AN OPTIMISATION OF THE AEROSPACE DESIGN PROCESS FOR FORM GENERATION AND STRUCTURAL ANALYSIS

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Abstract. The Aerospace Design Process is hindered by a lack of integration between design, analysis and manufacturing tools. This creates hand-off errors and design inefficiencies which ultimately results in a prolonged design cycle time. This research aims to address this issue by attempting to optimise the Aerospace Design Process using Parametric Design software. Parametric Design software like Rhino3D and Grasshopper3D can generate different iterations of a design within a short period of time, allowing for a greater exploration of form. User-created plugins also add additional functions to the base software; allowing for users to analyse their designs within the same software. This ultimately creates a streamlined workflow in which fewer file transfers are necessary; resulting in a shorter design cycle time. This potential will be explored by designing and analysing a series of elements with Aerospace Applications in Rhino and Grasshopper, and analyising them using finite-element analysis plugin Karamba3D. The results of the analysis will then be compared to existing analysis results to determine their accuracy and evaluate whether Karamba3D could be used as an analysis tool when designing for Aerospace Applications. Ultimately, a thorough exploration of this potential will highlight the benefits of utilising parametric design software; facilitating a greater presence of parametric design principles in the Aerospace Industry.

Keywords. FEA, Design Tool Integration, Parametric Design, Aerospace

1. Introduction: Research Motivations

Space-enabled services such as weather forecasting, GPS navigation, wireless communication and the Internet; enhance consumer’s quality of life and ultimately transform how they interact with the world and each other. In recent years, their has been an increased demand for space-enabled services, with many countries opening their own agencies; to provide services specific to their region. This has resulted in analysts stating that the value of the Global Space Industry will increase from US$345 billion in 2016 to US$1.1 trillion by 2040 (Anon., 2018). However, prevalent design issues in both aeronautics and astronautics suggests that this increased demand will be unable to be met.

The most prevalent of these issues is Design Tool Integration. A common issue in many design and engineeering disciplines, Design Tool Integration refers to the ability to transfer a file from one software to another. This interoperability is lacking in the Space Industry between design, analysis and manufacturing tools (Tam, 2004). This prolongs design cycle time, creates hand-off errors and contributes to overall design inefficiencies (Tam, 2004). In an era in which the demand for space-enabled services is increasing; this design process could not only become increasingly costly and hinder the ability of space agencies to engage in space exploration. It could also hinder the ability of consumers to gain access to new and improved space-enabled services.

This research addresses this issue by centralising the design and analysis functions of the Aerospace process within the same software. Utilising Parametric Design Software Rhino, Algorithmic Modelling Add-On Grasshopper and Finite Element Analysis (FEA) Plugin Karamba; this research highlights how Parametric Design Software can be used to optimise design and engineering processes, eliminating the need for file transfers and resulting in a shorter design cycle time. Drawing on existing designs and analysis results, this research will design and analyses a series of elements with Aerospace Applications. The new analysis results will then be compared to existing results and analysed to determine their accuracy and ultimately evaluate whether Karamba can be utilised in a professional capacity.

2. Research Aims and Objectives

The aim of this research is to address the issue of Design Tool Integration by exploring how Parametric Design Software can be used to optimise the Aerospace Design Process. Using Rhino and Grasshopper allows for an iterative design process in which users can modify a geometry by changing the parameters controlling; allowing for a greater exploration of form and function within a short period of time. Furthermore, user-created

Grasshopper plugins, add additional functions to the base software such as FEA, Form Optimisation and Form Finding; resulting a design process in which multiple stages can be centralised and performed within the same software.

Consequently, applying this software to the Aerospace Industry could address the issue of Design Tool Integration by centralising multiple stages of the design process within the same software; resulting in fewer file transfers and thus a shorter design cycle time. Accordingly, the first objective of this research is to design a series of elements with Aerospace Applications in Rhino using Grasshopper and then to analyse them using the FEA plugin Karamba. The second objective is to conduct a comparative analysis between the new analysis results and existing results to determine the accuracy of the new results; ultimately evaluate whether Karamba can be used in a professional capacity.

