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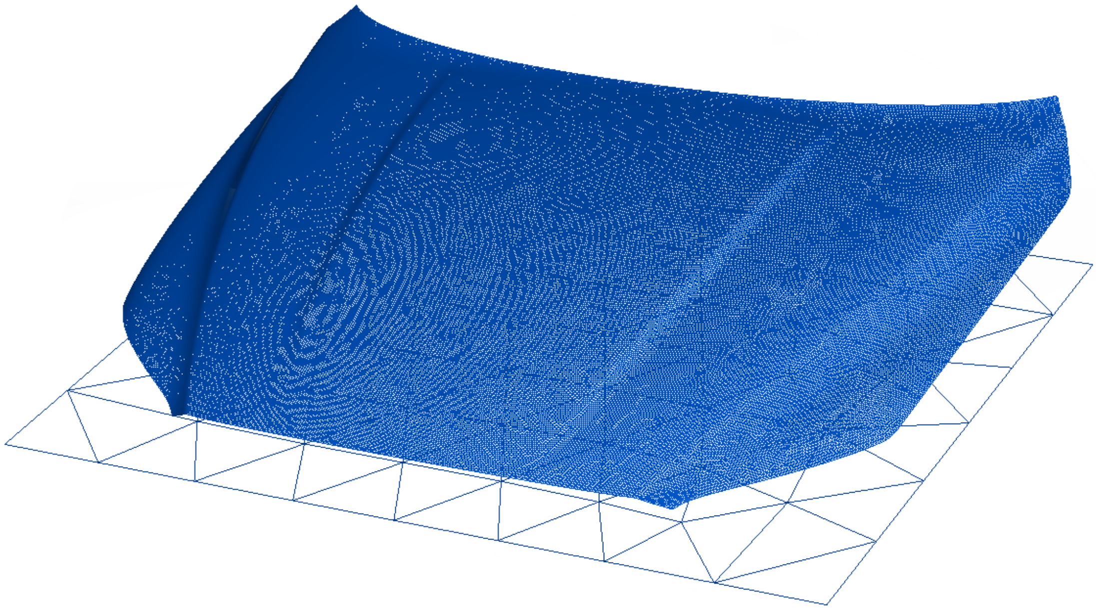

Simplified Techniques for Non-Rigid Variation Simulation

Master's Thesis in Product Development

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Department of Product and Production Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2014

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Cover:

A bonnet above a sparsely meshed plane that illustrates the Projection method. Further information about the method can be found on page 32.

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ABSTRACT

This Master thesis has been done at the department Robust Design and Tolerancing at Volvo Car Corporation. The department is simulating how geometrical deviation affects concept parts of cars when assembled. One big issue is to deal with non-rigid components that are forced to bend during the assembly, due to geometrical variation. Simulating these effects are demanding in many aspects. Currently a technique called Alternative Assemblies is used to simulate the non-rigid behaviour, since no meshed models are quite available for the early concept parts. Alternative Assemblies however, does virtually not consider the non-rigid behaviour, but analyses different assemblies separately. In addition, this technique requires a lot of manual work. As simulations are made for early concept parts, the accuracy is not the biggest concern. That is why there was room for developing new simplified, but efficient techniques.

The problem statement of this Master thesis has been to find and evaluate new techniques to prepare non-rigid models for variation simulations. Through researches made, three techniques were suggested for evaluation: Projection technique, Contour technique and Auto-AA. The latter is based on automating the current simulation technique while the two other techniques are based on simplifications to automatically generate finite element meshes. The techniques are compared with the current simulation technique and evaluated based on potential improvements with regard to: reducing simulation time, better comprehending non-rigid behaviour and increasing simulation confidence. The evaluations were made by modelling three different car components and use these models through three different experimental cases. During the cases the models were subjected to different kind of variation and deviation that was measured. Hence, the techniques could be evaluated, both on their simulation results, and possibilities to automate the model preparation as to facilitate the non-rigid variation simulation cycle.

It has been found that by using a Projection mesh, less effort is required to prepare models for simulations. Indeed, the confidence is also better followed by allow to comprehend a non-rigid behaviour.

None of the techniques found during this research are yet fully evaluated. Nevertheless, the team have seen potential in future development of techniques to actually create better models with less effort.

Keywords: Non-rigid, variation-simulation, robust design, mesh, geometry, concept, simplification, RD&T

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Furthermore, we would like to thank all members of the GSU-team, several PhD students at both Chalmers and Volvo, Perceived Quality, RD&T Technologies and many more.

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Gothenburg, September 2013

Christoffer Sylvén
Daniel Wickberg Runvik

ABBREVATIONS AND TERMINOLOGY

ANSA	A software used for creating three dimensional models used in CAE processes, such as meshes for RD&T
B-Rep	Boundary Representation, method for representing shapes using limits.
Case	A study were different techniques are compared through experiments
CAT	Computer Aided Tolerancing
DOF	Degrees of Freedom
Experiment	The simulations that were performed on the models to generate data
File format	E.g. VRML, JT and INP
GSD	Geometry System Developer, see 'GSU'
GSU	Geometri System Utvecklare (Eng. Geometry System Developer). Department at VCC that perform variation analysis to secure geometrical robustness.
INP	ABAQUS file format, used for describing meshes
JT	Lightweight format, which can be used in PLM applications, accepted by RD&T
Model	A representation of the part, in this report commonly referred to as a CAD model
Part	The physical or the real component, for example a Bonnet
Technique	Referred to as a way to create and prepare a model for experiments
VCC	Volvo Car Corporation
VRML	Virtual Reality Modelling Language, triangulated file format accepted by RD&T

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1 INTRODUCTION

Industries that manufacture physical products have to face the fact that all components differ from their nominal geometry (Dahlström, 2005). Besides the fact that it is practically impossible to produce two identical products is it also very costly to manufacture components with high accuracy. Thus, tolerances are defined in order to control how much a component is allowed to vary from its nominal geometry (Hågeryd et al., 2002). This variation implies that two components never will fit perfectly together and thus be forced into a position, requiring the component to deform (Dahlström, 2005).

Geometrical deviation can have great impact on both aesthetics and function. Several industries, such as the automotive and aircraft industry do at the same time develop products with very complex geometries (Dahlström, 2005). In such industries, decisions regarding how parts are located to each other are made early, creating a need for geometrical analysis already in the concept phase (Söderberg et al., 2006). Lacking geometrical analysis can otherwise result in sensitive systems that amplify the geometrical deviation.

Several companies that are designing complex products have departments that commonly are referred to as geometry system developers. These departments are designated to simulate how tolerances affect geometrical variation. To be able to understand the complex phenomena that occurs as a result of geometrical variation, software have been developed to simulate the effects of geometrical deviation and sometimes deformation on concept parts. The latter is mainly caused when parts positioning are overconstrained and therefore make them deform (Söderberg et al., 2006). This is called effects of non-rigid geometrical variation. Despite the simplifications implied by the use of a mathematical model, effects of non-rigid geometrical variation is a rather complex and time-consuming task to simulate.

This master thesis is thus focusing on the demand for reduced simulation and modelling time while maintaining or increasing the simulation confidence.

1.1 BACKGROUND

At Volvo Car Corporation, there is a department of geometry system developers called GSU. They are performing a variety of simulations applied on car concepts in order to analyse, verify and improve the geometrical quality. In order to optimise the assembly robustness of concept parts the GSU-team use a software called RD&T.

Sometimes there is a need for simulating compliance, e.g. how parts will bend if overconstrained when assembled, especially for plastic and sheet metal parts (Söderberg et al., 2006). At the stage in the development process where the GSU-team is working, the CAD-models are not yet developed and prepared for non-rigid simulation. Instead, non-rigid simulations are approximated using a technique called alternative assemblies, which means that different areas of the part will be studied separately; instead of actually calculating how the entire part will bend.

While the simulations using Alternative Assemblies gives results that substantially are considered satisfactory, there is still a need for further improvement. First and foremost, the technique requires a lot of manual preparation that has been proven to be very time consuming and repetitive. The manual management can also be a source of human caused errors. Secondly it is not as precise as finite element method (FEM) simulations nor does it show the phenomena that occur due to offsets of overconstrained locators. Instead the result is entirely user-dependent, as it is the user that designs the alternative assemblies.

The RD&T software does supports FEM simulations (RD&T Technology, 2013) but the feature has not been used at the department, since the CAD-models are not yet prepared for meshing. Creating meshes would require too much manual effort.

To summarize, there are three aspects of desired improvement: a better description of non-rigid phenomena, increased simulation confidence and reduced simulation time.

1.2 THEORETICAL GAP

Several researches have been performed on the subject that mainly focuses on increasing simulation confidence. For example Dahlström (2005) has studied which modelling aspects that needs to be considered for high accuracy of simulation results in sheet metal assemblies and Qin, Zang and Wan (2006) are presenting a more theoretical approach to optimise robust design.

Wagersten et al. (2013), on the other hand, suggests a simplified non-FEA based method for non-rigid simulation, using morphing. In Wagersten's study, morphing has been used to describe shape deformation with a non-linear mathematical function. However, the study was conducted with the purpose to simulate perceived quality, i.e. visualisation, and not for geometrical measurements.

There are currently no studies in this area that focus on simplification of simulating dispositions on non-rigid parts; how to reduce time and effort while maintaining a good confidence level.

1.3 PROBLEM STATEMENT

The GSU-team has an interest in being able to simulate non-rigid bodies, in order to identify phenomena that arise as a result of geometrical deviation. Meanwhile, the current simulation technique requires too much manual work. Thus the purpose of the thesis is to investigate alternative techniques for non-rigid simulation to evaluate if there is a way to: (1) reduce manual work, (2) understand non-rigid phenomena occurring in the geometries and (3) maintain or improve current simulation confidence.

The thesis will result in an analysis of possible simulation techniques and their effect on measurements and estimated work effort. The analysis is intended to result in recommendations for future development in RD&T.

1.3.1 RESEARCH QUESTION

What techniques are available or could be developed for simulating variance on non-rigid concept parts and what are their effects on the simulation cycle and final result?

1.3.2 RESEARCH CRITERIA

The techniques should fulfil the following criteria:

- The simulation confidence should at least be equal to that of GSU's current Alternative Assembly process.
- The total time for modelling and simulation should be shorter than GSU's current process.
- The solution should be integrated into a single software.

1.4 SCOPE AND DELIMITATIONS

This master thesis focused on development and evaluation of techniques used for variation simulation of non-rigid parts. In this process, there have been a few limitations:

- The project aim to facilitate the work for the GSU department, where perceived quality, i.e. visualization, is not considered. This means that the techniques only are evaluated in terms of how well they can simulate measured deviation of measurement points. Indeed, RD&T can visualise effects of deviation, but no consideration in aesthetical properties for the techniques are made.
- For any recommended technique, no technical description for final implementation is made.
- All CAT-tasks are performed using RD&T, as it is the software used at GSU.
- Furthermore, the simulated measurements used to evaluate the techniques are not compared to actual measurements, i.e. physical products. Instead, a high quality FE model is used as a reference, as FEM is the most accurate technique that can be implemented at this point in the development process.
- No more than three different parts are tested with the different techniques; focus is instead put on thorough analyses of the parts.
- The parts used for simulation are not guaranteed to represent a variety of other types of parts.
- The time that is required to prepare a simulation is certainly an important factor when testing the new simulation techniques. However, as the techniques are not yet developed to the level of their intended usability, the aspect of measuring preparation time was excluded from the study. In order to make an adequate comparison of the preparation time, a thorough study of several individuals and cases would have been required, which also would have entailed less time to evaluate the techniques.

2 THEORETICAL FRAMEWORK

This chapter goes through the findings from the literature review with the aim to provide understanding of the subject, its applications and users. The first section of the chapter focuses on what geometrical robustness and variation simulation is. In the middle of the chapter, file formats and software used in the variation simulation process is explained. Finally, the chapter is concluded with a description of the GSU department and more VCC specific car data.

2.1 ROBUST DESIGN

It is impossible to produce identical components, at least from an economical point of view (Evans, 1974). As a result, each component has a variation from its nominal geometry. This variation may in turn affect both component function and manufacturing costs. Wagersten (2011) states that in most cases, changing the manufacturing method for delimiting variation is not economically feasible. The idea of robust design is to make the component less sensitive to variation and thus ensure both functional quality as well as stabile manufacturing cost (Söderberg & Lindkvist, 1999). A simple model with a lever arm is commonly used for illustrating the principle of robust design as seen in Figure 1a and 1b below. By having a fixed input, the effects of the output can be reduced by having a more robust design, a design less sensitive to variation.

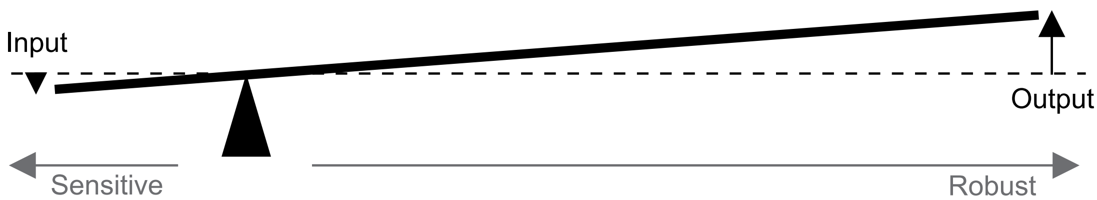

Figure 1a – A simple example of an unrobust system, were a small input generates a large output.

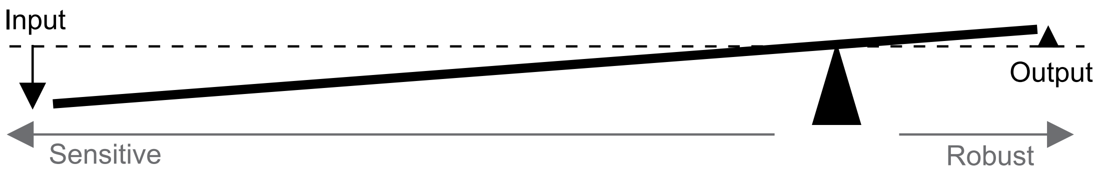

Figure 1b – A simple example of a robust system, were a large input generates a small output.

2.1.1 GEOMETRICAL ROBUSTNESS

The concept of geometrical robustness is considering how effects from geometrical deviation can be suppressed. Geometrical robustness can be divided into three main areas: part robustness, assembly robustness and functional robustness (Lorin, Forslund & Söderberg, 2010). Part robustness is the ability of the part to suppress variation from noise parameters such as raw material, process and tool variation. Assembly robustness is the ability of the assembly design to minimise effects of variation when assembling parts. Noise factors for assembly robustness are part variation, fixture and assembly variation. Functional robustness is the ability to suppress variation in functional properties due to part and assembly variation. This thesis focuses mainly on assembly variation and assembly robustness according the work of GSU.

There are different ways to suppress effects of geometrical variation. One of the most common is to improve the robustness by handle positions of locating points (Wagersten, 2011). The locating points can be described as fixation point between two components. Wagersten suggests that spreading the locating points may suppress effects of variation, resulting in a more robust design.

2.1.2 TOLERANCES

It is impossible to manufacture a component with exact dimensions from given specifications, but when using tolerances it is possible to confine the errors within strict limits (Hågeryd, Björklund & Lenner, 2002). The tolerance specifies an area in which the specific dimension is allowed to vary from its nominal position, such as both aesthetical and functional requirements can be fulfilled. Further, Hågeryd means that it is desirable to widen the tolerance range if it is possible to maintain the same functions. A wider tolerance range is simpler and less expensive to manufacture. Wagersten (2011) states that it is important to find a balance between quality and cost, which are affected by the tolerances.

2.1.3 MEASUREMENTS

To verify geometrical requirements different measurements are made, either by measuring physical components or simulated results.

When working with geometrical assurance the split line is commonly considered. The split line is the visible relationship between two parts (Forslund, et al. 2011). The split line can mainly be measured in two ways, namely gap and flush. The gap is the distance between the two edges in the split line and the flush is the level difference between the two parts. Figure 2 shows an example of gap and a flush, which also can be measured through different relationships such as parallelism and symmetry. A so-called point self-measurement is another kind of measurement. Opposed gap and flush measurement, a point-self measurement is considering a global dislocation, relative the whole assembly, while gap and flush only consider the relative measurement between two parts.

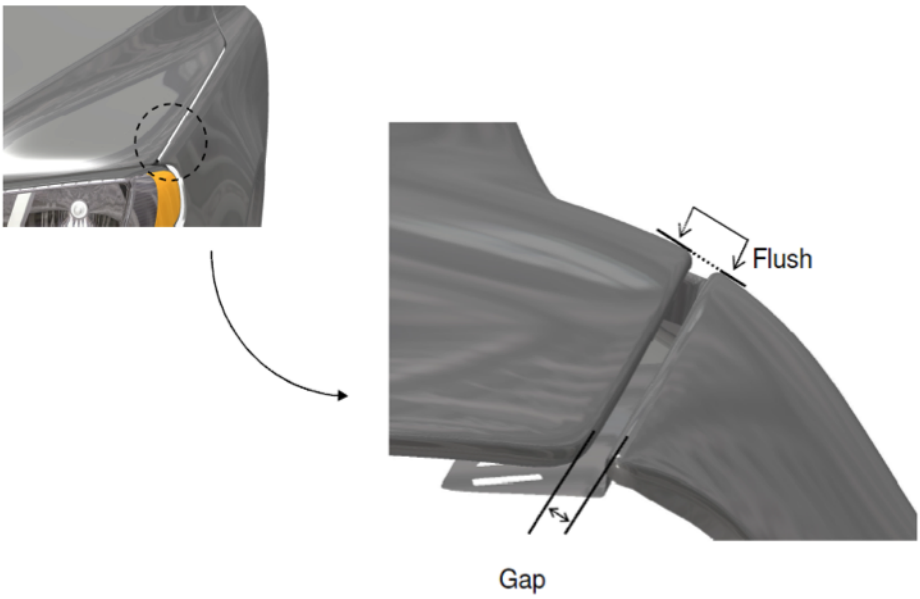

Figure 2 – An example of flush and gap between a Bonnet and a Fender (Wagersten, 2011).

2.1.4 SIGMA – STANDARD DEVIATIONS

The sigma value is describing standard deviations (RD&T Technology, 2013). The number of sigma describes a range that is considered for the normal deviation of a given population. In this project, 8 sigma is the deviation value used for the variation simulations used in the experiments.

2.1.5 POSITIONING SYSTEMS

Locators are defining the position of a part by locking its degrees of freedom. The locators can generally be described as the point where one component in positioned against another in an assembly (Wagersten 2011). According to Söderberg and Lindkvist (1999) the locators have a great impact on how the variation affects the products characteristics. The most common approach in the automotive industry is the 3-2-1 positioning system (Söderberg & Lindkvist, 1999; Qin, Zang & Wan, 2006), which fully constrains a component in all translation (T) and rotation (R) directions.

Figure 3 below illustrates how a part is defined by a 3-2-1 system. The bottom is locked by 3 degrees of freedom (TZ, RX, and RY); the side is locked by 2 DOF (TY, RZ) and the front by one DOF (TX) (Söderberg et. al, 2006). As the 3-2-1 positioning system fully defines the part position, adding more locators would result in an over defined positioning systems.

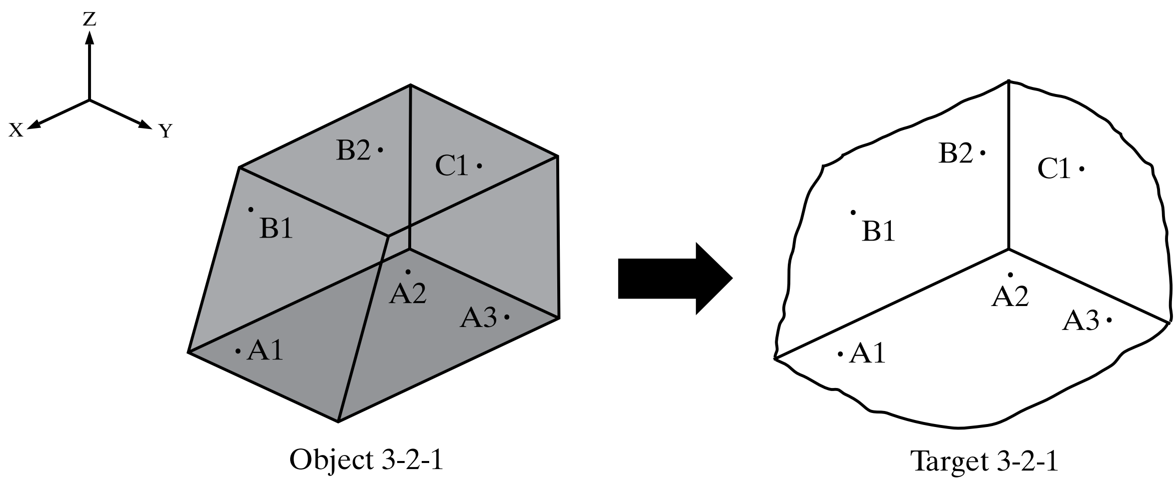

Figure 3 – Is illustrating the 3-2-1 system on a part, positioned against a target.

When considering systems that might deform, e.g. sheet metal parts, additional clamps are needed to control deformation during assembly (Dahlström, 2005; Hoffman, 2004). For deformable sheet metal parts Cai (2006) proposes N-2-1 locating principle, where N is the actual number of positioning points used, if more than 3. Indeed, a part can be overconstrained not only in the first direction. For simplicity however, N-2-1 will henceforward refer to all kind of overconstrained systems in this report. A simple example of the difference between 3-2-1 system and N-2-1 system can be seen in Figure 4. The system on the left hand side has a fully defined plane by using locators A1-A3. On the right hand side there is a system over defining a plane with locators A1-A4. Considering non-nominal geometry, only 3 of 4 locators can constitute a plane, while the fourth locator will force the plane to bend. Thus, the N-2-1 system requires to be considered non-rigid.

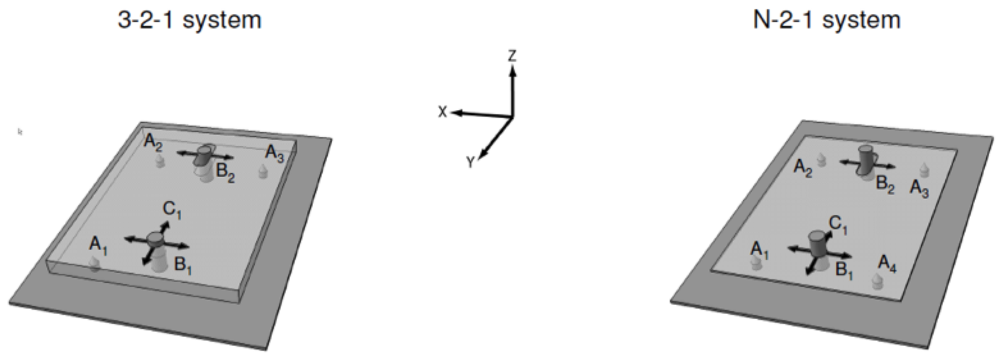

Figure 4 – Two cases of positioning systems. The left side is a 3-2-1 rigid system, while the right side is an N-2-1 non-rigid system (Wagersten, 2011).

2.2 SIMULATING NON-RIGID VARIATION

Non-rigid variation simulation considers how parts will bend when assembled. This type of simulation is more accurate than rigid simulation (Söderberg, Wickman & Lindkvist, 2008). There are several different ways to simulate the non-rigid behaviour. RD&T uses two main principles, FEM and Alternative Assemblies. The literature study also covered other existing techniques for simulating variance. Both the existing techniques and the RD&T implemented solutions will be further presented in the sections below.

2.2.1 ALTERNATIVE ASSEMBLIES

One way to deal with non-rigid, N-2-1 assemblies is to use a technique called Alternative Assemblies (RD&T Technology, 2013).

Alternative Assemblies is based on several separate assemblies that use different 3-2-1 positioning systems on the same part. Note that some systems might have one or several locators in common. To the different assembly systems, different measurement points can then be assigned. The different assemblies can be analysed separately with corresponding measurement points to the different assemblies. By doing so, different areas of the part can be studied locally, thus, the positioning can be overconstrained. Each system can have different measurement points to consider the local deformation. Note that Alternative Assemblies is not technically a non-rigid method, even though this approach can be used to approximate the non-rigid phenomena for simulation. An example is shown in Figure 5, showing a surface with two positioning systems, one considered at a time.

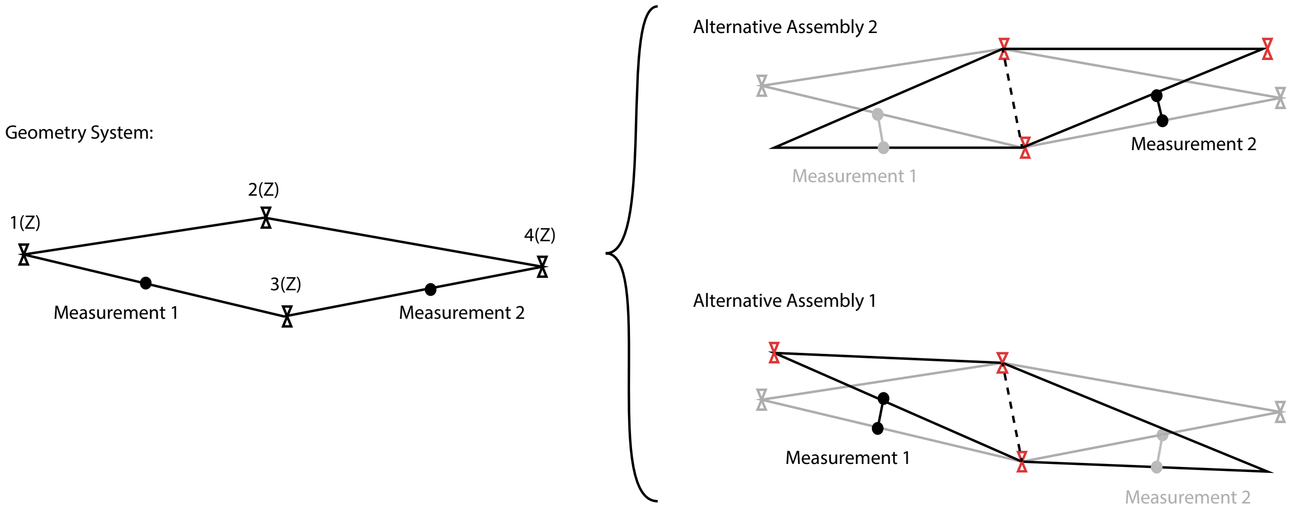

Figure 5 – Shows two Alternative Assemblies. An offset is made on the right and left system respectively causing the whole surface to move. The gray lines show the nominal position of the square.

2.2.2 FINITE ELEMENT METHOD

The Finite Element Method (FEM) is a tool used to solve complex calculation problems (Liu & Quek, 2003). The method allows physical laws to be applied to small elements with very simple shape. These shapes are often small triangular or square elements, describing an approximation of the parts geometry. These approximate geometries are called elements and are all together components of a mesh (Frey et al., 2008). An example of a meshed CAD-model can be seen in Figure 6. With FEM, a numerical approximate solution to the distribution of field variables can be found, for problems that are difficult or impossible to solve analytically (Liu & Quek, 2003). Thus, FEM can also be applied to variation simulation of overconstrained locating schemes analysing bending and deformation during assembly (RD&T Technology, 2013b).

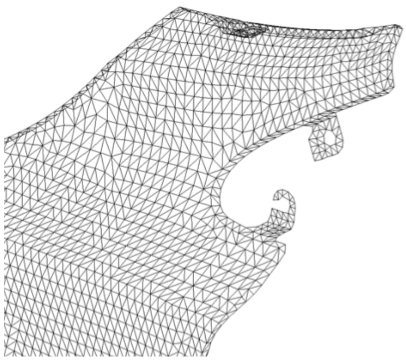

Figure 6 – An example of a triangular mesh, constituting a Fender of a car.

Issues with FEM

Commonly the computation time can be high when calculating the numerical FEM models, especially detailed models with small element size (Liu & Quek, 2003). Beside the need for a great amount of computational power, this method needs a mesh for calculation, which is hard to retrieve without faults, as described below.

Issues with Mesh Creation

Creating a mesh is not always a simple task. Even though automatic and semi-automatic mesh generation software have seen great improvement in the last few years, it still takes a good deal of time and might require a credible analyst to reach adequate mesh results (Liu & Quek, 2003).

Several different problems have been stated in various studies about issues with FEM and mesh. Borodin, Novotni and Klein (2002) discuss some common problems that occur in the mesh-geometry, which is degenerate faces, T-vertices (see Figure 7), narrow gaps and cracks (see Figure 8). Borodin et al. claims that the problem lies in lack of connectivity information between polygon patches. Yet, these difficulties vary depending on various factors, such as: topology, element type and geometry assembly configuration (White, Saigal & Owen, 2005).

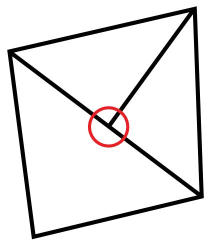

Figure 7 – An example of a T-vertice.

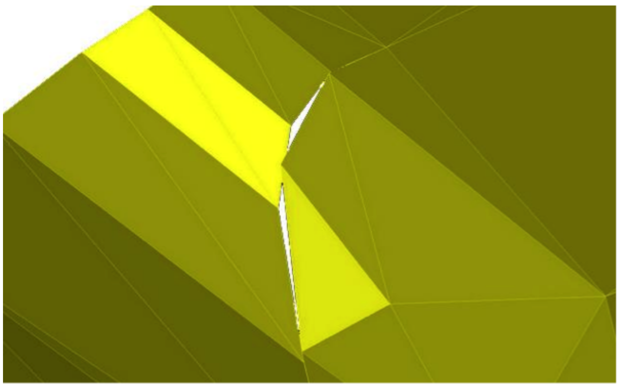

Figure 8 – A crack that have appeared between two surfaces.

Beall, Walsh and Shephard (2003) discuss issues within the CAD geometry, before generating the mesh. CAD systems are using B-Rep models to describe the model. Different programs are simplifying the model in different ways and use tolerances between entities to provide robustness to model operations. This can produce gaps in the model that are not evident in the CAD program as they are designed to manage the tolerances consequently, then, when the CAD model is transferred and converted between different systems, many problems can occur.

2.2.3 AUTOMATIC MESH GENERATION

Numerous software companies that provide meshing tools claims its convenience when it comes to mesh generation (Chong, Kumar & Lee, 2007), though there are articles describing the opposite: "...third party software modules can only rectify common geometry problems and a successful or unsuccessful outcome is possible. Thus there is yet no absolute solution for geometry/mesh healing of CAD models" (Piret, Remacle & Marchandise, 2012, p.2).

Repairing Automatically Generated Meshes

Mesh repair is a popular subject in research and a lot of software provider claim to be able to repair dirty meshes with their programs (Chong, Kumar & Lee, 2007). The technique is often based on algorithms that scan surfaces for cracks or merges edges and nodes. Even so, a successful outcome is far from certain since these software modules only correct common geometry errors.

For common mesh errors, such as cracks, nodes that do not match each other and T-vertices, there are methods to "heal" the model and actually reach sufficient results. Borodin, Novotni and Klein (2002) suggest methods for solving these issues. They do, however, require active user involvement to where the program suggests solutions that the user actively approves. Moreover, Chong, Kumar and Lee (2007) describe third party programs that automatically can repair dirty meshes, which work in many cases although exceptions are common.

Handling Several File Formats

To solve problems with file format translation as described by Beall, Walsh and Shephard (2003) above, the authors suggest a method called Unified

Topology Accessing Geometry, which allows multiple sources of geometry to be treated the same by the mesh generator. A few examples of mesh generators that handle multiple geometry sources native format were found, e.g. ANSA v.14 (BETA CAE Systems S.A., 2012).

2.2.4 MORPH ANALYSIS

The term morphing can be used in many different contexts and there is not a clear definition (Lazarus & Verroust, 1998). In contrast to the techniques mentioned above the morph analysis is not a Finite Element Analysis (FEA) and therefore no mesh is required (Wagersten et al., 2013; Zhao et al., 2003). An example of usage of morphing in automotive industry is suggested by Bosmans et al. (2005) that are describing it as a tool for evaluating different design concepts by using it to quickly modify the geometry of design models.

For the scope of this thesis, as to simulate geometrical variation, morphing can be used as a way to make a smooth transition on the surface between points that differs from nominal position. The method was tested in a similar way by Wagersten et al. (2013) as a way to describe perceived quality with geometrical deviations. The transition of the surface is described by a third degree polynomial function. An example of a morphed Bonnet using the described principles is seen in Figure 9 below.

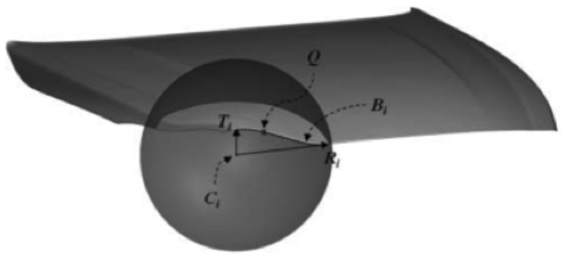

Figure 9 – An example of morphing used for visualizing deformations caused by geometrical deviation (Wagersten et al., 2013).

A morph function is currently implemented in the RD&T software. However, this function can only be used for visualisation and not for measurement.

2.2.5 MESH-FREE & ISOGEOMETRIC ANALYSIS

Mesh-free is not just one technique used for simulations, but rather a set of techniques; among these are the element free Galerkin method, the point interpolation method, the finite point method and several others (Liu, 2003). Mesh-free methods are techniques that at a minimum do not require a predefined mesh. Instead, they often use a set of nodes representing the problem domain, scattered on the boundaries of the domain. Compared to meshes, these nodes do not have any connectivity between them, making them especially interesting for simulations with large deformations and crack propagation, where elements often get distorted (Pettersson, 2007; Liu, 2003). However, what is gained in simulation preparing benefits is lost in computational calculation requirements and difficulties simulating complicated geometries.

An example of a mesh-free method is Isogeometric analysis, which is a relatively new technique that enables Finite Element Analysis on NURBS-based CAD-models, (Hughes, Cottrell & Bazilevs, 2005).

2.3 FILES AND FILE FORMATS

A part of understanding automatic mesh generation has been to investigate file formats and file management at VCC, as to be able to create script generating new meshes.

2.3.1 CAE FILE FORMATS AT VCC

When working with three-dimensional components in computer software, there are several different standardised file formats. These describe the geometry in different ways, storing different kinds of data. In this project, three CAE-formats were commonly used: JT, VRML and INP. The INP format can, opposed to JT and VRML, be used for simulating non-rigid models.

2.3.2 VCC FILE MANAGEMENT

There are certain standards used at Volvo Cars Corporation (VCC) to obtain the files, which is done through a PLM-database called Teamcenter. Due to these standards and routines it is complicated to switch file format, something that would be necessary to obtain meshed CAD files.

2.4 RD&T

RD&T (short for Robust Design & Tolerancing) is software, developed by RD&T Technology. The software is used to simulate statistical variation; typically to measure and visualise manufacturing and assembly fluctuation long before physical prototypes are available (RD&T Technology, 2013.). RD&T is used for supporting the whole geometry assurance process (see section Geometry Assurance Process at VCC), all the way from concept phase until production phase. RD&T also allows for non-rigid statistical variation that is either calculated using Alternative Assemblies or FEM. Both of these two techniques as well as other functions of the software are described in the following sections.

2.4.1 POSITIONING SYSTEMS IN RD&T

RD&T supports several different positioning systems, which can be described as different ways to define the locators. Principally 3-2-1 or N-2-1 systems are used as orthogonal systems, or non-orthogonal systems, for positioning of non-orthogonal parts; the latter with directions specified by the user (RD&T Technology, 2013). In RD&T a 3-2-1 system does not have to be specified by 6 points. For example 3 points can be used, where the first point is defining 3 directions, the second point 2 directions and the last point one direction. A 3-point system can also be used for N-2-1 system, but the fourth point will over constrain the positioning.

When using N-2-1 positioning system in RD&T, Alternative Assemblies, flex or compliant module must be used.

Rigid N-2-1 Systems in RD&T

Rigid N-2-1 positioning systems are simulated using several assemblies defined with either the Alternative Assemblies or Flex module in RD&T. The two modules work similarly, but flex positioning can assign all types of nodes to a positioning system, not just measurement points. Thus, the flex technique can be used to connect a long chain of components through different positioning systems.

Since Alternative Assemblies is the module used at VCC, Alternative Assemblies was used as the basis for the rigid comparison.

Compliant Module in RD&T

The Compliant module in RD&T allows for non-rigid calculations, using FEM (RD&T Technology, 2013). Simulation with the compliant module requires a sufficiently meshed CAD part in ABAQUS format (.inp), which requires preparation from external software, e.g. ANSA.

Combining Rigid and Compliant Simulations

RD&T offers the ability to simulate both rigid and non-rigid parts simultaneously, either Alternative Assemblies or Flex.

2.4.2 MONTE CARLO METHOD

The Monte Carlo analysis technique is a numerical procedure that use sample means to estimate population means (Dunn & Shultis, 2011). Doing so, complex problems can be analysed with simple techniques. The general principle is to use random variables to solve experiments in order to evaluate mathematical expressions (Gentle, 1998). As Monte Carlo is a sampling method, the result has a sampling error. In order to minimise these errors effect on the final result, a sufficient number of runs is needed. By increasing the number of Monte Carlo iterations, more rare statistical data can be obtained.

2.4.3 TOLERANCE ANALYSIS

RD&T simulates with Monte Carlo iterations, were specific points varies within an interval specified by the user. Tolerances can be specified on a global level, against the whole model's coordinate system, or as a local reference linked to only a specific point. Opposed to tolerance that use iterations for statistical data, an offset can be created to see effects of a known dislocation. This can be useful to test effects of a certain dislocation and to see geometrical phenomena occurring.

2.4.4 MEASUREMENT OUTPUT

When simulating in RD&T, different outputs can be obtained depending on what kind of simulation that is made. Two common simulation outputs are colour coding through stability analysis and measurement data, from variation or offset simulation. The measurement data output contains several columns of values, such as 6 sigma, 8 sigma and mean value, where the sigma values is of interest for variation simulation and mean value for offset simulations.

2.5 GEOMETRY SYSTEM DEVELOPERS

The department at VCC that this project is concerning is called GSU and is primarily working with geometry system development. This section describes the role of geometry system developers and how they process simulations.

2.5.1 GEOMETRY ASSURANCE PROCESS AT VCC

The geometrical assurance process contains several activities to verify that the product will meet geometrical requirements (Dahlström, 2005). The process that GSU is involved in, initiates from the general level where components and systems are decided, until all components are described in detail ready for manufacturing.

In the program start, GSU's involvement is not based on any kind of simulations, but rather suggestions or judgements regarding the design based on experiences. As the development proceeds and CAD models are created, GSU can start to define positioning systems and simulate effects of variation. From the simulations they can tell how well geometrical system fulfils esthetical and functional requirements.

