Development of CAD-models for Large Silencer Platform using Design Automation

Thesis Report

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Abstract

Scania is known as a front-runner in the development of power trains for heavy vehicles, marine, and general industrial applications. As the regulations on emissions for combustion engine vehicles are getting tougher with increasing awareness on sustainable solutions and reducing environmental impact, the goal at Scania is to develop combustion engines to achieve low-pollutant emissions whilst achieving higher efficiency. Consequently, the exhaust after-treatment systems must continuously evolve to meet changing legislative requirements and customer demands. To achieve this goal in this competitive market, Scania must adapt to these changes within a short period of time.

The purpose of this thesis is to explore and improve the existing development process for the exhaust after-treatment system particularly for Large silencer platform by introducing design automation intended for computational fluid dynamics simulations. The objective was to introduce a method to reduce development time and allow designers to generate CFD models as effectively as possible.

Two new methods were developed and proposed to create geometries intended for CFD simulation. The first method focuses on the extraction and splitting of internal volume/fluid region and these models will be utilized in the simulation solvers to perform CFD simulation. The second method was to standardize the naming of extracted surfaces specific to CFD simulation since every surface is treated differently in the simulation solvers. A simple user-friendly graphical user interface was created for easy operation and faster adaptability.

Finally, the developed methods were evaluated and it was shown that it has the potential to save a significant amount of time during the pre-processing of the development phase and thus allow the engineers to focus on other value-adding and important task.
Acknowledgement

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Sincerely,

Balagangadar Thilakar Arumugam

Mahim Kai
## Contents

1 Introduction .................................................. 1  
   1.1 Background .............................................. 1  
   1.2 Problem Formulation .................................... 2  
   1.3 Purpose and Objective  
      1.3.1 Objective ......................................... 2  
   1.4 Research Questions .................................... 2  
   1.5 Deliverables ............................................. 3  
   1.6 Delimitations .......................................... 3  

2 Theoretical Framework ...................................... 4  
   2.1 Computer Aided Design .................................. 4  
   2.2 CFD Simulation in Exhaust After-treatment Systems ........................................... 4  
   2.3 Naming Convention for CFD Simulation .......... 5  
   2.4 Parametric Modeling in CATIA  
      2.4.1 How CATIA Supports Automation  
         2.4.1.1 Scripting and Macros ......................... 6  
   2.5 Design of Experiments(DOE) ......................... 7  
   2.6 Simulation Driven Design .............................. 7  
   2.7 High level CAD modeling ....................... 7  
   2.8 Exhaust Aftertreatment System at Scania ..... 7  
   2.9 Data collection methods ............................. 8  
   2.10 Flow Chart ............................................ 9  
   2.11 Visual Studio .......................................... 10  

3 Thesis Methodology ........................................ 11  
   3.1 Pre-Development Stage  
      3.1.1 Literature Study .................................. 11  
      3.1.2 Interviews ......................................... 12  
      3.1.3 Former Thesis Works ............................. 12  
   3.2 Method Development Stage ............................ 12  
   3.3 Implementation Stage ................................. 12  

4 Results: Pre-Development Stage .......................... 14  
   4.1 Interpretation 1: CFD Model Extraction ........... 14  
   4.2 Interpretation 2: Standardising the Naming of Surfaces ........................................... 15  
   4.3 Interpretation 3: Parameters in the CAD Model ........................................... 16  

5 Results: Method Development Stage ..................... 17  
   5.1 Objective ............................................... 17  
      5.1.1 Requirements for extraction and splitting of fluid region ........................................... 18  
      5.1.2 Requirements for naming convention ........................................... 19  
      5.1.3 Requirements for fetching the Parameters from CAD model ........................................... 19  
   5.2 Approach ................................................ 19  
      5.2.1 Approach for extraction of internal volumes/fluid region ........................................... 20  
         5.2.1.1 Extraction of internal volumes/fluid region ........................................... 20  
         5.2.1.2 Splitting of extracted surfaces ........................................... 21  
         5.2.1.3 Removing of overlapping surfaces ........................................... 22  
         5.2.1.4 Applying unique color ........................................... 23  

4
5.2.2 Approach for naming convention

5.2.2.1 Pre-defining HTML table

5.2.2.2 Dynamically generating questions in user interface

5.2.2.3 Transferring names to CATIA

5.2.3 Approach for fetching parameters from CAD model

5.3 Execution

5.3.1 Automation of extraction of internal volumes/fluid region

5.3.2 Automation for naming convention

5.3.3 Automation of Fetching Parameters from CAD model

5.4 Evaluation

5.4.1 Geometry Check using ANSA

5.4.2 Simulation using OpenFOAM

6 Results: Implementation Stage

6.1 GUI for extraction and splitting of internal volume

6.2 GUI for naming convention

6.3 GUI for Fetching Parameters from the CAD Model

7 Discussion

7.1 Thesis Methodology

7.2 Simulation Specific CAD Model Extraction

7.3 Naming Convention

7.4 Parameters in the CAD Models

7.5 Version Handling of Scripts using GitLab

8 Conclusion

9 Future Work

A Interview Guide

B Interview Results

C User Guide
# List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Generic schematic illustration of the EATS for large silencer platform at Scania (Reproduced from [1])</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Flow chart symbols and meaning (Adopted from [2])</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>Thesis methodology</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>Development stage general workflow</td>
<td>17</td>
</tr>
<tr>
<td>6</td>
<td>Large silencer model</td>
<td>18</td>
</tr>
<tr>
<td>7</td>
<td>Naming convention for simulation</td>
<td>19</td>
</tr>
<tr>
<td>8</td>
<td>Parameters in a CAD Model</td>
<td>19</td>
</tr>
<tr>
<td>9</td>
<td>Internal volume/fluid region extraction</td>
<td>21</td>
</tr>
<tr>
<td>10</td>
<td>Cavity formation based on substrates</td>
<td>21</td>
</tr>
<tr>
<td>11</td>
<td>Overlapping surfaces at every inlet and outlet of substrate</td>
<td>22</td>
</tr>
<tr>
<td>12</td>
<td>Developed approach to overcome the overlapping of surfaces</td>
<td>22</td>
</tr>
<tr>
<td>13</td>
<td>Required simulation-specific extracted surfaces</td>
<td>23</td>
</tr>
<tr>
<td>14</td>
<td>Final Model</td>
<td>23</td>
</tr>
<tr>
<td>15</td>
<td>Naming convention versions</td>
<td>24</td>
</tr>
<tr>
<td>16</td>
<td>HTML table for naming convention</td>
<td>25</td>
</tr>
<tr>
<td>17</td>
<td>Dynamically generated questions</td>
<td>25</td>
</tr>
<tr>
<td>18</td>
<td>Naming convention</td>
<td>26</td>
</tr>
<tr>
<td>19</td>
<td>Method to fetch Parameters</td>
<td>26</td>
</tr>
<tr>
<td>20</td>
<td>Final execution workflow for extraction and splitting of internal volume</td>
<td>27</td>
</tr>
<tr>
<td>21</td>
<td>Overview of execution for extraction and splitting internal volume</td>
<td>27</td>
</tr>
<tr>
<td>22</td>
<td>Final execution workflow for naming convention</td>
<td>28</td>
</tr>
<tr>
<td>23</td>
<td>Steps followed for naming convention</td>
<td>29</td>
</tr>
<tr>
<td>24</td>
<td>Fetching Parameters from CAD model</td>
<td>30</td>
</tr>
<tr>
<td>25</td>
<td>Geometry check in ANSA</td>
<td>30</td>
</tr>
<tr>
<td>26</td>
<td>Penetration : Intersection Check in ANSA</td>
<td>31</td>
</tr>
<tr>
<td>27</td>
<td>Meshed Housing of a Large Silencer</td>
<td>31</td>
</tr>
<tr>
<td>28</td>
<td>Meshed Perforated Plate of a Large Silencer</td>
<td>32</td>
</tr>
<tr>
<td>29</td>
<td>Streamlines of Back Pressure Simulation</td>
<td>32</td>
</tr>
<tr>
<td>30</td>
<td>GUI for extraction and splitting of internal volume</td>
<td>33</td>
</tr>
<tr>
<td>31</td>
<td>GUI 1 for naming convention</td>
<td>34</td>
</tr>
<tr>
<td>32</td>
<td>GUI 2 for naming convention</td>
<td>34</td>
</tr>
<tr>
<td>33</td>
<td>GUI for Fetching Parameters</td>
<td>35</td>
</tr>
<tr>
<td>34</td>
<td>Modifying Parameter values in CATIA</td>
<td>36</td>
</tr>
</tbody>
</table>
Abbreviations

**EATS** Exhaust After Treatment System

**SCR** Selective Catalytic Reduction

**ASC** Ammonia Slip Catalyst

**DPF** Diesel Particulate Filter

**DA** Design Automation

**SDD** Simulation Driven Design

**CAD** Computer Aided Design

**CFD** Computational Fluid Dynamics

**HCV** Heavy Commercial Vehicle

**UNECE** United Nations Economic Commission For Europe

**FEM** Finite Element Method

**KBE** Knowledge Based Engineering

**MOKA** Methodology and software tools Oriented to Knowledge based engineering Applications

**EKL** Enterprise Knowledge Language

**VBA** Visual Basic Application

**PD** Product Development

**CAE** Computer Aided Engineering

**GUI** Graphical User Interface
1 Introduction

This master’s thesis was conducted in partnership with Scania CV AB, commonly referred to as Scania. The Fluid Dynamics and Acoustics Simulation group at Scania, which helps with the development of Exhaust After Treatment Systems (EATS) for trucks and buses, was the primary collaborator for this thesis work. Exhaust after-treatment systems serve the purpose of minimizing the emission of harmful pollutants from internal combustion engines utilized in vehicles and industrial machinery. The most widely used components in the after-treatment systems are catalytic converters, diesel particulate filters, and selective catalytic reduction (SCR) systems.

- **Catalytic converters** utilize a catalyst, mostly made of platinum, to convert the dangerous exhaust gases into less hazardous substances before they are emitted into the air.

- **Diesel particulate filters** are particularly utilized to collect ash and also eliminate particulate matter, also known as soot, from diesel engine exhaust gases. They capture the particulates and burn them off at high temperatures, thereby reducing their harmful effect on the environment.

- **SCR systems** use a reductant such as Ammonia to transform nitrogen oxides (NOx) present in diesel engine exhaust into nitrogen and water vapor, thus decreasing the emission of hazardous NOx into the atmosphere.