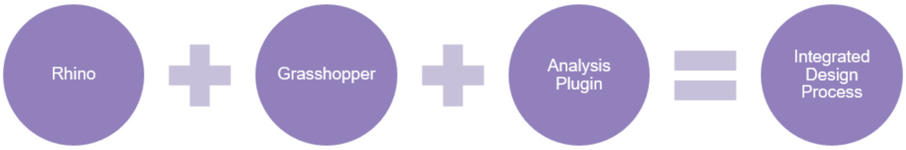

Figure 1: The Potential Design Process

3. Research Questions

This research aims to address Design Tool Integration by centralising the design and analysis functions of Aerospace Design Process using Rhino, Grasshopper and Karamba. Drawing on existing design’s and analysis results; this research will design an element with Aerospace Applications in Rhino using Grasshopper and then analyse the resultant form using Karamba. The analysis results will then be compared to existing results to determine the degree of accuracy and evaluate whether Rhino, Grasshopper and Karamba can be used in a professional capacity. Accordingly, the following research questions were formulated:

1. How can Parametric Design Software be utilised to optimise the Aerospace Design Process?
2. Can the Parametric Design Software be utilised in a professional capacity?

4. Methodology

The objectives of this research were to design and ~~analysis~~ a series of elements with Aerospace Applications using Rhino, Grasshopper and Karamba and to conduct a comparative analysis between new and existing analysis results of the same design. To address these objectives, this research utilised Stephen Kemmis's Action-Research Methodology of 'Plan', 'Action', 'Observe', 'Reflect'. Utilising the paradigm in Figure 2 (MacIssac, 1996), this research adapted the stages to suit the steps necessary to achieve the objectives of this research.

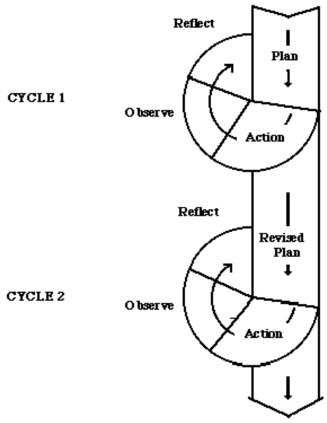

Figure 2: Stephen Kemmis's Action Research Methodology

'Plan' in this thesis involves searching and analysing finding peer-reviewed research papers to inform the design and analysis stages. These research papers will have to contain the dimensions of the element, allowing for the design of the form in Rhino using Grasshopper and the thickness, supports, loads and material properties, allowing for the analysis using Karamba and existing analysis results allowing for the comparative analysis.

'Action' involved designing the elements using the dimensions from the research paper and then analysing them using the supports, loads, material properties and thickness from the same source.

'Observe' involved comparing the new analysis results to existing results, extracted from the research paper. This comparative analysis will then be used in 'Reflect' to determine the accuracy of the new results and evaluate whether the software utilised could be used in a professional capacity. This process will then be repeated multiple times, each time with a different design and consequently, different results. Creating a series of iterations will ultimately allow this project to more effectively evaluate how Parametric Design can be used to optimise the Design Process and whether the Parametric Design Software can be used in a professional capacity.

5. Background Research

The purpose of this literature review is to outline the existing attempts to address the issue of Design Tool Integration in the Aerospace Industry. A prominent example is Vehicle Sketch Pad (VSP) (OpenVSP, 2018). VSP is a parametric aircraft geometry tool that allows the user to create a 3D model of an aircraft by combining ready-component components e.g. wings into the form of an aircraft (OpenVSP, 2018. These components can be altered by changing the variables controlling them e.g. wing span (OpenVSP, 2018). Upon creating a design, it can be analysed for Drag (wind resistance); structurally testing the model (OpenVSP, 2018). This results in a design process in which the user can create, optimise and analyse a design within the same software.

Studying and critically analysing VSP provided considerable insights on the strengths and weaknesses of the software which could be addressed in this research. The strengths of VSP are that it has effectively addressed the issue of Design Tool Integration, resulting in a streamlined design process. Another strength is that VSP can be used in aeronautics and astronautics, increasing its applications (Bauldree, 2016). The weakness of VSP is that creating custom components relies on the user having an existing knowledge of coding which has the potential to alienate uneducated users and hinder the design process (OpenVSP, 2018). Additionally, OpenVSP can only be used analyse whole models e.g. an aircraft as opposed to the individual components of a model e.g. a wing; limiting its functionality (OpenVSP, 2018). Accordingly, the gaps that can be addressed in this research project are the difficulty in creating new components and the ability to analyse individual components of a model.

