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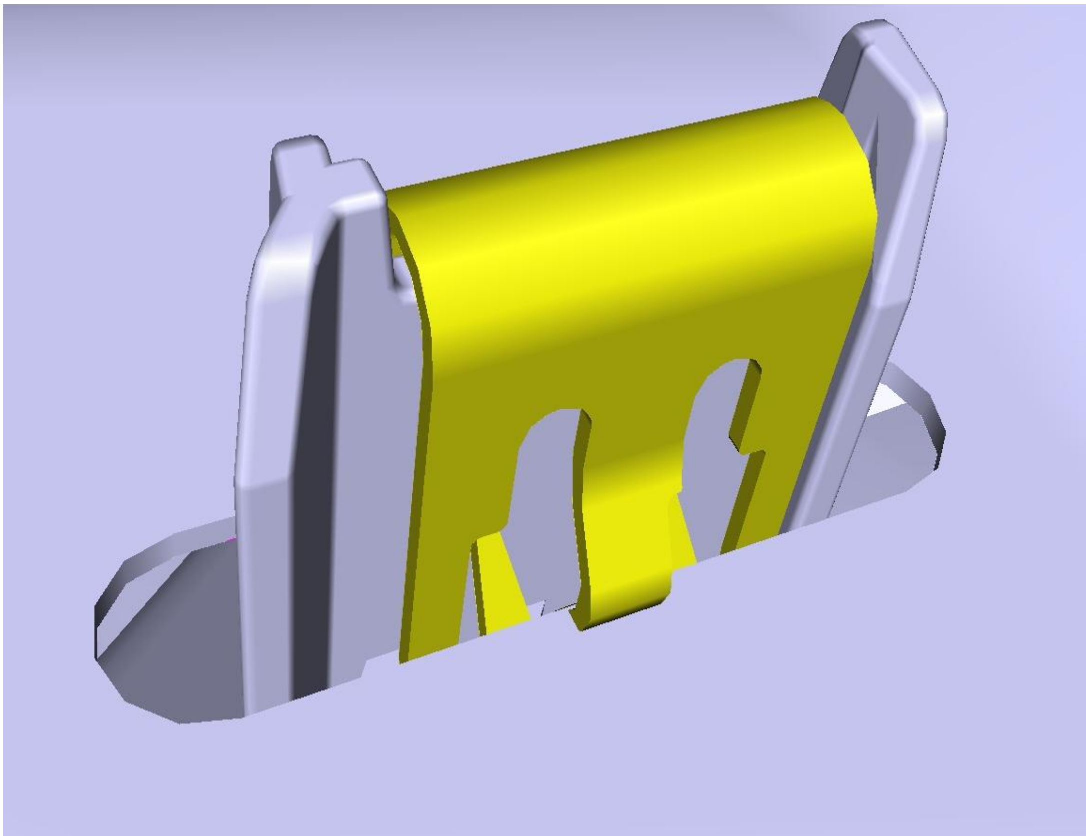

Modeling of Fasteners to Support Compliant Variation Simulation

Master of Science Thesis

VENO KRPO

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Department of Product and Production Development
Division of Product Development
CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: This is a fastener used in D-pillar and shows how the surrounding geometry highly influences the locking behavior of a fastening solution.

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Abstract

Volvo Car Corporation (VCC) is an automotive developer and manufacturer. Their core values are quality, design, safety and environment. In their strive for high quality products in the premium segment, VCC have adopted the concept of robust design and working with geometry assurance. This means developing products that are insensitive to variation from the manufacturing and assembly process. At VCC the prominent divisions which work with geometry assurance are GSU (Geometri System Utveckling, Swedish for Geometry System Development), GAE (Geometry Assurance Engineer) and PQ (Perceived Quality). For this purpose, they use the software Robust Design & Tolerancing (RD&T) which enables, among other functions, virtual evaluation of robustness and variation simulation. Eliminating or more accurately decreasing the effects of variation as early as possible in the product development processes reduces the need for late and costly redesigns and secures the aesthetical and functional demands of the product.

This thesis focuses on modeling of fasteners in compliant variation simulation in the software RD&T. The main objective is to facilitate the work with geometry assurance by introducing a library with predefined fasteners. The problems today are the extensive work needed to set up a compliant simulation and the lack of certain functions in RD&T. Functions such as compliant on compliant assemblies without the use of fixtures and weld and compliant on rigid contact modeling.

An inventory and study of fasteners was carried out. In addition to this, test simulations and interviews with engineers and managers with experience of compliant variation simulations were performed. The knowledge gained was used as input for concept generation. Three concepts were created: Single node concept, Multiple node concept and Feature concept.

The single node concept is based on representing a fastener in a single node or point. This is not the optimal way to represent a fastener, because the effects of area distribution are neglected. The other two concepts consider the fasteners area distribution and reflects reality better. Additional functions, such as contact modeling between compliant and rigid parts have also been proposed in order to enhance modeling ability. From these concepts one final concept was formed from the discussions with the different stakeholders.

In the final concept, the current locating system will be used together with a fastener module that will support and help to overconstrain the model. This will simplify calculations and create distinction between locators and fasteners, which is desired by some of the stakeholders. The final concept will facilitate the work with compliant simulations by having predetermined fasteners, require less steps to set up a simulation and have new functionality which will enable new ways of simulating different situations.

The recommendation for further development is that the developer can use the final concept as foundation for developing a fastener module and library in RD&T. The created module could then be evaluated and compared to current way of working. Results of variation simulation with help of this module should also be compared with the results obtained today and real measurement data in order to validate credibility.

Preface

This master thesis was carried out in the fall of 2011 through the early 2012 at the Department of Product and Production Development at Chalmers University of Technology and Perceived Quality division at Volvo Cars Corporation in Gothenburg.

Throughout this thesis our supervisor Ola Wagersten has been extremely helpful with answering questions, providing information and discussing with us. The unique experience and knowledge regarding the subject which this thesis is about could not have been explored to the degree it has been without the support and discussions we had with Ola Wagersten. So we wish to thank you for the time we were privileged to have spent with you.

We wish also to thank Chalmers Associate Professor and RD&T guru Lars Lindkvist which has on several occasions educated us and made himself available for us despite his hectic schedule.

We would also like to thank Professor Rikard Söderberg for giving us important feedback and input at the concepts presentation.

Further we would like to thank the entire PQ division for the constructive feedback and the general curiosity which made this thesis better.

We would also like to thank RD&T Business Application Developer Mikael Rosenqvist who has on multiple occasion given feedback which has been of great help.

We are also very thankful to Claes Hammarson, Kjell Stridh, Tomas Öberg and Dag Johansson at GSU and Lars Samuelsson for taking the time to answer our questions and giving us insight to how they work.

Finally we would like to thank our families and friends for their love and support not only during this thesis but the entire study time at Chalmers. Thank you!

Gothenburg, February 2012
Veno Krpo
Almir Smajic

Abbreviations/Terminology

TX, TY, TZ	Translation in x, y, z-direction - Movement that changes the position of an object, moving every point the same distance in the same direction, without rotation.
RX, RY, RZ	Rotation around x, y, z-axis - Circular movement around a center axis.
DOF	Degrees of freedom (see chapter 2.1)
MS	MS or Mating Surfaces - Denotes the surfaces on a fastener which are in contact with a given part.
Compliant	Refers to something that is non-rigid and has the ability to deform.
Global coordinate system	All parts in a given assembly are oriented and positioned in reference to a global coordinate system.
Local coordinate system	Refers to the fasteners own coordinate system.
Fastener	In this thesis, a fastener is referred to the single physical part which is used to join together two or more parts.
Fastening solution	Fastening solution will be used as a description of a fastener and the geometrical limitation which contributes to the overall behavior of that particular joining.
FEM	Finite Element Method (see chapter 2.3)
Overconstrained	When an objects all six DOF are all locked and additional points are used to lock the same DOF then the system is overconstrained.
Plug-in assembly system	An assembly process and production strategy which aims for an assembly without any positioning adjustment of the parts by the assembler.
VCC	Volvo Car Corporation
PQ	Perceived Quality
GSU	Geometri System Utveckling, Swedish for Geometry System Development

GAE	Geometry Assurance Engineer
RD&T	Robust Design & Tolerancing

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1 Introduction

In order to be competitive and profitable, manufacturing companies always strive to shorten their lead times in the product development process and in the manufacturing process. Using virtual simulations when developing, also known as Computer Aided Engineering (CAE), has become an important part of this strive. Tools like CAD (Computer Aided Design) and CAT (Computer Aided Tolerancing) enables companies to build virtual products, evaluate them with respect to functionality, quality and prepare the manufacturing process in a virtual environment.

An important aspect of CAE is to be able to make simulations models that reflect reality correctly. When it comes to CAT tools, variation simulation has previously been performed lion's share on rigid models and in very few instances compliant models. Also the use of simpler methods like spreadsheet calculations have been utilized due to the short time it takes to get data results. But as computer hardware and software has become more powerful and complexity of products has increased, so has the need for simulation of compliant parts.

The focus of this thesis will be on improving the fastener modeling in the CAT tool Robust Design and Tolerancing (RD&T) by creating a library of predefined fasteners. The purpose of this library is to facilitate the work with geometry assurance and thus reduce work effort and product development time.

This thesis was carried out together with Volvo Car Cooperation (VCC) at the Perceived Quality (PQ) division.

1.1 Background

Variation exists naturally in all types of manufacturing. It arises from machine precision, process precision, process variation etc. (Söderberg 1998). Variation stemming from the manufacturing process can cause problems with assembly, loss of function and of perceived quality (Söderberg, Lindkvist & Carlson, 2006). Therefore it has become crucial for manufacturing companies to control variation. One way of controlling variation is to decrease tolerances, but this usually leads to higher manufacturing cost, which is often difficult to justify economically (Wagersten, 2011). Another way is to work with geometry assurance and robust design (see chapter 2.5 and 2.6).

RD&T is computer software that facilitates the work with geometry assurance. It simulates variation, using the Monte Carlo simulation, and allows the user to manage tolerances and locating schemes on virtual parts (see chapter 2.2 and 2.7). Compliant variation simulation is a method used for calculating and predicting effects of variation on compliant components and assemblies. This support is today used especially in the automotive industry and applies mainly to sheet metal and Body-In-White (BIW) which are usually welded. There is less experience on simulating plastic and rubber parts that have a "plug in" assembly systems and that are usually not positioned with fixtures and then welded, but are manually assembled by an operator on an assembly line.

An important part of compliant variation simulation is to define appropriate locating schemes that will resemble reality and reflect the predicted deviation, of assembled parts, as result of variation in manufacturing and assembly. Locating points are used to define a locating scheme. These points often represent a fastener, for example a screw or a pin. The accuracy of the representation of fasteners in variation simulation will therefore affect the simulation result.

Today it is possible to define fasteners in RD&T to some degree. This is done by the use of locating points and support points (see chapter 3). But there are no predefined fasteners. This results in extensive preparation work for geometry assurance engineers. Another issue is that not all fastener types can be represented accurately.

1.2 Objective

The main objective is to facilitate the work with compliant variation simulation for geometry engineers by improved fastener modeling in RD&T. The secondary objective is to highlight missing functions in compliant variation simulation that are necessary for better fastener modeling. The result of the thesis will be a description of fasteners behavior, a library of commonly occurring fasteners, a proposed layout for the library in the software RD&T and a discussion on which additional function are needed to support a better fastener representation in RD&T.

1.3 Delimitations

This project will not undertake any programming changes to RD&T, nor will there be any demonstrators made during this thesis. It will only propose how the fastener module could look like. Also no economic analysis of the development cost will be performed.

No benchmarking will be performed due to the high licensing fee for competitive CAT software such as 3DCS.

Not all fasteners will be analyzed and added to the library. Only the most frequently occurring fasteners on compliant parts, preferably plastic parts, will be studied due to the time limitation of this thesis (20 weeks). A decision was made not to include welds, different dimensions of screws and every type of snap joint. Welds are not included due to the existing compliant variation simulations capabilities already available in current versions of RD&T and because welds are not used on the compliant parts that were studied.

To narrow down the scope of the thesis, not all properties that determine a fasteners behavior will be studied. A discussion regarding the relevance of all of the fasteners properties will be performed.

1.4 Stakeholders

Several divisions at VCC are using RD&T for different purposes. The divisions immediately affected by the results of this thesis are PQ (Perceived Quality), GSU (Geometri System Utveckling, Swedish for Geometry System Development) and GAE (Geometry Assurance Engineers). Chalmers University of Technology is also an important stakeholder because of their research on compliant variation simulation.

PQ look at the location and complexity of split lines, identifies critical areas that need to be prioritized and set up aesthetical geometrical demands for all visible relations on the vehicles. These demands are then sent to GSU. They also visualize the vehicles models for assessments regarding the visible effect of calculated maximum and minimum deviation of parts.

GSUs role description is to create design construction conditions regarding the positing system and tolerances of components. The developed positioning systems should fulfill aesthetical and functional requirements set on the parts by PQ. This is done all throughout of development.

The GAEs role is to drive industrialization and verification of the geometry system within the area regarding product and process influence as well as decided geometrical final requirements, both aesthetical and functional. GAE is involved from the early development by providing PQ and GSU with knowledge from production data regarding variation and deviations.

1.5 Method

The concept development is divided into different phases in order to make sure that all aspects of development are considered. The different phases are identification of stakeholder’s needs and requirement, establishing a target specification, generating concepts and concept selection. The concept development process proposed by Ulrich & Eppinger (2004) was used as a general base for the concept development. In figure 1, the modified concept development process that has been utilized for this project can be seen.

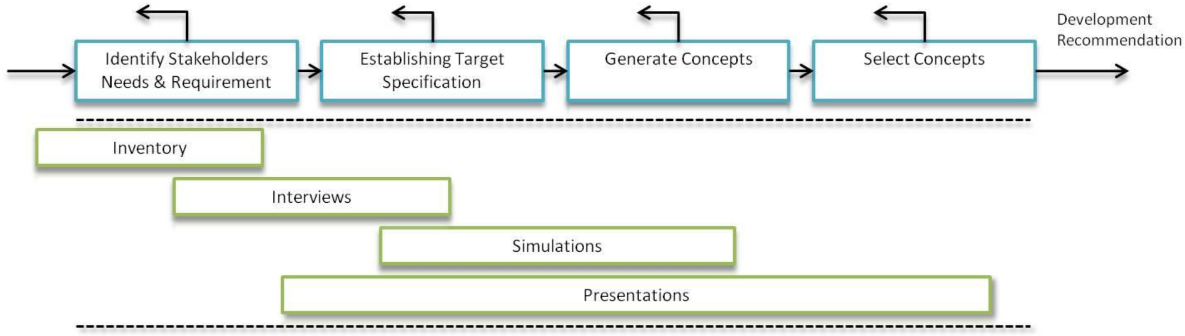


Figure 1: The concept development process which is inspired by Ulrich & Eppinger (2004).

The project will begin with an inventory and study of fasteners used at VCC so that fasteners of interest can be identified and their behavior can be determined. This will be done by studying current Volvo car models in the mock-up software VisMockup. Volvo models that already are in production will be studied, because of the availability of CAD data and less classification restrictions. Selected fasteners will be analyzed and categorized with respect to behavior like stiffness, constrained DOF and mating surface distribution. Interviews with key engineers will also impact which fastener behaviors are needed for the categorization in order to achieve accurate simulations.

The software RD&T will be used for trial simulations on compliant parts containing selected fasteners. The purpose of the trial simulations is to get a deeper understanding of the difficulty when modeling in compliant analysis, clarify what restrictions there are when modeling fasteners and to analyze how to facilitate it.

Because the study is performed on compliant parts, the software FEMAP will be used to mesh and create FE-models of parts so that RD&T´s ability to handle compliant part can be studied. Because FEMAP also utilizes locking of DOF´s, a comparison between RD&T and FEMAP will be made in ability to lock DOF´s. FEMAP is chosen since it is available for student at Chalmers University of Technology and the authors have previous experience in this particular software.

The primary method of gaining knowledge from engineers will be semi-structured interviews. Interviews is a qualitative method which allows the interviewer to ask follow up questions and interact with the interviewee so that the subjects that may not be throughout in advance can be address (McQuarrie 2006). The divisions which are working with RD&T at VCC where all contacted and interviewed. Interviews with engineers at PQ, GAE and GSU will be used to identify VCCs stakeholder's needs. The interviews also aim to elucidate the difficulty of modeling fasteners in complaint analysis and what geometry assurance engineers lack in functionality when it comes to modeling fasteners.

From the inventory, interviews and simulations, a target specification will be formed so that the generated concepts will fulfill the needs of the stakeholders. The target specification will be referred as the requirement specification.

To easily generate different concepts it is important to define the problem and break it down into smaller more manageable subproblems (Ulrich & Eppinger 2004). The objective is to facilitate compliant variation simulations for geometry engineers. To be more precise it is to improve and develop fastener modeling so that this can be achieved. To facilitate the concept generation a decomposition of the fastener modeling and in particular the key factors needed to fully describe and represent a fastener in compliant variation simulations in RD&T will be performed. An identification of the key factors will be performed with knowledge gained from the inventory, the simulations and interviews. To evaluate the different key factor solutions a modified Pugh matrix will be used as support for the decisions regarding the choice of concepts. The overall idea is not to eliminate a lot of solutions but to present most of the ideas to stakeholders so to increases their awareness of the possibilities for fasteners in compliant variation simulation.

With the knowledge based on the all the previously stated methods a concept generation will be performed. Because of the diversity of the stakeholders and the general lack of experience with fasteners and compliant variation simulation, several concepts will be presented to the stakeholders.

The different concept will serve as a foundation for discussion and input for the development of a final concept. Through presentations and stakeholder feedback the best parts of the different concepts will be combined and further developed to create the "best solution". For this concept development process to be as efficient as possible several iterations will be required on all levels of development. To verify the final concept, additional presentations will be performed with stakeholders where the different aspects of the proposed fastener modeling system will be presented. The interface for the conceptual fastener modeling module and its functions will be proposed in PowerPoint presentations and described in detail in chapters 6.2 and 7.

1.6 Layout of the report

To facilitate a better understanding of the report a description of the layout is presented here.

Theoretical framework - This chapter intends to give the reader basic knowledge and background about some of the theoretical concepts and terminology that are important to this thesis.

RD&T Introduction - Some basic knowledge about RD&T and some of its functions is described here. Focus will be on positioning systems and menus, which are relevant to this thesis.

Implementation - The steps introduced in the method chapter have been implemented and are presented here. In this section all the efforts to gain knowledge about fasteners, fastener behavior, meshing and compliant variation simulation will be described and summarized.

Requirements - From the implementation a number of wished and demands have been specified in a requirement specification. These serve as a foundation for the concept generation.

Concept generation - In this chapter the different subsolutions are presented. These are combined in three different concepts to form a base for discussions with stakeholders.

The final concept - One concept has been created with input from all the different stakeholders. Also the best parts from the three concepts have been combined in this Hybrid concept.

Area of use - The final concept that is proposed is put in context regarding the area of use. Who will use the concepts and in what stage to which degree?

Discussion and Conclusion - A discussion was held regarding the concepts and methods used to formed them.

Recommendation - How to continue the efforts to implement efficient compliant variation simulation will be presented here.

2 Theoretical framework

The following chapter has the intention to give the reader basic knowledge and background about some of the theoretical concepts and terminology that are important to this thesis.

2.1 Degrees of freedom

In three dimensional spaces there are six degrees of freedom for an object to move in. These are three translations in the three orthogonal directions and three rotations around the axis of each direction. Consider an object of arbitrary shape, in this case a cube, placed in space with a given coordinate system (see figure 2).

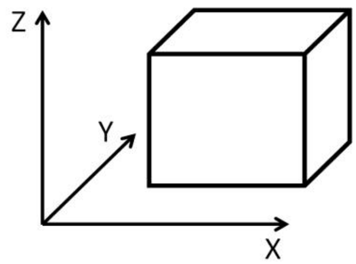


Figure 2: A cube in space with designated coordinate system

The cube can translate in z-, x- and y- direction (three DOF) and it can rotate around each axis of the coordinate system (three DOF).

2.2 Locating schemes

As stated earlier, an object in space has six degrees of freedom. In order to fixate this object in space, all six degrees of freedom must be locked. This is done by restraining points on the object from moving. The restrained points are called locating points and the whole scheme of points that locks an object in space is called a locating scheme (Söderberg, Lindkvist & Carlson, 2006). Locating schemes can also be referred to as positioning systems. There are different kinds of locating schemes in use in the industry. Figure 3 shows an example of the orthogonal 3-2-1 positioning system. If an object is locked in space with more points than necessary for the six degrees of freedom, it is said that the object is overconstrained.

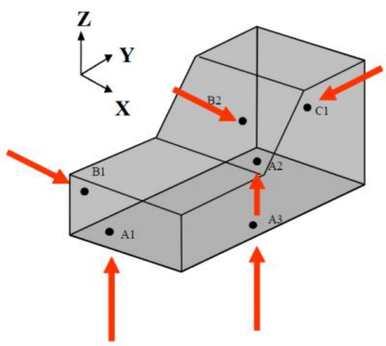


Figure 3: The 3-2-1 positioning system with locating points A1-A3, B1, B2 and C1 (Söderberg, Lindkvist & Carlson, 2006).

2.3 Finite element method (FEM)

The finite element method is a mathematical solution method for complicated differential and integral equations. The method is today widely used in modern mechanical, fluid and thermal calculation software. The idea is to divide the geometry of interest for calculations into small elements, often of quadratic or triangular shape. The elements are connected to each other via nodes that can be found on every corner of an element. By doing this, large and complex geometries, which often have non-linear mathematical behavior, can be approximated with these small element that have linear behavior (Hutton, 2004).

The grid that is built up of the small elements is often referred to as a mesh. Dividing geometry into elements is called meshing.

2.4 Styling- and engineering data

Geometrical data can basically be divided into two groups, styling data and engineering data. The difference between them is the maturity level. Styling data is obtained in the early product development phases, were the level of detail is low. Engineering data is obtained later, during detail design phases and the level of detail is higher (Wagersten, 2011). Figure 4 show an example of styling- and engineering data for a front bumper skin.

Figure 4: Styling data on the left and engineering data on the right. Note the difference in detail level. (Wagersten, 2011)

2.5 Robust Design

A Robust design is a design that is insensitive to variation input from manufacturing and assembly operations (Söderberg & Lindkvist, 1999).

The concept of robust design is to, with smart design and having uncoupled tolerance chains, eliminate the effects of variation on a product without actually removing the variation (Phadke, 1989). This is usually preferred instead of decreasing tolerances which is often very expensive. Robustness is illustrated in figure 5. The more the triangle in the figure moves to the right, the more sensitive the rod will be to variation input and the greater the output deviation and vice versa. In this context, deviation is defined as the offset from nominal position.

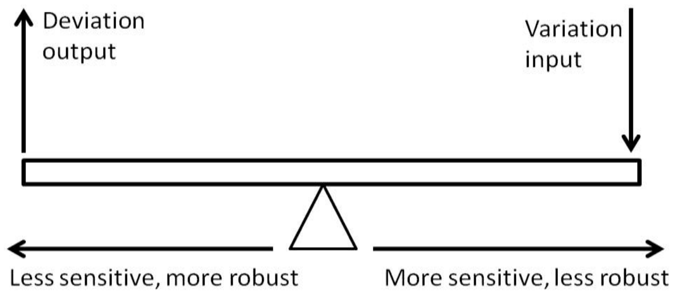


Figure 5: The concept of robustness in robust design context (Söderberg & Lindkvist, 2002)

2.6 Geometry Assurance

Managing and allocating tolerances and working towards a robust design is generally known as geometry assurance (Söderberg, Lindkvist & Carlson, 2006).

In the early phases of product development, a design solution is evaluated with respect to robustness and robust locating schemes are developed for the different parts of the product. Later in the process, when detail level is higher, variation analysis is preformed to verify functional and aesthetical requirements (Söderberg, Lindkvist & Carlson, 2006).

2.7 Monte Carlo simulation

A Monte Carlo simulation is a simulation based on the Monte Carlo method which is a mathematical method for generating pseudorandom numbers. They are called pseudorandom because the way they were produced is reproducible and thus predictable. But the population of generated numbers has statistical properties very similar to real random numbers (Trigg, 2005) making it suitable for simulation of variation. This makes the Monte Carlo simulation suiting for physical simulation and is therefore used widely in CAT applications (Wagersten, 2011).

3 RD&T introduction

This chapter has the intention to give the reader basic knowledge about RD&T and to illustrate some of its functions. Focus will be on positioning systems and menus, which are relevant to this thesis.

RD&T is computer software, which, among other functions, provides statistical variation analysis. It is used to simulate how assemblies will be affected by allocated tolerances and variation. In early phases, stability analysis can be performed to evaluate the robustness of assemblies. In later phases, when more data is available, variation simulation can be performed to visualize how the parts in the assembly deviate as a result of variation and which locators are contributing to this.

3.1 Positioning a part in RD&T

The first step to be performed is to import a part to RD&T. Depending on if rigid or compliant analysis is desirable, different type of file format will be imported. For rigid analysis VRML and JT files are usually used. For compliant analysis a mesh is required. RD&T supports ABAQUS ".inp" file format for meshes. In this example one mesh and one VRML file will be imported, D-pillar respective Luggage trim upper. This means that a compliant part will be positioned on a rigid part. Figure 6 shows the imported parts in RD&T.

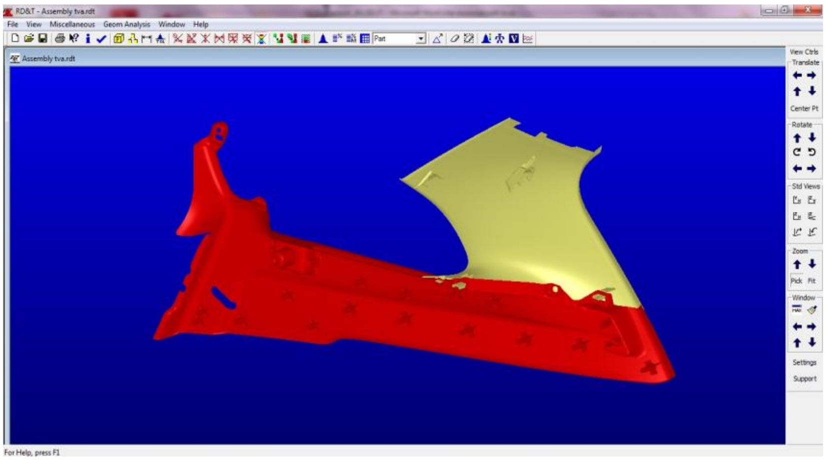


Figure 6: Assembly in RD&T. The red part is Luggage trim upper, the beige is D- Pillar.

The next step is to define the positioning system for the local part. Local part is the part that, in the assembly process, is positioned on the mating part. The other part is called target part. In this example D- pillar is the local part and will be positioned on the Luggage trim upper, which will be the target part. Note that the target part is a rigid part. Choosing positioning system is done when editing the local part. There are several positioning systems available in RD&T (see chapter 3.2) the one used in this example will be the 3-directions positioning system. Figure 7 illustrates how the menu for this positioning system looks like.

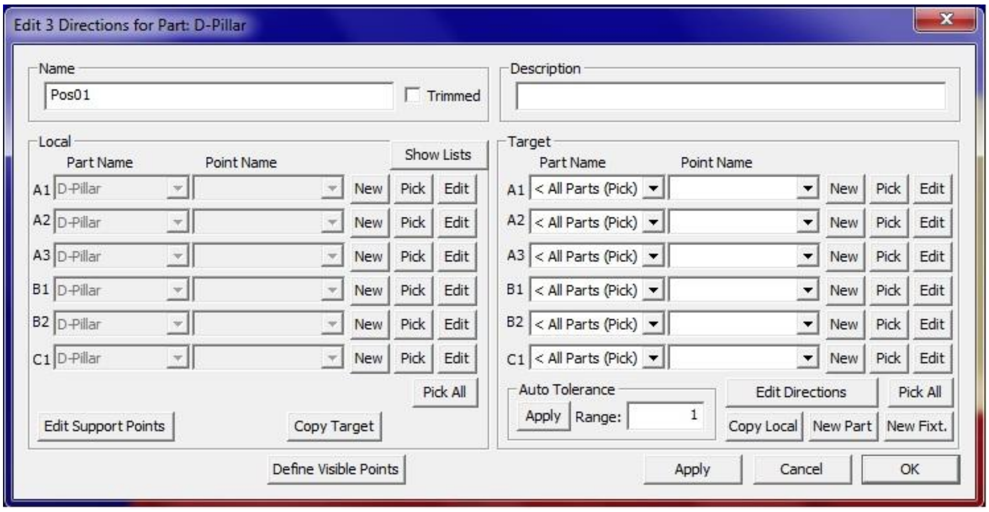


Figure 7: 3- directions positioning system menu

In the positioning system menu, locators for local frame is either chosen from the scroll down menus or by selecting the nodes directly from the model. A frame is the set of points that locks the parts degrees of freedom. After that, target frame locators can be selected in the same way. But, because target part is a rigid part, the function “copy local” can be used. This function will create points on the target frame corresponding the local frame locators. Now the model can be overconstrained by using support points. Support points are usually used to model additional fasteners. Thereafter, general tolerances can be applied to the target frame locators with the “auto tolerance” function or manually. Local part is now positioned on target part and the assembly is now prepared for the most basic analysis.

3.2 Positioning systems in compliant simulation

RD&T currently supports two types of positioning systems in compliant simulation. 3-directions and 6-directions positioning systems. It also allows the use of additional locators that are not available in rigid simulation. These are support points. These additional locators enable overconstrained positioning systems to be created. Weld points can also be utilized to simulate welds. In addition to this, contact points can be defined in order to simulate physical interference.

The following part will describe how these positioning systems, locators and contact points work.

3.2.1 6-directions positioning system

The positioning system is defined by six points on local frame and six on target frame. The locking (positioning) direction of each defined point can be adjusted manually to fit the users need. This system is usually used were the positioning planes are not perpendicular (Söderberg & Lindkvist, 2007).

