FINAL DESIGN REPORT: HEATMASTER SS G SERIES BOILER RE-DESIGN

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Executive Summary

The problem presented to the team by SteelTech Inc. was to recommend a number of design modifications to the G-Series furnaces to improve the serviceability of the furnace, as well as to make components modular. Due to the time constraints, the team focused on improving the furnace insulation and making the smoke bypass system modular.

After concept generation, selection processes, and collaboration with SteelTech, the team decided on the insulation and by-pass concept's to further develop. Polyiscocyanurate (ISO) Rigid Foam and the direct by-pass was our final concepts that was further developed in the report

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The final insulation design consists of ISO rigid foam sheets installed inside the exterior panels of the boiler. This design provides a greater thermal resistance rating of R-21.5, which was over the project need of R-19. Additionally, repairs and their servicing time, had been made shorter due to the insulated panel design, because removing the panels allows the user full access to the internal boiler components. Another advantage of this design, is that it allows incoming air to be preheated before entering the combustion chamber due to the increased air gap space between the insulation and water jacket, which increases the efficiency of boiler.

The final design of the bypass system is a simplified adaptation of SteelTech's current design which allowed the new boiler design to become modular. The shaft is inserted from the side of the boiler and engages inside of a hub welded onto the bypass valve. As well as being modular, this design can be easily fabricated with common manufacturing techniques that can be done in-house at SteelTech.

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1. INTRODUCTION

SteelTech produces various models of wood furnaces under the affiliate company known as HeatMasterSS. These wood furnaces are highly efficient, using 50% less wood when compared to a conventional furnace, and exceed government regulations on emissions by over 75% [1]. SteelTech has tasked our team to re-design the existing G Series Boiler line to allow for better functionality, modularization and servicing. A schematic of a G Series Boiler is shown in Figure 1. For the remainder of the report, the wood furnace will be referred to as the "boiler" and SteelTech will be referred to as the "client."

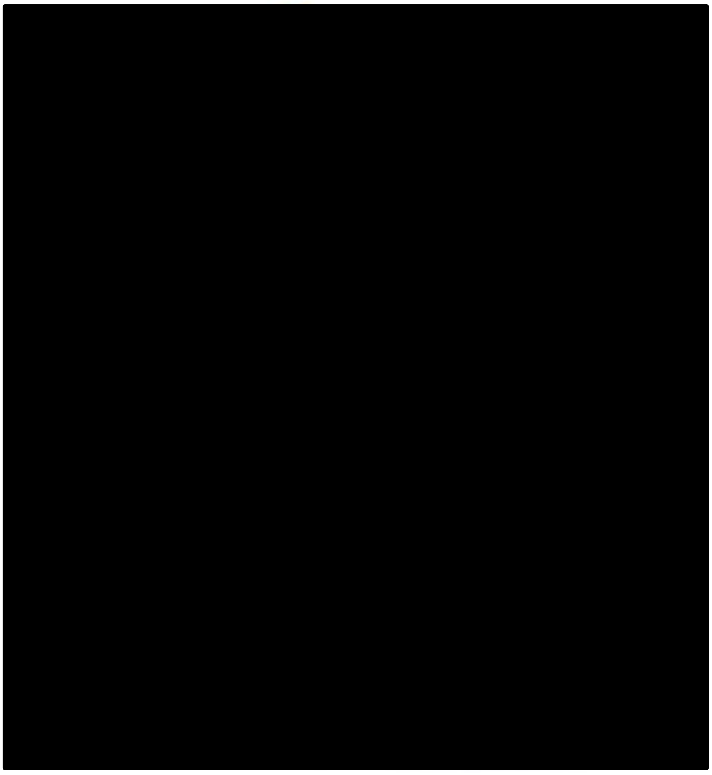

Figure 1: The internal combustion and heat transfer schematic in a G Series Boiler [1]

The client had started to notice some growing concerns with their current boiler design based on feedback from their dealers and consumers. Taken from the feedback, it was found that the current boiler design increased the serviceability time as the ability to reach the internal boiler components between the water jacket and outer walls, was restricted by the currently installed fiberglass batt insulation. Therefore causing the need to cut the insulation to reach the parts, and thus, producing more work as the insulation will need to be repaired as well.

It was also found from the feedback, that the consumers and dealers were interested in receiving modular boiler’s as it would leave the end consumer with some choices in what they would like in their boiler. Having a modular boiler would allow the consumers and dealers the option to choose between multiple upgradable components to better customize their boilers to their likings. This feedback came from the initial statement that some consumers would rather save some money by not getting the by-pass system installed in the boiler, as some deemed it unnecessary. The by-pass system is opened prior to the opening of the firebox when needing to insert more wood. The main function of the by-pass system is, when opened, the smoke will run straight up and out of the chimney rather than going through the whole system to reach the chimney. Therefore, allowing the smoke an easy exit and save the end user from the hassle of smoke in the face or blowback.

1.1 Project Definition

Based on the requirements from the client, our team's main objectives were to make the boilers modular and their components easily accessible for servicing. These main objectives can be broken down into general project needs as shown in the following:

- The boiler needs to be modular so that the consumers and dealers can start with a basic model which then will have optional features that can be added.
- The boiler needs to be easier to service for the dealers and consumers.
- The internal components must be easier to access and replace.
- The redesigned boiler components must be manufactured by an existing method and done in-house.
- The redesigned boiler components must effect profit efficiency positively for the client.

In order to meet these needs, various improvements for the boiler design was needed. In order to make these improvements, the team needed to focus on the key concerns of the boiler that would make a difference in the boilers servicing time and modular needs. To accomplish this, the team focused on the insulation process for the boiler, and the redesign of internal by-pass system as the project had a time constraint of three months.

A list of needs was identified during the initial meetings with the client and from the submitted project summary. These needs were then further assigned numeric values so that a clear visualization of their relative importance to the final design solution could be seen. These numeric values are considered the needs' importance rating, or the impact the need has on the project. These ratings are prioritized from 5 to 0, a high to low importance rating, respectively. The prioritized client needs can be seen in TABLE I.

TABLE I: PRIORITIZED CLIENT NEEDS

#	Need	Importance
1	The boiler design allows for modular/upgradable components	4
2	The boiler is manufactured cost-effectively	3
3	The boiler is manufactured in a timely manner	3
4	The boiler components are manufactured in-house	3
5	The boiler is cost sensitive on the different models to allow for profit efficiency	4
6	The boiler's internal components can be easily serviced	4
7	The boiler must maintain its' insulation standard while allowing for an ease of installation/removal for servicing	5
8	The boiler does not impede the servicing time on the electrical components or wires	3

The above importance rankings were decided on by the team based on the initial meetings with the client and with what fit within the desired scope of the project and timeline. The team then established a series of metrics for the needs which corresponded to values that were then assigned to each metric to create specific goals for the final design solution. Afterwards, each metric was evaluated to clarify the target specifications of the project. These target specifications are displayed in TABLE II and TABLE III.

TABLE II: METRICS AND UNITS

Metric #	Affected Needs	Metric	Ideal Value	Unit	Imp.
1	1	Modular/Upgradable Components	>2	Ea	4
2	6, 7, 8	Servicing Duration	< 1	Hours	5
3	2, 3, 4, 5	Cost	< 8495	$/unit	4
4	4, 7	Thermal Resistance Standard	R>19	$m^2 \cdot K/W$	2
5	1, 2, 3, 4, 5, 7	Manufacturing Lead Time	< 30	Hours	3
6	2, 3, 4	Weight	< 1300	lbs	2

The following ideal values in TABLE II were decided and agreed upon by the team and the client during our meetings.

TABLE III: METRICS AND THEIR RELATED NEEDS

	NEED	METRIC	Modular/Upgradable Components	Servicing Duration	Cost	Thermal Resistance Standard	Manufacturing Lead Time	Weight
			1	2	3	4	5	6
1	The boiler design allows for modular/upgradable components		*				*	
2	The boiler is manufactured cost-effectively				*		*	*
3	The boiler is manufactured in a timely manner				*		*	*
4	The boiler components are manufactured in-house				*	*	*	*
5	The boiler is cost sensitive on the different models to allow for profit efficiency				*		*	
6	The boiler's internal components can be easily serviced			*				
7	The boiler must maintain its' insulation standard while allowing for an ease of installation/removal for servicing			*		*	*	
8	The boiler does not impede the servicing time on the electrical components/wires			*				

These metrics acted as our guidelines when developing our designs for this project and aided with the concept selection. The listed metrics were created to ensure a safe design for the manufacturers and consumers. The designs will also be compliant with the client specified project constraint that any changes to the design will not affect the combustion or heat transfer processes. This constraint also involves ensuring we maintain the product's thermal efficiency and environmental certifications. Additionally, the design will adhere to the client's limitation that the manufacturing of the 409 stainless steel and mild steel for the boilers will remain in-house.

2. Concept Selection

Concept generation and selection processes were used to help break down the team's initial concepts to arrive at final selections that would move forward in the design analysis. These initial concepts came from research put into existing solutions in the current market and were developed during our team's brainstorming sessions. From these sessions came the preliminary concepts that were then compared to a reference concept and put through a screening matrix, which allowed our team to filter out some of the initial concepts. The remaining concepts were then placed in a concept scoring matrix and ranked based on a series of weighted criteria that was approved by the client. The preliminary designs that made it through the scoring matrix were then considered the ideal designs and moved on to analysis. To achieve the project's objectives, that met the client's needs within their specified constraints and limitations, our team decided to focus on the insulation process for the boiler and the redesign of the by-pass system. The following will present a brief overview of the by-pass and insulation scoring matrices, which conclude with the concepts selected for the optimization and analysis phase. For a more in depth discussion on the aforementioned concept selection methodology for both the insulation selection and the by-pass design selection, refer to Appendix A.

2.1 Concept Selection for Insulation

Through the use of the concept selection methodology, three top preliminary concepts for the insulation design on the client's boiler was selected. This was done by following the aforementioned concept selection processes of research, brainstorming, criteria selection, a concept screening matrix, criteria weighting and a concept scoring matrix. Where each step was taking in consideration for the project's needs, objectives, constraints, limitations and the client's feedback.

The current insulation design utilizes loose fiberglass batt insulation, which is tedious to work with. However, the main restriction with the current design is that the insulation increases the servicing time for the boiler for any maintenance repairs needed on its internal components. This issue stems from the fact that the insulation has been wrapped around the boiler and needs to be cut in order for the component to be reached so that it can be repaired.

Concluding the selection processes was the concept scoring matrix which gave an accurate ranking for each of the different concepts that made it through the concept selection matrix. For our concept scoring method, we gave a score of 0 (Poor), 1 (Average), 2 (Strong) and 3 (Exceptional) for each criteria for each concept. We then multiplied it with the criteria's weighted scoring. As a result, we were able to get the total score for each concept. The total scores for each concept are shown in TABLE IV.