There have also been several conceptual designs for tools which address the issue of Design Tool Integration. For example, the Parameter-based Comprehensive Aircraft Designer (PCAD) is an automated configuration design method and tool by Abdulaziz Azamatov, et al that aimed to realistically represent various aerospace vehicle geometries using fewer control parameters (Abdulaziz Azamatov, 2011). Drawing on elements of Parametric Design, their paper ‘Comprehensive aircraft configuration design tool for Integrated Product and Process Development’; outlined the framework for an efficient aerospace geometry design tool that allows the designer to create geometries in a step-by-step fashion using a list of predetermined components and manipulate them in real time (Abdulaziz Azamatov, 2011). The resultant forms could then be used in the conceptual and preliminary design phases (Abdulaziz Azamatov, 2011). Theoretically, this method and tool could be a part of an aerospace-related CAD package or be offered as a visualisation tool for grid generation or analysis software (Abdulaziz Azamatov, 2011).

Comparing PCAD to VSP, the main advantages both software have is the availability of step-by-step geometry creation. Whilst VSP directly addresses the issue of design tool integration by performing design and analysis; PCAD focuses primarily on improving the design stage by providing a parametric approach to geometry generation that allows for applications in conceptual and preliminary design as opposed to VSP which is purely preliminary (Abdulaziz Azamatov, 2011). Critically analysing PCAD provides insights regarding the prominence of the issue of design tool integration in the Aerospace Industry. Furthermore, it highlights the similarities between VSP and PCAD regarding the gaps both software's possess. Like VSP, creating new components requires a prerequisite knowledge of coding (Abdulaziz Azamatov, 2011). Additionally, the lack of any inbuilt analysis like VSP's drag analysis raises the question as to whether PCAD has effectively addressed design tool integration as it is understood in this research.

The Modelling and Simulation Tools for Systems Integration on Aircraft (MISSION) project is another example. The project's aim was to develop and demonstrate an integrated modelling, simulation, design and optimisation framework oriented to the Aerospace Industry (Anon., 2017). Based on the Model-Based Systems Engineering (MBSE) design approach; the framework will support the entire design, development and validation process of an aircraft, starting from conceptual aircraft-level design, towards capturing key requirements, system design, integration, validation and verification (Anon., 2017). The primary objective and motivation in this project was to achieve significant reductions in development time, cost and rework throughout the design, development and validation process (Anon., 2017). The outcome of the project at this stage is a detailed framework for an integrated toolset and a description of what each stage of the design process would comprise of (Anon., 2017). The eventual outcome is an integrated toolset which bridges the gaps between the design, analysis and manufacturing stages of the Aerospace Design Process (Anon., 2017). Whilst the development of the tool is theoretical at this stage, the development of the framework highlights prominence of design tool integration as an issue in the Aerospace Industry.

Analysing existing attempts to address the issue of Design Tool Integration provided considerable insights regarding the direction this research could take. Design Tool Integration as it is understood in this research, is the lack of interoperability between design, analysis and manufacturing tools. The attempts to address this issue have had three approaches. The first was to centralise the stages of a design process in the same software as evident through VSP. The second was to optimise a stage of the design process and develop it so it can easily integrate with other stages as evident through PCAD. The third was to design an entirely new framework which address the gaps between design, analysis and manufacturing as evident through the MISSION project. This research will address Design Tool Integration through the first approach as it most directly aligns with this research's notion of using a single software, Rhino to centralise the design and analysis stages of the Design Process.

6. Case Study

Following the approach of VSP, this research will centralise the design and analysis functions of the Aerospace Design Process in a single software. The software chosen for this research is Rhino. The open-source nature of Rhino and its addon Grasshopper, allows the creation of user-created plugins which can add additional functions to the base software such as FEA. This results in a design process in which users can design and analyse a form within the same software, resulting in a fully integrated design process between the design and analysis stages. Furthermore, using Rhino will address the gaps in VSP regarding the difficulty in creating new components and the ability to analyse the individual components of a model. Consequently, this research will conduct a case study in which a series of elements with Aerospace Applications are designed in Rhino using Grasshopper and then analysed using Karamba. Utilising Stephen Kemmis's action research methodology, this case study searched, analysed and selected peer-reviewed research papers provided they have the prerequisite information. This case study then designed the geometries in Rhino using Grasshopper, before analysing the geometry using Karamba. Specific analysis values from the research papers and the corresponding values from the Karamba analysis were extracted and used to conduct the comparative analysis.