The work will then result into system descriptions as a basis for negotiation with subcontractors.

2.5.2 SIMULATION INPUT

The geometry system developers uses CAD data of JT- or VRML format as input for performing simulations. The CAD data available for simulation depends on how far in the concept development process that the project has preceded. For new concepts nothing but early design surfaces are available, while more matured engineered concepts contains more information such as reinforcements and attachment point. Unfortunately, meshed data is commonly not available in the early stages of development. While there are other departments working with meshed CAD files, these files are not suitable, as those departments work on a different stage in the concept development.

2.6 THE GENERAL CAR COORDINATE SYSTEM

Since the aim of this study is to evaluate techniques used in non-rigid simulations for VCC, it was early decided to use actual car components for the simulations. All car models use the same coordinate system to describe the parts location in space. This is illustrated in Figure 10.

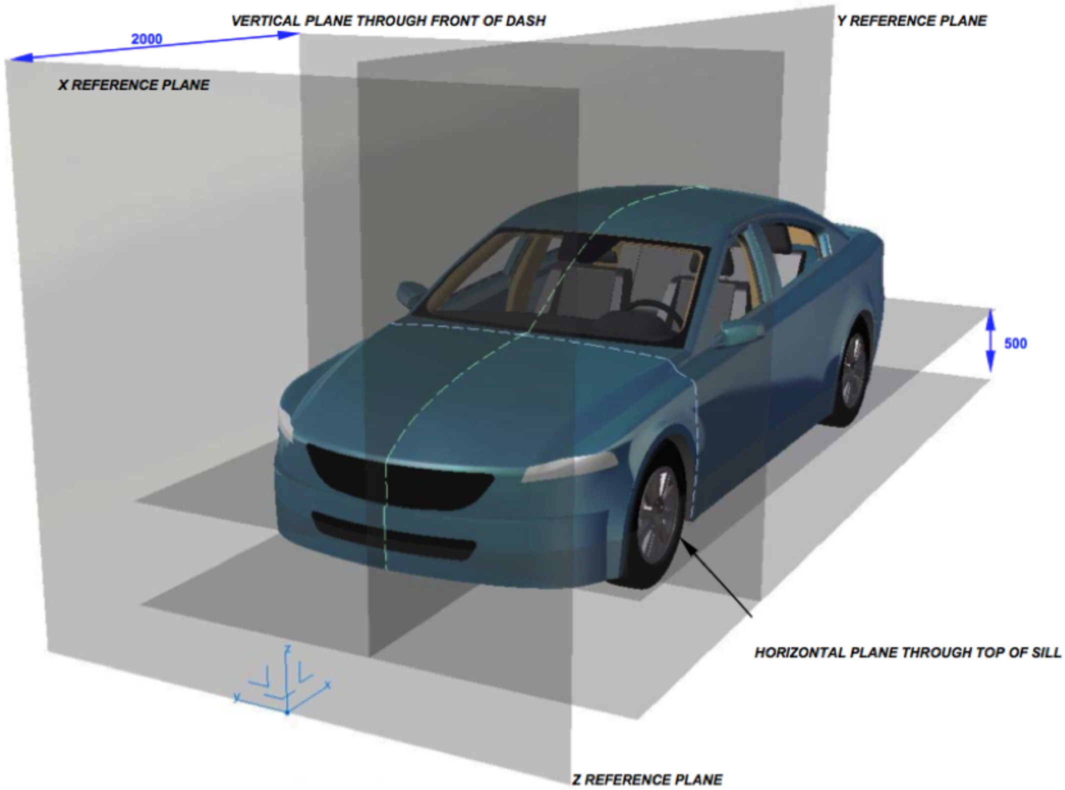

Figure 10 – The standard directions used as coordinate system on car at VCC.

3 METHODOLOGY

This chapter describes the research process used during this thesis project.

3.1 RESEARCH PROCESS

The research process has been designed according to the Research Methodology of Kothari (2004) and is visualised in the flow chart in Figure 11. The reason for using Kothari is that the method is conventional for the subject and was by the team, considered a convenient way to structure the research.

Figure 11 – Shows the steps suggested in Research Methodology of Kothari (2004).

Each step of the process is described in the sections below.

3.2 DEFINING RESEARCH PROBLEM

The research problem was defined based on a study performed by one of the team members during the summer of 2012 at VCC with guidance from the GSU department and a meeting held at the start of this master thesis. Present at the meeting, besides the team, was the examiner, supervisor and two industrial PhD students. The discussion at the meeting together with the results from the summer review was a basis for the formulation of the research problem.

As the number of techniques known to the team during the initiation of the project was rather limited, part of the research was to identify relevant techniques. Thus, the research question was formulated in a general manner.

3.3 REVIEWING CONCEPTS AND PREVIOUS RESEARCH FINDINGS

In order to identify relevant theory and simulation techniques, an exploratory pre-study was initiated. This would provide a basis for future research design and choice of data collection methods.

3.3.1 APPROACHES USED IN THE PRE-STUDY

Three primary approaches were used to gather the information:

- Interviews with specialists in the areas of FEM, CAT and CAD.
- Interviews with geometrical systems developers at the department.
- Reviewing literature on the subject of FEM, CAT, CAD, relevant file formats and other subjects emerging from the interviews.

On top of these three primary approaches, various software was tested in order to find alternative ways of performing geometrical analyses.

Interviews

The interviews were semi-structured in order allow the interviewee to bring up new ideas and let these thoughts lead the conversation. This meant that the group both could get answers to the predefined questions as well as retrieve information about techniques and people that was previously unknown.

Literature Review

The literature review was mainly based on keywords like: '8 Sigma, Alternative Assemblies, Assembly, CAD, CAE, CAT, Compliant, Degrees of Freedom, FEM, Geometry Assurance, Isogeometrical Analysis, JT, Mesh Generation, Mesh Issues, Mesh Repair, Mesh-Free, Morphing, Non-rigid, NURBS, RD&T, Robust Design, Tolerance Analysis, Variation Simulation and VRML'. These keywords were to a great extent generated from interviews and other literature.

3.3.2 IDENTIFYING RELEVANT SIMULATION TECHNIQUES

The identification of relevant simulation techniques did not only consider existing solutions found through the literature review and interviews. A few new concepts were also emerged through brainstorming sessions and experiments. All in all, six primary techniques were found; three of them were existing concepts found through the literature review and interviews while the other three were new concepts developed by the team. The existing solutions are presented in the theoretical framework and the new solutions in the pre-study results.

3.3.3 FOCUSING THE RESEARCH

According to Ulrich and Eppinger (2012) a scoring matrix is helpful when selecting concepts, typically if the concepts are well known.

In order to focus the research, the six identified solutions were narrowed down to three, by eliminating less promising concepts. The elimination was conducted after further research on the six techniques by using a concept-scoring matrix with seven criteria:

- Short Implementation Time
- Possibility to implement in RD&T
- Unexplored Technology
- Evaluation Possibility
- Level of Confidence
- Level of Automation
- Short Simulation Time

The evaluation was to a large extent based on the selection matrix and resulted in the elimination of three concepts. An extensive description of the evaluation and selection matrix can be read in Appendix II.

3.4 DEVELOPING THE OBJECTIVES

The team and the supervisors reviewed the objectives as the exploratory pre-study was completed. It was decided that the remaining concepts were to be compared to GSU's current simulation technique and a reference model. The reference model was decided to be a detailed compliant model, to be calculated through FEM, which is considered to be the most reliable method. In order to measure the technique mesh quality and simultaneously test the confidence compared to most realistic scenario possible, a reference model with high quality mesh and reinforcements was used. In models, when applicable, the mesh included reinforcements to further resemble the physical component.

In order to compare and also evaluate the mesh quality and behaviour of the technique, a mesh only considering the outer surface of the part, which excluding interior reinforcement geometry, was used. For the confidence comparison, the same mesh was reinforced with parts to create a more realistic behaviour in the computer model. The unreinforced model was called 'Comparison' model and the other plainly 'Reference' model.

During the review of the objectives, several sub-questions emerged from the original research question. These were documented in order for the team to have them in regard during the experimental phase and the analysis:

- Will the result be closer to the reference model than the current GSU solution?
- Which phenomena might occur and which might be overseen?
- Can the technique be more suitable for certain components?
- How much preparation is needed prior to the simulation?
- How extensive computation time is needed?
- Can any unexpected problems be identified using the technique?

3.5 DESIGNING THE RESEARCH

Considering the nature of the problem and that there were a clear selection of techniques to be analysed, the team used an experimental design, as described by Kothari (2004), for further evaluation. Kothari suggests using a test area and a control area, where the test area is introduced to treatment and the control area remains the same. The test area can then be compared with the control area.

Experimental design has been applied to the project where a number of equal data sets went through different simulations, representing the process of each of the techniques. GSU's existing procedure was used as 'control set', i.e. the original process. In addition to Kothari's method described above, a target value is introduced for the experiments; in this case the Reference models result.

The different techniques were compared to the target value. The difference between the control value and reference value constituted a maximum allowed difference. The goal with the experiments was that one or more of the other techniques were able to reach a value closer to the target value than the control set.

To evaluate the techniques, they were compared to the target value. The results were then evaluated against the control set to see if the new techniques could reach a value closer to target value than the control set.

3.5.1 PROCEDURES AND METHODS FOR INFORMATION GATHERING

The experimental process had to be well structured to replicate performed experiments as well as document each step in order to enable troubleshooting and diagnosing possible errors.

Minimise human caused errors

In order to minimise risks of human caused errors, thus increasing the reliability of the experiments, the team chose to automate as many of the processes as possible. This was mainly involved using Matlab and writing code to generate, convert and store data. Likewise, scripts were written to move RD&T measurement data to the MS Excel workbooks as well as combine measurements with .inp data files. In addition to the guarantee that all tasks were performed systematically and identically, in contrast to manual work, automation of iterative processes also saved the team a lot of time. However, automation required extra caution when writing the code as well as thorough testing in order to avoid possible errors. Thus, each code was carefully debugged before usage.

Consistent coordinates

In order to have all measurements and reference points in equivalent coordinates, all of the data sets needed meshed models. This meant that the rigid simulations also used meshed data models. Thus the team could not use the original GSU models from RD&T for data collection, so all models were redone. The meshes were collected from crash simulation at VCC, then separated and cleaned up using ANSA.

3.5.2 CHOOSING THE COMPONENTS TO BE STUDIED – THE PARTS

It was decided that three parts would be used for the experiments. Behind this decision was a balance between the reliability of the study and the accuracy behind each simulation as the time to perform the experiments was limited, why neither more nor less parts were selected.

As the team wanted to be able to present images and measurements from the parts, it was decided to use a released car model instead of any current project at GSU. At the same time, it was important to use relatively new specifications and RD&T-files in order to keep a relevance to the current operations. Thus CAD-models were used from the most recent Volvo model, Volvo V40, referred to as the project name Y555.

To make the experiments coherent with simulations used at GSU, it was decided to originate from their work. All the different parts were based on car model Y555, with locators and measurement points defined from the latest version of the department's model, where locators and measurement points were put in the same position for the different cases and techniques respectively.

The three parts were chosen in consultation with specialists at VCC, aiming to cover a large variety of component types. Three main aspects were taken into consideration when choosing the parts: material, geometry complexity and degree of reinforcement. In addition, it was decided to use exterior parts of the front of the car. As a matter of fact the front is a critical area for GSU to simulate, where a mixture of rigid and non-rigid parts are assembled. Further, this area has a complex dependency between different parts and several different simulation cycles are required before geometrical demands can be defined.

3.5.3 PREPARING THE TECHNIQUES

Before any of the techniques could be tested through experiments they needed to be prepared in different manners, depending on the nature of the techniques. The preparation included creation of the reference models, extracted from an original front vehicle model, to which the other techniques were originated. Further the other techniques were prepared by: creating the meshed CAD models and automating reference and measurement systems.

The preparation steps of the different techniques are as important as the upcoming experiments of the techniques as both preparation simplicity as well as simulation results are evaluated equally.

3.5.4 PLANNING THE EXPERIMENTS

All in all, three experiments were designed in order to collect the data needed to answer the research question. The choice of experiment designs were motivated by the research sub-questions. Mainly the four questions regarding: confidence compared to the current GSU simulations, ability to see phenomena as well as preparation and simulation time. The experiments were not designed in parallel but rather in sequence if the previous experiments did not sufficiently answer all questions. The three experiments performed are to be explained in more details in the following section.

Single part variation simulation

A variation simulation was conducted using 10 000 Monte Carlo iterations. The number was considered to be sufficient for this experiment, even though a higher number of iterations can result in a slightly wider range (Appendix III is showing how simulation results start to converge for 10 000 iterations). The tolerance range was chosen to 2 mm in every target locator that is a greater value than GSU's standard tolerances. However, since the relationship between range and output is almost linear, the value used for the target point variation is less important as long as the value is consistent between the sets.

Since the experiment used a regular variation simulation, the geometrical deviation is described using the 8-sigma values in the measurement output. The reason for choosing this variation simulation was the fact that it is the common process used at GSU, thus the result and way to analyse the results also resembles that of GSU.

A deficiency in the experiment was the possibility to see phenomena and analyse the relationship between cause and effect, as one specific deviation cannot be linked to a specific offset.

Single part sequential offset simulation

By making a single offset to one or a few target points at a time, it will clearly show the effect this particular disturbance will have on the deviation in each measurement point. Therefore this experiment enabled analysis of what effect individual geometry differences had on each component and between the different techniques.

This type of simulation is not common at the GSU department. It does however resemble the more commonly used contribution analysis in RD&T but with more translucent data and a possibility for the team to have full control over the process.

Full variation simulation

In order to make conclusions of modelling and simulation time using the different techniques, a full variation simulation experiment was conducted. This experiment considered the assembly variation of the entire vehicle front. The parts were mounted to the rest of the components in the vehicle front in order to imitate the process and simulations at GSU.

3.6 COLLECTING THE DATA

The experiments were conducted using standard personal computers at VCC. All variation simulations were done in the program RD&T, but several of the preparations; such as creating Contour meshes or Projection models, required other software, in particular ANSA and Matlab. Further, to manage and store the results from the simulations, the team used MS Excel.

3.7 ANALYSING THE DATA

As a lot of data that was processed in this study, it was of great importance to have a clear structure. This section will describe how the data was structured to ease the analysing.

3.7.1 VISUALISING AND MAPPING THE RESULTS

In order to begin the analysis of the data, the information was managed in three steps: (1) import measurement data, (2) categorise it and (3) create visual aids in order to understand the behaviour of the different techniques. Depending on the experiments nature, different categorisations and visualisations were needed.

Manage the part variation simulation data

The part variation simulation output was stored in data sheets in MS Excel. The data was visualised using bar diagrams with each technique as a specific dataset with every cell representing a measurement.

Manage the sequence offset simulation data

The offset simulations resulted in an extensive amount of data. In order to perform an analysis of the sequential offset data, the output from the experiments were grouped by case and sequence. From these groups, the team created several graphs and tables based on different compilations of the data. These were:

- Graphs over the measurement for each sequential set
- Graphs over the differentiation from the reference measurements for each sequential set
- Table over the difference-mean from the reference measurement for each sequence and technique
- Table over the maximum difference from the reference measurement for each sequence and technique
- Measurement-Sequence matrix

The raw data these graphs and tables were based upon are to be found in Appendix IV.

These graphs and tables were used to compare results between the different cases and sequences as well as finding discrepancies in the results.

In order to present the result from this experiment concisely in the Result Chapter, an average, median and maximum summary of the offset simulation average and maximum is presented. This provides a better overview, since the amount of data retrieved from the offset simulations were extensive.

Manage the full variation simulation data

The output of this experiment was measurement results from all simulations from all the parts simultaneously as well as the computation time.

The simulation data was stored as tables and graphs, with all the part deviation measurement for the different techniques in the same document. The graphs were divided so that they showed variation simulation for one part each.

3.7.2 CONSISTENCY IN THE ANALYSIS

To ensure consistency in the choice of which values to analyse, a few criteria were defined and automated to find the relevant numbers in the data. The criteria were formulated in consultation with the GSU supervisor.

3.8 INTERPRET AND REPORT

Although the interpretation and reporting is mentioned lastly in Kothari's methodology process, the process has been documented and evaluated continuously throughout the project.

3.8.1 INTERPRETATION AND GENERALISATION

Due to the extensive amounts of data, the generalisation has been difficult. As this was known early, it has been taken in consideration throughout the collection and analysing phase. Thus has it also been important to document questions that are not possible to answer in this thesis, for future research.

3.8.2 PREPARATION OF THE THESIS REPORT

The distribution between documentation and research has obviously shifted and more documentation is performed in the latter part of the process.

Besides the report writing, a summary of the current work and progresses has been compiled each week and sent to the supervisors. These weekly reports also worked as a support in the documentation process at times when there was a need to review previous work.

Halfway through the project, a presentation was held for the members of the GSU department.

3.9 RELIABILITY AND CRITICAL REVIEW OF THE METHOD

While CAE is a relatively new area, it is rapidly developed, and sources found might be obsolete. Several of the sources concerning computational software can be several years old and thus out-dated. Effort has however, been put on finding as recent research as possible.

Two issues in particular have complicated the analysis of the data: (1) the amount of data and (2) the difficulty to generalise the simulation results. In order to get an overview of the 12’000 cells in the offset simulation, the data sets were compiled to one set of average, median and maximum values per technique and simulations. These were in turn compiled once more to average, median and maximum values, this time of the previous compilation. This generalisation was however only used as a tool to get an overview of the patterns of the techniques. Each simulation was also visualised in separate charts and tables.

4 PRE-STUDY RESULTS

Through the pre-study, several simulation techniques has been found and developed. Existing techniques found during the pre-study has been explained in the theoretical framework. The new techniques that were developed by the team are presented in the "The New Techniques" section below. As an overview, all techniques that have been considered are shown in Table 1.

Moreover, the results from evaluation matrix, considering all suggested methods, are presented later in this chapter.

Table 1 - An overview of all the techniques that are considered in the thesis.

	Type of model	Description
New Techniques		
Automatic-Alternative Assemblies	Rigid	Automatically divide model into several areas to be analysed separately
Projection Technique	Simplified Mesh Model	Project meshed surface against CAD model
Contour Technique	Simplified Mesh Model	Generate a mesh from the contour between selected nodes
Existing Techniques		
Morphing Technique	Non-Rigid Morph Model	Create a smooth non-linear transition between offset points
Mesh Free	Nodes	Using nodes instead of a mesh to represent the model
Currently Implemented Techniques		
Mesh Model (Reference Model)	Conventional Mesh Model	Create a mesh from a CAD model, using a mesh generation software
Alternative Assemblies	Rigid	Manually divide a model into several areas to be analyzed separately.

4.1 THE NEW TECHNIQUES

Besides the existing techniques from the literature review (described in the Theoretical Framework), the team developed ideas for three new techniques. Their general properties and intended functions are described below. The techniques that were qualified for further development are presented in “Results from selection matrix” section.

4.1.1 AUTOMATIC-ALTERNATIVE ASSEMBLIES

Automatic-Alternative Assemblies, henceforward referred to as Auto-AA, is a further development of the existing technique Alternative Assemblies. Auto-AA uses a set of rules to define the Alternative Assemblies automatically, with intention to save manual work and reducing risk of human caused errors. Just like regular Alternative Assemblies, no FEA is performed on the part, i.e. no mesh is required.

4.1.2 PROJECTION TECHNIQUE MESH MODELLING

The Projection technique uses a simple surface, such as a plane or cavernous half sphere, with a meshed geometry to project the already connected nodes onto an unmeshed CAD-part. The idea is that cracks and other problems in the CAD part, that usually are problems when meshing, can be avoided. The technique shall detect if the projection is made outside the part contour and so the edges can be cut off. The result will be a mesh with rough edges depending on the mesh grid size. The mesh will only consist of one surface but can cover the part from different directions by using for example a cavernous half sphere when projecting. When the projection is finished, the mesh will be simulated using regular FEM calculations.

4.1.3 MESH MODELLING WITH CONTOUR TECHNIQUE

This new mesh creating procedure uses the simulation data used in RD&T to create a mesh regardless of the CAD models design. The idea is to connect the locators and measurement points to a closed set of edges, thus creating a contour. This set is then meshed to a surface containing all the important points in the CAD-part. Finally, the mesh can be used for regular FEM calculations.

This technique will not enable to visualise the non-nominal effects for the assembly, but only measured data. That is because the mesh is independent of the part and the analysis only consider the mesh, which is a rough simplification of the part's geometry. The biggest difference between Contour technique and Projection technique is that Contour technique only creates the mesh of what is considered important and therefore takes less consideration to the original geometry. Thus the mesh is less affected by eventual problems with the model, while on the other hand, fewer details are included.

4.2 IDEAS OF HOW TO SIMULATE THE TECHNIQUES

During the pre-study, the team studied ways to simulate how the techniques would be used, before any intended software could be developed. This was done before evaluating the concepts through the selection matrix, in order to consider if the testing of the techniques was applicable. As none of the existing simulation methods described in the theory has been used in the area of variation simulation, the testing of the existing techniques was also considered in this part of the pre-study.

4.2.1 HOW TO SIMULATE AUTOMATIC-ALTERNATIVE ASSEMBLIES

The team found that the easiest way to test Auto-AA was not to modify the existing function for Alternative Assemblies in RD&T, but to calculate alternative assembly systems externally. An idea was to use the coordinates for measurements and locators and calculate the assemblies based on these distances in Matlab. Then export a list with suggested assemblies that can be entered manually in RD&T.

4.2.2 HOW TO SIMULATE AUTOMATIC MESH GENERATION

Through the pre-study, it was observed that the computer program ANSA supports several functions for mesh generation. Further, the program has support for creating macros, which could be used to test if it is possible to fully automate the mesh generation process.

4.2.3 HOW TO SIMULATE MORPHING

Even though morphing has been used for a long time in areas of animation and visualisation its applications in the geometrical area is very limited. Some simple models were built in Matlab to test properties of morphing as well as evaluation of the morphing tool in ANSA.

4.2.4 HOW TO SIMULATE MESH-FREE ANALYSIS

Libraries for implementing Mesh-free analysis through different programming languages have been found. However, these do require a good deal of knowledge and work. The theory behind the technique was at the same time outside the teams' field of expertise. It was thus considered difficult to evaluate the Mesh-free technique.

4.2.5 HOW TO SIMULATE THE PROJECTION TECHNIQUE

RD&T proved to have support for measuring distances from nodes to other surfaces and export these as lists of data. The team has also analysed how the ABAQUS file format work and developed a script for adding the offset data to the meshed ABAQUS file, thus creating a projection.

4.2.6 HOW TO SIMULATE THE CONTOUR TECHNIQUE

The team ensured that ANSA could be used to create all the necessary surfaces and the mesh, by importing coordinates from RD&T. However, no automation has been implemented or evaluated.

4.3 RESULTS FROM THE SELECTION MATRIX

A selection matrix (see Table 2) was made to evaluate both the existing techniques described in the theoretical framework as well the techniques generated through the pre-study. According to the selection matrix, Projection technique, Auto-AA and Contour technique qualified for further development.

How the techniques were evaluated and motivation for the scoring is found in Appendix II.

Table 2 – The selection matrix used for elimination of concepts.

		Concept											
		Automatic Alternative Assemblies		**(Reference) Automatic Mesh Generation**		**Morphing**		**Meshfree Analysis**		**Projected Mesh Generation**		**Contour Mesh Generation**	
Selection Criteria: the development	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Short Development Time *	15%	5	0,75	3	0,45	2	0,3	1	0,15	4	0,6	3	0,45
Possibility to Implement in RD&T **	5%	5	0,25	3	0,15	3	0,15	1	0,05	4	0,2	3	0,15
Unexplored	10%	4	0,4	3	0,3	3	0,3	3	0,3	5	0,5	5	0,5
Evaluation Possibility *	20%	2	0,4	3	0,6	1	0,2	1	0,2	3	0,6	3	0,6
Selection Criteria: the user													
Level of Confidence *	20%	3	0,6	3	0,6	1	0,2	5	1	4	0,8	2	0,4
Level of Automation *	15%	4	0,6	3	0,45	3	0,45	4	0,6	3	0,45	4	0,6
Short Simulation Time *	15%	5	0,75	3	0,45	4	0,6	2	0,3	3	0,45	5	0,75
	Total Score	**3,75**		**3**		**2,2**		**2,6**		**3,6**		**3,45**	
	Rank	1		4		6		5		2		3	
	Continue?	Develop		No		No		No		Develop		Develop	

*) Presumed value, based on pre-study
**) According to developers at RD&T Technologies

5 RESEARCH RESULTS

This chapter describes the results of the experimental research that further evaluates the techniques selected in the pre-study.

First of all, the model geometries are presented. That is the result from preparing the models by using the selected techniques. The prepared geometries were then used as input for the simulation experiments.

The latter part of this chapter presents the results from the offset simulations. In this summary only the mean and maximum values are included. This simplification was made since each of the offset experiments contain between 10 and 25 offset simulations.

5.1 THE GEOMETRY OF THE MODELS

This section describes the geometrical results of creating and preparing all the models through the different techniques, regarding the geometrical properties. First, the general perception from every technique is described followed by more enhanced observations unique for each case. The different techniques are compared to the Reference model in order to see how many differences there are in the measured values. Further, the models are compared to the Comparison model in order to evaluate how much the actual mesh quality affects the simulation results.

As the different parts at some points had different properties, the techniques were slightly modified among the different parts. An overview of the techniques and cases can be seen in Table 3.

Table 3 – Showing the techniques that were used in the experiments. An x *means that a technique has been used for the corresponding case.*

Part/Technique Applicability			
	Fender	**Bonnet**	**Front Bumper**
Reference	x	x	x
Comparison	-	x	x
GSU-AA	x	x	x
Projection	x	x	x
Improved Projection	-	-	x
Contour	x	x	x
Auto-AA	x	x	x

5.1.1 THE REFERENCE MODELS

The reference models were high quality meshes with a resolution of 7 mm. The primary part consists of one continuous surface, where the Bonnet and Front Bumper had external reinforcements attached. Compared to the GSU CAD model, the mesh had its shortcomings when it came to describe details in the geometries, such as holes. However, the 7 mm resolution gave a good representation of the models. The rest of the models were all based on the reference model.

The Fender Reference Model

The reference model of the Fender is, opposed to the two other reference models, based on a single sheet of metal without reinforcements, just as it is originally manufactured. The Fender can be seen in Figure 12.

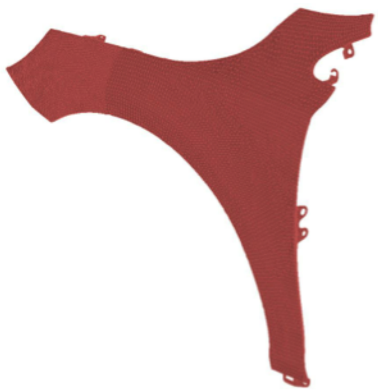

Figure 12 – The reference model of the Fender.

The Bonnet Reference Model

The Bonnet Reference was reinforced by an inner surface that was connected to the top; referred to as Bonnet bottom and Bonnet top respectively. The Bonnet top had its outer surface folded around the Bonnet bottom. For simulation in RD&T the Bonnet bottom was attached to Bonnet top by using weld points. Figure 13 below is showing the reference model of the Bonnet with its reinforcement and Figure 14 shows an overview of the two parts, with a transparent top part.

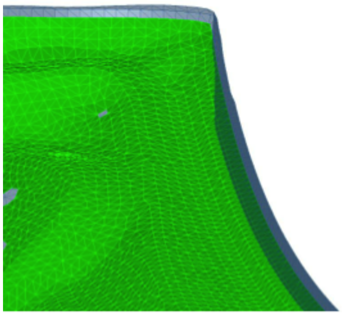

Figure 13 – Showing the bottom part of the Bonnet and how the top is folded around it.

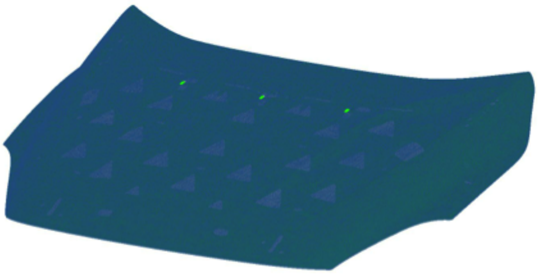

Figure 14 – The Reference model of the Bonnet. The model is slightly transparent so that the reinforcement can be seen below.

Front Bumper Reference model

The Front Bumper was a plastic part that had a lot of details inside of it; many were different kinds of reinforcements and fasteners. Each of them were added as a separate mesh, attached to the main surface. In order to include these reinforcements when simulating the model in RD&T, the welding points function was used. The Front Bumper with reinforcements can be seen in Figure 15.

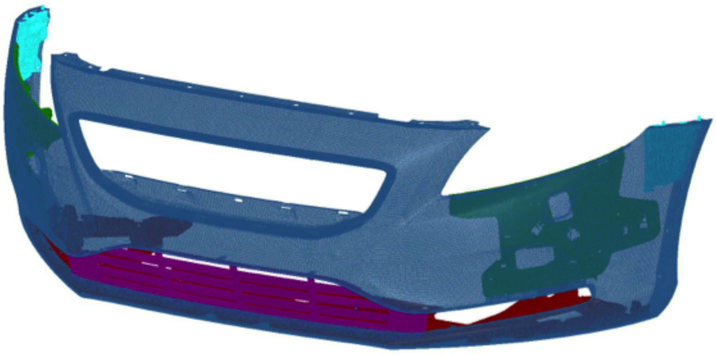

Figure 15 – The reference model of the Front Bumper. The model is slightly transparent, revealing the reinforcements inside.

5.1.2 THE COMPARISON MODELS

For the Comparison mesh models, only the outer surface of the parts was considered, i.e. the models were simulated without the welded reinforcements. The Comparison model was used to enable analysis of the mesh quality and was not used to compare the results to a realistic scenario. As the Fender did not contain any reinforcements it was not applicable in this category, as the Reference and the Comparison model are identical.

5.1.3 THE PROJECTION MESH MODELS

The Projection models did generally follow the original models well. The edges were a little bit rougher and the Projection technique did not quite capture all details. The mesh size for the Projection models was 10 mm (A more detailed description of how the Projection technique was applied can be found in Appendix V).

Projection Fender

For the Fender, the main difference from the original model was the smaller details such as the fasteners on the back. An example of that can be seen in Figure 16, where the Projection model lacks the fasteners from the original model. The reason was that the Projection only describes surfaces in its primary direction (Y), which leaves out any geometry behind the primary surface. That did, however, not affect the model to any greater extent as no measurements or locators were connected to these missing details. The full Projection model of the Fender is shown in Figure 17.

Figure 16 – Showing the original model of the Fender next to the Projection model. The comparison shows e.g. how the fastener on the side is missing for the Projection model.

Figure 17 – Projection Fender.

Projection Bonnet

The Projection model of the Bonnet had two major differences from original model. First of all did it only consist of a single surface, i.e. the reinforcement was not included in the Projection model. Secondly the folded edge as included in the original model was not captured when the projection was made, which might also affect the part stiffness. The mesh size for this model was 10 mm. The Projection model of the Bonnet can be seen in Figure 18.

Figure 18 – Projection Bonnet.

Projection Front Bumper

As the Front Bumper was facing different directions, the projection consequently needed to be performed from different directions as well. Thus, the projection was performed in the X-direction against the front as well as the Y-direction from both sides to better cover the model. This is shown in Figure 19.

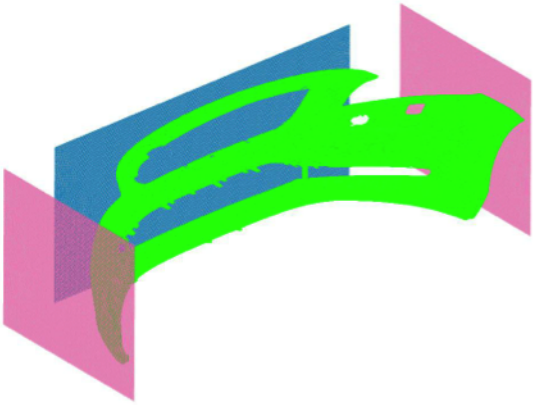

Figure 19 – Showing the original CAD model of the Front Bumper that is to be Projection by planes from three directions.

Performing the projection technique using different planes resulted in some gaps that were manually fixed in ANSA afterwards. As no projection was done from the top or bottom, some details were missing; especially important was an edge at the top, which contained several locators. This resulted in spikes caused by the script that generated the mesh. What happened was that the script adjusted the closest nodes to corresponding measurement or locating points, and here the offset became very long. A close up of the spikes can be seen in Figure 20 below. Further, Figure 21 illustrates the whole Projection Front Bumper.

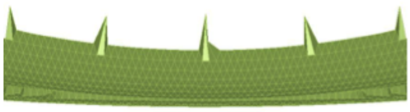

Figure 20 – Shows the spikes that occurred on the top of the Front Bumper. The spikes are caused when the mesh is generated and nodes are moved.

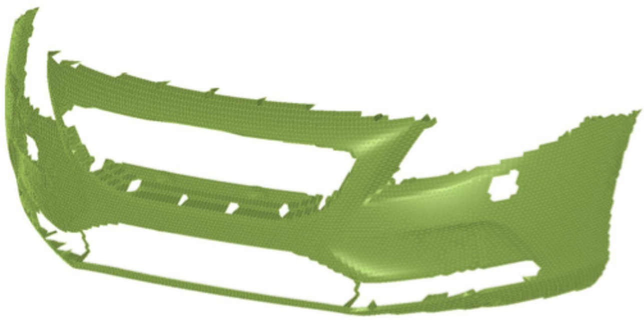

Figure 21 – Shows the Projection mesh of the Front Bumper.

Improved Projection Front Bumper

After having performed simulations with the Front Bumper Projection mesh model, some problems were found in the results, mainly caused by the locator-spikes. An improved model was created, with additional projections from above and below, with all small holes filled. ANSA was used to fill the holes and repairing the gap for the new Projection mesh model. The result of the improved model can be seen in Figure 22 below.

Figure 22 – Shows an improved model of the Projection mesh. It had no longer the spikes and had its small holes removed.

5.1.4 THE CONTOUR TECHNIQUE MODELS

The contour meshes had a few apparent deviations from the original models. Some locators and measurement points made the surface flat that unlike the original models, which instead had a smoother and more concave shape. Further the locators and measurement points were at some points not sufficient to fully describe the shape of the models. The mesh size for these models was 20 mm. A more detailed description of how the Contour technique was applied can be found in Appendix VI.

Contour technique mesh of the Fender

The contour mesh of the Fender is shown in Figure 23. Most remarkable for this model is the wheel arch that does not at all follow the original shape. As no measurement or locating points are given around the arch this shape is not considered in the contour mesh model.

Figure 23 – Shows the contour mesh of the Fender.

Contour mesh Bonnet and Front Bumper

When creating the Bonnet contour, it did lack a lot of its original shape. Compared to the other contour mesh models, it can be see that the Bonnet is flat, while the others have a more rounded shape. How this affects geometrical properties is further tested in the experiments. The contour mesh of the Bonnet can be seen in Figure 24.

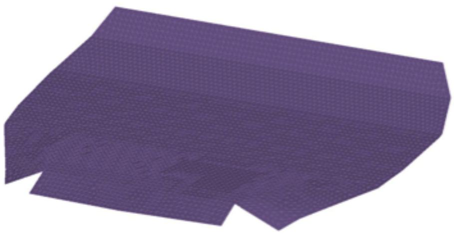

Figure 24 – Shows the contour mesh of the Bonnet.

Contour mesh Front Bumper

Although the complexity of the Front Bumper, the contour mesh managed to follow the geometry fairly well. The contour mesh of the Front Bumper can be seen in Figure 25.

Figure 25 – Shows the contour mesh of the Front Bumper.

5.1.5 AUTO-AA MODELS

The Alternative Assemblies used the original models but without utilising the compliant mode in RD&T. Hence, they were considered as rigid models.

No preparation work was needed with the models, except for calculating the assembly systems. Hence, the preparation work was to create the automated Alternative Assemblies. The output was a document showing the measurements points and what positioning system to be coupled to it. Indeed, this can be used for both Alternative Assemblies and flex positioning, although it has only been tested with Alternative Assemblies.

5.2 VARIATION SIMULATION RESULTS

Variation simulation was performed on the three different models. The results were compiled into diagrams and tables for comparison.

The diagrams show the variation simulation results on three different models with one diagram for each model. The columns in the diagrams shows the measurement offset in millimetres, when performing a 2 mm range disturbance on all locators, for all techniques. The marked lines shows, using the secondary axis, the difference between the reference model and the other techniques.

The simulations were clocked to see how the computation time differed between the techniques. The time measurements are solely made for the Front Bumper, since it is the most time consuming part to simulate.

The tables shows the average, mean and max values from the variation simulations performed.

The measurement points and locators used for the Fender, Bonnet and Front Bumper can be seen in Appendix VIII and the raw data is found in Appendix IV.

5.2.1 VARIATION SIMULATION RESULTS FENDER

The result from the variation simulation of the Fender is shown in Figure 26.

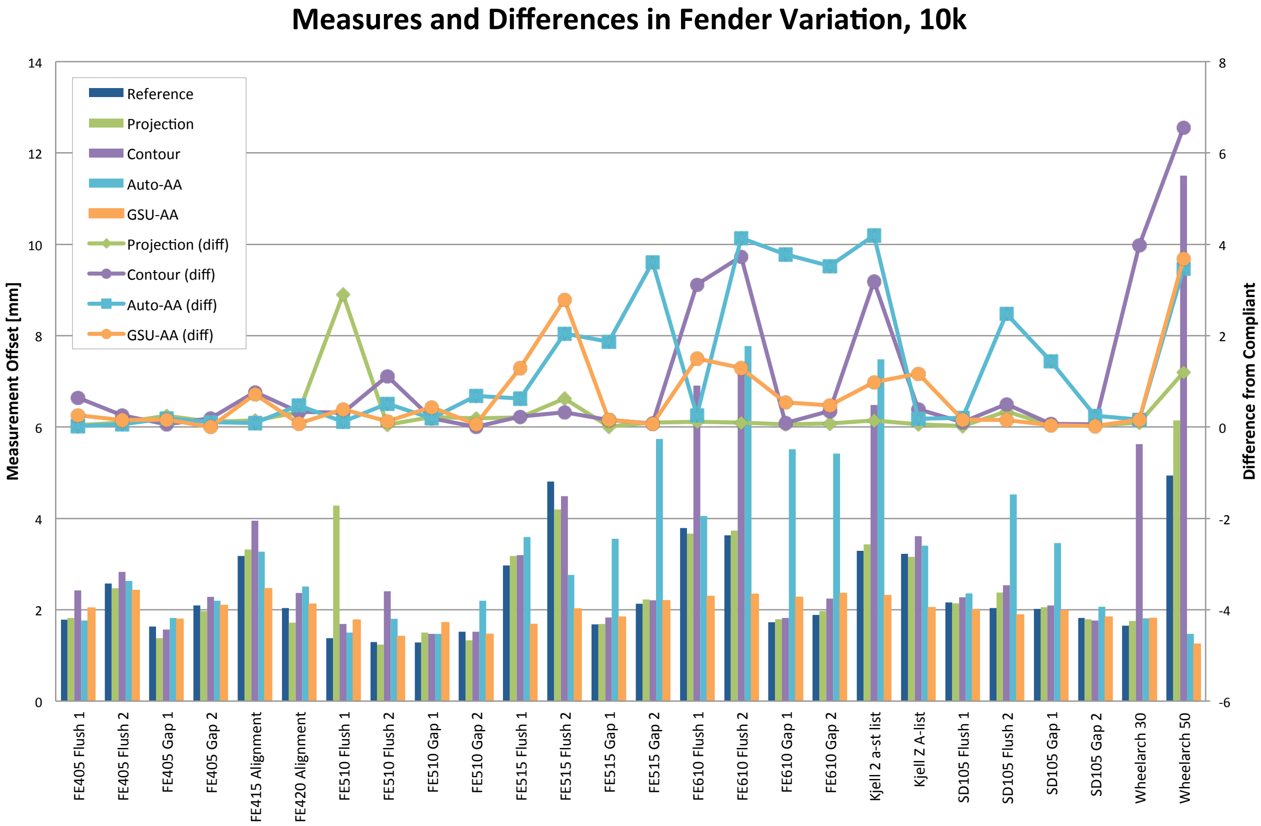

Figure 26 – Measures and Differences in Fender Variation, 10k Monte Carlo Iterations.