TABLE IV: CONCEPT SCORING MATRIX FOR INSULATION

		Concept Variants									
		Med/High Density Fiberglass Blanket		Extruded Polystyrene (XPS) Rigid Foam		Polyisocyanurate (ISO) Rigid Foam		Closed-Cell Spray Foam		Vacuum Insulated Panels (VIP)	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cost	0.20	2	0.40	2	0.40	1	0.20	1	0.20	0	0.00
Moisture Resistance	0.15	1	0.15	3	0.45	1	0.15	2	0.30	3	0.45
Thermal Resistance per Inch	0.20	2	0.40	2	0.40	3	0.60	2	0.40	3	0.60
Easy to Install	0.20	2	0.40	1	0.20	1	0.20	1	0.20	0	0.00
Durability	0.05	1	0.05	2	0.10	2	0.10	2	0.10	2	0.10
Handling Safety	0.10	1	0.10	2	0.20	2	0.20	0	0.00	1	0.10
Flammability	0.10	1	0.10	2	0.20	3	0.30	2	0.20	3	0.30
TOTAL SCORE		1.6		1.95		1.75		1.4		1.55	
Rank		3		1		2		5		4	
Continue?		Yes		Yes		Yes		No		No	

As indicated in TABLE IV, extruded polystyrene rigid foam, polyisocyanurate rigid foam and med/high density fiberglass blanket insulation were the best preliminary designs to solve the client's need and thus moved onto further analysis. As specified before, a detailed analysis for the concept selection of insulation can be found in Appendix A.

2.2 Concept Selection for By-Pass System

Applying the same concept selection methodology used for the insulation concepts, the top preliminary concept for the by-pass design was selected. The current bypass system had a complex linkage system and in order to make this system easier to service, install and remove, the concepts brainstormed strived for simplification.

The concept scoring matrix used for the by-pass concepts followed in suit with the insulation selection. A score of 0 (Poor), 1 (Average), 2 (Strong) and 3 (Exceptional) was given for each criteria for each concept. The rating from 0-3 was given to each concept based on how well it met the criteria, which was then multiplied by the weight of each criteria. The final scores for the by-pass concepts is shown in TABLE V.

TABLE V: CONCEPT SCORING MATRIX FOR BY-PASS SYSTEM

		Concept Variants							
		Direct		Extended Chimney		Butterfly Valve		Butterfly Valve with Extended Chimney	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Ease of Installation	0.20	3	0.60	0	0.00	2	0.40	0	0.00
Clean	0.07	1	0.07	3	0.21	1	0.07	3	0.21
Easy to Operate	0.20	3	0.60	3	0.60	3	0.60	3	0.60
Cost	0.40	3	1.20	0	0.00	2	0.80	0	0.00
Durability	0.07	2	0.14	1	0.07	2	0.14	3	0.21
Manufacturability	0.07	3	0.21	1	0.07	3	0.21	1	0.07
TOTAL SCORE		2.82		0.95		2.22		1.09	
RANK		1		4		2		3	

As shown by the weighting matrix, TABLE V, the direct bypass system scored the highest therefore indicating it is the best design and hence will be optimized. As indicated before, a detailed analysis for the concept selection of by-pass system can be found in Appendix A.

3. Concept Analysis

With the use of concept selection methodology, the preliminary concept selections for both insulation and the by-pass system were systematically chosen and will move onto further analysis. The following analyses will give justification to the selected concepts, verifing that the concepts will work and ultimately prove that the concept will satisfy the project and client's needs.

3.1 Insulation Design Analysis

The following section outlines the analyses performed on the preliminary insulation concepts to arrive at the final preliminary concept, which is put forward for recommendation. The following sensitivity analysis, cost analysis and manufacturing considerations will aid in the justification of the final preliminary concept.

3.1.1 Sensitivity Analysis

Considering the concept scoring matrix for insulation, TABLE IV, extruded polystyrene (XPS) rigid foam, polyisocyanurate (ISO) rigid foam and medium or high density fiberglass blanket were ranked from 1 to 3 respectively. However, as their total scores ranged in the values between 1.6-1.95 with 0.15-0.20 margin between the three concepts, it can be argued that the total scores do not achieve a clear understanding of which concept should be chosen for the final analysis. To ensure that our methodology used to select our final preliminary concept was not underestimating the effect of a slight change in values, we re-estimated some of the scores, using brainstorming sessions and continued research, to run a sensitivity analysis for the concept scoring matrix. The weightings for the selection criteria were not altered as they were already scrutinized with the client to achieve accurate values. To easily visualize the changes done to the scoring matric, a colour-code was used. This colour-code is shown in TABLE VI.

TABLE VI: SENSITIVITY ANALYSIS COLOUR CODE

Cell Colour	Meaning
(green)	Score increased from previous
(red)	Score decreased from previous

In the re-estimated matrix, the colour coding was applied to visulally show the changes done to the scoring matrix. It should be noted, that only the final three primlinary concepts that made it through the intial scoring matrix in TABLE VI, was put through the sensitivity analysis and displayed in TABLE VII.

TABLE VII: RE-ESTIMATED SCORING MATRIX FOR INSULATION SENSITIVITY ANALYSIS

		Concept Variants					
		Med/High Density Fiberglass Blanket		Extruded Polystyrene (XPS) Rigid Foam		Polyisocyanurate (ISO) Rigid Foam	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cost	0.20	3	0.60	1	0.20	1	0.20
Moisture Resistance	0.15	1	0.15	2	0.30	2	0.30
Thermal Resistance per Inch	0.20	1	0.20	2	0.40	3	0.60
Easy to Install	0.20	1	0.20	2	0.40	2	0.40
Durability	0.05	1	0.05	2	0.10	2	0.10
Handling Safety	0.10	1	0.10	2	0.20	2	0.20
Flammability	0.10	1	0.10	2	0.20	3	0.30
TOTAL SCORE		1.4		1.80		2.10	
Rank		3		2		1	
Continue?		No		No		Yes	

As shown in TABLE VII, the scores were either increased or lowered for each of the insulation concepts. During the team's brain storming sessions, the score values used for scoring matrix in TABLE IV, were scrutinized against the research done on the insulation to get a second opinion on if the score given intially was the ideal value. Looking back at the intial scoring matrix, the scores given out ranged from 0-3: 0 (Poor), 1 (Average), 2 (Strong) and 3 (Exceptional). As an example, the team wanted to run the sensitivity analysis to confirm that if a score that was given in the initial scoring matrix was strong (2), could be dealt into a category of either average (1) or exceptional (3). Comparing the concepts to one another, the values given before and the research, showed that:

- "**Cost**" for the Med/High density could be argued to have a value of 3. When comparing the cost values initially researched, the Med/High density insulation cost could be considered exceptional as it had a low cost of 37 Cents/sq.ft [2], whereas, XPS and ISO had 47 Cents/sq.ft [3] and 50 Cents/sq.ft [3] respectively. With that being said, it can also be argued that the cost difference between XPS and ISO is minimal, which was why the cost for XPS was decreased to a 1 to match the ISO value, as this cost was more suited as an average value.
- "**Moisture Resistance**" was increased for ISO from 1 to 2 as the type of insulation was argued to have more of a strong value rather than average. It was argued that compared to the average moisture resistance of the various different types of insulation in the market, ISO insulation had a strong resistance to moisture. The moisture resistance rating for the XPS insulation was discussed and ultimately decreased from 3 to 2 as XPS still absorbs water over time if submerged and therefore not classified as exceptional.

- “**Easy to Install**” was increased for both of the rigid foam insulation’s XPS and ISO from 1 to 2 and decreased for the Med/High Density Blanket from 2 to 1. It was reasoned that working with a solid board of insulation would be preferred as it is a rigid material and therefore, easier to handle and cut when compared to the alternative of loose Batt or foam material. For that reasoning, XPS and ISO was increased to a strong rating whereas the blanket insulation was decreased to an average rating.

As shown in TABLE VII, ISO Rigid Foam was the best concept as it had the highest total score after the sensitivity analysis was complete. It can also be noticed that there is a greater marginal spread, 0.20-0.30 between the three concepts total scores, which aids in confirming that the final preliminary concept is ISO Rigid Foam. Other analyses were then conducted to check the concepts cost and manufacturability to the project needs to confirm the concepts success.

3.1.2 Cost Analysis

Through the use of completing a cost analysis, we were able to analyze if our concept would meet the project’s need of being cost effective. The cost analysis was used to define our unit cost. As a result, the maximum benefit was determined by comparing the different insulation company’s costs and benefits. From the sensitivity analysis, polyisocyanurate (ISO) rigid foam had the highest total scores of the preliminary concepts after the re-estimation. As a result, the cost analysis will focus on the polyisocyanurate ISO rigid foam as it is the final preliminary concept. This allowed us to compare the different suppliers ISO and their cost for the insulation. The companies used in the cost analysis were chosen because of their availability to pick up or deliver the material in Manitoba.

The client provided that on average, they sell 25-40 boilers per month with an average cost of $8,495 and that the labor cost per hour was between $20-25. For this cost analysis the minimum amount of boilers sold per month, 25, was used for calculating the minimum amount of insulation needed per month. Calculations with the use of the client provided boiler model and drawings gave a required insulation area of 86.6 sq ft per boiler. Sample calculations for the required area needing to be insulated is shown in the following calculations:

Area of the Top: $62\frac{11}{16} \times 49\frac{11}{16} = 3114.785\ in^2$

Area of the Side R/H: $63\frac{1}{4} \times 57 - 12\frac{15}{16} \times 13 = 3437.063\ in^2$

Area of the Side L/H: $63\frac{1}{4} \times 57 = 3605.25\ in^2$

Area of the Rear wall: $59\frac{7}{16} \times 38\frac{15}{16} = 2314.348\ in^2$

Total area = Area of the top+ area of the side R/H+ area of the side L/H+ Area of the Rear wall

= 3114.785+3437.063+3605.25+2341.348

=12471.45 in^2

=86.6 ft^2

The thickness of the ISO insulation needed to achieve a thermal resistance over an R-Value of 19 was 3.5” and was included in the cost analysis as the cost varies for the panels by the thickness. Using the insulation area calculated by the model, the number of panels needing to be purchase to insulate the boiler was determined. Thus, the number of required panels needed for 25 boilers was obtained. A list for the cost of the insulation for the different companies is summarized in TABLE VIII. Convey Supply (Sopra insulation), Lowes and Home Hardware provided the price for the ISO rigid foam. Sample calculations of the material price, total price and R-Value per inch is shown in the following calculations. These sample calculations are for ISO rigid foam supplied by Lowe's:

Amount of required panels for the covered are a= 86.6/3 2= 2.7 < 3

Price for one panel with a thickness of 1.5" = $37.99

Price for one panel with a thickness of 1" = $27

In order to insulate the boiler with a thermal resistance value over 19, we needed to equal 3.5" of thickness. Therefore, two 1" panels and one 1.5" panel is required to make the 3.5" section, thus, a total cost for one boiler is:

Cost for one boiler: (37.99*3) + (27.99*6) = 113.97 + 167.94 = $281.91

Price for 25 boilers = 281.91*25 = $7047.75

Labor cost (Assuming an average of $23 per hour) = 23*25 = $575

Total cost = 575+7047.75 = $7622.75

TABLE VIII: INSULATION COST OF ISO INSULATION FOR 25 BOILERS

Insulation	Company	Installation time per boiler (Hours)	Thickness (in)	R Value per Inch	Total Price for 25 Boiler
Polyisocyanurate (ISO) Rigid Foam	Lowe's	1	3.5	6.00 [4]	$7622.75
	Home Hardware	1	3.5	6 [5]	$4235
	Conovy Supply (Sopra)	1	3.5	5.85 [6]	$5037.5

According to TABLE VIII, among the three companies, Home Hardware provides the cheapest price for ISO with the considerations of labor cost. In conclusion, Home Depot will be the final choice to supply the ISO rigid foam for the client's boiler. Besides being the most cost effective out of the respective companies, ISO rigid foam can supply an ease of handling and installation because of its rigid exterior. This was why it was considered an advantage for installation time in the cost analysis and therefore, can be considered an advantage for the manufacturing process.