6.1. PLAN

The 'plan' phase of the action research methodology involved searching for peer-reviewed research papers. These papers contained the design and FEA analysis results of an element with Aerospace Applications in order to conduct the design and analysis in the 'Action' stage and the comparative analysis in the 'Observe' stage. Utilising peer-reviewed journals, websites and the UNSW Library Search Engine; three articles were found with the dimensions, the material properties, the supports, the loads, the thickness and the existsing analysis results. Karamba compared to the FEA software's utilised in the Papers required different inputs. Consequently, a portion of the values were calculated manually. Furthermore, material property databases online were necessary to obtain some of the values. The following information is exactly what was used for the case study, it by no means represents the breadth of the information evident in the research papers.

6.1.1. Paper One

Paper One is “A Finite Element Method Simulation for Rocket Motor Material Selection”. Conducted by T.Kritsana, et al, the paper is a study of the mechanical properties of different materials which could potentially be used as a material for a Rocket Motor Casing (RMC) (T. Kritsana, 2014). Applying loads to a thin-wall pressure vessel using FEA, allowed the researchers to study the viability of different materials in a practical application (T. Kritsana, 2014). Analysing this paper, it was evident that the required information was available. Consequently, this research paper was chosen.

6.1.2. Paper Two

Paper Two is “Design and Analysis of Composite Rocket Motor Casing”. Conducted by G. Avinash, et al, the paper conducts a comparative analysis between an RMC, meaning it is comprised of only one material and a composite RMC (CRMC), meaning it is comprised of multiple materials (G. Avinash, 2014). Similar to Paper One, Paper Two uses FEA to apply loads to two forms; each comprised of different materials, to study their viability (G. Avinash, 2014). This research paper in addition to containing the prerequisite information, revolved around the analysis of an actual element with Aerospace Applications. Consequently, this paper was chosen.

6.1.3. Paper Three

Paper Three is “Design and Analysis of Solid Rocket Motor Casing for Aerospace Applications”. Conducted by P.Mahesh Babu, et al, the paper studies the structural viability of different materials by analysing an RMC multiple times, each time with a different material (P. Mahesh Babu, 2015). Similar to the previous papers, Paper Three uses FEA to apply loads to a single form, each time with a different material assigned (P. Mahesh Babu, 2015). The form provided in Paper Three was representative of existing RMC’s in the Aerospace Industry. This in addition to breadth of information provided regarding the dimensions of the form was why this paper was chosen.

TABLE 1. Information extracted from research papers

	Paper One	Paper Two	Paper Three
Supports	Fixed Support on both ends of Cylinder	Fixed Support at Igniter Skirt End	Fixed Support at the outer portion of the flat plate
Loads (kN/m^2)	Internal Pressure = 22000	Axial Force = 4800 Internal Pressure = 10000	Internal Pressure = 12750
Material Properties			
Material	AISI4130	HE-15 A1	Maraging Steel
Young’s Modulus (kN/cm^2)	20640	7000	21000
Shear Modulus (kN/cm^2)	8000	2692.3	7700
Yield Tensile Strength (kN/cm^2)	46	41.5	175
Specific Weight (kN/m^3)	76.93	26.46	78.67

6.2. ACTION

The ‘Action’ stage consisted of designing the three forms in Rhino using Grasshopper, using the dimensions from the research papers and analysing them using Karamba, inputting the material properties, supports, loads and thickness. The intended outcome would be analysis results for displacement, principal stress, von mises stress and utilisation.

The dimensions provided in Papers One – Three were used to create the geometries, using base components in Grasshopper. The geometries were then made into meshes, before being input into Karamba along with the supports, loads, thickness and material properties. Fortunately, inputting the form into Karamba didn’t provide any errors; allowing the geometries to be analysed using FEA. This provided the case study with the intended outcome for all three iterations.