In this simulation, the Comparison model was not included, as the reference model did not contain any external reinforcements. The diagram shows that the Projection technique was close to the target value in all but two measurements; resulting in a mean deviation less than 0.29 millimetres. This is a deviation that is less than half the GSU-AA mean deviation. On the contrary, the Contour and Auto-AA, had a wider distribution with several more peaks.

5.2.2 VARIATION SIMULATION RESULTS BONNET AND FRONT BUMPER

The Bonnet and Front Bumper simulations, shown in Figure 27 and Figure 28, does also include a Comparison model, in addition to the Reference. The Comparison models does only consider the primary surface of the part, in order to compare the quality of the mesh. When a measurement result is deviant compared to the Reference model but close to the Comparison model, the difference might be caused by reinforcements.

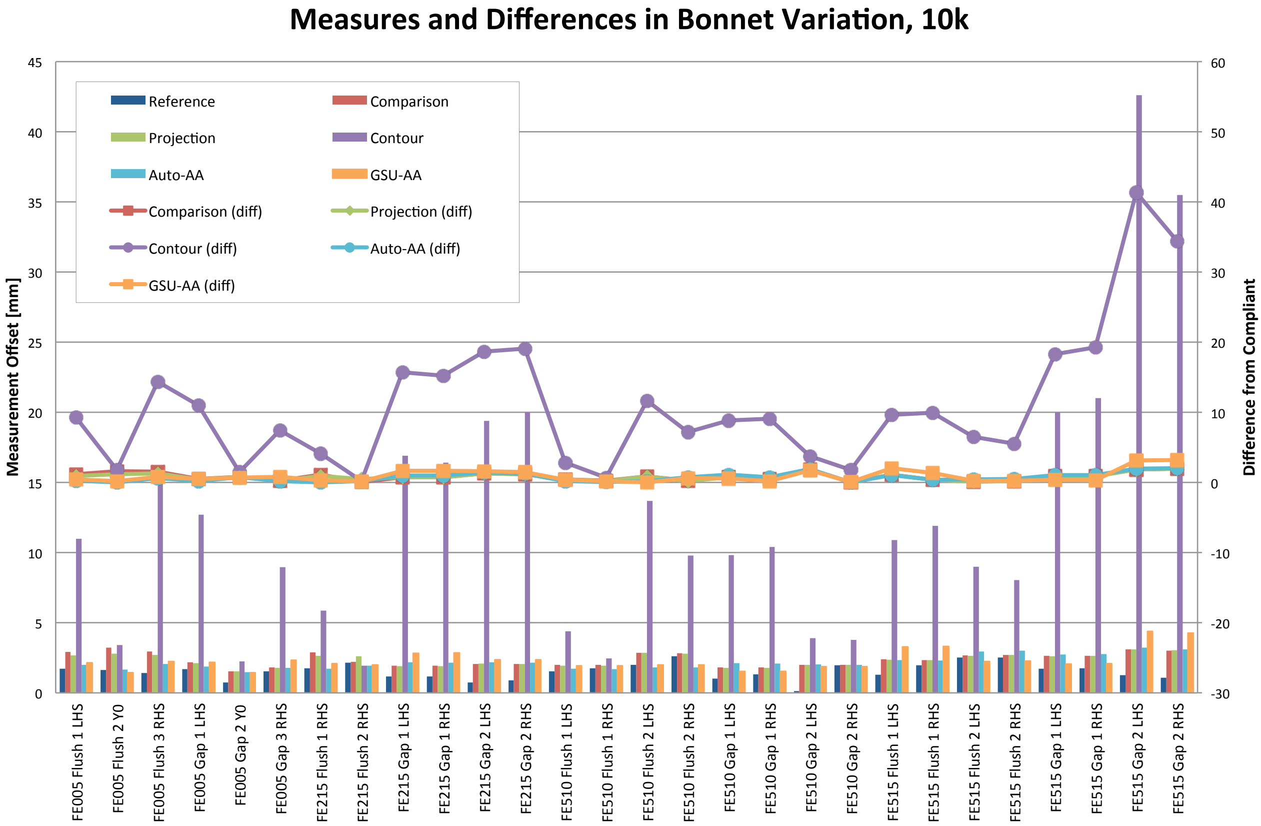

Figure 27 – Measures and Differences in Bonnet Variation, 10k Monte Carlo Iterations.

The diagram in Figure 27 illustrates, inter alia, that the Projection model followed the comparison model well. It is also shown that the Auto-AA overall was closest to the Reference model results. The most conspicuous part of the diagram is though, the large differences in the contour model, in close to all of the measurements. The almost consistent error found in this Bonnet Contour model is neither present in the Fender nor Front Bumper Contours. However, the Contour technique has several large peaks in the Front Bumper simulations as well (see Figure 28).

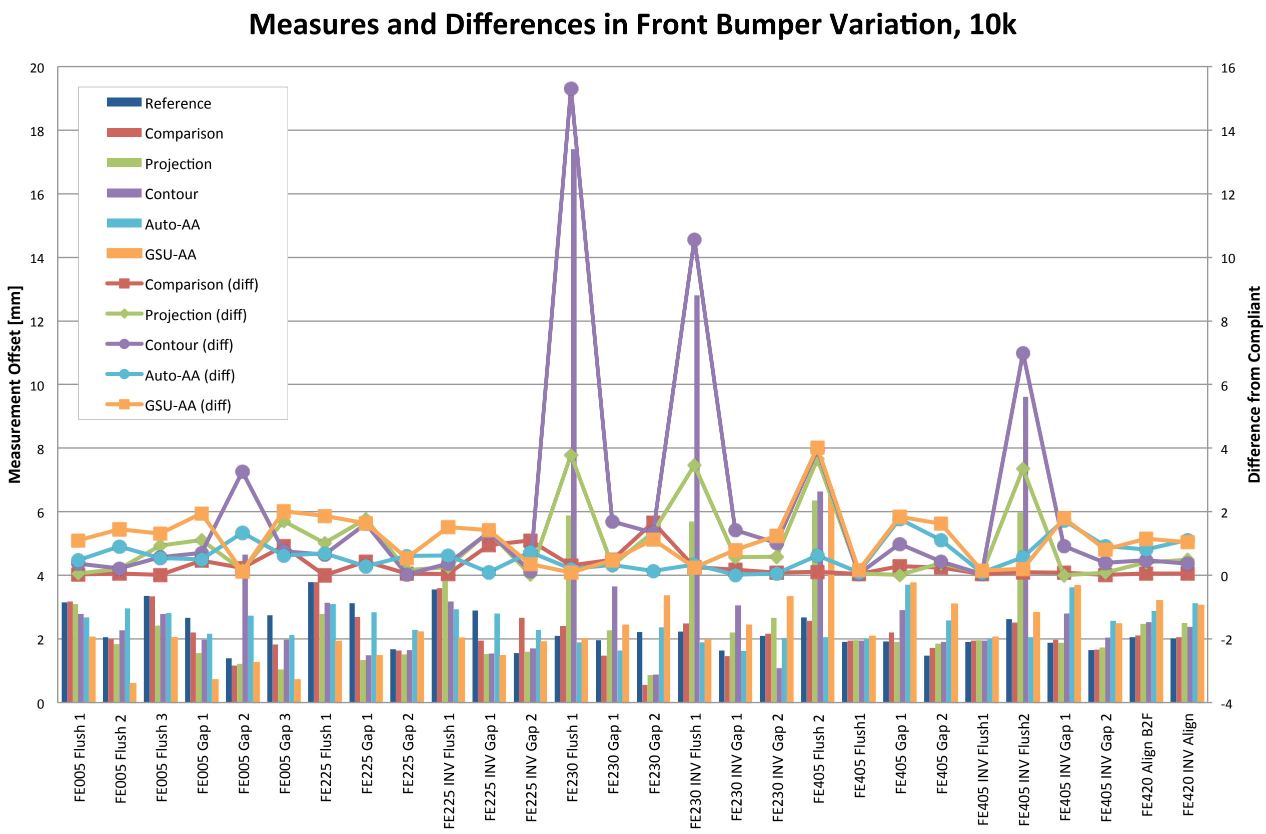

Figure 28 – Measures and differences in Front Bumper variation, 10k Monte Carlo iterations.

Figure 28 also show that the Comparison model followed the Reference model well in the Front Bumper simulation. The Auto-AA and Projection mesh had slightly larger differences, with some higher peaks on the Projection technique. The peaks in the Projection can be found in the same measurements as the peaks in the Contour model.

5.2.3 TIME MEASUREMENTS FOR THE FRONT BUMPER VARIATION SIMULATION

When performing the variation simulations on the Front Bumper, the simulation times were recorded. The result is compiled in Table 4.

Table 4 – Simulation times for variation simulations of the Front Bumper, using 10 000 iterations.

Simulation Times for the Front Bumper				
	Reinforced	**Projection**	**Contour**	**AutoAA**
Time to Calculate Compliant Matrices	07:40	00:04	00:09	-
Static Variation Simulation (10'000 it)	04:06:00	00:51	00:18	05:39
Total Simulation Time (10'000 it)	04:14:00	00:55	00:27	05:39

The table show that both the Projection technique and Contour technique are several times faster than Auto-AA. The Reference model however, takes over 250 times longer to simulate than the Projection technique and over 550 times longer compared to the Contour technique. Furthermore, the Projection technique has the shortest compliance matrix creation time: over 100 times faster than the Reference model.

Auto-AA lacks the compliance matrix creation time as the technique uses a rigid simulation method.

5.2.4 VARIATION SIMULATION RESULT SUMMARY

Table 5 below is a summary of the mean, median and maximum values of each technique for each case, compared to the Reference model and Table 6 shows the same values compared to the Comparison model.

Table 5 – Summary of the Variation Simulation Difference from Reference.

Variation Simulation Difference from Reference				
Fender				
	Projection	**Contour**	**Auto-AA**	**GSUAA**
Mean value	0,29	1,03	1,33	0,65
Median value	0,11	0,32	0,49	0,21
Max value	2,90	6,56	4,19	3,69
Bonnet				
	Projection	**Contour**	**Auto-AA**	**GSUAA**
Mean value	0,80	11,04	0,73	0,89
Median value	0,77	9,18	0,68	0,51
Max value	1,96	41,34	2,02	3,21
Front Bumper				
	Projection	**Contour**	**Auto-AA**	**GSUAA**
Mean value	0,98	2,00	0,62	1,15
Median value	0,45	0,73	0,59	1,14
Max value	3,79	15,31	1,78	4,02

Table 6 – A summary of the Variation Simulation Difference from the Comparison.

Variation Simulation Difference from Comparison				
Bonnet				
	Projection	**Contour**	**Auto-AA**	**GSUAA**
Mean value	0,07	10,21	0,37	0,58
Median value	0,03	8,29	0,25	0,54
Max value	0,42	39,51	1,56	1,77
Front Bumper				
	Projection	**Contour**	**Auto-AA**	**GSUAA**
Mean value	0,88	1,90	0,66	1,14
Median value	0,43	0,49	0,57	1,1
Max value	3,78	14,99	1,81	4,13

It is important to note that Table 6 do not contain any comparison to the simulations performed on the Fender part, since no comparison model is made on the Fender.

To summarise, the following can be seen in the three simulations:

- The Projection model did overall follow the Reference model well.
- The Projection model had a few peaks in the Front Bumper simulation, matching the Contour models larger peaks.
- The Contour mesh showed several large peaks in all three simulations, especially in the Bonnet model, delivering the worst result compared to the Reference model.
- Out of the three techniques, the Auto-AA gave the best mean value in three out of five comparisons.
- Looking at the median value, the Projection technique had the best result of the three techniques in four out of five comparisons.

5.3 OFFSET SIMULATION RESULTS

The offset simulation results showed the displacement of the measurement nodes when performing a single disturbance on one or several nodes in sequence. The offset was set 3 mm in the locator's direction.

As mentioned in the Methodology chapter, the data is displayed as an average, median and maximum of the offset simulation average and maximum values, in order to overview the extensive amount of data. The offset simulations are also compared to two different values, the Comparison model and the Reference model. These are described below.

It is also important to notice that the Improved Projection technique was only used for the Front Bumper case and is thus not shown in the other two cases.

The raw data that the presented results are compiled from can be found in Appendix IV.

5.3.1 COMPARING OFFSET RESULTS TO THE COMPARISON MODEL

The first comparison is made with the Comparison model and thus is not the Fender included in this table. To the Bonnet and Front Bumper, this comparison rather resembles a calculation made on style sheets than that of the finished car.

A summary of the average offset-differences to the Comparison model is shown in Table 7.

Table 7 – Average difference to Comparison offset simulation.

Difference to Comparison Offset Simulations (Average)					
Bonnet					
	Projection	**Improved Projection**	**Contour**	**Auto-AA**	**GSU-AA**
Average of mean:	0,07	-	1,91	0,60	0,58
Median of mean:	0,06	-	0,58	0,57	0,56
Max of mean:	0,12	-	12,80	1,08	1,01
Front Bumper					
	Projection	**Improved Projection**	**Contour**	**Auto-AA**	**GSU-AA**
Average of mean:	0,30	0,15	0,58	0,44	0,49
Median of mean:	0,23	0,10	0,30	0,33	0,46
Max of mean:	0,70	0,47	1,66	0,93	0,96

The data in the table is presented as average, median and maximum values of a series of average measurement differences, from the offset simulations. It can be seen that Projection technique (and the Improved Projection technique) consistently had the values closest to the target value.

Other than that, the table shows that the Contour mesh generally had a higher difference than the other techniques, except for in the Fender case where the Auto-AA had the highest difference. In the Bonnet case, the Contour's maximum of the average is even alarmingly high. The reason will be shown later in the summary of the maximum values. However, the median of the Contour technique tends to have low differences and even a frequently better result than both of the AA techniques several times.

Comparing the GSU-AA and Auto-AA results, the GSU-AA model, did overall have a better result than Auto-AA, even though they were close to each other throughout the table.

The maximum values from the offset-differences are summarised in Table 8.

Table 8 – Maximum difference to Comparison offset simulation.

Difference to Comparison Offset Simulations (Maximum)					
Bonnet					
	Projection	**Improved Projection**	**Contour**	**Auto-AA**	**GSU-AA**
Average of max:	0,27	-	6,43	1,80	1,78
Median of max:	0,32	-	1,69	1,89	1,69
Max of max:	0,42	-	44,87	2,46	4,04
Front Bumper					
	Projection	**Improved Projection**	**Contour**	**Auto-AA**	**GSU-AA**
Average of max:	1,09	0,90	2,17	1,82	3,12
Median of max:	0,96	0,50	1,60	2,06	2,80
Max of max:	2,19	3,24	6,14	2,89	5,57

The big differences between the median and maximum values, in combination with the rather low average values, do indicate that there were one or a few divergent extreme values in the series of mean values. This is the case with several of the offset simulations, especially the Bonnet Contour that had one extreme measurement as high as 43 millimetres, which belong to the same simulation as the 12-millimetre average seen in Table 9.

It is also worth to note that the maximum value of the Improved Projection technique increased compared to the Projection technique. This increase also made the maximum value of the maximum difference in the Improved Projection technique higher than the Auto-AA model.

5.3.2 COMPARING OFFSET RESULTS TO THE REFERENCE MODEL

The second comparison is made between the different techniques and the Reference model. A summary of the average results is presented in Table 9.

Table 9 – Average difference to Reference offset simulation.

Difference to Reference Offset Simulations (Average)					
Fender					
	Projection	**Improved Projection**	**Contour**	**Auto-AA**	**GSU-AA**
Average of mean:	0,26	-	0,40	0,78	0,58
Median of mean:	0,11	-	0,35	0,57	0,51
Max of mean:	0,85	-	1,40	1,88	1,22
Bonnet					
	Projection	**Improved Projection**	**Contour**	**Auto-AA**	**GSU-AA**
Average of mean:	0,19	-	1,79	0,44	0,46
Median of mean:	0,20	-	0,40	0,43	0,39
Max of mean:	0,27	-	12,76	0,83	0,93
Front Bumper					
	Projection	**Improved Projection**	**Contour**	**Auto-AA**	**GSU-AA**
Average of mean:	0,38	0,25	0,60	0,51	0,54
Median of mean:	0,28	0,20	0,33	0,45	0,48
Max of mean:	0,96	0,68	1,71	1,13	0,95

Table 9 shows that the Projection technique (and Improved Projection technique) consistently delivers the results closest to the target value (i.e. as low values as possible), just as in Table 7 and 8.

Looking at Table 9 it is also evident that all models were in general closer to the Comparison model than to the Reference model. This is true for both the average, median and maximum values. Looking at the summary of the maximum values for the Reference model comparison in Table 10, the same statement is still true.

Table 10 – Maximum difference to Reference Offset Simulation.

Difference to Reference Offset Simulations (Maximum)					
Fender					
	Projection	**Improved Projection**	**Contour**	**Auto-AA**	**GSU-AA**
Average of max:	3,44	-	3,25	9,48	5,72
Median of max:	5,76	-	17,19	24,98	11,10
Max of max:	1,56	-	2,91	5,20	4,00
Bonnet					
	Projection	**Improved Projection**	**Contour**	**Auto-AA**	**GSU-AA**
Average of max:	0,84	-	6,10	1,27	1,55
Median of max:	0,69	-	1,26	1,27	1,34
Max of max:	1,28	-	44,82	1,93	4,10
Front Bumper					
	Projection	**Improved Projection**	**Contour**	**Auto-AA**	**GSU-AA**
Average of max:	1,52	1,43	1,86	1,85	2,54
Median of max:	1,07	0,91	1,12	2,15	2,41
Max of max:	2,88	4,39	6,11	2,82	3,91

Table 10 also shows that the maximum of the maximum value of the Front Bumper Improved Projection technique did increase compared to the original Projection technique. At the same time did the median and average maximum values decrease for the same comparison.

5.4 COMPLETE VARIATION SIMULATION RESULTS

The complete variation simulation was an experiment intended to show how parts from the new modelling techniques would serve in a more real world simulation environment. Time was also a factor of considerable interest. To actually be able to test how long the simulation would take; it required using a real model that analysed a whole assembly. Hence, a front model assembly was chosen as a third experiment, which included the Fender, Bonnet and Front Bumper together with the surrounding parts. The simulated reference model can be seen in Figure 29.

Figure 29 – Shows the model used for complete variation simulation of the compliant models. This illustration shows the reference model.

In this final experiment only the Projection models compared to the Reference models, was tested and compared to the GSU-AA and Reference model.

The projection model was used in this test because it was considered the most promising model and was thus qualified for the final test. It has been seen that the different CAD-models without reinforcements virtually takes the same amount of time to simulate and will therefore represent simulation time of all non-reinforced meshed models. This is true because the grid size is about the same for all models.

5.4.1 SIMULATION TIME

To fully test the simulation time, all measurements in the complete model were used. As a matter of fact, using all measurements will include all the Alternative Assemblies, which affects the simulation time, times the number of assemblies. In the model used for testing, 14 different Alternative Assemblies were used. Also, time required for RD&T to calculate compliant matrices was included, which is necessary in RD&T after a modification in the position systems has been made. In Table 11 below it can be seen that there is a big difference in simulation time weather reinforcements are used or not.

Table 11 – Simulation times for the entire Front Body model, for each of the techniques.

Simulation Times, Front Body	
Reinforced Model	
Simulation Time, 10 iterations	03:30
Time to Calculate Compliant Matrices	12:00
Extrapolated Time, 10'000 iterations	58:20:00
Total Time	58:32:00
Projection Model	
Simulation Time, 1'000 iterations	00:51
Time to Calculate Compliant Matrices	00:06
Extrapolated Time, 10'000 iterations	08:30
Total Time	08:36
GSU-AA Model	
Simulation Time, 10'000 iterations	00:27
Time to Calculate Compliant Matrices	-
Total Time	00:27

The time measurements show that the Projection technique requires significantly less simulation time than the Reference model. Meanwhile the Alternative Assemblies model takes even shorter time to simulate.

5.4.2 SIMULATION RESULTS

Unfortunately, the simulation results did not show any correlation between the models. Many of the measured results were not at all equitable. Most likely the model contained errors that was not identified due to the limited time for the analysis. However, these measurements were not considered relevant as they was not needed for the conclusion. Thus, no results other than the simulation time measurements are presented from this experiment.

6 DISCUSSION

This chapter will reflect upon results described in the previous chapter. That includes: analysis of techniques used, discussing their behaviour, simulation results and possible modifications striving to increase simulation confidence and reducing preparing time.

6.1 REFERENCE MODEL AND COMPARISON MODEL

A brief discussion of what has been seen when simulating the Reference and Comparison model follows in this section.

6.1.1 REFERENCE AND COMPARISON MODEL SIMULATION RESULT REFLECTIONS

In this thesis, two high quality mesh model types have been used as references and comparison to generate target values: Reference model and Comparison model respectively.

It has been observed at several occasions during the simulations that differences occur between the Reference and Comparison models (this can for example be seen in the variation simulation of Front Bumper in Figure 28). This is assumed to be caused by increased stiffness properties in the Reference model. However, comparing the Comparison model with the other techniques, the Comparison models do generally show better results. An interesting exception, though, is when Alternative Assemblies actually shows a value closer to Reference than the Comparison model does. The reason for this phenomenon is that the reinforcements in some cases do affect the final results to that extent that the Alternative Assembly model becomes a better approximation than a finite element model lacking such reinforcements. An example of this can be seen in Figure 28, on the measures FE230 Gap2. These exceptions are however not a sufficient basis to question the confidence and purpose of the Comparison model in general.

6.1.2 SIMULATION TIME

It has been seen that the reference model takes a considerable amount of time to simulate. Indeed, FEM computation is time consuming and to additionally consider mechanical properties of reinforcements, as for the Reference model does, the simulation takes longer time to simulate. That is because the reinforcements are treated as separate parts making the calculation more complex.

In RD&T, when using Alternative Assemblies together with FEM models, the program simulates the FEM models for every Alternative Assembly. In the case of the third experiment (seen in section 5.4.1) with the reference model it took 58.5 hours. By only considering one assembly system the time would be 58.5/14 ≈ 4 hours. Hence, a convenient way to reduce the simulation time is to reduce the number of Alternative Assemblies, by not simulating the whole assembly model at a time. Deactivating measurements allocated to Alternative Assemblies when performing an analysis of the FEM model can do this.

While the Comparison model, only took 8:36 minutes to simulate, it must be considered that there can be other causes, increasing the simulation time. Firstly, the number of iterations used at the GSU department is up to 100 000, instead of 10 000 which is used for this simulation. Secondly, adding even more non-rigid parts than what has been used in this simulation would certainly increase the simulation time even more.

6.2 PROJECTION TECHNIQUE AS A SOLUTION

For the mesh Projection technique the measured results are in general good. Not only does it show simulation results with a confidence level higher than Alternative Assemblies. It does as a real compliant solution, just like the original mesh models, show several phenomena occurring in non-rigid assembly variation, a property the group found important during this study. Although the Projection mesh simulation technique is generally efficient, it still has its weak spots, and requires further development. Identified issues and ideas will further be discussed in the following sections.

6.2.1 PROBLEMS IDENTIFIED IN PROJECTION TECHNIQUE

Although the mesh Projection technique, at this early concept stage, still required more work than what could be called an automated solution, the technique did essentially enable appropriate mesh creation. Moreover, these meshes did, although several geometrical simplifications, frequently show measurement results close to the Reference model. Still, the technique has several issues remaining to be solved.

To enable arbitrary positioning of locators and measurement points, it was necessary for the Projection technique to move to the closest mesh nodes to the locating and measurement point positions. Unfortunately, there are cases where this transition can be problematic. A node might move between several measurement or locating points in case they have a common closest node. To avoid this in the performed experiments, locators or measurement points close to each other have been merged to the same point. Another possible way to avoid this is to have a mesh grid of a smaller size. It has also been considered to create an algorithm that only allows a node to move once, thus, moving the second closest node instead, if the measurement points or locators have a common closest node. This idea was not implemented because it might cause problems in the mesh, e.g. it could cause mesh grids to cross each other. Another suggestion for further development could be to locally increase the mesh resolution where locators and measurement points are too close.

The spikes that were found in this model were the biggest problem identified when using this technique. An example can be seen in Appendix IV where there is a big difference caused by locator 17(Z) compared to the reference model. Probably as the node creating the exemplified offset is located in a spike. This problem is solved in the improved Projection of front fender, which is further discussed in the upcoming section.

Many parts, such as the Bonnet and Fender, can be considered flat, i.e. having a surface that virtually is facing one direction. For those types of parts, the Projection technique is considered to be the most convenient. In those cases only one plane, in one direction needs to be projected to cover most of the part. However, from what has been seen in the example of the Front Bumper, only one plane is not always sufficient to cover the parts surface. This is also the reason to why the Front Bumper in the final version of the model was created from five planes, projected from different directions. Although the result of the Front Bumper did turn out well, it did require more manual work than a one-direction projection would. To enable automated projection of non-flat parts,

more development of the
Projection method is required. For example, five planes covering the part from different directions could be used for projection. This would require implementing conditions in the script to avoid mesh crossings. When testing the Projection technique in this project, the stitching was done manually when creating the Front Bumper mesh.

Another problem faced during the actual projection was that some surfaces were shaded from the projection. By using a half sphere as presented in the pre-study results, it would be possible to reach more of the part surface. The problem when projecting with a half sphere is that Projection nodes can get crossed, which the current script would not handle. It is however considered to be a feasible solution, although in need of further development.

6.2.2 IMPROVED PROJECTION TECHNIQUE FOR FRONT BUMPER

As the Front Bumper had a more complex shape, the Projection model was more difficult to create than the other models. Thus, the first model that was made had some issues that the team decided to solve by creating an improved model. This model did on one hand require more manual work in order to simulate the finished result, which might be harder to automatize. On the other hand, the manual improvements that were performed were made in a way that theoretically could have been automated, e.g. by making the projections from different angles automated. The following sections will discuss in what way the Improved Projection technique made the simulation results both better and worse than the original Projection technique.

From the offset simulation results in Table 9, it can be seen that in most cases the Improved Projection technique gave more confident simulation output than its predecessor. One main reason is that the Improved Projection model had no spikes.

Creating the Improved Projection model included removing small holes and improving the rigidness by further include top and bottom projection of the model. The improved model were in most cases closer to the reference values than before the improvement. It was though hard to actually associate these improvements to measurement values, i.e. in what specific way the improvements affected the results. Nevertheless, the improved model had more of the geometrical properties of the Reference model and with filled holes a greater stiffness.

As the spikes were removed it can be observed that the measured offsets caused by locator 17(Z) (seen in Appendix IV) were closer to the reference model compared to the original Projection Front Bumper.

The meshed model created with Improved Projection technique did not always perform better than the original Projection model. The observed phenomena showed an increase of the maximum deviation from the Reference model. It has not been feasible to identify the specific factor behind these effects, although educated guesses could be made.

First of all, the improved model has no small holes, which absorbs stress concentrations. Secondly it still has many spots that are weaker than the Reference model, while it is mostly stiffer than the Projection model. As a result, a locator displacement can make a concentrated deformation on weaker spots. The biggest displacements are found in the outer edges of the Front Bumper. The part structure has a weak spot between outer edges and the middle as seen in Figure 30. Due to its stronger properties compared to the original Projection model, more force could have been concentrated on its weaker spots, driving the outer edges to a large displacement.

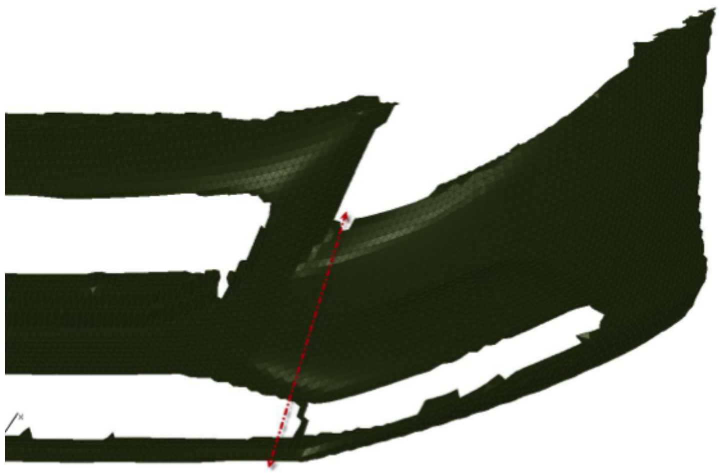

Figure 30 - Showing the improved front Fender. The red arrow shows the area of its weak spot to causing the outer part of the housing to bend.

It can also be discussed whether it would be feasible to try including the reinforcement parts in the model by creating a mesh for them as well. It was chosen not to use reinforced parts for any of the simplified models as to both compare the effects of the simplification while not actually make them more complicated. Additionally, the fact that GSU are commonly working with parts that does not have any kind of reinforcements was a reason for not including the reinforcement parts, not even for the improved Front Bumper model.

6.2.3 FUTURE POSSIBILITIES OF THE PROJECTION TECHNIQUE

The Projection technique could be developed so that projecting from different directions could be performed automatically: either by using different planes and repairing subsequent gaps in the mesh, or developing the idea of projecting from the inside of a spherical surface. This would likely require an extensive mathematical work to fully solve. As the solution in general shows good results it could be worth making an effort to develop it further.

6.3 CONTOUR MESH AS A SOLUTION

The Contour mesh model was one of the most novel solutions as the experiment evaluation started. The simulations however, presented results that were not completely satisfying. On one hand, however, the values of the contour mesh were regularly better than both of the Alternative Assemblies solutions; while on the other hand the maximum errors were quite substantial.

6.3.1 PROBLEMS IDENTIFIED IN THE CONTOUR MESH

Having in mind that the offset simulation results are average and maximum values of the raw data average and maximum values, it is necessary to examine the average values and raw data to understand what is causing the high maximum values. The average and maximum tables (Table 8-9 in Chapter 5) show that there are a few simulations causing the increase.

Table 9 and Table 10 showed an average close to 13 millimetres, and a maximum close to 45 millimetres. These values are from the same simulation and that error was, as the maximum value shows, extreme. It was not only one big offset value, but rather the entire model was to blame. The visual result of the simulation can be seen in Figure 31.

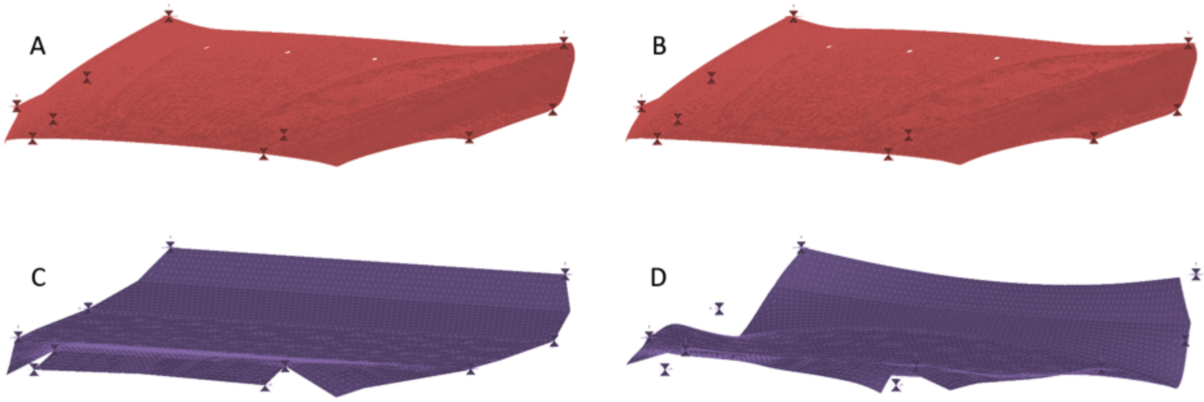

Figure 31 - Comparison of no-reinforcement and Contour Offset Animation.

Figure 31 A and B show the barely noticeable difference that should be taking place due to the offset in 1(Y) (see locators in Appendix VIII). However, using the Contour model, there is a force parallel to the plane direction causing the part to its odd behaviour, seen in Figure 31 D. The 1(Y) offset in the Bonnet thus show one of the largest deficiencies using the Contour technique.

Looking at the tables in the Variation Simulation Result Summary chapter, they show that the Contour mesh generally delivers less accurate results doing variation simulations than offset simulations.

Not only the simulation results but also the creation of the model is an important factor to analyse. Important when comparing the techniques is the level of automation. Unfortunately it is not yet possible to automate the contour mesh technique. The problem lies in creation of surfaces from nodes, which are made from lines between the nodes. It is not possible with ANSA to automatically create such lines between the points. They had to be manually created by the user, both to cover the contour and also the interior of the part to make adequate surfaces. Thus, it has not been possible to fully test the level of automation for this technique, although the manual steps simulates the process and gives a better understanding of what is required to further develop the automation. Ideas for further development will be described in the following section.

6.3.2 FUTURE POSSIBILITIES AND IMPROVEMENTS OF THE CONTOUR MESH

The simulated Contour technique mesh results show that the technique generally generates a better result than both of the Alternative Assembly solutions. However, this is based on the difference being absolute and not sign dependent. The extreme maximum values also make the technique rather unpredictable.

The extreme deformations from 1(Y) disturbance however, could be prevented using some of the surface structure of the Bonnet instead of a straight plane. This could generate a better result than the Alternative Assembly, but the Contour solution would in that case start to intersect with the Projection technique. If the Contour technique uses a projection to be more accurate, it is also questionable if the savings of the computer capacity is worth the accuracy compared to the seemingly reliable Projection technique.

6.4 AUTO-AA AS A SOLUTION

This section will discuss the feasibility of Alternative Assembly technique and its remaining issues to be solved.

6.4.1 PROBLEMS IDENTIFIED IN AUTO-AA

The Auto-AA seems to be the technique that is easiest to develop and implement, as it is a derivative from the existing solution Alternative Assembly. The script works well to automatically generate assemblies for the Fender and the Bonnet, which are virtually flat parts. It is, however, more complicated for non-flat parts, like the Front Bumper. As the part has no primary planes, the algorithm for making Alternative Assemblies becomes more complicated. There is currently no clear way to determine which directions to be used for the plane, line and point for every 3-2-1 positioning system. An algorithm to solve this has empirically showed that it can create a functioning positioning system for the Front Bumper (as shown in Appendix VII). The algorithm has however not been tested to determine whether it works for other kinds of non-flat parts.

Further, the confidence among the measurement results differed between the models. Auto-AA generally got an average result close to the GSU-AA. Looking at the raw data however, the data is far from close in every

measurement. Instead they vary a lot, which makes it hard to evaluate the correctness of the technique, compared to the GSU-AA.

6.4.2 IMPROVEMENTS OF THE AUTO-AA

It is important to emphasise that the Auto-AA-algorithm used in this thesis is very simple. As the Auto-AA algorithm is neither based on any mathematical evidence nor broader empirical studies there is much room for development. It is probably possible to get an improved result, perhaps even a result that is several per cent better than the GSU-AA. Besides the possibility to get a better result, an automated Alternative Assembly could likely reduce modelling time significantly.

7 CONCLUSION

In total, 6 techniques has been identified and evaluated. How thoroughly they have been examined was dependent on their feasibility. Among the techniques, one has been found as the most promising for the purpose of GSU's work. That is the Projection technique. It is considered relatively easy to implement in RD&T, it reduces preparation time compared to current solution, shows non-rigid behaviour and generally generated the simulation results closest to the Reference models, among the tested techniques.

It has been seen that the time required for the computer to perform variation simulations was an important factor as it differed a lot among the techniques. It can firstly be concluded that much computation time is saved using the Projection technique, compared to the Reference. Secondly, the confidence difference compared to GSU-AA was significant. Finally, the authors are convinced that total time usage with the Projection technique is shorter than for ordinary Alternative Assemblies, due to the supposed short modelling times.

By automating the current Alternative Assemblies manual selection process, modelling times would probably decrease significantly. Even though the simulation confidence generated from the Auto-AA often was lower than the GSU-AA, an improved algorithm for generating the assemblies would probably have some potential. The decreased modelling time would also enable more time for analysis of the automated systems and the result. There are no guaranties that it will be fully possible to automatically create meshes for all type of non-rigid parts. Thus a way to reduce simulation time for Alternative Assemblies would still be of interest.

To sum up, the team sees most potential in the Projection technique and thus recommend focusing on the development of this solution. This would provide a FEM solution for a target group that today uses other rigid simulation methods, both because of lacking input data as well as shortage of time. The final result does not have as high confidence as a detailed FEM model, but in the GSU case it would offer the possibility to perform non-rigid simulations and likely decrease total modelling and simulation times. It is important to remember that a mesh does not need to be more detailed than what is necessary for an adequate result.

8 SUGGESTIONS

In the research area of variation simulation, studies have been made primary to increase simulation confidence rather than simplify the work. Thus, the study made in this project is based on many principles that have not been tested previously. Although there have been many findings through the completed researches and experiments, there is still much more to do; both to further develop suggested techniques as well as further test their properties. This chapter will cover areas that were not tested in the scope of this project, but still are considered important and therefore suggested for further development.

8.1 EXTENDING THE STUDY

The components used in this study did only represent a limited number of parts that could benefit from non-rigid simulation on the car. Thus, there is a need for more simulations on diverse types of parts to get a better understanding of the techniques and their areas of usability.