3.2.2 3-directions positioning system

Similar to the 6-directions system, but only three directions needs to be specified. One direction for three A-points, one for two B-points and one for one C-point (see figure 3). It should be pointed out that the locating points and their positioning directions, in both 3- and 6-directions system, should be picked with caution. If the defined system does not lock the parts in all degrees of freedom, a simulation won´t be possible.

3.2.3 Contact points

Contact points are used to simulate physical interference between parts. A local node, a target node and a direction are selected to define the contact condition (Söderberg & Lindkvist, 2007). Usually nodes in two assembled meshed parts do not coincide. Therefore a nominal distance between the nodes can be specified, which enables two adjacent nodes to simulate physical interference. Contact points are only available in the subassembly function.

3.2.4 Support points

Support points are used to lock the frame in additional nodes, apart from those in the positioning system. A support point can only lock one direction. If there is a need to lock a node in more than one direction, several support points can be defined on the same node, each locking one direction.

3.2.5 Weld points

Weld points, as the name indicates, are points that are supposed to simulate welds. A weld point locks a node in all three directions. Like contact points, weld points are only available in the subassembly function.

4 Implementation

This chapter will present the implementation of the steps described in the method chapter. The sections that will be addressed are Fastener inventory, Fasteners and their properties, Meshing, Test Simulations and Interviews.

4.1 Fastener inventory

By the use of visualization mock-up software in Volvos PLM (Product Life Management) system Teamcenter, an inventory of the fasteners was performed. Initially a general overview was conducted on several of Volvos vehicle models. The models that were examined were complete vehicle engineering CAD models. An early search revealed a diversity of fasteners used in the different models. The focus was on components that exhibit compliant behavior and is visible to the customers both on the exterior and interior. Exterior plastic components such as front and rear bumpers and the mud flaps were analyzed. The front fenders which are made by sheet metal (see figure 8) were also studied. The interior differs from the exterior in the amount of plastic components used. The interior consists of a variety of visible panels mounted to an underlying structure mainly with the help of plastic fasteners.

Figure 8: Exterior of a Volvo V60. Front and Rear Bumpers, Front Fender and Mud Flaps were analyzed.

The types of snap joints that are presented are Snap joint hook and Snap joint press. The selection and categorization was made after analyzing the variety of snap joints and determining their behavior. The fasteners which were found based on these criteria are presented in table 3.

To facilitate understanding of fastener behavior, a way of describing the fasteners and their positioning in relation to the parts it constrains and the global coordinate system will be proposed. When deciding in which direction a fastener locks one must often look at the global coordinate system in which the car or part is positioned in. This means that a fastener can lock translation in different directions, depending on how the fastener aligns with the global coordinate system, which makes categorization of locking DOF difficult. Therefore all the studied fasteners will be given a local coordinate system. All further discussion regarding which translation and rotation directions each fastener and fastener solution locks will refer to the local coordinate system. In table 3 the fasteners can be seen in a local coordinate system.

Generally the z-direction marks the primary mounting direction to either local or target frame. It should be noted that the global coordinate system directions are labeled as x, y and z in RD&T. The local coordinate system in the software should have a different labeling because same labeling of the global and local coordinate system can confuse both the software and engineer. Alternative labeling could be u, v and w.

4.2 Fasteners and their properties

The behavior of fasteners is based on several factors which interact to determine the kind of behavior a particular fastener has in reality. Materials, geometrical shape of fastener, shape of surfaces that are to be joined, DOF locking, material impacts, mating surface distribution, relaxation and friction all contribute to the behavior of a fastener solution.

Not all properties will be considered. Focus will be on DOF locking, shape of fastener and mating surface distribution.

4.2.1 Fasteners geometrical environment

Through the inventory it has become clearer that a fastener in most cases is highly dependent on the surrounding environment which limits its movements. This means that an arbitrary fastener in one situation can have certain properties but the same fastener has different fastening properties in another situation. This notion can be seen figure 9 and figure 10. In figure 9 it is evident that the fastening solution in the left situation has less DOF than the fastening solution to the right due to geometrical limitations.

These differences in behavior can be handled by the use of contact points in RD&T. Meaning that it would be sufficient to only study the behavior of the fastener and not its environment because environmental differences will automatically be handled by contact modeling. But PQ compliant simulation expert has pointed out the importance to be able to carry out variation simulation on both engineering- and styling data. Styling data often lacks the details that in the end can have impact on a fasteners behavior. Because these details are missing, they cannot be handled by contact points. Therefore the need to study both fasteners and the environment they are usually used in. Fastening solutions will therefore be used as a description of a fastener and the geometrical limitation which contributes to the overall behavior of that particular joining.

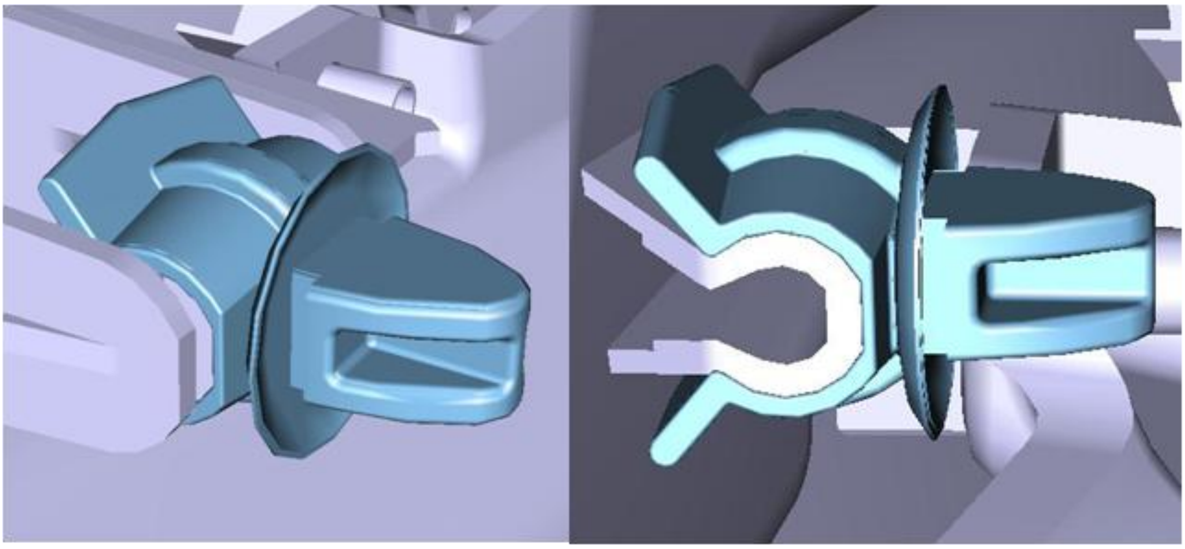


Figure 9: The same fastener to the left and right. It is clear that the geometrical limitation affect the fastening properties of that particular fastener.

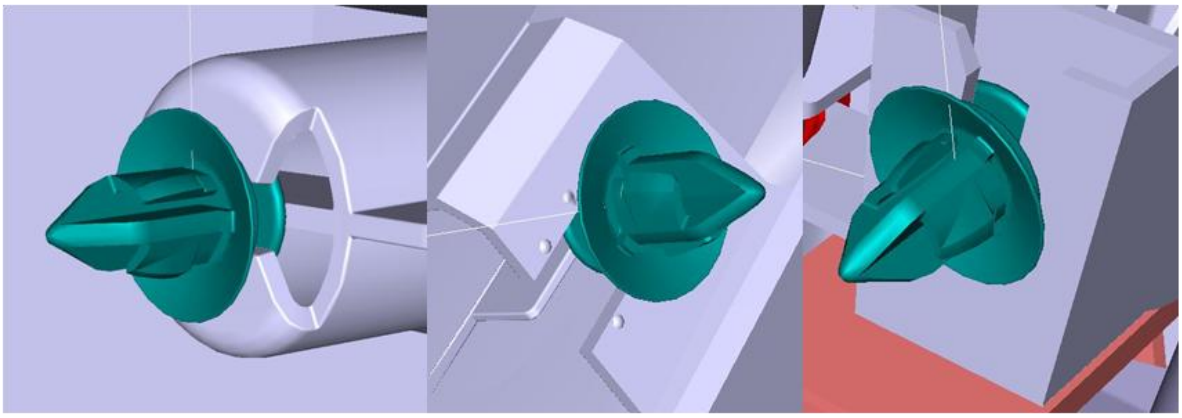


Figure 10: Three fastening solutions which have slightly different properties due to the given geometrical environment.

4.2.2 Materials

For the fasteners that were studied the material of choice was mainly plastics and particularly Polyoxymethylene (POM). It is characterized by its high strength, hardness and rigidity even at low temperatures (BASF, 2011). Due to its excellent dimensional stability it is used as the primary material for the plastic fastener. Several of the retainers were made of different types of steel. The fasteners will therefore be considered as rigid parts. This approximation is also made in order to simplify the fastener description.

4.2.3 Fastener Types

Throughout the inventory it was evident that there were several fasteners which looked and behaved similar. Therefore a categorization of the chosen fasteners was performed. The terminology used is based on Volvos own categorization on their Intranet, "Standard parts used within Volvo Cars". The types are rivet, retainer, screw, snap joint hook and snap joint press. The last two are the authors own labeling.

In table 3 fasteners no 1, 3, 4, 5, 7 can be seen. They are very similar with a circular body and mechanical locking of two parallel surfaces. Fastener no 6 only differs by its more rectangle shape like body, but works like the other rivets. Fastener no 2 has both properties of rivets and retainers due to the fact that it fastens two directionally opposite surfaces together but it does it by mechanical locking and its shape resembles more a rivet so it will be categorized as a rivet. Retainers are used to clamp two orthogonal surfaces together. Fasteners no 9 and 10 are mechanically lock the surfaces together while fastener no 8, does it primarily with friction. Fastener no 11 is similar to fastener no 2 but it is categorized as Retainer because it does not resemble a rivet. Both the rivets and retainers fasten surfaces that are not in direct contact with each other. The interaction the surfaces have is through the fasteners. This is not the case for screws, spring nuts and snap joints. The geometrical similarities become even more apparent when looking how the different fasteners are represented in RD&T which can be seen in Appendix B.

The snap joints differ from the other fasteners because they are not a separate part as they are a molded part of bigger geometry. Early on in the development phase the design models will not have snap joints. They will be designed and positioned later on in the development according to PQ compliant simulation expert.

4.3 Detailed description of selected fasteners and the fastening solutions

Throughout this report the following fasteners will be used in explanations and concepts as examples so it is important to get at comprehensive understanding of these fasteners, their DOF, their behaviors and their geometrical environment. The fasteners which are not presented in this chapter can be found in Appendix A.

In the following section the terminology of mating surfaces as MS will be used. Mating surface is refereeing to a surface on the fastener which is in contact with a part. The two components that will be joined together will be referred as parts (P). P1 is the part which the fastener is placed on first in the assembly. P2 is then the mating part. Depending on the assembly process, both P1 and P2 can be either local or target frame.

4.3.1 Fastener no 3

In table 3, fastener no 3 is used in both the front and rear doors. In Volvo V60 there are on the front door panel twelve and on the rear door panel eight of these rivets joining the door panels to an underlying structure. Figure 11 displays the two parts that are to be joined with this particular rivet. From left to right the sequence of assembly can be seen. The grey part, P1, is the door panel (left) and the yellow part, P2, is the underlying steel structure of the door (right). In figure 12 the mating surfaces can be seen as red areas for this fastening solution. MS1, MS2 and MS3 is the interface between P1 and the fastener. In the current fastening solution this is plastic to plastic contact. MS4 and MS5 is the interface between P2 and the fastener, currently plastic to sheet metal contact. The MS4 and MS5 contact areas are dependent on the thickness of P2. Depending on the thickness of P2, the MS5 varies. With larger thickness on P2, the MS5 get larger and vice versa. When P1 and P2 are joined together the nominal distance between them is 6.14 mm.

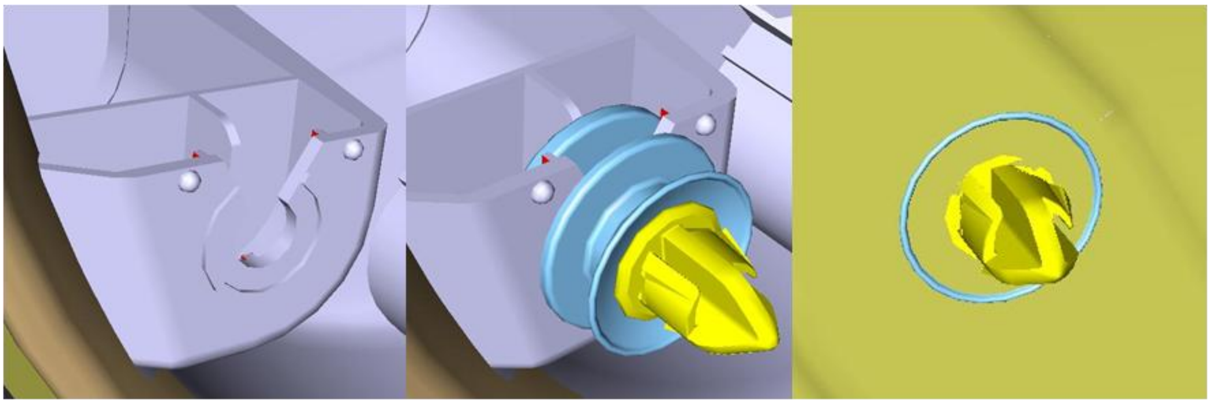


Figure 11: The rivet is placed on P1 and then P1 is assembled on to P2.

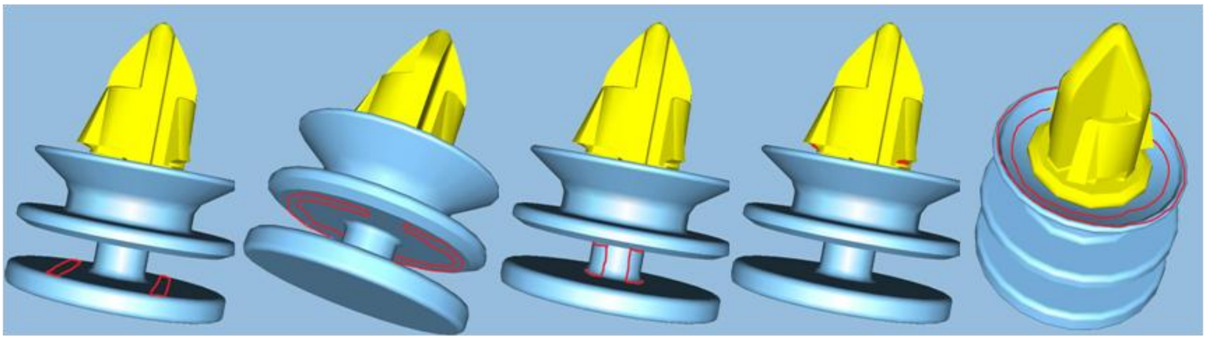


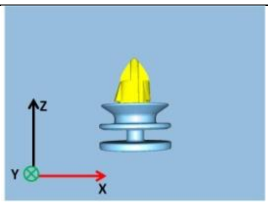
Figure 12: From left to right MS 1-5.

Due to differences in radius between the MS3 and the larger radius of the hole on P1, the MS3 cannot be estimated as a surface contact but more accurately it should be approximated as a line contact.

With the local coordinate system proposed earlier the DOF of this fastener and the fastener solution can be addressed. A distinction is done regarding the DOF locking on the local frame, in this case the door panel and DOF locking on the target frame, the door structure. As can be read in table 1 there is no difference in the locked DOF for local and target frame in this case. But in some cases, as evident in Table 3, there are differences. Therefore there is a need for making a distinction.

The rotations that are locked are RX and RY. The only rotation which is not locked is rotation around z-axis. This means that when the compliant door panel experiences deviation which would make P1 rotate around the fastener there would not be anything stopping that kind of movement. Logically and in reality there are several fasteners securing the position of a part meaning that the proposed rotation would be locked by the use of multiple fasteners. But when observing only one fastener, then the rotation is not locked. If that same variation wants to translate P1 in x-direction then that movement would be hindered by the rivets inherent properties. P2s geometrical shape and more specifically the round hole on P2 with MS4 will lock all translations and rotation except rotation around z-axis. This kind of DOF behavior is typical for the circular bodied rivets that have been observed.

Table 1: The local coordinate system and the DOF for this rivet.

	DOF Local	DOF Target	Geometry limitation
	TX, TY, TZ, RX, RY	TX, TY, TZ, RX, RY	-

4.3.2 Fastener no 9

Fastener no 9 in table 3 is used in C-, D-pillar and in the IP-consol. D-pillar has two, C-pillar has one and on the IP-consol six could be observed. Figure 13 displays the order of assembly. The red part, P1, is the D-pillar (left) and the white part, P2, is the Luggage trim upper. The retainer is pressed on to P1 and then P1 is pressed on P2 as can be seen in figure 13.

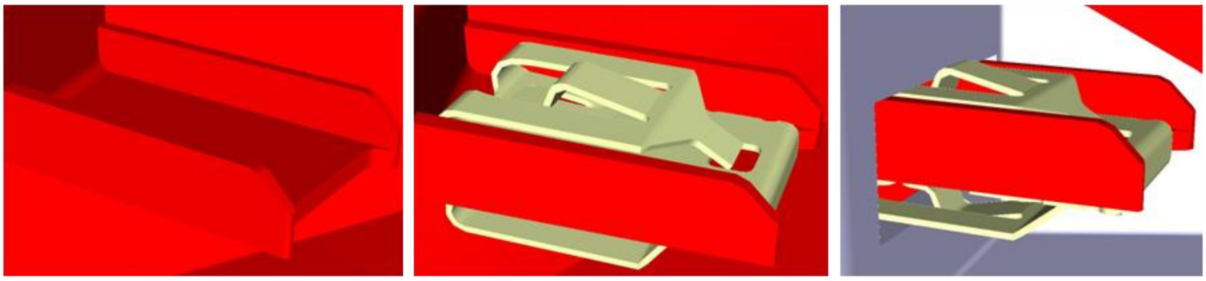


Figure 13: Fastener no 9 is placed on P1 and then P1 is assembled on to P2

MS1, MS2 and MS3 is the interface between P1 and the fastener, see figure 14. In the current application this is plastic to steel contact. MS4-MS7 is the interface between P2 and the fastener, currently steel to plastic. The MS1 and MS2 is composed dominantly of the four spikes. When the fastener is fitted in P1 the spikes bend up and lock the fastener in place. In the current applications the fastener is mounted on P1 which has a width of 11.13 mm and the fastener has a width of 9.50 mm. This difference should not be seen as play due to the mechanical and frictional locking by the spikes which holds the fasteners nominal position. In x-direction (see table 2) the fastener has no movement due to the tight fit.

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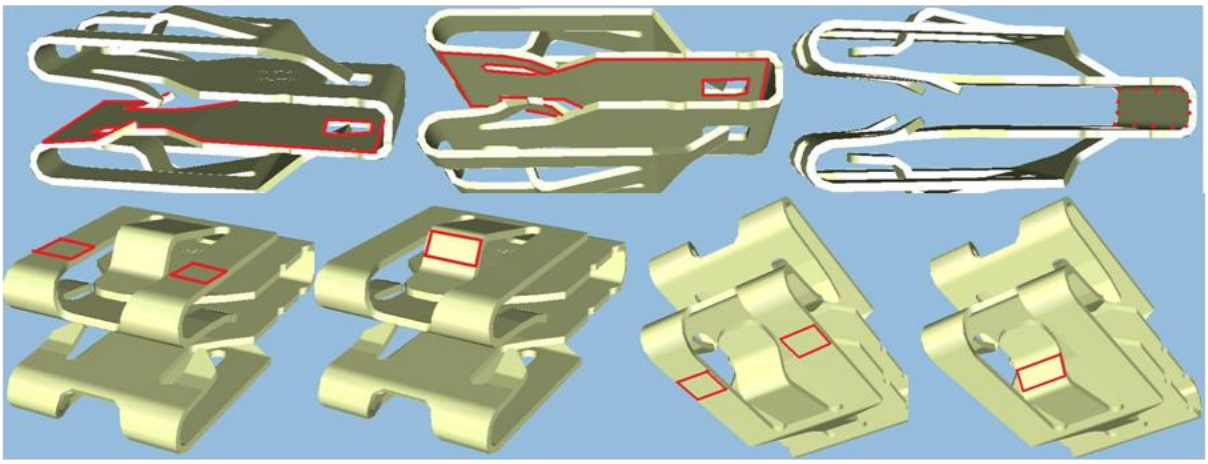
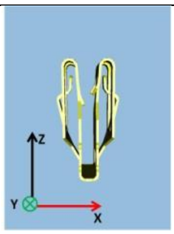


Figure 14: The upper row MS1, MS2, and MS3 and the bottom row MS4-MS7.

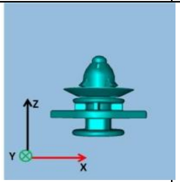
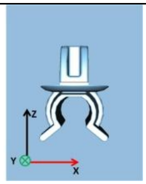
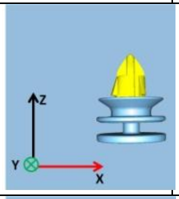
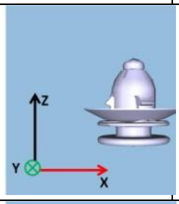
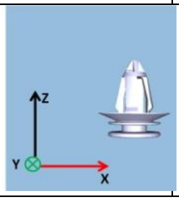
Contrary to the rivet, the retainer is a fastener where the surrounding environment influences to a high degree the limitations on translation and rotation. When the retainer is placed in P1 and joined to P2 as can be seen in figure 13 (right) the translation that will be locked is TZ relative the fasteners local coordinate system. It can be seen that for P1 the fasteners locks positive z- direction and for P2 it locks negative z- direction. In all the fastening solutions that could be observed were fastener no 9 was used the fastener locks translations in z-direction. This can be viewed in figure 13, the rectangle shaped hole in which the fastener fits through is approximately the same height as the fastener so there is no play in x-direction, therefore locking TX. But in y-direction there is a ± 1.59 mm play. RZ is locked due to that MS3 is spread out over the fastener, RY is also locked due to MS4 and MS6. RX is locked due to TY but as there is a play in y-direction there will some limited play in RX.

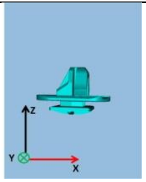
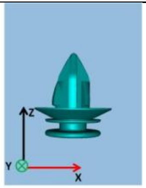
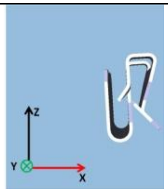
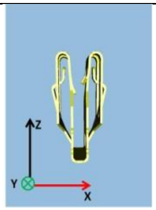
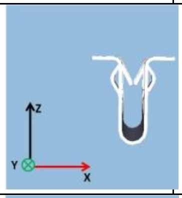
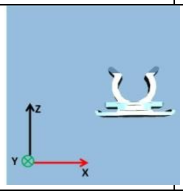
Table 2: The local coordinate system and the DOF for retainer.

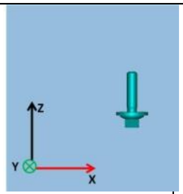
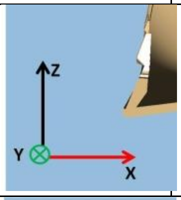
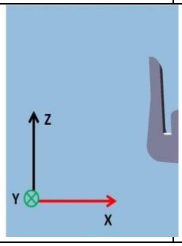
	DOF Local	DOF Target	Geometry limitation
	+TZ, TX	-TZ, TX	TY*,RY,RX*,RZ

*Locks the translation but have some play within that direction

Table 3: The fasteners that were found in the inventory and that meet the criteria that were set are presented in this table.

Fastener No	Figure	Volvo Part Nr	Type	DOF Local	DOF Target	Geometry limitation	Material	Region/ Component	Document No	Exists in models
1		30640643 VDR-GEOM-PROD-30640643-INS-01	Rivet	TX, TY, TZ, RX, RY	TX, TY, TZ, RX, RY		Plastic PA66 & POM	Mud flaps	1055788	V60, S60
2		1287317 VDRGEDRNUFO0865 05290101	Rivet	TX, TZ, RX, RZ	TX*, TY, TZ, RX, RY, RZ	TY, RY	Plastic POM	Luggage trim upper	01287317	V60, XC60, C30
3		1284853 VDRGEOMPROD012 816640101	Rivet	TX, TY, TZ, RX, RY	TX, TY, TZ, RX, RY		Plastic POM & TPE	Front & Rear door panel	01284853	V60, S60, V70**, XC60, S80, C30**
4		30640562 VDRGEOMPROD306 5344101	Rivet	TX, TY, TZ, RX, RY	TX, TY, TZ, RX, RY		Plastic POM	Rear header trim, Mud flaps, C-pillar	30653441	V60, XC60
5		8616645 VDRGEOMPROD861 66450101	Rivet	TX, TY, TZ, RX, RY	TX, TY, TZ, RX, RY		Plastic POM	A-pillar	1055200	V60, S60, V70**, XC60**, S80**, C30**

6		31216744 VDRGEOMPROD3121674401	Rivet	TX*, TY, TZ, RX, RY, RZ	TX*, TY, TZ, RX, RY		Plastic PA6	Mud flaps	1055567	V60, S60
7		30640607 VDR-GEOM-PROD-30640607-INS-01	Rivet	TX, TY, TZ, RX, RY	TX, TY, TZ, RX, RY		Plastic POM	Tail gate, B-pillar	1055751	V60, S60, V70**, XC60**, S80**
8		988088 VDR-GEOM-PROD-06815537-INS-01	Retainer	TX, TZ	TX, TZ	TY*	Steel HV 435-535	Front & Rear door frame panel	1054785	V60, S60, V70**, S80**
9		999442 VDRGEOMPROD9994420101	Retainer	+TZ, TX	-TZ, TX	TX,TY*,RY,RX*,RZ	Steel	D & C-pillar, IP-consol	1055519	V60, V70**, XC60, S80*, C30**
10		VDRGEOMPROD311119640101	Retainer	+TZ	-TZ	TX,TY*,RY,RX*,RZ	Steel	D-pillar		V60, V70**, XC60, S80**, C30*
11		3539879 VDRGEOMPACK035398790101	Retainer	TZ,TX,RY, RZ, RX	TZ,TX, RZ, RX	RY	(Plastic POM)	D-pillar	3539879	V60, V70

13		30624243 VDR-GEOM-PROD-30624243-INS-01	Screw	TX, TY, TZ, RX, RY	TX, TY, TZ, RX, RY		Steel, property class 8.8	Inner Roof	1054471	V60, S60, V70, XC60, S80, C30
14			Snap joint hook	TZ, TY*,TX, RZ,RX, RY	TZ, TY*,TX, RZ,RX, RY		Plastic	Rear lower bumper skin, B-pillar, Interior door trim		V60, S60, V70, XC60, S80, C30
15			Snap joint press	+TZ,TX,RY,RZ,RX*	-TZ,TX, RY,RZ,RX*	TY	Plastic	B-Pillar		V60, S60, V70, XC60, S80, C30

*Locks the translation but have some play within that direction

**Similar fastener with similar position as V60, but different part name

4.4 Test simulations

There were two significant test simulations performed, one in RD&T and one in FEMAP. The purpose with RD&T simulation was to observe the current compliant variation simulation capabilities of RD&T regarding the ability to represent fastener behaviors. The idea is also to see if several compliant parts can be assembled together in a way so that they affect each other. This is interesting because in reality deviation in one compliant part can propagate to other parts.

The simulation focused on a cluster of compliant parts located in the luggage compartment in a Volvo V60. A detailed description of the chosen cluster will be presented in the following chapter. The reason for choosing this cluster of parts is because of their difficult geometry, amount of complex fasteners and, as stated by GSU, the difficulties approximating variation on these parts using only rigid variation simulation.

The purpose of the FEMAP simulation was to see how locking of one and several nodes differ and what effect the different ways of locking will have on the overall deviation of a particular part. This is important to investigate in order to know what would be the best representation for a fastener. For example, representing a fastener in just one node may not be accurate enough, because the restraining capability of a fastener has an area distribution, which will not be represented if the fastener is defined in one node. The other notion was to investigate the difference between locking of nodes in RD&T and FEMAP, to see which system is more effective and user friendly.

4.4.1 Selected parts

The compliant parts which were used for the compliant variation simulation are: Rear header trim, D-pillar, Luggage trim upper, Luggage trim lower, and C-Pillar (see figure 15). The part which in this case can be seen as rigid is Upper body structure which is made of welded sheet metal pieces. The Upper body structure is relative to the interior panels rigid.

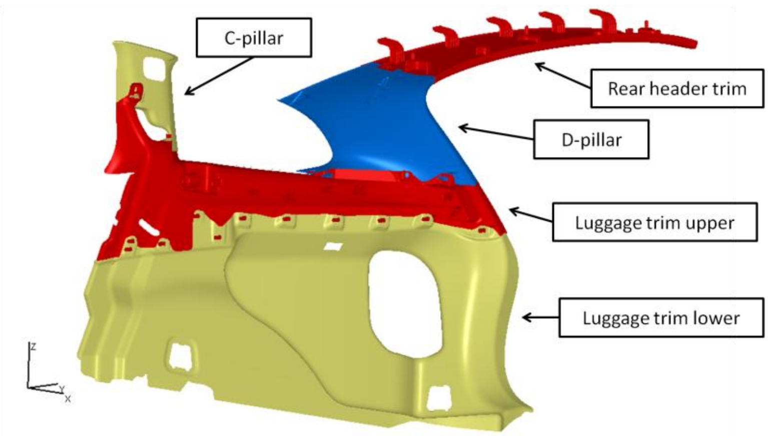


Figure 15: Shows the different parts of the luggage compartment of a Volvo V60.

Only Luggage trim lower and Luggage trim upper will be described in detail regarding their fastening solutions and the potential interference with other compliant parts, which all affect the ability for the current RD&T software to accurately simulate this cluster of parts. The purpose of their description is to give the reader a notion of how the parts are assembled in reality and to serve as a comparison to the assembly in RD&T. Further detailed description of the other parts is unnecessary and would lead focus of topic.