Meeting the emission standards set by regulatory bodies such as the US Environmental Protection Agency (EPA) and the European Union (EU) is critical, and these after-treatment systems play a crucial role in this. Proper maintenance and operation of these systems is necessary to ensure their continuous and effective functioning, reducing emissions throughout the engine’s lifespan.

1.1 Background

Scania is a renowned producer of heavy-duty vehicles, industrial engines, and power generation systems, headquartered in Södertälje, Sweden. The company has a reputation for prioritizing advanced technology and sustainability. To that end, Scania places a significant emphasis on reducing emissions from its products, and the Scania after-treatment system plays a crucial role in achieving this goal.

In order to stay competitive, it’s crucial to minimize the time and effort spent on manual, repetitive processes that involve many iterations. Design changes typically require input from engineers from multiple departments. Performing Computer Aided Engineering (CAE) simulations like Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEM) on these iterative processes requires a lot of time-consuming, non-creative work. Implementing design automation with parametric CAD model and Simulation Driven Design (SDD) can significantly shorten the lead time in development process.
1.2 Problem Formulation

The CFD simulation engineers at Scania who work on the after-treatment exhaust system for trucks face a significant challenge with modifying the CAD models they receive from the design team in the required way for simulation solvers. The pre-processing, or CAD cleaning process, is time-consuming and repetitive, even for small changes to the CAD models. The Large silencer platform, being a complex model made up of various components in a compact structure, makes the task of cleaning the CAD models and preparing them for CFD simulations even more difficult. To overcome this challenge, there is a strong need to develop a method to automate the extraction of simulation specific CAD models, which would help the simulation engineers complete their tasks more efficiently and allow them to perform a greater number of simulations by reducing the time spent on pre-processing.

1.3 Purpose and Objective

Multiple theses at Scania have successfully been carried out with the goal of reducing and eliminating the non-innovative or repetitive tasks through the use of Design Automation (DA). However, DA for Large silencer platform aiding for CFD simulation is completely new. This thesis aims to explore this further and create a reliable tool with which the extraction of CAD models and naming the surfaces can be automated in order to perform CFD simulation. Finally, the extracted CAD models will also be verified through simple CFD simulations.

1.3.1 Objective

The main objectives of this thesis are presented below:

- Evaluate the method or development process currently employed by Scania.
- Automatically generating the CAD models through CATIA V5 that are suitable for CFD simulations using DA.
- Implement an efficient naming system for CFD models that can be flexibly adapted to future changes.
- Develop a methodology to reduce the lead time required for pre-processing of CAD models prior to simulation.
- Version handling of visual studio scripts using Git Hub.

1.4 Research Questions

In order to fulfill the purpose and objectives from Scania and Linköping University, the following research questions will be answered and discussed in the thesis.

1. What are the challenges with current process and limitations of design automation for generating the simulation specific CAD models of EATS and how can they be overcome?
2. What are the best ways to apply design automation techniques to reduce the lead time in pre-processing CAD models before CFD simulation?
3. How can the naming convention of CAD models be efficiently managed to enable design automation for CFD simulations?
1.5 Deliverables

Below points presents the deliverable that have been settled upon as expectation.

- Tool to extract simulation specific CAD models using design automation
- Tool for implementing naming convention for the extracted CAD models and exporting them as .STL files
- Tool to get and modify the parameter values of the CAD models and exporting them as .STL files
- Documentation of the methods used and the results in a final report
- User manual for all the developed interfaces
- An executable .exe format of all the developed interfaces that can be accessed without additional software.

1.6 Delimitations

A set of delimitation is considered as follows.

- At Scania the thesis is performed for a duration of 20 weeks and it will be executed mainly with the focus on the large silencer.
- CATIA V5 will be used as a CAD tool and Visual studio 2019 will be utilized for writing the scripts and creating the user interfaces.
- ANSA will be used for pre-processing, the CFD simulation will be performed either on StarCMM+ or OpenFOAM.
2 Theoretical Framework

This section mainly focuses on the theoretical aspects used as a foundation for the thesis.

2.1 Computer Aided Design

Computer Aided Design (CAD) has various applications in engineering practice. Some professionals utilize it to create drawings and document designs, while others use it as a visual tool to generate shaded images and animated displays. Additionally, a third group may use CAD to perform engineering analysis on geometric models, such as finite element analysis. Overall, CAD is a software-based design tool that assists engineers, architects, and other professionals in creating detailed drawings and models of products or structures by utilizing computer technology. In this thesis, the extensive use of Computer Aided Design (CAD) for designing the large silencer model may not be necessary since the existing CAD model will be used to implement design automation. However, having a thorough understanding of CAD model of large silencer is crucial to perform design automation. This understanding plays a significant role in developing a methodology for extracting internal volumes and automating the process of extracting only the surfaces that are exposed to hot gases. These surfaces are then assigned names using a naming convention tool developed as part of this thesis work. Subsequently, these named surfaces undergo CFD simulation.

2.2 CFD Simulation in Exhaust After-treatment Systems

The utilization of computers and information technologies for design analysis and synthesis is known as Computer Aided Engineering (CAE). Computational Fluid Dynamics (CFD) simulation is a specific application of CAE that focuses on the numerical analysis of fluid flow and heat transfer phenomena. The CFD simulations in the Scania’s exhaust after-treatment system provides a virtual environment to visualize and investigate the behavior of the hot gases, particulate matter and other components within the system.

Here are some specific purposes of CFD simulation in Scania’s exhaust after-treatment system.

1. **Flow Analysis**: The utilization of CFD can provide insights into the distribution of flow, pressure drop, and velocity profiles within the EATS. These information play a vital role in the design and enhancement of various components like catalyst substrates, filters, and mufflers, enabling the optimization of their performance [6].

2. **Mixing and Reactions**: CFD simulations can mock-up the mixing of exhaust gases with the reactants such as urea or ammonia specifically in selective catalytic reduction (SCR) systems. This capability empowers engineers to fine-tune the reactant distribution, ensuring optimal conversion of pollutants into safe and harmless substances [6].

3. **Pressure Drop Analysis**: CFD offers valuable information about the characteristics of pressure drop, which holds significance in assessing its influence on engine performance and system efficiency [6].

4. **Optimization and Design Evaluation**: Engineers can leverage CFD simulations to assess diverse design configurations, optimizing the arrangement and shape of
components in order to attain specific performance objectives. These goals may include enhancing pollutant conversion efficiency, reducing pressure drop, or achieving compactness [6].

Apart from the above specified purposes, CFD simulation can also be used to analyze the back pressure exerted on the engine by the EATS. By understanding and minimizing the back pressure exerted on the engine, engineers can ensure that the exhaust after-treatment system operates efficiently without negatively affecting the engine’s performance, fuel consumption, or emissions.

It is essential to acknowledge that the design and analysis of exhaust after-treatment systems encompass various other factors such as pollutant conversion efficiency, thermal management, and compliance with emissions regulations. CFD simulation proves to be a valuable tool for evaluating and optimizing these aspects of the system’s performance.

2.3 Naming Convention for CFD Simulation

Naming conventions serve as guidelines or rules that ensure consistent and structured naming practices for files, variables, parameters, or entities within a specific context or domain. It plays an important role in CFD simulation for the following reasons.

1. **Organization and clarity**: Using an effective naming convention helps to organize and structure the simulation files, making it easier to understand and navigate the simulation setup. This practice ensures clarity and minimizes ambiguity, particularly in scenarios involving multiple simulations or engineers.

2. **Standardization**: Naming convention promotes standardization across different simulations and projects within a team or an organization as a whole. It establishes a common language and format, making it easier for the team members to collaborate, share files and understand each other’s work.

3. **Documentation and Reproducibility**: The use of transparent and uniform naming conventions simplifies the documentation of simulation cases, thereby enhancing the ability to replicate or reference specific simulations in the future. This improves the traceability of simulation configurations, boundary conditions, and outcomes, leading to improved quality control and verification processes.

4. **Efficiency in Post-Processing**: In order to efficiently analyze and post-process the simulation results, a well-structured naming convention will be helpful. By including relevant information in the names, such as simulation parameters, boundary conditions, etc., becomes handy to identify and compare different cases.

5. **Scalability and Longevity**: Naming conventions improve the scalability and adaptability as they evolve. It provides a means to effortlessly differentiate between various versions or iterations of simulations, enabling iterative enhancements and long-term management of simulation data.

In the context of CFD simulation in Scania’s EATS, naming conventions are particularly important for maintaining organization, clarity, and standardization of naming the surfaces of the extracted CFD models.
2.4 Parametric Modeling in CATIA

Automation involves embedding decision-making capabilities into non-living objects, which can either be physical (hardware) or virtual (software). For instance, hardware and software work together in robotic fabrication and assembly lines used to build computer chips, while software programs execute both deterministic and non-deterministic tasks for form synthesis and optimization. Software is the common denominator that enables both types of automation.

Most software consists of a core engine with functions designed to perform specific tasks. Nowadays, software tools often expose some of their internal functions to external control through application programming interfaces (APIs).

This article specifically focuses on CATIA, which is a computer-aided design (CAD) system renowned for its robust solid modeling kernel and assembly-based data model, used for parametric modeling.[7]

2.4.1 How CATIA Supports Automation

CATIA’s macros can automate tedious design tasks that involve multiple setups or repetitive actions. A macro is a sequence of functions written in a scripting language. By setting up macros correctly, time can be saved and errors resulting from time-consuming manual work can be reduced.[7]

2.4.1.1 Scripting and Macros

Three primary macro languages in CATIA can have a direct impact on the program’s design elements. Starting from CATIA V5 R8 and beyond, all versions support macros that are created using the following scripts.

- **VBScript**: This operates as a simplified version of Visual Basic (VB) and can be written directly on Notepad.
- **CATScript**: This is a portable version of VBScript developed specifically by Dassault Systems for CATIA.
- **Visual Basic Application (VBA)**: This is embedded directly in Microsoft applications such as Excel or Access and is equipped with its own editor, debugger, and help object viewer.

When developing a script in CATIA, users or developers are constrained by the system’s existing concepts and cannot create abstract ones. For instance, it is impossible to create a rounded-corner polygon object, so users have to construct it using a series of line segments and arcs.

However, scripts provide engineers with the ability to create and store macros as customized design building blocks in a macro library that can be used by team members or on various projects, rather than having to create complex parts or systems from scratch.

