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Mechanical design of snowblower for utility and all-terrain vehicles

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Abstract

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Title of the thesis

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Abstract

The ATV-connected snowblowers are widely utilized for various applications as they offer rapid and efficient snow removal in a controlled manner. These machines are particularly popular in Nordic countries where is a high demand for snow removal equipment during the winter season.

The snowblowers for the ATVs and UTVs demand convenient attachment and detachment to the various models of the vehicles, should be efficiently manufactured with application of Design for Manufacturing techniques for sheet metal. This thesis aims to address the customer needs by bringing the ergonomic, universal and functional mechanical design for any types of off-terrain vehicles.

The final prototype 3D assembly brings the development ideas to support the market with versatility and diversity in design as well as introducing the platform for various power source types.

Keywords

Snowblower, sheet metal, DFM, product development, mechanical design.

Contents

LIST OF SYMBOLS AND ABBREVIATIONS

ATV	All-Terrain Vehicle
CNC	Computerized Numerical Control
DC	Direct current
DFM	Design for Manufacturing
DFMA	Design for Manufacturing and Assembly
DSMF	Digital Sheet Metal Forming
DXF	Drawing Exchange Format
FEM	Finite Element Method
HP	Horsepower
ICE	Internal Combustion Engine
Kg	Kilogram
KW	Kilo Watts
LED	Light Emitting Diode
MPA	Mega Pascals
Nm	Newton Meters
SLDPRT	SolidWorks Part
UTV	Utility Terrain Vehicle

1 Introduction

The main goal of the thesis is to develop a snowblower prototype with its power source for all terrain and utility terrain vehicles. First, a broad range of mentioned service vehicle models are entering the market. Customers demand universal attachments for the snowblower that suit any type of ATV/UTV vehicle. The machine's functionality should be kept in mind in the first place during design Snowblower is attached and detached in the environments that require to make this process rapid and convenient.

Since the snowblower is mainly manufactured from sheet metal, the second objective of the thesis is to research the sheet metal fabrication industry and consider its core aspects during design. It is the technology that demands close attention to detail. The DFM techniques for sheet metal fabrication have to be implemented. This approach, with its own rules and techniques described, helps to overcome the challenges of the manufacturability of this technology. It also brings correlation efficiency between design and manufacturing steps during the development of the final prototype. Proper machine structure strength and lightness appear as a result.

The third aspect to be covered is the product development steps and their implementation in the design process of the snowblower. Customer feedback plays an important role in following design, so snow market research and vehicle owners' wishes must be formed clearly. Analysis and comparison of various power systems, transmission options, and features for the snowblower that could be implemented for future models have to be made. The prototype platform should be planned for their installation, ensure proper strength, proven with FEM simulations, and selection of proper material. The final concept must provide the most robust and affordable configuration of analysed features.

2 Modern ATV snowblowers development and types

2.1 Snowblowers development

All-terrain and utility terrain vehicles nowadays are highly versatile equipment, especially suitable for the Nordic countries where are a great number of forest roads and a significant amount of snow during the winter season. Owners of these vehicles utilize various attachments for the service of different private and public properties that include clearing snow during wintertime. While traditional snowplows mounted on the front of an ATV have been a popular choice for a long time, this method of pushing snow forward is not always efficient. An innovative solution to this problem came is the snowblower attachment, which has become increasingly popular in recent decades due to the development and advancements in ATV technology. Snowblower attachment offers numerous benefits over traditional snowplows. It can remove snow at a rate up to 10 times higher than a snowplow, making it significantly more efficient. Furthermore, it can direct the removed snow in the desired direction, which provides greater control over the snow removal process. The ATV snowblower is a self-contained machine that attaches to a vehicle, featuring its own power source and transmission for removing snow by blowing it away; particularly well-suited for removing snow from small and challenging areas such as private yards, sidewalks, and ski resorts. It is an excellent option where it is not reasonable to use larger machinery such as tractors due to limited access or other obstacles. This innovative attachment is an excellent addition to the range of tools available for clearing snow, providing a more efficient, flexible, and controllable way to remove snow compared to traditional snowplows and other equipment.

First ATV snowblowers were introduced between the 1980s and 1990s when All Terrain and Utility vehicle manufacturers supported their models with 4-wheel drive and started to use them for service work, utility, farming demands, and others. One of the first models that entered the market was the "Snowhogg" ATV snowblower attachment developed by the Canadian company GMI Industries in the 1980s. This attachment represented a single-stage snowblower that could be controlled from the driver's seat of the ATV, allowing the operator to clear snow from areas with limited access quickly. The Snowhogg was also designed to be easy to install and remove, allowing users to quickly switch between different attachments as needed.

Nowadays, ATV snowblowers have plenty of different features and options for different price ranges, such as multiple auger stages, headlights, various attachments, and others.

2.2 Principle of operation

The principle of operation of the snowblower is presented in Figure 1. Engine (3) rotates the impeller (2) of various types inside a sheet metal housing. The spinning auger spins with demanded rotational speed so it can pick up and propel the snow upwards through a discharge chute (1). The chute is usually adjustable by electric motors, and it can control the direction of the throw-out snow out of the way.

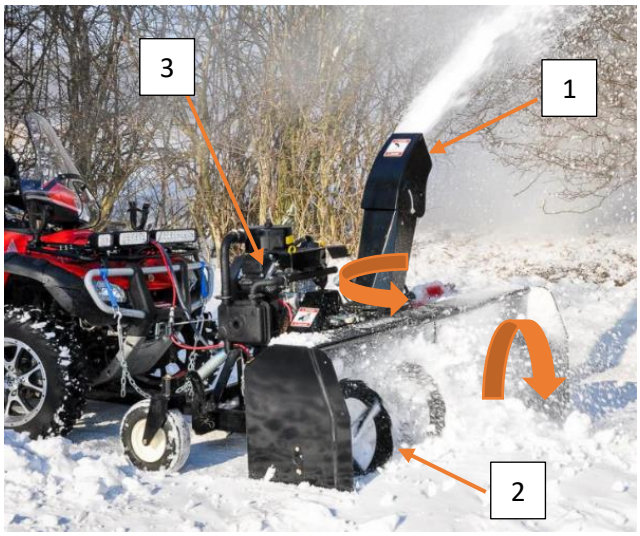

Figure 1. ATV Snowblower in operation (RodkildeATV 2016)

2.3 Various configurations of snowblowers

Nowadays, ATV/UTV snowblowers are extremely popular around modern snow removal machinery equipment. There is a broad catalogue of models and manufacturers around the world. The snowblowers can be divided into different types of operation principles by the following criteria:

- Single stage or two-stage
- Power source of the snowblower
- Type of auger
- Various attachment points and engine position

Several configurations of models are to be described and compared below by these criteria. The first type is the Polaris snowblower model introduced in the early 2000s (Figure 2). It is one of the first machines featured by ATV manufacturers. It is attached to the towbar and the winch. Polaris Snowblower has wheels on casters that support the weight of equipment

and make manoeuvring much easier. The engine is placed in the back of the ATV, and the drive shaft passes under the machine to the snowblower gearbox. The advantage of this configuration is that such engine position makes weight distribution better. Engine weight is not applied on the front wheels and ensures better steering during operation

Figure 2. First Polaris Snowblower model (Snowblower Forum 2001)

The second type of snowblower configuration type is a more powerful machine for UTV vehicles. It has a hydraulic power unit that is attached to the cargo box (Figure 3). The frame is attached to the bottom protection side-by-side. The weight distribution is also an advantage in such a configuration since the large, heavy unit is in the back cargo box. Additionally, there are utility terrain vehicles that have hydraulic equipment installed from the factory inside the machine and eliminate the utilization of large remote power unit

Figure 3. Erskine UTV hydraulic Snowblower (Accudraulics 2018)

The next following types of snowblowers are modern market blowers. The models described on the examples of two popular Nordic manufacturers IronBaltic and Rammy, and compared in a table form.

The third configuration (Figure 4) represents a snowblower with an engine in the middle. Attaching points are the towbar and the straps to the suspension arms. The specification is a two-stage snowblower. On a two-stage snow blower, the auger pulls snow into the machine and feeds it into a high-speed impeller, directing it out of a discharge chute. Two-stage snow blowers can manage deeper snow depths than single-stage ones. The ribbon flight screw is installed in this type of machine. It ensures performance in throwing the wet snow. Snowblower has wheels on casters.

Figure 4. Iron Baltic two-stage snowblower (Iron Baltic 2021)

Iron Baltic Snowblower	**Advantages**	**Disadvantages**
Two-stage	Two augers Larger snow capacity	Higher weight Higher fuel consumption
Ribbon flight screw	Better performance in wet snow	Complex to manufacture
Towbar Attachment	Simple and universal attachment	Long profile, more material needed
Engine in the middle	Better weight distribution	Machine is longer

Table 1. IronBaltic snowblower features.

The fourth type of blower, represented in Figure 5, has an attachment to the bottom protection of the ATV/UTV. It has an engine on its side as well as a transmission. Rammy is a single-stage snowblower. On a single-stage snow blower, only one impeller is installed. One important design trait in this configuration is that the impeller is placed in such a way that it has minimum distance space to the housing to ensure the demanded snow-throwing capacity. It pulls snow into the machine and directs it straight out from the discharge chute.

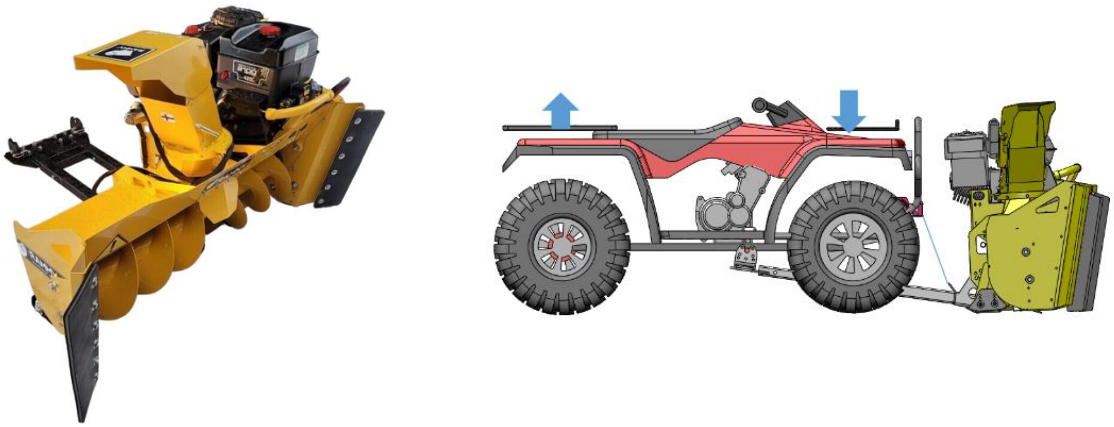

Figure 5. Rammy single stage Snowblower (Rammy 2021)

Rammy Snowblower	**Advantages**	**Disadvantages**
Single stage	Less length and weight	Less snow capacity
Flight screw	Easier to manufacture	Poor in wet snow
Bottom protection attachment	Less material spent	Inconvenient to attach, not suitable for all models
Engine placed on the side	Compact machine size	Only one stage possibility

Table 2. Rammy Snowblower features.