Luggage trim lower

The Luggage trim lowers position is determined by several fastening solutions. In figure 16 the different fastening solutions are illustrated and the adjacent parts are marked out. Two metal brackets are fastened with a screw to the much stiffer Upper body structure. The mating surface interface between the brackets and Luggage trim lower is illustrated as a red line around the two large rectangle shaped holes on the lower side of the part.

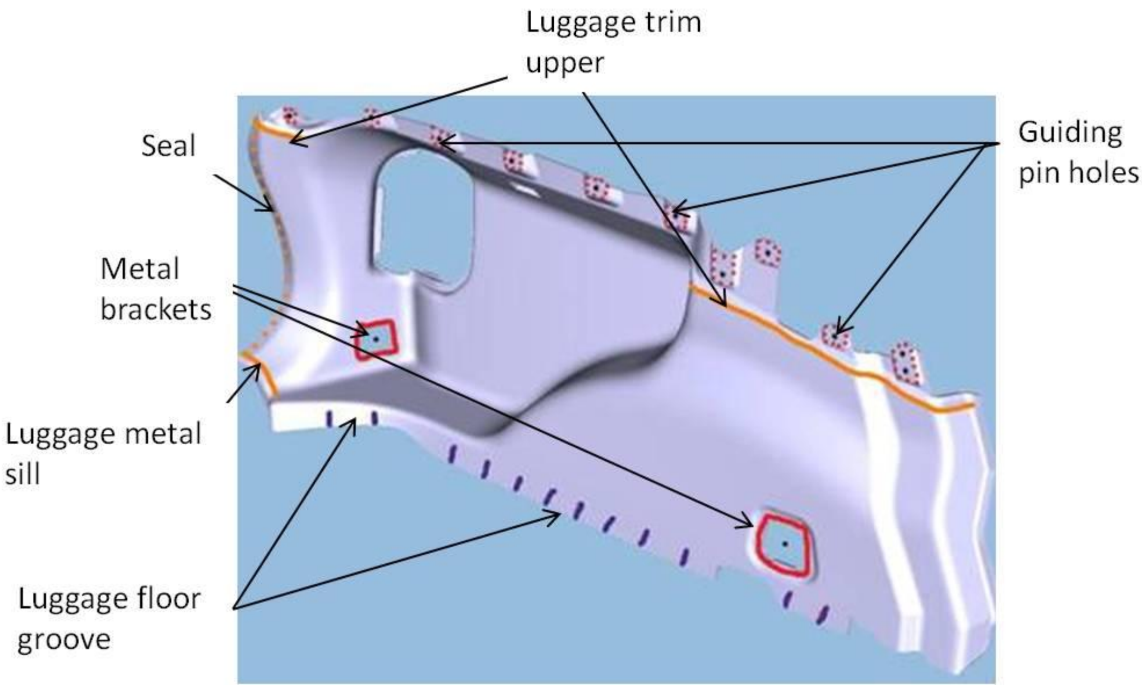


Figure 16: A-side of the Luggage trim lower.

On the back side of the brackets there are several spikes to prevent rotation in relation to the Luggage trim lower. When assembled, the Luggage trim lower is placed in a groove on the floor of the luggage compartment. In figure 16, the first two purple lines from the left are supported only from the backside. The rest of the purple lines are supported on both sides. The red dotted surfaces represent the contact surfaces to Luggage trim upper. In the center of these ten surfaces are twelve guiding pin holes. The orange lines display the area were the two parts, Luggage trim upper and Luggage metal sill, overlap Luggage trim lower. A seal which is shown as an orange dotted line pins this area on this part to the Upper body structure. The influence of this as a fastener solution is heavily dependent on the strength of the seal. For the sake of simulations and analysis these does not lock in any directions. Would this area experience any deviation it would be hidden in the seal.

Luggage trim upper

As can be seen in figure 17 the Luggage trim upper has several different kinds of fastening solutions. On this part alone there are 21 fastening solutions. Some are fastened to the much stiffer Upper body structure while some are used to fasten the Luggage trim lower to the Luggage trim upper which should be considered as compliant on compliant assembly. The fastener solutions which are used between Luggage trim upper and Upper body structure are fastener no 4, 2 the screw and the positioning pins. They are marked with red, black, orange and grey rings.

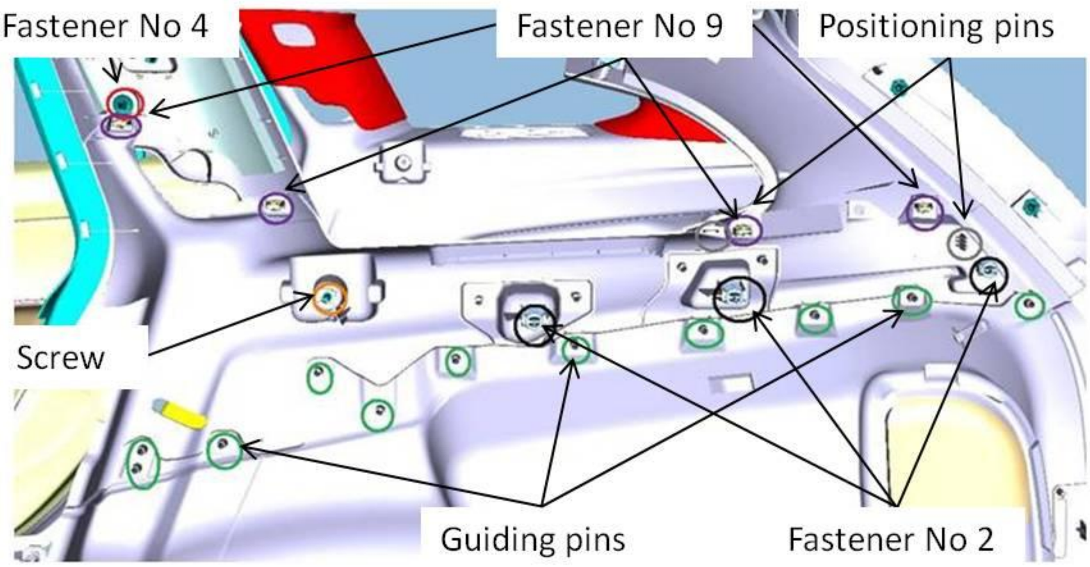


Figure 17: The B-Side of the Luggage trim upper.

All the properties and DOFs of the fasteners stated in table 3 would carry over it to the larger RD&T assembly. It should be noted that the two fastener no 2 on the left have different DOF from the one fastener no 2 on the right. As stated in chapter 4.2.1, this is due to geometrical limitations. The green circles are the guiding pins which fit into the holes of the Luggage trim lower. The nominal play between the pin and the hole is 0.4 m. Finally in figure 17 there are two grey markings. The one on the left marks the connection between the D-pillar and Luggage trim upper, the right ring marks the connection between Upper body structure and Luggage trim upper. The left guide has play of 1,1 mm in z-direction and 15,8 mm in x-direction and the right one has only a play of 2 mm in x-direction. On the A-side of the Luggage trim upper one can observe how the D- and C-pillar are overlapping the area which is marked with an orange line. The orange dotted line represents the same seal which is mentioned in the Luggage trim lower (see figure 18).

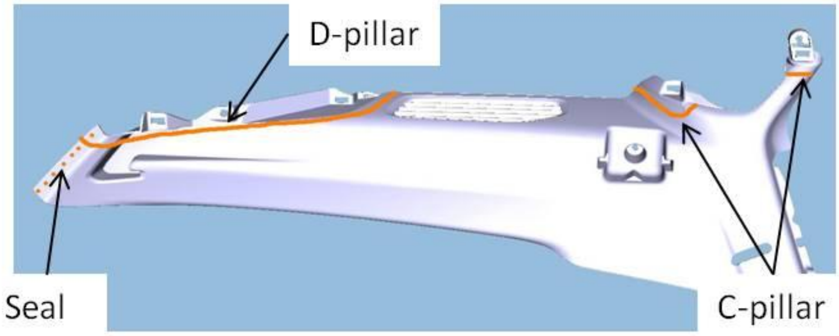


Figure 18: A-side of the Luggage trim upper.

4.4.2 Meshing

The luggage compartment region had a cluster of coupled parts and they were chosen for trial simulations and were meshed, so that compliant analysis was made possible. Surface mesh was the type of mesh that was created from the part. The reason for choosing surface meshes, instead of solid, was mainly to reduce the size of each mesh, that is the number of elements and nodes. This decreases the demand for high hardware performance and shortens the calculation time for simulations. The geometry of the parts, being thin relative to the surface area, also made them suitable for surface meshing.

Another action that was taken to reduce mesh size was that only the “front” side of each part would be meshed. The back side would be deleted and fastener positions, guide pins and other relevant geometry would be attached to the front side.

In order to be able to create useful meshes from the parts, each parts geometry had to be preprocessed before meshing them. This was done in several steps. It is important to point out that the following steps, which were done to create a meshed geometry, is not a recommendation in how PQ, GSU or GAE should mesh parts. These steps were carried out due to the limitations in FEMAP and therefore the following steps are not an optimal way of meshing parts.

The first step was to import the geometry to CATIA where the parts were stripped of small details and other geometry that was not of great importance to the mesh. This was mainly done to simplify the geometry of each part, making it easier to mesh and enable the use of larger element size. The possibility to modify and strip the parts in CATIA was greatly limited by interdependencies in the structure. Therefore the removal of the backside of each part had to be done in FEMAP, which will be explained later in this chapter. It should be mentioned that some reinforcement ribbons was stripped away on D-pillar and Rear header, making their geometries less stiff than they are in reality.

The second step was to import the geometry into FEMAP and group the surfaces of the geometry by coloring them in different colors. This is mainly done to facilitate the handling of the geometry. See figure 19 for an example with the Luggage trim upper part.

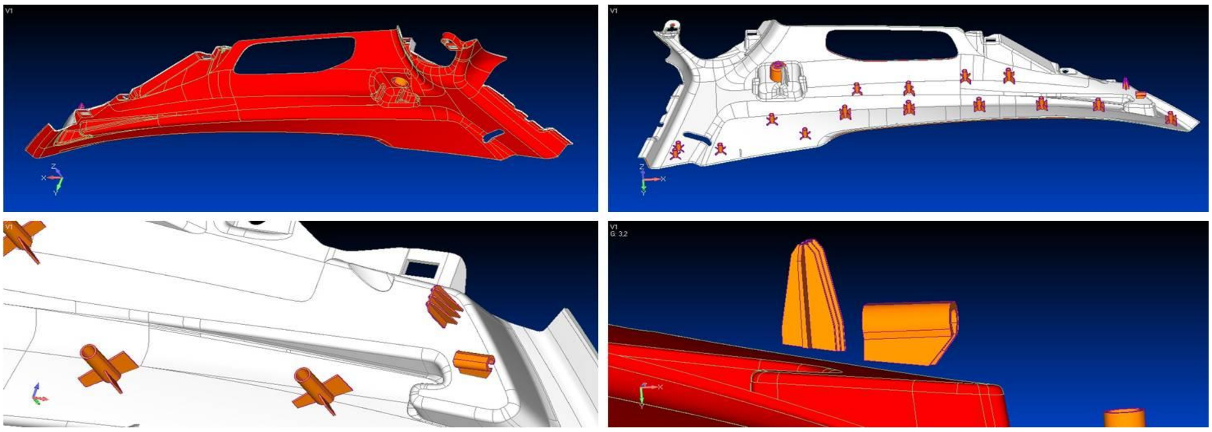


Figure 19: Shows how the Luggage trim upper part has been divided into groups by colors. The front side is red, the backside is white and fastener positions and guide pins are orange. The lower right picture also show how some parts are left “hanging in the air” after the removal of the backside.

The third step was to explode the geometry. Explode is a functions in FEMAP that separates the surfaces of a solid, making each surface an independent geometry. This is done to break the dependencies of surfaces that build up the geometry, making them easier to delete and modify. Otherwise FEMAP would not allow some delete or modification functions on surfaces, because it would interfere with the parts structural integrity.

The reason for wanting to modify the geometry in FEMAP is mainly to “clean up” the geometry, remove redundant surfaces such as the backside and to attach relevant geometry to the front side. Cleaning up geometry means removing sliver surfaces, spike surfaces and other “bad geometry” that can result in a bad mesh and/or low quality elements.

In step four, the geometry of every part is cleaned up and healed. Healing a geometry means patching over holes that are left from the cleanup, creating continuous surfaces throughout the model.

Because the part has been exploded, every surface in the model is recognized as an independent part. Also because of the removal of the backside, some parts of the geometry will not be connected to the front side (see figure 19, lower right picture). In the fifth step, the surfaces of the front side and other relevant geometry are stitched together into solid parts. These parts are then connected by extrusion, making the parts that are “hanging in the air” intersect with the front side. The redundant geometry from the extrusion is then split by a function in FEMAP, called intersection, which splits a solid at its intersection with another solid. The redundant geometry is then removed (see figure 20).

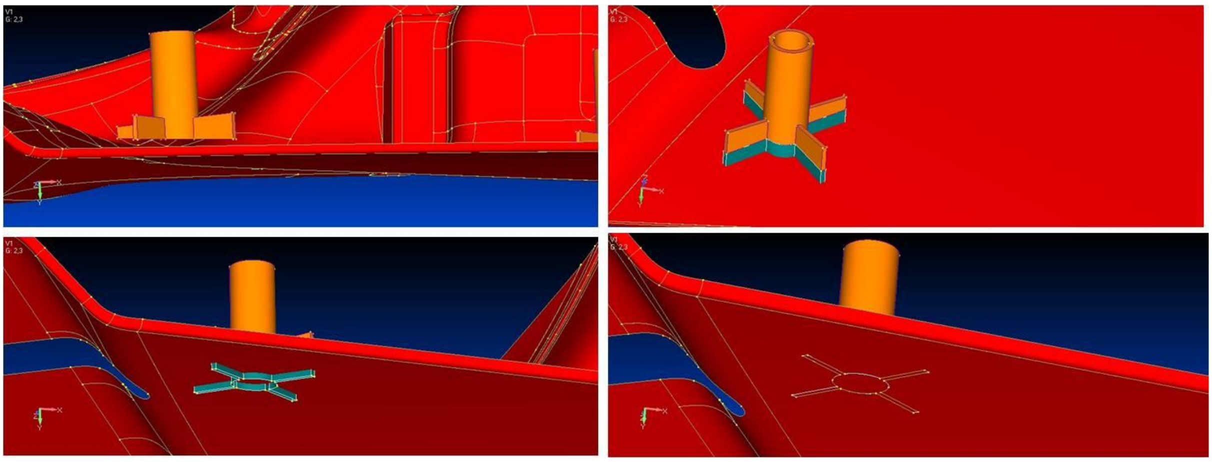


Figure 20: Upper left picture shows the unconnected pin. The upper right picture shows how the front side and the pin are connected with an extrusion. The lower left picture show the redundant geometry after the extrusion. The lower right picture shows the result after removing the redundant geometry.

In the sixth step a "non-manifold" operation is performed on the front side and the intersecting parts. The non-manifold functions ensure that the mesh will be connected and continuous at the intersecting curves between the front side and the connecting parts. All the parts are then stitched together, making FEMAP recognize the whole model as one solid.

In the seventh and final step mesh size is set on the model and the model is meshed. The mesh is automatically checked by FEMAP, ensuring that the produced mesh is usable. The mesh is then exported from FEMAP as an ABAQUS analysis model, resulting in an inp-file that can be imported to RD&T.

All of these steps are described because meshing is described as one of the big roadblocks for a larger implementation of compliant simulations. These steps on a complex geometry took without any macros or meshing focused software like Ansa or Hypermesh, approximately 90 min. The task that took the most time was the grouping of the individual small surfaces to facilitate further tasks. E.g. in Hypermesh this would not be necessary due to the inherent functions of Hypermesh which were lacking in FEMAP.

4.4.3 RD&T simulation

The idea of connecting several compliant parts together was presented to a developer of RD&T, who besides being the examiner served as technical support for this project. According to the developer, in order to achieve this, first the compliant parts had to be positioned on dummy parts. All parts were positioned on dummy parts with the 3-direction positioning system. After that, the whole assembly would be positioned onto a fixture through the subassembly function in RD&T. The 3-2-1 positioning system was used for positioning the parts on the fixture. By using the subassembly function, weld points could be utilized to create connections (serving as fastener representations) between the compliant parts. The use of welding points is today the only way to get two compliant parts to interact and propagate deviation to each other in RD&T. In order to create deviation in the subassembly, a support point was created on D-pillar and was offset from its nominal position. This will force D-pillar to deviate towards the support point and propagate deviation to the rest of the assembly.

It should also be noted that contact points were used, so that the parts would not "cut" into each other when deforming or deviating. Figure 15 displays the assembly and how the different parts are located on each other.

4.4.4 Results and reflection of the RD&T simulation

The simulation was successful from the point of view to make several compliant part interact and to propagate deviation between them. Because of time constraints, a validation test on real parts was never conducted. But the deformation and deviation did not show any abnormalities.

Several difficulties and restraints were noted during the preparation of the simulation. The difficulties will be presented in the following part.

The first observation that was made was the difficulty of representing a fasteners behavior in the positioning system. The master locators in the used positioning systems often under-represent a fasteners behavior in respect to the locking DOF´s of the fastener and its ability to lock rotation. The reason they under-represent is because every master locator locks translation in one chosen direction, while a fastener often locks translation in several directions and sometimes even have the ability to lock rotation to some extent. This can be compensated by the use of support points, which will provide additional locking. But this requires extra work for the geometry assurance engineer.

Another observation is that two compliant parts cannot be assembled together via the use of positioning systems. They must be welded together in the subassembly function through a fixture. The reason why is, that RD&T compliant module were originally developed for analysis of body plates that are welded to the body structure. In reality, that process involves the use of fixtures and welds. But in this case, where plastic parts that are assembled manually (plug-in systems) was to be analyzed, the use of weld points and fixtures was not appropriate. Another issue was the use of weld points to simulate fasteners. As described earlier, weld points locks translation in all directions, as welds do in reality. But this is incorrect for most other fasteners.

Contact point modeling is only possible to perform from the subassembly module. As mentioned earlier, the use of subassembly is not always desired. Since two compliant parts cannot be assembled without the subassembly function, this was not really an issue. But if RD&T is developed to handle two compliant parts without the use of subassemblies, ability to handle contact modeling outside of subassembly will be necessary.

It is also not possible to define contacts between a rigid and a compliant part. Contact modeling between rigid and compliant parts is necessary because many compliant variation simulations are done on a compliant part being assembled on a rigid part. The ability to model contacts between these would increase simulation accuracy and also eliminate the need for a play function in some cases. Instead, play could be handled with contact definitions.

4.4.5 FEMAP simulations

The simplest way to represent a fastener is to address all of the fasteners properties in a single node. In FEMAP this can be achieved with the function “constrains” where the user can decide the DOF of one node, several nodes or a feature. This function will be explained more detailed in the following chapter. To investigate what effect distribution of locking nodes has on the movement of a part, a simulation was set up were as in the first test only one node per fastening location was used to fasten the D-pillar. The single nodes were fixed which means that all translation and rotation were locked in that node. In the second test, two nodes per fastening location were fixed. In the both cases the same load was applied on the same node on the D-pillar. The results can be seen in figure 21. The key observations in figure 21 are the small yellow vectors. The other information in the figure is not of interest. The small vectors represent size and direction of movement. The one-node simulation shows how the part rotates around the fixed node. In the two node test the rotation is significantly smaller. The simulation where the entire line was fixed did not show any significant difference from the two node fixation. Note that the difference in locking ability between two nodes and a line is probably dependent on the distance between the two nodes chosen for the two node locking test. The distance between the two nodes must reflect the fasteners surface distribution. Otherwise, if the nodes are located to close to each other, the result will resemble the single node locking test. Figure 21 show the placement were fastener no 9 is used. The retainers mating surface is better approximated by a wider distribution between the fixed nodes than one node locking.

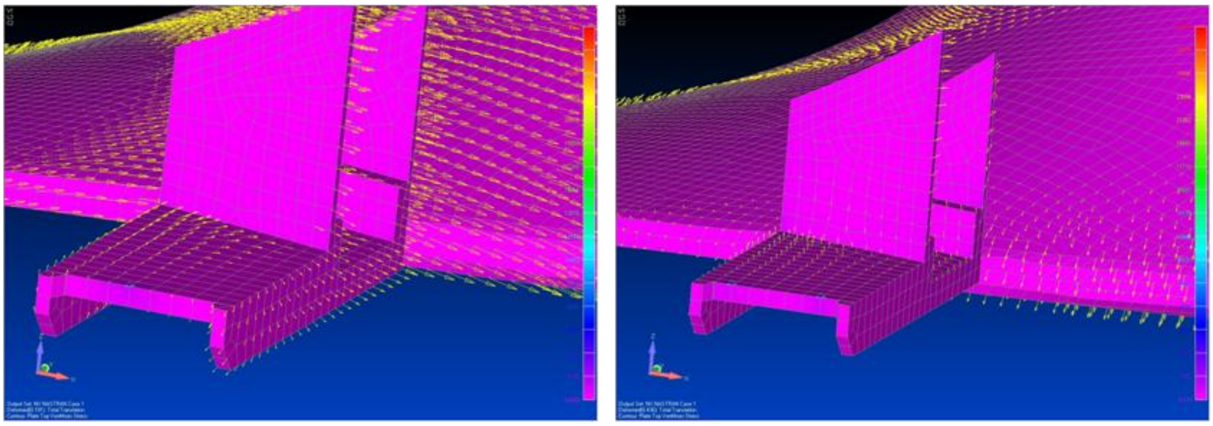


Figure 21: On the left, one node is fixed and on the right, two nodes are fixed.

4.4.6 Difference between RD&T and FEMAP when locking nodes

When a part is to be assembled the location of that fastener can be represented by a point, line or an area. In order to lock a compliant part in such a way to represent a fastener the engineer needs to use the support point function within the positing system. To lock an area around a hole like a screw or bolt, a minimum of three support points would be used. One point for each locking direction. In the most basic representation these nodes movements would be locked in all direction. As can be seen in table 4 there are big differences between the two software. In RD&T this process would take approximately seven steps to lock the support point in one direction. So to lock one node in three directions there will result in 21 steps.

Therefore it will take 63 steps to lock three nodes around a hole to represent that bolt. It should be noted that these steps are only necessary if the user wants to over constrain the model. Otherwise, significantly fewer steps are needed to set up a positioning system. Figure 22 and figure 23 illustrate the different menus used to lock any given nodes.

Table 4: The different steps required to lock node/nodes in RD&T and FEMAP.

Software	RD&T	FEMAP
Steps	Add a support point	Enter nodes
	Pick a support point	Click on the desired node
	Click on desired node	Click on the desired node
	Accept point XXXXXXXXXX Yes/No	Click on the desired node
	Active direction x, y, z	Ok
	Copy Local	Fixed
	Pick Part (Target)	Ok
Results	One node locked in one direction.	Three nodes are locked in all directions.

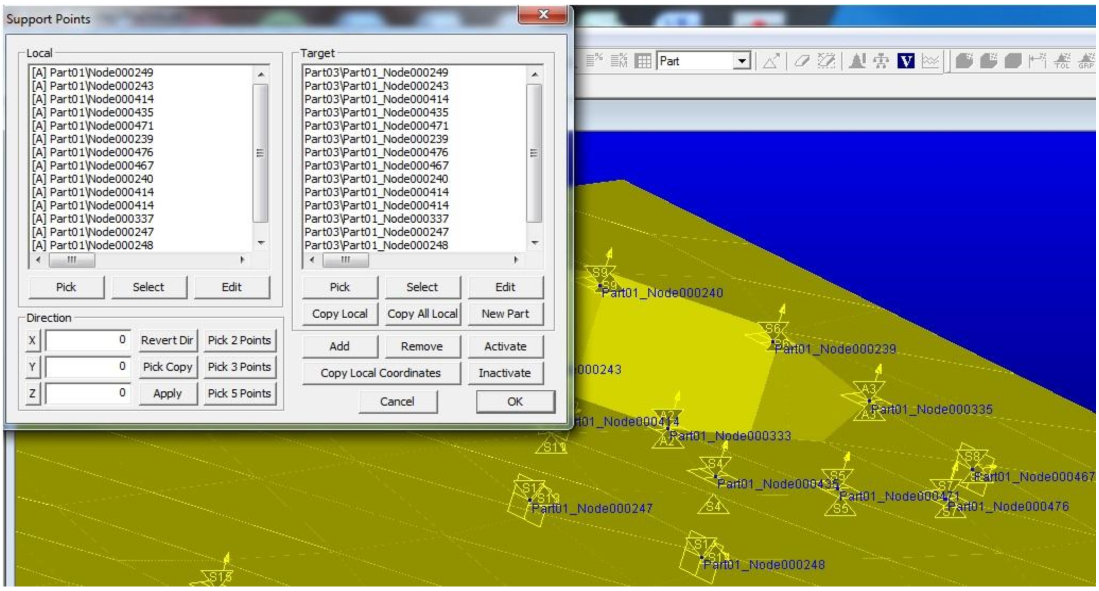


Figure 22: The support point functionality in RD&T.

Note that in this test the supporting points do not have any assigned tolerances. In the FEM software FEMAP the need to simulate the constraints of different fastening elements and solutions are presented in different way. In RD&T the focus is on the variation due to the positioning system whiles FEMAP focuses on simulating the behavior of the parts when constrained and affected by a load. In FEMAP the user can choose to define the constraint on a node, curve or a surface. Node locking will be utilized in order to be able to make a fair comparison. In order to make the constraints the model and constraint are chosen.

In FEMAP the total amount of steps for the above mentioned operation is seven compared to RD&Ts 63. There is a strong correlation between time spent performing these tasks and number of steps in both software.

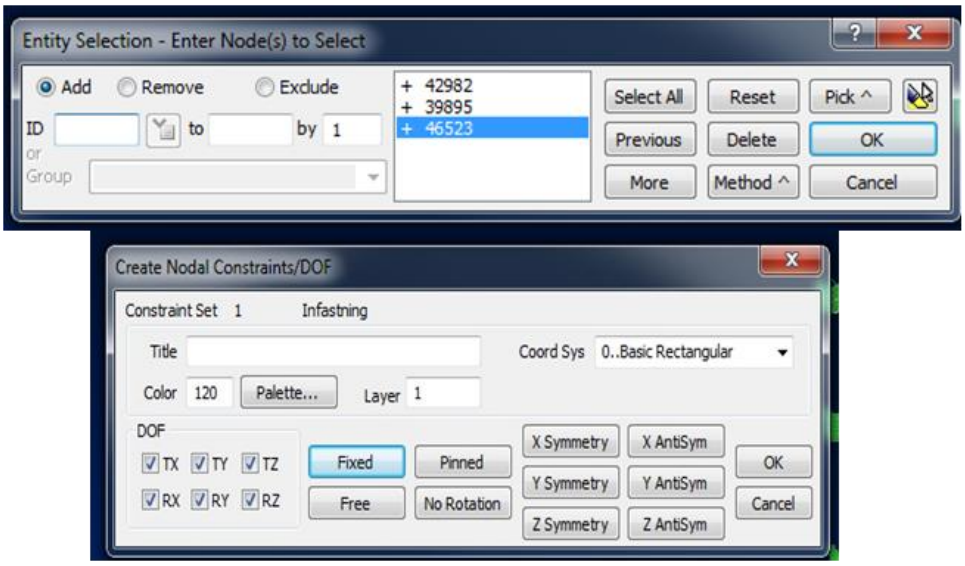


Figure 23: Selecting nodes in FEMAP and to the right choosing the DOF for the selected set of nodes.

4.5 Interviews

The following chapter will present the conducted interviews with Mikael Rosenqvist, GSU and Lars Samuelsson. The interviews were conducted at the workplace of the interviewees which was in this case at VCC Torslanda. The following section is a summarization and observations made at these interviews.

4.5.1 Business application manager

Business application manager and PE Geometry Development AB partner Mikael Rosenqvist is VCCs leading expert in RD&T. He explained how he has eight years of compliant variation simulation experience both as user and software developer. He is currently working at providing input for both development of the technology and methodology in geometry assurance tool RD&T.

He was asked about the current limitations to the software regarding particularly compliant variation simulation he spoke about several issues. Rosenqvist expressed the need for some new functions in RD&T. The ability to simulate play was an issue that users often mention to Rosenqvist. There are occasions were fasteners have play or the fastener is not determining the position of the part but rather assists assembly. A direct example is guiding pins. When variation affects these fasteners they can become position determining fasteners. Also these fasteners can in some instances deform the part if the deviation is large enough. Another instance where the software cannot replicate reality is fasteners which only lock translation in positive or negative directions. Currently if a fasteners locks in positive x-direction the geometry engineer would not be able to simulate this kind of behavior to the rigid or compliant variation simulation. These are the two most requested functions that users express to Rosenqvist. Other issue that users have is the time it takes to run simulations when working with large compliant parts. If more and more compliant simulations with larger and more complex shapes are to be simulated then there will be a need for more development in software performance and also the graphical performance. He continued to say with more compliant simulations performed the need will not only be to simulate one compliant part but a cluster of parts. Parts may deform and alter the positioning of other adjacent parts and split lines. So there is a need to assemble more compliant parts together similar the way Lars Samuelsson is working today but with interior parts fastened with rivets, screw and other fasteners instead of weld points.

When questioned about if he experiences some limitations when using positioning systems on compliant parts he replied that due to his extensive experience with RD&T he finds most aspects logical but users have expressed other opinions. Some users remark, especially beginners, that it is not intuitive to understand the current positioning systems.

Rosenqvist also explains that the designers receive a recommendation on the positioning system from GSU. When the designers construct the different parts they should think in 3-2-1 positioning system and design fasteners which lock the DOF similar to the recommendations from GSU. According to Rosenqvist a follow-up is done on the designers' fastener system based on the positioning system purposed by the GSU. Even though some may feel that the positioning system is not so intuitive, design engineers and GSU have a functioning relationship.