A deeper analysis concerning phenomena that arise during the simulation is also recommended. Although several differences have been identified between the models and techniques, even more can be analysed to better understand the cause and effects. For example, it has been noticed that the Improved Projection of the Front Bumper shows measurement results of higher confidence than the original Projection. As to fully relate improvements and new measurement results, improvement could be implemented one at a time, with a new simulation for every improvement. Thus, cause and effect could be coupled to understand how adjustments on the models affect the result.

8.2 IMPROVING THE TECHNIQUES

The team recommend to improve both the Projection technique and the Auto-AA technique.

The Projection technique must be able to automatically cover different sides of a part, to enable meshing of parts with diverse geometry. Possible ways to do that would be to use meshed planes from different directions or a meshed half sphere projected against the model. To do so, it is important that the meshes do not overlap. Further, it is important to develop the algorithm so that the nodes adapt to only one measurement point or locator.

The algorithm to generate Auto-AA systems could be further developed striving to increase confidence on the simulation results. Trying different algorithms that creates positioning systems in a similar way as how GSU creates Alternative Assemblies could do this.

Finally the team suggest an improvement in RD&T as to generally reduce simulation time for compliant models, no matter what kind of mesh that is used. When simulating compliant parts assembled to rigid parts, using Alternative Assemblies, the simulation of non-rigid parts has to be done for every assembly. A more convenient way to do that kind of simulation would be to let the compliant parts be simulated independently from the different assemblies.

8.3 MEASURING PREPARATION TIME

It has been hard to evaluate how much time and effort that will be required in total from the user to accomplish a full simulation cycle. The reason for that is because the techniques are not yet developed to fully represent their intended functional level and a user study would also require an extensive work.

The authors recommend a further development of techniques, like implementing the early prototypes in RD&T, before such user studies are made. Thus, to better be able to quantify the amount of time and manual work required.

9 REFERENCES

Beall, M. W., Walsh, J., & Shephard, M. S. (2003, September). Accessing CAD Geometry for Mesh Generation. IMR, pp. 33-42.

BETA CAE Systems S.A., (24 December 2012). Release Announcement ANSA / μETA v14.0.0 [online] Available at: <http://www.beta-cae.gr/news/20121224_announcement_ansa_meta_v14.0.0.htm> [Accessed 2 May 2013].

Borodin, P., Novotni, M. & Klein R., (2002). Progressive Gap Closing for Mesh Repairing. Advances in Modelling, Animation and Rendering, pp. 201-213

Bosmans, I., Brughmans, M., Brizzi, P. , Shiozaki, H., & Yanase, J. (2005). Application of morphing in concept phase of vehicle development. In Proc. 2005 JSAE Annual Congress pp. 19-22.

Chong, C. S., Kumar, A. S. & Lee, H. P., (2007.) Automatic mesh-healing technique for model repair and finite element model generation. Finite Elements in Analysis and Design, Volume 43, Issue 15, pp. 1109–1119.

Dahlström, S., Lindkvist, L., & Söderberg, R. (2005). Practical Implications in Tolerance Analysis of Sheet Metal Assemblies. In 9th CIRP Seminar on Computer-Aided Tolerancing, April 10-12, 2005, Tempe, Arizona, USA.

Dunn, W. L. & Shultis, J. K., (2011), Exploring Monte Carlo Methods, Elsevier Science.

Evans, E. H. (1974). Statistical tolerancing: the state of the art. Journal of Quality Technology, 6(4), 188-195.

Forslund, K., Wagersten, O., Tafuri, S., Segerdahl, D. Carlsson, J., Lindkvist, L. and Söderberg, R., (2011), Parameters Influencing the Perception of Geometrical Deviations in a Virtual Environment, Proceedings of the ASME 2011 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, August 28-31, Washington DC, 9 pp. 1105-1114.

Frey, P., & George, P. L. (2010). Mesh generation (Vol. 32). John Wiley & Sons

Gentle, J. E., (1998), Random Number Generation and Monte Carlo Methods (Statistics and Computing), Springer Verlag.

Grahn, H., Volk, T. & Wolters, H. J., (2000), 'NURBS in VRML', VRML '00 Proceedings of the fifth symposium on Virtual reality modelling language, pp. 35-43.

Hughes, T. J., Cottrell, J. A., & Bazilevs, Y. (2005). Isogeometric analysis: CAD, finite elements, NURBS, exact geometry and mesh refinement. Computer methods in applied mechanics and engineering, 194(39), 4135-4195.

Hågeryd, L., Björklund, S., & Lenner, M. (2002). Modern produktionsteknik del 1. Liber AB.

Kothari, C. R. (2004). Research methodology: methods and techniques. New Age International.

Lazarus, F., & Verroust, A. (1998). Three-dimensional metamorphosis: a survey. The Visual Computer, 14(8), 373-389.

Liu, G. R., & Quek, S. S., (2003). Finite Element Method: A Practical Course: A Practical Course. Butterworth-Heinemann, Oxford.

Liu, G. R., (2003). Mesh-free methods: moving beyond the finite element method. Florida: CRC Press LLC.

Petersson, V., (2007). An Implementation of Mesh Free Methods for Mechanical Problems at Large Strains. MSc. Thesis, Lund University.

Lorin, S., Forslund, K., & Söderberg, R. (2010). Investigating the Role of Simulation for Robust Plastic Design. In Proceedings of NordDesign2010 International Conference on Methods and Tools for Product and Production Development, Vol. 1, pp. 185-194.

Frey, P., & George, P. L. (2010). Mesh generation (Vol. 32). John Wiley & Sons.

Piret, C., Remacle, J. F., & Marchandise, E. (2012). Mesh and CAD Repair Based on Parametrizations with Radial Basis Functions. In Proceedings of the 20th International Meshing Roundtable, pp. 419-436. Springer Berlin Heidelberg.

Qin, G. H., Zhang, W. H., & Wan, M. (2006). A mathematical approach to analysis and optimal design of a fixture locating scheme. The International Journal of Advanced Manufacturing Technology, 29(3-4), 349-359.

RD&T Technology (2013), Robustness evaluation and tolerance analysis - Software manual, Mölndal, Sweden.

RD&T Technology, (2013b) Increasing amount of decisions must be taken early, based on digital models. RD&T is the Tool. [online] Available at: <www.rdnt.se/tool.html> [Accessed 10 April 2013].

Siemens, (2012). Siemens' JT Data Format Accepted as the World's First ISO International Standard for Viewing and Sharing Lightweight 3D Product Information. [press release] December 17, 2012. Available at: <http://www.plm.automation.siemens.com/en_us/about_us/newsroom/press/press_release.cfm?Component=205727&ComponentTemplate=822 > [Accessed 23 August 2013].

Söderberg, R., Lindkvist, L., & Dahlström, S. (2006). Computer-aided robustness analysis for compliant assemblies. Journal of Engineering Design,17(5), 411-428.

Ulrich & Eppinger (2012), Product Design and Development, pp. 154-158, McGraw-Hill

Wagersten, O. (2011). Towards Efficient Evaluation of Impacts of Geometrical Variation on Perceived Quality in Early Phases. Licentiate thesis, Chalmers University of Technology, Gothenburg, Sweden

Wagersten, O., Wickman, C., Lindkvist, L., & Söderberg, R., (2013). Towards non-FEA-based deformation methods for evaluating perceived quality of split-lines. Journal of Engineering Design, (ahead-of-print), 1-17.

White, D. R., Saigal, S. & Owen, S. J., (2005). Meshing complexity: predicting meshing difficulty for single part CAD models. Engineering with Computers, 2005:21 pp. 76-90.

Zhao, Y., Ong, H. Y., Tan, T. S., & Xiao, Y. (2003, July). Interactive control of component-based morphing. In Proceedings of the 2003 ACM SIGGRAPH/Eurographics symposium on Computer animation, pp. 339-348. Eurographics Association.

APPENDIX I - VISIT TO C-SHOP, VOLVO TORSLANDA

2013-06-24, Visit to C-shop

On Wednesday the 26th of June, the team visited the Torslanda plant in order to examine the behaviour of the physical components previously simulated in the computer and study how these parts where mounted onto the car. The components in question are the Bonnet, Fender and Front Bumper.

As the Y555-model (V40) is assembled in Gent, other models with similar components and equivalent mountings were observed. The cars assembled in the C-shop at Torslanda are among others S60 and the V60. Comparing to the V40, the updated S60 model has similar mountings on the upper rim of the Front Bumper. This particular mounting is an update to the original S60 Front Bumper, used to address an issue of uneven flush on the Front Bumpers wings; the use of screws instead of the usual bolts in the outer edges of the rim now enables after adjustments of the Front Bumper. A V60 was used for the examination of the Bonnet and Fender. The V60 in question was disassembled to a rather large extent and placed in a corner of the plant where the examination would not disturb the production, which also enabled a more comprehensive evaluation of these parts. Some observations also included the V60 Front Bumper, which was fully dismounted.

The study of the parts did not only confirm some of the behaviours that was previously expected from the simulations, but also generated questions and some general understanding for how the parts behave. One of the more expected observations was the difference in stiffness between the three components; the Bonnet is quite large and welded together from two rather thick metal sheets with a lot of structure in their geometry, thus a very rigid part. The Fender is also constructed out of metal, but consists mainly of one pressed metal sheet, making it less stiff than the Bonnet. Finally, the Front Bumper is injection moulded in a plastic material. Although the component consists of a large number of parts, ranging from electronics (such as sensors, wires and lamps) to plastic reinforcements (mainly used to stabilise and fixate the part), the Front Bumper is unmistakably non-rigid. In addition to its lightweight, it bends very easily, thus requiring a large amount of fixing points. The stiffness is of course related to the number of attachment points available for the component in question. For instance, the Bonnet can only have around four fixed points as it is hinged, thus it needs to be very rigid.

However, the stiffness impact on the simulation is important to consider when evaluating the methods, as the behaviour of the parts differ as much as they do. The fact that it takes more force to bend the stiff Bonnet 3 millimetres compared to bending a less stiff component the same distance should not matter, as the force needed to make the requested deflection is calculated and applied.

The visit also clarified the impact that gravity has on the parts. For instance, the team was told how the V40 Front Bumper fell inwards due to its own weight and how this required additional measures before production.

During the examination of the disassembled V60 some especially interesting observations was later tested in RD&T in order to validate the behaviour of the model. The most explicit was the rotation of the Fender along the wheel arch; as the lower Fender only was mounted with one bolt at the rear and the radiator support brace only was mounted with one bolt in the front, a pull at one end of the arch resulted in a movement in the opposite direction at the other end.

In order to verify the Fender computer model, an offset to the front of the arch was simulated. The result however showed that a positive offset in the front led to a positive result in the rear and vice versa, which was not coherent to the behaviour of the physical test. Thus an analysis of the result was conducted in order to find an explanation to the deviation of the result. One of the differences between the physical model and the simulation was the positioning of the reference points as the RD&T model is constructed according to the positioning scheme from GSU, not the actual mountings. Thus, a new test was constructed with updated reference points, consistent with the physical model.

The result from the new test corresponded to the witnessed behaviour at the C-shop, indicating the great relevance of the positioning of the reference points. The difference in behaviour between the two models was extensive; even though the reference points positions was only moved a few centimetres.

Conclusions made:

Stiffness among the components:

The differences in stiffness were surprisingly high. The Bonnet was the stiffest part, supported by its reinforcements. The Fender was less stiff, lacking reinforcements when assembled. The most compliant part, by far, was the Front Bumper, made in plastic. The stiffness does not affect the results however, according theoretical calculations in RD&T.

Own weight:

The own weight could be an important factor to consider. It is not considered in simulations made today, which eventually could be a factor that makes simulated models deviate from the actual produced products.

Fender phenomena:

The Fender did behave in a way hard to predict intuitively when subjected to external forces. Thus, a compliant simulation with accurate locators is needed to tell these phenomena.

APPENDIX II - ABOUT THE SELECTION MATRIX

A selection matrix was created and an analysis has been conducted, as a way to evaluate techniques from the pre-study and create a basis for elimination of less promising concepts. The data gathered for this evaluation is based on a literature review conducted over several weeks, thus only basic testing has been performed in order to verify the teams assumptions. This however, was to be seen sufficient for a first stage gate, in order to make the research more focused.

The concepts were scored using 1 to 5, against seven weighted criteria, were 5 was the best score. The criteria were weighted using a percentage and the total sum of the weights was 100 per cent. One of the techniques was chosen as a reference in the scoring, and thus all its values were set to three. If a technique was better it retrieved a higher score and vice versa. In this selection matrix, the Automatic Mesh Generation was used as a reference. The criteria were divided into two main groups; development possibilities and user related. The different criteria were of a general approach, mirroring most important requirements stated in the pre-study work.

The category development possibility includes: short development time, implementation feasibility in RD&T, unexplored and evaluation possibility. These criteria are described below.

The criterion short development time is the estimated time until the technique can be fully implemented in RD&T and be used by the end user. Naturally the sooner the better, but this criterion is not of biggest concern. Available techniques do work well today, even though a high performing technique is desirable in the future. Evaluation is based on how complicated the techniques are assumed to be and how big the gap is between what is available today and what more research that is required.

A constraint for this work is that the technique can be implemented into RD&T, possibly with automated support from external software. The techniques were evaluated from what currently is possible to do is RD&T and what more is feasible to implement in RD&T, according to Lars Lindkvist, head of programming the software. Implementation feasibility does not only reflect development time but also the confidence. A technique that does not fit the way RD&T is structured might result in bugs and false simulation data.

Unexplored is considered as something positive, controversy to the fact it might increase implementation time. Though, a big leap in science might be necessary to meet tough requirements in long-term future. With new research areas the research will also be of bigger interest in a scientific point of view. Not necessarily must completely new techniques be harder to implement even though it is likely.

Evaluation possibility concerns how easy it is to simulate a technique in order to make a fair evaluation. For e.g. the Mesh-free technique, the team were unable to simulate a simple test and thus the evaluation possibilities were insignificant.

The category user related includes: measurement confidence, level of automation and simulation time. These are together the most important criteria necessary for the user to perform the work. These are shortly described below.

Measurement confidence is one of the most important criterion, as this is the main aspect that affecting the deliverable from the end user. This is based on assumption that FEM with a high quality mesh generates the best result. The closer a technique is to high quality mesh, the higher is the assumed confidence.

Level of automation is how much work that can be done automatically in the computer minimizing the manual effort from the user. This is based on assumption of how many steps of preparation required before simulation can be performed.

Simulation time is how much time the computer takes to simulate. A complicated mesh will require more time than a rigid model. Assumed required simulation time is based on how much simplification is done for simulation.

Based on the selection matrix concepts that have qualified for further testing are Auto-AA, Auto-Mesh, Projection and Contour. Although the criteria are not weighted, their importance has been considered as to not choose a concept only scoring high on criteria of less importance.

Score-wise Auto-AA is a winner. Mostly because of its simplicity as it is a derivative of flex positioning that is an existing solution. Unfortunately this technique is lacking in simulation confidence, as it is a linear approximation.

Ranked second is Projection. This technique is more advanced, which results in longer development time, but is then interesting from a science perspective. Of the top scoring concepts this technique is assumed to have best confidence as it simulates with a tolerable mesh that according early testing works well.

The Contour is ranked third according to scoring and will be included for further evaluation as well. This technique is especially interesting from the criterion unexplored as no other technique similar to this one has been found. As this technique is a big simplification of meshing, it is uncertain if this can be used for simulating with enough confidence, hence low ranking on the measurement confidence.

The remaining techniques, Automatic Mesh Generation, Morphing and Mesh-free, will not be included for further evaluation. The primary reason for low ranking of the excluded techniques was that they were considered unfeasible to implement and test in the scope of this project. They are on the other hand not excluded as potential techniques recommended for future work.

Table 1– Evaluation Matrix showing how the different concepts were rated.

		Concept											
		Automatic Alternative Assemblies		**(Reference) Automatic Mesh Generation**		**Morphing**		**Meshfree Analysis**		**Projected Mesh Generation**		**Contour Mesh Generation**	
Selection Criteria: the development	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Short Development Time *	15%	5	0,75	3	0,45	2	0,3	1	0,15	4	0,6	3	0,45
Possibility to Implement in RD&T **	5%	5	0,25	3	0,15	3	0,15	1	0,05	4	0,2	3	0,15
Unexplored	10%	4	0,4	3	0,3	3	0,3	3	0,3	5	0,5	5	0,5
Evaluation Possibility *	20%	2	0,4	3	0,6	1	0,2	1	0,2	3	0,6	3	0,6
Selection Criteria: the user													
Level of Confidence *	20%	3	0,6	3	0,6	1	0,2	5	1	4	0,8	2	0,4
Level of Automation *	15%	4	0,6	3	0,45	3	0,45	4	0,6	3	0,45	4	0,6
Short Simulation Time *	15%	5	0,75	3	0,45	4	0,6	2	0,3	3	0,45	5	0,75
	Total Score	**3,75**		**3**		**2,2**		**2,6**		**3,6**		**3,45**	
	Rank	1		4		6		5		2		3	
	Continue?	Develop		No		No		No		Develop		Develop	

*) Presumed value, based on pre-study

**) According to developers at RD&T Technologies

APPENDIX III - MONTE CARLO CONVERGENCE

Data from three measurement points in the Front Bumper Auto-AA variation simulations has been extracted and compiled in Table 1 and visualized in Figure 1. A two-millimetre range was used in the model and this comparison showed how the 8sigma value in each measurement converged with the number of iterations.

Table 1 – A compilation of data from five variation simulations, using different numbers of Monte Carlo iterations.

Monte Carlo comparison, using 2mm tol. Range

	FE005 Flush 1	**FE005 Flush 2**	**FE005 Gap 1**
100 variations	2.77	3.04	2.12
1 000 variations	2.72	2.95	2.18
3 000 variations	2.69	2.94	2.18
5 000 variations	2.69	2.96	2.17
10 000 variations	2.68	2.96	2.17

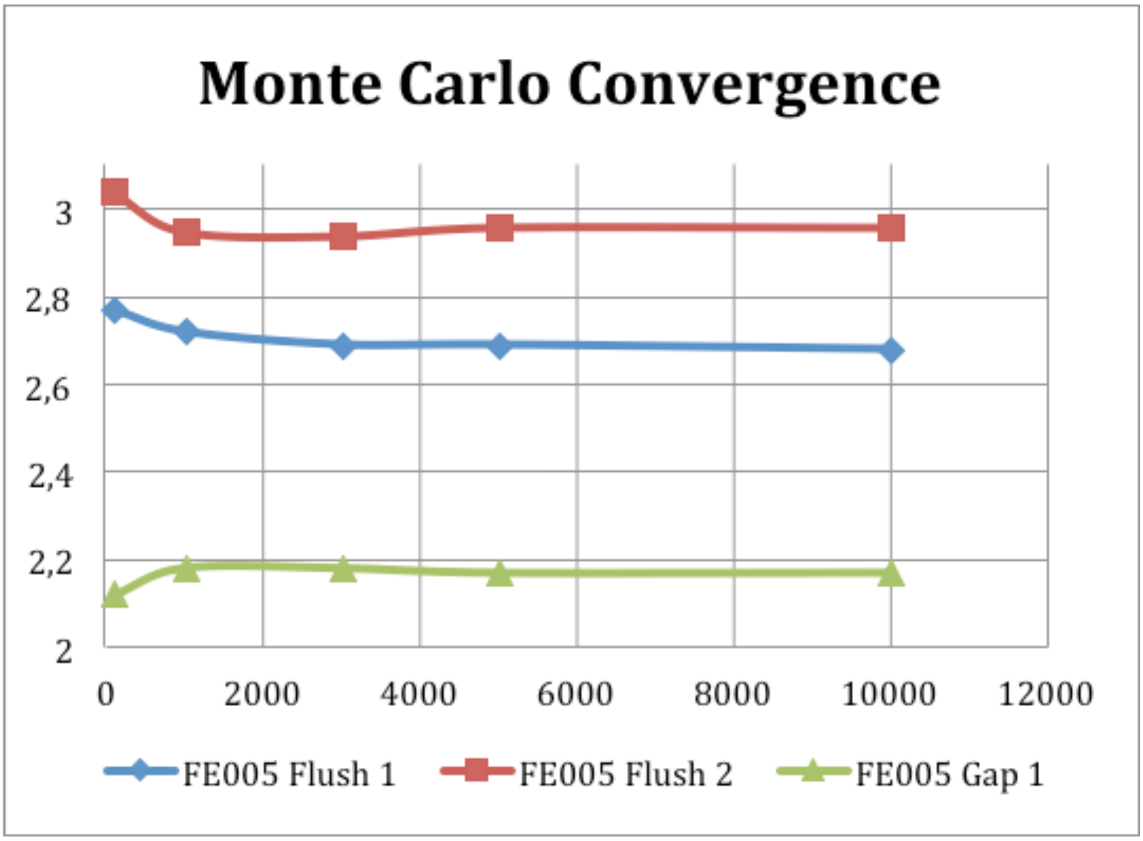

Figure 1 – Graph describing the convergence of the numbers in Table 1.

APPENDIX IV - RAW DATA RESULTS

This appendix contains all raw data that is collected from the variation simulation and offset simulation for the Bonnet, Fender and Front Bumper respectively.

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Bonnet Variation Simulations Results, 10k

Name	Reference	Comparison	Projection	Contour	Auto-AA	GSU-AA
FE005 Flush 1 LHS	1,73	2,91	2,68	11	2,01	2,16
FE005 Flush 2 Y0	1,64	3,23	2,81	3,42	1,67	1,46
FE005 Flush 3 RHS	1,43	2,95	2,71	15,8	2,05	2,24
FE005 Gap 1 LHS	1,7	2,18	2,13	12,7	1,89	2,18
FE005 Gap 2 Y0	0,744	1,53	1,53	2,25	1,48	1,45
FE005 Gap 3 RHS	1,55	1,82	1,79	8,95	1,77	2,33
FE215 Flush 1 RHS	1,74	2,88	2,65	5,87	1,71	2,08
FE215 Flush 2 RHS	2,14	2,2	2,61	1,93	1,95	2
FE215 Gap 1 LHS	1,17	1,93	1,9	16,9	2,18	2,84
FE215 Gap 1 RHS	1,17	1,93	1,9	16,4	2,15	2,85
FE215 Gap 2 LHS	0,756	2,07	2,08	19,4	2,17	2,36
FE215 Gap 2 RHS	0,886	2,06	2,07	20	2,15	2,37
FE510 Flush 1 LHS	1,54	1,99	1,95	4,39	1,71	1,94
FE510 Flush 1 RHS	1,75	2	1,95	2,46	1,69	1,95
FE510 Flush 2 LHS	2,01	2,87	2,85	13,7	1,83	2,01
FE510 Flush 2 RHS	2,6	2,84	2,81	9,8	1,83	2,01
FE510 Gap 1 LHS	1,01	1,82	1,77	9,83	2,11	1,55
FE510 Gap 1 RHS	1,32	1,81	1,77	10,4	2,09	1,53
FE510 Gap 2 LHS	0,122	2	1,99	3,89	2,03	1,87
FE510 Gap 2 RHS	1,98	2,01	2	3,77	1,99	1,89
FE515 Flush 1 LHS	1,29	2,41	2,38	10,9	2,34	3,3
FE515 Flush 1 RHS	1,96	2,35	2,34	11,9	2,31	3,32
FE515 Flush 2 LHS	2,51	2,66	2,65	8,99	2,94	2,24
FE515 Flush 2 RHS	2,53	2,71	2,7	8,04	3,01	2,29
FE515 Gap 1 LHS	1,72	2,63	2,61	20	2,75	2,07
FE515 Gap 1 RHS	1,75	2,65	2,63	21	2,78	2,08
FE515 Gap 2 LHS	1,26	3,09	3,1	42,6	3,24	4,4
FE515 Gap 2 RHS	1,07	3,01	3,03	35,5	3,09	4,28

Fender Variation Simulation Results, 10k

Name	Reference	Projection	Contour	Auto-AA	GSU-AA
FE405 Flush 1	1,78	1,82	2,42	1,76	2,04
FE405 Flush 2	2,57	2,47	2,83	2,63	2,42
FE405 Gap 1	1,63	1,38	1,57	1,82	1,79
FE405 Gap 2	2,09	1,97	2,28	2,2	2,09
FE415 Alignment	3,18	3,32	3,95	3,27	2,46
FE420 Alignment	2,04	1,72	2,37	2,51	2,12
FE510 Flush 1	1,38	4,28	1,69	1,5	1,77
FE510 Flush 2	1,29	1,24	2,4	1,8	1,42
FE510 Gap 1	1,28	1,5	1,47	1,47	1,72
FE510 Gap 2	1,52	1,33	1,52	2,2	1,46
FE515 Flush 1	2,97	3,18	3,2	3,59	1,68
FE515 Flush 2	4,81	4,19	4,49	2,76	2,02
FE515 Gap 1	1,68	1,69	1,83	3,55	1,84
FE515 Gap 2	2,13	2,23	2,21	5,74	2,2
FE610 Flush 1	3,79	3,67	6,91	4,05	2,29
FE610 Flush 2	3,63	3,73	7,36	7,77	2,34
FE610 Gap 1	1,73	1,79	1,82	5,51	2,27
FE610 Gap 2	1,89	1,97	2,24	5,42	2,36
Kjell 2 a-st list	3,29	3,43	6,48	7,48	2,31
Kjell Z A-list	3,22	3,16	3,61	3,4	2,05
SD105 Flush 1	2,16	2,14	2,27	2,36	2
SD105 Flush 2	2,04	2,38	2,54	4,52	1,89
SD105 Gap 1	2,02	2,06	2,09	3,46	1,98
SD105 Gap 2	1,82	1,79	1,76	2,07	1,84
Wheelarch 30	1,65	1,75	5,63	1,81	1,81
Wheelarch 50	4,94	6,14	11,5	1,47	1,25

Front Bumper Variation Simulations Results, 10k

Name	Reference	Comparison	Projection	Contour	Auto-AA	GSU-AA
FE005 Flush 1	3,15	3,18	3,09	2,78	2,68	2,05
FE005 Flush 2	2,05	1,99	1,84	2,27	2,96	0,6
FE005 Flush 3	3,35	3,34	2,42	2,78	2,81	2,04
FE005 Gap 1	2,67	2,21	1,56	1,97	2,17	0,723
FE005 Gap 2	1,39	1,16	1,22	4,65	2,73	1,26
FE005 Gap 3	2,74	1,82	1,04	1,98	2,12	0,72
FE225 Flush 1	3,79	3,79	2,78	3,14	3,1	1,92
FE225 Gap 1	3,12	2,69	1,34	1,49	2,84	1,48
FE225 Gap 2	1,68	1,63	1,51	1,65	2,29	2,22
FE225 INV Flush 1	3,55	3,59	3,81	3,18	2,93	2,03
FE225 INV Gap 1	2,9	1,95	1,53	1,54	2,8	1,48
FE225 INV Gap 2	1,56	2,66	1,59	1,7	2,29	1,91
FE230 Flush 1	2,09	2,41	5,88	17,4	1,89	2
FE230 Gap 1	1,96	1,47	2,27	3,65	1,63	2,43
FE230 Gap 2	2,22	0,549	0,866	0,885	2,36	3,35
FE230 INV Flush 1	2,23	2,49	5,69	12,8	1,89	1,98
FE230 INV Gap 1	1,64	1,46	2,21	3,06	1,62	2,44
FE230 INV Gap 2	2,09	2,17	2,67	1,08	2,03	3,33
FE405 Flush 2	2,68	2,57	6,35	6,64	2,06	6,7
FE405 Flush1	1,91	1,95	1,96	1,95	2,01	2,08
FE405 Gap 1	1,92	2,2	1,9	2,91	3,7	3,76
FE405 Gap 2	1,47	1,72	1,85	1,9	2,58	3,09
FE405 INV Flush1	1,91	1,95	1,96	1,95	2	2,06
FE405 INV Flush2	2,62	2,52	5,97	9,61	2,05	2,83
FE405 INV Gap 1	1,88	1,97	1,88	2,8	3,62	3,68
FE405 INV Gap 2	1,65	1,66	1,73	2,04	2,57	2,47
FE420 Align B2F	2,06	2,11	2,47	2,53	2,88	3,21
FE420 INV Align	2,01	2,06	2,5	2,38	3,12	3,05

Bonnet - Auto-AA, Offset Measurement Results [mm]

	1(Y)	4(Z)	6(Z)	8(Z)	4(Z)+6(Z)	4(Z)-6(Z)	4(Z)-7(Z)	5(Z)+6(Z)	5(Z)-6(Z)
FE005 FLUSH 1 LHS	-2,3287	0,0000	0,8279	0,4273	0,8279	-0,8115	0,2409	0,8279	-0,8115
FE005 FLUSH 2	0,0008	0,0000	1,1976	0,0000	1,1976	-1,1975	0,4376	3,1465	0,7513
FE005 FLUSH 3 RHS	0,0000	-0,2465	0,0000	0,0000	-0,2465	-0,2465	-0,2465	0,8251	0,8251
FE005 GAP 1 LHS	-0,1808	0,0000	-2,0798	-0,5862	-2,0798	2,0808	-0,1682	-2,0798	2,0808
FE005 GAP 2	-0,0157	0,0000	-0,5072	0,0000	-0,5072	0,5073	-0,2500	-1,4454	-0,4311
FE005 GAP 3 RHS	0,0000	0,1518	0,0000	0,0000	0,1518	0,1518	0,1518	-2,1476	-2,1476
FE215 FLUSH 1 RHS	0,0000	-0,2260	0,0000	0,0000	-0,2260	-0,2260	-0,2260	1,4842	1,4842
FE215 FLUSH 2 RHS	0,0000	0,0000	0,0000	-0,0551	0,0000	0,0000	0,0000	0,1209	0,1209
FE215 GAP 1 LHS	2,3323	0,0000	1,2974	0,4183	1,2974	-1,3101	0,0034	1,2974	-1,3101
FE215 GAP 1 RHS	0,0000	-0,0077	0,0000	0,0000	-0,0077	-0,0077	-0,0077	1,3383	1,3383
FE215 GAP 2 LHS	1,6292	0,0000	0,1998	0,7994	0,1998	-0,2230	0,0000	0,1998	-0,2230
FE215 GAP 2 RHS	0,0000	0,0000	0,0000	-0,0010	0,0000	0,0000	0,0000	0,2126	0,2126
FE510 FLUSH 1 LHS	-1,1410	0,7424	0,0000	2,0948	0,7424	0,7424	0,7424	0,0000	0,0000
FE510 FLUSH 1 RHS	0,0000	0,0000	0,0000	-0,1056	0,0000	0,0000	-0,7390	0,0000	0,0000
FE510 FLUSH 2 LHS	-1,2935	2,2452	0,0000	0,6367	2,2452	2,2452	2,2452	0,0000	0,0000
FE510 FLUSH 2 RHS	0,0000	0,0000	0,0000	-0,1860	0,0000	0,0000	-2,2611	0,0000	0,0000
FE510 GAP 1 LHS	-2,8332	-0,2505	0,0000	-0,7113	-0,2505	-0,2505	-0,2505	0,0000	0,0000
FE510 GAP 1 RHS	0,0000	0,0000	0,0000	-0,0261	0,0000	0,0000	0,2515	0,0000	0,0000
FE510 GAP 2 LHS	-2,9784	-0,1594	0,0000	0,0149	-0,1594	-0,1594	-0,1594	0,0000	0,0000
FE510 GAP 2 RHS	0,0000	0,0000	0,0000	0,0145	0,0000	0,0000	0,0903	0,0000	0,0000
FE515 FLUSH 1 LHS	-2,5916	1,8174	0,0000	-0,3818	1,8174	1,8174	1,8174	0,0000	0,0000
FE515 FLUSH 1 RHS	0,0000	0,0000	0,0000	0,0332	0,0000	0,0000	-1,7998	0,0000	0,0000
FE515 FLUSH 2 LHS	-0,2221	4,1624	0,0000	-1,1456	4,1624	4,1624	4,1624	0,0000	0,0000
FE515 FLUSH 2 RHS	0,0000	0,0000	0,0000	-0,0631	0,0000	0,0000	-4,1813	0,0000	0,0000
FE515 GAP 1 LHS	-1,3043	-2,7301	0,0000	0,7107	-2,7301	-2,7301	-2,7301	0,0000	0,0000
FE515 GAP 1 RHS	0,0000	0,0000	0,0000	0,2003	0,0000	0,0000	2,7411	0,0000	0,0000
FE515 GAP 2 LHS	1,6853	-1,3005	0,0000	1,3664	-1,3005	-1,3005	-1,3005	0,0000	0,0000
FE515 GAP 2 RHS	0,0000	0,0000	0,0000	-0,0831	0,0000	0,0000	0,5405	0,0000	0,0000

Bonnet - Comparison, Offset Measurement Results [mm]

	1(Y)	4(Z)	6(Z)	8(Z)	4(Z)+6(Z)	4(Z)-6(Z)	4(Z)-7(Z)	5(Z)+6(Z)	5(Z)-6(Z)
FE005 FLUSH 1 LHS	0,0262	-1,0180	1,3163	1,4415	0,3059	-2,3779	-0,7211	-0,5407	-3,2666
FE005 FLUSH 2	-1,3044	0,5243	2,5158	-1,6889	3,0385	-1,9763	-0,0218	5,0576	0,0633
FE005 FLUSH 3 RHS	2,3850	-0,2881	-1,8937	1,4090	-2,1891	1,6169	0,7515	-0,5545	3,2300
FE005 GAP 1 LHS	-0,6226	0,3910	-2,2071	-0,9890	-1,8160	2,6001	0,2727	-1,6472	2,7738
FE005 GAP 2	0,1434	0,0360	-0,8248	0,1964	-0,7879	0,8572	0,0007	-1,6710	-0,0275
FE005 GAP 3 RHS	-0,1590	0,0976	0,2344	-0,1871	0,3297	-0,1272	-0,2692	-1,7548	-2,2064
FE215 FLUSH 1 RHS	2,2042	-0,3147	-1,4097	1,2425	-1,7292	1,0967	0,7887	-0,0319	2,7681
FE215 FLUSH 2 RHS	0,5941	-0,0730	-0,3027	0,3001	-0,3786	0,2343	0,2174	-0,3421	0,2627
FE215 GAP 1 LHS	1,1940	0,0870	0,4257	0,7550	0,5062	-0,3075	0,0431	1,4707	0,6802
FE215 GAP 1 RHS	-1,1047	0,0358	1,0327	-0,6067	1,0751	-1,0147	-0,0231	1,4777	-0,6078
FE215 GAP 2 LHS	0,9562	0,3945	0,9022	-0,0765	1,2994	-0,5052	0,2852	0,8523	-0,9308
FE215 GAP 2 RHS	-0,6797	0,1037	-0,0436	-0,2600	0,0682	0,1298	-0,2893	0,8525	0,9281
FE510 FLUSH 1 LHS	-1,5001	0,5676	-0,2424	2,4081	0,3243	0,8137	0,5022	-0,1366	0,3545
FE510 FLUSH 1 RHS	-0,3571	0,0665	0,1142	-0,1730	0,1773	-0,0351	-0,4878	-0,1524	-0,3597
FE510 FLUSH 2 LHS	-2,8708	2,1172	-0,5257	0,9686	1,5879	2,6650	1,8695	0,1538	1,2531
FE510 FLUSH 2 RHS	-1,5683	0,2425	0,6956	-0,7864	0,9347	-0,4320	-1,8894	0,1408	-1,2043
FE510 GAP 1 LHS	-1,7588	-0,4473	0,3765	-0,6158	-0,0672	-0,8448	-0,3295	-0,3979	-1,1957
FE510 GAP 1 RHS	1,0710	-0,1150	-0,7738	0,5841	-0,8912	0,6600	0,3326	-0,3951	1,1443
FE510 GAP 2 LHS	-2,9097	-0,0899	0,1544	-0,1440	0,0659	-0,2479	-0,0815	0,0752	-0,2369
FE510 GAP 2 RHS	0,0190	-0,0017	-0,0602	0,0198	-0,0599	0,0530	0,0216	0,0852	0,1996
FE515 FLUSH 1 LHS	-2,6510	1,7736	-0,5502	-0,0300	1,2179	2,3416	1,8355	-0,1300	0,9959
FE515 FLUSH 1 RHS	-0,0126	-0,0677	0,4012	-0,0764	0,3325	-0,4679	-1,8462	-0,1171	-0,9217
FE515 FLUSH 2 LHS	-0,0075	3,8311	-0,5700	-0,4375	3,2569	4,4103	3,8680	-0,4620	0,6844
FE515 FLUSH 2 RHS	0,2202	-0,0414	0,1246	0,0505	0,0794	-0,1585	-3,9005	-0,4665	-0,7126
FE515 GAP 1 LHS	-0,5931	-2,1546	1,2574	-0,5894	-0,8851	-3,4452	-2,0630	0,5983	-1,9549
FE515 GAP 1 RHS	0,7043	-0,0947	-0,6800	0,4361	-0,7603	0,5440	2,0870	0,6070	1,9155
FE515 GAP 2 LHS	0,8677	-0,8853	1,2708	0,1551	0,4040	-2,1976	-1,0954	0,7710	-1,8026
FE515 GAP 2 RHS	-0,7005	0,1787	-0,5470	-0,1834	-0,3532	0,6962	0,3515	0,7182	1,7999

Bonnet - Contour, Offset Measurement Results [mm]