3.1.3 Manufacturing Considerations

The added benefit of using a rigid material is that it can easily be handled and worked on when compared to working with a flexible loose batt blanket. The current insulation solution is to roll loose batt insulation over the water jacket, shape the insulation to the shell, cut the insulation and squish it on with the outside panels. Problems with the current solution come from it being a tedious task to work with the loose insulation when shaping and cutting out the necessary insulation sections needed for the sensors and protrusions while it lays on the boiler. Also, by compacting the insulation with the outside panels it no longer gives it an R-Value of 19 since the thickness of the insulation to achieve that with the loose batt insulation is around 6.29" and there currently is only 3-4" of space between the boiler's water jacket, outer wall panels and roof. On top of all this, once manufacturing of the boiler has been completed and the boiler has been sold, the problems of insulation extends to the field in regards to the possible maintenance and servicing time to repair any broken components that may arise during operation. To service or repair any of the components that are internally on the boiler, the outside panels on the boiler need to be removed, followed by the removal of the insulation to get to the component. Thus, producing more repairs as the insulation now needs to be repaired. By switching to ISO rigid foam insulation, these problems can be rectified.

ISO rigid foam can supply an R-Value greater than R-19 due to its high R-value per inch of thickness rating. To achieve an R-Value of 19, the ISO insulation thickness would need to be 3.17”, and as shown in the cost analysis, the thickness that would be purchased is 3.5”, consequently achieving an R-Value greater than 19. However, ISO would not be able to be installed the current method due to its rigid form. As the outside panels currently designed, only have a thickness of 3-4”, they would not be able to fit over the insulation. However, this creates more of a solution rather than a problem because increasing the panel’s thickness and the use of the rigid material ISO, the insulation can now be installed in the panels which is similar to most Heating, Ventalation, and Air Conditioning (HVAC) applications.

In HVAC installations, as done in most fridge cooler scenario’s, insulation, such as spray foam, ISO and vacuumed insulated panels, are installed in the panels. Thus during installation, the outer walls are complete and do not require extra processes to manufacture and install. Therefore, the panels are all connected together like pieces of a puzzle that fit together tightly and with ease, which encloses the fridge cooler section and their HVAC systems. By following the same method as HVAC applications, installing the ISO rigid foam in the panels allows the client to achieve an ease of installation with the panels and insulation, as it will be one piece. Panels of ISO rigid foam can be measured ahead of time and have the appropriate holes cut out of the panels for the electrical box, wires, and any sensor’s or handles that protrude to the exterior of the boiler. Thus, the panels of the ISO can then be slid into the outside panels of the boiler to create an insulated wall panel. An example of an insulated wall panel is shown in Figure 2.

Figure 2: Rendered Solidworks image of the boiler and an example of what an insulated panel may look like

Due to ISO's density, installing the rigid foam in the outside wall panels would add approximately 15 lbs of extra weight; as a result, a worker, a dealer or a consumer would be able to pick up the entire panel. This weight was calculated using the calculated square foot of the right hand side panel and the ISO data sheet [7]. Having insulated removable panels would allow a maintenance worker, dealer or consumer access to the interior components of the boiler. Therefore, the internal components of the boiler can be easily serviced or repaired since loose batt insulation no longer needs to be cut. Consequently, the removable panels cut down on the servicing time and does not impede the servicing time on any electrical components or wires on the boiler.

3.2 Modular Bypass

The modular bypass design for SteelTech is based off of their current bypass design. This allows the new design to be integrated into the current boiler with minimal changes. A cutaway view of the new bypass design installed in the boiler is shown in Figure 3.

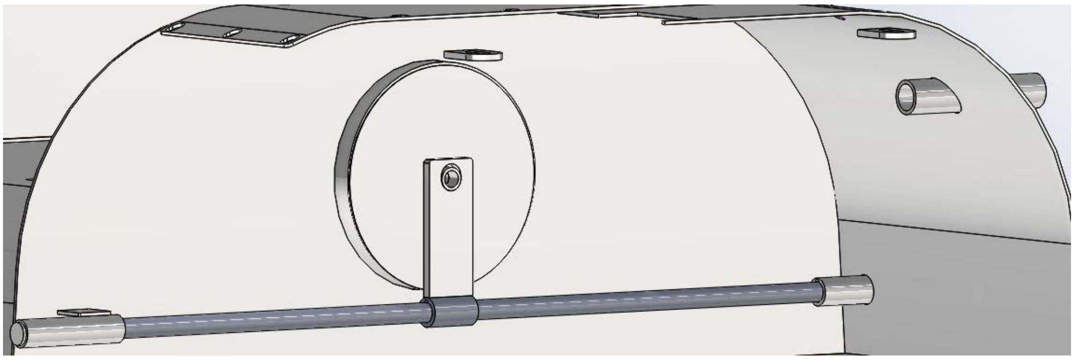

Figure 3: Modular bypass installed in the boiler

To make the bypass design modular the valve and connecting plate are installed during manufacturing. Then, the shaft can be inserted later if the customer wants to upgrade to adding the smoke bypass system.

3.2.1 Bypass Design

The critical aspect in making the bypass modular is to allow the shaft to be inserted after the boiler has been fully built. This is achieved by running the shaft through a hub welded on the valve connecting plate. There is a key in the shaft to transmit torque to opening the valve as shown in Figure 4.

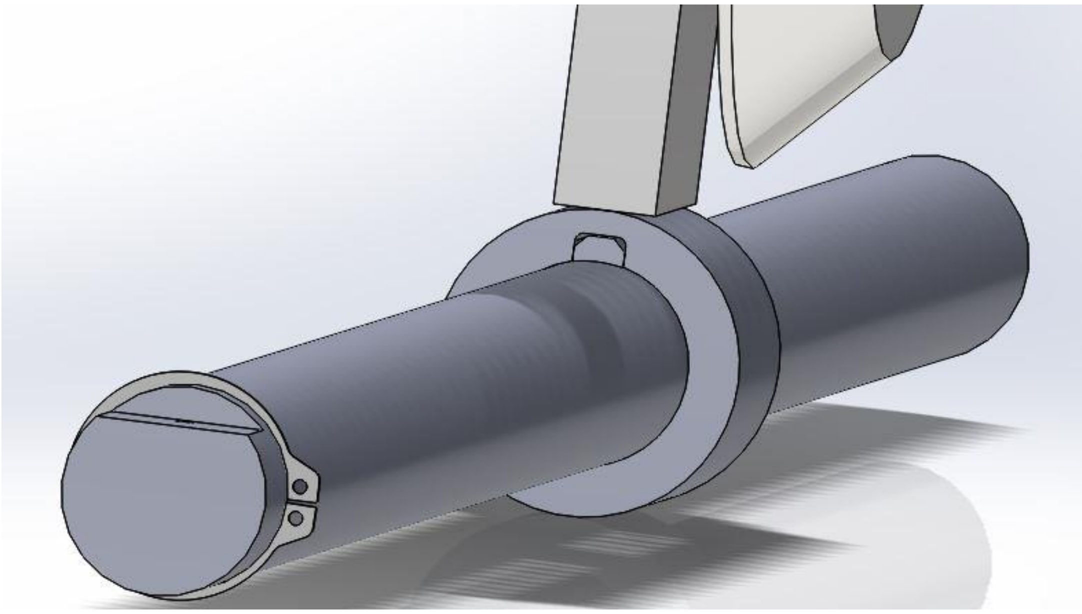

Figure 4: Modular bypass shaft with key locking into the hub

3.2.2 Shaft Design

The shaft design was based on the current shaft which is 0.75” in diameter and 37.5” long. The shaft and hub are made of 409 stainless steel. The hub has an outside diameter of 1.125” and is 2” long. For a shaft of this diameter the standard key size in 3/16” square [8]. The key is to be made out of mild steel. Assuming the key is the same length as the hub, 2”, the formula for the maximum torque the key can transmit is [8]:

$$T_{max} = \frac{\tau DWL}{2N}$$

Where the shear stress is assumed to be $0.577\sigma_{yld}$ and the safety factor (N) is taken as 2.

$$T_{max} = \frac{31200(0.75)(0.1875)(2)}{2(2)} = 2194\ in \cdot lb = 182.8\ ft \cdot lb$$

Along with the shear stress in the key, the bearing stress also has to be checked to determine the maximum torque that the key can bear, given by [8]:

$$T_{max} = \frac{\sigma_{yld} LDW}{4N} = \frac{54000(2)(0.75)(0.1875)}{4(2)} = 1898\ in \cdot lb = 158.2\ ft \cdot lb$$

Therefore, the maximum torque the key can transmit is 158.2 ft*lb. To prevent large stress concentration factors in the key and keyways, a fillet with a radius of 1/32" was applied to the keyway in both the shaft and hub. A 3/64" X 45˚ chamfer was applied to the key. The keyway fillet is shown in Figure 5 and the key chamfer in Figure 6.

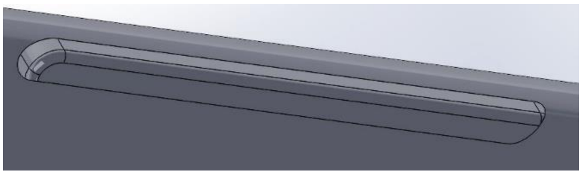

Figure 5: Shaft keyway with fillet

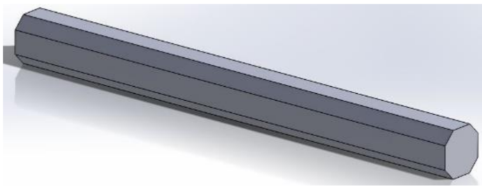

Figure 6: Key with chamfer

To determine the maximum torque that the shaft itself can transmit is given by the equation:

$$T_{max} = \frac{\tau \pi r^3}{N} = \frac{19560\pi(0.375)^3}{2} = 1620\ in \cdot lb = 135\ ft \cdot lb$$

The shaft is in fact weaker than the key, however, 135 ft*lb should be well above the torque the shaft will ever experience under normal operating conditions. A fatigue analysis on the shaft is simple because the shaft is not subjected to a bending moment, which is the primary cause for a fatigue failure in a shaft. The shaft is only subjected to a fully reversed torsional load. The fatigue strength (S_n) of 409 stainless is 47 ksi [9], so the torsional fatigue strength (τ_n) is 27.1 ksi. However, since τ_{yld} is only 19.6 ksi the shaft will never be subjected to a stress amplitude greater than the fatigue strength, therefore, fatigue failure is not an issue.