Key analysis results from the research papers were extracted, along with corresponding values from the Karamba analysis for the purpose of the comparative analysis in the ‘Observe’ stage. Consequently, the values complied in Table 2 are by no means the full extent of the information outputted by Karamba. It is simply the only information that can be used for the purposes of a comparative analysis.

TABLE 2. Values extracted from Karamba for the Comparative Analysis

	Form One	Form Two	Form Three
Analysis Results	Principal Stress = 43.8kN/cm^2	Maximum Von Mises Stress on Casing = 203kN/cm^2	Maximum Displacement on Nozzle = 0.0313cm Maximum Stress on Shell = 52.7kN/cm^2 Maximum Stress on Fore End = 22.6kN/cm^2 Maximum Stress on Nozzle = 7.54kN/cm^2

7. Significance of Research

Designing in the Aerospace Industry is hindered by a lack of integration between design, analysis and manufacturing tools; resulting in hand-off errors, design inefficiencies and a prolonged design cycle time. Attempts to address this issue have revolved around three approaches; centralising the stages of a design process within the same software, developing a stage of the process so it can easily integrate with others and desiging an entirely new framework. This research addressed the issue through the first approach.

As evident through the case study, this research centralised the design and analysis stages of the Aerospace Design Process by desiging an element in Rhino using Grasshopper and then analysing it using Karamba. This method eliminates the needs for file transfers altogether, resulting in a shorter design cycle time. This research has shown the potential for Parametric Design Software to optimise the Aerospace Design Process. Instead of using a mixture of commercial and in-house tools for design and analysis, utilising Rhino can centralise these stages; ultimately resulting in a streamlined and efficient design process. This is aided by the Open Source nature of the Add-On Grasshopper, which allows users to create their own plugins which add additional functions to the base software.

By conducting a case study in which a element was designed and analysed using a plugin in the same software, this research encourages the adoption of Rhino and Grasshopper into the Aerospace Industry. The ability for users to create their own plugins, could ultimately result in the creation of a design process in which the majority of the stages from preliminary design to final design are centralised within the same software.

8. Evaluation of research project

The aim of this research project was to address the issue of Design Tool Integration by centralising the design and analysis stages of the Aerospace Design Process within a single software. This potential would be demonstrated by designing an element with Aerospace Applications in Rhino using Grasshopper and then analysing it using FEA plugin Karamba.

The goal of addressing Design Tool Integration, was achieved within this research. By successfully designing and analysing the geometries within the same software, this research was able to demonstrate the impact Rhino, and by extension Parametric Design Software in general; could have on the Aerospace Design Process. Centralising multiple functions within the same software can eliminate the need for file transfers, resulting in an optimised and more efficient design process. This process could be adopted into the Aerospace Industry, and further developed through the creation of additional plugins which add more functions. Given further time, a more indepth exploration of design tool integration could be conducted in which additional funcitons such as form optimisation and geometry generation are explored.

Whether or not Rhino, Grasshopper and Karamba can be used in a professional capacity will require further evaluation. Following the dimensions extracted from the research papers, the geometries were able to be created and thus analysed using Karamba. Furthermore, the ability to assign numbers sliders to a parameter of the design; allowed the form to be modified easily by simply changing the slider. Accordingly, Rhino and Grasshopper would be recommended in a professional capacity. Karamba, however, wouldn’t be recommended at this current stage. This evaluation is driven by the results from the comparative analysis in Table 3. The values in Column Four were calculated using the Percentage Error Formula. Taking into account the new and existing analysis results, the Formula provided a percentage indiciating the degree of accuracy. The smaller the percentage, the greater the accuracy of the result.

*Percentage error = | Karamba Result – Research Paper Result | / Research Paper Result * 100* (1)

As evident in column 4, the values differ greatly with the greatest degree of accuracy being 0.23% and the smallest being 514%. Accordingly, whilst Karamba can perform FEA; it’s inability to output accurate results consistently, makes it unreliable and thus not recommended as an analysis tool to be utilised in a professional capacity. However, the Open-Source nature of Grasshopper means that the potential exists for the plugin to be modified to provide accurate results or for an entirely plugin to be created which can output results with greater accuracy.

Consequently, whilst Karamba can't be utilised in a professional capacity; Rhino and Grasshopper can be meaning that the notion of using Rhino, Grasshopper and a plugin which adds additional functions to address Design Tool Integration and centralising the design process is still valid.