Furthermore, CATIA enables the creation of custom features and assemblies that can be enhanced with such scripts, allowing for the development of self-configuring objects.
2.5 Design of Experiments (DOEs)

Design of Experiments (DOE) is a structured and systematic approach to planning, conducting, and analyzing experiments or tests to understand the relationship between variables (factors) and the outcomes (responses) they influence. It focuses on optimizing specific processes or systems by varying factors and levels in a controlled manner. The central aim is to understand how these variations affect the outcome and to identify the optimal settings for the factors of interest while keeping other conditions constant and also aims to find the optimal settings within a limited parameter range.

2.6 Simulation Driven Design

Simulation driven design is defined by Sellgren as "a design process where the major functions and related processes are verified and optimised with simulations on computer based product models". Simulation driven design involves the use of simulation tools such as CFD, FEM, costing, and other simulation-based studies to enhance performance. By generating various simulations during the early stages of product development, simulation driven design verifies and tests solutions, leading to improved product quality and reduced costs.

2.7 High level CAD modeling

CAD system in modern times present a range of instruments that enhance the adaptability of geometric models. Nevertheless, to employ these instruments advantageously, a requirement arises for generic modeling methods that are independent of tools. Organizing these methods into clear categories facilitate the path towards design automation as it serves three main purposes:

1. A backbone for discussions and descriptions of tasks involving geometry design automation.
2. A helpful guide to consult when searching for solutions.
3. A map to locate the required geometric design automation level more easily.

By utilizing modeling techniques employed in the automation process, CAD models are generated. Knowledge-Based Engineering can be utilized to facilitate the automation process as it stores rules and relations to support the CAD models. This enables the models to be automatically created during the design of new products.

2.8 Exhaust Aftertreatment System at Scania

The purpose of an EATS (exhaust after-treatment system) is to control the release of harmful gases into the atmosphere from engine exhaust as well as to reduce the noise and emissions produced by the engine by providing a controlled path for the exhaust gases to flow through. The combustion process generates a significant amount of noxious gases that can cause environmental damage. In general the normal combustion cycle produces oxides of nitrogen $NO_x$, $CO_2$ and water $H_2O$, while incomplete combustion leads to the
production of Carbon Monoxide (CO) and Hydrocarbons (HC). Since incomplete combustion is inherent in the normal combustion process, it is necessary to treat the exhaust gases before releasing them into the environment. The governments across the globe has set regulations and legislature that dictate the percentage or amount of particulate matter that can be emitted, and vehicles must meet these standards before being allowed to enter the market. The EATS processes the gases using chemical treatment (catalytic reactions) and/or particulate filters. A substrate typically refers to a component used within the EATS to facilitate the chemical processes that which converts harmful emissions into less harmful substances from the vehicle’s exhaust gases. The EATS at Scania is equipped with a catalytic converter substrate. The substrate contains a catalyst material, such as platinum or palladium, that promotes a chemical reaction that converts harmful emissions into nitrogen, water vapor, and carbon dioxide. At Scania, the large silencer is build to handle high mass-flow, i.e. it is used in conjunction with the V8 engine, which basically implies that the entire system to be divided into several subsystems. [11].

Figure 2 illustrates the main components of the EATS for large silencer platform.

![Figure 2: Generic schematic illustration of the EATS for large silencer platform at Scania (Reproduced from [1])](image)

2.9 Data collection methods

Harrell and Bradley [12] states that collecting primary data is a crucial component of numerous research endeavors. Employing appropriate methods guarantees the systematic and scientific collection of qualitative data. Elevating data collection techniques can boost the precision, authenticity, and dependability of research outcomes. Ultimately, implementing these approaches will aid in accomplishing the objective of conducting top-notch research with trustworthy findings. There are several ways of data collection defined by Harrell and Bradley as follows:

1. **Surveys**: They are predetermined collections of questions that can be conducted through various mediums such as paper and pencil, webforms, or by an interviewer who adheres to a precise script [12].

2. **Interviews**: Interviews are one-to-one conversations between an interviewer and a person that aim to obtain information on particular subjects. These discussions can
occur face-to-face or through phone calls. Compared to surveys, interviews typically have a higher degree of interaction structure. However, based on the degree of control, interviews can be further classified as unstructured, semi-structured and structured kind of interviews. In unstructured interviews, the researcher may have a definite outline, but they exert minimal influence on the respondent’s answers. Semi-structured interviews are frequently employed in policy research, wherein a guide consisting of predetermined questions and topics is used. While the interviewer has some flexibility in terms of the sequence of questions, the questions themselves are standardized, and supplementary probes may be utilized to guarantee that the necessary information is covered. This type of interview facilitates a detailed exchange of information in a conversational manner. Semi-structured interviews are a preferred method when researchers seek to explore a topic in depth and gain a comprehensive understanding of the responses provided. Structured interviews are the most tightly controlled type of interview, where questions are predetermined and asked in a specific sequence. Every participant is asked the same set of questions in the exact same order. Structured interviews are akin to reading a survey aloud with no deviation from the script [12].

3. **Focus groups:** These are conversations conducted among a collective of individuals who share similar backgrounds, experiences, expertise, or interests, with the goal of gathering data. In many instances, these discussions are instigated by participants and can stimulate innovative ideas among those involved, leading to more profound understandings of the topic. The involvement of multiple participants enables the collection of quantitative data in a shorter amount of time [12].

4. **Observation:** The act of collecting data through observation without the researcher’s active participation is known as non-participant observation. Instances of non-participant observation include observing surgeries or court proceedings. Nevertheless, it’s important to acknowledge that the mere presence of the researcher may impact the participants and their interactions. Although the researcher is unlikely to influence a surgeon or a Supreme Court justice, their presence could potentially affect other participants, such as young children playing [12].

5. **Extraction:** It is the act of gathering information from documents, records, or other archival sources, typically achieved by employing an abstraction method to retrieve the relevant data from the source. Instances of this process could involve obtaining the dates of diagnoses from medical records or decision dates from legal records [12].

6. **Secondary data sources:** Existing datasets, such as census data, can be used as secondary data sources by researchers who can choose which variables to analyze. Alternatively, they may merge data from multiple sources to form novel datasets [12].

### 2.10 Flow Chart

A flowchart is a graphical model that depicts various steps and logic used during the development of the method. Each step is depicted as blocks of various shapes which are interconnected by lines indicating the direction of sequence [2]. Figure 3 shows the different flow chart symbols used in this thesis and their description.
2.11 Visual Studio

Microsoft Visual Studio is an integrated development environment (IDE) used for developing software applications. It offers a workspace with tools like a code editor, solution explorer, and debugger to streamline coding, debugging, and testing. The IDE supports various programming languages such as C#, VB.NET, C++, F#, Python, and more and projects, manages code versioning, integrates with cloud services, and allows extensions for added functionality [13]. In this thesis VB.NET was extensively used for scripting and automating the process in CATIA V5. The GUI was developed using Microsoft Visual Studio software.
3 Thesis Methodology

This section explains the methodology followed to achieve the objectives of the thesis and how the work process is carried out.

![Thesis methodology diagram](image)

Figure 4: Thesis methodology

Figure 4 illustrates the overall workflow of the thesis, which mainly includes 3 stages: pre-development, methodology development, and implementation. The first stage involves literature study, interviews, and former works. The second stage includes the objective formulation, developing methods or the approach used, the different steps followed to execute the case study and evaluation of the approach used. The final stage comprises of the final automated tool developed and the GUI developed in Visual Studio.

3.1 Pre-Development Stage

The objective of this stage was to provide the authors with additional knowledge about CAD modeling strategies and the root causes of present challenges in integrating CAD, with a particular focus on design automation. It also aimed to identify potentially effective tools and methods for streamlining CAD integration. The research was carried out through a review of relevant literature, examination of data specific to the company and previous research, and conducting interviews.

3.1.1 Literature Study

The literature study is to examine the topics of Design Automation and CAD/CAE interaction, with a specific emphasis on CFD analysis in the context of simulation-driven design. The authors sought to gain insights into effective CAD modeling strategies that could lead to the creation of robust CAD models and enable the automation of idealization and extraction of CFD geometry. In addition, the review explored CAD/CAE interaction and pre-processing for CFD to comprehend the requirements of CFD geometries and the necessary data that must be communicated to the CAE software. Whenever necessary, the initial literature review was augmented with additional information throughout the thesis.

The literature review primarily consisted of accessing published papers, articles, and books through online databases available at Linköping University, internet, and Scania. Initially, previous theses were referred to as a basis to locate pertinent sources, and relevant
keywords were extracted from them to identify the latest information in the corresponding field. In cases where the information was still considered applicable or to ensure the usage of firsthand data, older sources were also considered.

3.1.2 Interviews

Conducting interviews is an effective method for obtaining insights about practices, experiences, and expert knowledge from a respondent [14]. The interviews had two main objectives: to gain a better understanding of Scania’s design process and to assess the effectiveness of methods used in previous theses. Furthermore, the interviews aimed to gather input from past thesis workers regarding potential areas of inclusion. Interviews also provided an opportunity for respondents to share their perspectives and ideas on specific topics.

As a part of this thesis, semi-structured interviewing approach was implemented to allow exploration of new issues. In general a guide is used in semi-structured interviews, which comprises of different questions to be asked as well as topics to be cover during interview process. Similarly, interviews at Scania a generic guide was used during the interview to make sure all questions were asked and answered. The interview guide and the answers can be seen in appendices A and B.

3.1.3 Former Thesis Works

This thesis builds upon previous research conducted at Scania on the extraction of CAD modeling for simulation-driven design. Earlier theses at Scania have carried out several studies on this topic, including one by [15] which provided the basis for this current research. Although this is the most recent thesis on the subject, the previous research focused on extracting internal volumes, splitting surfaces to aid in creating simulation-specific models, and validating the models and not from developing effective naming convention perspective. The latter is an advanced approach of implementing it on a parametric CAD model.

3.2 Method Development Stage

The method development stage, which is the central part of the case study, began with formulating objectives. The requirements from simulation engineers and design engineers were collected based on data from pre-development stage, and objectives were defined. Several approaches were considered to achieve these objectives. These approaches were implemented on a model, resulting in modifications specific to the simulation. The functionality of the resulting model was tested and discussed with the focus groups, and if it performed well, the approaches was scripted and automated independently and evaluated for effectiveness. If the model failed to meet its intended purpose, the process was repeated from the beginning, starting with formulating a new approach, execution, and evaluation. Thus, the method development stage followed an iterative process.