3 Sheet metal fabrication

Metal has been a versatile substance from the very beginning of its existence. It is used widely in almost all fields around the globe. The main reason behind its versatility is the metal forming process that stretches the metal parts and changes their geometry to meet the desired shape. Metal forming is the backbone of the modern manufacturing industry. (Binamra Poudel, 2018). Sheet metal fabrication is a very cost-effective way to produce metal parts. It is a high-quality technology for rapid prototyping as well. The process is relatively simple and does not require expensive tools or machines. A huge amount of new sheet metal fabrication applications developed every year. By 2026, the sheet metal fabrication industry is projected to reach $4.4 billion annually (Superior Steel, 2022). In Mechanical Engineering, sheet metal fabrication is used among various types of applications, but the largest consumer industries are aerospace and automotive. It is a particularly suitable material for producing aircraft parts such as wing panels, fuselage, and doors. The advent of sheet metal played a crucial role in the development of the automotive industry. It has become instrumental in the design of various automotive parts such as side panels, hoods, fenders, and roofs, without which automobiles would be significantly harder to manufacture. It would cost more to achieve efficient aerodynamic characteristics and the car's ergonomic, aesthetic design.

Snowblower body parts production is also a cost-effective deal when it comes to manufacturing with such technology utilization. The majority of machine parts such as housing, side plates, auger, discharge chute, and even the attachment of snowblower will be manufactured with this multifarious technology.

3.1 Technology overview

Sheet metal fabrication involves utilizing several manufacturing methods presented in Figure 9 to shape raw metal sheets into the desired component. To achieve successful results in any sheet metal fabrication project, it is crucial to have a comprehensive understanding of design principles and apply the best practices. (Rapid Direct, 2023). DFMA techniques serve as a great advantage to this technology.

3.1.1 Cutting.

There are several cutting technologies to cut raw steel sheets into the desired form of workpieces. They include laser cutting, plasma cutting, and water jet cutting. One thermal cutting method is laser cutting. It is one of the most effective, versatile methods of cutting sheet metal. In this process, a high-density light beam is created by stimulating lasing material

with an electrical discharge within an enclosed container. Optics are used to focus the created laser beam onto the small area of the workpiece, effectively cutting it by melting, vaporizing, or burning through it. The movement of the laser beam is controlled using CNC technology. Cutting with such a method ensures high cutting speed, high surface, and cut quality, with no finishing required for many steels. Laser cutting follows the standard ISO9013:2017. Cost-effectiveness for cutting sheets of metal with a thickness range of around 2-6 mm makes this cutting technology suitable for manufacturing snowblower parts that are going to be designed with mentioned thickness values.

3.1.2 Forming

Forming process includes bending. Sheet metals can be bent into “V” shapes, “U” shapes, and various angles of up to 120 degrees. Typically, manufacturing companies provide bending with an angle tolerance value of +-1 degrees. The thinner the sheet metal, the easier it is to bend. Also known as CNC folding, bending involves clamping the sheet metal between the upper tool and a die mould. There are several different machines that can accomplish this process, including a manual press brake, a robotic bending cell, and automated panel benders. The machine used for manufacturing depends on the size and complexity of the design. The most important factors in sheet metal design are bending radii and k factor. Perfect bend radius should be equal to or more than material thickness to achieve the desired strength properties. K factor represents the ratio of the neutral axis to the material thickness. Once developed, the value of the k-factor will enable a designer to predict the total amount of elongation that will occur within a given bend. The k-factor allows to calculate the bend allowance, the outside setback, and the bend deduction. Typically, its value varies in the range between 0,3 and 0,5. The geometrical features of the bend are shown in Figure 6.

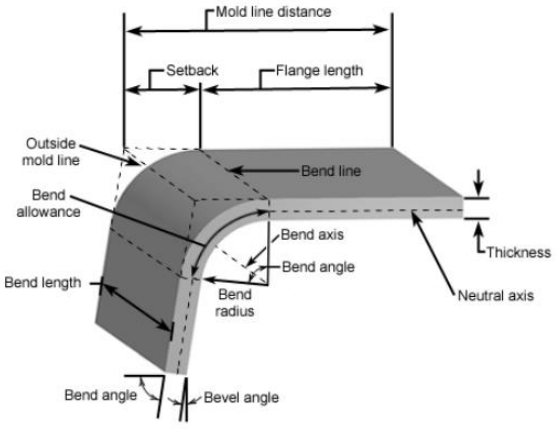

Figure 6. Bending Diagram (CustomPartNet 2021)

3.1.3 Digital forming

Just deforming metal sheets with bending is not enough for manufacturing the sheet metal components. The other processes, such as stamping applied to create holes and different features in a sheet metal part. A revolution in sheet metal forming came with digital sheet metal forming. The innovation is that sheet metal parts can be directly formed from 3D model. This technology resembles 3D printing but not with filament extrusion; instead, the platform in Figure 7 has a software-driven ceramic tool on an XY gantry that forms the sheet metal. The digital forming process of a cavity is presented in Figure 8. DSMF technology eliminates the need for a traditional stamping press or custom tools, moulds, and dies. Such revolutionary technology provides a sheet metal forming process that is accessible, flexible, and cost-effective at low and high volumes for automotive, aerospace, and others.

Figure 7. FIGUR G15 platform (desktopmetal 2022)

Figure 8. FIGUR G15 forming process (desktopmetal 2022)

3.1.4 Joining

Welding is commonly used to join the manufactured sheet metal components together in a single structure. There is a range of several welding techniques that can be done when working with sheet metal; this includes MIG welding, TIG welding, spot welding, projection welding, and robotic welding. The selected welding process depends on the sheet metal material and the complexity of the machine design, assembly, and workshop facilities. The welding procedure can be roboticized as well. Apart from welding, sheet metal parts can be joined by an applied rivet joining process and mechanical joints such as screws, bolts, and nuts.

3.1.5 Finishing

Powder coating is a dry coating process used as a metal finish, mostly on industrial equipment. The coating is applied as a dry powder through an electrostatic process, then cured with heat (Ametals, 2023). Powder coating is available in 2 types: thermosets and thermoplastic. When heated, thermoplastic powder coating becomes liquid and very soft, allowing easy removal and reuse without any chemical bonding. In addition, these coatings tend to be thicker than thermosets, making them highly durable and wear resistant. Thermoplastic polyester-based powder coating has several advantages and can be applied to a wide range of materials, making it an excellent choice for coating snowblower components. It results in a high-quality, uniform, and durable finish that complies with environmental policies and provides cost-effectiveness. Additionally, repels the water and other chemicals from metal, preventing corrosion and ensuring long-lasting operation lifetime.

Galvanization is a high-performance way to protect sheet metal from external effects. It is a process where a layer of zinc is applied to steel or iron to protect the underlying metal from corrosion. The process involves dipping the metal into a bath of molten zinc, which forms a coating on the surface. With the introduction of such technology by the Audi automotive company in 1985 for the Audi 100 and Audi 80 models, the 100% galvanized steel car body had enormous resistance to corrosion over 10 years of operation. As a result, many cars are in great condition today.

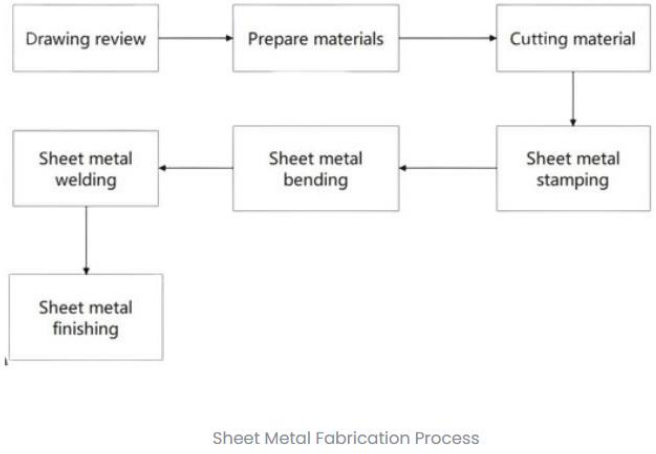

Figure 9. Sheet Metal Fabrication Process steps (KDM Fabrication 2022)

3.2 Sheet metal fabrication of snowblower

In the mechanical design of the snowblower, the manufacturing process of the components starts in the following way. When a 3D model is created in CAD software, technical drawings for each part are developed. The flat pattern view is included in each sheet metal part drawing. The flat pattern represents the unfolded component with bend lines and angles and is typically saved as a DXF format. This format is used for cutting the workpiece on the CNC laser cutting machine. Once the cutting process is complete, the sheet metal can be formed to the desired shape by bending. After the separate metal parts are ready, the assembly and welding stages come. Welding is essential to join metal pieces of the body together to create a single product. MIG welding type and mechanical components are utilized for joining parts in a single machine. The last aspect is the finishing of parts. Typically, in the ATV snowblower finishing process, the sandblasting of the parts is performed to maximize the adherence of the future paint. After it, the washing is performed. Finally, the powder-coated paint is applied on the surface. It is a thermoset polyester-based powder coating. This kind of finishing procedure improves the unequalled durability of the body. Moreover, it is a significant specification since the snowblower is operated in conditions where external effects such as sand and stones always contact the machine's body components.

3.3 Materials for sheet metal.

Choosing the proper material is essential to every sheet metal fabrication project. There is a broad range of materials that can be selected, from common-grade carbon steel to titanium for high-temperature applications. The material selection depends on the final sheet metal thickness of product parts, budget, fabrication facilities, finishing methods, and functional aspects. Some examples of typical steels in sheet metal fabrication with various surface finish options and mechanical properties are presented in Figure 10.

	SURFACE FINISH						YIELD	TENSILE	HARDNESS
	Powder coating	E-coating	Zinc plating	Dacromet	Anodized	Passivation			
Cold Rolled Steel (CRS)									
SPCC	X	X	X	X			≥210MPa	≥350MPa	HB 65 - 85
SAPH440	X	X	X	X			≥305MPa	≥440MPa	HB 80 ±30
Hot Rolled Steel									
Q235	X	X	X	X			≥235MPa	375 ~500MPa	HB 120 ±40
Q345	X	X	X	X			≥345MPa	490 ~675MPa	HB 120 ±40
Spring Steel									
65Mn	X	X					≥785MPa	≥980MPa	HB 190 - 340
Aluminium									
AL 1060	X				X		≥35MPa	≥75MPa	HB 26 ±5
AL6061 T6	X				X		≥276MPa	≥260MPa	HV 15 ~ 18
AL6063 T5	X				X		≥170MPa	≥250MPa	HB 25 ±5
AL5052 H32	X				X		≥70MPa	210 ~ 260MPa	HV 11 ±2
Stainless									
SS301	X					X	≥205MPa	≥520MPa	HB 76 ~ 187
SS304	X					X	≥205MPa	≥520MPa	HB 76 ~ 187
SS316	X					X	≥205MPa	≥520MPa	HB 76 ~ 187
Cold Galvanized Steel									
SGCC	X						≥200MPa	≥380MPa	HB 50 - 65

Figure 10. Industrial materials for sheet metal fabrication (Komaspec 2020)

Additionally, brass and copper materials can be added to the list of materials for light applications. The final selection of the snowblower body material will be performed in the product development chapter when all specifications are formed, and market research is described.