TABLE 3. Comparative Analysis between Reserch Paper Results and New Results

	Research Paper Reseults	Karamba Results	Accuracy of Karamba Results (%)
Paper One			
Principal Stress (kN/cm^2)	43.9	43.8	0.23
Paper Two			
Maximum Von-Mises Stress on Casing (kN/cm^2)	47.773	203	76.5
Paper Three			
Maximum Displacement on Nozzle (cm)	0.00509	0.0313	514
Maximum Stress on Shell (kN/cm^2)	50.4	52.7	4.6
Maximum Stress on Fore End (kN/cm^2)	25.3	22.6	10.7
Maximum Stress on Nozzle (kN/cm^2)	113	7.54	93.3

9. Conclusion

Design Tool Integration in the Aerospace Industry is an issue that is becoming increasingly relevant due to the increased demand for space-enabled services. To address this issue, this research explored the potential for Parametric Design Software, in particular Rhino to be utilised in the Aerospace Industry. This was driven by the open-source nature of the software which allowed users to create addons like Grasshopper and plugins like Karamba which add additional functions to the base software. Utilising this software to address Design Tool Integration; this research explored how Rhino, Grasshopper and Karamba could be used to centralise the Design and

Analysis stages of the Aerospace Design Process. This was successful as the design was able to be modelled and analysed in the same, single software. If this research were to be taken further, additional stages of the design process could be incorporated into the Rhino platform such as form optimisation and geometry generation, resulting in a more integrated workflow. Ultimately, this research not only encourages the adoption of Parametric Design to the Aerospace Industry. It also raises awareness amongst architects and computational designers about the potential impact their skills and softwares may have in another industry. Perhaps, one day, more industries will incorporate Parametric Design principles and software in their workflows.

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Appendix A: Design and Analysis of Geometries

Figure 3: Design and Analysis of Geometry from Form One

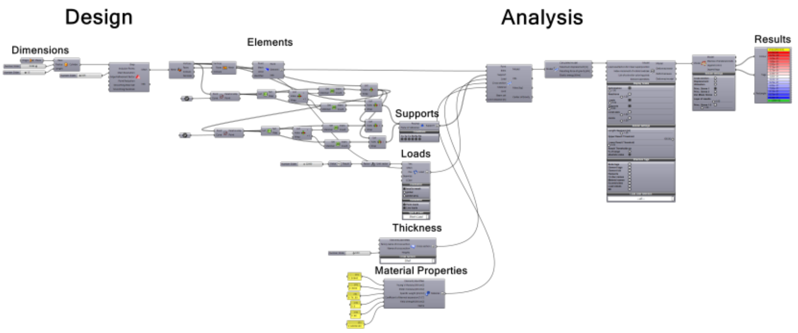


Figure 4: Design and Analysis of Geometry from Form Two

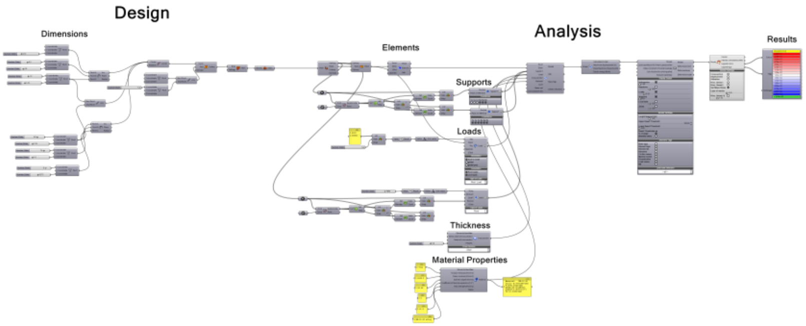
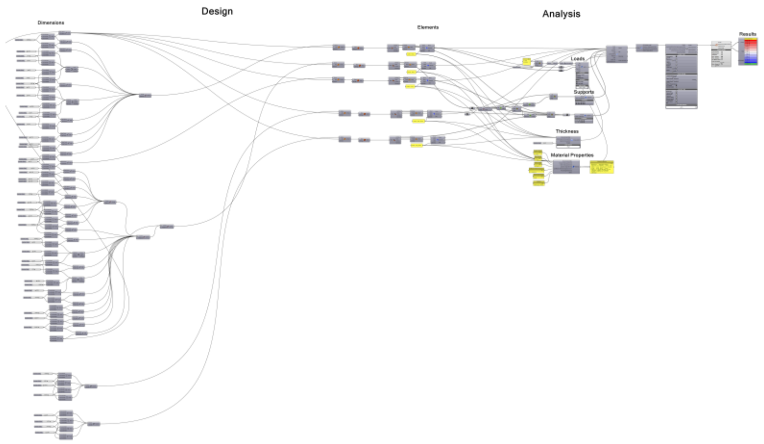