3.3 Implementation Stage

After collecting sufficient information from the pre-development stage and several iterations, and implementing changes in the method development stage, an automated tool was created by integrating the scripts of various methods or approaches. This marks the concluding phase of the project. The automated tool was then included in a user-friendly
graphical user interface (GUI) developed using Visual Studio, along with a comprehensive user guide that provides instructions on setting up and utilizing the tool.
4 Results: Pre-Development Stage

During the initial phase of this thesis, extensive discussions were held with the engineers from both design and simulation departments and various relevant sources were referred to gain detailed knowledge about the existing Exhaust After-treatment system (EATS). Though Scania has different silencer platforms, the focus was particularly on the work carried out with the large silencer platforms. These discussions formed the foundation for the thesis, aiming to address the design automation challenges. The collection of appropriate data and understanding user requirements were pivotal components of this study, involving regular meetings with focus groups consisting of professionals from both design and simulation departments.

As mentioned previously, Scania’s trucks and buses in the market are already equipped with the existing large silencer. However, these current large silencer only meet the EU 6 emission standards. In order to comply with the latest EU 7 emission standards, a new variant of existing large silencer needs to be developed. To achieve more stringent NOx emissions or to improvise other parameters of an existing silencer, engineers at Scania needs to come up with either a new CAD design or a modified version of an existing design, and they have to perform simulations on those newly developed/modified CAD models to find an optimal design. This design and development of EATS undergoes several iterative processes such as design modification, CFD simulation, Acoustic simulation and FEM analysis before zeroing in on one best optimal design.

Following discussions with design and simulation engineers, it has been determined that certain tasks, such as extracting internal volumes, creating watertight CAD models, and splitting large surfaces, can be easily accomplished using the CATIA CAD tool. On the other hand, tasks like generating small surfaces, removing overlapping surfaces, and creating additional surfaces are more efficiently handled in the pre-processing tool ANSA.

However, it’s worth noting that most tasks can be done in either CATIA or during CAD cleaning and pre-processing in ANSA. The main difference lies in the time required for each specific task. Design automation becomes essential here, enabling the automation of the majority of tasks directly within CATIA, as these tools will primarily serve design engineers and thus helps to streamline the process from design team to simulation team.

After examining the information collected from various discussion sessions, it has been concluded that the implementation of design automation is feasible in different stages of the workflow conducted by both design and simulation engineers. Based on this interpretation, the focus of automation lies in streamlining tasks that typically consume a significant amount of time for engineers. Specifically, the identified tasks for automation include CFD model extraction and standardizing the naming of surfaces and parameters within CAD models.

The information collected during the pre-development stage was interpreted into three requirements such as CFD model extraction, Standardising the naming of surfaces and Parameters in the CAD Model.

4.1 Interpretation 1: CFD Model Extraction

The large silencer consists of multiple parts, and not all of them come into direct contact with the hot gases from the engine. When performing CFD simulation, it is crucial to
extract only the internal surfaces of the silencer that have direct interaction with the hot gases. This extraction process focuses specifically on the surfaces that are directly exposed to the gas flow. Given the presence of different components within the silencer, such as perforated plates, substrates, and mixers etc., it becomes necessary to differentiate and treat the surfaces of these internal components with the different simulation setup. Additionally, volumes such as the inlet volume, turn volume, mixer volume, volumes between the substrates, and outlet volume need to be split and treated with appropriate simulation setup. The surfaces and the volumes created are then assigned a Part Identification (PID) in ANSA, which helps in organizing and referencing parts of the silencer during the pre-processing. By assigning PIDs to parts, the engineers can easily differentiate and manage various components within the CAD model. Each PID requires its own unique simulation setup to accurately simulate its behavior and its interactions with the hot gases. By distinguishing and treating these component surfaces differently during the simulation, a more precise analysis of the silencer’s performance can be achieved.

Extracting internal surfaces from a watertight solid CAD model in CATIA is a relatively straightforward process. However, the subsequent task of splitting these surfaces for customized treatment during CFD simulation can be time-consuming in both CATIA and ANSA. Simulation engineers often spend a significant amount of time cleaning the extracted CAD model using ANSA during the pre-processing stage to ensure its readiness for simulation. Therefore, it is crucial to explore a method that automates the extraction of internal surfaces and the subsequent splitting of internal volumes. Such an automated approach would not only save time but also improve overall process efficiency, while also reducing the potential for manual errors.

4.2 Interpretation 2: Standardising the Naming of Surfaces

The simulation engineers utilize many simulation tools, which offers a functionality to treat extracted surfaces with unique simulation setups based on predefined naming templates. By ensuring that all extracted surfaces are appropriately named, Star CCM can assign the corresponding simulation setup to each surface consistently. This automation process allows for a uniform treatment of all surfaces that are created during the pre-processing of CAD models. Consequently, regardless of the simulation engineer or the number of times the simulation is performed, the obtained results will remain consistent.

Currently, the design engineers assign their own chosen names to the surfaces they create in the CAD models, which are then handed over to the simulation engineers. Upon receiving these CAD models, the simulation engineers perform CAD cleaning and generate additional surfaces needed for the CFD simulation during the pre-processing. However, they rename all the surfaces according to their own preferences. Moreover, there are slight variations in the simulation setups employed by different simulation engineers. Consequently, these factors contribute to differences in the simulation results obtained. After the discussion sessions with the focus group, it is understood that the absence of standard naming convention is the cause for naming the extracted surfaces randomly which is also affects the simulation results. Thus the interpretation reveals a strong need to establish a naming system and implement it into the work flow. Such an implementation would standardise the naming of the surfaces for simulation, ensuring consistent results regardless of simulation engineer involved, it would save considerable amount of time for the simulation engineers during pre-processing by eliminating the need to create simulation setups for each individual surfaces and to analyze the simulation results during post-processing as well.
4.3 Interpretation 3: Parameters in the CAD Model

CAD design modifications can be accomplished through two approaches: by making complex changes to the CAD geometry such as adding a new part, removing the existing part and by adjusting parameter values. Parameterization of a CAD design proves beneficial when engineers need to generate a large number of design experiments (DOE) to simulate the performance of the silencer model with various parameter values. In cases where complex changes are necessary in the CAD geometry, simulation engineers must liaise with the design engineers to carry out the required modifications. Presently, even simple changes in parameter values must be executed by the design engineers, as most simulation engineers may not possess the necessary familiarity to make such changes in CATIA.

Furthermore, whenever there are modifications in the CAD design, the internal volumes of the silencer need to be extracted to accommodate the changes if they are performed in CATIA. To address these challenges, it is worthwhile to create parameters that allow simulation engineers to independently perform simple and essential changes. However, due to the complexity of the large silencer system and time limitations for completing the thesis work, developing a comprehensive parametric model is not feasible. It is also worth to note that this will not be the main focus of this thesis work, as the changes required by the simulation engineers are often very less and the modified part can independently integrated into the existing cleaned CAD model in the ANSA tool, but at the same time it is very handy to have this tool if in case there exist a parameters in the CAD model and the simulation engineers are in need of creating more DOEs. Consequently, after discussions with the focus group, it was interpreted and understood that a tool with a user-friendly graphical interface (GUI) could be developed. This tool would retrieve existing parameters from the CAD model, provide an option to modify parameter values using the same interface, and allow for saving the CAD files in .STL format in order to export them into ANSA.
5 Results: Method Development Stage

The method development is the core part of this thesis. This stage explains in detail the formulation of the objectives to achieve effective CAD models, the approach utilized, how the approach was executed by scripting methods and logic used, and finally evaluation of the developed method.

5.1 Objective

During the initial stage, also known as stage 1 or the pre-development stage, the collected data underwent analysis to establish a foundation for finding the optimal solution to the given problem. This involved breaking down the development stage into smaller iterative processes aimed at exploring different methods to reduce manual processes in CATIA and develop an efficient automated process.

![Development stage general workflow](image)

**Figure 5: Development stage general workflow**
Throughout the development stage, a general workflow was followed, as depicted in figure 5. The workflow began by employing a simple and manual approach in CATIA, utilizing various available operations and functions. Subsequently, the approach was discussed with simulation and design engineers to gather feedback and identify areas for improvement. If the results were unsatisfactory, the process would be repeated. Next, the model was checked in ANSA for functionality, and if it did not meet the intended criteria, an alternative approach was undertaken. This initial process looped through several iterations until a functional approach was achieved.

Once positive feedback from the engineers and a successful geometry check in ANSA were obtained, the manual approach was automated using scripting in Visual Studio (VB.NET). The script was then tested on the actual model. If the model performed as intended, it was further verified for functionality in ANSA. If the results were satisfactory, the script was refined to ensure robustness and eliminate errors. This iterative workflow loop was generally employed for parameterization and the extraction and splitting of the fluid region. However, for the naming convention, the overall workflow remained the same, but with reduced time spent in CATIA and increased emphasis on scripting.

The following section outlines the CAD model requirements for the corresponding simulations.

5.1.1 Requirements for extraction and splitting of fluid region

The below figure 6a represents the CAD model of Large silencer platform EATS. Figure 6b represents the fluid region where the exhaust gases come in contact with the inner surface, which is the main requirement for the simulation engineers to perform CFD simulations. This model consists of multiple surfaces and is colored uniquely. If required the geometries will be modified or simplified in ANSA to avoid irregularities formed which can be easily solved in ANSA compared to CATIA.
5.1.2 Requirements for naming convention

To streamline CFD simulations, a specific naming system is necessary for the extracted surfaces. These surfaces are handled differently by simulation engineers. Figure 7a demonstrates surfaces named based on the designer’s assumption, while figure 7b showcases surfaces named to meet simulation-specific requirements. Currently, simulation engineers have to rename all surfaces whenever new models are received from the designers. By adopting simulation-specific naming as shown in figure 7b from the designer’s side, the pre-processing time can be significantly reduced.

![Figure 7: Naming convention for simulation](image)

(a) Assigned names from designers  
(b) Required names for simulation

5.1.3 Requirements for fetching the Parameters from CAD model

The process of parameterizing a CAD design becomes advantageous when engineers require the generation of a significant number of design experiments (DOE). This parameterization enables the simulation of the silencer model’s performance with diverse values for the parameters. The tool which will be developed is primarily to fetch the available parameters from the CAD model. Hence, it is necessary to parameterize the CAD model by generating corresponding parameters, similar to the example depicted in Figure 8.