He also spoke about the advantages of a point based system, being simple and sufficient in many cases. But he expressed a desire to handle features (Surfaces, Lines and Arcs) instead of points. It would be easier to model contacts and to some extent also positioning systems.

Rosenqvist was presented with the idea of a fastener library that the user could utilize to position and over constrain parts with. He was positive to the idea and mentioned that the user should in that case have the ability to adjust the predefined properties in order to be able to adapt the fasteners to larger variety of situations. He thought that a visual representation of the fasteners on the model would be favorable in order to make the software more pedagogical. The notion of the fastener being an actual part in the assembly was ruled out by Rosenqvist because he thought that the fasteners will then interfere with tolerance chains and there would be too many parts to handle.

4.5.2 Compliant simulation expert

Lars Samuelsson is one of few at Volvo who currently works with compliant variation simulation. He, Björn Lindau and Ola Wagersten, have experience with compliant simulations. Samuelsson told that he is essentially the person at Volvo who works with virtual matching of body structure. When interviewed, Samuelsson was working on an upper body structure section of a new model. He explained how he scans a physical model and imports the virtual geometry into his computer. Because of the way the scanning process is performed some defects occur on the virtual model. He locates the defects and performed several actions in order to create a usable geometric surface model. From the scanned data he then cut the model in to different part so that he can in later stages join the different parts together again with weld points and contact points. To create a compliant part of the geometric models he used Ansa to mesh the parts. He took time to show this process. In just few minutes he created a mesh with some few defects but he assured that the defects would not affect the outcome of the simulations.

Samuelsson described the newest version of RD&T as very good and that it meets his requirements. When asked how come his version is so good, he replied that he is the one that comes with suggestions for improvement to the developer of RD&T Lars Lindkvist. So therefore the software is designed especially for him and for working with sheet metal and welding. Samuelsson expressed that he never works with fasteners and never has had the need to use any fasteners other than weld points. Questions regarding compliant interior parts and fasteners used, he simply responded that he does not work with those parts and therefore he could not give any suggestions or answers regarding eventual solutions for those applications.

4.5.3 GSU

The interviewees were manager Claes Hammarson, engineers Kjell Stridh and Tomas Öberg.

Hammarson focused on describing how the GSU works with geometry assurance and fastener management. Firstly they receive styling data from the designers. Through the use of RD&T and experience from pervious projects they choose the most robust positioning system. This means that they choose where different components are to be fastened for the most robust solution. When picking these locations they are not thinking of the fasteners as screws, snap joints or rivets but only the position of these. When the "best" positioning system is chosen then these are sent to design engineers. Then design engineers are responsible to make sure that the right fastener or design is chosen to fulfill the requirement set by different divisions, e.g. PQ. After detail design is done verification is performed to make sure that the initial results are matching with the new design. If not, a discussion is done with the part designers and GSU to solve the problem and come to a best possible solution.

The interviews were asked in what way they work with compliant variation simulation today. The respond was that they do not work with compliant variation simulation in the sense that the components that are used when simulated are non-rigid but they said that they compensate the compliant properties of the parts by dividing parts into areas which are then analyzed individually. According to GSU, this way is accurate enough to create valid variation simulation measurement even when simulating compliant parts such as the inner roof.

When asked about problems with compliant variation simulation, meshing the parts was mentioned as a big issue. GSU felt that it was too time consuming compared to the benefits it gave.

Hammarson was open to the notion to start using more compliant simulations if someone could explain the benefits of compliant variation simulation over the current way of simulating. He believed that GAE or GSU-chassis had more of a use of the potential fastener management and compliant variation simulation than GSU. Even if they did not at this moment in time see any obvious advantages with compliant simulations and fastener management they addressed a single part in the current V60 model. The rear lower trim panel is quite problematic to simulate due to its shape, fastening positions and non-rigid behavior.

5 Requirements

The foundation for the requirement specification has been gained by interviews, discussions with key engineers at VCC and Chalmers and by the testing and modeling observations made. These are presented in chapter 4. The suggestions, whishes and demands that have been expressed have been documented and are presented in table 5. These have been categorized in whishes (W) and demands (D), where 1 is the most important and 5 the least important. It should be noted that these requirements regard both the concepts that are to be developed in this thesis and general improvement in RD&T.

Table 5 Requirements based on interviewees and discussions with key personal in VCC and Chalmers.

ID	Description	Value for Users
1.	Be able to mesh in RD&T.	**W 4**
2.	Locking of only one direction of a coordinate (one-sided elements).	**W 2**
3.	The ability to simulate with fasteners on both engineering data and design data (immature data).	**D**
4.	Possibility to have graphical representation of the fasteners, without having the fastener as a part.	**W 3**
5.	Be able to handle features, like curves, surfaces.	**W 3**
6.	Be able to define contact points outside of assembly.	**W 4**
7.	Be able to define play.	**D**
8.	Be able to select multiple points/nodes at the same time.	**W 2**
9.	Be more pedagogical than the current way of handling compliant parts and positioning systems.	**D**
10.	Be faster than current solution for the same accuracy.	**D**
11.	Have an acceptable standard level of accuracy in simulations without additional operations.	**W 2**
12.	Be able to set a desired level of accuracy with additional operations.	**W 4**
13.	Have a library of fasteners to chose from in RD&T.	**D**
14.	Fasteners should have predetermined properties.	**D**
15.	The fasteners should simulate how the real fasteners have surface contact with several components which it fastens.	**D**
16.	Be able to lock all rotation and translation in one point.	**W 3**
17.	The solution should not require a lot of performance.	**W 5**
18.	The solution should be applicable on every compliant part and fastener on a car both exterior and interior.	**W 2**
19.	Incorrect use of proposed solutions should be expressed to the user so that misleading result could be minimized.	**W 3**

Table 6: These criteria are stated based on the information received in interviews and discussions. The grading reflects the value for the users of compliant variation simulation in RD&T.

Value for User	
Grade	Criteria
W 5	Not so important
W 4	Good to implement in later versions
W 3	Good if it could be implemented
W 2	Important
W 1	Borderline Demand, very important
D	Demand

6 Concept generation

Generating concepts from the stakeholder's needs and requirement to the final concept is presented here. The two sections in this chapter are the sub-solutions which can with a Morphological- and Phugmatrix be used to combine the subsolutions to viable concepts. In Appendix C the methods used to form the three concepts which served as a base for discussion with stakeholders can be found. Also the three concepts will be presented here.

6.1 Sub solutions

To generate different concepts it is important to define the problem and break it down into smaller more manageable subproblems. To facilitate the concept generation a decomposition of the fastener management system and in particular the key factors needed to fully describe and represent a fastener in compliant variation simulations in RD&T. An identification of the key factors was performed with knowledge gained during the inventory, the simulations and interviews. The key factors are fastener description, fastener representation, connectors and fastener positioning. The following key factors and their solutions are the central parts needed in order to create a viable and effective fastener management system. To manage these key factor solutions additional general solutions may be required. These will be presented under section 6.1.5

6.1.1 Fastener description

The physical fastener can be interpreted in a few ways. To transfer the information regarding the fastener into RD&T the fastener needs to be described.

Surfaces - meshed fastener can be used where the different surfaces on the fastener have stated properties. The elements and nodes are connected to the surfaces and thereby the DOF and other properties can be stated with regards to the surface. The mesh and nodes contain all the available information about this fastener so there is no need for approximations and simplifications. E.g. one surface can have the DOF locked in every node octagonal to the surface and not to some global/local coordinate system. (see figure 24)

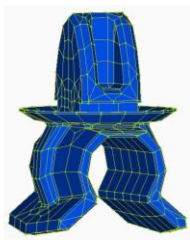


Figure 24: Surfaces

Points - The same fastener as in surfaces concept but instead of having all the nodes and elements being used a collection of relevant nodes are used (see figure 25). The active nodes are used for connection between local and target parts and will represent all the behavior of the full fastener. This could be done manually by a geometry engineer who chooses nodes on a meshed fastener and then states the DOFs for every chosen node. When this kind of model is to be implemented in RD&T only the active nodes will be computed.

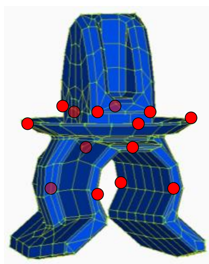


Figure 25: Points

Levels - One of the most basic descriptions of a fastener is by the manner it locks between two parts. So to describe the fastener with two levels would make the process as simple as possible. So one level is for the local DOF and one is for the target DOF. This interpretation will have an area of distribution and the DOF for the levels. This description is not absolute and exact due to the choice of where to place the levels as can be seen in figure 26. The upper level is in the "correct" position but the lower level can be approximated on several positions.

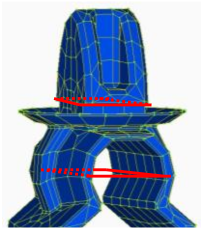


Figure 26: Levels

6.1.2 Fastener representation

There are several ways how one fastener solution can be described and represented as can be seen in the previous paragraph. The fasteners are three dimensional physical parts with numerous stated mating surfaces and properties. The representations of these predetermined properties are stated below.

Node-Node - All the behavior of a particular fastener or fastener solution would be applied to a single node on the local frame and a single node on the target frame (see figure 27). So the engineer only chooses two nodes that would inherent all the properties that are predetermined for that fastener solution.

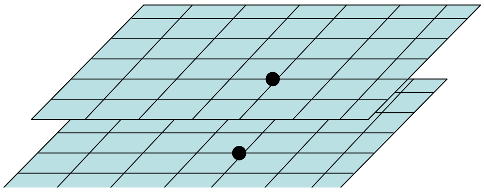


Figure 27: Node-Node

Nodes-Nodes - Several nodes are chosen to represent a fastener solution. The nodes are spread over a certain area giving this kind of representation a geometrical distribution (see figure 28). Metaphorically this would mean that several node-node fasteners would represent a more accurate fastener. The nodes are ordered into groups. One group contains local frame nodes and one target frame nodes.

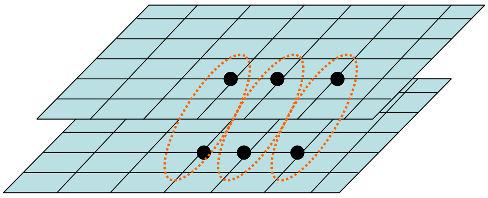


Figure 28: Nodes-Nodes

2 Sets - The mating surfaces of the fasteners are defined by stating their shape and DOF. The mating surfaces are represented by several nodes on the compliant and/or rigid parts and will make up sets of nodes. A set is a group of nodes which together inherent the properties of a particular mating surface of the fastener (see figure 29). This kind of representation would be appropriate when working with surfaces. In this case the number of nodes or points between the sets does not necessarily match

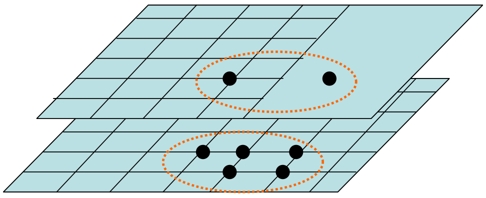


Figure 29: 2-Sets

2+ Sets - To fully represent the fastening behavior of two three dimensional meshes, there is a need to describe all the mating surfaces. This could mean that in order to fully describe the mating surfaces of a fastener five sets would be required. In this illustration only three sets are used to represent three different mating surfaces of a random fastener solution (see figure 30). Every set could have different DOF and properties.

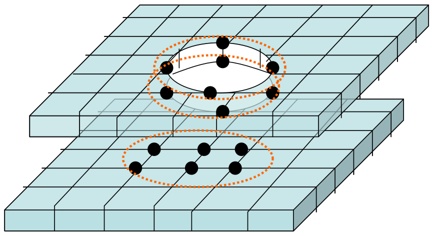


Figure 30: 2+Sets

6.1.3 Connectors

To connect nodes, points or levels to each other so that a coherent and relevant representation can be achieved a connection and information transfer channel is required. So when nodes or points are chosen on two different parts and variation occurs on one part a transfer of geometrical variation information is conveyed from one part to the other.

Nominal distance nodes - To transfer the variation from one part to the other a nominal distance between the nodes is kept. This means that there is a nominal distance connection between every Node-Node concept (see figure 31).

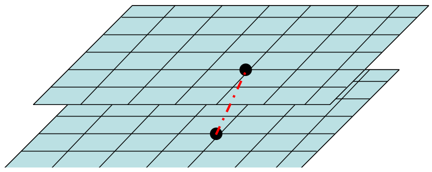


Figure 31: Nominal distance nodes

Nominal distance groups - Similar to the nominal distance nodes but this need less of connectors between the two parts. This means that not every node would be connected to other. There is three connectors between groups so that within the groups (see figure 32). This kind of representation is much more feasible to implement if there are many nodes selected on several levels.

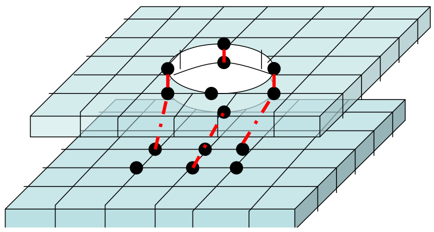


Figure 32: Nominal distance groups

Mesh - To connect the local and target nodes a mesh is created (see figure 33). The mesh contains both the material and mechanical properties of a fastener. It is possible to calculate the force it takes to assemble a given fastener when sequence assembling fasteners while influenced by variation. The simplest connector would be a line mesh and the most advanced can resemble the actual fastener.

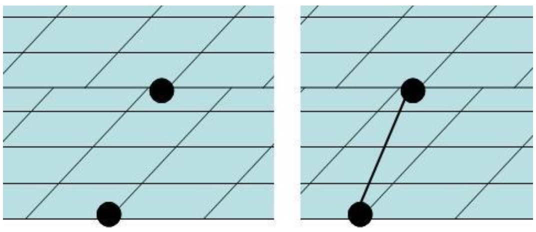


Figure 33: Mesh

Rigid Part - Currently it is possible to connect a node to a rigid part. So to connect two or more nodes together they can be connected to a common rigid part (see figure 34). This kind of solution would most definitely affect the analysis and the presentation of the results. The

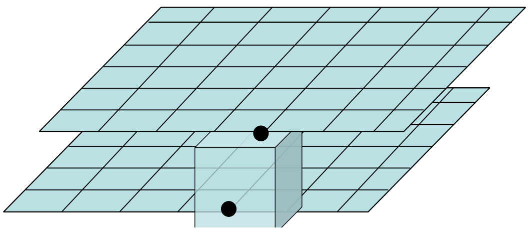


Figure 34: Rigid Part

solid can have the shape of the actual fastener.

Deform Nodes - The problem with connecting nodes which are not in direct contact can be circumvented by actually connecting the nodes. This can be achieved by deforming the mesh so that nodes are actually in direct contact (see figure 35). Similar to the mesh solution the deform nodes solution would have material and mechanical properties but they will be properties of the parts and not the intended fastener solution. Also any deformation based on variation will probably be different than if the mesh was not deformed.

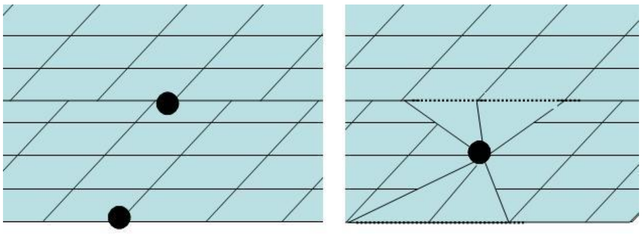


Figure 35: Deform Nodes

6.1.4 Fastener positioning

To assemble the local and target parts the fastener solution, fastener or fastener properties need to be placed in the correct position on the respective parts. The following solutions present a way in how to achieve this.

One node - To select the position of the fastener, a single node would be picked in the region where the fastening solution is desired (see figure 36). The orientation of the fasteners local coordinate system would need to be coordinated to the global by selecting orientation for the fastener solution by picking and defining a specific direction.

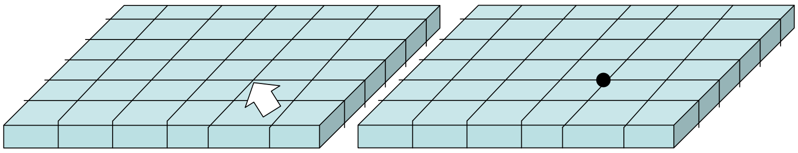


Figure 36: One node

Sequence - If the fastening solution is to be described by several nodes or a set then some specific nodes can be picked that corresponds to the predetermined set that describes the fastener. The active nodes that describe the fastener are numbered. So when choosing the position of the fastener one would choose were node nr 1 is placed, and so on (see figure 37).

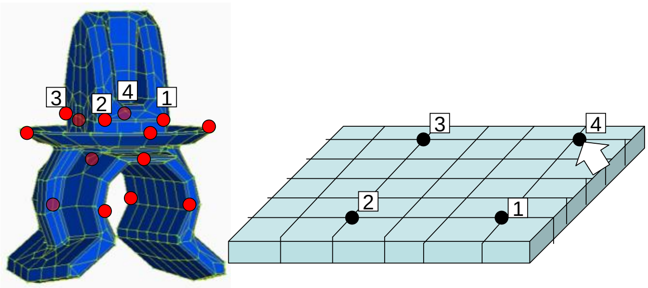


Figure 37: Sequence

One node plus shape – In order to speed up the node selection process all the nodes within, on or in the stated vicinity from the shape can inherent the properties from a predetermined fastener behavior (see figure 38). The shape can be one, two or three dimensional. The shape can also have the dimensions of a fasteners mating surface.

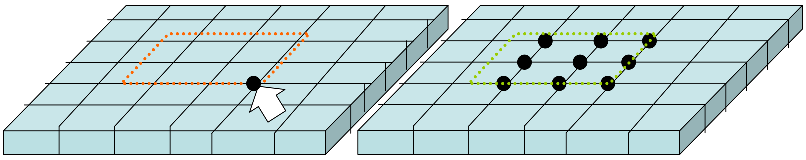


Figure 38: One Node plus shape

One node plus automatic distribution - One node is chosen and then automatically a few nodes are chosen to create a distribution and positioning (see figure 39). The automatic function could with the knowledge about the area of the mating surfaces on the fasteners illuminate all the nodes that are in that region volume vise, distance vise and so on.

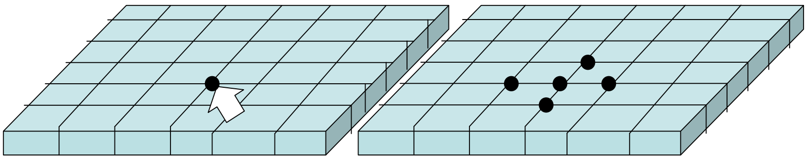


Figure 39: One node plus automatic distribution

Feature - One surface or line is picked and that corresponds to a given mating surface on a fastener, so all the available nodes in that area would represent a given mating surface. (see figure 40).

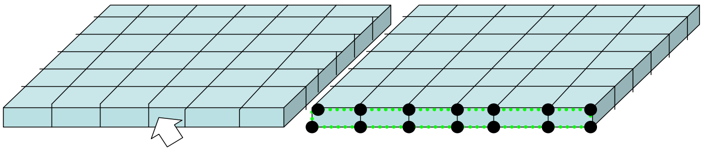


Figure 40: Feature

6.1.5 General solutions

To improve the overall performance over any concept generated from the sub solutions some general solutions are presented here. These are not a part of the key factors but have a large influence on the ability for the concepts to reach their potential are needed.

Closest link – It is a function which automatically searches for the closet node in a given direction. It is a function which could be very useful in different functions in RD&T such as for contact point modeling, play or the automatic distribution sub solution function. A Closest link like function is already used in FEMAP.

Several node selection – To increase the efficiency of selecting many nodes several node selection functionality is needed. The functionality would give the geometry engineer an option to keep selecting nodes without being sent back to a different window. The function should only show and keep adding the nodes which are chosen to one window so that additional rules or other options can be made on all the chosen nodes.

Node projection – There can arise situations were a Node to Node or Nodes to Nodes connections cannot be established. This can occur when modeling with compliant and rigid parts. The rigid parts would not have nodes for the other node to connect to. Also the fastener properties of the other part would not be represented accurately. A solution would be to then project the node to the surface of the non compliant part. This projected node would then not be a node but a point to which the connection can be made.

Unified Menu system – A menu system which contains all the necessary functions to assemble the parts with appropriate fastening solutions.

6.2 The concepts

The following sections will describe in detail the three concepts that were generated. All three concepts are generated on the stated requirements in chapter 5. The concepts were generated by combining the sub solutions into concepts (see Appendix C). The concepts were generated with different purposed. One was to be as simple as possible, the other would be an intermediate and one would incorporate functionality available in FEM and CAD software.

All concepts will have a centralized positioning system menu, which allows the user to over define the system with use of positioning points. The idea is also to gather all locator types in the menu, so the user do not have to jump to other functions, like subassembly, in order to use contact points.

The concepts will be more pedagogical through visualization. The idea is to utilize visualization of fasteners both in the menu and in the model, so that the users' perception of the fastener and its location in the model is improved.

All the concepts will have predefined fasteners, with predetermined behavior. The user can also adjust this behavior so it fits the intended fastener better.

All concepts must be able to handle both styling- and engineering data, with respect to fasteners, which enables both early and late variation simulations trough the development process.

6.2.1 Single node concept

The idea behind this concept is that it should resemble, as much as possible, the current system in use in RD&T. This means that it is not too complicated for the developer to implement the proposed system (small technical jump) and therefore can be implemented rather quickly. It also means that the adjustment for the user will be small and the user will adapt quickly. An example of the proposed positioning system menu can be seen in Figure 41.

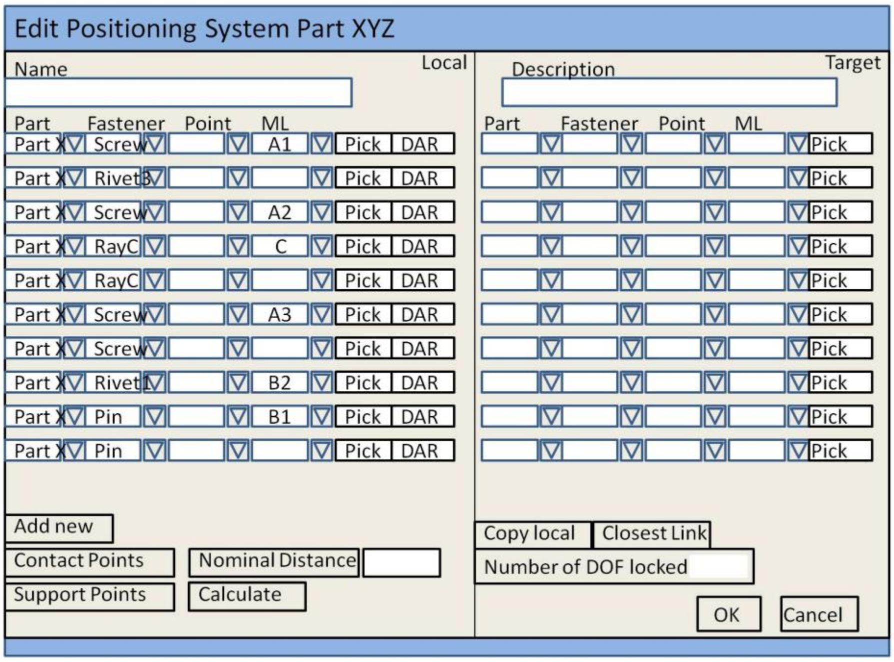


Figure 41: Positioning system menu in the single node concept

As seen in figure 41, two new scroll down menus are introduced: the fastener and the master locator (ML) menu. The fastener scroll down menu enables the user to quickly choose a predefined fastener and the ML menu enables the user to define which positioning points are master locators. Because the difference in fastener behavior depending on its environment (described in chapter 4.2.1), there will be two sets of the same fasteners available in the scroll down menu. One set for dealing with engineering data and one for styling data. The difference between the sets will be that the engineering data set will only lock DOF that the fasteners actually locks and the styling data set will lock fastening solutions DOF.

Note that ten positioning points and fasteners can be defined as default in the menu, compared to six in the current system. This means that the user can already here overconstrain the system and thus the need for defining which points are master locators. For the same reason, there is a DOF counter that keeps track of how many DOF have been locked. If there is a need for more than ten positioning point to fasten the part, the function "Add new" can be used. The idea is that for every time the user clicks on this button, a new locating point row appears.

The idea is that the user will access the positioning system menu for the local frame in the same way as before. The user will then define which kind of fastener that will be used for positioning the part. After that, a point or node on the model will be picked to represent the chosen fastener and the point will inherit the fasteners predetermined behavior. But, by selecting the positioning points, the user will only locate the fastener in the model and not orient it. Therefore an additional menu called "Define Attribute Rules" (DAR) was created. Figure 42: The DAR-menu. shows an example of the DAR-menu. Here the user can go in and orient the fastener in the model and at the same time assign additional attributes that can be relevant for a fastener, such as play or if the fastener only locks one direction of a translation.

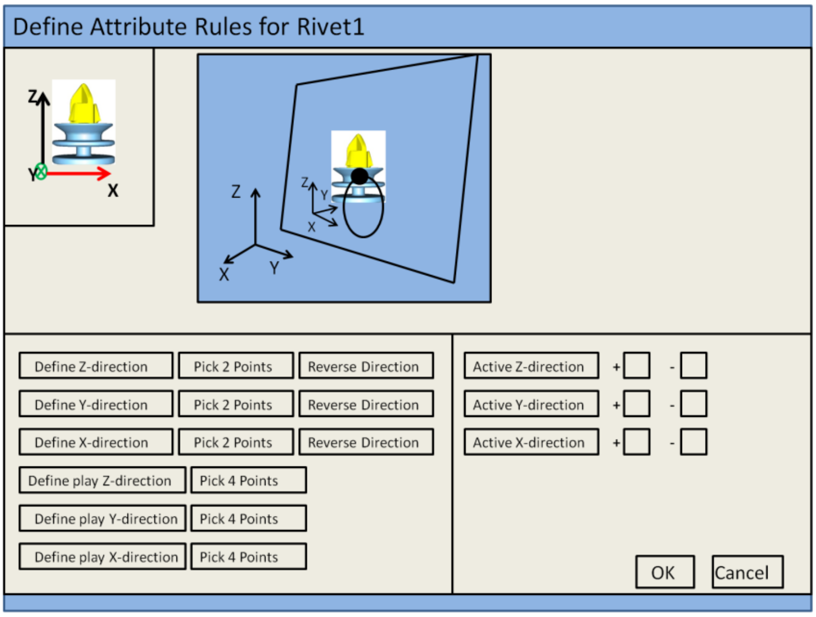


Figure 42: The DAR-menu.

As seen in figure 42, the DAR-menu has two visualization screens. The one on the left shows the chosen fastener and its local coordinate system. The one to the right shows where on the model the fastener is defined and its orientation relative to the model, showing both the global and local coordinate systems.

Define z-, y- and x-direction functions are used to orient the part in the model. This is done by picking two points. For example, two points are picked to define the z- direction for an arbitrary fastener. Then the local z-direction of the fastener will coincide with the direction of the two chosen points.

If necessary, play can be defined with the "define play" function in desired direction. This is done by selecting two points on the local part and two points on the target part. Figure 43 illustrates this.

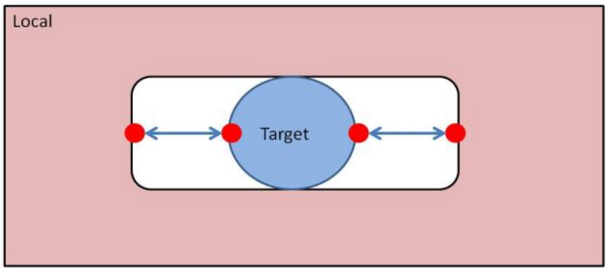


Figure 43: The principle of defining play

What direction the fastener locks can be manipulated through the "active direction" check boxes. This also enables the user to define fasteners that, for example, have locking in positive z- direction, but not negative.

After defining attributes and orienting the fasteners in the model, the user is supposed to choose locating point on target frame, which is done in the positioning system menu (see figure 41). If a compliant part is positioned on a rigid part, then the current function "copy local” can be used to create new points on target frame, corresponding to the local frame nodes. But if two compliant parts are assembled together then the Closest link function can be used to find the closest located nodes on target frame. This function demands that the local and target frame nodes are locked to each other on a relative distance, because nodes on two meshed parts rarely coincide. The nodes on the target frame can also be picked manually, but they still need to be locked on a relative distance from the local frame nodes.

The contact point menu has similar functions for picking and locating nodes on local respective target frame. As before, depending on if a compliant part is assembled on another compliant part or a rigid part, the functions “copy local” or “closest link” can be utilized. If a compliant part is assembled on a rigid part, then only nodes on the local frame need to be picked by the user. With the function “copy local” new points, corresponding to the point on local frame, will be created on target frame. See figure 44 for an example of the contact point menu.

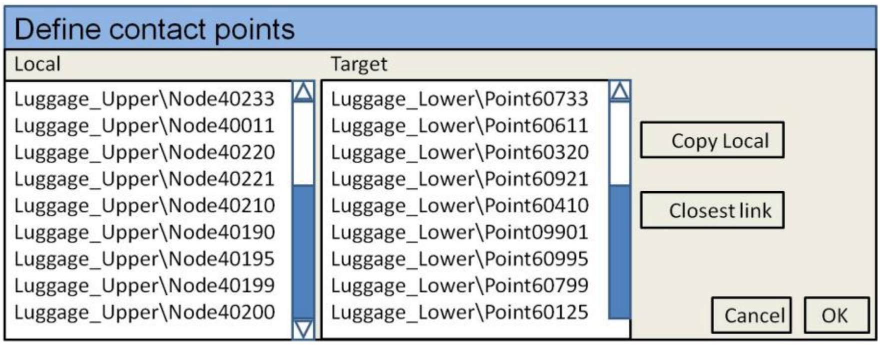


Figure 44: Contact point menu

The contact point menu is supposed to show up next to the model, when being utilized, so that the user can easily keep track of how many and which nodes have been picked. Selected nodes or points will also be highlighted in the model. An example of how it could look like in RD&T is shown in figure 45.