3.4 DFMA for sheet metal

The common problem in the sheet metal industry is that the CAD designed model with sheet metal tools is difficult or impossible to manufacture. Mechanical design engineers are often unaware of the difficulties their design can cause to the manufacturing workshop since there is a large gap between these processes. Commonly, manufacturing workshops spend 30 to 50% of their time fixing errors, and almost 24% of those errors are related to the manu-

facturability of designed parts (Metal Working Magazine, 2016). These problems significantly increase the project production time and cost since the part is not manufactured and the material is wasted.

Companies whose goal is always focused on quality and improving it continuously apply Design for Manufacturing and Assembly to avoid these kinds of issues by taking manufacturing into account during the product development stage. By applying DFMA beneficial practices in sheet metal fabrication, designed parts become easier in manufacturing, reliability, and quality during the multiple operations increase as well. Additionally, when the parts are sent to the other manufacturing companies for production, quotes for correctly designed parts are produced faster, eliminating the clarification discussions with customers and guaranteeing production time to be more efficient and rapid.

For the Snowblower machine, the DFMA tools during the product development phase are going to be applied and described further with SolidWorks software utilization.

4 Definition and targets

4.1 Market research

The market of ATV snowblowers is growing alongside the ATV and UTV vehicles development and newer models coming on the market. The sheet metal industry is rapidly growing as well; it is versatile, and a broad range of workshops all over the world offer their manufacturing services

In terms of geography, Europe and North America are estimated in Figure 11 to be the largest snowblower markets due to the favourable climate conditions and large consumer base. In the last years, the number of contractors operating in the snow moving and management business in Europe has significantly increased. Rapidly growing infrastructure estimate to create high growth opportunities for snowblower manufacturers and dealers as well (Persistence market research, 2017).

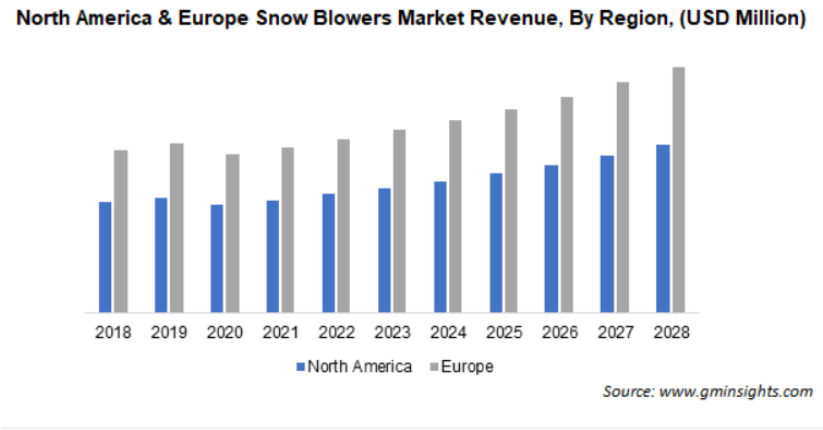

Figure 11. Snow blower market revenue estimate. (gminsights 2022)

The popular players that proved themselves with quality on the American and European markets are Bercomac, Husqvarna, Rammy, IronBaltic, and others.

These days, customers mostly choose snowblowers with an internal combustion engine since it proves great reliability and does not cause many problems during cold operation, ensuring efficient fuel consumption. One of the most successful products on the North American market is the Bercomac snowblower from a Canadian manufacturer. The Bercomac Vantage model is presented in Figure 12. It is very satisfying to use, it is extremely powerful, and it works with all types of snow. Many ATV owners in North America with large properties use the Bercomac Vantage to remove snow quickly and efficiently. It is also suitable for light commercial use. People who have chosen the Bercomac Vantage

enjoy it for its ease of use. This includes remote features such as starting and stopping the snowblower, turning and adjusting the chute, lifting, and emergency shutdown. The Bercomac Vantage is also known for its excellent build quality. It is made from thick gauge steel, and its superb design incorporates high-performance components. Bercomac Vantage owners also like how easy it is to attach to their UTV. First, the machine is attached to the towbar, and next, straps or brackets to the front control arms of the vehicle.

Figure 12. Bercomac Snowblower (Bercomac 2022)

What comes for the price range, dealers offer this attachment for ATVs for 6000 €; for UTV vehicles, the snowblower price can achieve 8000 €.

Another Finnish company, Rammy, produces lighter and cheaper snowblowers mostly for the Nordic market but has great success in export sales. It is an efficient machine suitable for gardens and long driveways with great manoeuvrability and can be operated in different kinds of snow. It has an adjustable frame and is compatible with all lengths of all-terrain machines. The price range starts at 4950 € for ATV models, and for UTV models, the price is 7000 €.

The success in the sales of the mentioned companies is attributable due to the wide size range of models for ATV and UTV as well as various extra options availability. It attracts customers since they can select the snowblower from catalogue suitable for their personal vehicle power and size, their own budget, and the amount of snow to be removed.

4.2 Customer needs

Customer demands definition is an essential part of the mechanical design process. Engineering specifications are not just built by engineers. They are also based on customer wishes in this type of product. Since the product is developed for the final client, his satisfaction depends on how the product will be designed by engineers. By performing market research for the snowblowers market and gathering customer feedback, it is possible to highlight the most demanded features and then build engineering specifications.

First and foremost, the customers consider the size of a snowblower. During the market research, it was found that most ATV owners use their machines for removing snow from private lands and farms. Apart from the private owners, utility services and ski resort crews appear to be the second customer sector. All of them operate this machine where heavy machinery cannot pass. Manoeuvrability comes in first place in this kind of task. If the area has obstacles that require making tight manoeuvres, a large and heavy snowblower is inconvenient to use. It makes the job take much longer and increases fuel consumption significantly. Customers commonly use bigger snowblowers with UTVs for cleaning driveways and smaller snowblowers with ATVs for cleaning private lands and yards. The more power vehicle has, the larger snowblower could be. The most suitable size is 1200 mm, and this value is selected for the product width.

Secondly, the important feature is the simplicity and ease of operation. The installation should also be rapid and simple as possible. Customers do not wish to buy a product that is complex to use or causes difficulties in fitting the machine to the utility vehicle. The customers from Finland and ATV Snowblower Forum had highlighted that attachment to the towbar is much more convenient; it takes around 4 minutes of installation time and less effort to start the machine operation.

The next described demand is functionality. It is beneficial that the speed of the auger is adjustable to include the possibility of electric remote control of the thrown-out snow direction. It is an important feature for users of Utility terrain vehicles that have closed cabins. The remote control is a must-on feature for them. Additionally, the headlight LED beam is a great addition, especially for Nordic climates with long and polar nights, to improve visibility.

The last point that the customer is focusing his attention on is the build quality. The snowblower is designed to work under stressful environmental conditions, can hit the rocks, and the sand could be propelled out within the auger and discharge chute. The quality, as well as the paint of body components, must be great. Also, snowblower should have various

protection straps on the edges. To summarize all the gathered information, it was decided to interpret it in a form of Table 3.

Manoeuvrability and lightness
Simple to attach/detach
Can be attached to broad range of ATV models
Suitable size for ATV
Remote control of auger speed and discharge chute
Good quality
Durability
Simple maintenance

Table 3. Raw data

4.3 Engineering Specifications

Specifications are measurable engineering criteria for the designed product established in a formal document, commonly in the form of a table. The requirements regarding the design are going to be adhered to during the completion. Snowblower specifications are presented in Table 4 below.

Demand/Wish	**Geometry**	**value**
D	Width	1200 mm
D	Width with optional widenings	1400 mm
D	Housing height	550 mm
D	Length with attachment	3200 mm
D	Diameter of auger	340 mm
D	Auger type	Ribbon flight

D	Capacity	1000 m^3/h
D	Mounting to ATV	hitch and straps to the levers
	Kinematics	
D	Engine type	Internal Combustion, 4 stroke
D	Engine Torque	28.5 N/m
D	Engine volume	420 cc
D	Cooling type	air cooling
D	Fuel consumption	2 l/h
D	Transmission type	Belt transmission
D	Clutch type	Mechanical or electromagnetic
D	Discharge chute control	Servo motor
D	Capacity	1000 m^3/h
	Manufacturing	
D	Manufacturing Processes	laser cutting, bending, welding, powder coating
D	Sheet metal material	Domex 420 hot rolled steel
	Operation	
D	Continuous operation	>2 hours
D	Operating temperature:	-30 to +20 degrees
	Costs	
W	Target market cost:	4000 €
	Safety	
W	Minimizing the electrical and mechanical risks	

Table 4. Engineering specifications

5 Product Development

5.1 DFM techniques and tools for sheet metal

The DFM techniques will be applied with SolidWorks and different fabricator's websites utilization. Many sheet metal manufacturers nowadays have automated websites where the mechanical designer can upload the SLDPRT or DXF file during the design stage. The program will highlight the errors that could cause some difficulties during the manufacturing of the parts. It is one of the beneficial tools to avoid the large gap between the design and manufacturing stages. One of the companies that provide such services for their clients is Komacut. It is a Canadian-owned company that offers on-demand high-quality parts. The webpage includes a broad range of functions. For example, the designer can select the sheet metal steel material, thickness, various finishing options, tolerances, and see the final price of the ordered component.

Once the part is designed in CAD software, the designer can upload the part to the site to check it for manufacturing errors. The uploaded part in Figure 13 detected a big radius on the part, and many other errors occur due to it as well.

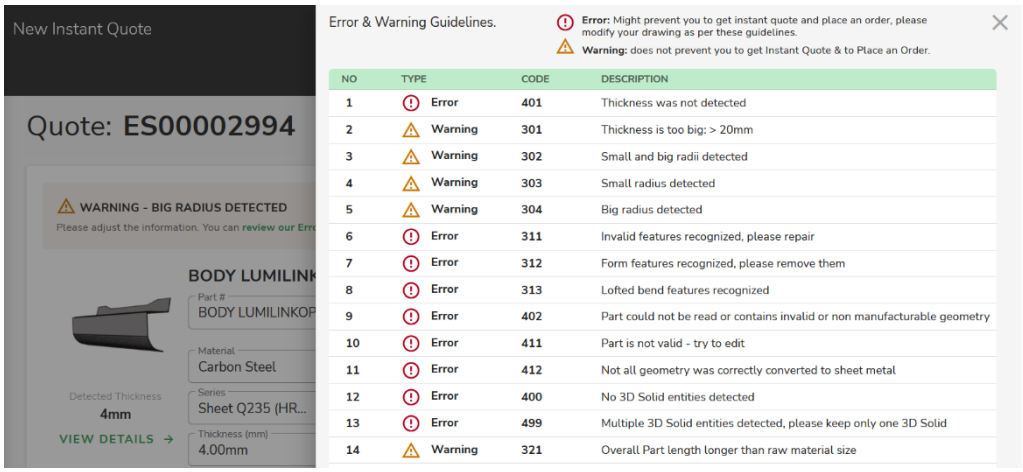

Figure 13. Quote with uploaded SolidWorks part errors (Komacut 2023)

When creating a sheet metal part that contains a large bend radius that cannot be achieved by standard tooling, a technique called bump bending at the press brake is used to achieve the demanded radius. This technique can achieve a course or fine radius depending on the number of bends made in this area. In this way, the part was redesigned with bump bending taken into mind. After the part is redesigned (Figure 14), it can be uploaded again to the webpage (Figure 15) and ordered with no errors and warnings. The price is visible, as well

as various finishing options. Other bend radiuses are 5 mm which follows recommended design for manufacturing rule: r>= material thickness.