Other features on the shaft include a retaining ring groove, to limit how far the shaft can be inserted during installation. There is a flat section at the end of the shaft to mount the handle on, as well as serving to index the shaft when being installed. There is also a small hole for a pin to restrain the handle. These features are shown in Figure 7. All drawings for the bypass can be found in Appendix A.

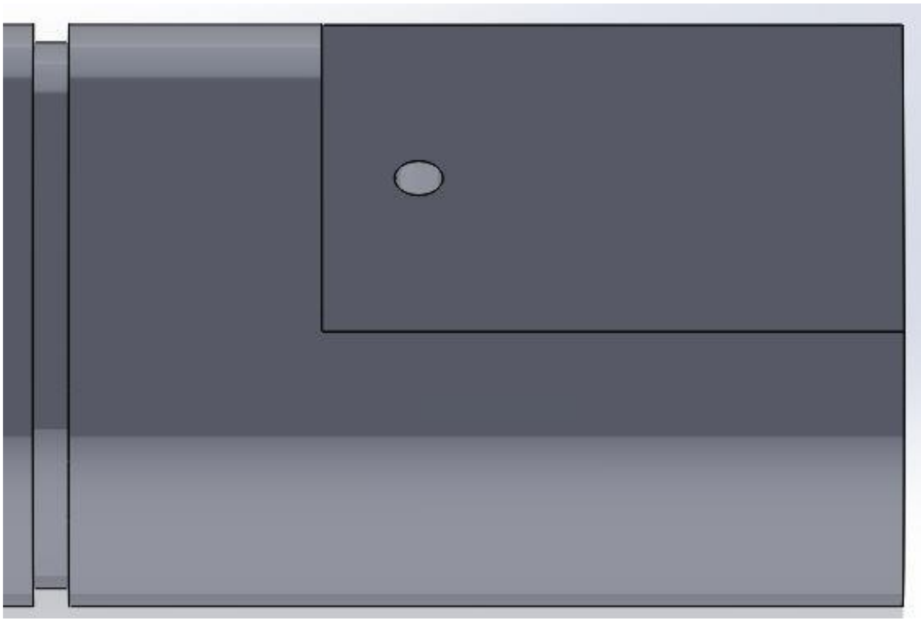

Figure 7: Other shaft features

3.2.3 Installation

If a customer orders a G Series furnace without the smoke bypass option, the valve is still installed into the furnace during the manufacturing process. The valve would still be put into place, then held in its position using either a high temperature tape or sealant. A selection of such products are produced by ADL Insulflex. If the customer wishes to upgrade to the smoke bypass the shaft can then be inserted through the sheath, as shown in Figure 8. Note that the sheath needs to be broached with the same keyway as the hub. Before inserting the shaft, it is recommended to apply Loctite 9432NA Hysol Epoxy Structural Adhesive to the key. After inserting the shaft, allow the Loctite to cure before operating the bypass to break the high temperature tape or sealant securing the valve.

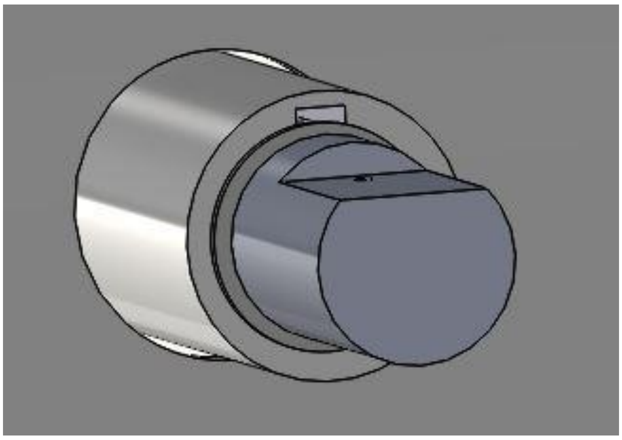

Figure 8: Installed shaft exterior view

3.2.4 Risk Management

A risk analysis was performed during the bypass design process. Two tables, TABLE IX and TABLE X, were created to analyze the probability of each risk occurring and the impact should the risk occur on a scale from 1 to 5, 1 being extremely unlikely and 5 being almost certain.

TABLE IX: PROBABILITY SCALE

Scales	Likelihood	Probability of occurrence
1	Rare	0-20%
2	Unlikely	20-40%
3	Even Chance	40-60%
4	Likely	60-80%
5	Almost Certain	80-100%

TABLE X: IMPACT SCALE

Scales	Consequence
1	Little or no consequence to performance
2	Minor reduction in performance
3	Moderate reduction in performance
4	Significant degradation in performance
5	Severe degradation in performance

The probability ranking then is multiplied with the impact ranking to give the risk priority number (RPN) as shown in Figure 9. The RPNs are tabulated in a matrix and colour coded from green to red to visually indicate relative risk, green being low risk and red being extremely high risk.

Probability	**5**	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
Scales		**1**	**2**	**3**	**4**	**5**
		Severity				

Figure 9: RPN Matrix

The full risk ranking based of the RPN, with the associated colour code, is shown below in TABLE XI. Also shown in the table is a description of the actions needing to be taken in order to deal with the types of risk based on severity.

TABLE XI: THE RISK RANKING

RPN	Risks Ranking		Description
1-3		Low Risk	Manage by routine procedures and operations
4-6		Moderate Risk	Manage by specific monitoring or response procedures
8-12		High Risk	Appropriate actions need to taken
15-25		Extreme Risk	Immediate action required with all team members involved

A list of potential risks for the bypass design were then generated. These risks, their description and RPN are tabulated in TABLE XII.

TABLE XII: THE DESCRIPTION AND RANKING OF POTENTIAL RISKS

Risks #	Risk Title	Description	Probability	Severity	RPN
1	The drawing of the bypass system is not accurate	Inaccurate dimensioning will impede the manufacture of the boiler.	1	3	3
2	The material of the bypass system	The material is not tough enough. The bypass system might break or malfunction during service	1	4	4
3	The cost of new designed bypass system beyond the expected	New design drives the price of the boiler to high causing profit margins to be too small.	2	2	4
4	Leakage of smoke from the closed bypass system	During the boiler service the smoke may leak because of the gaps in the bypass system.	2	2	4
5	The valve of bypass system is seized up	The friction around the valve is too large so the user cannot use the handle to open the bypass system easily.	3	3	9

To mitigate both the occurrence and effect of each risk a response strategy for each risk is shown in TABLE XIII.

TABLE XIII: APPROACHES AND STRATEGIES FOR POSSIBLE RISKS

Risks #	Risk Title	Response Strategies	Trend
1	The drawing and dimension of the bypass system is not accurate	Research	Improving
2	The material of the bypass system	Accepted	Unchanging
3	The cost of new designed bypass system beyond the expected	Mitigate	Improving
4	Leakage of smoke from the closed bypass system	Mitigate	Improving
5	The valve of bypass system is seized up	Mitigate	Improving
6	The heat conduct through shaft to the handle	Mitigate	Improving

3.3 Future Recommendations

Due to the time constraints of this project, the team focused on improving the boiler's insulation, as well as making the smoke bypass system modular. However, in order to increase the competitive advantage of the boiler for the client, our team has offered the following suggestions for the client as possible future modifications based on our brainstorming and research. The following three recommendations for future boiler upgrades are Wi-Fi module, electric heating package and a damper motor for cleaning the flues.

Wi-Fi module

The Wi-Fi module is an advanced device that provides a way to interact between a smart phone and boiler. It not only helps monitoring the status of the boiler, but also helps operating the boiler based on the order of the customer. As a result, a customer is able to operate the boiler conveniently and comfortably from any location as done with most smart thermostats these days. The following Wi-Fi module can be seen in Figure 10.

[redacted]

Figure 10: Example of Wi-Fi module [10]

Electric heating package

The use of an electric heating package can help pre heat the boiler's water tank prior to use, as well as provide another means of pre-heating the air going into the firebox, which would increase the efficiency of the boiler. A standard heating package can include components such as a energy storage tank, electric heating elements, electric element box and power controller, as shown in Figure 11 [11]. The package shown in Figure 11, is used to heat up the water during the day which can save the energy of burning more wood at night due to the water having been pre-heated during the day.

[redacted]

Figure 11: Electric heating package components [11]

Damper motor

Finally the use of a simple damper motor can aid the client and the consumer in avoiding unwanted repair scenarios with the flue cleaners currently on the boiler. To clean the flues in the boiler, the consumer needs to rotate a lever five times which causes the spiral blades inside to move up and down consequently cleaning the heat exchanger tubes. However, when there is the case that the consumer forgets to clean the heat exchanger tubes over a long period of time, they can get clogged and the lever to clean them will no longer work. To repair this mechanism and clean the flue now becomes a tedious task.

With the use of a simple damper motor, which can also be controlled by a Wi-Fi system, a regular cycle can be setup to turn on the damper motor and cause the spiral blades to go up and down ultimately cleaning the heat exchanger tubes. Since common damper motors rotate at 90 degrees, it would be a useful application to add to the boiler as it eliminates the lever that cleans the tubes and removes the human error of forgetting to clean the heat exchanger tubes. Therefore, removing the unnecessary need to repair them if the heat exchanger tubes were ever to be clogged.

This is also another means of modularization for the boiler as inputting a damper motor into the boiler can be classified as an upgrade and therefore can be sold as an upper model. The insertion of the damper motor instead of the lever would be an relatively easy change out as the motor would just need to be secured to the boiler, wired to the electrical box and attached to the already designed flue cleaners. An example of a damper motor built by Honeywell, can be seen in Figure 12.