![Figure 8: Parameters in a CAD Model](image)

5.2 Approach

In this section, the selected approach by the authors after several iterations performed as described in section 5.1 is explained in detail. This section is divided into 3 parts, part 1 mainly focuses on the approach for parameterization, part 2 focuses on the approach for extraction and splitting of the fluid region, and the last part focuses on the approach for naming convention.
5.2.1 Approach for extraction of internal volumes/fluid region

During the initial stages of development, two different methods were analyzed and discussed for extracting the fluid region. The first method involved converting the .CATProduct file to .CATPart using the "Generate .CATPart from Product" function in CATIA. Since the silencer were designed and developed in the product file, this process was relatively simple and widely used by most designers in Scania. The second method explored was the development of a generic surface parametric model with a less complex design, where all the parameters would be linked to the surfaces. This would enable the generation of Design of Experiments (DOEs) for simulations and facilitate multi-disciplinary design optimization by assigning lower and upper bounds to these parameters. Considering that the large silencer platform EATS was still under development, the second method was deemed unfeasible for utilization in this project. Therefore, the first approach was considered more feasible and can be easily implementable for other silencer as well. The details of the approach for the extraction and splitting of surfaces will be explained in the subsequent sections.

5.2.1.1 Extraction of internal volumes/fluid region

Typically the extraction of the surface begins by converting the .CATProduct to .CATPart. This converts all the part bodies in the product file into a .CATPart consisting of multiple part bodies in it. All these part bodies are combined to a single part body excluding the substrate part bodies using the boolean add operation in CATIA. The substrate part bodies are excluded as it becomes difficult to extract the internal volume. By doing this eliminates all the intersection and surface combining between different bodies. Once the part bodies are combined, the next step is to extract the complete surface the boolean added part body with "Extract" built-in function in CATIA. This extraction mainly consists of two different surfaces, one on the outside and one on the inside (i.e., the fluid region required for simulation). In order to get the internal volume, the extracted surface is disassembled by domain with the built in function in CATIA. The disassemble by domain is executed based on the volume of the surface and generally the second surface is the second largest volume which is the internal volume required. Figure 9 illustrates the internal volume extracted in CATIA.
5.2.1.2 Splitting of extracted surfaces

The ideal requirement from the simulation engineers is to receive the geometries by splitting the extracted internal surface based on the intersecting between the substrates and the extracted internal volume. To accomplish this splitting of extracted surface begins by solid filling the extracted internal volume using "Close Surface" function in CATIA as shown in figure [10a]. Next, the substrate part bodies are boolean removed to the solid filled part body which creates cavity of the substrate. As it can be seen from the figure [10b] after boolean removing the substrate the cavities are formed.

![Solid fill for extracted internal volume](image1.png) ![Boolean removed by substrates](image2.png)

Figure 10: Cavity formation based on substrates

The extraction of the boolean removed part body is performed. With this extraction, new surface at the cavity is formed at the place of substrate. Now, the disassemble by domain is performed again, which creates split surfaces based on the substrates. However, this approach of extracting and splitting of surfaces creates an overlap at every inlet and outlet of substrate surfaces as shown in figure [11].
Essentially for the simulation engineers it required to have 3 different surfaces consisting of inlet of substrate, substrate body and outlet of the substrate. In order to overcome the overlapping of surfaces as illustrated in figure 11 an approach was formed in the following sections.

5.2.1.3 Removing of overlapping surfaces

The below figure 12 illustrates the flow chart for the developed approach to overcome the overlapping of surfaces.

![Flow chart for removing overlapping surfaces](image)

This approach begins by joining all the extracted surfaces without the substrates called Join 1 and joining all the extracted surfaces of the substrates called as Join2. Then a split operation (Split 1) is performed in which the element to cut is Join 1 and cutting element is...
Join 2. Then the boundary (Boundary) function is executed on the Split 1 which generates the circular profile on every intersecting path on the substrate. Now that the boundaries are extracted, it becomes easier to perform 3 more split operations, eventually removing the overlapping surfaces. The first split operation (Split 2) is executed in which the element to cut is the Join 2 and the cutting element is the Boundary. The second split operation (Split 3.1) is executed in which the element to cut is Join 1 and cutting element is the Boundary. The final split operation is similar to Split 3.1, only the direction of split is changed. The results of Split 2, Split 3.1 and Split 3.2 is shown in figure 13. Finally all the three splits are disassembled by domain, resulting in the extracting and splitting of fluid region.

![Figure 13: Required simulation-specific extracted surfaces](image)

5.2.1.4 Applying unique color

The final step is to color all the surfaces uniquely after the disassemble by domain is performed. This helps the simulation engineers to visualize different surfaces when opened in ANSA. Figure 14 shows the final result of the extraction and splitting of the fluid region.

![Figure 14: Final Model](image)
5.2.2 Approach for naming convention

The naming convention generally refers to all the information included in the extracted surface model, as the simulation solver is scripted accordingly to automatically perform meshing operations and subsequently apply boundary conditions based on the assigned name. Hence, it is very important for the names to be exactly correct before sending them to simulation solvers. As described in section 5.1.2, the current process is highly repetitive and higher pre-processing time. Typically, simulation-specific names involve complex jargon, making it challenging for designers to comprehend. These names are separated by underscores. For example, if the first name is ”Scania,” the second name is ”Large Silencer,” and the third name is ”SCR 1,” the simulation-specific name would be ”scn_lrg_scr1.”

During the pre-development stage, several approaches were analyzed and discussed for their functionality. The authors decide on the final approach which is more feasible. In this approach, the method development is mostly performed by scripting in Visual Studio and less amount of work in CATIA. Eventually, it begins by pre-defining an HTML table with different versions. This table contains all the required information for any particular CFD simulation since the names and the approach for naming vary from one simulation engineer to another. These data from the HTML table will be accessed and a user-friendly interface will be dynamically generated to assign names to the surfaces. This process will be explained in detail in later stages.

5.2.2.1 Pre-defining HTML table

A simple HTML table (Link: https://nxps.sdocs.net/nxps_stl/versions.html) was created consisting of all the version type and every version type includes all the required information in the form of a table. These tables will be created by the simulation engineers every time when a new version is needed. For instance, if the naming is done on a Large silencer model then a version specific to it can be created. Figure 15 shows the list of version type and figure 16 represents the table for a particular version type.

![Figure 15: Naming convention versions](image-url)
As it can be seen from figure 16 it mainly consists of 5 columns. The first column contains the question type which is the script-specific requirement, if it is a DropDown the script creates a drop down command, and if it is FreeText it creates a textbox. The second column includes the questions for the user to read and understand. The third column consists of all the options required to be included in the DropDown and these options are the actual names that the user answers. The fourth column consists of the encoding names or the jargon that are specific to the simulation and these names are listed in the same order as listed in the third column. The last column is used to assign a default value for the drop down or textbox command. It is worth noting that the naming convention is currently in the initial development phase, and the number of columns in the HTML table can be adjusted for improved functionality if necessary.

5.2.2.2 Dynamically generating questions in user interface

The approach for generating questions in the interface is executed by accessing the data from the HTML table, based on the version type and the script automatically creates drop down and textbox in the user interface. Figure 17 shows an example of dynamically generated question from the table data as depicted in figure 16.

As the questions are generated dynamically, the user can easily answer the question by selecting the available options in the drop down and entering the text in textbox. For instance, if the user answers all the question as shown in the figure 17 the final result will be "v00a_scn_cs1_e3_evp". This name will be automatically assigned based on the selected answers.
5.2.2.3 Transferring names to CATIA

The process of transferring begins by creating a duplicate of the actual geometrical set (this geometrical set is one which contains all the surfaces that needs to be renamed accordingly) and pasting all the surfaces within the geometrical set as result with link in CATIA. Once, all the naming convention is executed successfully the script automatically transfers the name to duplicated geometrical set in CATIA. Figure 18a & 18b shows an example of before and after transferring simulation specific names in CATIA. These surfaces in figure 18b can be exported to STL file format.

5.2.3 Approach for fetching parameters from CAD model

The approach followed is to extract all the parameters from the CAD part and parsing them to the user form where the user can modify the values of the parameters of interest and update the CAD part consequently. Figure 19 shows the steps followed in order to fetch the parameter values from a CAD model, as the first step would be to have a parametric CAD model and then fetching the parameters from that CAD model, in which the parameter values will be modified in the next step and in the final step the CAD part will be updated to visualize the changes that are made and to save the CAD file in .STL format.

5.3 Execution

In this section the outline of the approach developed for the realization of design automation and illustrates the seamless flow of data across various modules, ensuring the successful execution of the vb.net script.

5.3.1 Automation of extraction of internal volumes/fluid region

The figure 20 below illustrates the method or the final approach for extraction and splitting of internal volume/fluid region on the EATS.
This workflow begins with the user opening the silencer CAD model and performing visual checks on the model, as it is required for the model to be watertight from the inside in order for the script to execute successfully. Then the user needs to convert the product file to a part file with the CATIA built-in function.

Now, the user begins by plugging both the inlet and the outlet of the model if not already plugged. To plug the inlet, the user selects a closed curve (single or multiple curves) and the script automatically creates an extract, extrapolates and thick surface is added to it. For plugging the outlet, the method is similar to plugging the inlet. Refer to Appendix C for instructions. In case if the model is already plugged from the inlet and outlet before, the user can directly follow the below procedure. Now that the model is plugged at the inlet and outlet, and sealed from the inside. Next, the user needs to select all the substrate part bodies. Refer Appendix C for instructions on how to select the substrate part bodies. After the substrates part bodies are selected, the script automatically boolean adds all the part bodies excluding the substrates. The script then performs consecutive operations of extraction of internal volume, disassembling by domain, splitting of extracted surface and finally coloring of extracted surfaces as described in section 5.2.1. All the extracted surfaces will be appended in a newly created geometrical set. Figure 21 below represents the basic overview of steps in execution for extraction and splitting internal volume.
5.3.2 Automation for naming convention

![Diagram of the final execution workflow for naming convention]

The method or the final approach developed, along with their execution order, to achieve the naming convention for CFD models is illustrated in Figure 22. Initially, the user opens the silencer CAD model, which comprises all the surfaces (PIDs) to be named, within a geometrical set. The process outlined in section 5.2.2.1 explains the naming convention version, assuming that the user is familiar with selecting the version type. Subsequently, the user chooses the version type, and the script searches the HTML web page for the corresponding version name. For instructions to select the geometrical set and version type refer to Appendix C. The table data linked to the version name is accessed and stored in a database, leading to the dynamic generation of a user-friendly GUI. Figure 17 showcases the resulting GUI, which encompasses all the relevant questions.