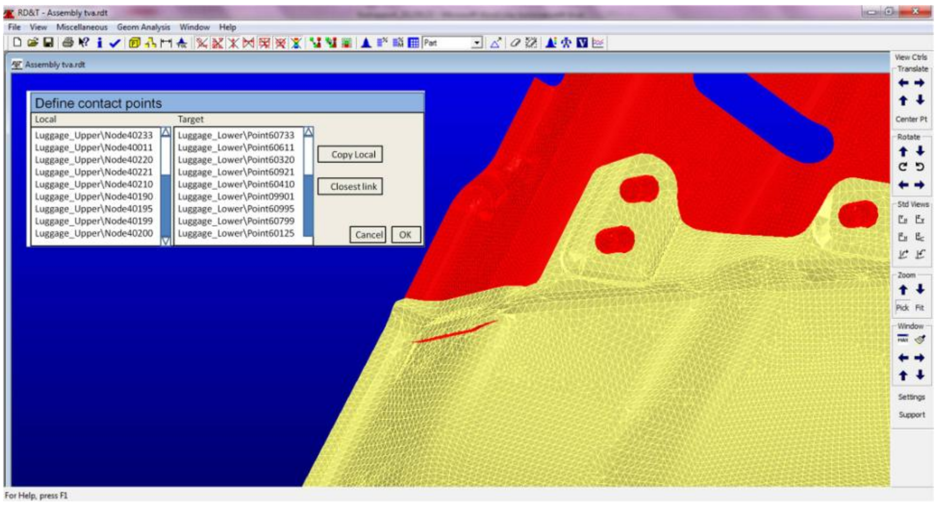


Figure 45: Contact point menu in RD&T

If two compliant parts are assembled together then the “copy local” function cannot be used because it would not make any sense creating new points on a mesh. Instead the “closest link” function can be used. This function already exists in RD&T and it finds the closest corresponding nodes on a target part, when desired nodes on local frame have been chosen.

Single node concept advantages and disadvantages

With this concept the preparation of a model would probably be faster, because of the predefined fasteners. It would also be easier to overconstrain the model, which would also contribute to facilitate the set up of an analysis. A centralized positioning system menu would eliminate the need to jump between different modules in RD&T which would further enhance the user friendliness.

Improved contact modeling with the ability to define contacts between compliant and rigid parts would improve the virtual evaluation of deviation on assemblies. It would also contribute to better analysis result.

The use of fasteners, instead of locating points, is more intuitive and would facilitate understanding of models, especially for new users.

The disadvantage with this concept is the use of one node or point to represent a fastener, which is not optimal, as shown earlier. Using one node representation also means that fasteners like tape, string welds or corresponding fasteners with large distribution area will have to be approximated with several fasteners in RD&T, resulting in an increased workload for the geometry assurance engineer.

6.2.2 Multiple nodes concept

This concept is a further development of the single node concept. The thought is to increase the accuracy of the fastener representation in RD&T by defining a fastener with several nodes and hence model a distribution area. By representing a fastener in several nodes, locking of rotation can be achieved with a single fastener, which is not possible in the previous concept.

In the multiple nodes concept, further development of the different menus has been made in order to make the software more pedagogical. Focus is shifted more towards fasteners instead of locating points in the positioning system menu. The reason for this shift is because it is more intuitive to position a part with a fastener instead of a locating point. An example of the positioning system menu can be seen in figure 46.

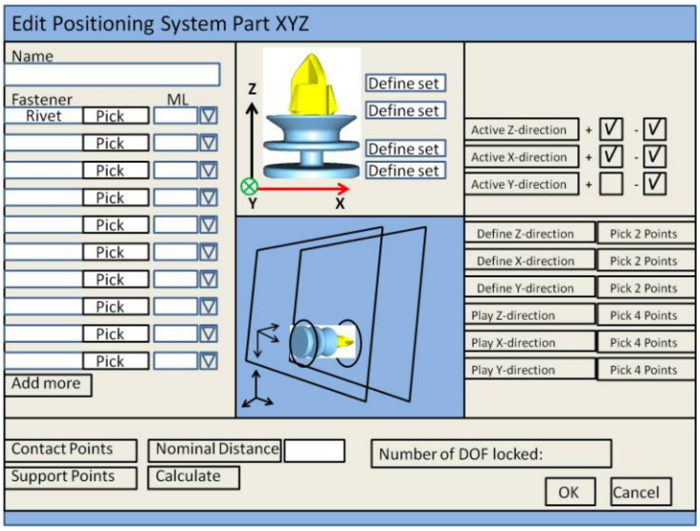


Figure 46: Positioning system menu for the multiple nodes concept

As seen in figure 46, the two visualization windows and all the attributes from the DAR menu in the single node concept have been relocated to the positioning system menu. But they still serve the same function as in the single node concept. The rows for choosing fasteners and locating points for local and target frame have been replaced by a fastener selection column. In this menu, the user chooses a fastener by pressing “pick”. Then a library in the form of a menu appears on the screen (see figure 47). In the library, the user can go in and read about different fasteners. The library will provide general information, what DOF´s the fastener lock and which mating surfaces it usually has with assembled parts. Like in the previous concept, there will be two sets of fasteners, depending on if the CAD data is engineering data or styling data.

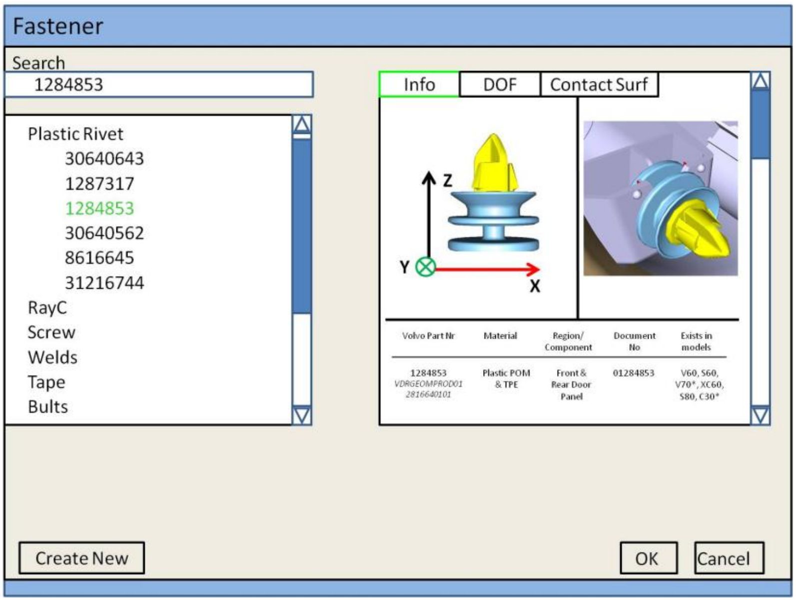


Figure 47: General fastener library applied on the multiple nodes concept

When the fastener is chosen, it will appear on the visualization screens of the positioning system menu as shown in figure 46. Now the user can define the sets of nodes and points that will represent the fastener in the model. In the concept presented here, there are four sets that can be defined. Two sets for local frame and two sets for target frame. These sets are supposed to represent contact and mating lines that the fastener usually have with local and target frame. A discussion and recommendation about the number of sets needed per fastener can be found in chapter 9. The two first sets to be defined will automatically be the local frame sets and the two following sets will be target frame sets.

The user defines the sets by first clicking on the button “Define set” in the positioning system menu. The “define set” menu will appear. Figure 48 illustrates and example of the menu for the local frame. The menu for target frame is slightly different. Instead of the “find distribution” function it has the functions “copy local” and “closest link” (see figure 48).

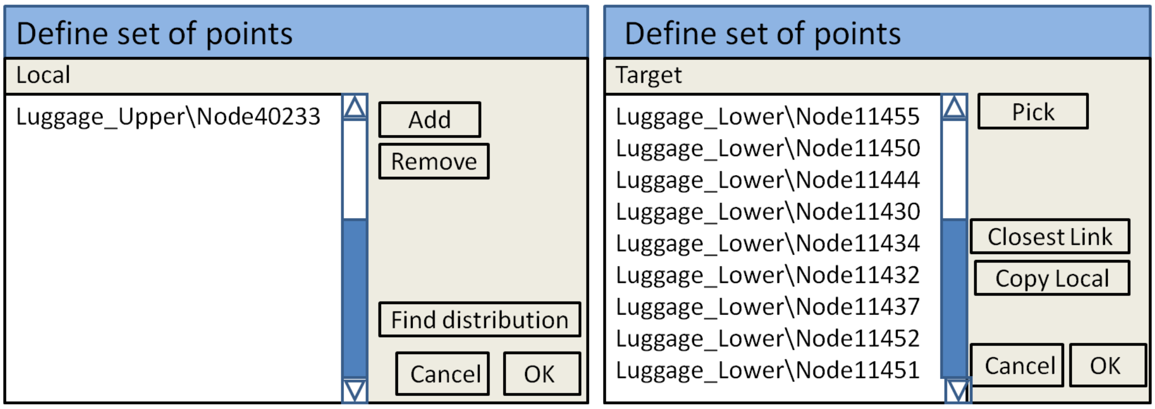


Figure 48: The define set menu for local (on the left) and target frame (on the right)

The idea is that the user only needs to define one node on the local frame and then the “find distribution” function will find adjacent nodes and add them to the scroll down menu (see figure 49). The nodes will also be highlighted in the model so that the user can get perception of the proposed distribution. If some nodes are redundant or if there are nodes missing, the user can add or remove nodes by the functions “add” and “remove”. Defining sets for target frame can be done by using copy local for rigid part, closest link for compliant parts or simply manually picking adequate nodes with the “pick” function.

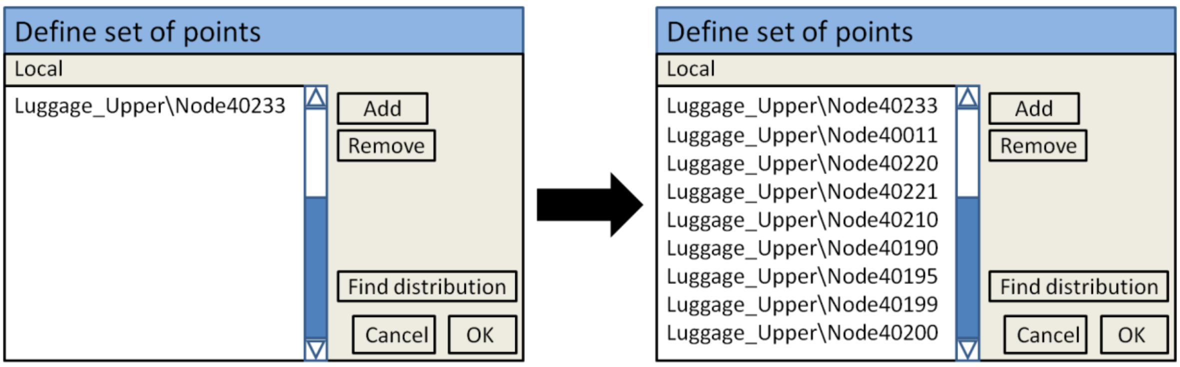


Figure 49: The find distribution function automatically locates adjacent nodes and adds them to the menu.

Multiple nodes concept advantages and disadvantages

This concept has the same advantages as the single node concept. Because a fastener is represented in several nodes or points a better reflection of reality is achieved and fasteners like string welds and tape can be defined as one fastener, decreasing the work load of the geometry assurance engineer.

Improved menus and added visualization windows makes this concept more pedagogical and further facilitates understanding, in comparison with the single node concept. Having a standalone fastener library, containing fastener information, informs the user and further increases understanding.

The disadvantage with the concept is that performance could be affected negatively because of increased number of nodes or points in the calculations. Another disadvantage, compared to the single node concept, is that it would probably take longer time and more effort to develop this concept.

6.2.3 Feature concept

This concept is based on the use of features to define fasteners, an ability that RD&T today lacks. The technology of handling features in software is well known and widely used. Feasibility for modeling of features in RD&T was checked with the developers of RD&T who confirmed that it was possible.

The positioning system menu for this concept is similar to the menu from the multiple nodes concept, but without the visualization windows and attributes (see figure 50). New entries for fastener selection can obtained with the function “add more”. The user simply selects desired fastener by clicking on “pick”. As in the previous concept, a library of fastener will appear (see figure 44 for an example). When desired fastener has been chosen, locating nodes need to be defined for selected fastener. The menu for defining locating nodes can be accessed by clicking on “pick” under “locator” (see figure 50). If several fasteners of the same type are desired, the user can just select the fastener for the first row, then mark the checkbox and click on “add new”. This will add a new fastener row with the same type of fastener already selected.

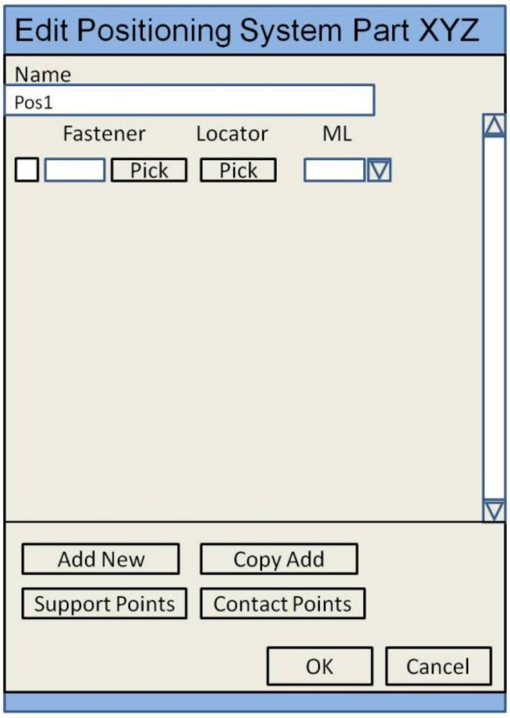


Figure 50: Feature concept positioning system menu

The locator menu can be seen in figure 51. In the concept presented here, only two sets, MS1 and MS2 need to be defined. The user selects which set to define first by clicking on it. The first set that is defined will automatically be the local frame set. Then the user selects what kind of feature will be picked on the model. This step simplifies the selection of features on the model because only features of selected type will be highlighted when in contact with the mouse pointer, instead of every feature being highlighted. The user then simply click on desired feature on the model and all the nodes within that feature will be added as locators in the menu (see figure 51). If the distribution area (mating surface) of the selected fastener is bigger or smaller than selected feature, the distribution will adjust to the size of the mating surface. Redundant nodes can be removed with the function “remove” and additional nodes can be added manually with the function “node”. A coordinate system will appear in the middle of the selected feature to illustrate the fasteners orientation in space (see figure 52). By clicking on the axis of the coordinate system a “pick two points to define direction” function will be initiated. For example, if the user first clicks on the black axis (z- direction) then the user will just have to pick two points and the axis will align with the defined direction.

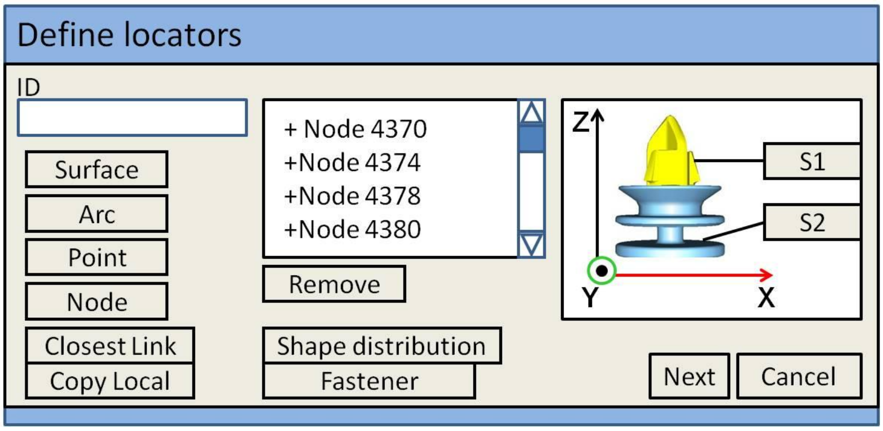


Figure 51: Locator menu

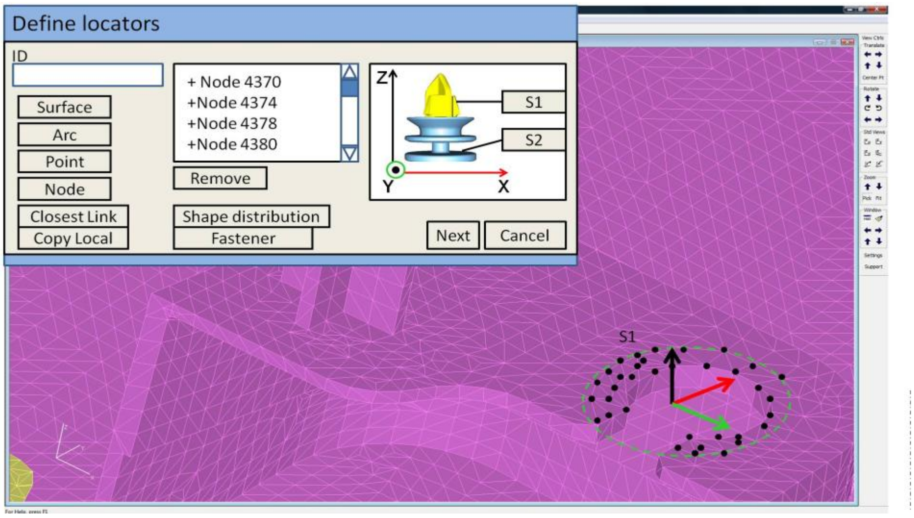


Figure 52: Selecting nodes with the help of features

The second set that is defined will automatically be the target frame set. Like in the previous concepts, “closest link” and “copy local” can be used to define the target set.

If there is a need to adjust the fasteners predefined behavior, the fastener property menu can be accessed by clicking on the button “Fastener” (see figure 48). Similar to the DAR menu in the single node concept, the user can manipulate the fasteners behavior by checking the translation and rotation boxes (see figure 53). It should be noted that the boxes refer to the fasteners local coordinate system and not the models global system.

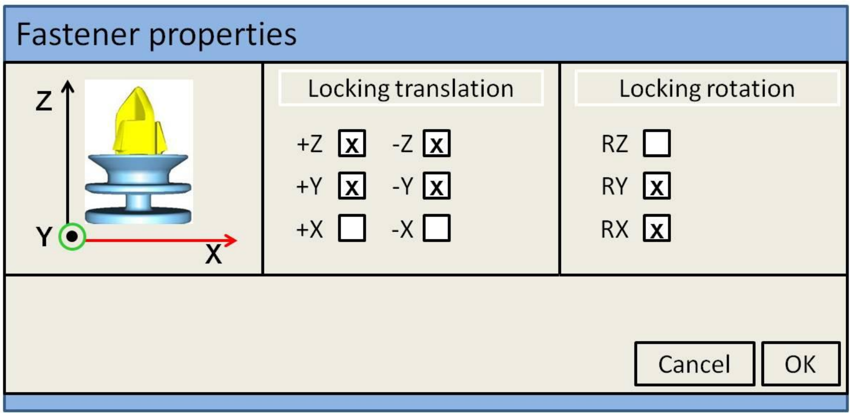


Figure 53: Fastener properties menu

As the previous concepts, there will be two sets of fasteners available in the fastener library. One set for modeling with engineering data and one set for styling data. The issue with this concept is that on styling data there is usually a lack of features (low level of detail in the design). To deal with this problem, the “shape distribution” has been utilized. As before, the user only needs to define one node and the function will automatically find adjacent nodes around it, following a certain shape. The shape is determined by the shape of the fastener (see one node plus shape in chapter 6.1.4).

Feature concept advantages and disadvantages

This concept bares all the advantages of the single node and multiple nodes concept. With the ability to handle features contact modeling would be further facilitated. The effort to set up models would also be decreased. It would also be easier to model fasteners with large distribution areas compared to the other two concepts.

The disadvantage is the effort and time to implement handling of features in RD&T together with all the other suggested improvements.

6.3 Additional functionality

In connection with the presentation of the concepts to the developers of RD&T, additional functionality for the concepts was discussed. One idea was the ability to pass on features on styling data models through the use of fasteners. The other was the ability to early simulate the forces required for assembling compliant parts.

When positioning styling data models with fasteners, certain geometry is presupposed on the model. For example, if rivets are used to position a part, then holes are presupposed where the rivets are positioned. It would be favorable to be able to document this need for a geometrical feature that is connected with a type of fastener. This could be done if, when selecting fastener, a suitable feature is passed on to the model, which would indicate what kind of geometry is needed to realize the positioning system. This would also mean determining the design to some extent, on relevant criteria, in an earlier phase in the development.

To assemble a door panel to the underlying door structure requires several rivets. The order of assembly may affect the forces required for assembly to be successful. Because of the variation and subsequent deviation, the forces needed to assemble the compliant parts may vary. The mounting forces may also differ for the individual rivets based on were in the assembly order it comes. Simulating mounting order can be achieved with implementation of fasteners in RD&T. Generally the first fasteners would require nominal mounting forces but after hand due the deviations and compliant behavior of parts, the mounting forces for fasteners which comes further down in mounting order would be affected. The concepts which have predetermined properties, an area distribution can be used to evaluate how ergonomic the assembly may be. This can be achieved as early as with the initial styling data.

7 The final concept

The three concepts that were generated were presented to several of the stakeholders, among others GSU, PQ, GAE and Chalmers representatives. Through discussion with the stakeholders, a final concept was created. Interesting subsolutions were pointed out by the stakeholders and added up to a final concept.

The idea behind the final concept is that the current locating system would still be used and that the modeling of fasteners would support the locating system and help to overdefine the system if necessary. There are two important arguments to keep the current locating system in use. The first one is, as pointed out by RD&T developer, that it simplifies the calculations. The second one is, as stated by a GSU technical expert, that there needs to be a distinction between locators that position the part and fasteners that fastens the part.

The 3-direction positioning system can be seen in figure 54. Here the user will position the part with the help of locating points, as it is done today. Then the user will access the fastener

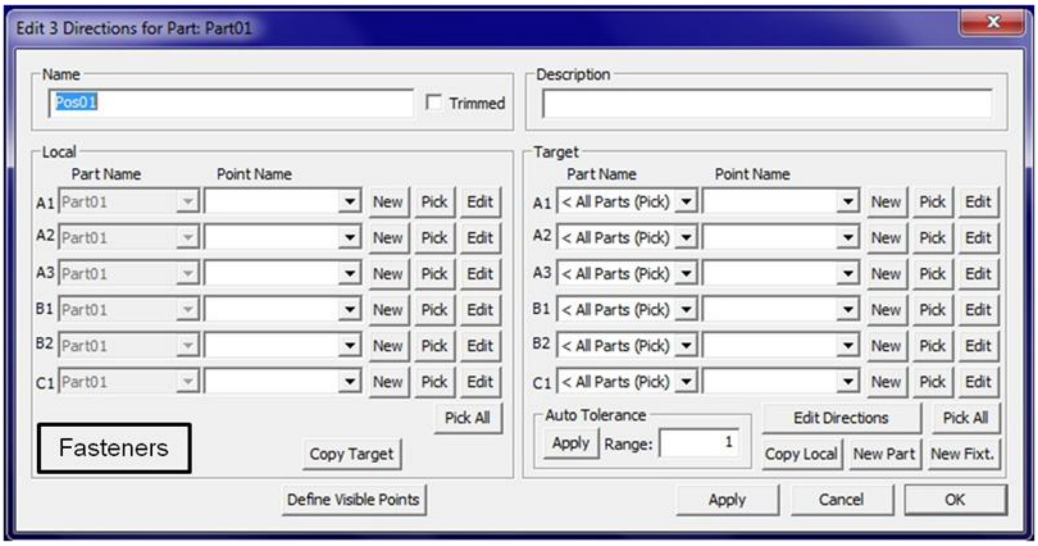


Figure 54: The positioning locator menu woth the fastener module added.

module by clicking on the “Fasteners” button. An interface similar to the multiple nodes concept interface will appear (see figure 55). As can be seen, the ML selection has been removed from this menu, because there is no need to define master locators on fasteners anymore. Also, three new attributes that can be defined has been added: D1, D2 and Distance. The D1, D2 and Distance represent the geometrical shape of the fastener. These can be seen in Appendix B.

As before, the user clicks on “Pick” and the fastener library from the feature concept appears, where the user can select desired fastener. When fastener has been selected, the user will get back to the menu in figure 55. The fastener will now appear in the visualization windows (see figure 56). The default values for the fastener will be filled in automatically and the user has the ability to change these if necessary.

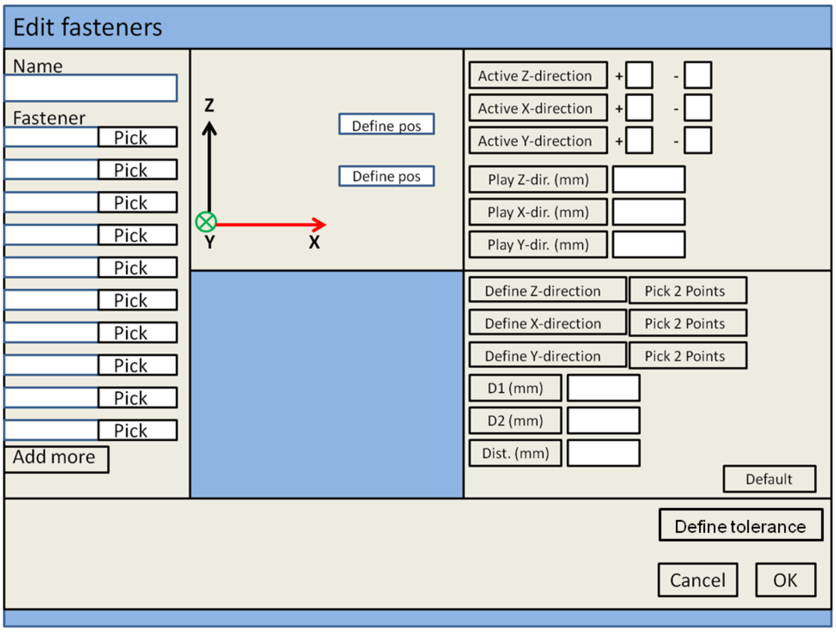


Figure 55: The fastener module similar to the multiple nodes concept.

To position the fastener, the user clicks on the upper “Define pos.” and selects a node on the local frame. The software will then automatically search the area, equal to the size of D1, for adjacent nodes and add them as contact points for the fastener (see figure 57). Same thing is done for the target frame and then an area corresponding to D2 is searched for adjacent nodes. According to the developer of RD&T it is possible to facilitate so that the user will only have to define position on the local frame and the rest will be handled automatically by RD&T.

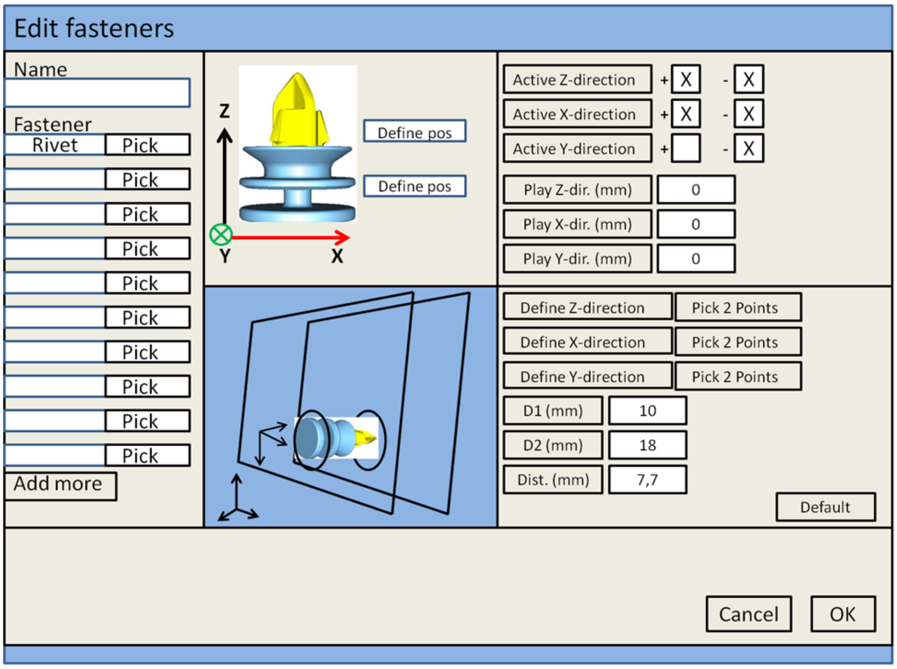


Figure 56: When a fastnerner is choosen all the predetermined properties appearand can be modified.