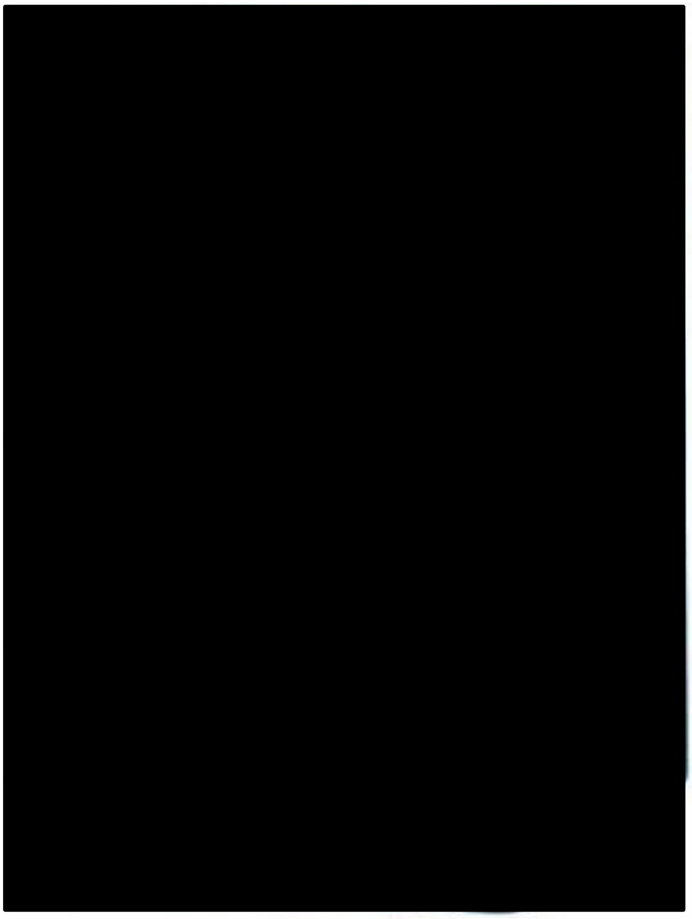

Figure 12: Honeywell damper actuator [12]

4.0 Conclusion and Summary of Final Design

Through research, analysis and discussion, the final conceptual design had been concluded for insulated material and by-pass system for SteelTech. Due to the restricted time of this project, only insulated material and by-pass system had been considered. In order to increase the competitive advantage, our team suggested Wi-Fi module, electric heating package and damper motor as reference future modification for SteelTech Company.

4.1 Insulation Panels

Based on the sensitivity analysis, the team has chosen polyisocynaurate rigid foam as the final design for insulated material. Home Hardware was chosen to be the final supplier company for polyisocynaurate rigid foam because it is the least expensive ($4235) compared to the other companies' suppliers. Meanwhile, the design provides a greater thermal resistance rating of R-21.5, which was over the project need of R-19. Additionally, repairs and their servicing time, had been made shorter due to the insulated panel design, because removing the panels allows the user full access to the internal boiler components. Another advantage of this design, is that it allows incoming air to be preheated before entering the combustion chamber due to the increased air gap space between the insulation and water jacket, which increases the efficiency of boiler.

4.2 Bypass

The final design of the bypass system consists of a valve, hub, shaft and key. All the components, except the key, are made of 409 stainless steel. The key is made of mild steel. The bypass is actuated by the user through a handle directly attached to one end of the shaft. The final design meets SteelTech's needs for the bypass. First and foremost, this design makes the bypass modular, which was SteelTech's primary desire for the bypass. Additionally, the bypass meets the need of being simple and cost effective to manufacture. A rendered image of the modular bypass design installed in a boiler is shown in Figure 13.

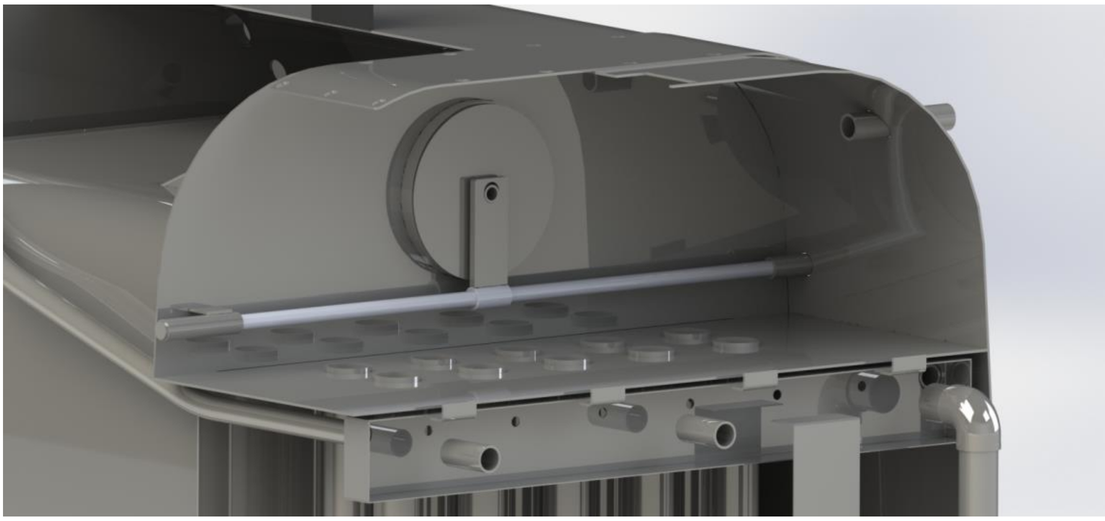

Figure 13: Render of installed bypass

Our team has been successful in meeting the design requirements laid out by SteelTech. The ISO rigid foam insulation panels provide the required R19 insulation value that the current bat insulation does not provide. Additionally, the insulation panels provide easy installation and service as well as improving the efficiency of the boiler. The bypass successfully meets SteelTech's requirements by being made a modular component as well as being simplistic design to manufacture. The team is confident that final designs will effective improvements for SteelTech.

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Appendix A – Concept Selection

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A.0 Concept Selection

Concept generation and selection processes were used to help break down the team's initial concepts to arrive at possible final selections that would move forward in the design analysis. These initial concepts came from research and were developed during our team's brainstorming sessions. From these sessions came our team's preliminary concepts that were then compared to a reference concept and put through a screening matrix which allowed our team to filter out some of the initial concepts. The remaining concepts were then placed in a concept scoring matrix and ranked based on a series of weighted criteria. The concepts that were selected were then analyzed and optimized to produce the final design. The following elaborates on the aforementioned concept selection methodology for both insulation selection and the by-pass design selection.

A.1 Concept Selection for Insulation

This section produced three top preliminary concepts for the insulation on the client's boiler. This was done through research and the use of the concept selection methods.

There are a number of broad categories insulation on the market. The categories of insulation explored in this section were blankets, rigid foam, loose-fill, spray foam and vacuum insulated panels. These categories of insulation each have their own advantages and disadvantages. Research on the existing insulation solutions allowed our team to compare the advantages, disadvantages and specifications of the different types of insulation to our projects goals and needs. The information to follow was gathered by the team during our research phase of the project and goes through the various insulation types and their key details. This information is summarized in TABLE XIV.

TABLE XIV: SUMMERIZED KEY DETAILS FOR VARIOUS INSULATION TYPES

Type	Insulation Materials	Advantages	Disadvantages	Cost	Thermal Resistance (R) per inch
Fiberglass Blanket: Batt or Rolls	Low Density	-Inexpensive -Easy Installation	-Range of R-Value is considered low -Fiberglass particles pose a health hazard during installation -Vulnerable to moisture which leads to mold [13]	31-36 (Cents/sq.ft) [2]	R-2.9 to R-3.8 [2]
	Med/High Density	-Higher R-Value compared to the low density blankets -Easy Installation -Relatively inexpensive -Greater value of R in return for cost	-Fiberglass particles pose a health hazard during installation -Vulnerable to moisture which leads to mold [13]	37-42 (Cents/sq.ft) [2]	R-3.7 to R-4.3 [2]
Rigid Foam	Expanded Polystyrene (EPS)	-Cheapest out of the three -Does not degrade over time [14]	-Low R-Value range -Vapor Permeable (Vapor can pass through it) -Less efficient when wet [15]	31 (Cents/sq.ft) [10]	R-3.6 to R-4.2 [14]
	Extruded Polystyrene (XPS)	-High compressive strength -Water resistant [14] -Semi-impermeable [14]	-Damaging to the environment to manufacture [15]	47 (Cents/sq.ft) [3]	R-5 [14]
	Polyisocyanurate (ISO)	-High R-Value -Performs better under warmer conditions [15] -Reflective sides	-Expensive -Absorbs water easy if foam is exposed [3]	50 (Cents/sq.ft) [3]	R-6 to R-6.5 [14]
Loose-Fill	Cellulose	-82%-85% made from recycled paper products [16] -Packs tightly into small cavities	-Needs mechanical machinery to install -Settles over time and loses R-Value	40 (Cents/sq.ft) [17]	R-3.6 to R-3.8 [16]
spray foam	SPF closed-cell medium density	-Water and air resistance -High compression strength	-Need license to install [18]	1-1.7 (Dollar/sq.ft) [19]	R-5 to R-6 [20]
	polyurethane (SPF) Open cell light density	-Sound reduction	-Vapor permeable -Air resistance only when 5.5 inches or more [18]	0.5-0.75 (cent/sq.ft) [19]	R-3.8 [20]
Vacuum insulated panel	Fumed Silica Chemical (getter) [22]	-Heat loss reduce significantly -Water proof -High R compared to traditional ways	-High cost -Performance affected by air loss	10-12 (Dollar/sq.ft) [21]	R-25 [21]

A.1.1 Concept Criteria and Weighting for Insulation

To evaluate the conceptual designs, unique and independent criteria, that reflected the client's needs, were determined. The different insulation types were weighed using these criteria in order to select our top concepts. The selected criteria were based upon the characteristics of the project which was determined by the team during our meetings with the client. These criteria are summarized in TABLE XV, and were used to evaluate the preliminary concepts through concept screening and concept scoring.

TABLE XV: CRITERIA SUMMARY FOR INSULATION

Criteria	Definition
Cost	Cost is one of the more important criterion as the new product cannot have a significantly higher cost than what is currently being used.
Moisture Resistance	Some insulation materials can deteriorate over time after absorbing moisture. As a result, boiler efficiency will be effected.
Thermal Resistance Per Inch	Thermal Resistance is the one of the key parameters during the design process since it affects the cost and operational efficiency of the product. Most thermal resistance values are measured per inch of thickness.
Easy to Install	This criterion entails that the client will be able to either install the product themselves with their in-house workers or still have an available option that allows for an ease of installation with the product.
Durability	The product must survive the harsh environment and last for an extended period of time without failure
Flammability	Material flammability has to be as low as possible to ensure the material will not catch on fire.
Handling Safety	Safety is the top priority for the client. If the product is not safe enough to handle due to specific chemicals or particles, there is a chance that someone might be injured or develop health problems over long-term exposure.
Product Availability	Product availability is one of the selected criteria due to the fact that the product needs to be readily available within Manitoba. Ensuring that the product is available will allow the client to save time and therefore money.

The importance of each criterion was evaluated relative to one another, as shown in TABLE XVI. Each occurrence was recorded and used to determine the overall weight of the corresponding criterion.

TABLE XVI: CRITERIA WEIGHTING MATRIX FOR INSULATION

	Insulation Criteria	A	B	C	D	E	F	G
A	Cost		A	C	D	E	F	G
B	Moisture Resistance			C	B	E	F	G
C	Thermal Resistance per Inch				C	E	C	C
D	Easy to Install					E	F	G
E	Durability						E	G
F	Handling Safety							G
G	Flammability							
	Total Hits	1	1	5	1	5	3	5
	Weighting	0.05	0.05	0.24	0.05	0.24	0.14	0.24

From TABLE XVII, a clear understanding of how the criteria weighted against one another was shown and aided in quantifying the concepts in the scoring matrix.