Next, the script duplicates the selected geometric set in CATIA and pastes all the surfaces as result with link in order to avoid link breakage. For the user to better visualize the surfaces, the script automatically captures images of all the surfaces in the selected geometrical set.

As the process above explained is executed successfully, then a fully executable GUI is displayed and now the user needs to assign simulation-specific names to the corresponding surfaces by selecting. The steps followed to perform the naming of surfaces (PIDs) are shown in figure 23. There can be "n" number of questions to answer and surfaces to select as shown in figure 23. The user begins by selecting the surfaces to name in step 1, answers all the questions specific to the selected surface in step 2, and the assigned named is displayed in step 3.
Further, the script stores all the assigned names to a data set and all the names will be transferred to CATIA resulting in simulation-specific named surfaces.

### 5.3.3 Automation of Fetching Parameters from CAD model

The automation the fetching of parameters from the CAD part is simple and straightforward. In CAD models, parameters can be generated in two ways: either directly under the Parameter node in the CATIA specification tree or within different parameter sets. The tool should be capable of retrieving both the direct parameters under the parameter node and the parameters within parameter sets. Once all the parameters are obtained within the user interface, users can input new values for these parameters, which will subsequently update the CAD part accordingly by a click of a button. Additionally, it should be possible to export the modified part as an .STL file after the CAD part has been updated. From Figure 24, the image(a) represents the parameter sets and the parameters that are available within the CAD model. The tool will fetch all the parameter set in the user form which is represented in image(b) and upon selection of the parameter set, the direct parameters under the selected parameter set should displayed in a separate user form which is represented in image(c). The user form with all parameters is where the user will be able to enter parameter values and update the CAD part and optionally saving the CAD part as .STL file.
5.4 Evaluation

Prior to considering the developed methods as a tool, it is essential to test the efficiency of the resultant models and the extent to which the models fulfill the intended requirement. Consequently, all the methods developed were tested, evaluated, and explained in detail in this section.

5.4.1 Geometry Check using ANSA

In order to send the geometry to Star-CCM+ or OpenFOAM, it is necessary for all checks to pass. The figure 25 represents the geometry check performed on the surfaces extracted using the tool developed during the course of this thesis work. All the geometry checks such as Unchecked faces, collapsed cons, Needle faces, overlap faces, cracked faces needs to be passed (indicated by a green tick), except triple cons. Commonly, the failing checks, such as needle faces or unchecked faces, are relatively straightforward to address, and the pre-processor tool ANSA can often automatically fix them.

Figure 25: Geometry check in ANSA
However, the most challenging issues to resolve are the penetrations: intersections. Typically, these require manual intervention to rectify. Addressing these cases may involve performing manual adjustments or modifications to eliminate the penetrations and ensure a valid geometry for simulation in Star-CCM+. The figure 26 is an example of faces with intersection, indicated by the white border. Cleaning such intersections in CATIA is not a straightforward or automated process. Hence, the simulation engineers need to spend some time of around 20 minutes to make this CAD model ready for CFD simulation.

Figure 26: Penetration : Intersection Check in ANSA

5.4.2 Simulation using OpenFOAM

As a proof of concept, a basic back pressure simulation was conducted in OpenFOAM using a CAD model extracted through the developed tool, with surfaces appropriately named using the naming convention tool.

Figure 27: Meshed Housing of a Large Silencer

The figure 27 shows the meshed housing of a large silencer with a mesh value of 2mm
derived from the specific simulation setup corresponding to the surface named according to the proposed naming convention.

![Figure 28: Meshed Perforated Plate of a Large Silencer](image1)

The figure 28 below displays the meshed perforated plate of a large silencer with a mesh value of 1mm obtained from the specific simulation setup corresponding to the surface named according to the proposed naming convention.

The presented figures clearly demonstrate that the surfaces extracted and appropriately named are treated as distinct entities within the simulation software as indented. This differentiation is evident through the use of different PIDs and their corresponding names and the figure 29 represents the streamlines of the back pressure simulation which helps the simulation engineer to visualize and gain insights into the distribution and intensity of the fluid velocity.

![Figure 29: Streamlines of Back Pressure Simulation](image2)
6 Results: Implementation Stage

This section explains the developed user-friendly GUI tools, the buttons included and all other toolbars. For more information on steps to use refer to Appendix C

6.1 GUI for extraction and splitting of internal volume

Figure 30 shows the visual studio developed GUI consisting of several buttons responsible for performing the extraction and splitting of internal volume. A proper work follow is maintained from step 1 to step 3 to successfully execute the script. Also, the GUI includes a short description of the included button for the user to easily understand.

![Figure 30: GUI for extraction and splitting of internal volume](image)

In step 1 the **Inlet Port** button is used to plug the inlet of the EATS and after the inlet is plugged the script boolean adds the part body. Similar in step 2 the **Outlet Port** button is used to plug the outlet of the EATS. However, any of these buttons can be utilized to plug other holes or gaps in the model to make it watertight from the inside. Now that the model is fully sealed and to extract the internal volume the user clicks on the **Extract Fluid Region** button. Then the user selects all the substrate part bodies and clicks on the finish button in CATIA. For more information regarding the steps involved in selecting the substrate part bodies refer to Appendix C Further, the script extracts and splits the internal volume as shown in figure 14. The link at the bottom left of the GUI **Link for User Guide** can be used to open the user guide. Since there are fewer manual inputs required from the user, the GUI contains only 3 buttons to execute the script.

6.2 GUI for naming convention

The developed tool for effective naming convention mainly consists of 2 GUIs, as second GUI is executed based on the input from first GUI. GIU 1 is used to select the version type and select the geometrical set in CATIA. The GIU 2 is where the user performs the naming of the surfaces and the steps involved will be explained in detail in the later stages.
Figure 31: GUI 1 for naming convention

Figure 31 represents GUI 1. In the drop-down toolbar, the user selects the version type and all the version names included in the HTML web page as described in section 5.2.2.1 will be listed in the drop-down as shown in circular call-out in figure 31. In step 2 the selected geometrical set name will be displayed upon clicking the Next button. Then the script is processed and the GUI 2 is displayed as shown in figure 32.

Figure 32: GUI 2 for naming convention

The GUI can be mainly divided into 3 sections as shown in figure 32. The sections are described as follows:
**Section 1:** Here all the question from the selected version is dynamically generated. The user directly answers the question based on the command toolbar.

**Section 2:** In this section all the surfaces in the selected geometrical set are listed with the actual name existing in CATIA. The user can easily select the desired surface to assign name.

**Section 3:** This part of the GUI 2 is used for only visualizing the selected surface. Upon selecting the surface from section 2, the script displays the corresponding surface in isometric and multi-section view as shown in figure.

The **Default Value** button can be used if the user wants to change the default value of the answers in the command toolbar. In order to assign the simulation-specific name to the selected surface click on the **Assign Name Button**. To transfer the names to CATIA after all the surfaces are assigned uniquely to all surfaces click on the **Transfer Name** button. After all the names are transferred to CATIA the **Save as STL** button will be enabled. By clicking on this button all the surfaces will be combined into a single STL file. In certain cases, multiple surfaces can have the same names irrespective of the question command in section 1. Then the user can uncheck the **Strict Mode** checkbox and the script appends a sequential number to the end of the name which is duplicate. Finally, the user can view the user guide by clicking on the **Link for User Guide**. For more instruction regarding steps to select and assign names refer to Appendix C.

### 6.3 GUI for Fetching Parameters from the CAD Model

Upon running the tool, an user interface with the list box and a button to extract the parameter sets will show up. As step 1, the user needs to click on the 'Get Parameters' button to retrieve all the parameter sets from CATIA. Step 2 would be choose the parameter set. After choosing the specific parameter set, the parameters under the selected parameter set will show up in the new user form where the parameters will be listed with the existing and new value information. Step 4 and 5 would be to update the CAD part and save it as .STL file. An example of the steps that needs to be followed by the user is shown if Figure 33.

(a) Parameters under Parameter Set : Substrate

(b) Parameters under Parameter Set : Parameters

**Figure 33:** GUI for Fetching Parameters
The Figure 34 below is an example how the specification tree looks before and after performing the changes using the tool. Here in this example, three highlighted parameter values are modified.

(a) Parameters before change

(b) Parameters after change

Figure 34: Modifying Parameter values in CATIA
7 Discussion

7.1 Thesis Methodology

The thesis methodology was set up with three distinct phases namely pre-development, method development and implementation. The pre-development phase initiated by conducting a literature study, focusing on design automation and CAD interaction, particularly in the context of CFD simulation. Extensive study was carried out on Scania’s Exhaust After-treatment System (EATS) to gain better understanding about the system in order to explore the opportunities of design automation. To gain knowledge about the current process employed by Scania, many interviews were conducted with both design engineers and simulation engineers. The interviews served as a platform to gather information about the current challenges faced by the engineers and to impart knowledge from professionals who are having hands on experience with the design and development of Scania EATS. Interviews also provided an opportunity for respondents to share their perspectives and ideas on specific topics. Additionally, the interviews provided an opportunity for respondents to share their perspectives and ideas on specific topics. The pre-development phase also involved reviewing previous thesis work to gain further insight into design automation approaches and assist in organizing the plan for the current thesis work.

During the method development phase, various approaches were considered and discussed with a focus group consisting of design and simulation engineers. Their feedback played a crucial role in refining the methods and determining the most effective way to proceed with the thesis work. The final part of the methodology involved in automating the identified methods from the development phase. Graphical user interfaces (GUIs) were developed and tested for functionality. Furthermore, based on feedback from design engineers, the GUIs were modified and made more user-friendly.

7.2 Simulation Specific CAD Model Extraction

The initial phase of the CAD model extraction for simulation involved exploring existing methods and identifying time-consuming and iterative manual tasks that could be automated. While extracting the internal volume as a whole presented fewer challenges, automating the process of splitting the volume into different surfaces and volumes proved to be quite difficult. The last obstacle in automating the CAD model extraction was dealing with overlapping surfaces. Through various discussions with different design engineers, a method was developed to address the surface splitting and removal of overlapping surfaces. Although this surface extraction method primarily focuses on large silencer platforms, it can be adapted for implementation across all silencer platforms with minor adjustments to the developed method. By implementing this method, not only will it save time, but it will also enhance the efficiency of engineers at Scania, enabling them to explore a larger design space and find optimal solutions for the EATS.