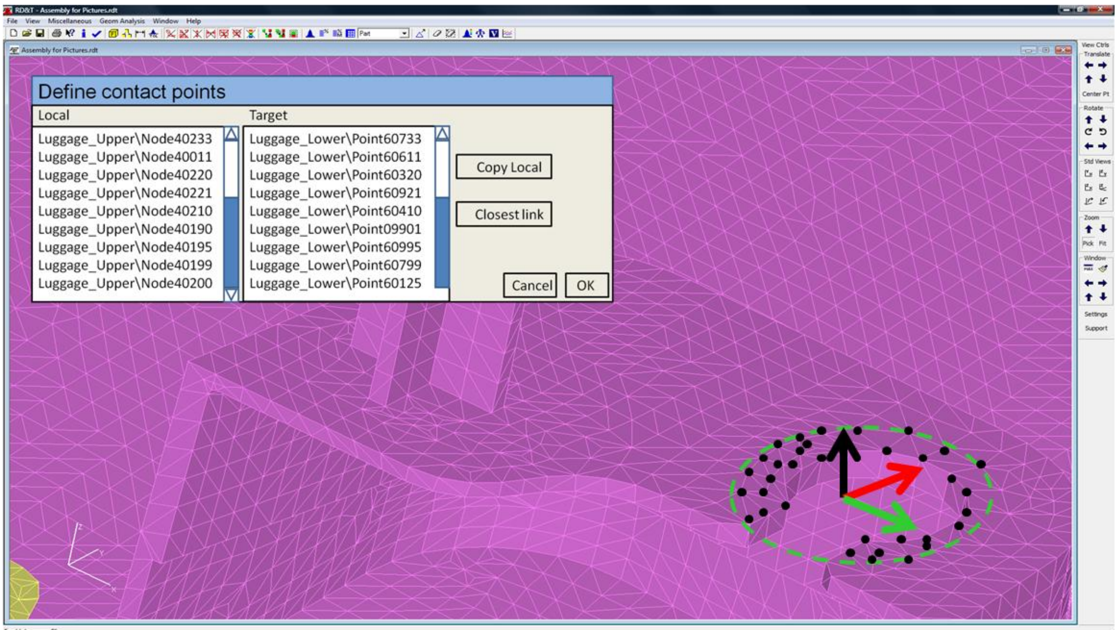


Figure 57: Within the area D1 or D2, the avialable nodes get marked and selected.

As in the previous concepts, the fastener can be oriented in space by the use of the define direction functions.

When desired fasteners have been chosen, positioned and oriented the user can define tolerance for the target part by using the function “Define tolerance”. A tolerance for the distance between D1 and D2 will be predefined and can be changed in the fastener library with the use of “Edit fastener” function.

8 Area of use

To put the results and concepts of this thesis into a context for the different stakeholder, this following chapter will give an example of how the different divisions at VCC can utilize the concepts. The area of use differs somewhat for the different divisions because they use RD&T to accomplish different tasks.

8.1 Perceived Quality

Early in the product development process, when a design has been selected for further development, the division of Perceived Quality receives the styling data and analyzes it. Among other things, they look at the location and complexity of split lines, identify critical areas that need to be prioritized and set up aesthetical geometrical demands for the model. These demands are then sent to GSU.

PQ could utilize the proposed library and functions to easier set up compliant variation simulation models that would help them in their work to evaluate split lines and identifying critical areas. By looking at historic data, fasteners that have usually been used for parts of interest can be picked for the evaluation model. Then a compliant variation simulation can be preformed, based on historical variation data, and this could give PQ a perception of how different parts will deviate and deform and how split lines will be affected by the deviation.

8.2 GSU

GSU also receives styling data at the same time as PQ does. They then start to evaluate the robustness of the concepts and start preparing locating schemes. When they receive the aesthetical demands from PQ, further development is made on the locating schemes in order to fulfill the demands. When satisfying locating schemes have been developed, GSU sends the models further to the design division that actualizes GSU´s locating schemes into the design.

GSU is currently working with rigid models and are achieving good results in predicting the behavior of analyzed part. The reason that they achieve good results with rigid analysis, although the parts being compliant, is because they divide a part into several areas. Every area is then analyzed individually.

With the proposed library and functions, GSU could easier set up compliant models and could also utilize the possibility to overconstrain parts. This would eliminate the need to divide parts into sections, but rather analyze the part as whole. Another benefit would be that they could consider the compliant behavior of parts as well.

With the proposed ability for passing on features to the model with the choice of fasteners, GSU could actually determine some design features and pass that information on to the design division. This would facilitate the designers work and give the designer input of what fastener is sufficient to fulfill the geometrical system. This would also eliminate possible mismatches between intended locating scheme and the designer’s translation of them.

8.3 GAE

GAE secures the interface between delivery units and acts from a complete vehicle perspective. They cooperate with GSU and secures that developed geometrical systems fulfills both aesthetical and functional requirements from a manufacturing point of view. This implies that they are also working with models where types of fasteners have been selected. When simulating on their models, GAE tries to replicate the behavior of the selected fasteners with the use of current positioning points, which can sometimes result in extensive work.

The proposed library would provide fasteners with predefined behavior and would facilitate GAE´s work by eliminating the need to replicate fastener behavior with the use of support points. The concepts where fasteners distribution area can be simulated would provide more accurate simulations and display the interaction between fastener and part behavior better. This could also facilitate their fault search.

9 Discussion and Conclusion

In this section the concepts, the approximations and general impressions during the implementation will disused. Also the methods used throughout the project will be addressed.

9.1 The approximations and difficulties with the concepts

One important approximation was made regarding the fasteners mechanical and material properties. The approximation was that the fasteners are rigid. The assumption that all that fasteners are rigid is made for two reasons. Firstly it is to simplify the fastener description and secondly to facilitate possible implementation. With the approximation that fasteners are rigid some information is lost. In several instances there is plastic to steel contact. When assuming fasteners as rigid, then there is no possibility for fastener deformation. But there are situations were deformation could happen. Also some fasteners are made of spring steel (e.g. fastener no 9) which in some cases could buckle and affect the parts in some way. Consultations with the developers of RD&T concluded that approximating POM and steel fasteners as rigid is sufficient at this stage.

Early in the inventory it became evident that the fasteners have many mating surfaces. The notion that the concepts would replicate all the mating surfaces and their DOFs was seen as complex and time consuming. For example fastener no 9 has eight mating surfaces, which would all then need to be defined. Also there is a difference when working with surface mesh and solid mesh. If the models are surface mesh then it is logical to only have two levels to represent local and target. If the model is a solid mesh then all the mating surfaces could be used. Even when there is a solid mesh the approximation is made that most of the information in the mating surfaces can be represented in two levels. So to simplify all the mating surfaces the notion of two levels was coined. Creation of two levels, one local and one target was thought as the mere minimum of information needed as a representation of the fastening solution. So the description of these levels contains all the information about all the other mating surfaces but is located in one set of nodes. With this approximation some fastener properties and behaviors are lost. Behaviors such as a loosely fit where e.g. a rivet wiggles inside the hole cannot be simulated and analyzed because of nominal distance connectors and the not specified rotational play. This could be specified but would increase the complexity so much that it would not be practical. Other fastener properties and behaviors which are not prioritized due to complexity are material impacts, friction and relaxation. Despite these approximations and simplifications the concepts have the most critical information, DOFs and material distributions specified and that will be enough for the first concept development. The 80/20-rule is a good representation of the importance about the other properties and behaviors. The DOFs and material distribution contains 80% of the information.

The unified menu system rests on the notion that everything associated with fasteners can be determined from one single menu. The central focus was that overconstraining could be achieved in that unified menu window. Also when all the fasteners are defined at given locations then the master locator is appointed as one or more of the fasteners. The fasteners have their DOF and together fasteners could define the master locator without the need to specify which fasteners is A, B, C. The reason for the incorporation of the master locator is because the way the current RD&T version functions work and also to document which fasteners are master locators. This was the original though for the three concepts but as a discussion with GSU and developers of RD&T the importance of differentiating fastener system from the positioning system became more evident. There is a difference between positioning a part in space and fastening it to some other part. This distinction was not as clear when creating the three concepts. Small modifications to the concepts would make this differentiation more clear. Emphasize that the positioning system needs to be appointed firstly before the fasteners can be used could solve this problem.

When simulating with rigid components the master locator can be re-positioned to find a better and more robust positioning system. With compliant this is not possible. The presented concepts and final concept suggest that fasteners are a set of points on several levels. So when a compliant variation simulation model is built, a simulation is performed, the results are acquired and if iteration is needed then a new model needs to be set up. In rigid models a function is used to alter the position of the locators. This is clear disadvantage with compliant variation simulation. So early on in product development when a robust positioning system is wanted then it would be more appropriate to used rigid simulation so that a robust system can be established. When deviations are to be visualized a compliant variation simulation with the fasteners could be used. This would solve the problem with re-positioning fasteners in the near future but a more long term solution would be to develop re-positioning for compliant parts.

Another function which works with rigid but not with compliant is the ability to define points outside the surface of a given part. This notion is crucial in the beginning when working with styling data. When geometry engineers are defining were the locators should be placed much of the time these are located outside of the styling data models surface. The place where the locators should be placed has not yet been designed so it creates problems for the compliant simulations. The geometry engineers circumvent this problem when working with rigid but would not be able to when simulating compliant parts.

9.2 Methods used for implementation

Interviews were a central part of the information gathering process alongside the inventory and simulations. The interviews were held early on in the project when there was not all that much knowledge as was later on in the project. The questions reflected the knowledge level at that time as they were very wide and general. Also when the interviewees answered, follow-up questions were not asked to the extent that would have been if these interviews were held later. There should have been formal second interviews. This was compensated through the several presentations about implementation and the concepts for PQ, a Business application manager, developers of RD&T, GSU and GAE. After the presentations, feedback was received which altered the concepts and implementation to some extent.

The Pugh and Morphological matrixes did not have a great effect on the different concepts that were presented. When the concept generation was performed only feasible and logical sub solutions were generated due to all the constraints on the current RD&T version and the point based software then elimination was not considered necessary. Also the selection of the concepts was based on predetermined idea of creating concepts that would interest all the different stakeholders. This notion has had a great impact on concept generation and the creative process of brainstorming.

The selection of the final concept was as stated before a process where the stakeholders came with a lot of input regarding the different concepts. The stakeholder with the most interest in this project came with the most input, so the final concept is skewed towards the needs of the stakeholder with the most interest in the project. This means that the input from the stakeholders does not necessarily reflect the needs of the users.

10 Recommendation

The developer can use the final concept as fundament for developing a module that handles fasteners in RD&T. Interface solutions from the other concepts can then be used, instead of the proposed ones for the final concept, if the developer finds them better. The idea is that the developer can pick and choose good solutions from all the concepts to create one that is suiting for development and the users.

For the first version of the library, fasteners that have been studied in this thesis can be used, which we believe is sufficient enough for evaluation. The developer can use the information gathered in the appendix to create the fasteners in RD&T.

A simple version of a fastener library and the ability to handle fasteners should be developed and then evaluated. Both by the developers and by potential users, such as PQ, GSU and GAE. Feedback from the trial evaluations should be gathered and used in order to customized the library for the user and further improve it. This would also help to customize the module for the different divisions.

We also believe that a case study with the developed concept should be performed. The focus on the study should be where and how this module could be used in VCC´s product development process, in order to determine where it is most beneficial to use and how it could be incorporated. Results of variation simulation with help of this module should also be compared with the results obtained today and real measurement data in order to validate credibility.

A study on which mesh size will have sufficient confidence level in simulation should also be performed to determine which mesh size should be used. This is important both for the users and for a possible mesh module in RD&T.

The possibility to handle mounting and demounting forces of fasteners and to simulate the effect of these in RD&T should be investigated. As stated by GSU, this is an important aspect which sometimes leads to elimination of proposed design. Being able to simulate if a fastener will come off as a result of part spring back is also interesting.

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Verbal

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Hammarson, C., Johansson, D., (2012-02-16) GSU Manager & GSU Technical Expert, VCC.

Lindkvist, L., (2011-09-2012-02), RD&T Developer & Associate Professor, Chalmers University of Technology.

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Samuelsson, L., (2011-11-15), GSU BIW engineer & compliant simulation expert, VCC.

Wagersten, O., (2011-09-2012-02), PQ compliant simulation expert & PhD student, VCC & Chalmers University of Technology.

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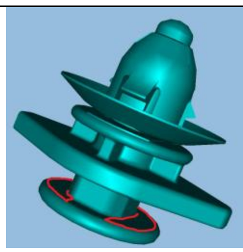
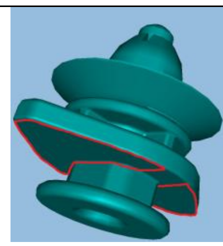
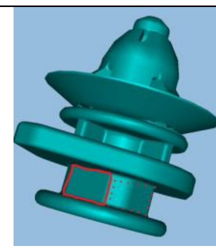
Appendix A: Fastener description regarding mating surfaces and assembly

<table>
<tr><td>Name</td><td colspan="2">Material</td><td>Drawing document</td></tr>
<tr><td>Plastic Rivet, 30640643</td><td colspan="2">Plastic PA66 & POM</td><td>1055788</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">Mating Surface 1 (MS1), MS2 and MS3 is the interface between part 1 (P1), (Mud Flaps) and the fastener. In the current application this is plastic to plastic contact. MS4 and MS5 is the interface between P2 (Upper body structure) and fastener, currently plastic to sheet metall. The MS4 and MS5s areas are dependent on the thickness of P2. Dependent on the thickness of P2 the MS5 area changes. With larger P2, larger MS5 and vice versa.
MS3 has a contact with P1 on both side of the fastener, illustrated with a doted boundary.
When assembled with C1 and C2 the fastener acts as a spacer. The nominal distance between S2 and S4 is according to drawing 8.1 mm.
Note the four small stops in the slot on P1. They are there do secure that the fastener is in the right position when assembled.</td></tr>
<tr><td colspan="4">Surfaces</td></tr>
<tr><td>MS1</td><td colspan="2">MS2</td><td>MS3</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
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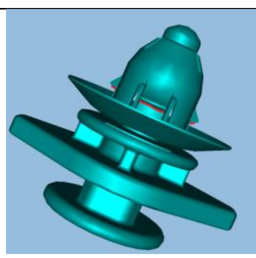
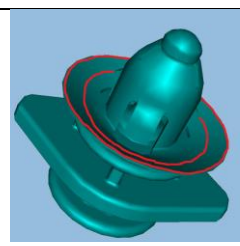
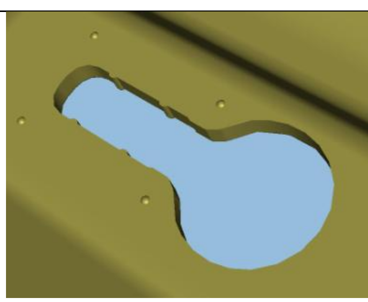
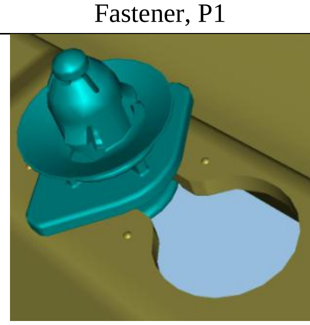
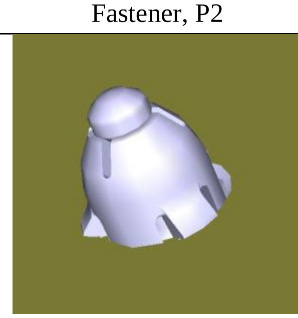
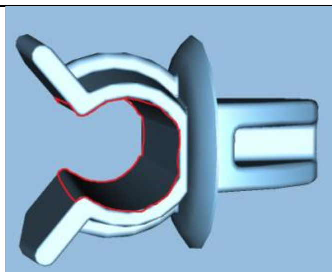
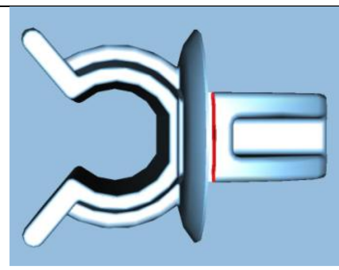
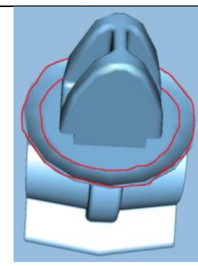
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="4">Assembly</td></tr>
<tr><td colspan="2">P1</td><td>Fastener, P1</td><td>Fastener, P2</td></tr>
<tr><td colspan="2"></td><td></td><td></td></tr>
</table>

Name	Material	Drawing document
Plastic Rivet, 1287317	Plastic POM	01287317
Description		
MS1 is the interface between P1v1, P1v2 (Luggage Trim Upper) and the fastener. In the current application this is plastic to plastic contact. MS2 and MS3 is the interfaces between P2 (Upper Body Structure) and fastener, currently plastic to sheet metall. The MS2 and MS3s areas are dependent on the thickness of P2. The MS1 is not an entirely circular surface area, as can be seen there is a part which is a plane. This will stop any rotation when the parts are assembled dependent that the components contact point has the same design. There are two different variants of P1 contact points. They differ in that the design of P1v1 does not allow free translation along the width of the contact. When the fastener is in place it is clear how the movement is hindered. The P1v2 doses allow that kind of movement. In both instances when assembled to P2 the fastener has the freedom to move in vertical translation. The P2 hole is 10mm high and the fastener is 6,5 mm high		
Surfaces		
MS1	MS2	MS3
		
Assembly		
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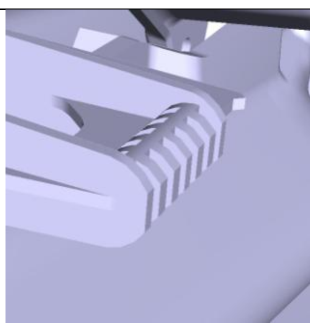
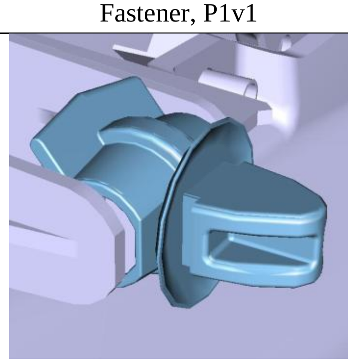
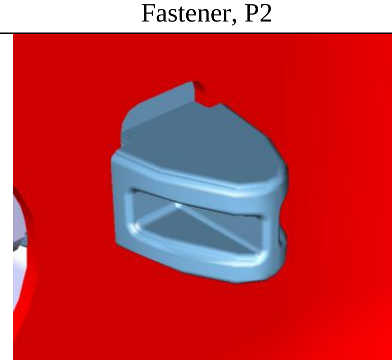
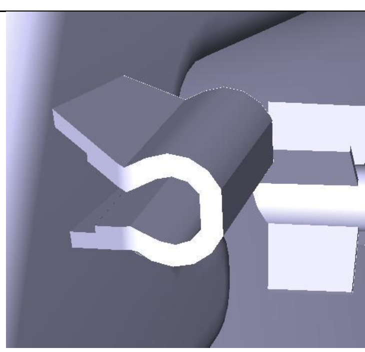
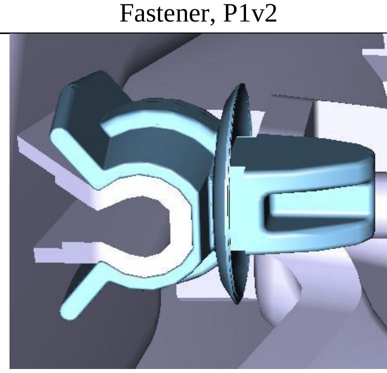
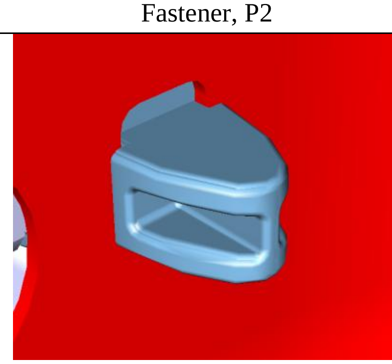
		
P1v2	Fastener, P1v2	Fastener, P2
		

<table>
<tr><td>Name</td><td colspan="2">Material</td><td>Drawing document</td></tr>
<tr><td>Plastic Rivet,1284853</td><td colspan="2">Plastic POM &TPE</td><td>01284853</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">MS1, MS2 and MS3 is the interface between P1 (Front & Rear Frame Door Panel) and the fastener. In the current application this is plastic to plastic contact. MS4 and MS5 is the interface between P2 (Upper Body Structure) and fastener, currently plastic to sheet metall. The MS4 and MS5s areas are dependent on the thickness of P2.

Due to the larger hole radius of P1 then the radius of MS3 the interface between them can be estimated as a line contact instead of a surface area contact.</td></tr>
<tr><td colspan="4">Surfaces</td></tr>
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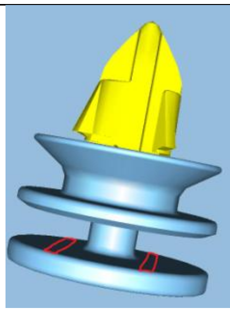
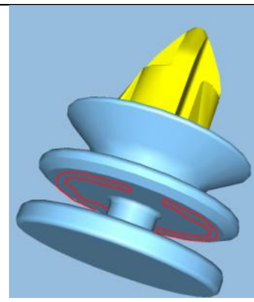
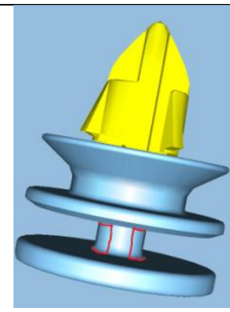
<tr><td></td><td colspan="2"></td><td></td></tr>
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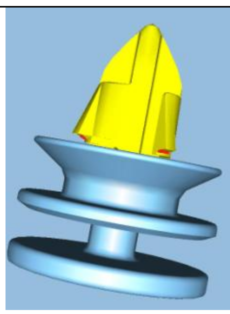
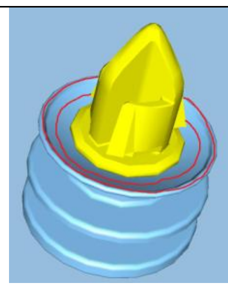
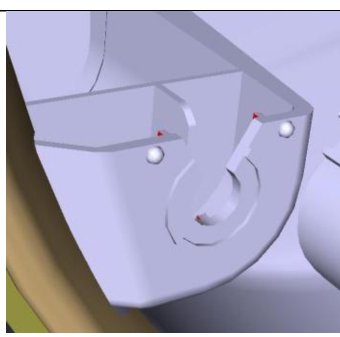
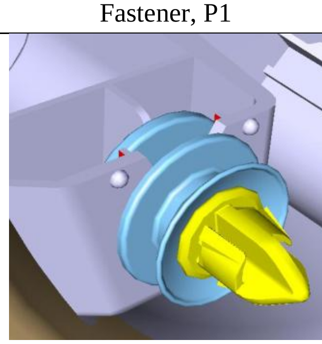
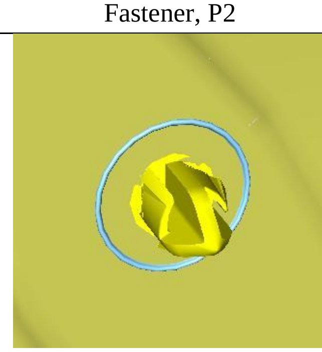
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="4">Assembly</td></tr>
<tr><td>P1</td><td colspan="2">Fastener, P1</td><td>Fastener, P2</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
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<table>
<tr><td>Name</td><td>Material</td><td colspan="2">Drawing document</td></tr>
<tr><td>Plastic Rivet 30640562</td><td>Plastic POM</td><td colspan="2">30653441</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">MS1, MS2 and MS3 is the interface between P1v1, P1v2 (Rear Inner Roof panel and Luggage Trim Upper) and the fastener. In the current application this is plastic to plastic contact. MS4 and MS5 is the interface between P2v1, P2v2 (Upper Body Structure) and fastener, currently plastic to sheet metall. The MS4 and MS5s areas are dependent on the thickness of P2.

When assembled in the P1v1 position MS2 will the primarily contact between P1v1 and fastener, but in P1v2 the same cannot be said. Due differences in radiuses of the holes on P1v1 and P1v2 the MS3 will only have an approximated line contact and not area contact.</td></tr>
<tr><td colspan="4">Surfaces</td></tr>
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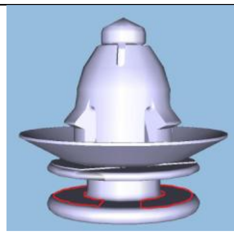
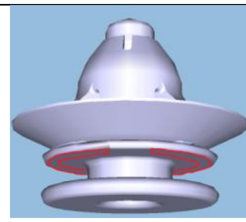
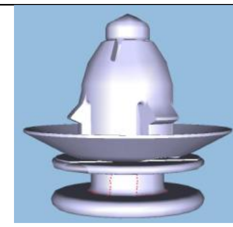
<tr><td></td><td></td><td colspan="2"></td></tr>
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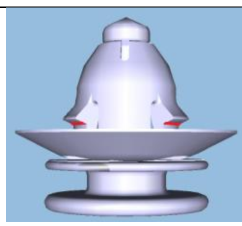
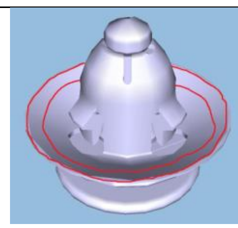
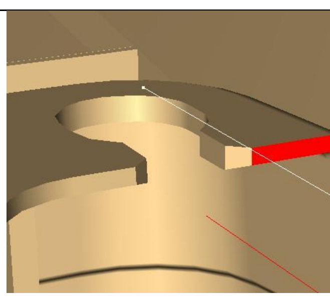
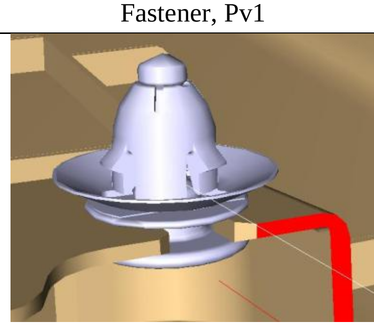
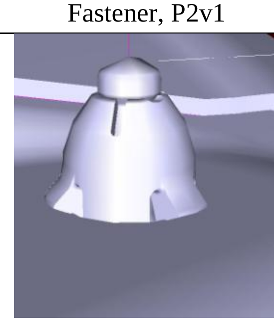
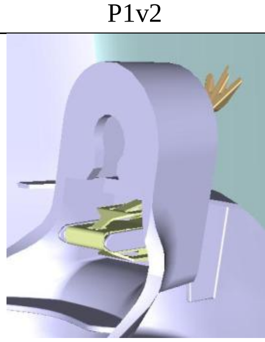
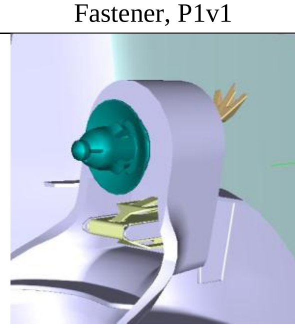
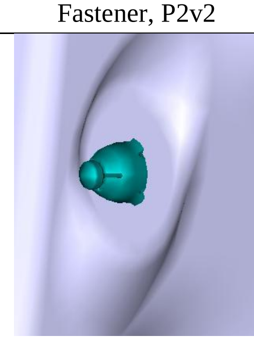
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td colspan="4">Assembly</td></tr>
<tr><td>P1v1</td><td>Fastener, Pv1</td><td colspan="2">Fastener, P2v1</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
<tr><td>P1v2</td><td>Fastener, P1v1</td><td colspan="2">Fastener, P2v2</td></tr>
<tr><td></td><td></td><td colspan="2"></td></tr>
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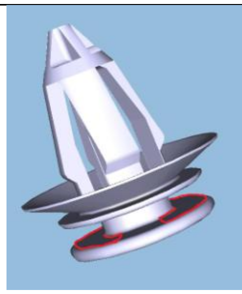
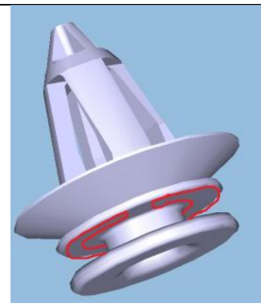
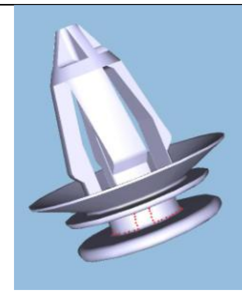
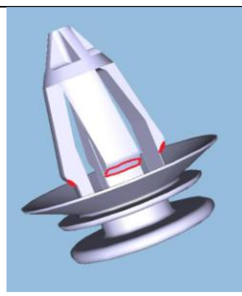
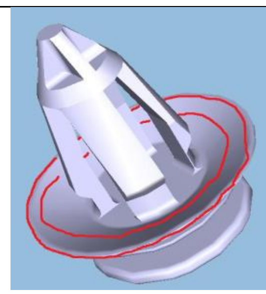
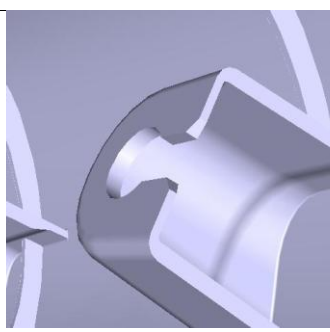
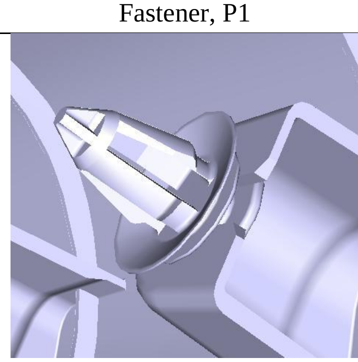
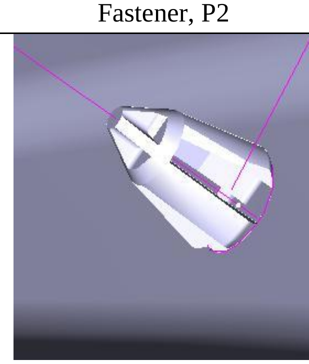
<tr><td>Name</td><td colspan="2">Material</td><td colspan="2">Drawing document</td></tr>
<tr><td>Plastic Rivet 8616645</td><td colspan="2">Plastic POM</td><td colspan="2">1055200</td></tr>
<tr><td colspan="5">Description</td></tr>
<tr><td colspan="5">MS1, MS2 and MS3 is the interface between P1 (A-Pillar Panel) and the fastener. In the current application this is plastic to plastic contact. MS4 and MS5 is the interface between P2 (Upper Body Structure) and fastener, currently plastic to sheet metall. The MS4 and MS5s areas are dependent on the thickness of P2.