	1(Y)	4(Z)	6(Z)	8(Z)	4(Z)+6(Z)	4(Z)-6(Z)	4(Z)-7(Z)	5(Z)+6(Z)	5(Z)-6(Z)
FE005 FLUSH 1 LHS	-12,6561	-0,0112	1,2738	0,1076	1,2667	-1,2217	0,0058	1,0790	-1,2576
FE005 FLUSH 2	2,9613	0,0163	1,8694	-0,5317	1,8857	-1,8753	0,0041	3,7482	-0,0569
FE005 FLUSH 3 RHS	17,7548	-0,0132	-0,2079	-0,1609	-0,2270	0,0850	0,0039	1,0767	1,1341
FE005 GAP 1 LHS	13,1146	-0,0019	-2,3185	-0,3917	-2,3185	2,2093	-0,0040	-2,2930	2,0318
FE005 GAP 2	-1,7204	-0,0019	-0,8782	0,2833	-0,8795	0,8877	-0,0022	-1,7640	0,0295
FE005 GAP 3 RHS	-8,9165	0,0017	-0,0129	0,1855	-0,0136	0,0906	-0,0003	-2,3361	-2,0946
FE215 FLUSH 1 RHS	6,7158	-0,0083	-0,0621	-0,2333	-0,0753	0,0213	-0,0099	1,7524	1,7550
FE215 FLUSH 2 RHS	0,1108	0,0017	-0,0181	-0,0405	-0,0190	0,0277	0,0187	0,0921	0,1385
FE215 GAP 1 LHS	18,8621	0,0151	1,1726	0,4875	1,1840	-1,2687	0,0147	1,3320	-1,3658
FE215 GAP 1 RHS	-18,3106	-0,0019	0,1622	-0,1074	0,1644	-0,0437	-0,0124	1,3705	1,4280
FE215 GAP 2 LHS	-19,5946	-0,0028	0,2608	0,7644	0,2580	-0,0988	-0,0137	0,2267	0,1994
FE215 GAP 2 RHS	20,2008	0,0110	-0,0276	0,0128	-0,0078	-0,1398	0,0132	0,2393	-0,1965
FE510 FLUSH 1 LHS	-4,6376	0,2794	-0,5112	2,9105	-0,2324	0,8174	0,3098	-0,5243	0,5754
FE510 FLUSH 1 RHS	1,9805	-0,0269	-0,0082	0,0771	-0,0373	-0,0270	-0,3148	-0,5002	-0,5198
FE510 FLUSH 2 LHS	-14,9859	1,5235	-0,5213	1,6900	0,9989	2,1579	1,6495	-0,5126	0,8526
FE510 FLUSH 2 RHS	-9,5562	-0,1359	0,0570	0,0818	-0,0818	-0,1127	-1,6758	-0,5112	-0,3986
FE510 GAP 1 LHS	-11,6124	-0,1017	0,2341	-1,0160	0,1341	-0,2763	-0,1134	0,1680	-0,1130
FE510 GAP 1 RHS	12,1967	0,0115	-0,0763	-0,0449	-0,0664	0,0023	0,1154	0,1629	0,0512
FE510 GAP 2 LHS	-5,2755	-0,0944	0,0659	-0,0929	-0,0277	-0,1443	-0,1041	0,0587	-0,0212
FE510 GAP 2 RHS	5,1427	0,0059	-0,0171	-0,0019	-0,0094	-0,0204	0,0543	0,0460	-0,0412
FE515 FLUSH 1 LHS	10,0427	1,3272	-0,1829	0,2052	1,1415	1,4241	1,3605	-0,1416	-0,0481
FE515 FLUSH 1 RHS	-11,2113	-0,0243	0,0349	0,0961	0,0090	0,0291	-1,3258	-0,1409	0,0461
FE515 FLUSH 2 LHS	9,0746	3,1584	-0,0077	-0,2183	3,1486	3,1007	3,1450	0,0200	-0,1711
FE515 FLUSH 2 RHS	-8,0497	0,0185	0,0264	-0,0231	0,0415	0,0616	-3,1333	0,0170	0,1556
FE515 GAP 1 LHS	-21,5976	-2,0379	0,3207	-0,1635	-1,7106	-2,2187	-2,1777	0,2783	0,0897
FE515 GAP 1 RHS	22,6606	0,1326	-0,0546	-0,0146	0,0906	-0,0169	2,1778	0,2837	-0,1562
FE515 GAP 2 LHS	-44,0055	-0,9267	0,0458	1,0200	-0,8714	-0,6509	-0,8238	-0,0915	0,8298
FE515 GAP 2 RHS	36,6335	-0,0963	-0,1200	0,0938	-0,2012	-0,2912	0,2778	-0,0754	-0,7047

Bonnet - GSU-AA, Offset Measurement Results [mm]

	1(Y)	4(Z)	6(Z)	8(Z)	4(Z)+6(Z)	4(Z)-6(Z)	4(Z)-7(Z)	5(Z)+6(Z)	5(Z)-6(Z)
FE005 FLUSH 1 LHS	-2,3287	0,0462	1,4549	0,0000	1,5060	-1,4253	0,0462	0,9489	-1,9859
FE005 FLUSH 2	0,0008	-0,0902	1,4799	0,0000	1,3901	-1,5713	-0,0902	2,7987	-0,1627
FE005 FLUSH 3 RHS	2,3692	0,0478	-0,5960	0,0000	-0,5548	0,6522	0,0478	0,9518	2,1362
FE005 GAP 1 LHS	-0,1808	-0,2981	-2,6077	0,0000	-2,9054	2,3077	-0,2981	-2,2008	3,0105
FE005 GAP 2	-0,0157	0,0833	-0,7113	0,0000	-0,6277	0,7940	0,0833	-1,2789	0,1435
FE005 GAP 3 RHS	0,6382	-0,2936	0,8483	0,0000	0,5531	-1,1409	-0,2936	-2,2327	-3,9341
FE215 FLUSH 1 RHS	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,4243	0,9819	0,9819
FE215 FLUSH 2 RHS	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,1267	-0,0313	-0,0313
FE215 GAP 1 LHS	-1,3864	-0,1101	0,8816	0,9474	0,7692	-0,9951	-0,1101	0,8816	-0,8873
FE215 GAP 1 RHS	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,1583	0,9006	0,9006
FE215 GAP 2 LHS	2,4545	0,0985	0,2902	0,6410	0,3960	-0,2044	0,0985	0,2902	-0,2956
FE215 GAP 2 RHS	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,1854	0,3541	0,3541
FE510 FLUSH 1 LHS	-0,9579	0,3434	-0,2872	2,6729	0,0547	0,6338	0,3434	-0,2872	0,2889
FE510 FLUSH 1 RHS	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,4095	-0,3389	-0,3389
FE510 FLUSH 2 LHS	-1,7666	1,2899	-0,5452	1,9471	0,7447	1,8381	1,2899	-0,5452	0,5483
FE510 FLUSH 2 RHS	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-1,6455	-0,6427	-0,6427
FE510 GAP 1 LHS	-0,9312	-0,1317	0,0776	-0,9338	-0,0545	-0,2095	-0,1317	0,0776	-0,0782
FE510 GAP 1 RHS	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,1714	0,0809	0,0809
FE510 GAP 2 LHS	-2,7782	-0,0619	0,0755	-0,1343	0,0150	-0,1396	-0,0619	0,0755	-0,0763
FE510 GAP 2 RHS	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0244	0,0788	0,0788
FE515 FLUSH 1 LHS	-4,3646	1,3905	0,0164	0,0526	1,4084	1,3779	1,3905	0,0164	-0,0112
FE515 FLUSH 1 RHS	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-1,8052	-0,0310	-0,0310
FE515 FLUSH 2 LHS	-0,8227	3,1380	-0,0286	-0,1652	3,1080	3,1698	3,1380	-0,0286	0,0304
FE515 FLUSH 2 RHS	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-3,9584	-0,2746	-0,2746
FE515 GAP 1 LHS	0,0636	-1,5646	0,6562	-0,8786	-0,9005	-2,2338	-1,5646	0,6562	-0,6613
FE515 GAP 1 RHS	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	2,0182	0,8562	0,8562
FE515 GAP 2 LHS	4,9097	-1,0199	-0,0597	1,0827	-1,0746	-0,9751	-1,0199	-0,0597	0,0498
FE515 GAP 2 RHS	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,6644	0,0826	0,0826

Bonnet - Projection, Offset Measurement Results [mm]

	1(Y)	4(Z)	6(Z)	8(Z)	4(Z)+6(Z)	4(Z)-6(Z)	4(Z)-7(Z)	5(Z)+6(Z)	5(Z)-6(Z)
FE005 FLUSH 1 LHS	-0,1820	-0,9884	1,2438	1,4029	0,2627	-2,2737	-0,7963	-0,3710	-2,9464
FE005 FLUSH 2	-0,8861	0,3838	2,3348	-1,3712	2,7174	-1,9401	-0,0239	4,7041	0,0607
FE005 FLUSH 3 RHS	2,1318	-0,1799	-1,6456	1,1354	-1,8331	1,4794	0,8244	-0,3721	2,9227
FE005 GAP 1 LHS	-0,5288	0,3707	-2,1998	-0,9560	-1,8290	2,5717	0,2837	-1,7124	2,6916
FE005 GAP 2	0,1224	0,0427	-0,8171	0,1812	-0,7734	0,8564	-0,0004	-1,6526	-0,0239
FE005 GAP 3 RHS	-0,0750	0,0764	0,1855	-0,1279	0,2596	-0,1003	-0,2688	-1,8091	-2,1650
FE215 FLUSH 1 RHS	1,9633	-0,2152	-1,1846	0,9899	-1,4048	0,9734	0,8490	0,1444	2,5004
FE215 FLUSH 2 RHS	0,5759	-0,0525	-0,2536	0,2539	-0,3090	0,2059	0,2491	-0,3302	0,1770
FE215 GAP 1 LHS	1,1721	0,1212	0,5063	0,6832	0,6209	-0,3537	0,1086	1,4746	0,5236
FE215 GAP 1 RHS	-1,1064	0,0049	0,9591	-0,5422	0,9707	-0,9719	-0,0842	1,4766	-0,4616
FE215 GAP 2 LHS	0,9462	0,4169	0,9600	-0,1264	1,3797	-0,5404	0,3277	0,8556	-1,0428
FE215 GAP 2 RHS	-0,6728	0,0818	-0,1005	-0,2121	-0,0106	0,1648	-0,3334	0,8525	1,0418
FE510 FLUSH 1 LHS	-1,5314	0,6220	-0,1521	2,3008	0,4689	0,7782	0,5734	-0,0885	0,2229
FE510 FLUSH 1 RHS	-0,3719	0,0490	0,0724	-0,1473	0,1180	-0,0105	-0,5517	-0,1160	-0,2393
FE510 FLUSH 2 LHS	-2,8946	2,1772	-0,3860	0,8413	1,7876	2,5855	1,9790	0,1678	0,9882
FE510 FLUSH 2 RHS	-1,5703	0,1931	0,5688	-0,6820	0,7585	-0,3546	-1,9967	0,1508	-0,9407
FE510 GAP 1 LHS	-1,7351	-0,4885	0,2798	-0,5275	-0,2051	-0,7895	-0,4031	-0,4096	-1,0145
FE510 GAP 1 RHS	1,0746	-0,0810	-0,6859	0,5125	-0,7692	0,6060	0,4082	-0,4042	0,9592
FE510 GAP 2 LHS	-2,8944	-0,0958	0,1447	-0,1317	0,0504	-0,2442	-0,0870	0,0673	-0,2258
FE510 GAP 2 RHS	0,0307	-0,0033	-0,0623	0,0239	-0,0636	0,0534	0,0227	0,0797	0,1979
FE515 FLUSH 1 LHS	-2,5927	1,7902	-0,5332	-0,0494	1,2515	2,3407	1,8789	-0,1427	0,9478
FE515 FLUSH 1 RHS	0,0118	-0,0815	0,3880	-0,0558	0,3055	-0,4688	-1,8692	-0,1232	-0,9020
FE515 FLUSH 2 LHS	0,0484	3,8061	-0,5945	-0,3948	3,2074	4,4093	3,8407	-0,4910	0,7031
FE515 FLUSH 2 RHS	0,2697	-0,0400	0,1210	0,0586	0,0773	-0,1540	-3,8773	-0,4923	-0,7324
FE515 GAP 1 LHS	-0,5771	-2,1824	1,1964	-0,5326	-0,9738	-3,4122	-2,1144	0,5926	-1,8390
FE515 GAP 1 RHS	0,7110	-0,0722	-0,6243	0,3889	-0,6821	0,5107	2,1341	0,6047	1,8016
FE515 GAP 2 LHS	0,8527	-0,8526	1,3464	0,0850	0,5123	-2,2403	-1,0385	0,7821	-1,9422
FE515 GAP 2 RHS	-0,6852	0,1552	-0,6079	-0,1322	-0,4376	0,7335	0,3040	0,7185	1,9215

Bonnet - Reference, Offset Measurement Results [mm]

	1(Y)	4(Z)	6(Z)	8(Z)	4(Z)+6(Z)	4(Z)-6(Z)	4(Z)-7(Z)	5(Z)+6(Z)	5(Z)-6(Z)
FE005 FLUSH 1 LHS	-0,9381	-0,4586	1,5515	0,5513	1,1010	-2,0440	-0,3638	0,4276	-2,7422
FE005 FLUSH 2	0,0720	-0,0945	1,6991	-0,2587	1,6061	-1,7929	0,0326	3,4282	0,0342
FE005 FLUSH 3 RHS	1,4692	-0,1696	-0,9577	0,5631	-1,1347	0,8119	0,2753	0,3558	2,2976
FE005 GAP 1 LHS	-0,2622	0,1397	-2,4168	-0,5380	-2,2766	2,5532	0,1092	-2,0782	2,7494
FE005 GAP 2	0,0364	0,0805	-0,7497	0,0843	-0,6683	0,8282	-0,0048	-1,5503	-0,0533
FE005 GAP 3 RHS	0,1042	0,0507	0,0847	0,0269	0,1345	-0,0302	-0,0985	-2,0905	-2,2526
FE215 FLUSH 1 RHS	1,4169	-0,0904	-0,8707	0,5148	-0,9669	0,7939	0,5421	0,8533	2,6015
FE215 FLUSH 2 RHS	0,5421	-0,0373	-0,1590	0,1762	-0,1990	0,1270	0,2363	-0,2745	0,0449
FE215 GAP 1 LHS	1,1412	0,2250	0,7812	0,4343	0,9997	-0,5231	0,2651	1,5420	0,0449
FE215 GAP 1 RHS	-1,1129	-0,0620	0,7630	-0,3976	0,7065	-0,8415	-0,2567	1,5237	-0,0218
FE215 GAP 2 LHS	0,9550	0,3297	0,8173	0,0518	1,1508	-0,4868	0,2368	0,7503	-0,8655
FE215 GAP 2 RHS	-0,6968	0,0944	-0,0836	-0,2046	0,0179	0,1608	-0,2394	0,7633	0,9188
FE510 FLUSH 1 LHS	-1,1264	0,6331	0,0400	2,2069	0,6722	0,5943	0,6346	-0,1362	-0,2176
FE510 FLUSH 1 RHS	0,0283	0,0224	-0,1837	0,0265	-0,1648	0,2152	-0,5492	-0,1879	0,1904
FE510 FLUSH 2 LHS	-3,1093	2,2209	-0,0393	0,6116	2,1790	2,2846	2,0284	0,2206	0,3544
FE510 FLUSH 2 RHS	-1,7656	0,1762	0,2925	-0,5357	0,4639	-0,0929	-2,0595	0,1843	-0,3500
FE510 GAP 1 LHS	-1,6719	-0,4660	0,1420	-0,4915	-0,3211	-0,6298	-0,3989	-0,3605	-0,6925
FE510 GAP 1 RHS	1,1259	-0,0575	-0,5046	0,3798	-0,5636	0,4478	0,4040	-0,3374	0,6630
FE510 GAP 2 LHS	-2,8908	-0,1087	0,0733	-0,0786	-0,0340	-0,1857	-0,0981	0,0481	-0,1025
FE510 GAP 2 RHS	0,0263	-0,0071	-0,0168	0,0090	-0,0219	0,0042	0,0283	0,0630	0,0906
FE515 FLUSH 1 LHS	-2,2673	1,7044	-0,7116	0,1732	0,9870	2,4307	1,8597	-0,3369	1,1026
FE515 FLUSH 1 RHS	0,3660	-0,1501	0,3557	0,0794	0,2049	-0,5090	-1,8462	-0,3264	-1,0506
FE515 FLUSH 2 LHS	0,1144	3,6793	-0,6807	-0,2126	2,9947	4,3673	3,6631	-0,5894	0,7742
FE515 FLUSH 2 RHS	0,3323	0,0131	0,0967	0,0528	0,1068	-0,0781	-3,6937	-0,5892	-0,7829
FE515 GAP 1 LHS	-0,6089	-2,2170	0,9503	-0,3804	-1,2546	-3,2014	-2,1919	0,6008	-1,3402
FE515 GAP 1 RHS	0,6470	-0,0226	-0,3837	0,2135	-0,3917	0,3204	2,2068	0,6392	1,3570
FE515 GAP 2 LHS	0,8115	-0,8344	1,3021	0,0917	0,4874	-2,1795	-0,9977	0,7778	-1,8598
FE515 GAP 2 RHS	-0,7684	0,1596	-0,5616	-0,1632	-0,3881	0,6930	0,2978	0,7345	1,8475

Fender - Reference, Offset Measurement Results [mm]

	4(Y)	5(Y)	6(Y)	2(Z)	3(Z)	1(X)	7(Y)	8(Y)	9(Y)	10(Y)	11(X)	12(Y)	13(Z)	14(Z)	15(Y)	4(Y)-12(Y)	-4(Y)+12(Y)	7(Y)-8(Y)	-7(Y)+8(Y)	9(Y)-10(Y)-15(Y)	-9(Y)+10(Y)+15(Y)
FE405 Flush 1	-0,0051	-0,0229	-0,0358	-0,0345	-0,0993	-0,0715	-0,4011	-2,6008	-0,0011	0,0087	-0,0650	0,0011	0,0013	0,0998	0,0599	-0,0063	0,0062	2,1997	-2,1997	-0,0697	0,0697
FE405 Flush 2	-0,0382	-0,0406	0,8324	-0,2013	1,3353	-1,0803	-3,3287	0,0063	-0,0109	0,1117	0,0338	0,0112	0,0088	-0,3820	-0,2524	-0,0494	0,0503	-3,3350	3,3350	0,1298	-0,1298
FE405 Gap 1	-0,0709	0,0016	-0,7788	-0,2943	-1,8663	-1,0834	0,4207	-0,2560	-0,0165	0,2208	0,3301	0,0250	0,0181	-0,6533	-0,3584	-0,0959	0,0917	0,6767	-0,6767	0,1212	-0,1212
FE405 Gap 2	0,0003	0,0927	-0,8507	0,0671	-2,7603	-1,1669	-0,0120	-0,1883	0,0001	0,0053	0,0957	-0,0014	-0,0061	0,0141	0,1237	0,0017	-0,0041	0,1763	-0,1763	-0,1289	0,1289
FE415 Alignment	-0,0728	-0,1238	1,5573	-0,4136	3,4849	-1,7077	-2,1220	0,4914	-0,0207	0,2061	-0,0112	0,0211	0,0198	-0,7015	-0,4927	-0,0939	0,0959	-2,6134	2,6134	0,2660	-0,2660
FE420 Alignment	0,0059	0,0553	-1,1876	0,0796	-2,3455	1,4388	0,5043	-0,2548	0,0044	-0,0013	0,2612	0,0029	0,0014	-0,0368	-0,0182	0,0030	-0,0071	0,7591	-0,7591	0,0238	-0,0238
FE510 Flush 1	-0,0141	-0,0246	-1,2782	-0,0838	1,4485	-0,5071	0,0869	0,0321	-0,0069	0,0387	-0,0038	0,0032	-0,0062	1,0819	-0,5045	-0,0172	0,0170	0,0549	-0,0549	0,4590	-0,4590
FE510 Flush 2	-0,0049	0,0036	0,3765	0,0363	-0,0722	-0,4406	-0,0243	-0,0191	0,0389	0,0171	0,1329	0,0058	0,1453	2,5078	-1,8267	-0,0107	0,0112	-0,0052	0,0052	1,8485	-1,8485
FE510 Gap 1	-0,0118	-0,0368	0,9038	-0,0677	1,4802	-0,2820	0,0716	0,0272	-0,0036	0,0320	0,0069	0,0035	0,0008	1,0265	0,7355	-0,0154	0,0152	0,0444	-0,0444	-0,7710	0,7710
FE510 Gap 2	-0,0310	0,1220	-0,3016	-0,1499	-0,4886	-0,7062	0,0356	0,0658	-0,0020	0,0966	0,0582	0,0061	0,0446	2,6364	2,1057	-0,0371	0,0370	-0,0302	0,0302	-2,2043	2,2043
FE515 Flush 1	-0,0737	-1,2183	0,9335	-1,0979	0,4684	-0,4988	-0,0347	-0,0174	0,6171	0,1570	0,1564	0,0333	2,6796	-0,3433	-2,8366	-0,1070	0,1111	-0,0173	0,0173	3,2968	-3,2968
FE515 Flush 2	-0,0636	-1,8555	0,1450	-2,6859	0,0736	-0,4160	0,0196	0,0400	1,0976	0,1594	-0,2087	0,0092	6,1750	-1,0606	-1,0801	-0,0728	0,0786	-0,0204	0,0204	2,0182	-2,0182
FE515 Gap 1	-0,0174	0,8587	0,0596	0,5405	-0,0645	-2,2091	-0,0040	0,0019	0,1527	0,0606	0,1677	0,0078	0,5603	0,7315	0,1811	-0,0252	0,0244	-0,0059	0,0059	-0,0889	0,0889
FE515 Gap 2	0,0106	0,8377	-0,1020	1,2553	-0,0657	-2,6136	0,0202	0,0256	0,4597	-0,0319	-0,1197	-0,0058	0,7666	-0,9264	-0,5322	0,0164	-0,0178	-0,0054	0,0054	1,0237	-1,0237
FE601 Gap 2	0,0179	-0,0422	-0,0458	-0,1583	-0,0136	2,3609	-0,0203	-0,0334	-1,0225	-0,0378	0,1474	-0,0011	0,7260	1,0715	0,9361	0,0191	-0,0198	0,0131	-0,0131	-1,9208	1,9208
FE610 Flush 1	0,0544	1,5731	-0,5716	1,1994	-0,4186	-0,2663	0,0049	-0,0167	-5,0614	-0,0973	0,1346	-0,0160	-0,4985	0,7155	1,3020	0,0704	-0,0727	0,0216	-0,0216	-6,2660	6,2660
FE610 Flush 2	0,0930	1,9480	-0,8923	1,9678	-0,5427	-0,7334	0,0203	-0,0102	-4,1773	-0,1963	-0,0361	-0,0321	0,8789	-0,0550	1,4160	0,1252	-0,1279	0,0305	-0,0305	-5,3970	5,3970
FE610 Gap 1	0,0105	-0,2102	0,2064	0,2248	0,1858	2,4882	-0,0228	-0,0287	0,2354	-0,0424	0,0947	0,0034	0,3804	0,6496	0,3405	0,0072	-0,0077	0,0060	-0,0060	-0,0627	0,0627
Kjell 2 a-st list	-0,0832	-1,6117	0,8881	-1,4329	0,5456	0,7099	-0,0221	0,0064	3,7784	0,1694	0,0576	0,0309	-1,4864	0,1189	-1,3322	-0,1140	0,1160	-0,0285	0,0285	4,9412	-4,9412
Kjell Z A-list	-0,0170	-0,7205	-0,1453	-1,2772	-0,1041	-0,4828	0,0182	0,0231	-0,4764	0,0535	-0,1442	-0,0024	4,5352	-0,7356	-0,3911	-0,0145	0,0180	-0,0049	0,0049	-0,1388	0,1388
SD105 Flush 1	0,0441	-2,4271	-0,4386	1,8079	-0,4669	-0,5210	0,0016	-0,0161	0,0640	-0,0210	0,2990	-0,0085	-0,1321	0,9946	0,7773	0,0526	-0,0523	0,0177	-0,0177	-0,6923	0,6923
SD105 Flush 2	-2,8987	0,2041	0,0149	0,0806	-0,0067	0,0851	0,0090	0,0197	-0,0001	-0,7755	-0,0680	0,4942	0,0042	-0,0844	-0,0670	-3,3929	3,3931	-0,0107	0,0107	0,8424	-0,8424
SD105 Gap 1	0,0218	-0,3889	0,0090	-0,4668	0,0520	2,9371	-0,0142	-0,0250	0,0048	-0,0360	0,0629	-0,0031	-0,0104	0,4248	0,4303	0,0249	-0,0246	0,0108	-0,0108	-0,3895	0,3895
SD105 Gap 2	-0,3227	0,0361	-0,0524	0,0430	-0,0841	0,3657	0,0098	0,0166	0,0019	-0,0612	2,6343	0,3427	0,0001	0,0410	0,0295	-0,6655	0,6654	-0,0069	0,0069	0,0336	-0,0336
Wheelarch 30	0,0943	-0,0372	-0,4644	0,3155	-0,5163	0,5288	-0,1068	-2,1614	0,0149	-0,3079	-0,5645	-0,0410	-0,0290	0,1913	0,0106	0,1352	-0,1361	2,0545	-2,0545	0,3122	-0,3122
Wheelarch 50	0,6780	-0,1309	-2,4882	1,3291	-3,5669	3,3094	0,3114	0,4628	0,0726	-2,7630	-3,3024	-0,9095	-0,0896	2,2259	1,7761	1,5874	-1,5905	-0,1514	0,1514	1,0596	-1,0596

Fender - Projection, Offset Measurement Results [mm]

	4(Y)	5(Y)	6(Y)	2(Z)	3(Z)	1(X)	7(Y)	8(Y)	9(Y)	10(Y)	11(X)	12(Y)	13(Z)	14(Z)	15(Y)	4(Y)-12(Y)	-4(Y)+12(Y)	7(Y)-8(Y)	-7(Y)+8(Y)	9(Y)-10(Y)-15(Y)	-9(Y)+10(Y)+15(Y)
FE405 Flush 1	0,0092	-0,0356	-0,4114	-0,0598	-0,5624	0,1839	-0,1978	-2,5993	-0,0035	-0,0449	-0,3203	-0,0082	0,0000	0,5895	0,2951	0,0174	-0,0177	2,4015	-2,4015	-0,2537	0,2537
FE405 Flush 2	-0,0102	0,0290	0,7831	-0,0792	1,3120	-0,9637	-3,2633	-0,0124	-0,0171	0,0380	-0,0827	0,0098	0,0020	-0,4740	-0,2659	-0,0200	0,0208	-3,2509	3,2509	0,2108	-0,2108
FE405 Gap 1	-0,0353	0,0916	-0,5179	-0,0636	-1,5204	-1,0948	0,2640	-0,2340	-0,0224	0,1388	0,3415	0,0319	0,0093	-1,2212	-0,5291	-0,0671	0,0630	0,4981	-0,4981	0,3678	-0,3678
FE405 Gap 2	-0,0131	0,0006	-0,6821	0,0135	-2,5193	-1,3556	-0,2069	-0,1610	-0,0018	0,0534	0,2844	0,0092	-0,0014	-0,1780	0,1709	-0,0223	0,0199	-0,0459	0,0459	-0,2261	0,2261
FE415 Alignment	-0,0198	0,0842	1,7755	-0,1181	3,7521	-1,6196	-2,1448	0,4844	-0,0305	0,0763	-0,0992	0,0194	0,0038	-1,2481	-0,8003	-0,0393	0,0413	-2,6292	2,6292	0,6935	-0,6935
FE420 Alignment	-0,0120	0,0294	-0,8923	0,0854	-2,0037	1,2409	0,2998	-0,2272	0,0112	0,0539	0,4592	0,0109	0,0050	-0,3882	-0,1633	-0,0229	0,0190	0,5269	-0,5269	0,1205	-0,1205
FE510 Flush 1	0,0326	1,2626	0,9878	1,3910	4,6279	-1,1165	-0,0637	-0,1476	0,0974	-0,1219	0,6055	-0,0307	0,0026	-3,5813	-3,6845	0,0633	-0,0623	0,0839	-0,0839	3,9038	-3,9038
FE510 Flush 2	-0,0048	-0,2953	0,3081	-0,0001	0,4576	-0,7325	-0,0375	-0,1575	0,1374	0,0717	0,4248	0,0150	0,2296	1,9301	-1,4708	-0,0199	0,0206	0,1199	-0,1199	1,5366	-1,5366
FE510 Gap 1	-0,0007	0,0907	1,1627	0,0985	1,8638	-0,3647	0,0278	0,0116	0,0080	0,0054	0,0895	0,0009	0,0036	0,4739	0,4150	-0,0016	0,0016	0,0162	-0,0162	-0,4124	0,4124
FE510 Gap 2	-0,0135	0,2619	-0,0758	0,1196	-0,1074	-0,7171	0,0054	0,0382	-0,0020	0,0416	0,0691	0,0109	0,0180	2,0122	1,8303	-0,0243	0,0243	-0,0328	0,0328	-1,8739	1,8739
FE515 Flush 1	-0,0856	-2,5893	-0,1130	-2,0706	-0,1212	-0,8616	-0,0220	-0,0735	1,0536	0,3518	0,5192	0,0725	2,8774	1,0212	-1,0352	-0,1580	0,1623	0,0514	-0,0514	1,7370	-1,7370
FE515 Flush 2	-0,0480	-1,4618	0,5404	-1,6592	0,6766	-0,3387	-0,0079	0,0301	0,9257	0,1381	-0,2860	0,0327	5,5110	-2,0266	-1,6783	-0,0807	0,0857	-0,0380	0,0380	2,4659	-2,4659
FE515 Gap 1	-0,0220	0,5592	-0,2199	0,3283	-0,2855	-2,2216	0,0011	0,0047	0,2395	0,0902	0,1802	0,0179	0,6193	1,1058	0,6301	-0,0398	0,0391	-0,0035	0,0035	-0,4808	0,4808
FE515 Gap 2	0,0092	1,0778	-0,0160	1,3929	-0,0570	-2,6555	0,0109	0,0226	0,2602	-0,0222	-0,0777	-0,0071	0,5404	-0,8466	-0,6538	0,0163	-0,0181	-0,0117	0,0117	0,9362	-0,9362
FE601 Gap 2	0,0026	-0,1984	-0,1190	-0,3163	-0,1218	2,3907	-0,0058	-0,0195	-0,9036	-0,0126	0,1177	-0,0016	0,8746	1,1892	1,0092	0,0042	-0,0048	0,0137	-0,0137	-1,9002	1,9002
FE610 Flush 1	0,0532	1,8181	-0,1673	1,2550	-0,2216	-0,0364	0,0112	0,0100	-4,9032	-0,1890	-0,0954	-0,0409	-0,0684	0,0333	0,5808	0,0941	-0,0958	0,0013	-0,0013	-5,2950	5,2950
FE610 Flush 2	0,0819	2,5520	-0,0178	2,3404	-0,0492	-0,4455	0,0186	0,0271	-4,0406	-0,2982	-0,3240	-0,0645	1,2480	-1,2898	-0,0877	0,1464	-0,1485	-0,0085	0,0085	-3,6547	3,6547
FE610 Gap 1	-0,0100	-0,5627	-0,1219	-0,1412	-0,1276	2,3976	-0,0072	-0,0247	0,3178	0,0412	0,1853	0,0090	0,4416	1,2677	0,8502	-0,0190	0,0185	0,0175	-0,0175	-0,5736	0,5736
Kjell 2 a-st list	-0,0762	-2,2492	-0,0740	-1,9424	-0,0696	0,3919	-0,0165	-0,0297	3,6132	0,2850	0,3755	0,0609	-1,8310	1,5878	0,3086	-0,1371	0,1384	0,0131	-0,0131	3,0196	-3,0196
Kjell Z A-list	0,0041	-0,3924	0,3384	-0,7275	0,4191	-0,3382	0,0004	0,0205	-0,4298	-0,0353	-0,2887	-0,0055	4,5008	-1,7740	-1,1575	0,0097	-0,0062	-0,0202	0,0202	0,7630	-0,7630
SD105 Flush 1	0,0057	-2,3193	-0,3904	2,0205	-0,5224	-0,2945	0,0102	0,0199	0,0461	-0,0114	0,0725	-0,0041	-0,1233	0,8288	0,6199	0,0098	-0,0096	-0,0097	0,0097	-0,5624	0,5624
SD105 Flush 2	-3,0850	0,0684	-0,5251	0,1106	-0,8816	0,6588	0,0681	0,1700	0,0298	-0,8556	-0,6417	0,6853	0,0347	0,7303	0,4463	-3,7703	3,7701	-0,1019	0,1019	0,4391	-0,4391
SD105 Gap 1	0,0000	-0,3770	0,0063	-0,3977	0,0306	3,0038	-0,0059	-0,0117	0,0044	-0,0124	-0,0038	-0,0011	-0,0203	0,3870	0,3962	0,0011	-0,0009	0,0058	-0,0058	-0,3794	0,3794
SD105 Gap 2	-0,3483	-0,0035	-0,0997	0,0182	-0,1633	0,3943	0,0117	0,0288	0,0059	-0,0277	2,6057	0,3499	0,0040	0,1411	0,0831	-0,6982	0,6982	-0,0171	0,0171	-0,0496	0,0496
Wheelarch 30	0,0506	-0,2166	-0,7535	-0,0052	-1,1680	0,6422	-0,1591	-1,9882	0,0202	-0,2217	-0,6779	-0,0518	-0,0240	1,1589	0,3214	0,1024	-0,1035	1,8291	-1,8291	-0,0796	0,0796
Wheelarch 50	0,2788	-1,2030	-3,5961	0,1740	-5,5972	3,4450	0,3474	0,6807	0,1609	-2,0173	-3,4380	-0,8239	-0,1900	5,5117	3,1812	1,1027	-1,1066	-0,3333	0,3333	-1,0030	1,0030

Fender - Contour, Offset Measurement Results [mm]

	4(Y)	5(Y)	6(Y)	2(Z)	3(Z)	1(X)	7(Y)	8(Y)	9(Y)	10(Y)	11(X)	12(Y)	13(Z)	14(Z)	15(Y)	4(Y)-12(Y)	-4(Y)+12(Y)	7(Y)-8(Y)	-7(Y)+8(Y)	9(Y)-10(Y)-15(Y)	-9(Y)+10(Y)+15(Y)
FE405 Flush 1	0,0039	0,1129	0,3502	0,2440	1,1005	-0,4893	-0,1850	-3,0044	0,0397	0,0383	0,3529	0,0084	0,0858	-1,4632	-0,3619	-0,0046	0,0051	2,8194	-2,8194	0,3632	-0,3632
FE405 Flush 2	-0,0078	0,0771	0,9131	0,0822	1,9754	-1,1703	-3,1517	-0,1873	0,0199	0,0351	0,1238	0,0113	0,0745	-1,3712	-0,4190	-0,0191	0,0203	-2,9643	2,9643	0,4038	-0,4038
FE405 Gap 1	-0,0077	0,0439	-0,6665	0,0382	-1,8497	-0,7936	-0,0030	0,1372	0,0073	0,0178	0,0404	0,0061	0,0288	-1,0129	-0,3469	-0,0139	0,0095	-0,1402	0,1402	0,3365	-0,3365
FE405 Gap 2	-0,0112	0,0692	-0,8667	0,0419	-3,1869	-0,9170	-0,1030	-0,0880	0,0025	0,0027	-0,1542	0,0034	0,0161	0,4439	0,1615	-0,0146	0,0120	-0,0151	0,0151	-0,1616	0,1616
FE415 Alignment	-0,0133	0,0916	1,6000	0,0601	4,4941	-1,8467	-1,8028	0,2138	0,0203	0,0491	0,1279	0,0167	0,0936	-2,2582	-0,7312	-0,0299	0,0323	-2,0166	2,0166	0,7024	-0,7024
FE420 Alignment	0,0137	-0,0875	-1,1450	-0,0330	-2,8596	1,6081	-0,0024	0,1850	-0,0090	-0,0242	0,0919	-0,0107	-0,0572	0,6486	0,1912	0,0244	-0,0288	-0,1874	0,1874	-0,1761	0,1761
FE510 Flush 1	-0,0041	0,3007	-0,7453	0,3351	1,9369	-0,4881	0,0370	0,0084	-0,0115	0,0044	-0,0229	0,0025	-0,0859	0,2541	-1,2594	-0,0065	0,0064	0,0286	-0,0286	1,2435	-1,2435
FE510 Flush 2	-0,0046	-0,2366	-0,0320	-0,2935	-0,5686	-0,3884	-0,0123	0,0368	0,0463	0,0197	0,0808	0,0074	0,2079	3,2716	-1,2578	-0,0120	0,0124	-0,0490	0,0490	1,2844	-1,2844
FE510 Gap 1	-0,0031	0,0084	1,0964	0,0404	1,7156	-0,2821	-0,0034	0,0159	0,0206	0,0088	0,0070	0,0028	0,0675	0,6163	0,5753	-0,0060	0,0059	-0,0193	0,0193	-0,5635	0,5635
FE510 Gap 2	-0,0042	0,3409	0,0540	0,4848	0,2958	-0,6680	0,0025	0,0181	0,0168	0,0134	0,0200	0,0038	-0,0244	1,2862	1,6521	-0,0081	0,0080	-0,0156	0,0156	-1,6487	1,6487
FE515 Flush 1	-0,0258	-1,2154	0,4755	-1,8654	-0,3703	-1,2637	-0,0476	0,3752	0,4172	0,1647	0,9213	0,0565	1,8260	2,1156	-2,6437	-0,0822	0,0853	-0,4228	0,4228	2,8962	-2,8962
FE515 Flush 2	-0,0119	-1,3230	0,1673	-2,8470	-0,0260	-0,7793	-0,0108	0,0708	0,6153	0,0448	0,1546	0,0195	5,7707	-0,3960	-1,1022	-0,0315	0,0368	-0,0816	0,0816	1,6727	-1,6727
FE515 Gap 1	-0,0200	1,0392	0,1917	1,4292	0,4198	-2,0206	-0,0024	0,0481	0,1038	0,0444	-0,0208	0,0148	0,1275	-0,2088	-0,1186	-0,0348	0,0334	-0,0506	0,0506	0,1781	-0,1781
FE515 Gap 2	-0,0231	1,1153	-0,1044	1,6033	-0,2042	-2,4797	0,0005	-0,0254	0,1083	0,0244	-0,2535	0,0092	0,4002	-0,7696	-0,4230	-0,0324	0,0303	0,0259	-0,0259	0,5069	-0,5069
FE601 Gap 2	0,0201	0,5496	-0,0544	0,1996	-0,1650	2,1422	-0,0062	0,0845	-1,5825	0,0031	0,3661	-0,0072	-0,1703	1,7606	0,7419	0,0273	-0,0293	-0,0907	0,0907	-2,3275	2,3275
FE610 Flush 1	0,0011	4,0581	-0,5840	2,9575	-1,2897	-0,4059	-0,0137	0,1339	-7,5830	0,0573	0,2741	-0,0025	-3,6694	2,9972	1,0984	0,0036	-0,0106	-0,1477	0,1477	-8,7386	8,7386
FE610 Flush 2	-0,0015	5,1704	-0,8123	4,1237	-1,7158	-0,8962	-0,0119	0,0971	-7,4618	0,0492	0,1266	-0,0071	-3,0880	2,9264	1,1398	0,0055	-0,0142	-0,1090	0,1090	-8,6508	8,6508
FE610 Gap 1	0,0201	-0,6052	0,0831	-0,2073	0,1388	2,3060	-0,0022	0,0420	0,5704	-0,0153	0,2770	-0,0073	0,6234	0,8858	0,4064	0,0274	-0,0275	-0,0442	0,0442	0,1793	-0,1793
Kjell 2 a-st list	0,0012	-4,6492	0,7435	-3,4742	1,5517	0,8378	0,0093	-0,0714	6,8232	-0,0383	-0,0704	0,0076	2,1417	-2,4718	-0,9954	-0,0063	0,0137	0,0808	-0,0808	7,8568	-7,8568
Kjell Z A-list	-0,0014	-0,7503	-0,0588	-1,5399	-0,0826	-0,4029	0,0054	-0,0774	-0,3923	-0,0241	-0,2240	-0,0033	5,0000	-0,9588	-0,3546	0,0019	0,0022	0,0829	-0,0829	-0,0136	0,0136
SD105 Flush 1	-0,0068	-2,3782	-0,3024	2,2055	-0,5067	-0,1610	-0,0021	0,0311	0,1401	0,0195	-0,0611	0,0000	-0,1514	0,6563	0,4756	-0,0068	0,0070	-0,0332	0,0332	-0,3550	0,3550
SD105 Flush 2	-3,1148	0,1432	-0,3895	0,5926	-0,8596	1,1060	-0,0155	0,2791	0,0688	-0,8211	-1,0889	0,6456	0,0874	0,1739	0,2077	-3,7604	3,7601	-0,2945	0,2945	0,6822	-0,6822
SD105 Gap 1	0,0223	-0,3962	-0,0752	-0,8403	-0,1727	2,7659	-0,0019	0,0287	-0,0148	-0,0233	0,2341	-0,0110	0,0212	0,9913	0,4694	0,0334	-0,0330	-0,0307	0,0307	-0,4609	0,4609
SD105 Gap 2	-0,3317	0,0011	-0,0758	0,0589	-0,1689	0,4340	-0,0022	0,0369	0,0075	-0,0242	2,5660	0,3292	0,0050	0,1050	0,0595	-0,6610	0,6609	-0,0391	0,0391	-0,0278	0,0278
Wheelarch 30	-0,0142	-0,4104	-2,1617	-0,9267	-4,6245	1,6276	0,0391	-1,3968	-0,1747	-0,1872	-1,6633	-0,0432	-0,4305	5,9434	1,3517	0,0290	-0,0317	1,4358	-1,4358	-1,3392	1,3392
Wheelarch 50	0,8324	-1,5561	-4,1998	0,3887	-9,5270	5,8860	-0,0817	1,1751	0,1423	-2,3617	-5,8790	-1,1739	-0,3492	9,3869	4,2382	2,0062	-2,0120	-1,2568	1,2568	-1,7342	1,7342