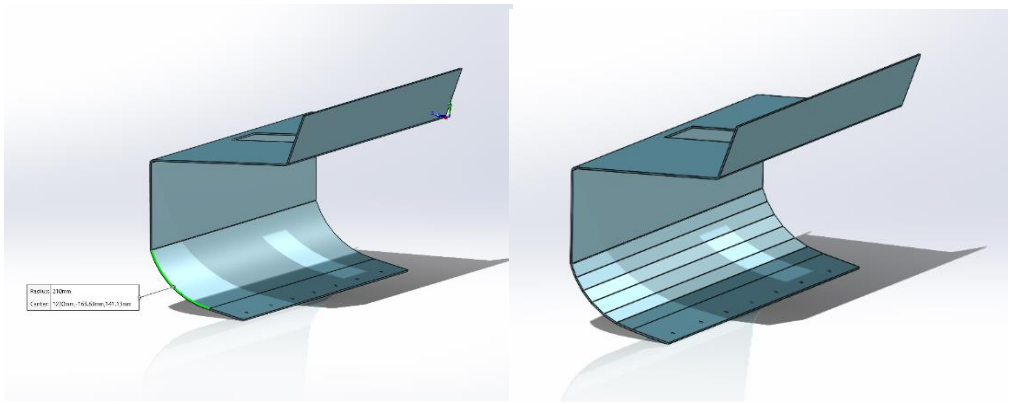

Figure 14. Corrected bent housing of snowblower

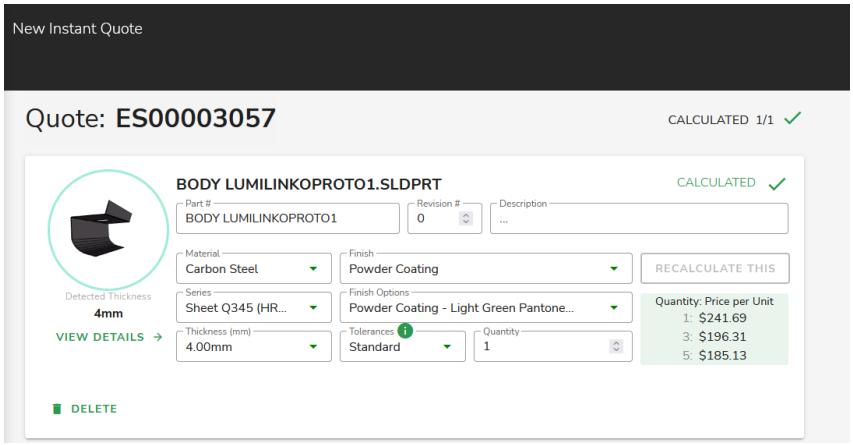

Figure 15. Corrected quote for ordering part (Komacut 2023)

Another important aspect to ensure the component's manufacturability is to consider the case when two or sometimes three bends meet in a corner, like a box or left plate of snow-blower. The relief in such cases is often called Corner relief. These circle cuts allow for less stress on the inner radii of the flanges and keep the corners of the bends from interfering with the base material. In the examples in Figure 16 and Figure 17, two bends meet at the corner, and the corner relief feature is applied. A small relief in the corner allows the edges of the bends to come together tightly in the design. Additionally, this distance between flange edges can be controlled in SolidWorks. If the corner needs to be welded, the gap has to be relatively small. Commonly manufacturers recommend ensuring the gap size is not less than 0,4 mm.

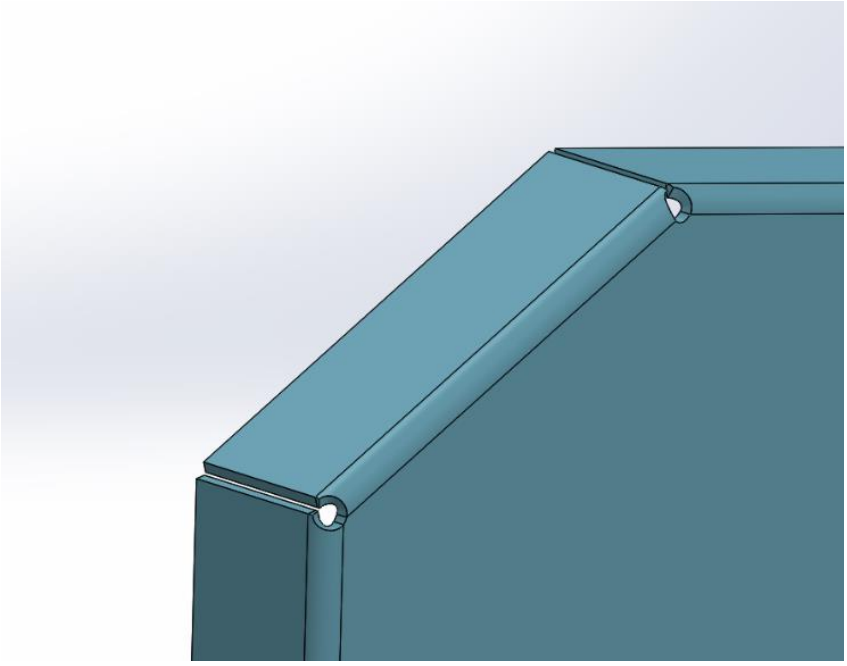

Figure 16. Corner relief feature

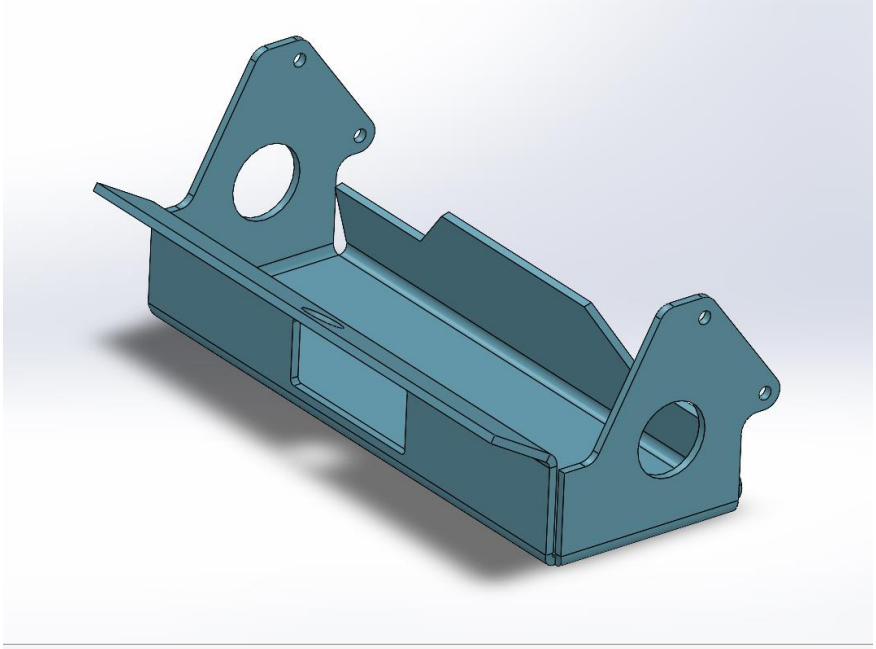

Figure 17. Attachment for housing

Another feature to consider is the bend relief. Bend relief is needed when the edge bend is not across the whole edge of the part. When the material is bent, some of that material is stretched (the outside of the bend), and some of the material is compressed (the inside of the bend). Bend reliefs, as in the example in Figure 18, are necessary to prevent the sheet metal from tearing either during the manufacturing process or after stress is put on the part. Commonly manufacturers recommend ensuring the gap size not less than 0,4 mm.

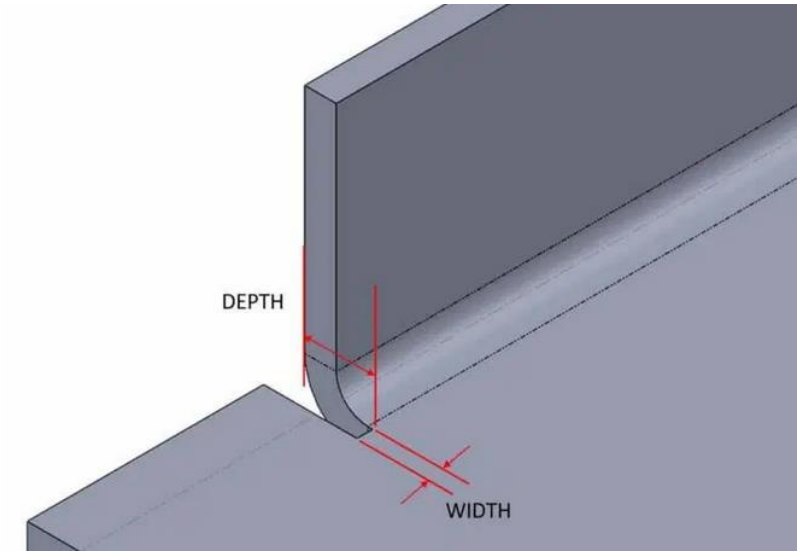

Figure 18. Bend relief feature (sendcutsend 2022)

The third important DFM tip concerns the positions of the holes with respect to the bends, holes dimensions, and quantity. The main basic rules related to this tip are the following:

- hole diameter must be more than material thickness
- spacing between holes must be two times more than the material thickness
- distance between holes and a bend must be 1.5 times the sheet thickness plus the bend radius

For example, in Figure 19 holes spacing and radius meets the manufacturing requirements

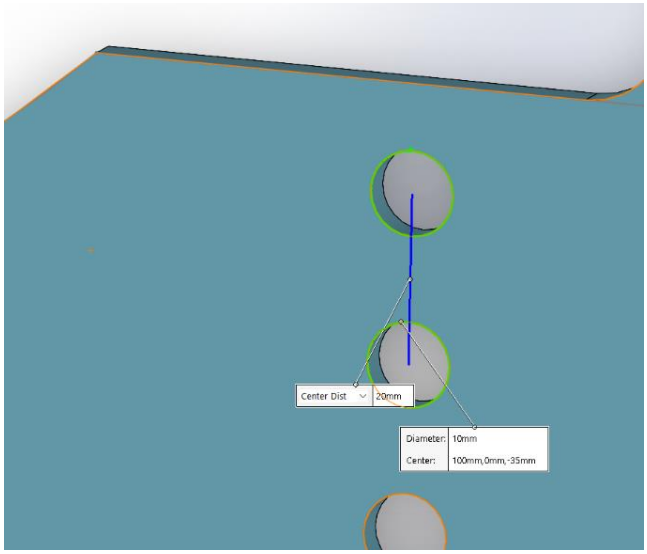

Figure 19. Holes placement

Another company with a website that provides sheet metal manufacturing quotes from 3D models is Fractory. It is EU oriented service that provides the costs in Euros. In Figure 20, the webpage shows the issue that the short distance from holes is kept in the designed part. A short distance between the hole and the bend may cause hole deformation. The part was redesigned according to the mentioned error. Figure 21 shows that it passed manufacturability checks.