Due to the larger hole radius of P1 then the radius of MS3 the interface between them can be estimated as a line contact instead of a surface area contact.</td></tr>
<tr><td colspan="5">Surfaces</td></tr>
<tr><td colspan="2">MS1</td><td colspan="2">MS2</td><td>MS3</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="2">MS4</td><td colspan="2">MS5</td><td></td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="5">Assembly</td></tr>
<tr><td>P1</td><td colspan="3">Fastener, P1</td><td>Fastener, P2</td></tr>
<tr><td></td><td colspan="3"></td><td></td></tr>
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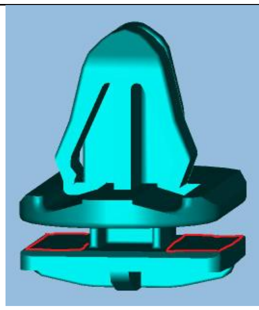
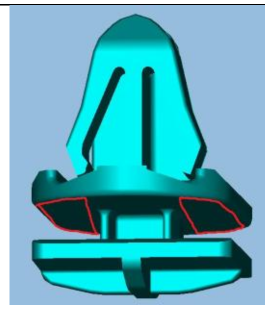
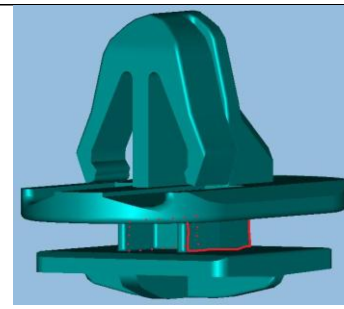
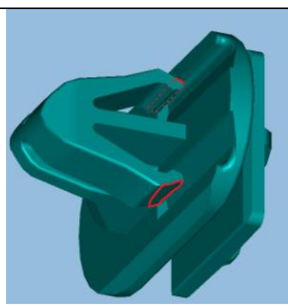
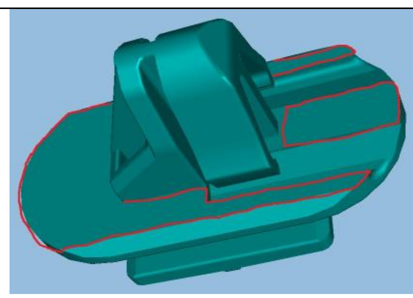
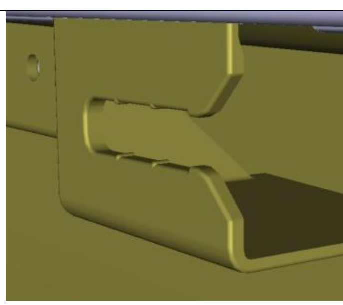
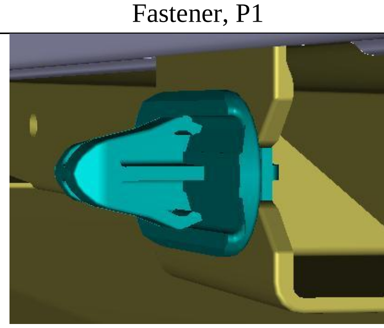
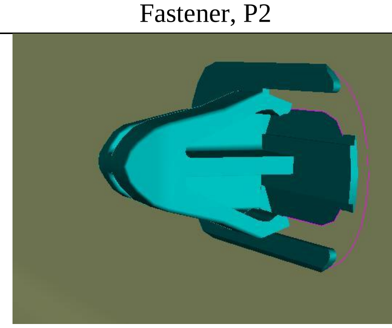
<tr><td>Name</td><td colspan="2">Material</td><td>Drawing document</td></tr>
<tr><td>Plastic Rivet 31216744</td><td colspan="2">Plastic PA6</td><td>1055567</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">MS1, MS2 and MS3 is the interface between P1 (Mud Flaps) and the fastener. In the current application this is plastic to plastic contact. MS4 and MS5 is the interface between P2 (Upper body structure) and the fastener, currently plastic to sheet metall.

MS3 has a contact with P1 on both side of the fastener, illustrated with a doted boundary.

Note the four small stops in the slot in assembly P1. They are there do secure that the fastener is in the right position when assembled.</td></tr>
<tr><td colspan="4">Surfaces</td></tr>
<tr><td>MS1</td><td colspan="2">MS2</td><td>MS3</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td>MS4</td><td colspan="2">MS5</td><td></td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="4">Assembly</td></tr>
<tr><td>P1</td><td colspan="2">Fastener, P1</td><td>Fastener, P2</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
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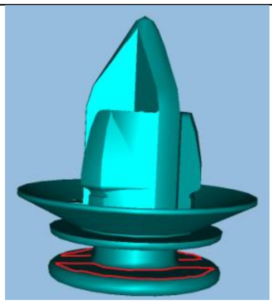
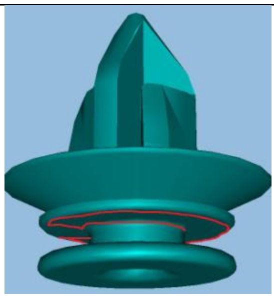
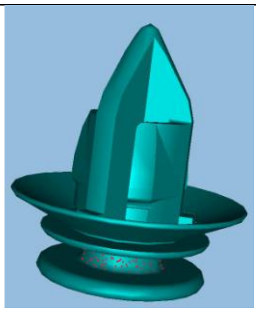
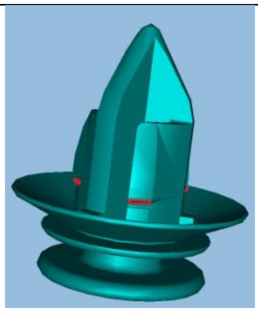
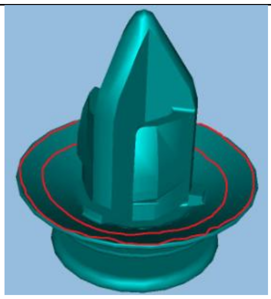
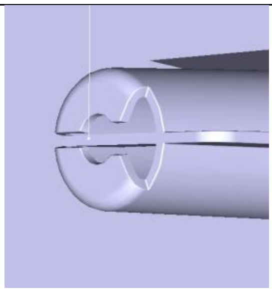
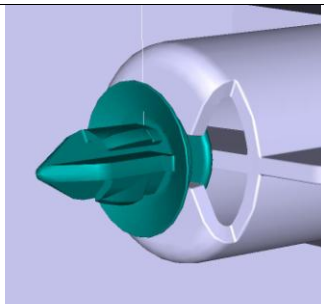
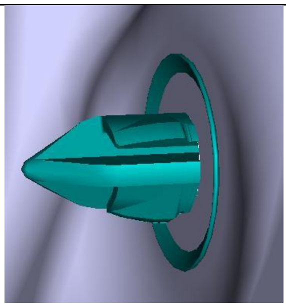
<tr><td>Name</td><td colspan="2">Material</td><td>Drawing document</td></tr>
<tr><td>Plastic Rivet 8616645</td><td colspan="2">Plastic POM</td><td>1055751</td></tr>
<tr><td colspan="4">Description</td></tr>
<tr><td colspan="4">MS1, MS2 and MS3 is the interface between P1v1 (Tail Gate Lower Panel), P1v2 (Tail Gate Side and Upper Panel) and P1v3 (B-pillar Panel) and the fastener. In the current application this is plastic to plastic contact. MS4 and MS5 is the interface between P2v1 (Tail Gate Structure) and P2v2 (Upper Body Structure), currently plastic to sheet metall. The MS4 and MS5s areas are dependent on the thickness of P2.

Due to the different versions of P1 the characterization of the MS3 and the DOF might change but the tree different P1 are similar enough that the surfaces MS1-MS5 can be estimated to be the same.

Due to the larger hole radius of P1 then the radius of MS3 the interface between them can be estimated as a line contact instead of a surface area contact.</td></tr>
<tr><td colspan="4">Surfaces</td></tr>
<tr><td>MS1</td><td colspan="2">MS2</td><td>MS3</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td>MS4</td><td colspan="2">MS5</td><td></td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
<tr><td colspan="4">Assembly</td></tr>
<tr><td>P1v1</td><td colspan="2">Fastener, P1v1</td><td>Fastener, P2v1</td></tr>
<tr><td></td><td colspan="2"></td><td></td></tr>
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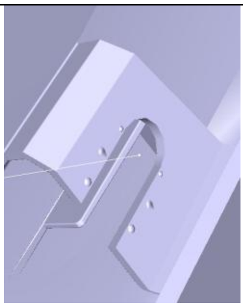
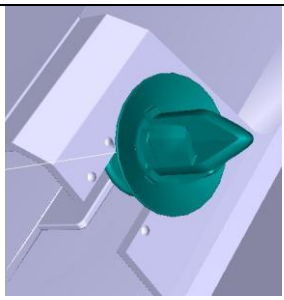
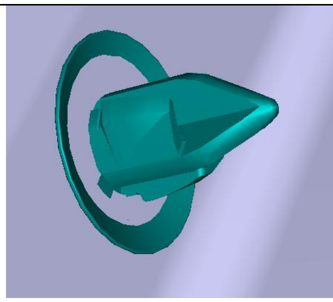
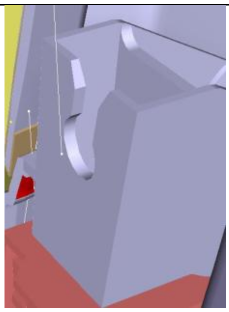
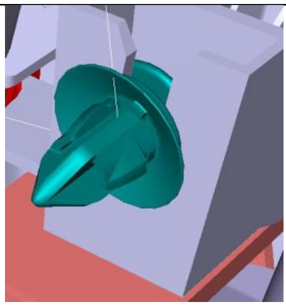
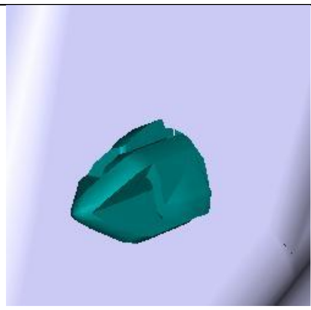
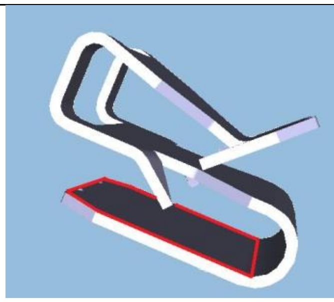
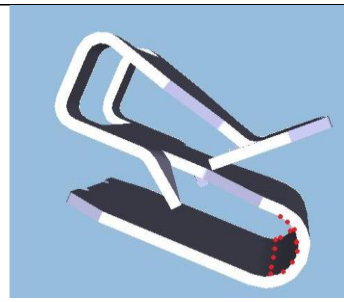
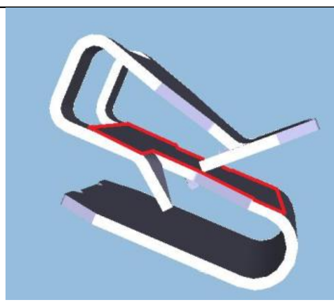
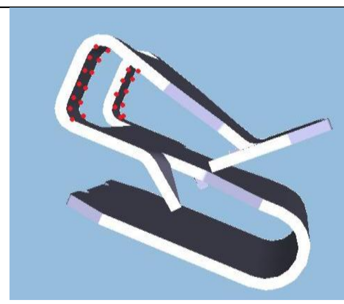
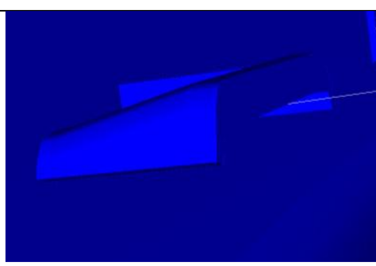
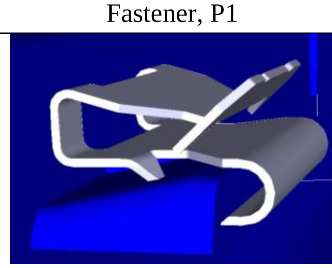
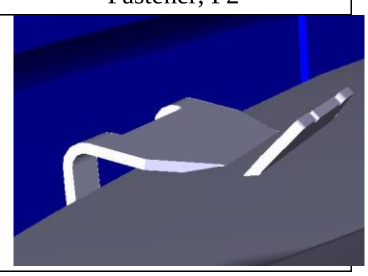
P1v2	Fastener, P1v2	Fastener, P2v2
		
P1v3	Fastener, P1v3	Fastener, P2v3
		

Name	Material	Drawing document
Retainer 988088	Steel HV 435-535	1054785
Description		
MS1, MS2 and MS3 is the interface between P1 (Upper Dorr Frame Panel) and the fastener. In the current application this is plastic to steel contact. MS4, MS5 and MS6 is the interface between P2 (Dorr Frame Structure) and fastener, currently steel to sheet metall. The primary function of this fastener is to "clamp" together P1 and P2. When the fastener is fitted in P1 the spikes bend up and lock the fastener in place The bottom part of P1 contact point guides the fastener in to the right position. The slot which the fastener fits in on P1 has a width of 16 mm while the fastener has a width of 13mm. The MS2 and MS5 are surfaces which in their nominal position in Fastener and P2 are not in contact with either P1 or P2. It could be noted that most probably there will be some kind of contact with both the MS2 and MS5		
Surfaces		
MS1	MS2	MS3
		
MS4	MS5	MS6
		
Assembly		
P1	Fastener, P1	Fastener, P2
		

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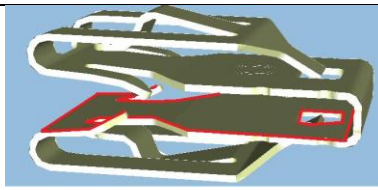
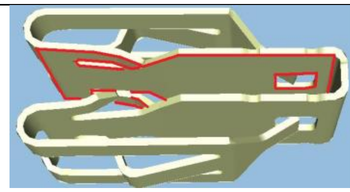
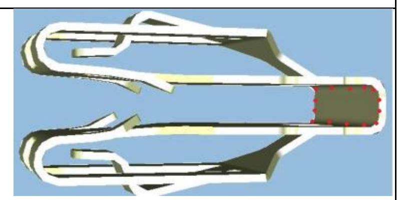
<tr><td colspan="4">Name</td><td colspan="4">Material</td><td colspan="4">Drawing document</td></tr>
<tr><td colspan="4">Retainer 999442</td><td colspan="4">Steel</td><td colspan="4">1055519</td></tr>
<tr><td colspan="12">Description</td></tr>
<tr><td colspan="12">MS1, MS2 and MS3 is the interface between P1 (D-pillar) and the fastener. In the current application this is plastic to steel contact. MS4, MS5, MS6 and MS7 is the interface between P2 (Luggage Trim Upper) and fastener, currently steel to plastic. The MS1 and MS2 are dominantly the four spikes. When the fastener is fitted in P1 the spikes bend up and lock the fastener in place. In the application that is used the fastener doesn't have any play in any direction. If the fastener is not correctly places on the P1 then there could be problems with the D-pillar not having a tight fit.</td></tr>
<tr><td colspan="12">Surfaces</td></tr>
<tr><td colspan="4">MS1</td><td colspan="4">MS2</td><td colspan="4">MS3</td></tr>
<tr><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
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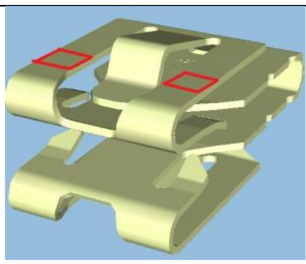
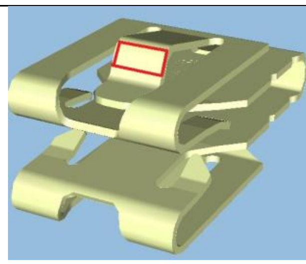
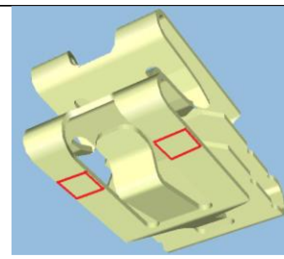
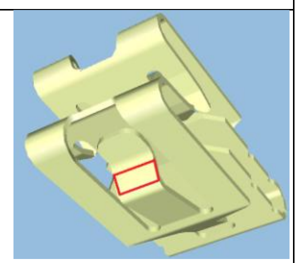
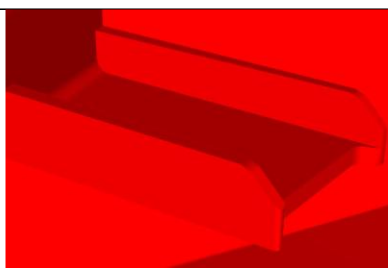
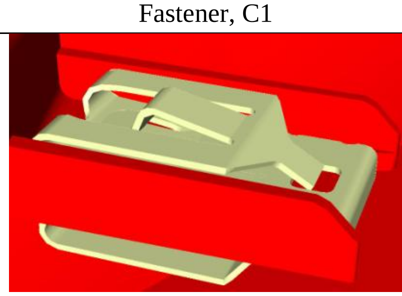
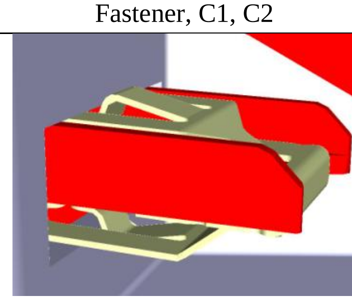
<tr><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="12">Assembly</td></tr>
<tr><td colspan="4">C1</td><td colspan="4">Fastener, C1</td><td colspan="4">Fastener, C1, C2</td></tr>
<tr><td colspan="4"></td><td colspan="4"></td><td colspan="4"></td></tr>
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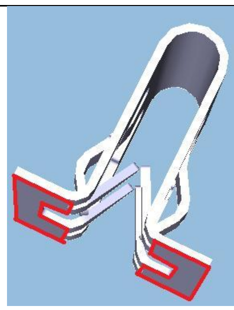
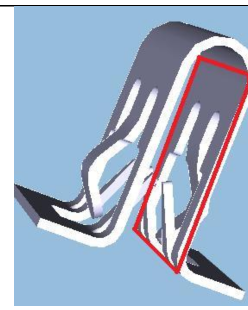
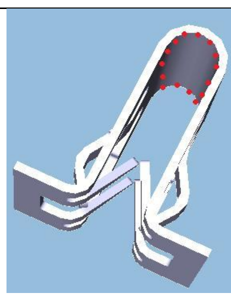
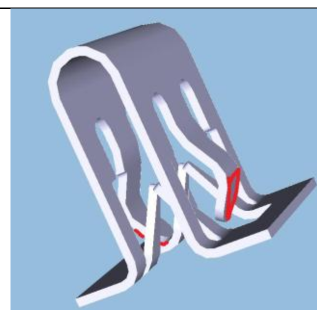
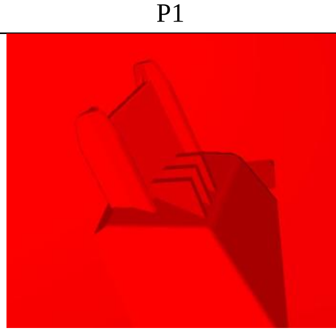
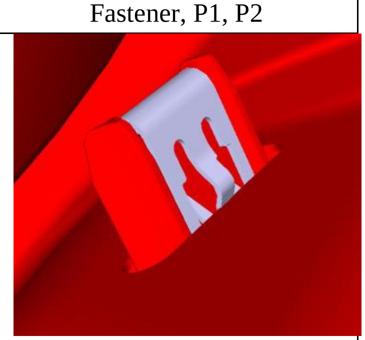
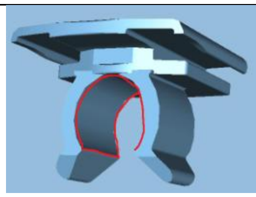
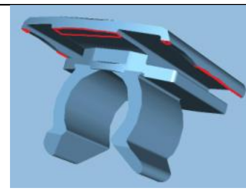
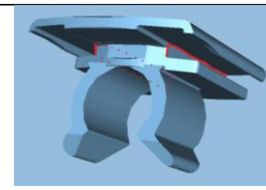
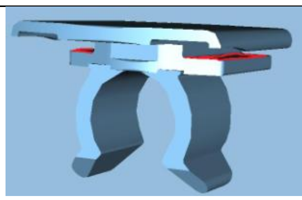
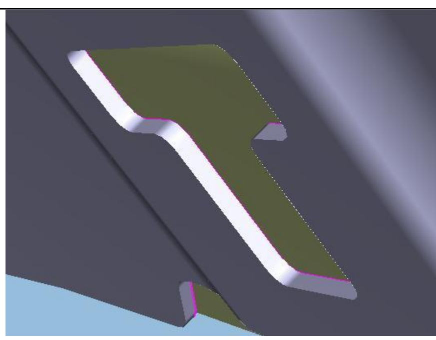
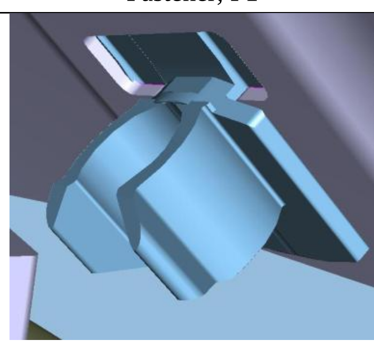
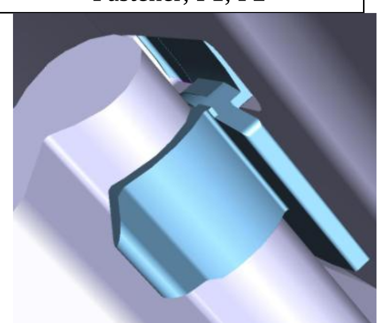
Name	Material	Drawing document
Plate Clip	Steel	-
Description		
MS1, MS2, MS3 and MS4 is the interface between P1 (D-pillar) and the fastener. In the current application this is plastic to steel contact. MS5 is the interface between P2 (Upper Body Structure) and fastener, currently steel to steel. To keep this fastener in place the four spikes on MS2 and MS31are used for that purpose. When the fastener is fitted in P1 the spikes bend up and lock the fastener in place. In the application that is used the fastener has limited play with regards to the P1. But the fastening solution P1, Fastener has some play in relation to P2 as can be seen in (Fastener, P1, P2). Unfortunately there has been a difficulty to identify this fastener so no drawing or Volvo part name could be found when this report was printed. The values were extracted from VisMockup.		
Surfaces		
MS1	MS2	MS3
		
MS4	MS5	
		
Assembly		
P1	Fastener, P1	Fastener, P1, P2
		

<table>
<tr><td>Name</td><td>Material</td><td>Drawing document</td></tr>
<tr><td>Retainer 3539879</td><td>Plastic POM</td><td>3539879</td></tr>
<tr><td colspan="3">Description</td></tr>
<tr><td colspan="3">MS2, MS3 and MS4 is the interfaces between P1 (Upper Body Structure) and the fastener. In the current application this is plastic to steel contact. MS1 is the interface between P2 (D-pillar Panel) and fastener, currently plastic to plastic. The assembly locks the movement of C2 orthogonally to the surface of P1. The fastener dose doe allow movement along the center axis of the surface of MS1.</td></tr>
<tr><td colspan="3">Surfaces</td></tr>
<tr><td>MS1</td><td>MS2</td><td>MS3</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>MS4</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td colspan="3">Assembly</td></tr>
<tr><td>P1</td><td>Fastener, P1</td><td>Fastener, P1, P2</td></tr>
<tr><td></td><td></td><td></td></tr>
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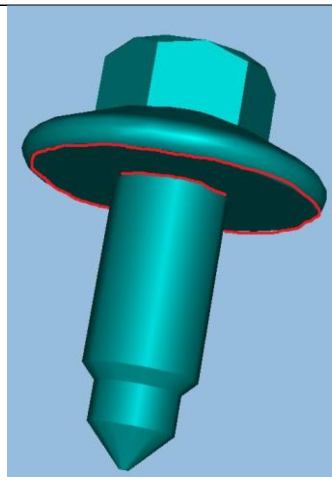
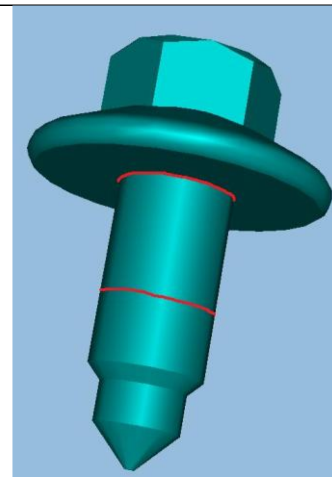
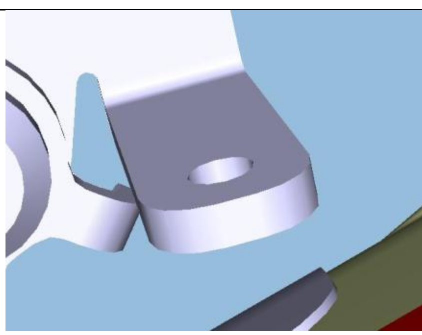
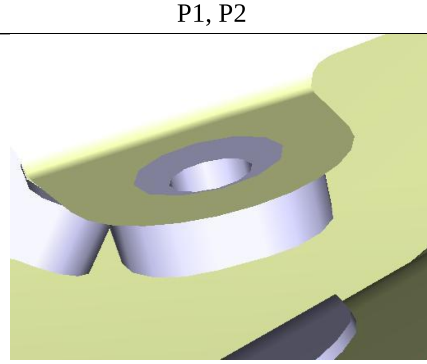
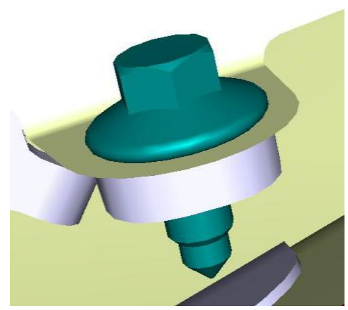
<table>
<tr><td colspan="2">Name</td><td colspan="2">Material</td><td colspan="2">Drawing document</td></tr>
<tr><td colspan="2">Screw 999223</td><td colspan="2">Steel, property class 8.8</td><td colspan="2">1054436</td></tr>
<tr><td colspan="6">Description</td></tr>
<tr><td colspan="6">Throughout the inventory several screws were found this is a screw which will be used as an example.
MS1 is the interface between P2 (Front Fender) and the fastener. In the current application this is steel to sheet steel contact. MS2 is the interface between P1 (Hood Bracket) and fastener, currently steel to steel. Like many other screw there is no play between the components. When fastened there is a possibility that the moment and friction twists the fender locally to some extent. MS2 is dependent on the component that is fastened.</td></tr>
<tr><td colspan="6">Surfaces</td></tr>
<tr><td colspan="3">MS1</td><td colspan="3">MS2</td></tr>
<tr><td colspan="3"></td><td colspan="3"></td></tr>
<tr><td colspan="6">Assembly</td></tr>
<tr><td colspan="2">P1</td><td colspan="2">P1, P2</td><td colspan="2">P1, P2, Fastener</td></tr>
<tr><td colspan="2"></td><td colspan="2"></td><td colspan="2"></td></tr>
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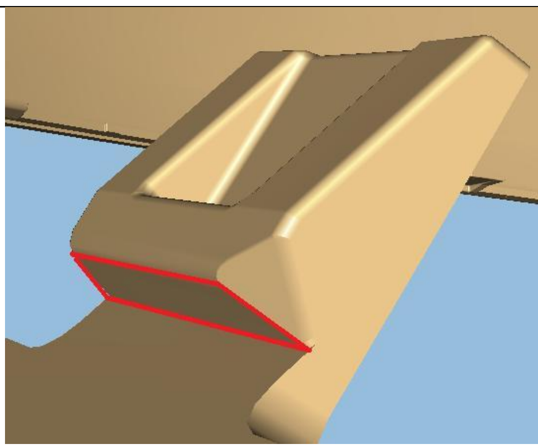
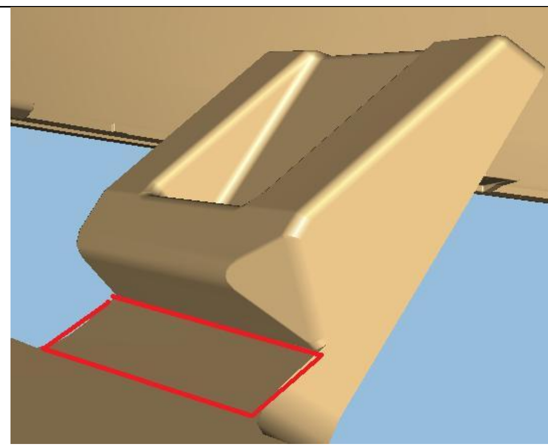
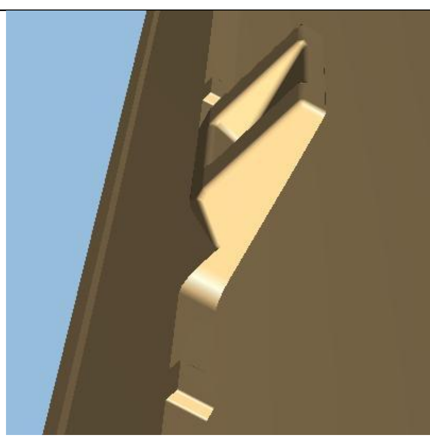
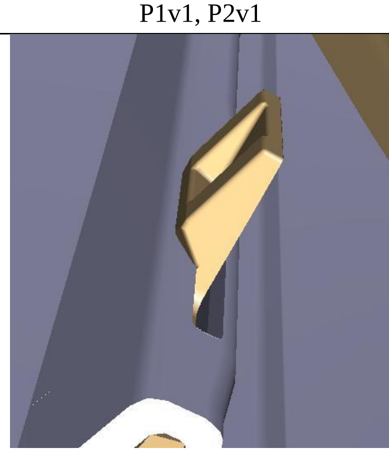
<table>
<tr><td>Name</td><td>Material</td><td>Drawing document</td></tr>
<tr><td>Snap Joint Hook</td><td>Component based</td><td>See specific part</td></tr>
<tr><td colspan="3">Description</td></tr>
<tr><td colspan="3">MS1 and MS2 can be generalized as the common interface between P1vX and P2vX. In the current application this is plastic to plastic contact. The MS1 and MS3 are affecting the mating part in different ways. MS1 is the surface which locks P1 and P2 together while MS2 merely pressing on the P2 .Through observation it is evident that there are a lot of components in today's cars that are assembled with snap joints. It is common that several snap joints are used when securing two components together. E.g. Front Upper Bumper Skin and Lower Bumper Skin are joined by 32 separate snap joint. It is important to point out that in early development when the CAD-models are merely styling data then these fastener types are not located on the parts. This is done later in the design process when the CAD- models reach a higher maturity level.