7.3 Naming Convention

The naming convention is an unfamiliar aspect for Scania’s design and simulation teams. As this is a new process being implemented into the workflow, there was limited knowledge on how to proceed. Consequently, the development of a tool to manage the naming of extracted surfaces presented unforeseen challenges. These challenges included determining the format of the names, handling different versions, and naming CAD models for various
silencer platforms. Creating surface names that incorporate relevant information for the simulation setup and devise an effective naming method proved to be a challenging task. However, through multiple discussion sessions and feedback from Scania’s engineers, an approach was developed, and a tool to handle surface naming was created. The graphical user interface (GUI) was designed in a manner that avoids storing any knowledge within the tool itself. Instead, it retrieves data from an HTML table and processes the information to generate the desired output.

By adopting this approach, the tool maintains its versatility in accommodating both current and future requirements related to the naming conventions of different silencer models. By simply modifying the table data, the tool can adapt to future needs and ensure efficient handling of naming conventions for different silencer models.

7.4 Parameters in the CAD Models

In addition to the main objectives of the thesis work, Scania also expressed the need for a graphical user interface (GUI) to manipulate parameters. However, this requirement was not given significant emphasis during the course of this thesis. Presently, none of the silencer CAD models are parameterized due to the complexities associated with creating parametric CAD models for the intricate geometry of the Exhaust After-treatment System (EATS). This tool was developed to work with any CAD part and extract the available parameters. The purpose of this tool is to assist simulation engineers who may not have prior experience working with CATIA, enabling them to create a large number of Design of Experiments (DOEs). Furthermore, the tool’s capabilities can be enhanced by enabling it to handle a range of values for the parameters, thus providing greater flexibility for generating DOEs.

7.5 Version Handling of Scripts using Gitlab

During the course of this thesis work, the management of script versions was demonstrated using GitLab. Currently, Scania’s scripts are stored as macros within Excel workbooks, making it challenging for engineers to access and further develop the tools. To address this issue, the Visual Studio scripts developed in this thesis work were stored in a GitLab repository. This repository will be accessible to engineers at Scania in the future, providing a centralized location for the scripts. Furthermore, this allows for the continued development and adaptation of the tools to accommodate future changes as needed.
8 Conclusion

RQ1: What are the challenges with current process and limitations of design automation for generating the simulation specific CAD models of EATS and how can they be overcome?

Design automation for generating ideal CAD models for simulation possess several challenges and limitations. However, these constraints can be overcome with careful consideration and implementation of methods that are developed by taking various design automation factors into consideration.

The complexity of Exhaust After-treatment Systems (EATS) poses a significant challenge in designing automation for generating ideal CAD models. EATS consists of numerous interacting components within a compact structure, making it difficult to develop an automated method for extracting the fluid region. Additionally, in terms of software tools, the pre-processor tool ANSA allows for a relatively straightforward process of generating a new surface from a part of an extracted surface, while accomplishing the same task in CATIA proves to be considerably more challenging. Another aspect of the automation process involves splitting the extracted internal volume into different surfaces and smaller volumes to replicate regions that interact with hot gases. While the developed tool effectively handles the extraction of the internal volume as a whole and enables splitting it into various volumes and surfaces, automating the entire pre-processing task does have limitations. For example, CATIA cannot handle the removing or cleaning the faces with intersections, necessitating manual intervention from simulation engineers to obtain completely cleaned CAD models for simulation.

RQ2: What are the best ways to apply design automation techniques to reduce the lead time in pre-processing CAD models before CFD simulation?

Design automation techniques can be effectively applied to reduce the lead time during the pre-processing of CAD models before CFD simulation. By automating various manual pre-processing tasks such as model cleanup, geometry simplification, workflow integration, parametric modeling, and ensuring validation, the overall efficiency and productivity of the simulation process can be significantly improved.

The developed design automation tools can be employed to automatically clean up CAD models by removing redundant or unnecessary features, or overlaps, and ensuring watertight geometry. By speeding up the extraction process the simulation engineer can large number of simulations in a shorter time frame compared to the traditional way of extracting and cleaning up the CAD model.

RQ3: How can the naming convention of CAD models be efficiently managed to enable design automation for CFD simulations?

With the aid of the developed tool, all extracted surfaces can be named appropriately, enabling the simulation software to uniformly process all surfaces created during the pre-processing of CAD models. This single tool can be utilized to assign names to surfaces across all silencer platforms once the different versions of the HTML table are prepared, containing all the necessary data. Additionally, the tool offers a visualization feature that
allows engineers to selectively view specific parts of the CAD model while assigning names to surfaces. This visualization capability enhances accuracy and confidence, enabling engineers to verify that they are assigning the correct names to the appropriate surfaces.
9 Future Work

Extraction of CFD Models

- There is potential for further work to enable the retrieval of standard components, such as inlet pipes, outlet pipes, and others, from a database.

- In addition to generating STL files, it should be feasible to generate an "info.txt" file containing metadata such as STL bounds and other relevant information.

- The method developed to extract the internal volumes of large silencer can be tweaked a bit and utilized across all the silencer platforms.

- The extraction process is not completely automated. However, solutions can be explored further to improve the automation process of internal volume extraction and splitting.

- Further work can be dedicated to finding solutions and implementing techniques that effectively address and resolve the errors during the boolean adding of solid part bodies in CATIA.

Naming Convention

- Developed naming convention tool can be further modified to accommodate the requirements of the user in terms of functionality.
References


42
Appendix A  Interview Guide

Interview Guide (Design Engineers)

Parametric Modelling

1. Is the CAD model currently in use parameterized?
2. What factors needs to be considered when designing a parametric model?
3. How the parametric CAD model can reduce the lead time?
4. How frequently do simulation engineers request modifications to the geometry?
5. Which parts are typically easy to control through parametric design?

Design Automation

1. What is the more challenging and time consuming task while extracting the internal volume surfaces?
2. What extent the design automation is already implemented in the design process?
3. How extensively has design automation been integrated into the extraction of internal volume surfaces?
4. How does your approach vary when working with CFD, Acoustics, and FEM CAD models?

Interview Guide (Simulation Engineers)

Parametric Modelling

1. What steps do you take to modify the geometry of a CAD model when necessary?
2. Which task takes up the most time during the simulation process?
3. How long does it typically take to clean a CAD model?
4. In what ways can a parametric CAD model contribute to reducing lead time?
5. How often the change request is made to the design engineer’s to modify the geometry?

Design Automation

1. In what stages of the simulation process can design automation be incorporated?
2. To what degree has design automation been integrated into the simulation process already?
3. What is your preferred method for obtaining the CAD models you need?
4. What file format do you prefer for obtaining the CAD models you require?

Naming Convention

1. Does Scania adhere to a specific naming convention as a standard practice?
2. How does having a naming convention benefit the simulation process?
3. What is the estimated time required to set up names for the surfaces during the pre-processing stage?
4. Is it likely that the surface names will be modified at any point in the future?
Appendix B  Interview Results

Interview Results (Design Engineers)

Parametric Modelling

1. Is the CAD model currently in use parameterized?
The current CAD models are not parameterized due to the complexity of the geometry which makes it more difficult to have a robust model. CAD models with complex shapes, such as organic or free-form surfaces, can be difficult to parameterize effectively. This is because the number of parameters required to describe the geometry accurately can be very high, and this can lead to a large number of constraints and equations that must be satisfied simultaneously. As a result, the parametric model may not be robust, and small changes to the geometry can result in significant changes to the parameter values, making it challenging to control and modify the model.

2. What factors needs to be considered when designing a parametric model?
When designing a parametric model, there are several factors that need to be considered, including: 1. Purpose and Scope, 2. Parameters, 3. Data, 4. Validation and Testing, 5. Flexibility, 6. Complexity and 7. Documentation.

3. How the parametric CAD model can reduce the lead time?
Parametric CAD modeling can reduce lead time in the design process by facilitating faster design changes, automating design iterations, improving collaboration, providing more accurate predictions, and reducing errors and rework. Moreover, parametric CAD modeling can allow individuals with less experience in design to modify the geometry of the model by simply entering acceptable values, ensuring that the CAD model can be recreated successfully without errors.

4. How frequently do simulation engineers request modifications to the geometry?
The need for significant alterations to the CAD model is infrequent, as most of the time minor adjustments suffice. Geometry modifications are only requested when substantial changes are necessary to obtain more favorable feasible results in both CFD and acoustic simulations.

5. Which parts are typically easy to control through parametric design?
While complex shapes, such as organic or free-form surfaces, can be challenging to parameterize, the majority of EATS parts can be effectively parameterized.

Design Automation

1. What is the more challenging and time consuming task that is difficult to automate while extracting the internal volume surfaces?
When extracting the surfaces, the difficult task to automate is the splitting of the internal volumes appropriately for CFD and acoustic simulations.

2. What extent the design automation is already implemented in the design process?
At present, there is no design automation in place for extracting the internal volumes of a large silencer platform.

3. How extensively the design automation can be integrated into the extraction of internal volume surfaces?
Design automation can be incorporated into nearly every stage of extracting CFD and acoustic simulation models from CATIA.

4. How does CFD, Acoustics simulation models vary from each other?
For the design engineer, there is no distinction between the CFD and acoustic simulation models, as they are treated differently only for the purpose of conducting specific simulations.
Interview Result (Simulation Engineers)

Parametric Modelling

1. What steps do you take to modify the geometry of a CAD model when necessary?
   The internal volumes can be modified as required in ANSA during the pre-processing of CFD and Acoustic simulation models.

2. Which task takes up the most time during the simulation process?
   Cleaning of the simulation models in order to make them a sealed model and setting up the PIDs to mesh and treat the internal volumes differently, takes more time in the simulation process.

3. How long does it typically take to clean a CAD model?
   For the fresh CAD model, it is currently taking about a week to clean and make it ready for simulation.

4. In what ways can a parametric CAD model contribute to reducing lead time?
   Parametric model can help the simulation engineer to modify the geometry by themselves without requesting the design engineers to do the changes in the CAD models.