Fender - Auto-AA Offset Measurement Results [mm]

	4(Y)	5(Y)	6(Y)	2(Z)	3(Z)	1(X)	7(Y)	8(Y)	9(Y)	10(Y)	11(X)	12(Y)	13(Z)	14(Z)	15(Y)	4(Y)-12(Y)	-4(Y)+12(Y)	7(Y)-8(Y)	-7(Y)+8(Y)	9(Y)-10(Y)-15(Y)	-9(Y)+10(Y)+15(Y)
FE405 Flush 1	0,0000	0,0000	0,0000	0,0000	-0,0806	0,0000	-0,3831	-2,6221	0,0074	0,0000	0,0000	0,0000	0,0000	-0,0915	0,0000	0,0000	0,0000	2,2378	-2,2410	0,0074	-0,0077
FE405 Flush 2	0,0000	0,0000	0,6288	0,0000	0,5021	0,0000	-3,2359	0,0000	-0,0599	0,0000	0,0000	0,0000	0,0000	-0,8103	0,0000	0,0000	0,0000	-3,2359	3,2762	-0,0599	0,0555
FE405 Gap 1	0,0000	0,0000	0,0000	0,0000	-2,7764	0,0000	-1,3531	0,7218	-0,2928	0,0000	0,0000	0,0000	0,0000	-0,7991	0,0000	0,0000	0,0000	-2,3332	1,8678	-0,2928	0,2866
FE405 Gap 2	0,0000	0,0000	-0,8616	0,0000	-4,1022	0,0000	-0,2235	0,0000	0,1137	0,0000	0,0000	0,0000	0,0000	0,3137	0,0000	0,0000	0,0000	-0,2235	0,1027	0,1137	-0,1215
FE415 Alignment	0,0000	0,0000	0,6140	0,0000	2,3440	0,0000	-1,0499	0,0000	-0,0170	0,0000	0,0000	0,0000	0,0000	-1,7081	0,0000	0,0000	0,0000	-1,0499	1,1467	-0,0170	0,0099
FE420 Alignment	0,0000	0,0000	0,0000	0,0000	-1,1833	0,0000	-1,4203	0,6887	-0,2676	0,0000	0,0000	0,0000	0,0000	0,6047	0,0000	0,0000	0,0000	-2,3572	1,9244	-0,2676	0,2666
FE510 Flush 1	0,0256	0,0000	-1,0945	0,0000	1,0679	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,8526	-0,6052	0,0256	-0,0257	0,0000	0,0000	0,5974	-0,6052
FE510 Flush 2	-0,0600	0,0000	0,1455	0,0000	-0,3076	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,4437	2,1727	-1,5172	-0,0600	0,0606	0,0000	0,0000	1,5196	-1,5172
FE510 Gap 1	0,0231	0,0000	1,0803	0,0000	1,2885	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,8713	0,6143	0,0231	-0,0232	0,0000	0,0000	-0,6188	0,6143
FE510 Gap 2	-0,0231	0,0000	-0,5233	0,0000	-0,6480	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,3586	1,6803	2,6394	-0,0231	0,0230	0,0000	0,0000	-2,6440	2,6394
FE515 Flush 1	0,0000	-2,1108	0,0000	-2,2034	-0,3424	0,0000	-1,1695	0,0000	0,0000	0,0000	0,0000	0,0000	4,0272	0,0000	1,5351	0,0000	0,0000	-1,1695	1,4120	-0,6252	1,5351
FE515 Flush 2	0,0000	1,4345	0,0000	-0,3028	-0,6247	0,0000	-0,4048	0,0000	-2,5196	0,0000	0,0000	0,0000	2,7892	0,0000	0,0000	0,0000	0,0000	-0,4048	0,4045	-2,5196	2,5701
FE515 Gap 1	0,0000	-0,5014	0,0000	-0,9181	-2,0414	0,0000	-1,6999	0,0000	0,0000	0,0000	0,0000	0,0000	2,6164	0,0000	3,7617	0,0000	0,0000	-1,6999	1,8039	-3,4272	3,7617
FE515 Gap 2	0,0000	4,4114	0,0000	4,4481	-2,7332	0,0000	-0,3504	0,0000	-3,7626	0,0000	0,0000	0,0000	-3,7315	0,0000	0,0000	0,0000	0,0000	-0,3504	0,3475	-3,7626	3,4149
FE601 Gap 2	0,0000	2,0389	0,0000	2,1400	-0,1318	0,0000	0,1725	0,0000	-5,2152	0,0000	0,0000	0,0000	-1,2256	0,0000	0,0000	0,0000	0,0000	0,1725	-0,1728	-5,2152	5,0431
FE610 Flush 1	0,0000	5,4921	0,0000	5,7287	-0,7696	0,0000	-0,0462	0,0000	-7,7695	0,0000	0,0000	0,0000	-3,7114	0,0000	0,0000	0,0000	0,0000	-0,0462	0,0453	-7,7695	7,2960
FE610 Flush 2	0,0000	-3,8938	0,0000	-3,0469	2,5829	0,0000	0,3343	0,0000	4,2173	0,0000	0,0000	0,0000	4,5299	0,0000	0,0000	0,0000	0,0000	0,3343	-0,3341	4,2173	-4,0830
FE610 Gap 1	0,0000	-3,7554	0,0000	-3,3286	2,5083	0,0000	0,4267	0,0000	3,2381	0,0000	0,0000	0,0000	5,0068	0,0000	0,0000	0,0000	0,0000	0,4267	-0,4264	3,2381	-3,1132
Kjell 2 a-st list	0,0000	-5,4146	0,0000	-5,3455	0,7675	0,0000	0,0826	0,0000	7,6244	0,0000	0,0000	0,0000	3,3142	0,0000	0,0000	0,0000	0,0000	0,0826	-0,0817	7,6244	-7,1755
Kjell Z A-list	0,0000	2,5590	0,0000	1,4523	-0,6270	0,0000	-0,3133	0,0000	-4,0095	0,0000	0,0000	0,0000	0,8916	0,0000	0,0000	0,0000	0,0000	-0,3133	0,3128	-4,0095	3,9172
SD105 Flush 1	0,0000	-1,7743	0,0000	2,9627	-0,2221	0,0000	0,0077	0,0000	-0,2869	0,0000	0,0000	0,0000	-0,7754	0,0000	0,0000	0,0000	0,0000	0,0077	-0,0077	-0,2869	0,2586
SD105 Flush 2	-5,9807	0,0000	0,0000	-0,0083	0,0000	0,0000	-0,2389	0,0000	0,0000	0,0000	0,0171	3,2336	0,0000	0,0020	0,0000	-9,1853	9,2412	-0,2389	0,2390	0,0000	0,0000
SD105 Gap 1	0,0000	-2,2343	0,0000	-2,0855	3,0000	0,0000	0,2102	0,0000	2,1413	0,0000	0,0000	0,0000	2,1487	0,0000	0,0000	0,0000	0,0000	0,2102	-0,2099	2,1413	-2,0362
SD105 Gap 2	-0,5773	0,0000	0,0000	-0,3156	0,0000	0,0000	-0,0156	0,0000	0,0000	0,0000	3,0000	0,3673	0,0000	0,3152	0,0000	-1,4003	0,4971	-0,0156	0,0159	0,0000	0,0000
Wheelarch 30	0,0000	0,0000	-0,0772	0,0000	-0,0415	0,0000	0,0000	-2,7118	-0,2151	0,0000	0,0000	0,0000	0,0000	-0,0336	0,0000	0,0000	0,0000	2,7074	-2,7118	-0,2151	0,2148
Wheelarch 50	0,0000	0,0000	0,0000	-0,0588	0,0070	0,0000	-0,5806	0,0000	0,0000	-2,0982	0,0000	-0,3223	0,0000	-0,0443	0,0000	0,3195	-0,3223	-0,5806	0,5804	2,0956	-2,0982

Fender - GSU-AA Offset Measurement Results [mm]

	4(Y)	5(Y)	6(Y)	2(Z)	3(Z)	1(X)	7(Y)	8(Y)	9(Y)	10(Y)	11(X)	12(Y)	13(Z)	14(Z)	15(Y)	4(Y)-12(Y)	-4(Y)+12(Y)	7(Y)-8(Y)	-7(Y)+8(Y)	9(Y)-10(Y)-15(Y)	-9(Y)+10(Y)+15(Y)
FE405 Flush 1	-0,8371	0,6820	-2,8442	-0,0367	0,0040	-0,1365	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,8371	0,8357	0,0000	0,0000	0,0000	0,0000
FE405 Flush 2	-0,5116	0,8862	-3,0846	-0,3259	1,0867	-1,0465	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,5116	0,5120	0,0000	0,0000	0,0000	0,0000
FE405 Gap 1	0,0871	-0,1458	-0,7529	-0,3208	-2,4749	-0,7533	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0871	-0,0915	0,0000	0,0000	0,0000	0,0000
FE405 Gap 2	-0,0605	0,1949	-0,9644	0,1321	-2,8172	-1,0712	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0605	0,0579	0,0000	0,0000	0,0000	0,0000
FE415 Alignment	-0,1226	0,2544	-0,6879	-0,6888	3,0784	-1,7188	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,1226	0,1245	0,0000	0,0000	0,0000	0,0000
FE420 Alignment	0,0120	-0,0356	-0,8647	0,2424	-2,5436	1,7000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0120	-0,0162	0,0000	0,0000	0,0000	0,0000
FE510 Flush 1	-0,0012	-0,2142	-1,4520	0,3476	2,0928	-0,5110	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0012	0,0010	0,0000	0,0000	0,0000	0,0000
FE510 Flush 2	-0,0683	-0,5977	-0,7673	1,2722	1,3450	-0,3076	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0683	0,0683	0,0000	0,0000	0,0000	0,0000
FE510 Gap 1	-0,0112	0,2793	1,4537	0,3546	2,0852	-0,2752	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0112	0,0112	0,0000	0,0000	0,0000	0,0000
FE510 Gap 2	-0,0491	1,0787	1,0682	0,9994	1,0430	-0,6480	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,0491	0,0494	0,0000	0,0000	0,0000	0,0000
FE515 Flush 1	0,3105	-1,9203	-0,8337	1,2170	0,4882	-0,3424	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,3105	-0,3103	0,0000	0,0000	0,0000	0,0000
FE515 Flush 2	0,7363	-1,8146	-0,4590	2,1546	0,3435	-0,6247	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,7363	-0,7383	0,0000	0,0000	0,0000	0,0000
FE515 Gap 1	0,0401	1,0971	0,1634	1,4420	0,3255	-2,0414	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0401	-0,0416	0,0000	0,0000	0,0000	0,0000
FE515 Gap 2	0,0632	0,9958	-0,3786	1,4701	-0,4408	-2,7332	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0632	-0,0658	0,0000	0,0000	0,0000	0,0000
FE601 Gap 2	0,1886	0,0000	0,2281	0,9987	0,0000	0,0000	0,0000	0,0000	-3,2434	0,0000	0,1741	0,0000	0,0000	0,0000	0,0000	0,1886	-0,1891	0,0000	0,0000	-3,2434	3,2421
FE610 Flush 1	0,3907	0,0000	0,0681	2,2497	0,0000	0,0000	0,0000	0,0000	-2,2902	0,0000	0,4856	0,0000	0,0000	0,0000	0,0000	0,3907	-0,3923	0,0000	0,0000	-2,2902	2,2872
FE610 Flush 2	0,0358	0,0000	0,1355	1,4426	0,0000	0,0000	0,0000	0,0000	0,3236	0,0000	-0,4222	0,0000	0,0000	0,0000	0,0000	0,0358	-0,0368	0,0000	0,0000	0,3236	-0,3264
FE610 Gap 1	0,1205	0,0000	0,2373	1,6276	0,0000	0,0000	0,0000	0,0000	-0,6037	0,0000	-0,5070	0,0000	0,0000	0,0000	0,0000	0,1205	-0,1218	0,0000	0,0000	-0,6037	0,6006
Kjell 2 a-st list	-0,4185	0,0000	-0,0200	-2,2553	0,0000	0,0000	0,0000	0,0000	2,2639	0,0000	-0,4225	0,0000	0,0000	0,0000	0,0000	-0,4185	0,4202	0,0000	0,0000	2,2639	-2,2611
Kjell Z A-list	0,4309	0,0000	-0,3257	2,4170	0,0000	0,0000	0,0000	0,0000	-1,7689	0,0000	-0,2249	0,0000	0,0000	0,0000	0,0000	0,4309	-0,4331	0,0000	0,0000	-1,7689	1,7693
SD105 Flush 1	0,0000	-2,0028	0,0357	2,2035	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0973	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
SD105 Flush 2	0,0000	-0,2445	0,0424	-0,0063	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0155	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
SD105 Gap 1	0,0000	-0,0108	0,0131	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0134	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
SD105 Gap 2	0,0000	-0,0068	0,0084	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	2,7554	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
Wheelarch 30	-0,7631	0,3266	-2,5656	-0,0135	-0,0251	-0,0357	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-0,7631	0,7614	0,0000	0,0000	0,0000	0,0000
Wheelarch 50	-1,5197	-0,7655	-0,7151	-0,0766	-0,0263	0,0070	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	-1,5197	1,5182	0,0000	0,0000	0,0000	0,0000

Front Bumper - Reference, Offset Measurement Results

	2(Z)	4(Z)	6(Z)	8(Y)	10(Y)	12(Y)	14(X)	16(X)	17(Z)	18(Y)	19(X)	1(Z)+2(Z)	1(Z)-2(Z)	-5(Z)+6(Z)	-7(Y)+8(Y)	7(Y)-8(Y)	8(Y)-18(Y)	-8(Y)+18(Y)	8(Y)-10(Y)	-8(Y)+10(Y)	13(X)-14(X)	15(X)-16(X)	-15(X)-16(X)
FE005 FLUSH 1	0,03	0,33	0,31	0,01	-0,31	-0,24	0,39	-2,80	-0,08	-1,80	1,21	-0,07	-0,13	0,26	0,01	-0,01	1,81	-1,81	0,33	-0,33	-0,48	2,54	3,06
FE005 FLUSH 2	-0,50	1,16	0,19	-0,03	0,14	0,18	-0,24	0,61	1,01	-0,10	-2,00	-0,94	0,04	0,06	-0,06	0,06	0,07	-0,08	-0,17	0,17	0,03	-0,03	-1,18
FE005 FLUSH 3	-0,12	0,20	0,06	0,00	0,06	0,08	-0,11	-0,27	-0,07	1,77	1,28	-0,07	0,16	-0,22	0,02	-0,02	-1,78	1,78	-0,07	0,07	0,50	-2,58	3,12
FE005 GAP 1	-0,13	1,66	0,82	0,04	-0,85	-0,41	0,93	0,32	0,14	1,61	-0,23	-0,44	-0,17	0,78	0,01	-0,01	-1,57	1,57	0,89	-0,90	-1,13	-0,10	-0,53
FE005 GAP 2	-0,43	0,98	0,13	-0,02	0,10	0,13	-0,20	0,47	-0,08	-0,01	2,18	-0,82	0,03	0,04	-0,05	0,05	-0,02	0,01	-0,13	0,13	0,01	-0,02	-0,91
FE005 GAP 3	-0,40	0,69	0,07	-0,04	0,20	0,07	-0,23	0,25	0,15	-1,71	-0,25	-0,48	0,31	-0,55	0,03	-0,03	1,67	-1,67	-0,24	0,23	1,23	0,01	-0,51
FE225 FLUSH 1	-0,14	0,22	0,08	-0,02	0,11	0,12	-0,15	-0,30	-0,07	1,59	1,44	-0,11	0,16	0,26	0,02	-0,02	-1,61	1,61	-0,13	0,13	0,56	-2,77	3,38
FE225 GAP 1	0,24	-0,42	-0,01	0,02	-0,09	0,01	0,09	-0,39	-0,17	2,82	1,06	0,32	-0,15	0,66	-0,01	0,01	-2,80	2,80	0,11	-0,11	-0,62	0,15	0,63
FE225 GAP 2	0,12	-0,28	-0,01	0,02	-0,10	-0,02	0,07	-0,14	-0,05	1,26	0,01	0,37	0,13	0,32	0,07	-0,07	-1,24	1,24	0,12	-0,12	0,14	-0,08	0,36
FE225 INV FLUSH 1	-0,02	0,56	-0,33	0,03	-0,39	-0,34	0,45	-3,03	-0,06	-1,55	1,34	-0,15	-0,13	-0,39	0,01	-0,01	1,58	-1,58	0,42	-0,42	-0,60	2,76	3,30
FE225 INV GAP 1	0,11	-0,99	-0,88	-0,02	0,41	0,09	-0,41	-0,31	-0,16	-2,72	1,01	0,28	0,04	-0,88	0,00	0,00	2,70	-2,70	-0,42	0,42	0,49	-0,04	0,66
FE225 INV GAP 2	0,24	-0,91	-0,45	0,06	-0,10	-1,45	0,24	-0,26	-0,04	-1,28	0,01	0,33	-0,14	-0,45	0,08	-0,08	1,34	-1,34	0,16	-0,16	-0,18	0,13	0,39
FE230 FLUSH 1	0,08	-0,06	-0,02	0,04	-0,15	-0,11	0,10	-0,11	-0,02	1,22	0,17	0,71	0,55	-0,20	0,51	-0,51	-1,18	1,18	0,20	-0,20	-2,79	1,21	-0,99
FE230 GAP 1	-0,02	-0,04	0,05	-0,13	0,47	0,26	-0,27	0,21	0,05	-1,25	0,03	1,36	1,40	0,04	-0,01	0,01	1,12	-1,12	-0,60	0,60	0,84	-0,91	0,49
FE230 GAP 2	-0,48	0,74	0,15	-0,13	0,56	0,32	-0,50	0,24	0,14	-1,38	0,37	-0,97	-0,02	-0,17	-0,05	0,05	1,25	-1,26	-0,69	0,69	0,83	-0,88	0,40
FE230 INV FLUSH 1	0,70	-0,19	0,26	0,48	-1,13	-0,82	-2,72	1,11	-0,02	-1,29	0,19	0,73	-0,70	0,27	0,53	-0,53	1,78	-1,77	1,61	-1,61	2,83	-1,23	-0,99
FE230 INV GAP 1	1,38	1,37	0,01	0,13	0,09	0,13	0,37	-0,67	0,05	1,25	0,02	1,37	-1,39	-0,03	0,01	-0,02	-1,12	1,12	0,04	-0,05	-0,64	0,88	0,47
FE230 INV GAP 2	-0,52	2,58	0,42	0,07	-0,47	-0,01	0,29	-0,56	0,13	1,34	0,36	-0,92	0,13	0,32	-0,06	0,06	-1,27	1,27	0,54	-0,54	-0,76	0,77	0,35
FE405 FLUSH 2	0,99	-0,57	0,31	-0,41	-1,18	0,36	-2,52	1,25	-0,02	-1,64	0,24	0,97	-1,03	0,31	-0,37	0,36	1,23	-1,23	0,76	-0,78	2,57	-1,40	-1,11
FE405 FLUSH1	-0,05	-0,03	0,01	-2,97	-0,02	0,04	-0,19	0,05	0,00	-0,06	0,01	-0,06	0,04	0,01	-2,96	2,96	-2,90	2,90	-2,94	2,94	0,20	-0,06	-0,05
FE405 GAP 1	3,34	-0,37	-0,03	0,02	0,10	-0,07	0,67	0,14	-0,02	-0,40	-0,06	3,38	-3,31	-0,01	0,08	-0,08	0,42	-0,42	-0,07	0,07	-0,54	-0,23	-0,06
FE405 GAP 2	1,91	0,89	0,03	0,19	-0,19	0,08	1,29	-0,33	0,03	0,65	0,03	1,92	-1,90	0,01	0,11	-0,11	-0,47	0,47	0,37	-0,37	-1,45	0,45	0,21
FE405 INV FLUSH1	0,00	0,01	0,00	0,00	-0,01	-0,01	0,01	-0,01	0,00	0,07	0,01	-0,02	-0,02	-0,01	-2,94	2,94	-0,07	0,07	0,02	-0,02	-0,16	0,07	-0,05
FE405 INV FLUSH2	0,00	0,01	-0,01	0,05	-0,17	-0,10	0,07	-0,15	-0,02	1,65	0,20	0,95	0,96	-0,22	-0,36	0,36	-1,61	1,61	0,21	-0,21	-2,58	1,41	-1,11
FE405 INV GAP 1	0,06	-0,07	-0,03	0,05	-0,22	-0,11	0,14	-0,09	-0,02	0,41	-0,06	3,38	3,27	0,00	0,09	-0,09	-0,35	0,35	0,27	-0,27	0,53	0,24	-0,07
FE405 INV GAP 2	-0,01	-0,05	0,03	-0,08	0,29	0,16	-0,16	0,12	0,03	-0,64	0,03	1,92	1,92	0,00	0,11	-0,11	0,56	-0,56	-0,37	0,37	1,45	-0,46	0,22
FE420 ALIGNMENT	-2,38	0,10	0,08	0,18	-0,35	0,10	1,84	0,19	0,01	-0,13	0,08	-2,41	2,34	0,07	0,16	-0,16	0,31	-0,31	0,53	-0,54	-1,91	-0,17	-0,21
FE420 INV ALIGNMENT	-0,06	0,07	0,01	-0,02	0,10	0,04	-0,07	0,02	0,01	0,14	0,08	-2,41	-2,29	-0,05	0,17	-0,17	-0,16	0,16	-0,12	0,12	1,90	0,17	-0,21

Front Bumper - Comparison, Offset Measurement Results

	2(Z)	4(Z)	6(Z)	8(Y)	10(Y)	12(Y)	14(X)	16(X)	17(Z)	18(Y)	19(X)	1(Z)+2(Z)	1(Z)-2(Z)	-5(Z)+6(Z)	-7(Y)+8(Y)	7(Y)-8(Y)	8(Y)-18(Y)	-8(Y)+18(Y)	8(Y)-10(Y)	-8(Y)+10(Y)	13(X)-14(X)	15(X)-16(X)	-15(X)-16(X)
FE005 FLUSH 1	0,07	0,35	0,30	0,06	-0,25	-0,19	0,23	-2,66	-0,09	-2,05	1,19	0,04	-0,11	0,28	0,06	-0,06	2,10	-2,10	0,30	-0,30	-0,26	2,37	2,95
FE005 FLUSH 2	-0,27	1,14	0,02	-0,03	0,15	0,01	-0,17	0,64	0,93	-0,09	-2,22	-0,54	0,00	0,01	-0,06	0,06	0,06	-0,06	-0,18	0,18	0,01	0,00	-1,27
FE005 FLUSH 3	-0,03	0,11	0,03	0,00	0,00	0,03	-0,02	-0,31	-0,09	2,02	1,25	0,04	0,11	-0,24	0,06	-0,06	-2,02	2,02	0,01	-0,01	0,27	-2,40	3,03
FE005 GAP 1	0,11	1,73	0,70	0,15	-0,64	-0,27	0,54	0,73	0,06	0,68	-0,39	0,01	-0,20	0,74	0,16	-0,16	-0,53	0,53	0,78	-0,78	-0,49	-0,61	-0,84
FE005 GAP 2	-0,24	0,96	-0,01	-0,03	0,12	0,01	-0,14	0,50	-0,15	0,00	2,00	-0,47	0,00	0,00	-0,05	0,05	-0,02	0,02	-0,15	0,15	0,00	0,00	-1,00
FE005 GAP 3	-0,11	0,40	-0,05	0,02	-0,05	-0,24	0,04	0,13	0,07	-0,74	-0,43	0,01	0,22	-0,58	0,18	-0,18	0,75	-0,75	0,07	-0,07	0,56	0,56	-0,83
FE225 FLUSH 1	-0,04	0,12	0,03	0,00	0,00	0,06	-0,03	-0,36	-0,09	1,86	1,39	0,02	0,09	0,24	0,06	-0,06	-1,86	1,86	0,01	-0,01	0,28	-2,57	3,29
FE225 GAP 1	0,07	-0,25	0,06	-0,01	0,04	0,23	-0,05	-0,33	-0,12	2,21	1,18	0,02	-0,12	0,66	-0,11	0,11	-2,22	2,22	-0,05	0,05	-0,26	-0,16	0,82
FE225 GAP 2	0,03	-0,15	0,04	0,00	0,01	0,14	-0,03	-0,06	0,00	0,41	0,14	0,14	0,08	0,25	-0,03	0,03	-0,41	0,41	-0,01	0,01	0,24	-0,27	0,38
FE225 INV FLUSH 1	0,05	0,59	-0,36	0,05	-0,25	-0,38	0,27	-2,86	-0,09	-1,87	1,28	0,01	-0,10	-0,38	0,06	-0,06	1,92	-1,92	0,30	-0,30	-0,30	2,53	3,19
FE225 INV GAP 1	-0,03	-1,02	-0,79	-0,07	0,31	-0,03	-0,23	-0,52	-0,11	-2,18	1,11	0,02	0,08	-0,84	-0,08	0,08	2,11	-2,11	-0,38	0,38	0,18	0,22	0,82
FE225 INV GAP 2	0,11	-1,07	-0,30	-0,02	0,04	-2,15	0,23	-0,36	0,00	-0,42	0,13	0,13	-0,08	-0,33	-0,02	0,02	0,40	-0,40	-0,06	0,06	-0,26	0,31	0,42
FE230 FLUSH 1	0,00	0,06	-0,03	0,00	-0,01	-0,19	0,06	-0,08	-0,02	1,18	0,21	0,71	0,71	-0,29	0,57	-0,57	-1,18	1,18	0,01	-0,01	-2,95	1,34	-1,18
FE230 GAP 1	0,06	-0,14	0,01	-0,02	0,08	0,06	-0,02	0,07	0,00	-0,63	-0,14	1,56	1,44	0,12	-0,01	0,01	0,61	-0,61	-0,10	0,10	0,55	-0,67	0,54
FE230 GAP 2	-0,12	0,35	0,00	0,01	-0,02	0,00	-0,05	0,01	0,03	-0,11	0,09	-0,36	-0,13	-0,13	0,00	0,00	0,12	-0,12	0,04	-0,04	0,02	-0,25	0,22
FE230 INV FLUSH 1	0,72	-0,34	0,38	0,56	-1,09	-0,97	-2,92	1,28	-0,02	-1,22	0,24	0,72	-0,72	0,39	0,56	-0,56	1,78	-1,78	1,65	-1,65	2,98	-1,37	-1,20
FE230 INV GAP 1	1,51	1,52	-0,16	0,03	0,25	0,21	0,35	-0,60	0,00	0,65	-0,15	1,56	-1,45	-0,16	0,01	-0,01	-0,62	0,62	-0,22	0,22	-0,36	0,67	0,52
FE230 INV GAP 2	-0,23	2,80	0,17	-0,01	0,07	0,07	-0,04	-0,20	0,03	0,08	0,09	-0,34	0,12	0,17	0,00	0,00	-0,09	0,09	-0,08	0,08	-0,01	0,22	0,19
FE405 FLUSH 2	0,95	-0,63	0,48	0,55	-1,95	0,75	-3,07	1,73	-0,02	-2,34	0,32	0,94	-0,97	0,48	0,60	-0,60	2,89	-2,89	2,49	-2,49	3,18	-1,95	-1,51
FE405 FLUSH1	-0,06	-0,01	0,01	-2,97	-0,01	0,03	-0,17	0,04	0,00	-0,04	0,01	-0,07	0,06	0,01	-2,97	2,97	-2,93	2,93	-2,96	2,96	0,17	-0,04	-0,03
FE405 GAP 1	3,32	-0,46	0,05	-0,02	0,16	-0,09	0,64	0,17	-0,01	-0,30	-0,02	3,31	-3,32	0,06	0,01	-0,01	0,28	-0,28	-0,18	0,18	-0,57	-0,23	-0,12
FE405 GAP 2	1,99	0,97	-0,07	0,11	-0,06	0,13	1,25	-0,26	-0,01	0,22	-0,09	2,04	-1,94	-0,06	0,10	-0,10	-0,10	0,10	0,18	-0,18	-1,24	0,29	0,23
FE405 INV FLUSH1	-0,01	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,01	-0,03	-0,02	-0,01	-2,96	2,96	-0,05	0,05	0,00	0,00	-0,13	0,05	-0,04
FE405 INV FLUSH2	-0,02	-0,02	-0,01	0,05	-0,20	-0,18	0,12	-0,21	-0,01	2,27	0,28	0,94	0,97	-0,34	0,63	-0,63	-2,21	2,21	0,26	-0,26	-3,12	1,90	-1,48
FE405 INV GAP 1	0,00	0,01	-0,01	0,03	-0,13	-0,08	0,07	-0,05	-0,01	0,30	-0,02	3,31	3,32	-0,05	0,02	-0,02	-0,27	0,27	0,16	-0,16	0,57	0,22	-0,12
FE405 INV GAP 2	0,05	-0,13	0,00	-0,01	0,03	0,01	0,02	0,03	-0,01	-0,21	-0,09	2,04	1,93	0,04	0,10	-0,10	0,20	-0,20	-0,04	0,04	1,23	-0,28	0,23
FE420 ALIGNMENT	-2,38	0,16	0,06	0,28	-0,46	0,16	1,82	0,20	0,00	-0,23	0,07	-2,37	2,38	0,05	0,27	-0,27	0,51	-0,51	0,75	-0,75	-1,84	-0,20	-0,20
FE420 INV ALIGNMENT	0,01	-0,03	0,01	-0,02	0,06	0,02	-0,03	0,00	0,00	0,22	0,06	-2,37	-2,38	-0,03	0,27	-0,27	-0,24	0,24	-0,07	0,07	1,85	0,19	-0,19

Front Bumper - Projection, Offset Measurement Results

	2(Z)	4(Z)	6(Z)	8(Y)	10(Y)	12(Y)	14(X)	16(X)	17(Z)	18(Y)	19(X)	1(Z)+2(Z)	1(Z)-2(Z)	-5(Z)+6(Z)	-7(Y)+8(Y)	7(Y)-8(Y)	8(Y)-18(Y)	-8(Y)+18(Y)	8(Y)-10(Y)	-8(Y)+10(Y)	13(X)-14(X)	15(X)-16(X)	-15(X)-16(X)
FE005 FLUSH 1	0,37	0,70	-1,14	0,16	-0,92	-0,91	0,94	-3,40	0,39	0,04	1,31	0,20	-0,55	-1,15	0,11	-0,11	0,13	-0,13	1,09	-1,09	-1,32	3,36	3,43
FE005 FLUSH 2	-0,16	0,64	-0,02	-0,02	0,13	0,18	-0,17	0,19	1,77	-0,06	-1,33	-0,31	-0,01	-0,01	-0,05	0,05	0,04	-0,04	-0,15	0,15	-0,01	0,01	-0,40
FE005 FLUSH 3	-0,17	0,55	0,00	-0,05	0,30	0,57	-0,37	-0,02	0,36	0,03	1,28	0,20	0,52	1,03	0,11	-0,11	-0,08	0,08	-0,35	0,35	1,25	-3,31	3,35
FE005 GAP 1	0,02	1,54	1,23	0,06	-0,28	0,33	0,18	1,03	-0,07	-0,07	-0,29	0,01	-0,03	1,25	0,06	-0,06	0,13	-0,13	0,34	-0,34	-0,13	-0,97	-1,10
FE005 GAP 2	-0,16	0,67	-0,03	-0,02	0,13	0,18	-0,17	0,20	0,30	0,04	2,66	-0,33	-0,01	-0,01	-0,06	0,06	-0,07	0,07	-0,16	0,16	-0,02	0,02	-0,42
FE005 GAP 3	-0,02	0,13	-0,02	0,00	-0,02	-0,14	0,05	0,06	-0,07	0,06	-0,29	0,01	0,04	-1,10	0,07	-0,07	-0,06	0,06	0,02	-0,02	0,16	0,94	-1,07
FE225 FLUSH 1	-0,18	0,64	0,00	-0,05	0,31	0,53	-0,36	-0,01	0,38	-0,01	1,30	0,21	0,57	2,23	0,15	-0,15	-0,04	0,04	-0,36	0,36	1,38	-3,61	3,63
FE225 GAP 1	-0,12	0,32	0,02	-0,04	0,26	0,58	-0,34	-0,06	0,33	0,03	1,18	0,13	0,37	2,06	0,03	-0,03	-0,07	0,07	-0,30	0,30	0,88	-1,24	1,36
FE225 GAP 2	-0,01	-0,04	0,02	-0,01	0,06	0,19	-0,09	0,01	0,03	0,17	0,07	0,14	0,15	0,38	0,02	-0,02	-0,18	0,18	-0,06	0,06	0,44	-0,43	0,40
FE225 INV FLUSH 1	0,39	1,55	-2,49	0,20	-1,11	-0,80	1,08	-3,65	0,40	0,05	1,30	0,20	-0,59	-2,49	0,14	-0,14	0,15	-0,15	1,32	-1,32	-1,46	3,64	3,67
FE225 INV GAP 1	0,27	-0,63	-2,28	0,09	-0,52	-0,96	0,62	-1,38	0,34	0,01	1,18	0,14	-0,41	-2,30	0,04	-0,04	0,08	-0,08	0,60	-0,60	-0,97	1,32	1,44
FE225 INV GAP 2	0,15	-1,03	-0,47	0,03	-0,24	-2,04	0,37	-0,45	0,03	-0,18	0,08	0,14	-0,16	-0,48	0,02	-0,02	0,21	-0,21	0,27	-0,27	-0,46	0,47	0,44
FE230 FLUSH 1	-0,05	0,11	0,02	-0,03	0,24	0,71	-0,33	0,02	0,20	0,61	0,60	0,83	0,92	-0,27	0,70	-0,70	-0,64	0,64	-0,28	0,28	-2,42	1,01	-1,06
FE230 GAP 1	0,08	-0,18	-0,02	0,03	-0,21	-0,44	0,26	-0,04	-0,12	-0,29	-0,36	1,48	1,32	0,07	-0,03	0,03	0,33	-0,33	0,24	-0,24	0,22	-0,45	0,53
FE230 GAP 2	-0,09	0,29	0,00	-0,02	0,10	0,10	-0,11	0,06	0,05	0,05	0,12	-0,31	-0,14	0,00	-0,05	0,05	-0,07	0,07	-0,12	0,12	0,01	-0,23	0,12
FE230 INV FLUSH 1	0,87	-0,72	0,33	0,69	-1,90	0,20	-2,76	1,04	0,19	-0,61	0,60	0,83	-0,93	0,32	0,66	-0,66	1,30	-1,30	2,58	-2,58	2,43	-1,02	-1,06
FE230 INV GAP 1	1,40	1,73	-0,09	-0,06	0,70	-0,49	0,27	-0,47	-0,12	0,28	-0,34	1,49	-1,31	-0,08	-0,02	0,02	-0,34	0,34	-0,76	0,76	0,00	0,42	0,51
FE230 INV GAP 2	-0,21	2,93	0,01	-0,06	0,24	0,17	-0,14	-0,11	0,04	0,00	0,10	-0,29	0,12	0,00	-0,08	0,08	-0,06	0,06	-0,30	0,30	0,04	0,16	0,05
FE405 FLUSH 2	1,20	-1,17	0,32	0,57	-3,08	2,53	-2,65	1,25	0,25	-1,11	0,79	1,09	-1,33	0,28	0,51	-0,51	1,67	-1,67	3,65	-3,65	2,05	-1,17	-1,32
FE405 FLUSH1	-0,05	-0,03	-0,01	-2,93	-0,12	0,14	-0,15	0,02	0,01	-0,01	0,03	-0,06	0,03	-0,01	-2,94	2,94	-2,92	2,92	-2,81	2,81	0,12	-0,01	-0,03
FE405 GAP 1	3,34	-0,52	0,05	-0,08	0,27	-0,12	0,63	0,15	0,01	-0,11	0,05	3,34	-3,34	0,06	-0,07	0,07	0,04	-0,04	-0,35	0,35	-0,64	-0,16	-0,14
FE405 GAP 2	1,93	1,08	-0,02	0,04	0,21	-0,33	1,23	-0,22	-0,07	0,10	-0,20	2,00	-1,86	-0,01	0,06	-0,06	-0,06	0,06	-0,18	0,18	-1,07	0,18	0,25
FE405 INV FLUSH1	-0,02	0,03	0,00	-0,01	0,04	0,05	-0,04	0,01	0,01	0,01	0,03	-0,02	0,01	0,01	-2,92	2,92	-0,02	0,02	-0,04	0,04	-0,07	0,01	-0,03
FE405 INV FLUSH2	-0,12	0,17	0,05	-0,06	0,43	1,22	-0,60	0,08	0,26	1,10	0,79	1,09	1,31	-0,23	0,54	-0,54	-1,16	1,16	-0,50	0,50	-2,02	1,14	-1,30
FE405 INV GAP 1	0,00	0,01	0,00	0,00	0,00	0,06	-0,02	-0,01	0,01	0,11	0,06	3,34	3,34	-0,05	-0,05	0,05	-0,11	0,11	0,01	-0,01	0,65	0,15	-0,14
FE405 INV GAP 2	0,06	-0,13	-0,02	0,03	-0,14	-0,24	0,16	-0,03	-0,07	-0,11	-0,20	2,00	1,87	0,01	0,08	-0,08	0,14	-0,14	0,17	-0,17	1,08	-0,19	0,26
FE420 ALIGNMENT	-2,38	0,14	0,07	0,20	-0,40	0,27	1,83	0,18	0,03	-0,18	0,09	-2,36	2,39	0,07	0,20	-0,20	0,38	-0,38	0,61	-0,61	-1,88	-0,19	-0,18
FE420 INV ALIGNMENT	0,01	-0,04	0,00	0,00	0,03	0,16	-0,05	0,00	0,03	0,17	0,09	-2,36	-2,39	-0,05	0,22	-0,22	-0,18	0,18	-0,03	0,03	1,90	0,17	-0,17