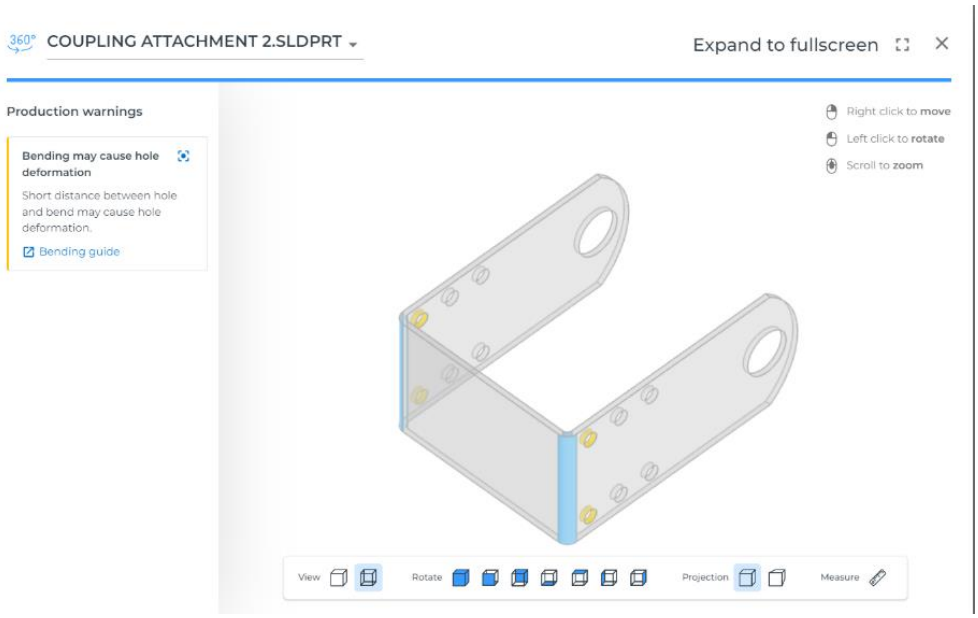

Figure 20. Coupling quote with error (Fractory 2023)

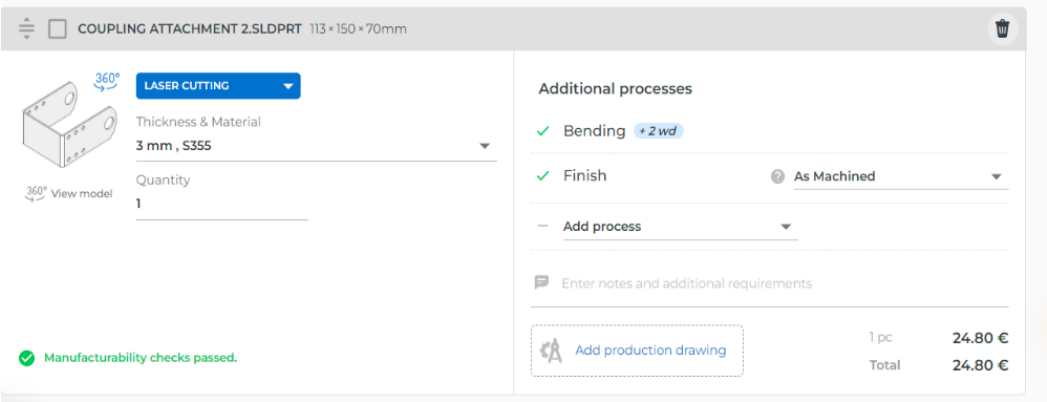

Figure 21. Corrected quote (Fractory 2023)

5.2 Materials selection

In the snowblower, there are several critical components that require excellent durability against external factors such as sand, stones, gravel as well as ensuring high strength against heavy snow pressure and possible collisions during operation. These components are:

- auger housing
- auger
- side plates
- lower plate
- housing attachment
- discharge chute
- skids

The mentioned components must be manufactured from steel type that suits these functional aspects. Additionally, a powder coating option must be available to ensure the protection and durability as well as aesthetic appearance. To select the suitable steel the aspects are going to be combined into a Table 5 with their related properties for convenient analysis.

Functional aspects for snowblower parts	**Material properties related to f.a.**	**Values**
Must provide excellent wear resistance	Hardness	~ 200 HBW
Strong housing resisting high loads	High yield strength	>= 400 MPA
Can absorb energy without breaking	Good toughness at low temperatures	27 J at - 40 °
Vibration resistance, resistance of cyclic loads	Fatigue strength	230 MPA at 10^7 cycles
Manufacturing aspects		
Parts can be joined	weldability	
Parts can be bended without breaking	formability	
Powder coating option available	chemical resistance	

Table 5. Material requirements

According to the table properties and searching the market, it is possible to select the suitable steel. The two steel options that can be highlighted are suitable for manufacturing snowblower parts. One of the best choices that can be utilized for snowblower design is Domex 420 steel. It is a high strength, low alloy, hot rolled steel grade produced by Swedish manufacturer SSAB. It combines great engineering properties. First, it has high yield strength of 420 MPA, which means it can withstand high loads and stresses compared to common-grade steels. Secondly, it has excellent weldability. The third great aspect of this steel is high fatigue strength which ensures resistance to impact and shock loads. Finally, steel provides great corrosion resistance when powder coated.

The second favourable choice for the snowblower parts is Grade 50 high-strength low alloy hot rolled steel. It is also proven for its high strength; however, the values are slightly lower than Domex 420. Nevertheless, durability, great weldability, and formability ensure that this steel is suitable for snowblower parts manufacturing as well.

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5.3 Power sources comparison

It is imperative to consider the power output of the snowblower engine, as it directly influences the clearing performance and snow-throwing capacity. Various power options must be studied and compared to ensure sufficient torque to clear both light and heavy snow. These options can be integrated during the development phase of the snowblower. The primary focus is to design a versatile machine that is compatible with all types of ATVs and UTVs, bringing diversity to the snowblower market. Therefore, multiple power options must be available for customers, which can be bolted onto the machine's platform. The three primary power options to be considered are the internal combustion engine, the hydraulic motor, and the electric motor. Torque and power values, as well as rpm values for spinning the snowblower auger with 1095 mm length and 340 mm diameter, should be estimated. The required capacity is 1000 m^3/hour. The density of heavy and wet snow is around 720 kg/m^3. The material factor is around 2 for wet snow. With this given input specifications data, it is possible to estimate the horsepower value for the motor of the snowblower (Conveyor Eng. & Mfg. Co 2012, 22)

Horsepower calculations:

Input values:

$Capacity = 1000\ m^3/h = 35314\ ft^3/h$

$D(auger) = 340mm = 13.4\ in$

$D(snow) = 721\ kg/m\text{^}3 = 45\ lb/ft^3$

$L = 1095\ mm = 3{,}6\ ft$

$Material\ factor\ (Fm) = 2$

$Diameter\ factor\ (Fd) = 78$

$Bearing\ factor\ (Fb) = 1$

$efficiency(e) = 0.9$

The first equation is material horsepower:

$$HP = \frac{C * L * D(snow) * Fm}{1000000} = \frac{35314 * 3.6 * 45 * 2}{1000000} = 11{,}44\ HP\ (1)$$

The second equation is friction horsepower of auger:

$$FHP = \frac{L * N * Fd * Fb}{1000000} = \frac{3{,}6 * 1000 * 78 * 1}{1000000} = 0.3\ HP\ (2)$$

To calculate the total power for rotation of the loaded impeller, power is divided by efficiency of 2 pulley transmission:

$$THP = \frac{MHP + FHP}{e} = \frac{11{,}44 + 0{,}3}{0.9} = 13\ HP\ (3)$$

$$13\ HP * 0{,}735 = 9.56\ kW\ (4)$$

It is visible that 13 HP or 9,6 KW engine is needed to deal with the following snow capacity. At this point, it is essential to describe the suitable power sources and compare them.

Internal combustion engine.

Most of the engines nowadays installed to the ATV snowblower are internal combustion engines. Commonly, they are 4 stroke engines from various manufacturers such as Briggs and Stratton, Honda, Husqvarna, Loncin, and others. It is installed on the snowblower housing and does not need to be connected to the vehicle with the hoses or wires. ICE results as a fully independent power source with its own fuel tank. This fact makes it simple to attach and detach. Apart from it, it is quite efficient and consumes only 1-2 litres of petrol per hour. The rotational speed is adjustable.

Advantages	**Disadvantages**
Simple installation	Increases weight of snowblower
Simple maintenance	Less efficiency
Does not depend on vehicle type	High noise

Table 6. Internal combustion engine comparison

One of the internal combustion engines which suits the power requirements can be Briggs and Stratton Snow Series 420 cc model presented in Figure 22. It has power value of 13 HP.

Figure 22. Snow Series 420cc Engine (BriggsandStratton 2022)

The second calculation is performed to estimate the rotational speed of the auger. From Figure 23, the peak of the selected engine's torque is at 2800 rpm, and its value is 28.5 Nm. It appears to be the most efficient engine speed for the operation of the blower. According to the specifications of single-stage ATV/UTV snowblowers manufacturers, the speed for an auger of diameters around 340 mm varies in the range of 700-1000 rpm. Such rotational speed provides a suitable throw-out flow of specified snow capacity. To check if the selected design meets the requirements, the speed of the auger with assumed pulleys sizes at motor rotation value that provide maximum output torque (2800 rpm) and maximum rotational value (3600 rpm) must be estimated.