5. How often the change request is made to the design engineers to modify the geometry?
   The need for significant alterations to the CAD model is infrequent, as most of the time minor adjustments suffice. Geometry modifications are only requested when substantial changes are necessary to obtain more favorable feasible results in both CFD and acoustic simulations.

Design Automation

1. In what stages of the simulation process can design automation be incorporated?
   Most of the tasks such as creating PIDs as required, changing the materials properties can be automated through design automation.

2. To what degree has design automation been integrated into the simulation process already?
   At present, there is no design automation in place for pre-processing the simulation models.

3. What file format do you prefer for obtaining the CAD models you require?
   STL, IGES, STEP or a Part file.

Naming Convention

1. Does Scania adhere to a specific naming convention as a standard practice?
   At present the naming convention is not standardised in Scania, the design and simulation engineers follow their own method of naming the surfaces and the internal volumes of CAD models.

2. How does having a naming convention benefit the simulation process?
   During the simulation process, the internal volumes are treated differently as there will be change in the pressure differences in the internal volumes of the simulation models. For instance, the substrates in the EATS needs to be finely meshed in order to obtain more accurate results. The simulation tool STAR CCM is setup in such a way that it treats the internal volumes differently according to the name of the surface and the mesh size will be set according to the name of the surface. Hence, it is necessary to follow a standard names for the internal volumes in order to get rid off setting up the mesh type and size again and again for each simulation models.

3. What is the estimated time required to set up names for the surfaces during the pre-processing stage?
   The naming of surfaces will take around 10 - 15 minutes.

4. Is it likely that the surface names will be modified at any point in the future?
   Yes, there will be change in the surface names, whenever there is a major change in geometry of the CAD models as well as when the simulation engineers want to combine the surfaces as they want.
User Guide for GUI

Development of CAD models for Large Silencer Platform using Design Automation

-Master Thesis, NXPS

by

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ARUMUGAM BALAGANGADAR THILAKAR
Overview
This user guide provides instructions on how to use the features provided in the graphical user interface (GUI) tool for extraction and splitting of geometries intended for CFD simulation and the tool for effective naming convention of the extracted surfaces. These GUIs are in .exe format and could be directly accessed without any pre-installation or setup.

Tool for extraction and splitting of geometries ideal for CFD simulation
This GUI is a generalized tool used to extract the fluid region, where the exhaust gases come in contact with the inner surfaces of the exhaust aftertreatment system (EATS). The tool also splits the extracted surfaces based on substrate intersections and assigns unique colors to each split surface. Below figure 1 represents the GUI for the extraction and splitting of geometries.

Before utilizing the GUI, it is necessary to fulfill certain prerequisites and conduct a geometry check to ensure successful script execution. It is imperative to have a fully sealed or water-tight model, meaning the model should not contain any gaps or holes except for the inlet and outlet of the EATS.

And also the user needs to convert the .CATProduct to .CATPart in the case of the product file in CATIA

**Step 1:** To achieve the full extraction of the partbody the user needs to seal the inlet and outlet of the EATS, by using the Inlet Port and Outlet Port buttons from steps 1 & 2 as shown in Figure 2.

Plug Inlet:
As the user clicks on the Inlet Port button, a tool palette window is opened in CATIA. Now the user needs to select a closed curve at the inlet and click on the finish button in the tool palette as shown in Figure 3. This creates an extract of the selected closed curve and thickness is applied on both sides, finally resulting in a plugged inlet as shown in Figure 4.
In certain situations, it may be necessary to select multiple curves to obtain a closed curve for sealing the inlet. In such cases, the user should hold the control key and select multiple curves until a closed curve is chosen, and then click on the finish button.

**Plug Outlet:**

The process for sealing the outlet port of the EATS follows a similar procedure to seal the inlet port, but a different button is used to accommodate the specific requirements of the script. The user clicks on the Outlet Port button, which triggers the appearance of a tool palette window in CATIA. From there, the user selects a closed curve at the outlet and clicks on the "Finish" button, as depicted in Figure 5. This action creates an extract of the selected closed curve, and thickness is applied on both sides, resulting in a plugged outlet, as illustrated in Figure 6.

![Figure 5](image1.png) ![Figure 6](image2.png)

**Note:** In the rare case scenario, the user can also use any of these two buttons to seal any other holes or openings in the EATS model to make the model water-tight from the inside.

**Step 2:** Once the inlet and outlet ports are sealed. Click on the Extract Fluid Region button as shown in Figure 7.

![Figure 7](image3.png)

Upon clicking the button, a tool palette window appears on CATIA. Here the user needs to select all the substrates of the EATS and click on the finish button as shown in Figure 8.

![Figure 8](image4.png)

After the finish button is clicked, all partbodies are boolean added excluding the selected substrate partbodies. Then the script automatically extracts the fluid region, splitting the surfaces by intersection based on substrates and finally assigning a unique color to each extracted surface in a geometrical set named
"CFD_Surface_Extract". The outcomes before and after executing the script are depicted in Figure 9 and Figure 10, respectively.

![Figure 9](image1.png) ![Figure 10](image2.png)

**Naming Convention GUI**
This GUI is a generalized tool used to assign simulation specific names for the extracted surfaces in CATIA. This tool mainly consists of two GUls as shown in Figures 11 and 12.

![Figure 11: GUI 1 for naming convention](image3.png)

![Figure 12: GUI 2 for naming convention](image4.png)
For the GUI to execute without failing certain prerequisites or geometric checks need to be done as follows:

- The selected model needs to be .CATPart
- Only one geometrical set consisting of all the surfaces to be named needs to be selected.
- This GUI fetches data from the HTML web page (Link) to dynamically generate questions as shown in Figure 12. Hence the user needs to be aware of the version type to proceed.

**Step 1:** GUI 1 mainly consists of 3 toolbars dropdown box, a textbox, and a button. The dropdown box includes all the version types available from the HTML web page (Link), the textbox is used to only view the name of the selected geometrical set in CATIA and the Next button to proceed further. The user selects the version type from the dropdown, selects the geometrical set in CATIA, and the name is displayed in the textbox, and finally clicks on the next button. Figure 13 shows an example of GUI 1.

![Figure 13](image)

**Step 2:** As the user clicks on the Next button a message box appears instructing to "Is it the correct geometric set selected: (Name of geo set)" as shown in figure 14. Click "Yes" to proceed further or click "No" to change the version type/geo set.

![Figure 14](image)

If the user clicks the "Yes" button, the script will duplicate the geometric set. It will then paste all hybrid shapes as results, linking them, and name the geometric set with the appended name "Simulation_Specific_Name" followed by the original geometric set name. After that, it will capture images of each surface in Multi-View and Iso View modes and store them in the "C-drive/User/User ID folder/SurfaceImages" directory. If there is an existing folder in the same path, it will be deleted and a new folder with the same name will be created. Finally, the script will access the HTML web page. This process may take some time depending on the number of hybrid bodies. Throughout these processes, a progress window will appear in the background, as depicted in Figure 15.

![Figure 15](image)
Step 3: GUI 2 will be loaded after all the process is completed as shown in Figure 16.

Figure 16 is described in detail based on section number as follows:

1. Based on the version type the script dynamically generates all the questions, a dropdown box with all the input values, and a textbox, which can be seen in Figure 16 section 1.
2. This part of the window includes all the hybridshapes from the geo set selected initially. This listview mainly has 3 columns, the first column has the serial number, the second column has the actual hybridshape names and the third column is where the simulation specific names are assigned. Also, the surfaces can be selected by clicking on it as shown in Figure 16 section 2.
3. Here the user can easily visualize the selected surfaces without going back to CATIA. Upon clicking any surface from Section 2, the corresponding image will be displayed as shown in Figure 16 section 3. If the user selects more than one surface, then no image will be displayed.
4. Initially for the questions commands certain default values are assigned after loading. However, if the user wanted to change the default values, the Default Value button can be used.

Step 4: Now to assign names to the surfaces, the user needs to select the surface from listview as shown in Figure 16 section 2, answer the question in Figure 16 section 1 and finally click on the Assign Name button. Figure 17 represents the name assigned to the selected surface.

Note: The user can also select multiple surfaces and assign names to all the selected surfaces as shown in Figure 18
Step 5: Once the user has assigned unique names to all the surfaces, then the names can be transferred to CATIA by clicking on the Transfer Name button. Then a message box appears instructing "Are you satisfied with the renaming of all the surfaces?" as shown in Figure 19. Click the Yes button to transfer the names to CATIA.
Figure 20 shows before and after transferring names to CATIA.

Step 6 (Rare case scenario): In some cases, certain surfaces could have the same names with questions available. In that case, the user can uncheck the Strict Mode checkbox and click on the Transfer Name button as shown in Figure 21, by doing this a sequential number will be appended in the last with the underscore before. If the Strict Mode checkbox is checked, then all the surfaces need to have unique names.

Step 7: After all the names are transferred to CATIA, the Save as STL button gets activated. If the user wants to save as STL click on Save as STL button. Upon clicking a browser window opens as shown in Figure 22, where the user needs to select the folder to save the STL file and click OK. The script then saves all the surfaces as STL with the assigned names and also creates a new STL by combining all other STLs into one in a different folder.

Note: If the user selects the same folder to save as STL deletes the combined STL file if it exists and creates a new one with the same name.
Shortcut Keys
1. Ctrl + A – Select all the surfaces in the listview
2. Ctrl + C – Copies the assigned name
3. Ctrl + P – Pastes the copied name
4. Esc – Clears all the selected surfaces in the listview
5. Delete – Deletes the assigned names
6. Enter – Assigns the simulation specific name
7. Alt + T – Transfer names to CATIA
8. Alt + S – Save as STL

GUI 2 User Interactiveness
This section describes different cases on how the command questions vary based on the surface selection in the listview as follows:

Case 1: If there are no surface selected in the listview, then the questions in the command window displays the default value from the HTML web page unless the user has not changed the default value. Figure 23 represents case 1.

![Figure 23](image_url)

Case 2: If a surface with name assigned other than default value is selected, then the questions in the command window displays only the respective answers. Figure 24 represents case 2.
Case 3: If multiple surfaces with assigned names are selected, then the questions in the command window displays only the answers common between the selected surface and not common answers will remain blank. If the user changes any one answer for the selected surface only that name will be changed or assigned. Figure 25 represents case 3.

Case 4: If multiple surfaces selected has both assigned name and empty value, then the questions in the command window displays all answers as blank. If the user changes any one answer for the selected surface only that name will be changed or assigned. Figure 26 represents case 4.