Front Bumper - Improved Projection, Offset Measurement Results

	2(Z)	4(Z)	6(Z)	8(Y)	10(Y)	12(Y)	14(X)	16(X)	17(Z)	18(Y)	19(X)	1(Z)+2(Z)	1(Z)-2(Z)	-5(Z)+6(Z)	-7(Y)+8(Y)	7(Y)-8(Y)	8(Y)-18(Y)	-8(Y)+18(Y)	8(Y)-10(Y)	-8(Y)+10(Y)	13(X)-14(X)	15(X)-16(X)	-15(X)-16(X)
FE005 FLUSH 1	0,09	0,22	0,39	0,05	-0,24	-0,15	0,21	-2,66	-0,10	-1,94	1,27	0,05	-0,13	0,35	0,04	-0,04	2,00	-2,00	0,29	-0,29	-0,30	2,36	2,96
FE005 FLUSH 2	-0,27	1,13	0,03	-0,03	0,13	0,17	-0,19	0,66	0,94	-0,11	-2,21	-0,53	0,01	0,02	-0,05	0,05	0,08	-0,08	-0,16	0,16	0,01	-0,01	-1,30
FE005 FLUSH 3	-0,04	0,11	0,05	-0,02	0,07	0,12	-0,08	-0,29	-0,10	1,94	1,27	0,05	0,13	-0,28	0,04	-0,04	-1,95	1,95	-0,09	0,09	0,30	-2,39	2,98
FE005 GAP 1	0,12	1,61	0,81	0,12	-0,53	0,03	0,40	0,82	0,08	0,62	-0,30	0,05	-0,19	0,80	0,11	-0,11	-0,51	0,51	0,64	-0,64	-0,45	-0,66	-0,99
FE005 GAP 2	-0,24	0,95	0,01	-0,02	0,11	0,13	-0,17	0,51	-0,15	-0,02	2,02	-0,47	0,01	0,01	-0,04	0,04	0,00	0,00	-0,14	0,14	0,01	-0,01	-1,02
FE005 GAP 3	-0,08	0,27	0,01	-0,01	0,04	0,03	-0,05	0,18	0,08	-0,63	-0,35	0,05	0,20	-0,61	0,12	-0,12	0,62	-0,62	-0,05	0,05	0,49	0,63	-1,00
FE225 FLUSH 1	-0,06	0,17	0,06	-0,02	0,09	0,14	-0,10	-0,32	-0,09	1,81	1,40	0,05	0,16	0,57	0,06	-0,06	-1,83	1,83	-0,11	0,11	0,40	-2,65	3,29
FE225 GAP 1	0,03	-0,12	0,03	0,00	0,02	0,07	-0,02	-0,35	-0,13	2,10	1,13	0,00	-0,06	0,90	-0,05	0,05	-2,10	2,10	-0,03	0,03	-0,13	-0,26	0,96
FE225 GAP 2	0,04	-0,15	0,01	0,00	0,00	0,03	0,00	-0,08	-0,01	0,59	0,09	0,13	0,06	0,27	-0,02	0,02	-0,59	0,59	-0,01	0,01	0,21	-0,23	0,38
FE225 INV FLUSH 1	0,11	0,84	-0,74	0,09	-0,39	-0,15	0,32	-2,93	-0,08	-1,79	1,36	0,05	-0,18	-0,79	0,06	-0,06	1,88	-1,88	0,48	-0,48	-0,43	2,63	3,24
FE225 INV GAP 1	0,00	-0,78	-1,12	-0,03	0,14	-0,13	-0,08	-0,64	-0,12	-2,08	1,10	0,02	0,02	-1,15	-0,04	0,04	2,05	-2,05	-0,18	0,18	0,06	0,31	0,97
FE225 INV GAP 2	0,10	-0,93	-0,39	-0,01	0,00	-2,00	0,23	-0,33	-0,01	-0,64	0,09	0,13	-0,06	-0,40	-0,01	0,01	0,62	-0,62	-0,02	0,02	-0,22	0,26	0,40
FE230 FLUSH 1	0,10	-0,36	0,05	0,00	0,00	0,08	0,02	-0,20	0,02	2,68	0,43	0,84	0,63	-0,23	0,76	-0,76	-2,69	2,69	0,00	0,00	-3,42	1,92	-1,52
FE230 GAP 1	0,04	-0,02	-0,04	0,04	-0,18	-0,20	0,14	0,03	-0,03	-1,07	-0,30	1,47	1,40	0,08	0,03	-0,03	1,11	-1,11	0,22	-0,22	0,61	-0,81	0,75
FE230 GAP 2	-0,14	0,44	0,02	-0,02	0,11	0,10	-0,12	0,11	0,03	-0,59	0,07	-0,36	-0,08	-0,03	-0,07	0,07	0,56	-0,56	-0,13	0,13	0,20	-0,44	0,22
FE230 INV FLUSH 1	0,79	-0,34	0,36	0,71	-1,43	0,35	-3,20	1,49	0,03	-1,92	0,50	0,83	-0,76	0,32	0,69	-0,69	2,63	-2,63	2,14	-2,14	3,12	-1,62	-1,35
FE230 INV GAP 1	1,47	1,48	-0,16	0,04	0,24	-0,67	0,60	-0,81	-0,02	1,24	-0,28	1,48	-1,45	-0,14	0,06	-0,06	-1,21	1,21	-0,20	0,20	-0,51	0,88	0,74
FE230 INV GAP 2	-0,22	2,79	0,04	-0,12	0,40	-0,92	0,11	-0,34	0,01	0,94	0,01	-0,36	0,08	0,03	-0,13	0,13	-1,06	1,06	-0,52	0,52	-0,20	0,48	0,20
FE405 FLUSH 2	0,95	-0,20	0,47	0,50	-1,96	4,00	-3,92	2,52	0,01	-5,12	0,67	1,15	-0,79	0,41	0,50	-0,50	5,62	-5,62	2,46	-2,46	3,95	-2,95	-2,08
FE405 FLUSH1	-0,07	0,00	0,02	-2,99	0,06	0,12	-0,23	0,08	0,00	-0,16	0,03	-0,05	0,07	0,01	-2,99	2,99	-2,83	2,83	-3,05	3,05	0,22	-0,09	-0,07
FE405 GAP 1	3,32	-0,43	0,05	-0,01	0,16	0,09	0,58	0,22	-0,01	-0,46	0,01	3,33	-3,31	0,05	0,00	0,00	0,45	-0,45	-0,17	0,17	-0,53	-0,28	-0,17
FE405 GAP 2	1,97	0,99	-0,08	0,14	-0,14	-0,24	1,38	-0,37	-0,02	0,42	-0,17	2,00	-1,93	-0,06	0,16	-0,16	-0,29	0,29	0,28	-0,28	-1,29	0,37	0,36
FE405 INV FLUSH1	0,01	-0,02	0,00	-0,01	0,03	0,03	-0,02	0,00	0,00	0,14	0,04	-0,02	-0,03	-0,01	-2,98	2,98	-0,14	0,14	-0,03	0,03	-0,17	0,09	-0,08
FE405 INV FLUSH2	0,21	-0,82	0,07	0,01	-0,04	0,06	0,08	-0,41	0,01	5,13	0,55	1,14	0,71	-0,26	0,46	-0,46	-5,12	5,12	0,05	-0,05	-3,96	2,94	-2,12
FE405 INV GAP 1	0,07	-0,19	-0,01	0,05	-0,23	-0,24	0,18	-0,13	-0,03	0,93	-0,08	3,32	3,18	-0,06	0,00	0,00	-0,88	0,88	0,28	-0,28	0,29	0,49	-0,23
FE405 INV GAP 2	0,07	-0,14	-0,03	0,05	-0,20	-0,21	0,17	-0,05	-0,03	-0,15	-0,20	1,99	1,86	0,02	0,15	-0,15	0,20	-0,20	0,25	-0,25	1,15	-0,24	0,34
FE420 ALIGNMENT	-2,37	0,21	0,05	0,30	-0,54	0,60	1,73	0,29	0,01	-0,58	0,11	-2,35	2,39	0,04	0,29	-0,29	0,88	-0,88	0,84	-0,84	-1,76	-0,32	-0,25
FE420 INV ALIGNMENT	0,00	-0,03	0,02	-0,03	0,13	0,16	-0,10	0,01	0,02	0,29	0,14	-2,34	-2,33	-0,01	0,28	-0,28	-0,32	0,32	-0,17	0,17	1,89	0,20	-0,22

Front Bumper - Contour, Offset Measurement Results

	2(Z)	4(Z)	6(Z)	8(Y)	10(Y)	12(Y)	14(X)	16(X)	17(Z)	18(Y)	19(X)	1(Z)+2(Z)	1(Z)-2(Z)	-5(Z)+6(Z)	-7(Y)+8(Y)	7(Y)-8(Y)	8(Y)-18(Y)	-8(Y)+18(Y)	8(Y)-10(Y)	-8(Y)+10(Y)	13(X)-14(X)	15(X)-16(X)	-15(X)-16(X)
FE005 FLUSH 1	0,33	-3,14	0,67	0,10	-0,71	-3,32	0,81	-2,87	4,72	1,79	0,80	0,76	0,11	1,31	0,10	-0,10	-1,68	1,68	0,81	-0,81	-0,70	2,46	3,27
FE005 FLUSH 2	-0,09	-0,10	0,07	0,00	0,09	-0,05	-0,07	0,04	2,97	-0,13	-1,23	-0,15	0,02	0,03	-0,01	0,01	0,12	-0,12	-0,09	0,09	0,02	-0,01	-0,07
FE005 FLUSH 3	0,41	-1,44	-0,67	-0,01	-0,24	0,68	0,08	-0,39	4,38	-1,57	0,86	0,71	-0,10	-1,40	0,09	-0,09	1,56	-1,56	0,24	-0,24	0,64	-2,44	3,22
FE005 GAP 1	0,06	0,53	1,97	0,01	-0,08	0,34	0,06	1,00	0,65	-0,34	-0,03	0,12	0,00	2,06	0,02	-0,02	0,35	-0,35	0,09	-0,09	0,00	-1,05	-0,94
FE005 GAP 2	-0,09	-0,12	0,07	0,00	0,09	-0,08	-0,07	0,04	1,57	-0,01	2,77	-0,16	0,02	0,03	-0,01	0,01	0,00	0,00	-0,09	0,09	0,01	-0,02	-0,07
FE005 GAP 3	0,09	-0,54	-0,14	0,01	-0,09	-0,23	0,08	-0,08	1,04	0,31	-0,02	0,18	0,00	-1,95	0,02	-0,02	-0,31	0,31	0,10	-0,10	0,02	1,03	-0,86
FE225 FLUSH 1	0,52	-1,91	-0,84	0,00	-0,33	0,68	0,13	-0,49	5,57	-2,07	0,97	0,88	-0,14	-0,99	0,11	-0,11	2,07	-2,07	0,32	-0,32	0,73	-2,65	3,63
FE225 GAP 1	0,18	-0,48	-0,31	-0,01	-0,08	0,59	-0,01	-0,18	1,92	-0,48	0,59	0,35	-0,01	1,56	0,04	-0,04	0,47	-0,47	0,07	-0,07	0,42	-0,62	0,98
FE225 GAP 2	-0,01	0,19	0,00	-0,01	0,03	0,27	-0,05	0,00	-1,02	2,02	0,16	0,01	0,02	0,40	0,00	0,00	-2,03	2,03	-0,04	0,04	0,11	-0,25	0,25
FE225 INV FLUSH 1	0,42	-3,46	-0,21	0,13	-0,87	-3,72	0,97	-3,19	6,05	2,17	0,90	0,96	0,15	0,59	0,13	-0,13	-2,05	2,05	1,00	-1,00	-0,80	2,68	3,70
FE225 INV GAP 1	0,18	-1,85	-1,85	0,06	-0,40	-2,07	0,47	-0,83	2,24	0,66	0,56	0,38	0,04	-1,54	0,05	-0,05	-0,60	0,60	0,46	-0,46	-0,46	0,64	1,02
FE225 INV GAP 2	0,00	-0,04	-0,41	0,00	-0,03	-0,27	0,04	-0,24	-1,15	-2,08	0,15	-0,02	-0,02	-0,43	0,00	0,00	2,08	-2,08	0,03	-0,03	-0,10	0,26	0,23
FE230 FLUSH 1	0,09	0,15	-0,18	-0,02	0,03	0,98	-0,12	-0,10	-1,66	4,38	0,65	0,38	0,20	-2,41	-0,08	0,08	-4,40	4,40	-0,05	0,05	-3,17	1,51	-1,31
FE230 GAP 1	-0,23	0,72	0,38	0,01	0,12	-0,56	-0,02	0,22	-0,71	-3,36	-0,59	1,38	1,84	1,68	-0,22	0,22	3,36	-3,36	-0,11	0,11	1,10	-1,06	0,61
FE230 GAP 2	0,13	-0,56	-0,21	0,00	-0,10	0,03	0,06	-0,12	1,61	0,51	0,25	0,00	-0,27	0,30	-0,01	0,01	-0,51	0,51	0,10	-0,10	-0,12	-0,19	0,44
FE230 INV FLUSH 1	0,44	-0,79	1,88	0,06	-1,16	3,15	-2,95	1,11	-0,26	-3,90	0,63	0,62	-0,28	2,16	0,05	-0,05	3,95	-3,95	1,22	-1,22	2,90	-1,28	-0,94
FE230 INV GAP 1	1,60	2,44	-1,29	-0,21	0,62	-2,77	0,79	-0,76	-0,85	3,06	-0,54	1,37	-1,82	-1,63	-0,21	0,21	-3,27	3,27	-0,83	0,83	-0,81	0,98	0,55
FE230 INV GAP 2	-0,13	2,70	-0,51	-0,01	0,11	0,47	-0,05	-0,30	1,51	-0,45	0,22	-0,01	0,26	-0,32	0,00	0,00	0,44	-0,44	-0,12	0,12	0,11	0,18	0,41
FE405 FLUSH 2	0,61	-1,08	1,79	-1,02	-0,34	3,03	-2,59	1,05	0,05	-3,75	0,61	0,82	-0,43	2,09	-1,03	1,03	2,73	-2,73	-0,68	0,68	2,56	-1,24	-0,86
FE405 FLUSH1	-0,08	-0,03	0,05	-3,02	0,06	0,08	-0,18	0,03	0,02	-0,11	0,02	-0,07	0,08	0,06	-3,02	3,02	-2,90	2,90	-3,08	3,08	0,18	-0,04	-0,02
FE405 GAP 1	3,34	-0,85	0,33	0,16	-0,12	0,82	0,51	0,20	0,37	-0,87	0,16	3,42	-3,27	0,45	0,16	-0,16	1,03	-1,03	0,28	-0,28	-0,49	-0,27	-0,13
FE405 GAP 2	2,04	1,54	-0,70	-0,05	0,11	-1,60	1,57	-0,42	-0,65	1,75	-0,32	1,89	-2,18	-0,92	-0,05	0,05	-1,80	1,80	-0,16	0,16	-1,59	0,55	0,28
FE405 INV FLUSH1	0,01	-0,04	-0,02	0,00	-0,01	0,02	0,00	-0,01	0,06	0,14	0,03	-0,02	-0,05	-0,07	-3,01	3,01	-0,14	0,14	0,01	-0,01	-0,13	0,04	-0,02
FE405 INV FLUSH2	0,17	-0,30	-0,30	-0,01	-0,05	0,82	-0,05	-0,17	-0,54	4,10	0,65	0,73	0,39	-2,16	-1,07	1,07	-4,12	4,12	0,03	-0,03	-2,70	1,36	-1,02
FE405 INV GAP 1	0,08	-0,27	-0,13	0,00	-0,05	0,14	0,01	-0,07	0,36	0,93	0,17	3,42	3,26	-0,45	0,16	-0,16	-0,93	0,93	0,04	-0,04	0,48	0,28	-0,13
FE405 INV GAP 2	-0,14	0,46	0,23	0,00	0,08	-0,30	-0,02	0,13	-0,52	-1,88	-0,34	1,91	2,19	0,93	-0,04	0,04	1,88	-1,88	-0,07	0,07	1,64	-0,58	0,32
FE420 ALIGNMENT	-2,45	0,32	0,12	-0,05	-0,11	0,04	1,98	0,07	-0,26	-0,12	0,01	-2,46	2,43	0,10	-0,06	0,06	0,07	-0,07	0,05	-0,05	-2,00	-0,06	-0,08
FE420 INV ALIGNMENT	-0,01	0,04	0,01	0,00	0,01	0,03	-0,01	0,01	-0,15	0,11	0,01	-2,44	-2,43	-0,07	-0,04	0,04	-0,11	0,11	-0,01	0,01	2,01	0,05	-0,06

Front Bumper - Auto-AA, Offset Measurement Results

	2(Z)	4(Z)	6(Z)	8(Y)	10(Y)	12(Y)	14(X)	16(X)	17(Z)	18(Y)	19(X)	1(Z)+2(Z)	1(Z)-2(Z)	-5(Z)+6(Z)	-7(Y)+8(Y)	7(Y)-8(Y)	8(Y)-18(Y)	-8(Y)+18(Y)	8(Y)-10(Y)	-8(Y)+10(Y)	13(X)-14(X)	15(X)-16(X)	-15(X)-16(X)
FE005 FLUSH 1	0,00	0,00	0,24	0,00	0,00	-2,46	-0,36	-1,19	0,31	0,00	0,00	0,16	0,16	0,24	0,00	0,00	0,00	0,00	0,00	0,00	0,37	1,19	1,19
FE005 FLUSH 2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,53	-0,08	-1,28	-0,30	-0,30	-0,48	0,00	0,00	0,08	-0,08	0,00	0,00	0,00	0,00	0,00
FE005 FLUSH 3	0,16	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,31	0,00	0,00	0,16	-0,16	-0,25	0,00	0,00	0,00	0,00	0,00	0,00	-0,38	-1,17	1,17
FE005 GAP 1	0,00	0,00	2,88	0,00	0,00	0,18	0,11	0,92	0,01	0,00	0,00	-0,08	-0,08	2,88	0,00	0,00	0,00	0,00	0,00	0,00	-0,11	-0,92	-0,92
FE005 GAP 2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,09	0,00	2,72	-0,31	-0,31	-0,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,01	0,01
FE005 GAP 3	-0,10	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,05	0,00	0,00	-0,10	0,10	-2,87	0,00	0,00	0,00	0,00	0,00	0,00	0,12	0,91	-0,91
FE225 FLUSH 1	0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,34	0,00	0,00	0,13	-0,13	0,10	0,00	0,00	0,00	0,00	0,00	0,00	-0,45	-1,23	1,23
FE225 GAP 1	0,18	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,28	0,00	0,00	0,18	-0,18	2,55	0,00	0,00	0,00	0,00	0,00	0,00	-0,22	0,24	-0,24
FE225 GAP 2	0,15	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,23	0,00	0,00	0,15	-0,15	1,26	0,00	0,00	0,00	0,00	0,00	0,00	0,44	-0,49	0,51
FE225 INV FLUSH 1	0,00	0,00	-0,17	0,00	0,00	-2,47	-0,41	-1,26	0,36	0,00	0,00	0,12	0,12	-0,17	0,00	0,00	0,00	0,00	0,00	0,00	0,41	1,26	1,26
FE225 INV GAP 1	-0,59	-1,52	0,00	0,00	-2,19	0,00	1,81	-1,76	0,00	0,00	0,00	-0,52	0,67	0,00	0,00	0,00	0,00	0,00	2,19	-2,19	-1,77	1,79	1,79
FE225 INV GAP 2	0,00	0,00	-1,27	0,00	0,00	-2,68	0,44	-0,51	-0,20	0,00	0,00	0,13	0,13	-1,27	0,00	0,00	0,00	0,00	0,00	0,00	-0,42	0,52	0,52
FE230 FLUSH 1	0,13	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,33	0,08	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,90	-0,52	0,53
FE230 GAP 1	-0,12	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,73	1,96	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,30	0,14	-0,14
FE230 GAP 2	-0,41	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,11	0,00	0,00	-0,41	0,41	-2,29	0,00	0,00	0,00	0,00	0,00	0,00	-0,02	-0,18	0,17
FE230 INV FLUSH 1	0,21	0,43	0,00	0,00	-2,53	0,00	-0,89	-0,52	0,00	0,00	0,00	0,35	-0,08	0,00	0,00	0,00	0,00	0,00	2,53	-2,53	0,90	0,52	0,52
FE230 INV GAP 1	1,83	1,07	0,00	0,00	1,04	0,00	-0,45	0,11	0,00	0,00	0,00	1,72	-1,95	0,00	0,00	0,00	0,00	0,00	-1,04	1,04	0,45	-0,12	-0,12
FE230 INV GAP 2	0,00	0,00	2,35	0,00	0,00	0,22	-0,02	-0,16	1,04	0,00	0,00	-0,38	-0,38	2,35	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,16	0,16
FE405 FLUSH 2	0,42	0,11	0,00	0,00	-2,68	0,00	-1,23	0,10	0,00	0,00	0,00	0,62	-0,22	0,00	0,00	0,00	0,00	0,00	2,68	-2,68	1,22	-0,10	-0,10
FE405 FLUSH1	-0,08	0,02	0,00	-3,00	0,00	0,00	-0,13	-0,01	0,00	0,00	0,00	-0,08	0,09	0,00	-3,00	3,00	-3,00	3,00	-3,00	3,00	0,12	0,01	0,01
FE405 GAP 1	3,26	-0,39	0,00	-0,09	0,00	0,00	0,91	-0,10	0,00	0,00	0,00	3,28	-3,23	0,00	-0,09	0,09	-0,09	0,09	-0,09	0,09	-0,91	0,10	0,10
FE405 GAP 2	2,19	0,71	0,00	0,00	0,38	0,00	0,94	0,00	0,00	0,00	0,00	2,11	-2,26	0,00	0,00	0,00	0,00	0,00	-0,38	0,38	-0,94	0,00	0,00
FE405 INV FLUSH1	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,04	-0,05	0,00	-3,00	3,00	0,00	0,00	0,00	0,00	-0,07	-0,01	0,01
FE405 INV FLUSH2	0,19	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,61	0,23	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-1,21	0,09	-0,09
FE405 INV GAP 1	0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	3,28	3,23	0,00	-0,09	0,09	0,00	0,00	0,00	0,00	0,91	-0,10	0,10
FE405 INV GAP 2	-0,07	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,11	2,26	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,94	0,01	0,00
FE420 ALIGNMENT	-2,45	0,30	0,00	-0,31	0,00	0,00	2,28	-0,23	0,00	0,00	0,00	-2,47	2,43	0,00	-0,31	0,31	-0,31	0,31	-0,31	0,31	-2,29	0,22	0,22
FE420 INV ALIGNMENT	-0,02	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-2,47	-2,43	0,00	-0,31	0,31	0,00	0,00	0,00	0,00	2,28	-0,23	0,22

Front Bumper - GSU-AA, Offset Measurement Results

	2(Z)	4(Z)	6(Z)	8(Y)	10(Y)	12(Y)	14(X)	16(X)	17(Z)	18(Y)	19(X)	1(Z)+2(Z)	1(Z)-2(Z)	-5(Z)+6(Z)	-7(Y)+8(Y)	7(Y)-8(Y)	8(Y)-18(Y)	-8(Y)+18(Y)	8(Y)-10(Y)	-8(Y)+10(Y)	13(X)-14(X)	15(X)-16(X)	-15(X)-16(X)
FE005 FLUSH 1	0,00	0,00	0,77	0,00	0,00	0,00	0,00	-1,82	0,06	-2,46	0,00	0,00	0,00	0,89	0,00	0,00	2,46	-2,46	0,00	0,00	0,00	2,07	1,55
FE005 FLUSH 2	0,00	0,00	-0,23	0,00	0,00	0,00	0,00	-0,64	3,14	-0,08	0,00	0,00	0,00	0,01	0,00	0,00	0,08	-0,08	0,00	0,00	0,00	-0,01	1,28
FE005 FLUSH 3	0,00	0,00	-0,13	0,00	0,00	0,00	0,00	0,26	0,10	2,46	0,00	0,00	0,00	-0,91	0,00	0,00	-2,46	2,46	0,00	0,00	0,00	-2,09	1,55
FE005 GAP 1	0,00	0,00	2,78	0,00	0,00	0,00	0,00	1,07	0,20	0,18	0,00	0,00	0,00	2,95	0,00	0,00	-0,18	0,18	0,00	0,00	0,00	-1,12	-1,03
FE005 GAP 2	0,00	0,00	-0,75	0,00	0,00	0,00	0,00	1,36	2,88	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-2,71
FE005 GAP 3	0,00	0,00	-0,23	0,00	0,00	0,00	0,00	-0,05	0,30	-0,18	0,00	0,00	0,00	-2,96	0,00	0,00	0,18	-0,18	0,00	0,00	0,00	1,12	-1,03
FE225 FLUSH 1	0,00	0,00	-0,11	0,00	0,00	0,00	0,00	0,18	0,00	2,46	0,00	0,00	0,00	-0,60	0,00	0,00	-2,46	2,46	0,00	0,00	0,00	-1,72	1,27
FE225 GAP 1	0,00	0,00	-0,02	0,00	0,00	0,00	0,00	0,26	0,00	2,16	0,00	0,00	0,00	2,04	0,00	0,00	-2,16	2,16	0,00	0,00	0,00	-0,68	0,19
FE225 GAP 2	0,00	0,00	-0,42	0,00	0,00	0,00	0,00	0,45	0,00	2,68	0,00	0,00	0,00	0,50	0,00	0,00	-2,68	2,68	0,00	0,00	0,00	-2,23	1,57
FE225 INV FLUSH 1	0,00	0,00	0,44	0,00	0,00	0,00	0,00	-1,76	0,00	-2,47	0,00	0,00	0,00	0,54	0,00	0,00	2,47	-2,47	0,00	0,00	0,00	2,01	1,50
FE225 INV GAP 1	0,00	0,00	-2,02	0,00	0,00	0,00	0,00	-0,26	0,00	-2,19	0,00	0,00	0,00	-1,99	0,00	0,00	2,19	-2,19	0,00	0,00	0,00	0,46	0,05
FE225 INV GAP 2	0,00	0,00	-0,92	0,00	0,00	0,00	0,00	-0,80	0,00	-2,68	0,00	0,00	0,00	-0,51	0,00	0,00	2,68	-2,68	0,00	0,00	0,00	0,90	0,68
FE230 FLUSH 1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,49	-1,21	1,18
FE230 GAP 1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,03	1,39	-1,40
FE230 GAP 2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,38	-0,21	0,17
FE230 INV FLUSH 1	0,00	0,00	0,00	0,00	0,00	0,00	-0,47	-1,21	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,45	1,18	1,18
FE230 INV GAP 1	0,00	0,00	0,00	0,00	0,00	0,00	-0,13	1,38	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,15	-1,38	-1,38
FE230 INV GAP 2	0,00	0,00	0,00	0,00	0,00	0,00	-0,39	-0,16	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,37	0,12	0,12
FE405 FLUSH 2	-0,57	0,00	0,00	-2,68	0,00	0,00	-1,13	0,00	0,00	0,00	0,00	-0,57	0,70	0,00	-2,68	2,68	-2,68	2,68	-2,68	2,68	1,13	0,00	0,00
FE405 FLUSH1	-0,20	0,00	0,00	-3,00	0,00	0,00	-0,13	0,00	0,00	0,00	0,00	-0,20	0,21	0,00	-3,00	3,00	-3,00	3,00	-3,00	3,00	0,13	0,00	0,00
FE405 GAP 1	5,09	0,00	0,00	-0,09	0,00	0,00	0,81	0,00	0,00	0,00	0,00	5,09	-5,14	0,00	-0,09	0,09	-0,09	0,09	-0,09	0,09	-0,81	0,00	0,00
FE405 GAP 2	-0,91	0,00	0,00	0,38	0,00	0,00	0,95	0,00	0,00	0,00	0,00	-0,91	0,91	0,00	0,38	-0,38	0,38	-0,38	0,38	-0,38	-0,95	0,00	0,00
FE405 INV FLUSH1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,13	-0,13	0,00	-2,97	2,96	0,00	0,00	0,00	0,00	-0,08	0,00	0,00
FE405 INV FLUSH2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,08	-0,08	0,00	1,13	-1,14	0,00	0,00	0,00	0,00	-1,13	0,00	0,00
FE405 INV GAP 1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	5,13	5,13	0,00	0,19	-0,21	0,00	0,00	0,00	0,00	0,81	0,00	0,00
FE405 INV GAP 2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-0,98	-0,98	0,00	-0,21	0,22	0,00	0,00	0,00	0,00	0,95	0,00	0,00
FE420 ALIGNMENT	-3,64	0,00	0,00	-0,31	0,00	0,00	2,06	0,00	0,00	0,00	0,00	-3,64	3,52	0,00	-0,31	0,31	-0,31	0,31	-0,31	0,31	-2,06	0,00	0,00
FE420 INV ALIGNMENT	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-3,56	-3,56	0,00	0,32	-0,39	0,00	0,00	0,00	0,00	2,06	0,00	0,00

APPENDIX V - CREATING THE PROJECTION MESH

This section describes the procedure the group did to create the Projection mesh. Some basic knowledge of the programs used is expected from the reader to fully follow the procedure. This procedure is intended for experimental purpose but not as a final solution, for generating projected mesh.

The general principles used for the projection technique is that a mesh plane is created, where distances from the plane to a part is measured for every node. Then those distances are added to the nodes to offset them into right position. Nodes outside the surface will be deleted. Then the mesh is ready to be exported and used in RD&T. The whole procedure is further described in more details below.

To perform this procedure following software are needed: ANSA, MATLAB and a developers version of RD&T.

STEP 1: FIND THE GEOMETRY OUTER COORDINATES [RD&T]

Before creating the plane the coordinates of the plane, which defining its position and size, must be known. The part should be positioned in RD&T such that its surface that will be projected should be facing up (in this experiment it does only work for a direction perpendicular to the global XY, XZ or YZ plane.) Take notes of the parts outer dimensions such that a plane will fully cover the part. Then the third dimension must be considered so that the plane will have an offset from the part. Figure 1a and 1b gives an idea of the how a plane will look like considering outer dimensions and offset.

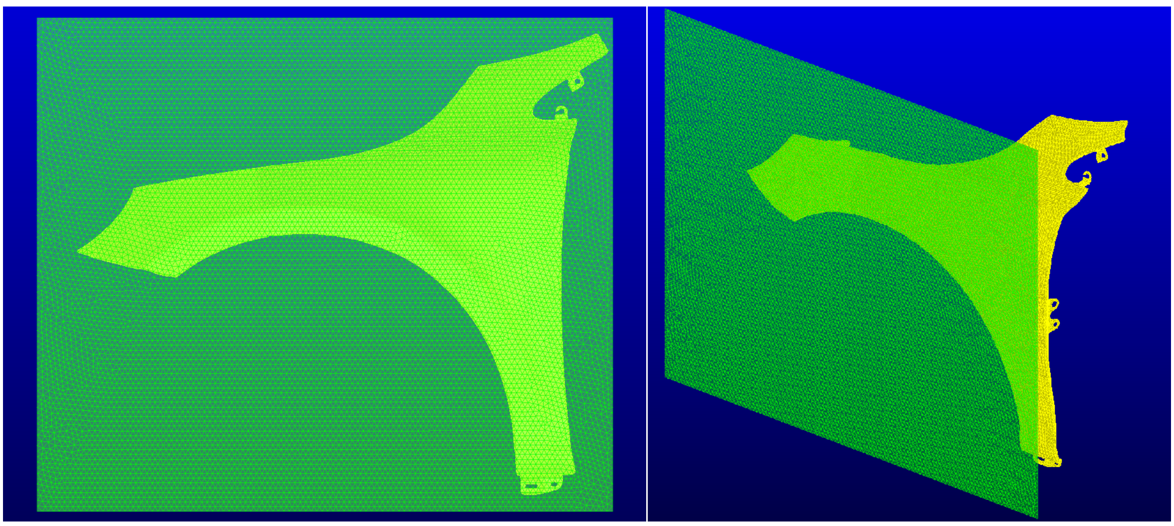


Figure 1a – The outer boundaries has been identified in XZ direction where the part is fully covered by the plane. Figure 1b – The plane has an offset in the third dimension.

STEP 2: CREATING THE PLANE [ANSA]

Create the four corners in ANSA; In the TOPO module select [Points – NEW- Num.Input]. Enter coordinates of the four corners of the plane that was collected in step 1. It is recommended to exaggerate the outer boundaries as well as the offset to be certain the part will be fully covered. Draw a rectangle by drawing a line between the four corner-points with [CURVEs – New – Pick] tool. Make a surface with [SURFs COONS] tool. Select the MESH module and use [MESH GEN. – FREE –visible] tool to create the mesh. Now the plane is ready and can be exported to ABAQUS format.

STEP 3: PROJECTING THE PLANE TO THE GEOMETRY [RD&T]

Import the mesh created in the previous step in the same RD&T- file as the part to be projected to.

First add tolerances to all nodes in the plane by Selecting [RDI/Analysis – Miscellaneous – Create Mesh tolerances]. Select the plane in the list that appears. By clicking [Toggle Tolerance visibility] tolerances appear on the screen, perpendicular against the plane in both directions. The measurement offsets will measure in the same directions as these tolerances.

Next step is to create measurements in the tolerances. Select [Volvo Documents – Matching – Scan data from measurement program, new]. Select the plane as "Data part" and the part file as "Scanned part". Make sure to choose a needle length long enough so the plane offset will completely reach the part, see figure x. Click [Toggle measure visibility], and offsets that reached part surface will appear pointing in the same direction as the tolerances previously added, see Figure 2 below.

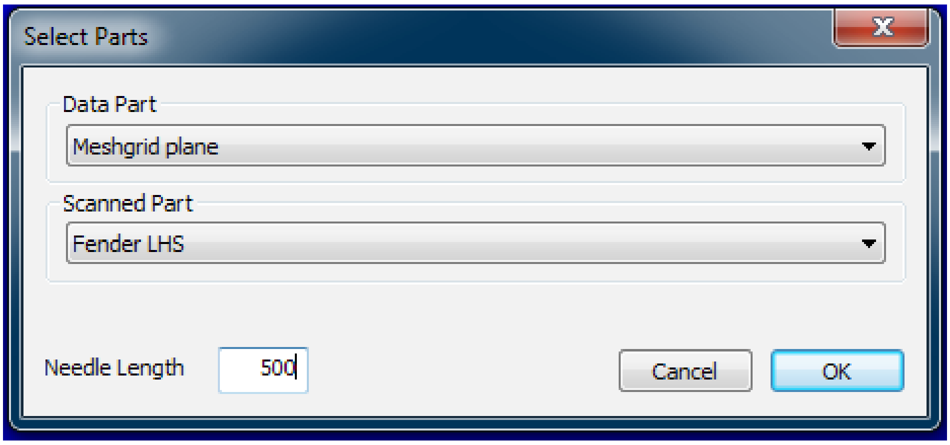


Figure 2 - "Mesh grid plane" is to be projected to the part "Fender LHS" with an offset of 500mm.

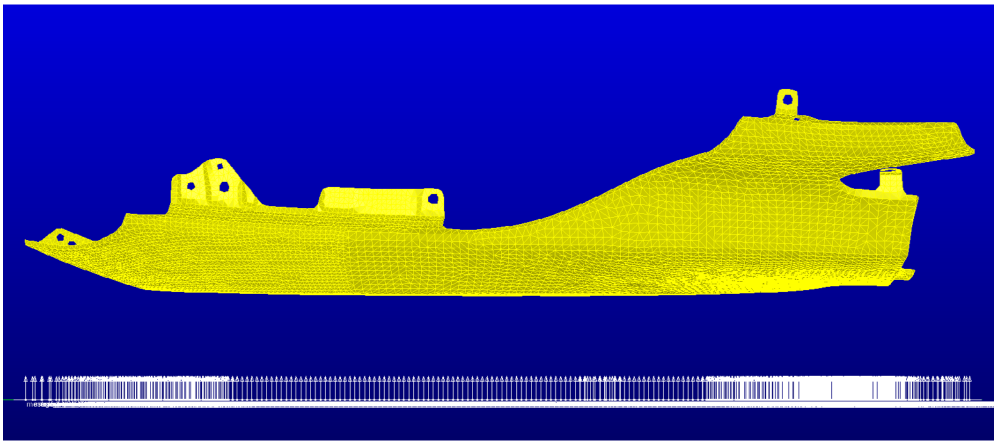


Figure 3 - Showing measurement points based.

Now the measurement is done and the results can be exported. This is done by selecting [Misc. – create PCA-files]. Note that there will be one measurement document for every part from the RD&T. Use the one with the same file name as the plane in the next step.

STEP 4: [MATLAB]

To create the final projection mesh a MATLAB-code is written. The principle functions of the program are importing the meshed-plane-file created in step 2 together with the offset measure file from step 3 into the program. The program will add the measured offsets to the nodes of the plane, which makes them move to its projected position. Measured offsets that did not find surface will be identified with value 10^4 in the offset measurement list. The program recognizes this value and removes those nodes. Thus, outer boundary and holes of the part will be cut off. When all nodes are moved or removed the program converts the mesh to .inp format that is ready for usage in RD&T.

The reader can follow the code in detail below.

