape optimization process. The process is efficiently integrated into the available compute hardware resources.

o   The ANSA morphing process is definitely capable of supporting vehicle exterior CFD DOE and Optimization Studies
o   The ability to perform feature line capture is critical to the "pseudo-parameterization of the base vehicle surface mesh.
o   Dividing the vehicle into modules is an effective strategy which minimizes the potential for poor quality (distorted mesh) morphs
o   Development of an initial morphing strategy typically requires 1-3 days per module.
o   Morphing strategies, once developed, can be used as templates and applied to support future vehicle programs

The high degree of automation imbedded into this new process will enhance engineering efficiency. The capability to perform complex designed experiments and true shape optimization will ultimately lead to improved fuel economy.

REFERENCES

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