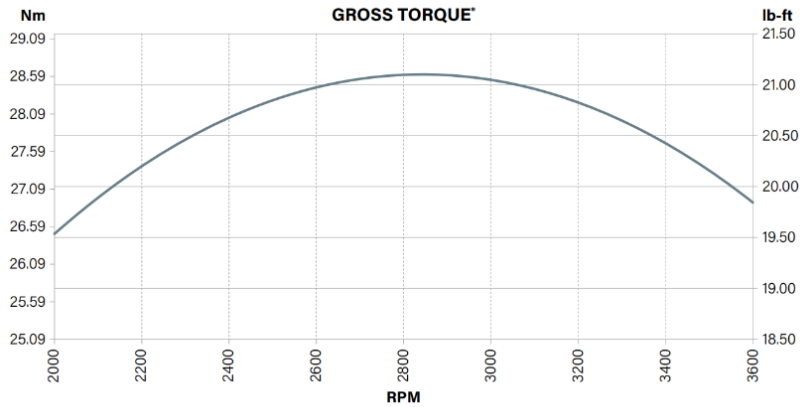

Figure 23. Snow Series 420cc engine torque curve (BriggsandStratton 2022)

Input values:

$N(middlespeed) = 2800\,rpm$

$D(motorpulley) = 67\,mm$

$D(augerpulley) = 250\,mm$

$N(\text{augermaxspeed}) = 3600\,rpm$

Calculation at motor's shaft rotation value of 2800 rpm that provides maximum output torque:

$$N(middlespeed) * D(motorpulley) = N(augerspeed) * D(augerpulley) \quad (5)$$

$$2800 * 67 = N(augerspeed) * 250 \quad (6)$$

$$N(augerspeed) = 750\,rpm$$

Calculation at maximum rotational speed of engine's shaft:

$$3600 * 67 = N(augermaxspeed) * 250 \quad (7)$$

$$N(augermaxspeed) = 965\,rpm$$

The values achieved suit the single stage snowblower impellers rotational speed range and ensure the required cleaning capacity. The model of snowblower with internal combustion engine is presented in Figure 24.

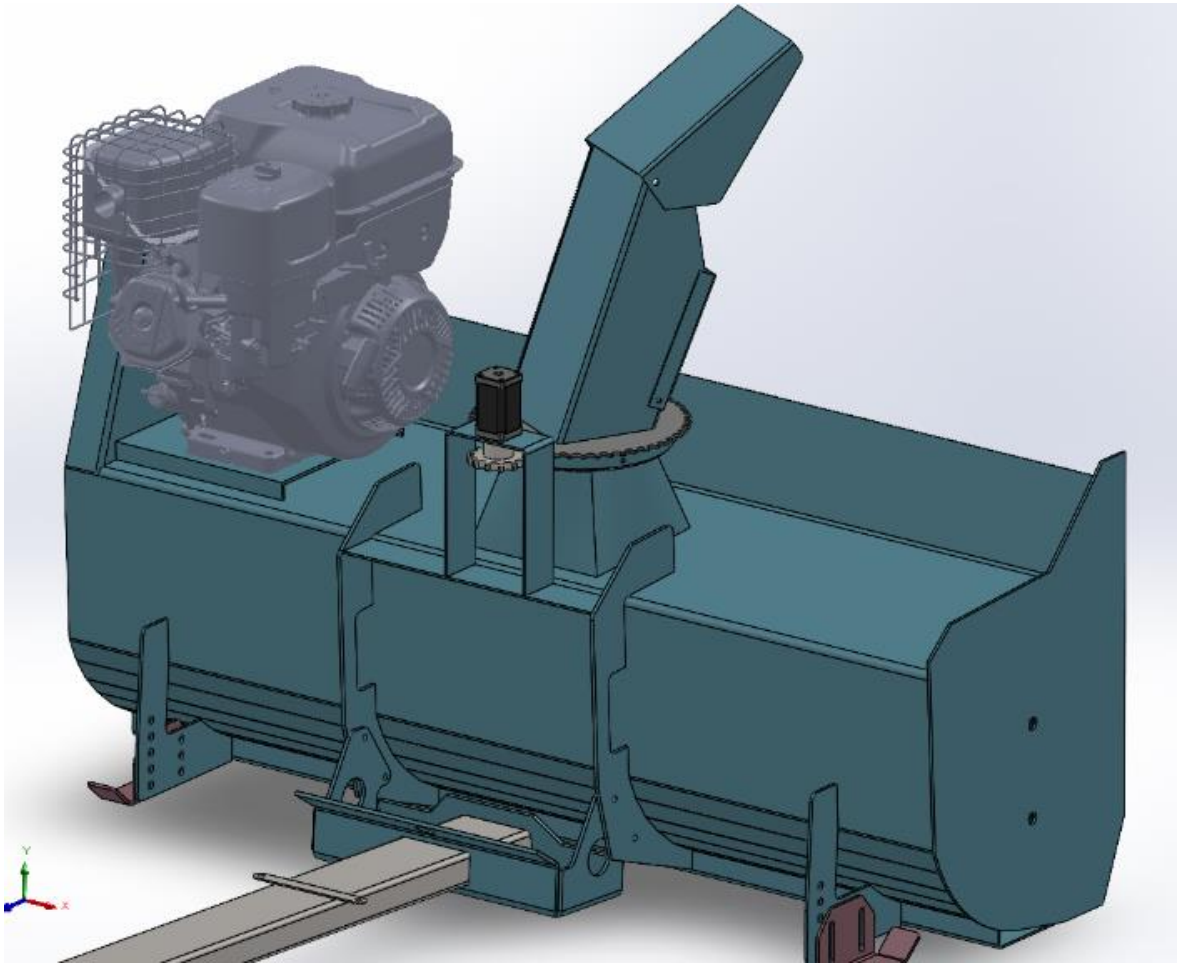

Figure 24. Snowblower body prototype with ICE.

Hydraulic motor

Several utility terrain vehicle models equipped with an integrated hydraulic system. This system operates on UTVs, and agricultural tractors based on the following principle. An engine-driven hydraulic gear pump generates hydraulic fluid flow and pressure, which is then regulated by the control valve. The hydraulic fluid is directed through hoses to an external hydraulic motor that can be fixed onto a snowblower or other attachment. As the hydraulic fluid flows through the motor, it causes the motor's internal rotor to spin, thereby transmitting torque to the auger. The rotational speed of the motor can be adjusted by the control valve. Hydraulic circuit example with motor is presented in Figure 25.

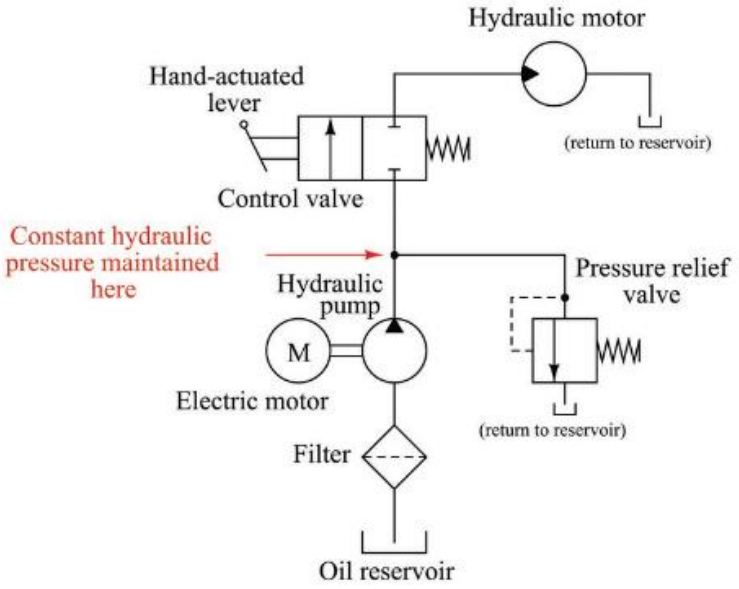

Figure 25. Hydraulic circuit with motor. (Instrumentationtools 2015)

One of the utility terrain vehicles that have its own hydraulic equipment is Polaris Brutus model. As an example, how is such system implemented in this UTV, the equipment scheme can be seen in the Figure 26 below. Number 21- oil tank, 11 – filter, 6- gear pump, 33- relief valve.

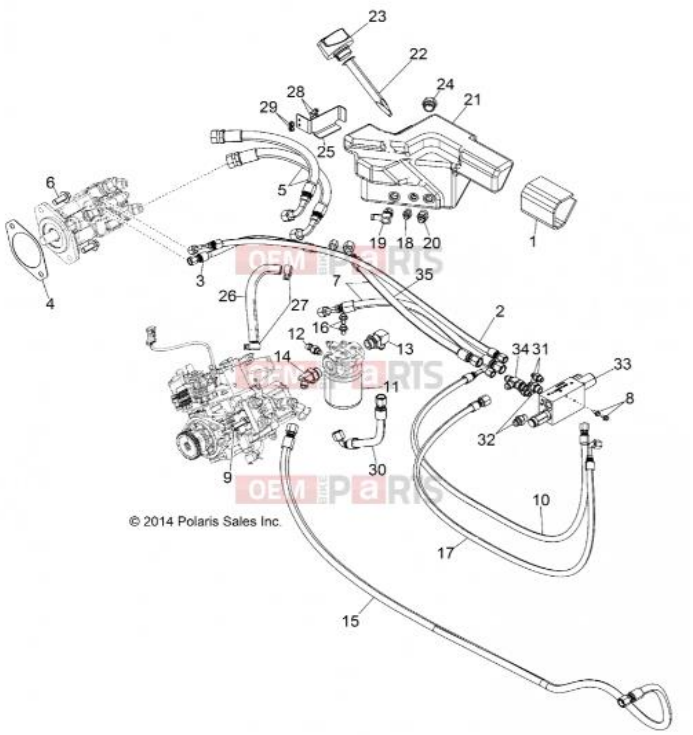

Figure 26. Polaris Brutus hydraulic system (oemparts 2023)

Advantages	**Disadvantages**
High efficiency, high power output	Limited by vehicle type and equipment
Low noise and high reliability	Complex in installation
Lowest weight	Complex maintenance

Table 7. Hydraulic system comparison.

As for the specific hydraulic motor choice that meet the power requirements, Bosch Rexroth gear motor (Figure 27) can be selected as a suitable hydraulic power source of snowblower.

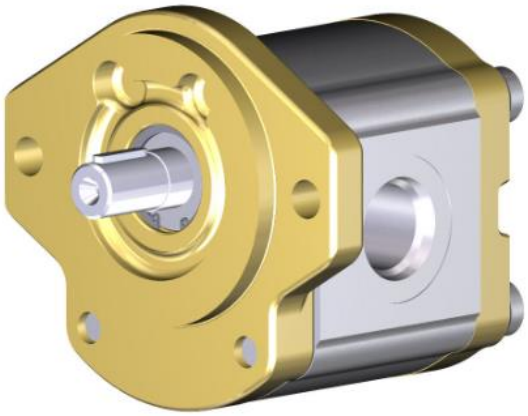

Figure 27. Bosch gear motor (Bosch Rexroth 2023)

External gear motors have the main function of transforming hydraulic energy, which is composed of flow and pressure, into mechanical energy, represented by torque and rotational speed. Rexroth external gear motors have been constructed to be highly efficient, with the goal of reducing heat loss. The selected one has 8 ml^3/rev displacement, 25 MPA working pressure, a maximum rotational speed of 4000 rpm, and an efficiency value of approximately 0.9.