TABLE XVII: RESULTS OF WEIGHTING MATRIX FOR INSULAITON

Criteria	Thermal Resistance per Inch	Durability	Flammability	Handling Safety	Cost	Moisture Resistance	Easy to Install
Ordered Ranking	1	1	1	2	3	3	3
Weighting Percentage	24%	24%	24%	14%	5%	5%	5%

However, an important basis of any design project is constant communication and clarity with the client in order to make sure the project is staying on track with the client’s needs. After reviewing our weighted insulation criteria with the client, they proposed alternative weightings for the criteria that they felt were better suited for the concept scoring matrix. Thus, from the conversation with the client, came a new criteria weighting for the insulation as shown in TABLE XVIII.

TABLE XVIII: CRITERIA WEIGHTING FOR INSULATON AFTER CLIENT FEEDBACK

Criteria	Thermal Resistance per Inch	Durability	Flammability	Handling Safety	Cost	Moisture Resistance	Easy to Install
New Ordered Ranking	1	1	1	2	3	3	3
New Weighting Percentage	20%	5%	10%	10%	20%	15%	20%
Weighting Percentage Before Feedback	24%	24%	24%	14%	5%	5%	5%

According to TABLE XVIII, "Thermal Resistance per Inch", "Cost" and "Easy to Install" were the most important characteristics, while the "Moisture Resistance", "Handling Safety", "Flammability" and "Durability" were the least important. These results were used to score the preliminary concepts that move forward past the concept screening matrix. The top three insulation types that made it through the concept scoring matrix moved forward for analysis.

A.1.2 Concept Screening for Insulation

Having determined the design criteria, each preliminary conceptual design was evaluated using a concept-screening matrix. For the concept screening process, we selected an arbitrary design as a baseline concept to compare the other concepts. This design was then given a baseline score of (0) for all criteria. For this case, low density fiberglass blanket insulation was used as the reference design. The other designs were compared to the reference design for each criteria and was given a 1 if better, a -1 if worse or a 0 if it was considered the same. The results of the screening matrix are shown in TABLE XIX.

TABLE XIX: CONCEPT SCREENING MATRIX FOR INSULATION

Criteria	Concept Variants								
	Low Density Fiberglass Blanket	Med/High Density Fiberglass Blanket	Expanded Polystyrene (EPS) Rigid Foam	Extruded Polystyrene (XPS) Rigid Foam	Polyisocyanurate (ISO) Rigid Foam	Cellulose Loose-Foam	Open-Cell Spray Foam	Closed-Cell Spray Foam	Vacuum Insulated Panels (VIP)
Cost	0	-1	0	-1	-1	-1	0	-1	-1
Moisture Resistance	0	0	-1	1	0	0	-1	1	1
Thermal Resistance per Inch	0	1	1	1	1	1	0	1	1
Easy to Install	0	0	0	0	0	-1	-1	-1	-1
Durability	0	0	-1	1	1	-1	0	1	1
Handling Safety	0	0	1	0	0	-1	-1	-1	1
Flammability	0	0	0	0	1	1	1	1	1
Score	**0**	**0**	**0**	**2**	**2**	**-2**	**-2**	**1**	**3**
Rank	**4**	**4**	**4**	**2**	**2**	**5**	**5**	**3**	**1**

TABLE XIX, shows that the scores for the concepts only ranged from values from 1 to 5, which does not give a strong interpretation of what best concept is. Therefore, we used the weighted concept scoring methodology to analyze the concepts further. However, with the use of TABLE XIX, we were able to eliminate three concepts due to their low scores against the reference concept, as well as, the reference concept itself because of its rank. The concepts removed were cellulose loose-foam, open-cell spray foam, low density fiberglass blanket and EPS rigid foam. EPS rigid foam was eliminated because thermal resistance will decrease due to poor moisture resistance during a long time service. The med/high density insulation blanket was selected over the reference concept because it has a higher thermal resistance.

A.1.3 Concept Scoring for Insulation

For our concept scoring method, we gave a score of 0 (Poor), 1 (Average), 2 (Strong) and 3 (Exceptional) for each criteria for each concept. We then multiplied it with the criteria's weighted scoring from the previous section. As a result, we were able to get the total score for each concept. The total scores for each concept are shown in TABLE XX. This approach gave us a more accurate ranking of each of the different concepts.

TABLE XX: CONCEPT SCORING MATRIX FOR INSULATION

		Concept Variants									
		Med/High Density Fiberglass Blanket		Extruded Polystyrene (XPS) Rigid Foam		Polyisocyanurate (ISO) Rigid Foam		Closed-Cell Spray Foam		Vacuum Insulated Panels (VIP)	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Cost	0.20	2	0.40	2	0.40	1	0.20	1	0.20	0	0.00
Moisture Resistance	0.15	1	0.15	3	0.45	1	0.15	2	0.30	3	0.45
Thermal Resistance per Inch	0.20	2	0.40	2	0.40	3	0.60	2	0.40	3	0.60
Easy to Install	0.20	2	0.40	1	0.20	1	0.20	1	0.20	0	0.00
Durability	0.05	1	0.05	2	0.10	2	0.10	2	0.10	2	0.10
Handling Safety	0.10	1	0.10	2	0.20	2	0.20	0	0.00	1	0.10
Flammability	0.10	1	0.10	2	0.20	3	0.30	2	0.20	3	0.30
TOTAL SCORE		1.6		1.95		1.75		1.4		1.55	
Rank		3		1		2		5		4	
Continue?		Yes		Yes		Yes		No		No	

As indicated in TABLE XX, extruded polystyrene rigid foam, polyisocyanurate rigid foam and med/high density fiberglass blanket insulation were the best preliminary designs and thus were the designs that were analyzed further.

A.2 Concept Selection for By-Pass System

In order to generate design concepts of the bypass system, our team did individual brainstorming followed by a collective brainstorming session. The team came up with four reasonable designs, all of which have the potential to solve the problem presented by the client. The current bypass system has a complex linkage system and in order to make this system easier to service, install and remove, the concepts strive for simplification.

A.2.1 Concept Criteria and Weighting for By-Pass System

After setting out the criteria for selecting the concept that was pursued for further design, the criteria were put in a matrix to determine their relative importance, as seen in TABLE XXII. The weighted criteria was used to determine the concept that most closely meet the client's needs. These criteria are summarized TABLE XXI, and are used to evaluate the preliminary concepts through concept screening and concept scoring.

TABLE XXI: CRITERIA SUMMARY FOR BY-PASS SYSTEM

Criteria	Definition
Ease of Installation	Must allow for modularization as well as service.
Clean	The bypass must not vent excessive amounts of combustion particulates.
Easy to Operate	Easy for customer to operate bypass handle
Cost	Cost is the most important criterion whether the project will be accepted by SteelTech.
Durability	The product must survive the harsh environment and last for an extended period of time without failure.
Manufacturability	Must be able to be manufactured by SteelTech with current equipment and without major process changes.

Thus, the importance of each criterion was evaluated relative to one another as shown in TABLE XXII. Each occurrence was recorded and used to determine the overall weight of the corresponding criterion.

TABLE XXII: CRITERIA WEIGHTING MATRIX FOR BY-PASS SYSTEM

	By-Pass System Criteria	A	B	C	D	E	F
A	Ease of Installation		A	A	D	A	F
B	Clean			C	D	D	B
C	Easy to Operate				D	C	C
D	Cost					D	D
E	Durability						E
F	Manufacturability						
	Total Hits	3	1	3	6	1	1
	Weighting	0.20	0.07	0.20	0.40	0.07	0.07

As shown by the matrix, TABLE XXII, cost was the most important criteria for selecting a concept, followed by ease of installation and ease of operation. Cleanliness, durability and manufacturability was deemed the least important. This was summarized in TABLE XXIII.

TABLE XXIII: RESULTS OF WEIGHTING MATRIX FOR BY-PASS SYSTEM

Criteria	Ease of Installation	Clean	Easy to Operate	Cost	Durability	Manufacturability
Ordered Ranking	2	3	2	1	3	3
Weighting Percentage	20%	6.66%	20%	40%	6.66%	6.66%

A.2.2 Concept Screening for By-Pass System

In order to determine how the concepts compared with the current bypass design, a screening matrix was used to rate the different concepts. The current design was set as the baseline and the concepts were rated as better (1), the same (0), or worse (-1) on each of the criteria as shown in TABLE XXIV.

TABLE XXIV: CONCEPT SCREENING MATRIX FOR BY-PASS SYSTEM

	Concept Variants				
Criteria	Current	Direct	Extended Chimney	Butterfly Valve	Butterfly Valve & Chimney Ext.
Ease of Instalation	0	1	-1	1	-1
Clean	0	0	1	0	1
Easy to Operate	0	0	0	0	0
Cost	0	1	-1	1	-1
Durability	0	1	-1	1	0
Manufacturability	0	1	-1	1	-1
Score	**0**	**4**	**-3**	**4**	**-2**
Rank	2	1	4	1	3

The screening matrix, TABLE XXIV, showed that only the direct bypass and butterfly valve concepts were better than the current design. However, they both received the same score which made it unclear as to which concept was better. Therefore, the concept scoring methodology was used to produce the final premlinary concept that would move onto further analysis.

A.2.3 Concept Scoring for By-Pass System

To determine exactly which concept was the best for the client, a weighted scoring matric was used. Each concept was given a rating from 0-3 on how well it met the criteria, which was then multiplied by the weight for each criteria. The final scores for the concept is shown in TABLE XXV.

TABLE XXV: CONCEPT SCORING MATRIX FOR BY-PASS SYSTEM

		Concept Variants							
		Direct		Extended Chimney		Butterfly Valve		Butterfly Valve with Extended Chimney	
Selection Criteria	Weight	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Ease of Installation	0.20	3	0.60	0	0.00	2	0.40	0	0.00
Clean	0.07	1	0.07	3	0.21	1	0.07	3	0.21
Easy to Operate	0.20	3	0.60	3	0.60	3	0.60	3	0.60
Cost	0.40	3	1.20	0	0.00	2	0.80	0	0.00
Durability	0.07	2	0.14	1	0.07	2	0.14	3	0.21
Manufacturability	0.07	3	0.21	1	0.07	3	0.21	1	0.07
TOTAL SCORE		2.82		0.95		2.22		1.09	
RANK		1		4		2		3	

As shown by the weighting matrix, the direct bypass system was the best and hence was the design that was optimized. After presenting the concept selection to the client, they expressed concerns about the functionality of the extended chimney concepts. The client's issue regarding the extended chimney idea was that by connecting the chimney directly to the by-pass it would essentially keep the draft inducer from being able to pull air from the flues when the by-pass is open. Therefore, the flue gas would have to go down through the refractory, up the flues and then to the draft inducer, rather than the by-pass acting as a short cut for the flue gas to go directly through to the draft fan. However, since neither of these concepts had the highest total score in TABLE XXV, they were not the top choice and were not developed, therefore not affecting the top preliminary concept design chosen