The slot that the different snap joints fit in very in dimension. P2v1, P2v3, P2v4 and P2v5 have clearly room for movement. P1v1s snap joint is approximately 20mm wide and the P2v1s slot is 40 mm long This means that the snap joint can move 10 mm in each direction from the nominal position.</td></tr>
<tr><td colspan="3">Surfaces</td></tr>
<tr><td>MS1</td><td colspan="2">MS2</td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td colspan="3">Assembly</td></tr>
<tr><td>P1v1</td><td colspan="2">P1v1, P2v1</td></tr>
<tr><td></td><td colspan="2"></td></tr>
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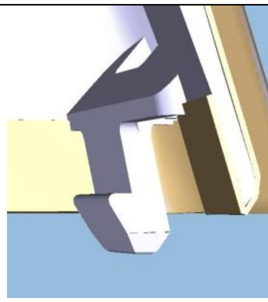
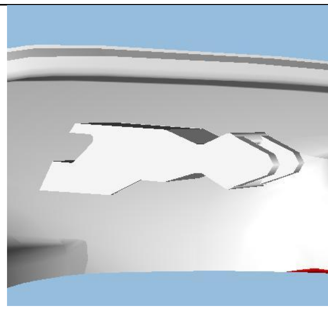
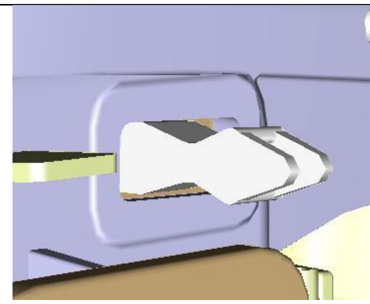
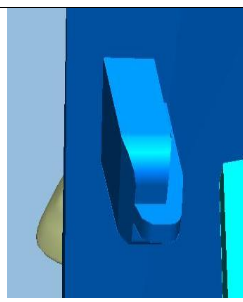
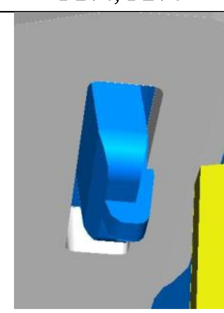
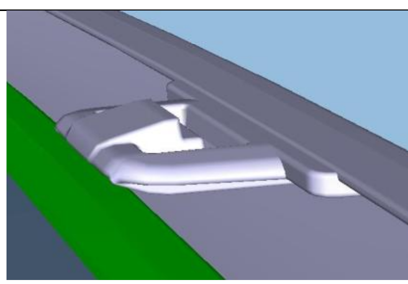
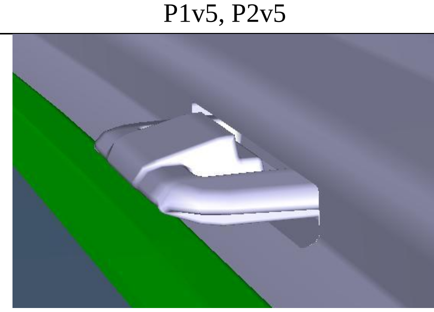
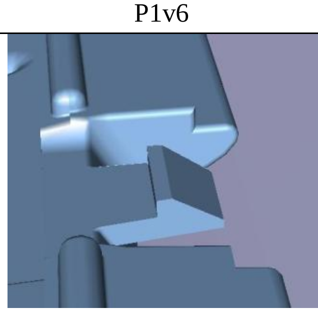
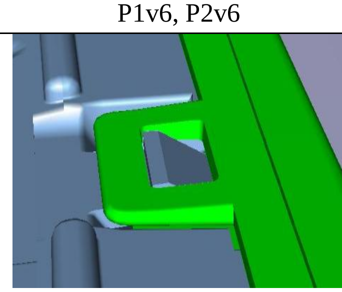
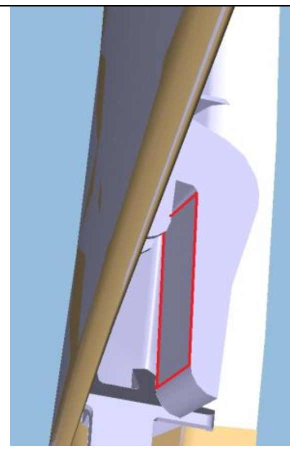
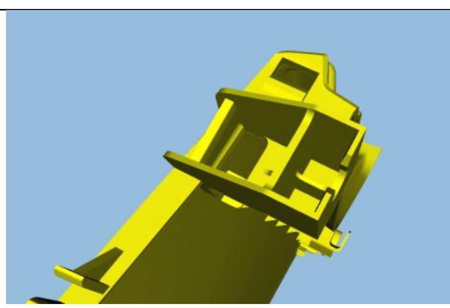
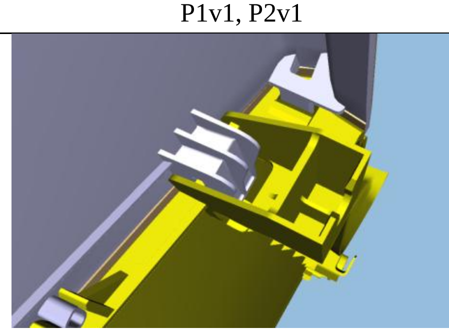
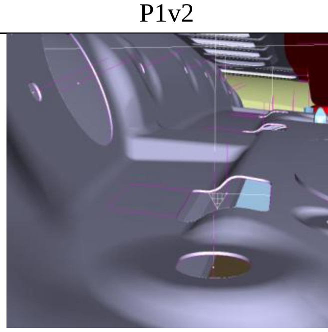
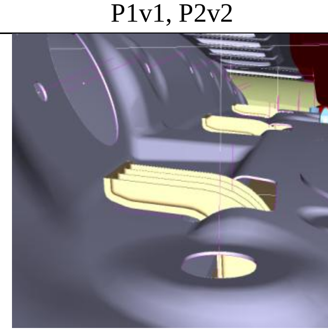
P1v2	P1v2, P2v2
	
P1v3	P1v3, P2v3
	
P1v4	P1v4, P2v4
	
P1v5	P1v5, P2v5
	
P1v6	P1v6, P2v6
	

<table>
<tr><td>Name</td><td>Material</td><td>Drawing document</td></tr>
<tr><td>Snap Joint Press</td><td>Component based</td><td>See specific part</td></tr>
<tr><td colspan="3">Description</td></tr>
<tr><td colspan="3">MS1 is the only interface between P1 (B-Pillar Panel) and P2 (Lower B-Pillar Panel). On most of the observations made, the material contacts were plastic to plastic contact. But as can be seen, P1v2 is the Upper Body Structure and is made of steel. Throughout observation it is evident that there are a lot of components in today's cars that are assembled with snap joints. It is common that several snap joints are used when securing two components together. It is important to point out that in early development when the CAD-models are merely styling data then these fastener types are not located on the parts. This is done later in the design process when the CAD- models reach a higher maturity level.</td></tr>
<tr><td colspan="3">Surfaces</td></tr>
<tr><td colspan="3">MS1</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">Assembly</td></tr>
<tr><td>P1v1</td><td colspan="2">P1v1, P2v1</td></tr>
<tr><td></td><td colspan="2"></td></tr>
<tr><td>P1v2</td><td colspan="2">P1v1, P2v2</td></tr>
<tr><td></td><td colspan="2"></td></tr>
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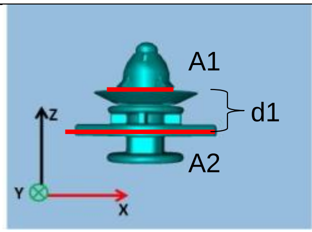
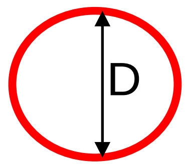
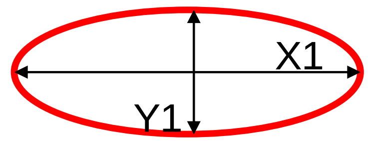
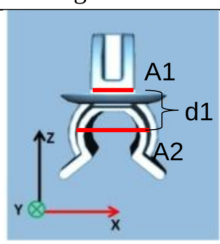
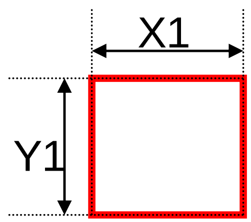
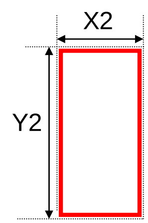
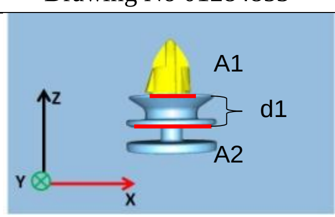
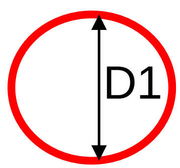
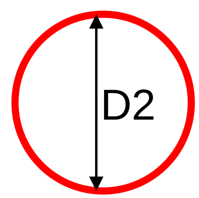
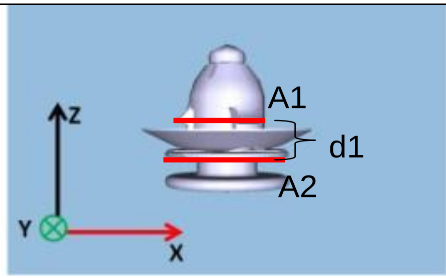
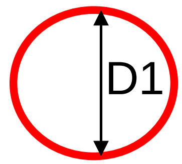
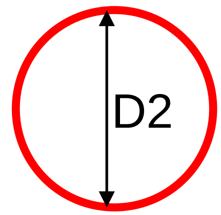
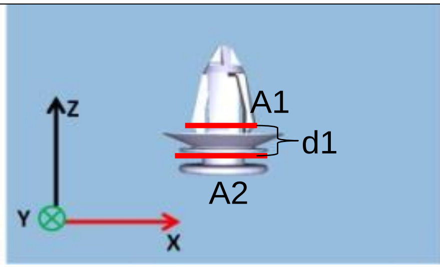
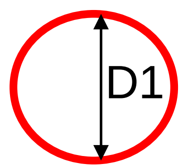
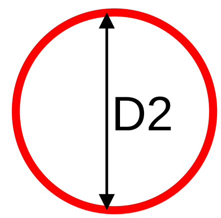
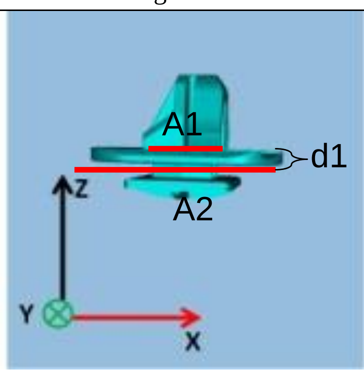
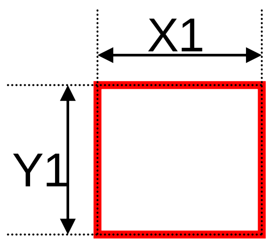
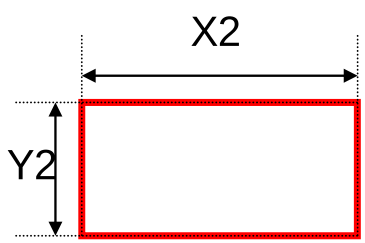
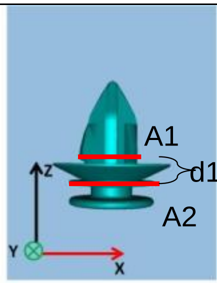
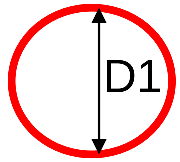
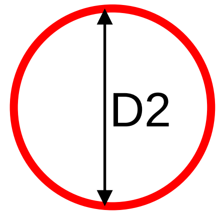
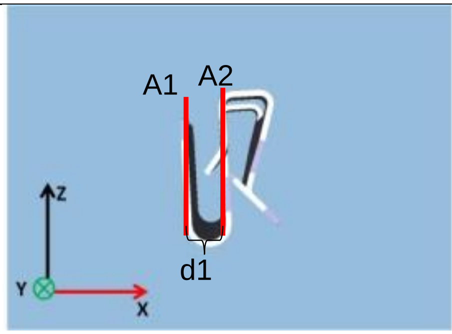
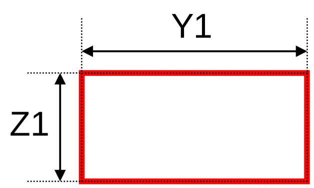
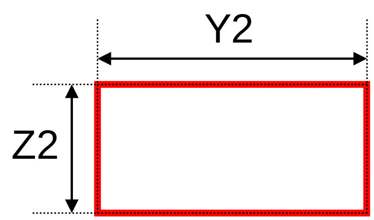
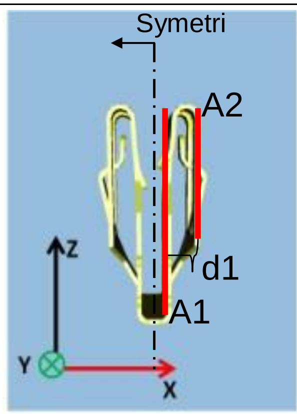
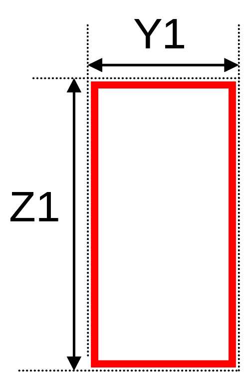
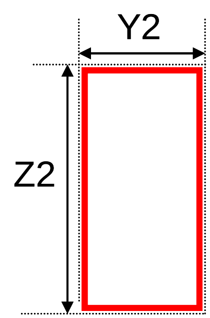
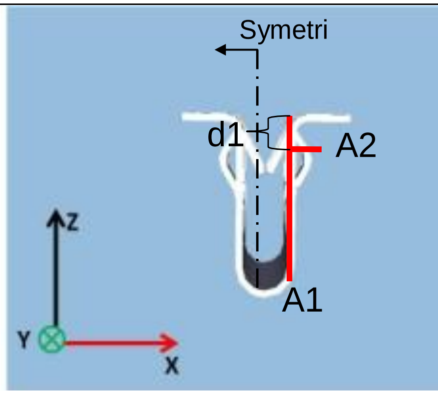
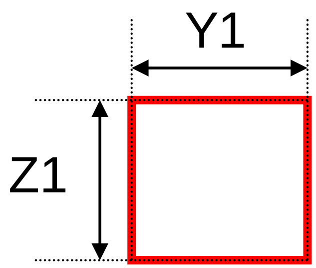
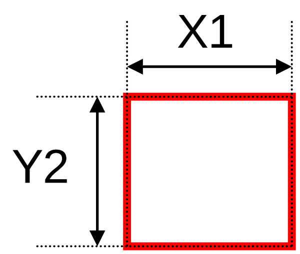
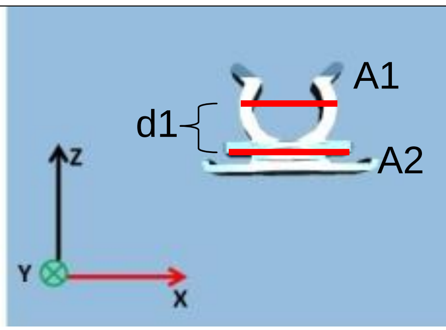
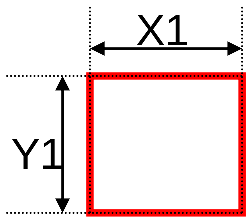
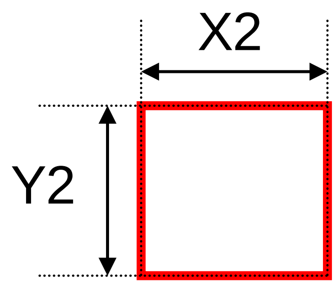
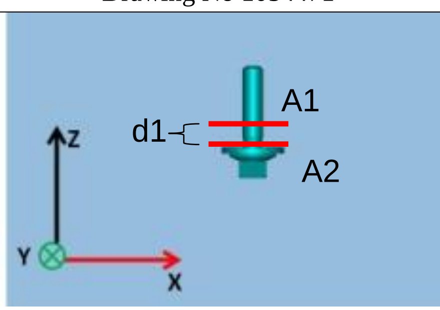
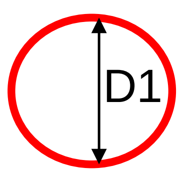
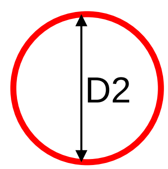
Appendix B: Generic shape of local and target mating surfaces

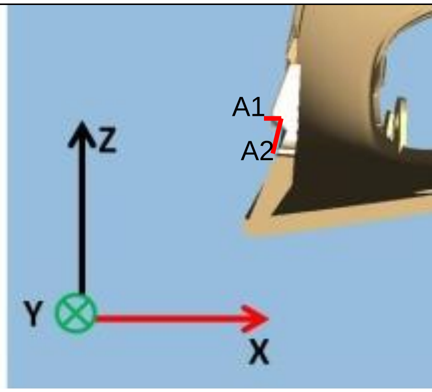
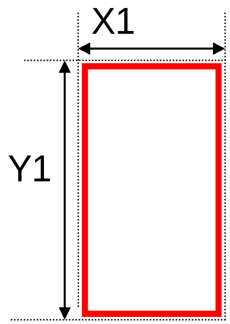
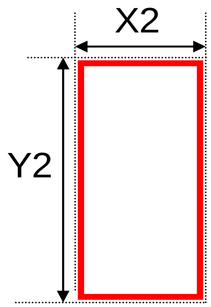
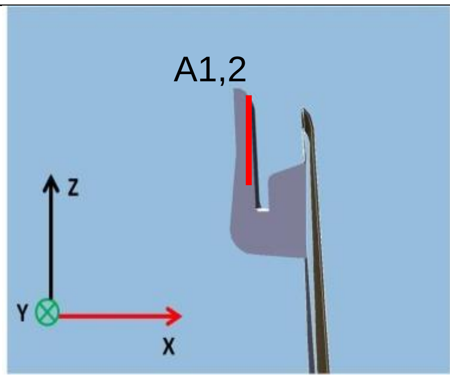
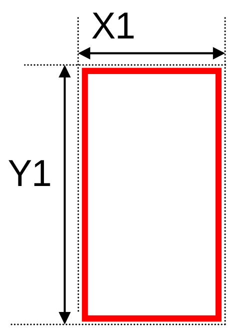
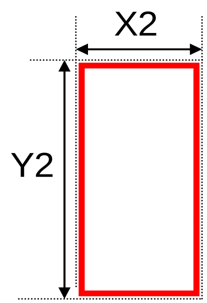
The mating surfaces which are crucial for assembling a local and a target part are presented here. A1, A2, An, are surfaces which represent the marked mating surfaces. They are dimensioned according to drawings found. It should be noted that the surfaces are approximated and simplified. Also the forces for mounting and demounting these fasteners are presented in this table. The forces detailed for mounting and demounting are maximum for mounting and minimum for demounting. These can be found in fastener specifications.

Mating Surfaces	Generic shape of Local/Target Mating Surfaces			
Drawing No 1055788	A1	A2	Variable	Value
			D	10.3 mm
			X1	24 mm
			Y1	16 mm
			d1	8.1 mm
			Mount	80 N
			Demount	225 N
Drawing No 01287317				
			X1	6.5 mm
			Y1	9.2 mm
			X2	7.5 mm
			Y2	15 mm
			d1	7.35 mm
			Demount	90 N
Drawing No 01284853				
			D1	10 mm
			D2	18 mm
			d1	7.7 mm
			Mount	50 N
			Demount	175 N

<table>
<tr><th>Drawing No 30653441</th><th>A1</th><th>A2</th><th>Variable</th><th>Value</th></tr>
<tr><td rowspan="6">
</td><td rowspan="6">
</td><td rowspan="6">
</td><td>D1</td><td>10.3 mm</td></tr>
<tr><td>D2</td><td>13 mm</td></tr>
<tr><td>d1</td><td>3.5 mm</td></tr>
<tr><td>Mount</td><td>80 N</td></tr>
<tr><td>Demount</td><td>225 N</td></tr>
<tr><td></td><td></td></tr>
<tr><td>Drawing No 1055200</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="6">
</td><td rowspan="6">
</td><td rowspan="6">
</td><td>D1</td><td>9.6 mm</td></tr>
<tr><td>D2</td><td>13.2 mm</td></tr>
<tr><td>d1</td><td>3.4 mm</td></tr>
<tr><td>Mount</td><td></td></tr>
<tr><td>Demount</td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td>Drawing No 1055567</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="8">
</td><td rowspan="8">
</td><td rowspan="8">
</td><td>X1</td><td>13 mm</td></tr>
<tr><td>Y1</td><td>10.8 mm</td></tr>
<tr><td>X2</td><td>32 mm</td></tr>
<tr><td>Y2</td><td>16 mm</td></tr>
<tr><td>d1</td><td>4.85 mm</td></tr>
<tr><td>Mount</td><td>50 N</td></tr>
<tr><td>Demount</td><td>200 N</td></tr>
<tr><td></td><td></td></tr>
</table>

Drawing No 1055751	A1	A2	Variable	Value
			D1	8.6 mm
			D2	13 mm
			d1	3.6 mm
			Mount	100 N
			Demount	200 N
Drawing No 1054785				
			Y1	12.5 mm
			Z1	10.1 mm
			Y2	12.5 mm
			Z2	10.1 mm
			d1	2.3 mm*
			Mount	
			Demount	
			* Based on the thickness of panels used, these are recommended values	
Drawing No 1055519				
			Y1	9.5 mm
			Z1	18.1 mm
			Y2	9.5 mm
			Z2	10.9 mm
			d1	3.35 mm*
			Mount 1**	80 N
			Mount 2**	60 N
			Demount **	20 N
			Demount 2**	100 N
			*This can varies based on the part 1 thickness. ** This fastener is mounted first on part1 then part 2.	

Part ID VDRGEOMPROD311119640101	A1	A2	Variable	Value
			Y1 Z1 Y2 X1 d1 Mount Demount *Values are acquired from VisMockup.	12 mm* 12 mm* 2.5 mm* 2.7 mm* 3 mm*
Drawing No 3539879				
			X1 Y1 X2 Y2 d1	7.7 mm 8 mm 18.5 mm 18 mm 5 mm
Drawing No 1054471				
			D1 D2 d1 *This is dependent of the screw chosen. ** This is dependent on the thickness of parts joined.	* * **

<table>
<tr><th>Snap Joint Hook**</th><th>A1</th><th>A2</th><th>Variable</th><th>Value</th></tr>
<tr><td rowspan="7">
</td><td rowspan="7">
</td><td rowspan="7">
</td><td>X1</td><td>*</td></tr>
<tr><td>Y1</td><td>*</td></tr>
<tr><td>X2</td><td>*</td></tr>
<tr><td>Y2</td><td>*</td></tr>
<tr><td>Mount</td><td>*</td></tr>
<tr><td>Demount</td><td>*</td></tr>
<tr><td colspan="2">* All these values are dependent on deign and maturity level of models.
**It is very difficult to build generic shapes due to the vast diversity of designs for Snap Joint Hook.</td></tr>
<tr><td>Snap Joint Press</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="7">
</td><td rowspan="7">
</td><td rowspan="7">
</td><td>X1,2</td><td>*</td></tr>
<tr><td>Y1,2</td><td>*</td></tr>
<tr><td>Mount</td><td>*</td></tr>
<tr><td>Demount</td><td>*</td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">* All these values are dependent on deign and maturity level of models.</td></tr>
</table>

Appendix C: Matrixes related to the used method

In this appendix the different matrix used will be presented. As can be seen the Pugh matrixes are presented before the morphological matrix. The Pugh matrixes were done on sub solutions instead of the complete concepts. The Sub solutions which were not eliminated were all too some extent incorporated in the final three concepts.

Fastener Description

Criteria	Alternative		
	Part All	Part Point	Levels
Complexity		1	2
Accuracy	R	-1	-1
Usability	E	1	2
Software Performance	F	1	2
Time to perform task		-2	-1
Future compatible		-2	-1
Fastener predetermination		0	2
Sum +	0	3	8
Sum 0	0	1	0
Sum -	0	5	3
Net value	0	-2	5
Rank	3	2	1
Elimination/Conclusion	Yes	Yes	No

Fastener Representation 1

Criteria	Alternative			
	Node-Node	Nodes-Nodes	2 Sets	2+Sets
Complexity		0	0	1
Accuracy	R	1	2	2
Usability	E	0	0	-1
Software Performance	F	-1	-1	-2
Time to perform task		-2	-1	-1
Future compatible		0	1	1
Fastener predetermination		0	0	-1
Sum +	0	1	3	4
Sum 0	0	4	3	0
Sum -	0	-3	-2	-5
Net value	0	-2	1	-1
Rank	2	4	1	3
Elimination	No	No	No	No

Fastener Representation 2

Criteria	Alternative			
	2 Sets	Nodes-Nodes	Node-Node	2+Sets
Complexity		0	0	-1
Accuracy	R	0	-2	1
Usability	E	-1	0	-1
Software Performance	F	-1	1	-1
Time to perform task		-1	0	-1
Future compatible		-2	-1	1
Fastener predetermination		1	0	0
Sum +	0	1	1	2
Sum 0	0	2	4	1
Sum -	0	-5	-3	-4
Net value	0	-4	-2	-2
Rank	1	4	2	2
Elimination	Yes	No	Yes	No

Connectors 1

Criteria	Alternative				
	Nominal Node	Nominal group	Mesh	Rigid	Deform Mesh
Complexity		-1	-1	0	0
Accuracy	R	0	2	-1	-2
Usability	E	0	0	-1	-1
Software Performance	F	1	-1	0	-1
Time to perform task		1	0	-2	-2
Future compatible		0	2	-2	-2
Fastener predetermination		0	0	0	0
Sum +	0	2	4	0	0
Sum 0	0	4	3	3	2
Sum -	0	-1	-2	-6	-8
Net value	0	1	2	-6	-8
Rank	3	2	1	4	5
Elimination	No	No	No	Yes	Yes

Connectors 2

Criteria	Alternative		
	Mesh	Nominal Node	Nominal group
Complexity		2	1
Accuracy	R	-1	-1
Usability	E	0	0
Software Performance	F	1	0
Time to perform task		0	0
Future compatible		-1	-1
Fastener predetermination		0	0
Sum +	0	3	1
Sum 0	0	3	4
Sum -	0	-2	-2
Net value	0	1	-1
Rank	2	1	3
Elimination/Conclusion	No	No	No

Fastener Positioning 1

Criteria	Alternative				
	One Node	Sequence	Plus shape	Auto distri.	Feature
Complexity		-2	-1	-1	-2
Accuracy	R	2	2	1	2
Usability	E	-1	0	0	1
Software Performance	F	-1	-1	-1	-1
Time to perform task		-1	0	0	-1
Future compatible		-1	1	1	2
Fastener predetermination		-1	0	0	0
Sum +	0	2	3	2	5
Sum 0	0	0	3	3	1
Sum -	0	-7	-2	-2	-4
Net value	0	-5	1	0	1
Rank	3	5	1	3	1
Elimination	No	Yes	No	No	No

Fastener Positioning 2

Criteria	Alternative			
	Feature	Plus shape	Auto distri.	One Node
Complexity		1	1	2
Accuracy	R	-1	-2	-2
Usability	E	-1	-1	0
Software Performance	F	2	1	2
Time to perform task		0	1	1
Future compatible		-1	0	-2
Fastener predetermination		0	0	0
Sum +	0	3	3	5
Sum 0	0	2	2	2
Sum -	0	-3	-3	-4
Net value	0	0	0	1
Rank	1	1	1	3
Elimination	No	No	No	No

+2 meets criterion much better than ref
+1 meets criterion better than ref
0 meets criterion as well as ref
- 1 meets criterion not as well as ref
-2 meets criterion much worse than the ref

Complexity	Is estimated by development time, cost and general complexity to implement function in RD&T
Accuracy	The level of approximation that is need to this function/model, High level of approximation means low level of accuracy
Usability	Intuitive and logical function
Software Performance	The amount of calculation required of the software to perform function
Time to perform task	The amount of steps required to perform task
Future compatible	To what extent is this function equipped to adapt to new technologies and methods.
Fastener predetermination	The time needed for the developer to implement a fastener library.

Morphological Matrix - Node Concept						
Key Factors		1	2	3	4	5
Fastener Description	A	Surface	Points	Levels		
Fastener Representation	B	Node-Node	Nodes-Nodes	2Stets	2+Sets	
Connectors	C	Nominal distance nodes	Nominal distance group	Mesh		
Fastener Positioning	D	One node	Sequence	One node plus shape	One node plus automatic distribution	Feature
General Solutions	E	Closest link	Several node selection	Node projection	Unified menu system	

Morphological Matrix - Multiple nodes Concept						
Key Factors		1	2	3	4	5
Fastener Description	A	Surface	Points	Levels		
Fastener Representation	B	Node-Node	Nodes-Nodes	2Stets	2+Sets	
Connectors	C	Nominal distance nodes	Nominal distance group	Mesh		
Fastener Positioning	D	One node	Sequence	One node plus shape	One node plus automatic distribution	Feature
General Solutions	E	Closest link	Several node selection	Node projection	Unified menu system	

Morphological Matrix - Feature Concept						
Key Factors		1	2	3	4	5
Fastener Description	A	Surface	Points	Levels		
Fastener Representation	B	Node-Node	Nodes-Nodes	2Stets	2+Sets	
Connectors	C	Nominal distance nodes	Nominal distance group	Mesh		
Fastener Positioning	D	One node	Sequence	One node plus shape	One node plus automatic distribution	Feature
General Solutions	E	Closest link	Several node selection	Node projection	Unified menu system	