$\Delta p = 25\ Mpa$

$V_k = 8\ ml^3/rev$

$\eta_{hm} = 0.9$

The real torque of the hydraulic motor can be calculated by following formula:

$$M_{real} = \frac{\Delta p * V_k * \eta_{hm}}{2\pi} = 28.65\ Nm \quad (8)$$

This value suits the torque requirements of the machine. Example, on how the motor can be installed is presented in Figure 28.

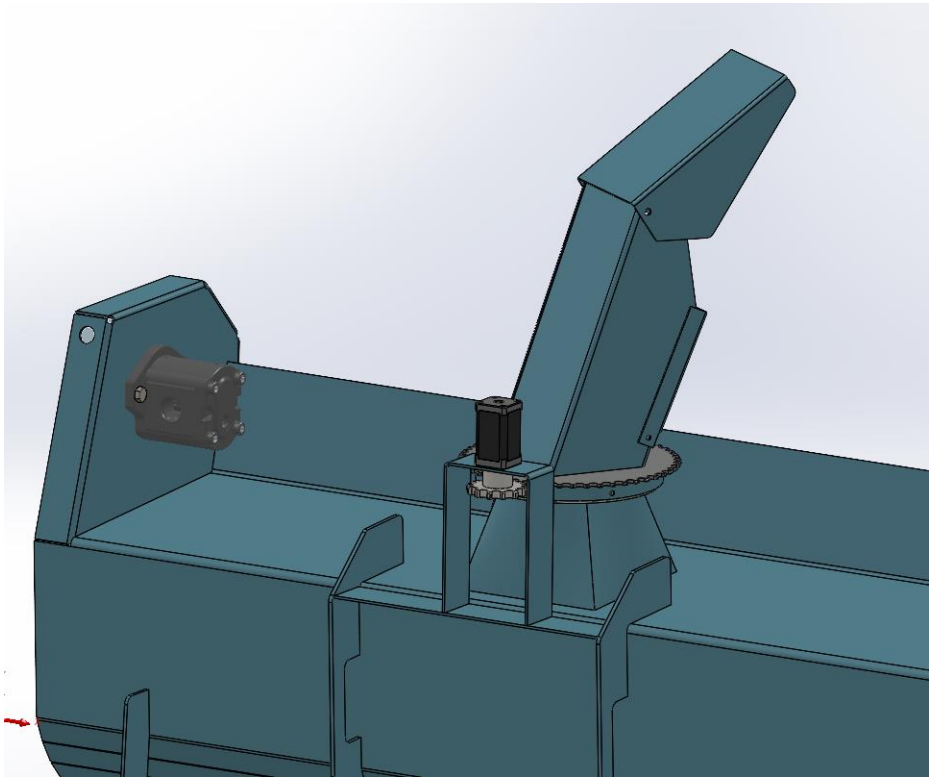

Figure 28. Concept with hydraulic motor

Electric motor.

More and more all-terrain vehicle manufacturers are introducing vehicles with electric power. The electric-powered 10 Kw DC motor can be installed on the snowblower and connected to the vehicle's battery. It is a great solution for light duty and short snow removal applications. Such power source type can be a valuable solution for future efficient development as well.

Advantages	**Disadvantages**
High efficiency, easy to control power	Limited by vehicle type and equipment
Low noise and high reliability	Limited operation time in freezing environments
Simple to install	Expensive power option
Instant torque from start	Expensive setup

Table 8. Electric motor comparison.

Since most ATVs and UTVs do not have a hydraulic pump, the most well-established and widespread source of power in snowblowers nowadays is the internal combustion engine. However, it is essential to consider and develop other power sources, such as electric and hydraulic, for bringing versatility to future development, lowering the weight of snowblowers, and emission abatement. Hydraulic system is more complicated to implement; however, it ensures the highest performance, does not need to be refilled with petrol, and requires less maintenance. The electric motor brings efficiency to a higher level and provides instant torque from the beginning of the operation. The approximate costs of power sources are presented in Table 9.

	Briggs and Stratton 420 cc	Bosch Rexroth gear motor	DC Electric motor
Costs (Euro)	750	600	900

Table 9. Costs of power sources

5.4 Suitable transmission options

The role of transmission in a snowblower is to transmit the torque from the engine to the auger. The impeller does not have to rotate instantly with the engine, so it raises demand in the clutch. The clutch discontinues torque transmission from the engine to the auger and hence stops its rotation. The simplest and cheapest option is to implement a belt tightener which is adjusted with a mechanical lever (Figure 30). When the belt is not tightened, it slips through the pulleys, and the impeller is not rotating. When it is tightened by the lever the driver pulley transmits the rotation to the auger.

Alternatively, the more sophisticated and costly option is the electromagnetic clutch (Figure 29). Electromagnetic clutches are commonly used in applications where mechanical on/off switching is done remotely and electronically. This type of clutch is mounted on the engine's shaft. It closes when a DC voltage is applied and transmits torque from the engine friction-ally. As soon as the current is cut, springs open the clutch. It eliminates the demand for the linkage from the gearbox and hence, discontinues the torque from the engine with the button pressed by the operator. The cost of an electromagnetic clutch for a snowblower is around 350 Euros. It is an expensive but convenient feature that provides easier control.

Figure 29. Electromagnetic clutch example for snowblower (Kimpex 2023)

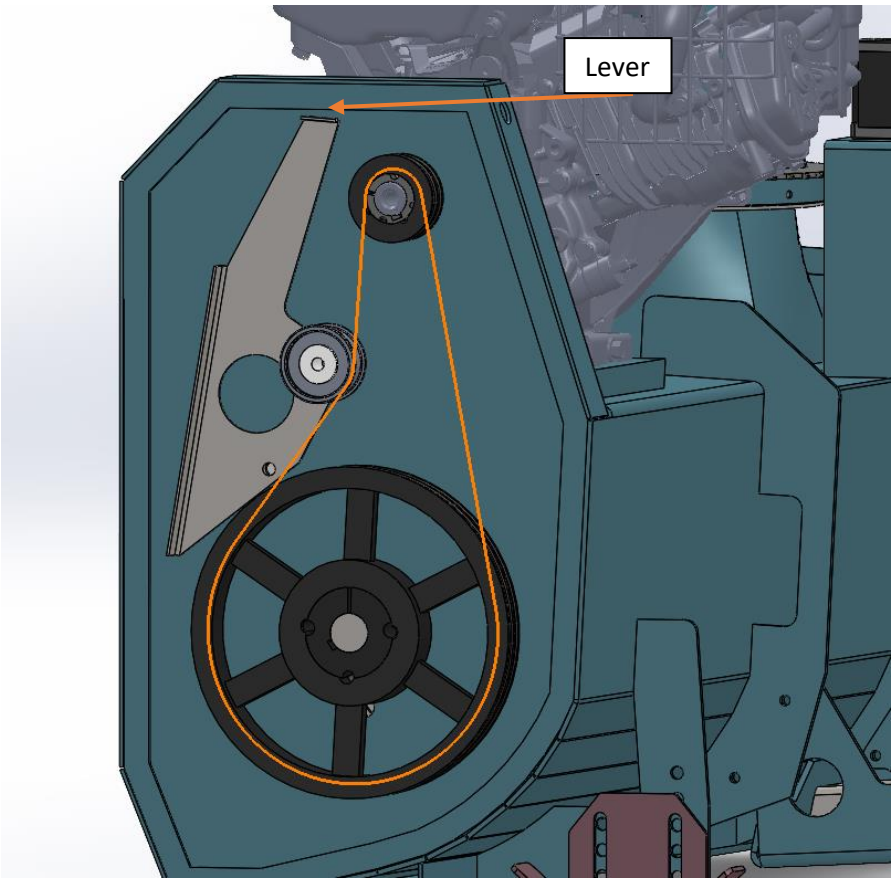

Figure 30. Transmission with mechanical lever

5.5 FEM Simulations

The following FEM simulations are going to be performed to assure the functionality and strength of the snowblower housing, engine platform, and attachment since they are the most critical components. Housing and attachment can absorb the collisions. The engine platform should support the engine's weight and torque during the operation without serious deformation.

The first one is the engine platform FEM study. The Briggs and Stratton 420 cc engine curb weight is 39,8 Kg. The force value that the engine applies attached in horizontal position equals 390 N. The torque equals 28.5 Nm. The thickness of the engine platform is 3 mm. During the simulation, a remote torque feature is used, and remote coordinates are placed on the end of the engine's shaft, where the pulley on a taper lock is fixed. The force of 390 N was applied as equally distributed to the platform.

$$F = m * g = 39{,}7 * 9{,}81 = 390\ N \quad (9)$$

As can be seen from Figure 31, Von Mises appears to be lower than the yield strength value of Domex 420 steel. It provides a reserve for more powerful and heavy engines to be installed. From Figure 32, it is visible that the maximum displacement on the left side is 0.22 mm. It appears to be a suitable value too.

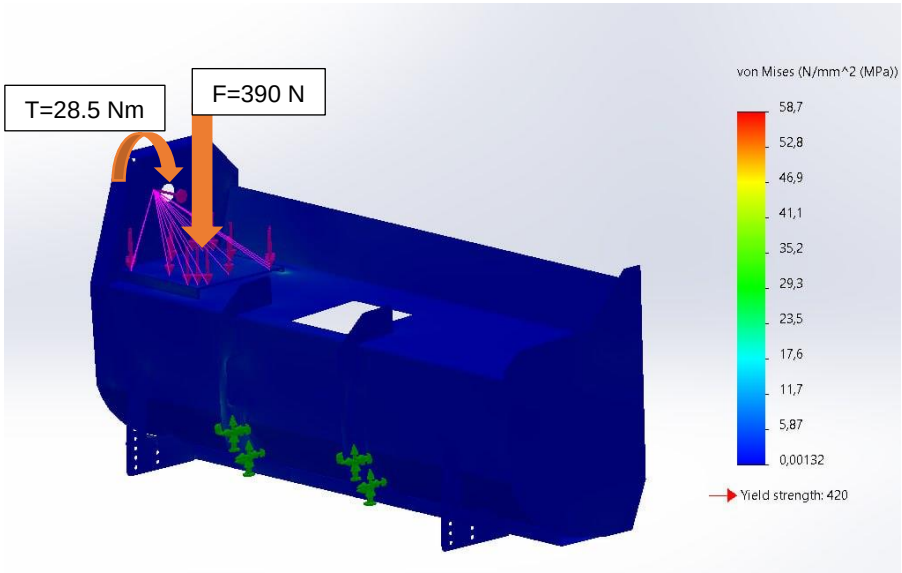

Figure 31. Simulation for engine platform (Von Mises)

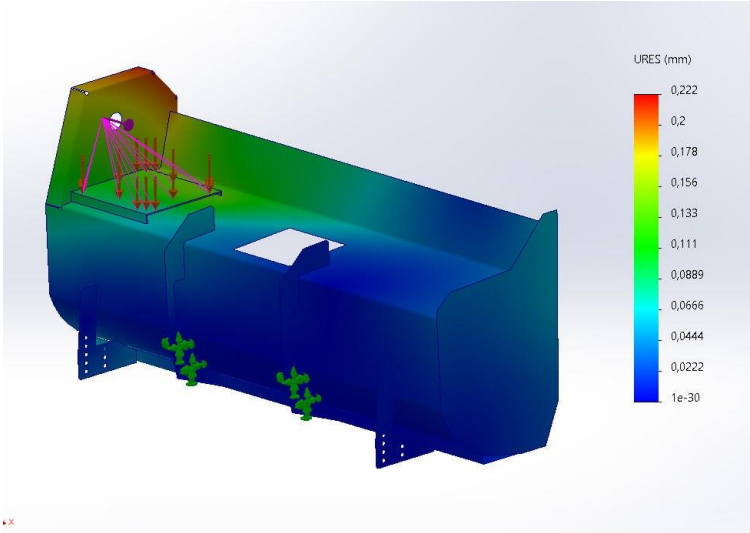

Figure 32. Displacement simulation for engine platform

The second simulation concerns the attachment of the snowblower. The position for simulation represents the case when the housing is lifted by a winch truss connected to the attachment (Figure 33). The housing is fixed with 4 M8 10.9-grade bolts with tightening torque of 41 Nm to the attachment. The attachment is therefore fixed to a longer tube profile that goes to the towbar. All other components are assumed to be welded. The same force of 390 N is applied to the engine platform as well as 50 N force on the top of the housing is applied since the discharge chute will cause this extra load.