Appendix B – Preliminary Concept Design Drawings

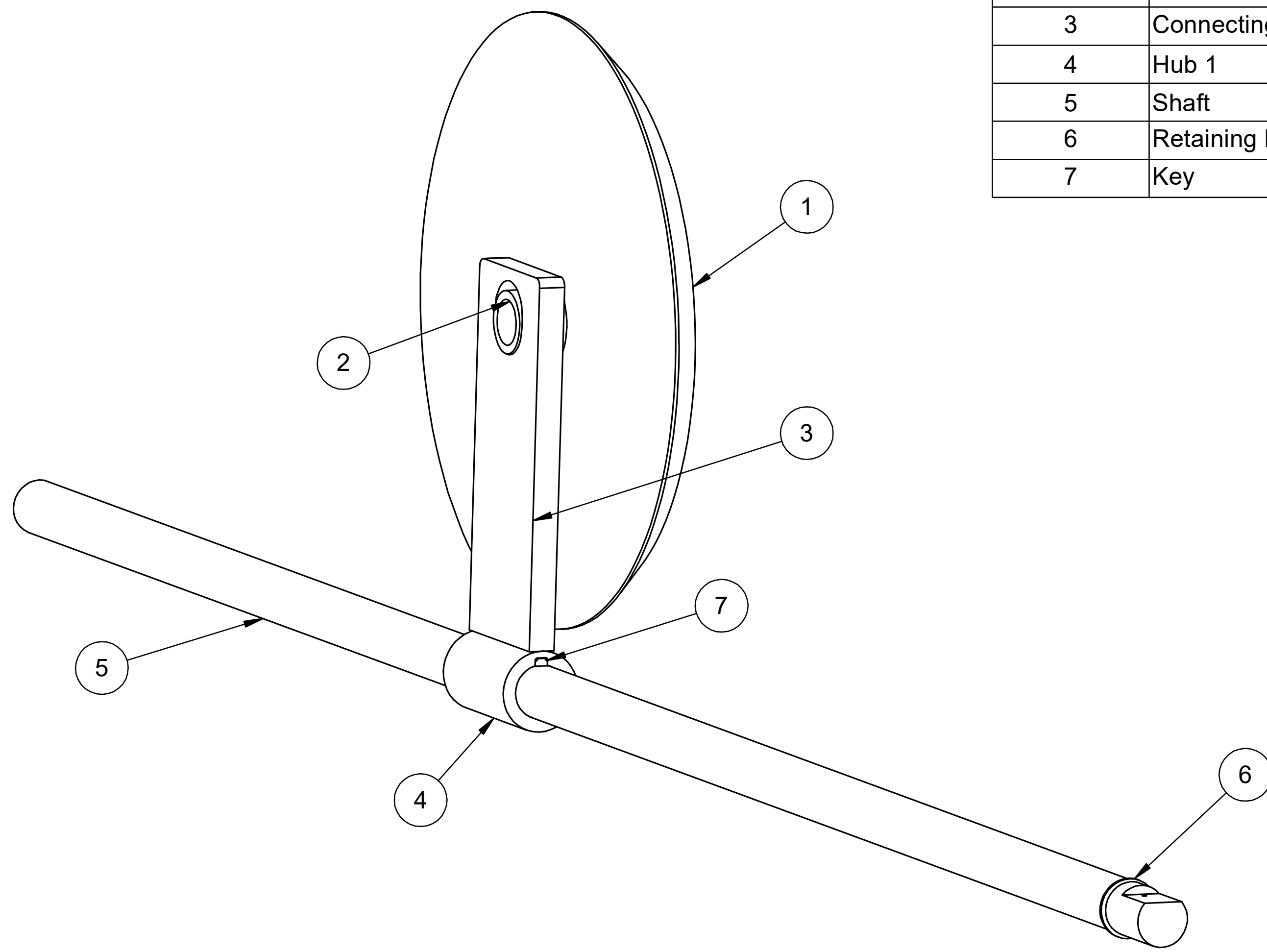
The following preliminary Solidworks drawings are shown in the subsequent section:

- By-Pass Assembly
- Connecting Plate
- Hub
- Shaft
- Key

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	G200-ST0199B		1
2	G100-ST0184		1
3	Connecting Plate		1
4	Hub 1		1
5	Shaft		1
6	Retaining Ring	McMaster Carr 91590A128	1
7	Key		1

REV 0

DWG. NO. G Series Bypass



REV	DATE Y/M/D	DESCRIPTION		
A	16/11/25	INITIAL RELEASE	DWN	T. SEALE
			CKD	

UNLESS OTHERWISE SPECIFIED
GD&T PER ASME Y14.5-2009
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

DIMENSIONAL UNIT: MILLIMETER

N/A = NOT APPLICABLE

GENERAL TOLERANCE
N/A

CHAMFERS N/A
FILLETS N/A
BREAK SHARP N/A
SHARP N/A

TAP HOLES EXTERNAL THREADS AT ØMAJOR INTERNAL THREADS AT ØMINOR

PRELIMINARY DRAWINGS ONLY

MATERIAL

FINISH NO PLATING REQUIRED

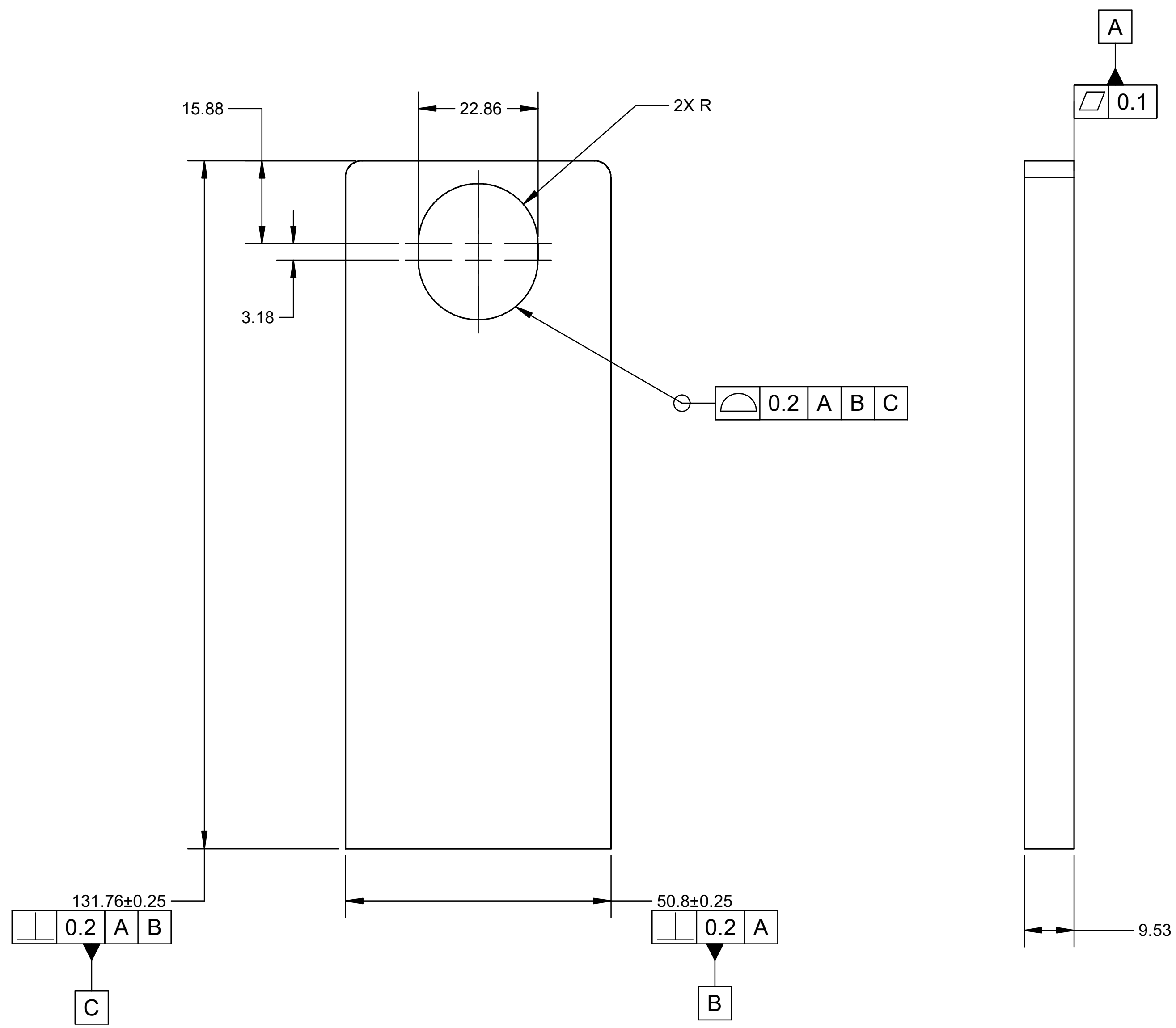
DO NOT SCALE DRAWING

MECH 4860

TITLE:
Bypass Assembly

SIZE **B** | DWG. NO. G Series Bypass | REV 0

SCALE: 1:2 | WEIGHT: N/A | SHEET 1 OF 5



REV 0
DWG. NO. G Series Bypass

REV	DATE Y/M/D	DESCRIPTION		
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
A	16/11/25	INITIAL RELEASE	DWN	T. SEALE
			CKD	

UNLESS OTHERWISE SPECIFIED
GD&T PER ASME Y14.5-2009
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