Figure 5: Design and Analysis of Geometry from Form Three



Appendix B: Analysis Results

Figure 6: Principal Stress of Form from Paper One

Figure 7: Corresponding Analysis Results from Karamba

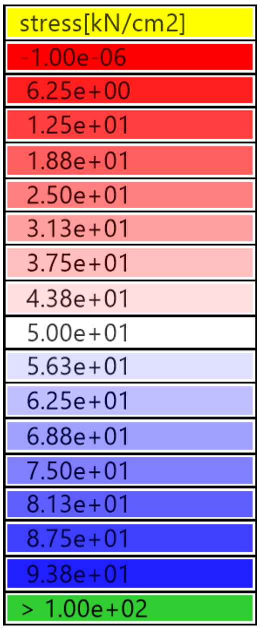


Figure 8: Von Mises Stress of Form from Paper Two

Figure 9: Corresponding Analysis Results from Karamba

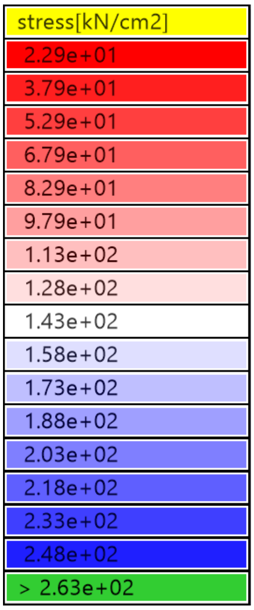


Figure 10: Displacement of Form from Paper Three

Figure 11: Corresponding Analysis Results from Karamba

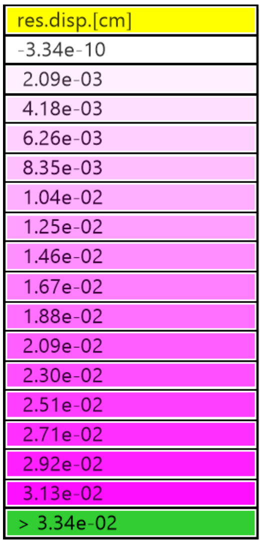
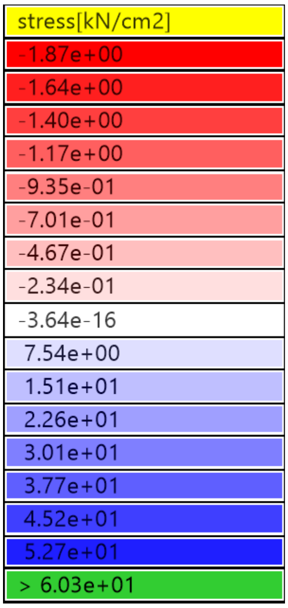