The results achieved during the second simulation is 286 MPA value for von Mises stress shown in Figure 34. Maximum displacement is 0.8 mm, shown in Figure 35. Maximum stress appears in the bolt's connections. The highest stress appears at attachment bolted connections. Maximum displacement is at the highest and furthest points. It is realistic and in applicable values for this case.

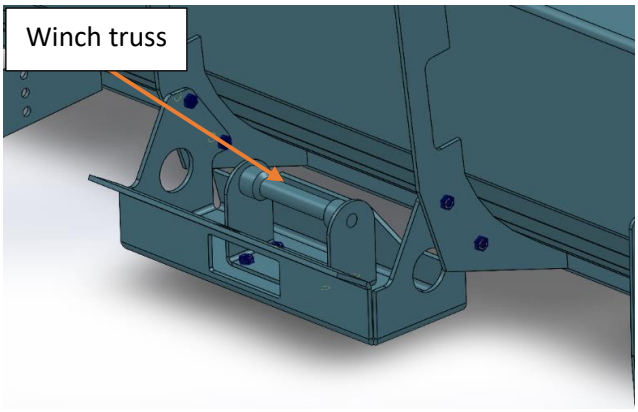

Figure 33. Housing attachment

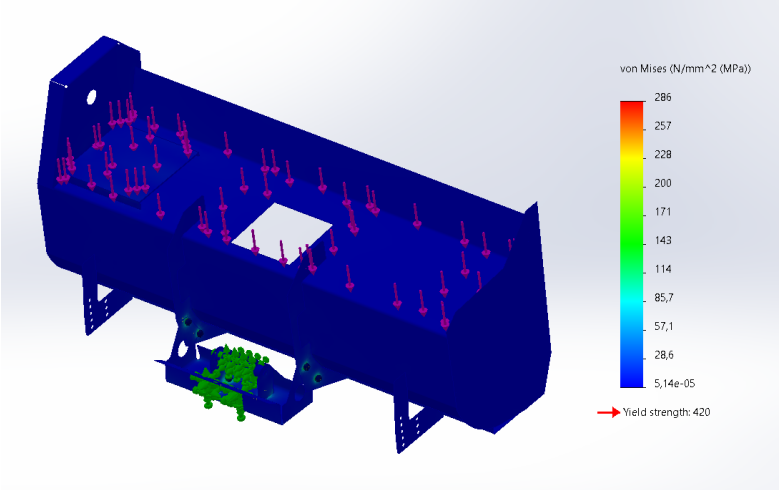

Figure 34. Attachment simulation (Von Mises)

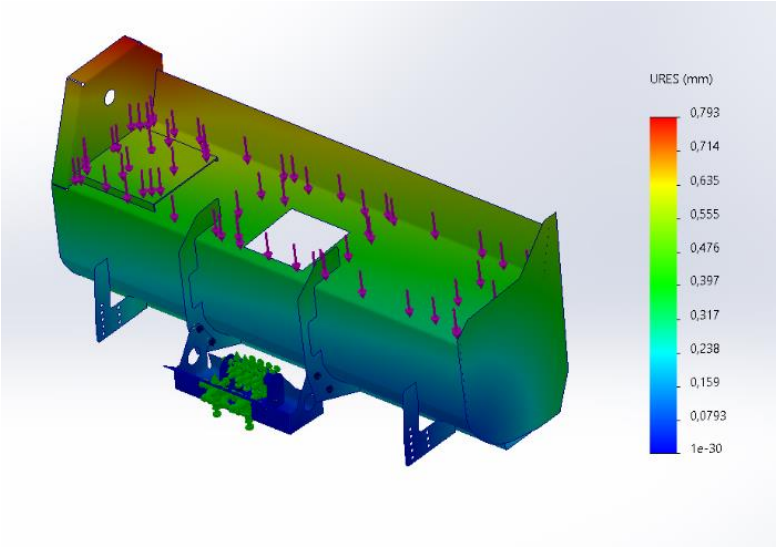

Figure 35. Attachment simulation (displacement)

The third simulation concerns the bump case at a straight wall during the operation. The simulations for the right and left sides of snowblower housing are to be performed. The force of 1000 N is applied alternately on the right and left sides of the housing. The displacement in Figure 36 equals the value of around 4-5 mm at the right and left sides, which is not vital if the assumed hit occurs at the operational speed of around 4 km/h. This meets the durability specifications requirement. The yield point of the material is exceeded during the bump case and equals 721 MPA (Figure 37).

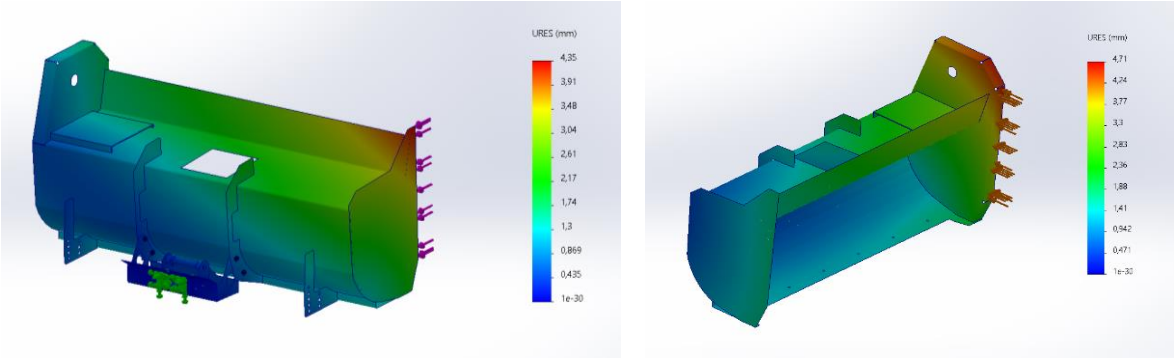

Figure 36. Right and left bumps displacements results

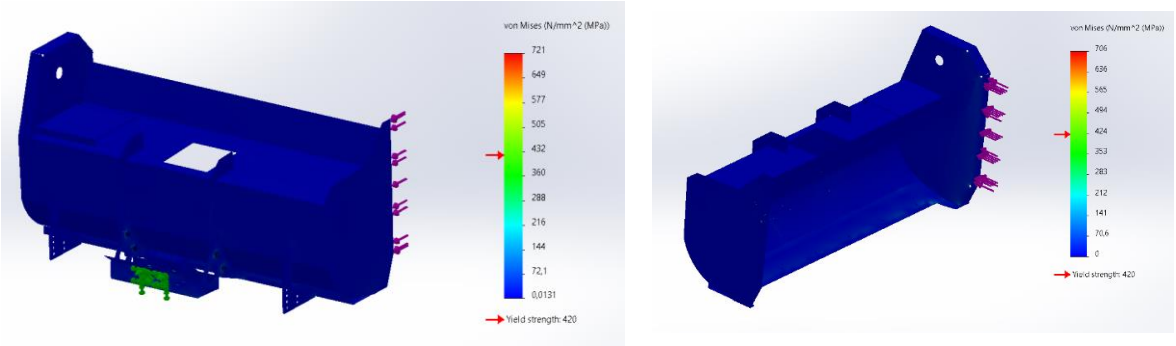

Figure 37. Right and left bumps Von Mises stresses results

To sum up the FEM part, it is important to keep in mind that performed studies show the preliminary approximate results. Before manufacturing and assembly, detailed simulations and calculations have to be performed when all purchased and manufactured components are specified and approved.

5.6 Costs

It is essential to estimate the costs of the prototype during the development phase to ensure its profitability on the future market and meet the target cost. The final cost of the product is formed from the price for sheet metal material, manufacturing of snowblower parts, and price of various purchased components. These components include:

- power source
- clutch
- taper locks and pulleys
- transmission belt
- servo motor
- hitch ball attachment
- profile tube
- impeller
- flange ball bearings

Costs will to be estimated for the configuration with an internal combustion engine and electromagnetic clutch. Manufacturing costs with raw materials are estimated according to the Fractory Metal Fabrication Services website (Fractory 2023).

	Manufactured Parts Costs	Purchased Components Costs	Final Cost
Costs (Euro)	1040	1430	2470

Table 10. Cost estimation of product.

Target cost includes only the raw cost for the components of the concept. It is important to mention that the costs for the purchased components strongly depend on the manufacturer and may vary to the higher or lower price range.

6 Conclusion

Functionality and manufacturability were two main goals that were kept in mind during the development stage. The following thesis work resulted in a prototype of the snowblower that can be utilized with various types of all-terrain and utility terrain vehicles.

Technical aspects, various configuration types and options, as well as operating principles of snow removal machinery for utility demands, were described, analysed, and compared.

The sheet metal fabrication field was investigated with its milestones, geometrical aspects, and materials. Such impressive technology allows to create the diverse, ergonomic, and aesthetic designs. However, it demands close attention from the mechanical designer to the minor details and material behaviour during modelling to ensure the manufacturability of parts that form the final product. Attention to DFM tools and their application for each component during the prototype development resulted in the prevention of possible issues between the design and future manufacturing stages. On top of that, by applying these comprehensible aspects, it is possible to prove that the development stage process becomes overall more efficient, and the quality of the product grows. To support the quality discussion, it is essential to point out that ideally, the development of such a machine with multiple components has to be done not by one person but in a team of diverse field experts. It will definitely bring more efficiency and market-related knowledge.

The product development part in the thesis was based on the combination of what is used in the current industry and the personal experience of the author with the maintenance and operation of all-terrain vehicles. The assumed hydraulic motor options, power electric snowblower machine possibilities, and other features aim to bring versatility to the snow blower future models. Furthermore, the thesis brings the idea of utilizing the platform that assures the various power types and transmission installation.

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Appendix 1. Prototype assembly