MAIN CODE - PROJECTION TECHNIQUE

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%% Projection Technique %%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% This program is used for the "projection technique" to
% automatically generate a projection. The program needs the
% original plane mesh (.inp) and the exported text file (.txt) from
% RD&T containing the offsets. The program will add the offsets to
```

```
% the plane and is also able to cut of edges to get the components
% contour. This by removing  nodes with an offset of 10^4 which is a
% number for indicating ?no hit?.
%
% This program is supported by external function files:
%
% "move_nodes.m" - This function is used to move the closest node to
% a reference- or measurement point's direction.
%
% "save_inp_nostr.m" - Saves the final result to .inp format.

clear variables
%file_name = 'hood_test_20130520/mesh_10mm.inp';
file_name = 'Bumper_real_NH_20130628/Bumper_meshgrid10_6_merged_3_
smallholes_filled.inp';
offset_file_name = 'Bumper_real_NH_20130628/LeftMesh.txt';
result_name = 'Bumper_real_NH_20130628/bump_smallholesfilled.inp';
ref_list_name = 'Bumper_real_NH_20130628/refandmeapoints_Bumper_no-
LLP.txt';

offset_direction = 2;   % 1: X, 2: Y and 3: Z
direction_sign = 1;     % defines if the direction should be positive
or neg.

offset = 0; % 0: do not offset the points, 1: offset the points in the
mesh
cut = 0;    % 0: do nothing to the edges, 1: trim the edges
move = 1;   % 0: do nothing to the nodes, 1: move the nodes
save = 1;   % 0: do nothing with the result, 1: save to inp-file

%% Read data
inp_str = fileread(file_name);    % Read data from file

%% Find node data
node_start = strfind(inp_str,'*NODE');  % Find where the node begins

node_str = inp_str(node_start:end);     % Create a string that starts
with the nodes.
node_str(1) = '%';                     % Replace the * with a % to re-
```

```
move the text from MATLABs scanning

node_end = strfind(node_str,'*');   % Find the end of the nodes by
finding the first * in the str
node_end = node_end(1)-1;            % Since we only need the first, we
can remove all other results

node_str = node_str(1:node_end);    % Create the new node_str, con-
taining only the important data

%% Save node data to file
n_fid = fopen('nodes.txt','w');     % open node.txt (or create it if
it does not exist)
fprintf(n_fid,'%s',node_str);       % write node_str to the opened
nodes.txt-file
fclose(n_fid);                      % close the file
clear node_str n_fid;               % clear node_str and n_fid to save
space

%% Find element data
elem_start = strfind(inp_str,'*ELEMENT');   % Find where the node be-
gins

elem_str = inp_str(elem_start:end);     % Create a string that starts
with the nodes.
elem_str(1) = '%';                   % Replace the * with a % to re-
move the text from MATLABs scanning

elem_end = strfind(elem_str,'*');   % Find the end of the nodes by
finding the first * in the str
elem_end = elem_end(1)-1;            % Since we only need the first, we
can remove all other results

elem_str = elem_str(1:elem_end);    % Create the new node_str, con-
taining only the important data


%% Save element data to file
e_fid = fopen('elements.txt','w');  % open elements.txt (or create it
```

```
if it does not exist)
fprintf(e_fid,'%s',elem_str);       % write node_str to the opened el-
ements.txt-file
fclose(e_fid);                      % close the file
clear elem_str e_fid;               % clear elem_str and e_fid to save
space

%% Load the data into matrices and structures
node_load = load('nodes.txt');       % load nodes into matrices
elem_load = load('elements.txt');    % load elements into matrices

%% Modify the nodes (no struct)
% This lets us loop through each coordinate and add a value to it.
% This requires that we add the points for each direction separatly
if (offset)

    node_offset = load(offset_file_name);        % Name of the file that
should be loaded

    if (cut)
        % We do want to cut the edges, so let us loop through the
        % nodes in order to remove all emelents containing nodes
        % with 1e4 as their value
        for i=1:length(node_load(:,1))
            if ( node_offset(i) == 1e4 )
                % Using the function structfind we get an array of
                % all indexes of the elements containing the current
                % node-id. These elements are then deleted.
                remove = find(elem_load(:,2) == node_load(i,1));
                elem_load(remove,:) = [];
                remove = find(elem_load(:,3) == node_load(i,1));
                elem_load(remove,:) = [];
                remove = find(elem_load(:,4) == node_load(i,1));
                elem_load(remove,:) = [];
            end
        end
        disp('elements removed')
    end
```

```
    % The move of the coordinates by adding the offset. 2 rep. x, 3
    % rep. y and 4 rep. z. Remember to change the direction by
    % changing the + or - as well
    % UPDATE: Now the offset direction is set in the program head
    node_load(:,offset_direction+1) = node_load(:,offset_direction+1) -
direction_sign*node_offset';     % Now it is x dir
    disp('nodes offseted')

    if (cut)
        rem_element = find(node_offset == 1e4);
        node_load(rem_element,:) = [];

        disp('nodes removed')
    end
end

%% Move nodes to ref. or measurmentpoints
if (move)
    node_load(:,2:4) = move_nodes(node_load(:,2:4),ref_list_name);
    disp('moved')
end
%% Save the changes to abaqus format (.inp)
if (save)
    save_inp_nostr(file_name, result_name, node_load, node_start,
node_end, elem_load, elem_start, elem_end)
    disp('saved')
end
```

FUNCTION FILE “MOVE_NODES”

```
function node = move_nodes(node,ref_list_name)

ref_list = load(ref_list_name);   % load elements into matrices

for i=1:length(ref_list(:,1))
    nearest = knnsearch(node,ref_list(i,:),'k',1);
    node(nearest,:) = ref_list(i,:);
end
end
```

FUNCTION FILE “SAVE_INP_NOSTR”

```
function save_inp_nostr(file_name, result_name, node, node_start,
node_end, elem, elem_start, elem_end)

inp_str = fileread(file_name);          %Read data from file

inp_intro = inp_str(1:node_start-1);    % Get the first part of the
inp-file
inp_nodes = '*NODE';
inp_middle = inp_str(node_start+node_end:elem_start-1);   % Get the
middle part of the inp-file
elem_f_s = strfind(inp_str(elem_start:end), sprintf('\n'));   % Get
the position of the end of the element sentence
inp_elem = inp_str(elem_start:elem_start-1+elem_f_s(1));   % Get the
element sentence from the two positions
inp_end = inp_str(elem_start+elem_end:end);   % Get the last part of
the inp-file

fid = fopen(result_name, 'w');
fprintf(fid,'%s\n',inp_intro);
fprintf(fid,'%s\n',inp_nodes);
for row=1:length(node(:,1))
    fprintf(fid, '\t%u,\t%f,\t%f,\t%f\n', node(row,1), node(row,2),
node(row,3), node(row,4));
end

fprintf(fid,'%s',inp_middle);
fprintf(fid,'%s',inp_elem);
for row=1:length(elem(:,1))
    fprintf(fid, '\t%u,\t%u,\t%u,\t%u\n', elem(row,1), elem(row,2),
elem(row,3), elem(row,4));
end

fprintf(fid,'%s\n',inp_end);

fclose(fid);

end
```

APPENDIX VI - APPLYING THE CONTOUR MESH TECHNIQUE

This section describes the procedure of creating the contour mesh. Some basic knowledge of the programs used is expected from the reader to fully be able to redo the procedure. This procedure is intended for experimental purpose but not as a final solution, for generating contour mesh.

The different types of software needed to perform this procedure are RD&T and MATLAB.

STEP 1: IDENTIFYING LOCATORS AND MEASUREMENT POINTS [RD&T]

In this step write down coordinates for all the locators and measurement points that are to be included in the model.

STEP 2: CREATING THE CONTOUR [ANSA]

Create all the nodes in ANSA; In the TOPO module select [Points – NEW- Num.Input]. Enter coordinates of the measurement points and locators that were collected in step 1, the node will appear as example shown in Figure 1a. Create the contour by drawing lines between the -points with [CURVEs – New – Pick] tool. It can sometimes be hard to create a surface only by drawing lines of the outer contour. Therefore it is recommended to also draw lines inside of the contour as example shown in Figure 1b below. Make a surface with [SURFs COONS] tool. Select the MESH module and use [MESH GEN. – FREE –visible] tool to create the mesh, like example shown in Figure 1c. Now the part is ready and can be exported to ABAQUS format.

Figure 1a, b and c are showing the three steps when creating a contour mesh of a front Fender.

STEP 3: USE THE MODEL [RD&T]

Import the contour mesh into RD&T. It can be useful to use the function “check mesh” before start working with it, to make sure the mesh is working correctly.

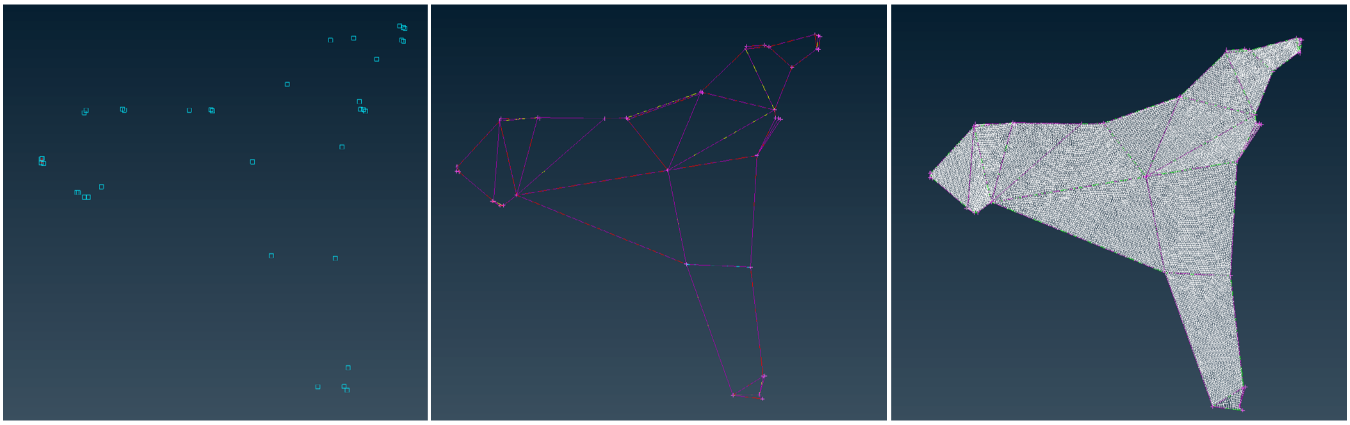


Figure 1a-c - Visualisation of the three steps used to create a contour mesh

APPENDIX VII - APPLYING THE AUTO-AA TECHNIQUE

This section describes the procedure of creating the Alternative Assemblies. Some basic knowledge of the programs used is expected from the reader to fully be able to redo the procedure. This procedure is intended for experimental purpose but not as a final solution, for generating Alternative Assemblies.

The different types of software needed to perform this procedure are RD&T and MATLAB.

STEP 1 NOTE LOCATORS AND MEASUREMENT POINTS [RD&T]

Note the locators and measurement points in separate lists. The locators have to be divided into three directions that are concerning the whole part. For example all x-directions reference points are put in the A-list, all y-direction reference points are put in the B-list and all z-direction reference points are put in the C-list. The A, B and C directions refer to the 3-2-1 positioning system where A is a plane represented by 3 locators, B is a line defined by 2 locators and C is a point defined by the last locator.

STEP 2 AUTOMATICALLY GENERATE POSITIONING SYSTEMS [MATLAB]

Import the locators and measurement points as two separate matrixes.

For every measurement point a new 3-2-1 system is automatically generated. Firstly the A-system locators are selected. The script starts searching for A-direction locators, choosing the two closest ones and the third one furthest away. It is important that the plane is perpendicular* to the A-direction. During the experiments, there were two cases where perpendicularity was not achieved and reselection of the second closest locator was made to solve this. Secondly, B-direction locators are selected selecting the closest locators in B-direction. Here it is important that the locators constitute a line perpendicular to B-direction. Finally the C-direction locator is selected based on the node closest in C direction. The code used is provided below.

STEP 3 APPLYING THE POSITIONING SYSTEMS [RD&T]

Use the suggested systems generated from the MATLAB code either by using Alternative Assemblies or flex positioning in RD&T.

An example of output could be:

Ref.Sys Name: AA Ref. System No7

A1-3: A1, S4 & S6

B1-2: B1 & S8/S9

C1: C1

Measurement Name: SD105 Gap 2

AA No: 7

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%% Alternative Assembly Finder Script %%%%%%%%%%%%%%%%%%%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% This script was written as a part of the Master Thesis; Alternative
% techniques for non-rigid variation simulation, in order to find
% and order the closest Alternative Assembly (AA) system. The goal
% was to have a simple script that generated the closest achievable
% AA system from a simple algorithm. This script lets the user enter
% coordinates and names for all Reference Points (RP) separated into
% A, B and C categories (rather than pre-defined directions) as well
% as Measurement Points (MP).
%
% For each MP, the script finds the three closest A-points, the two
% closest B-points and the closest C-point. These points constitute
% an AA-system
% (3-2-1 system), that is recommended for that specific MP.
%
% The second part of the script compares the AA-systems in order
% remove duplicates and then updates the measurements references to
% each system.
% Finally the user is given a list of reference systems (AA-systems)
% and each measurements system connection. Here is an example:

clear variables


%% First Part of the script %%
```

```
%% Load the data
m = load('mea.txt');     % Load measurement points from txt-file
a = load('ref_a.txt');   % Load A reference points from txt-file
b = load('ref_b.txt');   % Load B reference points from txt-file
c = load('ref_c.txt');   % Load C reference points from txt-file

% Load in the names of the nodes from txt-files. The files should only
% contain the nodenames and each name is to be separated by a line-
break.
m_nodename_txt = fileread('mea_nodename.txt');      % Read names for
the measurements
a_nodename_txt = fileread('ref_a_nodename.txt');    % Read names for
the A-nodes
b_nodename_txt = fileread('ref_b_nodename.txt');    % Read names for
the B-nodes
c_nodename_txt = fileread('ref_c_nodename.txt');    % Read names for
the C-nodes

% For each of the name-variables, create an array by spliting the
% rows in the document into elements.
a_nodename = regexp(a_nodename_txt,'\s+\n','split');
b_nodename = regexp(b_nodename_txt,'\s+\n','split');
c_nodename = regexp(c_nodename_txt,'\s+\n','split');
m_nodename = regexp(m_nodename_txt,'\s+\n','split');

% Clear the variables that we do not need beyond this point.
clear a_nodename_txt b_nodename_txt c_nodename_txt m_nodename_txt;

%% Find the closest coordinates

aa(length(m)) = struct('a',[], 'b',[], 'c',[], 'm',[]);

% We loop through the measurements...
for i=1:length(m)
    % ... and for each measurement we preform a nearest neighbour
    % search. The function uses knnsearch in order to do this. This
    % search return the index of the nearest points in a, b and c-
    % arrays respectively compared to the measurement coordinates.
    % knnsearch also let us specify how many nearest neighbours we
```

```
    % would like to recieve in the output. For A, B and C we thus
    % want 3, 2 and 1 respectively.
    aa(i).a = sort( knnsearch(a,m(i,:),'k',3) );
    aa(i).b = sort( knnsearch(b,m(i,:),'k',2) );
    aa(i).c = sort( knnsearch(c,m(i,:),'k',1) );
    aa(i).m = m(i,:);
end
% This results in three systems of coordinates for each measurement,
% one for A, one for B and one for C. The "total" AA-system for the
% measurement is created by combining these A, B anc C-systems.

% Clear the variables that we do not need beyond this point.
clear a b c;

%% Second part of the script %%
%% Compare and minimise number of A, B and C-systems respectively

mea(length(m)) = struct('a_num',[], 'b_num',[], 'c_num',[], 'ref_
num',[], 'name',[], 'a_name',[], 'b_name',[], 'c_name',[]);

% Predefine some variables used in the loop
a_num = 1;
b_num = 1;
c_num = 1;

% Since there are as many systems as there are measurements, we loop
% through each A-, B- and C-system in order to find duplicates.
for i=1:length(m)
    % First we check if we have any A-system registred, if not we
    % create it below...
    if( exist('a_system','var') )
        % If there is a system, we check if it contains any
        % duplicates of the current system aa(i).a. If we have a
        % match...
        [equal pos] = isequal_cell(a_system,aa(i).a);
        if(equal)
            % ... we save the position of that system in a-num.
            mea(i).a_num = pos;
        else
```

```
        % If we do not have a match we crate a new system from
        % the one we currently have and add it to our a_system-
        % variable.
        mea(i).a_num = a_num;
        a_system{a_num} = aa(i).a;
        a_num = a_num+1;
    end
else
    % Since we did not have any A-systems, we create a variable
    % containing them. Since the current system obviously is not
    % registered yet, we add it to the a_num of the measure as
    % well as adding it to the new a_system-variable.
    mea(i).a_num = a_num;
    a_system{a_num} = aa(i).a;
    a_num = a_num+1;
end

% Same as previous system, but for the B-systems...
if( exist('b_system','var') )
    [equal pos] = isequal_cell(b_system,aa(i).b);
    if(equal)
        mea(i).b_num = pos;
    else
        mea(i).b_num = b_num;
        b_system{b_num} = aa(i).b;
        b_num = b_num+1;
    end
else
    mea(i).b_num = b_num;
    b_system{b_num} = aa(i).b;
    b_num = b_num+1;
end

% Same as the previous A- and B-system, for C...
if( exist('c_system','var') )
    [equal pos] = isequal_cell(c_system,aa(i).c);
    if(equal)
        mea(i).c_num = pos;
    else
```

```
            mea(i).c_num = c_num;
            c_system{c_num} = aa(i).c;
            c_num = c_num+1;
        end
    else
        mea(i).c_num = c_num;
        c_system{c_num} = aa(i).c;
        c_num = c_num+1;
    end
end

% Clear the variables that we do not need beyond this point.
clear a_num b_num c_num;

%% Create unique and complete AA-systems from the smaller A,B and C-
systems

% Predefine a variable used in the loop
ref_num = 1;

% Once more we loop through all measurements, only this time we actu-
ally
% want to loop through the measurements: For each measurement...
for i=1:length(m)
    % ... we do a similar control as to the previous one: does it ex-
ist a
    % variable containing the reference systems...
    if( exist('ref_system','var') )
        % ... if so, we compare the a combination of the current A-,
B- and
        % C-system to the previous systems.
        [equal pos] = isequal_cell(ref_system,[mea(i).a_num mea(i).b_
num mea(i).c_num]);
        if(equal)
            % If the previous combined systems contain a duplicate,
we save
            % the index for this duplicate ...
            mea(i).ref_num = pos;
        else
```

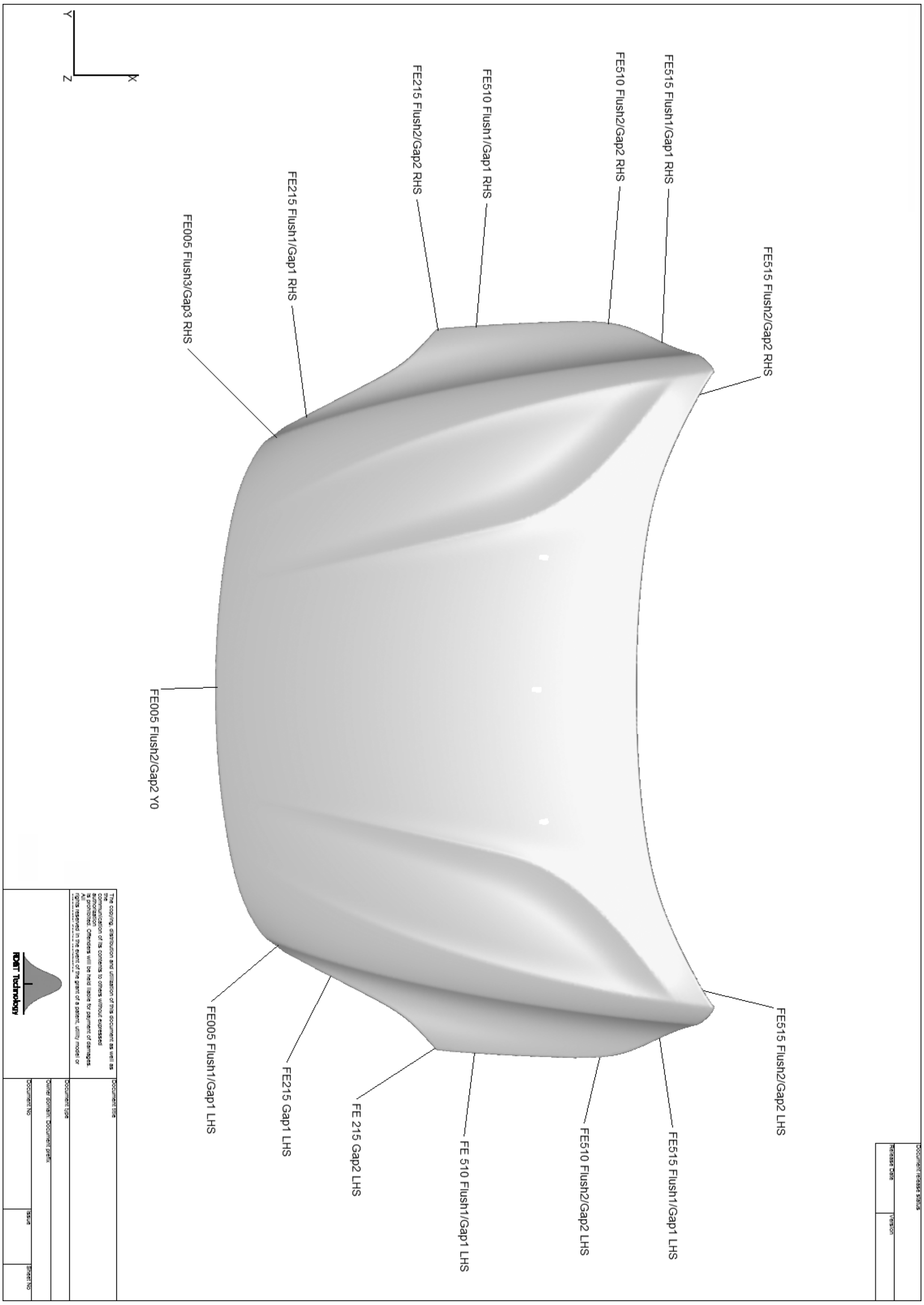
```
            % ... else we save the current combined system as a new
            % post and assign it to the index-variable
            mea(i).ref_num = ref_num;
            ref_system{ref_num} = [mea(i).a_num mea(i).b_num
mea(i).c_num];
            ref_num = ref_num+1;
        end
    else
        % ... if we do not have any ref_system-variable we have not
saved
        % any systems previously. Thus this system is new, and we
save it
        % to the new variable.
        mea(i).ref_num = ref_num;
        ref_system{ref_num} = [mea(i).a_num mea(i).b_num mea(i).c_
num];
        ref_num = ref_num+1;
    end

    % Finally in this loop, we assign the node-names and measurement
    % name to the measurement cell array. These are recieved by
    % referring the node-name index to the aa(i) system index.
    mea(i).name = m_nodename(i);
    mea(i).a_name = a_nodename(aa(i).a);
    mea(i).b_name = b_nodename(aa(i).b);
    mea(i).c_name = c_nodename(aa(i).c);
end

%% Display the results

% In order to display the total amount of unique complete AA-systems
% of reference points, we loop through each reference system and ...
for i=1:length(ref_system)
    % ... generate an output from the system data, firstly name ...
    fprintf('Ref.Sys Name: AA Ref. System No %u\n',i);
    % and secondly node-names for A, B and C-nodes respectivly.
    fprintf('\tA1-3: \t%s, %s & %s\n',a_nodename{a_system{ref_
system{i}(1)}(1)},a_nodename{a_system{ref_system{i}(1)}(2)},a_
nodename{a_system{ref_system{i}(1)}(3)})
```

```
    fprintf('\tB1-2: \t%s & %s\n',b_nodename{b_system{ref_system{i}
(2)}(1)},b_nodename{b_system{ref_system{i}(2)}(2)})
    fprintf('\tC1: \t%s\n\n',c_nodename{c_system{ref_system{i}(3)}
(1)})
end

% In order to display which measurement that is connected to which
% system, we generate an output displaying the measurement name and
% the related system-number.
for i=1:length(m)
    fprintf('Measurement Name: %s\n',mea(i).name{:});
    fprintf('\tAA No: %u\n\n',mea(i).ref_num)
end

%% In order to remember the connections between the variables:
% refsystemen a_nodename{a_system{ref_system{mea(%measurement num-
ber%).ref_num}(%If it is an A,B or C-system%)}(%If it is node 1, 2 or
3%)}
```

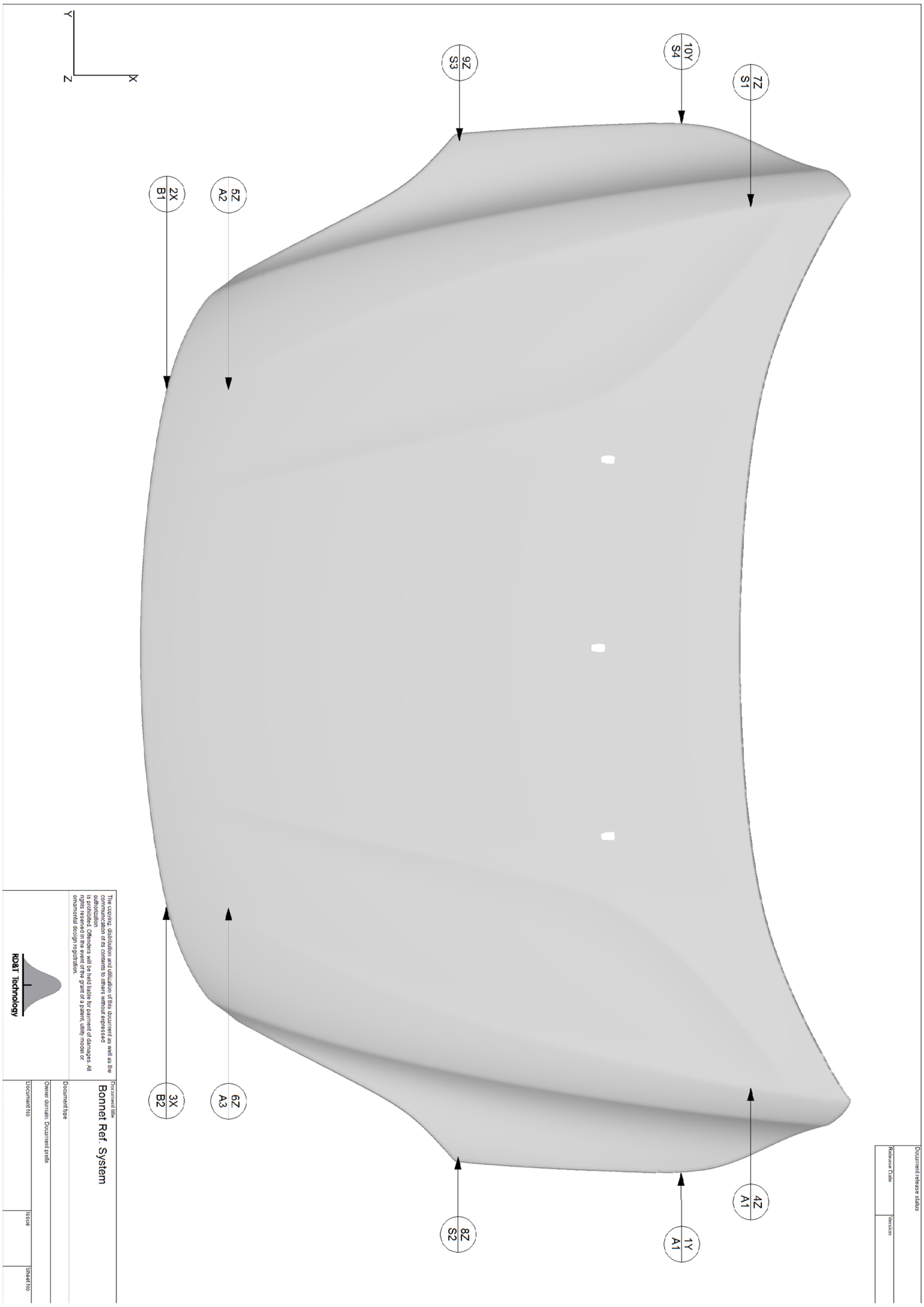
APPENDIX VIII - THE MODELS

In this section the measurement- and locating points position are illustrated for the Bonnet, Fender and Front Bumper respectively.

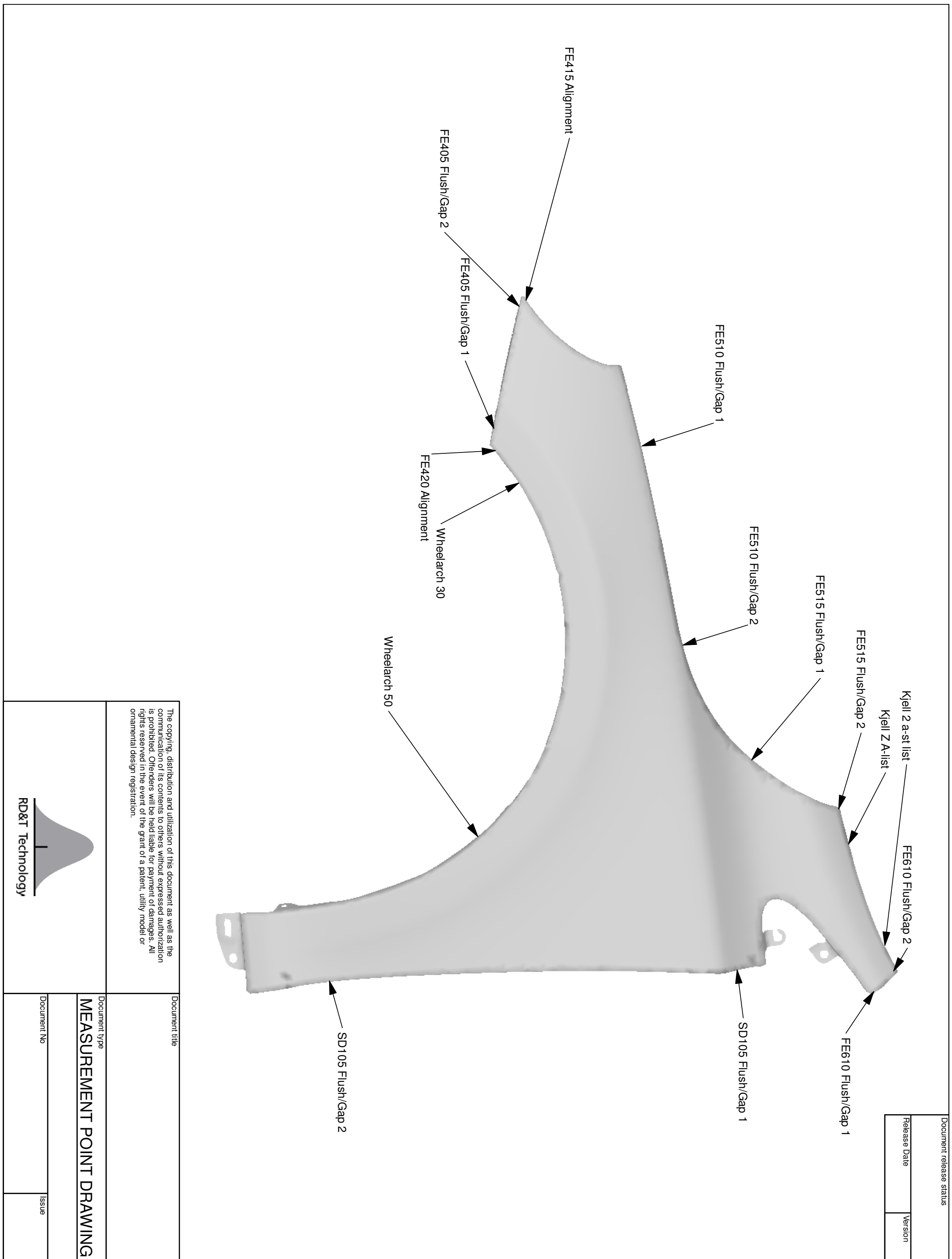
MEASUREMENT POINTS, BONNET



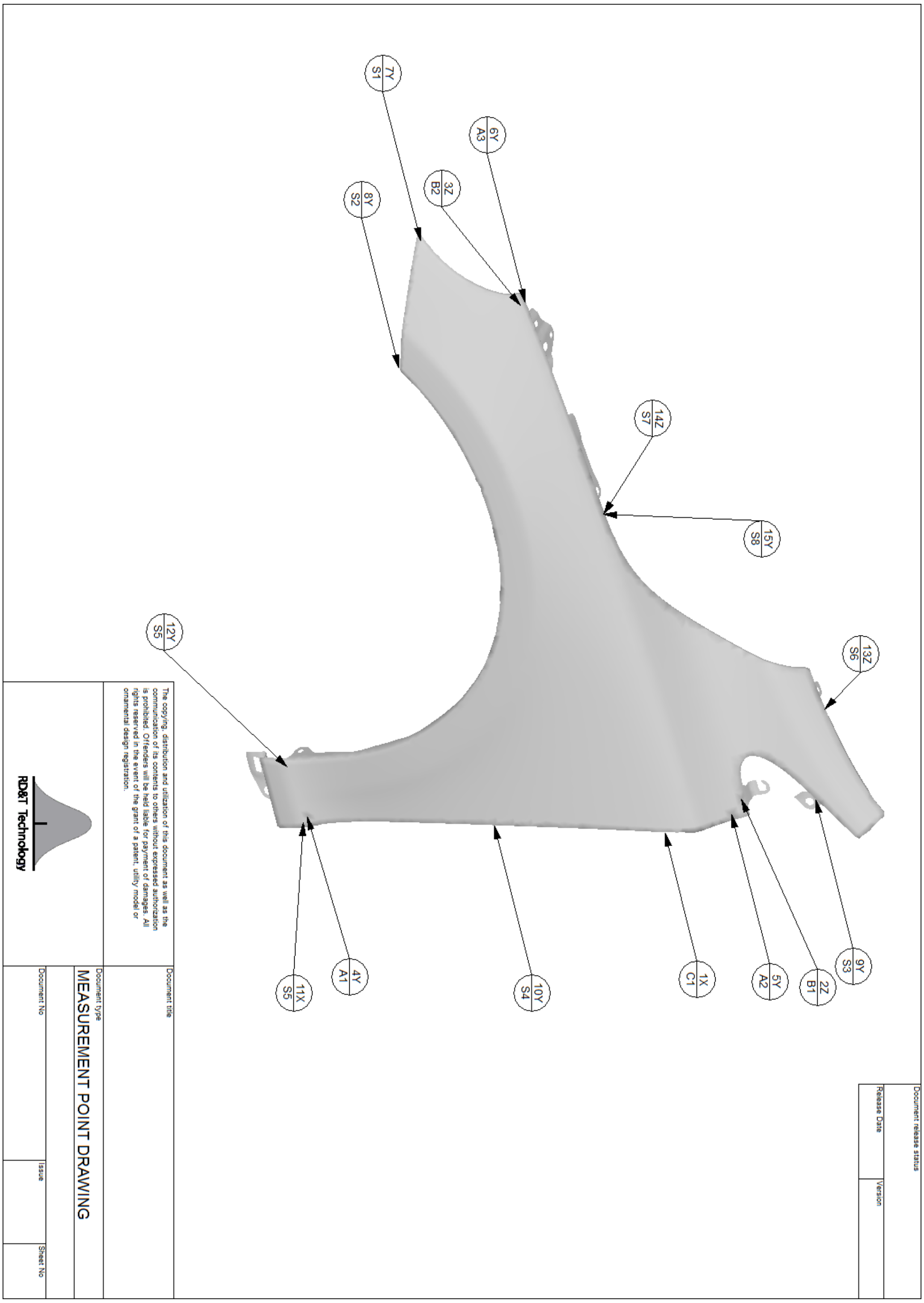
LOCATORS, BONNET



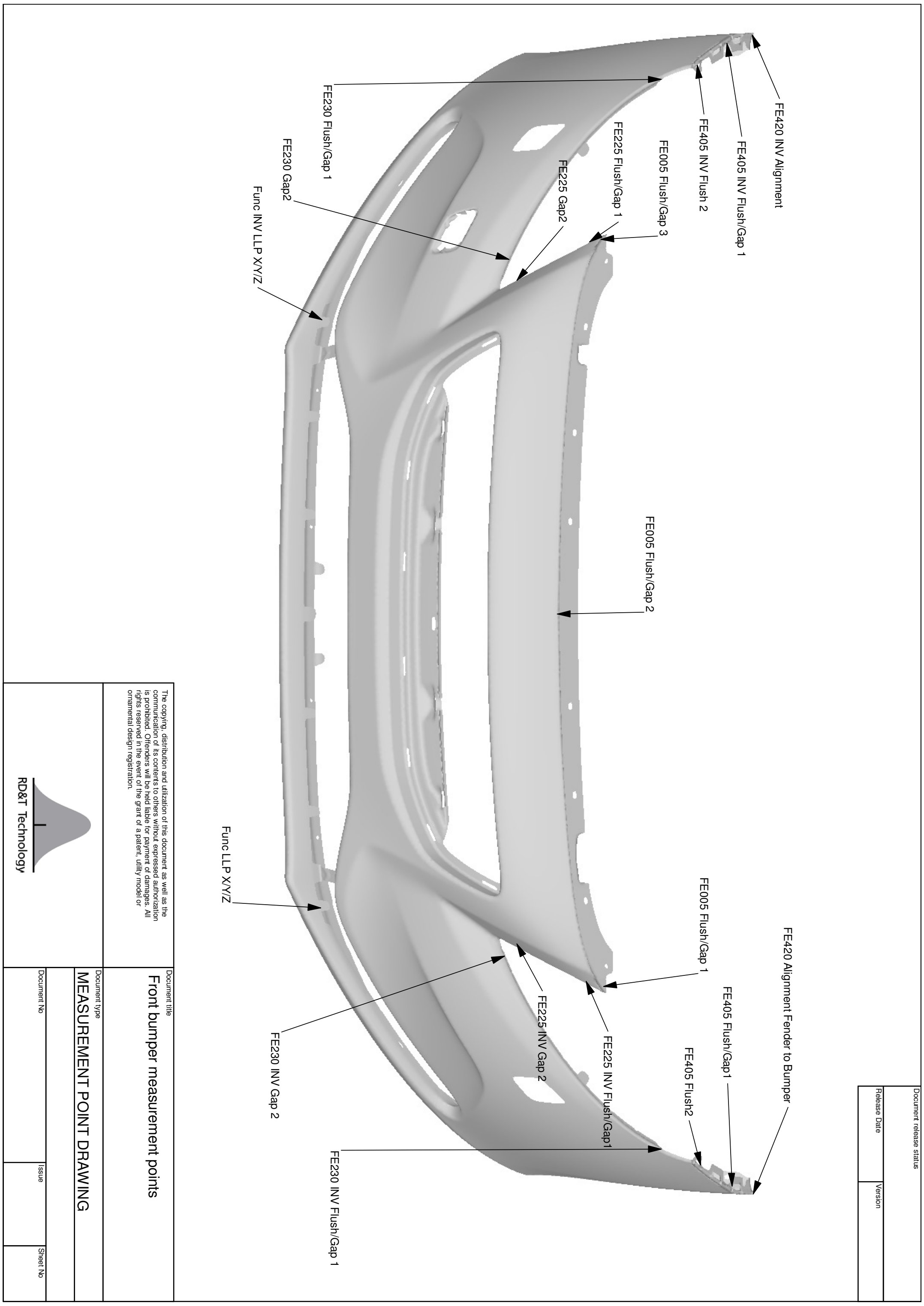
MEASUREMENT POINTS, FENDER



LOCATORS, FENDER



MEASUREMENT POINTS, FRONT BUMPER



LOCATORS, FRONT BUMPER