DIMENSIONAL UNIT: MILLIMETER

N/A = NOT APPLICABLE

GENERAL TOLERANCE 0.3 A B C

TAP HOLES EXTERNAL THREADS AT ØMAJOR, INTERNAL THREADS AT ØMINOR

CHAMFERS N/A
FILLETS R3.18±0.25
BREAK SHARP N/A
SHARP N/A

PRELIMINARY DRAWINGS ONLY

MATERIAL 409 Stainless Steel

FINISH NO PLATING REQUIRED 2.0

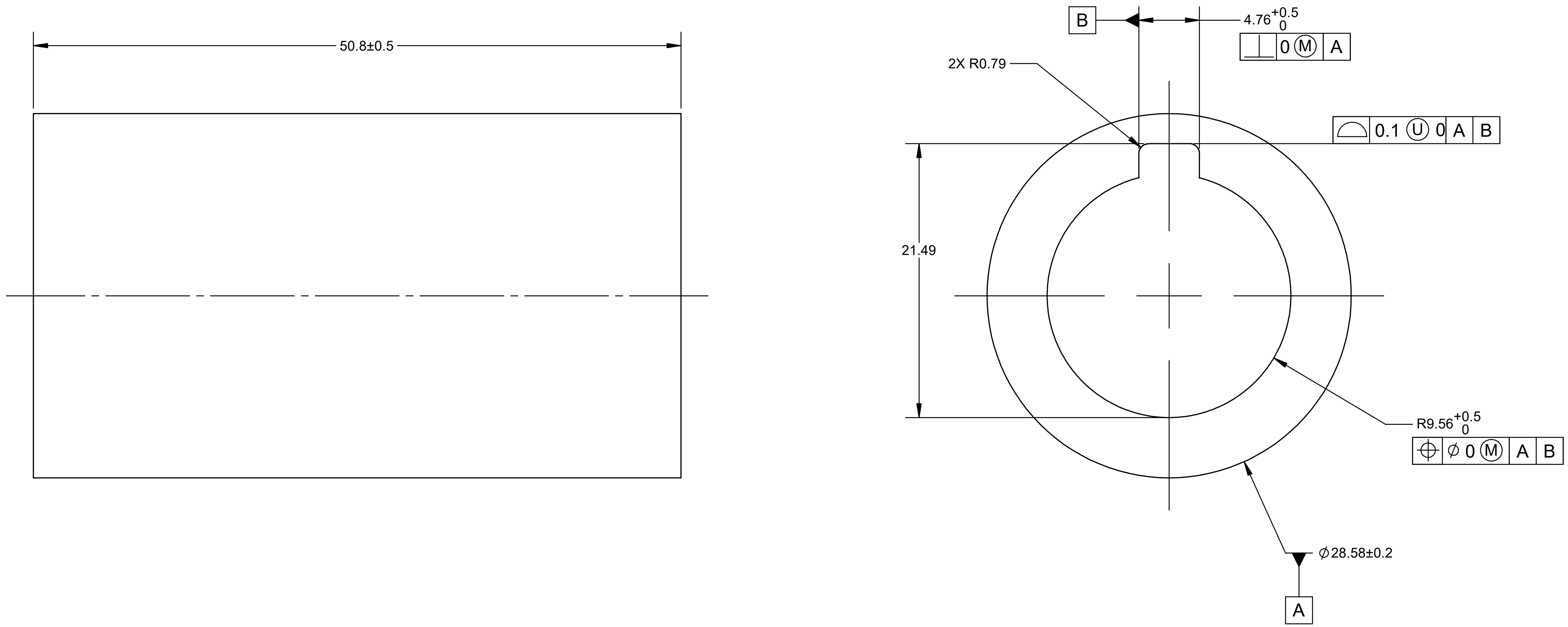
DO NOT SCALE DRAWING

MECH 4860

TITLE: Connecting Plate

SIZE B | DWG. NO. G Series Bypass | REV 0

SCALE: 1:1 | WEIGHT: N/A | SHEET 2 OF 5



REV 0

DWG. NO. G Series Bypass

REV	DATE Y/M/D	DESCRIPTION		
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			DWN / CKD	
			DWN / CKD	
			DWN / CKD	
A	16/11/25	INITIAL RELEASE	DWN	T. SEALE
			CKD	

UNLESS OTHERWISE SPECIFIED
GD&T PER ASME Y14.5-2009
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

DIMENSIONAL UNIT: MILLIMETER

N/A = NOT APPLICABLE

GENERAL TOLERANCE ⌓ 0.3 A B

TAP HOLES EXTERNAL THREADS AT ∅MAJOR, INTERNAL THREADS AT ∅MINOR

CHAMFERS N/A
FILLETS N/A
BREAK SHARP N/A
SHARP N/A

PRELIMINARY DRAWINGS ONLY

MATERIAL: 409 Stainless Steel

FINISH: NO PLATING REQUIRED 2.0

DO NOT SCALE DRAWING

MECH 4860

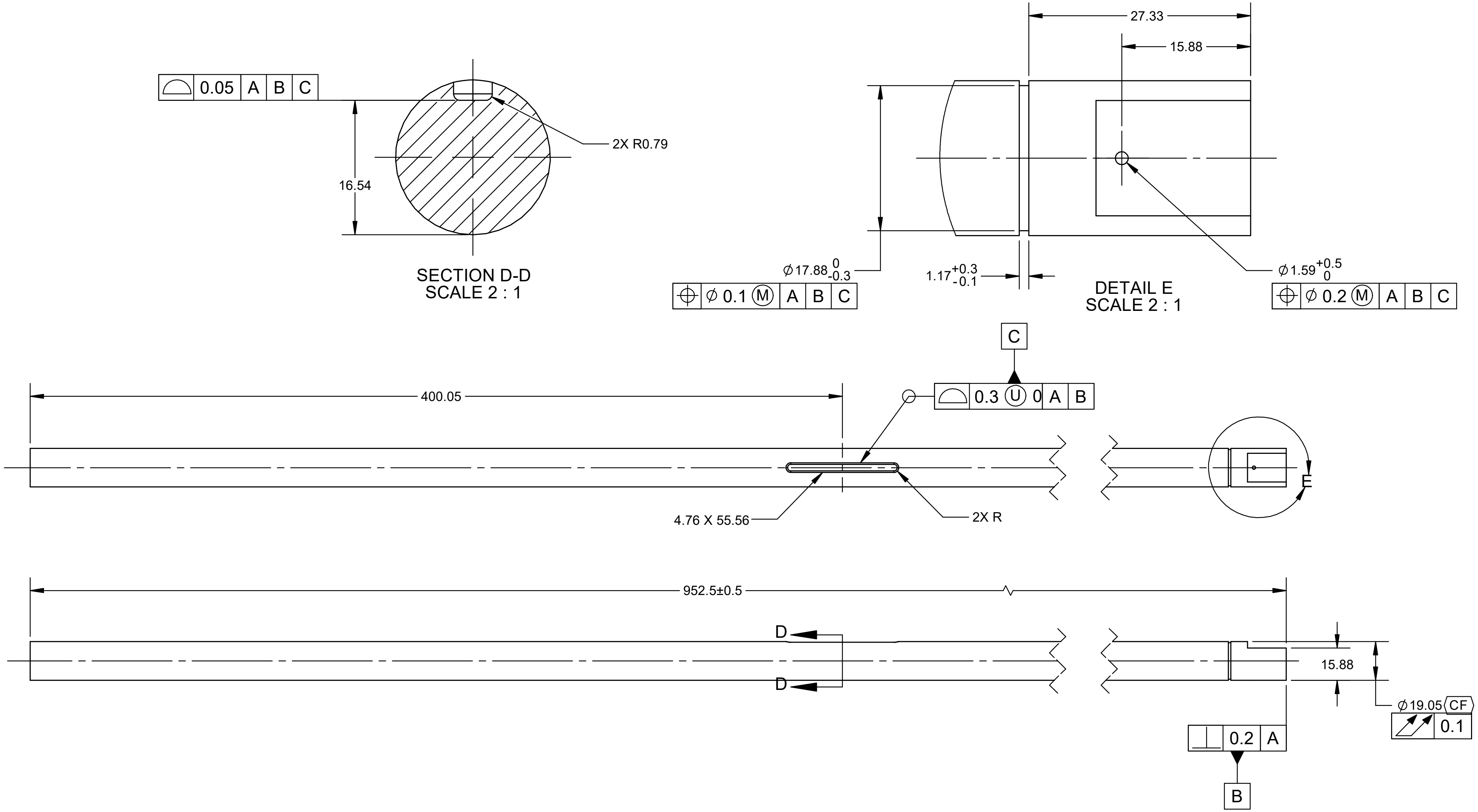
TITLE: Hub

SIZE: B | DWG. NO. G Series Bypass | REV 0

SCALE: 3:1 | WEIGHT: N/A | SHEET 3 OF 5

REV 0

DWG. NO. G Series Bypass



REV	DATE Y/M/D	DESCRIPTION		
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			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
			DWN	
			CKD	
A	16/11/25	INITIAL RELEASE	DWN	T. SEALE
			CKD	

UNLESS OTHERWISE SPECIFIED
GD&T PER ASME Y14.5-2009
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

DIMENSIONAL UNIT: MILLIMETER

N/A = NOT APPLICABLE

GENERAL TOLERANCE
0.3 | A | B | C

TAP HOLES EXTERNAL THREADS AT ⌀MAJOR INTERNAL THREADS AT ⌀MINOR

CHAMFERS N/A
FILLETS N/A
BREAK SHARP N/A
SHARP N/A

PRELIMINARY DRAWINGS ONLY

MATERIAL 409 Stainless Steel

FINISH NO PLATING REQUIRED 2.0

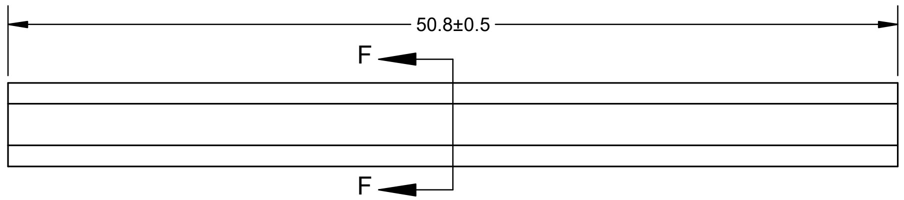
DO NOT SCALE DRAWING

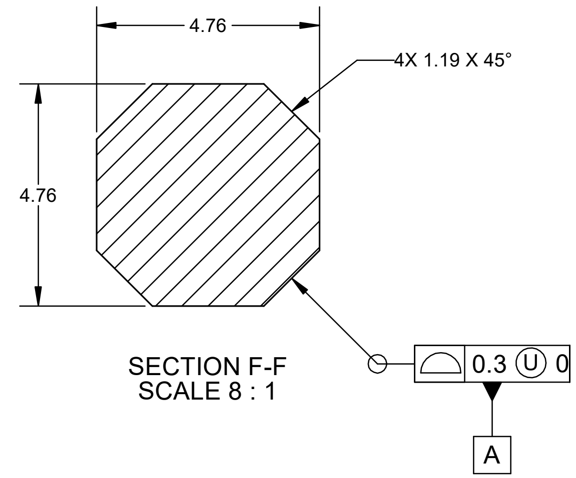
MECH 4860

TITLE: Shaft

SIZE B | DWG. NO. G Series Bypass | REV 0

SCALE: 1:2 | WEIGHT: N/A | SHEET 4 OF 5





SECTION F-F
SCALE 8 : 1

REV 0
DWG. NO. G Series Bypass

REV	DATE Y/M/D	DESCRIPTION		
			DWN / CKD	
			DWN / CKD	
			DWN / CKD	
			DWN / CKD	
A	16/11/25	INITIAL RELEASE	DWN / CKD	T. SEALE

UNLESS OTHERWISE SPECIFIED
GD&T PER ASME Y14.5-2009
NONTOLERANCED DIMENSIONS ARE BASIC
CAD MODEL IS BASIC
NONDIMENSIONED GEOMETRIES PER CAD MODEL

DIMENSIONAL UNIT: MILLIMETER

N/A = NOT APPLICABLE

GENERAL TOLERANCE N/A

TAP HOLES EXTERNAL THREADS AT ⌀MAJOR, INTERNAL THREADS AT ⌀MINOR

CHAMFERS N/A
FILLETS N/A
BREAK SHARP N/A
SHARP N/A

PRELIMINARY DRAWINGS ONLY

MATERIAL: Mild Steel

FINISH: NO PLATING REQUIRED
2.0

DO NOT SCALE DRAWING

MECH 4860

TITLE: Key

SIZE	DWG. NO.	REV
B	G Series Bypass	0

SCALE: 3:1 | WEIGHT: N/A | SHEET 5 OF 5