Figure 12: Principal Stress of Form from Paper Three

Figure 13: Corresponding Analysis Results from Karamba



Appendix C: Dimensions of the Form

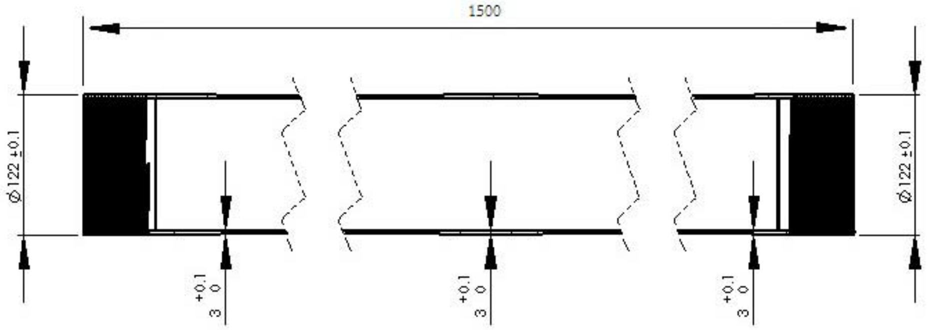


Figure 14: Dimensions of Form One

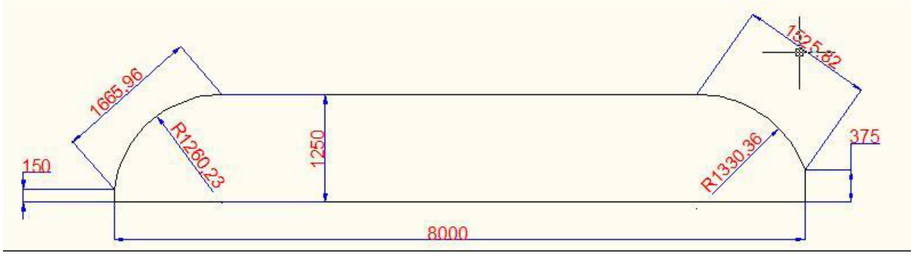


Figure 15: Dimensions of Form Two

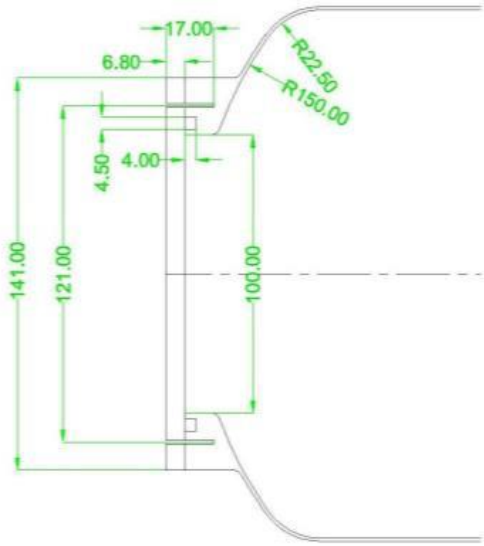


Figure 16: Dimensions of Form Three – Fore End

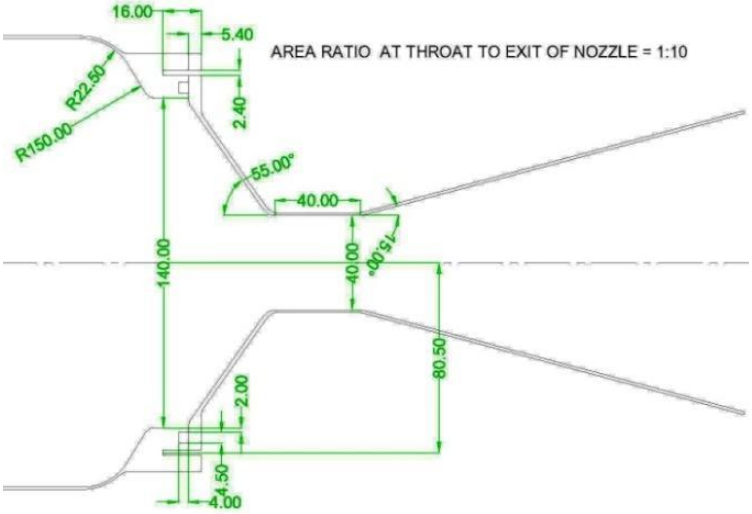


Figure 17: Dimensions of Form Three – Nozzle

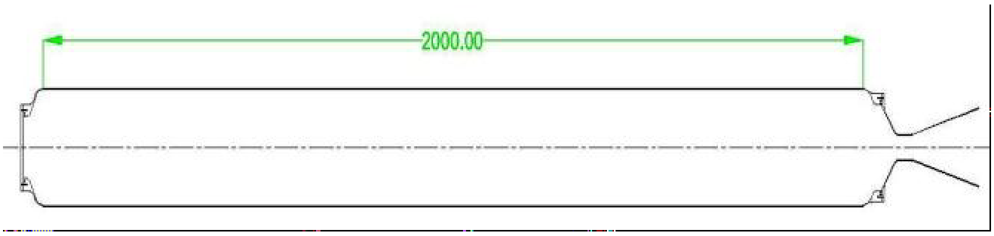


Figure 18: Dimensions of Form Three – Casing